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Existence analysis of populations of *Mosla hangchowensis*, an endangered plant

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Abstract. *Mosla hangchowensis* Matsuch is an annual herb, which is found only on the seacoast of Zhejiang province in southeast China. The species has declined in numbers and is now endangered. The survival ratio, seminal power, reproductive success ratio, and density as well as other factors were measured from 1993 to 1996, and an existence analysis was performed. There are two environmental sieves during the life history of this species, and the survival curve is between the Deevey-I and Deevey-II. A constant proportion of individuals died throughout the life cycle. The optimum niche of *M. hangchowensis* is a habitat with soil depth 20-30 cm, with moderate to slightly wet conditions, with neither too intense nor too shaded light. The realized niche now is on the top of rocky hills or along gravel roadsides. Sites are few and dispersed. Loss of the optimum niche and a decrease of realized habitats as a result of human activities, the disparity between the realized niche and the optimum, and a low dispersal ability of populations are currently contributing to the endangerment of *M. hangchowensis*.

Keywords: Endangered; Existence analysis; *Mosla hangchowensis*; Population.

Introduction

Because of the rapid expansion of human activities, many species have fewer and fewer suitable habitats for their existence, and more and more species are becoming endangered or extinct. In recent years, many studies on conservation biology have been conducted all over the world in order to prevent biodiversity from disappearing. Not only have large-scale perennial species become endangered, many annual herbs have too (Hibig, 1982).

According to the basic principle of conservation biology, the survival ratio, seminal power, reproductive success ratio, population structure, species diversity, and density are the basic parameters that determine a species' degree of endangerment (Primack, 1993). If a low survival ratio was the primary cause of a species being endangered, then population trends and population survival analysis should be conducted (Feng, 1982) in order to find the time period in which high mortality occurred from the death density function curve. The environmental factors that caused death can be identified through a comparative analysis and used to define the environmental sieve that limits the growth of the population (Jiang, 1992).

Mosla hangchowensis Matsuch, an annual herb (0.2-1.2 m in height), belonging to the mint family (Labiatae), has a small distribution area. There are only 5 small local populations extant along the coast in the eastern part of subtropical China, where it is endangered. The species is predominantly outcrossing and had a smaller seed-set (77.5%) than did the congener, *M. chinensis* (95%), which is predominantly self-fertile and cosmopolitan (Zhou et al., 1996). *Mosla hangchowensis* possesses higher genetic diversity (Zhou et al., 1996) and lower seed germination (Ge et al., 1998a) than *M. chinensis*. In the study presented here, the survival of *M. hangchowensis* from young seedling to adult was analyzed, and the factors that caused the plant death were determined by a study of population ecology. Based on the trends in the growth and decline, we present the mechanism, leading factors, and key periods of population decline. Moreover, possibilities for remediation are discussed.

Study Sites

Mosla hangchowensis is distributed in island-shaped soil on big, bare rocks or along the sunny side of hill peaks. One local population can have three kinds of habitats:

(1) Open land habitat: There exist big bare rocks (from several to some ten square meter) with island-shaped soil covering them, the soil islands varying from ten square centimeters to several square meters, and the soil depth from 1-25 cm, 5-8 cm on average. There are two types of community: a. *Mosla hangchowensis* is the single dominant species in the community accompanied by only a few herbaceous and woody climber species, such as *Commelina communis* and *Trachelospermum jasminoides* living at the lower strata, the total biomass of which was only 3-5% of the total community. The population density of young plants in this habitat was high, varying from 100 to 2,400 individuals/m^2. b. *Mosla hangchowensis* is not the dominant species; it intermixed with *C. communis* and *T. jasminoides* and some other species. In open land

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habitat, the type 'a' community is bigger than type 'b' in area.

(2) Forest edge habitat: At the edge of forest, usually bound with rocks, or at the roadside, the average soil depth is 10-15 cm, thicker than in open land habitat. The community structure is similar to that of the open land habitat.

(3) Under forest habitat: 2-5 m inside from the edge of the forest, the average soil depth, 20-30 cm is the thickest of the three habitats. *Mosla hangchowensis* lives mixed with the shade-tolerant herbs, which takes up a large proportion of the community. The population density of *M. hangchowensis* is smaller than those of the former two habitats. The forest consists of trees such as *Quercus* sp., *Ligustrum lucidium* and *Broussonetia kazinoki*, with heights of 8-10 m and crown density of 0.7-0.8 in summer.

The largest of five local populations lives in the Geling Ridge in Hangzhou (120°10'E, 30°15'N). In this region, the differences in air temperature, precipitation, and evaporation between 1993 and 1996 (Figure 1) were obvious: there were hot-arid periods with obviously high temperatures and evaporation, low precipitation in summer of 1994 and 1995, and a period with extremely high temperatures in spring (early March) in 1995.

Materials and Methods

The experiment was carried out in Hangzhou from April 1993 to December 1996. Each year a total of 12 sample quadrats in perpetual sample plots of different habitats—including open habitat (4 quadrats), forest edge habitat (4), under forest habitat (4)—were selected in every spring from March onward. The area of every sampling was 50×50 cm^2. Each year, 817, 540, 136 and 106 young plants were marked. In every quadrat, the survival number, height, crown range, and branch number were measured about every two weeks. Because the seed of *M. hangchowensis* is small and falls off at any time after maturity, the fecundity calculated on the harvested seed number is always lower than the actual number. Since the spikes do not fall off, the spikelet numbers and the seed numbers per spike were used to correct the fecundity.

On the basis of the above experimental data and the theory of life history analysis (Feng, 1982; Muenchow, 1986; Yang, 1991), the life table was constructed. The mortality density function f (t) was calculated by the formula (Feng, 1982):

$$f(t_{mi})=1/h_i(1-P_i)P_{i-1}\ldots\ldots P_1 \quad (1)$$

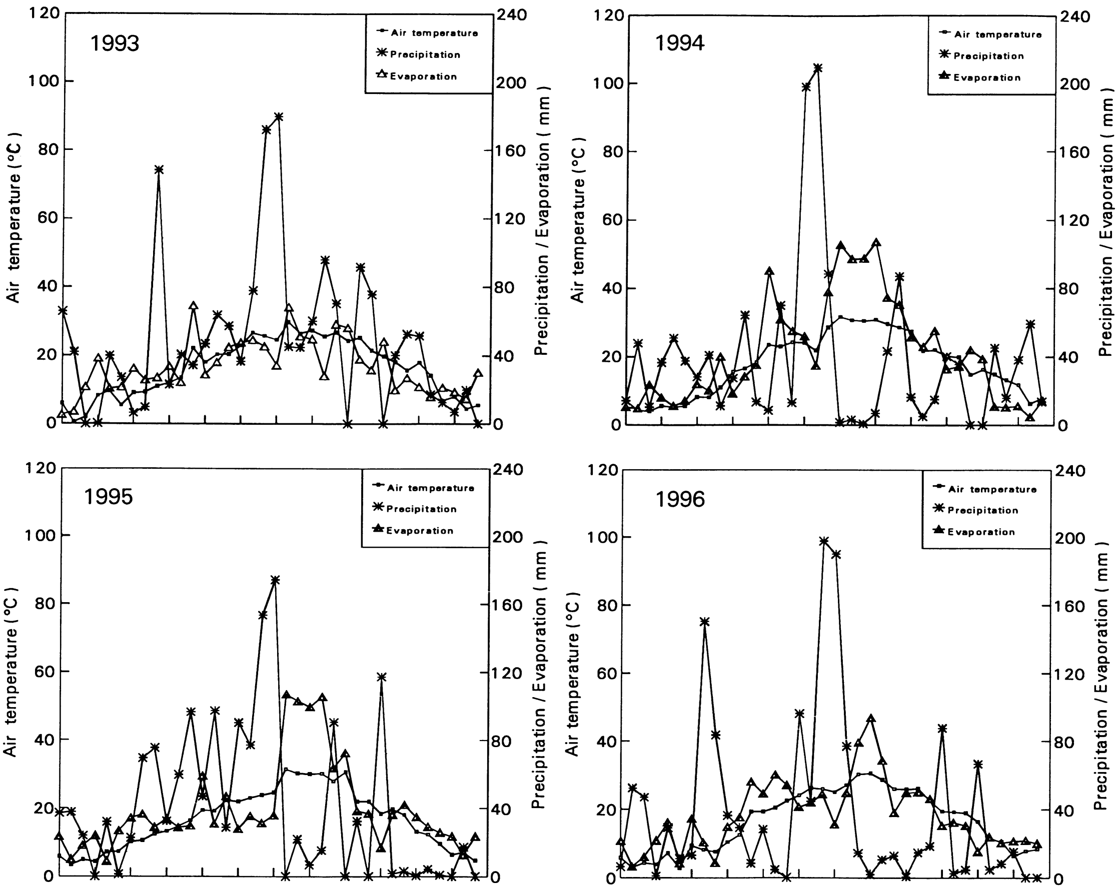

Figure 1. Seasonal changes of temperature, precipitation, and evaporation in study area.

where, h_i = interval time between two measurements; t_{mi} = middle of the interval time; P = survival ratio. That means the mortality density function f (t) is the mortality ratio per unit time.

Results

Annual Change of Natural Population

In natural conditions, the seed germination ratio and all the survival ratios of young plant of *M. hangchowensis* (Table 1) were lower than those of many other annual plants (Silvertown, 1982). That means environmental limitations have more effect on the life history of *M. hangchowensis*. If the survival ratio is low, individuals can enlarge their volume and increase their fecundity, so the individual's fecundity in a year with low density is bigger than that in a year with high density, but the total seed yield in a low survival ratio year is still lower than that in a higher survival ratio year.

Survival Analysis

Individuals were marked from the time the seedling broke the ground surface. The survival curve of *M. hangchowensis* was intermediate between the Deevey-I and II (Figure 2). This suggests that there existed great dangers of death throughout the life cycle. There were two evident periods of high mortality density. That means there had two environmental sieves: a. Environmental sieve in young plant period: the mortality density showed a high peak before 40-day-old, and the height was lower than 30 cm. b. Environmental sieve before flowering period: the second high mortality density appeared near the beginning of the flowering period.

From 1993 to 1996, after the two danger periods above, the survival ratios of the marked plants in flowering were only 0.272, 0.074, 0.184 and 0.46. After that, some individuals died continuously, but there were no high mortality peaks from flowering to fruiting period, the survival ratios in fruiting period being 0.184, 0.028, 0.051 and 0.245.

Differences Among the Habitats

Detailed analysis showed different characters among the three habitats (Figure 3). In the under forest habitat, the mortality density remained high between the two peaks (Figure 3), which was quite different from the open land habitat, in which the value between the two mortality den-

Table 1. Life table of *M. hangchowensis* population.

Year	Seed percent germination	Seedling number	Survival ratio (%)	Fecundity seed/plant
1993	-	817	18.4	60
1994	4.8	540	2.8	324
1995	15.5	136	5.1	319
1996	-	106	24.5	-

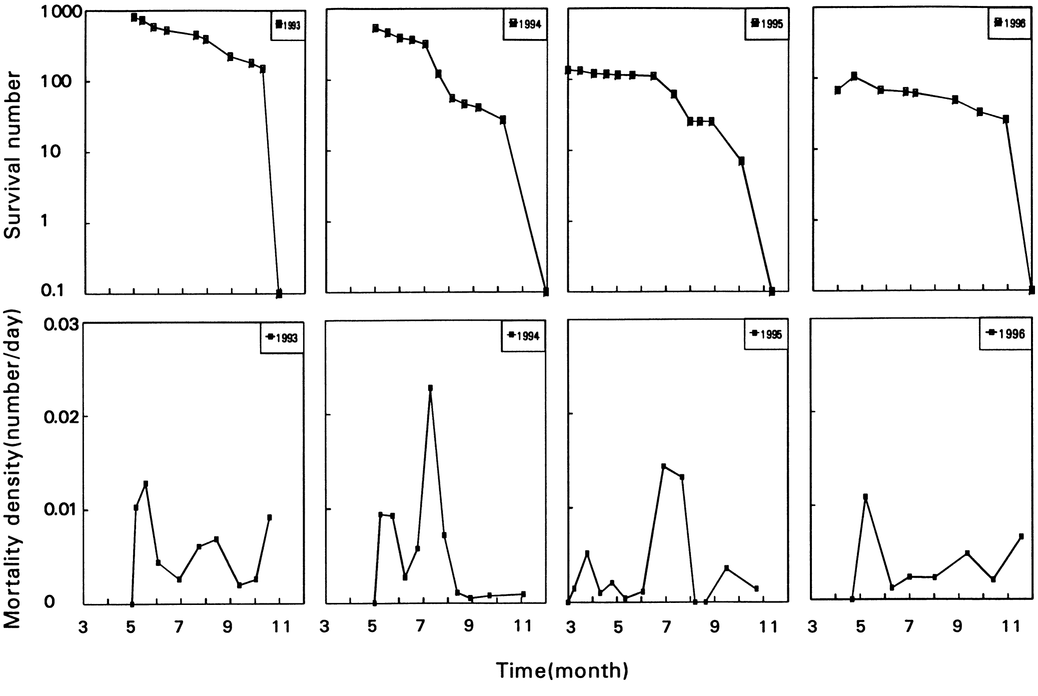

Figure 2. Survival curve and mortality density function of *M. hangchowensis* 1993-1996.

sity peaks was very low. In the forest edge habitat, the mortality density was in the middle of the above two habitats between the two peaks, but its survival ratio after the second mortality density peak was the biggest among the three habitats (Table 2). All individuals in the under forest habitats died after flowering. The fruiting period of the individuals in the open land and forest edge habitats generally appeared within 20 days, from early to late October, when only a very few individuals died, so the total seed number was calculated only, but those curves were not drawn in this paper.

An analysis of the relation between the survival ratio of plants and soil depth (Table 3) showed that the survival ratio in the forest edge habitat increased with soil thickening in 1994 and 1995, but no such relationship appeared in 1993.

Discussion

Environmental Sieve

From 1993 to 1996, the first peak of the mortality density appeared in May, except for 1995, when it appeared in March, and it was smaller than in the other three years (Figure 2). The average temperature in March 1995 was the highest (>10°C) among the four years (Figure 1). Is there any relationship between the mortality density peak and the high temperature? Through physio-ecological studies, it was found that the volume and biomass of *M. hangchowensis* were seriously restricted by low temperature (Chang et al., 1999). In 1995, the temperature in early spring was higher than in other years, so the plants grew faster, and the competition for nutrition and survival space came earlier. Then, the first peak of mortality density also appeared earlier. Moreover, the rainfall was the most abundant and consistent in 1995, so the mortality density peak was the lowest among the four years. In a word, the first environmental sieve of mortality density should be the competition for the nutrition and space. The competitors of *M. hangchowensis* should be individuals from the same species and other species nearby.

The peak values of mortality density in the summer of 1994 and 1995 were bigger than those in 1993 and 1996. Taking weather into consideration, we found that it was continuously hot and dry in 1994 and 1995. Further analysis showed that the second peak of mortality density in

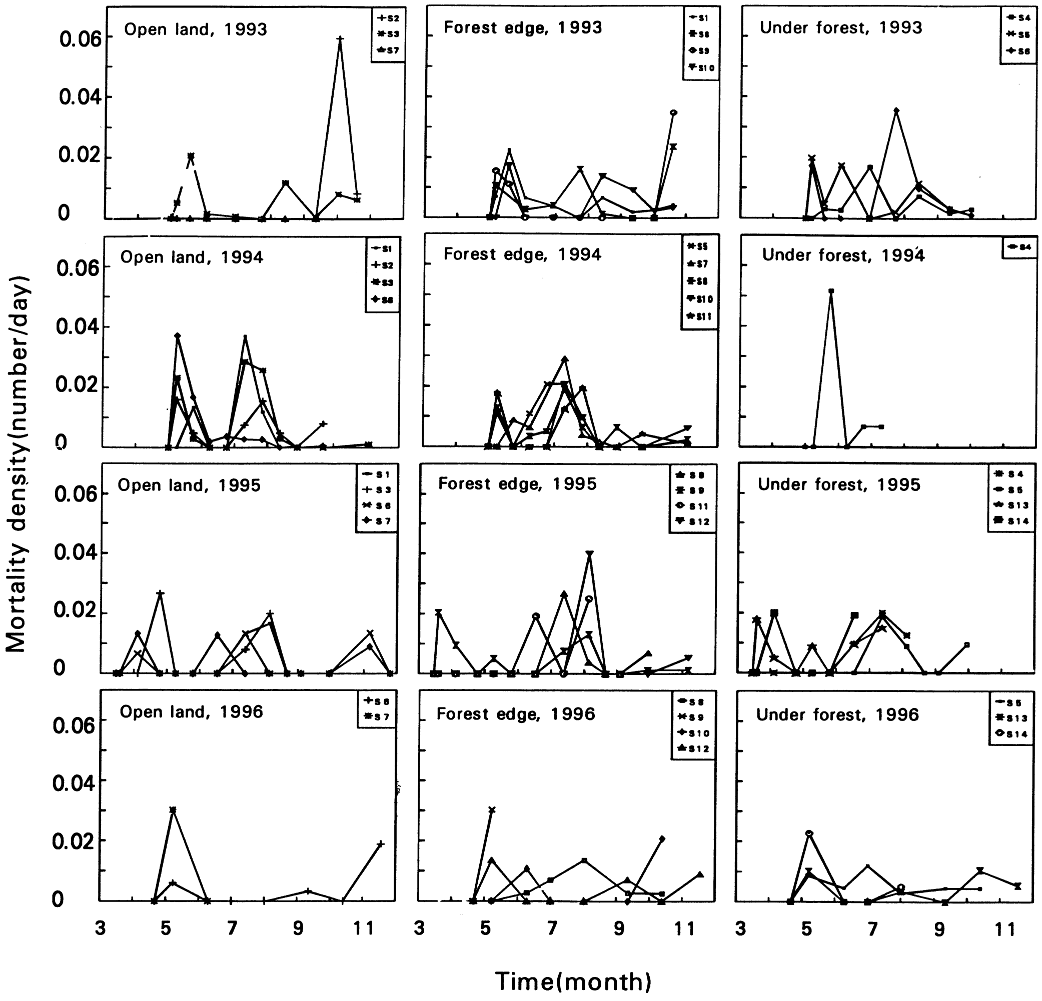

Figure 3. Mortality density functions of *M. hangchowensis* in different habitats 1993-1996.

Table 2. Cumulative percent survival to either flowering and fruiting period of *M. hangchowensis* population in different habitats.

Year	Flowering period			Fruiting period		
	Open land	Forest edge	Under forest	Open land	Forest edge	Under forest
1993	30.59	35.08	9.32	12.94	28.02	0.00
1994	5.07	12.21	0.00	1.09	11.27	0.00
1995	23.53	18.52	19.35	23.53	14.77	0.00

Table 3. Survival ratio in fruiting stage of *M. hangchowensis* population in different soil thicknesses in forest edge habitat.

Items	1993				1994					1995			
Soil thickness (cm)	1-2	4	5	6	1-2	2-3	4-5	3-15	5-6	2-3	4-5	5-6	3-15
Survival ratio (%)	46.8	54.2	6.9	8.6	0	6.7	10.7	13.9	33.3	0	9.3	20.0	25.6

1995 started earlier from June on, when the rainfall was plentiful and the evaporation was low, i.e. the weather was not dry in due time. That suggested that the second sieve was caused by combinations of two environmental factors: a. heat + drought, and b. low sunlight + high humidity. Serious stress of heat and drought caused *M. hangchowensis'* high mortality rate, but most of the companion plants could not survive at all. Thus *M. hangchowensis* is a victor in such a severe environment. When the sieve involved a combination of low sunlight and high humidity, *M. hangchowensis* also had a high mortality rate, but the companion plants grew very well. In that case, *M. hangchowensis* was only an accompanying species in the community, not a victor in competition.

The reason the peaks of mortality density in the under forest habitat were different from those of open land habitat is probably insufficient light under the forest (Figure 3). Experiments (blocked light in) of control light showed that when the light intensity was lower than 20% of full sunlight, *M. hangchowensis* grew better in the early period (before June), but a great number died later (Ge et al., 1998b). In the under forest habitat, no individuals of *M. hangchowensis* could keep alive until fruiting period, though there were only a few other plants in competition nearby. So the death of the plant this time must have been principally caused by the environmental sieve of insufficient light.

The light intensity and the mortality density curve in the forest edge habitat were situated between those of the above two habitats. Some individuals died due to insufficient light while greatest part of them completed their life histories. The survival ratio during the flowering and fruiting period in the forest edge habitat from 1993-1995 was the biggest among the three habitats on the whole, for the stress in this habitat was not as serious as in the other two. But, there was an exception in 1995, when the survival ratio in forest edge habitat was lower than that in open land. The reason is probably a long period of plentiful rainfall, low evaporation, and insufficient light in due time.

In short, *M. hangchowensis* faces two environmental sieves in its lifetime. The first is the competition for nutrition and survival space in the spring; the second is the combination of heat + drought or the combination of insufficient light + high humidity in summer. In the under forest habitat, no individuals could pass the sieve that combined low light + high humidity. While in open land habitat, most individuals could not survive the hot and dry summer, the combination of heat + drought was the main cause of mortality. As to the forest edge habitat, the working effect of the two sieves was not so serious as in the other two habitats, so the survival ratio was higher.

Optimum Niche

Physio-ecological studies have shown that *M. hangchowensis* is a tolerance species. Its optimum soil water condition is middle to slightly wet, and the light saturation point of photosynthesis is 30Klux, far smaller than the full sunlight intensity in summer (90-120Klux). Viewed from the physiological and anatomical characters of this species, *M. hangchowensis* should be a mesophyte species (Chang et al., 1999). That tallies with the discussion above, i.e. the forest edge was the habitat with the biggest survival ratio for *M. hangchowensis*, for the light intensity at the forest edge was about 40% of full sunlight. It means that the forest edge habitat should be the suitable niche.

In 1994 and 1995, the summers were very hot and dry, at which time the survival ratio of *M. hangchowensis* at the forest edge decreased on thin soil. In contrast, the summer in 1993 was not very hot and dry, and the survival ratio at the forest edge was unrelated to soil depth (Table 3). Therefore, individuals of *M. hangchowensis* at the forest edge with thin soil also suffered high mortality in the year under the serious stress of hot and dry weather. However, the fecundity in 1994 and 1995 was not less than that in 1993 (Table 1).

Population studies have shown that *M. hangchowensis* is not good at competition in the plane with thick soil. It cannot grow well, and most of the individuals cannot live until fruiting period because other herbs grow much faster in the spring, when many herbs grow to 50-140 cm tall. Flowering in late May and June, *M. hangchowensis* reaches 15-25 cm high and remains under the top layer of the community, meaning that it cannot grow in the center of grassland or cropland. It can only be distributed at the edge of a plane with thick soil.

Synthesizing the physio-ecological and population ecological (including interspecific competition) characters, it can be deduced that the optimum niche for *M. hangchowensis* is an environment with light intensity at 30-80% sunlight and soil depth between 20-30 cm. The forest edge and cropland, roadsides, and so on are places that meet the above characters.

Realized Niche

Through careful observation, we found *M. hangchowensis* only lives on the top of rocky hills or beside gravel roadside these days. The environmental characters of the habitats in reality are different from its optimum niche in some aspects. Most of the realized niches now are the edge of its ecological range.

The realized habitat of *M. hangchowensis* is normally a long, narrow place, the seed often distributed in open land and under forest, so the individuals were often found in these two habitats. Population analysis showed that *M. hangchowensis* could not survive in the under forest habitat because of insufficient light and high relative humidity, but in open land it succeeded, and in 1994, when the weather was extremely hot and dry, *M. hangchowensis* was almost the only survivor in the community. Physio-ecological studies showed that this species had a very strong drought resistance (Chang et al., 1999). So both the open land and forest edge in sunny places without a steep slope were the realized habitats of *M. hangchowensis*.

Reasons for Endangerment

In plain, *M. hangchowensis* was discovered about 40 years ago. There were field roads and ridges among fields only slight disturbed by people at that time. In such a place some weeds can grow, including *M. hangchowensis*. As human beings altered more and more of the plains for city use and so on, *M. hangchowensis* lost more and more optimum habitats. For example, *M. hangchowensis* was found in Genshanmen, formerly at the edge of Hangzhou city, but the vegetation had disappear to the core since 30 years ago because of urbanization.

In the mountains, there were some places with deep soil and suitable natural sunlight. *Mosla hangchowensis* was distributed there some years ago. Those belt-shaped habitats were between the forest and big rocks or beside roads. In recent years, it has been damaged by humans for garden use, artificial forests, or construction. For example, there was a small population on Jinshan Mountain, which belonged to the Linhai local population of *M. hangchowensis* (Zhou et al., 1996). The habitat was destroyed by garden construction in 1998, causing the population to disappear.

At present, most *M. hangchowensis* can only occupy the edge of its original habitat, which due to too intense sunlight and thin soil, cannot support it well. This species is in stress. Even though these realized habitats are not very good for *M. hangchowensis,* even they are disturbed by humans more and more frequently. The natural “edge” of the field is shrinking, and the realized habitat is continuously reduced. Meanwhile, this species has a poor ability to disperse. On one hand, the seed of *M. hangchowensis* is round, with no attachments on it (Ge et al., 1998a). We did not find any birds or other wildlife eating it during 6 years of study. Seed dispersal relies mainly on weight although the action of wind and rain can afterwards move them for short distances. In the next spring before germination, the dispersal range was only 0.7-0.9 m out from the mother plant. On the other hand, it cannot pass through the forest generation by generation because of its low tolerance for low light intensity. That should be the reason that the *M. hangchowensis* population cannot go to another suitable place to enlarge its distribution area. Natural recovery seems impossible now.

Recovering Way

Studies on evolution have shown that after being acclimated, many species have the ability to adapt to and adjust their ecological niches to the new environment (Holt and Lebaron, 1990; Guo and Zhao, 1997; Cao and Miao, 1997). At the same time, however, their competitive edge in the original environment is reduced after the adjustment (Hickey and Mcneilly, 1975; MacNair, 1981; Grime and Hodgson, 1987; Holt and Lebaron, 1990). If the new environment which suited the species was widely existent, the population would increase; otherwise, it would decrease. People have pushed out many species from their original habitats, and these species, unable to adapt to the new environments, became endangered and extinct. On the basic principle of genetics, the adjustment of the niche should be the adjustment of the ratio of the genotypes in population, so the genotype suited to their original environment still existed within a relatively short term, though the ratio would not be high. At this time, the ratio of genotypic individuals suited the original environment could be recovered by restoring the original environment (Allendorf and Leary, 1986; Holt and Lebaron, 1990; Wauters and Hutchinson, 1994; Guo and Zhao, 1997). In view of the above, it was thought that the goals of the study of endangered species should be: to analyze the reason for endangerment, comprehend the optimum habitat, and calculate the possibility of recovering the genotype ratio by cultivating it in an artificial or semi-natural optimum habitat for some generations, and then removing the endangerment. This method is particularly suited to plant species with short life spans, such as annual or biannual herbs. At present *M. hangchowensis* often grows in a habitat of thin soil under full sunlight. The ratio of individuals that tolerate shade has been reduced. The chance of recovering its original habitat is also decreasing. Further study should focus on two areas: the first is *in situ* conservation, so as to conserve the existing genetic diversity as much as possible; the second is the recovering study of genetic diversity by multi-habitat *ex situ* cultivation.

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瀕危植物杭州石薺苧（*Mosla hangchowensis*）種群的生存分析

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杭州石薺苧（*Mosla hangchowensis* Matsuch）為一年生草本植物，只分佈在中國南部浙江省沿海地區，已呈瀕危趨勢。在1993-1996年間對杭州石薺苧種群的存活率、生殖力、再生產成功率、密度等被研究中，我們發現在杭州石薺苧的生活史中有兩個環境篩，存活曲線介於Deevey-I型和II型之間，在整個生活史過程中均有一些個體死亡。杭州石薺苧的最適生境應該是厚土（20-30 cm深）、水分中等略少、光照比全光照略低的環境條件，但現在的實際生境是山頂石壁上、路邊林緣多石薄土處，這種環境很少並且分散。人類強度改變環境引起的理想生態位消失、實際生境減少，實際生態位與理想生態位的差異，以及種群散佈能力低是該植物種瀕危的重要生態學原因。

關鍵詞：瀕危；生存分析；杭州石薺苧（*Mosla hangchowensis*）；種群。