Short Communication

Current status and conservation strategies for *Isoetes* in China: a case study for the conservation of threatened aquatic plants

Xing Liu, Jing-Yuan Wang and Qing-Feng Wang

Abstract There are four known species of *Isoetes* (Family Isoetaceae) from China: *I. hypsophila*, *I. sinensis* and *I. yunguiensis* on the mainland, and *I. taiwanensis* on Taiwan. In a 4-year study we documented the distribution and habitat characteristics of all four species and evaluated their conservation status using IUCN criteria. All four species are facing a high risk of extinction and should be categorized as Critically Endangered on the IUCN Red List. Habitat degradation and loss, water pollution and eutrophication, competitive exclusion, and human disturbance are the main factors causing the decline and extirpation of *Isoetes*. Only *I. taiwanensis* is protected *in situ* in Yangmingshan National Park on Taiwan. None of the species or habitats of *Isoetes* on mainland China are presently protected, although all species have been designated by the government as State Key Protected Wild Plants. Our results suggest that conservation strategies should be implemented urgently, particularly on the mainland.

Keywords Aquatic plants, China, conservation status, *ex situ*, *in situ*, *Isoetes*, Taiwan.

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More than 400 aquatic plant species have been reported in China (Diao, 1990), of which an increasing number face a high risk of extinction and require urgent conservation action (Wang & Chen, 1994; Chen *et al*., 1998; Yu, 1999; Gituru *et al*., 2002). Only five aquatic species (*Isoetes japonica* A. Br., *Isoetes sinensis* Palmer, *Oryza officinalis* Wall. Ex Watt, *Oryza rufipogon* Griff., and *Ottelia acuminata* (Gagnep.) Dandy), are designated as threatened in the *China Plant Red Data Book* (Fu & Jin, 1992). *I. japonica* was previously a misidentified taxon in China, and is now known to be a diploid species *I. yunguiensis* Wang & Taylor ($2n = 22$) (Wang *et al*., 2002). Only one freshwater plant species, *Nelumbo nucifera*, is the main conservation target of a wetland nature reserve (Jiang *et al*., 1998).

Isoetes (Family Isoetaceae, quillworts) is a small, cosmopolitan genus of heterosporous lycopsids with *c*. 150 living species (Taylor & Hickey, 1992). The genus is considered to be the only remaining living representative of ancient taxa that were characterized by a strongly reduced plant body (Takhtajan, 1956). It is an ancient group dating back to the Devonian (Foster & Gifford, 1974) and occupies a unique position in land plant evolution (Pigg, 1992).

Following preliminary reports on *Isoetes* in China (Palmer, 1927; Diao, 1990; Fu & Jin, 1992; Chen *et al*., 1998; Ding & Zeng, 2001; Xue & Huang, 2002), the genus has recently received more attention (Liu *et al*., 2002; Wang *et al*., 2002; Liu *et al*, 2003; Pang *et al*., 2003; Wen *et al*, 2003). There are four known species of *Isoetes* from China: *I. hypsophila* Hand.-Mazz (Handel-Mazzetti, 1923), *I. sinensis* Palmer (Palmer, 1927) and *I. yunguiensis* on the mainland, and *I. taiwanensis* on Taiwan (DeVol, 1972). Although all *Isoetes* species in China are listed as first class State Key Protected Wild Plants (Yu, 1999), none of the species or their habitats are protected.

Here we describe the status and distribution of *Isoetes* species and populations on mainland China and Taiwan, analyse the causes of their decline and propose conservation strategies. Information on specific localities of wild populations has been deliberately omitted to reduce the risk of illegal collection.

Known localities were determined from herbarium specimens (herbaria of CDBI, HGAS, KUN, NAS, PE, IBK, ZJFC and PYU; abbreviations follow Index Herbariorum, 2003) and the available literature, and field investigations were carried out during 2000–2003. At each locality, altitude, water pH (which has an important affect on the development and growth of *Isoetes*; Keeley, 1998), and associated plant species were recorded.

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Populations that could not be relocated were considered extirpated. Specimens (3–5 individuals from each population) were collected and cultivated under protection in a greenhouse for artificial reproduction and *ex situ* protection. Using the collated information, the conservation status of the four *Isoetes* species was assessed using the IUCN Red List criteria (IUCN, 2001).

Our investigation indicates that 14 populations of four *Isoetes* species are extant, including 10 populations discovered by us during 2000–2003 (Appendix 1; Fig. 1), and 16 populations of three species are extinct (Appendix 2; Fig. 1). *I. sinensis* and *I. taiwanensis* are already categorized as Critically Endangered on the IUCN Red List (IUCN, 2004). Based on our work we propose that all four species fulfil the criteria for categorization as Critically Endangered but with criteria for *I. sinensis* and *I. taiwanensis* different from those currently designated (Table 1).

The threats to individual extant populations are summarized in Appendix 1. Ovegrazing by cattle is damaging the habitat of the single population of *I. yunguiensis*. The six populations of *I. sinensis* have declined because of shrinking water bodies and invasion by other species. During our fieldwork the area occupied by the population JD1 fell from 20 m^2 to <2 m^2 and the total number of individuals from 800–1,000 to 40–60. Although there is limited disturbance of the mountain location of the six *I. Hypsophila* populations, they have recently become

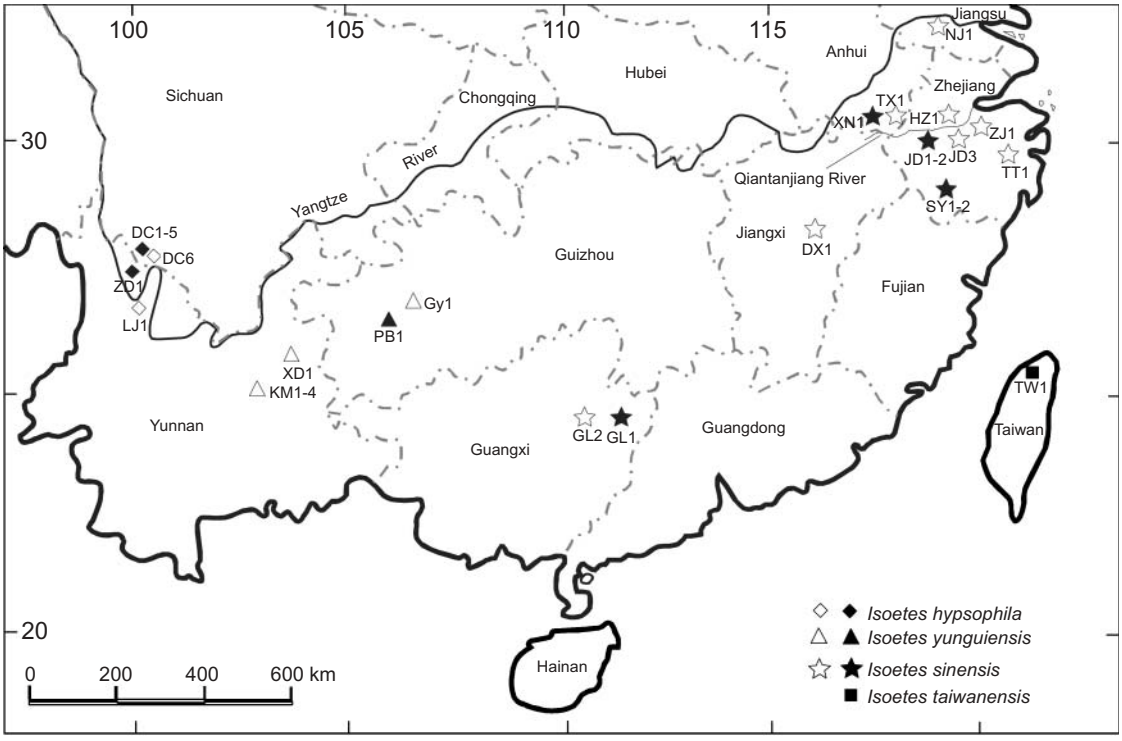

Fig. 1 The distribution of extant (filled symbols) and extinct (unfilled symbols) populations of the four species of *Isoetes* in mainland China and Taiwan.

Table 1 Estimated area and population sizes, and current (IUCN, 2004) and proposed Red List categories and criteria for *Isoetes* on mainland China and Taiwan.

Species	Vernacular name	Estimated area with wild populations (m^2)	Estimated population size	Current Red List category & criteria	Proposed Red List category & criteria
I. yunguiensis	Yunguishuijiu	<60	<200		CR A2abcde +3bcde; B2ab(i,ii,iii,iv,v); C1+2a (ii)
I. sinensis	Zhonghuashuijiu	<427	$<4,350$	CR A2c	CR B2ab(i,ii,iii,iv,v)
I. hypsophila	Gaohanshuijiu	*c.* 40,520	*c.* 10,100		CR B2ab(i,ii,iii,iv,v)
I. taiwanensis	Taiwanshuijiu	<10	<50	CR A2c	CR A2abcde +3bcde; B2ab(i,ii,iii,iv,v); C1+2a (ii)

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threatened by overgrazing and road construction. Tourism constitutes the major disturbance to the single population of *I. taiwanensis* (Chang & Hsu, 1977; Huang & Yang, 1992), and an earthquake in 1999 led to a reduction in the area occupied from *c.* 2,000 m^2 to <10 m^2, and the population declined from *c.* 5,000 to <50. The habitats of extirpated populations (Appendix 2) were exploited for tourism, fish farming and cultivation. Pollution and eutrophication of these habitats have generally raised values of pH, dissolved carbon dioxide, water hardness, and nitrates (Wen *et al.*, 2003).

Our study indicates that there are four main factors contributing to the decline and extirpation of *Isoetes* in China: habitat degradation or loss, water pollution and eutrophication, competitive exclusion by associated plants, and human disturbance. We suggest four main conservation strategies for the genus in China and Taiwan.

(1) To develop strategies for sustainable development of wetlands and protection of the habitats of *Isoetes* and other freshwater plants. (2) To control water pollution and eutrophication, and institute integrated multidisciplinary studies for the conservation of these freshwater ecosystems. (3) To protect the populations of *Isoetes in situ* and *ex situ* by: (i) monitoring and managing the habitats of *Isoetes*, (ii) forbidding illegal collection and overgrazing, (iii) controlling invasive plants to reduce interspecific competition, and (iv) the government working with the managers of nature reserves to re-establish wild populations. (4) To strengthen conservation research and enhance public education by: (i) promoting a programme to sensitize stakeholders to the importance of research and conservation for *Isoetes* and other threatened aquatic plants, (ii) assessing genetic diversity for establishing conservation measures for *in situ* and *ex situ* populations, (iii) investigating the breeding system and dispersal strategy to understand the distribution patterns of *Isoetes*, and (iv) analysing the phylogenetic relationships of Chinese *Isoetes* in relation to the global occurrence of the genus.

By the end of 2000, 289 wetland nature reserves had been established and the China National Wetlands Conservation Action Plan formulated (State Environmental Protection Administration of China, 2001). We have been researching the artificial reproduction, genetic diversity, origin and evolution of *Isoetes* (Chen *et al.*, 2004; Liu *et al.*, 2004) and this, with the present work, should inform the future conservation of the genus in China.

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Appendices 1–2

The appendices for this article are available online at http://journals. cambridge.org

Biographical sketches

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