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Potential Challenges of Climate Change to Orchid Conservation in a Wild Orchid Hotspot in Southwestern China

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Abstract Southwestern China including Guangxi Province is one of nine world hotspots for orchid. Warming in the region in the past century was around 0.5°C, slightly lower than the global average of 0.7°C, while rainfall has remained the same. It is projected that the warming trend will continue for the next two centuries, while precipitation will increase slightly, and soil moisture level will decrease. We identify a number of threats due to climate changes to orchid community in the Yachang Orchid Nature Reserve in Guangxi (hereafter refer to as Yachang Reserve), a good representative of the region. Firstly, decreased soil moisture is likely to have a negative effect on growth and survival of orchids, especially terrestrial and saprophytic ones. Sixty eight (50%) orchid species in the Yachang Reserve are in this category. Secondly, the greater majority of the orchids in Yachang Reserve (72%) have populations on or close to the limestone mountain tops. These populations are likely to shrink or even become extinct as the warming continues because they have no higher places to which they are able to migrate. Natural poleward migration is unlikely for these populations because of the complex terrain, small size of the reserve and human-dominated surroundings. Species with narrow distributions (14%) and/or small population sizes (46%) will be the most vulnerable. In addition, populations represent the southern limit of the species (24%) are also prone to local extinction. Thirdly, extreme rainfall events are projected to occur more frequently, which can exacerbate erosion. This may impact orchid populations that grow on steep cliffs. Fifty seven species (42%) of the orchids in Yachang have cliff populations. Fourthly, the majority of orchid species have specialized insect pollination systems. It is unknown whether the change or lack of change in plant phenology will be in synchrony with the potential phenological shifts of their pollinators. Fifty four (40%) orchid species in Yachang Reserve flower in the spring and are potentially subject to this threat. Finally, mycorrhizal fungi are vital for seed germination for all orchids and important for post-seedling growth for some species. Yet there is a lack of knowledge of the nature of mycorrhiza on all orchids in the region, and little is known on the responses of these vital symbiotic relationships to temperature and soil moisture. Overall, 15% of the orchid species and a quarter of the genera bear high risk of population reduction or local extinction under the current projection of climate change. While studies on predicting and documenting the consequences of climate change on biodiversity are increasing, few identified the actual mechanisms through which climate change will affect individual species. Our study provides a unique perspective by identifying specific threats to a plant community.

Keywords Biodiversity · Climate Change · Global Change · Nature Reserve · Orchids · Phenology · Plant Conservation · Rare Species

Introduction

The Southwestern China Orchid Hotspot and its Conservation Status

Southwestern China, consisting of Yunnan, Guangxi and Guizhou Provinces, is one of the nine world orchid hotspots (Cribb et al., 2003). Orchid conservation issues in the region, however, are acute. In addition to threats from rapid habitat destruction and alteration associated with rapid economic growth and rural development during the past three decades, Chinese wild orchids are facing destructive collecting pressures due to large cultural, horticultural and ethnobotanical demands and the primitive horticultural techniques in the country (Luo et al., 2003; Liu et al., 2009).

In 2004 several Chinese botanists discovered more than 100 species of orchids, some of which with extremely large, relatively undisturbed populations, in a 220 km^2 state forestry reserve in a remote area in northwestern Guangxi Zhuang Autonomous Region. This area was made a provincial nature reserve soon after the discovery and more recently, it was elevated to the status of national nature reserve, namely the Yachang Orchid Nature Reserve (Liu & Luo, 2010). Yachang is the first nature reserve in China, and second of its kind in the world defined by a national government primarily on the basis of protecting wild orchids. Protection of the rich orchid resources in Yachang, however, is not without problems, especially with the projected rapid global climate change. In this paper we identify a few specific challenges that may be posed by the current and projected climate changes as well as potential solutions.

The Challenges of Current Climate Change to Biological Conservation

In the past 2.5 million years, cycles of climate change driven by natural factors have occurred over periods of decades, centuries, and millennia (Wright, 1989; Bond et al., 1997, 2001; Diaz & Markgraf, 2000). For example, over 40 glacial/interglacial cycles were detected using oxygen-isotope analysis of ice cores from the Greenland ice sheet (Wright, 1989). These cycles were driven by variations in primary orbital cycles of the Earth (Zachos et al., 2001). Abundant evidence worldwide indicates that life on earth had responded to climate change at each of these scales in the past (Jackson et al., 1987; Thompson, 1990; Grayson, 1993).

Darwin speculated that species migration in response to climate change had proceeded in an orderly manner and that entire communities had shifted poleward together as a unit (Darwin, 1859). However, studies of pollen and fossils during the past glacial and inter glacial periods tell a different story (Miller & Brubaker, 2006). Species responses were individualistic such that population increases or decreases did not appear to be in synchrony with climate change, especially when climate changes were extreme and abrupt, and non-analog ecological communities (i.e., communities that do not exist in present time) were common (Miller & Brubaker, 2006).

How species or population respond to climate change depends on the species biology and the geographic location of the population. In general, populations in a relatively flat terrain migrated poleward during a warming period (Jackson et al., 1987), while those in mountainous areas with mild slopes migrated upward along an elevational gradient (Thompson, 1990; Grayson, 1993). However, in regions where habitats were complex, highly patchy, and with steep and discontinuous gradients, species, especially rare species, responded primarily with shrinking in population sizes, minor geographic range shifts, or local extinctions (Heusser, 2000; Maschinski et al., 2006).

The current anthropogenic driven climate changes are worrisome to conservation biologists because the projected warming in the next 100 years will result in an earth that is hotter than most extant species have ever seen (Barnosky, 2009). In addition, the rate of warming is at least twice as fast as what nature has experienced in the past (Davis & Shaw, 2001; Barnosky, 2009). It is therefore questionable whether current species migration can keep up with the speed and magnitude of the warming. A case in point, upward migrations of Andean cloud forest tree communities due to warming in the past 5 years has been approximately 2 m/yr, less than 4 times slower than is required to keep pace with the speed of warming (Kenneth J Feeley, Florida International University, pers. com.). Finally current natural habitats are highly fragmented and isolated by anthropogenic landscapes such as cities, farmlands, pastures and so on (Barnosky, 2009). Such landscape features make natural migration, one of the main responses to climate change, challenging if not impossible.

Hypotheses on how plants will respond to climate change are largely derived from studies on forest canopy species, especially those with wind dispersed pollen (Miller & Brubaker, 2006). Modern phenological monitoring also focuses primarily on common tree species, because they are easy to observe and can be compared across a wide range of locations (Schwartz, 2003; Chen, 2003; Zhu & Wan, 1983; Wan, 1986, 1987). The response of herbaceous understory species to climate change are, however, largely unknown. These plants include orchids, many of which are rare and threatened.

Current and Projected Climate Change in Southwest China and its Challenges to Orchid Conservation

The Yachang Orchid Nature Reserve is situated between 24°44′16″ to 24° 53′ 58″ N , and 106° 11′ 31″ to 106° 27′ 04″ and is influenced by the subtropical climate—as is the case with most of southwestern China (Corlett, 2009). In this region, there are pronounced seasonal variations in both rainfall and temperature (Corlett & Lafrankie, 1998; Huang et al., 2008), with nearly 60% of the rainfall occurring in the hot summer months and less than 10% in the cold winter months (Huang et al., 2008). Phenology of woody plants in southwestern China is characterised by regular, annual cycles at the individual, population, and community level (Corlett & Lafrankie, 1998; Wan, 1986, 1987), probably triggered by temperature and/or water availability (Corlett & Lafrankie, 1998).

Records indicate that warming in southwestern China in the past 100 years was around 0.5°C, slightly lower than the global average of 0.7°C (IPCC, 2007; Huang et al., 2005), and the warming has been largely due to increase in winter, spring and fall temperatures (Chen et al., 2008; He et al., 2007; Wang et al., 2008). Total annual rainfall, on the other hand, has remained the same or has increased slightly for the region (Huang et al., 2005; Bates et al., 2008). It is projected that the warming trend will continue during the next two centuries in Southwest China (Jiang et al., 2005; IPCC, 2007; Xu et al., 2009). Precipitation, on the other hand, is projected to increase only slightly (Bates et al., 2008; Jiang et al., 2005; Xu et al., 2009), but will not keep pace with the increase in evaporation rates due to warming (Bates et al., 2008). As such a slight decrease in soil moisture is predicted (Bates et al., 2008).

Challenge 1—Lower Soil Moisture

Orchids are notorious for their stringent habitat requirements, a factor contributing to their rarity (Cribb et al., 2003). The projected increase in precipitation and evaporation rate will result in a lower level of soil moisture (Bates et al., 2008). This will likely to impact mostly the terrestrial orchids. Sixty eight (50%) of the orchids in Yachange are either terrestrial or saprophytic.

Challenge 2—Geographical Barriers and Limits to Natural Migration

Complex terrain and habitat fragmentation and non-availability may hinder natural poleward migration. The Yachang Orchid Nature Reserve, as in adjacent areas in southwestern China, is characterized by many low to medium height limestone hills (elevations of 1,200 m or less), separated by steep valleys or rivers. Species in such complex terrain are expected to respond primarily by shrinking in population size (Heusser, 2000). This may happen to more than 100 species of orchids in Yachang (73%), since they are currently growing on the mountain tops (Table 1), with no higher places to migrate to. The most extraordinary feature in Yachang is that populations of some orchid species are extremely large (Shi et al., 2007b; Liu et al., 2009). Conservation of these unusually large populations is one of the conservation priorities for the Yachang Reserve. Most of these large populations are located on or near the hill tops. Thus, the projected warming in the region will likely threaten the long-term persistence of these large populations unless these populations possess a high micro-evolutionary potential which will enable them to evolve in accordance to the environmental changes related to climate changes (Holt, 1990). This group of species includes several species with horticultural importance or potentials, e.g. *Bulbophyllum andersonii, Coelogyne fimbriata*, *Cymbidium cyrprefolium, Eria*

Table 1 List of Orchids (139 species in 47 genera) in Yachang Orchid Nature Reserve[a,b] and Potential Threats from Climate Change

Species	Terrestrial[c]	Narrow endemic[d]	Spring flower[e]	Mountain top population[f]	Cliff population[g]	Very small population[h]	South most range	Risk score	Genus mean score
Acanthephippium sylhetense Lindl.	Yes	No	Yes	No	No	Yes	No	3	3
Anoectochilus elwesii (Clarke ex Hook. f.) King & Pnatl.	Yes	No	No	Yes	No	No	Yes	3	3.3
Anoectochilus moulmeinensis (Par. et Rchb. f.) Seidenf.	Yes	No	No	Yes	No	Yes	No	3	
Anoectochilus roxburghii (Wall.) Lindl.	Yes	No	No	Yes	Yes	No	Yes	4	
Aphyllorchis montana Rchb. f.	Yes (S)	No	No	No	No	Yes	No	2	2
Bletilla formosana (Hayata.) Schltr.	Yes	No	Yes	Yes	No	Yes	Yes	5	4.3
Bletilla ochracea Schltr	Yes	No	No	Yes	No	Yes	Yes	4	
Bletilla striata (Thunb. ex A. Murray) Rchb. f.	Yes	No	Yes	Yes	No	No	Yes	4	
Bulbophyllum ambrosia (Hance) Schltr.	No	No	Yes	Yes	No	Yes	No	3	3
Bulbophyllum andersonii (Hook. f.) J. J. Smith	No	No	Yes	Yes	Yes	No	No	3	
Bulbophyllum kwangtungense Schltr.	No	No	No	Yes	Yes	No	No	2	
Bulbophyllum longibrachiatum Z. H. Tsi	No	Yes	No	Yes	Yes	No	No	3	
Bulbophyllum odoratissimum (J. E. Smith) Lindl.	No	No	Yes	Yes	Yes	No	No	3	
Bulbophyllum tianguii k. Y. Lang et D. Luo	No	Yes	No	Yes	Yes	Yes	No	4	
Calanthe argentro-striata C. Z. Tang et S. S. Ying	Yes	No	Yes	Yes	Yes	No	No	4	3.5
Calanthe davidii Franch	Yes	No	No	No	No	Yes	Yes	3	
Calanthe hancockii Rolfe	Yes	Yes	Yes	No	No	Yes	Yes	5	
Calanthe reflexa (Kuntze) Maxim	Yes	No	No	Yes	No	Yes	Yes	4	
Calanthe sylvatica (Thouars) Lindl.	No	No	Yes	No	No	Yes	No	2	
Calanthe triplicata (Willem.) Ames	Yes	No	Yes	No	No	Yes	No	3	

Table 1 (continued)

Species	Terrestrial[c]	Narrow endemic[d]	Spring flower[e]	Mountain top population[f]	Cliff population[g]	Very small population[h]	South most range	Risk score	Genus mean score
Cephalanthera longifolia (L.) Fritsch	Yes	No	No	Yes	Yes	Yes	No	4	4
Cheirostylis chinensis Rolfe	Yes	No	Yes	Yes	No	No	No	3	2.5
Cheirostylis yunnanensis R.	Yes	No	Yes	No	No	No	No	2	
Cleisostoma menghaiense Z.H.Tsi	No	Yes	No	Yes	Yes	Yes	No	4	2
Cleisostoma nangongense Z. H. Tsi	No	Yes	No	No	No	Yes	No	1	
Cleisostoma paniculatum (Ker-Gawl.) Garay	No	No	No	Yes	No	No	No	1	
Cleisostoma williamsonii (Rchb. f.) Garay	No	No	Yes	Yes	No	No	No	2	
Coelogyne fimbriata Lindl.	No	No	No	Yes	Yes	No	No	2	3
Coelogyne flaccida Lindl.	No	No	Yes	Yes	Yes	Yes	No	4	
Cremastra appendiculate (D. Don) Makino	Yes	No	No	Yes	No	Yes	No	3	3
Cymbidium bicolor subsp. *obtusum* Du Puy & Cribb	Yes	No	Yes	No	Yes	No	No	3	3.3
Cymbidium cyperifolium Wall. et Lindl.	Yes	No	No	Yes	No	No	No	2	
Cymbidium aloifolium (L.) Sw.	No	No	No	No	Yes	No	Yes	2	
Cymbidium ensifolium (L.) Sw.	Yes	No	No	Yes	No	No	No	2	
Cymbidium faberi Rolfe	Yes	No	Yes	Yes	No	Yes	Yes	5	
Cymbidium floribundum Lindl.	Yes (semi)	No	Yes	Yes	Yes	No	No	4	
Cymbidium goeringii (Rchb. f.) Rchb. f.	Yes	No	Yes	Yes	No	Yes	Yes	5	
Cymbidium goeringii var. *serratum* (Schltr.) Y.S.Wu et S.C.Chen	Yes	No	Yes	Yes	No	Yes	Yes	5	
Cymbidium kanran Makino	Yes	No	No	Yes	No	Yes	No	3	
Cymbidium lancifolium Hook.	Yes (semi)	No	No	Yes	Yes	No	No	3	
Cymbidium macrorhizon Lindl.	Yes (S)	No	No	Yes	No	No	No	2	

Cymbidium nanulum Y. S. Wu et S. C. Chen	Yes	No	No	No	No	Yes	No	2	
Cymbidium qiubeiensis K. M. Feng et H. Li	Yes	Yes	No	Yes	No	No	No	3	
Cymbidium sinense (Jackson ex Andr.) Willd.	Yes	No	No	Yes	No	Yes	No	3	
Cymbidium tortisepalum var. longibracteatum (Y. S. Wu & S. C. Chen) S. C. Chen & Z. J. Liu	Yes	Yes	Yes	Yes	No	Yes	Yes	6	
Cymbidium tracyanum L. Castle	No	No	No	Yes	Yes	No	No	2	
Cypripedium henryi Rolfe	Yes	No	Yes	Yes	No	Yes	Yes	5	5
Dendrobium aduncum Wall et Lindl.	No	No	No	No	Yes	No	No	1	2.9
Dendrobium aphyllum (Roxb) C. E. C. Fisch	No	No	Yes	Yes	No	No	No	2	
Dendrobium aurantiacum Rchb. F. Var. *denneanum* (kerr) Z. H. Tsi.	No	No	Yes	Yes	Yes	No	No	3	
Dendrobium chrysanthum Lindl.	No	No	No	Yes	No	No	No	1	
Dendrobium devonianum Paxt	No	No	Yes	Yes	Yes	Yes	No	4	
Dendrobium fimbriatum Hook.	No	No	Yes	Yes	Yes	No	No	3	
Dendrobium hancockii Rofle	No	No	No	Yes	Yes	Yes	Yes	4	
Dendrobium henryi Schltr.	No	No	No	Yes	Yes	Yes	No	3	
Dendrobium hercoglossum Rchb. f.	No	No	No	No	Yes	Yes	No	2	
Dendrobium lindleyi Stendel	No	No	Yes	No	No	No	No	1	
Dendrobium loddigesii Rolfe	No	No	Yes	Yes	Yes	No	No	3	
Dendrobium lohohense T. Tang & F. T. Wang	No	No	No	Yes	Yes	Yes	Yes	4	
Dendrobium nobile Lindl.	No	No	Yes	Yes	Yes	Yes	No	4	
Dendrobium officinale Kimura et Migo	No	No	Yes	Yes	No	Yes	Yes	4	
Dendrobium williamsonii Day & Rchb. f.	No	No	Yes	Yes	Yes	Yes	No	4	
Epipactis helleborine (L.) Crantz.	Yes	No	No	Yes	No	Yes	No	3	3
Eria clausa King et Pantl.	No	No	Yes	Yes	Yes	Yes	No	4	3
Eria *Corneri* Rchb. f.	No	No	No	No	Yes	No	No	1	
Eria coronaria (Lindl.) Rchb. f.	No	No	Yes	Yes	Yes	No	No	3	

Table 1 (continued)

Species	Terrestrial[c]	Narrow endemic[d]	Spring flower[e]	Mountain top population[f]	Cliff population[g]	Very small population[h]	South most range	Risk score	Genus mean score
Eria lasiopetala (Willd.) Ormerod	No	No	Yes	Yes	Yes	No	No	3	
Eria obvia W.W.Smith	No	No	Yes	Yes	Yes	Yes	No	4	
Eria rhombodalis T. Tang et F. T. Wang	No	No	Yes	Yes	Yes	No	No	3	
Eria spicata (D. Don) Hand.-Mazz.	No	No	No	Yes	Yes	Yes	No	3	
Eulophia bracteosa Lindl.	Yes	No	Yes	No	No	Yes	No	3	2.7
Eulophia flava (Lindl.) Hook. F.	Yes	No	Yes	No	No	No	No	2	
Eulophia zollingeri (Rchb. f.) J. J. Smith	Yes (S)	No	Yes	Yes	No	No	No	3	
Flickingeria albopurea Seidenf	No	No	No	Yes	Yes	No	No	2	2.7
Flickingeria angustifolia (Bl.)Hawkes	No	No	No	Yes	Yes	Yes	No	3	
Flickingeria calocephala Z. H. Tsi et S. C. Chen	No	Yes	No	Yes	Yes	No	No	3	
Galeola lindleyana (Hook. f. et Thoms.) Rchb. f.	Yes (S)	No	No	Yes	No	No	Yes	3	3
Gastrodia eleta Bl.	Yes (S)	No	No	Yes	No	No	Yes	3	3
Geodorum densiflorum (Lam.) Schltr.	Yes	No	No	No	No	No	No	1	1.7
Geodorum eulophioides Schltr.	Yes	Yes	No	No	No	Yes	No	3	
Geodorum recurvum (Roxb.) Alston	Yes	No	No	No	No	No	No	1	
Goodyera henryi Rolfe	Yes	No	No	No	No	No	No	1	1.5
Goodyera schlechtendaliana Rchb. f.	Yes	No	No	Yes	No	No	No	2	
Habenaria ciliolaris Kraenzl.	Yes	No	No	Yes	No	No	No	2	2.6
Habenaria davidii Franch.	Yes	No	No	Yes	No	Yes	Yes	4	
Habenaria dentata (Sw.) Schltr	Yes	No	No	Yes	No	No	No	2	
Habenaria fordii Rolfe	Yes	Yes	No	Yes	No	No	No	3	
Habenaria petelotii Gagnep.	Yes	No	No	No	No	Yes	No	2	

Herminium bulleyi (Rolfe) Tang et Wang	Yes	Yes	No	Yes	No	Yes	Yes	5	3.5
Herminium lanceum (THunb.) Vuijk	Yes	No	No	Yes	No	No	No	2	
Kingidium braceanum (Hook. f.) Seidenf.	No	Yes	No	Yes	No	Yes	No	3	3
Lecanorchis multiflora J. J. Smith	Yes (S)	No	No	No	No	Yes	No	2	2
Liparis bootanensis Griff.	No	No	No	No	Yes	Yes	No	2	2.2
Liparis cordifolia Hook. f.	Yes	No	No	Yes	No	No	Yes	3	
Liparis distans C. B. Clarke	No	No	Yes	Yes	Yes	No	No	3	
Liparis esquirolii Schltr.	No	Yes	No	Yes	Yes	Yes	Yes	5	
Liparis inaperta Finet	No	No	No	Yes	Yes	No	No	2	
Liparis japonica (Miq.)Maxim.	No	No	No	No	Yes	Yes	Yes	1	
Liparis nervosa (Thunb.ex A. Murray) Lindl.	No	No	Yes	No	Yes	Yes	No	3	
Liparis nigra Seidenf.	No	No	Yes	Yes	No	No	No	2	
Liparis stricklandiana Rchb.f.	No	No	No	No	No	Yes	No	1	
Liparis viridiflora (Bl.) Lindl.	No	No	Yes	No	Yes	No	No	2	
Luisia teres (Thunb. ex A. Murray.) Bl.	No	No	Yes	Yes	No	No	No	2	2
Malaxis acuminata D. Don	Yes	No	No	Yes	No	No	No	2	2
Malaxis biaurita (Lindl.) Kuntze	Yes	No	No	Yes	No	No	No	2	
Malaxis latifolia J. E. Smith	Yes	No	No	Yes	No	No	No	2	
Malaxis monophyllos (L.) Sw.	Yes	No	No	No	No	Yes	Yes	3	
Malaxis purpurea (Lindl.) Kuntze	Yes	No	No	No	No	No	No	1	
Nervilia fordii (Hance) Smitin	Yes	No	No	No	No	No	No	1	1.5
Nervilia plicatao (Andr.) Schltr.	Yes	No	No	Yes	No	No	No	2	
Oberonia ensiformis (J. E. Smith) Lindl.	No	No	No	Yes	Yes	No	No	2	2
Oberonia myosurus (Forst. f.) Lindl.	No	No	No	Yes	Yes	No	No	2	
Pachystoma pubescens Bl.	Yes	No	Yes	No	No	Yes	No	3	3
Panisea cavalerei Schltr.	No	Yes	Yes	Yes	Yes	No	No	4	4
Paphiopedilum dianthum T. Tang et F.T.Wang	No	Yes	No	Yes	Yes	Yes	No	4	4.3

Table 1 (continued)

Species	Terrestrial[c]	Narrow endemic[d]	Spring flower[e]	Mountain top population[f]	Cliff population[g]	Very small population[h]	South most range	Risk score	Genus mean score
Paphiopedilum hirsutissimum (Lindl. et Hook.) Stein	Yes (semi)	No	Yes	Yes	Yes	No	No	4	
Paphiopedilum micranthum T. Tang et F. T. Wang	Yes (semi)	Yes	Yes	Yes	Yes	Yes	No	6	
Peristylus affinis (D.Don) Seidenf.	Yes	No	No	No	No	Yes	No	2	2.7
Peristylus flagellifer (Makino) Ohwi	No	Yes	No	Yes	No	Yes	Yes	4	
Peristylus mannii (Rolfe) Makerjee	No	No	No	Yes	No	Yes	No	2	
Phaius flavus (Bl.) Lindl.	Yes	No	No	Yes	No	No	No	2	2.5
Phaius tankervilleae (Banks ex L'herit.) Bl.	Yes	No	Yes	Yes	No	No	No	3	
Pholidota cantonensis Rolfe	No	No	Yes	Yes	Yes	No	No	3	3
Pholidota leveilleana Schltr.	No	Yes	No	Yes	Yes	Yes	No	4	
Pholidota missionariorum Gagnep.	No	Yes	No	Yes	Yes	No	No	3	
Pholidota yunnanensis Rolfe	No	No	No	Yes	Yes	No	No	2	
Pleione yunnanensis (Rolfe) Rolfe	Yes	No	Yes	Yes	No	No	No	3	3
Pogonia japonica R.	Yes	No	No	No	No	Yes	Yes	3	3
Robiquetia succisa (Lindl) Seidenf.	No	No	No	No	Yes	No	No	1	1
Spathoglottis pubescens Lind.	Yes	No	No	Yes	No	Yes	No	3	3
Spiranthes sinensis (Pers.) Ames	Yes	No	No	Yes	Yes	No	No	3	3
Tainia angustifolia (Lindl.) Benth. et Hook. f.	Yes	No	No	Yes	No	Yes	No	3	3

Tainia macrantha Hook. f.	Yes	Yes	No	No	No	Yes	No	3	
Thelasis pygmaea Hook. f.	No	No	Yes	Yes	Yes	Yes	No	4	4
Vanda concolor Bl.	No	No	Yes	No	No	No	No	1	1
Vandopsis gigantea (Lindl.) Pfitz	No	No	Yes	No	No	No	No	1	1
Vanilla siamensis Rdfe ex Downie	No	No	Yes	Yes	Yes	No	No	3	3
Zeuxine goodyeroides Lindl.	Yes	No	No	Yes	No	Yes	No	3	3.5
Zeuxine strateumatica	Yes	No	Yes	Yes	No	Yes	No	4	
Number of species (%)	72 (51.8%)	20 (14.4%)	55 (39.6%)	101 (72.7%)	58 (41.7%)	65 (46.8%)	34 (24.5%)	33 (23.7% with a score ≥4)	7 (14.9% with a score ≥4)

[a] Species list were complied based on "The Comprehensive Investigation Report of Guangxi Yachang Orchids Natural Reserve" by The Comprehensive Scientific Investiation Team of Guangxi Yachang Orchid Nature Reserve (2007), "Picture book of Wild Orchids in Guangxi Yachang" by Luo et al. (2008), and Feng et al. unpublished data

[b] Information on global distribution is derived from "Flora of China, Orchidaceae" by Chen et al. (2009b)

[c] Saprophytes are considered terrestrial. (*S*) indicates Saprophytes, and (semi) indicate populations in Yachang are found to be both terrestrial and epiphytic

[d] A species is considered a narrow endemic if its current range include only Guangxi, Guizhou, Yunnan and northern Vietnam or fewer areas because these areas are adjacent to one another and share similar limestone and climatic characteristics

[e] Spring flower species are those whose flowering periods include any month from January to April

[f] Populations found at 1,200 m or above is considered mountain top populations because the geographical feature of Yachang Reserve, i.e. the area is composed of many low- and mid-elevation mountains

[g] Species with cliff populations are those grow on steep rocky surfaces in Yachang Reserve

[h] Species are found in less than 3 locations within the Yachang Reserve and each has less than 100 reproducing plants

coronaria, Liparis viridiflora, L. chapaensis, L. cordifolia, Oberonia myosurus, Paphiopedilum hirsutissimum, *Panisea calalerei, Pholidota yunnanensis,* and *Vanilla siamensis*.

Sixty five orchid species (47%) currently consist of very small populations in Yachang, and 20 species (14%) have narrow distributional ranges. These orchids, which face high risk of extinction without the climate change (Rabinowitz, 1981), may also face high level of threat from climate change, especially if they are found on hill tops. Species in this category include *Bulbophyllum tianguii, Cymbidium goeringii*, *C. longibracteatum*, *C. nanulum*, *C. tracyanum*, *Dendrobium officinale*, *P. micranthum* (Table 1). In addition, populations that represent the southern limit of the species distributions (34 orchid species or 25% in Yachang) are also vulnerable to local extinction (Lavergne et al., 2006). Yachang Orchid Nature Reserve is located in transitional zone of warm subtropical to cool subtropical climate and harbors some southern-most populations of temperate orchid species (Table 1). For example, Yachang is one of the few places where *Paphiopedilum*, a genus of tropical lady's slipper orchids, co-occur with the temperate lady's slipper orchids, *Cypripedium* species. The only *Cypripedium* species in Yachang, *C. henryi* are found in very small numbers on a hill top. This population, being small, on hill top, and at the south limit of the species' distribution, is certainly the one most vulnerable to local extinction (Table 1).

Challenge 3—Erosion Induced by Extreme Weather

Extreme rainfall events are predicted to occur more frequently even though overall rainfall has been and is projected to increase only slightly in the region (IPCC, 2007, Chen Yegou, Guangxi Meteorology Bureau, pers. comm.). Extreme rainfall event can accelerate erosion. Nearly half of the orchid species in Yachang (42%) have populations on steep cliffs (Table 1) that have probably adapted to the disturbance caused by frequent runoffs associated with rain and occasional erosions. However, increased degree and frequency in erosion may negatively affect the cliff populations. Orchids in this category include *Coelogyne fimbriata*, *Eria coronaria*, *E. rhomboidalis*, *E. spicata*, *Paphiopedilum dianthum*, *P. hirsutissimum*, *Pholidota yunnanensis*, *Oberonia ensiformis, O. myosurus*.

Challenge 4—Flowering Responses to Climate Change

The fourth challenge for orchid conservation in the region relating to climate changes is the potential mismatches in phenology between orchids and their pollinators due to spring warming.

The majority of orchid species have specialized insect pollination system, relying on one to a few pollinator species (Cingel, 2001; Tremblay et al., 2005). This is likely to be the case for orchids in Yachang. Pollination systems of 10 orchid species in Yachang have been studied and all are pollinated by a single species of pollinator (Cheng et al., 2007, 2009; Shi et al., 2007a, 2008, 2009; Shangguan et al., 2008; Luo et al., unpubl data). One species (*Geodorum densiflora*) can also self-pollinate, possibly requiring the assistance of rain (Liu et al., unpbl. data).

Long-term phenological data are rare for orchid species (Willis et al., 2008). However, fluctuations in flowering time due to fluctuations in spring temperatures have been well documented for many temperate woody species and a limited number of herbaceous species (Wan, 1986, 1987; Chen, 2003; Dose & Menzel, 2006). Early initiation of flowers and other spring events due to the current global warming has also been reported for many temperate species (Fitter & Fitter, 2002; Menzel et al., 2006; Miller-Rushing & Primack, 2008). Little data is available on the response of subtropical species response to global climate change. Nevertheless, phenology of some subtropical species can be temperature driven, especially in areas with pronounced annual fluctuation in temperature (Corlett & Lafrankie, 1998; Feng et al., unpbl. data). Warming in winter and spring are therefore likely to affect the flowering phenology of some orchid species in southwestern China, including those in the Yachang Reserve.

The majority of orchid pollinators are insects (Pemberton, 2010). Yet, our knowledge of insect responses to current climate change is just beginning to accumulate. There is evidence that some butterflies and moths have migrated poleward or upwards within the past 5 decades in responding to the warming (Parmesan et al., 1999; Chen et al., 2009a). European honey bees (*Apis mellifera*) have been reported to respond to spring temperature fluctuations by coming out of their annual dormancy either early or late in the warm or cool springs, respectively, in temperate China (Wan, 1986, 1987). There is a need for studies to determine whether the Chinese honey bee (*A. cerana*), a major orchid pollinator in southwestern China, and other insect pollinators have similar responses to changes in spring temperatures.

The ability to track global warming varies among species (Miller-Rushing & Primack, 2008). It is unknown whether the change or lack of change in plant flowering phenology will be in synchrony with its pollinator's activity. A simulation of the impacts of global warming on generalist plant-pollinator webs indicated disruptions and even extinction of some of these crucial interactions (Memmott et al., 2007). Climate change might have induced asynchronized shifts in space and time between peak flowering of the British orchids and the peak flight times of the orchid's pollinators (David Roberts, Kew, pers. comm.). It is logical to expect that specialized pollination relationships, such as the ones borne by orchids and their pollinators, will be more vulnerable to such mismatch than the more generalist interactions (Ashworth et al., 2004; Dixon, 2009). This vulnerability is due in part to the skewed relationships between orchids and pollinators, with the orchid being much more dependent on the pollinators than vice versa (Dixon, 2009; Pemberton, 2010; Vereecken et al., 2010). Fifty five species or 40% of orchids in Yachang flower in the Spring and are therefore likely to be impacted the most (Table 1), these include *Cymbidium faberi, C. floribundum, C.goeringii, C. longibracteatum, Geodorum densiflora, G. eulophioides, G. recurvum*, *Paphiopedilum hirsutissimum*, and *P. micranthum,* to name a few.

Challenge 5—Lack of Knowledge on Response of Orchid-Fungi Mycorrhizal Relationship to Climate Changes

The symbiotic relationship between orchid and mycorrhizal fungi is considered to be critical in natural seed germination and seedling growth of all orchid species (Rasmussen & Rasmussen, 2009). This relationship is also essential in post-seedling growth in many orchid species (Dearnaley, 2007; Rasmussen & Rasmussen, 2009; Liu et al., 2010, this volume). However, despite the significant advance made on orchid mycorrhiza research in the past two decades (Rasmussen & Rasmussen, 2009), our knowledge on orchid-mycorrhizal fungi relationships is limited, particularly in the case of Chinese wild orchids (Liu et al., 2010, this volume). The function and stability of orchid mycorrhiza can be sensitive to environmental factors (Batty et al., 2001). However, it is not known whether and how the role of mycorrhizal fungi in orchid germination and growth will be maintained with rising temperature and reduced soil moisture.

Potential Solutions

A number of actions can be taken to alleviate the threats imposed by climate change on orchids in this orchid hotspot.

Ranking Vulnerability of Species Due to Climate Change

Prioritizing the species based on vulnerability of wild orchids to climate change can be performed using their habit, flowering time, population size, distribution patterns in elevational range as well as their geographic range as indicators. We attempted such a ranking system in Table 1. We first assigned a value of 1 to each positive answer of the threatening factors listed, and then summed the values for each species. Species with a score of four or greater in this exercise were considered highly vulnerable. Overall, nearly a quarter of the species facing high risk and they spread across 19 genera. Each of these threats impacts 14% to 72% of the species, and each species is threatened by at least one of these factors (Table 1).

We also calculate the average risk for each genus in Yachang Reserve to see whether there is a risk pattern in this higher taxonomic level. There are 7 genera which have a mean score of 4 or higher, with *Bletilla*, *Cypripedium*, and *Pahiopedilum* most at risk (risk scores of 4.3 and above). Both *Dendrobium* and *Cymbidium*, two genera of high market values for horticultural and Chinese medicinal use, respectively, are not at particularly high risk, yet, but some members in these genera are (Table 1). Whether a species is subject to high collecting pressure can influence the species' extinction probability. We did not list this factor because it is independent of climate change. One could also weigh each of the factors differently based on the degree of its potential impacts on population dynamics. Restoration experiments should be started on the most vulnerable species.

Establishing Long-Term Phenological Monitoring for Plants and Pollinators

Currently, rangers are assigned to patrol areas where large populations of orchids occur. These rangers may be trained to collect phenological data using data sheet designed by, and under the supervision of, conservation ecologists. Some rangers have already been trained to assist in long-term population monitoring of large populations in Yachang Reserve. This can also be supplemented by phenological studies from the herbarium specimens. If there are indeed mismatches in phenological responses to spring temperature fluctuations between orchids and their pollinators, it will be useful to know the magnitude of the mismatch and how this may contribute to the overall population decline.

Assisted Migrations

As mentioned earlier, natural poleward or upward migration of orchids, especially mountain top species, would be very difficult if not impossible for orchids in the Yachang Reserve because, like many other protected areas in the world, it is of small size (18 km south-north, by 26 km west-east), and surrounded by, or interspersed with, disturbed or human-dominated landscapes. In addition, there are 89 mountains of elevation 1,000 m or higher. However, only 19 of these are above 1,500 m. Nevertheless, all hills are not equally occupied by orchids. Thus, micro- and macro-habitat analyses, including using remote sensing data, will be useful to determine what are suitable and projected suitable sites and vegetation successional stages. Projected suitable but unoccupied sites can be used as experimental artificial planting or restoration sites. Such restoration approach can provide opportunity to determine how orchids in the area can better cope with the predicted climate changes.

Before a network of protected areas in this orchid-rich region are established, human-assisted migration of selected orchids to protected areas in Guizhou (to the north of the Reserve) or to Yunnan (to the west, more inland, and with higher mountains) provinces may be required. Human-assisted migration (alternatively referred to as "assisted colonization", "artificial transplantation", or "managed translocation") of rare and endangered species in relation to climate change has been advocated and implemented elsewhere (Fox, 2007; McLachlan et al., 2007; Zimmer, 2007; Hoegh-Guldberg et al., 2008; Richardson et al., 2009). However, such efforts will also require co-ordination among provinces, which can be challenging. In addition, habitat destruction is worse in Guizhou than in the other two neighboring provinces and it is questionable whether appropriate habitat can be identified there. Nevertheless, this measure, along with assisted migration to locations within Yachang with higher elevations, may be a good option for the narrow endemic species, such as *Bulbophyllum tianguii*, *Geodorum eulophioides*, and *Paphiopedilum dianthum*. Following the general rules of temperature gradient along elevational or latitudinal gradients (Colwell et al., 2008; Jump et al., 2009), a 500 m upward or 500 km pole-ward migration will be sufficient for a species to track the 2.5°C projected change in southwestern China for the next century (Jiang et al., 2005; IPCC, 2007; Xu et al., 2009).

Orchid Restoration Using Symbiotic Seed Germination and Seedling Growth

Before human-assisted migration is conducted, mycorrhiza relationships should be studied in detail for selected orchid species in Yachang Reserve. Besides identifying the orchid mycorrhizal fungi partners and determining their roles in orchid population dynamics, the effects of temperature and moisture on these relationships should be investigated with other environmental variables. Transplanting symbiotic plants (e.g. seedlings inoculated with appropriate mycorrhizal fungi) are expected to overcome impediment from lack of adequate symbiotic fungi. Therefore, knowledge on the identities and roles of mycorrhizal fungi of orchids will determine in part whether such a restoration project will be successful (Dearnaley, 2007; Swarts & Dixon, 2009, Liu et al., 2010).

Intra-Species Hybridization

Another possible tool in conservation of the orchid species is to hybridize plants from warmer areas of a species' distribution with those in Yachang. This may improve the heat tolerance of the local populations (Fox, 2007). However, the microevolutionary potential of the spectacularly large populations of certain orchid species in Yachang should be investigated before taking the hybridization approach.

Concluding Remarks

We acknowledge that some of the potential conservation measurements are controversial. Yet, depending on the objectives of the Yachang Reserve, e.g. preventing species from extinction, and maintaining the large populations unique to the Reserve, they may be the best options to accomplish these goals in light of the projected climate change. In addition to in-situ conservation options proposed here, ex-situ conservation measures, especially seed banking of highly vulnerable species, should be implemented to buffer species extinction (Seaton et al., 2010). Other non-climate change related conservation measures, such as conserving resources that pollinators depend on (Pemberton, 2010; Vereecken et al., 2010; Bernhardt & Meier, 2010), should be promoted. For example, a wasp species (*Vespula* sp.) was found to be the sole pollinator for *Coelogyne fimbriata* (Cheng et al., 2009), however the wasp itself is collected by the local people for consumption. Regulated exploitation of the wasp is one obvious measure that could be pursued by the Reserve.

Climate change is considered to be one of the biggest threats to diversity. But in most studies the actual mechanisms through which climate change will affect individual species have remained ambiguous or undefined. Here we identified seven specific threats that climate change may pose to the orchids of the Yachang Reserve and the specific species that are most likely to be impacted. Although there are potentially more that we did not look at, this study provides a scientific framework for conservation workers in the southwestern China orchid hotspot to prioritize their conservation efforts.

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