

## Endangered Pteridophytes and Their Distribution in Hainan Island, China

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**ABSTRACT.**—With decreasing population sizes and fragmentation of the original habitats of pteridophytes in Hainan Island, the abundance of most pteridophytes has been dramatically reduced, and some species may be at the brink of extinction. To assess the natural distribution of pteridophytes on Hainan Island, we conducted three analyses: flora, niche, and habitat. Thirty-two species of endangered pteridophytes in 21 families were found in Hainan Island, accounting for 8% of the 400 pteridophytes species there. Floristic studies showed that 9% of these 32 species are tropical, 50% are tropical Asian, 20% are pan-tropical, 3% are from East Asia, 3% from the Southern Hemisphere, and 15% are endemic to Hainan Island. Niche analysis showed that 21 of the 32 species (66%) are epiphytic or semi-epiphytic, while 11 (34%) are terrestrial. About 24 species of endangered pteridophytes are distributed in protected, conservation regions and the others are distributed partly in the conservation and non-conservation regions. In species-poor families (< 6 species), most of the species are endangered.

**KEY WORDS.**—Hainan Island, pteridophyte, flora, endangered species, conservation

Hainan Island is located in the northern margin of the tropics and has a complex terrain and a tropical climate. Many rare and endangered species of pteridophytes find their home in the diverse environments of the island. Pteridophytes form essential links in the plant ecosystem of Hainan Island and are indicators of plant biodiversity. Many pteridophyte species of the Malaysia floristic region, India floristic region, Eastern Asiatic floristic region, Indochina Peninsula floristic region and Polynesian floristic region are found on the island (Yang *et al.*, 2007; Dong, 2004). Integration of multiple floras can promote the evolution of new species of pteridophytes (Wulff, 1964). However, with the increase of human populations and rapid economic development, the natural habitats of pteridophytes are becoming small and fragmented with pteridophytes scattered in patches in tropical mountain rainforests. Here we assessed the natural distribution of endangered pteridophytes in Hainan Island with flora, niche, and habitat analyses. The results showed that some pteridophyte populations have dramatically decreased in numbers and are facing extinction, and demonstrate the need for protecting pteridophyte diversity in Hainan Island.

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## MATERIALS AND METHODS

*Study Area.*—Hainan Island is located along the continental shelf of the southernmost tip of the Chinese continental marginal sea. It is separated from the Leizhou Peninsula of Guangdong by the 18-mile-wide Qiongzhou Strait (Fu, 1954). It is a typical continental island with a total area (satellite islands not included) of 33,900 km<sup>2</sup>. Low and flat along its coastline, Hainan Island reaches its highest altitude of 1867.1 meters at the Yinggeling Ridge of Wuzhishan Mountain, located at the center of the island. Connecting the ridge and the coastline are mountains, hills, and plains forming a terraced landscape. The northern part of the island is a broad plateau composed of shallow sediments and basalts, and is 50 meters above sea level. The granite hills of Danzhou, Tunchang, and other areas form a barrier to the cold winds from the north. Hainan has a tropical moist monsoon climate, often with strong winds, frequent tropical storms and typhoons. The sunshine duration throughout the year is 1750 to 2650 hours, with the average annual temperature between 23–25°C and there is no winter season. Most areas of the island have plenty of rainfall with average annual precipitation greater than 1600 mm. The central and eastern coastal areas are humid, especially during the typhoon season. The southeast coast has the highest annual precipitation (2000–2500 mm). The west coastal area has the lowest annual precipitation (800–1000 mm) and the evaporation is 1–10 times greater than the precipitation. Therefore the western side of Hainan Island is the driest place for vegetation. Other regions of the island are sub-humid as shown in Fig. 1 (Ren, 1985).

*Background information.*—We collected literature on Hainan pteridophytes published in Chinese and English since 1964 (Fu, 1954, 1957; Wu and Qin, 1991; Chen, 1964; Qin *et al.*, 1959, 2001), including reports and supplemental materials on the flora, niche, and habitat. We classified the locations of pteridophytes on Hainan Island into two categories: non-protected and protected areas (nature reserves and forest parks). The distribution of pteridophytes shows a marked discontinuity where the regional abundances of genera and species are distinctly different on either side of a curved line across the island from northwest to southeast. We named it “Lingao-Qiongzong-Wanning” line as shown in Fig. 2. This line seems to have great significance as it overlaps the “Wangwu-Wenjiao” geologic fault zone. We have carried out preliminary investigations of the causes of the line (Yang *et al.*, 2007).

*Evaluation of endangered species.*—We used the “IUCN Red List of Threatened Species Categories and Criteria version 3.1” (IUCN, 2001; Fig. 3) as the main criteria to determine the current status of species, determining if they are endangered, critically endangered, threatened, etc. Furthermore, some of the species’ data are from “China Plant Red Data Book” (Fu, 1991), “National Protected Plants List (first batch)” (Chinese State Forestry Administration, the Ministry of Agriculture, 1999), “China’s rare and endangered plant list” (State Environmental Protection Agency, the CAS Institute of Botany, 1987) and the

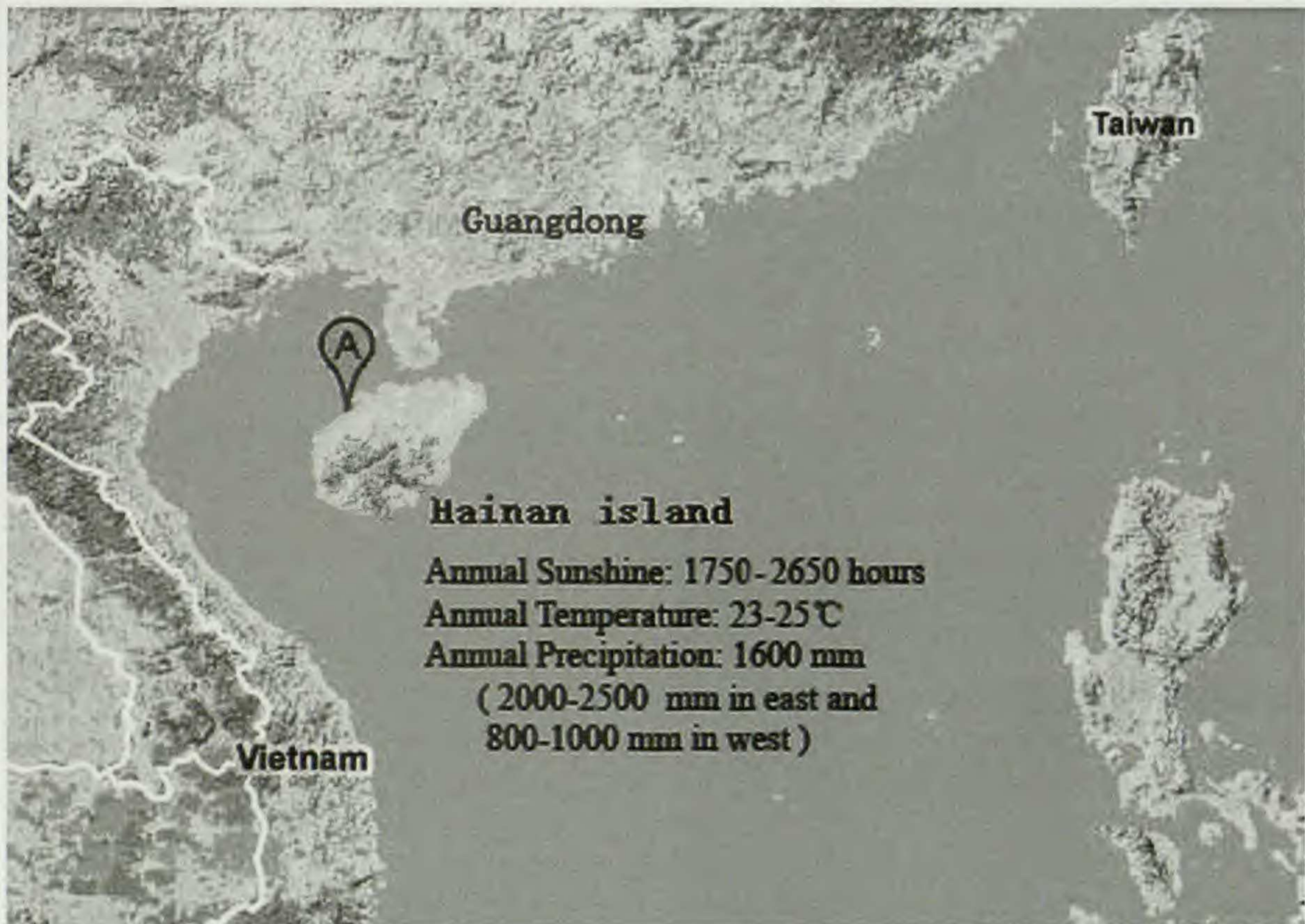


FIG. 1. Overview of Hainan Island.

new version of the “Hainan priority protected terrestrial wild plants directory” (The Hainan Provincial People’s Government, China, 2006).

*Field investigation.*—Field investigations were performed to collect species’ information. Data categories included: species name, number of individuals and environment (soil, temperature, humidity, sunlight). We identified and recorded 264 species of wild pteridophytes and took more than 1,000 photos and 700 specimens of local pteridophytes. Some important populations have been periodically re-visited. We conducted field investigations over a five-year period at conservation areas in Wuzhishan National Nature Reserve, Baihualing and Bawangling National Nature Reserve, Jianfengling National Forest Park, and Diaoluoshan Nature Reserve.

*Flora and ecotype.*—The flora of Hainan Island contains elements of several floras. Floras of neighboring areas like Guangdong, Taiwan, Vietnam, Kalimantan and even Polynesia have some similarities with Hainan Island. Ecological data were collected on niche diversity (epiphytic and semi-epiphytic, ground living) and habitat diversity (wet habitats, high altitude, other habitats including limestone, coastal, mesad, etc.)

## RESULTS

*Endangered wild pteridophyte species and their distribution on Hainan Island.*—Of all the species of pteridophytes on Hainan Island (Fu,



FIG. 2. The distribution of pteridophyte species in Hainan Island (follows the Hainan map of 2004). The thick line is the “Lingao - Qiongzhang - Wanning” line. Each grid indicates a pteridophyte species. The distribution data shows few species in the northeast and more in the southwest in Hainan Island. There is an obvious boundary line; in the nine distributions northeast of this line (Lingao, Chengmai, Qiongzhang, Haikou, Wenchang, Ding’an, Tunchang, Qionghai, Wanning) there are 43 fern genera (36%), and 79 species (17%). In the nine distributions southwest of the line (Danzhou, Changjiang, Baisha, Dongfang, Ledong, Baoting, Sangya, Lingshui, Tongzha) there are 113 fern genera (94%), and 433 species (95%). Some species are located in the northeast and southwest, and are counted in each region.

1954, 1957; Wu, Qin, 1991; Chen, 1964; Qin *et al*, 1959,2001), we identified 32 threatened species (Table 1). Of these, six species were rated critically endangered and 26 were rated endangered, and five species were identified as endemic to Hainan Island.

The endangered pteridophytes of Hainan Island represent a combination of elements from adjacent floras including the Tropics, East Asia, and the Southern hemisphere, and also includes an endemic Hainan element in different proportions (Table 2). Most of the endangered pteridophytes of Hainan Island are from the Tropic flora (almost 79%), while the East Asia and Southern hemisphere elements account for only 6% (relics of paleophytic province) and the Endemics comprise 15% (Yang *et al.*, 2007) of the Hainan pteridophytes.

Tropical pteridophytes have adapted to diverse environmental niches in term of sunlight and humidity, therefore characteristics of niches and habitats of threatened pteridophytes are of great interest. The 32 endangered species have different niches (Table 3). The majority (66%) of the 32 endangered species were epiphytic and semi-epiphytic, while 34% were terrestrial.

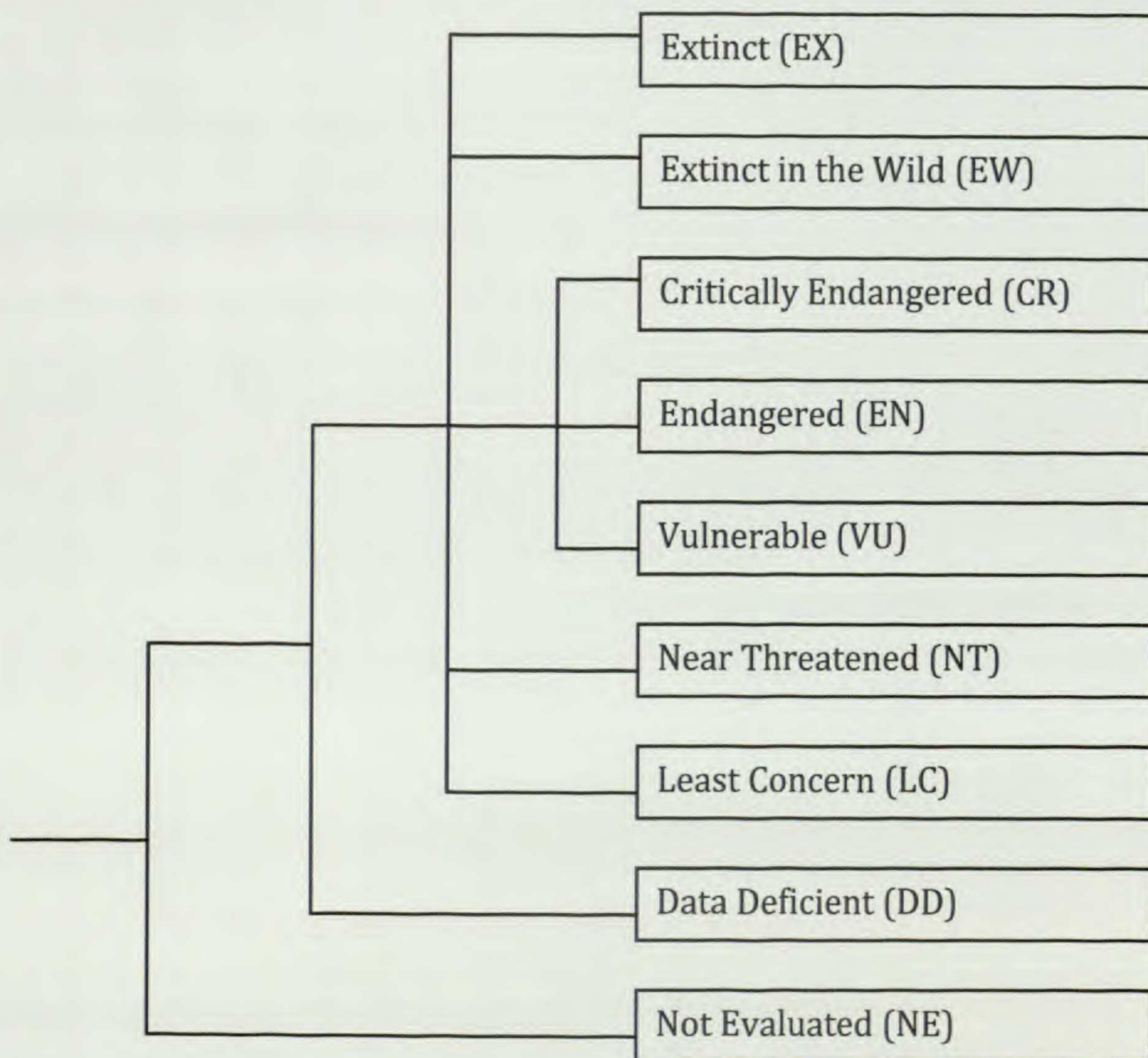


FIG. 3. Structure of the categories at regional level. **EX**: A taxon is Extinct when the last individual has died. No record an individual life form in surveys; **EW**: A taxon is Extinct in the Wild when it is known only to survive in human cultivation; **CR**: A taxon is Critically Endangered when the evidence indicates it is facing an extremely high risk of extinction in the wild; **EN**: A taxon is Endangered when the evidence indicates that it is facing a very high risk of extinction in the wild; **VU**: A taxon is Vulnerable when the evidence indicates that it is facing a high risk of extinction in the wild; **NT**: A taxon is Near Threatened when it is close to qualifying for a threatened category in the near future; **LC**: A taxon is of Least Concern when it has been evaluated against the criteria and does not qualify for Critically Endangered, Endangered, Vulnerable or Near Threatened; **DD**: A taxon is Data Deficient when there is inadequate information to make an assessment; **NE**: A taxon is Not Evaluated when it is has not yet been evaluated against the criteria (IUCN, 2001).

In species-poor families with less than five species, the percentage of species endangered is higher than in species-rich families (Table 4).

#### DISCUSSION

The endangered pteridophytes can be divided into three types according to their natural geographical environment and their presence or absence in nature

TABLE 1. Pteridophyte distribution and habitat. CR = critically endangered; EN = endangered; \* = endemic species.

Species	Location	Habitat	Level
<i>Psilotum nudum</i> (L.) Beauv.	Bofangling, Ganzhaling, Yajiadaling, Diaoluoshan	Tree trunk or rock aperture. Altitude: 200–500 m	CR
<i>Ophioderma pendula</i> Presl	Diaoluoshan	Tree trunk in rain forest. Altitude: 600–700 m	CR
<i>Schizaea digitata</i> (L.) Sw.	Xinglong, Qionghai, Lehui, Nanshanling	Sandy loam open forest on foothills. Altitude: 2–200 m	CR
<i>Christiopteris tricuspis</i> (Hook.) Christ	Diaoluoshan, Yinggeling	Epiphytic. Altitude: 500–800 m	CR
<i>Helminthostachys zeylanica</i> (Linn.) Hook.	Wanning, Wuzhishan	Under the moist open forest. Altitude: 20–800 m	CR
<i>Gymnogrammitis dareiformis</i> (Hook.) Ching ex Tard. – Balot et C. Chr.	Wuzhishan	Tree trunks or rocks, with bryophyte. altitude: 1500–2700 m	CR
<i>Oleandra undulata</i> (Willd.) Ching	Lingshui, Changjiang, Baoting, Ledong	Rock surface or aperture, hilly. Altitude: 300–1800 m	EN
<i>Oleandra hainanensis</i> Ching	Ledong	Rock surface under forest. Altitude: 300–1800 m	EN*
<i>Hemionitis arifolia</i> (Burm.) Moore	Ledong, Sanya, Luojiang	Wetland under forest, rock aperture and bush. Altitude: 975 m	EN
<i>Diplazopsis brunoniana</i> (Wall.) W. M. Chu	Nangaoling, Wuzhishan, Bofangling	Undergrowth. Altitude: 1000–1800 m	EN
<i>Dictyodroma hainanense</i> Ching	Nangaoling, Wuzhishan	Valley under forest. Altitude: 800–1000 m	EN*
<i>Boniniella cardiophylla</i> (Hance) Tagawa	Yajiadaling, Bawangling, Baihualing, Wangxia, Wuzhishan, Qionghai	Rocks or sands in forest streamlet. Altitude: 400–600 m	EN*
<i>Brainea insignis</i> (Hook.) J. Sm.	Jianfengling, Qiongzong	Tailo. Altitude: 450–1700m	EN
<i>Stenochlaena hainanensis</i> Ching et chiu	Wenchang	Valley tree trunks. Altitude: 2–100 m	EN*
<i>Arachniodes hasseltii</i> (Bl.) Cing	Wuzhishan, Diaoluoshan, Jianfengling	Valley under forest. Altitude: 900–1200 m	EN
<i>Ctenitopsis sagenioides</i> (Mett.) Ching	Shabaoling, Jianshan	Ravine under rain forest. Altitude: 120–220 m	EN
<i>Lastreopsis subrecedens</i> Ching	Hongmaoshan	Riverside. Altitude: 120–220 m	EN*
<i>Hemigramma decurrens</i> (Hook.) Cop.	Jianfengling, Sanya	Under forest or living on rocks. Altitude: 100–700 m	EN
<i>Lomariopsis spectabilis</i> (Kunze) Mett.	Baishiling, Diaoluoshan, Baoting, Qiongzong, Wanning	climbing on tree trunks. Altitude: 620–700 m	EN
<i>Acrostichum speciosum</i> Willd.	Qinglan	Coastal wetland. Altitude: 0–35 m	EN

TABLE 1. Continued.

Species	Location	Habitat	Level
<i>Cheiropleuria bicuspis</i> (Blume) C. Presl	Changjiang, Ledong, Baisha	Limestone under forest. Altitude: 1000 m	EN
<i>Dipteris conjugata</i> (Kaulf.) Reinw.	Bawangling	Under forest. Altitude: 600 m	EN
<i>Drynaria rigidula</i> (Sw.) Bedd.	Bawangling, Limushan	Hilly forest or rocks. Altitude: 0-2000 m	EN
<i>Belvisia annanensis</i> (C. Chr.) Tagawa	Wuzhishan, Jianfengling, Diaoluoshan, Qixianling	Humid tree trunks with bryophyte under forest. Altitude: 800-1000 m	EN
<i>Phynatosorus longissimus</i> (Blume) Pic. Serm.	Danzhou, Ding'an, Baisha	Streamside under open forest. Altitude: 100-240 m	EN
<i>Phymatopteris triloba</i> (Houtt.) Pic. Serm.	Wuzhishan, Diaoluoshan	Tree trunks or wet rocks under open forest. Altitude: 400-1300 m	EN
<i>Schellolepis persicifolia</i> (Desv.) Pic. Serm.	Jianfengling, Diaoluoshan	Tree trunks. Altitude: 700-1000 m	EN
<i>Leptochilus cantoniensis</i> (Baker) Ching	Baoting, Danzhou, Ledong, sanya	Ground or wet rocks under forest. Altitude: 120-280 m	EN
<i>Calymmodon asiaticus</i> Copel.	Wuzhishan, Diaoluoshan	Tree trunks or wet rocks, usually living with bryophytes, 400-1000 m	EN
<i>Grammitis dorsipila</i> (Christ) C. Chr. et Tardieu	Wuzhishan	Under forest or streamside rocks. Altitude: 400-800 m	EN
<i>Prosaptia contigua</i> (G. Forst.) C. Presl	Wuzhishan	Wet rocks. Altitude: 600-1500 m	EN
<i>Seleroglossum pusillum</i> (Blume) Alderw	Wuzhishan	Tree trunks or rocks. Altitude: 800-1000 m	EN

TABLE 2. Floristic element.

Flora type	Ratio	Species
Tropics	9%	<i>Psilotum nudum</i> , <i>Helminthostachys zeylanica</i> , <i>Ophioderma pendula</i>
Tropic Asia	50%	<i>Oleandra undulata</i> , <i>Diplaziopsis brunoniana</i> , <i>Hemionitis arifolia</i> , <i>Brainea insignis</i> , <i>Arachniodes hasseltii</i> , <i>Ctenitopsis sagenioides</i> , <i>Hemigramma decurrens</i> , <i>Lastreopsis spectabilis</i> , <i>Cheiropleuria bicuspis</i> , <i>Dipteris conjugata</i> , <i>Belvisia annanmensis</i> , <i>Christiopteris tricuspis</i> , <i>Phynatosorus longissimus</i> , <i>Phymatopteris triloba</i> , <i>Schellolepis persicifolia</i> , <i>Leptochilus cantoniensis</i>
Pan-tropics	20%	<i>Achrostichum speciosum</i> , <i>Drynaria rigidula</i> , <i>Calymmodon asiaticus</i> , <i>Grammitis dorsipila</i> , <i>Prosaptia contigua</i> , <i>Seleroglossum pusillum</i>
East Asia	3%	<i>Gymnogrammitis dareiformis</i>
Southern hemisphere	3%	<i>Schizaea digitata</i>
Endemics	15%	<i>Oleandra hainanensis</i> , <i>Dictyodroma hainanense</i> , <i>Boniniella cardiophylla</i> , <i>Lastreopsis subrecedens</i> , <i>Stenochlaena hainanensis</i>

reserves. First, some endangered pteridophytes with small populations like *Ophioderma pendula*, *Christiopteris tricuspis*, *Brainea insignis* are only distributed in nature reserves. The possibility of their habitats being destroyed is less likely than if they were outside the preserve. However, it also means the distribution of these pteridophytes is restricted and the population is small, so continued protection is urgent. Secondly, some endangered species, like *Schizaea digitata*, are only found outside of nature reserves. These species are not yet under protection, however the distribution of these species is scattered, and thus they are vulnerable for extinction. These endangered pteridophytes require immediate human intervention for preservation and protection. Thirdly, in contrast to the above, there are some endangered pteridophytes, like *Hemigramma decurrens*, *Drynaria rigidula* and *Leptochilus cantoniensis*, that exist both within and outside the nature reserves but grow well because of their wider distribution and apparently better adaptability. If environmental conditions are appropriate, these species may be eventually removed from the endangered species list. According to the results of our field investigations and information from the literature, we found 24 endangered species which were found within national and provincial nature reserves and national forest parks around the island, accounting for 75% of total endangered species. However, eight endangered pteridophytes are distributed outside nature reserves or only partially distributed in nature reserves, accounting for 25% of total endangered species.

We analyzed the causes of endangered pteridophytes on Hainan Island.

*Geological history changes.*—The extinction of plant species is a process of interaction between species and the environment. The processes of species



TABLE 3. Niche diversity.

Niche	Ratio	Species
Epiphytic, semi-epiphytic	21 species, 66%	<i>Psilotum nudum</i> , <i>Ophioderma pendula</i> , <i>Gymnogrammitis dareiformis</i> , <i>Oleandra undulata</i> , <i>Oleandra hainanensis</i> , <i>Hemionitis arifolia</i> , <i>Boniniella cardiophylla</i> , <i>Stenochlaena hainanensis</i> , <i>Hemigramma decurrens</i> , <i>Lastreopsis spectabilis</i> , <i>Cheiropleuria bicuspis</i> , <i>Drynaria rigidula</i> , <i>Belvisia annanensis</i> , <i>Christiopteris tricuspis</i> , <i>Phymatopteris triloba</i> , <i>Schellolepis persicifolia</i> , <i>Leptochilus cantoniensis</i> , <i>Calymmodon asiaticus</i> , <i>Grammitis dorsipila</i> , <i>Prosaptia contigua</i> , <i>Seleroglossum pusillum</i>
Ground living	11 species, 34%	<i>Schizaea digitata</i> , <i>Helminthostachys zeylanica</i> , <i>Diplaziopsis brunoniana</i> , <i>Dictyodroma hainanense</i> , <i>Lastreopsis subrecedens</i> , <i>Brainea insignis</i> , <i>Arachniodes hasseltii</i> , <i>Ctenitopsis sagenioides</i> , <i>Dipteris conjugate</i> , <i>Phynatosorus longissimus</i> , <i>Achrostichum speciosum</i>

formation, development, endangerment and extinction are determined by a variety of factors, among which genetic variation and dramatic changes in the environment are the most important factors. The genetic variation of a species is defined by a process of accumulation of new mutations and adaptation of species to the changing environment. This evolutionary process takes a long time. Thus, a sudden and drastic change in the environment can endanger the survival of a species of limited amount of genetic variation (Humphries and Parenti, 1999; Craw *et al.*, 1999).

The earth has experienced a number of geological changes in its history – the movement of plates, volcanic eruptions, floods, earthquakes, glaciers, meteorites and other severe environmental rebuilding. Such catastrophic changes wiped out most of the species once flourishing on the planet. Clearly, some species survived and were retained in unique environments or so-called “safe havens”, and thus became relic species. After the Cretaceous period, seed plants began flourishing on the earth, whereas the vast majority of spore plants (mainly pteridophytes on land), such as *Rhynia*, *Psilophyton* and *Asteroxylon* of Psilophytina, *Lepidodendron*, *Sigillaria*, *Lepidocarpon* and *Baragwanathia* of Lycopsidea, and *Calamite*, *Hyenia* and *Calamophyton* of Sphenopsida, gradually declined in number and became extinct (Editorial Board of Paleontology Basic Theory, 1983). Of these early genera, only *Psilotum*, *Lycopodium*, *Palhinhaea*, *Lycopodiastrum*, *Huperzia*, *Phlegmarium*, *Selaginella*, and *Equisetum* remain (Editorial Board of Paleontology Basic Theory, 1983).

*Environmental deterioration.*—Soil, water and air are the major components of an ecosystem in addition to plants and animals. Industries are booming and the human population is growing in Hainan Island, and development brings along soil contamination, air pollution and acid rain. The island ecosystem is therefore seriously damaged. In addition, logging, local fire, and farm-land expansion accelerate forest destruction. Global warming can cause extreme

TABLE 4. Percentage of endangered species in each family on Hainan Island. The numbers are from Flora of China (Qin *et al.*, 1959, 2001).

Family	Number of species endangered	Total number of species	Percent endangered
Polypodiaceae	6	42	14.2%
Grammitaceae	4	7	57.1%
Oleandraceae	2	2	100%
Hemionitidaceae	1	4	25%
Athyriaceae	2	30	6.6%
Aspleniaceae	2	35	5.7%
Aspidiaceae	2	21	9.5%
Psilotaceae	1	1	100%
Ophioglossaceae	1	2	50%
Schizaeaceae	1	1	100%
Helminthostachiaceae	1	1	100%
Gymnogrammitidaceae	1	1	100%
Thelypteridaceae	1	30	3.3%
Blechnaceae	1	4	25%
Stenochlaenaceae	1	2	50%
Dryopteridaceae	1	25	4%
Lomariopsidaceae	1	2	50%
Acrostichaceae	1	2	50%
Cheiropleuriaceae	1	1	100%
Dipteridaceae	1	1	100%
Drynariaceae	1	4	25%

climate change, which in turn may strongly influence the habitats of vegetation (Chen *et al.*, 2007). The resulting changes in humidity, temperature, sunlight, wind, could also perturb the reproduction and life-cycle of pteridophytes.

*Invasions.*—In the 1980s, a large number of plant species, including crop species and soil and water conservation plants, were introduced into Hainan Island from Africa and the American continents for the development of local agriculture. Due to the improper management of the introductions and the lack of natural enemies or competitors, these alien plants have proliferated, replacing the native species by producing harmful substances to indigenous plants (Shan, 2006). The allelopathy of alien species can have a devastating impact on the local ecological system, which has been extended to all areas of Hainan Island. *Eupatorium odoratum* L., *Mimosa invisa* Mart. ex Colla, *Eupatorium catarium* Veldkamp, and other invasive plants have been found on the edge of Jianfengling, Bawangling and others have been found in older forest reserves.

*Population growth and emigration.*—According to Chen (1933) the total human population of Hainan in 1928 was 2,195,600. From 1952 to 1979, up to 330,000 reclamation workers were relocated from the mainland to the island. In 1990, the total population of Hainan was 6,558,100. According to the report of the fifth census, the current population of Hainan is 7,867,500 (Hainan Provincial Bureau of Statistics, 2000). Human population growth and emigration have brought a huge demand for living space, farmland, firewood,

causing destruction of large areas of tropical forests. For example, cultivation of rubber, betel nut and other economic crops that replaced the original vegetation might have led to soil erosion and ecosystem imbalance. In the early 1930s, there were 18 million acres of natural forests on Hainan Island, but by 1984 there were only 3.7 million acres (Situ, 1991).

*Hybrid pteridophyte flora.*—Hainan Island and the Malaya pteridophyte flora have in common a total of 45 genera, accounting for 35% of all 130 genera of Hainan pteridophytes; the Indian pteridophyte flora has 49 genera in common, accounting for 38%; the Indo-China peninsula pteridophyte flora has 60 genera in common, accounting for 46%; and the East Asia pteridophyte flora has 56 genera in common, accounting for 43% (some genera are like *Lepisorus*, *Colysis* and *Pyrrosia* are distributed in several floras) (Yang *et al.*, 2007; Dong, 2004). The difference of shared genera between Hainan Island and all other regions is not very significant and no single flora component dominates the floristic composition of pteridophytes in Hainan Island (Yang *et al.*, 2007). Therefore, the present pteridophyte flora in Hainan Island is a combination of multiple floras (Wulff, 1964).

*The limitations on pteridophyte abundance.*—The majority of pteridophytes grow in the mountain rainforests or patchy rainforest valleys. Thus, their habitats are severely restricted. As a result, except for the photophilous pteridophytes and a small fraction of sciophilous pteridophytes, most other pteridophyte populations in Hainan Island are small.

As Hainan Island is at the northern margin of the tropics, it is the southernmost distribution of some pteridophyte species, such as *Gymnogrammitis dareiformis*, which originated from north subtropics or the Himalayas. Such species are distributed only at high altitude as in Wuzhishan (Dong, 2004). Although there are 21 mountains on Hainan Island with a high altitude (above 900 m), these species were only found existing in small population sizes on Wuzhishan Mountain. Since some pteridophyte species originated from the center of equatorial tropics (Editorial Board of Paleontology Basic Theory, 1983), Hainan Island, located at the northernmost boundary, cannot provide the best environments for the survival and reproduction of these species in terms of temperature and sunlight. Thus, these tropical species have a limited range on Hainan Island, and their populations are relatively small. Pteridophytes such as *Ophioderma pendula*, *Schizaea digitata*, *Ctenitopsis sagenioides*, *Schelloiepis persicifolia*, *Drynaria rigidula* have Hainan as their most northern boundary.

In conclusion, flora, niche, and habitat analyses indicated that 8% of the pteridophyte species in Hainan Island are endangered due to a combination of historical and current factors. Some populations are small, not protected by in conservation regions, and are likely facing extinction if not protected. As in many places of the world, the situation is urgent. Our analyses have demonstrated the necessity for protecting pteridophyte diversity in Hainan Island.

## LITERATURE CITED

- CHEN, H. Y. 1964. Hainan Flora. Beijing: Science Press.
- CHEN, M. S. 1933. Hainan Island chorography. Shanghai: Shenzhouguoguang Press.
- CHEN, X., Z. L. TAO, Z. X. WU and Z. D. ZHOU. 2007. Analysis of Effects of Climate Changes on Ecological Carrying Capacity in Hainan Island. *Journal of South China University of Tropical Agriculture*. 13(1):33–37.
- CRAW, R. C., J. R. GREHAN and M. J. HEADS. 1999. *Panbiogeography - tracking the history of life*. Oxford University Press, New York.
- DONG, S. Y. 2004. The Classification, Geographical Fauna and Conservation of Ferns on Hainan Island. CAS doctoral dissertation.
- EDITORIAL BOARD OF PALEONTOLOGY BASIC THEORY (SERIES). 1983. *Palaeobiogeographic Provincialism in China*. Beijing: Science Press.
- FU, L. G. 1991. *China Red Data Book of Plants – Rare and Endangered Plants (Volume 1)*. Beijing: Science Press.
- FU, S. X. 1954. *Chinese Pteridophytes Flora*. Beijing: Chinese Academy of Sciences Publishing House.
- FU, S. X. 1957. *Introduction and Pictures of China's major plants - Pteridophyta*. Beijing: Science Press.
- HAINAN PROVINCIAL BUREAU OF STATISTICS. 2000. *The Bulletin of fifth population census of Hainan province*.
- HUMPHRIES, C. J. and L. R. PARENTI. 1999. *Cladistic Biogeography – Interpreting patterns of plant and animal distributions*, 2nd ed. Oxford University Press, New York.
- IUCN. 2001. *IUCN Red List Categories and Criteria version 3.1*. Switzerland and Cambridge.
- QIN, R. C., G. X. XING and W. M. ZHU, et al. 1959–2001. *Flora of China (Volume 2–6)*. Beijing: Science Press.
- REN, M. E. 1985. *Outline of the Chinese Physical Geography*. Beijing: Commercial Press.
- SHAN, J. L., F. C. YANG and X. Q. ZHENG. 2006. Exotic Plants in Hainan Province. *Subtropical Plant Science* 35(3):39–44.
- SITU, S. J. 1991. *Historical Land Development Research on Hainan Island*. Hainan: Hainan Press.
- STATE ENVIRONMENTAL PROTECTION AGENCY, THE CAS INSTITUTE OF BOTANY. 1987. *The Rare and Endangered Plant List of China*. Beijing: Science Press.
- STATE FORESTRY ADMINISTRATION, THE MINISTRY OF AGRICULTURE. 1999. *Focal Protection Plant List of China (First batch)*.
- THE HAINAN PROVINCIAL PEOPLE'S GOVERNMENT. 2006. *Hainan priority protected terrestrial wild plants directory*.
- WU, Z. H. and R. C. QIN. 1991. *Families and Genera of Chinese Pteridophytes*. Beijing: Science Press.
- WULFF, E. B. 1964. *Historical Plant Geography*. Beijing Science Press.
- YANG, F. C., X. W. HU and L. L. YOU. 2007. Geographical Distribution and Floristic Composition of Pteridophytes in Hainan Island. *Acta Botanica Yunnanica*, 29(2):155–160.