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Tropical Forest Ecosystem Resources Management as a Strategy for Mitigating Climate Change

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Abstract:
This paper discusses one of the techniques for mitigating global climate change, namely the management of tropical forest ecosystems. The removal of vegetation and land use changes account for a significant emission level of greenhouse gases. The information is based on research findings from a survey of secondary sources of data. The aim of managing tropical forests efficiently and effectively is, among other things, the curbing or reduction of deforestation and the emission of greenhouse gases from tropical forests. Forest ecosystems, through deforestation, release between 1.1 and 1.7 Gt of carbon per year to the atmosphere. The strategies for controlling or reducing greenhouse gas emissions from tropical forests fall into five main categories. The first category contains activities dealing with conservation and sustainable utilization, such as the establishment and management of protected forests, nature reserves, national parks, ecotourism and bioprospecting. The second category contains activities dealing with forestry and agroforestry, such as afforestation, reforestation, agro-forestry and agricultural intensification. The use of multi-disciplinary and inter-disciplinary approaches to forest management constitutes the third category of forest ecosystem resources management. The final category involves activities or participation at the international level by signing forest conservation treaties, agreements, declarations and protocols on the international arena. Adopting these strategies, techniques and practices can lead to the control and reduction of greenhouse gas emissions from tropical forests and agricultural lands into the atmosphere. The end results are the control of, and reductions in greenhouse gas concentrations. This will mitigate the effects of global warming, climate change and the attendant disorders.

Keywords: *climate change, forest, tropical, ecosystem, management, mitigation*

1. Introduction

Global mean temperatures increased by about 0.6 ^{o}C over the 20th century and concentrations of CO_2 in the atmosphere rose by nearly 40 percent since the industrial revolution (Smith, 2006). Concentrations of other greenhouse gases such as methane, nitrous oxide and halocarbons have increased similarly (Smith, 2006). The observed warming is not accounted for by natural variation in climate, but is consistent with the expected effects of anthropogenic greenhouse gases based on global climate models (Smith, 2006; IPCC, 2001).

In the 21st century, global mean surface temperature is projected to rise by 1.4 to 5.8 ^{o}C (Smith, 2006). There are uncertainties in climate projections because of the imprecision in models and because future greenhouse gas emissions are unknown, but many changes are robustly and consistently projected using a variety of models and methods. Projected impacts of warming on the Earth and climate include: further retreat of glaciers, sea ice and polar ice sheets; sea-level rise; higher rainfall in some regions, but drying in others; more frequent flooding and drought; more powerful tropical cyclones; shifts in agro-ecological zones; and decrease in productivity of croplands and grasslands (Sahoo, 2004; IPCC, 2001).

Munasinghe and Swart (2005), Bolin *et al* (2000), IPCC (2001), Moomaw *et al* (2001), Bashmakov *et al* (2001), Kaupi *et al* (2001), and Sathaye *et al* (2001), have among them identified seven major sources of greenhouse gas emissions, and the contributions of each source to global \emissions. They are (i) the domestic sector, which contributes almost one-third to global energy-related carbon dioxide emissions; (ii) the transport sector, which has the most rapidly rising greenhouse gas emissions worldwide, and contributes more than 20% of global energy-related carbon dioxide emissions; (iii) the industrial/ manufacturing, which contributes more than 40% to global carbon emissions; (iv) the energy sector, particularly fossil fuel production, transport, conversion, and utilization, which contributes more than one-third to global carbon-derived emissions; (v) the agricultural sector, which contributes to greenhouse gas emissions in three ways, namely (a) through vegetation removal, land use changes, and fossil fuel consumption on farms, which contribute between 21-25% of global carbon dioxide emissions, (b) various agricultural activities such as rice paddies, land-use changes, biomass burning, enteric fermentation of ruminant livestock, and animal waste, which cause 55-60% of the global emissions of methane, and (c) nitrogenous fertilizers and animal wastes, which cause 65-80% of global emissions of nitrous oxide; (vi) waste management, which affects greenhouse gas emissions through methane emissions from landfill, substitution of fossil fuels by waste combustion, material and energy savings in extractive and manufacturing industries by recycling, carbon storage in forests because of decreased demand for virgin paper through recycling, and energy use related to transport of waste; and (vii) forest ecosystems, which through deforestation, release between 1.1 and 1.7 Gt of carbon per year to the atmosphere (Bolin *et al.*, 2000).

This paper focuses on the last of these seven major sources of greenhouse gases, namely forest ecosystems, and the biological mitigation options for greenhouse gases. Biological mitigation options relate to the potential of the biosphere to sequester carbon from the atmosphere and store it, i.e. in forests and agricultural soils, often called 'carbon sinks'. About 100 Gt of carbon can be sequestered by biological mitigation options over the next half century (Kauppi *et al.*, 2001). These options deserve separate attention because the potential is considerable, especially in the tropical regions. In addition, there is a very evident link between these options and wider sustainable development strategies (Munasinghe and Swart, 2005), thus warranting special treatment. Mitigation options relating to agricultural soils in the tropics have been dealt with in some detail elsewhere (Gatsi and Muzari, 2010; Bationo *et al.*, 2000; Dalal and Carter, 2000; Lal and Kimble, 2000). Therefore, the following sections will focus primarily on climate change mitigation options with particular reference to tropical forest ecosystems.

2. Tropical Forest Ecosystem Carbon and the Impacts of Human Activities on Greenhouse Gas Emissions

Tropical ecosystems play an important role in global processes, economic issues and political concerns. Among numerous processes, tropical ecosystems affect the global carbon cycle. In their natural state, tropical ecosystems support a large quantity of above-ground and below-ground biomass, and constitute a major part of the terrestrial carbon (C) pool (Lal *et al*., 2000).

The relative importance of tropical forests in the global carbon cycle has been debated over the past four decades, with several estimates of their contribution to the increase in atmospheric carbon dioxide (Woodwell *et al*., 1978; Houghton *et al*., 1987; Detwiler and Hall; 1988; Hall, 1989; Post *et al*., 1990; Woomer *et al*., 2000). Currently, there is a general agreement, based on land use change data and atmospheric change data, that the tropics are a net source of C to the atmosphere (in the range of 1.1 to 2.1 x 10^{15} g per year, i.e. 1.1 to 2.1 billion tons of C per annum). The primary cause of this net source is deforestation in the tropical regions. Sanchez *et al*. (1994), estimate total tropical deforestation to be nearly 630 million hectares, with 120 million hectares of these lands subject to shifting cultivation or slash-and-burn agriculture.

Deforestation, primarily in the tropics, currently releases between 1.1 and 1.7 Gt of carbon per year to the atmosphere (Bolin *et al.*, 2000). There have been several long-term scenario studies with very different outlooks, the difference being caused by different assumptions and methods with reference to the development of the driving forces. There are two groups of long-term scenarios (Alcamo and Swart, 1998). According to one perspective, decreasing rates of population growth, continuous increases in agricultural activities, and increased emphasis on forest conservation lead to decreasing rates of deforestation and associated net carbon emissions from now onwards (Munasinghe and Swart, 2005). According to another perspective, continued pressure on the forests (e.g. by logging enterprises and landless farmers) will lead to increased rates of deforestation in the next decades (Munasinghe and Swart, 2005). This second perspective gains more credibility when historical and current trends are taken into account, as evidenced by empirical results reported in an increasing body of literature.

For example, Woomer *et al*. (2000) reports that forests in developing countries (located largely in tropical regions) are ravaged by indiscriminate cutting, with accompanying degradation of soils, silting of rivers and desertification. The greatest destruction of biological communities in forests has occurred during the last 150 years (Woomer *et al*., 2000). Human numbers have increased because birth rates have remained high while mortality rates have declined as a result of both modern medical discoveries (especially control of disease) and the presence of more reliable food supplies (Woomer *et al*., 2000). Population growth has slowed down in the industrialized countries of the world but is still high in many parts of tropical Africa, Latin America and Asia, where the greatest forest biological diversity is found (Woomer *et al*., 2000).

Deforestation in tropical regions releases large quantities of greenhouse gases that are significant both in their present impact and in terms of their implied potential for long-term global warming from continued clearing of remaining forests (Fearnside, 2000). Both tropical forest and tropical savanna ecosystems are the last frontiers. These tropical systems are being rapidly converted to arable, pastoral and silvicultural land uses in Africa, Australia, Asia, Central and South America. Consequently, large amounts of C (as CO_2 and CH_4) are emitted from these ecosystems to the atmosphere (Fearnside, 2000). Therefore, land use and land cover changes in these eco-regions are directly related to concerns about the "greenhouse effect". Tropical deforestation accounts for about 15% of total global warming potential comprising 10% due to CO_2, and 5% due to other trace gases (e.g. N_2O, CH_4 and NO) (Lal and Kimble, 2000). The annual rate of tropical deforestation is about 20 million hectares. Deforestation leads to emissions of CO_2, N_2O and NO_X when the biomass is removed, burnt, or allowed to decompose. Estimates of CO_2 release by deforestation range from 4.0 x 10^{14} g to 2.5 x 10^{15} g per year (Lal and Kimble, 2000). Depending on the subsequent land use and management, there also occurs loss of soil organic carbon pool.

The growing demand for fuelwood and other forest products and a market for medicinal plant species have threatened forest resources and thereby hampered sustainable human development (Anderson, 1992). Further, the race for development and cultivation of improved varieties has also threatened forest resources. Some causes of tropical deforestation include development pressure (construction, forest based industries, mining, oil drilling, resource extraction, and roads); encroachment (agriculture, expansion of forest villages, grazing by domestic animals, new settlements, shifting cultivation or slash-and-burn agriculture); exploitation (collection of plants by scientific/ educational institutions, firewood collection, game hunting [i.e. setting fires to clear forests to ease hunting], timber harvesting and unregulated collection of medicinal plants); and human resources (inadequate trained human resources in forest management strategies and utilization techniques, ignorance/ lack of awareness, inappropriate land use, lack of effective management, dilution of traditional conservation values, human harassment by forest/ game guards, ignoring local people's needs by

governments in the planning of forest and wildlife resources, and lack of political will in conservation) (Dasmann *et al*., 1973; Anderson, 1992; Kumar and Asija, 2004).
Farmers practicing slash-and-burn agriculture are clearing forests to produce food and seek improvements in the standards of living of their families. In most cases, they are marginalized from society and government support programmes, and live in relative poverty (Kumar and Asija, 2004). In addition, shifting cultivation is often practiced because farmers are unwilling to spend the time, effort and other resources to develop more permanent forms of agriculture on land that they do not own and may not occupy for very long. Some rural poor destroy biological resources because they are poor and have no land of their own (Browder, 1988; Downing et al., 1992). In many countries, there is extreme inequality in the distribution of wealth, with the majority of the wealth (good farmland, timber resources, etc.) owned by a small percentage of the population. A common pattern in many tropical countries is that local farmers are forced off their land by large landowners and business interests, often backed up by the government, the police, and the army. These local farmers have no option except to migrate to remote, undeveloped forest lands and attempt to eke out a living through shifting cultivation (Woomer e*t al*., 2000). Political instability, lawlessness, and war, also force farmers off their land into these remote areas where they feel safer. Shifting cultivation is a major contributor to the emission of greenhouse gases from tropical forest ecosystems. Efforts to reduce deforestation and greenhouse gas emissions from deforestation must address these root causes (Woomer et al., 2000).
An additional problem causing tropical deforestation has to do with funding of development projects (Goodland, 1992). Forest resources are concentrated in the tropical countries of the developing world, much of which are relatively poor (Primack, 1993). These countries are often willing to conserve forests, but they are often unable to pay for the needed research, habitat preservation, management and infrastructure required for the task (Rich, 1990). Increasingly, groups in the developing world are realizing that if they want to preserve forest biological diversity in species-rich but cash-poor countries, these groups must pay for it themselves (Goodland, 1992). However, the rate of tropical deforestation and habitat destruction has sometimes been accelerated by poorly conceived development projects whose aim has been economic development at the expense of destroying natural ecosystem resources over a wide area (Primack, 1993). Because of this outcome, some of the multi-lateral development organizations implementing such projects are now making the conservation of biodiversity part of their assistance policy, and are requiring new projects to be more environmentally responsible (Norse, 1987; Rich, 1990; Goodland, 1987, 1989, 1992; Pearl, 1989).

3. Tropical Forest Ecosystem Resources Management and Mitigation of Greenhouse Gas Emissions

The strategies for controlling or reducing greenhouse gas emissions from tropical forests fall into five categories, namely:

a) conservation and sustainable utilization (protected forests, nature reserves, national parks, ecotourism, and bioprospecting);
b) forestry and agroforestry activities (reforestation, afforestation, agroforestry, protection, agricultural intensification);
c) interdisciplinary management approach;
d) substitution of biological products for fossil-fuel or energy-intensive products
e) international level participation

3.1. Conservation and Sustainable Utilization

One of the more formal steps in protecting biological communities (including forests and forest products) is the establishment of legally protected areas (Meffe and Carroll, 2004). While legislation and purchase of land will not by themselves ensure forest conservation, they represent an important starting point (Meffe and Carroll, 2004). Protected areas can be established in a variety of ways, but the two most common are government action (often at a national level, but also locally and regionally), and purchases of land carried out by private conservation organizations. Protected areas can be governed by laws that allow various degrees of commercial resource use by local people, and recreational use (Barnes, 2004).
Reserves designed to protect forests, game and other species must include local citizenry in their planning and must incorporate their traditional lifestyles into the resource if they are to be sustainable (Bass *et al*., 2004). Reserves cannot be “locked away” from humans; they can provide sustainable means of livelihood and can thus receive critical local support (Barnes, 2004). However, in most cases only a few benefits are perceived as advantageous by local people. The most important effects of parks, as far as most Africans are concerned, are often negative: opportunity costs (due to the prevention of cultivation and grazing in the park), and crop damage caused by wild animals from the park (Bass *et al*., 2001; Meffe and Carroll, 2004).
If the purpose of a protected area is explained to local residents and most residents agree with the objectives and respect the rules of the park, then the area may maintain its natural resources (Lewis *et al.*, 1990). In the most positive scenario, local people become involved in park management and planning, are trained and employed by the park authority, and benefit from the protection and regulation of activity within the park. Also, a portion of the park revenues could be used to fund community projects such as schools, clinics, roads, and community businesses, which benefit the whole village or community (Lewis *et al*., 1990). At the other extreme, if there is a history of bad relations and mistrust between local people and the government, or the purpose of the park is not explained adequately, the local people may reject the park concept and ignore park regulations. In this case, the local people will come into conflict with park personnel to the detriment of the park (Lewis *et al*., 1990).
Park managers throughout the tropical regions frequently cite conflicts with local people as their most serious constraint. The major problems are associated with the illegal collection of wildlife, removal of plant materials, poor relations with local people, and conflicting demands with local people (Machlis and Trahnell, 1985). In the developing world, local people typically obtain the products they need, including food, fuelwood, and building materials, from the environment (McKinnon *et al*., 1992). Without these products, some local people may not be able to survive (Clay, 1991). If the park provides overall benefits to local human communities in terms of employment, revenue sharing, and regulated access to natural products, then the community may accept the park. It is to be

expected that when the existence of a park prevents local people from obtaining the resources they need to survive, they will resist park regulations; Dasmann, 1991). In order to survive, local people will violate park boundaries, sometimes resulting in confrontation with park officers. In effect, the creation of a national park often turns local people into poachers, even though they have not changed their behaviour (Clay, 1991). Even worse, they may begin to exploit the resources of the park in a destructive manner. In the last few decades conservationists have been forced by the growing conflict between parks and local communities to rethink the way protected areas should be managed. They are working to reconcile the goals of conservation with the need to enhance the welfare of the surrounding communities (McKinnon *et al*., 1992).

Ecotourism is emerging as a popular approach to protecting natural forests throughout the world, particularly in tropical areas. Ecotourism is estimated to bring in ten times more revenue than either hunting or plantation agriculture in some African countries (Lindberg, 1992; Ceballos-Lascurain, 1993). By itself, ecotourism is not the answer to environmental destruction, but if carried out properly, and in concert with other protective measures, it can contribute to ecologically sustainable and economically rewarding use of natural resources (Mendelsohn, 2004).

Bioprospecting is another possible measure for sustainable utilization and conservation of tropical forests (Bass *et al*, 2000). It refers to the exploration of forests for commercially valuable genetic and biochemical resources including crop genes, medicines, insecticides, enzymes, micro-organisms, fragrancies and fungicides, although to date this has been dominated by the search for products with a possible pharmaceutical value (Bass et al., 2001). Bioprospecting has come to be viewed as a possible means to realize the potential of forest biodiversity values that have so far not been tapped. It, therefore, offers a possible win-win opportunity for bolstering commercial, livelihood and conservation goals (Reid *et al*., 1993; Ten Kate, 1995; Bell, 1997).

3.2. Forestry and Agroforestry Activities

More than 90% of the tropical land will remain outside of protected areas, according even to the most optimistic predictions (Primack, 1993). Strategies for reconciling human needs and conservation interests in these unprotected areas are critical to the success of conservation plans (Primack, 1993). An important opportunity for conservation outside of protected areas is the chance to participate in the restoration of damaged or degraded ecosystems. Some ecosystems are so degraded by human activity that their ability to recover is severely limited. Restoration of degraded savanna woodlands is not possible as long as the land continues to be overgrazed by introduced cattle; reduction of the grazing pressure is obviously the key starting point in restoration efforts (Primack, 1993). Recovery is also unlikely when many of the original species have been eliminated over a wide area. For example, grassland biological species have been eliminated when the land was converted to agriculture. Restoration ecology provides theory and techniques to address the various types of degraded ecosystems.

Three main approaches are available in restoring biological communities and ecosystems. They are:

(i) *restoration* of the area to its original species composition and structure by an active programme of reintroduction, in particular planting and seeding of the original species;
(ii) *rehabilitation* of at least some of the ecosystems functions and some of the original species, such as replacing a degraded forest with a tree plantation;
(iii) *replacement* of a degraded ecosystem with another ecosystem type, for example replacing a degraded forest area with a productive pasture (Cairns, 1986; Bradshow, 1990).

To be practical, restoration ecology must also consider the speed of restoration, the cost, the reliability of the results, and the ability of the final biological community to persist with little or no further maintenance (Bradshow, 1990). Practitioners of restoration ecology must have a clear grasp of how natural systems work and what methods of restoration are feasible (Cairns, 1986).

Owing to the large proportion of tropical ecosystem C residing in trees of the tropical forests, the obvious opportunities to conserve or sequester carbon involve the protection or reestablishment of trees (Woomer *et al*., 2000). Forestry activities and agricultural management techniques such as reforestation, afforestation, and agroforestry, are a strategy of sequestering carbon pools by adding to the carbon pools. First, forest plantations can be established. Already, 61.3 million hectares were under forest plantations worldwide by 1990, and this is increasing by, on average, 3.2 million hectares each year, balancing part of the carbon losses from deforestation (Munasinghe and Swart, 1995; Makundi *et al*., 1998). Carbon sequestration by such terrestrial ecosystems provide an active mechanism of biological removal of carbon dioxide from the atmosphere (Munasinghe and Swart, 2005). They act as reservoirs of photosynthetically-fixed carbon by storing it in various forms in plant tissues and dead organic material. Second, the amount of carbon stored in existing forests can be increased through various forest management techniques, including protection against fire, diseases, herbivores, insects, and other pests; changing rotation; controlling stand density; enhancing available nutrients; water table control; species and genotype selection; biotechnology; reducing regeneration delays; reduced-impact logging; managing logging residues; recycling wood products; and improving forest product manufacturing efficiency (Kauppi *et al*., 2001).

From a sustainable development point of view, establishing forest plantations and actively managing forests for maximizing carbon sequestration can have other positive and/ or negative side-effects. Plantations can affect biodiversity negatively if they replace biologically rich native grassland, wetland habitats, or natural forest (Munasinghe and Swart, 2005). In addition, there could be negative social effects, e.g. interference with resource utilization opportunities for local people, displacement of local populations, and reduction of incomes (Munasinghe and Swart, 2005). Utilization of manure, artificial fertilizers and/ or pesticides in plantations can have negative consequences for local soil and water quality. On the other hand, forest plantations play three important roles, as physical pools of carbon; substitutes of more energy-intensive materials; and raw materials to generate energy (Burschel, Kuerston & Larson, 1993; Matthews *et al*., 1996). Another positive side-effect is that forest plantations reduce the pressure on natural forests, leaving greater areas to provide for biodiversity and other environmental services (Sedjo & Botkin, 1997). Forests also help to conserve water resources and prevent flooding.

Agroforestry can both sequester carbon and produce a range of economic, environmental and socioeconomic benefits. For example, trees help improve soil fertility through control of erosion, maintenance of soil organic matter and physical properties, increased nitrogen availability, extraction of nutrients from deep soil horizons, and promotion of more closed nutrient cycling (Young, 1997). Forest cover could also have secondary climate consequences through their feedback in the albedo of the Earth, the hydrological cycle, cloud cover, and the effect of surface roughness on air movements (Garrat, 1993).

An important criterion comparing the environmental benefits of various measures is their potential for deflection from deforestation (Woomer *et al*., 2000). Sanchez (1990) noted the important role of national agricultural policies in halting deforestation, particularly through government sponsored settlement programmes. Sanchez described the socioeconomic effects likely to result from widespread tropical deforestation. The effects occur when the poor with inadequate land, management skills and inputs migrate to tropical forests and practice shifting cultivation or 'slash-and-burn' agriculture. He speculated that each hectare placed into permanent, profitable agriculture has the potential to offset deforestation of 5 to 10 additional hectares by shifting cultivators, a concept known as "deflection from deforestation". Harwood (1996) describes the need for capital and technical inputs required within agricultural intensification, suggesting that they remain a barrier to agricultural change.

While it is acknowledged that agroforestry systems offer potential for carbon sequestration, it is debatable whether these systems deflect from deforestation. For example, in Cameroon, farmers adopted cacao agroforestry, but continued to clear forest margins to cultivate annual crops for food and market (Kotto-Same, 1997). Farmers in Theobroma who participated in carbon dynamics studies were converting degraded pastures to fruit orchards, but continuing to clear additional forest for pasture. It may therefore seem naïve to suggest that new agricultural opportunities are sufficient to eliminate the perceived need to clear forests (Woomer *et al.*, 2000).

3.3. Interdisciplinary Management Approach

It is not sufficient just to have environmentally sound management in tropical areas. Sustainable development must be integrated across disciplines (Hartshorn, 1994). Unless tropical forest management initiatives and projects are economically viable, socially responsible, politically acceptable, and ecologically sound, they have little chance of being sustainable, but more likely will be added to the long list of failed development projects (Hartshorn, 1994). Tropical forest systems can be managed on a sustained-yield basis for timber and non-timber forest products, while protecting biotic habitats and ecological services, generating adequate returns for local communities, promoting local well-being, and providing politically acceptable models for sustainable development (Hartshorn, 1994).

Sustainability in the management and utilization of tropical forest products can arise from a better understanding of local or regional biodiversity resources and their value to humanity at large (Sittenfeld and Villers, 2004). These resources are becoming better appreciated by drug companies and industries that are beginning to pay for the rights to use natural products found in developing countries. Such moneys are being ploughed back into the conservation of these biotic resources, thereby sustaining them in the long run (Sittenfeld and Villers, 2004).

3.4. Substitution of Biological Products for Fossil-Fuel or Energy-Intensive Products

Another category of options for biological carbon sequestration is the substitution of biological products such as wood for fossil fuels, or energy intensive products (Munasinghe & Swart, 2005). This category offers the potential for a continuous contribution to reduced carbon emissions. Wood, and its derivative, charcoal, can be used as a renewable source of energy, thereby replacing fossil fuels like oil, coal, and natural gas (Munasinghe and Swart, 2005). It can play this role most effectively if the combustion is as efficient as possible. This, however, is currently not the case in many in many applications, e.g. woodstoves for cooking, and brick production, etc, (Kauppi *et al*., 2001). Therefore, an important option is to enhance the efficiency of the combustion process and the production of charcoal (Kauppi *et al*., 2001).

It should be noted however, that fuelwood combustion has often detrimental effects for local and indoor air quality, and fuelwood supply is increasingly difficult in many tropical regions (Kauppi *et al.,* 2001). Woodburning stoves are therefore often replaced by kerosene stoves if incomes permit. In addition to fuel, wood can be used as construction material.

Options to increase long-term sequestration of carbon in wood products include the encouragement of production and consumption of wood products; improving their quality and processing efficiency; and enhancing their recycling and use (Kauppi *et al*., 2001).

3.5. International Level Participation

On the international arena, techniques and strategies of forest management have included the signing and implementation of international conventions on the environment, forest and biodiversity conservation (UN, 1993), and climate change (Munasinghe & Swart, 2005; Baker, 2006). While the major control mechanisms that presently exist in the world are based on individual countries, agreements at the international level are increasingly being used to protect forest species and habitats (de Klemm, 1990, 1993). One of the reasons why international cooperation is important is that there is international trade in biological products; a strong demand for a product in a wealthy country can result in the overexploitation of the species by people in a poor country to satisfy the demand (UN, 1993). To prevent overexploitation, control and management of the trade are required at both the points of import and export (UN, 1993). Second, the benefits of forest biodiversity are of international importance: the community of nations benefits from the species and varieties that can be used in agriculture and medicine, the ecosystems that help regulate the climate and control flooding, and the national parks and biosphere reserves that are of international scientific and tourist value (Dyer and Holland, 1991). Wealthy countries of the temperate zones that benefit from tropical forest biodiversity need to help the less wealthy countries of the world, located largely in the tropics, that preserve it. Finally, many of the factors that threaten ecosystems are international in scope and require international cooperation (de Klemm, 1993). Such threats include atmospheric pollution and acid rain, pollution of water bodies, ozone depletion, and the emission and buildup of greenhouse gases leading to global warming and global climate change.

It was not until 1987, when the World Commission on Environment and Development (WCED), published its report, *Our Common Future*, that the links between the social, economic, and ecological dimensions of development were explicitly addressed (WCED, 1987). *Our Common Future* is sometimes known as the Brundtland Report, because the WCED was chaired by the then Prime Minister of Norway, Gro Harlem Brundtland. The Brundtland Report set an international agenda for the promotion of sustainable development: the construction of effective, international cooperation to manage ecological and economic interdependencies (Baker, 2006).

By the 1990s there were a number of specific international environmental regimes, dealing with an array of environmental factors, from hazardous waste, ozone depletion and biodiversity loss to climate change (Baker, 2006). An international environmental regime exists when there are agreed-upon formal and informal institutional structures, principles, norms, rules and decision-making procedures and action programmes to address a specific environmental issue (Young, 1997).

The main events in international environmental governance up to 2002, are summarised in Baker, pp. 69-70). They include the UN Environment Summits: UN Conference on the Human Environment, Stockholm, 1972; UN Conference on Environment and Development, Rio de Janeiro, 1992 also known as the Earth Summit; UN General Assembly Special Session to Review Agenda 21, New York, 1997; and the World Summit on Sustainable Development, Johannesburg, 2002.

Some related conferences include the International Conference on Population and Development, Cairo, 1994; the World Summit for Social Development, Copenhagen, 1995; Fourth World Conference on Women, Beijing, 1995; UN Conference on Human Settlements, Habitat I, Vancouver, 1978; First Global Ministerial Environmental Forum, Malmo, Sweden, 1999; and the UN Conference for Financing Development, Monterrey, 2002.

Major environmental Reports and Declarations include the *First Report of the Club of Rome,* 1972; UNEP *World Conservation Strategy*, 1980; WCED, *Our Common Future*, 1987; *Rio Declaration on the Environment and Development*, 1992; *Agenda 21*, 1992; *We the Peoples*, millennium report of the UN Secretary General, 2000; WTO Doha Declaration, 2001; Monterrey Consensus. 2002; and the Johannesburg Declaration on Sustainable Development, 2002.

Major developments in international environmental law include the Vienna Convention on the Protection of the Ozone Layer, 1985; Montreal Protocol on Substances that Deplete the Ozone Layer, 1987; UN Framework on Climate Change, 1992; Kyoto Protocol, 1997; Cartagena Protocol on Biosafety, 2000; and the UN Convention to Combat Desertification, 1995.

Examples of international treaties and programmes with specific focus on forests and biodiversity include the Convention on International Trade in Endangered Species (CITES); the Convention Concerning the Protection of World Cultural and Natural Heritage; UN Convention on Biological Diversity, 1992; Forest Principles, 1992; and the UNESCO Biospheres Reserves Programme, just to name a few (United Nations, 1993, Dyer and Holland, 1991; Baker, 2005).

The role of the international conservation community in sustainable forest and natural resource management, biodiversity conservation, and climate change mitigation, involves meeting several challenges, namely (i) *getting at the source*, or supporting development that is economically and ecologically sustainable; (ii) *dealing with the effects*, or enforcing environmental protection measures and resource management; (iii) *assessing global risks*, or identifying, assessing and reporting on risks of irreversible damage to natural systems and threats to the survival, security and well-being of the world community; (iv) *making informed choices*, or supporting the involvement of an informed public, NGOs and the scientific community; (v) *providing legal means*, or ensuring that national and international law keeps up with the accelerating pace and expanding scale of impacts on the ecological basis of development; and (vi) *investing in our future*, or ensuring that multilateral financial institutions make a fundamental commitment to sustainable development, and that bilateral agencies adopt a new priority and focus (WCED, 1987; Baker, 2005).

The international conservation community can help to establish the guidelines and find opportunities to protect biological diversity, sustainably manage forest ecosystem resources, and mitigate climate change. But in the end, it is up to national and local governments to determine their own conservation priorities. In recent years, the preparation and implementation of National Environmental Action Plans, and Tropical Forest Plans, has characterized conservation initiatives at the national level (Primack, 1993).

4. Conclusion

The paper has reviewed and analyzed forest resource problems and management strategies in the tropics, as identified and recommended by ecologists, land management specialists, biological and chemical scientists, meteorologists, and conservationists. The rapid increase in atmospheric concentration of CO_2 and other greenhouse gases like methane and dinitrogen oxide has raised numerous questions of global significance. Some of the questions which this paper has sought to answer are: What is the role of tropical forest ecosystems as sources or sinks of atmospheric carbon dioxide? How do anthropogenic perturbations (i.e. human activities) affect atmospheric carbon dioxide concentrations? What is the role of tropical forests in the global carbon cycle? What forest management options can exploit the full potential of these resources to mitigate greenhouse gas emissions and the resultant changes in climate?

The paper has addressed these questions from a sustainable tropical ecosystem resources management perspective. In particular, current problems caused by human activities in tropical regions were highlighted, the aim being to find feasible, practical methods for reducing the concentration of carbon dioxide and other greenhouse gases in the atmosphere. The ultimate goal is to minimize global changes in climate arising from the “greenhouse effect” and global warming.

The application of appropriate forest ecosystem management techniques will result in the enhancement of tropical ecosystems as sinks of atmospheric carbon, reduction in the rates of emission of carbon dioxide, methane, and other greenhouse gases from these ecosystems to the atmosphere.

The final impact will be a mitigation of the greenhouse effect and global warming, together with the resultant chain of disastrous events. Effects offset through mitigation include the melting of mountain glaciers and thawing of polar ice-caps, which would lead to a rise in ocean levels and the flooding and inundation of low-lying coastal areas, posing a danger to human and animal life and economic activity; high incidence of hurricanes and cyclones; more flooding during monsoons; shifting of the zones suitable for agriculture; decrease in productivity of croplands and grasslands; increase in droughts and floods; high mortality of flora and fauna which may not be able to cope with frequent environmental changes; significant desertification of what are now temperate zones; etc.

There are three main approaches to biological mitigation of carbon emissions through tropical forest ecosystems management. The first approach involves the protection of existing carbon reservoirs (i.e. forests). This entails slowing down or stopping tropical deforestation. Techniques available to achieve this include conservation and sustainable forest utilization activities. Examples include the establishment of legally protected areas such as scientific reserves and strict nature reserves, national monuments and landmarks, managed wildlife sanctuaries and nature reserves, protected landscapes, resource reserves, national biotic reserves, anthropological reserves, and multiple management areas. Ecotourism is emerging as another popular approach to protecting natural forest areas in the tropics. Bioprospecting has come to be viewed as another possible measure for sustainable utilization and conservation of tropical forest ecosystem resources.

The second approach to biological mitigation of carbon emissions involves expanding existing carbon reservoirs and creating new ones. This can be achieved through forestry and agroforestry activities such as establishing forest plantations, growing fruit trees on agricultural lands, reforestation, afforestation, and agricultural intensification.

The third approach involves reducing fossil fuel emissions by substituting fossil fuels with biological products.

To ensure and guarantee sustainability in biological mitigation using the above three approaches, an interdisciplinary forest ecosystem management approach needs to be adopted. Incorporating different relevant disciplines in planning, designing, implementing and managing tropical forest initiatives and projects will ensure their sustainability. The forest initiatives and projects are therefore likely to become economically viable, socially responsible, politically acceptable, culturally relevant, and ecologically sound. A necessary condition for this interdisciplinary approach is the involvement of all stakeholders, including local communities, political structures, religious organizations, NGOs and environmentalists, in the design and operation of forest conservation activities.

On the international arena, techniques and strategies for forest management include the signing and implementation of international conventions, treaties, and protocols on forest and biodiversity conservation.

Adopting the strategies, techniques and practices of sustainable forest ecosystem resource management and conservation can lead to the control and reduction of emissions of greenhouse gases from tropical forest and agricultural ecosystems into the atmosphere. The end results are the control of, and reduction in, atmospheric concentration of greenhouse gases, thus mitigating the effects of global warming, climate change and its attendant disorders.

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