CHAPTER 2: TROPICAL DEFORESTATION: THE SCALE OF THE PROBLEM

2.1: Introduction

Human activities associated with land use have changed the atmosphere's chemical composition and restructured the Earth's surface; both, in turn, have an impact on our climate. Currently, land areas are being altered in many different ways: forest clearing for agriculture; conversion of grassland to agricultural lands; abandonment of managed lands that regrow into grassland or woodland; management of forests including logging for forestry products, harvesting of fuelwood, and establishing or operating forest plantations; and urbanisation. All these forms of land changes by humankind have effects on the climate system. For example, the increases in anthropogenic greenhouse gas concentrations in the atmosphere observed in recent centuries are due not only to the combustion of fossil fuels but also to human use of land. Removal of forests for conversion into farmland and subsequent burning of non-utilised biomass releases large volumes of carbon dioxide, methane and other radiatively active gases and particles to the atmosphere. This rise in atmospheric pollutants considerably perturbs the energy budget of the planet, and leads to changes in global climate (Houghton *et al.*, 1996). Forest biomes are potential carbon sinks that could help dampen these greenhouse effects. Through photosynthesis, forests absorb large amounts of carbon dioxide and fix the carbon as wood. Under the natural decay processes of forests, this fixed carbon is converted to soil, peat, coal, and hydrocarbons. In an equilibrium state, forests play an important role in maintaining a balance in atmospheric composition.

General circulation model (GCM) simulations suggest that global climatic change may result from land use changes, particularly tropical deforestation. The main mechanisms for this are changes in surface albedo and changes in hydrological processes, governed by complex interactions between the land surface and atmosphere. The land surface influences the atmosphere via three principal modes of exchange: radiation fluxes, transfer of momentum, and transfer of sensible and latent heat.

It is becoming generally accepted that forest destruction is environmentally and sociologically undesirable, and the possible contribution of tropical deforestation to climate change has been the subject of a large number of discussions at all scientific and political levels. Scientific communities and policy makers have addressed a number of major related issues especially on the extent and rate of conversion of tropical forests, causes and processes of tropical deforestation, and policy intervention in tropical deforestation. In the following sections, an overview of the present status and outlook of tropical deforestation will be provided. This qualitative assessment of the character and potential scale of the process of deforestation is used to design the modelling experiments that are the core of this research.

2.2: Tropical Forest Extent

Increased attention has been paid in recent years to the assessment of the geographical distribution of tropical forests so as to provide reliable and globally consistent information on their present state. This work is a necessary prerequisite to the development of studies on the environmental implications of deforestation and forest degradation. According to a recent Food and Agriculture Organization of the United Nations report (FAO, 1993), during the early 1990s, the total tropical forest cover was 1,756 million hectares. The greatest extent of tropical forest cover was in Latin America and Caribbean (918 million ha: 52% of the total tropical forest area), followed by Africa (528 million ha: 30%), and Asia and the Pacific (311 million ha: 18%). The FAO (1993) report divides tropical forest into two major groups. The first group is lowland formations comprising 1,544 million ha or 88 percent of the total tropical forest area at end 1990. The second group is upland (hill and montane) formations (204 million ha or 12 percent at end 1990). Then, lowland formations are subdivided into tropical rain forests (718 million ha or 41 percent), moist deciduous forests (587 million ha or 33 percent) and dry and very dry zone forests (238 million ha or 14 percent). Clearly, among the lowland formations, tropical rain forests constituted the biggest portion.

Tropical rain forests are evergreen and limited to regions where adequate moisture for plant growth is available all year round. According to the third report of the Enquete Commission, "Protecting the Earth's Atmosphere" (Enquete-Kommission, 1995), evergreen tropical rain forest is forest that receives average annual rainfall between 2,000 and 3,000 mm; with an extreme case of exceeding 12,000 mm. For this evergreen tropical forest area, the dry season lasts no more than two months and these regions are mostly found in the inner tropics, between roughly 10^{o}N and 10^{o}S. Most of the evergreen tropical rain forest is found in tropical lowland areas at altitudes of up to 800 metres above sea-level. This is limited to the Amazon Basin in South America, the Gulf of Guinea and the Congo Basin in Africa, also, Sri Lanka, Thailand, Indochina, the Philippines, Malaysia, New Guinea and Indonesia in Asia (Enquete-Kommission, 1995).

Tropical forests, as defined by Myers (1991) are "evergreen or partly evergreen forests, in areas receiving not less than 100 mm of precipitation in any month for two out of three years, with mean annual temperature of 24-plus ^{o}C and essentially frost-free; in these forests some trees may be deciduous; the forests usually occur at altitudes below 1,300 metres (though often in Amazonia up to 1,800 metres and generally in Southeast Asia up to only 750 metres); and in mature examples of these forests, there are several more or less distinctive strata." Myers (1991) reports the situation of tropical forests as of 1989 from the results of his survey. This author says that tropical forests still cover almost 800 million hectares of the humid tropics. According to Myers's report, more than 70 countries of the humid tropics feature moist forest. However, only 34 countries (Table 2.1) account for 778.35 million hectares of forest, or 97.5% of the present biome estimated to the above total tropical forests that still cover the humid tropics. From the list of countries given, and the definition of tropical forest by Myers (1991), we therefore can deduce the tropical forest covers referred to by Myers (1991) are mostly rain forests plus some moist deciduous forests under lowland formations categorised by FAO (1993). Note that Myers (1991) refers to those forests as "tropical moist forests" throughout his report rather than "tropical rain forests" and his inclusion of partly evergreen forest in his definition can be inferred as moist deciduous forests. Differences in definitions can cause problems in assessing changes in forest areas.

2.3: The Rate of Conversion of Tropical Forests

2.3.1: Difficulties in deriving rates of changes

Fearnside (1987) describes the extent and rate of deforestation in the Brazilian Amazon prior to the late 1980s and emphasises a probable underestimate of the rate given by LANDSAT satellite imagery. According to Fearnside, because of limitations of the satellite image interpretation, true cleared areas are probably larger than suggested. These limitations of satellite imagery arise from the inability to detect very small clearings, and the difficulty in distinguishing secondary growth from virgin forest. Deforestation rates based on remotely sensed data may, therefore, be underestimated.

Thus, there are serious difficulties in determining rates of deforestation. Sedjo and Clawson (1983) maintain that conversion of forested areas is a rather modest and localised process with implications far less serious than often suggested. Sedjo and Clawson state that, although some local effects of deforestation may be severe, the evidence does not support the view that either the world or the tropics are undergoing rapid aggregate deforestation. Turner *et al.* (1993) comment that, although land cover change in the tropics is a dynamic process involving loss of forest, the loss is partly offset by rapid regrowth of secondary vegetation.

The above examples show that the discussion of the rate of tropical deforestation involves conflicting views, most likely due to the difficulty in defining "deforestation." The terms "deforested", "degraded" and "fragmented" forests often seem to be subjectively defined, resulting to uncertainties in estimating deforestation rates. Assessment of current levels and rates of deforestation, which must ultimately form the basis of future deforestation scenarios, has been confounded by this uncertainty.

Lanly (1982) uses the term deforestation mostly in the strict sense of a complete clearing of tree formation (closed or open) and replacement by other use of the land ("alienation"). All other less radical alterations of tree populations are not regarded by Lanly under the term deforestation. Similarly, Myers (1991) uses the term deforestation to indicate the complete destruction of forest cover through clearing activities. However, the FAO (1993) define two different types of deforestation. First, as conversion of forest to wooded land cover (either to shrubs or agriculture land) where a certain amount of woody biomass remains; Second, as conversion of forest to non-wooded area that represents the total loss of woody biomass.

Forest degradation is specified by the FAO (1993) as a decrease of canopy density or an increase of perturbation. The changes are grouped together on an increasing scale of biomass loss within the continuous forest group due to reduction in density (closed to open forest) or conversion of forest to long fallow. Forest degradation can occur through damage to residual trees and soil from poor logging practices, log poaching, fuelwood collection, overgrazing and anthropogenic fire. Fragmentation is defined by the FAO (1993) as partial deforestation, where on average this process represents a loss of two-thirds of the original forest area replaced by increasing agricultural practices through progressive clearing of small patches of forest, which creates a mosaic of forest and non-forest. In turn, fragmented forest is mainly altered to other forms of land cover (permanent agriculture), which implies that fragmentation is an intermediate stage towards permanent agriculture. Skole and Tucker (1993), in their survey of the Amazon Basin, suggest that forests that are below 10,000 hectares and surrounded by a deforested area can be designated as fragmented forests. Fragmentation is seen, therefore, as a prelude to complete deforestation.

Based on the earlier definitions by FAO, Enquete-Kommission (1995) considers deforestation, degradation and fragmentation according to the following definitions: deforestation is a reduction of the percentage of ground covered by tree crowns to below 10 percent; degradation refers to a reduction of productivity or biomass density, causing thinning of the forest stand although the degree of cover remains above 10 percent; and fragmentation means a division of primary forest into isolated smaller stands surrounded by and interspersed with cleared areas.

2.3.2: The most authoritative studies

Myers (1991) and FAO (1993) are generally considered to be the most authoritative of recent studies of deforestation rates. These two reports are quite comparable to each other as both estimate deforestation rates for the same period during the 1980s, and provide estimates of mean annual tropical deforestation rates for that decade.

Myers (1991) carried out his survey mainly as a 'desk research' investigation. The survey relied primarily on the professional literature (over 400 papers and publications and personal communications). The survey's findings depended upon remote-sensing data, weather satellite imagery, side-looking radar or aerial photography backed up by ground-truth checks. With additional reference to his earlier surveys, Myers (1991) concludes that the deforestation rate in the humid tropics had expanded by almost 90% during the 1980s as compared with the 1970s. In his estimate, Myers gives the rate of tropical deforestation for the decade 1981-1990 as 13.9 million hectares per annum (Table 2.1).

FAO (1993) reports its extensive remote sensing-based survey using high-resolution satellite data integrated with statistical data and using a geographic information system. The project used a deforestation model (or a forest area adjustment function) which correlates forest cover change in time with other variables including population density and population growth for the corresponding period, initial forest cover area and ecological zone under consideration. The assessment of deforestation was made by geographical and ecological region. According to the report, tropical forest cover was 1,910 million hectares at the end of 1980 and 1,756 million hectares at end 1990. The rate of destruction increased since the 1970s from just less than seven million hectares per year to around 17 million hectares per year by the end of the 1980s. Some 154 million hectares of tropical forest were destroyed between 1981 and 1990. Therefore, over the period 1981-1990, an average of 15.4 million hectares of tropical forest was destroyed each year. The assessment also shows that annual loss of the tropical rain forest alone for the decade 1981 - 1990 was 4.6 million hectares. The FAO survey also identified that 76 percent of the tropical rain forest zone was still covered with forest when comparing forest area to land area ratio for each ecological zone at the end of 1990. From a similar survey, FAO also gives a report on forest harvested and degraded. For example, about 5.9 million hectares per year of tropical forests were logged during 1986-90, and most logging occurred in mature forests (83%) rather than secondary forests.

For tropical forests as a whole, the FAO (1993) survey's annual deforestation rate estimate is 1.5 million hectares more than Myers's (1991) tropical moist forests estimate. The difference is quite reasonable, as the FAO's scope was larger than that of Myers. However, the annual deforestation rate for the tropical rain forests given by FAO is only 4.6 million hectares, much different from Myers's estimate of 13.9 million hectares per annum for tropical moist forests. The most probable reason for the difference is that the two surveys used different definitions of tropical forests and deforestation. Moreover, different methodologies were used in the surveys. Myers's study was only based on 34 countries in the case of tropical moist forests, but the project by the FAO covered a total of 90 countries.

After looking at the overall findings of the two surveys, an important point to note is that the estimates of forest extent and deforestation rates are subject to large uncertainties. In fact, a similar caution has been given by FAO (1993). Nevertheless, from their figures, we can not rule out the conclusion that, overall, tropical forests are experiencing high rates of loss at an increasing rate, at least to 1990. Intergovernmental Panel on Climate Change (IPCC) reports (Houghton *et al.*, 1996; Watson *et al.*, 1996) endorse the rate estimated by FAO (1993). However, it should be noted that, based on a few groups' reports, Watson *et al.* (1995) indicate a decreased rate of deforestation during the last decade for a few tropical countries. Ravindranath and Hall (1994), Skole and Tucker (1993) and Dixon *et al*. (1994) have shown a decrease of deforestation rate for this period for India, Brazil and Thailand, respectively.

2.4: The Causes and Processes of Tropical Deforestation

Tropical rain forest, which still covers more than 700 million hectares, is being cleared in many different ways. There is a wide range of human uses of, and influences on, tropical forest ecosystems. The result of these uses and impacts varies widely from one tropical zone to another. The range of possibilities includes a patchwork of agricultural land, bodies of water, thinned forest stands, isolated pockets of primary forest and successional areas of secondary forest of varying density. Some of these areas are heavily degraded and no longer usable. We can summarise the causes of tropical forest conversion as follows:

- conversion of forests and woodlands to agricultural land;
- development of cash crops and cattle ranching;
- commercial logging which destroys trees as well as opening up forests for agriculture;

and,

- felling of trees for firewood and building material.

2.4.1: Forest conversion in the developing world

There are various processes of forest conversion in the developing world which could partly destroy or might eradicate the forest ecosystem in the future. Most of the causes are small- to large-scale agriculture activity including cattle raising, and timber trade-related activity. Historically, the 2,000-year-old phenomenon of shifting cultivation has already caused rapid disruption of virgin forest (Myers, 1980). In many areas the numbers of shifting cultivators did increase to a point where there were often three or more times as many people per square kilometre as in earlier times, therefore, limiting local migration and promoting intensive and extensive demands on forest environments. With this, local ecosystems might not have sufficient time to recover from disruption. In terms of the timber trade, the main reason tropical forests are being more extensively exploited is because of the increasing demands for wood, not only in tropical countries but also in the developed world. Currently, the extensiveness of the above activity seems to create more and more pressure on the tropical forest.

According to Southgate (1990), small farmers are the primary agents of deforestation throughout the developing world. They migrate to forested hinterlands for several reasons. In Indonesia, Brazil, and elsewhere, many colonists have participated in settlement projects organized and directed by the public sector (Repetto and Gillis, 1988). Most colonization, however, is "spontaneous", stimulated by a variety of push and pull factors. Agricultural colonists in many countries also benefit from grace periods for development credit and other subsidies (Pearce and Myers, 1988). Besides being induced to migrate to frontier areas, Southgate (1990) and Southgate and Runge (1990) suggest that agricultural colonists in third world countries face tenure regimes that promote deforestation when removal of trees and other vegetation is a prerequisite for establishing formal property rights. For example, deforestation-induced land degradation in developing countries is a direct result of land tenure systems that ease property-right acquisition in idle lands.

Fearnside (1987), in his essay on causes of deforestation in the Brazilian Amazon, describes proximal and underlying causes of deforestation. The proximal causes motivate landowners and claimants to direct their efforts to clearing forest as quickly as possible. Among them are land speculation, tax incentives, tax penalties, negative interest loan as well as subsidies and special crop loans. On the other hand, underlying causes link wider processes in economic activities either to proximal motivations of each individual deforester or to an increase in the numbers of deforesters present in a region. One common in Amazonia that promotes extensiveness of land use is inflation causing speculation in real property, especially pasture land. Inflation also increases the attractiveness of low-interest bank loans for forest clearing. Turner *et al*. (1993) also discuss proximal and underlying causes in relating land use and global land-cover change by referring to proximate sources as activities that affect land cover dynamics, such as agricultural expansion and cattle raising. These activities, in turn, are the result of underlying driving forces from policies and attitudes of socioeconomic and political institutions that motivate and constrain production and consumption. In fact, every causal mechanism linked to deforestation is bound to either the proximal or underlying case.

Will these trends continue? According to Pahari and Murai (1997), various researchers have conducted studies trying to relate deforestation to factors such as population, GNP, external trade, land ownership, etc. However, it has been found that population has been the single most significant driving force for global deforestation. Considering that loss of global forest has already become a matter of serious concern, it is important to make predictions regarding the state of forests in the future when the population is expected to reach almost 8 billion in 2025 and 9.40 billion in 2050 based on the United Nation medium variant long-term population projection. Pahari and Murai (1997) undertook a study to predict the future state of global forest cover through a correlation model linking population with forest loss. The spatial forest loss projections were based on the above United Nations medium variant long-term population projections, in particular for the years 2025 and 2050. The total accumulated forest loss has been defined as the percentage area of forest loss to the current level of human impact compared to the potential natural land cover without human impact. While the potential natural land cover is defined as the land cover that might exist under given climatic conditions without human impacts, the current land cover (for 1990) is based on dynamic analysis of NOAA GVI data from Murai and Honda (1991).

Pahari and Murai found that out of various analyses carried out to establish the relationship between population and deforestation, the correlation between the logarithm of population density and the total accumulated forest loss is the most significant, with the correlation coefficient ranging from 0.71 to 0.91 for various regions of the world [Tropical Asia, Tropical Latin America, Tropical Africa, Tropical Central Americal/Mexico, Sahelian Africa and Europe (incl formal USSR)]. For Tropical Asia, the correlation factor is 0.79. Figure 2.1 shows the correlation plots of logarithm of population density and total forest loss for Tropical Asia from Pahari and Murai's study.

The results of Pahari and Murai's prediction for population and forest loss in 2025 are summarised in Table 2.2. Their predictions show that the deforestation is likely to continue at a very significant rate, especially in the developing countries. Deforestation will be most severe in Tropical Africa, where it is predicted that more than 30% of the forest in 1990 will be lost by 2025, which corresponds to an annual deforestation rate of 1.06%. Following the Sahelian Africa, Tropical Asia has a percentage loss of forest by 21% from 1990 to 2025, which can be considered as significant as a rate of change just over a 35 year period. Pahari and Murai's predictions of forest loss until 2050 are also presented here in Table 2.3 and the corresponding rates of growth of population are given in Table 2.4. According to their results, deforestation will continue even after 2025, though the speed will be significantly slower. However, as concluded by Pahari and Murai, the problem of deforestation is likely to continue at a significant rate in the developing countries, and again the problem is most severe in the case of Africa (both tropical and the Sahelian region).

2.4.2: The causes of deforestation in Southeast Asia

According to Kummer and Turner (1994), deforestation throughout the Southeast Asia region does not seem to be a simple function of population growth or demands emanating from an expanding regional economy. National population growth *per se*, for example, has not been demonstrated to be an adequate predictor of the patterns and scale of deforestation; in some cases, migration of farmers into particular areas of the region may not have taken place without the convenience of logging roads, partially cleared forests, and/or government sponsorship.

All tropical countries in Southeast Asia that have forest within their political boundaries (see Table 2.1) can be categorised as part of the developing world. The national politics of Southeast Asian countries, as mentioned earlier, are similar to those of Amazonia and this greatly influences the pattern of deforestation in these developing nations. According to Potter (1993), examination of the role of national governments (or, in the case of Malaysia, state governments) in managing the forests of Southeast Asia reveals a number of similarities. Southeast Asia has forests with a high commercial value and have been logged heavily for export. Almost all forest land in Philippines, Indonesia, Malaysia and Thailand is owned or controlled by national governments (with the exception of Malaysia, where state ownership prevails) and managed by government forestry departments whose primary objective appears to be (or has been) to increase commercial logging and the export of wood products (Byron and Waugh, 1988). According to Callaham and Buckman (1981), the forest sector in all four countries has been a theatre of large-scale corruption and illegal activity circumventing regulations designed to control logging. In addition, agriculture in Southeast Asia has expanded in concert with logging through both spontaneous settlement after logging and government-planned agricultural projects (Kummer and Turner, 1994).

Potter (1993) reports that a forest land-use classification in Southeast Asia, in general, will usually contain at least three categories: protection (hydrological), conservation (ecological) and production. There may also be areas on forestry maps specifically earmarked for permanent conversion to agriculture, mines, dams or settlements, sometimes in belated recognition of a conversion which has long since occurred. While protected and conservation areas are supposed

to be reserved, the production forests are either leased out for logging to private concessionaires or given out for working by various kinds of state-controlled production enterprises.

There is a problem in managing the forest in Southeast Asia which involves the role of government in land-use planning. According to Potter's report, there is little or no demarcation of reserved areas on the ground in most countries of Southeast Asia bringing incursions by both loggers and small settlers as a common problem in this region. Potter comments that a plethora of regulations usually exist (on paper) in an attempt to control logging and to force those in charge of production to adopt what should be systems of sustainable management. Such controls, however, have failed in most cases, either because of a universal shortage of forestry personnel to police them or lack of political will or inability to stand up to powerful interests and lobby groups. Commercial logging without control not only depletes the forest resource, but affects its ability to regenerate. Selectively cutting an individual commercial-grade tree invariably damages several trees surrounding it and potentially affects ecosystem diversity. In Indonesia, logging increased six-fold between 1961-1965 and 1976-1979. During the same period, wood exports increased from 125,000 cubic metres to 19 million cubic metres and domestic processing increased from 5,000 cubic metres in 1968 to 526,000 cubic metres a decade later (Caulfield, 1982). For Malaysia, according to Caulfield, one half of Peninsular Malaysia's rain forests had been logged during the 20 years from early 1960's to early 1980's.

During the second half of 1997 and early 1998, forest and land fires in Indonesia dominated daily news and conversation worldwide. Extensive effects on neighbouring countries as well as to the global environment have been the concerns of the worldwide community (Murdiyarso, 1998). The information sheet on Southeast Asian forest fires and their impact on the rainforests published by World Wildlife Fund (WWF) states that the rainforests in Indonesian Borneo and Sumatra burn because of clearing and destructive logging. Rainforests usually will not burn, they are dark and wet. But once they are severely damaged, they dry out and will burn, particularly under severe drought conditions such as those prevailed in Southeast Asia because of the El Niño. During the same period, rainforest fires have also been reported in Papua New Guinea, Philippines, Vietnam, Thailand and Malaysia. Linden (1998) comments that, even without the effects of El Niño, tropical forests in Southeast Asia are increasingly vulnerable, and the blame lies with human activity. People are literally paving the way for fire's intrusion. Roads penetrating tropical forests provide access to loggers, peasant farmers, ranchers and plantation owners, all of whom use fire to clear land. Logging in particular creates incendiary conditions by leaving combustible litter on the forest floor and allowing sunlight to penetrate the forest canopy and dry out vegetation. Forest waste removal, after logging or land clearing for agricultural projects, is very costly and the easiest and cheapest way is burning (Murdiyarso, 1998). WWF has estimated that over 50 percent of the remaining intact rainforests in Southeast Asia are currently threatened by logging, either directly or indirectly.

2.5: Discussion and Conclusions

As noted earlier, according to Watson *et al.* (1996), there are already countries where deforestation has been reduced in their territories during the last decade. Ravindranath and Hall (1994), Skole and Tucker (1993) and Dixon et al. (1994) have shown a decrease of deforestation for this period for India, Brazil and Thailand, respectively. This has been achieved by strong forest conservation legislation, a large forestation programme, and community awareness. Trexler and Haugen (1995), however, comment on the weakness of past international efforts to curb deforestation, such as the Tropical Forestry Action Plan by FAO, which according to them have met with limited success only. Major factors are the absence of comprehensive agricultural policies that meet the needs of resource-poor farmers and the growing global demand for food, fibre, and the increasing human population (Brown, 1993; Grainger, 1993). It seems likely that deforestation will not cease in the foreseeable future.

Rates of tropical deforestation are notoriously difficult to calculate on a comparative basis, largely because of different definitions of "tropical forest" and methods of categorising vegetation regrowth. Attempts to compare earlier forest cover (estimates) with present forest areas (measured) are also difficult and annual rates of deforestation may not be calculated satisfactorily. Data are not available for all countries and different sources reach widely divergent estimates. In terms of the Southeast Asia forest, it is possible that rates of deforestation are even higher than previously reported. With rapid deforestation, there are numerous side effects that may prevent changes in forest cover being noticed immediately. One such change is the change in the landscape and land-quality of the forest areas and the effects that it may bring about later in controlling forest degradation. In satellite imagery of forest areas where active logging activity occurs, for example, although the images of forest are full of growth, most of the soils that support the growth may have become highly unproductive and there is no guarantee that trees can grow back on the impoverished soil. This is another uncertainty in predicting the future of tropical forest cover.

Based on the results by Pahari and Murai (1997), of particular interest in this thesis is the scenario of continuing deforestation in Tropical Asia. The average annual rate of deforestation in Tropical Asia for 1990-2050 modelled by population density as an independent variable is low, only 0.56%. However, the correlation factor of 0.79 between the log of population density and total accumulated forest loss for the Tropical Asia, as given by the Pahari and Murai's statistical model, reveals that 38% of the variance is not yet explained. Additional factors such as GNP, external trade, land ownership, economic pressure, local politics etc. should be for example included in the model. Potter (1993) refers to one study in her review, quoting that "the rapid rates of deforestation observed in Malaysia, Indonesia and Brazil, are not the result of population pressure but, rather, reflect macro level decisions made by government officials … increased emphasis should be placed on the socio-economic context in which deforestation takes place". The caution given by Fearnside (1987) regarding the probable underestimation of the rate given by the satellite imagery should also be taken into consideration. Even Pahari and Murai, in their concluding remarks, indicate the need for a more refined global dataset in their recommendation for further studies. For example, there is a great difference between the status of the total tropical forest cover in 1990 as given by Pahari and Murai (1,555 million hectares) and the extent of tropical forest cover around the same time given by FAO (1993) (1,756 million hectares), which also based on satellite data. As mentioned earlier in Section 2.2, such a difference illustrates the problems in deducing changes of forest cover in the past as well as in the future. Ongoing collection and more accurate analysis of satellite data is needed, and new improved technologies are necessary to efficiently archive and analyse the vast amounts of data involved.

The studies discussed in this chapter indicate the nature and scale of the issue of deforestation, in particular for Southeast Asia. They show that deforestation is likely to continue at a significant rate in the developing countries, including over Southeast Asia. However, they do not provide a clear indication of what the level of forest cover will be in the future that could be used in this model investigation of tropical deforestation.

To assess the nature of regional or global climate changes due to tropical deforestation, modellers have elected, in most experiments to date, to use an extreme scenario for the deforestation case, usually described as degraded pasture or impoverished grassland. As Henderson-Sellers and Gornitz (1984) stated in describing the first general circulation model deforestation experiment, the objective was ". . . to try to estimate the maximum impact likely to occur as a result of tropical deforestation by maximising the changes important to climate." As commented by Giambelluca *et al* (1996), this was clearly a sound strategy at the outset of such experiments in that were significant climate changes not predicted under the most extreme and extensive land surface change, other less extreme scenarios would not then need to be examined. This study also resorts to the extreme case, where deforestation is defined as uniform conversion to grassland at each grid-box of the perturbation experiments. In selecting grassland to represent the post-forest land cover we intentionally choose the land cover which contrasts strongly with forest in order to examine the sensitivity of the simulated coupled climate system to land cover change.