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Human disturbance and natural habitat: a biome level analysis of a global data set

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This paper presents an analysis of conversion of natural habitat to human use on a global scale. Human disturbance of natural systems is classified in a three-category system and ranked using a Habitat Index based on remaining undisturbed and partially disturbed land. Data is analysed by biome and biogeographic province, allowing identification of the biomes and provinces which have been the most impacted by human activity. Temperate biomes are found to be generally more disturbed than tropical biomes. Four of the top five most disturbed biomes are temperate. Certain biomes and geographic areas stand out as conservation priorities, notably the islands of Southeast Asia, Mediterranean vegetation types, Temperate Broadleaf Forests and Tropical Dry Forests. Areas for which data deficiencies exist are identified.

Keywords: human disturbance, natural habitat, biome, biogeographic province.

Introduction

Human conversion of natural habitat is the largest single cause of loss of biological diversity. The balance between natural habitat and human dominated landscapes will determine the future of biological diversity conservation over large areas of the planet. It is therefore important to map and quantify the degree of human conversion of natural habitat to human-disturbed and human-dominated landscapes. The results of the first attempt at global quantification of the balance between remaining natural habitat and disturbed landscapes has recently been reported by country and biogeographic region (Hannah *et al.*, 1994; World Resources, 1994). This paper presents an analysis of these results by biome.

The implications of this work for global priority setting in conservation of biological diversity are significant. For the first time, a uniform assessment of the world's rarest habitat types is possible. This assessment is based on early data, but it confirms many priorities previously identified in the literature, and suggests avenues for future attention. Further refinement of this database and its analysis will form an important foundation on which more detailed global, regional and local priority setting exercises can be built.

The results presented here are a product of the Global Habitat Database, which is a joint project of Conservation International and the World Resources Institute. This project seeks to map natural habitat and human modified landscapes on a global scale. The database is intended for use in biological diversity conservation priority setting, but it also has applications in global climate change modelling. The project builds on the Human Disturbance Mapping Project initiated by Conservation International. The first product of these efforts is a global data set which maps natural habitat, human modified landscapes

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and human dominated landscapes (Hannah *et al.*, 1994). Ongoing work will upgrade this database, refine the classification system and improve Geographic Information System (GIS) analysis of the database.

Existing references present results of analysis of this database by country and geographic region. Hannah *et al.* (1994) describe the methodology and a breakdown of natural habitat by continent and biogeographic realm. World Resources (1994) presents a breakdown of the database by country. This paper presents additional detail on the methods used in compiling the database and an analysis of the database by biome and more detailed biogeographic analysis at the province level. This analysis permits identification of the biogeographic provinces and biomes most in danger of losing all natural habitat worldwide.

Materials and methods

Human disturbance was mapped using a three-category system which classified ecosystems as undisturbed, partially disturbed, or human dominated. Detailed definitions and criteria for each category are given in Hannah *et al.* (1994).

Areas were classified as Undisturbed where there was a record of primary vegetation, and where there was no evidence of disturbance combined with very low human population density (under 10 person km^{-2} or under 1 person km^{-2} in arid/semi-arid and tundra communities). Partially Disturbed areas were defined where there was record of shifting or extensive agriculture, evidence of secondary vegetation, livestock density over carrying capacity or other evidence of human disturbance. Human Dominated classification reflects a record of permanent agriculture or urban settlement, removal of primary vegetation or record of desertification or other permanent degradation.

A broad range of source map material was partitioned using the classification system and mapped onto Lambert Azimuthal equal area projection base maps (Rand-McNally environment series) at a scale of 1:20 000 000 (1:15 000 000 for Europe). The regional maps were digitized and transferred into the Conservation International Geographic Information System (CISIG). Surface areas in each disturbance category were determined by sampling each regional map on a 1000 km^2 grid in CISIG. CISIG's overlay capacity was used to determine the surface area of each disturbance category within each biogeographic province as defined by Udvardy (1975). The Udvardy system was used because it remains the only uniform global system of biogeographic classification, although it was recognized that this system has numerous flaws and is in serious need of overall revision. Only one correction to Udvardy (1975) has been made, in which the Indo-Malayan islands apparently erroneously identified as Mixed Mountain Systems have been reclassified as Mixed Island Systems.

A derived habitat index was used to rank remaining natural habitat by continent, biogeographic realm, biome, and province. This permits comparative ranking of provinces and biomes based on a single index number reflecting both disturbance categories (undisturbed and partially disturbed) which indicate actual or potential remaining habitat. The index used was:

$$\text{Habitat Index} = \frac{\text{Undisturbed area} + 0.25\ (\text{Partially Disturbed area})}{\text{Total area}} \times 100 \qquad (1)$$

This index represents the percentage of undisturbed vegetation in the area analysed,

plus one-quarter of the partially disturbed vegetation. A low index value indicates a large area of disturbed ecosystem and relatively little remaining natural habitat, while a large index value indicates that a large amount of natural habitat remains.

Source materials were gathered from the general literature, journal literature, and special sources. Sources showed great variability in geographic scope and quality. The majority of the source references were region- or country-specific, while certain source materials were used in all or most regions. In many cases the comprehensive data sets were the most useful and most reliable source materials. In general, good data existed for developed countries and tropical moist forest, while tropical grasslands and woodlands had the least reliable data.

Data sets which were applied globally included the Rand-McNally environment series maps (Rand-McNally, 1980) and the World Conservation Monitoring Center (WCMC) tropical forest cover maps (Collins, 1990). Other sources which were used for more than one region included Bourliere (1983), Bruenig (1987), Campbell and Hammond (1989), Grigg (1984), Heathcote (1983), Kaul (1970), Matthews (1985), Newbury (1980), Schmidt and Yeates (1985), Squires (1981), and UNESCO (1958).

The Rand-McNally maps, themselves a compilation from a wide range of sources, were used in all regions to indicate urban and agricultural lands and in some areas as source material for forest cover. This data set was spot-checked using the University of California-Santa Barbara global Landsat collection and found to be remarkably accurate in representing agricultural usage. However, the Rand-McNally series in general overestimated forest cover, particularly in the tropics, and did not distinguish between primary and secondary forest. In the tropics, the WCMC data set gave a better estimation of forest cover, as judged against other available source materials. The WCMC data was limited to moist forest, so tropical dry forest estimates came from sources which were region-specific. The largest global data deficiency was in population mapping. No detailed global population density map was identified in the project literature search. Detailed population density maps were available for the United States and select other countries, but were generally not available for tropical countries. The Goodes World Atlas population series maps (Espenshade and Morrison, 1975), which were used where no other more detailed information was available, were considered at best a very general approximation of actual population distribution.

Region-specific source references and data gaps are described below.

Africa

Sources included Arntzen and Veenendaal (1986), Boudet (1976), Brandstrom *et al.* (1979), Ford (1990), Kishk (1986), Knight and Newman (1976), Kowal and Kassam (1978), Le Houerou (1989), MacDonald *et al.* (1986), Nuttonson (1961), Olang (1984), Phillips (1959), Pritchard (1971), Simson (1979), Willett (1985), and WCMC (1991). Data on tropical forest cover was available from WCMC and UNEP/GRID. This was complemented by relatively detailed data for agricultural development in eastern and southern Africa. Extensive areas of grassland and savanna in Africa were difficult to document for disturbance except by stocking density, for which there was substantial data. Little useful data were found for South-central African woodlands and the level of disturbance is probably underestimated. The division between disturbed Sahel and undisturbed Sahara is also difficult to identify. The present division is based primarily on population.

Asia

Sources included Amin and Schilz (1976), Bishop (1990), Ewell (1984), Gunatilleke and Gunatilleke (1990), Gupta *et al.* (1984), Hsieh (1973), Ishwaran (1990), Kaplan *et al.* (1979), Kish (1960), Kou (1976), Oxford (1987), Pryde (1972), Prakaser (1986), Richardson (1966), Robinson (1989), Shotski (1979), Singh and Joshi (1990), Smil (1983), Symons (1983), Tseplyaev (1965), Tsujii and Okutomi (1975), Wang (1961), Yoshino (1984), and Young and Wang (1989). Exceptionally abundant data were found for India, which was particularly helpful in outlining remaining areas of dry forest. Extensive conversion to agriculture in eastern China was well documented by several sources. Little data was available for central Asian deserts or Siberia. Level of disturbance may be underestimated in these areas.

South East Asia and Australia

Sources included Aiken and Leigh (1985), Boulbet (1982), Cranbrook (1988), Donner (1987), Hirsch (1987), Hope *et al.* (1976), Humphrey and Bain (1990), Ishi (1978), O'Reilly and McDonald (1983), Paauw (1962), Rand (1988), Seddon (1984), Stott (1978), Ulack and Paver (1989), Ward and Lea (1970), Westing (1984), Whitten *et al.* (1987), and Young and Reggiani (1988). Very good data on Thailand provided dry forest information to complement WCMC moist forest data. Data on defoliation missions flown by the United States provided information on forest disturbance in Vietnam. Agricultural development and livestock density were well documented for Australia, but the division between partially disturbed range and undisturbed desert is primarily based on human population.

Europe

Sources included Asztalos *et al.* (1966), Coppack (1971), Dickinson (1953), Gottman (1969), Houston (1964), Kampp (1975), Kardell *et al.* (1986), Pincherrel (1969), Profous (1989), Pesci and Sarfali (1977), Ratcliffe (1984), and Stamp (1962). Generally good information was available, except in the far north. Very little information was available distinguishing primary from secondary forests in northern Europe, and the extent of undisturbed forests there is certainly overestimated.

North America

Sources included Browning (1971), Conzen (1990), Dalichow (1972), Dayton (1990), Evans (1986), Ewell (1984), Morrison (1988), Pick *et al.* (1989), Thomas (1978), Troughton (1982), US Census (1987), and Venezian and Gamble (1969). Generally good information was available for agricultural development in the United States and southern Canada. Information on logging activities in northern Canadian forests was not as complete as for the USA, where remaining primary forests had been mapped. Information on wetlands in the southeast USA was considered inadequate. Disturbance is probably underestimated for these areas.

South America

Sources included Brannon (1967), Fearnside (1986), Fienup *et al.* (1969), Heaton (1969), Hecht (1982), Matteucci *et al.* (1982), Moran (1983), National Geographic (1992), and Wilgus (1967). Reliable information was available for the Amazon and the wet forests through WCMC and NASA. FAO vegetation mapping provided useful information on agricultural use of dry forest and savanna. Agricultural development in southeastern

Brazil was well documented. Fair to good information was available for other areas, except in southern Chilean forests, and Patagonia, where disturbance may be underestimated. Disturbance is also probably underestimated for grassland, woodland and dry forest in the south-central portion of the continent, where recent, rapid conversion to agriculture, particularly soybeans, is not fully reflected in available map sources.

Results

Human disturbance and remaining natural habitat by biogeographic province is presented in Table 1. The most and least disturbed provinces of this data set are discussed in Hannah *et al.* (1994). The most disturbed provinces are found in the Indo-Malayan and Palearctic Realms, corresponding to the Southeast Asian and European centres of population. Fig. 1 summarizes these data by biogeographic realm and includes area-adjusted averages for tropical and non-tropical realms. Among the tropical realms, the Indo-Malayan Realm stands out as having a markedly greater level of habitat loss. Differences in disturbance between tropical and non-tropical areas are largely obscured in this presentation because the non-tropical realms, the Palearctic and Nearctic, aggregate little-disturbed boreal areas with highly disturbed temperate areas. Analysis of this data by biome is necessary to reveal differences in tropical and temperate disturbance.

The same data aggregated by biome are presented in Table 2. Each biogeographic province falls within a major vegetation type, or biome, in the Udvardy system. These have been summed with all similar areas worldwide and ranked by habitat index in the Table. Fig. 2 illustrates temperate, tropical and boreal/arctic habitat index patterns in the biome data. Fig. 3 presents these data graphically along an approximate latitudinal gradient.

Temperate biomes are on average much more disturbed than tropical biomes, and boreal/arctic biomes are least disturbed. In this aggregation based on habitat index (Fig. 2), temperate and tropical differences stand out clearly. Temperate biomes, primarily areas of high population density, are much more widely disturbed than tropical biomes. This is reflected in a low habitat index value. The aggregate temperate habitat index (23.9) is similar to the aggregate habitat index for the Indo-Malayan Realm, the most highly disturbed tropical area. Boreal and Arctic biomes are little disturbed, and have a high habitat index. The intermediate habitat index value for tropical biomes reflects a combination of intense use, such as in the dry forests of India, balanced by large areas of low disturbance, such as the Amazon.

There is a general trend of increasing habitat loss from tropical to temperate areas (Fig. 3). This trend reverses moving from the temperate zone to higher latitudes, where the boreal and arctic biomes have relatively much lower levels of habitat loss. An exception to the overall pattern is the tropical dry forest biome, which shows a much greater level of habitat loss than other tropical biomes.

Temperate Broadleaf Forest is the most disturbed biome worldwide. It is also the most disturbed temperate biome. It has the lowest aggregate percentage of undisturbed area (6.1%) and the lowest habitat index (9.2) of all biomes. It has a very low total undisturbed area of 580 000 km^2. Evergreen Sclerophylous Forest has a habitat index of 12.9 and the least undisturbed area of any biome, at 420 000 km^2. This vegetation formation is highly disturbed in the Mediterranean, the Cape, Australia, California and elsewhere. The correspondence of these two biomes with climates desirable for human habitation has left them the two most disturbed habitat types on the planet.

Table 1. Human disturbance by biogeographical province

Realm Biome Province	Total area km^2	% Undisturbed	% Partially disturbed	% Human dominated	Habitat index*
AFROTROPICAL					
Evergreen Sclerophyllous Forests					
Cape Sclerophyll	99 963	13.5	19.8	66.7	18.5
Mixed Mountain Systems					
Central African Highlands	261 361	35.5	47.4	17.1	47.4
East African Highlands	61 436	50.8	40.7	8.5	61.0
Ethiopian Highlands	621 644	0.0	95.0	5.0	23.8
Guinean Highlands	85 385	9.8	81.7	8.5	30.2
South African Highlands	254 072	0.4	59.4	40.2	15.3
Tropical Dry Forests					
Congo Woodland/Savanna	1 593 159	43.9	38.5	17.6	53.5
East African Woodland/Savanna	1 328 675	13.8	67.7	18.5	30.7
Malagasy Thorn Forest	63 518	14.8	31.1	54.1	22.6
Malagasy Woodland/Savanna	459 205	7.3	0.9	91.8	7.5
Miombo Woodland/Savanna	2 881 223	61.7	21.1	17.2	67.0
South African Woodland/Savanna	1 764 971	27.7	44.8	27.5	38.9
West African Woodland/Savanna	3 364 378	18.5	61.3	20.2	33.8
Tropical Humid Forests					
Congo Rainforest	2 195 019	61.2	21.4	17.3	66.6
Guinean Rainforest	709 112	8.4	19.4	72.2	13.3
Malagasy Rainforest	147 862	39.4	0.0	60.6	39.4
Warm Deserts and Semi-Deserts					
East Sahel	1 351 582	6.1	77.7	16.2	25.5
Kalahari	614 356	64.9	34.4	0.7	73.5
Karroo	509 186	60.5	14.5	24.9	64.1
Namib	537 301	74.4	20.2	5.4	79.5
Somalian	2 363 707	24.2	70.3	5.5	41.8
West Sahel	3 206 103	49.4	43.5	7.1	60.3

Realm Biome Province	Total area km^2	% Undisturbed	% Partially disturbed	% Human dominated	Habitat index*
ANTARCTIC					
Temperate Rainforests					
New Zealand	297 759	27.1	4.2	68.7	28.2
Tundra Communities and Arctic Desert					
Marielandia	3 884 979	100.0	0.0	0.0	100.0
Maudlandia	9 324 004	100.0	0.0	0.0	100.0
AUSTRALIAN					
Evergreen Sclerophyllous Forests					
Brigalow	248 651	1.7	89.0	9.2	24.0
Eastern Sclerophyll	629 086	4.4	61.3	34.3	19.7
Southern Sclerophyll	234 975	40.7	13.8	45.5	44.2
Western Sclerophyll	437 625	41.2	13.8	45.0	44.7
Temperate Grasslands					
Eastern Grassland and Savanna	575 004	0.3	62.7	37.0	16.0
Temperate Rainforests					
Tasmanian	71 487	34.8	30.4	34.8	42.4
Tropical Dry Forests					
Northern Coastal	300 246	83.6	16.4	0.0	87.7
Tropical Humid Forests					
Queensland Coastal	228 758	15.8	65.8	18.5	32.3
Tropical Grasslands					
Northern Grasslands	938 034	43.9	56.1	0.0	57.9
Northern Savanna	609 194	65.2	34.8	0.0	73.9

Realm Biome Province	Total area km^2	% Undisturbed	% Partially disturbed	% Human dominated	Habitat index*
Warm Deserts/Semi-Deserts					
Central Desert	2 166 990	94.6	5.4	0.0	96.0
South Mulga	817 439	82.4	17.0	0.5	86.7
Western Mulga	998 332	97.3	1.7	1.1	97.7
INDO-MALAYAN					
Mixed Island Systems					
Borneo	826 345	63.6	5.0	31.4	64.9
Celebes	205 282	51.7	9.9	38.3	54.2
Java	153 132	0.0	14.9	85.1	3.7
Lesser Sundas	44 565	0.0	30.9	69.1	7.7
Philippines	315 272	3.2	9.6	87.2	5.6
Sumatra	504 435	27.1	17.5	55.5	31.5
Taiwan	41 246	0.0	34.5	65.5	8.6
Tropical Dry Forests					
Burma Monsoon Forest	464 612	0.0	55.0	45.0	13.8
Ceylon Monsoon Forest	47 104	0.0	77.3	22.7	19.3
Coromandel	114 306	0.0	29.1	70.9	7.3
Deccan Thorn Forest	327 846	0.0	35.2	64.8	8.8
Indus Ganges Monsoon Forest	1 859 022	0.1	43.1	56.8	10.9
Mahanadian	247 913	0.0	48.3	51.7	12.1
Thailand Monsoon Forest	1 152 995	18.7	14.1	67.2	22.2
Thar Desert	799 517	0.0	68.5	31.5	17.1

Realm Biome Province	Total area km^2	% Undisturbed	% Partially disturbed	% Human dominated	Habitat index*
Tropical Humid Forests					
Bengali Rainforest	203 860	0.0	19.3	80.7	4.8
Burman Rainforest	216 661	0.0	40.5	59.5	10.1
Ceylon Rainforest	25 122	0.0	27.5	72.5	6.9
Indochinese Rainforest	565 119	3.8	25.3	71.0	10.1
Malabar Rainforest	265 040	0.0	38.2	61.8	9.6
Malayan Rainforest	189 163	0.0	43.1	56.9	10.8
Southern Chinese Rainforest	216 660	0.0	14.4	85.6	3.6
Warm Deserts/Semi-Deserts					
Thar Desert	799 517	0.0	68.5	31.5	17.1
NEARCTIC					
Evergreen Sclerophyllous Forests					
Californian	218 307	18.4	38.5	43.1	28.0
Mixed Mountain Systems					
Madrean-Cordilleran	820 968	10.8	33.5	55.7	19.2
Rocky Mountain	1 899 343	40.4	50.4	9.2	53.0
Sierra-Cascade	239 541	21.6	70.6	7.9	39.3
Temperate Broadleaf Forests					
Eastern Forest	2 330 415	0.1	17.3	82.6	4.4
Austroriparian	746 231	12.1	32.8	55.1	20.3
Temperate Needleleaf Forests					
Yukon Taiga	1 252 409	99.8	0.0	0.2	99.8
Canadian Taiga	5 646 006	88.1	4.8	7.1	89.3
Temperate Rainforests					
Oregonian	165 424	26.7	42.5	30.8	37.3
Sitkan	381 463	93.6	6.4	0.0	95.2

Realm Biome Province	Total area km^2	% Undisturbed	% Partially disturbed	% Human dominated	Habitat index*
Temperate Grasslands					
Grasslands	2 728 765	1.9	30.5	67.5	9.5
Tundra Communities and Arctic Desert					
Alaskan Tundra	818 787	100.0	0.0	0.0	100.0
Aleutian Islands	113 883	100.0	0.0	0.0	100.0
Arctic Archipelago	715 706	100.0	0.0	0.0	100.0
Arctic Ice	2 253 904	100.0	0.0	0.0	100.0
Canadian Tundra	1 698 684	100.0	0.0	0.0	100.0
Greenland Tundra	498 741	100.0	0.0	0.0	100.0
Warm Deserts/Semi-Deserts					
Chihuahuan	634 127	21.1	61.1	17.9	36.4
Sonoran	548 067	39.0	52.1	8.9	52.0
Tamaulipan	209 488	2.2	61.1	36.8	17.5
Cold-Winter Deserts					
Great Basin	829 464	28.5	62.7	8.8	44.2
NEOTROPICAL					
Evergreen Sclerophyllous Forests					
Chilean Sclerophyll	47 988	36.1	38.9	25.0	45.8
Mixed Island Systems					
Cuban	118 899	1.9	14.3	83.8	5.5
Greater Antillean	113 237	11.0	12.0	77.0	14.0
Mixed Mountain Systems					
Colombian Montane	181 288	64.7	11.0	24.3	67.5
Northern Andean	298 593	25.0	7.1	67.9	26.8
Puna	513 206	29.1	66.5	4.4	45.7
Southern Andean	754 480	51.8	36.7	11.5	61.0
Yungas	566 526	87.5	6.8	5.6	89.2

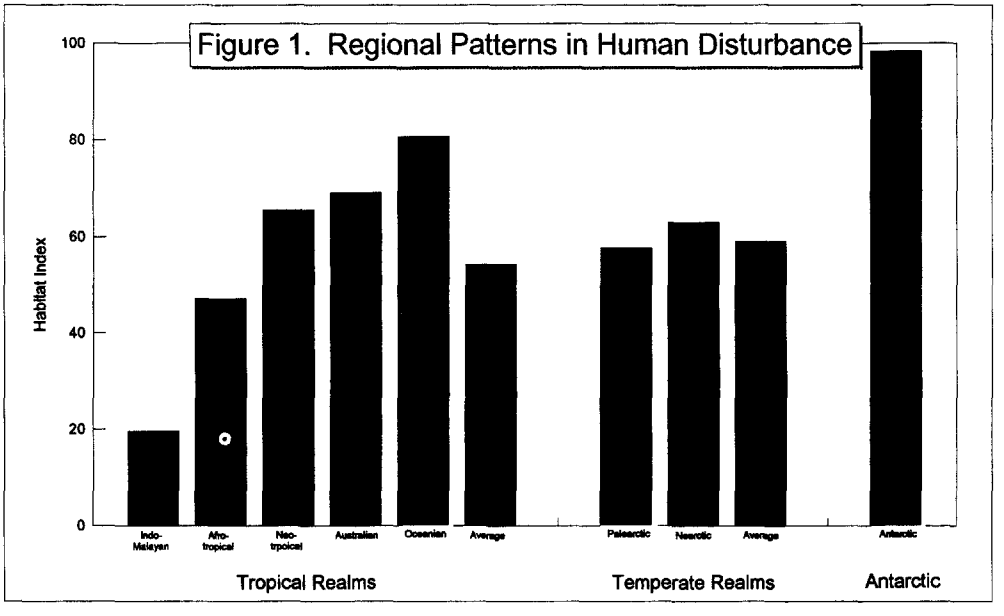
Realm Biome Province	Total area km^2	% Undisturbed	% Partially disturbed	% Human dominated	Habitat index*
Temperate Grasslands					
Argentinian Pampas	561 194	2.1	26.8	71.0	8.8
Uruguayan Pampas	541 199	0.7	79.3	20.0	20.5
Temperate Broad-Leaf Forests					
Araucarian Forest	22 661	41.2	0.0	58.8	41.2
Temperate Rainforests					
Brazil Planalto	229 277	18.0	35.5	46.5	26.9
Brazil Rainforest	1 716 908	38.1	21.5	40.4	43.5
Chilean Nothofagus	126 635	100.0	0.0	0.0	100.0
Valdivian Forest	110 639	62.7	0.0	37.3	62.7
Tropical Dry Forests					
Caatinga	1 063 736	32.0	52.4	15.7	45.1
Central American	404 256	26.1	17.1	56.9	30.4
Ecuadorian Dry Forest	75 981	10.5	43.9	45.6	21.5
Everglades	9 059	50.0	25.0	25.0	56.3
Gran Choco	1 023 746	80.3	14.1	5.6	83.8
Guereran	231 003	13.7	47.1	39.2	25.5
Warm Deserts/Semi-Deserts					
Monte	1 322 339	35.1	60.0	4.9	50.1
Pacific Desert	269 267	5.9	89.1	5.0	28.2
Sinaloan	177 782	26.1	19.1	54.8	30.9
Venezuelan Deciduous	75 981	5.3	68.4	26.3	22.4
Venezuelan Dry Forest	337 250	27.7	62.5	9.9	43.3
Yucatanean	48 692	18.6	2.3	79.1	19.2

Realm Biome Province	Total area km^2	% Undisturbed	% Partially disturbed	% Human dominated	Habitat index*
Tropical Humid Forests					
Amazonian	2 864 623	98.0	0.0	2.0	98.0
Campechean	279 695	33.6	8.5	57.9	35.7
Colombian Coastal	273 266	45.9	25.4	28.8	52.3
Guyanan	1 090 396	94.5	2.3	3.2	95.1
Madieran	1 988 840	81.5	2.1	16.4	82.0
Panamanian	128 872	90.0	0.0	10.0	90.0
Serra do Mar (Atlantic Forest)	223 944	6.5	24.4	69.0	12.6
Tropical Grasslands					
Babacu	362 577	41.2	30.1	28.7	48.7
Campos Cerrados	2 118 142	87.5	7.2	5.3	89.3
Campos Limpos	346 581	100.0	0.0	0.0	100.0
Llanos	422 562	92.4	5.0	2.5	93.7
Cold-Winter Deserts					
Patagonian	509 207	47.1	52.9	0.0	60.3
OCEANIAN					
Mixed Island Systems					
New Caledonia	23 622	0.0	100.0	0.0	25.0
Papuan	910 061	77.0	12.6	10.3	80.2
PALAEARCTIC					
Evergreen Sclerophyllous Forests					
Iberian	328 131	0.7	17.8	81.5	5.2
Oriental Deciduous Forset	2 859 224	0.0	16.8	83.2	4.2
Mediterranean Sclerophyll	1 455 778	1.5	22.7	75.7	7.2

Realm Biome Province	Total area km^2	% Undisturbed	% Partially disturbed	% Human dominated	Habitat index*
Mixed Mountain Systems					
Altai Highlands	1 107 288	47.1	31.9	21.0	55.1
Balkan Highlands	277 446	0.5	33.0	66.5	8.8
Caucasu-Iranian Highlands	949 777	7.1	65.0	28.0	23.4
Central European Highlands	436 364	0.0	26.5	73.5	6.6
Himalayan Highlands	909 091	48.2	45.0	6.8	59.5
Hindu-kush Highlands	341 098	16.1	73.0	10.9	34.4
Lake Baikal Region	95 310	80.9	14.1	5.0	84.4
Pamir Tian-Shan Highlands	759 416	48.8	32.7	18.5	57.0
Scottish Highlands	38 278	5.5	2.8	91.7	6.2
Szechwan Highlands	661 835	11.1	74.1	14.8	29.6
Temperate Broad-Leaf Forests					
Atlantic	667 613	1.4	13.3	85.3	4.7
Boreonemoral	1 393 475	1.9	25.4	72.6	8.3
British Islands	255 272	0.2	1.1	98.7	0.5
Icelandian	102 162	77.8	1.3	20.9	78.1
Kamchatkan	314 405	100.0	0.0	0.0	100.0
Manchu-Japanese Mixed Forest	1 545 131	27.5	33.3	39.2	35.8
Middle European Forest	1 758 116	0.2	18.2	81.6	4.8
Pannonian	123 280	0.4	7.1	92.5	2.2
Subarctic Birchwoods	187 558	70.0	30.0	0.0	77.5
West Anatolian	73 123	0.0	29.1	70.9	7.3
Temperate Needle-Leaf Forests					
East Siberian Taiga	6 367 585	94.7	1.0	4.4	95.0
West Eurasian Taiga	5 564 709	61.8	13.8	24.4	65.3
Temperate Rainforests					
Chinese Subtropical Forest	880 392	0.0	26.3	73.7	6.6
Japanese Evergreen Forest	252 315	0.0	28.8	71.2	7.2

Realm Biome Province	Total area km^2	% Undisturbed	% Partially disturbed	% Human dominated	Habitat index*
Temperate Grasslands					
Atlas Steppe	514 392	45.3	26.9	27.7	52.0
Lowarctic Tundra	2 163 951	94.0	5.0	1.0	95.3
Mongolian Manchurian Steppe	2 418 195	33.3	51.3	15.4	46.1
Pontian Steppe	2 571 794	8.9	23.9	67.2	14.9
Tundra Communities and Arctic Desert					
Arctic Desert	68 508	100.0	0.0	0.0	100.0
Higharctic Tundra	1 260 757	89.3	10.7	0.0	92.0
Warm Deserts/Semi-Deserts					
Arabian Desert	2 998 863	76.2	23.2	0.6	82.0
Sahara	8 439 579	89.9	8.5	1.6	92.0
Cold-Winter Deserts					
Anatolian Iranian Desert	2 715 299	15.7	68.0	16.3	32.7
Takla-Makan-Gobi Desert	2 468 626	63.9	33.1	2.9	72.2
Tibetan	1 540 134	78.0	20.8	1.2	83.2
Turanian	2 323 815	53.4	32.9	13.7	61.6
Iranian Desert	544 217	8.3	91.3	0.4	31.1
WORLD					
Total	162 052 691	51.9	24.2	23.9	58.0
Adjusted for rock, ice and barren land		27.0	36.7	36.3	36.2

*Undisturbed + ¼ partially disturbed.



Temperate Grasslands and Temperate Rain Forests follow Temperate Broadleaf Forests and Evergreen Sclerophyllous Forest in habitat index, making four of the top five most disturbed biomes temperate. Farmlands in North America and Europe have reduced Temperate Grasslands and Broadleaf Forests in these areas to remnants. Temperate Grasslands in Australia and South America are also highly disturbed. The Temperate Rain Forest biome includes sub-tropical humid forests in the Udvardy classification, and is therefore somewhat more difficult to interpret, but logging has heavily impacted these forests in western North America. Fig. 4 illustrates the habitat index of two of the most disturbed temperate biomes, Temperate Grasslands and Temperate Broadleaf Forests, which are much below the average habitat index for all other biomes.

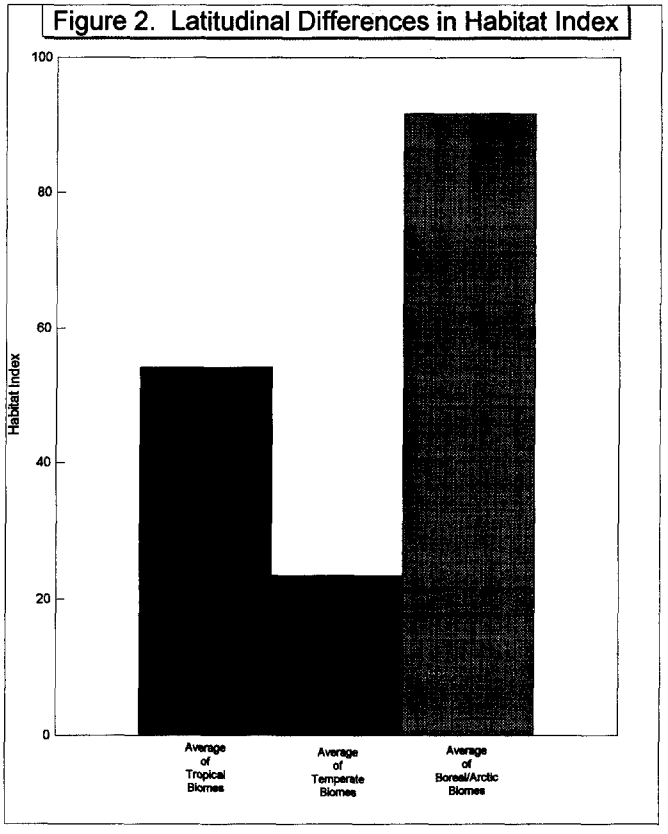
Tropical biomes show a much broader range of disturbance. Tropical Dry Forest is the most disturbed tropical biome, and is the fifth most disturbed biome overall. Tropical Humid Forest ranks as one of the least disturbed biomes worldwide. However, this ranking of the Tropical humid Forest by habitat index is misleading, because of the large heterogeneity of disturbance in the Humid Tropical Forest biome. Remaining undisturbed area of Tropical humid Forest is large (7.5 million km^2), but is primarily in the Amazon and Zaire basins. These large areas of remaining habitat mask the fact that the biome also includes some of the most disturbed provinces in the world, such as the very threatened rain forest provinces of Southeast Asia (Indo-Malayan Realm). Fig. 5 illustrates the relative habitat index values for tropical dry and humid forests, with the average of all other biomes for comparison. This relationship is discussed in more detail below.

The least disturbed biome globally is Tundra and Arctic Desert. Taiga (Temperate Needleleaf Forest) is also lightly populated and little disturbed. Temperature extremes and low precipitation pose obvious restriction to human habitation, limiting disturbance of these biomes. The areas in these biomes are large. The area of undisturbed Tropical Humid Forest, for instance, is less than one-half of that found in Tundra and Arctic Desert.

Mixed Mountain Systems, Mixed Island Systems, and deserts are all pan-global biomes

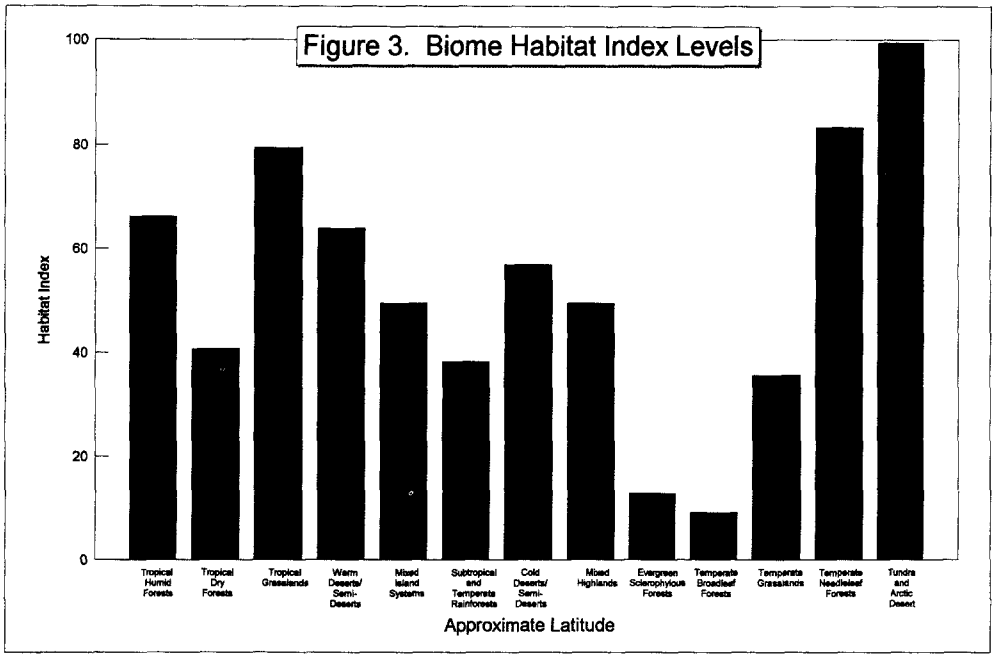
Table 2. Habitat and human disturbance by biome

Biome	Total area (km^2)	% Undisturbed	% Partially disturbed	% Human dominated	Habitat index
Temperate Broadleaf Forests	9 519 442	6.1	12.0	81.9	9.2
Evergreen Sclerophyllous Forests	6 559 728	6.4	25.8	67.8	12.9
Temperate Grasslands	12 074 494	27.6	32.0	40.4	35.6
Subtropical and Temperate Rainforests	4 232 299	33.0	20.9	46.1	38.2
Tropical Dry Forests	19 456 659	30.5	41.1	45.9	40.8
Mixed Mountain Systems	12 133 746	29.3	45.0	25.6	40.6
Mixed Island Systems	3 256 096	46.6	11.6	41.8	49.5
Cold Deserts/Semi-Deserts	10 930 762	45.4	46.1	8.5	56.9
Warm Deserts/Semi-Deserts	29 242 021	55.8	32.0	12.2	63.8
Tropical Humid Forests	11 812 012	63.2	11.9	24.9	66.2
Tropical Grasslands	4 797 090	74.0	21.3	4.7	79.3
Temperate Needleleaf Forests	18 830 709	81.7	6.4	11.8	83.3
Tundra and Arctic Desert	20 637 953	99.3	0.7	0.3	99.5



in the Udvardy system. All of these rank as moderately disturbed in the global context. Mixed mountain systems rank as the most threatened of the pan-global systems, reflecting the high disturbance levels in some Afromontane and Euromontane systems, moderated by lesser degrees of disturbance in Nearctic and Neotropical mountain systems. Mixed Island Systems reflect a moderate overall rank resulting from extremes of disturbance. Many Mixed Island Systems are highly disturbed, such as Java, Taiwan and the Philippines, while others, most notably New Guinea (Papuan province) are dominated by natural habitat. Disturbance by livestock reduces the habitat index of desert pan-global systems. Heavily disturbed semi-deserts such as the Sahel also affect the ranking of Deserts and Semi-deserts, making this limited habitability biome more disturbed than the Tundra/ Arctic Desert or Temperate Needleleaf Forest biomes.

Since average habitat index masks heterogeneity of disturbance within a biome, other analyses are needed to reveal biome-level patterns. A second measure of biome disturbance is the number of highly disturbed provinces found in the biome. Highly disturbed province analysis can indicate areas in which aggregation of habitat index is masking heterogeneity within a biome. To assess highly disturbed provinces within biomes, the number of provinces with a habitat index of 20 or lower were totalled for each biome. Comparison of biomes based on this measure is presented in Table 3. The Table lists total provinces in the biome, the number of highly disturbed provinces in the biome, and the relative rank of the biome in the habitat index comparison.



Tropical Humid Forest ranks as the biome with the most highly disturbed provinces. The biome ranks tenth in habitat index. This is the largest difference of any biome in ranking between the habitat index and highly disturbed province analysis. The next highest shift is in the Subtropical and Temperate Rainforest biome, which drops five places. Mixed Island Systems move up three places. Most other biomes shift only one or two places between the two rankings.

The strong difference in Tropical Humid Forest ranking is due to the strong heterogeneity in disturbance in the Tropical Humid Forests. There is a strong polarity within the biome between the undisturbed Amazon and Zaire (Congo) forests and the highly disturbed Southeast Asian forests. The highly disturbed province analysis reveals this polarity, and indicates that analysis by habitat index alone must be treated with caution for this biome.

The relative ranking of Tropical Dry Forest and Tropical Humid Forest changes markedly between the two analyses. The contrast in highly disturbed province and habitat index ranking for Tropical Humid Forest and Tropical Dry Forest is illustrated in Fig. 5. Tropical Humid Forest ranks as the most disturbed tropical biome, and the most disturbed biome worldwide, by highly disturbed province analysis. Tropical Dry Forest closely follows Tropical Humid Forest as one of the two most disturbed biomes worldwide. Tropical Dry Forest moves three places in rank, from fifth in the habitat index comparison, to second in the highly disturbed province analysis.

The only biomes with no highly disturbed provinces were Tundra and Arctic Desert, Temperate Needleleaf Forests, Tropical Grasslands, and Cold Deserts/Semi-Deserts. Most other biomes had between three to seven highly disturbed provinces. Only Tropical Humid Forests (9), Tropical Dry Forests (8), Mixed Island Systems (7) and Temperate Broadleaf Forests (7), had more than six highly disturbed provinces.

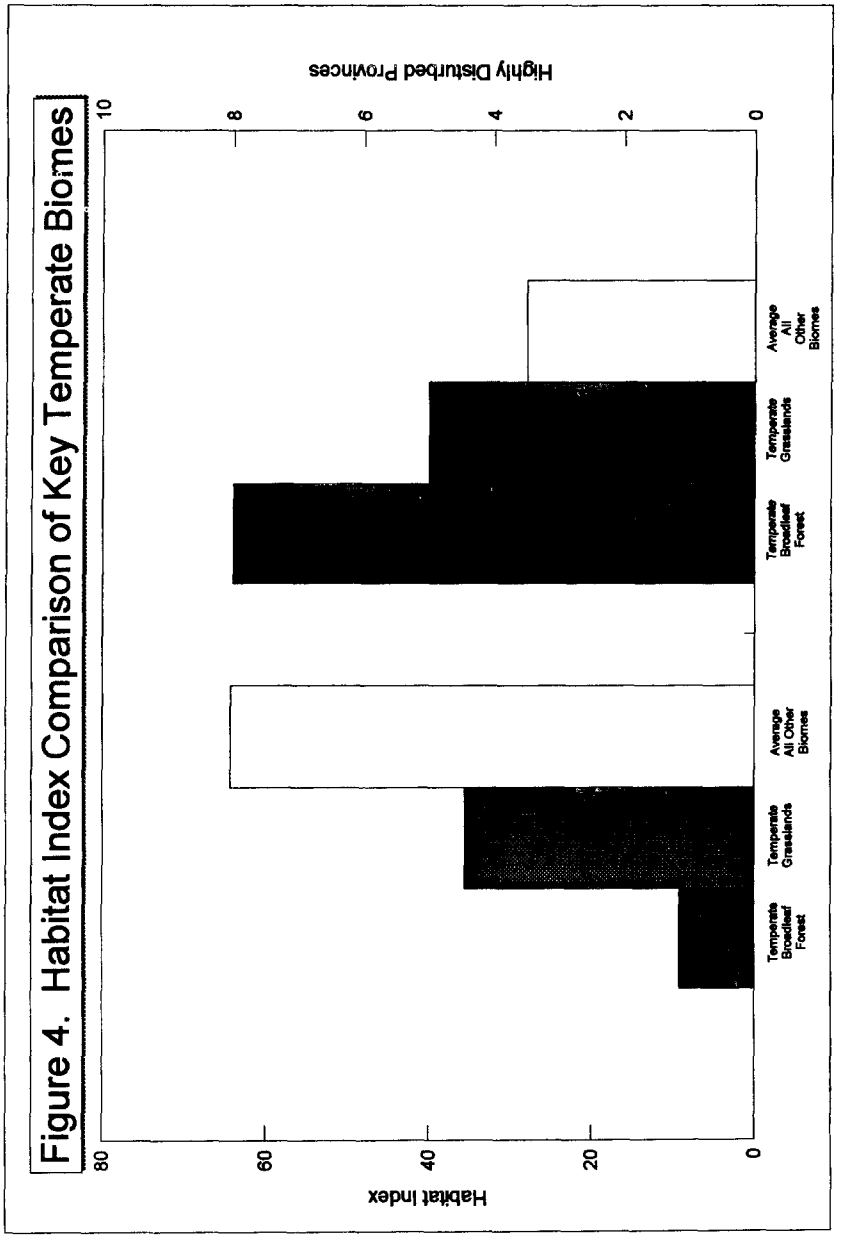


Figure 4. Habitat Index Comparison of Key Temperate Biomes
Habitat Index
0
20
40
60
80
Highly Disturbed Provinces
0
2
4
6
8
10
Temperate Broadleaf Forest
Temperate Grasslands
Average All Other Biomes
Temperate Broadleaf Forest
Temperate Grasslands
Average All Other Biomes

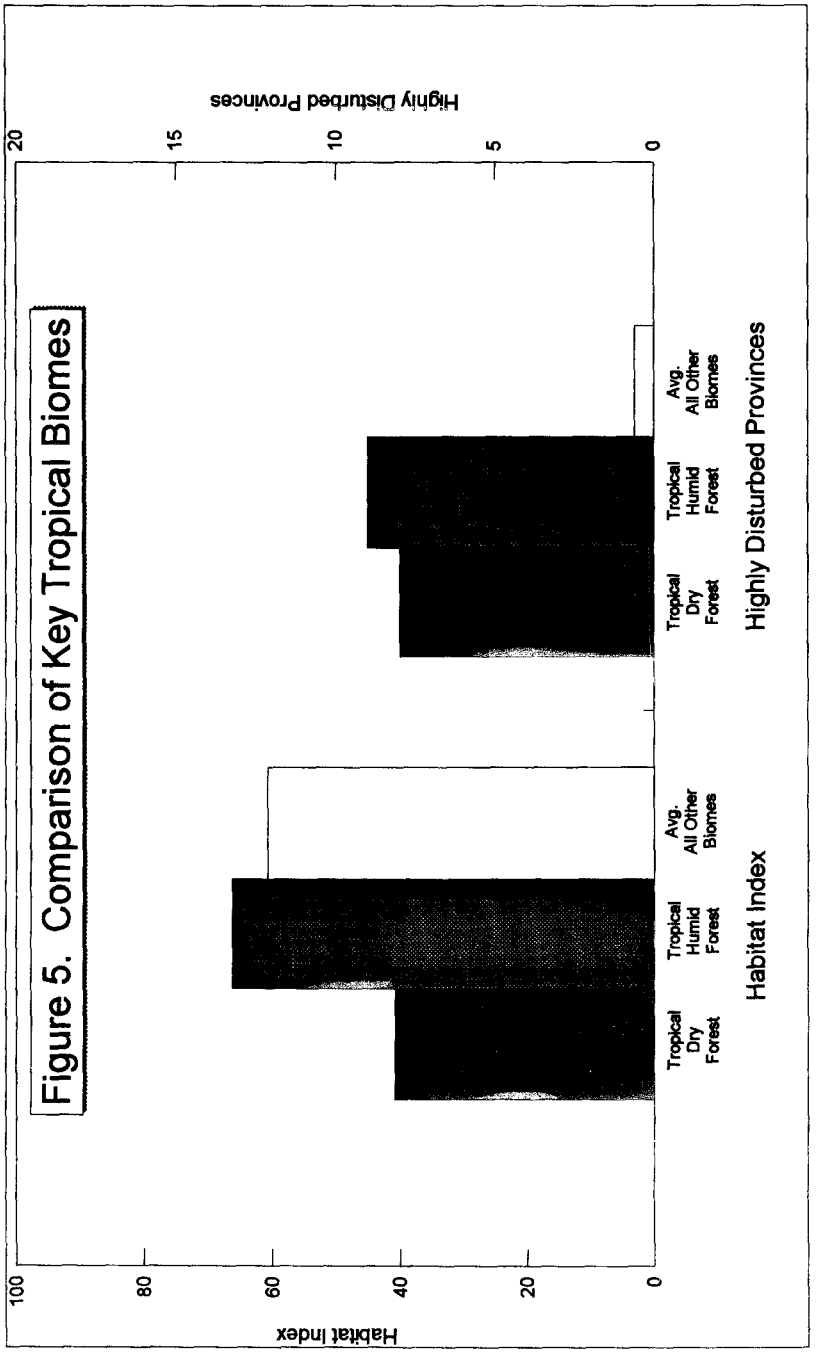


Figure 5. Comparison of Key Tropical Biomes
Habitat Index
100
80
60
40
20
0
Tropical Dry Forest
Tropical Humid Forest
Avg. All Other Biomes
Habitat Index
Highly Disturbed Provinces
20
15
10
5
0
Tropical Dry Forest
Tropical Humid Forest
Avg. All Other Biomes
Highly Disturbed Provinces

Table 3. Highly disturbed provinces by biome

Biome	Total provinces	Highly disturbed provinces*	Rank in habitat index analysis
1. Tropical Humid Forests	18	9	10
2. Tropical Dry Forests	22	8	5
3. Temperate Broadleaf Forests	13	7	1
4. Mixed Island Systems	11	6	7
5. Evergreen Sclerophyllous Forests	10	5	2
6. Mixed Mountain Systems	23	5	6
7. Temperate Grasslands	8	4	3
8. Warm Deserts/Semi-Deserts	21	3	9
9. Subtropical and Temperate Rainforests	9	2	4
10. Tundra and Arctic Desert	10	0	13
11. Tropical Grasslands	6	0	11
12. Cold Deserts/Semi-Deserts	7	0	8
13. Temperate Needleleaf Forests	4	0	12

*Habitat index < 20.

Some biomes contain provinces for which there is little available data, but this is not believed to have affected the general conclusions of the present analysis. Lack of data in the present study resulted in a high percentage of the biome being classified as partially disturbed. None of the biomes were dominated by partially disturbed area (see Table 2). The highest percentage of partially disturbed area in a biome was 45% in the Mixed Mountain biome.

To determine whether data deficiencies in specific provinces may have affected the biome ranking, provinces with in excess of 70% Partially Disturbed area were examined. These provinces are listed in Table 4. Roughly one-fourth of the low data provinces and one-half of the low data area is in the Warm Desert and Semi-Desert biome. Since the area in the low-data provinces is a small proportion (0.15) of the total Warm Desert biome area, any distortion of the biome rankings by this data deficiency is expected to be slight. The majority of the remaining low data provinces are in Mixed Mountain or Tropical Dry Forest biomes. Tropical dry forests and highlands often have relatively low human population densities but are under significant pressure from grazing and fuelwood gathering. The Partially Disturbed categorization may accurately reflect the level of disturbance of the provinces in these biomes. Reconnaissance-level data gathering for the low-data provinces in these biomes would improve accuracy of future global priority-setting exercises. Other low-data provinces, such as the Brigalow of Australia, are in biomes in which natural habitat is rare, and warrant more detailed regional analysis.

Discussion

This analysis indicates that temperate biomes have suffered a greater degree of destruction than more publicized tropical biomes. The analysis helps to confirm the relative rarity of

Table 4. Provinces with over 70% of total area classified as Partially Disturbed

Province	Total area km^2	% Undisturbed	% Partially disturbed	% Human dominated	Habitat index
Ethiopian Highlands	621 644	0.0	95.0	5.0	23.8
East Sahel	1 351 582	6.1	77.7	16.2	25.5
Guinean Highlands	85 385	9.8	81.7	8.5	30.2
Somalian	2 363 707	24.2	70.3	5.5	41.8
Brigalow	248 651	1.7	89.0	9.2	24.0
Ceylon Monsoon Forest	47 104	0.0	77.3	22.7	19.3
Sierra-Cascade	239 541	21.6	70.6	7.9	39.3
Uruguayan Pampas	541 199	0.7	79.3	20.0	20.5
Pacific Desert	269 267	5.9	89.1	5.0	28.2
New Caledonia	23 622	0.0	100.0	0.0	25.0
Szechwan Highlands	661 835	11.1	74.1	14.8	29.6
Iranian Desert	544 217	8.3	91.3	0.4	31.1
Hindu-kush Highlands	341 098	16.1	73.0	10.9	34.4

tropical dry and evergreen sclerophyllous forests, confirms the urgent conservation needs in the humid tropics, and suggests that the forests of Southeast Asia are highly threatened and should be considered high priority for conservation action. The data gaps of the present study suggest priority areas for research into extent and degree of habitat destruction. These results indicate that priority-setting exercises must balance large temperate/tropical discrepancies not only in biodiversity and economic power, but also in degree of habitat loss, extent of knowledge, and cost of recovering representative examples of nearly extinct temperate habitats.

The habitat index analysis of this study confirms the assertion of Janzen (1988) and others that Tropical Dry Forests are rarer than Tropical Moist Forests. This discussion in the literature was one of the first examples of moving beyond subjective priority-setting, towards more objective comparison based on degree of destruction and biological value (Parker *et al.*, 1993). The present results add quantitative confirmation. While the original extent of Tropical Dry Forests was almost double that of the Tropical Moist Forests, remaining undisturbed Tropical Dry Forest (5.9 million km^2) is now significantly less than that for Tropical Moist Forest (7.5 million km^2).

The pattern of destruction for the two forest types is very different. A large proportion of tropical dry forest is degraded, and almost equal areas of natural habitat, degraded and human dominated exist. Moist tropical forest has a distribution strongly split between undisturbed and human dominated, with relatively little degraded area. This confirms previous observations that tropical dry forest is subject to degradation due to burning and shifting agriculture, while tropical moist forest is most often clear-cut and fails to regenerate. While the rapid conversion of tropical moist forest is of global significance, the low percentage of remaining undisturbed tropical dry forest should also be of international concern.

The disturbance of Tropical Humid Forests is polarized also around a strong regional dichotomy. Large undisturbed areas in the Amazon and Zaire basins are counterpoint to extreme rarity in Southeast Asian forests. Habitat index comparison must be considered in tandem with highly disturbed province analysis for this biome. The moderate habitat index for Tropical Moist Forests is not an accurate index of this biome's status. As is widely recognized, parts of this biome are among the most threatened worldwide. The highly disturbed province analysis (Table 3) of this study confirms this conclusion.

Southeast Asia stands out in this analysis as a conservation priority area. The findings of the present study show that ten provinces in the Indo-Malayan Realm have a Habitat Index under 10, making it the area with least undisturbed habitat worldwide. This confirms the work of Myers (1988) and others who have argued for emphasis on the highly threatened, highly diverse forests of this area. Most of the highly disturbed provinces are island systems within the realm. These are also typically areas of high endemism. These biologically unique areas are subjected to a combination of high population pressure and high levels of commercial forest exploitation which makes even the remaining large forest tracts in the region less than secure.

Priorities for other provinces and biomes may need to be re-examined. Some ecosystems have been previously overlooked because they are already nearly totally destroyed. Many of these habitats are in developed countries, where perhaps it has been more convenient to ignore their condition. The lowest Habitat Index worldwide belongs to the British Islands province. While the biological importance of the tropics and cost-effectiveness of saving habitat before it is lost cannot be disputed, if global goals include conservation of

representative ecosystems, conservation in developed countries needs renewed emphasis and scrutiny.

For instance, the present analysis shows that Evergreen Sclerophyllous Forest (Mediterranean vegetation types) is one of the rarest biomes in the world. Many of these formations are found in relatively affluent countries in Europe, Australia and North America which have the resources to support greater conservation efforts. Since these are fire-prone systems, simple fire management and post-fire revegetation measures, particularly re-seeding after fires with native rather than exotic species, may provide major protection for natural ecosystem function. Such measures are well within the means of the countries involved. In other cases, greater political will is required to set aside protected areas where this habitat type is under heavy pressure for development, such as the Santa Monica mountains in California.

Other temperate systems require greater attention as well. Temperate Grasslands as a whole are much rarer than Tropical Grasslands. This confirms discussions in the literature emphasizing the rarity and need to restore temperate North American grasslands, for instance (Conzen, 1990). It also suggests that grasslands may be particularly vulnerable to degradation, and that greater attention to the status of Tropical Grasslands may be warranted to prevent their following the Temperate Grasslands into rarity. Temperate Rain Forests are more disturbed than their more publicized tropical counterparts, and Temperate Broadleaf Forest is the rarest biome worldwide. Temperate countries with available resources must renew their commitment to ecosystem conservation if these issues are to be addressed. In this sense, this study underscores the need for efforts such as the US National Biological Survey.

The results presented here are among the first global data available to confirm what many biologists have known qualitatively for years. Temperate ecosystems in Europe and North America are heavily altered to the extent that natural ecosystems are absent over large areas. The tropics, more biodiverse and generally more intact, are under pressure which varies considerably between regions and between biomes. The discussion above elaborates many of the highlights of the tropical situation, while the tabular data provide opportunities for further analysis and comparison. Global priority setting needs to take account of this information, both to allocate substantial resources of industrial countries at home and to allocate scarce global resources to the varying pressures facing the biodiverse tropics.

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