

ISSN 1385-0237, Volume 209, Number 2

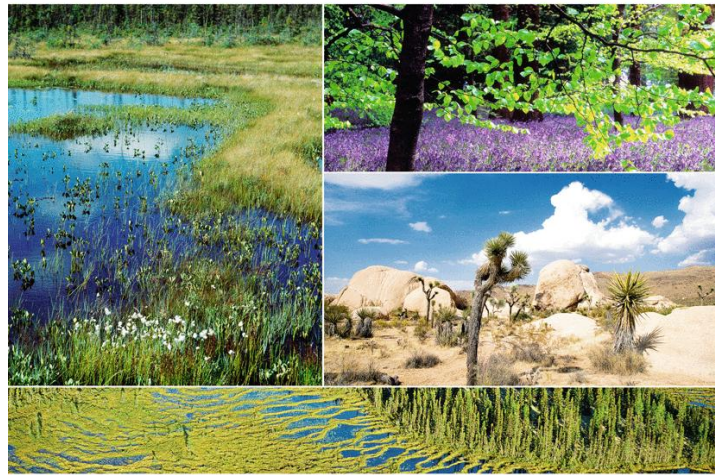
Plant Ecology

VOLUME 209 NUMBER 2 AUGUST 2010

ISSN 1385-0237

Special Issue: China
Guest Editor: Neal J. Enright

AN INTERNATIONAL JOURNAL



 Springer

**This article was published in the above mentioned Springer issue.
The material, including all portions thereof, is protected by copyright;
all rights are held exclusively by Springer Science + Business Media.**

**The material is for personal use only;
commercial use is not permitted.**

**Unauthorized reproduction, transfer and/or use
may be a violation of criminal as well as civil law.**

Moss is a key nurse plant for reintroduction of the endangered herb, *Primulina tabacum* Hance

Hai Ren · Guohua Ma · Qianmei Zhang ·
Qinfeng Guo · Jun Wang · Zhengfeng Wang

Received: 13 October 2009 / Accepted: 3 March 2010 / Published online: 21 March 2010
© Springer Science+Business Media B.V. 2010

Abstract The rare and endangered plant *Primulina tabacum* is a calciphilous perennial herb found only at the entrances of a small number of karst cave drainages in southern China. In a conservation effort, we identified potentially suitable habitats and reintroduced *P. tabacum* plantlets (propagated in vitro) to one historical and two new cave entrances. The transplanted seedlings survived (10%) at only one new location where a moss, *Gymnostomiella longinervis* Broth, existed. Our field observations indicate that it is probably impossible for this rare plant to naturally recolonize the places where it went extinct because the habitats have changed. Transplanted *P. tabacum* grew slower than wild *P. tabacum*. The transplanted *P. tabacum* performed especially well under the cover of the nursing moss. Positive interactions between species, i.e., nurse plant effects, are important for reintroduction of success. Although light and soil conditions also appeared to be critical for transplantation success, the presence of moss should be considered as a useful and convenient indicator of suitable habitat for *P. tabacum*. This study case suggests that the use of new propagation

methods and nurse plants can facilitate the reintroduction of rare and endangered herbs.

Keywords Conservation · Moss · Nurse plant · *Primulina tabacum* · Reintroduction · Survival rate

Introduction

Primulina tabacum Hance is a calciphilous perennial herb belonging to the family Gesneriaceae. Its distribution is restricted to the entrances of karst cave drainages along the border between northern Guangdong and southern Hunan, China (Flora of China Editorial Committee 1990). *P. tabacum* is on the list of the “First Class Protected Key Wild Plants of China” in 1999 (Peng and Cheng 2002). Its abundance exhibits a bell-shaped curve along an environmental gradient from the entrance of caves to deeper within caves. *P. tabacum* relies on alkaline calciferous groundwater and grows in poor soils (Ren et al. 2003). Because of recent climate change and increasing anthropogenic disturbances, the population size of *P. tabacum* has drastically decreased during the last three decades (He and Li 2005).

Specimens of *P. tabacum* were first collected by Henry Cox, an American churchman, in 1881 at Lianzhou, Guangdong, China. Because of its conservation status, the taxonomy (Hance 1883; Flora of China Editorial Committee 1990), ecological and biological characteristics (Ren et al. 2003), genetic diversity

H. Ren (✉) · G. Ma · Q. Zhang · J. Wang · Z. Wang
Department of Ecology, South China Botanical Garden,
Chinese Academy of Sciences, Guangzhou 510650, China
e-mail: renhai@scib.ac.cn

Q. Guo
USDA FS—Eastern Forest Threat Center,
200 WT Weaver Blvd, Asheville, NC 28804, USA

(Ni et al. 2006; Wang et al. 2008), pollination biology (Li et al. 2006), pollen morphology (Cao et al. 2007), and the close relationship of the species with moss (Ren et al. 2010) have been investigated subsequently.

We began *P. tabacum* conservation efforts and attempted to reintroduce *P. tabacum* to appropriate sites in 2002. We performed seed germination tests at the South China Botanical Garden during 2003–2006 to determine whether seeds could be used for reintroduction but no seeds germinated (unpublished data). However, we were successful in obtaining tissue culture and plantlet regeneration in 2007 (Ma et al. 2007), which led to the reintroduction of in vitro-propagated *P. tabacum* plantlets to the plant's historical and original habitats.

Reintroduction has been regarded as an extinction-prevention strategy for plant species for at least 100 years (Armstrong and Seddon 2007). Successful reintroduction requires knowledge about the taxonomy, reproductive biology, demography, horticulture, and ecology of the reintroduced species (Kleiman 1989; IUCN 1998; SER 2002; Armstrong and Seddon 2007; Godefroid and Vanderborght 2009). Although there are some success stories, most reintroduction attempts have failed, and the causes remain unknown (Griffith et al. 1989; Maschinski and Wright 2006; Maschinski and Duquesnel 2006; Gibbs et al. 2007). In “Global Strategy for Plant Conservation,” Target 8 was ex situ conservation and recovery plans for threatened and endangered species to reintroduce about 10% of endangered plants to wild habitats (BGCI 2003). In those reintroductions, reintroduction biology has traditionally focused on factors affecting population establishment and spread to determine whether reintroductions are successful or not. The research, however, has largely concerned the collecting and analyzing of monitoring data rather than the answering of specific questions that might explain successful and unsuccessful reintroductions (Ollero and Bermejo 1979; Sarrazin and Barbault 1996; Vittoz et al. 2006; Armstrong and Seddon 2007).

Bryophytes are important components of ecosystems (Smith 1982; Frego 2007) and could be useful for the reintroduction of *P. tabacum*. Previous studies of bryophytes have mainly focused on taxonomy and have largely ignored their ecological functions (Smith 1982; Ye et al. 2004). Bryophytes have a very strong ability to absorb and retain water and therefore affect water circulation in ecosystems. Bryophytes can also absorb a large quantity of nutrient elements and

therefore affect nutrient cycling (Smith 1982; Wu et al. 2003; Frego 2007). Bryophytes can adapt to various habitats and survive in rocky, desert, and other extreme environments (Foote 1966; Rochefort 2000), where they are important pioneers and primary producers (Hein and Van Tooren 1990). These properties of bryophytes can help the growth of other plants in the same communities. For example, a recent study by Groeneveld and Masse (2007) shows that the bryophyte moss, *Polytrichum strictum*, could facilitate the return of *Sphagnum* species or other boreal plants after disturbances. Our previous study also demonstrates strong relationships between mosses and *P. tabacum* in wild communities (Ren et al. 2010).

In this study, we examined the survival and growth of reintroduced populations of *P. tabacum* to determine whether the reintroductions established self-sustaining populations. We focused on the following questions: (1) Are the historical locations appropriate for reintroduction? (2) How do the reintroduced *P. tabacum* survives and grows compared with wild *P. tabacum*? and (3) What factors influence the growth and survival of the reintroduced plants?

Materials and methods

Study area

This study was conducted at three neighboring caves (caves A, B, and C) at Dixiahe (25°1' N, 112°21' E), Lianzhou City, Guangdong Province, southern China, which collectively delimited the historical and current distribution area of *P. tabacum* (24°59'–25°58' N, 111°98'–113°11' E). The climate is central subtropical monsoon, and the elevation ranges from 130 to 450 m above sea level. The zonal original soil is lateritic, a heavy acid soil. The mean annual temperature is 19.5°C, and the mean annual rainfall is 1,571 mm. The vegetation is dominated by evergreen broad-leaved forests typical of the subtropics. Representative plant families of a climax community include Lauraceae, Euphorbiaceae, and Fagaceae.

Propagation of *P. tabacum* and preliminary experiment and survey

We established an efficient in vitro propagation and plant regeneration system using biotechnology at the

South China Botanical Garden; plantlets were produced with leaf explants (Ma et al. 2007). Before conducting the field experiments, we conducted a preliminary experiment to determine how to increase the survival of transplanted *P. tabacum* plantlets. We transplanted *P. tabacum* plantlets into a planting bed with original soil (from the caves at Dixiahe, Lianzhou City) in the greenhouse of the South China Botanical Garden. We found that survival of plantlets kept in vitro for 8–11 months was increased if the plantlets had a 1-month acclimation period before they were transplanted. During acclimation, the plantlets were grown in a soil mix (sand, vermiculite, limestone, and half original soil) in a wet, shaded environment. A survey of the wild *P. tabacum* population at Dixiahe caves indicated that the density of these wild populations was about 20 individuals/m²; we used this value to guide the planting density used in the experiments.

Experiment 1

Experiment 1 was conducted in three neighboring caves (A, B, and C) at Dixiahe. Cave B was where *P. tabacum* was historically distributed but was now extinct, and caves A and C had *P. tabacum* during this study. At each cave, we established three 1 m × 1 m quadrats along a transect with distance intervals of 3, 15, and 45 m from the entrance of the cave to deep into the cave (three quadrats per cave). A light gradient existed among the quadrats at each cave because the light exposure declined with distance from the cave entrance. The quadrats at cave A were designated A1, A2, and A3 (3, 15, and 45 m from the cave entrance, respectively). A similar terminology was used to describe the quadrats at caves B and C.

Experiment 1 was performed twice (experiment 1A and 1B). For experiment 1A, we used leaf explants from the *P. tabacum* population at cave C for tissue culture on January 2007 and obtained about 4,000 plantlets in vitro in July. A former genetic diversity study (Wang et al. 2008) suggested that *P. tabacum* populations at caves A and C belonged to two pure but different populations. We acclimated these plantlets at the South China Botanical Garden on 25 September 2007 as described earlier. During the acclimation period, 7.2% of the plantlets died from desiccation. The plantlets were transplanted into

the three caves on 26 October 2007 (the dry season). At transplanting, the plantlets were 1.5 ± 0.1 cm in height and 3.0 ± 1.0 cm × 3.5 ± 1.0 cm in crown size. A total of 20 plantlets were evenly spaced in each 1 m × 1 m quadrat. The soil in each quadrat was 50% sterilized soil used for acclimation and 50% original soil. The transplants were watered on day 1 and day 3. The quadrats were not fenced, fertilized, or mulched.

Experiment 1B was identical to experiment 1A except that plantlets were generated with leaf explants from cave A and were transplanted on 16 April 2008 (the wet season). During the acclimation period, 7.9% of the plantlets died from desiccation. The transplants were 3 ± 0.1 cm in height and about 5.0 ± 1.0 cm × 5.0 ± 1.0 cm in crown size.

After transplantation in experiment 1A and 1B, we monitored the survival, and height of all transplants, and inferred the causes of death (i.e., insect defoliation, fungal decay, nutrient deficiency, lack of water, strong radiation). In experiment 1A, data were collected on Dec. 1, 2007; Dec. 31, 2007; Jan. 31, 2008; Feb. 29, 2008; Mar. 10, 2008; May 7, 2008; Aug. 1, 2008; Sept. 1, 2008; Oct. 7, 2008; Nov. 7, 2008; Dec. 7, 2008; and Jan. 17, 2009. In experiment 1B, data were collected on April 16, 2008; May 7, 2008; Sept. 1, 2008; and Jan. 17, 2009.

Experiment 2

To examine the role of mosses on reintroduction, we established six additional 1 m × 1 m quadrats at cave C, three with mosses and no other plants (designated CY1, CY2, CY3) and three without mosses or any other plants (CN1, CN2, CN3). Plantlets were generated with leaf explants from cave C and were transplanted on 26 October 2007. Transplanting procedures were identical to those in experiment 1. As before, quadrat numbers indicated distance from the cave entrance (1, 2, and 3 refer to 3, 15, and 45 m, respectively). We also selected and labeled five similar-sized wild *P. tabacum* individuals close to each of these quadrats; these 15 wild plants were used to compare the growth of wild and transplanted plants. The initial size of labeled wild individuals was similar to that of the transplants. Plants were monitored as described for experiment 1 at all same dates.

Habitat measurements

Because the soils at the cave entrances were very thin, soil samples were randomly collected from five points in each quadrat using a 5-cm diameter soil corer to the soil depth. A composite soil sample of about 0.5 kg from each quadrat was collected. The samples were air-dried and sieved for analysis. We measured soil chemicals including water content (g of water/100 g of dry soil), pH (1:2.5 soil water extracts), N content (decomposed with NaOH, absorbed with boracic acid, titrated with hydrochloric acid), P content (extracted with HCl/NH₄F, analyzed with a spectrophotometer), K content (extracted with CH₃COONH₄, analyzed by atomic absorption spectrophotometry), and soil organic matter (digested with H₂SO₄/K₂Cr₂O₇, titrated with FeSO₄) (Standford and English 1949; Olsen et al. 1954; Institute of Soil Science CAS 1978; MEWAM 1986).

The photosynthetically active radiation (PAR), CO₂ concentration, air temperature, and relative humidity were measured with a Li-6400 Photosynthesis System (Li-COR Co. Ltd., Lincoln, Nebraska, USA) at each quadrat in each cave in July and Oct. 2007, and Jan. and April of 2008. Measurements were taken between 8:00 and 18:00 and on the same dates when photosynthetic rate and transpiration rate of

P. tabacum were measured (unpublished data). The average values of each variable were calculated throughout the day with measurements recorded at hourly intervals at each site.

Results

Cave characteristics

Four plant species were present in cave A and five were present in cave C (Table 1), and most were shade-tolerant species. A moss, *Gymnostomiella longinervis* Broth, was broadly distributed at both caves A and C, and the wild *P. tabacum* always grew under the cover of *G. longinervis*. In contrast, cave B contained no mosses and only one vascular plant species (a liane) (Table 1).

The major environmental conditions at the study sites are listed in Table 1. Soil pH ranged from 7.66 to 7.72. The contents of N, P, K, and organic matter in the soils were relatively low. The PAR densities (between 60.3 and 86.3 $\mu\text{mol m}^{-2} \text{s}^{-1}$) were also low. The soil water content was low and relative humidity was high. The temperature was relatively stable. The CO₂ concentration at the sites was relatively high, ranging from 382 to 401 ppm.

Table 1 Plant species and ecological factors (mean $\pm$ SD) at the three caves

Factor	Cave A	Cave B	Cave C
Plant species present	<i>Pilea notata</i> C. H. Wright <i>Lindasea orbiculata</i> Mett <i>Primulina tabacum</i> Hance <i>Gymnostomiella longinervis</i> Broth	<i>Pueraria phaseoloide</i> (Roxb.) Benth	<i>Pilea notata</i> C. H. Wright <i>Lindasea orbiculata</i> Mett <i>Primulina tabacum</i> Hance <i>Pteris cretica</i> Linn. <i>Gymnostomiella longinervis</i> Broth
Soil water content (%)	9.3 $\pm$ 1.5	7.0 $\pm$ 3.8	8.1 $\pm$ 0.2
pH	7.66 $\pm$ 0.12	7.68 $\pm$ 0.08	7.72 $\pm$ 0.05
P (ppm)	105.93 $\pm$ 64.10	77.27 $\pm$ 1.08	51.98 $\pm$ 2.81
K (ppm)	270.18 $\pm$ 63.01	87.15 $\pm$ 5.12	341.84 $\pm$ 31.89
Soil organic matter (%)	3.77 $\pm$ 0.37	1.84 $\pm$ 0.63	2.82 $\pm$ 0.41
N (%)	0.05 $\pm$ 0.03	0.02 $\pm$ 0.00	0.02 $\pm$ 0.01
PAR ($\mu\text{mol m}^{-2} \text{s}^{-1}$)	65.0 $\pm$ 40.1	86.3 $\pm$ 12.7	60.3 $\pm$ 40.1
Relative humidity (%)	96.0 $\pm$ 2.0	85.3 $\pm$ 1.0	97.0 $\pm$ 2.0
Air temperature (°C)	20.0 $\pm$ 2.1	21.3 $\pm$ 5.0	19.7 $\pm$ 2.0
[CO ₂] (ppm)	398.24 $\pm$ 32.21	364.00 $\pm$ 8.12	400.36 $\pm$ 44.59

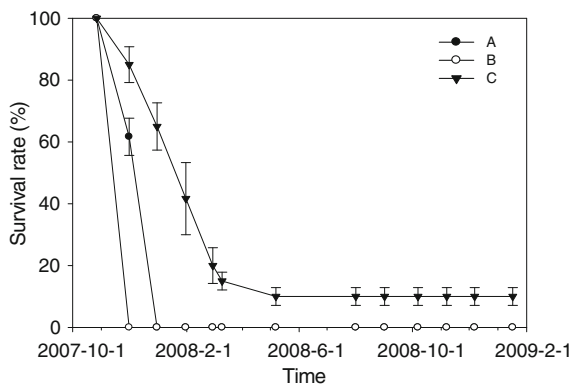


Fig. 1 Survival of transplanted *P. tabacum* at caves A, B, and C (experiment 1A). Values are the means ($\pm$ SD) of the three quadrats in each cave

Survival of *P. tabacum* plantlets in experiment 1

In experiment 1A, all transplanted *P. tabacum* transplants had died after 1 month in cave B and after 3 months in cave A (Fig. 1). The death rate of transplants was high at cave C (quadrats C1, C2, and C3) during the first 5 months, and the survival rate was about 10% thereafter (a total of six individuals survived in the three quadrats); the survival rate in cave C was stable after September 2008 (Fig. 1). At cave C, three of the transplanted seedlings bloomed and produced seeds on 1 September 2008, indicating initial reintroduction success.

In experiment 1A, the possible causes of mortality of the transplants differed somewhat among the caves. Fungal disease, nutrient deficiency, and lack of water accounted for 33, 50, and 17%, respectively, of the

mortality in cave A. Plantlets cave B died from lack of water; note that cave B had strong radiation, low humidity, and no moss. In cave C, fungal disease and defoliation by a larval Noctuidae accounted for 80 and 20%, respectively, of the mortality of the transplants.

When experiment 1 was repeated (experiment 1B), survival was similar, i.e., all transplants died in caves A and B and about 25% of the transplants survived in cave C (Table 2). The causes of mortality were also similar to those in experiment 1A.

Survival and growth of *P. tabacum* plantlets in experiment 2

In cave C quadrats CN1, CN2, and CN3, which lacked moss, all *P. tabacum* plantlets had died by 31 January 2008 (Fig. 2). In cave C quadrats CY1, CY2, and CY3, which had moss, survival initially declined but then stabilized at about 10% after September 2008 (Fig. 2). In quadrats with moss, survival rate was highest in the middle of the cave (CY2), was lowest deep in the cave (CY3), and was intermediate at the cave entrance (CY1) (Fig. 2). Plant height (Fig. 3) in quadrats with moss, however, decreased from the entrance to locations deeper into the cave; in other words, growth of transplants decreased as light decreased. All transplanted plants grew slower than wild plants (Fig. 3).

Discussion

The success of plant reintroduction is case-specific, and there is no substitute for local knowledge of

Table 2 Numbers of surviving *P. tabacum* in experiment 1B

Cave and location	April 16, 2008	May 7, 2008	September 1, 2008	January 17, 2009
A1	20	12	1	1
A2	20	6	0	0
A3	20	6	0	0
B1	20	10	0	0
B2	20	0	0	0
B3	20	0	0	0
C1	20	17	5	5
C2	20	16	6	6
C3	20	15	4	4

On 16 April 2008, 20 plantlets were transplanted into three locations in caves A, B, and C. The number following the cave letter indicates distance from the cave entrance into the cave (1, 2, and 3 = 3, 15, and 45 m, respectively)

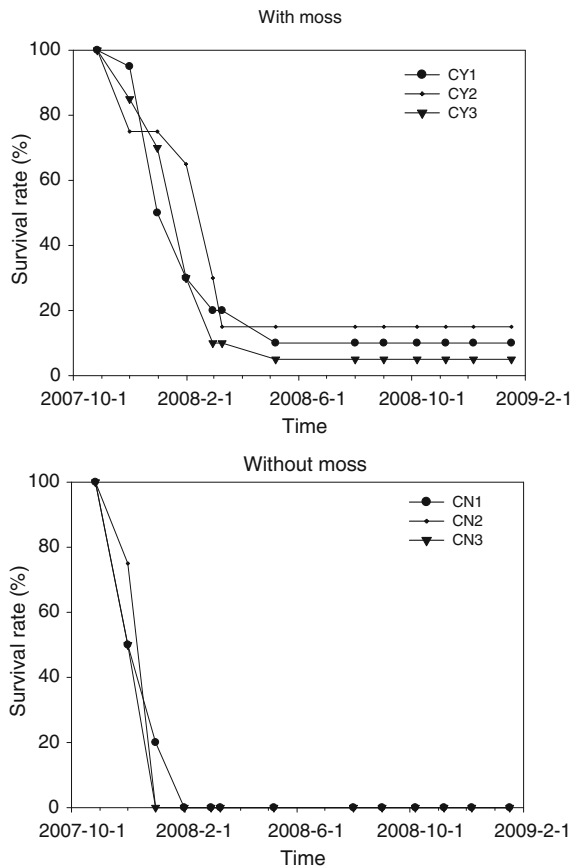


Fig. 2 Survival of transplanted *P. tabacum* as affected by the presence or absence of moss and distance from cave entrance at cave C (experiment 2). CY1, CY2, and CY3 (3, 15, and 45 m from cave entrance, respectively) represent quadrats with moss, and CN1, CN2, and CN3 (3, 15, and 45 m from cave entrance, respectively) represent the quadrats without moss

species and systems. In this study, we show that moss may positively affect the survival and growth of endangered *P. tabacum*, which highlights the importance of restoring essential components of the community/ecosystem as part of restoration ecology and conservation efforts. Previous study showed that, as a nurse plant of *Sphagnum*, *Polytrichum strictum* could maintain the humidity of peatland fragments (Groeneveld and Masse 2007). As a nurse plant, moss may increase the storage and availability of water and nutrients in the *P. tabacum* community. Nurse plants may be highly useful for the reintroduction of rare and endangered plants. The reintroduction of *P. tabacum* in the karst drainage caves in this study appears to have been partially successful in that; more than three reintroduced individuals bloomed

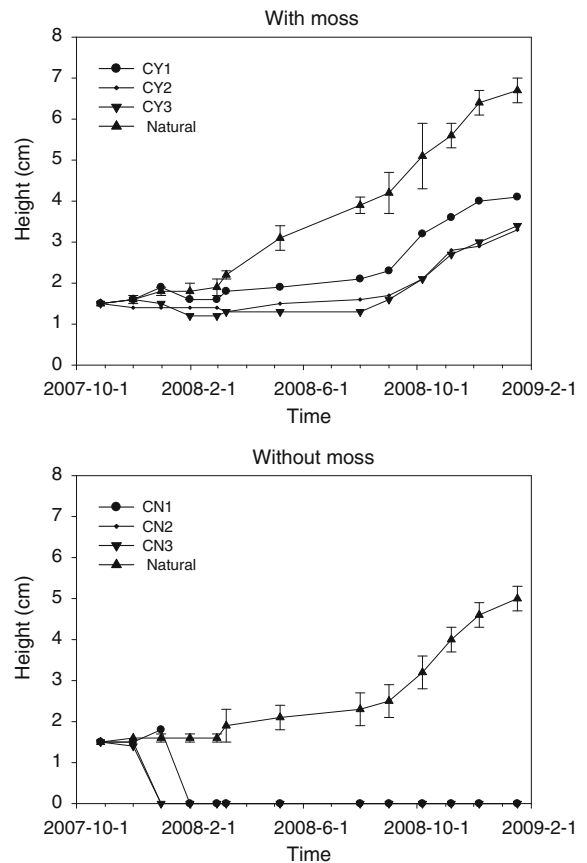


Fig. 3 Height of transplanted *P. tabacum* as affected by the presence or absence of moss and distance from cave entrance at cave C (experiment 2). CY1, CY2, and CY3 (3, 15, and 45 m from cave entrance, respectively) represent quadrats with moss, and CN1, CN2, and CN3 (3, 15, and 45 m from cave entrance, respectively) represent the quadrats without moss. The height of nearby wild *P. tabacum* (five plants per mean) is shown for comparison

and produced seeds at cave C. The causal mechanisms, however, require further investigation and confirmation.

The environmental conditions at the study sites suggest that *P. tabacum* can only grow in alkali and poor soils. It prefers low light, relatively wet soils, and humid habitats (similar to the habitats at caves A and C). *P. tabacum* might be intolerant of highly fluctuating temperatures but be tolerant of relatively high atmospheric CO₂ levels. Our experiments indicate that it is virtually impossible for this rare and endangered plant to naturally colonize and establish at locations where it went extinct. For example in the case of Cave B, the cave has become dryer and

suffered moss extinction because of ecotourism impacts (Ren et al. 2010), the *P. tabacum* population also suffering local extinction.

In our previous reintroduction studies, plantlet growth was greatly affected by microhabitat factors and insect predators (Ren et al. 2003). The results showed that growth stagnancy and nutrient uptaking may result in unusual growth of the transplanted seedlings. However, wild individuals are apparently adapted to such microenvironments. Our current experiment indicates that the best way to conserve rare and endangered plants is by in situ protection. Because the geographic distributions of rare species are likely to shift under global climate change, reintroduction/translocation of such species to similar habitats might become necessary for effective conservation (Dormann 2007).

Our study emphasizes the importance of experimental approaches and historical distribution in identifying microsites suitable for the species. Some *P. tabacum* reintroduction sites are better than others, and some historical locations are no longer suitable for *P. tabacum*. There is still much room to develop better technologies to reduce the mortality of transplants; mortality could perhaps be reduced by irrigation, fertilization, protection against fungal pathogens and insects, and the identification and use of nurse plants. Periodic introductions of nursery-grown individuals could contribute to population stability (Vandenbergh et al. 2009).

Reintroduction of rare and endangered plants is often costly, and the success rate is low. For future successful reintroductions, we need a better understanding of the microhabitats and biotic conditions required for rare plant seedling establishment. Reintroduction success clearly varies with transplanting location, microhabitat, and the number of plants that are transplanted. Subsequent long-term monitoring is required to assess whether the populations are self-sustaining (Buisson et al. 2008), and multiple reintroductions may be necessary. If done with novel genotypes, this can bolster the genetic diversity (Maschinski and Wright 2006; Armstrong and Seddon 2007). In the future, we intend to introduce experimental populations into different sites to increase the probability that populations of rare species persist.

Although light and soil conditions seemed critical for successful transplantation of *P. tabacum*, the presence of the moss *G. longinervis* should serve as a

useful and convenient indicator of suitable habitats for transplantation of this rare herb species. The positive results obtained with *G. longinervis* in this study indicate that nurse plants could be a valuable tool for the reintroduction of rare and endangered herbs. This research will help with the implementation of the “*Globe Plant Conservation Strategy*” in China. In the future, we will determine the physiological mechanisms that underlie successful reintroduction and elucidate why *P. tabacum* tolerates high CO₂ concentrations. Our future research will also consider metapopulation dynamics and ecosystem changes associated with successful and failed attempts at the reintroduction of rare and endangered plants.

Acknowledgments This research was supported by the National Basic Research Program of China (2008BAJ10B03, 2007CB411600) and the Guangdong Sci-Tech Planning Project (07118249, 2008A060207017, 2007A060306011). We thank Mr. Xiao Lei for monitoring, Mr. Guowei Chu for nutrient element analysis, Prof. Li Zhang for moss species identification, Prof. Chonghui Liao for the insect species identification, and Dr. Shijin Li, Dr. Wenjun Duan, Mr. Xiangxu Huang, and Miss Changxin He for fieldwork assistance. We also thank the anonymous reviewers for their valuable comments on an earlier version of the manuscript. Thanks also to Prof. Bruce Jaffee for polishing the English.

References

- Armstrong DP, Seddon PJ (2007) Directions in reintroduction biology. *Trends Ecol Evol* 23:20–25
- BGCI (2003) Global strategy for plant conservation. Botanical Garden Conservation International. www.bgci.org
- Buisson E, Anderson S, Holl KD, Corcket E, Hayes GF, Peeters A, Butoit T (2008) Reintroduction of *Nassella pulchra* to California coastal grasslands: effects of topsoil removal, plant neighbour removal and grazing. *Appl Veg Sci* 11:195–204
- Cao M, Li SJ, Cao LM, Zhang DX (2007) Pollen morphology of three Chinese endemic genera in Gesneriaceae. *Guihaia* 27:669–672
- Dormann CF (2007) Promising the future? Global change projections of species distributions. *Basic Appl Ecol* 8:387–397
- Flora of China Editorial committee (1990) *Flora of China*, vol 69. Science Press, Beijing
- Footo KG (1966) The vegetation of lichens and bryophytes on the limestone outcrops in the driftless area of Wisconsin. *Bryologist* 69:265–292
- Frego KA (2007) Bryophytes as potential indicators of forest integrity. *For Ecol Manag* 242:65–75
- Gibbs JP, Marquez C, Sterling EJ (2007) The role of endangered species reintroduction in ecosystem restoration:

- tortoise-cactus interactions on Espanola island, Galapagos. *Restor Ecol* 17:1–6
- Godefroid S, Vanderborght T (2009) How successful are plant species reintroductions? Conference abstracts of SERI 2009 world conference on ecological restoration. Perth, Australia, p 163
- Griffith B, Scott JM, Carpenter JW, Reed C (1989) Translocation as a species conservation tool: status and strategy. *Science* 245:477–480
- Groeneveld EVG, Masse A (2007) Rochefort L *Polytrichum strictum* as a nurse-plant in peatland restoration. *Restor Ecol* 15:709–719
- Hance D (1883) *Primulina tabacum*. Hance. *J Bot* 21:169
- He KJ, Li YD (2005) Plant resources of national protection grade I in Guangdong Province. *J Trop Subtrop Bot* 13:519–525
- Hein JD, Van Tooren BF (1990) Bryophyte interactions with other plants. *Bot J Linn Soc* 104:79–98
- Institute of Soil Science CAS (1978) Soil physical and chemical analysis. Shanghai Technology Press of China, Shanghai
- IUCN (1998) Guideline for reintroductions. Prepared by IUCN/SSC re-introduction specialist group. IUCN. www.iucnsscrsg.org
- Kleiman DG (1989) Reintroduction of captive mammals for conservation. *Bioscience* 39:152–161
- Li SJ, Zhang DX, Zhang RQ (2006) The pollination of rare and endangered plant *Primulina tabacum* Hance. In: Proceedings on the 9th systematic and evolution symposium in China. Xi'an, China, p 58
- Ma GH, Ren H, Zhang QM, Li SJ (2007) The tissue culture propagation and wild planting of *Primulina tabacum* Hance. Chinese Patent ZL 200710030266.0. 26 Mar 2007
- Maschinski J, Duquesnel J (2006) Successful reintroductions of the endangered long-lived Sargent's cherry palm, *Pseudophoenix sargentii*, in the Florida Keys. *Biol Conserv* 134:122–129
- Maschinski J, Wright SJ (2006) Using ecological theory to plan restorations of the endangered Beach jacquemontia (*Convolvulaceae*) in fragmented habitats. *J Nat Conserv* 14:180–189
- MEWAM (1986) Methods for the determination of metals in soils, sediments and sewage sludge and plants by hydrochloric-nitric acid digestion. Methods for the examination of waters and associated materials. Her Majesty's Stationary Office, London
- Ni XW, Wu L, Huang YL, Zhou RC, Shi SH (2006) Genetic diversity of the endangered Chinese endemic herb *Primulina tabacum* (Gesneriaceae) revealed by amplified fragment length polymorphism (AFLP). *Genetica* 127:177–183
- Ollero HS, Bermejo JEH (1979) Experimental reintroductions of endangered plant species in their natural habitats in Spain. *Biol Conserv* 16:195–206
- Olsen SR, Cole CV, Watanabe FS, Dean LA (1954) Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA Circ. 939. USDA, Washington, DC
- Peng SL, Cheng WC (2002) Rare and endangered plants in Guangdong. Science Press, Beijing
- Ren H, Peng SL, Zhang DX, Jian SG (2003) The ecological and biological characteristics of an endangered plant, *Primulina tabacum* Hance. *Acta Ecol Sin* 23:1012–1017
- Ren H, Zhang QM, Wang ZF (2010) Community ecology knowledge for conservation through possible re-introduction: a case study of a rare plant *Primulina tabacum* Hance in China. *Plant Species Biol* 25:43–50
- Rochefort L (2000) Sphagnum a keystone genus in habitat restoration. *Bryologist* 103:503–508
- Sarrazin F, Barbault R (1996) Reintroduction: challenges and lessons for basic ecology. *Trends Ecol Evol* 11:474–478
- SER (2002) The Society for Ecological Restoration (SER) primer on ecological restoration. SER. www.ser.org
- Smith AJC (1982) Bryophyte ecology. Chapman and Hall, London, pp 59–104
- Standford S, English L (1949) Use of flame photometer for analysis of Na, K and Ca. *Agron J* 41:446–447
- Vandenbergh C, Smit C, Pohl M, Buttler A, Freléchoux F (2009) Does the strength of facilitation by nurse shrubs depend on grazing resistance of tree saplings? *Basic Appl Ecol* 10:427–436
- Vittoz P, Wyss T, Gogot JM (2006) Ecological conditions for *Saxifraga hirculus* in central Europe: a better understanding for a good protection. *Biol Conserv* 131:594–608
- Wang ZF, Ren H, Zhang QM (2009) Isolation and characterization of microsatellite markers for *Primulina tabacum*, a critically endangered perennial herb. *Conserv Genet* 10:1433–1435
- Wu YH, Chen GD, Gao Q (2003) Bryophyte's ecology functions and its significances in revegetation. *J Desert Res* 23:215–220
- Ye J, Hao ZQ, Yu DY, Yan HB, Feng DQ (2004) Research advances in bryophytes ecological function. *Chin J Appl Ecol* 15:1939–1942