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Source: Mountain Research and Development, 31(4) : 343-350

Published By: International Mountain Society

URL: https://doi.org/10.1659/MRD-JOURNAL-D-11-00004.1

Mountain Research and Development (MRD)
An international, peer-reviewed open access journal
published by the International Mountain Society (IMS)
www.mrd-journal.org

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Habitat Fragmentation, Degradation, and Population Status of Endangered *Michelia coriacea* in Southeastern Yunnan, China

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The endangered tree Michelia coriacea *Chang et B. L. Chen (Magnoliaceae) is endemic to southeastern Yunnan, China. It is found in limestone outcrop habitats in a few localities at 1300–1700 m. Its habitat has been severely fragmented and degraded by overexploitation, including logging, road construction, and agricultural development in recent decades, with only 4 populations remaining at present. The population dynamics of* M. coriacea *are practically unknown. We investigated all 4 populations and studied the demography and ecology to create a scientific base for recommendations on conservation and restoration of the species. The census was repeated in 5 consecutive years from 2006 to 2010. Over that period, the annual mortality rate was 68.9% during early recruitment (individuals under 70 cm high), but mortality decreased to 23.3% after seedling/sapling establishment. The population of* M. coriacea *is clearly declining. The major factor threatening its continued existence is poor regeneration caused by ecological conditions, including habitat destruction, invasive plants, and low recruitment. Unless conservation measures are undertaken, the species will not maintain its natural population. The information provided here will apply to conservation of not only* M. coriacea *but also other plants having similar population dynamics and growing in unprotected areas in fragile mountain ecosystems.*

Keywords: Michelia coriacea*; population structure; habitat destruction; mortality; regeneration; conservation; China.*

Peer-reviewed: *August 2011* ***Accepted:*** *September 2011*

Introduction

Destruction, fragmentation, and degradation of natural habitats have been the main causes of world biodiversity decline. They have left numerous plant species facing the risk of extinction (Lande 1988, 1998; Cox and Moore 1993; Tilman et al 1994; Clark et al 1999; Laurance et al 2000; Myers et al 2000; Thomas et al 2004). Historical and contemporary losses in forest cover associated with human activities have occurred in many regions of the world (Lamb et al 2005). China has experienced a major loss of natural habitats, particularly from the 1930s onward, mainly due to the overlogging of forests for timber, fuelwood, and paper, as well as from the conversion of natural forests into monospecific plantations and croplands (Wu 1980; Tang et al 2007, 2010a, 2010b, 2011; Tang 2010).

The population dynamics of plant species can be described in terms of demographic variables such as the recruitment, mortality, and growth rate of individuals (Watkinson 1997). Demographic monitoring and analysis are especially crucial for managing the conservation of threatened, endangered, and rare species (Menges and Gordon 1996; Caswell 2001; Caswell and Kaye 2001). Studies have focused on identifying ecological factors that affect population dynamics and have found that populations and species more often become extinct for ecological and demographic reasons than for lack of genetic variation (Jennersten 1988; Aizen and Feinsinger 1994). In many plant species, the largest loss of reproductive potential occurs mostly between seed and seedling establishment, and biotic and abiotic factors acting during early recruitment may have profound effects on the dynamics and spatial structure of the population (Schupp and Fuentes 1995; Clark et al 1999).

Many genera of seed plants endemic to China are found in southeastern Yunnan (Li 1994; López-Pujol et al 2011). Limestone outcrops in southeastern Yunnan occur in a variety of configurations, from scattered small patches to extensive landscapes. Among subtropical regions, the Karst areas have an exceptionally high floristic richness and degree of endemism (Shui and Cheng 2003). The extensive removal of native vegetation has resulted in fragmentation and small-grained patchiness among the remaining vegetation across the landscape. China—and Yunnan in particular—harbor a high number of Magnoliaceae species, many of them in danger of extinction due to habitat destruction (Fu and Jin 1992; Cicuzza et al 2007). Among these species, one of the most threatened is *Michelia coriacea* Chang et B. L. Chen, which is endangered by habitat destruction, fragmentation, and degradation while its distribution range is entirely unprotected. Active management is required to halt this continued decline and to restore populations and habitat. Such management requires a sound understanding of demography and ecology.

Until now, the patterns of emergence and survival of *M. coriacea,* as well as the causes of its mortality and their effect on recruitment, have been practically unknown. To establish a baseline for conservation of the species, we studied its recruitment and regeneration and analyzed its population structure. We aimed to provide ecological insights regarding in situ conservation of this plant and to answer the following questions: (1) To what extent do demographic variables explain the population status of the species? (2) What role does the seedling stage play in its life history? (3) What guidelines emerge for its possible conservation in the fragile mountainous region?

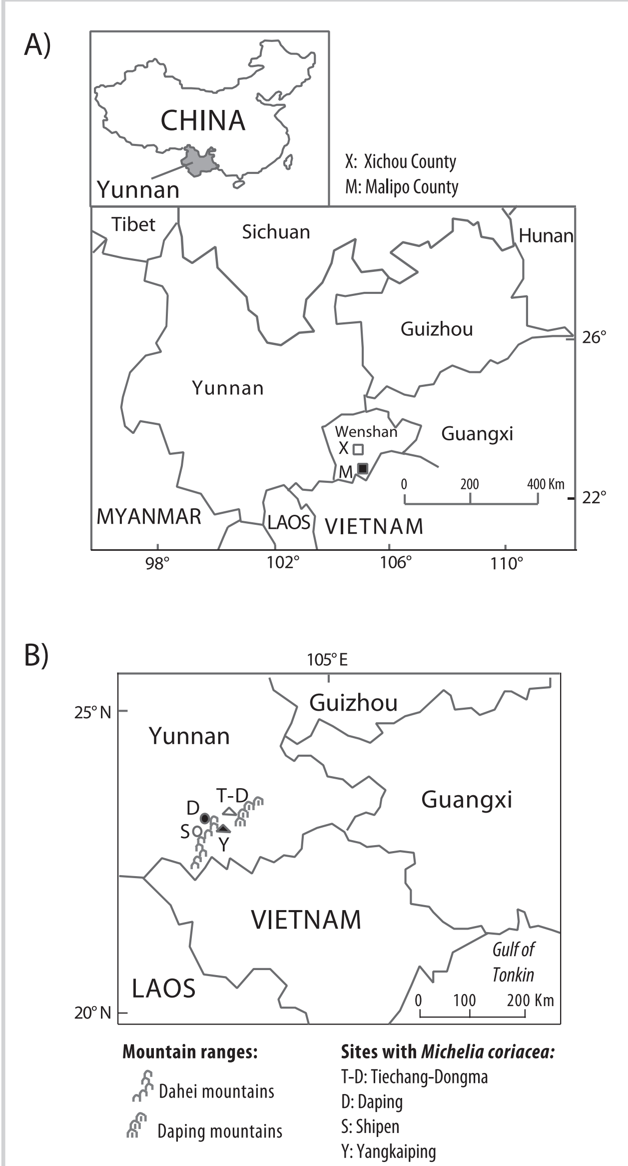
Material and methods

The study area, species, and populations

In the study area (23°05′–23°11′N, 104°35′–104°40′E) of Malipo and Xichou counties, located in Wenshan, southeastern Yunnan, near the border with Vietnam (Figure 1A), intensive agricultural development began in the 1950s and has resulted in widespread fragmentation of forests, leaving many patches smaller than 0.10 ha. The study sites were severely logged or partially cut 25–80 years ago as development proceeded. The local climate is typified by that of the Xichou climatic station (23°27′N, 104°41′E, 1473.5 m): subtropical monsoon, with a mean annual precipitation of 1269.1 mm, of which 80% occurs in the summer months of June to September. The annual evaporation is 1180.7 mm. The mean annual temperature is 16.4°C, with a mean monthly minimum temperature of 9.6°C in January and a maximum of 21.3°C in July. The mean annual relative humidity is 83.5%, with a minimum of 79.3% in April and a maximum of 86.6% in August (unpublished data). The study sites are characterized by limestone outcrops, with a soil depth of 10–40 cm. According to our analysis of field soil samples from the study sites, the surface soils (0–15 cm) have a pH ranging from 5.2–7.2, organic matter from 15–58%, C:N ratio from 11.2–15.6%, and available calcium 3323–16,354 mg/kg.

M. coriacea (Magnoliaceae) is an evergreen tree growing up to 22 m in height and an endangered species endemic to southeastern Yunnan. It grows only on limestone outcrop habitats in a few localities at 1300–1700 m in

FIGURE 1 The location of Malipo and Xichou of Wenshan, Yunnan (A), and the 4 populations of *M. coriacea* in Malipo and Xichou areas (B). M, Malipo; X, Xichou; D, Daping, S, Shipen; Y, Yangkaiping; T-D, Tiechang-Dongma.



Malipo and Xichou counties. Its timber is valuable. It is capable of reproducing sexually, as well as asexually by sprouting. The solitary flowers are composed of 6–7 creamy yellow petals. The flowering period commences in early February and ends in early April. The flowers are generally visited by various insects. The fruits are aggregated. The fruiting period is September–October. Animals may act as dispersal agents to some extent (personal observation).

The altitudinal range of 1300–1700 m (based on our own investigation) is in an area originally belonging to the monsoon evergreen broad-leaved forest. However, the indigenous vegetation has been highly fragmented by human activities. We searched all individuals of *M. coriacea* in the distributed areas as known to botanists and local people and found 4 populations located 30 km or more from each other, all in unprotected areas. We are aware that one population in Guangnan is already extinct. Each population was small (no more than 50 individuals each). All of them were situated on sites originally occupied by forests, but now converted into secondary forests after clear or partial cutting during the 1930s–80s. No fires have been recorded in the study area.

Field data

At the study sites, including Daping, Shipen, and Yangkaiping in Malipo county, and Tiechang-Dongma on the border between Xichou and Malipo counties (Figure 1B), 8 permanent plots (20 m × 20 m for 7 plots and 30 m × 30 m for 1 plot) containing *M. coriacea* were established. We subdivided each plot into 5 m × 5 m quadrats. To have sufficient data for statistical analysis of seedlings and saplings, we established 30 additional quadrats (5 m × 5 m each) surrounding each 20 m × 20 m plot and the 30 m × 30 m plot. We recorded tree species diversity, Dbh (diameter at breast height, 1.3 m above ground level), and height for all woody species ≥1.3 m in the study plots. All seedlings/saplings of *M. coriacea* were measured for height and counted in each quadrat. We distinguished the microsites as the edges of stands (ES), canopy gaps (Gap), under canopy (UCP), and under parent trees (UPT) for the seedling/sapling survey. The census was repeated in August of 2006, 2007, 2008, 2009, and 2010, when we recorded newly recruited and dead seedlings/saplings and sprouts.

Annual censuses of fruit production within the plots were conducted for each plant. In October 2008, we collected 30 aggregated fruits from each of 10 trees, determined the number of seeds and the number of filled seeds, and weighed the seed mass.

To measure the age of trees, the increment core samples were taken from 26 main stems at a height of 1 m above the stem base. The annual growth rings were counted in the laboratory using a dissecting microscope. Our observations (188 of 200 individuals 1 m in height are 4 years old) from the *M. coriacea* nursery in Wenshan allowed us to estimate that an individual 1 m high is about 4 years old. For age classification, we added 4 years to the tree ring data taken at a height of 1 m above the stem base to represent the true age of individuals.

To determine the dominant species in plant communities containing *M. coriacea,* dominance analysis (Ohsawa 1984; Kikvidze and Ohsawa 2002) was applied.

As life history stages, 7 growth stages (S1 to S7) according to height (H) and Dbh were delimited for stems: S1, 0 cm $< H <$ 20 cm; S2, 20 cm $\leq H <$ 40 cm; S3, 40 cm $\leq H <$ 70 cm; S4, 70 cm $\leq H <$ 100 cm; S5, 100 cm $\leq H <$ 130 cm; S6, $H \geq$ 1.3 m and Dbh $<$ 3 cm; S7, $H \geq$ 1.3 cm and Dbh $\geq$ 3 cm.

Based on the number of human disturbance factors (selective logging for timber, harvesting of wood for fuel, creating agriculture lands, and building roads), each site was assigned one of the following disturbance values: 5, if there was only one disturbance factor; 11, if there were 2 factors; 20, if there were 3 factors; 30, if there were 4 factors (Uotila and Kouki 2005; Tang et al 2010a, 2010b; Tang et al 2011).

Differences in the number of individuals ($H <$ 1.3 m) of the 4 populations for each year for the period 2006–2010 were analyzed by Friedman's two-way nonparametric analysis of variance (ANOVA). Differences in the number of current seedlings among different habitats were analyzed using the one-way ANOVA.

Results

Fragmented stand characteristics and degraded habitats

Our explorations led to the discovery of 4 populations of *M. coriacea* surviving in forest fragments and degraded habitats. Tree age and stem diameter show a significant correlation ($y = 1.71x - 3.61$, $r^2 = 0.87$, $n = 26$, $P < 0.001$). Based on the floristic composition of the 8 plots and using Sørensen's similarity index and group average clustering, 4 groups were identified (Figure 2; Table 1).

1. Group 1: a *Michelia–Lithocarpus–Ormosia–Ilex* stand (plots 1 and 2) in Daping, an old secondary stand remaining after being partially logged in the 1950s–1980s, though a single *M. coriacea* tree was found to be 206 years old.
2. Group 2: a *Michelia–Cyclobalanopsis* stand (plots 6, 7, and 8) in Yangkaiping, a secondary stand remaining after being clear-logged in 1930–1935 and partially logged in the 1970s–1980s, where the maximum age of *M. coriacea* was 91 years.
3. Group 3: a secondary stand of *Michelia* in Shipen (plot 3) left after partial logging in the 1950s–1980s, though it contained a few 90- to 121-year-old *M. coriacea* trees.
4. Group 4: a *Lithocarpus–Neocinnamomum–Sapium–Michelia* stand (plots 4 and 5) in Tiechang-Dongma, a young secondary stand growing after being clear-logged for road construction in the early 1970s, where the oldest *M. coriacea* tree was only 40 years of age.

The stands in Daping, Shipen, and Yangkaiping were codominated by evergreen *M. coriacea, Lithocarpus fenestratus* (Roxb.) Rehder, *Cyclobalanopsis myrsinaefolia* (Blume) Oerst., *Ilex macrocarpa* Oliv., and deciduous *Ormosia olivacea* L. Chen. Deciduous broad-leaved *Celtis cerasifera* Bl. was also present in these stands. More numbers of deciduous broad-leaved species such as *Sapium chihsinianum* S. K. Lee, *Carpinus tsaiana* Hu, and *Cryptocarya chinensis* (Hance) Hemsl. were mixed with *M. coriacea.* Other evergreen broad-leaved species such as *Sloanea sinensis* (Hance) Hemsl. and *Neocinnamomum delavayi* (Lec.) H. Liou were in the young secondary stand at

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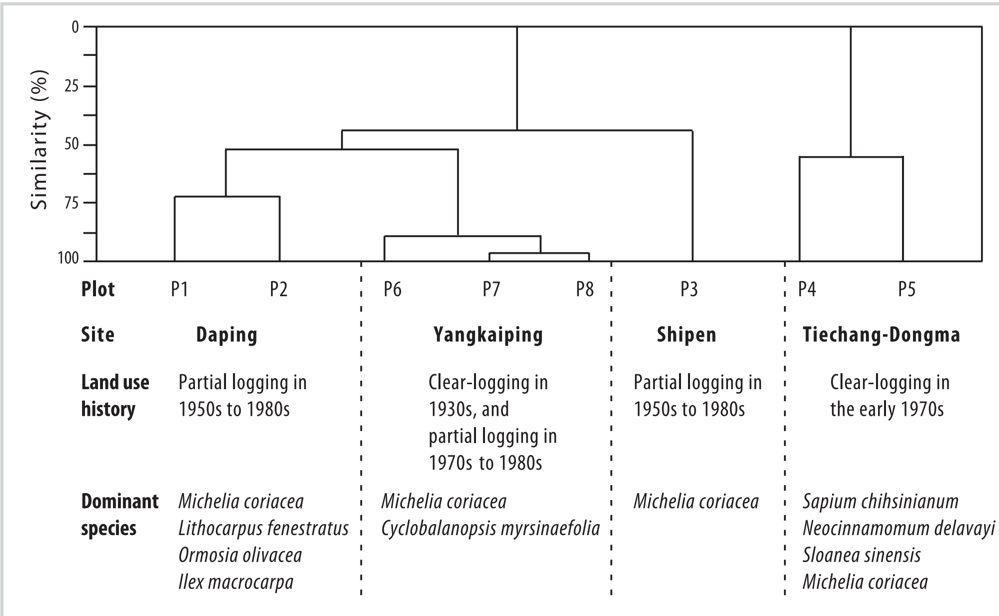
FIGURE 2 Similarity dendrogram using relative Sørensen's similarity index and group average clustering for the stands containing *M. coriacea*.



Tiechang-Dongma. Notably, the coverage of the invasive plant *Eupatorium adenophorum* Spreng significantly increased with greater degrees of human disturbance (Figure 2; Table 1).

Population status

Size structure and regeneration: The populations examined were small, comprising 23, 27, 50, and 8 individuals (greater than 1.3 m of height) of *M. coriacea* in Daping, Shipen, Yangkaiping, and Tiechang-Dongma, respectively. Dbh class and age class frequency distribution are shown in Figure 3. A total of 108 plants ($H \geq 1.3$ m) with 54 sprouts were recorded. The overwhelming impression at all 4 sites is the general lack of smaller plants. These appeared to be insufficient to sustain current densities of mature plants.

The Daping population had scattered individuals, with one 206 years old and a 125 cm Dbh. In the Shipen population, a few stems were found in Dbh classes 10–50 cm, with a few individuals 90–121 years old and 55–77 cm Dbh. The Yangkaiping population had more stems at 15–25 cm Dbh, with ages of 20–50 years. Here, because of frequent physical damage by landslides on the steep slope (50–60 degrees of inclination), more sprouts occurred than at the other 3 sites (15–37 degrees of inclination). Seven trees of 48–54 cm Dbh with ages of 88–91 years were found. In the Tiechang-Dongma population, few stems were found with a Dbh less than 20 cm, and the maximum age was 40 years.

In general, there were from 2 to 6 embryos per fruit, but only about 1 filled seed per mature fruit. The mean single filled-seed weight ($\pm$ SD) was 0.24 ± 0.09 g. However, most fruit traits showed considerable variation from one plant to another. Based on our experiment on the germination of the species, the germination rate reached 96%. This species does not have dormancy before germination. Trees started to reproduce at an age of about 15–35 years (equivalent to Dbh of 10–20 cm). The number of individuals ($H < 1.3$ m) significantly changed with years and populations ($P < 0.01$ by Friedman test) (Table 2).

We pooled the data at the 4 sites for statistical analysis according to microhabitats, that is, the ES, Gap, UCP, and UPT as described above. Relatively more seedlings were found in Gap than at the other 3 microsites ($P < 0.0001$ by one-way ANOVA) (Figure 4), with height growth greater in Gap and ES than elsewhere. This suggests that *M. coriacea* is a shade-intolerant species. Sprouts from the basal root were common. Current-year sprouts were more numerous than seedlings. Both recruitment and mortality fluctuated temporally. The annual mortality before stage 4 was 68.9%, while it was 23.3% in the seedling-to-sapling phase (from stage 4 to stage 6) (Figure 5).

Discussion

The annual mortality of seedlings at early stages (individuals under 70 cm high) indicates very limited recruitment. The scanty seed production may be an aftereffect of earlier logging. In general, there were 2 to 6 embryos per fruit, but only about 1 filled seed per mature fruit. This may be due to abnormalities in sexual development (Zhao and Sun 2009). The growth and survivorship of this species may be superior where there is adequate sunlight. However, the invasive weed *E. adenophorum* threatens *M. coriacea* habitats by reducing the availability of light, water, and nutrients. Competition for

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TABLE 1 Species composition for woody species ≥1.3 m in height in the plots containing *M. coriacea*, showing relative basal area (RBA) ≥0.05%. Dominant species are indicated by boldface. (Table continued on next page.)

Site	Daping		Yangkaiping			Shipen	Tiechang-Dongma	
Plot characteristics								
Plot identity	P1	P2	P6	P7	P8	P3	P4	P5
Plot area (m^2)	400	400	400	400	400	900	400	400
Altitude (m)	1649	1651	1305	1305	1387	1480	1413	1462
Degree of human disturbance (score)	5–11	5–11	20	20	20	5–11	30	30
Maximum age of *M. coriacea* (years)	206	76	85	91	80	121	40	24
Invasive plants[a)] coverage in the understory (%)	18	22	45	39	52	25	96	85
Species	**RBA** (%)	**RBA** (%)	**RBA** (%)	**RBA** (%)	**RBA** (%)	**RBA** (%)	**RBA** (%)	**RBA** (%)
Michelia coriacea	**45.30**	**89.80**	**37.95**	**45.80**	**64.40**	**43.10**	**9.7**	**5.90**
Lithocarpus fenestratus	**13.70**	0.30	0.20	0.08			**19.1**	3.40
Ormosia olivacea	**13.30**							
Ilex macrocarpa	**10.80**		0.06	0.05				
Machilus verruculosa	6.40	0.60	1.10		1.40			
Sloanea sinensis	4.30	2.60	1.42		2.70	0.03		**23.40**
Morus macroura	3.20			4.50	1.60	2.20		
Lindera communis	2.30	0.20		2.90	8.58	0.40		4.70
Celtis cerasifera	0.50	0.30	5.09	7.21	2.41	8.00	1.3	0.07
Neocinnamomum delavayi	0.08	0.05	6.18	4.78	6.74	3.60	**16.7**	**11.50**
Cyclobalanopsis myrsinaefolia		4.30	**33.87**	**14.70**		0.20		
Bothrocaryum controversum			5.17	1.93				
Sapium chihsinianum			3.54	3.32	2.38	8.00	**23.0**	**18.30**
Machilus sichourensis			3.04	1.36	2.45	6.40	**7.5**	5.50
Photinia serrulata			1.21	5.99				
Carpinus tsaiana			0.87	7.00	6.68	1.10	5.8	1.10
Podocarpus neriifolius						7.60	1.2	1.70
Litsea monopetala						6.60		
Phoebe microphylla						6.00		

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TABLE 1 Continued. (First part of Table 1 on previous page.)

Site	Daping		Yangkaiping			Shipen	Tiechang-Dongma	
Caryota urens						5.80		0.03
Phoebe angustifolia							6.2	
Platycarya strobilacea							4.1	6.90
Rapanea verruculosa							2.4	6.70
Cryptocarya chinensis							1.4	8.00
Juglans cathayensis								2.60

[a] *Eupatorium adenophorum*.

seedling establishment sites with invasive weed species may have caused the high annual mortality in early recruitment and contributed to the decline of *M. coriacea* populations; this requires further study. We consider our data from the 5-year census to show definitively that the limited recruitment in the early seedling stages is especially critical for *M. coriacea* and not adequately counteracted by its longevity.

M. coriacea now living in outcrops of limestone can develop extensive root systems in extremely thin soils and can sprout after being injured. On the steep slope (50–60 degrees of inclination) of Yangkaiping, *M. coriacea* is notable for

FIGURE 3 Dbh-class and age-class frequency distribution of *M. coriacea* (H ≥ 1.3 m at height). Filled bars, main stems; open bars, sprouts. Arrows show the category at which trees start reproducing.

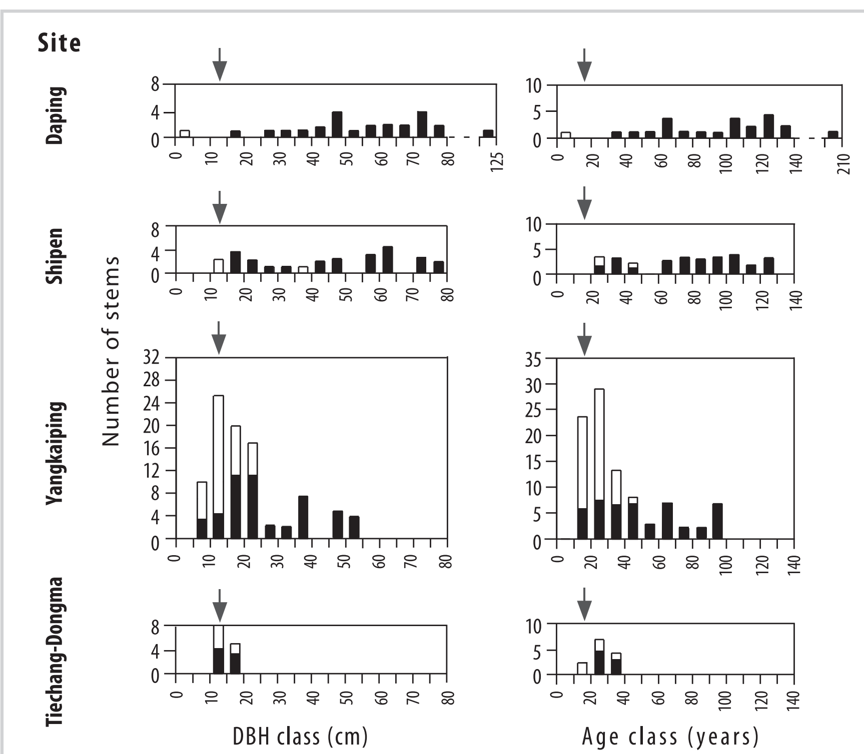


TABLE 2 Number of individuals (H $<$ 1.3 m) of the 4 populations for each year during 2006–2010. The number of individuals significantly changed both by year and by population ($P < 0.01$ by Friedman test).

Year	Populations in the 4 sites			
	Daping	Yangkaiping	Shipen	Tiechang-Dongma
2010	9	32	14	16
2009	11	36	16	17
2008	14	47	25	21
2007	15	50	29	22
2006	17	53	32	26

vigorous sprouting at the base of stems (Figure 3), which may compensate for the scarcity of seedlings in the Yangkaiping population. The ecological performance is similar to that of other endangered trees, including *Davidia involucrata* Baill., *Tetracentron sinense* Oliv., and *Cercidiphyllum japonicum* var. *sinense* Siebold. et Zucc. (Tang and Ohsawa 2002) and *Ginkgo biloba* L. (Del Tredici 1992).

Conclusions

The species is threatened by ecological factors including habitat damage, invasive plants, and low recruitment. The regeneration of the *M. coriacea* population is poor. In the most disturbed area, the species is represented by just a few young individuals. While the population in Tiechang-Dongma cannot be completely protected due to easy access from a nearby road, we strongly suggest designation of the sites in Daping, Shipen, and Yangkaiping as protected habitats, where prevention of damage, logging, and cutting for firewood is of high priority. The invasive plant *E. adenophorum* invades aggressively in the habitats disturbed by humans, limiting the tree's regeneration by shading the understory. We need further study on the effects of this invasive plant. Removal of this invasive plant at the 3 sites is necessary for the establishment of seedlings/saplings. Seedling nurseries in situ will be an important need, as the species shows weak recruitment. The findings will be of use in establishing priorities for recovery and conservation of endangered species, not only *M. coriacea* but also other plants having similar population dynamics and growing in unprotected areas in fragile mountain ecosystems.

FIGURE 4 The emergence of current-year seedlings and sprouts of *M. coriacea* for the 4 populations. ES, edges of stands; Gap, canopy gaps; UCP, under canopy; UPT, under parent tree.

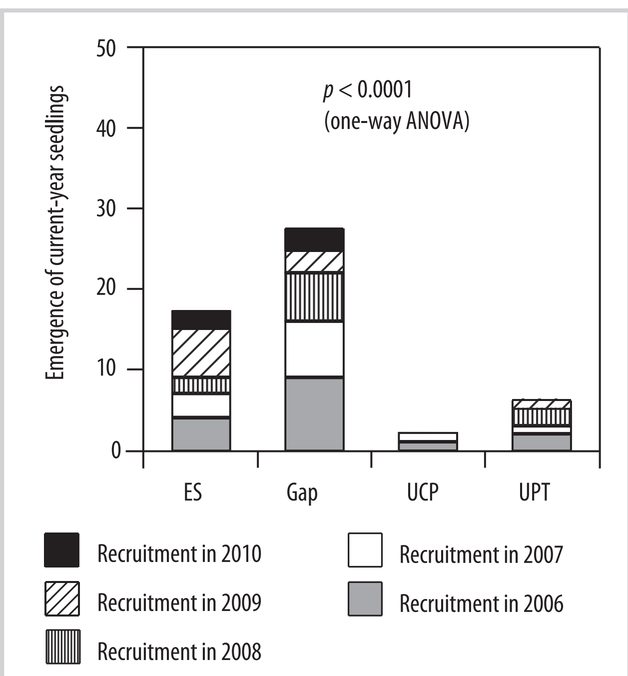
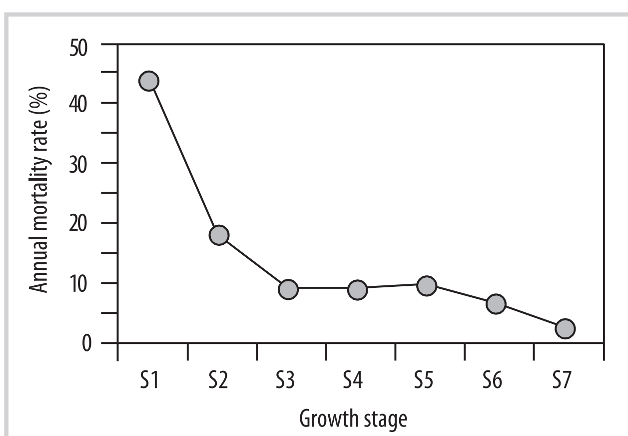


FIGURE 5 Annual mortality of stem according to growth stage. See text for abbreviations of growth stages (S1–S7).



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ACKNOWLEDGMENTS

We thank 2 anonymous reviewers, whose valuable comments greatly helped us to improve the paper, and Associate Editor Dr Anne B. Zimmermann for her critical reading of the manuscript. This study received financial support from grant No S0801024 from Tokyo University of Information Sciences.

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