Human Health and Forests: An Overview

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Although the causal pathways are complex and indirect, human health has in general benefited from the clearance and modification of forests for agriculture and cities. For example, the vast forests of Europe have largely been cleared, and the population supported by that land today is mostly prosperous and healthy. It is also much larger. Although the health of at least some hunter-gatherer populations appears to have surpassed that of many early and even some recent agriculturalists (Sahlins, 1972; Diamond, 2002; Holden, 2006), the larger populations facilitated by forest clearance have stimulated and permitted many of the specializations and technologies that make modern civilization possible. Some people (including some readers) may aspire to the allegedly simpler and perhaps richer life of our long-dead forest-dwelling ancestors, but forest clearance has generally been associated with improvements in human wellbeing. In China, where forests have been largely cleared, the health and prosperity of its truly vast population are improving, and a future that provides abundant ecosystem services, high technology, a long life expectancy and wellbeing for the average citizen remains possible. Nevertheless, the clearance and manipulation of forests have often harmed people, and this phenomenon continues today. The proportion of the global population directly harmed by forest clearance and modification remains small, but as an absolute number it is substantial.

The relentless increase in human population may continue to drive the conversion of forests to cropland, especially in the tropics (for example, in Brazil; see Naylor et al, 2005). Although population growth, as a percentage, crested in the late 1960s, the world's total population, now about 6.7 billion, continues to rise by at least 70 million per annum (discussed further in Chapter 6). The harm to human health and wellbeing caused by forest clearance is often disguised by scale, time and the socioeconomic and cultural distance between the policy-makers whose decisions facilitate forest clearance and those who suffer. There is a paucity of appropriate economic and other feedbacks that percolate to policy-makers and wealthy populations. Consequently, the agents of privileged populations continue to make policy and purchasing choices that harm forests, as well as many other ecosystems. In the short run, such decisions are likely to continue without obvious harm to wealthy populations. In the long run, however, even wealthy populations may be placed at risk if present trends continue.

This chapter considers some of the immediate and local health hazards resulting from forest conversion. It discusses the relationship between forests and health, especially for people living in tropical countries, and reviews the major diseases associated with forest environments. It also looks at the benefits to health and wellbeing that flow from the three main forms of ecosystem services that forests provide for human beings (Millennium Ecosystem Assessment, 2003): broadly, provisioning services (e.g., food, fibre and pharmaceutical products); regulating services (e.g., water-flow, climate regulation and – perhaps – infectious disease mediation); and cultural services (e.g., the aesthetic, psychological and spiritual benefits that accrue to some people who dwell in forests).

FROM FORESTS TO AGRICULTURE

Originally, humans evolved from hominids, who inhabited forest and savannah in tropical regions for millennia. On leaving Africa, human expansion is thought to have mainly been coastal at first (Stringer, 2000). However, population pressure, new technologies, and human curiosity and ingenuity gradually allowed and provoked humans to explore and to colonize many inland regions, much of which was forested.

Until soon after the start of the current interglacial, the Holocene, all humans, including those dwelling in forests, were hunter-gatherers. Many (perhaps most) of these populations appear to have had reasonably good nutrition (Eaton and Konner, 1985; Cordain et al, 2005), although many forest-dwelling hunting populations were prone to infection. At least some also suffered from chronic parasitic infections, as a consequence of eating poorly cooked meat, especially *Trichinella*-infected pork (Owen et al, 2005). They probably also had knowledge of medicinal plants.

Today, no known populations who live in or near forests survive exclusively as hunter-gatherers. Most rely on gardens and/or fishing (Webb et al, 2005) to supplement their diet. Thus many of the diseases they experience may be associated with agricultural land use, with an allied forest fringe effect or with river pollution.

Where agriculture developed, it allowed higher human population densities. Several early agricultural sites (in Mesoamerica, Amazonia and – probably – New Guinea and West Africa) were in tropical forests (Diamond, 2002). The limited evidence available suggests that the health of many early agriculturalists (including, presumably, swidden farmers) was inferior to their hunter-gather predecessors (Diamond, 1991; Boyden, 2004). Health is believed to have deteriorated as the quality of diet fell and leisure decreased. The average farmer consumed more carbohydrates but ate less iron and protein-rich meat and fish, and consumed fewer micronutrient-rich plants (and perhaps insects) than his or her hunter-gatherer predecessor. However, this nutritional disadvantage was outweighed, on a population basis, by the larger human populations that could be supported in a cultivated area than in an equivalent area of 'natural' forest (Noble and Dirzo, 1997). Bigger populations permitted greater specialization and more privileged elites, as well as bigger raiding parties and, eventually, standing armies. In many cases, neighbouring populations must have been forced to either migrate or to also adopt agriculture to compete and survive.

In some regions agriculture took the form of silviculture: the deliberate planting of food-bearing trees, such as Brazil nuts (Mann, 2002), coconuts and fruit trees. In other cases, human occupation and land management may have increased tree diversity, as in the rainforests of Thailand (Kealhofer, 2003).

HEALTH: A MULTIDIMENSIONAL CONTINUUM

Soon after its founding, the World Health Organization (WHO) defined health as a state of 'complete physical, mental and social wellbeing and not merely the absence of disease or infirmity' (World Health Organization, 1978). This highly idealized goal is rarely if ever attainable over any but the briefest period. Even states of physical, mental and social wellbeing that fall short of perfection rely on numerous contributing, interacting factors.

An adequate physical foundation is essential for health, in the form of sufficient nutrition, shelter and energy. Safety and security are also vital for good health, ideally coupled with love and nurturing (especially in childhood) and freedom from excessive anxiety. Health also requires a good social fabric. Humans cannot survive as individuals but are social animals, whose wellbeing is supported by their social position, which often entails both duties and entitlements. Our duties often are to provide security and care for other people, and our socially determined entitlements often guarantee us a minimum of care and insurance in times of hardship. We depend on the services and duties of a large social network. We may sometimes grumble about our onerous social duties, but without at least some duties, our health is likely to suffer.

In addition to those foundations, health increasingly depends on knowledge, technology and science, which in turn depend on an adequate social capacity for their delivery. Knowledge (such as knowing the benefits of drinking clean water) and health services (such as the administration of a vaccine, medication or surgical intervention) require a long chain of individuals for their production, dissemination and preservation. Interestingly, some ancient populations learned of potential health harm from certain exposures and managed to embed protective knowledge in their culture, and in some cases, their religion. Two examples are the risk of parasitism from eating pork, and the possibility of acquiring leprosy from close contact. Other societies have preserved cultural knowledge concerning 'famine foods' (Diamond, 2001), including their safe preparation (such as cyanogen-containing cassava) (Tylleskär et al, 1992).

Analogously, a rapidly expanding literature describes traditional means of protecting ecosystem services and resources, including forests, through myriad means, including customs, songs, rituals, laws, and spiritual and religious practices (Berkes et al, 1998; Folke, 2004; Xu et al, 2006).

Many developing countries with populations that inhabit and partly depend upon tropical forests have limited governmental and societal capacity to deliver (and, in some cases, even to receive) new knowledge and health services. Even worse, some traditional societies have become so demoralized and fragmented that their capacity to maintain traditional knowledge and health-care systems has been damaged. Many Indigenous Australian populations, for example, suffer from high levels of violence (including towards children) and substance abuse, especially alcohol use and petrol sniffing. Traditional laws, customs and behaviours in these societies have weakened, and the laws and society of the white newcomers have often been poor substitutes.

Such a fate is not confined to marginalized people in developed countries (Ohenjo et al, 2006). Xu et al (2006) describe the plight of the Kuchong people, until recently nomadic hunter-gatherers who lived in the tropical forests on the border of Yunnan (China) and Vietnam. The forests within the mosaic landscapes that had been preserved by local people and their cultural beliefs for generations have been largely replaced by plantations of rubber, tea and sugar cane. The worship of holy hills and watersheds has frequently been regarded as superstitious and suppressed by the state. Other attempts by the modern Chinese state to 'civilize' the Kuchong people include the building of permanent homes and the introduction of fried foods. Xu et al (2006) report that the changes have had a significant and harmful impact on the Kuchong, and that social problems, including alcoholism, are now prevalent in the community.

Similar self-reinforcing processes of social disintegration may be underway in many parts of sub-Saharan Africa, particularly because of HIV/AIDS. This epidemic has had a devastating and disproportionate impact on the health and vitality of young adults. In some countries, more nurses and teachers are dying of HIV/AIDS than are graduating (Piot, 2000; Lewis, 2006). Countless African children are being raised in orphanages or by grandparents (Save the Children, 2006). Many children are bringing themselves up with little adult guidance. Perhaps, after another generation or so, this tragic situation will improve. In the meantime, despite extraordinary human resilience, the collective social capacity of many of these countries is in decline, further eroding their ability to deal effectively with their crisis.

INFECTIOUS DISEASES IN THE TROPICS

Many people in tropical countries carry the double burden of poverty and infectious disease, as well as a high incidence of chronic non-infectious diseases. Some of the infectious diseases are unique to the tropics; others occur there with greater frequency and virulence. Though more common in the tropics, measles, acute respiratory illness and tuberculosis can legitimately be considered diseases of poverty rather than of rainfall and latitude. But this is not the case with malaria, which was ranked in 1990 as the 11th leading global cause of disability-adjusted life years (DALYs) in a study of the global burden of disease (Murray and Lopez, 1997). *Falciparum* malaria, which causes 200 million to 300 million infections and 1 million to 3 million deaths annually (Breman, 2001), is probably the most important disease confined to tropical regions. Although some forms of malaria once occurred in more temperate regions, such as the UK and the northern US states, it existed at these latitudes only in one of its milder forms, *Plasmodium vivax*. Unlike *P. falciparum*, *P. vivax* is debilitating and (unless properly treated) chronic, but rarely fatal.

Although some epidemics of *P. falciparum* have occurred in extra-tropical regions (such as the Indian Punjab; Zurbrigg, 1994), large-scale transmission in these areas was 'unstable', rarely if ever lasting for more than a few months a year. Sometimes droughts limited transmission for more than a year, making control, and perhaps even eradication, far more feasible (Coluzzi, 1999).

In contrast, many parts of the tropics, especially in Africa, have long experience of 'holo-endemic' malaria – the relentless transmission of malaria on such a scale that virtually every child, in the absence of treatment, becomes chronically infected. Combined with poverty and inadequate funding, holo-endemicity continues to thwart serious attempts to eradicate malaria in most of tropical Africa (Kager, 2002).

The debility of such chronic diseases is not merely a consequence of poverty but also a cause of poverty: it saps stamina, reduces learning capacity and leads to economic underperformance. This effect of malaria has been recognized for at least a century (Bynum, 2002) but was recently quantified and publicized by the WHO Commission on Macroeconomics and Health (Sachs and Malaney, 2002).

Tropical forests and vector-borne infectious diseases

Many infectious diseases that are unique to the tropics have a special relationship with forests. Their life cycles can involve three species (the pathogen, a vector and humans) and even a fourth (a 'reservoir' species). Most vectors are insects, including mosquitoes, *reduviid* (kissing) bugs, sand flies, tsetse flies and ticks. Water-inhabiting snails, a form of mollusc, are essential for the transmission of schistosomiasis, a disease found near water in Africa, southern China, southeastern Asia and parts of Brazil. Some forest-associated diseases are transmitted directly by mammals, such as rabies (not a purely tropical disease; see Chapter 8, this volume, for a broad discussion of animals as vectors).

Nipah virus, which causes encephalitis, has a more complex ecological causation. The first known outbreak, in Malaysia in 1998, killed more than 100 people and temporarily crippled the Malaysian pig industry (Chua et al, 2000; Epstein et al, 2003). Infected humans were closely associated with pigs, which in turn appear to have been infected by close contact with bats, which were eating fruit from trees that shaded the pig farms (Dobson, 2006). The bats appear to have been displaced from their usual habitat by the haze and smoke of the particularly severe deforestation and fires associated with the severe El Niño event of 1998. (Such fires, which can be very extensive and last weeks, are also clearly harmful to human health.)

The more recent outbreaks of Nipah encephalitis in humans in Bangladesh have not involved pigs; here, the disease has mainly affected young boys, who may have been directly exposed to bat droppings (Enserink, 2004). However, the ecological drivers of the Bangladeshi outbreaks have been less well characterized (Hsu et al, 2004). Nipah virus has also been identified in Cambodia and Thailand, but not yet in humans in these countries (Reynes et al, 1995; Wacharapluesadee et al, 2005).

Bats have also been implicated in the ecological epidemiology of Ebola virus (Leroy et al, 2005) and sudden acute respiratory syndrome (SARS) (Dobson, 2006). Ebola is a significant cause of death among gorillas, chimpanzees and duikers, as well as humans (Leroy et al, 2004; 2005). Most, if not all, primary Ebola infections have occurred after the handling of carcasses of infected bushmeat (described in Box 12.1). Secondary (person-to person) Ebola infections have occurred mainly within health-care settings and are caused by inadequate infection control measures (Bennett and Brown, 1995). This is also the case for Marburg, a related haemorrhagic fever (Enserink, 2005). Contact with infected primates in Africa is also believed to be the mechanism by which HIV and several less virulent infections have entered the human population (Wolfe et al, 2004).

Rodent urine is the source of the tropical arenaviruses, including Lassa fever, a haemorrhagic fever first described in eastern Nigeria and Cameroon (Richmond and Baglole, 2003). Many other haemorrhagic fevers have also been described. Some, such as Junin, Guanarito and Machupo virus, appear to have a particular relationship with forest inhabiting rodent species in Latin America.

Because these diseases all involve other species, they can be viewed as having an ecological dimension. (At a microscopic scale, of course, all infectious diseases are ecological, in the sense that they involve at least two species: humans and pathogens.) Many of these tropical illnesses exist near to, and are sometimes dependent upon, tropical forests. Some, such as HIV, have long ago left their forest origins behind and occur mostly in urbanized populations. Ebola is one that remains restricted to the forest environment and to patients, staff and caregivers in close contact with infected patients.

Tick-borne diseases

Several tick-borne diseases, including Lyme disease, Rocky Mountain spotted fever and tick-borne encephalitis, occur in temperate forests. Lyme disease responds to antibiotics, but chronic sequelae, including debilitating musculoskeletal, cardiac and neurological ailments, can occur if treatment is not prompt. The incidence and prevalence of Lyme disease have increased greatly in recent years, especially in the USA, partly because of the increased use of forests for low-density housing and recreation by humans seeking the cultural benefits of forest exposure.

Ecological changes also play an important role in the observed increase in Lyme disease. Tick density has increased alongside the populations of the preferred hosts for its larval and adult forms: the white-footed mouse and the white-tailed deer, respectively. Populations of those hosts, in turn, may have risen with the extermination of the passenger pigeon (once the most common bird in the USA, numbering an estimated 5 billion), which once competed with the mouse and the deer for acorns (Blockstein, 1998). Another cyclic feedback involves increased populations of gypsy moths, which defoliate oak trees. Mice eat moth pupae. Therefore, high or low mouse population density, can respectively suppress or release moth populations through altered pupal predation (Jones et al, 1998). Jones et al (1998) caution against attempts to reduce Lyme disease by reducing acorn masting because it might lead to reduced oak populations, perhaps with other harmful effects. Ostfeld and Keesing (2000) also point out that a more diverse range of vertebrates can, at least theoretically, reduce Lyme disease, because other hosts may be less competent incubators of the causal agent for Lyme disease than are mice. They call this a dilution effect and speculate that it could be widespread, implying that biodiversity may help reduce disease severity.

Tick-borne encephalitis is a potentially severe viral disease that occurs in central and northern Europe. Although it has no cure, it can be prevented by a vaccine. This disease has been closely studied as an indicator of climate change, with growing consensus that its range is moving northwards (Lindgren and Gustafson, 2001). The total area affected may be little changed, however, perhaps because of shrinkage along its southern border. Like Lyme disease, the incidence of tick-borne encephalitis is affected by changing human behaviour and, probably, altered ecological conditions. However, its preventable nature complicates its eco-climatic-epidemiological analysis (Randolph, 2001).

Two viral 'forest' diseases

Two viral diseases are so associated with forests that the word appears in their common names. Kyasanur forest disease, a tick-borne haemorrhagic fever, was first reported in Karnataka, India (Banerjee, 1996) and has since been identified in the Andaman and Nicobar islands (Padbidri et al, 2002). Barmah forest disease is a mosquito-borne alphavirus, similar to Ross River fever. It has a wide distribution within Australia, far wider than the forest from which its name is derived (Lindsay et al, 1995).

PROVISIONING AND REGULATING SERVICES

Forests provide many goods essential for human health and wellbeing, such as timber, fuelwood, game meat, medicinal plants and fodder. But through silviculture, conversion to agriculture and the establishment of plantations to provide oil, fibre or rubber, forests' provision of ecosystem services has been increased by human intervention (Daily, 1997;Millennium Ecosystem Assessment, 2003).

The influence that forests can have on local climate and salinity can be considered examples of 'regulating' ecosystem services. The mitigation of catastrophic landslides and the amelioration of drought by standing forests may be another important regulating service, although the extent of this has recently been questioned (FAO and CIFOR, 2005). Supporting the idea that forests affect flooding is the recent finding that plantations lower the water table in many areas. This effect, documented in some cases to last at least two decades (Jackson et al, 2005), can reduce stream flow and impair irrigation-dependent agriculture in nearby areas. In China, the catastrophic floods along the Yangtze River valley in 1998 contributed to a major rethinking of Chinese forest policy, a slowing of deforestation in the river's catchment and active afforestation (Zhang et al, 2000). In the former case, forest plantations can, at least where the water supply is marginal, harm wellbeing. In the latter case, excessive forest clearing can contribute to flooding.

Trade in forest products, such as paper, lumber, palm oil (for food and increasingly fuel), rubber, nuts and oils for cosmetics, is now a global business. This has many implications for health, some of which could be truly dramatic and transcontinental. For example, the use of Asian gangs, accompanied by Asian sex workers, to log the rich stands of forests that remain in Liberia may introduce yellow fever to Asia (Nisbett and Monath, 2001) if the logging company fails to immunize workers against this viral haemorrhagic fever. Similarly, African strains of HIV could be easily transmitted to Asia. Centuries ago, the transatlantic slave trade is believed to have introduced both malaria and yellow fever into the immunologically naïve populations of the Americas (McNeill, 1976).

The provisioning services that flow from forest conversion generally facilitate better human health because the change in land cover increases not only the supply of food, fibre and fuel, but also employment and trade. But such improvements need not be inevitable, and they are unlikely to be uniform. Whether ecosystem services bring widely shared improvements in health and wellbeing depends critically on human factors (including governance) and the rules, mores and institutions that influence their distribution (Butler and Oluoch-Kosura, 2006). Large-scale forest conversion has often been imposed on forest-dwelling peoples without their informed consent or adequate compensation (Dauvergne, 1997; White et al, 2006), and when this happens, their health and wellbeing are very likely to suffer.

Tropical forests and infectious disease 'mediation'

The ecological aspects of some infectious diseases were recognized centuries ago, well before the understanding of their parasitological or microbiological nature, or their vectors or animal sources. An early name for malaria was 'paludism', from the Latin word *palus*, 'swamp'. According to the Chinese environmental historian Mark Elvin, the Bai people of Yunnan province and the Han Chinese who lived near and among them were aware of the link between malaria and the anopheles mosquito from at least the 14th century (Elvin, 2004). Ronald Ross, awarded the Nobel Prize for showing (500 years later) that mosquitoes transmitted malaria, devoted much of his subsequent career to attempts to change environmental and ecological conditions to reduce mosquito numbers.

The idea that entering, disturbing or modifying forest ecosystems can increase the transmission of many infectious diseases, including malaria, is probably old. A more recent corollary is the concept that undisturbed ecosystems can retard infectious disease transmission. This has been called infectious disease 'regulation' (Patz et al, 2005) or infectious disease 'mediation' (Foley et al, 2005).

Patz et al (2005) list many fascinating and suggestive examples in support of the general concept. Although the theory cannot be extrapolated to all ecosystems, infectious diseases or populations, it warrants publicity and further research. Modification of ecosystems, including forests, *beyond a threshold* in many cases may facilitate the widespread transmission of new diseases. If such thresholds could be identified, and avoided, then huge costs – both human and financial – might be saved, because our environment could be harnessed in ways that would enable us to reduce or even block the spread of disease.

Four caveats regarding infectious disease mediation

The theory of infection disease mediation is, however, subject to four caveats.

Confounding factors

Many factors are involved in the epidemiology of tropical diseases, including poverty, human population density, human migration, climatic changes and the presence or scarcity of human capability (Sen, 1999). Modification of forest ecosystems may be *necessary*, but is rarely *sufficient* to increase disease transmission or to generate an epidemic.

Time and scale

The increased disease potential from ecosystem modification has dimensions of both time (chronotones) (Bradley, 2004) and scale. In many cases, the increased risk of disease transmission may be temporary. As development proceeds, the likelihood of many infectious diseases declines, as a function of both increased human capacity and – at least in some cases – of additional ecological changes that prove unfavourable to disease transmission.

In the Amazon, de Castro et al (2006) describe a rise and fall of malaria risk as forest clearance and agricultural settlement proceed. They describe how weak institutions, low community cohesion, politically marginalized settlers and high rates of in- and outmigration combine to thwart malaria control programmes in newly deforested regions, with the revealing exception of corporate-sponsored forest clearance. In these cases, the transformation of the landscape was faster, and the personnel involved had more knowledge of the risk of malaria and were better able to take protective measures against mosquito exposure. As a result, malaria was minimal.

The Punjab of pre-Independence India, which straddled present-day India and Pakistan, experienced a vast expansion of irrigation, population inflow and deforestation from 1860 until the Second World War. The death toll from a succession of malaria epidemics increased until 1908 but then greatly declined, despite the ongoing expansion of irrigation and the lack of effective pesticides. This decline has been attributed to an early warning system, the development of organized civil society, and the judicious use of limited supplies of quinine, targeted especially at immunologically naïve children (Swaroop, 1949; Butler, 1997). Better nutrition may have also played a role in reducing mortality (Zurbrigg, 1994).

The term 'paddies paradox' has been used to describe situations in Africa where irrigation has increased vector populations without any increase in malaria (Ijumba and Lindsay, 2001). For instance, villages surrounded by irrigated rice fields in Kenya showed a 30- to 300-fold increase in the number of the local malaria vector, *Anopheles arabiensis,* compared with those without rice irrigation, and yet were found to have had a significantly lower malaria prevalence (0–9 per cent versus 17–54 per cent) (Mutero et al, 2004). This has been attributed to the zoophilic biting preference of *A. arabiensis*, rather than any deliberate intervention from better-educated or more affluent humans (Patz et al, 2005). If so, the introduction of cattle could be seen as an ecological mediator, in this case operating within a highly modified ecosystem. However, even if this malaria 'zooprophylaxis' is valid in Kenya, it was not found to be in Pakistan (Bouma and Rowland, 1995).

Opposite effects

The third caveat is that ecosystem modification is sometimes used to *reduce* disease transmission. Two clear illustrations come from Africa. The three forms of African trypanosomiasis (sleeping sickness) are transmitted by savannah- and scrub-dwelling tsetse flies. Game animals and cattle constitute the reservoir for two of these forms (*Trypanosoma brucei rhodesiense* and *T. brucei brucei*). A large region of savannah in Africa, otherwise suitable for the rearing of cattle, consequently has a very low human population density (Robinson, 1985).

Onchocerciasis (river blindness) is caused by a filarial worm transmitted by species of the black fly (*Simulium* spp). This problem is particularly severe in savannah regions of West Africa, where the black fly breeds in the white-water rapids of fast-flowing rivers, an intact ecosystem. In recent years, intensive and generally promising efforts to eradicate this disease have been made by attempting to exterminate the black fly. Serious setbacks in this programme have been attributed to tropical deforestation, facilitating the expansion of the savannah species into the newly deforested areas, and perhaps expanding the zone of onchocerciasis transmission, and providing another example of how ecosystems influence infectious diseaes (Patz et al, 2005).

Besides HIV and Ebola, other diseases appear to have crossed into the human population as a consequence of intimate contact with comparatively undisturbed forest ecosystems. In the Brazilian Amazon, 32 distinct arboviruses associated with human disease have so far been described. Almost all of these are maintained within complex cycles in the forest, but epidemics are mostly reported in newly cleared areas adjacent to forests, or in the vicinity of dams (Patz et al, 2005).

A large literature, especially from South and Southeast Asia, describes high rates of malaria transmission among tribal peoples living in heavily forested regions. This literature consistently identifies forest exposure as a risk factor for malaria (e.g., Erhart et al, 2004) but makes few comments about the presence of gardens, the degree of nearby agricultural expansion or the increased light at the forest edge. Because no peoples are today purely hunter-gatherers, it is possible that much of the risk of malaria in these populations may more accurately be attributed to forest garden exposure rather than purely to forest exposure.

However, mosquitoes do occur in forests, sometimes in high concentrations. Both *Aedes* and *Haemagogus* species breed in forest canopies, and *Aedes* mosquitoes breeding in tree holes in moist savannah can sometimes reach very high densities (Monath, 2001). In support of the concept of infectious disease mediation, genetic evidence suggests that the modern form of *Plasmodium falciparum* is comparatively recent and may have co-evolved with humans and vectors following the introduction of slash-and-burn agriculture in Africa 5000 or 6000 years ago (Volkman et al, 2001).

In the highlands of Uganda, Lindblade et al (2001) studied two populations living near swamps. Slightly higher (though not statistically significant) rates of malaria were found in villagers living near swamps that had been drained and cultivated, compared with villagers near unmodified papyrus swamps. Rather than attributing this to the 'mediating' function of the intact swamp, the researchers thought that malaria might have increased near the drained swamps because the ecosystem modification had inadvertently caused a slightly higher temperature more favourable to the breeding of mosquitoes.

Romantic notions

The idea of infectious disease 'regulation' by 'pristine' forests could be conflated with the conceit of an intrinsically benign 'nature'. A corollary is that 'wild' nature, rich in biodiversity, should be preserved to reduce outbreaks of human disease. It seems more plausible that numerous species, including humans, vectors and pathogens, have long been driven by co-evolutionary forces involving competition, synergism and cooperation. Few environments are likely to be intrinsically benign to humans, though human ingenuity and intelligence have been able to modify almost all terrestrial environments to accommodate human habitation. Wherever there has been animal life in forests where people dwell, there have been hunters, and human hunters are always likely to have accepted the reward of nutritious (and often status-enhancing) meat in exchange for health risks, whether from injury, parasites or strange zoonotic infections.

Indeed, to support a larger human population, the limited food-provisioning services in 'undisturbed' forests provide an incentive for their modification that appears far stronger than any drive to preserve forests intact to reduce hypothetical epidemics. Viewed this way, the continuing transformation of forest ecosystems to grow food or feed is unlikely to slow as long as the human population continues to expand and becomes affluent enough to demand more meat (Naylor et al, 2005; McMichael et al, 2007).

It is highly likely that human actions have at times modified ecosystems in ways that inadvertently favoured vectors and pathogens and thus promoted infectious disease transmission. But at other times, humans have modified not only ecosystems but also their own behaviour to reduce the risk of infectious disease, including lowering the populations of vectors and pathogens. Many natural forests may host comparatively little transmission of many vector-borne diseases. But these forests are also places with a low human population density, and in the absence of non-human reservoir species, they therefore have low concentrations of pathogens. Large-scale forest modification may increase opportunities for vectors to breed, particularly by creating puddles and irrigation canals. Similarly, the in-migration of workers, who are often disproportionately poor and lack both health care and knowledge of vector-borne diseases, is likely to create conditions that favour pathogens (such as malarial parasites). Combined, these effects set the stage for the outbreak of many epidemics (MacDonald, 1973).

The suggestion that an intact forest regulates or even mediates most or even many vector-borne diseases, in my view, over-interprets the evidence. No one would suggest that the absence of an epidemic on an ocean liner is evidence that the boat, or indeed the ocean, regulates or mediates the epidemic, when a simpler explanation is simply that insufficient conditions exist for such an outbreak. At the same time, newly cleared alpine forest will not lead to a malarial epidemic even if it is irrigated and tilled by the most deprived population. The temperature will simply be too low for the mosquito vectors to become sufficiently numerous. Some (perhaps many) intact, sparsely inhabited forests are unsuitable environments for large-scale vector-borne epidemics, but I am less convinced that it therefore follows that these forests regulate such outbreaks.

In many such cases, the forests may be a potent reservoir of latent infection, ready to erupt if disturbed. When considered this way, tropical forests appear to be sources of danger if disturbed to improve their provisioning services. One can see how the idea of infectious disease regulation has developed, but I hope the reader will also see its limitations.

West Nile virus, yellow fever and 'ecosystem immunity'

Although there are limits to the mediation or regulation of infectious disease by intact ecosystems, there are nonetheless several intriguing examples in which the spread of infectious disease appears to be reduced by large-scale ecological factors. One example may be the failure (to date) of West Nile virus to become established in Australia. Antibodies to a similar flavivirus, called Kunjin virus, have been suggested as cross-protective to West Nile. It has been suggested that these antibodies are so widely distributed among the potential host species in Australia that West Nile is unlikely to take hold there (Mackenzie et al, 2003).

Conversely, yellow fever has not been introduced to Asia despite the presence of large numbers of its vector, the *Aedes* species. This risk is now well recognized and guarded against, mainly by scrupulous enforcement of yellow fever vaccination for travellers. Nevertheless, the long history of human contact and trade between East Africa (where yellow fever has long occurred) and India, going back millennia, suggests that an as-yet unidentified protective factor in Asia prevents the introduction of yellow fever.

Indeed, as with West Nile virus, Monath (2001) has suggested that cross-protective antibodies from dengue fever, which is widely distributed, may be protective against yellow fever. A second point is that the ecosystems in both East Africa and Asia have been extensively changed. If the disease-mediating hypothesis of an intact ecosystem is valid in this case, then the threshold of ecosystem modification required to permit the establishment of yellow fever in Asia may be very high – though perhaps vaccination is the critical protective factor. It certainly seems prudent to continue this programme, particularly since the vaccine is comparatively cheap, safe and effective, and the disease has a high fatality rate and no treatment.

The Amazon jungle provides several well-documented cases of introduced diseases that have failed to have a severe impact (at least to date). These include schistosomiasis, *kala azar* (*Leishmania donovani*) and cholera (Patz et al, 2005). *Kala-azar*, a disease common in parts of Bihar, India, the Nepali Terai, Bangladesh and in arid areas such as parts of Sudan (Thomson et al, 1999), has become established only in two geographically restricted areas of the Brazilian Amazon: a savannah area in the northern part and a peri-urban setting in the central part (Confalonieri, 2000). Schistosomiasis has been introduced to parts of Brazilian Amazonia but has not been established, apparently because a widespread lack of mineral salts necessary for shell formation has limited populations of the snail species *Biomphalaria* (Sioli, 1953, cited in Patz et al, 2005).

On the other hand, both yellow fever and malaria are thought to have been successfully introduced to Brazil – including, presumably, its forests – hundreds of years ago as a result of the slave trade (McNeill, 1976). Here the comparatively undisturbed ecosystem proved an inadequate defence. Dengue and yellow fever now co-exist in Brazil, unlike in many parts of Asia. This suggests that the explanation proposed by Monath for the absence of yellow fever in Asia – that it is inhibited by dengue – is unlikely to be complete.

CULTURAL SERVICES

From an ecosystemic perspective, the conversion of many unique forest ecosystems (e.g., to fields of rice or soy) is an enormous loss. Many populations, species and – in some cases – entire ecosystems have been destroyed or irrevocably changed. Elvin (2004) remarks how, in China, the cultural admiration of whole forests is now expressed as veneration for an individual tree, an apparent symbol of an entire ecosystem.

Many indigenous peoples have long engaged in practices that have had the effect, if not the conscious intent, of ecosystem protection and preservation (Berkes et al, 1998; Folke, 2004; Xu et al, 2006). For such people, the loss must often be demoralizing. Self-esteem and health are also intimately connected to culturally determined livelihoods and responsibilities. Among the Kenyah Dayaks in East Kalimantan, for instance, women's roles are intimately connected with swidden rice cultivation. Although men also work in the fields, the women derive status and satisfaction from this work (Colfer, 1991). Similarly, in parts of Amazonia many men gain community respect and self-esteem from participating in a successful hunt (Siskind, 1973).

One of the many problems with conventional measures of economic growth is that they accord no value to self-esteem or social cohesion. Sometimes, mechanization, globalization or other external factors can deprive both women and men of core responsibilities in ways that hurt self-worth and satisfaction and can lead to alcoholism, depression and despair.

The loss of biodiversity from wide-scale forest conversion (and increasingly from climate change) is also keenly felt by many scientists and conservationists. E. O. Wilson (2002) has suggested that humans are biophilic, in having a deep sense of connection with other living beings. The spontaneous emergence of the 'green' movement in the 20th century may illustrate an expression of population-scale biophilia. The loss and degradation of species and entire ecosystems are undoubtedly painful for many people; they may also impair human health.

The psychological and spiritual relationships between many humans and ecosystems and their species (and in some cases wild individuals) illustrate the third main class of ecosystem services: cultural services (Butler et al, 2003). There is growing evidence that these cultural services provide substantial health benefits and, in some cases, spiritual connection and fulfilment (Frumkin, 2002). Some indigenous peoples describe cultural relationships with 'sacred groves' (Ramakrishnan et al, 1998). Others describe links with totemic species, sometimes in mosaics that appear to encourage the conservation of biodiversity over large areas. Although this subject is poorly researched, it is likely that the psychological – and hence physical – health of many indigenous people who lose contact with sacred groves, or whose totemic species is endangered or extinct, is impaired. There is also growing evidence that the health of many urbanized people is improved by contact with nature, including forests (Frumkin, 2002; Maller et al, 2006).

FORESTS, CLIMATE CHANGE AND THRESHOLDS

The rate of forest clearance, whether tropical (Achard et al, 2002; Hansen and DeFries, 2004), temperate or boreal, is debatable. Globally, the forested area may be stabilizing because of an expansion of plantations and temperate forests. However, there is consensus that both the quality and the quantity of tropical forests are continuing to decline. The ongoing clearance of tropical forests is particularly important for both biodiversity (including as-yet undiscovered pharmaceuticals; see Chapter 3, this volume) and global climate change.

Modelling shows feedback cycles in which climate change may lead to drought and fires within tropical forests, including the Amazon, and this forest loss could then exacerbate climate change, causing further forest loss (Cox et al, 2000).

From a purely human perspective, the conversion of forests to generate increased provisioning services, even if at the expense of some regulating services (including perhaps mediation of some infectious diseases) has clearly enhanced human wellbeing and health. This is true in the narrow sense that the total number of humans – supported by intact forests, modified forests and lands that were formerly forested – is larger than ever. Many of these people also have, on average, a comparatively long lifespan. Again, there are caveats.

First, the conversion of natural capital to support an ever-expanding population of fairly long-lived humans has arisen as a consequence of history and geography, rather than because of any general consensus that this trade-off is desirable, even from an anthropocentric view. Second, the aggregation of populations and effects to calculate averages masks the large number of comparative losers, including many indigenous and tribal populations whose traditional property rights and management strategies are discounted, if not entirely ignored. Last, the comparative success of the human species does not guarantee that the process can continue indefinitely. Evidence is mounting that the transformation of forests and other ecosystems is on a scale sufficient to cause many unexpected effects that appear harmful to human wellbeing and, in the long run, human health.

POLICY IMPLICATIONS

Not all of the land that once supported forest and now supports agriculture is as fertile as is most of Europe. In addition, there is more to human welfare than the total number of people who can be supported at a given lifespan. Critics of deforestation argue that through indirect effects, particularly upon global climate and biodiversity, the current rate and scale of tropical forest clearance has the potential to harm the health and wellbeing of many more people than those who are currently being displaced.

It is difficult to conclude that large-scale forest transformation will – at least over the next few decades – cause net harm to human health, but it will clearly damage some desirable forest products, many non-human species and cultural systems (some unique), many ecosystems, and biodiversity as a whole. More importantly, the conversion of forests into agricultural land cannot continue indefinitely without great harm, not only to the forests themselves, but also to human health and wellbeing.

Any driver aware of a sharp bend in the road ahead knows to slow down to safely negotiate the curve. Analogously, the undeniable consequences of infinite forest clearance should modify the views and intentions of far-sighted policy-makers. Unfortunately, misleading economic signals obstruct their vision and domestic, international and intergenerational inequality constrain action.

In some ways, forests are comparable to other poorly regulated environmental public goods (McMichael et al, 2003), such as the global climate and ocean fisheries. The 'tragedy of the commons' (Gordon, 1954; Hardin, 1968) has been extensively lamented at a small scale. Yet in numerous cases, functioning, intact societies have successfully recognized, practised and enforced institutions to protect common resources, including forests, grazing land and near-shore and freshwater fisheries (Buck, 1985; Adams et al, 2003).

On the global scale, however, institutions to protect resources from plunder remain embryonic. Despite increasing recognition among academics that sanctions are required to protect global public goods (Berkes et al, 2006; Gürerk et al, 2006), effective and widely accepted international laws are lacking. Instead, comparatively untrammelled market forces continue to fuel a race to the environmental bottom.

The Millennium Development Goals, if they can be achieved, will provide a modest but important stimulus to protect common resources, including forests. This is likely because realization of the goals will help level the playing field between those who disproportionately profit from exploiting these resources and those who lose, thus increasing the leverage that the poor – those who are most immediately vulnerable to catastrophic loss of environmental public goods – have on global policy. However, progress toward the goals is very slow. There is a real risk that global society will continue to evolve towards an unsustainable and highly dangerous 'fortress world', in which growing inequalities and the resulting violence prompt wealthy populations to increase their own security, creating a feedback loop that further exacerbates the problems and eventually plunges the world into chaos (Butler and Oluoch-Kosura, 2006).

MISLEADING INDICATORS OF PROGRESS

Conventional measures of economic growth, such as gross domestic product and personal income, account for the market goods that flow from the provisioning services of forests and formerly forested land. They ignore the change in forms of non-financial capital, such as natural capital (e.g., mineral stocks or standing forests) and social capital (or social cohesiveness) (Butler, 1994; Dasgupta, 1996; Arrow et al, 2004). They also fail to capture non-market provisioning services, such as those used by subsistence populations. They ignore changes in health and the distribution of wealth and income, and they fail to measure externalities that follow from the change of ecosystem regulation and cultural services, each of which has implications for human wellbeing. Policy-makers need to consider these complex dimensions if their goal is to maximize sustainable human health and wellbeing.

Despite the problems with conventional economic measures, the dominant economic theorists make the implicit assumption that human welfare is directly proportional to them.

Because the harm from forest clearance rarely affects policy-makers or consumers, they have little incentive to support policies that might limit this example of the tragedy of the commons.

In some cases, policies have created a dual harm, not only destroying the qualities of the pre-existing forest (with consequent harm to the peoples dependent on them), but also failing to produce viable agricultural land in exchange. The best example of this is probably the failure to convert substantial amounts of forest in Kalimantan, Indonesia to rice. The peaty underlying soil was unsuitable for rice, and problems were exacerbated by translocation and cultural differences, especially between the Madurese newcomers and the indigenous Dayak population (Carey, 2001; Aldhous, 2004).

The harm to human health and wellbeing is often disguised by scale, time and the socioeconomic and cultural distance between the policy-makers whose decisions facilitate forest clearance and those who suffer. There is a paucity of appropriate economic and other feedbacks that percolate to policy-makers and wealthy populations. Consequently, these privileged populations continue to make policy and purchasing choices that harm forests and other ecosystems. In the short run such decisions are likely to continue, without obvious harm to wealthy populations. In the long run, however, even wealthy populations are likely to be placed at risk.

CONCLUSION

In the past century, the process of converting forests to meet the needs and wants of a substantial part of the global human population has reached a scale that was once unimaginable. One question is whether the scale of global forest conversion could exceed a threshold beyond which the quality of modern civilization significantly deteriorates.

Such a possibility may seem far-fetched to some, but there are several well-accepted cases in which pre-modern humans altered their forest environment on such a large scale that their civilization – and, by implication, their health – was undermined. Three examples are Easter Island, the Indus Valley and Mesopotamia.

In the first, a frenzy of statue-building led to the cutting of almost all of the island’s forest, including timber needed for boat-building. Thus, indirectly, deforestation led to significant food shortages, especially of fish (Hunt and Lipo, 2006). In the Indus Valley, the vast quantities of wood used to bake bricks required the clearing of forest on such a large scale that the local climate is thought to have changed. In Mesopotamia, extensive deforestation – probably mainly to permit the growing of wheat – is thought to have contributed to salinization. As the salt built up, wheat was replaced by comparatively salt-tolerant barley (Jacobsen and Adams, 1958), but eventually this strategy also faltered.

With greater attention to equity, education and basic health, many of the health problems associated with forest clearance and agricultural settlement can be lessened. The incidence of strictly forest-associated diseases, such as Ebola, can also be reduced by better education and nutrition so that hunters do not handle and cook infected bushmeat carcasses. The burden of large-scale vector-borne diseases, including malaria, can be reduced by a combination of improved treatment and prevention, including the judicious use of insecticides, such as dichlorodiphenyltrichloroethane (DDT). The recent decline in the incidence of HIV, observed in southern India and in many African countries, shows that education, assistance and governance can improve health. Although governance need not be perfect to effect these improvements, leadership at all scales is needed if the health of populations dependent upon forests is to be improved. Ultimately, it is in the interest of us all for this to occur.

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