Threatened Biotas: "Hot Spots" in Tropical Forests

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Summary

The mass-extinction episode underway is largely centred on tropical forests, insofar as they contain at least half of all Earth's species and they are being depleted faster than any other biome. But species distributions and depletion patterns are anything but uniform throughout the biome. This paper identifies 10 areas that, a) are characterised by exceptional concentrations of species with high levels of endemism and b) are experiencing unusually rapid rates of depletion. While these "hotspot" areas comprise less than 3.5 percent of remaining primary forests, they harbour over 34 000 endemic plant species (27 percent of all plant species in tropical forests and 13 percent of all plant species worldwide). They also feature 700 000 endemic animal species and possibly several times more. Unfortunately, they appear likely to lose 90 percent of their forest cover as soon as the end of the century or shortly thereafter, causing the extinction of almost 7 percent of Earth's plant species and at least a similar proportion of animal species, this occurring in only 0.2 percent of Earth's land surface. By concentrating on such areas where needs are greatest and *where the pay-off from safeguard measures would also be greatest, conservationists can engage in a more systematised response to the challenge of large-scale extinctions impending in tropical forests.*

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Introduction

There are many prognoses (Ehrlich and Ehrlich, 1981; Myers, 1987a; Raven, 1987; Western and Pearl, 1989; Wilson, 1988) of a mass extinction of species during the next few decades, notably in tropical forests. This paper proposes that we can identify a number of localities in tropical forests that;

a) feature exceptional concentrations of species with exceptional levels of endemism, and that,

b) face exceptional degrees of threat.

These "hotspot" areas, 10 of which are identified in this paper, total only 292 000 km^2 (3.5 percent) of a biome of 8.5 million km^2 of primary forest remaining. But they feature a large proportion, possible a majority, of the 125 000 higher plant species, both local endemics and wide-distribution species, that exist in tropical forests overall. Moreover, the areas are exceptionally rich in animal species too. If present exploitation trends persist in these forests (they are likely to accelerate), there may be little left of the hotspot areas, except in severely degraded form, by the start of the next century or shortly thereafter.

Thus, there appears to be a major extinction spasm impending in these areas alone. Conversely, of course, if conservationists can identify key localities of biotic richness under acute threat, they can determine their conservation priorities in a more informed and methodical manner than has often been the case to date.

Right from the start, however, the analysis is bedevilled by lack of basic data. We know all too little about the numbers of species, especially of animal species, in hotspot areas. In tropical forests overall, defined here as forests with a mean annual rainfall of 1500 mm or more, and a mean monthly minimum of 100 mm, there could be anything from 2.5 million to 30 million (conceivably 50 million) animal species (Erwin, 1988), yet to date we have identified little more than 0.5 million of them. So for the purposes of this paper, attention will be confined to species of vascular plants, also known as "higher plants" of which flowering plants comprise 88 percent, and henceforth referred to simply as plant species.

This is not to leave animal species entirely out of account. Species-area inventories in diverse sectors of tropical forests suggest there are at least 20 animal species for every one plant species, assuming a minimum planetary total of all species of 5 million. This means that if the hotspot areas feature, say, half of all plant species in tropical forests, viz. about 62 500 species (the true total could be a good deal greater), they presumably contain at least 1.25 million animal species, though as noted, the actual figure for animal species could be far higher, indeed several times higher.

Biotic Richness of Tropical Forests

The abundance of tropical-forest species is well documented. In the central portion of the La Selva Forest Reserve in Costa Rica, totalling only 13.7 km^2, there are almost 1500 plant species, more than in the whole of Great Britain with its 243 500 km^2. In the Reserve there are 388 bird species (spanning 56 families and 273 genera), 63 bat species (9 and 37), 42 fish species (13 and 17), 122 herptile species (23 and 63), and 143 butterfly species (11 and 59). These totals are to be compared with species numbers for the continental USA: 650 birds, 40 bats, 775 fish, 455 herptiles and 415 butterflies.

As an example of an entire country, Ecuador contains an estimated 20 000 plant species, the bulk of them in its forests and at least 4000 of them endemic. By contrast, the temperate zone state of Minnesota, twice the size of Ecuador, has 1700 plant species, only one of them endemic (Gentry, 1986a). Ecuador harbours more than 1300 known bird species, or almost twice as many as in the USA and Canada combined.

Moreover, tropical forests feature much higher levels of plant endemism than regions elsewhere; for details see the descriptions of hotspot areas below. Similarly, endemism among birds is pronounced; in tropical forests of South America, 440 species of birds, about 25 percent of the total, have ranges of less than 50 000 km^2, by contrast with 8 species, or 2 percent of the total, that have similarly restricted ranges in the USA and Canada (Terborgh and Winter, 1983).

Plainly, endemic species are extremely vulnerable to extinction when their localised habitats are deforested. Not so plainly, the ecological specialisations of many tropical-forest species, such as sensitive positions in complex food webs, leave them subject to summary demise when their support ecosystems are merely destabilised through forest disturbance and degradation (Gilbert, 1980; Janzen, 1975; Terborgh, 1986). In particular, the marked phenomenon of outbreeding among tropical-forest plants means that when they are reduced to small populations, they become specially susceptible to sudden extinction.

Hot Spot Areas: Quality of Data

Now to consider 10 discrete areas in tropical forests that rank as "hot spots" by virtue of their floristic richness and deforestation rates. See Fig. 1 for their location and Table 1 for summarised data; and Table 2 for a comparison with other parts of the world. Since the critical data are presented in compressed form, the accounts are supported with numerous references. Where no reference is given, the information derives from the author's own experience while working intermittently in the countries in question over a period of 17 years.

In a broad-ranging review of this sort, the data are bound to vary considerably in quality. In many instances the statistical information is considered accurate to within 5 percent or better. In many others it is sufficiently accurate to rank as sound support for "working estimates". In some it is regarded as qualitatively correct, even though the quantitative data are deficient: indicative information and best-judgement appraisals have their role to play in a paper such as this, provided their constraints are recognised. In a few further instances, which are identified as such, the information base is so poor that we have nothing better than "educated assessments", even rough-and-ready estimates that occasionally amount to little more than guesstimates, albeit carefully conservative.

The author believes that this overall approach, uneven as it is, is justified in an analytical

TABLE 1 "Hotspot" Areas in Tropical Forests.

Area	Extent of forest (km^2) Original	Present (primary)*	Plant species in original forests	Number of endemics in original forests (percentage)		Original endemics as proportion of Earth's plants total (percent)	Present forest area as proportion of Earth's land surface (percent)
Madagascar	62000	10000	6000	4900	(82)	1.96	0.00675
Atlantic coast Brazil	1000000	20000	10000	5000	(50)	2.00	0.0135
Western Ecuador	27000	2500	10000	2500	(25)	1.00	0.0017
Colombian Chocó	100000	72000	10000	2500	(25)	1.00	0.0486
Uplands of Western Amazonia	100000	35000	20000	5000	(25)	2.00	0.0236
Eastern Himalayas	340000	53000	9000	3500	(39)	1.40	0.0358
Peninsular Malaysia	120000	26000	8500	2400	(28)	0.96	0.0175
Northern Borneo	190000	64000	9000	3500	(39)	1.40	0.04
Philippines	250000	8000	8500	3700	(44)	1.48	0.0054
New Caledonia	15000	1500	1580	1400	(89)	0.56	0.001
Totals	2204000	292000	**	34400		13.8	0.2
For comparison:							
Hawaii	14000	6000	825	745	(88)	0.30	0.004
Queensland	13000	6300	1165	435	(37)	0.17	0.004

* Some, though not many, primary forests species can survive in degraded forests.

** It is unrealistic to sum total these figures for plant species, on the grounds that there is some overlap between adjacent regions, e.g. some plants occur in Peninsular Malaysia, Northern Borneo and the Philippines.

Note: There is a great range of accuracy in these figures (and many are rounded anyway). At one end of the range, some figures are thoroughly well documented and can be generally considered accurate to within 5 percent or better. At the other end of the range, they are little more than "informed assessments" or even "educated guesstimates". The rest fall between these two extremes, with more of them clustered towards the "accurate" end of the range than the "imprecise" end.

Sources: numerous, as cited under the area reviews in the text.

TABLE 2 Plant Species World-wide: Areas, Species Concentrations and Endemics. In the tropical countries listed, most species occur in forests.

Country/region	Area (km^2)	Plant species	Endemism (percent)
Costa Rica	50899	8-10000	15
La Selva Reserve	13.7	1500	
Panama	78513	8500	14
Barro Colorado Island	15.6	1369	
Colombia	1138914	45000 or so	
Chocó Department	47200	10000 or so	25
Ecuador	461477	20000 or so	20
Rio Palenque Research Station	1	1250	4
Peru	1285215	20000 plus	
Manu National Park	18000		
Tambopata Reserve	55	(215 tree species listed)	
Madagascar	587041	10000 plus	80 plus
India	3166828	15000	33
Sri Lanka	65610	3365	27
Borneo	757000	10000 plus	34
Philippines	299498	8500	44
New Guinea	875821	11000	90
New Caledonia	19154	3138	75
For comparison:			
Continental USA	9337532	16500	
California Floristic Province	324000	4452	48
Minnesota	219000	1700	0.06
Hawaii	16641	1100	90
Europe (outside Soviet Union)	5680000	11300	
British Isles	302470	1822	0.8
Soviet Union	22400000	21100	
Australia	7682300	25000	
South Africa			
Cape Floristic Kingdom	18650	8579	68

Source: Davis *et al.*, 1986, and numerous references cited in text.

exercise that seeks to delineate the conservation challenge of a mass-extinction episode in its full scope. Moreover, in cases where there is inadequate documentation of a quantitative sort, one should not be preoccupied with what can be counted, if that is to the detriment of what also counts. After all, to decide that an area should not be evaluated because we lack a conventional degree of accurate data is effectively to decide that its conservation needs cannot be evaluated either, in which case its cause tends to go by default.

A further brief point arises. In many instances a patch of primary forest may be grossly disrupted without being destroyed outright. Or, when an area cleared of its forest regenerates the result is secondary forest, with species complements that differ markedly from the original primary forest. But this paper confines itself to primary forest cover for two reasons. First, only primary forest contains the high species diversity that characterises the biome. Secondly, the biome features only small amounts of secondary forest, whereas "conversion" of primary forest generally results in total and permanent elimination of forest cover. In any case, there is little overlap in species composition between primary forest and secondary forest. In Rondonia State in Brazilian Amazonia, for instance, secondary vegetation as much as 15 years old shows little regeneration of primary forest species, even though the new vegetation is structurally similar to the original forest (Lisboa *et al.*, 1988).

TABLE 3 Three Critical "Hotspot" Areas: Madagascar, Atlantic Coast Brazil and Western Ecuador.

Area	Original forest (km^2)	Remaining primary forest in 1987 (km^2)	Total of original plant species	Total of original plant endemics (percentage of original species)	Total of plant species eliminated or on the verge of extinction[1,2]	Remaining forest area as proportion of Earth's land surface	Total of original plant species as proportion of all Earth's plant species (percent)
Madagascar	62000	10000	6000	4900 (82)	2450[3]	0.00675	2.4
Atlantic Coast Brazil	1000000	20000	10000	5000 (50)	2500	0.0135	4.0
Western Ecuador	27000	2500 at most	10000	2500 (25)	1250	0.0017	4.0
Totals	1089000	32500	26000	12400	6200	0.02	10.4

Notes:
1. In the light of the findings of the theory of island biogeography.
2. The number of animal species in a similar situation can be roughly estimated by multiplying the number of plant species by 20, thus supplying a *minimum* estimate. According to the calculations presented here, the total number of animal species in question is 124 000. The actual could be several times higher.
3. That is, when remaining Madagascar primary forest declines to 10 percent of original extent, which is likely within the next decade at most.

Sources: See references cited in text.

Ten "Hotspot" Areas

1. Madagascar

This ancient island is famous for its unique biota. Yet nationwide, only 5 percent of the original vegetation remains (Guillaumet, 1984; Jenkins, 1987; Jolly *et al.*, 1984; Leroy, 1978; Lowry, 1986; Mittermeier, 1986). Fortunately, the situation is somewhat better in a strip of moist forest along the island's eastern side, where more than 6000 plant species occur of which 4900 (82 percent) are endemic. Virtually all of the narrow coastal plains and the lower slopes have been deforested, but on the higher slopes some tree cover persists, amounting today (early 1988) to rather less than 20 000 km^2 (32 percent of the original 62 000 km^2) (Sussman *et al.*, 1988). Around half of these relict patches have been degraded through intensive slash-and- burn cultivation, which is now eliminating 1000-1500 km^2 of forest per year. The forest remnants that feature greatest species diversity and endemism, notably in the northern part of the strip, are precisely those forest tracts under most pressure from agricultural settlers.

Thus there is little hope that more than 10 percent of original forest will survive beyond the end of the century. Madagascar's population growth remains high at 2.8 percent per year. Rural poverty is pervasive. Existing farmlands are among the most eroded anywhere; and because they are generally unable to support the rural population, growing throngs of peasants seek new lands to cultivate, notably in the forests.

2. Atlantic Coast Brazil

Along its Atlantic coast, Brazil possesses a discontinuous strip of remnant forest. This strip, floristically far different from Amazonia, once featured about 10 000 plant species, with an endemism level around 50 percent (53 percent for trees, 64 percent for palms) (Boom *et al.*, 1983; Fonseca, 1985; Mori, 1988). From the onset of Portuguese colonisation, the forest has been heavily and repeatedly logged for timber and charcoal. Worse, extensive sectors have been cleared for plantations of sugar-cane, coffee, cocoa and other cash crops. Of the original 10 000 km^2 of forest, only 5 percent remains today, a mere 2 percent in primary form, and less than 0.1 percent is protected as parks and reserves.

3. Western Ecuador

The lowland wet forest of western Ecuador, once covering 27 000 km^2, and now reduced to 2500 km^2 at most, shows some floristic affinity with the Colombian Chocó (see next item), but its many unique features, e.g. its abundant endemic epiphytes, allow it to rank as a distinct phytogeographic zone. It once contained some 10 000 plant species, around 2500 of them endemic to the area (Dodson and Gentry, 1978). The original forest was almost completely converted to cash-crop plantations and other non-forest uses within just 12 years from 1960 onwards.

An idea of the former biotic diversity may be gained from the Rio Palenque Science Center at the southern tip of the area, where less than 1 km^2 of primary forest survives. In this fragment there are 1200 plant species, 25 percent of them endemic to western Ecuador (Dodson and Gentry, 1978). As many as 100 of these Rio Palenque species have proved to be new to science; 43 are known only from the site, and a good number exists in the form of just a few individuals, some as a single individual.

About 8 km east of Rio Palenque is the Centinella Ridge, isolated from the main Andean range. Some 600 m high, and measuring only 20 km long by 1 km wide, the ridge formerly supported almost 100 endemic plant species (Gentry, 1986a). Between 1980 and 1984 it was cleared for settlement agriculture and its native vegetation, including its endemic species, was eliminated. Several dozen other semi-isolated ridges along the base of the Andes could well show similar species richness and high endemism, but they remain little explored botanically. If they prove to match the floristic richness of the Centinella Ridge, they could well contain at least 1000 undiscovered species, many of them endemic. Around half have recently been cleared for agriculture (Gentry, 1987).

Western Ecuador, and the other two areas described above, rank as the hottest of hot spots insofar as they are the richest and the most threatened of all the areas considered in this paper. In these three areas together there must have already occurred a mini-spasm of extinctions. In the light of the data presented, it is realistic to suppose that until recently they supported a total of 26 000 plant species, together with well over 500 000 animal species, indeed many more animal species if original numbers were proportionally higher than postulated on the basis of a minimum planetary complement of 5 million species. Endemism levels ranged from 25

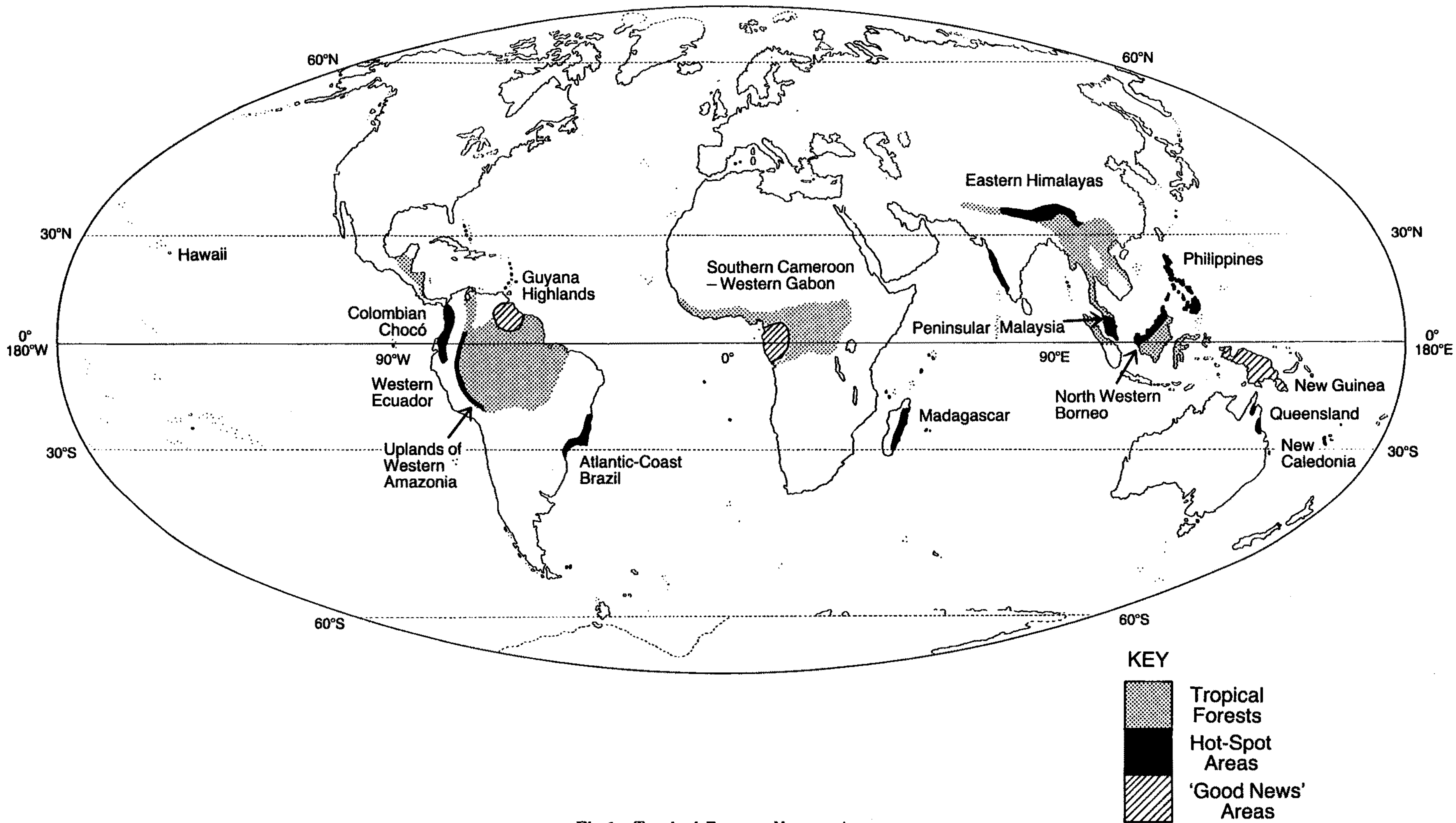

Fig.1. *Tropical Forests: Hotspot Areas.*

to 82 percent. In each area less than 10 percent of original vegetation remains today, or is likely to last beyond the end of the century. According to the well- established theory of island biogeography (MacArthur and Wilson, 1967), when a habitat loses 90 percent of its original extent it can no longer support more than 50 percent of its original species. In these three areas alone, then, recent or near-future extinctions could well total some 6200 plant species and at least 124 000 animal species. Alternatively stated, a collective area of originally 1 089 000 km^2 of tropical forest, amounting to only 0.74 percent of Earth's land surface, formerly supported 10.4 percent of Earth's plant species; and it is now surely experiencing the extinction of almost 2.5 percent of Earth's plant species and at least a similar share of animal species. See Table 3 for a consolidated summary.

Let us suppose, moreover, that the great majority of these extinctions will have occurred during the last 50 years of this century (much deforestation overtook Madagascar and Atlantic coast Brazil before 1950, whereas western Ecuador did not start deforestation until 1960). The calculations above indicate that in these three areas alone an average of one plant species will have been eliminated every three days, and several animal species, possibly as many as five species, every day.

Of course these are crude calculations. They are advanced solely as a preliminary exploration of a mass-extinction episode already underway: no more, no less.

4. The Colombian Chocó

The Colombian Chocó is an expanse of mainly coastal-plain forest, extending from the Panama border right through to the Ecuador boarder, and formerly comprising almost 100 000 km^2 of forest. While only a little more than 3500 plant species have been recorded, there are probably at least 8000, and possibly 9000, in just the Chocó Department, with a total of at least 10 000 in the whole of the Chocó region. Of these, 25 percent are believed to be endemic (Gentry, 1982a, 1982b; Forero and Gentry, 1987). Similarly high rates of endemism apply to birds (Terborgh and Winter, 1983) and butterflies (Brown, 1982).

Since the beginning of this century there has been a steady stream of settlers spreading out along the rivers, drawn by the timber stocks and mining potential, and pushed by socio-economic problems, such as land hunger in the Colombian highlands (Gentry, 1987; Kirkbride, 1986). In 1980, two-thirds of rural households were either landless or they worked insufficient land to sustain themselves (Sinha, 1984); and today the mal-distribution of farmlands has become still more skewed. Moreover, there are growing throngs of workless people. Of a labour force of 9 million people in 1984, unemployed and under-employed amounted to 40 percent; and increasingly these impoverished people seek to support themselves through settlement agriculture in the Chocó and in Amazonia (see next item).

Since the early 1970s, deforestation has proceeded apace. The northern part of the Chocó has virtually all been deforested by logging and the spread of agriculture. In much of the central Chocó, forest accessible from rivers, including tributaries, has been all but eliminated, apart from a few remote localities. In the southern sector adjoining the Ecuador boarder, forest has given way to oil-palm plantations (Gentry, 1987). All in all, undisturbed forest in 1979 amounted to less than 80 000 km^2, meaning that roughly 20 percent of the forest cover had already been removed (Gentry, 1987). Today there is probably no more than 72 000 km^2 left and deforestation is proceeding faster than ever.

5. Uplands of Western Amazonia

This area includes upland sectors between 500 and 1500 m of the Andean slopes that border Western Amazonia, with high rainfall year-round and fertile soil. It comprises a belt mainly 50 km wide, sometimes only 25 km. It extends about 2200 km from the southern part of Colombian Amazonia, through Ecuador, and right along the Amazonian fringe of Peru. Thus it encompasses no more to than 100 000 km^2. Not only is it extremely rich in species, it is probably undergoing more forest depletion than is occurring in the 15 times larger Brazilian State of Amazonas.

Western Amazonia as a whole,i.e. lowlands as well as uplands, is surely the richest biotic zone on Earth (Brack, 1987; Caballero, 1981; Gentry, 1986a, 1988a; Parker, T.A., 1987; Remsen, 1987; Stark and Gentry, 1988; Terborgh, 1987). Indeed it deserves to rank as a kind of global epicentre of bio-diversity (Munn, 1987). In south-eastern Peru, the forests of the 15 000 km^2 Manu Park contain at least 8000 described plant species, or almost half as many as in the 520 times larger USA. There are also 200 animal species, or more than in the USA and Canada, and 900 bird species, or more than 10 percent of all those on Earth. Manu extends from the Amazon plain far up in the Andean slopes and, as elsewhere alone the fringes of Western Amazonia, much of the flora and fauna of the lowlands are found in the "upper tropics" as well. But the converse does not apply to the same extent. Of 1200 bird species in Peruvian Amazonia, 75 percent of the country's total, there are many more above the 1000 m line than below; and of 160 tanagers in the whole of Amazonia, more than 120 occur in the upper tropics (Parker, T.A., *et al.*, 1982; see also Haffer, 1985 and Terborgh *et al.*, 1984; for similar findings in Colombia and Ecuador, see Cracraft, 1985; Hilty and Brown, 1984).

Despite the extreme biotic richness of this part of Western Amazonia, we know all too little about the flora of the area. We cannot even advance a substantiated estimate of the total number of plant species. Of an estimated 10 000 plant species awaiting discovery in the Neotropics, many are surmised to be in Western Amazonia (Gentry, 1988b). There are reputed to be 4000 species in the relatively small Ecuadorian sector alone (Balslev, 1988). For the purposes of this paper, and on the basis of comparative assessments (Gentry, 1987), we can hazard an "informed assessment to the effect that Western Amazonia may well support 20 000 plant species.

More important still, there is a higher level of endemism in the uplands than in the lowlands (Brack, 1987; Dourojeanni, 1986; Duellman, 1987; Gentry, 1986a; 1988a; 1988b; Gentry and Dodson, 1987a; 1987b; Patton, 1987; Remsen, 1987). This probably occurs, in part at least, because the Andean slopes are divided by deep valleys. In just eight valley systems of eastern Peru, several as small as 5000 km^2 in extent, there are 65 endemic bird species (Parker, T.A., *et al.*, 1982). For vertebrate species generally in five separate drainages, the endemism level appears to be of the order of 30 percent (Parker, T.A.,1987; Terborgh, 1987). While the level of plant endemism is little documented, we know from other biotically rich areas in tropical forests of South America that endemism among plants often matches that of animals (Gentry, 1987). So it is realistic to suppose that the endemism level for plant species in the area could well be 25 percent, if not higher, and this figure is accepted for the purposes of this paper.

Throughout much of the area there has been extensive road building for at least two decades. This fosters the spread of subsistence farming and plantation agriculture (coffee, tea, cocoa, coca) in the area with its rich soils. The result has been large-scale conversion of forest, both by outright deforestation and by gross disruption of forest ecosystems. In the Colombian sector, the influx of new settlers in the late 1970s was eliminating between 1500 and 2000 km^2 of forest per year and degrading a good deal more (Marsh, 1983). According to scattered reports and the author's own field findings in south-eastern Colombia, the amount of land deforested and otherwise converted so far could well amount to 10 000 km^2, viz. virtually the entire upper tropics zone.

In the Ecuador sector there were only 45 000 people in 1950, but almost 300 000 today (Salalar, 1986). Since the late 1960s, the sector has been Ecuador's most important source of petroleum, which has been paying for a large share of the national budget. There has been not only much road building and settlement but also rapid conversion of forest into oil-palm plantations; Ecuador has high hopes that palm-oil will join petroleum as a major source of foreign exchange for its ailing economy (Bromley, 1981; Hiraoka and Yamamoto, 1980; Rudel, 1983). The amount of forest converted to date could well be as much as 15 000 km^2, again almost all the remaining forest being in the upper tropics zone.

As for Peruvian Amazonia, the largest and biotically the richest part of the area, forest depletion is proceeding widely and rapidly, but because the upper tropics zone is much more extensive here than in Colombia and Ecuador, the forest has not yet been eliminated so widely. In the late 1970s, almost 30 000 additional people were entering Amazonia each year, mostly into the upper tropical zone (Dourojeanni, 1979; Myers, 1980). They were arriving primarily in response to land hunger in traditional farming areas of western Peru, where landlessness and near- landlessness amounted to 75 percent of small-scale farmers (Durham, 1979; Sinha, 1984). By 1979, lands under effective agricultural use in Peruvian Amazonia, mostly in the uplands, amounted to 13 200 km^2, with a further 37 400 km^2 of abandoned farmlands (Myers, 1980). Today, the total is put at more than 70 000 km^2, in the uplands and lowlands combined, with an annual deforestation rate of almost 3000 km^2 (Dourojeanni, 1988; Salati *et al.*, 1988).

In summary, and according to recent observers (Gentry, 1987; Munn, 1987; Parker, T.A., 1987; Patton, 1987; Salati *et al.*, 1988;

Terborgh, 1987), almost the entire upper tropics zone has been deforested in Colombia and Ecuador, while in Peru, the same applies at least from the Rio Marañon in the north to the Rio Apurimac in the south. This means that, roughly estimated, some 65 000 km^2 (65 percent) of the area's forest has already been cleared or otherwise converted. Moreover, deforestation is proceeding ever more rapidly. There is a progressive build-up of land hunger pressures in traditional farming territories of all countries concerned; and these pressures are being compounded by faltering economies and population growth. In addition, each of the governments in question perceives an incentive to speed up settlement of Amazonia as a means to assert sovereignty over the area with its abundant mineral resources. Given the accelerating deforestation trends of the past two decades, it is not unrealistic to surmise that at least 90 percent of forest will be converted by the year 2000, if not sooner, meaning that 50 percent of the species of the area will have disappeared or be on the point of elimination.

6. Eastern Himalayas

Phytogeographically, the Eastern Himalayas form a distinct floral region (Maheshwari, 1980; Ohashi, 1975; Palliwall, 1982; Polunin and Stainton, 1984; Sahni, 1979; Takhtajan, 1986). The area comprises Nepal, Bhutan and neighbouring states of northern India, plus a contiguous sector of Yunnan Province in south-western China. Although some Himalayan forests occur at altitudes of 1800 to 3500 m, where their physiognomy, structure, etc., make them more akin to temperate zone forests, and they all lie well north of the Tropic of Cancer, they will be considered here as tropical forests since they occur largely within the climatic tropics.

The Eastern Himalayas feature ultra-varied topography, a factor that fosters species diversity and endemism. Many deep and semi- isolated valleys are exceptionally rich in endemic plant species. In Sikkim, in an area of 7298 km^2, of 4250 plant species, 2550 (60 percent) are endemic (Palliwall, 1982).

In India's sector of the area some 5800 plant species occur, roughly 2000 (36 percent) of them being endemic (Jain and Mehra, 1983; Jain and Sastry, 1982; Maheshwari, 1987; Nair, 1987; Ramakrishnan, 1985; Rao, 1980; Nayar and Sastry, 1987). In Nepal there are an estimated 7000 plant species, many of which overlap with those of India, Bhutan and even Yunnan (totals for the Eastern Himalayas). Of these plant species, at least 500 (almost 8 percent) are thought to be endemic to Nepal (Hara *et al.*, 1978- 82; Shrestha *et al.*, 1986). Bhutan possesses an estimated 5000 species, of which as many as 750 (15 percent) are considered to be endemic to the Eastern Himalayas (Grierson and Long, 1983).

As for China, it harbours an estimated 15 000 plant species in its tropical regions, which comprise some areas additional to the main locality in Yunnan (Anon., 1985; Hou, 1983; Takhtajan, 1986; Zheng-Yi, 1980). Yunnan alone, with its centres of exceptional endemism (Tsun-Shen and Zhi-Song, 1984; Zaifu, 1984; Zang, 1987; Zhenzhou, 1987), is believed to possess almost 12 000 species, mostly in its tropical forest zone that now covers only 10 percent at most of the 436 200 km^2 province. Plant endemism rates range from 10 to 34 percent according to locality. But regrettably, no good data are available for species numbers and distribution. For the purposes of this paper and its attempts to come up with "working estimates" of species totals, let us consider an informed and strictly conservative assessment, based on the author's communications with Chinese botanists (Youxu, 1987; Zang, 1987; Zhenzhou, 1987): Yunnan's tropical forest plants total 7000 species, some overlapping with territories to the west; at least 1000 (14 percent) of them being endemic.

In summary then, in that portion of the region within the Indian sub-continent, i.e. excluding south-western China, there are an estimated 8000 plant species, some common to the Indian sub-continent, at least 1000 of them endemic. So a conservative estimate for the whole of the Eastern Himalayas can be set at 9000 species, with 3500 (39 percent) of them being endemic.

Early in this century, forest cover in the entire Himalayan range was still extensive, especially in the eastern portion. Today, much has been eliminated altogether, and most of the remainder is degraded (Gupta and Bandhu, 1979; Myers, 1986; Singh and Kaur, 1985). In the Indian sector of the eastern portion of the range, there is virtually no forest left below 2000 m, and in the next zone up to 3000 m it has declined from about 35 percent in 1950 to 8 percent or less today (Haig, 1984; Lall and Moddie, 1981; Maheshwari, 1987; Rao, 1987). The total can be tentatively put at 57 000 km^2, and as much as 66 percent is biologically depauperate. Population pressures are already acute: 70 percent of smallholdings in the Indian sector of the Eastern Himalayas are less than 1 ha each.

In Nepal, forest cover declined by 1982 to less than 25 000 km^2 (Bajracharya, 1983; Malla, 1986). Of today's forest, estimated at a little over 21 000 km^2, 33 percent is considered degraded to such an extent that it no longer retains more than a fraction of its biological productivity and biotic richness. If current rates of deforestation continue in Nepal, there will be virtually no forest left by the end of the century (Martens, 1982; Wallace, 1985). As for Bhutan, at least 23 000 km^2, or 50 percent of national territory, are still forested, but only 22 percent features closed or partially closed forest (Sargent *et al.*, 1985). Moreover, many forest tracts, especially those that are richest biotically, have been severely disrupted through logging and expanding agriculture (Sargent, 1985).

In the case of Yunnan, there is scant information available except that tropical forests are reported to have declined since 1950 from 55 to 21 percent of their former extent, i.e. to roughly 9000 km^2, due principally to heavy pressures from agricultural settlement (Chamberlain, 1987; Smil, 1985; Youxu, 1987; Zaifu, 1984; Zang, 1987; Zhang, 1986; Zhenzhou, 1987). Much of the remaining forest is degraded.

According to these data and best information available from recent researchers in the region, we can conclude, albeit tentatively, that former forest in the Eastern Himalayas as a whole was once some 340 000 km^2, but is reduced today to 110 000 km^2 at most, only 53 000 km^2 of that being primary forest.

7. Peninsular Malaysia

The Malaysia Peninsula features at least 8500 plant species in its 131 000 km^2, virtually all in the tropical forests which once covered pretty well the entire Peninsula (Aiken and Leigh, 1986; Ashton, 1982; Soepadmo, 1987; Whitmore, 1984). Of 2400 tree species, 654 (27 percent) are endemic; and this paper assumes a similar rate of endemism among all plants, for a total of 2,395 species. Of the endemic tree species, 343 (52 percent) are endangered; and of 66 such species recorded only in the State of Perak, many of them in tin-rich areas that have been heavily mined, the majority have not been seen since 1940 (Zakaria, 1987). Much the same appears to apply to all other endemic tree species in the Peninsula: according to two experts on the endemic species in the Peninsula (Ng and Low, 1982, "Their fate hangs in the balance".

Specially important are limestone outcrops. Totalling only 269 km^2, these outcrops feature 1,216 plant species of which 261 (21 percent) are endemic (Kiew, 1983). Virtually all outcrops are severly threatened by quarrying, mining and agriculture.

Ten years ago, only 53 500 km^2 of Peninsular Malaysia remained forested and of this, only 28 000 km^2 ranked as primary forest (Aiken and Leigh, 1985; Davison, 1982). Today, hardly any lowland forest, viz. the richest forest type, remains except in degraded form. Peninsular Malaysia has recently become a net importer of hardwood timber, a situation that directs still greater exploitation pressure at remaining upland forest.

8. Northern Borneo

The 757 000 km^2 island of Borneo contains at least 11 000 plant species, around 34 percent of them endemic, making it the richest of the Sunda islands (Davis *et al.*, 1986). As in the case of Peninsular Malaysia, virtually all the species occur in forests which constitute the overwhelmingly dominant type of vegetation on the island. That part of Borneo with the greatest species diversity by far is the northern sector that comprises most of Sarawak, the mini-state of Brunei and Sabah, totalling 175 000 km^2, or 23 percent of the island in terms of original forest areas (Takhtajan, 1986; Veldkamp, 1987). In this northern sector, a 10 hectare aggregate of forest can support 700 tree species, or as many as in the whole of North America (Ashton, 1977). Of Borneo's 267 dipterocarp tree species, 250 (94 percent) occur in Sarawak and Brunei, 68 of them (27 percent) being endemic (Ashton, 1982; see also Anderson, 1980; Chai and Choo, 1983). In Sabah there is a major centre of diversity at Mount Kinabalu, with its 4500 plant species, 700 to 1000 of them being orchids, or at least 25 percent of all orchids in South-east Asia (Luping *et al.*, 1978). Of Borneo's 135 fig tree species, 75 appear on Mount Kinabalu, 13 of them (17 percent) being endemic; while of the 100 or more *Ericaceae* species (rhododendrons and associates), 43 percent are endemic (Cockburn, 1980; Luping *et al.*, 1978). According to best-judgement, albeit little documented, estimates of experienced observers, northern Borneo, as defined here, is estimated to contain 9000 plant species of which at least 3500 species (39 percent) are believed to be endemic to the area.

Fig. 2. Logging Road through Tropical Rainforest, Borneo

Fig. 3. Large area of Tropical Rainforest cleared, Malaysia

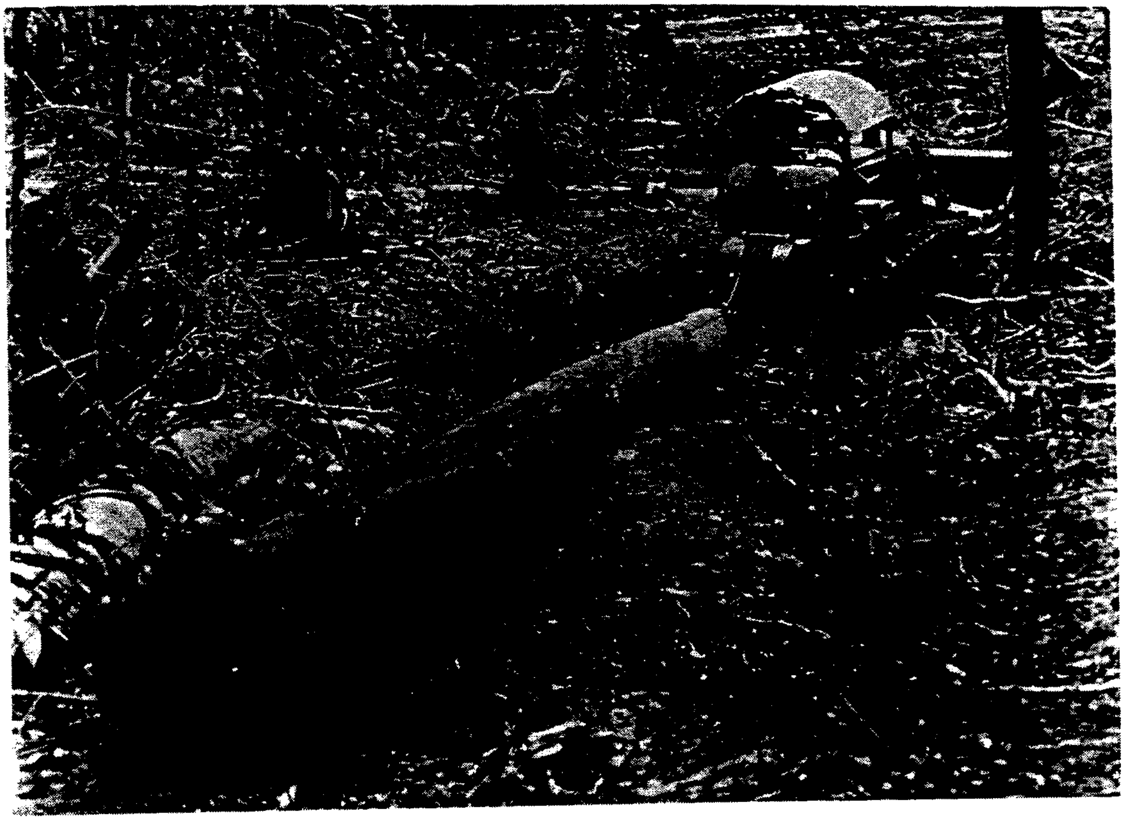

Fig. 4. Logging in progress. Digger dragging log, Borneo

Fig. 5. Shifting cultivation of Tapioca, Malaysia

The forests of the area are being depleted quite fast. In Sarawak, logging proceeds apace and there remains a maximum of 75 000 km^2 of forest in the State territory of 125 000 km^2 (Caldecott, 1986; Hong, 1987; Lee *et al.*, 1986). No more than 50 percent of this is considered to rank as primary forest; almost all remaining forest tracts in Sarawak have been given out to timber concessions, and the entire expanse could well be logged by the year 2000, if not earlier. In addition, the State government considers that a large portion of forest lands, as much as 27 000 km^2, are suitable for conversion to permanent agriculture.

In Sabah, 61 500 km^2 (87 percent) of the State were still under forest cover of one type or another in 1980, around 50 percent having been disrupted and degraded (Myers, 1980). Today the amount of primary forest is reputed to be no more than 24 000 km^2 (Marsh, 1987). Almost 21 000 km^2 of forest are considered by the government to offer agricultural potential and are scheduled for eventual conversion to agriculture and agro-industry. Forest Reserves, which permit logging, comprise another 24 000 km^2. Forest protection areas amount to less than 5000 km^2. Through a recent shift in policy, the forests are being rapidly felled with the aim of maximising immediate revenues.

Fortunately, Brunei still features around 3600 km^2 of forest in little disturbed state.

9. The Philippines

There are some 8500 plant species in the Philippines, occurring almost entirely in tropical forests that covered most of the archipelago as recently as the start of this century (Madulid, 1982, 1987; Quisumbing, 1967; Revilla, 1986). Some 3700 plant species (44 percent) are endemic (Heaney, 1986). Many of the endemic plants have been collected only once or twice, and despite recent efforts by botanists to re-collect them in their original forest habitats, many have not been found and are presumed to be extinct.

Species richness and endemism have been promoted by the fact that the Philippines comprises more than 7000 islands. Some islands are strictly oceanic, others are fragments of once larger islands, and still others have had recent land-bridge connections to the Asian mainland. As a result, islands with quite distinct flora and fauna are separated by only short distances (Heaney, 1986). Of 628 terrestrial vertebrates, 229 (37 percent) are single-island endemic, making them all the more vulnerable to summary extinction (Hauge *et al.*, 1987). A similar degree of highly localised endemism applies to plants (Madulid, 1987; Tan *et al.*, 1986).

Remaining forests cover no more than 55 000 km^2 (18 percent of the country), mostly in disturbed and degraded form. Old-growth dipterocarp forests in primary status, viz. the richest forests in both biotic and commercial senses, have been reduced to only 8000 km^2 at most, and they are expected to be logged out well before the year 2000 (Revilla *et al.*, 1987). Yet the principal factor in forest depletion is no longer the loggers. It is the slash-and-burn cultivators who occupy much of the country's uplands where most of the remaining forests are located, and who often feature population densities of 200 persons or more per km^2, i.e. far more than can be sustained by shifting cultivation of a traditional type (Cruz, 1986). These forest-land farmers now total at least 14.4 million. They mostly comprise susbsistence peasants who, finding themselves landless in the country's lowlands, migrate to remaining forest lands. Given the current population growth rate nationwide of 2.8 percent (no significant decline since 1980), and the closing of the agricultural frontier in the lowlands, this migratory trend is likely to accelerate until virtually all remaining forest of whatever sort has been eliminated within another two decades (Myers, 1988a).

10. New Caledonia

In the island's forests there are 1575 plant species of which nearly 1400 (89 percent) are endemic (Cherrier, 1986; Holloway, 1979; Lowry, 1986; Morat *et al.*, 1984). Even before Europeans arrived there was much burning of forests, and during the period 1870-1940 the best timber stands were logged. By the middle of this century many forest areas with the greatest biotic diversity had been either burned of logged, and by 1970, only 2000 km^2 at most, out of a total of 3740 km^2, could be considered to feature undisturbed forest (Thomson and Adloff, 1971). By today, the amount has declined still further to 1500 km^2 (Morat *et al.*, 1984).

According to the Forestry Department, certain of these primary forests, together with secondary forests, many of them degraded to savannah woodlands, continue to recede under the impact of over-exploitative logging, mineral extraction and wild fires (Boulet, 1987; Cherrier, 1986; Dahl, 1984). Much of the forest remaining is on steep slopes, so is less accessible to commercial logging, but the few remaining timber companies are still trying to harvest some last patches of primary forest (Dahl, 1984; Spiers, 1985). Moreover, all forests remain vulnerable to mining activities and frequent bush fires.

These, then are the 10 "hot spot" areas of special importance. In addition, there are several other, though smaller and less rich areas also under severe threat. They include the Mosquitia forest of Honduras and Nicaragua; the Darien Gap in Panama; five centres of diversity in Brazilian Amazonia; the south-western part of the Ivory coast; the "eastern arc" forests of Kenya and Tanzania; the Western Ghats of India; south-western Sri Lanka; southern Thailand; and Sumatra. Altogether, these areas possibly support as many as 5000 endemic plant species, by contrast with 34 200 in the hotspot areas.

Comparisons: Hawaii and Queensland

For comparison, let us briefly consider two hot spot areas in the developed world where conservation resources are much more plentiful than in the developing world, and where extinction threats can be much more readily reduced.

1. Hawaii

Covering only 16 707 km^2, the islands harbour at least 1100 native plant species, some 990 (90 percent) of them being endemic and nearly half of them threatened (Carlquist, 1980; Mueller-Dubois *et al.*, 1981; Stone and Scott, 1985). At least 75 percent of plant species and an estimated 825 of endemic species occur in the island's forests, which are now reduced to well under 50 percent of their original extent. Deforestation continues in response to a tax system which encourages forest clearing for agricultural expansion.

A comprehensive conservation strategy has recently been formulated (Nature Conservancy of Hawaii, 1987). Of roughly 150 ecosystem types, the bulk of them in the forests, 88 are considered so endangered that they will certainly be eliminated within another two decades unless they are protected forthwith. At least 30 of these ecosystems, representing 33 percent of the critically imperilled communities, could be saved for a cost of $10 million, while the rest could be secured for a further $150 million.

2. Queensland

In northern Queensland, another developed-world area, there are 6300 km^2 of wet forest remaining out of some 13 000 km^2 half a century ago. In this tiny tract, less than 0.1 percent of the surface area of Australia and actually a patchwork of forest remnants, there are at least 1165 plant species, of which 435 (37 percent) are endemic to the area (Aiken and Leigh, 1987; Keto, 1984; Parker, P.K., 1987; Rainforest Conservation Society of Queensland, 1986; Tracey, 1982). As in many tropical areas, some plant species are so restricted that they occur in a single valley or on a single hilltop. Moreover, of the world's 19 primitive flowering-plant families, 13 occur here, two of them endemic to the area, giving the area the highest concentration of such plant families anywhere.

Yet despite the scientific value of the area, it continues to be logged, with support from the Queensland Government in the form of abundant subsidies. The area has been designated by the Government of Australia as a candidate for World Heritage Listing, a move that is being legally contested by the Queensland Government.

"Good News" Areas

Fortunately, there are a number of tropical forest areas with unusual concentrations of species, including many endemic species, and where there are few threats of imminent depletion. An instance is the Guyana Highlands, covering the south-eastern half of Venezuela and extending into Guyana, and a little into Brazil, amounting to 500 000 km^2. The area contains more than 400 endemic species described, out of a predicted flora of about 8000 species (Davis *et al.*, 1986; Maguire, 1970; Steyermark, 1984). Human populations are sparse and there seems little prospect that primary forests will be modified within the foreseeable future.

Another such area comprises southern Cameroon and western Gabon, extending into parts of Congo and covering roughly 300 000 km^2 (Brenan, 1978; Catinot, 1978; Hamilton, 1976; Letouzey, 1976; Stuart, 1987). Southern Cameroon supports probably the richest flora in continental tropical Africa, though statistical evidence is regrettably sparse. Gabon, while little explored botanically, is reputed to harbour around 8000 plant species of which 1750 (22 percent) are endemic. Congo contains an estimated 4000 plant species, 880 (22 percent) of them endemic; and the western portion of Congo's northern forests is considered to be one of the most species-rich areas in the entire Zaire Basin. With human populations in Gabon and Congo totalling only 3 million people in 610 000 km^2, and no more than 5 million in southern Cameroon, population pressures on the forests are slight, though in Gabon there is some threat from logging interests.

New Guinea also ranks as a good news area for the most part. In the Papua New Guinea (PNG) portion there are more than 350 000 km^2 of forest left, covering about 75 percent of the country; and a roughly similar amount exists in the Irian Jaya sector of Indonesia, which is slightly smaller. These 700 000 km^2 of forest contain the great majority of the island's 11 000 plant species, 90 percent of them endemic (Gressitt, 1982; Morauta *et al.*, 1982; Paijmans, 1976). While 40 percent of the forests of PNG have been disturbed or destroyed through slash-and-burn farming, outright clearing amounts to only about 3000 km^2 per year. Broadly similar figures apply to Irian Jaya, where the government plans to devote about 20 percent of the territory to protected areas of various sorts. PNG contains only 3.5 million people and Irian Jaya 1.2 million, so population pressures are slight so far.

The forests of these three areas could well contain as many as 15 000 endemic plant species.

The Role of Parks and Reserves

Parks and reserves can play only a limited role in preserving species in hot spot areas, even though certain areas, notably Western Amazonia and Peninsular Malaysia, feature several protected areas of good size. The cost of establishing a network of parks and reserves, i.e. sufficient to safeguard a representative array of high-value forest ecosystems, would be high. A recent assessment (World Resources Institute and World Bank, 1985) estimates that to establish an adequate, though less than comprehensive, system of protected areas throughout the biome might require an outlay of $800 million over 5 years.

In any case, there are severe limitations to protected areas as a long term safeguard strategy, due to the "islandizing effect". This occurs when a patch of habitat becomes a park and its environs are given over to alien activities, leaving the park as an isolated patch of habitat. For the park to serve as a viable ecological entity that can safeguard 50 percent of its original species complement, it must generally constitute at least 10 percent of the original expanse of habitat, which is hardly ever the case. As a consequence of the "islandizing effect" and the processes of "ecological equilibration", there ensues a delayed fallout of species. Even in the best managed park, delayed fallout eventually causes the species complement to decline to less, often a good deal less, than before the islandization occurred.

The same process applies to those many forest areas that do not become parks, but are islandized through fragmentation of forest tracts. The remnants of primary forest in the Philippines have almost all become far smaller than 10 percent of their original extent. This means that they are too small already to constitute independent eco-units with full panoply of species in perpetuity, even if they were to be protected as parks forthwith. Much the same applies to large parts of remaining forests in Madagascar, Atlantic-coast Brazil, the Eastern Himalayas, Peninsular Malaysia and New Caledonia, where most of the remaining forests have been reduced to relict eco-islands. Indeed, in these six hot spot areas there must have been a sizeable fallout of species already.

For a graphic illustration of delayed fallout, consider Amazonia. According to Simberloff (1986), if deforestation continues at present rates until the year 2000 (and it is likely to accelerate), but then halts completely, we should anticipate an eventual loss of about 15 percent of the plant species of Amazonia. Were the forest cover to be ultimately reduced to those areas now set aside as parks and reserves, we should anticipate that 66 percent of plant species will eventually disappear, together with almost 69 percent of bird species and similar proportions of other major categories of animal species.

The Climate Connection

In any case, the best protected areas may shortly suffer severely through climatic disruptions. In Amazonia it is becoming apparent that even if sizeable amounts of forest cover were to be safeguarded but the rest were to be "developed out of existence", there could soon emerge a hydrological feedback effect that would allow a good part of the region's moisture to be lost to the ecosystem (Salati and Vose, 1984). In turn, this could impose a steady desiccatory process on the remaining forest until it became more like a woodland; with all that would mean for the species communities that are adapted to forest habitats. Even with a set of forest safeguards of exemplary type and scope, Amazonia's remaining biotas would be more threatened than ever.

There are other climatic changes impending, with potential impact on tropical-forest biotas that could prove yet more pervasive and profound. By the end of the century or shortly thereafter, a planetary warming will surely be emerging, caused by a build-up of carbon dioxide and other "greenhouse gases" in the global atmosphere (Bolin *et al.*, 1986). In addition there will be some redistribution of rainfall patterns, with disruption of monsoon systems and other seasonal rainfall patterns (Davis, 1986; Emanuel, 1987; Myers, 1988b; Zong-Ci Zhao and Kellogg, 1988). Among hotspot areas that could be vulnerable to this form of perturbation are Eastern Himalayas, Philippines and New Caledonia (also Hawaii and Queensland).

Equally to the point, these climatic changes could work in amplificatory accord with other factors, such as deforestation and ecological sensitivity of species, to deplete species communities more than would be the case if they worked in isolation from one another. These synergistic responses could serve to impose a still greater scale of extinctions, and do so more rapidly, than is sometimes anticipated (Myers, 1987b).

Analysis and Summary Assessment

The findings presented in this paper indicate that unless far more vigorous conservation measures are instituted in the 10 areas in question, we can anticipate the extinction of a sizeable number of plant species by the end of the century or shortly thereafter. Assuming that endemic plants in these areas total rather more than 34 200 (Table 1), and assuming that their habitats are reduced to 10 percent or less of their original extent within the foreseeable future, there will ensue, according to island biogeography, the extinction of half these species, or more than 17 000 species. This extinction spasm, accounting for more than 13 percent of all plant species in tropical forests, will occur in a total area of only 292 000 km^2 or 3.5 percent of remaining tropical forests. These calculations also mean that almost 7 percent of Earth's plant species are now at terminal risk in 0.2 percent of Earth's land surface.

As for animal species, the number in danger is 350 000, assuming a minimum planetary total of 5 million species. The true total could well be several times higher.

Furthermore we should not think only in terms of sheer numbers of species. There is a qualitative aspect to biotic depletion. In some cases there will be elimination of taxa beyond the species level. For instance, in the forests of Madagascar four or five families of plants are endemic to the area; and in New Caledonia, five families. In all of the hot spot areas, many plant genera are endemic. This makes the extinction spasm underway a yet more impoverishing phenomenon than is suggested by a simple count-up of species.

There is yet a further repercussion for the plant kingdom. Large plants have existed on land for the last 430 million years; and by 65 million years ago, flowering plants (the great majority of the plants considered in this paper) totalled somewhere between 100 000 and 150 000 species, constituting about 75 percent of all plant species on land. Today there are 220 000 such species, or 88 percent of 250 000 species (Knoll, 1986). But during the late Cretaceous mass-extinction episode, plant life on land seems to have escaped with moderate losses at most, possibly with only a few losses, as compared with animal life. Thus the impending depletion of the plant kingdom in hot spot areas alone seems set to match the worst mass extinction during the entire history of vascular plants; and it will surely prove greater than any other such episode. Alternatively stated, of the 15 million (maximum estimate) vascular plant species that are thought to have existed during the past 400 million years, 14.75 million have become extinct through natural, *i.e.* non-human caused, reasons. This works out at a very crude average of 1 species every 27 years (more in recent times, as the standing stock of species has increased). During the next 25 years or so, we can expect that the extinction rate in 10 hot spot areas alone may well average almost 2 per day, or almost 20 000 times the "background" rate.

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