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Structure and dynamics of natural populations of the endangered plant *Euryodendron excelsum* H. T. Chang

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Abstract *Euryodendron excelsum* H. T. Chang is an endangered species of the family Theaceae endemic to China. It is listed as a second-class endangered plant for state protection in the Red Data Book of Plants in the People's Republic of China. The species is restricted to one remnant population with less than 200 individuals in the Bajia region of Yangchun County, Guangdong Province. This study was conducted to determine the status of the population, analyze the past population structure and forecast the future population dynamics of *E. excelsum*. The size structure and height structure of the population of *E. excelsum* were tabulated and analyzed. Based on these data, we estimated the values of the parameters such as survival curve, mortality curve and life expectancy. Population dynamics was predicted by a time-sequence model. The size distribution of the whole population generally fit a reverse "J" type curve, suggesting a stable population. The number of young individuals was larger than that of middle-aged and old individuals. The analysis of life table and survival curves show that under environmental screening and human disturbance, the population had one peak of mortality in size class II and only 11.43% individuals could survive from size class II to size class III. The life expectancy of *E. excelsum* was the highest in size class IV. The survival curve of the population belongs to the Deevey-III type. Time-sequence models for *E. excelsum* population predict that the number of different size classes will increase after two and five years. As a result, the crucial factors for the natural regeneration and restoration of *E. excelsum* are the protection of living individuals and their habitat.

Keywords population structure, life table, survival

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curve, time sequence analysis, *Euryodendron excelsum* H. T. Chang

1 Introduction

The plant stand structure, which includes individuals at different ages and size stages, reflects the composition status of the individuals, stand conditions and its relation to the environment (Li et al., 2002). Life table and survival curve are used as important and simple tools in the study of population structure and dynamics of plants. It can exhibit survival and death rates in a direct way (Diaz et al., 2000; Hong et al., 2004). In addition, the life table, combined with the analysis of time sequence, will effectively forecast the future fluctuation in population (He, 2005). Therefore, the analyses of the natural population structure and dynamics based on size structure, life table, survival curve and modeling studies by time sequence can not only tell the current population status, but also the historical population structure and exotic disturbance. These analyses can also be used to forecast the future population dynamics and to evaluate the population fitness to environment. So, these analyses are especially significant to the effective conservation and management of endangered species (Xie et al., 1999).

Euryodendron excelsum H. T. Chang is a perennial woody species of the family Theaceae. It is an endangered species from the monotypic genus of *Euryodendron*, which is endemic to China. *E. excelsum* is an evergreen tree that grows up to 25 m tall. The leaves are ellipse and sharp with dense serrate margins. It is between *Eurya* and *Cleray* in morphology (Wang et al., 2002a). The species is only scattered rarely in the Bajia region of Guangdong Province, south China. Early incomplete investigation on this species found only three adult trees existing in the Bajia region (Lin, 1992, 1998; Ying and Zhang, 1994). Thus, *E. excelsum* has been ranked as a second-class protected plant in the Red List of China. In terms of the IUCN criteria, this plant has been listed as a critically endangered category (Hilton-Taylor, 2000), which means that it is facing the risk

of extinction. Fortunately, according to the later field investigation, Wang et al. (2002a) estimated that more than eighty members, including seedlings, saplings, juveniles and adults, are still living in the Bajia region. Though the number of the living individuals is larger than we used to know, the species is still in danger due to the small population size and restricted distribution. For the conservation and population recovery of the species, more detailed investigation on this species is urgently needed.

In order to find out the endangering causes and mechanisms, some studies on *E. excelsum* have been conducted (He et al., 2001; Wang et al., 2002a; Wang et al., 2002b; Wang et al., 2006), most of which focused on the distribution, biological and ecological characteristics and conservation genetics of the plant. No study of its stand characteristics, including the population structure and quantity dynamics, was reported, probably because that its extremely limited distribution and population size make it almost impossible to be studied that way. However, the population status of the species cannot really be fully understood by people unless a thorough investigation is carried out. The stand characteristics are the essential information for effective conservation and population recovery of the species (Han et al., 2007). We conducted a comprehensive field survey of *E. excelsum* in the Bajia region in Guangdong Province. Then, the size structure and height structure of the population of *E. excelsum* were tabulated and analyzed. Based on these data, we estimated the values of parameters such as survival curve, mortality curve and life expectancy. Population dynamics was predicted by a time-sequence model. The results will provide a theoretic modification model when the population structure changed by exotic factors, and they will also be very important basal data for conservation strategies.

2 Study site

E. excelsum is a monotypic woody species endemic to China. In 1960s it was reportedly distributed in the Yangchun County of Guangdong Province and the Pingnan County of Guangxi Province, but now only exists in the Bajia region of Yangchun County, Guangdong Province. The topography of the Bajia region (21°57'N, 111°24'E) is flat with abundant low hills. The mean elevation is 160 m. The soil types belong to red soil and lateritic red soil with high sand content on the surface. The pH value is from 6.0 to 6.8. The south of Bajia region is the Heiwei Mountain with the highest elevation of 1182 m, and the north is the Yunwu Mountain range. The Hewei Mountain belongs to the Yunkai Mountain range which is one of the best conserved areas with good vegetations west of Guangdong Province. According to the data from Bajia weather station, the average annual temperate is 21.7°C, and the total is

from 7000 to 8000°C. The mean coldest monthly temperature is 13°C. The lowest temperate is 1.5°C occurring in 1997 and the highest 38.2°C in 1998. The annual rainfall in this region is more than 2000 mm with a range from 1581.9 to 3759.9 mm. It has a high annual humidity of 80%. The climate belongs to a south semi-tropical climate.

The *E. excelsum* trees are mainly growing in secondary forests adjoining the local villages in the Bajia region where human activities are frequent. Very few individuals can be found now in Bajia and the habitats are highly fragmented so they can only form some fragmented patches. These patches are all very close to the local villages and their community composition and the habitats are all similar. The mainly accompany arbor species are: *Cinnamomum camphora*, *Litsea sebifera*, *Syzygium bullockii*, *Elaeocarpus sylvestris*, *Phoebe neurantha*, *Melia dubia*, *Schefflera insignis* and *Cunninghamia lanceolata*. Other plants such as *Ficus heteromorpha*, *Fluggea virosa*, *Eurya chinensis*, *Pavetta hongkongensis*, and *Camellia oleifera* are also found in the shrub layer. The herb is poor and only *Hedyotis auricularia*, *Carex* sp., *Lygodium japonicum*, *Pteris semipinnata*, *Scleria biflora* and *Clematis meyeniana* are found. The community structure exhibits obvious secondary forest characteristics.

3 Methods

3.1 Field survey

A comprehensive field survey was conducted during 2004–2006. We used a global positioning device (GPS) to locate the precise position of *E. excelsum* individuals in its whole distribution range (21°55'39"–21°57'37"N, 111°23'01"–111°55'39"E). The distance among each individual was also measured. According to the above data, we drew a projection diagram (1:1000) on a linear coordinate paper. A total of 36 sequential sampling plots were investigated corresponding to the patch size. In each plot, the height, diameter at breast height (DBH) and canopy of each *E. excelsum* member was measured (start measure size class with $DBH \geq 3.0$ cm). The number of seedlings and saplings with $DBH < 3.0$ cm was also counted. In addition, we visited the local villagers to know the historical distribution and the way of the local use of *E. excelsum* to analyze its population surviving status.

3.2 Population structure

3.2.1 Size and height class

The size structure has been widely used to analyze the population structure when the age is difficult to estimate,

especially for some rare and endangered plants (Cai and Song, 1997; Chen et al., 2006; Kang et al., 2007). In this study, we used size structure instead of age structure to analyze the population characteristics of *E. excelsum*, considering its rarity and lack of dendrochronological data. Based on its biological characteristics, consulting the size category defined previously (Li et al., 2002), we categorized *E. excelsum* population into six classes: I, seedling (S1) with height (H) $0 < H \leq 100.0$ cm; II, sapling (S2), $H > 100.0$ cm, DBH < 3.0 cm; III, juvenile1 (S3), $3.0 \text{ cm} \leq \text{DBH} < 10.0$ cm; IV, middle tree (S4), $10.0 \text{ cm} \leq \text{DBH} < 15.0$ cm; V, adult (S5), $15.0 \text{ cm} \leq \text{DBH} < 45.0$ cm; VI, senescent tree (S6), $\text{DBH} \geq 45.0$ cm. The height structure of *E. excelsum* population was also categorized into six classes with a 2 m margin for demography and analysis.

3.2.2 Structural characteristics

Individuals were counted according to the size and height classes. The size structure and height structure were tabulated. The size and height classes are shown on axis X and the individuals of each class on axis Y . The quantitative method of Cheng (1998) was used to analyze the population dynamics. The population structure type was defined according to Leak (1975). Detailed calculation methods are:

$$V_n = \frac{S_n - S_{n+1}}{\max(S_n, S_{n+1})} \cdot 100\% \quad (1)$$

$$V_{pi} = \frac{1}{\sum_{n=1}^{k-1} S_n} \cdot \sum_{n=1}^{k-1} (S_n \cdot V_n) \quad (2)$$

where V_n is the quantitative dynamic index from class n to $n + 1$ of individuals, V_{pi} is the quantitative dynamic index of the whole population, S_n or S_{n+1} is the number of individuals at size class n or $n + 1$, respectively. When we considered the exotic disturbance, they became:

$$V_{pi} = \frac{\sum_{n=1}^{k-1} (S_n \cdot V_n)}{K \cdot \min(S_1, S_2, S_3, \dots, S_k) \cdot \sum_{n=1}^{k-1} S_n} \quad (3)$$

$$P_{\max} = \frac{1}{K \cdot \min(S_1, S_2, S_3, \dots, S_k)} \quad (4)$$

where K is the number of population size class. The value of V_{pi} and V_n will reflect the dynamics of the population, by which < 0 , 0 and > 0 stand for increasing, stable and regressive populations, respectively. P is the risk probability from the exotic disturbance to population. The

population dynamics V_{pi} will be affected fiercely when P reaches the zenith.

3.2.3 Time-sequence forecast model

We used once the moving average method (Xiao et al., 2004) to simulate and forecast the future population structure of *E. excelsum*.

$$M_t^{[1]} = \frac{1}{n} \sum_{k=t-n+1}^t X_k \quad (5)$$

where n is the number of the future years to forecast, $M_t^{[1]}$ is the population size in the future n years, X_k is the population size with k size class. In this study, we will forecast the future population dynamics with time sequence after two and five years.

4 Results

4.1 Population status and structural characteristics

In our field survey, we found *E. excelsum* only distributed in hills with elevations ranging from 50 to 160 m, and the area covers nearly 25 km². A total of 179 individuals of *E. excelsum* were found in the Bajia region. The population has a relatively high proportion of seedlings and saplings. Only 23 individuals are big trees with $\text{DBH} \geq 15.0$ cm, and the maximum DBH is 106.8 cm. The high frequency of human activities affects the survival of *E. excelsum* remnant population because the *E. excelsum* trees grow close to the local villages. As a result, the population is scattered in ten isolated patches. The total area occupancies of the ten patches are 0.036 km² (only 0.15% of total area covers). These patches are isolated mainly in local farmlands, roads and villages. The farthest distance from one patch to another is 8.7 km, and the nearest is 0.2 km. Most patches have less than ten individuals and only a single adult tree in two patches. The biggest patch has 62

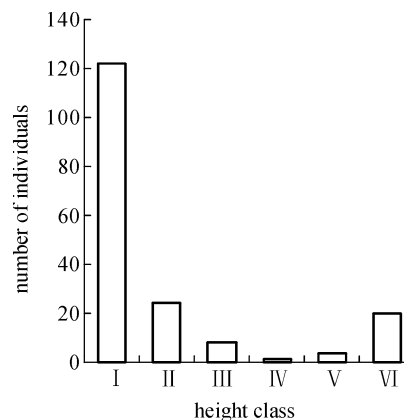


Fig. 1 The height structure of *E. excelsum* population

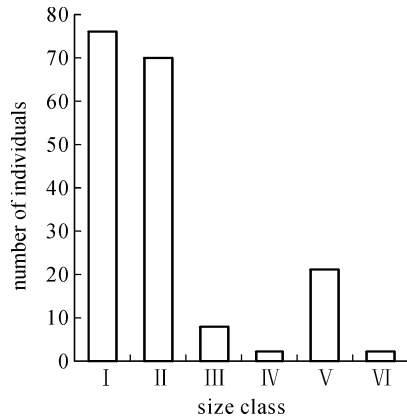


Fig. 2 The size structure of *E. excelsum* population

individuals, and the mean is 17.9. The density of patches is between 50 and 123 individuals/hm². The habitat and distribution pattern of *E. excelsum* are similar with the other two critically endangered species *Scrophularia valdesii* (Bernardos et al., 2006) and *Pulsatilla patens* (Malliovirta et al., 2006).

The height and size structure reflect the components of spatial and temporal distribution, stand conditions and environmental differences from populations. Therefore, the analysis of height and size structure is one of the approaches to display the population surviving status and regeneration strategy (Wang et al., 1998; Hou et al., 2005). According to the height structure (Fig. 1) and size structure (Fig. 2) of *E. excelsum* population, we can conclude that the number of individuals is decreasing with the increase of height and size class. However, the number of individuals will gradually increase after class V. The size structure shows that most individuals (81.56%) were in the seedling (S1) and saplings (S2) stages. Middle trees and adults are

dramatically few and only 1.12% individuals are middle trees (S4) in *E. excelsum* population. The whole population structure tends to be a reversed “J” curve, suggesting a stable structure, although the population is still under a process of fluctuation with fewer individuals. According to the quantitative analysis of *E. excelsum* population, the quantitative dynamic index from class n to $n+1$ of individuals is $V_1=7.89\%$, $V_2=88.57\%$, $V_3=75.00\%$, $V_4=-90.48\%$ and $V_5=90.48\%$. The whole population quantitative dynamic index is $V_{pi}=51.52\% > 0$. When the exotic disturbance considered, the population quantitative dynamic index is $V_{pi}=4.29\% > 0$, and the disturbance sensitive index is $P=0.08333$. It also means a stable structure but with rather sensitivity to external disturbance.

4.2 Life table and survival curve

The life table is one of the important tools to estimate the future survival trends of population. The analysis of life table and survival curve can not only reflect the current population status, but also exhibit the competition of plant population and environment. It is essential for the effective conservation and management of the endangered plants (Li et al., 2002; Manuel and Molles, 2002; Chen et al., 2006). The static life table which is also called time specific life table has been widely used in natural population demographical analysis, especially for long life plants. In this study, we used the static life table to analyze the population dynamics of *E. excelsum*, based on the hypothesis that the growth at each class is constant.

Static life table (Table 1) and survival curve (Fig. 3) indicate that the number of the young stage individuals is obviously larger than that of the later stages. The survival curve of *E. excelsum* tends to be the Deevey-III type. The population size declines dramatically from size class II to

Table 1 The standard life table of *E. excelsum* population

age stage	interval scale	a_x	l_x	d_x	q_x	L_x	T_x	k_x	e_x	$\ln l_x$
I	H: 0–100 cm	76	1000	79	0.08	960.5	1852.0	0.08	1.85	6.91
II	H > 100 cm DBH < 3.0 cm	70	921	816	0.89	513	891.5	2.18	0.97	6.83
III	3.0–9.0 cm	8	105	79	0.75	65.5	378.5	1.41	3.61	4.65
IV	9.0–15.0 cm	2	26	–79	–3.04	65.5	313.0	–1.41	12.04	3.26
V	15.0–21.0 cm	8	105	53	0.51	78.5	247.5	0.70	2.35	4.65
VI	21.0–27.0 cm	4	52	13	0.25	45.5	169.0	0.29	3.25	3.95
VII	27.0–33.0 cm	3	39	0	0	39.0	123.5	0	3.17	3.66
VIII	33.0–39.0 cm	3	39	0	0	39.0	84.5	0	2.17	3.66
IX	39.0–45.0 cm	3	39	13	0.33	32.5	45.5	0.4	1.17	3.66
X	> 45.0 cm	2	26	—	—	13.0	13.0	3.26	0.50	3.26

a_x : number of alive organisms at age x ; l_x : proportion organisms surviving from the beginning of the life table to age x , $l_x = a_x/a_0 \times 1000$; d_x : number of dead organisms from age x to $x+1$, $d_x = l_x - l_{x+1}$; q_x : mortality rate from age x to $x+1$, $q_x = d_x/l_x$; L_x : number of survivors from age x to $x+1$, $L_x = (l_x + l_{x+1})/2$; T_x : total number of alive organisms from age x to $x+1$, $T_x = \sum L_x$; e_x : life expectancy at age x , $e_x = T_x/l_x$; $\ln l_x$: the natural logarithm of l_x ; k_x : age-specific mortality, $k_x = \ln l_x - \ln l_{x+1}$.

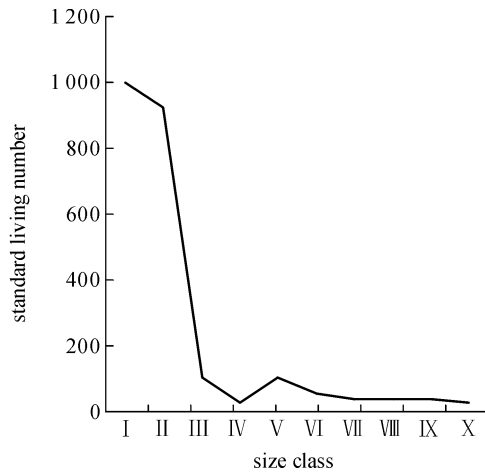


Fig. 3 Standard survival curve of *E. excelsum* population

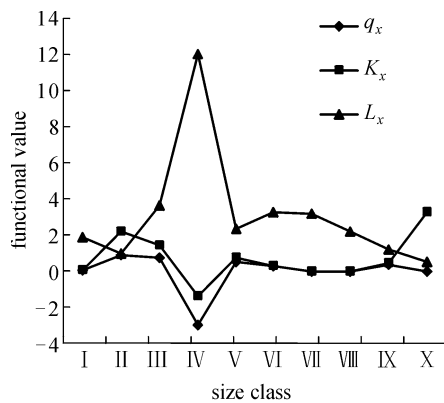


Fig. 4 Mortality (q_x), killing power (K_x) and life expectancy (L_x) curve of *E. excelsum* population

size class III, only 11.43% individuals growing to size class III. This phenomenon indicates that the developing process of *E. excelsum* from the young stage to adult is not always smooth. Based on our previous research (Wang et al., 2002a), we thought the main reasons for the abundance of young individuals are the normal flowering, abundant production of fruits and high rate of seed germination. However, the growth of young individuals needs a shady environment. The young trees of this species are less competitive in the community. With the growth of seedlings and saplings, the demand for nutrition, space and light resource will be gradually increased. Thus, only few young individuals can grow to middle stage due to environment sieve effect. Field investigations also found that young individuals of *E. excelsum* grow mainly inside of the forest with high canopies. Middle individuals survived after the environment sieve lives to the edge of each patch. As these patches mostly adjoin the local villages, the conscious or unconscious destruction from local villagers makes it very difficult for the natural growth of young individuals to adulthood. Therefore, it becomes a bottleneck for the population's regeneration and

recovery. Once it overcomes that growth bottleneck, the population size does not decline, with the population size from size class V increasing to size class X. By contrast to the destruction of young individuals, some old trees are well preserved by local people. According to our interviews with local villages, some blessing scripts were tagged on the big and old trees including the *E. excelsum* individuals with DBH > 15.0 cm. These trees were forbidden to be cut by the local villagers as part of their religious practice. This practice reduced the extinction risk of the *E. excelsum* population. This is quite similar with the case in *Cathaya argyophylla* due to the sacred forest (Xie and Chen, 1999).

The variation trends of mortality and killing power curve of *E. excelsum* population are similar (Fig. 5). The killing power reached two peak values in the size class II and X. The first value means a cost with high mortality from the young stage to the adult stage. The result is similar with the analysis of the survival curve. Another peak value implied a contiguous physiological senescence of *E. excelsum* individuals, and was subsequently with high mortality. Life expectancy reflects the average survival ability of individuals in the class X. The life expectancy of *E. excelsum* has a peak in the class IV size, suggesting the most appropriate survival quantity with a bloom of physiological growth in this class. However, the population keeps a stable life expectancy between the size class V and size class VII. The main interpretation is that there is less environmental competition among *E. excelsum* individuals after they overcome the environmental sieve and external disturbance. A gradual declining trend occurred between the size class VII and size class X, suggesting the population reaches physiological senescence.

4.3 Time sequence forecast

Time sequence analysis combined with the time-array is an integrated method for predicting and regression forecast. It focuses mainly on the future trend forecast based on the past time sequence variation, rather than analyzing the causal relationship (Zu et al., 1999). Therefore, the method is suitable for many complicated conditions. He proposed (2005) that the time sequence analysis combined with the life table is a useful tool to forecast the population dynamics of endangered species, after using this method to forecast the *Disanthus cercidifolius* population dynamics.

Time sequence analysis of *E. excelsum* (Table 2) indicated that the young and middle stage individuals will exhibit an increasing trend in the future two and five years, such as individuals in the size class III, IV and V. The trend is corresponding to the high proportion of seedlings and saplings. The number of middle stage individuals will increase, while the adults will still keep stable, such as those in size class VIII, IX and X. This trend is mainly caused by the low growth of *E. excelsum*. Thus, the *E.*

Table 2 Time sequence analysis of size structure of *E. excelsum* population

size	primary data	$M_2^{[1]}$	$M_5^{[1]}$	size	primary data	$M_2^{[1]}$	$M_5^{[1]}$
I	76			VI	4	6	18
II	70	73		VII	3	4	5
III	8	39		VIII	3	3	4
IV	2	5		IX	3	3	4
V	8	5	33	X	2	3	3

excelsum population is still keeping the recovery potential if its current distributions and habitats could be well preserved.

5 Discussion and conclusions

The *E. excelsum* population is mainly distributed to the local villages with high frequency of human activities. This distribution pattern is markedly different from other endangered plants, most of which are distributed in the natural conserved areas. All *E. excelsum* patches were exposed to human activities. The high levels of human disturbance, such as deforestation, road and settlement building, and the irrational land use led to the habitat fragmentation of *E. excelsum*. The current *E. excelsum* population is distributed in ten fragmented patches. These patches were isolated by some heterogeneous substrate including roads, farmlands and buildings, and finally formed the local population in the limited area. Wretten (1980) has proposed that the life table formed from varied forests can unite as a standard life table. In the research on *Picea aspoerata* population, Jiang (1992) also pointed out that the life table from all types of forests is a changed form of the standard life table, only representing the population size and dynamics, and only the standard life table can reflect the population basic characteristics. Zhang et al. (1999, 2004) also used the standard life table when he studied the population characteristics of *Larix potaninii* and *Adenophora lobophylla*. Thus, we also adopted this method in our study. We tabulated the standard static life table and analyzed the survival curve, mortality curve and life expectancy based on the individuals demography data of *E. excelsum* population. These analyses of natural population structure and dynamics can reflect the population characteristics very well.

The analysis of population structure and static life table indicated that the population size of *E. excelsum* is very small. In this limited population, there are relatively more seedlings and saplings, while there are much fewer individuals in the middle stage with a fixed number of

adults. Two reasons can explain this structure characteristic. Firstly, the adults of *E. excelsum* can produce abundant fruits and seeds and the seeds germination rate can reach to 60%. The population subsequently has a high proportion of seedlings and saplings. Another reason is that the young individuals are difficult to grow to the adult stage because of its weak competition under the external environment sieve and exotic disturbance. This has undoubtedly limited the natural regeneration and formed the survival and propagation bottleneck of the *E. excelsum* population. The individuals who survived through the environment sieve can obtain suitable growth resources. The stable life expectancy between size class V and size class VII suggested a normal growth of *E. excelsum* in these stages without much environmental stress. At the same time, the adults of *E. excelsum* were also conserved by local villagers' socio-religious beliefs and taboos. These practices not only saved the population size, but also guaranteed the future regeneration of *E. excelsum* population. The population survival curve tended to be of the Deevey-III type, which suggested a continuous population structure. Thus, we may conclude that the population of *E. excelsum* is still keeps its stability when considering only its population structure. It is similar with the characteristics of the *Abies yuanbaoshanensis* population (Li et al., 2002). The time sequence forecast also indicates that the *E. excelsum* population still has potential of recovery if the current distribution status and habitats can be preserved.

According to the current status and dynamics of *E. excelsum* population, we suggest that the remnant population and the habitats should be conserved unconditionally. The destruction of seedlings and juveniles from human activities should be prevented. Some suitable habitat should be selected and controlled to promote the natural regeneration of the *E. excelsum* population. Meanwhile, the total 20 adults are the only resource to maintain the current survival and future regeneration. The population size of *E. excelsum* will directly decline if these adult trees cannot survive, and consequently, future regeneration will also cease. This will undoubtedly lead to a high risk of extinction. Therefore, these 20 adult trees are the key of the population, and they must be conserved urgently. Moreover, due to the slow growth of *E. excelsum*, artificial propagation by seed germination and seedling establishment should be considered. These measures will help increase the number of individuals, and thus, the population size could be increased. Then, *E. excelsum* could play more important roles in the community. All these conservation measures and managements will ultimately help the population recovery of *E. excelsum*.

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