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RESEARCH PAPER

Conservation ecology of endangered species *Paphiopedilum armeniacum* (Orchidaceae)

Liu Zhongjian[1], Liu Kewei[2,3], Chen Lijun[1], Lei Sipeng[1], Li Liqiang[1], Shi Xiaochun[4], Huang Laiqiang[2,*]

1 *The National Orchid Conservation Center, Shenzhen 518114, China*
2 *The Center for Biotechnology and BioMedicine, Graduate School at Shenzhen, Tsinghua University, Shenzhen 518055, China*
3 *School of Life Sciences, University of Science & Technology of China, Hefei 230027, China*
4 *Yunnan Gaoligongshan National Nature Reserve Bureau, Baoshan 678000, China*

Abstract: *Paphiopedilum armeniacum* is an endangered orchid species, endemic to China. During the period of April 2000 to October 2005, 66 observation sites were selected in Luoshapo of Nushan Mountains in Yunnan, China, to carry out the conservation ecological research on *P. armeniacum*. A total of 443 genets (1302 ramets in total) of *P. armeniacum* were sampled, their biological characteristics such as reproductive pattern, phenology, and life cycle were observed, and the ecological habits of the species such as the habitat and the structure of communities were studied. Experiments on ex-situ conservation were conducted, and the cloned ramets were replanted to their original habitat after ex-situ reproduction in Shenzhen, Guangdong, China. The relationships between *P. armeniacum* and climate, vegetation, other environmental factors in the original habitat, and the biological characteristics of asexual offsprings of *P. armeniacum,* which were replanted to the original habitat after ex-situ cultivation and reproduction, were investigated. The studies show that *P. armeniacum* in Luoshapo grows very well in secondary shrub boskets or in tussocks on limestone hills. It has both sexual and asexual reproduction. Asexual reproduction serves to complete the sexual reproduction and to extend the lifetime of genets, while it does not reduce sexual reproduction. There are two modes of asexual reproduction—by tillering or by producing rhizomes. The litter of shrub boskets or tussocks provides *P. armeniacum* with humus, and the rhizome reproduction of *P. armeniacum* is an adaptation to the litter-covered condition, i.e. to escape from the unfavorable environment. Blooming rate of ramets is 7.39% ± 1.02%, and fruit set rate from the blooming ramets is 32.23% ± 12.08%. *P. armeniacum* is able to invade the moderately destroyed forests and those in early restoring but is unable to grow in large dense forests. *P. armeniacum* also grows very well in artificial spare woods in Shenzhen and can reproduce many cloned ramets, which can normally bloom and yield fruits after being replanted to the original habitat. The results of this study show that *P. armeniacum* can be conserved by ex-situ conservation and by replanting the ex-situ reproduced ramets to original habitat. On the basis of the analysis of endangered mechanisms of *P. armeniacum*, it can be concluded that *P. armeniacum* has strong capability of both asexual and sexual reproductions, and an emergency mechanism consisted of massive production of rhizomes to cope with damage. Because highly effective pollinating insects that facilitate pollination in *P. armeniacum* are present in the habitat, flowering ramets produce fruits with large quantity of seeds, many of which in turn grow into new genets that can reproduce many cloned ramets. *P. armeniacum* makes very effective use of its environment and has distinct characteristics of enduring harsh environmental conditions; therefore, rather than its own inherent biological defects, the main threats facing this species are the destruction of its survival space and the wipe-out collecting of the plants as a result of trading. Based on the analysis mentioned above, certain appropriate strategies have been proposed for the conservation of *P. armeniacum*.

Key Words: *Paphiopedilum armeniacum*; environment; reproduction; life cycle; endangered mechanism; ex-situ conservation; replant to original habitat; conservation strategy

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*Corresponding author. E-mail: huanglq@sz.tsinghua.edu.cn

The entire wild orchids in the world are protected by *Convention on International Trade in Endangered Species of Wild Fauna and Flora* (CITES) and about 90% of all the plant species are under the conservation[1]. The study and conservation of wild orchids in China play an important part in the study and conservation of orchids worldwide. In both in-situ and ex-situ conservations, the integrated application of novel techniques and methods such as habitat resumption, plant reintroduction, and rejuvenation form the core of conservation strategies. Such undertakings involve integrated studies of the biological characteristics, community biology, ecology, and reproduction biology of orchids, and provide a scientific basis for the conservation strategies of wild orchids. At present, study on wild orchids in China still focuses particularly on taxology and system studies, whereas conservation research is still in the primary phase[1].

The conservation of wild orchids is such a complex issue that it depends not only on the development of education and economy but also relatively more on the biological characteristics of orchids[2]. In recent years, there have been studies on the biological embranchment of certain species in some genera, but the conditions of the plants themselves, especially the biological factors that lead to the extinction of wild orchids, remain poorly understood[2].

Studies on life cycle and history of wild orchids can help understand the habitat in which the species survive and the environmental conditions are most desirable for different life stages of the species, thus enabling effective management of wild orchids. Although such studies have been reported with certain species[3−5], quite limited knowledge is available, especially on the lifespan of individual orchids in the natural habitat, and therefore ex-situ conservation in the real sense has not yet been initiated[1]. Therefore, conducting mass reproduction and reintroduction studies is presently among the most urgent and important tasks with regard to the conservation of wild orchids in China.

The genus of *Paphiopedilum* Pfitz (slipper orchids) is one of the most valuable taxa of orchids that are grown for ornamental purposes, and it grows mainly in China. Due to excessive collection, rampant smuggling export, and destruction of habitat, the quantity of beautiful orchids have decreased sharply in recent decades and are on the verge of extinction[1,6−8]. To date, there have been many short-term investigations on wild species of *Paphiopedilum* in China[1−17], but no long-term and detailed on-site studies have been reported except on *P. purpuratum* — a species growing on non-karst land[18].

P. armeniacum Chen et Liu, a species that has been found recently, is a *Paphiopedilum* species endemic to China[19]; it is an attractive and popular plant worldwide and has won the highest Golden Awards and First Class Certificate (FCC) in many international flower exhibitions and orchid exhibitions[2]. Thus it is necessary and highly significant to study its distribution, structure of its community, pollination biology and conservation biology. In the present extensive studies aimed at understanding the conservation biology of *P. armeniacum*, site-specific observations have been carried out; biological characteristics have been determined; ex-situ conservation, artificial breeding, and reintroduction experiments on wild *P. armeniacum* native to Luoshapo Mountain of Lushui County, Yunnan Province, China have been conducted; mechanisms leading to its extinction have been analyzed; certain conservation measures have been put forth.

1 Geographic location and climate of observation and experiment sites

The site for studying the habitat of *P. armeniacum* is located in Luoshapo Mountain, Laowo village of Lushui County, Yunnan (99°03′E, 25°54′N), where the climate type is a subtropical upland monsoon. The site for ex-situ conservation is at The National Orchid Conservation Center in Wutongshan Mountain in Shenzhen, Guangdong, China (114°10′E, 22°35′N), with subtropical ocean climate. The perennially dominant wind comes from southeast. The site is often affected by typhoons in the summer[22]. Climatic parameters in the native and ex-situ sites are summarized in Table 1.

During the observation in Luoshapo Mountain, the daytime temperature range was 10℃ (recorded at 6:00 a.m.) to 46℃ (recorded at 16:00 p.m., the temperature of the earth's surface under sunlight), and the humidity was 12% (day) to 100% (night). Sometimes it snows during the winter. The pedogenic parent rock in this site is composed chiefly of weathering limestone, and the solum is barren. The shallow surface layer consists of some soil mostly on top of limestone pieces, 1–2 cm in diameter. The slope is 60–70° (90°). Under sunshine,

Table 1 Climatic parameters of native and ex-situ sites

Site	Alt. (m)	Average tem. (℃)			Extreme tem. (℃)		Annual Frost-free (d)	Annual rain (mm)	Less rain season	Rainy season	Annual sunshine (h)	High tem. season	Low tem. season
		Annual	Coldest month	Hottest month	Max.	Min.							
In-situ	1700–2150	15.1	9.1	19.6	31.8	0.6	282	1213	Nov. – May	Jun. – Oct.	2045	Jul.–Aug.	Dec. – Feb.
Ex-situ	30–50	22.4	14.1	28.2	38.7	0.2	355	1883	Oct. – Mar.	Apr. – Sep.	2120	Jun.–Sep.	Dec. – Feb.

the air is heated, rising and forming mountain breeze.

2 Methods

2.1 Biological characteristics

2.1.1 Habitat and growth

During April and June 2000, 40 sampled sites (1 m × 1 m) were randomly selected for habitat and growing conditions of research from the growing area of *P. armeniacum* in Luoshapo Mountain to count the number of genets in each site, observe the habitat (community canopy density, plants, and landform), and record the growth condition (soil condition), the growing behavior (with or without environmental stress), the spreading of roots (depth, spreading direction, and extent) of each genet. Specimens of plants in each site were collected for identification and analyses.

2.1.2 Blossom and fruit

During May and June 2001, 8 sites (2 m × 2 m), located at an altitude ranging from 1700 m to 2150 m and spaced apart by an altitude of 50 m, were selected and observed at three time points: the first was in the blooming period, the second after the florescence, and the third during the fruit-ripening period. The following messages were recorded: the cloned form and size of each genet, and the blossom state and the quantity of fruits which could successfully produce seeds after natural fertilization in each sample. During May and September 2004, flowering ramets were randomly selected and marked for observation to verify the results.

2.2 Characteristics of asexual reproduction

During the observation of blossoms and fruits, the asexual reproduction of *P. armeniacum* was also simultaneously observed in each site, and the pattern, quantity, and growth process of cloned ramets of each genet were recorded.

2.3 Ex-situ tests on biological characteristics and the modes of asexual reproduction

During May 2001, the 120 genets selected randomly from original habitat in Yunnan were transported to Shenzhen and planted (divided into 4 groups, 30 genets each, n = 30) in the artificial spare woods (canopy density of 0.4–0.6 and good drainage) and in the large, dense forest (canopy density of nearly 1 and good drainage). Two groups of 30 cm × 30 cm were planted in the artificial spare woods by embedding the whole root but exposing the sheath basal, and then one of the two groups was covered with humus up to the region of the leaves (deep-buried group, n = 30), whereas the other without any treatment (shallow-planted group, n = 30). The other two groups were planted in the dense forest in the same way as in the spare woods. The growth and breeding of *P. armeniacum* in each treatment were then observed.

2.4 Observation of life cycle

During May 2001, 10 fruiting genets were randomly selected from Luoshapo Mountain and 10 sampled plots (50 cm × 50 cm) were set up, with each genet in the center (n = 10). The soil was dug loosely to check in detail and confirm that there was no protocorm, and then the dug area was again filled with the soil. After fruits had split, the processes of seed germination, growth and development, blossom, fruiting, tillering and withering of *P. armeniacum,* and its germination capacity were observed and recorded to determine its life cycle.

2.5 Ex-situ conservation and reintroduction

To check the growing state of *P. armeniacum* in the ex-situ site and in the original habitat after reintroduction, 10 genets were collected (during the flowering stage but not during fruiting) from each sampled site during May 2000, and were transferred as bare-rooted genets to the ex-situ site, The National Orchid Conservation Center in Shenzhen. The genets from each sampled site were then divided into 2 groups (an average of 5 genets in each group) for the asexual reproduction test. One group was cultured in a pot (n = 8, and 40 genets in total), and the other was directly planted in the sandy soil (n = 8, and 40 genets in total). The number of reproduced ramets was counted during May 2001 and 2002. For reintroduction experiments, the newly formed ramets from each pot were transported back to the native habitat, separately planted during April 2003 in the original sampled site (n = 8), with 20 ramets (genet with a single bud) in each site, and watered once. Their growing and blooming stages were monitored and recorded in May and October in both 2004 and 2005.

2.6 Destruction caused by human activities

For the assessment of human impact on *P. armeniacum*, its distribution area was regularly inspected and the local flower markets and nurseries in the Nushan Mountain region were visited by the authors to investigate the collecting, trading, and other destruction activities brought about by human beings to the wild *P. armeniacum*.

3 Results and analyses

3.1 Biological characteristics

3.1.1 Vegetation and community

The vegetation of the wild research area is secondary broadleaf shrub boskets and tussocks, and the vegetation distribution is fasciculate and is compartmentalized by limestone. The shrub boskets are 1–1.5 m tall, and the canopy density is 70%–90%. Because of the slope and the rock gap, the setting sun shines over the area. Plants in the research site include shrubs: *Rhododendron yunnanense* Franch., *Q. gilliana* Rehd. et Wils, *Traillliaedoxa gracilis* W. W. Smith et Forr, *Campylotropis polyantha* (Franch.) schindl, *Q. guyavaefolia* Levl, *Q. acutissima* Carr, *Castanopsis delavayi* Franch., *Q. fannosa* Hand. -Mazs, *H. beanie* N. Robson, etc; herbs: *Carex longipes* D. Don, *S. delavayi* (Hack.) Bor, *C. drepanarhyncha* Frand, *Osyris wightiana* Wall. ex C. H.Wright, *Shiraea myrtilloides* Rehd, *Leptodermis scissa* H. Winkl, etc; Orchideace: *Cymbidium faberi* Rolfe, *C. tortisepalum* Fukuyama, *C. goeringii* var. *serratum* Y. S. Wu et S. C. Chen, *C. cyperifolium* var. *szechua-*

nicum S. C. Chen et Z. J. Liu, *Cyperipedium plectrochilum* Franch, etc.

3.1.2 Habitat and growth characteristics

P. armeniacum grows mostly on the northeast of a mountain, entirely terrestrial with blocky distributions in bosk, tussock, bare slope, and rock gap. It has the gregarious characteristic and the density is (29.75 ± 5.93) ramets/m^2 (n = 40). *P. armeniacum* grows more densely in those communities with *Quercus* and herbaceous plants and with *H. beanni* nearby or on rock surface close to these plants. It grows thick and rapidly in places with dense forests and soft gradient. *P. armeniacum* can grow in forests with 0–90% canopy density, endure strong sunlight or grow in forests (with steep slope) with high canopy density with setting sunlight; however, it has never been found in dense forests of large trees, moist and flat lands with puddles or mountains whose altitude is greater than 2250 m.

The shrubbery in the habitat is alpine deciduous plant, xerophil, with thick cutin on leaves, which will become humus and whose hard-to-decay veins and spines can keep the humus loose. The herbaceous plants can hold the humus by their roots and hold the seeds to prevent from flowing with water; therefore, the seeds can germinate in the rich humus. Therefore, *P. armeniacum* mostly grows on rock surfaces with more humus in bosk or tussock and where a rivulet is blocked. Some *P. armeniacum* can grow on and along the nearly upright crags, some in shallow holes of limestone, and some on bare limestone with little humus in the lacunose surface.

P. armeniacum growing in different, small habitats has no obvious difference in the growth and size of ramets; however, those on bare rock surface or on crags have yellowish and wizened leaves because of lack of water during the dry seasons, and in severe cases, some leaves dry out or leaf apex is sun-burned. However, no plants died from drought, and no plants were found harmed by snow or frost.

The roots of *P. armeniacum* spread shallowly, mainly on the top of humus of crush rocks, about 1–2 cm deep and no more than 5 cm. The transverse extension is wider but asymmetrical: developed better and outspread more widely on the richer side of humus, 2–3 times wider than the plant's coverage area. Even so, *P. armeniacum* can be easily pulled out because of its weak adherence to the ground.

P. armeniacum has the abilities of self-reintroduction into nature and of self-rejuvenation. For instance, there are mass *P. armeniacum* plants growing on the surface of artificial slope and trench (at an altitude of 1900m) dug in 1984 at the site that was built for a hydraulic power station, and many small, well-developed *P. armeniacum* communities on the remnant wall of an abandoned temple at an altitude of 2130 m. In addition, there are dense and well-developed genets of *P. armeniacum* in thick tussocks of destroyed vegetation, which have undergone several asexual or sexual generations.

3.1.3 Blooming and fruiting

In the 8 selected sites, the blooming behavior of totally 1302 ramets of 443 genets were observed. The ramets began blooming over the last 10 days of April, fully bloomed over the first 10 days of May and completed blooming over the first 10 days of June. Fruits matured from the second 10 days of September to early October. The duration of blooming without insect pollination was (31.2 ± 4.7) days (n = 30). The blooming stages at each site from 3 observations of 10 May, 10 June and 8 October 2001 are summarized in Table 2.

Eighty-six sampled flowers were randomly selected on 1 May 2004, of which 32 flowers (37.21%) were fertilized and fruited on 16 June, and the other 54 flowers dried out and fell off; by 20 September there were 28 matured fruits, equivalent to 32.56% of the sampled flowers that transformed into fruits. These results were similar to those from the 8 sampled sites.

The flowering period of *P. armeniacum* fluctuates markedly, which depends largely on the onset of the rainy season: *P. armeniacum* germinates alabastrum in autumn and in dry winter, and the alabastrum remains in dormancy, ending its dormancy when spring rain arrives, after which its stalk elon-

Table 2 Blooming of *P. armeniacum* at eight sites

Site no.	Alt. (m)	Quantity		Quantity of blooming or fruiting ramet			Quantity of unsuccessfully blooming ramet		∑	Rate of blooming (%)	Fruit quantity	Fruit set rate (%)
		Genets	Ramets	Flowering	Budding	Fruiting	Destroyed by insects	Fading in bud				
01	1700	52	146	2	3	3	1	1	10	6.85	5	50.00
02	1750	55	163	2	2	4	2	2	12	7.36	6	50.00
03	1800	56	171	3	4	4	1	2	14	8.19	4	28.57
04	1850	59	178	4	3	4	2	1	14	7.87	5	35.71
05	1900	51	149	3	2	2	1	0	8	5.37	2	25.00
06	1950	53	145	2	3	3	1	1	10	6.90	2	20.00
07	2000	62	186	4	2	5	2	2	15	8.06	3	20.00
08	2150	55	164	6	4	4	0	0	14	8.54	4	28.57
∑		443	1302	26	32	29	10	9	97	59.14	31	257.85
$\overline{x}$		55.38	162.75	3.25	2.88	3.63	1.25	1.13	12.13	7.39	3.88	32.23
±SD		±3.66	±15.25	±1.39	±0.83	±0.92	±0.71	±0.83	±2.53	±1.02	±1.46	±12.08

gates and it blooms; if spring is dry, the florescence will be delayed. Each *P. armeniacum* ramet can blossom only once in its life cycle and does not germinate any more after its first germination, regardless of whether the first germination leads to successful blossom.

3.2 Characteristics of asexual (cloned) reproduction

There are two modes of asexual (cloned) reproduction in *P. armeniacum*: by tillering new plants from the ramet basal, and by producing rhizomies from the ramet basal and breaking the ground to grow into new plants.

Tillering reproduction is the usual mode of asexual reproduction of normally growing genet: a ramet will bloom when it reaches the 3–6-leaved stage, after which the tillering bud will form from the sheath basal. The tillering bud will in turn germinate alabastrum when it grows 3–6 leaves. One genet may grow 2 or 3 tillering buds at the same time, and the ramets in fasciculate genet with several buds will all germinate tillering buds after blooming. Ramets without sexual phase (post-blooming) usually do not have tillering reproduction.

P. armeniacum has very strong capability of rhizomic reproduction. After being covered by shatter and earth, the genet basal will germinate rhizome, which exhibits apical dominance and gradually develops that it can break the covering, extends to unthread the covering and then grows into a new individual. The length of rhizome ranges from 3–5 cm to 10–15 cm, which depends on the covered depth. One genet can have several rhizomes, each of which can grow into new plants. The rhizome will grow sheath and leaves after breaking the covering and grow new roots from the sheath basal to form a new individual. The rhizome will rot and wither after the apex has grown into new ramet, which will detach from the mother plant to become a new, independent individual, and the mother genet will die by being covered. Seriously covered genets will die because the rhizomes can not unthread the covering. Uncovered genets can only grow tillering buds but not rhizomes. Genets which are pulled out or washed out by rain and placed on the ground surface will grow rhizome in the wet and shady conditions. The individuals developing from rhizomic reproduction will mature and bloom in 2 years.

3.3 Ex-situ tests of biological characteristics and the mode of asexual reproduction

After one month in the artificial spare woods, the living genets of shallow-planted group (SPG) all grew tillering buds and those of deep-buried group (DBG) all grew rhizomes. Results of reproduction modes under different treatments are summarized in Table 3. The quantity of tillering buds had obvious difference between shallow-planted group and deep-buried group (t = 2.971, df = 58, p < 0.001), so did the quantity of rhizomes (t = 3.082, df = 58, p < 0.001). The results show that the production of rhizome is highly correlated with the degree of overlay on genets, which is consistent with the result of research on the wild plant.

The genets in dense forest (DF) or in spare forest (SF) all grew new buds or rhizomes in a month, but the buds or rhizomes in dense forests were etiolated, weak and gradually withered. The survival rates with respect to the treatments are shown in Table 4. The survival rate of genets in the spare forest and in the dense forest (n = 30) had obvious difference (t = 3.551, df = 58, p < 0.001), which indicates that *P. armeniacum* can grow well in the spare forest but not in the dense forest of large trees; such results were consistent with the observation made on the wild population.

3.4 Life cycle

In the last 10 days of September 2001, all fruits of the 10 sampled plants had split and scattered seeds; in June 2002, the seeds grew into protocorms of 1.5 cm diameter, which produced underground stems unthreading the earth; in July 2002, the apex bud of underground stems started to grow leaves and had 2–3 leaves till October 2002. On average, there were (2.3

Table 3 Reproductive mode (RM) of *P. Armeniacum* in SPG and DBG in spare forest

Group	RM	Sample no.																														$\overline{x}$ ±SD
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
SPG	Tiller	1	2	3	2	1	3	3	2	1	3	2	2	2	1	2	3	2	1	3	2	2	2	2	1	1	1	2	3	3	3	2.03±0.76
	Rhizome	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DBG	Tiller	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Rhizome	2	3	4	5	2	3	4	3	4	3	2	3	3	1	2	4	3	3	2	2	3	3	2	2	3	3	4	2	1	3	2.80±0.92

Table 4 Statistic of *P. armeniacum* viable rate cultivated in DF and SF

Sample no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	$\overline{x}$ ±SD
SF	100	0	100	100	0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	93.33%±25.37%
DF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

± 1.3) genets (n = 10) in each sampled plots. By May 2003, each genet had 4–6 leaves; 8 genets had bloomed during May to June 2004, 3 of which had fruited; during May to June 2005, 15 genets bloomed, 6 of which had fruited. All ramets started to grow tillering buds after florescence and fruiting. Some strong genets via artificial culture may grow 1–2 tillering buds from the ramet basal after germinating alabastrum.

It would take 1–4 years for *P. armeniacum* genet to grow from the budding stage to the stage when all the leaves senesce, leaving behind remnant stems; however, the growth period varies considerably among individuals. When the tillering bud emerges from the mother ramet in spring it could have 4–5 leaves in the same year; some new tillering buds could not bloom normally in case of damage of the apex by insects, and so they would grow new tillering buds during that autumn. Generally, *P. armeniacum* can only germinate tillering buds once a year; when it has 4–5 leaves or more, its vegetative growth will stop and differentiation of alabastrum occurs. Ramets would bloom in 1–2 years, then germinate tillering buds and gradually senesce and wither away, but the underground stems could survive for years which, when artificially divided, would germinate tillering buds again and grow into new genets. The quantity of tillering buds and the senescence of ramets from sexual reproduction are dependent on the microenvironment: under favorable conditions, ramets could have 4 generations, whereas under unfavorable conditions, they would wither after one generation. A genet typically maintains 2 or 3 cloned ramets.

3.5 Ex-situ conservation and wild reintroduction

3.5.1 Ex-situ conservation

Potted *P. armeniacum* could grow many rhizomes or tillering buds in the first year, bloom in 2 years, and fruit and produce seeds by artificial crossing or self-pollination; ramets would germinate tillering buds after blooming. *P. armeniacum* planted on the ground in forests showed the same results as the potted *P. armeniacum*. The results of the reproduction under different planting conditions at the ex-situ site are shown in Tables 5 and 6. The results show that *P. armeniacum* plants, either planted in pots or in earth, are able to reproduce by both asexual and sexual modes at ex-situ site, indicating that *P. armeniacum* can be ex-situ conserved or mass-reproduced.

3.5.2 Reintroduction

The data on the growth and blossom of *P. armeniacum* plants reintroduced to the native habitat are shown in Table 7. By the statistics of 2004, the survival rate of genets after rein-

Table 5 Reproductive state of cultivated potted *P. armeniacum* in eight sites

Site no.	Quantity of genet	Quantity of cloned ramet		Quantity of cloned ramet		∑	Growth rate(%)
		Tiller	Rhizome	Tiller	Rhizome		
01	5	0	15	2	0	22	340
02	5	1	8	1	1	16	220
03	5	2	12	3	0	22	340
04	5	3	4	1	2	15	200
05	5	0	14	2	0	21	320
06	5	0	18	3	0	26	420
07	5	2	9	2	1	19	280
08	5	1	8	2	0	16	220
∑	40	9	88	16	4	157	292.50
$\bar{x}$ ±SD	5±0	1.13±1.13	11±4.57	2±0.76	0.5±0.76	19.63±3.81	292.5±76.30

Table 6 Reproductive state of cultivated *P. armeniacum* in forest of eight sites

Site no.	Quantity of genet	Quantity of cloned ramet		Quantity of cloned ramet		∑	Growth rate(%)
		Tiller	Rhizome	Tiller	Rhizome		
01	5	0	15	2	1	23	360
02	5	1	8	1	2	17	240
03	5	2	12	2	0	21	320
04	5	3	4	3	0	15	200
05	5	0	14	2	0	21	320
06	5	0	18	1	1	25	400
07	5	2	9	2	1	19	280
08	5	1	8	1	1	16	220
∑	40	9	88	14	6	157	292.50
$\bar{x}$ ±SD	5±0	1.13±1.13	11±4.57	1.75±0.71	0.75±0.71	19.63±3.50	292.5±70.05

Table 7 Growing and flowering stages of *P. armeniacum* replanted in original habitat

Site no.	Quantity of replanted genet	2004				2005			
		Quantity of viable genet	Quantity of cloned ramet	Quantity of flowering ramet	Quantity of fruiting ramet	Quantity of cloned ramet	Quantity of flowering ramet	Quantity of fruiting ramet	Fruit set rate (%)
01	20	11	31	5	1	36	8	3	37.50
02	20	7	12	1	0	15	3	1	33.33
03	20	9	20	3	1	22	7	3	42.86
04	20	4	28	4	2	28	7	2	28.57
05	20	6	11	2	1	14	3	1	33.33
06	20	8	16	1	0	18	5	2	40.00
07	20	12	20	6	2	23	6	1	16.67
08	20	4	7	1	1	10	3	1	33.33
∑	160	61	145	23	8	166	42	14	265.60
$\overline{x}$ ±SD	20±0	7.63±2.97	18.13±8.34	2.88±1.96	1±0.76	20.75±8.40	5.25±2.05	1.75±0.89	33.20±8.04

troduction was 38.13% ± 13.91% (n = 8). The living genets could normally grow and bloom in wild and their blooming rate is 14.38% ± 9.16% (n = 8). *Eristalis lenax*, *Ceratina morawitzi* and *Lasioglossum pronotale* were found to pollinate the flowers of *P. armeniacum*; the flowers produced fruits, and the fruiting rate of the blooming ramets is 35.83% ± 30.31% (n = 8). In 2005, the blooming rate was 26.25% ± 9.60% (n = 8). The results show that there is no significant difference between the fruiting rate of the wild plants and that of the ramets reintroduced to the original habitat, which was obtained as a result of artificial asexual reproduction ex-situ (t = 0.1878, df = 14, p = 0.8537).

3.6 Stage of destruction

The destruction of *P. armeniacum* habitat is mainly attributed to the growing space deprivation by land exploitation and utilization such as maize planting, over-pasturing, and natural vegetation being logged, which results in the distribution of *P. armeniacum* as small communities in a small habitat. Such problems are more serious in low mountainous areas.

Another kind of destruction is the wipe-out collecting of *P. armeniacum,* which is of high ornamental value because of its beautiful dappled leaves, large colorful flowers, and long florescence. Because of the failure of tissue culture of *P. armeniacum*, the plants in markets and nurseries are of wild origin, which has havoced the conservation of the species. *P. armeniacum* plants were found for sale in nearly all the flower markets around its habitat; unfortunately, some people join hands with some foreigners to smuggle out the wild plants with alabastrum, which results in the decrease in the quantity of flowering plants and thereby reduce the sexual reproduction of *P. armeniacum*.

4 Discussion

4.1 Discussion of biological characteristics

P. armeniacum has some biological characteristics suitable for ex-situ and in-situ conservations; it can grow in environments of high temperature (31–38℃) and low temperature (0.2–0.6℃), rain and drought, and high altitude and low altitude, both in original habitat and ex-situ conservation site, which reflects that this species has a great adaptability to the climate and the habitat, indicating that it is amenable to ex-situ conservation and it plays an important part in its ecological evolution. *P. armeniacum* is the vanguard plant in vegetation recovery; it could resuscitate synchronously with the vegetation recovery when the destruction in habitat was stopped, and can even grow faster than other plants. *P. armeniacum* has not been found in woody environments but it largely grows in secondary forests, man-made forests, made-made slash meadow, and even bare rock surface, indicating that *P. armeniacum* has some weed-like characteristics and its growing environment needs to be disturbed somewhat, which should be taken into consideration in the conservation.

Based on the life cycle of *P. armeniacum*, it does not require a long period for *P. armeniacum* to grow from the stage of development of seeds to the stage at which it completes its generation and it needs no special skills to invade new habitat, which indicates that it has strong adaptability. Thus, it is believed that *P. armeniacum* would be a dissimilative species during its evolutive process; it well adapts to worsened environment and even depends on such environment; therefore, moderate environmental deterioration or destruction is good for its multiplication①. An observatory report from a Chinese organization showed that *P. armeniacum* had a tendency in mass increase, which may reflect the true condition of *P. armeniacum* during that time[6], i.e., its distribution environment might have incessantly worsened; however, it would become extinct when the worsened environment exceeds its toleration limits. On the other hand, if the plant communities in the distribution area has adapted to those conditions as in the dense

① Liu Z J, Zhou Q, Liu K W, *et al*. Variations in population performance of *Paphiopedilum armeniacum* under different floristic composition patterns, unpublished material forest of large trees in Gaoligong Mountains on the western Nujiang River, it would become extinct because of the terrestrially short plants which could not twine around the trees similar to *P. villosum*[25], which may be one reason for its narrow distribution. These results may show that *P. armeniacum* would be the "successor" or a more evolutive species. It is necessary to gain a balance between the favorable habitat and the unfavorable habitat for successful self-multiplication or effective artificial conservation of *P. armeniacum*.

P. armeniacum would only grow rhizomes when deep-buried, and only grow tillering buds but no rhizomes when shallow-planted, which is an adaptation for survival of *P. armeniacum* to the environment. In wild, genets of *P. armeniacum* are often covered by shatters and loose earth, or else they would be swept away with roots by rain; they could only survive by unthreading the superstratum or reentering into the earth, or else they would die; thus, *P. armeniacum* grows rhizomes to produce new individuals, which is another mode of rhizomic reproduction as well as a kind of survival strategy evolved from environmental adaptation, by which it overcomes the unfavorable environment and even escapes from death. Another survival strategy of *P. armeniacum* is the ability to control aging process after fruiting: in favorable environment, ramets would dry rot in 4 years, whereas in unfavorable environment the mother genet would begin aging after germinating tillering buds to support the growth of new plants with its limited resource, which could avoid the conflict between parental generations and filial generations[23]. This self-controlling ability is a balance in the life history of *P. armeniacum*[24].

P. armeniacum has both germinal reproduction and vegetative reproduction; offspring of vegetative reproduction (ramets) could distribute either sparsely (rhizomic reproduction) or densely (tillering reproduction), and they are linked both bodily and physiologically with mother genets, which this linking would keeps tight and last longer in the ramets of tillering reproduction but last shorter in the ramets of rhizomic reproduction. Under emergency, it selectively retains the ramets in good rhizomes, which thereby results in the death of the mother genet. The cost of rhizomic reproduction is higher than that of tillering reproduction, so it can only be used under emergency. For genets, cloned growth can surely help the genets escape aging because it continuously splits asexual ramets; but for ramets, the final resource accumulated from its vegetative growth is maximally used for the sexual reproduction and for the production of new ramets after sexual reproduction, which in turn results in self-aging.

The fruiting rate of *P. armeniacum* blooming ramets is about one-third, not very high, which is due to its imitation of those flowers of plants closely related to *P. armeniacum* to attract pollinating insects. Such a skill is much more evolutionary, and so it is easily intermitted by environmental factors, but the quantity of seeds can reach 50000 in one capsule①, which indicates that the sexual reproduction is still effective and the cloned growth must occur after sexual reproduction. Therefore, it is known that the cloned growth of *P. armeniacum* is totally for sexual reproduction and will not result in the loss of sexual reproduction.

4.2 Ex-situ conservation and wild reintroduction

P. armeniacum, since it is first known, has spread to many places in the world by different means. There are well cultivated plants of *P. armeniacum* in international orchid exhibitions[2], which shows that *P. armeniacum* can be artificially cultivated in ex-situ. Based on the analyses of Section 4.1 and the ex-situ conservation test, it is known that this species can be ex-situ conserved absolutely, and by the test of reintroduction, those plants of asexual reproduction are well seasoned with the original habitat. Therefore, there should be no technical obstacle for ex-situ conservation and reintroduction of *P. armeniacum*, and the methods are simple, easy to handle, and less expensive. By artificial mass-multiplication to meet market needs, by reducing the destruction of the wild resource of *P. armeniacum* as a result of human activities, and by reintroducing the genets of asexual reproduction to the original habitat, the wild communities of *P. armeniacum* can be rejuvenated. Certainly the community transmissibility of *P. armeniacum* should be taken into consideration when such measures are carried out to preserve its resource diversity.

4.3 Endangered mechanism and conservation strategy

P. armeniacum has the powerful ability to reproduce both asexually and sexually. The asexual reproduction could produce many tillering buds and has the contingency mechanism of production of mass rhizomes to cope with damage. Effective pollinating insects in its habitat can result in fruiting of many plants. Many seeds of fruits could effectively grow into new genets. Meanwhile, it has the characteristics of effectively using environment and enduring harsh environmental conditions, the strategies of prolonging lifespan and escaping death, and the ability of controlling the aging process. Thus, *P. armeniacum* could not become extinct because of its own biological defects. At present, the threats encountered by *P. armeniacum*, except for the mass gathering, are from the destruction of its habitat as a result of human activities, which thereby reduces the area available for growth or causes irreversible changes in its habitat. This is the main reason that leads to the extinction of *P. armeniacum*.

P. armeniacum is a species with a narrow distribution in China and its "special center" in Nushan Mountain. Since it has the outward diffusibility and the invading ability, *P. armeniacum* could be kept in a certain amount in brushes of *Q. gilliana* and the like in limestone area, while it would soon invade the nearby habitat and massively multiply after resum-

① Liu K W, Liu Z J, Huang L Q, *et al*. Pollination biology of endangered species *Paphiopedilum armeniacaum* (Orchidaceae), unpublished material ing of small habitats such as plantation returned to forest and earth no longer dug or washed out by rain. Therefore, conservation of *P. armeniacum* should start with the protection of its own habitat: to set up the conservation sites, to establish mother communities, to implement the close protection, to eliminate the threats to *P. armeniacum* posed by human activities of economic trade to maintain habitat stability, to meet the growth condition of rocks in limestone area, to protect environment completely for pollinating insects, etc. At present, it is necessary to carry out the ex-situ conservation and the artificial reproduction of *P. armeniacum* as soon as possible, to store up mass seedlings of artificial reproduction prepared for wild re-introduction, to renew this endangered species and to make it thriving and prosperous. Under the uncontrollable conditions of man-made collecting, reclamation of slope area, speed-up development of stockbreeding and artificial forest building of exotic trees in large area, especially the avoidless business collecting in poor mountain areas.

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