Collectanea Botanica **34: e007**
enero-diciembre 2015
ISSN-L: 0010-0730
http://dx.doi.org/10.3989/collectbot.2015.v34.007

Orchid diversity in China's Hainan Island: Distribution and conservation

X.-Y. HU, J. ZHU, X.-Q. SONG & R.-X. HE

Key Laboratory of Protection and Developmental Utilization of Tropical Crop Germplasm Resources, Ministry of Education/College of Horticulture and Landscape Architecture, Hainan University, CN-570228 Haikou, People's Republic of China

Author for correspondence: X.-Q. Song (songstrong@hainu.edu.cn)

Editors: M.-X. Ren & A. Susanna

Received 28 October 2014; accepted 16 February 2015

Abstract

Orchid diversity in China's Hainan Island: Distribution and conservation.— Orchidaceae are widely distributed in many terrestrial ecosystems except for polar and desert areas and constitute a "flagship group" in biological conservation. As the largest tropical island of China, Hainan has five tropical forest vegetation types, namely deciduous monsoon forest, lowland rainforest, montane rainforest, montane evergreen forest, and montane cloud forest. There are 317 orchid species in the island, including 33 endemic, 158 epiphytic, 148 terrestrial, and 11 saprophytic species. Most orchids, which are mainly located in central and southern parts of the island, are generally distributed in damp tropical forests in mountains at an altitude of 500–1500 m. Highest level of endemism is also centred in these areas. Orchids are especially threatened by habitat fragmentation because they grow in small populations, and fragmentation may block gene flow and result in lower genetic diversity. In addition, due to their ornamental and medicinal value, many orchids are over-collected. Therefore, orchid conservation in Hainan Island is very urgent. The aim of this article is to determine the distribution pattern of orchids and expound research and conservation status in Hainan Island, and to propose conservation strategies for the future.

Key words: biodiversity; endemics; genetic diversity; in situ and ex situ conservation; Orchidaceae.

Resumen

Diversidad de orquídeas en la isla de Hainan en China: distribución y conservación.— Las *Orchidaceae* se distribuyen ampliamente en muchos ecosistemas terrestres con excepción de las zonas polares y desérticas, y constituyen una suerte de «buque insignia» de la conservación biológica. Siendo como es la mayor isla tropical de China, Hainan tiene cinco formaciones vegetales de bosques tropicales, a saber, bosque monzónico caducifolio, selva tropical de tierras bajas, bosque pluvial montano, bosque siempreverde montano y bosque mesófilo de montaña. Hay 317 especies de orquídeas en la isla, incluyendo 33 endémicas, 158 epífitas, 148 terrestres y 11 especies saprófitas. La mayoría de las orquídeas, que se localizan principalmente en el centro y el sur de la isla, se distribuyen típicamente en condiciones húmedas de los bosques tropicales en las montañas a una altitud de 500 a 1500 m. El máximo nivel de endemismo también se centra en estas áreas. Las orquídeas están especialmente amenazadas por la fragmentación del hábitat debido a que crecen en pequeñas poblaciones, y la fragmentación puede bloquear el flujo de genes, lo que resulta en una menor diversidad genética. Además, debido a su valor ornamental y medicinal, muchas orquídeas son recolectadas de forma excesiva. Por lo tanto, la conservación de las orquídeas en la isla de Hainan es muy urgente. Nuestro objetivo en este artículo es determinar el patrón de distribución de las orquídeas y exponer el estado de investigación y conservación en la isla de Hainan y, además, proponer futuras estrategias de conservación.

Palabras clave: biodiversidad; conservación *in situ* y *ex situ*; diversidad genética; endemismos; *Orchidaceae*.

摘要

中国海南岛的兰科植物多样性：分布和保育状况。— 兰科植物广泛分布于除北极和沙漠地区之外的陆地生态系统，是保育生物学中的旗舰类群。海南岛为中国最大的热带岛屿，具有落叶季风林、低地雨林、山地雨林、山地常绿林和山地云雾林五种热带森林类型。海南岛分布有317种兰科植物，包括158种附生兰、148种

地生兰和11种腐生兰；其中33种为海南岛所特有。大多数兰科植物分布在海南岛中部和南部的山区，其栖息地为潮湿的热带森林，海拔约为500–1500 m；此地区同样为兰科植物的特有性中心。海南岛兰科植物居群较小，生境片段化阻碍居群间的基因流，使其面临着居群多样性减小从而导致居群衰退的威胁。加之兰科植物较高的观赏和药用价值，许多的野生植株被盗采盗挖。因此，海南岛兰科植物的保育工作非常迫切。本文致力于阐述海南岛兰科植物的分布特征，分析其保育状况并提出将来的保育策略。

关键词：生物多样性；兰科植物；特有性；遗传多样性；原地保护和迁地保护。

Cómo citar este artículo / Citation
Hu, X.-Y., Zhu, J., Song, X.-Q. & He, R.-X. 2015. Orchid diversity in China's Hainan Island: Distribution and conservation. *Collectanea Botanica* 34: e007. doi: http://dx.doi.org/10.3989/collectbot.2015.v34.007

INTRODUCTION

As one of the largest angiosperm families, Orchidaceae contains about 870 genera and 27,000 species (Cribb *et al*., 2003). The family is widely distributed in a variety of terrestrial ecosystems (especially in tropics), although it is absent from polar and desert areas (Romero, 1996). As a result of the long evolution, in the family Orchidaceae the flower structure has become highly specialized and breeding systems have also actively evolved, so it is considered as one of the most advanced families within the angiosperms (Chen & Luo, 2003). Orchids have highly specialized pollination systems; about 60% of orchids present only one pollinator (Cingel, 2001). For this reason, they are also considered a model to illustrate the important role of pollinators in plant species differentiation (Tremblay *et al*., 2005). If compared with other families, orchids' complex life-history and special habitat requirements (Fay & Chase, 2009; Schödelbauerová *et al*., 2009), together with the fact that most species show small populations and a narrow-pattern distribution (Chung *et al*., 2005; Rodrigues & Kumar, 2009), make them more vulnerable to the threats derived from habitat loss and degradation (Coates & Dixon, 2007; Swarts & Dixon, 2009). Furthermore, because most orchids have high ornamental and medicinal value, over-collection has become another significant threat to the survival of Orchidaceae (Hágsater & Dumont, 1996; Koopowitz *et al*., 2003). All wild orchids in the world were included into the scope of Convention on International Trade in Endangered Species (CITES), accounting for more than 90% of plants that should be protected based on this convention. Thus, the Orchidaceae should be regarded as a "flagship group" in biological conservation (Luo *et al*., 2003).

In Hainan, orchid species are distributed in various forest types (Wang, 2004; Song, 2005; Yu, 2006; Liu *et al.*, 2010; Wu, 2013; Yang, 2013; Zhang, 2013; Hu, 2014). Hainan Island, the largest tropical island of China, has a diverse tropical rainforest including deciduous monsoon forest, lowland rainforest, montane rainforest, montane evergreen forest, and cloud forest. Hainan has a rich biodiversity and it is one of the most valuable areas for biodiversity conservation not only in China but also among the world's tropical rainforest areas (Sun *et al*., 1999).

In this article, we aim to determine the orchids' distribution pattern and to identify the diversity and endemic centres in Hainan Island. We will also introduce the state-of-the-art of the research and conservation status of Hainan's orchids, in order to discern whether or not the location of the current nature reserves is reasonable. Furthermore, according to the data collected, we propose conservation strategies for the future.

SPECIES DIVERSITY AND DISTRIBUTION PATTERN

There are 102 genera and 317 orchid species distributed in Hainan Island (Table 1), including 33 endemic species of this area, 158 epiphytic species, 148 terrestrial species, and 11 saprophytic species. This area has only less genera than Yunnan, and less species than Yunnan and Taiwan provinces (Table 2). However, the species density of Hainan Island is the highest among the five provinces included within the tropical regions of China.

Geographic distribution of orchids tends to be not homogeneous. Both the species diversity and endemism centres are located in the central and southern

Table 1. Orchid genera and species numbers in Hainan Island, China.

Genus	Species number	Genus	Species number	Genus	Species number
Acampe	3	*Epigeneium*	2	*Pachystoma*	1
Acanthephippium	2	*Epipogium*	2	*Panisea*	5
Agrostophyllum	1	*Eria*	4	*Paphiopedilum*	3
Anoectochilus	4	*Erythrorchis*	1	*Parapteroceras*	1
Aphyllorchis	3	*Esmeralda*	1	*Pecteilis*	1
Apostasia	3	*Eulophia*	4	*Peristylus*	4
Appendicula	2	*Flickingeria*	2	*Holcoglossum*	2
Arachnis	2	*Galeola*	1	*Phaius*	3
Arundina	1	*Gastrochilus*	6	*Phalaenopsis*	3
Bulbophyllum	25	*Gastrodia*	1	*Pholidota*	3
Calanthe	11	*Geodorum*	3	*Phreatia*	1
Campanulorchis	1	*Goodyera*	7	*Pinalia*	3
Cephalantheropsis	1	*Grosourdya*	1	*Platanthera*	1
Ceratostylis	2	*Habenaria*	13	*Podochilus*	1
Chamaegastrodia	1	*Hancockia*	1	*Pomatacalpa*	1
Cheirostylis	2	*Herminium*	1	*Pteroceras*	1
Chrysoglossum	1	*Hetaeria*	5	*Renanthera*	1
Cleisostoma	11	*Hippeophyllum*	1	*Rhomboda*	1
Coelogyne	1	*Lecanorchis*	1	*Rhynchostylis*	1
Collabium	2	*Liparis*	18	*Robiquetia*	2
Conchidium	2	*Ludisia*	1	*Schoenorchis*	2
Corymborkis	1	*Luisia*	2	*Spiranthes*	1
Crepidium	6	*Malleola*	2	*Stereochilus*	1
Cryptochilus	1	*Micropera*	1	*Sunipia*	1
Cryptostylis	1	*Microtatorchis*	1	*Taeniophyllum*	1
Cymbidium	17	*Mischobulbum*	2	*Tainia*	5
Cystorchis	1	*Mycaranthe*	1	*Thelasis*	1
Dendrobium	18	*Myrmechis*	2	*Thrixspermum*	6
Dendrolirium	2	*Nephelaphyllum*	2	*Trichotosia*	2
Didymoplexiella	1	*Nervilia*	4	*Tropidia*	3
Didymoplexiopsis	1	*Neuwiedia*	1	*Vanda*	3
Didymoplexis	1	*Oberonia*	10	*Vanilla*	1
Dienia	1	*Odontochilus*	3	*Vrydagzynea*	1
Diploprora	1	*Oxystophyllum*	1	*Zeuxine*	9

parts of the island, which are mountainous regions. Species in Baoting, Lingshui and Sanya counties account for more than 80% of the total number in Hainan Island (Fig. 1). This region is the main centre of diversity and has a very high value for protection. Benefited from the humid and warm environment, more epiphytic than terrestrial orchids are found in most of the counties in Hainan Island. However, there are still five counties with more terrestrial orchids than epiphytic species, namely Dongfang, Haikou, Lingao, Tunchang, and Wenchang (Fig. 1).

The concept "species irreplaceability" first came up in Pressey *et al*. (1994). If a species is found in more than one area, these areas have low irreplaceable value; conversely, if a species is found only in one area as an endemic species, the irreplaceabil-

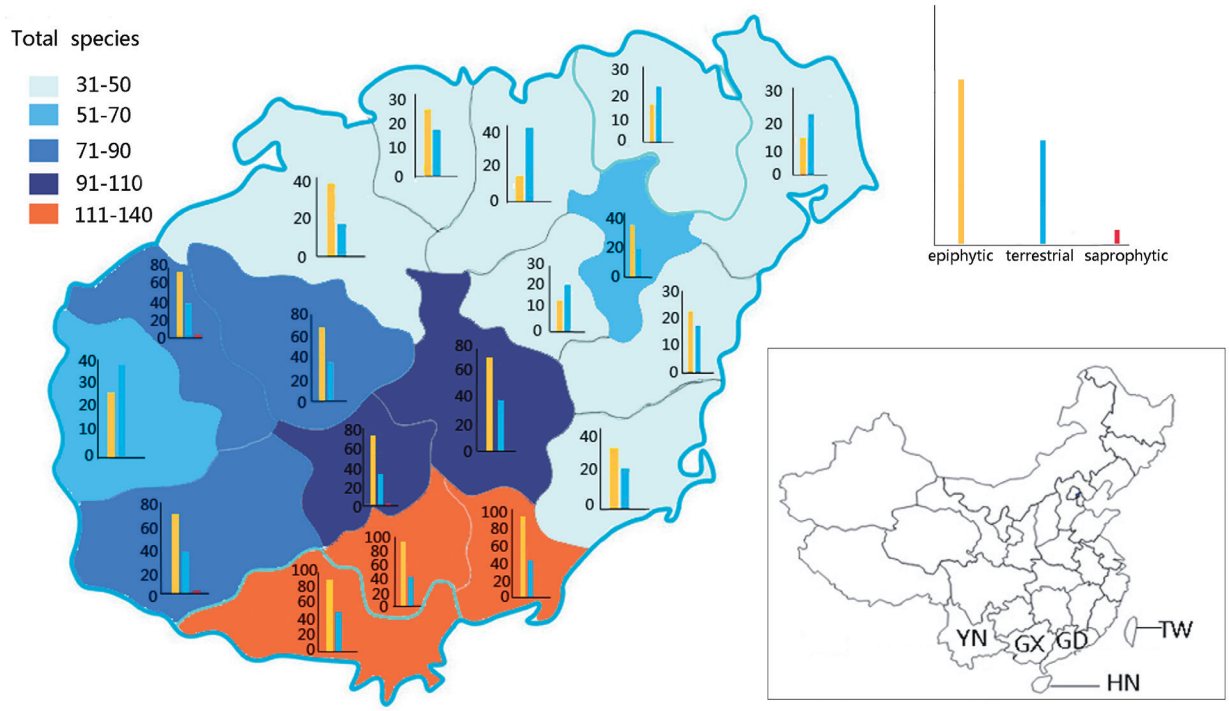

Figure 1. Distribution pattern of wild orchids in Hainan Island. For the names of the administrative divisions of Hainan, see Fig. 2. Codes of the provinces in the inset map: GD, Guangdong Province; GX, Guangxi Province; HN, Hainan Island; TW, Taiwan Island; YN, Yunnan Province.

ity is 100% (Pressey *et al*., 1994). When species are threatened, such areas should have priority for protection. Numbers of endemic species in Baoting, Lingshui and Sanya are the highest in Hainan Island (Fig. 2) and thereafter irreplaceability of the three areas is quite high. Besides, these areas are very rich in species and consequently they deserve the highest priority for protection.

HABITAT AND POPULATION STATUS

In Hainan Island, orchids are mainly distributed in tropical forests of mountains at an altitude of 500–1500 m. There are a lot of epiphytic orchids in the tropical forests. Epiphytic orchids mainly grow on the trunks or branches of tall trees. Many populations of wild orchids are small, and easily destroyed by habitat fragmentation. As a result, recruitment of new individuals in populations is diminished. Until now, specific research in population dynamics has been carried out in several orchid species such as *Dendrobium sinense* Tang & F. T. Wang (Wu, 2013), *Paphiopedilum appletonianum* (Gower) Rolfe (Chen *et al*., 2009), and *Phalaenopsis pulcherrima* (Lindl.) J. J. Sm. (Yang, 2013), and all these works indicated that wild populations were experiencing a rapid decline.

GENETIC DIVERSITY

The conservation of biological diversity is ultimately depending on the preservation of genetic diversity (Wang & Hu, 1996). Since the basic unit of evolution is the population (Dobzhansky, 1937; Stebbins, 1963), genetic diversity studies must be focused on genetic diversity at the population level. However, currently, research on the genetic diversity of Orchidaceae in Hainan Island is still limited. There are some researches in *Dendrobium* and *Oncidium* (Ren *et al*., 2007, 2008, 2013), but they are at the species level. The only report on population genetic diversity is about *Phalaenopsis pulcherrima* (Hu, 2014). Thus, there is still an important lack of information on the genetic diversity of Orchidaceae in Hainan Island, especially at the population level. Genetic diversity is the basis for the identification of key spots

Table 2. Comparison of orchid species richness in Hainan Island and in neighboring areas.

Province	Area (km²)	Genera	Species	Number of species / 100 km²
Hainan Island	33,920	102	318	0.94
Taiwan Island	35,873	101	322	0.90
Yunnan Province	420,645	135	746	0.18
Guangdong Province	179,800	83	263	0.15
Guangxi Province	236,700	94	286	0.12

that need to be protected, and also the intuitive manifestation of the population adaptability and evolutionary potential. Therefore, it is extremely urgent to carry out new research on genetic diversity at the population level.

THREATS AND CONSERVATION STATUS

Many orchids are specialists depending on only one (or a few) mycorrhizal fungi and pollinators. This specificity added to its narrow range and small population sizes make orchids especially vulnerable to climate change, human disturbance, and habitat fragmentation. Furthermore, many orchids have high ornamental (Hu, 2014) and medicinal value (Wu, 2013). For these reasons, orchids have been excessively collected and seriously destroyed in Hainan Island (Hu, 2014).

In situ conservation is aimed to protect wildlife in their natural habitats, which ensures the maintaining of ecological processes and the ongoing processes of evolution. At present, there are ten National Nature Reserves established in Hainan Island, namely Yinggeling, Bawangling, Jianfengling, Tongguling, Wuzhishan, Diaoluoshan, Datian, Dongzhaigang,

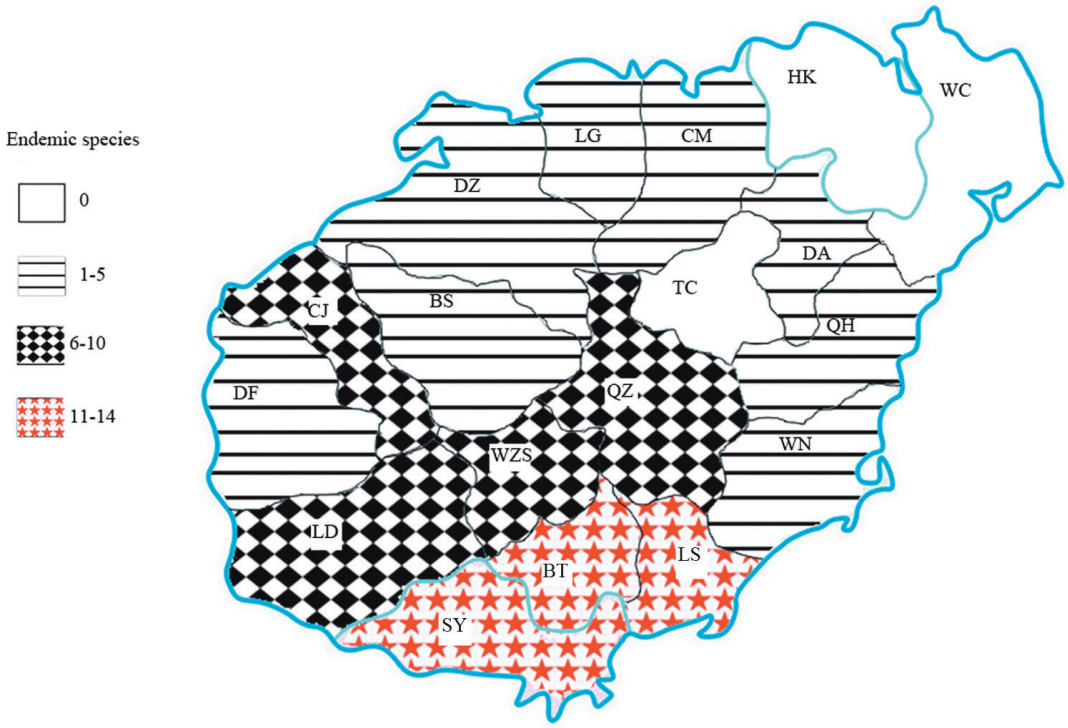

Figure 2. The endemic species of wild orchids in Hainan Island. Codes of administrative divisions of Hainan: BS, Baisha; BT, Baoting; CJ, Changjiang; CM, Chengmai; DA, Ding'an; DF, Dongfang; DZ, Danzhou; HK, Haikou; LD, Ledong; LG, Lin'gao; LS, Lingshui; QH, Qionghai; QZ, Qiongzhong; SY, Sanya; TC, Tunchang; WC, Wenchang; WN, Wanning; WZS, Wuzhishan.

Sanya Coral Reefs, and Dazhou Island (Ministry of Environmental Protection, 2012). Except for the last three marine natural reserves, orchids are found in the other seven nature reserves (Yu, 2006; Wu, 2013; Yang, 2013; Zhang, 2013; Hu, 2014). However, no national nature reserves have been established in Baoting, Lingshui and Sanya counties, where many orchids are distributed (Figs. 1 and 2). It is urgent to establish new nature reserves at the appropriate level in these three areas where orchid diversity is high.

Nevertheless, many requirements should be met to establish a nature reserve. Besides, ex situ conservation can be used as a complementary method for orchid conservation. In the context of ex situ conservation, the endangered orchids can be transferred to new locations for special protection and management, including botanical gardens or "endangered species breeding centers", in order to increase their probabilities of survival and reproduction.

At present, the main method of ex situ conservation of Orchidaceae in Hainan Island is the establishment of nurseries through tissue culture, and current research focuses on the study of mycorrhizal biology to improve seedlings' survival rate in several species, including *Dendrobium loddigesii* Rolfe, *Dendrobium nobile* Lindl., *Dendrobium sinense*, and *Phalaenopsis pulcherrima* (Ke *et al.*, 2008; Zhou *et al*., 2009; Chen *et al*., 2010*b*, *c*, 2011; Cui & Song, 2011; Li *et al*., 2011). However, we should be aware that ex situ conservation is not a "natural" protection. Only if introduced into their natural habitat (i.e. reintroduction) the individuals can evolve naturally, which ensures species long-term survival (Chen *et al*., 2010*a*). The only reported reintroduction was that carried out with *Dendrobium sinense* (Yang, 2013). In sum, ex situ conservation of orchids in Hainan Island needs considerable work, especially concerning reintroduction.

FUTURE STUDY DIRECTIONS

Genetic diversity of orchids

Establishment of natural reserves should not be only based on genetic and species diversity but also on ecological diversity. Because it is not possible to comprehensively assess the genetic diversity of over 300 orchid species in a short time, priority should be given to a smaller set of species. The most endangered, rare and regionally unique species should be in the front row for molecular studies on population genetic structure. Populations with higher genetic diversity should be protected with in situ methods such as establishing natural reserves, whereas conservation of populations with lower genetic diversity should be complemented with ex situ conservation measures (such as artificial breeding and reintroduction techniques).

Origin and evolution of island endemic species

In Hainan Island up to 397 endemic species have been recorded so far (Francisco-Ortega *et al*., 2010). Due to the importance and irreplaceability of endemic species, it is urgent to carry out studies on their speciation mechanisms and evolutionary trends. In general, both extrinsic and intrinsic factors can accelerate speciation and evolution of endemic species. An important external factor could be, for example, the blocking of gene flow via pollinators. If gene flow is restricted for long periods of time, different species could be originated. On the other hand, the occurrence of gene mutations is an intrinsic factor that could also result in speciation. Achieving a better knowledge of mechanisms and evolutionary trends will allow us to design more suitable tools to protect plant biodiversity.

Conservation through artificial propagation and reintroduction

Regions with low species diversity of orchids in Hainan Island are not among the best candidates to be covered by nature reserves, as occurs elsewhere. In this case, ex situ conservation is probably the only option to reduce the declining of populations or endangered species. Plants can be taken back to the breeding bases and nurseries to propagate them with tissue culture methods and the use of mycorrhizal interactions. Tissue cultured experiments of artificial hybridization can also be carried out in plantlets for improving diversity. When the conditions are appropriate, these plants can be reintroduced into their natural habitats. Therefore, large-scale propagation and mycorrhizal biology research of orchids should become one the most urgent and important issues regarding their conservation. In addition, the reintroductions should be combined with population genetics research to assess adaptation after reintroduction.

Working with conservation organizations and local governments or communities

The scientific and feasible approaches to strengthen conservation of orchids in Hainan Island are important. What is more, there should be some regulations to solve the problem that local people collect orchids excessively to pursuit the profit stemming from the high ornamental and medicinal value of these plants. We must also take some non-academic actions to collaborate and co-work with local governments, communities and NGOs to promote the conservation of orchids.

ACKNOWLEDGMENTS

We thank Prof. M.-X. Ren and Dr. Q. Ding for their helpful suggestions. This research was supported by the National Natural Science Foundation of China (31160178) and Special Fund for Agro-scientific Research in the Public Interest (201303117). It is also partially supported by Academic Discipline Construction Project in the Central and Western Regions of China to Hainan University (ZXBJH-XK008).

REFERENCES

Chen, B.-L., Song, X.-Q, Hu, M.-J. & Yang, F.-S. 2011.美花石斛菌根真菌接菌方式与接种效应初步研究 [Inoculation methods and effects of beneficial symbiotic fungi of *Dendrobium loddigesii* Rolfe. (Orchidaceae)]. *Bulletin of Botanical Research* 31: 79–84 [in Chinese].

Chen, B., Song, X., Yu, W., Chen, J. & Luo, Y. 2010*a*. 濒危兰科植物再引入技术及其应用 [Re-introduction technology and its application in the conservation of endangered orchid]. *Acta Ecologica Sinica* 30: 7055–7063 [in Chinese].

Chen, B.-L., Zhou, Q.-S. & Song, X.-Q. 2010*b*. 美花石斛组培苗菌根化中共生条件优化研究 [Optimization of mycorrhizal inoculation with seedlings from *Dendrobium loddigesii* in flask]. *Chinese Horticulture Abstracts* 2010(8): 1–4 [in Chinese]. http://dx.doi.org/10.3969/j.issn.1672-0873.2010.08.001

Chen, F., Wang, J. & Song, X. 2009. 海南霸王岭卷萼兜兰种群分布格局研究 [Distribution pattern of *Paphiopedilum appletonianum* in Bawangling Mountain in Hainan, China]. *Tropical Agricultural Engineering* 33: 18–21 [in Chinese].

Chen, J.-H., Hu, M.-J., Song, X.-Q., He, M.-G. & Luo, Y.-B. 2010*c*. 野生五唇兰菌根显微结构观察 [Microscopic observation on mycorrhiza of *Doritis pulcherrima*]. *Mycosystema* 29: 26–30 [in Chinese].

Chen, S.-C & Luo, Y.-B. 2003. 中国几个植物类群的研究进展 I. 中国兰科植物研究的回顾与前瞻 [Advances in some plant groups in China. I. A retrospect and prospect of Orchidology in China]. *Acta Botanica Sinica* 45 (Suppl.): 2–20 [in Chinese].

Chung, M. Y., Nason, J. D. & Chung, M. G. 2005. Patterns of hybridization and population genetic structure in the terrestrial orchids *Liparis kumokiri* and *Liparis makinoana* (Orchidaceae) in sympatric populations. *Molecular Ecology* 14: 4389–4402. http://dx.doi.org/10.1111/j.1365-294X.2005.02738.x

Cingel, N. A. van der 2001. *An atlas of orchid pollination: America, Africa, Asia and Australia*. A. A. Balkema, Rotterdam.

Coates, D. J. & Dixon, K. W. 2007. Current perspectives in plant conservation biology. *Australian Journal of Botany* 55: 187–193. http://dx.doi.org/10.1071/BT07037

Cribb, P. J., Kell, S. P., Dixon, K. W. & Barrett, R. L. 2003. Orchid conservation: A global perspective. In: Dixon, K. W., Kell, S. P., Barrett, R. L. & Cribb, P. J. (Eds.), *Orchid conservation*. Natural History Publications, Kota Kinabalu: 1–24.

Cui, H. & Song, X.-Q. 2011. 菌根真菌对春石斛幼苗生长发育的影响 [Effects of mycorrhizal fungi on growth and development of *Dendrobium nobile* type seedlings]. *Journal of Southwest Forest University* 31: 20–23 [in Chinese]. http://dx.doi.org/10.3969/j.issn.1003-7179.2011.02.005

Dobzhansky, T. 1937. *Genetics and the origin of species*. Columbia University Press, New York.

Fay, M. F. & Chase, M. W. 2009. Orchid biology: from Linnaeus via Darwin to the 21st century. *Annals of Botany* 104: 359–364. http://dx.doi.org/10.1093/aob/mcp190

Francisco-Ortega, J., Wang, Z.-S., Wang, F.-G. *et al*. 2010. Seed plant endemism on Hainan Island: A framework for conservation actions. *The Botanical Review* 76: 346–376. http://dx.doi.org/10.1007/s12229-010-9055-7

Hágsater, E. & Dumont, V. (Eds.) 1996. *Orchids – Status survey and conservation action plan*. IUCN, Gland & Cambridge.

Hu, X. Y. 2014. 五唇兰居群遗传结构 [*Population genetic structure of* Phalaenopsis pulcherrima]. Master Thesis, Hainan University, Haikou [in Chinese].

Ke, H.-L., Song, X.-Q., Luo, Y.-B., Zhu, G.-P. & Ling, X.-B. 2008. 五唇兰菌根化育苗技术 [Seedling cultivation of *Doritis pulcherrima* Lindl. with mycorrhizal fungi]. *Acta Horticulturae Sinica* 35: 571–576 [in Chinese]. http://dx.doi.org/10.3321/j.issn:0513-353X.2008.04.017

Koopowitz, H., Lavarack, P. S. & Dixon, K. W. 2003. The nature of threats to orchid conservation. In: Dixon, K. W., Kell, S. P., Barrett, R. L. & Cribb, P. J. (Eds.), *Orchid conservation*. Natural History Publications, Kota Kinabalu: 25–42.

Li, H., He, Y., Shen, Z., Yang, F., Song, X. & Zhou, Z. 2011. 菌根化五唇兰组培苗的光合生理特性 [Effect on photosynthesis characteristic of *Doritis pulcherrima* Lindl., inoculated with mycorrhizal fungi]. *Chinese Journal of Tropical Crops* 32: 1060–1063 [in Chinese]. http://dx.doi.org/10.3969/j.issn.1000-2561.2011.06.015

Liu, G.-F., Zang, R.-G., Ding, Y., Wang, W.-Y., Li, R.-C., Chen, S.-W. & Zhou, Z.-L. 2010. 海南霸王岭不同森林类型附生兰科植物的多样性和分布 [Diversity and distribution of epiphytic orchids in different types of old-growth tropical forests in Bawangling National Nature Reserve, Hainan Island, China]. *Chinese Journal of Plant Ecology* 34: 396–408 [in Chinese]. http://dx.doi.org/10.3773/j.issn.1005-264x.2010.04.005

Luo, Y.-B., Jia, J.-S. & Wang, C.-L. 2003. 中国兰科植物保育的现状和展望 [A general view of the conversation status of Chinese orchids]. *Biodiversity Science* 11: 70–77 [in Chinese].

Ministry of Environmental Protection 2012. 海南国家自然保护区名录 [*List of national nature reserves in Hainan Province (till the end of 2011)*]. Ministry of Environmental Protection of the People's Republic of China, Beijing [in Chinese].

Pressey, R. L., Johnson, I. R. & Wilson, P. D. 1994. Shades of irreplaceability: towards a measure of the contribution of sites to a reservation goal. *Biodiversity and Conservation* 3: 242–262. http://dx.doi.org/10.1007/BF00055941

Ren, Y., Yang, G., Lu, S, Xu, S., Huang, S. & Yin, J. 2013. Analysis of genetic diversity of *Dendrobium* by RSAP marker. *Agricultural Science & Technology* 14: 1710–1713.

Ren, Y., Yang, G. & Yin, J., Zhan, Y. & Xian, H. 2007. 石斛种质资源遗传多样性的RAPD分析 [Analysis of genetic diversity in *Dendrobium* germplasm by RAPD markers]. *Chinese Agricultural Science Bulletin* 23: 598–600 [in Chinese]. http://dx.doi.org/10.3969/j.issn.1000-6850.2007.06.129

Ren, Y., Yin, J. & Yang, G. 2008. 海南石斛属植物亲缘关系的SRAP分析 [Analysis of genetic relationship of *Dendrobium* in Hainan by SRAP markers]. *Chinese Journal of Tropical Crops* 29: 767–770 [in Chinese]. http://dx.doi.org/10.3969/j.issn.1000-2561.2008.06.017

Rodrigues, K. F. & Kumar, S. V. 2009. Isolation and characterization of microsatellite loci in *Phalaenopsis gigantea*. *Conservation Genetics* 10: 559–562. http://dx.doi.org/10.1007/s10592-008-9569-2

Romero, G. A. 1996. The orchid family. In: Hágsater, E. & Dumont, V. (Eds.), *Orchids – Status survey and conservation action plan*. IUCN, Gland & Cambridge: 3–4.

Schödelbauerová, I., Roberts, D. L. & Kindlmann, P. 2009. Size of protected areas is the main determinant of species diversity in orchids. *Biological Conservation* 142: 2329–2334. http://dx.doi.org/10.1016/j.biocon.2009.05.015

Song, X.-Q. 2005. 海南石斛属野生植物种质资源及华石斛保育生物学研究 [*Studies on the wild* Dendrobium *germplasm resoures in Hainan Island with special reference to conservation biology of* D. sinense]. PhD Thesis, Beijing Forestry University, Beijing [in Chinese].

Stebbins, G. L. 1963. V*ariation and evolution in plants*. Columbia University Press, New York.

Sun, Y.-J., Wang, X.-K. & Wang, R.-S. 1999. 五指山保护区生态环境质量评价研究 [The characteristics of eco-environmental quality in Five-finger Mountain Nature Reserve]. *Acta Ecologica Sinica* 19: 365–370 [in Chinese]. http://dx.doi.org/10.3321/j.issn:1000-0933.1999.03.013

Swarts, N. D. & Dixon, K. W. 2009. Terrestrial orchid conservation in the age of extinction. *Annals of Botany* 104: 543–556. http://dx.doi.org/10.1093/aob/mcp025

Tremblay, R. L., Ackerman, J. D., Zimmerman, J. K. & Calvo, R. N. 2005. Variation in sexual reproduction in orchids and its evolutionary consequences: a spasmodic journey to diversification. *Biological Journal of the Linnean Society* 84: 1–54. http://dx.doi.org/10.1111/j.1095-8312.2004.00400.x

Wang, H. & Hu, Z. 1996. 植物的繁育系统、遗传结构和遗传多样性保护 [Plant breeding system, genetic structure and conservation of genetic diversity]. *Biodiversity Science* 4: 92–96 [in Chinese].

Wang, Y. 2004. 海南省五指山兰科植物资源调查 [Investigation of orchid resources in Wuzhishan, Hainan Province]. *Journal of Qiongzhou University* 11: 55–56 [in Chinese].

Wu, H.-Z. 2013. 华石斛种群动态研究 [*Research on population dynamics of* Dendrobium sinense]. Master Thesis, Hainan University, Haikou [in Chinese].

Yang, Q. 2013. 五唇兰野外种群监测和重引入研究 [*Monitor and the reintroduction of* Phalaenopsis pulcherrima *into wild populations*]. Master Thesis, Hainan University, Haikou [in Chinese].

Yu, W.-G. 2006. 海南岛野生兰科植物种质资源保护策略研究 [*Strategies to protect germplasm resources of wild orchids in Hainan Island*]. Master Thesis, Hainan University, Haikou [in Chinese].

Zhang, Z. 2013. 东亚特有种五唇兰繁殖生态学研究 [*Reproductive ecology of* Phalaenopsis pulcherrima *(Orchidaceae), a species endemic to East Asia*]. Master Thesis, Hainan University, Haikou [in Chinese].

Zhou, Y.-J., Yang, F.-S., Song, X.-Q., Zhu, G.-P. & Hu, M.-J. 2009. 菌根真菌对华石斛幼苗生长及光合性能的影响 [Effects of mycorrhizal fungi on seedling's growth and photosynthetic capability of *Dendrobium sinense*, endemic to Hainan]. *Northern Horticulture* 2009(12): 11–15 [in Chinese].