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A Tropical Montane Evergreen Forest and other Vegetation on Hainan Island, southern China[1)]

中国南部海南島における熱帯山地常緑広葉樹林および他の植生

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Synopsis

The original vegetation of Hainan included diverse tropical lowland and montane forests, most of which were converted to rubber plantations or other economic use since 1950. An area of remaining evergreen low-montane forest at Jianfengling nature reserve, in the mountains of southwestern Hainan, was studied and described by the Braun-Blanquet method for comparison with similar forests elsewhere. The most important canopy tree is *Dacrydium pierrei* (Podocarpaceae), along with *Xanthophyllum hainanense*, *Lithocarpus fenzelianus*, and *Polyspora* (*Gordonia*) *balanse*, making this site quite typical of "low montane rain forest" on Hainan. The relative lack of lianas and epiphytes in the upper layers conflicts with the usual concept of rainforest, however, and suggests rather a montane version of the "seasonal evergreen forest" type which is widespread in tropical Asia. The canopy structure and lack of seedlings at Jianfengling suggest that the forest is mature, though perhaps subject to some disturbance as by typhoons. Much of lowland and lower montane Hainan is now covered by rubber-tea plantations or by secondary scrub dominated by Australian species.

Introduction

The relatively undeveloped tropical island of Hainan (literally: "south of the sea", located just across the Qiongzhou Strait from the Guangdong mainland) has offen been seen as China's tropical paradise (cf. Wu 1937, Wu and Zhi 1981-82, Han 1984, Tan 1988; see also Figure 1). More recently Hainan has appeared as a one remaining opportunity for expansion and development (e.g. Beijing Review 1983, Deng 1988). As late as the early 1960's much of the island still carried relatively natural vegetation, including significant areas of mangrove forest, lowland and montane rainforest, tropical seasonal forests, and more xeric seasonal woodlands, savannas, and psammophyte vegetation (Wang 1961, Guangdong Plant Research Institute 1977). Although Indochinese settlers have for centuries come across the northern Gulf of Tonkin to western Hainan (cf. Alley 1980), settlement and development increased dramatically after establishment of the People's Republic (1950 in Hainan), especially during the Cultural Revolution, when urban youth from the mainland

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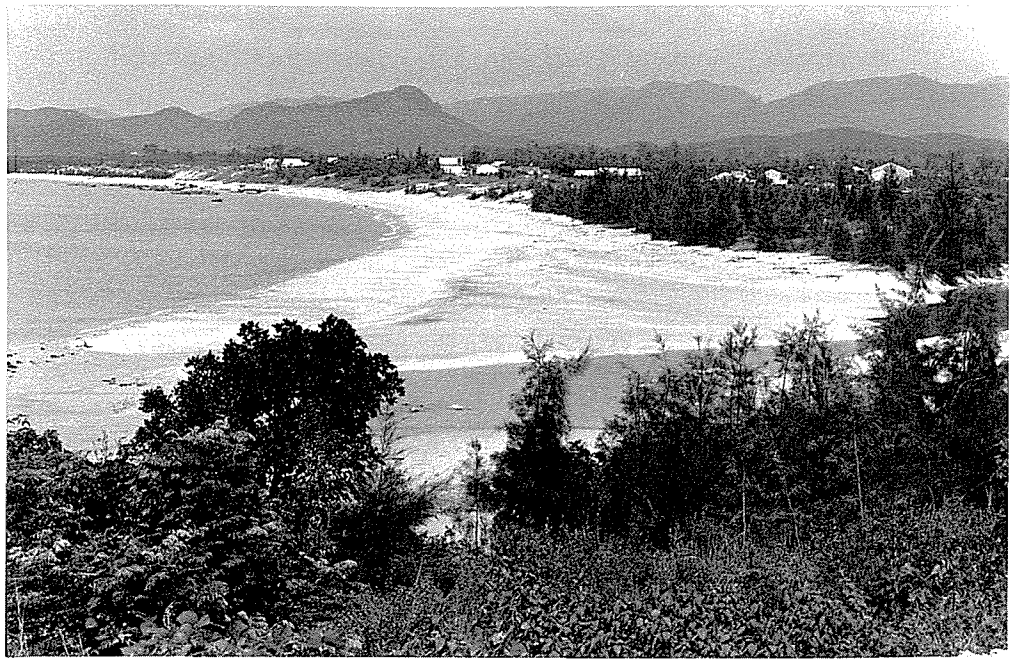

Figure 1. South Coast of Hainan near Tian-ya Hai-jiao, the Chinese "end of the world".

were "sent down" (xià xiāng: 下乡) to Hainan in a crash program, under army control, to convert Hainan's forested mountains into rubber plantations (see Enderton 1984). Much of the remaining natural vegetation, including large areas of rainforest and seasonal forest in the lowlands and low mountains, was quickly destroyed, and Hainan's forest cover dropped from 25.7% in 1950 to 7.2% by 1980 (Hainan Ribao 1980). (For a relatively complete description in English of Hainan's physical geography as well as social and environmental history, see Enderton 1984).

In September 1986, the first two authors had the opportunity to visit Hainan and study a montane forest as well as remaining mangrove vegetation and the current lowland vegetation, as guests of the Institute of Tropical Crops and the Hainan Botanical Garden for Tropical Economic Plants, located northwest of Danxian (Nada) in north-central Hainan. The garden was established in 1958 in order to introduce and acclimatize economically useful plants from other countries. It is run by the Academy of Tropical Crops of South China (under the Ministry of Agriculture) and maintains over 600 species, with special collections of *Vatica* and *Hopea* (Dipterocarpaceae), *Barringtonia* (Lecythidaceae), *Tarrietia* (=*Heritiera*, Sterculiaceae), and *Dacrydium* (Podocarpaceae), as well as exhibition centers for tropical fruit-trees, spice, oil and medicinal plants, and tropical woody and ornamental plants. Another function of the garden is to preserve the endangered native species of Hainan, such as *Vatica astrotricha*, *Hopea hainanensis*, and *Antiaris toxicaria* (Moraceae), each being the only species of its genus which occurs in Hainan.

In visiting Hainan, the first two authors were especially interested in studying remaining mangroves and evergreen broad-leaved forests (cf. Fujiwara 1987a, 1987c, Box and Fujiwara 1988) as well as current land uses and substitute vegetations. Thinking of biogeographic zonation, we were also interested in Chinese concepts and usage of general

terms such as 'tropical' (cf. Song 1988) and 'rainforest'. Time limitations permitted data collection at only one natural forest site, the Jianfengling tropical forest preserve in the mountains of southwestern Hainan, one of seven nature preserves established in Hainan between 1956 and 1980. This paper briefly describes the natural and current vegetation of Hainan and provides structural data and an initial interpretation of the tropical montane forest at Jianfengling, including forest dynamics and biogeographic relationships.

Physical Environment

Hainan lies between 18° and 20° north latitude. This and the location on the east side of Eurasia (see Figure 2) make Hainan definitely tropical and comparable, for example, to the larger Caribbean islands and Hawaii, and similar to southernmost Taiwan and Okinawa, all lying within the tropical wetdry climatic zone. As a result, there is a distinct summer rainy season (augmented by the Asian monsoon) and a winter dry season, during which some rainfall can also occur (due to the island situation). Lowland mean monthly temperatures reach about 28° C in summer, do not fall below about 18° C in winter in the southern part, and frost does not occur in the lowlands (absolute minimum at Haikou: 2.8°). The highest mountains reach over 1800 meters in elevation and do have significant frost in winter (Map Press Editorial Dept. 1979, China Natural Geography Comm. 1984).

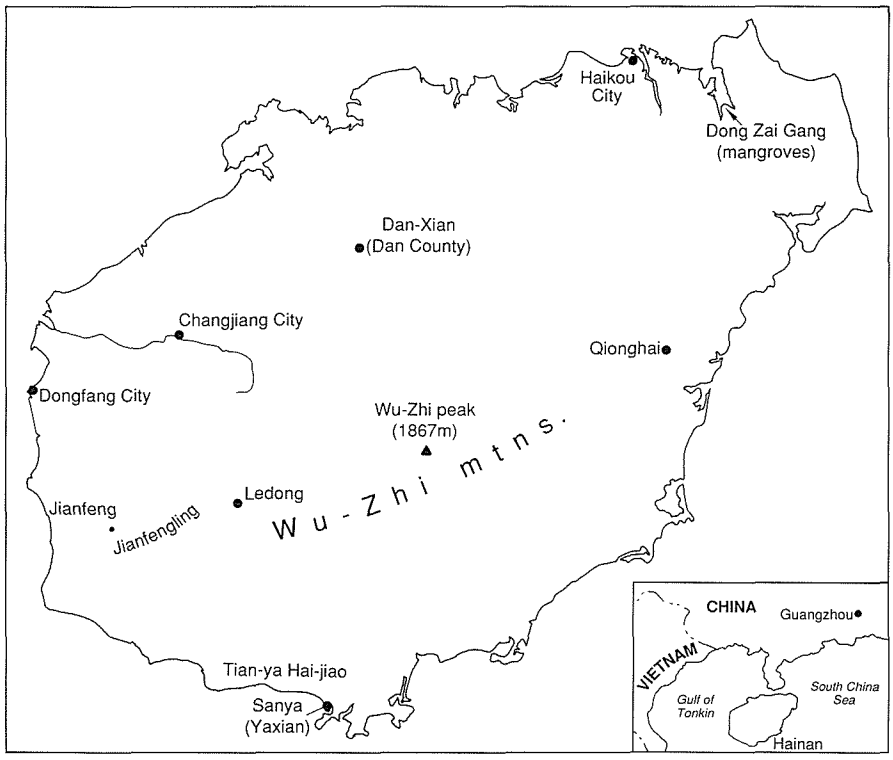

Figure 2. Location of Hainan, Main Features and Study Sites.

Hainan is subject to both northeasterly trade winds and the Pacific summer monsoon, as well as late-summer typhoons. As a result, rainfall decreases west-southwestward, as suggested by the climate diagrams in Figure 3 for Qiongdong (near Qionghai, east coastal plain) and Sanya (south coast). Average annual rainfall on the eastern coastal area and mountains generally exceeds 2000 mm, reaching about 2800 mm on the southeast side of the

Wu-Zhi mountains. Southwestern Hainan is driest, with average annual rainfall falling to about 990 mm in Dongfang and other areas along the west coast. Soils are generally described as tropical red lateritic but with yellow clay forest soils in the central mountains. Extensive areas of sandy soil occur along the drier western coastal plain. Hainan is a continental island, formed from mainly volcanic basalt in the northeast and granite in the southwest. There is little limestone. Of the 1500 km of shoreline, about half is sandy and about 25% muddy, mainly in embayments.

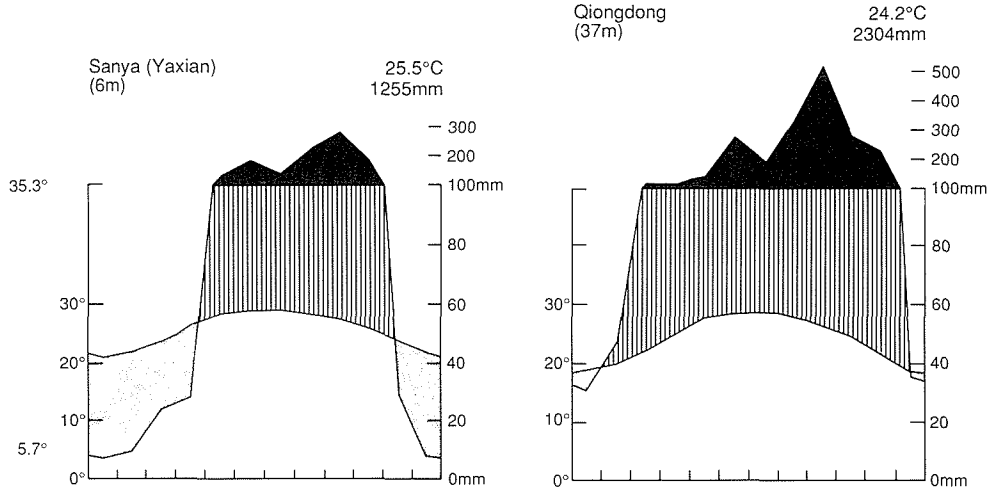

Figure 3. Climates of Western (left) and Eastern (right) Hainan.

The climate of windward eastern Hainan is a tropical humid monsoonal climate with no significant dry season and generally 1800-2200 mm of rainfall per year, as suggested by the diagram at right for Qiongdong (near Qionghai on the eastern coastal plain). Western Hainan has a well developed monsoonal wet season but also a dry season of up to 5-6 months on the west coast, with total precipitation falling as low as 900 mm around Dongfang. The climate diagram at left, for Sanya on the south coast, is representative for much of western Hainan.

Natural Vegetation of Hainan

The flora of Hainan has been described in a four-volume "Flora Hainanica" by the Guangdong Plant Research Institute (1965-77). This major reference manual includes 3500 species in 1347 genera and 259 families, each species portrayed by a line drawing and with seasonality information. Compared with mainland Southeast Asia and other tropical areas, 3500 is not a large number of species, due probably to the island location. According to Ho and Xu (1955), Hainan can be divided into two main floristic regions, the southwestern quadrant versus the rest of the island. About 90% of Hainan's species occur across the southern half of the island, especially in the southwestern mountains (including Jianfengling). Most species also occur on the adjacent mainland.

The "Flora Hainanica" (vol. 4) also includes a description of the main natural vegetation types and a vegetation map (1 : 1,000,000) showing both natural vegetation regions and the current vegetation status. In addition, the "Guangdong Vegetation Cover" (Guangdong Plant Research Institute 1976) includes a somewhat more detailed coverage of Hainan vegetation (since Hainan was until recently part of Guangdong Province). Because these main vegetation descriptions are in Chinese only, a summary is attempted here and in

Table 1, based on these two sources.

Tropical rainforest is considered to have covered large areas of lowland southeastern Hainan, usually involving three tree strata and especially taxa such as *Vatica* and *Hopea* (Dipterocarpaceae), *Tarrietia* and *Reevesia* (Sterculiaceae), *Casearia* (Flacourtiaceae), and *Amesiodendron chinense* (Sapindaceae, from a monotypic genus endemic to China). Three main rainforest types are recognized by the "Guangdong Vegetation Cover" (p. 46):

1. *Tarrietia-Vatica-Sarcosperma-Hopea* communities
2. *Tarrietia-Dysoxylum-Diospyros-Hopea* communities
3. *Vatica-Tarrietia-Litchi-Mallotus-Pinanga* communities.

Tarrietia (=*Heritiera*) *parvifolia*, with large buttresses, is one of the characteristic trees of Hainan rainforests and is closely related to *H. littoralis*, which occurs in coastal strand forests throughout much of southeastern Asia, including Okinawa (e. g. Ohno 1989). *Vatica astrotricha* and *Hopea hainanensis* are among the most important constituents of the original Hainan rainforests but have been greatly reduced by logging. *Dysoxylum* (especially *D. binectoriferum*, Meliaceae), *Diospyros* spp. (Ebenaceae), and *Litchi chinensis* (Sapindaceae, the Chinese "queen of fruits"), plus species of *Syzygium* and other Myrtaceae, *Cryptocarya* (Lauraceae), *Sarcosperma laurinum* (Sapotaceae), *Xanthophyllum hainanense* (Xanthophyllaceae, cf. Polygalaceae), etc. are especially common in the first tree understorey. In addition there are many palms (e.g. *Calamus* and *Licuala* spp., *Daemonorops margaritae*, *Arenga pinnata*, *Pinanga discolor*), lianas (e.g. *Fissistigma* and *Parabarium* spp., *Entada phaseoloides*), forbs (especially *Alpinia* spp. and *Alocasia odora*), *Selaginella* spp., and smaller vines and epiphytes (e.g. *Pothos* spp., *Neottopteris nidus*, *Trachelospermum jasminoides*, *Epipremnum*, *Hoya*, *Psilotum*, etc.).

Several other rainforest types are distinguished in the mountains, including low-montane rainforest (25-30m in height, from 500 to 1100m in elevation), mid-montane rainforest (to 20m, above 1100m elevation), montane ravine rainforest (to 40-50m in height, in lower-montane ravines), and a mossy dwarf forest (6-10m) which is best developed on ridges and summits around 800-1000m in elevation. Whereas the lowland forests are conspicuously "tropical" in their paucity of Fagaceae, Lauraceae, Theaceae, and other taxa familiar from subtropical and warm-temperate forests, these taxa reappear in the montane forests, first mixed with more purely tropical taxa (low-montane rainforest, see Table 1) but increasing dramatically in importance as one goes higher. Conifers are also important in the montane forests, including relatively broad or linear-leaved *Dacrydium*, *Podocarpus*, *Cephalotaxus*, and *Keteeleria* as well as *Pinus*. Tropical pine forests (*Pinus ikedai*, cf. *P. caribbea*) occurred in the mountains as well as in small lowland areas, especially on sand (with *Podocarpus nagi*).

Most of the remaining lowlands of Hainan, where the dry season is more pronounced, were once covered by shorter "tropical seasonal rain forests" (i.e. tropical seasonal forests), apparently with a gradual gradation from evergreen to semi-evergreen and more completely deciduous types. The "Flora Hainanica" (vol. 4, p. 524) describes "evergreen seasonal-rain forest" in which *Ficus* and *Artocarpus* spp., plus *Vatica astrotricha*, *Gironniera* (evergreen Ulmaceae, S China and Indomalaysia), and the Hainan endemic *Antiaris toxicaria*, etc. are the co-dominants (reaching 20-25m in height). Somewhat similar forest types are described by the "Guangdong Vegetation Cover" as semi-evergreen, including *Radermachera hainanensis* (deciduous Bignoniaceae), *Baccaurea ramiflora* (Euphorbiaceae), etc. More completely deciduous forests (10-15m) covered much of drier western Hainan but still contained some evergreen species. The main types recognized by the "Guangdong Vegetation Cover" are a *Terminalia-Albizzia* type (with quantitative data, see pp. 86), a *Quercus* type (with evergreen *Qu. kerrii* and *Castanopsis*),

Table 1. Summary of Natural Vegetation Types of Hainan.

The vegetation types and species lists are from the summary of Hainan vegetation given in the "Flora Hainanica", volume 4 (Guangdong Vegetation Institute 1965-77, in Chinese). The Chinese description used terms such as "high tree layer", "next tree layer", etc., which are rendered here as T_1, T_2 layers, etc. The vegetation names, especially involving the words 'rain forest', are directly from the Chinese and might be altered in more general English ecological usage (cf. seasonal forest or seasonal rainforest).

Tropical Rainforest

Height: 35-40m; occurrence: under 500 m elevation, with precipitation 2100 mm or more.

T_1 trees: *Tarrietia parvifolia, Amesiodendron chinense, Vatica astrotricha, Hopea hainanensis, Reevesia longipetiolata, Casearia aequilateralis*

T_2 trees: *Litchi chinensis, Cryptocarya* spp., *Diospyros* spp., *Dysoxylum* spp., *Syzygium* spp., *Dillenia turbinata*

T_3 trees: *Mallotus hookerianus, Gironniera* spp., *Coelodepas hainanensis, Alphonsea monogyna*

Palms: *Calamus* spp., *Liceuala* spp., *Daemonorops margaritae, Arenga pinnata, Pinanga discolor*

Lianas: *Entada phaseoloides, Fissistigma* spp., *Parabarium* spp., *Ancistrocladus tectorius*

Herbs: *Rhaphidophora pinnata, Rh. hongkongensis, Scindapsus maclurei, Pothos repens, Neottopteris nidus.*

Low-Montane Rainforest

Height: 25-30m; occurrence: 500 to 1100 m elevation.

T_1 trees: *Dacrydium pierrei, Castanopsis hystrix, Schima superba, Lithocarpus fenzelianus, Pentaphylax euryoides, Altingia obovata, Cleyera obscurinervia, Castanopsis tonkinensis, Xanthophyllum hainanense, Quercus bambusifolia, Madhuca hainanensis, and Alseodaphne hainanensis.*

T_2 trees: *Syzygium hancei, Randia canthioides, Cryptocarya metcalfiana, C. densiflora, Cinnamomum burmanii, Endiandra hainanensis, Memecylon ligustrifolium, Ormosia semicastrata* f. *litchifolia, Castanopsis fissa, Podocarpus* spp.

Other important spp.: *Gnetum montanum, Miscanthus floridulus*

Mid-Montane Rainforest

Height: to 20m; occurrence: above 1100 m (highest mountains around 1900m).

T_1 trees: *Castanopsis hystrix, Lithocarpus brachystachyus, Quercus championii, Machilus* (=*Persea*) spp., *Altingia obovata, Syzygium araiocladum, Reevesia longipetiolata, Lithocarpus fenzelianus*

T_2 trees: *Olea brachiata, Linociera parvilimba, Ternstroemia gymnanthera, Symplocos chunii*

Other small trees: *Rapanea* (=*Myrsine*) *neriifolia, Ilex* spp., *Syzygium* spp., *Magnolia* spp.

Conifers: *Cephalotaxus sinensis, Keteleeria hainanensis, Pinus kwangtungensis, P. fenzeliana*

Temperate-zone taxa: Ericaceae, *Nyssa javanica, Acer* spp., *Paris, Carpinus lanceolata*

Shrub/herb layer: *Lasianthus* spp., *Maesa* spp., *Ardisia* spp., *Psychotria rubra, Tricalysia viridiflora, Blastus cochinchinensis, Prismatomeris tetrandra, Cyathea gigantea.*

Montane Ravine Rainforest

Height: to 40-50m; occurrence: lower montane ravines (350-1100 m elevation)

T_1 trees: *Podocarpus imbricatus, Quercus blakei, Endiandra hainanensis, Beilschmiedia longipetiolata, Xanthophyllum hainanense*

T_2 layer: *Lasianthus trichophlebys, Cryptocarya densiflora, Glochidion wrightii, Canarium album, Schefflera octophylla, Carallia brachiata, Garcinia oblongifolia, Licuala spinosa, Calamus* spp., *Indocalamus.*

Mountain-top Dwarf Forest

Height: 6-10 m; occurrence: best developed at 800-1000 m elevation

Trees and treelets: *Quercus blakei, Rapanea* (=*Myrsine*) *neriifolia, Castanopsis hystrix, Rhaphiolepis indica, Elaeocarpus dubius, Symplocos chunii, Ternstroemia gymnanthera, Syzygium* spp.,

Rhododendron spp., *Ficus variolosa*, plus *Arundinaria* spp.

Shrub layer: *Rhodomyrtus tomentosa, Wikstroemia pachyrachis, Enkianthus quinqueflorus, Rhododendron* spp., *Lyonia rubrovenia*

Evergreen Seasonal-Rain Forest

Height: 20–25 m; occurrence: areas with typically 1500–1800 mm annual rainfall and 3–4 dry months (less than 50 mm rainfall)

T_1 trees: *Gironniera cuspidata, Artocarpus* spp., *Ficus* spp., *Pouteria annamensis, Vatica astrotricha, Heteropanax fragrans, Endospermum chinense, Nephelium topengii, Antiaris toxicaria, Pseudostreblus indica, Radermachera hainanensis*

T_2 trees: *Sarcosperma laurinum, Baccaurea ramiflora, Sterculia* spp., *Syzygium* spp., *Garcinia* spp., *Hydnocarpus hainanensis, Walsura robusta*

Arborescents: *Litsea verticillata, Arytera littoralis, Bridelia balansae, Ficus* spp., *Garcinia* spp., *Harpullia cupanioides, Syzygium levinei*

Shrub layer: *Memecylon* spp., *Rapanea* (=*Myrsine*) spp., *Rhodomyrtus tomentosa, Syzygium* spp., *Phyllanthus* spp., *Phoenix hanceana*

Mixed Seasonal-Rain Forest (half evergreen or deciduous)

Height: 10–15 m; occurrence: areas with typically 800–1300 mm annual rainfall and seasonally low rainfall and humidity

Trees: *Cratoxylon ligustrinum, Croton laevigatus, Meyna hainanensis, Syzygium cominii, Lannea grandis, Dillenia pentagyna, Pterospermum heterophyllum, Dolichandrone caudafelina, Radermachera hainanensis, Oroxylum, indicum, Terminalia hainanensis, Spondias pinnata, Albizzia* spp., *Dalbergia* spp., *Gossampinus malabarica, Streblus asper*

Grasses (drier areas) : *Heteropogon contortus, Eragrostis zeylanica, Aristida chinensis, Imperata cylindrica* var. *major*, plus *Eupatorium odoratum* (forb)

Tropical Needle-Leaved Forests

Flat lowland areas: *Pinus ikedai*

Flat coastal sandy areas (small patches): *Podocarpus nagi*

Mountain areas: conifers usually mixed with broad-leaved trees but some areas of *Pinus ikedai* forest

Mangroves

Height: Generally less than 11–12 m; occurrence: scattered estuaries and other protected coastal areas

T_1 trees: *Bruguiera gymnorrhiza, B. sexangula, B. cylindrica, Rhizophora apiculata, Rh. mucronata, Kandelia candel, Ceriops tagal, Lumnitzera racemosa, L. littorea, Sonneratia caseolaris, Scyphiphora hydrophyllacea, Heritiera littoralis, Xylocarpus granatum, Excoecaria agallocha*

Shrubs: *Aegiceras corniculatum, Acanthus ilicifolius, Avicennia marina, Clerodendron inerme*, plus *Nypa fruticans* (palm)

Fern: *Acrostichum aureum*

Vines: *Flagellaria indica, Dischidia chinensis, Derris trifoliata, Caesalpinia nuga, Stenochlaena paludstris*

Forbs: *Hoya* sp.

Halophytic forbs: *Sesuvium portulacastrum, Suaeda* spp., *Zoysia metrella, Sporobolus virginicus*

Semi-mangrove plants (back-mangrove, etc.) : *Hibiscus tiliaceus, Calophyllum inophyllum, Cerbera manghas, Pandanus tectorius, Ficus* spp., *Cocos nucifera*

Coastal Psammophytic Vegetation

Outer beach zone: *Ipomoea pes-caprae, Canavalia maritima, Vitex trifolia*

Coastal dunes: *Spinifex littoreus, Fimbristylis sericea, Opuntia dillenii, Aloëera* var. *chinensis, Barringtonia racemosa, Carmona microphylla, Azima sarmentosa, Harrisonia perforata, Bambusa bambos, Scaevola sericea, Brucea javanica, Pluchea indica*

Dry coastal grassland (west coast): *Heteropogon contortus*

Coastal marsh (northeast coast): *Leptocarpus sanaenis*

a *Lagerstroemia-Heteropanax-Chukrasia* type (diverse; see data on pp. 89), and a *Hainania-Meynia-Lannea-Walsura* type. These forests also generally involved more Bignoniaceae (*Radermachera, Dolichandrone, Oroxylum,* etc.), Leguminosae (e.g. *Albizzia, Dalbergia*), and Anacardiaceae (e.g. *Lannea, Spondias*), and other species quite different from those of the rainforests.

The coastal lowlands show a strip of "psammophytic thorn-scrub steppe" mapped ("Flora Hainanica" map) almost continuously around the island. This apparently involved some non-native succulents (*Opuntia, Aloë*) and other scrub elements mixed with tropical xeric grasses such as *Spinifex.* Some of the scrub taxa seem to have rather restricted distributions but do occur outside Hainan, e.g. *Harrisonia perforata* (Simaroubaceae, 1–2m, thorny), *Carmona microphylla* (=*Ehretia,* Boraginaceae, 1–4m), *Brucea javanica* (Simaroubaceae but once called *Rhus javanica*), and *Pluchea indica* (a relatively leafy Compositae, 1–3m, originally included in *Baccharis*). Another element, *Scaevola sericea* (Goodeniaceae), on the other hand, is a fleshy-leaved, spreading evergreen shrub (to 5m) found commonly along coastlines thoughout much of the tropical and subtropical Indo-Pacific region.

Site and Methodology

Torpical montane forest was studied at the Jianfengling (尖峰岭) Tropical Primary Forest Nature Preserve near Jianfeng town and about 25 km from the southwest coast (see Figure 2). The preserve covers 1635 ha centered on mountains reaching about 1400 meters in elevation (Figure 4) and is administered by the Jianfengling Forestry Bureau, along with a much larger area (about 150,000 ha) under less protection (see Enderton 1984, pp. 208). The preserve contains over 800 tree species and a research station, which also grows many exotic tree species. The natural vegetation of the Jianfengling mountains (cf. Table 1)

Figure 4. Location of the Jianfeng (=pointed peak) Forest Site, in the Jianfengling Mountains (reaching 1400m).

consists of scrub and grass-covered hills below about 600m (plus some areas of seasonal forest), tropical montane "rain forest" from 600 to 1100m, and mossy forest above that. When the research station was established in 1958, there were few people living in the area. With road construction, though, more people have moved in, including a Li commune (cf. Gao 1981) now located just at the edge of the forest preserve (see Enderton 1984, p. 210).

Vegetation sampling was done by the Braun-Blanquet relevé method, a very standard methodology well suited to rapid but extensive sampling, structural description, and subsequent geographic comparisons (see Westhoff and van der Maarel 1973, Mueller-Dombois and Ellenberg 1974, or in more detail, Fujiwara 1987b). Our forest relevé at Jianfengling required four days, one for the relevé and three for travel — plus the assistance of local taxonomists. Plant growth form and seasonal foliation habit were recorded with the species cover and sociability codes (or obtained later) so that some aspects of structure and potential forest dynamics could be inferred. Some more quantitative data for similar forests are given by the "Guangdong Vegetation Cover" (pp. 63-64) and by Lu et al. (1986) for the Bawangling nature preserve about 50 km to the northeast.

The Montane Forest at Jianfengling

In addition to the general climatic description for Hainan (Figure 3), an attempt is made in Table 2 to estimate the climatic conditions at the Jianfeng forest itself, based on nearby data and lapse rates. The Jianfeng forest site sampled (890 meters above sea level) is still in a tropical wet-dry climate with strong monsoonal influence, similar to that at Sanya (Figure 3) but with more rainfall. The dry season is ameliorated by the cooler montane location, but it has not disappeared. Within the forest itself, which maintains its own more moderated, more humid

Table 2. Estimated Climatic Conditions at the Jianfenging site.

Climatic data, based on a 13-year record, were given by Lu et al. (1986) for Changjiang County, in the more humid lowland about 65 km north of Jianfeng. Data for Dongfang were available from the Chinese authors. Ambient (macro) climatic conditions at the Jianfeng forest are estimated based on an average of the Dongfang and Changjiang data and local vertical change of temperature and precipitation quoted by Zhao (1986, p. 152). The water balance at Jianfeng forest is more favorable than in the lowlands, due to reduced temperatures and increased precipitation, thus ameliorating the winter dry season. Xu and Zeng (1985) found that Bowen ratios at the " bottom of Jianfeng mountain" increased from 0.3-2.3 during the early dry season to 2-8 toward the end of the dry season. Latent heat flux ranged from 28% of net radiation on the driest days to 90% on days after rainfall (during the dry season), averaging 45% on normal sunny days. Annuail potential evapotranspiration is estimated by the method of Holdridge (1959) ; monthly PET and moisture index values were estimated in proportion to monthly temperatures.

	Dongfang	Changjiang	Jianfeng forest (890m)
Mean annual temperature	24.7°	24.2°	19.7°
Mean July temperature	29°	28°	24°
Mean January temperature	19°	19°	14°
Average annual precipitation	993 mm	1677 mm	2500 mm
Annual potential evapotranspiration (PET)	1456 mm	1426 mm	1160 mm
Annual moisture index (precip./PET)	0.68	1.18	~2.1
Avg. precipitation of driest month (January)	7 mm	10 mm	~15 mm
Estimated January PET	91 mm	93 mm	~70 mm
Estimated moisture index of January	0.08	0.11	~0.21

microclimate, the dry season is not as strong as the winter rainfall and moisture index suggest. Nevertheless, the importance of deciduous trees in the adjacent lowlands and the length of the climatic dry season suggest that 890m is not yet sufficient elevation to eliminate the significant seasonal climatic pulse, which may favor at least some deciduous trees at Jianfengling and which must certainly synchronize such events as re-foliation, even in the evcergreen trees.

As for the forest itself (see Figure 5), the composition and structure are shown in Table 3 in the form of a relevé partially reorganized by growth forms. There is a total of 109 species in the 18 x 25m quadrat, of which 78 species are in the shrub layer. The canopy reaches 35m in height and has 12 species, while the understorey tree layer has 16 species, generally only about 12m high but with some trees reaching 18m. All but 10 of the 109 species are described in the "Flora Hainanica", the others being either more recently identified or perhaps having synonyms which we could not trace. Five of these remaining 10 species were mentioned by Wu (1980).

Of the 12 species listed as typical canopy species in low-montane rain forest ("Flora Hainanica", vol. 4, p. 526), six occur as T_1 or T_2 trees in the Jianfeng relevé. Among these the most important are *Dacrydium pierrei* (Podocarpaceae) and *Xanthophyllum hainanensis* (Xanthophyllaceae), which are also the main canopy species in the montane forest at Bawangling, (Lu et al. 1986). The other important, typical canopy co-dominants include *Lithocarpus fenzelianus*, *Alseodaphne hainanensis* (Lauraceae), and *Madhuca hainanensis* (Sapotaceae), plus *Pentaphylax euryoides* (Pentaphylaceae) in the T_2 layer (cf. Table 1). It seems, then, that the Jianfeng relevé shown in Table 3 is indeed representative of "tropical low-montane rainforest" on Hainan.

Figure 5. Jianfeng Forest Site, at 890 meters elevation.

Table 3. Composition of the Montane Forest at Jianfengling (890 m).

Montane "monsoon" forest			890 m, 15° slope to SE	17 Sept. 1986
T_1	35m	85%		
T_2	18m	60%	18 x 25 m	
S	5m	70%		
H	0.4m	20%		KF, HY, ZY, FQ, CZ, LZ, EB

T_1:

- 3 · 3 *Dacrydium pierrei* (Podocarpac.) (1m DBH)
- 2 · 3 *Xanthophyllum hainanensis* (Xanthophyllac.)
- 2 · 2 *Lithocarpus fenzelianus* (Fagac.)
- 2 · 1 *Polyspora* (=*Gordonia*) *balansae* (Theac.)
- 1 · 2 *Alseodaphne hainanensis* (Laurac.)
- 1 · 2 *Madhuca hainanensis* (Sapotac.)
- 1 · 1 *Cyclobalanopsis fleuryi* (Fagac.)
- 1 · 1 *Lithocarpus amygdalifolius* var. *praceipitorum* (Fagac.)
- 1 · 1 *Alstonia scholaris* (Apocynac.)
- \+ *Beilschmiedia tungfangensis* (Laurac.)
- 1 · 1 *Cinnamomum ovatum* (Laurac.)
- (1 · 1) *Cyclobalanopsis patelliformis* (Fagac.) (30m)

T_2:

- 2 · 2 *Turpinia glaberrima* (Staphyllac.) (EG?)
- 2 · 2 *Decaspermum cambodianum* (Myrtac.)
- 1 · 2 *Symplocos lancilimba* (Symploc.)
- 1 · 1 *Cyclobalanopsis blakei* (Fagac.)
- 1 · 1 *Schima superba* (Theac.) (T_1)
- 1 · 1 *Ilex kobuskiana* (Aquif.)
- \+ *Adinandra millettii* (Theac.)
- \+ *Pentaphylax euryoides* (Pentaphyllac., endemic)
- \+ *Rhus succedanea* (Anacardiac.) (decid)
- \+ *Michelia balanse* (Magnol.)
- \+ *Diospyros eriantha* (Ebenac.)
- \+ *Altingia obovata* (Hamamelidac.) (decid.?)

vines:

- \+ *Kadsura heteroclita* (Schisandrac.) (EG?)
- \+ *Hypserpa nitida* (Menispermac.)

epiphytes:

- \+ *Drynaria quercifolia* (fern)
- \+ *Neottopteris nidus* (fern)

S:

- 1 · 2 *Madhuca hainanensis* (T_1)
- 1 · 2 *Ilex kobuskiana* (T_2)
- 1 · 2 *Neolitsea ellipsoidea* (Laurac.)
- 1 · 2 *Neolitsea pulchella* (Laurac.)
- 1 · 2 *Dasymaschalon trichophorum* (Annonac.)?
- 1 · 1 *Schima superba* (T_2)
- 1 · 1 *Neolitsea ferruginea* (Laurac.)
- 1 · 1 *Magnolia paenetalauma* (Magn.)
- 1 · 1 *Glochidion hypoleucon* (Euphorb.)
- 1 · 1 *Acer decandrum* (Acerac.)
- 1 · 1 *Prismatomeris tetrandra* (Rubiac.)
- \+ · 2 *Lithocarpus pseudovestitus* (Fag.)
- 1 · 2 *Decaspermum cambodianum* (T_2)
- 1 · 2 *Symplocos caudata* (Symploc.)
- 1 · 2 *Syzygium araiocladum* (Myrtac.)
- 1 · 2 *Canthium dicoccum* (Rubiac.)
- 1 · 2 *Sterculia hainanensis* (Sterculiac.)
- 1 · 1 *Cryptocarya maclurei* (Laur.) (T)
- 1 · 1 *Cinnamomum tsoi* (Laurac.)
- 1 · 1 *Ixonanthes chinensis* (Erythroxylac.)
- 1 · 1 *Calophyllum membranaceum* (Guttif.)
- 1 · 1 *Decaspermum gracilenium* (Myrtac.)
- \+ · 2 *Pithecellobium clypearia* (Leg.)
- \+ · 2 *Alyxia* sp. (Apocynac.)

S (continued):

- \+ *Xanthophyllum hainanensis* (T_1)
- \+ *Alstonia scholaris* (T_1)
- \+ *Cryptocarya chingii* (Laur.) (T)
- \+ *Diospyros* sp. (Ebenac.) (T)
- \+ *Machilus monticola* (Laur.) (T)
- \+ *Magnolia lotungensis* (Magn.)
- \+ *Photinia serrulata* (Rosac.) (T)
- \+ *Lithocarpus fenzelianus* (T_1)
- \+ *Cyclobalanopsis* cf. *patelliformis* (T_1)
- \+ *Castanopsis tonkinensis* (Fag.) (T)
- \+ *Podocarpus neriifolius* (conif.) (T)
- \+ *Elaeocarpus limitaneous* (Elaeoc.) (T)
- \+ *Gironniera aequalis* (Ulmac.) (T)
- \+ *Castanopsis fissa* (Fag.) (T)

+ *Lindera kwangtungensis* (Laur.)
+ *Linociera ramiflora* (Oleac.) (UT)
+ *Ormosia semicastrata* f. *litchiifolia.*
+ *Symplocos lancilimba* (Sympl.) (T_2)
+ *Tutcheria championi* (Theac.)
+ *Ardisia virens* (Myrsinac.)
+ *Syzygium buxifolium* (Myrtac.)
+ *Lasianthus lancilimbus* (Rubiac.)
+ *Anodendron* sp. (Apocynac.)
+ *Olea dioica* (Oleac.)
+ *Meliosma laui* (Sabiac.)

+ *Ixora nienkui* (Rubiac.) (S)
+ *Daphniphyllum paxianum* (Daphn.)
+ *Polyosma cambodiana* (Escalloniac.)
+ *Euonymus* sp. (Celastrac.)
+ *Tutcheria* sp. (Theac.)
+ *Ardisia quinquegona* (Myrsinac.)
+ *Platea parvifolia* (Icacinac.)
+ *Symplocos* sp. (Symploc.) (thin lvs.)
+ *Olea* sp.(Oleac.) (aucuboid)
+ *Apocynaceae* sp. (*Anodenron affine?*)
+ *Reevesia thyrsoidea* (Sterculiac.)

palms:

2・2 *Calamus rhabdocladus* (UT)
2・2 *Licuala spinosa* (S)
+ *Pandanus* sp.

2・2 *Calamus pulchellus*
+ *Livistona saribus* (T)

bamboo:

2・2 *Indoealamus pseudosinicus*

vines and climbers:

1・2 *Smilax corbularia* (Liliac.)
1・1 *Erycibe obtusifolia* (Convolv.)
1・1 *Psychotria serpens* (Rubiac.) (ep.)
+ *Strychnos confertiflora* (Log.)
+ *Millettia* oosperma (Leg.)
+ *Smilax* sp. (Liliac.)

1・1 *Parabarium hainanense* (Apocyac.)
1・1 *Strychnos angustiflora* (Loganiac.)
+・2 *Smilax opaca* (Liliac.)
+ *Fissistigma* sp. (Annonac.)
+ *Jasminum* sp. (*laurifolium?*) (Oleac.)

epiphyte:

+ *Pholidota chinensis* (Orchidae)

H: clubmoss:

2・2 *Selaginella hainanensis*

woody seedlings:

1・2 *Psychotria rubra* (S)
+ *Nephelium topengii* (Sapindac.)

+ *Blastus cochinchinensis* (Melastom.)

forbs:

1・2 *Oldenlandia* (=*Hedyotis*) *communis*

+・2 *Alpinia maclurei* (Zingiberac.)

ferns:

+・2 *Adiantum induratum*
+ *Angiopteris* sp.

+ *Adiantum soboliferum*

vine:

+ *Parabarium hainanense* (Apocynac.)

Sedges:

+ *Carex* sp. 1 (wide leaves)

+ *Carex* sp. 2

In looking at Table 3 one can see that there were no lianas or epiphytes recorded in the canopy and only a few individuals in the T_2 layer. This paucity of vines and epiphytes suggests a significant degree of water stress in the dry season and conflicts with a common physiognomic criterion for true tropical rainforests (e.g. Richards 1952, Fosberg 1967, Walter 1973, Whitmore 1975; cf. Webb 1959). Even so, most of the trees appear to be evergreen, the only clear exception in the tree layers being *Rhus succedanea.* This mainly evergreen structure but without abundant epiphytes and lianas is similar to the tropical seasonal evergreen forests of various parts of South and Southeast Asia (e.g. Champion and Seth 1968, Ogawa et al. 1961, Williams 1975).

The shrub layer includes both young individuals of potential T_1 and T_2 trees and many typical understorey arborescents (woody plants of shrub size but usually with a single main stem, cf. Box 1981, de Laubenfels 1975), especially from "understorey families" such as Myrsinaceae but also Rubiaceae, Myrtaceae, etc. Other understorey growth forms include palms (4 spp.) and *Pandanus,* an understorey bamboo (*Indocalamus pseudosinicus*), understorey vines and climbers (11 spp.), only two forb spp. and three ground fern spp., plus two *Carex* spp., *Selaginella,* and one epiphytic orchid. Of these understorey forms, only the palms (except *Livistona saribus,* a potential tree found growing individually), the bamboo, and *Selaginella* had cover values of 5% or more (see Figure 6). This low cover and relative poverty of herbaceous understorey forms is also not characteristic of true rainforest. Of course the forest is quite wet during the summer rainy season, and we could still find a few leeches during our visit in mid-September, near the end of the rainy season.

Figure 6. Forest Understorey at the Jianfeng Site.

Foest Dynamics

The importance of common canopy co-dominants in the T_1 layer of the Jianfeng relevé (with little apparent regeneration) suggests that the forest is mature. The co-occurrence of other species in the overstoreys, e.g. cosmopolitan *Rhus succedanea*, may indicate recovery from disturbance, but the forest is not at all a successional forest. The physiognomic structure and potential dynamics of the forest are summarized in Table 4. As one can see, only five of the 12 canopy species occur in lower layers and most shrub-layer species do not occur in higher layers. No seedlings of higher-layer species could be found at all, though some young individuals of potential trees were evident in the shrub layer. In temperate-zone forests this apparent lack of regeneration would suggest senescence, but in the tropics, germination of tree species does not occur every year and growth can be quite rapid once germination does occur and/or a seedling is "released" by the formation of a canopy gap permitting light to enter (e.g. Hartshorn 1978, Orians 1982, Pickett 1983, Brokaw 1985, Pickett and White 1985). One might also notice that at least half of the shrub-layer species are known tree species, some with canopy potential. Although East Asian "laurel forests" and monsoon forests often have their greatest species richness in the shrub layer, the Jianfeng situation seems rather extreme (78 of 109 total species). This also suggests disturbance, reminding us in particular of forests recovering from typhoon damage.

Table 4. Physiognomic Structure and Potential Dynamics of the Jianfeng Forest.

The physiognomy of the forest is described in terms of numbers of species of particular growth forms in each forest layer. Species occurring in more than one layer are listed (vertically) in the highest layer in which they occur, with lower occurrences listed horizontally (on the same line). Thus one can see that, of 12 canopy tree species, only 5 occur in lower layers; and of 60 shrub-layer arborescent or frutescent species, 51 are new to the shrub layer and only 9 occur also in higher layers. The herb layer involves only one species, a vine, which occurs in any higher layer. The forest thus appears to be relatively stable, with little regeneration of tree species (even though many of the shrub-layer species are young trees with canopy or tree-understorey potential).

	T_1	T_2	S	H
Canopy trees (T_1)	12	0	5	0
Understorey trees (T_2)		12	4	0
Vines/lianas	0	2	0	0
Epiphytes	0	2	0	0
Shrub layer:				
Shrubs/young trees (not T_1 or T_2)			51	0
Palms			5	0
Vines (not T_1 or T_2 spp.)			11	1
Bamboo			1	0
Herb layer:				
Woody seedlings (new spp.)				3
Forbs (non-epiphytic)				3
Graminoids (non-bamboo)				2
Clubmoss				1
Total	12	16	78	12

Biogeographic Relations

If one looks mainly at the tree layers at Jianfeng, one can see a suggestion of endemism, with several species carrying the species epithet 'hainanensis' (or 'tungfangensis',= Dongfang). In addition, *Dacrydium pierrei* and *Pentaphylax euryoides* occur only or mainly on Hainan, as do *Sterculia hainanesis*, *Parabarium hainanense*, *Selaginella hainanensis*, and others in the understoreys. There are many wide-ranging generalists (e.g. *Schima superba*, *Rhus succedanea*, *Ardisia quinquegona*, *Psychotria rubra*), however, and few species appear to be true endemics. *Pentaphylax euryoides*, for example, is the only member of the family Pentaphylaceae, but it occurs from southern China to Sumatra (Mabberley 1987) and is similar to the Theaceae. Most of the other tree species also occur throughout southern China and adjacent areas, many in both southeastern China (Guangdong) and southwestern China (Yunnan). These other tree-layer species in particular also involve mainly large, wide-ranging families such as the Fagaceae, Lauraceae, and Theaceae, as well as Apocynaceae, Anacardiaceae, Magnoliaceae, etc. The most important regionally endemic taxa on Hainan appear to belong more to the lowland forests, especially species of *Hopea* and *Vatica* and the truly endemic *Antiaris toxicaria*.

Mangrove Vegetation

The original vegetation of Hainan included mangrove forests at various places (perhaps continuously) along the shoreline. At Dong Zai Gang, southeast of Haikou (northeastern Hainan), is a nice mangrove museum with dried herbarium samples on display showing several dozen of the important mangrove plant species. There is also a small, recovering remnant of what was probably once a tall mangrove forest. A mangrove zonational profile from Hainan is given by Zhao (1986, without location) and was found (Veg. of Guangdong Committee 1976, p. 120) to be from Wenchang, on the east coast of Hainan. Although many species are the same, the mangrove at Dong Zai Gang showed rather different zonation, involving mainly *Ceriops tagal* and *Aegiceras as corniculata* as apparent pioneers and *Rhizophora stylosa* or *Avicennia marina* (generally not occurring together), plus *Bruguiera gymnorrhiza* and sometimes *Kandelia candel* on apparently more stable areas a bit further away from the shoreline. At Yen Feng Zen, near Dong Zai Gang, we were able to inspect a back-mangrove area, dominated by *Excoecaria agallocha* (to 2.5m), *Acrostichum aureum* and *Hibiscus tiliaceus* (to 2 m), plus 12 other species (including *Dalbergia candenatensis*, *Pluchea indica*, *Wedelia biflora*, and *Acanthus ilicifolium*). Especially on the windward eastern side of Hainan, mangrove height and development were probably limited by typhoon frequency, as in south Florida and on many Caribbean islands. More complete destruction was done by man, however, in the form of cutting for firewood and charcoal production. Much of Hainan's original mangrove area was probably destroyed during the 1960's and 1970's.

Actual Vegetation

Though threatened by rapid, illegal deforestation, some of the montane rainforest, lowland secondary forest (replacing tropical rainforest), and (montane) tropical needle-leaved forest still remain. Much of the coastal psammophyte scrub and some of the dry psammophyte savanna in the west (*Heteropogon contortus*) and moist psammophyte grassland in the northeast (a marsh dominated by *Leptocarpus sanaensis*, Restionaceae) also remain, though disturbed to varying degrees. The status of the other forest types is indicated (as of

the late 1970's) by the map legend, with current actual vegetation status shown by the indented items under each natural forest type:

Colline rain forest and secondary forest
- — secondary grassy slopes with few trees but evidence of forest

Evergreen seasonal rain forest
- — secondary evergreen seasonal rain forest
- — scrub, with few trees
- — with scattered mesomorphic trees and grass patches remaining
- — with scattered more xeric trees and grass patches remaining

Mixed seasonal rain forest
- — with few trees and grass patches remaining
- — with remaining broad-leaved trees and thorn-tree scrub
- — with more xeric thorn-scrub and grass patches remaining

Cultivated areas.

The main types of these mainly anthropogenic grasslands, in Hainan as well as on the adjacent Leizhou Peninsula of the mainland, are shown in Table 5.

Much of the low-montane area of Hainan is now covered by rubber and other plantations, as are some of the lowlands. A special feature of the Hainan rubber plantations is the combination of rubber trees with a tea understorey (Figure 7), insuring some economic continuity in case the rubber trees are damaged by a typhoon. Climatic considerations, productivity, and economics of these rubber plantations on Hainan are described by Hao (1985).

Much of the remainder of lowland Hainan is now also covered by secondary vegetation, especially scrub dominated by *Acacia*, *Eucalyptus*, and *Casuarina* spp. At two places we took relevés of mantle (edge) vegetation, as shown in Table 6. The roadside mantle near Nada is in the region of transitition from wetter eastern Hainan to the dry climates of the

Table 5. Grassland Types of Hainan and the Leizhou Peninsula.
Only the tropical vegetation types (excluding coastal types) are listed (Guangdong Plant Research Institute 1976).

Tropical Grasslands

Xeric-mesic grassland: *Eremochloa ciliaris-Aristida chinensis*

Xeric-mesic savanna: *Baeckia frutescens-Eriachne pallescens*, with *Pinus massoniana* and *Pinus ikedai*

Heteropogon contortus-Aristida chinensis, with *Streblus asper* and *Albizzia procera*

Mesic grasslands:
1. *Imperata cylindrica* v. *major-Cymbopogon caesius*
2. *Imperata cyl.* v. *major-Cymbopogon caesius*, with *Rhodomyrtus, Rapanaea, Aporosa, Dodonaea*
3. *Ischaemum aristatum-Imperata cyl.* v. *major*, with *Phoenix hanceana, Pandanus tectorius*

Hydric grassland (marsh): *Vetiveria nigritana*

Montane grasslands:
1. *Imperata cyl.* v. *major-Arundinella nepalensis*, with *Syzygium, Lannea, Dillenia*
2. *Imperata cyl.* v. *major-Arundinella nepalensis-Ischaemum ciliare*
3. *Saccharum arundinaceum-Miscanthus sinensis*

Figure 7. Rubber Plantation with a Tea Understorey, near the southeast coast of Hainan.

west side. The species are mainly widespread species which occur over much of East and Southeast Asia, especially *Passiflora foetida, Paederia scandens,* and *Eupatorium odoratum.* The coastal mantle at Tian-ya Hai-jiao (the Chinese "end of the world" on the southern coast of Hainan) was behind large rocks affording some protection from salt spray and also shows mainly species with wide distributions in tropical and subtropical East Asia.

Table 6. Two Mantle Communities from Hainan.

The roadside mantle (edge community) at the left was growing atop a roadside embankment next to the main highway southwest from Nada (Dan County). The coastal mantle, at right, was growing behind protective rocks about 50 meters from the shoreline at Tian-ya Hai-jiao in southernmost Hainan.

Roadside mantle	Coastal mantle at Tian-ya Hai-jiao
H 1.3 m 100% 2 x 4 m	H 2 m 4 x 6 m 100%
H: 5 · 5 *Passiflora foetida*	H: 4 · 4 *Colubrina asiatica* (Rhamnac.)
3 · 3 *Saccharum arundinaceum*	3 · 3 *Caesalpinia crista*
2 · 2 *Paederia scandens* v. *tomentosa* (Rubiac.)	2 · 2 *Clerodendron inerme* (Verbenac.)
2 · 2 *Eupatorium odoratum* (Comp.)	2 · 2 *Pongamia* (=*Millettia*) *pinnata* (Leg.)
1 · 2 *Merremia hederacea* (Colvolv.)	+ · 2 *Opuntia dillenii* (Cactac.)
1 · 2 *Fluggea virosa* (Euphorbiac.)	+ *Coccinia cordifolia* (Cucurbitac.)
+ · 2 *Ipomoea obscure* (Convolv.)	(1 · 1) *Melia azedarach* (Meliac.)
+ *Digitaria longiflora* (Gram.)	
+ *Markhamia* (=*Dolichandrone*) *cauda-felina* (Bignon.)	
+ *Achyranthes aspera* (Amaranthac.)	
+ *Celtis sinensis* (Ulmac.)	

Conclusion

Many of the genera occurring in the forests of Hainan are the same as in other parts of southern China as well as adjacent areas on the mainland of Southeast Asia (and South Asia) and on the tropical Pacific islands (e.g. Taiwan, the Philippines, the Ryukyu Islands). As a result, forest structure on Hainan is similar in some ways to these other parts of tropical and subtropical Asia. The genera are largely different in tropical and subtropical North America but the families are mostly the same, so there appear to be some similarities in forest structure between Hainan and even the islands of the Caribbean and perhaps mainland areas such as south Florida and the Yucatan peninsula of Mexico. The natural vegetation of Hainan is now largely gone, destroyed mostly in the last 20–30 years. Images of the original vegetation of Hainan, including the rainforests, seasonal semi-deciduous forest, *Pinus ikedai* forest, mangroves, the *Heteropogon* and *Imperata* savannas, and the coastal thorn-scrub, can still be seen in the photographs accompanying the "Vegetation Cover of Guangdong" (Guangdong Plant Research Instiute 1976).

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