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Tropical ecology: an overview

S.P. SINGH[1,2,*] & C.M. SHARMA[1]

[1]*H.N.B. Garhwal University, Srinagar, Uttarakhand*
[2]*CHEA, 09, Weldorf Compound, Mallital, Nainital, Uttarakhand 263001*

Abstract: This article briefly describes the major tropical biomes, outlines various forces that are currently driving changes in human-natural ecosystem interactions, and discusses the Himalaya - Gangetic Plains relationships. Tropical rain forests of different continents differ widely in key biological factors and threats to which they are subjected. In Amazonia and Himalayas - Gangetic Plains system, tropics have two extraordinary systems of global significance. While Amazonia stands out for its unbelievable biodiversity and the sheer dimensions of the river basin, Himalayan ecosystem services sustain the agricultural activity in the Gangetic Plains that supports nearly 500 million people. Tropical countries are predicted to suffer more from global warming, and it will be a great setback to the poor of the world who only now have begun to taste some benefits of a rapid economic growth. Tropical countries have comparatively much lower eco-footprints than developed countries, but situation is changing at least in some countries. There is a positive relationship between per capita GDP and environmental quality, but this may not hold true for a much larger population at a high consumption rate .The temperate region countries could maintain a clean environment despite their high per capita consumption, partly by exploiting environment of other countries. Tropical countries would not have freedom to exploit environment of other countries, and their development activities are going to encounter a severe energy crisis, and problems of a world the carrying capacity of which has already been exceeded.

Resumen: Este artículo describe brevemente los principales biomas tropicales, esboza varias fuerzas que en la actualidad están provocando cambios en las interacciones entre los humanos y los ecosistemas naturales, y discute las relaciones en las Planicies Himalayo-Gangésicas. Los bosques tropicales lluviosos de diferentes continentes difieren ampliamente respecto a factores biológicos clave y las amenazas a las que están sometidos. En la Amazonía y en el sistema de las planicies Himalayo-Gangésicas los trópicos poseen dos sistemas extraordinarios de importancia mundial. Mientras que la Amazonía destaca por su increíble biodiversidad y las puras dimensiones de su cuenca fluvial, los servicios ecosistémicos himalayos sostienen la actividad agrícola en las planicies gangésicas que dan sustento a casi 500 millones de personas. Se predice que los países tropicales sufrirán más por el calentamiento global y esto representará un gran retroceso para los pobres del mundo que apenas ahora comienzan a saborear algunos de los beneficios de un crecimiento económico rápido. Los países tropicales dejan huellas ecológicas comparativamente mucho menores que los países desarrollados, pero la situación está cambiando por lo menos en algunos países. Hay una relación positiva entre el PIB per capita y la calidad ambiental, pero ésta podría no mantenerse para una población mucho más grande con una tasa de consumo alta. Los países de la región templada podrían mantener un ambiente limpio a pesar de su alto consumo per capita, en parte gracias a la explotación del ambiente de otros países. Los países tropicales no tendrían la libertad de explotar el ambiente de otros países y sus actividades dirigidas al

* *Corresponding Author*; e-mail: surps@yahoo.com

desarrollo enfrentarán una crisis energética severa, así como los problemas de un mundo cuya capacidad de carga ya fue rebasada.

Resumo: Este artigo descreve de uma forma breve os principais biomas tropicais, salienta as várias forças de mudança nas interacções homem-ecossistemas naturais, e discute as relações Himalaias - Planícies Gangéticas. As florestas tropicais de chuvas dos diferentes continentes diferem substancialmente quanto aos factores biológicos chave e ameaças a que estão sujeitos. Nos trópicos, na Amazónia e no sistema Himalaias – Planícies Gangéticas, há dois sistemas extraordinários de significância global. Enquanto as parcelas no Amazonas sobressaem pela sua biodiversidade inacreditável e a extraordinária dimensão da sua bacia hidrológica, os serviços do ecossistema dos Himalaias sustentam a actividade agrícola das planícies Gangéticas que suportam cerca de 500 milhões de pessoas. Prevê-se que os países tropicais venham a sofrer mais por via do aquecimento global e será um grande contratempo para os pobres do globo que só agora principiaram a experimentar alguns benefícios do rápido crescimento económico. Os países tropicais têm comparativa mais baixos traços ecológicos do que os países desenvolvidos, mas a situação está mudando pelo menos em alguns países. Há uma relação positiva entre a capitação do PDB e a qualidade do ambiente, mas isto não deverá manter-se assim para uma população muito mais alargada a uma mais alta taxa de consumo. Os países da região temperada podem manter um ambiente limpo não obstante as suas elevadas taxas de capitação do consumo, parcialmente pela exploração do ambiente de outros países. Contudo, os países tropicais não têm a liberdade para explorar o ambiente de outros países, e as suas actividades de desenvolvimento vão defrontar severas crises energéticas, e problemas da capacidade mundial de sustentação as quais já se encontram ultrapassadas.

Key words: Amazonia, climate change, conservation issues, eco-footprints, Himalaya-Gangetic system, forest degradation, tropical rainforests.

Introduction

The tropical ecosystems, spread across a wide range of eco-climatic conditions along equatorial region, represent oppressively hot lowlands to snow-clad mountains and areas of unusually sharp seasonality in precipitation to persistently humid conditions (Dickinson & Murphy 2007). Such a variation in the climate has given rise to a wide range of ecosystems such as tropical rain forests, cloud forests, moist and dry deciduous forests, savannahs, grasslands and deserts. Variation in temperature due to sharp gradient in elevation in the tropical mountains can have more profound effects on the dispersal of flora and fauna than in temperate regions. There are many more wet areas, with annual precipitation above 2500 mm in tropical zone than in temperate and boreal zones. At the same time several areas fall within the region of very low (< 200 mm) precipitation.

Of all the tropical ecosystems, the tropical wet evergreen forests, popularly known as rainforests are most spectacular and have attracted most attention of ecologists and conservationists world wide (Mittermeier *et al.* 2000; Primack & Corlett 2005; Whitmore 1998). When we think of these forests, several mental images begin to rush: multi-layered stands with tall trees of numerous species, branches covered with epiphytes many of which store water in the cup like leaf bases, several forms of primates, pollinating birds in canopy interspersed with gliding animals, and a great variety of insects which, possibly can never be counted. These forests have enormous conservation significance as at least 80% of the human diet in developed world originated in the tropical forests. At least 3000 fruit species are found in the rainforests, of which only 200 are now in use in the western world. They play a key role in the protection of the global environment against global warming, as potential carbon sinks, regulated and managed through global economic and financial instruments (Cramer *et al.* 2004; Niesten 2002).

Though the tropical rainforests cover only 7 per cent of the earth's surface, they are home to nearly half of all the species and about 70-80 per cent of tree species that occur on this planet. Currently, tropical deforestation and its consequences, particularly the depletion of biodiversity and emission of green house gases (GHG) in the atmosphere are the principal areas of global environmental concern. The greatest rate of species extinction since last dinosaurs disappeared is taking place in the tropical rain-forests that circle the equator.

The humid tropics are also known for uncontrolled human population growth, poverty, shifting cultivation, seemingly uncontrollable diseases like malaria and now HIV. In fact, people believed until recently that the tropical countries are incapable of becoming wealthy. For the first time in the modern history, some tropical countries now have begun to taste the fruits of wealth. Some of them, like India are now slated to become major political power centres in future. Then, countries in tropics are getting increasingly connected to rest of the world in an increasingly globalize world.

In this paper we give an overview of ecology and conservation in tropical forests with special focus on rainforests. The range of floral and faunal diversity among various rain forests, gaps in the ecological information, conservation issues, linkages of rain and moist tropical forests within larger landscapes especially the Amazonian and Himalaya - Gangetic Plain Ecosystems, anthropogenic pressures and conservation perspectives at regional and global scales have been discussed.

The rainforests around tropics: an ecological review

The tropical rainforests are common in South-East (SE) Asia, Africa, South America, Central America, and many of the Pacific Islands. Minimum annual rainfall is between 1,750 mm and 2,000 mm. Mean monthly temperatures exceed 18 °C during all months of the year. These forests represent tall, dense, evergreen forest vegetation occurring in moist and hot areas with a short or no dry period. Characteristic features include exceptionally high biodiversity compared to other ecosystems, presence of several layers of vegetation, dominance of phanerophytes in the flora, generally nutrient poor soil, presence of highly efficient nutrient conservation mechanisms, and significant role of birds, bats and primates in seed distribution. Fruit bats and other gliding animals occupy canopy, apart from birds and primates. Among mammals, bats are most diverse groups in the tropical forests with an estimate of over 360 species (more than one-third of the total bat species known). Characteristic features of three important rainforest regions *viz*., South America (Neotropical), Africa and SE Asia have been summarized in Table 1.

Patterns of diversity

While about 200 tree species in a plot of 0.1 ha is quite common in them (Gentry 1982), other forests types seldom have more than 20-25 species in the same size. Rainforests are home to two-thirds of all the living animal and plant species on the planet. It has been estimated that many hundreds of new species of plants, insects, and micro-organisms are still undiscovered and, as yet, unnamed by science. Two reasons are often cited for high biodiversity in tropical rainforests: (i) high rate of speciation, and (ii) highly favourable environment for species (Linsenmair 1997). The latter implies that the extinction rate is much lower in tropics than in temperate region.

The Neotropical rain forests are characterized by abundance of Bromeliaceae in the canopy (Table 2). Members of this family have special devices to store water which is used by many canopy animals. These forests exhibit an extra-ordinary evolutionary diversification of humming birds and the red flowers of various taxa such as species of *Passiflora*, that are pollinated by birds since red colour stands out in the green background which can be distinguished by birds unlike insects; primates and cavimorph rodents diversified along very different lines with giant long-legged rodents partly filling niches occupied by ungulates in Africa and Asia; the fruit bats represent entirely separate evolutionary radiation with unique flight sensory and fruit processing abilities; unique are also leaf-cutter ants bringing cut-leaf pieces to their underground nests, and cultivating fungi. Plots having over 250 tree species per hectare have been recorded from western Amazonia (Primack & Corlett 2005). In the American rainforest, primate communities are dominated by arboreal, small to medium-sized (less than 12 kg) insects - and fruit-eating monkeys.

Table 1. A summary of the characters of three main rainforest regions (derived from Primack & Corlett 2005).

Parameters	South America	Africa	SE Asia
Representative geographical region and country	Amazon river and Andes mountains; Brazil	Congo river basin; Democratic Republic of Congo	Peninsula and Islands of Sunda shelf; Indonesia
Area (million ha)	400	180	250
Annual Precipitation (mm)	2000-3000	1500-2500	2000-3000
Key biological features	Abundance of Bromeliads, the epiphytes with water tanks; great diversification of humming birds as major pollinaters, abundance of small primates, fruit bats, leaf cutting ants, and so on.	Lower plant diversity, but more diverse in termites and primates; presence of forest elephants, and many large ground mammals, including gorilla the largest primate	Tall Diptecocarps, and also oaks and chestnuts; mast fruiting of many species coinncide over a large area; large primates common; abundance of gliding animals.
Number of plant species	93,500 [a]	20,000 [b]	61,700 [c]
Tree species richness (no per ha)	> 200	< 200	> 200
Overlap in plant species composition	Almost no Overlap among the three regions		
Tree basal area (m^2 ha^{-1})	30-45	30-70	30-45

[a] Most diverse also for birds, bats, and butterflies; [b] 12000 in Madagascar; [c]45000 in Indonesia and Malaysia, 10,000 in Indochina and 4000 in western Ghats of India.

Table 2. Important plant families in different rainforest regions (Source: Turner 2001). Italicized families are found only or almost only in that region. V=vines and climbers; E=primarily epiphytic family in rain-forests; H=large herbs, other families having predominantly trees.

South America	Africa	SE Asia
Leguminosae[1]	Leguminosae	*Dipterocarpaceae* (386 species)[*]
Vochysiaceae (*Vochysia*)	Dichapetalaceae	*Fagaceae* (oak and chestnut)
Bignoniaceae (*Catalpa*)	Oleaceae (African walnut)	Myrtaceae (*Eugenia* 500 species)
Chrysobalanaceae	Lauranceae (laurels)	Palmae (palm)
Lecythidaceae (Brazilnut)	Moraceae (fig)	Aselepidaceae (milkweed) E
Palmae (palm)	Palmae (palm)	Moraceae (Ficus 500 species)
Pandanaceae (screwpine)	Orchidaceae (orchid) E	
Bromeliaceae (pineapple) E	(fewer laurels, palms, epiphytes and	
Cactaceae (cactus) E	woody vines)	
Cyclanthaceae (Panama hat) V		
Passifloraceae (passion flower)		
Heliconiaceae (*Heliconia*) H		

[1] Highest number of species in 39 out of 43 sites investigated in a study (Source: Turner 2001).
[*] In the Himalayas that form the northern edge of tropical Asia, dipterocarps (at low altitudes) and oaks (*Quercus spp*, and also *Lithocarpus* and *Castanopsis*, at mid-altitudes) dominate forests.

The rain forests in Africa tend to be drier and less diverse than those of Neotropical region and SE Asia. However, they are more diverse in primates and termites. Megaherbivores such as elephants and largest primate – gorilla, are key features. Presence of unique endemic group of frugivorous birds, a diverse assemblage of lemurs are characteristic features of Madagascar, where tree species are reported to be as high as 200 ha^{-1}, unlike Africa (Turner 2001).

The rainforests in SE Asia are dominated by tall trees of Dipterocarpaceae. Of the 386 species of dipterocarps that occur in this region (Table 2), many of them show mast fruiting at 2-7 yrs intervals. Abundance and diversity of gliding animals is a common feature and so is presence of megaherbivores such as elephant and rhinoceros. These forests differ from other rainforests in having a fair representation (60 species) of gliding animals, including flying squirrels, flying geckos (40 species), flying frogs and flying snakes. With size ranging between 15-25 cm, *Draco* species can soar from tree to tree with the help of a brightly coloured fan made by expanding ribs. Plots with more than 250 tree species have been recorded from Sarawak, Malaysia (Turner 2001). In SE Asia, New Guinea has special significance in terms of flora and fauna. Characterized by Asian flora with un-Asian fauna, without primates or placental carnivores, this region has bats and rodents only placental mammals and marsupials occupy most other mammalian niches.

While at the level of plant families and genera overlap between the regions is substantial, it is almost absent at the species level (Table 1).

Primates vary across the tropical regions in diversity and ecological roles. For example, in many parts of tropics the primate population have dwindled due to over hunting studies required to know ecological consequences of local extinction of such primates and other animal communities which play key role in ecosystem functioning. Close relationship has evolved between different groups of organisms, such as birds and plants. For example, the American hummingbirds hover while they feed on flowers, whereas sunbirds in Africa and honey eaters in Australia usually perch while feeding (Westerkamp 1990). Several evolutionary questions related to plant animal interactions in various forests remain unanswered. Similarly, there is a need to build on the work of Pearson (1977) on differences in bird communities across major regions of tropical rainforests.

Gaps in ecological research

Do tropical rainforests differ from other forests also in ecosystem functioning as they do in species diversity? The data on ecosystem functioning on these forests in general, are so poor that it is difficult to make generalizations. The tropical forests contain about 25% of carbon in terrestrial biosphere or 59% in all forests (Bonan 2008). They can become the net source of carbon with temperature rise and moisture depletion. Accurate characterization of net primary productivity (NPP) of these forests will be fundamental for realistic global and regional carbon budgeting and for projecting how these will be affected by climate and the gaseous composition of atmosphere. On the basis of NPP data from about 70 old-growth forest sites, occurring between 23.5 N and 23.5 S lat. (Clark *et al*. 2001) following gaps in ecological research can be listed: (i) Some of the sample plots were extremely small (0.04-0.16 ha), and they could overestimate NPP values because of plot biases. (ii) All studies considered only aboveground net primary productivity (ANPP), and none had adequate data for belowground NPP components. Increment in coarse root was not directly measured, and biomass of coarse roots was measured only at a few sites by taking a few monoliths. (iii) Fine aboveground litter fall was most commonly measured, but because of large variations in the type of material collected and incomplete documentation of data, interpretation is problematic. Estimates of litter fall varied widely from 0.9 to 6.0 Mg C ha^{-1} yr^{-1}. (iv) Leaf herbivory was measured only at 5 sites, and biogenic volatile organic compounds (BVDCs) were not measured any where. (v) Compared to boreal forests, the proportion of total carbon in belowground part is far less in tropical forests.

Conservation status

Status within different countries

As shown in Table 3, because of the large forest area, with about 40% still as frontier forest, and moderate human population size approaching stabilization, situation in Brazil is still healthy. However, the high cattle population (close to human population) and ranching, sugarcane production (also to produce ethanol) and road development may assume serious threats to the future of the forest.

Unlike most developed countries, deforestation and other land use changes account for the large fractions (60-70%) of total CO_2 emission in tropics (Ayukawa *et al*. 2007). Popua New Guinea too has a high proportion of area under the frontier forest, but due to high fertility rate (4.3 per woman) and

Table 3. Some statistics indicting rainforest condition (Source: WRI 2003).

	S. America	Africa	SE Asia	Papua New Guinea	Madagascar
	Brazil	Democratic Republic of Congo	Indonesia		
Area of all natural forests (000 km^2, 2000)	5,389	1,351	951	305	114
Percentage of original forest cover remaining in 1996	66	60	65	85	13
Percentage of frontier forest (1996)	42	16	28	40	0
Annual change in forest cover (1990-2000)	-0.4	-0.4	-1.5	0.4	-1.0
Annual timber production (1990-2001 in million m^3)	234	69	124	9	10
Number of cattle (million) in 1996-98	163	1	12	0.1	10
Human population (million) 2002	175	54	218	5	20
Fertility (children per woman) 2000	2.2	6.7	2.3	4.3	5.7
Per capita GDP, US$, 2000	4,624	-	986	989	239

infrastructural development in future, the forest protection is not ensured. The rate of forest loss is the highest (1.5%) in Indonesia largely because of logging. Situation may improve with better economic options and given the fact that the population growth is slowing down.

Africa and Madagascar

Population growth and poverty are the greatest threat to rainforests in Africa and Madagascar. Since fertility rates are high (e.g., 6.7 childern per woman in Democratic Republic of Congo and 5.7 in Madagascar), threat to forests may increase further. However, when poverty is extreme, and infrastructure is poor, forests may be in good condition because of inaccessibility and remoteness. That is why Congo has large intact forests. With a larger human population density (up to 100 people km^{-2}), forest degradation is a serious problem in Madagascar. Based on ariel photographs and land set images, Harper *et al.* (2007) have reported decrease in forest area by 40% from 1950's to 2000, with loss of core forest (forest >1 km from non-forest edge) of about 80% since endemism is extremely high (85% of plants, 51% of birds, 90% of mammals, > 90% of reptiles, and 99% amphibians) many species are on the verge of extinction. Commercial hunting of wildlife for bush meat is a major threat to wild animals throughout the African continent (Wilkie & Carpenter 1999).

SE Asia

Logging and cash crop cultivation, such as oil palm, rubber and cocoa are the biggest causes of deforestation in SE Asia. For example, in Philippines much of the land was under forest cover until year 1900, but by 1992 only a small area of primary forest was left. Since timber of numerous dipterocarp species can be easily marketed, and dipterocarps generally dominate forest stands and make a good timber, a much larger proportion of forest stands is harvested in SE Asia than in other regions. Whitmore (1998) reported that from a hectare on an average 33 m^3 is logged from an Asian dipterocarp forest, compared to 13 m^3 from an African forest and 8 m^3 from a South American forest. Species with very dense wood (700 kg per m^3) which do not make a good timber are common in American forests.

Brazilian Amazon

Road construction with the aid of multibillion loans from World Bank, and other developmental activities are main causes of deforestation in Brazilian Amazon. The region was sparsely populated until recently (2 persons km^{-2}) except along rivers (2-10 persons km^{-2}). The new roads and encouragement of migration and economic activities particularly ranching and cultivation of crops led to a rapid deforestation during 1980s and 1990s (Morgan 1993). Though the rate of deforestation is only 0.4% per year because of large expanse of forests, each year huge areas are cleared. Logging, clearance for agriculture and now for the producing bio-fuels, fragmentation, hunting and infestation with alien invasive species, all have affected rain-forests of the world.

Key issues

Population, poverty, deforestation and forest degradation

Six out of 10 countries with the largest population in the world are in the tropics. The number is predicted to rise to 8 out of 10 countries by 2050 (Table 4). Some 1.1 billion people of the world lived below 1$ per day in 2001, according to a World Bank recent report. Nearly half of the sub-Saharan Africa (46%), and 31% of South Asia live on less than 1$ a day (Chen & Ravallion 2004).

In parts of Cameroon, Congo and Central African Republic, about 75% of the people live below poverty line of US $ 1 per day (Sayer *et al.* 2007). One of the major ecological consequences of poverty is the dependence of people on natural systems to meet their daily needs and degradation of forests and other ecosystems. Deforestation is generally taken as reduction in forest area due to tree cutting or forest clearing, and its estimates are often based on remote-sensed data. In tropics the loss of forest also occurs because of forest degradation, in which the size and density of standing crop keep on declining with no let up in biomass extraction and no respite to the system to recover. On a given day the biomass extraction is invisible; it may be in the form of collection of a few head loads of firewood, or tree leaf fodder or ground litter. Singh (1998) calls it chronic disturbance in contrast to acute disturbance in which whole trees are cut or forests are cleared from an area. The use of forest resources by local people for day-to-day living is common in much of tropics. The groups of such people are hunter-gatherers, shifting-farmers, forest-in-migrants, and permanent field farmers living near forests. People in Himalayan region, as an example collect firewood for cooking, fodder (both from woody plants and herbs) for their livestock, and litter from forest floor to prepare organic manure. Apart from these, people in tropics collect medicinal plants, mushrooms and morels, berries, seeds, flowers, honey, lichens, dyes, resins, canes, fodder, firewood, fibers and other non-timber forest products (NTFPs). Forests deteriorate even if biomass extraction is within the carrying capacity with respect to forest productivity because regeneration fails to occur.

Table 4. Ten most populous countries of the world in 2050 (Source: The Population Reference Bureaus 2007).

Country	Population (million)
India	1,747
China*	1,434
United States*	420
Indonesia	297
Pakistan	295
Nigeria	282
Brazil	260
Bangladesh	231
Democratic Rep. of Cango	187
Philippines	150

* Non-tropical

Tropical deforestation is known to contribute about 20% of yearly CO_2 accumulation in the atmosphere, however, there is no provision for giving incentives to people for protecting forests under Kyoto Protocol. Called as "avoided deforestation", it should be given importance in strategies addressing the global climate change. Rural Indonesia has become a major emitter of greenhouse gases (3.3 billion tons of CO_2 annually) almost entirely from deforestation. There are several other advantages associated with avoided deforestation in tropics including conservation of biodiversity rich areas. By getting credits for carbon sequestration, people may be motivated to avoid destructive logging and ranching. Carbon credit can also be used to address poverty reduction particularly for the people who live around forests. For those poor people even a $ 100 cash could be major incentive to avoid deforestation.

Then, hunting and poaching are quite common in some areas. According to an estimate of Bennett & Robinson (2000) in some African countries people obtain more than 20 percent of their protein from wild meat and fish. In Congo Basin, people consume more than 1 million tonnes of wild meat each year, which is equivalent to 4 million cattle (Wilkie & Carpenter 1999). Tropical forests are source of many western pharmaceutical products (Colfer *et al.* 2006). Traditional health care systems that have evolved around tropical forests play a significant role particularly where formal health care services are unavailable. In India alone about 500 million people entirely or partly depend on medicines derived from forests.

Climate change and tropics

Carbon uptake by forests account for ~ 33% of anthropogenic carbon emission from fossil fuel and landuse change. The role of forest in modifying the course of climate change is suggested to vary among major forest biomes. Climate model simulations indicate that tropical forests mitigate warming through the cooling that its evapo-transpiration (ET) brings about; in contrast the effect of boreal forests is a positive climate forcing (Bonan 2008). In Amazonia the large-scale conversion of forest to pastures has created a warmer and drier climate as ET and precipitation declined. Though tropical forests have lower albedo than grasslands hence cause warming, the effect is surpassed by strong cooling through ET. Unfortunately, future of tropical forests is at risk because of global warming and increasing human activities. Tropics were losing forests at the rate of 152,000 km^2 yr^{-1} during 1990's (Hassan *et al.* 2005).

One of the major impacts of global warming on countries is expected to be the change in land availability. While tropical countries are likely to lose land, cold regions may get additional land. Tropical areas being already hot, would become unbearably hotter with global warming and less desirable as human habitation (Easterbrook 2007). Most of these countries are still undeveloped with low capita CO_2 emission (Table 5), and have just begun to taste benefits of economic growth, India being the best example. Many of them, such as Bangladesh, Indonesia and India may lose land and face the problem of shifting people to safe areas as a consequence of rise in sea level or

Table 5. Per capita CO_2 emission in 2002 (metric tons): a comparison between temperate and topical countries (Source: Population Reference Bureaus 2007).

Tropical		Temperate	
Africa		Canada	16.5
Sudan	0.3	United States	19.9
Gunean Bissan	0.2	Sweden	5.9
Mali	0.1	United Kingdom	9.2
Nigeria	0.7	France	6.3
Senegal	0.4	Germany	10.5
Ethiopia	0.1	Netherlands	11.1
Kenya	0.3	Switzerland	6.2
Medagascar	0.1	Hungary	5.7
Tanzania	0.1	Romania	4.3
Uganda	0.1	Russia	10.6
Congo Democrative Republic	3.1	Croatia	4.8
Botswana	2.3	Greece	8.6
America		Italy	7.8
Costa Rica	1.3	Australia	17.3
Mexico	3.8	New Zealand	8.6
Panama	2.4	China	2.9
Brazil	1.9		
Colombia	1.4		
Asia			
Saudi Arabia	13.7		
United Arab Emirates	23.6		
Bangladesh	0.3		
India	1.1		
Indonesia	1.6		
Malaysia	5.6		
Philippines	0.9		
South Korea	10.6		

undesirably hot conditions. Unfortunately, these countries have high density of human population and are left with little unoccupied land. Since in many parts of tropics temperatures may be close to the higher side of tolerance ranges of many organisms including humans, further rise in temperature may threaten their survival. One computer model of future climate change due to greenhouse gas emissions shows that the Amazon rainforest could become unsustainable under conditions of severely reduced rainfall and increased temperatures, leading to an almost complete loss of rainforest cover in the basin by 2100 (Cox *et al*. 2000).

The tropical mountains including the Himalaya are getting warmer at a higher rate than global average. Consequently, the Himalayan glaciers are melting faster than glaciers of other regions, and it can have severe consequences on water supply in Indian subcontinent. Records are there to suggest that warming in Nepal increased progressively within a range of 0.2 and 0.6 ºC per decade between 1951-2001 (Jianchu *et al.* 2007). The loss of glaciers is expected to have impact on water resources in lowland regions, and may increase the rate of warming further by decreasing albedo.

Alien invasive species

The rapid invasion by alien species (AIS) is a major cause of concern in many parts of tropics. Although, the number of non-native species of birds and mammals decline drastically from temperate to tropical region when plotted in 5° latitudinal bands on the American continents (Elton 1958; Sax 2001), the proportion of AIS is much higher in the new world than the old world (di Castri 1989; Lockwood *et al.* 2006). Why are there more non-native species in one region than the other connected by commerce? Sax (2001) suggests that tropics have low number of non-native species because of the lower introduction attempts or lower sampling efforts; they may not be inherently less vulnerable to invasion. This could also be related to a much lower scale of the economic activities in tropics that cause the spread of non - native species- e.g., recreation, water reservoir and construction and movement of matter and humans.

Human migration - a demographic and environmental factor

Migration has always been a source of environmental change in human history. Its scale has expanded with globalization, and it is going to be the principal demographic factor, once global human population stabilizes somewhere around 2050. Migrations are both internal and international. People generally migrate from rural to urban areas, but rural-to-rural migration also occurs e.g., some people from high mountain villages of Nepal end up as agricultural labour in Indian Himalaya (Gran & Aide 2007). According to a UN report 191 million people worldwide are international migrants (data of 2005), but within countries migrants are far more. Migration driven by globalization, which is getting an irreversible trend, and related economic factors are expected to play a significant role in shaping the future of ecosystems, landuse and biodiversity.

The temperate-tropical divide and sustainability of resource use

The Stockholm conference of 1972 and Rio conference of 1992 are the two most important international events in the area of environmental sustainability of human enterprises. They are important because they represent the formal institutional arrangement in response to the people's concern for global environmental problems. The general anxieties of the people were driven by dooms day scenarios resulting from population explosion in developing countries, general shrinking of resource base and spreading pollution (Carson 1962; Meadows *et al.* 1972). While developed countries (mostly of temperate region) showed concern for environmental degradation resulting from industrialization, the developing countries (mostly of tropical region) highlighted poverty as the cause of environmental problems, such as soil erosion, desertification and diminishing water and forest resources. Recognition of poverty alleviation as the overriding factor of the environmental degradation in the Stockholm conference facilitated the forging of compromise between rich and poor countries, as the basis for further international programmes and accords. The World Commission on Environment and Development (WCED) (also known as Brundtland Commission) in its 1987

report, Our Common Future, clearly established that sustainable development would give importance to (i) inter-generation connections, (ii) alleviation of poverty and (iii) a bigger role of developing countries in global economic relations.

Conservation perspectives: regional and global

Possible role of developed countries

Developed countries cause deforestation because of their high consumption of timber, and other products like orange juice, meat, soybeans, paper, coffee, and bananas for the production of which forests are cleared. Rich people buy wild animals to keep them as exotic pets or for zoos, and medical experiments. They also affect rainforests by promoting loans from World Bank and International Monetary Funds, which are used to exploit them. Being the wealthy beneficiaries, developed countries should contribute to rainforest conservation far more than they do currently. Some of the steps are as following: (i) Stopping trade of the species directly threatened by export. The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) has been signed by over 160 countries. (ii) Paying premium for products produced without damaging the forests instead of boycotting the forest-related products (e.g., timber, soybean and palm oil). Certification scheme such as Forest Stewardship Council (FSC) can play an effective role. (iii) Carbon trade, that includes both avoiding deforestation and raising new plantations need to be made acceptable.

Role of protected areas

It has been increasingly recognised that local people's participation and support are necessary to implement conservation programs (Arnold 2002). To achieve peoples' support there is a need to keep livelihood concerns and future development needs at centre (Sunderland *et al.* 2007). About 15% of the current tropical forest area is under 1938 reserves, which collectively encompass 1.63 million km^2. However, some tropical protected forests have been referred to as ineffective "paper parks" (Currant *et al.* 2004), while many other reserves have been found to have much lower human activities such as livestock grazing, hunting, logging, shifting cultivation and fire than forests outside them (Nepstad *et al.* 2006). Wright *et al.* (2007) analysed the condition of tropical forest reserves by taking data on the incidents of fire inside 823 tropical and subtropical moist reserves. In 575 of 823 reserves, fire was detected between 2002 and 2004. The ratio of fire detection densities (detection per km^2) inside reserves to their contagious buffer areas was used as an index of reserve effectiveness. Reserves had always significantly lower fire density than buffer areas, but the ratio varied by five orders of magnitude among reserves. Countries which were poor and were beset by corruption such as Guatemala, Paraguay and Sierra Leone had high fire frequencies. The successful countries at reducing fire were Costa Rica, Jamaica, Malaysia, Taiwan and Indonesian island of Java. Integrated conservation and development projects have been designed to improve income levels of people, and their health care and education, as well as to improve conservation of biodiversity (Christensen 2004). In central Africa alone there are about 17000 'conservation refugees'. Obviously, there is a need to have more reliable data and to develop strategies that are based on multiple perspectives of conservation and income generation of poor people (Sunderland *et al.* 2007).

Amazonia and Gangetic watershed, the two extraordinary systems

Tropics have several extraordinary ecological systems, of which the two *viz.*, Amazonia and Himalaya-Gangetic systems are of global significance. They, however, differ in many ways. While the large expanse of tropical rain forest and the world's greatest river system are the main features of Amazonia, the "nursing effect" of Himalayan forests and rivers have created Gangetic Plain in Indian sub-continent, where about 500 million people live. While people are familiar with Amazonia's global significance contributions of Himalayas-Gangetic system are less appreciated.

The Amazonian rainforests

The Amazonian rainforest has been described as the "Lungs of our Planet" because it provides the essential environmental service of continuously recycling carbon dioxide into oxygen.

More than 20 percent of the world oxygen is produced here and these forests account for about 10% of the world's terrestrial primary productivity (Melillo *et al*. 1993) which represents 1.1 x 10^{11} MT of carbon (Tian *et al*. 2000). Amazonian forests are estimated to have accumulated 0.62 ± 0.37 t C ha^{-1} yr^{-1} between 1975 and 1996 (Tian *et al*. 2000). In terms of species diversity the Amazonian rainforests surpass all other forests of the world. A single hectare plot easily contains more than 250 tree species and 1500 species of higher plants. The region is home to about 2.5 million insect species, tens of thousands of plants, and some 2000 birds and mammals. To date, at least 40,000 plant species, 3,000 fish, 1,294 birds, 427 mammals, 428 amphibians, and 378 reptiles have been scientifically classified in the region (Da Silva *et al*. 2005). Scientists have described between 96,660 and 128,843 invertebrate species in Brazil alone (Lewinsohn & Prado 2005). One in five of all the birds in the world live in the rain forests of the Amazon. To date, an estimated 438,000 species of plants and animals of economic and social interest have been registered in the region with many more remaining to be discovered or catalogued. A pond in Brazil may have more fish than an entire river of Europe. Though human population is only about 30 million, deforestation rate is 18000 km^2 yr^{-1} since 1990; nearly 16% forests have already disappeared. Needless to say that the Amazonian rainforests need global attention in terms of long term conservation and scientific research.

The Himalayas and the connected Gangetic Plains

Being source of 9 river basins, the Himalaya are called the 'water towers of Asia'. These mountains have more area under snow and glaciers (35,000 km^2) than other regions outside the Polar Regions. Himalayas and the adjacent Gangetic Plains (GP) together form a great geo eco-anthropogenic system. Though the vast alluvial plain spreads north of the Tropic of Cancer, it is tropical because of the climatic control of massive Himalayan mountain chains that form a east-to-west arc of more than 2500 km with width generally between 200 km and 350 km. Temperature lapse rate in Himalayas (0.45 ^{0}C per 100 m rise in altitude) is possibly the lowest among mountains of the world (Hodges 2006; Singh & Singh 1992). The young and still rising Himalayan mountains with immature geology and unconsolidated rocks are unusually vulnerable to erosion leading to deposition of enormous silt in the GP. For example, yearly sediment yield per hectare is 15.7 t in Ganga in Bangladesh, compared to 0.8 to 5.1 t for rivers of Trans-Himalayan region, where rainfall is low (Holeman 1984). The high amount of sediments carried by Himalayan rivers work as natural fertilizer for the cropfields in the GP and create new alluvial surfaces each year. In GP the alluvial soil bed could be more than 100 m deep at places holding large amount of water in its body. The following testify the flow of ecosystem services from Himalayan forests to the GP: (i) Increase in proportion of sand and gravel in downstream areas subsequent to deforestation in upstream areas, (ii) The grasslands in plains adjacent to mountains are among the most productive ecosystems of the world. In many parts of the world (e.g., western coastal United States) the ecosystem productivities are much lower in plains than in the adjacent mountains (Zobel & Singh 1997). In some regions, forest vegetation in mountain is surrounded by vast deserts in plains. In GP productivity is higher than in the mountains indicating a favourable upstream downstream connection, (iii) Crop cultivation in GP for several thousands of years without a widespread degradation, and (iv) High humidity during much of the year in the Gangetic Plains. A part of it is due to the water vapours that result from evapotranspiration of the 3000 m high forest cover in the Himalayas. The linkages among water vapour flows, food production and terrestrial ecosystem services are strong in many areas of the world. Globally the annual continental water vapour flow is estimated at about 70,000 km^3, of which 80% is attributed to forests (Rockstrom *et al*. 1999).

Understanding the ecology of the Himalayas and GP connections can be an extraordinary research enterprise, that may enable us to address several important ecological questions and of management issues. Science based knowledge helps solving conflicts among countries sharing a common resource. Droughts and floods associated with the Gangetic watershed are already serious conflict issues, warranting negotiations among Nepal, India, Bangladesh and Pakistan. The global warming may severely affect the flow of some of the watershed services flowing from the Himalayas.

Eco-footprints and future development of the tropics

Wackernagel *et al.* (1997), have used the consumption of resources (production + import – export of a given resource) for estimating eco-footprint of nations. In this, consumption of resources was converted into land and water areas required to supply them, using average productivity data. For fossil fuels the area was derived by estimating forested area required to sequester the carbon emissions from the use of fossil fuels. The world average productivity was taken to calculate bio-productive area of a country required to supply resources. The average per capita earth share is estimated at 1.9 ha. Compared to this, with per capita footprint of 9.6 ha, the share of USA is nearly 5 times the sustainable share. Many tropical countries had values lower than 1.9 in 1995: India 1.0, Indonesia 1.3, and Bangladesh 0.6, but situation can change rapidly in time (Table 6). The country-level footprint situation was determined by several factors like population, consumptive traits, forest cover and flow of ecosystem services. Even with low footprint India's total footprint exceeds its total bio-capacity (9.35 million km^2 *vs.* 4.47 million km^2). Because of the rapid degradation of forests and land the eco-footprint of Philippines (956000 km^2) is about twice as much as of its bio-capacity. In contrast, because of its large area and resources, and small population, the bio-capacity of Brazil (14.54 million km^2) is much more than its eco-footprint (5.6 million km^2).

There is a positive relationship between the quality of environment and Gross Domestic Products (GDP) across the nations of the world emphasizing that with more economic growth environment improves. This has worked effectively except in case of green house gases, the principal contributors to which are the countries with high GDPs. In fact, climate change is the most convincing evidence against the belief that economic growth (largely driven by ever - increasing consumption and technological innovations) can address all environmental problems. However, countries with similar GDPs differ in their efforts to maintain environmental quality, indicating thereby that increase in GDP is not the sole factor in improving environment. Then, some countries

Table 6. Ecological Footprints (EF) of nations in relation to their available Bio - Capacities (BC): (data are of 1995) (from Wackernagel *et al.* 1997).

	Average per capita		Difference between the two	Total national EF (km^2) vs available BC (km^2) (in thousands)	Ratio of the two
	EF (ha)	BC (ha)			
Tropical					
Bangladesh	0.6	0.2	0.4	659 vs 275	2.4
Brazil	3.6	9.1	5.6	5,670 vs 14,545	0.38
Costa Rica	2.8	2.0	0.8	96 vs 68	1.41
India	1.0	0.5	0.5	9,353 vs 4,472	2.09
Indonesia	1.3	2.6	1.3	2,509 vs 5,199	0.48
Mexico	2.5	1.3	1.2	2,306 vs 1,158	1.99
Malaysia	3.2	4.3	1.1	642 vs 872	0.74
Nigeria	1.0	0.6	0.4	1069 vs 656	1.62
Philippines	1.4	0.8	0.6	965 vs 523	1.84
Temperate & other					
China	1.4	0.6	0.8	17,3111 vs 7,323	2.4
Australia	3.0	4.4	1.4	1672 vs 2305	0.72
Canada	7.2	12.3	5.1	2,122 vs 3,615	0.59
Netherlands	5.6	1.5	4.1	867 vs 238	3.64
New Zealand	6.5	15.9	9.4	230 vs 565	0.40
UK	4.6	1.5	3.1	2,667 vs 903	2.95
USA	9.6	5.5	4.1	25,532 vs 14,697	1.73

are able to keep their environment clean by exploiting environment of other countries. For example, the Netherlands cultivates flowers in some African countries, and some other rich countries use poor countries for the disposal of their industrial wastes.

The main concern with regard to a hugely populous countries like India is whether increase in GDP can improve environmental quality at all levels of population and density, regardless of their "bio-capacities" and resource bases. A small country, like Singapore with a few millions people could do so, despite poor resource base. Can India and other such tropical countries sustain their economic growth in future, without increasing CO_2 emission by increasing overall energy use efficiency? The gain from energy efficiency is likely to be eaten up by increase in per capita energy consumption. Can the planet support all sizes of "human metabolism (biological *plus* cultural and technological)"? The accumulation of GHGs in the atmosphere is only one of the consequences of increasing human metabolism. Its other consequences could include direct warming of towns due to the heat release, and widespread generation of toxics.

The future changes in ecological condition would largely depend on how effectively the conflicts between tropical and temperate countries would be addressed. In this the focus will be on energy issues particularly role of energy in poverty relief and supply of energy services that avoid dangerous climate change. The climate change may hasten the adoption of nuclear energy since it allows economic growth without GHGs emission. However, a massive energy use can directly contribute to global warming. Odum (1975) shows concern that the access to a large amount of energy may change the order of human metabolism to an unsustainable level, disrupting the biotic fabric of the planet irreversibly. According to him (Odum 1975) the economic growth of last century has involved total metabolism by humans of 4 per cent of the organic budget and 0.005 percent of heat budget, whereas the availability of an unlimited nuclear energy can be at least an order of magnitude higher. Such an increase in the use of a high quality energy (nuclear energy) may disturb the earth's billion years old life supporting system.

Therefore, it is important for a sustainable development of the tropical world that countries growing economically avoid committing the past mistakes of temperate countries. For example, rapid urbanization is a common pattern of development. We do not know about cross-scale interactions of urban heat islands with global warming. It may be remembered that tropics have higher temperatures than temperate regions. Forest ecosystems in tropical countries are more vulnerable to disturbances than of temperate regions, and they are much more valuable for their high biodiversity and cooling effects on global climate. However, tropical countries would have to be more considerate towards developed countries (which are largely temperate) in international negotiations for future development.

Conclusions

The global significance of tropical belt primarily lies in its extraordinarily rich biodiversity and great ecological systems like Himalayas-Gangetic systems and Amazonia. At present the ecology of tropical landscape is under the impact of a variety of anthropogenic activities, ranging from those associated with stone-age life style (e.g. collection of firewood and fodder for subsistence) to those associated with a highly consumptive traits in a highly interconnected world (e.g. luxurious living, export, transportation and human migration). That is why tropical forests are depleted both by deforestation and degradation.

In much of the tropical humans are physically inseparable form natural systems, because of the day-to-day dependence of poor people for their subsistence living. Climate change is likely to be a major setback to the economies of tropical countries, many of which have just begun to achieve a repaid economic growth. Because tropical countries have limited capacities to deal with climate change, this overarching environmental shift may disrupt not only socio-economic condition, but also severely damage rich biodiversity of these countries. Perhaps, the emergence of large-area-based ecological networks can help local people to address some of the environmental problems. Some of the tropical countries, however, may need international support in several areas including research and education.

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