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Diversity and Ecology of Mountain Bamboos in the Shennongjia National Nature Reserve of Central China:

Implications for Resource Management and Biodiversity Conservation

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ABSTRACT

The Shennongjia National Nature Reserve (Shennongjia in the following) in Central China, where bamboo dominates the understorey of the forests in the mountain ranges, used to be a habitat of the giant panda. To evaluate the possibility for reintroducing the giant panda to Shennongjia and to achieve a better understanding of the diversity and ecology of bamboo species in this region, a study on mountain bamboos was carried out with regard to species diversity, vegetative growth, flowering habit, and ecological importance. The species inventory recorded four genera and eleven bamboo species in Shennongjia. Of these, four species (*Phyllostachys nigra* var. *henonis*, *Ph. heteroclada*, *Ph. nidularia* and *Ph. bambusoides*) are running bamboos with monopodial rhizomes; three species (*Fargesia spathacea, F. murielae* and *Yushania confusa*) are clumping bamboos with sympodial rhizomes; and four species (*Indocalamus latifolius, I. longiauritus, I. wilsoni* and *I. tessellatus*) are semi-running bamboos with amphipodial rhizomes.

The vegetative growth of three representative bamboo species was studied: *Ph. nigra* var. *henonis, I. latifolius,* and *F. spathacea*. During the growing season, the vegetative growth of the bamboo takes place in three successive phases: shoot sprouting, height growth and branch spreading. The study showed that new shoots of *Ph. nigra* var. *henonis* emerged from late April to late May, and reached an average density of 2.7 shoots m^{-2} within the sprouting phase of 16 days. A total of 32 % of the bamboo shoots died back before maturity. Shoots grew to the full height of 400 cm in about 34 days. New shoots of *I. latifolius* emerged between late March and mid May, and reached an average density of 8 shoots m^{-2} within the sprouting phase of 22 days. A total of 18 % of the bamboo shoots died back before maturity. Shoots grew to the full height of 191 cm within 98 days. New shoots of *F. spathacea* emerge between late March at low elevations and late May in high altitudes, and reached an average density of 10 shoots m^{-2} within the sprouting phase of 25 days. The beginning of the sprouting phase was progressively delayed by 2.7 days with each 100 m increase in altitude, and the end delayed by 1.6 days correspondingly, the sprouting phase thus being shortened.

The flowering pattern and seedling establishment of the endemic *F. murielae* was studied. In Shennongjia, over 95 % of the bamboo clumps of *F. murielae* flowered gregariously and died in 1996-2000, extending from lower elevations to the higher mountains along the altitude. Bamboo seedlings emerged after simultaneous flowering, reaching an average density of 5,460 seedlings m^{-2} in the autumn of the first year after flowering. After a high mortality rate throughout the first winter, seedling density remained stable in following 2-4 years (1,130-1,230 seedlings m^{-2}). However, over 70 % of the bamboo clumps in a burned stand did not produce seedlings after flowering, indicating that a historical fire may have an extended effect on the sexual regeneration in the bamboo life cycle.

The possibility for reintroducing the giant panda in Shennongjia is discussed in terms of food availability, carrying capacity, and predicted bamboo flowering. Based on the comparison of the bamboo species recorded in Shennongjia with what is known to be the panda's diet, three species (*F. spathacea, F. murielae*, and *Y. confusa*) are considered as the preferred forage bamboos. Based on aerial photos, these three species currently cover 12 %, 8 %, and 3 % of the land area of Shennongjia, respectively. On a seasonal basis, *F. spathacea* may provide the panda with fresh shoots from early April

to June. When shoots of *F. spathacea* become fibrous, the panda can move to upper mountains to feed on new shoots from *F. murielae*, which produces suitable shoots from June to July. The carrying capacity is estimated based on the distribution and area coverage of the preferred forage bamboos (23 % of the land area in Shennongjia) and the panda density in bamboo-covered habitats (3.3-3.8 km^2 $panda^{-1}$). Estimations show that the preferred forage bamboos in Shennongjia could feed 194-223 giant pandas. However, simultaneous flowering of the forage bamboos may lead to a reduction in food supply. The flowering habits of bamboos in Shennongjia imply that in 1879-1888, three preferred food species, i.e., *F. spathacea, F. murielae,* and *Y. confusa*, simultaneously flowered and died back, which resulted in a shortage of food. In the past, such shortages usually forced the panda to migrate to a new habitat where forage bamboos were available. But in the late 19th century, Shennongjia had become separated from other panda habitats by densely populated agricultural zones. Such a habitat isolation and simultaneous flowering of the different forage bamboo species might have been the reason for the extinction of the giant panda in Shennongjia. Given the possibility of simultaneous flowering of the different forage bamboo species, reintroducing the giant panda to this isolated habitat is not without risks.

ZUSAMMENFASSUNG

Die Shennongjia National Nature Reserve (im Folgenden Shennongjia) in Zentralchina, wo Bambus die Strauchschicht der Bergwälder dominiert, gehörte früher zum Verbreitungsgebiet des Großen Pandabären. Um die Möglichkeiten der Wiedereinführung des Pandas dort abzuschätzen, und um die Diversität und Ökologie der Bambusarten in dieser Region besser zu verstehen, wurde eine Studie über Artenvielfalt, vegetatives Wachstum, Blühverhalten und ökologische Bedeutung des Bambus durchgeführt. Es wurden vier Bambusgattungen und elf Arten gefunden: vier Arten (*Phyllostachys nigra* var. *henonis*, *Ph. heteroclada*, *Ph. nidularia* und *Ph. bambusoides*) sind ausläuferbildend mit monopodialen Rhizomen, drei Arten (*Fargesia spathacea, F. murielae* und *Yushania confusa*) horstbildend mit sympodialen Rhizomen und vier Arten (*Indocalamus latifolius, I. longiauritus, I. wilsoni* and *I. tessellatus*) teil-ausläuferbildend mit amphipodialen Rhizomen.

Das vegetative Wachstum von drei repräsentativen Bambusarten wurde untersucht: *Ph. nigra* var. *henonis, I. latifolius,* and *F. spathacea*. Während der Wachtumsperiode findet das vegetative Wachstum in drei sukzessiven Phasen statt: Austrieb, Höhenwachstum und Verzweigung. Die Studie zeigt, dass die neuen Triebe von *Ph. nigra* var. *henonis* zwischen Ende April und Ende Mai erschienen und innerhalb der Austriebsphase von 16 Tagen eine durchschnittliche Dichte von 2.7 Trieben m^{-2} erreichten. Insgesamt starben 32 % der Bambustriebe ab, bevor sie ausgewachsen waren. Die Halme erreichten ihre volle Höhe von 400 cm in ca. 34 Tagen. Neue Triebe von *I. latifolius* erschienen zwischen Ende März und Mitte Mai und erreichten eine durchschnittliche Dichte von 8 Trieben m^{-2} innerhalb von 22 Tagen. Insgesamt starben 18 % der Triebe ab, bevor sie ausgewachsen waren. Die Halme erreichten ihre volle Höhe von 191 cm innerhalb von 98 Tagen. Die neuen Triebe von *F. spathacea* erschienen zwischen Ende März in niedrigen Höhenlagen und Ende Mai in größeren Höhen und erreichten eine durchschnittliche Dichte von 10 Trieben m^{-2} innerhalb von 25 Tagen. Der Beginn bzw. das Ende der Austriebsphase verzögerte sich stufenweise pro 100 m Höhenzunahme um 2.7 Tage bzw. 1.6 Tage, wodurch die Austriebsphase verkürzt wurde.

Blühmuster und Keimlingsbildung des endemischen *F. murielae* wurden untersucht. In Shennongjia blühten von 1996 bis 2000 95 % der Individuen synchron und starben von den unteren bis in die oberen Höhenlagen ab. Bambuskeimlinge erschienen nach der Massenblüte und erreichten eine durchschnittliche Dichte von 5.460 Keimlingen m^{-2} im Herbst des ersten Jahres nach der Blüte. Nach einer hohen Mortalitätsrate während des ersten Winters blieb die Keimlingsdichte in den folgenden 2-4 Jahren stabil (1.130-1.230 Keimlinge m^{-2}). Über 70 % der Horste in einem verbrannten Stand produzierten jedoch keine Keimlinge nach der Blüte. Dies deutet darauf hin, dass sich ein früheres Feuer auf die sexuelle Regeneration des Bambus auswirkt.

Die Möglichkeit einer Wiedereinführung des Großen Pandabären wird im Zusammenhang mit Nahrungsangebot, Tragfähigkeit und vorausgesagte Blüte diskutiert. Durch den Vergleich der Bambusarten in Shennongjia mit den Kenntnissen über die Ernährungsgewohnheiten des Pandas wurden drei Arten (*F. spathacea, F. murielae, and Y. confusa*) als die bevorzugten Futterarten ermittelt. Aus Luftbildern wurde ersichtlich, dass diese Arten z. Zt. 12 %, 8 %, bzw. 3 % des Shennongjiagebietes

bedecken. Die jungen Triebe von *F. spathacea* bieten dem Panda Nahrung von Anfang April bis Juni. Wenn die Triebe von *F. spathacea* faserig werden, kann der Panda von Juni bis Juli in die höheren Lagen abwandern und sich dort von den neuen *F. murielae* Trieben ernähren. Die Tragfähigkeit wird auf der Grundlage der Verteilung und des Deckungsgrades der bevorzugten Futterarten (23 % des Shennongjiagebietes) und der Pandadichte in den mit Bambus bedeckten Lebensräumen (3.3-3.8 km^2 $Panda^{-1}$) geschätzt. Die Schätzungen zeigen, dass die bevorzugten Futterarten in Shennongjia 194-223 Große Pandas ernähren könnten. Ein gleichzeitiges Blühen dieser Bambusarten könnte zu einer Reduzierung des Nahrungsangebotes führen. Die Blühgewohnheiten der Bambusarten in Shennongjia deuten darauf hin, dass von 1879 bis 1888 drei bevorzugte Futterarten, d.h., *F. spathacea, F. murielae,* und *Y. confusa*, gleichzeitig blühten und abstarben, was zu einer Nahrungsknappheit führte. In der Vergangenheit führten solche Knappheiten i.d.R. dazu, dass der Panda in neue Lebensräume, wo die Futterarten noch vorhanden waren, migrierte. Seit Ende des 19 Jahrhunderts ist Shennongjia durch dicht besiedelte Gebiete von den anderen Lebensräumen der Pandas abgetrennt. Eine solche Isolierung des Lebensraumes und das gleichzeitige Blühen der verschiedenen Futterarten sind eventuell die Gründe für das Aussterben des Großen Pandas in Shennongjia. Da ein gleichzeitiges Blühen der verschiedenen Bambusarten wieder möglich ist, ist eine Wiedereinführung des Großen Pandas in diesem isolierten Lebensraum nicht ohne Risiko.

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1 GENERAL INTRODUCTION

1.1 Background and objectives

Bamboos, ranging from woody to herbaceous taxa, belong to the family *Poaceae* (*Gramineae*), forming the subfamily *Bambusoideae* (Liese 1985; Dransfield and Widjaja 1995). There are approximately 85-90 genera and 1,200-1,500 species of bamboos (Soderstrom et al. 1988; Ohrnberger 1999), native to all continents except Europe and Antarctica (McClure 1993; Liese 2001). They are found especially in Asia and South America, primarily in China (39 genera and 500 species; Zhu et al. 1994; Keng and Wang 1996), India (18 genera and 128 species; Tewari 1992; Seethalakshmi and Kumar 1998), Southeast Asia (20 genera and 200 species; Dransfield and Widjaja 1995), and Latin America (20 genera and 429 species; Londoño 2001). Thirty-two and five species are to be found in Madagascar and Australia, respectively (Wrigley and Fagg 1996; Dransfield 2000), while North America has only one native species, *Arundinaria gigantea* (Walt.) Muhl. (Shor 2002).

1.1.1 Historical importance of bamboo

Before the advent of industrialization and cash-based transactions, bamboo had played a significant role in the self-sustaining economies in many nations that are now grouped together as developing countries (Quintans 1998). For centuries, bamboos have been closely related to agriculture, cottage industries, arts, culture and day-to-day life of more than half of the world's population (Tewari 1992; Quintans 1998; Mohanan 1998; Liese 2001). In southern Asia, bamboo was named "timber of the poor", an inferior substitute for wood products for poor people with low income and purchase power (Liese 1991, 2001). However, bamboo is now used for multifarious purposes such as basketry, weaving, mats, furniture, industrial ply-bamboo panels, flooring materials, papermaking, essential oils and medicines and as nutrition in the form of bamboo shoots (Liese 1985; Dransfield and Widjaja 1995). In fact, very few plant species have inspired such a wide variety of uses as bamboo – quite apart from its role in culture and art, especially in Asia.

China has the richest bamboo diversity in the world in terms of number of species (ca. 500 species) and area of plantation (3.5 million ha, Zhu 1987; Keng and

Wang 1996; Yi 1997). Bamboo played an indelible role in China's self-sustaining economies and traditional cultures for thousands of years. Archaeological evidence suggests that some 5,300 years ago, during the New Stone Age, bamboo had already been used to weave mats, baskets and other articles in eastern China (Wu and Ma 1987). Up to 3,500 years ago, bamboo culms were split into slices for recording and writing, and "books" were made by stringing the bamboo slices together (Zhu 1987); since 1,700 years ago, bamboo has been applied for making paper (Xiao and Yang 2000). Bamboo was so important in Chinese culture and history that when a Prime Minister of the Song Dynasty, Wen Tian Xiang (1236-1282), before he was killed by the Mongol conquerors wrote a poem: "Whoever could be alive without death? But my loyalty will be shining on the bamboo forever", indicating the important role of bamboo in the history of China. Another famous poet, Su Dongpo (1037-1101), wrote, "Meals can be without meat, but living cannot be without bamboo. The lack of meat makes one thin; the lack of bamboo makes one vulgar." He commented: "There are bamboo houses for living, bamboo hats for shading, bamboo paper for writing, bamboo rafts for carrying, bamboo shoes for wearing, bamboo shoots for eating and bamboo fuel for heating. Indeed, we cannot live without bamboos for a single day." This is a succinct summary of the close relationship between bamboo and the Chinese people.

1.1.2 Current role of bamboo

Today, bamboo shows an enormous potential for alleviating many problems - both environmental and social - facing the world (Liese 2001). For example, as a renewable natural resource with the advantage of annual production and growth, bamboo can be a plant that provides a possible solution for the environmental consequences of deforestation in tropical and subtropical regions (Hunter and Wu 2002). In China, in the past two decades bamboo plantation increased by 30 % (Lei 2001), while bamboo exports increased 650 %, from US$ 46.1 million in 1981 to US$ 300 million in 2000 (Lu 2001). Australia has five native bamboo species, but they do not produce edible shoots. Increasing consumption of bamboo shoots in Australia has created a domestic market to the amount of US$ 10-20 million, which completely depends on the import of canned products (Midmore 1997, 1998; Barnes et al. 1999). This situation is stimulating the establishment of bamboo plantations in Australia to supply fresh shoots to replace

imports, and also the development of an export market for fresh shoots to Asian countries during the Northern Hemisphere winter (Midmore 1998; Barnes et al. 1999). Using bamboo as a substitute for timber can save the diminishing rainforests. For example, in Costa Rica, 1,000 bamboo houses are built every year with material coming from a bamboo plantation only 60 ha in size (Adamson and López 2000). If an equivalent project used timber, it would require 500 ha of tropical rainforest.

As a rapidly growing plant, bamboo can contribute to subsequent CO_2 fixation (Scurlock 1999; Liese 2001; Hunter and Wu 2002). One of the most pressing environmental problems of the late twentieth century is the global warming associated with the use of fossil fuels. Kleinhenz and Midmore (2001) estimate the average total biomass of a bamboo stand between 130 and 142 t ha^{-1}; the ability of carbon sequestration from a bamboo plantation is, therefore, nearly as high as that of a forest in middle latitudes. Large bamboos usually have a high primary productivity, e.g., in central Japan, aboveground productivity of a six-year-old clump of *Phyllostachys bambusoides* was reported at 24.6 t ha^{-1} $year^{-1}$ (Isagi 1993); in eastern China, aboveground woody biomass of *Phyllostachys pubescens* increments averaged 7.7 t ha^{-1} $year^{-1}$ (Qiu et al. 1992); in southern India, aboveground productivity of *Bambusa bambos* reached 47 t ha^{-1} $year^{-1}$ (Shanmughavel and Francis 1996). Since bamboo generates a new crop every year, the stands can maintain the ability for fixing CO_2 for as long as 30-120 years without replanting. Based on this concept, bamboo is considered as a new crop. North America has only one native bamboo species, *Arundinaria gigantea* (Walt.) Muhl.; however, to date, about 441 kinds (species, subspecies, varieties, forms, cultivars, and clones) of bamboo have been introduced in the USA since the late 19th century (Shor 2002). Bamboo is considered as a high-potential crop for replacing tobacco in the southeastern United States (Shoch and Stoney 2001), since tobacco cultivation dropped from 831,000 acres in 1992 to 492,300 acres in 2000 and alternative crops are in high demand (USDA 2000). There is no bamboo native to Europe, though it existed naturally in Europe some three million years ago in the Tertiary period but vanished during the ice age (Liese 2001). Since the 19th century, bamboos from China and Japan have been introduced to Europe (Gielis and Oprins 2000). Almost a century ago, over 100 different bamboos were known in Europe, mostly temperate species (Chao 1989). At present, over 400 kinds of bamboo

are grown or cultivated in Europe (Gielis and Oprins 2000). Historically, bamboo was solely cultivated as an ornamental plant in gardens and its ecological and economic values were mostly neglected in Europe. However, an ongoing project, "Bamboo for Europe", is assessing the possibilities of growing and using bamboo in European countries (Gielis et al 1997; Liese 2001).

With numerous rhizomes and evergreen leaves, bamboo is a valuable ally in the fight against soil erosion and water loss (Liese 1991, 2001). The root system of bamboo can create an effective mechanism for watershed protection, stitching the soil together along fragile riverbanks, deforested areas, and in places prone to earthquakes and mud slides (Shoch and Stoney 2001). Bamboo is a pioneer plant and can be grown in soil damaged by overgrazing and poor agricultural techniques. In contrasting to most trees, the bamboo plant is not killed by proper harvesting so topsoil is held in place. Recent research shows that bamboo rhizomes have some associated microorganisms that can fix nitrogen (Wu and Gu 2001) and prevent the soil from acidification (Takamatsu et al. 1997). This indicates that bamboo plantations might be an efficient way of improving degraded land by fixing nitrogen from the atmosphere and increasing soil nutrients.

The increasing importance of bamboo has led to a high demand for bamboo species which could be planted under ecologically and/or economically favorable conditions. The majority of bamboos thrive in the subtropics and tropics, where annual temperatures range from 8.8-36 °C and annual rainfall is above 1,000 mm (Keng and Wang 1996). In the temperate zones of Europe and North America where frost and snow are common, most tropical and subtropical bamboos do not grow naturally. Therefore, cold-resistant bamboos, especially the mountain species, have long been considered as priority for introduction.

1.1.3 Giant panda and bamboo

The conservation of the giant panda (*Ailuropoda melanoleuca*) is a critical issue connected with bamboo occurrence in China. The giant panda is a highly specialized carnivore whose diet consists almost entirely of various species of bamboo. Fossil evidence shows that the giant panda was once widespread in southern and eastern China and in neighboring Myanmar and North Vietnam (Schaller et al. 1985; Taylor et al.

1991; Reid and Gong 1998; Loucks et al. 2001). The panda's range has shrunk considerably in recent history, due to increased human settlement (Schaller et al. 1985; O'Brien et al. 1994; Fong and Li 2001; Liu et al. 2001). By 1800, the giant panda was only to be found in two isolated mountain regions: On the east slope of the Tibetan plateau in central Sichuan and southern Gansu, stretching east to the Qinling Mountains of south-central Shaanxi; and in the hilly country covering southern Shaanxi, eastern Sichuan, western Hubei, and the north western Hunan provinces, with Shennongjia as the highest peak and distribution center (Fongand Li 2001). However, by 1900, the pandas had obviously become extinct in the eastern region, including Shennongjia (Schaller et al. 1985; Reid and Gong 1998).

Bamboo availability has long been considered as a key factor affecting the survival of the giant panda (O'Brien and Knight 1987; Taylor et al. 1991; Fong and Li 2001). Bamboo comprises 99 % of giant panda's diet (Schaller et al. 1985), but of the more than 500 species of Chinese bamboos, the panda favors only about 15 species (Campbell and Qin 1983; Yi 1985; Taylor et al. 1991; Carter et al. 1999). Most of these bamboos (i.e., *Fargesia spathacea*, *F. robusta, F. denudata* and *Bashania fangiana*) are monocarp and flower synchronously at estimated intervals of 30-80 years, depending on the species (Campbell and Qin 1983; Campbell 1987). In the past, when one forage bamboo flowered and died, pandas would normally switch to other species, or expand their home ranges to access areas where the bamboo had not flowered (Schaller 1987; Taylor et al. 1991; Fong and Li 2001; Li and Denich 2001). However, in recent centuries, increasing human settlements and environment changes have made it difficult for the giant panda to reach new food supplies. For example, in 1975-76, three bamboo species flowered synchronously and died in the Min Mountains, where 138 pandas were found dead due to starvation (Schaller et al. 1985; Fong and Li 2001). As at that time, there were only about 1,500 wild pandas in China, the death of so many animals caused widespread concern among government officials and conservationists (Schaller et al. 1985; O'Brien and Knight 1987; Taylor and Qin 1991). Because of the serious problems due to bamboo flowering and environment degradation in panda habitats in Sichuan, the Chinese government proposed removing the starving giant pandas to their historical habitat, Mount Shennongjia in Central China, where there is a plentiful supply of bamboo and there are few human impacts (Cui 1996).

1.1.4 Objectives of bamboo research in Shennongjia

Despite increasing research efforts, the bamboos have remained somewhat mysterious plants (Liese 1991, 2001; Gielis et al 1997). They still hold many secrets about their biology, and much more information is required for more efficient conservation and utilization (Liese 1991). For example, we know that bamboos are useful plants, but we do not know how many species there actually are in the world, especially in the remote mountains in East Asia. We know that the giant panda existed in Central China for thousands of years until the late 19th century, but we do not know which bamboo formed its staple diet and why the giant panda became extinct in this region. We know that bamboos are fast growing plants, but for most species, we do not how they grow. We know that bamboos die after flowering at an interval from several years to over a century, but "why bamboos wait so long to flower" (Janzen 1976) is still a mystery.

Given the worldwide interesting in bamboo and the giant panda, the study in Shennongjia aimed to create an overall understanding of the diversity and ecological features of mountain bamboos in order to assess the *ex-situ* protection of the giant panda in this region. Specifically, three objectives support the general aim:

Objective 1: Bamboo diversity and distribution

- To make a sound understanding of bamboo taxa in the mountain ranges in Shennongjia
- To analyze the distribution patterns of the bamboo diversity along the altitudinal gradients in Shennongjia
- To estimate the land coverage of the bamboo species that comprise the panda diet
- To assess the potential carrying capacity of the giant pandas based on the food supply from staple food bamboos

Objective 2: Vegetative growth of bamboos

- To create a knowledge infrastructure that illustrates the vegetative growth of bamboo species in Shennongjia
- To compare the sprouting and growing of new shoots among bamboos with different rhizome types, namely, monopodium, sympodium and amphipodium

- To assess the food supply of giant panda on time scale which matches the sprouting habits of the bamboos

Objective 3: Simultaneous flowering of bamboo

- To analyze the flowering pattern of *Fargesia murielae* in both temporal and spatial scales
- To analyze the effects of the historical fire on the regeneration of *F. murielae*
- To analyze the effects of bamboo growth on species diversity in local vegetations
- To assess the effects of bamboo flowering on the survival of the giant panda in Shennongjia

1.2 Review of bamboo classification

1.2.1 Classification systems

The classification of bamboos is far from satisfactory (Campbell 1985, 1991; Stapleton 1994; Dransfield and Widjaja 1995). Generally, the flower is the feature that is used to classify plants as being related or not. Bamboo presents the enigmatic problem of a long vegetative period between flowerings and often subtle differences between vegetative parts (Liese 1985). A few bamboo species flower almost annually, like the plants we are used to, but most flower at long intervals of 30 to 120 years (Janzen 1976; Campbell 1985; Young 1985; Taylor et al.1988, 1991, 1992; Abe et al. 2001), periods often long enough to outlive the individual botanists. Thus, early researchers such as Munro (1868), Gamble (1896), Bentham (1883) and others (e.g., Rendle 1903; Gamus 1913), who practiced the orthodox system of classification based on flower and fruit characteristics, could not establish a stable taxonomic system for the bamboo classification due to the limited number of flowering samples available for their study.

The difficulties in bamboo classification have been enhanced by the fact that bamboo chiefly grows in Asia and South America, but early bamboo classification was mainly conducted in Europe based on herbarium specimens (Tewari 1992; Keng and Wang 1996). The specimens are usually leafy or flowering branches and show neither the complex periodic flowering behavior, nor elaborate vegetative morphology such as rhizome system, culm sheathes and branch architecture (Campbell 1991; Stapleton

1994). Taxonomic descriptions based on the incomplete specimens caused a splitting between early Western literature and the taxonomic treatments in Asian countries, especially in China and Japan (Zhu et al. 1994; Takashi 2000). For example, nearly all mountain bamboos were originally placed in the genus of *Arundinaria* Michaux. However, over the past decades, many new genera (e.g. *Bashania* Keng f. et Yi, *Indocalamus* Nakai, *Yushania* Keng f., and *Sinarundinaria* Nakai) have been described in China and Japan by separating *Arundinaria* or defining it in a narrowed sense (Zhang 1992; Stapleton 1994). These new genera were not always recognized in other countries, which sometimes caused confusion in the nomenclature in Asian bamboos.

So far, at least three bamboo classification systems have been proposed. One was set up by Clayton and Renvize (1986), recognizing 49 genera, another by Soderstrom and Ellis (1987), proposing 54 genera. The third system was proposed by Ohrnberger (1983, 1999), in which 85 genera of woody bamboos were defined. Although none of the proposals has been universally accepted by all taxonomists, Ohrnberger's system (1999) seems more successful in synthesizing Western and Eastern knowledge.

1.2.2 Progress in China

Before 1940, most of the classification work on Chinese bamboos was done by non-Chinese botanists who mainly described new species and genera (Zhang 1992). McClure (1925, 1931, 1935, 1940) is the pioneer of the classification of Chinese bamboos (Keng 1983). He lived and worked in China from 1924 to 1940, and contributed the most to the early knowledge of Chinese bamboos. McClure described three genera and many species, published papers on bamboo utilization and even discussed bamboo culture (McClure 1925, 1931, 1935, 1993).

The first Chinese botanist working on Chinese bamboos was Keng Yi-Li (1935, 1940), and since the 1940s, Chinese botanists, led by Keng Yi-Li and his son, Keng Pai-Chieh (or Geng Bojie, 1948, 1981, 1987a, 1987b, 1991, 1996) have worked extensively on the Chinese bamboos. In 1959, Keng Yi-Li published the remarkable work "Flora Illustrialis Plantarum Primarum Sinicarum – Gramineae", in which 20 genera and 71 species of Chinese bamboos were presented in detail.

Since the 1970s, Chinese botanists have been increasingly contributing to the investigation and classification of the Chinese bamboos. Among these, Yi (1985, 1988, 1997), Hsueh (1980, 1988), and P. C. Keng (1991, 1996) contributed substantially to the knowledge about mountain bamboos in China. Extensive work led to the publication of two milestone works, *viz.* "A Compendium of Chinese Bamboo" (Zhu et al. 1994) and "Flora Republicae Popularis Sinicae, Tomus 9(1)" (Keng and Wang 1996). A total of 39 genera and more than 500 species have been included in these two books. Species records increased seven times in just three decades (1960s-1990s).

1.2.3 Studies in Shennongjia

The Shennongjia National Nature Reserve (Shennongjia in brief), the study region, comprises steep rugged mountains and elevations that range from 420 m to 3,105 m asl.. The extreme relief coupled with the elevation range leads to climatic conditions ranging from northern subtropics through cold temperate conditions, thus forming habitats for an abundance of bamboo species (Ban et al. 1995; Zhu et al. 1999). However, bamboos in Shennongjia are little known, especially the mountain species of the genera of *Fargesia, Bashania,* and *Yushania.* For example, Shennongjia contributed type specimens to three important bamboo species: *Fargesia murielae* Gamble (*Wilson 1462*), *Thamnocalamus spathaceus* (Franch.) Soderstrom (*Henry 6938*), and *Yushania confusa* (McClure) Z.P. Wang et G.H. Ye (*Henry 6832*) (Keng 1987; Yi 1988; Stapleton 1995; Li 1996). However, there is no record of these three species in the local botanical accounts. Furthermore, Shennongjia is a historical habitat of the giant panda; however, the species preferred by the pandas are also still unknown. An inventory of bamboo species is an essential step toward understanding the diversity and ecology of mountain bamboos in Shennongjia.

1.3 Review of bamboo growth

There are two distinct parts of the bamboo plant - the aboveground and the belowground parts. The belowground parts are the rhizomes and the roots, while the aboveground part has several names depending on the stage of growth. When it forms on the rhizome node, it is a bud; as it emerges from the ground and until it develops side branches, it is called a shoot; once the side branches form, it is called a culm (McClure

1993; Yi 1997). All bamboo culms sprout and grow to their full height and diameter in one growing season, usually in 60 to 90 days (Liese 1985; McClure 1993). In succeeding years, the wood of the bamboo culms will increase in strength and silica content and the plant will put out new leaves, but the culm will never grow taller or increase in diameter after the first growing season.

1.3.1 Rhizome types

The spatial pattern of bamboo culms is determined by the rhizome system since there is no central trunk to frame the plant structure of bamboo (Liese 1985; Li et al. 1998a). There are two basic types of rhizomes: pachymorph (sympodial) and leptomorph (monopodial) (McClure 1993). Sympodial (clumping) bamboos have short thick rhizomes that form clumps. How tight or open a clump is depends on the length of the rhizome of the particular species (Yi 1997). They are most commonly tropical to sub-tropical plants with some of them able to tolerate light frost (Dransfield and Widjaja 1995; Keng and Wang 1997). Monopodial (running) bamboos have long adventitious rhizomes that are cylindrical and segmented like the culms. These bamboos give rise to evenly spaced culms some distance apart. The larger species form groves that resemble timber pole forests, the culms are very straight and because of the light conditions have branches only on the upper parts. They are temperate-climate plants that tolerate annual snow cover and even frost (Yi 1997). Besides the sympodial and monopodial rhizome type, some bamboos (e.g., bamboos of the genera of *Bashania* Keng f. et Yi, *Indocalamus* Nakai, and *Sasa* Makino et Shibata) have an amphymorph rhizome type (with both sympodial and monopodial rhizomes), which gives the underlying bamboos a flexible ability to either occupy open habitats with spreading rhizomes or hold particular niches with clumping rhizomes (Yi 1997).

1.3.2 Vegetative growth

Bamboo is known to be one of the fastest growing plants in the world (Liese 1985; Janssen 1991). Bamboo can reach its maximum height within several weeks to a few months; however, height shows an enormous variability, depending on species. The culms of one Burma original bamboo, *Dendrocalamus giganteus* Wallich ex Munro, can attain a height of about 30 m and a diameter of 30 cm (Kao et al. 1989; Zhu et al.

1994; Dransfield and Widjaja 1995), while the culms of a West Indies bamboo, *Arthrostylidium capillifolium* Griseb., are only 13-25 cm long (McClure 1973; John and Nadgauda 2001). All woody bamboos follow a similar vegetative growth pattern independent of size: Culms are produced annually from the youngest rhizomes and reached their full height in the first vegetative period (McClure 1993; Liese 1985; Janssen 1991). Height growth rate of new shoots ranges from 4 to 120 cm day^{-1} (e.g., Yang et al 1992; Qin et al. 1993; Li et al. 1998, Qiu et al. 2001). Growth rate is usually affected by environmental factors such as altitude, soil permeability and, most important, rainfall (Fliervort et al. 1989; Schlegel 1991; Jolly et al. 1999; Kumar 2001).

In China, studies have been conducted on the growth behavior of some cultivated bamboos such as *Phyllostachys pubescens* (Li et al 1998; Qiu 2001) *Ph. heteroclada* (Jing et al. 1999), *Ph. makinoi* (Huang and Ma 1994), *Ph. nidularia* (Zhang 1995), *Chimonobambusa utilis* (Zhang et al. 1998), *Dendrocalamus oldhami* (Dong 2000), *D. latiflorus* (Zhou 1999), and on wild bamboos such as *Fargesia scabrida* (Huang 1993), *F. denudata* (Wang et al. 1991; Huang 1994), *F. robusta* (Qin et al. 1993), *Bashania fangiana* (Taylor and Qin 1988; Zhou and Huang 1998), which are the diet of the giant panda.

1.3.3 Studies in Shennongjia

There has been no relevant research on the bamboo growth in Shennongjia to date. Therefore, three species, namely henon bamboo (*Phyllostachys nigra* var. *henonis* (Mitf.) Munro), tamale bamboo (*Indocalamus latifolius* (Keng) McClure), and arrow bamboo (*Fargesia spathacea* (Franchet) Yi) might be able to represent the growth behavior of different bamboo types in Shennongjia. With regard to bamboo size, henon bamboo represents the large bamboos (5-8 m high), arrow bamboo the medium-size bamboos (2-4 m high), and tamale bamboo the small bamboos (1-2 m high). With regard to rhizome patterns, henon bamboo is the monopodial, umbrella bamboo the sympodial, and tamale bamboo the amphipodial type. With regard to altitudinal distributions, tamale bamboo occurs in the low mountains (500-1,200 m), arrow bamboo in the higher mountains (1,200-2,600 m), and henon bamboo in the agricultural belt (500-1,800 m). For each species, the following themes are used to illustrate vegetative growth of bamboos: 1) When and how the new bamboo sprouts emerge from

the ground. 2) How the young bamboo shoots survive over the first vegetative growing season. 3) How the environmental gradient affect the sprouting phase of the bamboo. 4) How the new shoots reach full height in terms of growing period and growth rate.

1.4 Review of bamboo flowering

1.4.1 Flowering types

Bamboos are known to have a peculiar flowering habit (Janzen 1976; Liese 1985; Campbell 1985). Flowering in bamboo is a botanical enigma. The factors that switch a bamboo plant from the vegetative to the flowering state are not fully understood (Campbell 1985; Keeley and Bond 1999, 2001; Liese 2001). Some species, e.g., *Pleioblastus pumilus* (Mitford) Nakai (syn. *Arundinaria pumila* Mitford), *Bambusa arundinacea* (Retz.) Willd, and *Pseudoxytenanthera albociliata* (Munro) Nguyen (syn. *Gigantochloa albociliata* (Munro) Kurz) have populations composed of individuals that grow to maturity and then flower and seed annually for many years (Anantachote 1987). Many of the common bamboo species have populations made up of individuals that seed synchronously at regular and long supra-annual intervals (Campbell 1985; Dransfield and Widjaja 1995; Keng and Wang 1996; Keeley and Bond 1999, 2001). After growing by rhizome for a species-specific period of 3-120 years, nearly all the members of one species in one area produce wind-pollinated flowers, set large quantities of seed, and die (Janzen 1976).

Dransfield and Widjaja (1995) classified bamboo flowering as three basic types: gregarious, sporadic, and continuous. When gregarious flowering occurs, a whole population flowers over a period of 2-3 years and then dies, although the rhizomes may still be alive. Most bamboo species follow this pattern, especially the mountain bamboos from the genera of *Fargesia* (Wang et al 1991; Qin et al. 1993; Taylor and Qin 1993; Huang 1994; Stapleton1995), *Bashania* (Zhou and Huang 1998), *Yushania* (Taylor and Qin 1993; Gratzer et al. 1999; Abe et al. 2001), and *Dendrocalamus* (Jolly et al. 1999; Kumar et al. 2001). Sporadic flowering indicates that the individuals flower seasonally or occasionally, and only the flowering culms die afterwards, while the rhizomes continue to live. Only few bamboo species follow this sporadic pattern, e.g., *Gigantochloa scortechinii* Gamble (Dransfield and Widjaja 1995), *Bambusa multiplex* (Lour.) Raeusch, *Bambusa textilis* McClure, and *Indocalamus wilsoni* (Rendle) Chao et

Chu (Li and Denich 2001). Continuously flowering species produce flowers all year round. The culms that produce flowers do not die. A few tropical species show this yearly flowering habit, e.g., some species of the genus *Arundinaria* in India (Tewari 1992), *Ochlandra* in Madagascar (Dransfield 2000), and *Schizostachium* in Thailand (Anantachote 1987).

1.4.2 Flowering hypotheses

Gregarious flowering of woody bamboos usually leads to a dieback of the species on a population level (Young 1985; Taylor and Qin 1988). Although a wide range of research and discussion is going on, the flowering of bamboo is still unexplained (Campbell 1985; Keeley and Bond 1999, 2001). One reason is that the flowering cycle of a bamboo species may be 30-120 years or more, much longer than the active professional life of a researcher, so that one person usually does not have the opportunity to observe a full cycle or conduct respective experiments. Another reason is that scientists have only recently started to study the flowering phenomenon at the genetic or molecular level (Li 1997; Nadgauda 1997; Gielis 1998, 2000), and the results so far are insufficient to encode the flowering cycles at gene level.

There are at least three theories concerning the causes of flowering and dieback of bamboo. The earliest explanation, namely the resource-matching hypothesis, postulated that simultaneous flowering of bamboo is controlled by available resources via external controls on physiological processes (Brandis 1899). Campbell (1987) has tried to further explain this theory by linking the flowering cycles of Sino-Himalayan bamboos with natural factors such as droughts and sunspots. Another explanation, named as predator satiation, is a widely accepted theory proposed by Janzen (1976), who assumes that irregular fruiting cycles are sufficient disequilibria to inhibit seed predators from maintaining populations large enough to decimate a “mast year” of fruiting. Janzen's theory recognizes that the flowering cycle is derived by the genetic force, rather than by resource availability. Recently, Keeley and Bond (1999; 2001) developed a “fire cycle hypothesis”. They argue that lightning-ignited wildfires synchronize flowering by creating the conditions for monocarp reproduction of clones at long intervals and delaying of reproduction. Although the fire cycle hypothesis is

facing criticism (e.g., Saha and Howe 2001), it provides an acceptable assumption for the synchronous flowering over a geographical scale.

1.4.3 Studies in Shennongjia

In Shennongjia, umbrella bamboo (*Fargesia murielae* (Gamble) Yi) simultaneous flowered in 1996-2000 over the mountain ranges. *Fargesia murielae* is a native bamboo endemic to Shennongjia. It was successfully introduced in European gardens by Ernest Wilson in 1907 (Ebert 1996). From 1993 to 1998, *F. murielae* plants simultaneously flowered and died all over Europe and North America (Gielis et al. 1999; Shannik 1999). The worldwide synchronous flowering provides a centurial chance to assess the flowering and seeding of this species. The research on flowering in the present study includes three aspects: 1) Presenting the flowering pattern of *F. murielae* in its natural habitats on both temporal and spatial scales, especially on the time scale across the altitudinal range. 2) Assessing the effect of fire on the flowering regeneration of bamboo; a comparison between burned clumps and unburned clumps is carried out to present the post-fire regeneration on both vegetative phase and flowering phase of umbrella bamboo. 3) Analyzing the effect of bamboo flowering on the species diversity in the local forest, as umbrella bamboo is an essential part of the local vegetation. 4) Predicting the effect of bamboo flowering on the survival of giant pandas in Shennongjia.

2 DESCRIPTION OF THE STUDY AREA

Summary: The Shennongjia National Nature Reserve, established in 1982, is an extensive national nature reserve of steep rugged mountains, which focuses on the protection of mountainous forest ecosystems and biodiversity in subtropical China. The background climate is a transitional type between subtropical and temperate climates, with warm, rainy summers and cold, windy winters. However, elevations mould the mountain climate into five altitudinal belts: sub-tropics (400-800 m), warm temperate (800-1,200 m), temperate (1,200-2,200 m), cold temperate (2,200-2,600 m) and frigid temperate (2,600-3,105 m). Accordingly, vegetation and soil also present an elevational variation. Five types of soils strongly relate to the altitude: yellowish brown forest soil (600-1,500 m), brown forest soil (1,500-2,200 m), darkish brown forest soil (2,200-2,600 m), meadow soil (1,700-3,000 m), and brownish dark forest soil (3,000-3,100 m). These complex landforms and natural environments provide habitats for a rich flora and fauna. Currently, 2,762 species of vascular plants, 75 species of mammals, 308 species of birds, 40 species of reptiles and 23 species of amphibious are recorded, respectively accounting for 43 %, 69 %, 68 %, 40 % and 41 % of the total species of the Hubei Province. There are five vegetation types in the reserve: 1) coniferous forest, 2) broadleaved forest, 3) bamboo forest, 4) shrub thickets, and 5) meadows.

2.1 Geography

The Shennongjia National Nature Reserve (Shennongjia in brief) is a member of the World's Reserve Network organized by the Man and Biosphere (MAB) of the UNESCO (Zhu and Song 1999). It is located in the northwestern Hubei Province of the Peoples' Republic of China, at 110º03'05" to 110º33'50" east longitude and 31º21'20" to 31º30'20" north latitude (Figure 2.1). The total area of the reserve is 70,467 ha, divided into two separate parts. The eastern part covers 10,467 ha with Laojunshan (Old-God Mountain) as its center, while the western part encompasses an area of about 60,000 ha with Dashennongjia and Xiaoshennongjia as its core area (Figure 2.2). Shennongjia is about 570 km east of Wuhan, the capital city of Hubei Province, and 200 km northwest of Yichang, the biggest city in Western Hubei.

Shennongjia geographically belongs to the eastern part of the Dabashan

Mountains, a transitional mountainous belt connecting China's highest morphologic terrace, the Tibetan plateau in the west, with the hilly middle terrace in the east (Zhu and Song 1999). The current skeleton of Shennongjia was formed 615 million years ago on land that had emerged out of the sea almost 200 million years earlier (Cui 1996). The geological rift and fold, enhanced by following erosion and shearing, formed a complex landform with elevations ranging from 420-3,100 m, where several plant species of the Tertiary Period survived, such as *Ginkgo biloba* (Ginkgoaceae), *Cephalotaxus oliveri* (Cephalotaxaceae), *Amentotaxus argotaenia* (Taxaceae), *Davidia involucrata* (Nassaceae), *Liriodendron chinense* (Magnoliaceae), and *Tetracentron sinensis* (Tetracentraceae) (Zheng et al. 1980; Ban et al. 1995; Ge et al. 1997).

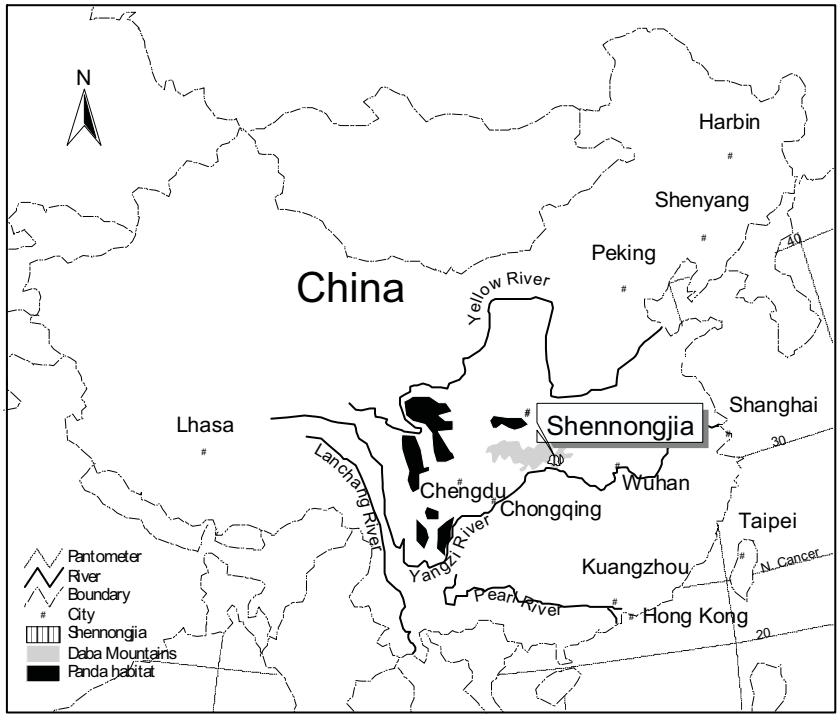

Figure 2.1: Location of the Shennongjia National Nature Reserve (Shennongjia) and current distribution of the giant panda in China.

Most mountain peaks are more than 1,500 m above sea level, including more than 20 peaks with elevations over 2,500 m, and 6 peaks over 3,000 m. The highest summit, Shennongding, with an altitude of 3,105 m, is the highest peak in Central China. The lowest area, Liujiahe in the southwest of the reserve, is only 420 m above sea level. With a relative height difference of 2,685 m, the slopes are very steep. The

mountaintops, however, are relatively flat and open, covered by bamboos and coniferous forests.

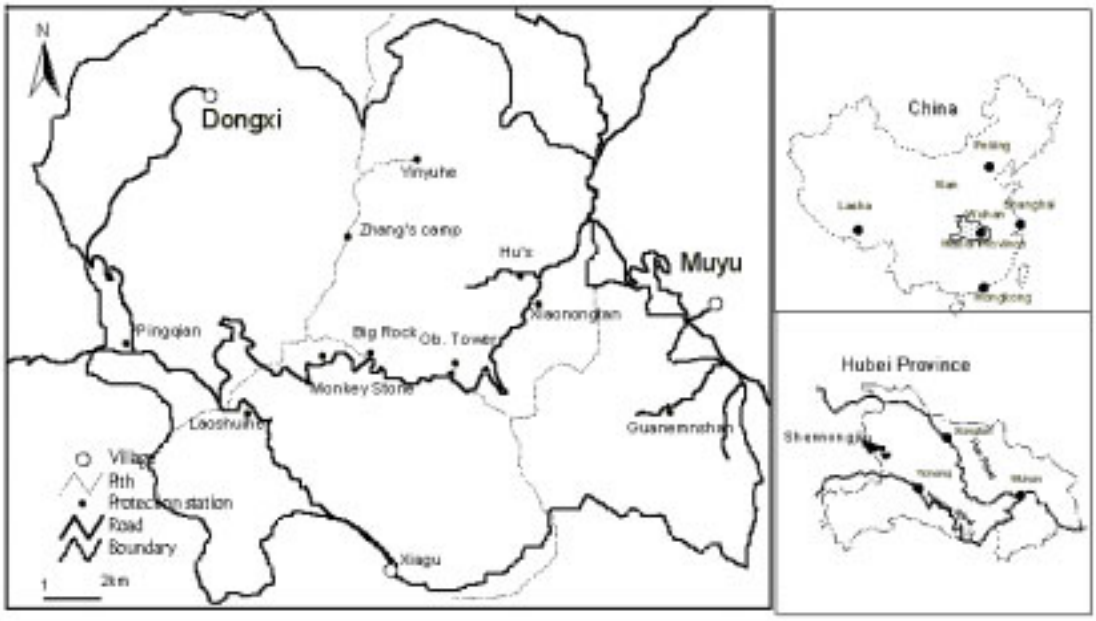

Figure 2.2: Map of the Shennongjia National Nature Reserve (western part, ca. 60,000 ha).

2.2 Climate

The background climate in Shennogjia is a transitional type between subtropics and the warm-temperate (Zhu and Song 1999). The meteorological records in Songpei (930 m asl) represent the climate in low mountains. Here, the annual average temperature is 12.1 ºC, with average temperatures of 0.7 ºC in the coldest month (January) and 22.8 ºC in the hottest month (July). The mean annual precipitation is 965.5 mm, with 79 % precipitation falling between May and October (Figure 2.3).

In the high mountains, it is foggy and rainy in summer and autumn, and cold in winter. Precipitation is higher than evaporation and relative air humidity is high. For example, field records from the Observation Tower (2,930 m, Figure 2.2) show that the annual average temperature is only 2.2 ºC, with cold winters (averaged -9.4 ºC in January) and cool summers (averaged 8.1 ºC in July). Annual precipitation is 2,780 mm. The climate follows a gradient that basically corresponds to the elevations. Meteorological data (Cui 1996; Zhu and Song 1999) from five stations over the elevation (Yangri 460 m, Songpei 930 m, Dajiuhu 1,700 m, Changyanwu 2,300 m and

Observation Tower 2,930 m) were adapted to predict such an altitudinal gradient in terms of temperature, frost-free period, and precipitation. Linear modeling suggests that with every 100 m increase of the elevation, the mean annual temperature, average January temperature and frost-free period tend to decline 0.51 ºC, 0.46 ºC, and 7.1 days, respectively. In addition, the mean annual precipitation tends to increase by 83 mm (Table 2.1). The temperature gradient results in a climatic spectrum across the elevation from the mountain foot to the summit (Figure 2.5): northern subtropics (400-800 m), warm temperate (800-1,200 m), temperate (1200-2200 m), cold temperate (2,200-2,600 m), and frigid temperate (2,600-3,105 m).

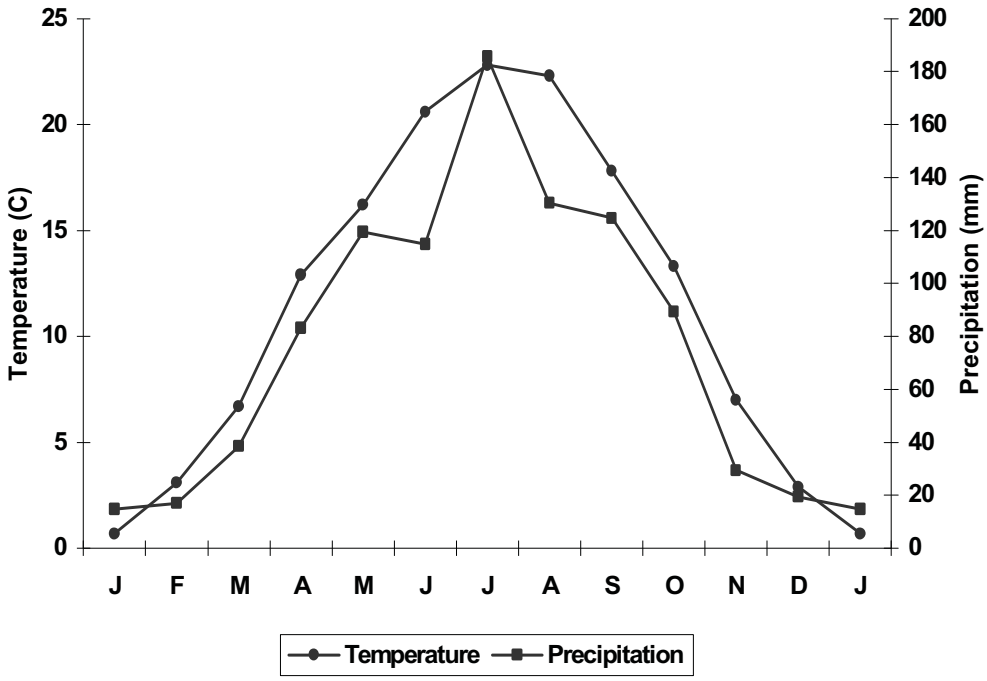

Figure 2.3: Climate diagram based on data gathered from 1975 to 1990 by the meteorological station at Songpei (altitude 930 m), capital town of the Shennongjia Forest Region, Hubei Province.

2.3 Soil

There are five main soil types along the altitudes in the Shennongjia reserve (Zheng 1986; Zhu and Song 1999):

1) Mountainous yellow-brown soil is distributed from altitude 800-1,800 m on the northern slope, and 1,200-1,800 m on the southern slope, where the mean annual temperature is 9-15 ºC and the total annual precipitation is 1,200-1,800 mm. The

vegetation to be found in this climate belt is the thermophile broad-leaved deciduous forests, with mixed some cold-tolerant evergreen tree species. In this soil belt, several bamboo species such as *Fargesia spathacea, Indocalamus longiauritus*, *I. latifolius* and *Phyllostachys nidularia* occur naturally in the forests as understorey, while some running bamboos, e.g., *Phyllostachys bambusoides*, *Ph. heteroclada* and *Ph. nigra* var. *henonis* are planted in the agricultural zone, mainly around the farmhouses. Figure 2.4(I) shows a profile of this mountainous yellow-brown soil at an altitude of 1,450 m.

Table 2.1: Summary of linear regressions between environmental features and elevation in Shennongjia, Central China. In the equations, *y* indicates environmental factors and *x* indicates altitudinal step in 100 m.

Factors	Equations	R^2	d.f.	F-value	Sig.
Climate					
Mean annual temperature (ºC)	Y=16.26-0.506X	0.995	5,3	467.55	0.000
Mean January temperature (ºC)	Y=4.16-0.461X	0.985	5,3	192.30	0.001
Frost-free period (days)	Y=283.54-7.148X	0.964	5,3	80.13	0.003
Mean annual precipitation (mm)	Y=235.48+82.663X	0.951	5,3	58.62	0.005
Soil					
Soil-organic matter (%)	Y=-0.122+0.254X	0.814	9.7	30.60	0.001
Overall nitrogen (%)	Y=0.0369+0.0086X	0.993	9,7	97.84	0.000
pH	Y=6.6143-0.042X	0.305	7,5	2.19	0.199

2) Mountainous brown soil is a typical mountainous soil type in the warm-temperate zone of China. In Shennongjia, brown soil is generally distributed from 1,800-2,200 m, but in some particular areas it can extend up to 2,400 m. Here, the mean annual temperature is 6-9 ºC and the total annual precipitation is 1,600-2,200 mm. The vegetation covering this belt is a mixed forest of coniferous trees such as *Pinus armandii* and *P. henryi* with a number of deciduous broadleaved tree species dominated by *Fagus engleriana*, *Populus davidiana*, *Quercus aliena* var. *acuteserrate*, *Toxicodendron succedoneum*, and several species from the genera of *Acer* and *Betula*. A profile of this soil is presented in Figure 2.4(II). The main bamboo species growing on this soil are *Fargesia spathacea*, *F. murielae,* and *Indocalamus wilsoni*. The *Fargesia* bamboos usually form a dense bamboo undergrowth layer, while *I. wilsoni* normally covers the ground in the open forest and between shrub thickets.

3) Mountainous dark-brown soil is a zonal soil that occurs in the temperate zone of north China where the mean annual temperature is between 0 ºC and 5 ºC. In Shennongjia, this soil is distributed between 2,200 m and 2,900 m. According to the local vegetation, the dark-brown soil in the reserve can be sub-divided into three types: dark-brown soil, meadow dark-brown soil and dark-brown loamy soil. Dark-brown soil (Figure 2.4(III)) mainly occurs on the shaded slopes from 2,200-2,700 m in the transitional belt of the mixed forest to conifer forest (*Abies fargesii*). Meadow dark-brown soil (Figure 2.4(IV)) generally occupies the open mountaintops from 2,500-2,900 m. The main vegetation covering this soil is sub-alpine meadow. Woody species such as *Abies fargesii*, *Sorbus hupehensis*, *Malus kangsuensis*, and umbrella bamboo (*Fargesia murielae*) usually occur within the meadows as mosaic communities. Dark-brown loamy soil mainly occurs in the steep slopes, where it is very difficult for the plants to establish a stable community due to the extreme natural conditions.

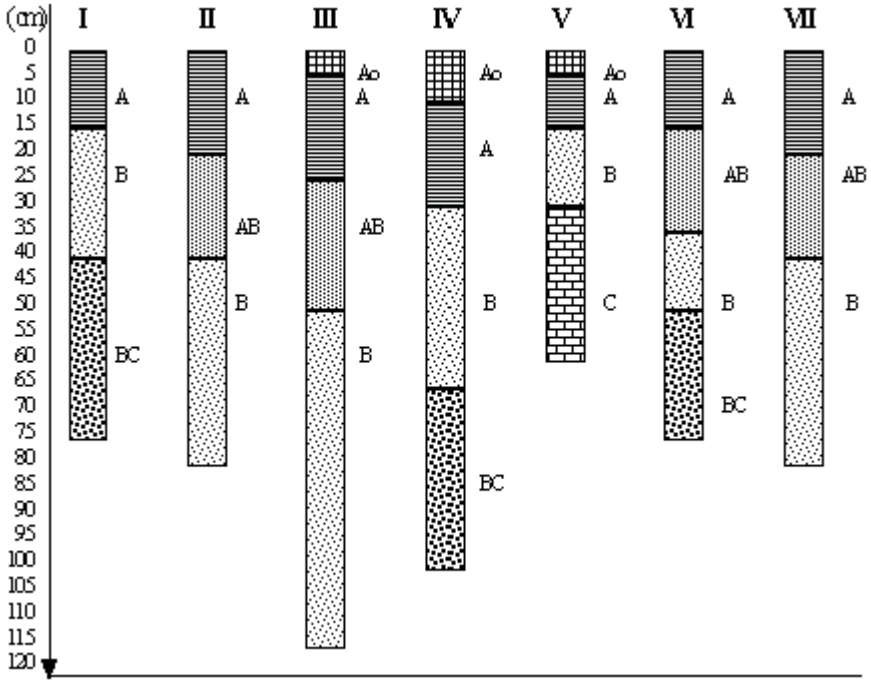

Figure 2.4: Diagram of main horizon sequences in major soil types in Shennongjia. I. Mountainous yellow-brown soil (1,450 m), II. Mountainous brown soil (2,100 m), III. Mountainous dark-brown soil under forest (2,400 m), IV. Mountainous dark-brown soil under sub-alpine meadow (2,800 m), V. Brown coniferous soil (3,100 m), VI. Mountainous meadow soil under dwarf shrubs with grasses (2,700 m), VII. Mountainous meadow soil with grasses only (2,610 m).

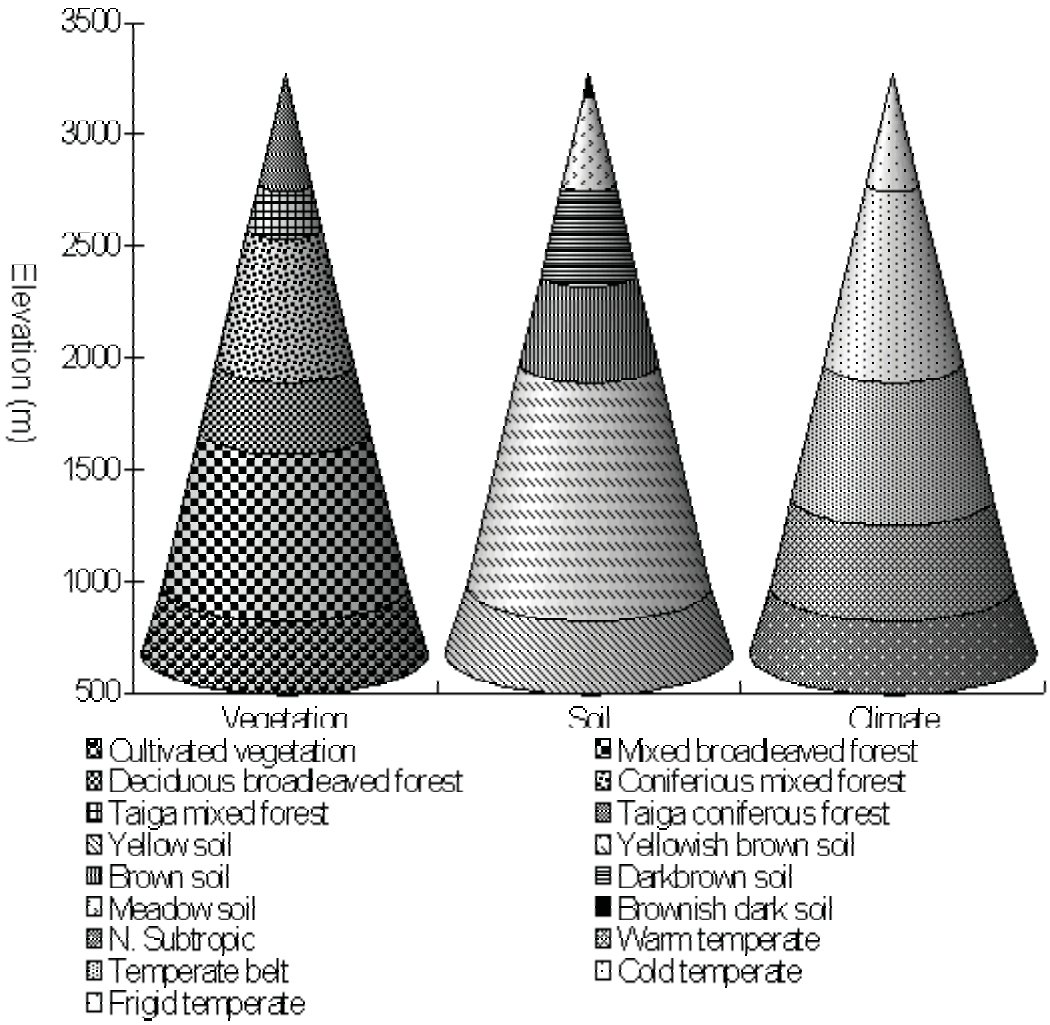

Figure 2.5: Vertical spectrum of vegetation, soil and climate in Shennongjia from the lowest valley (420 m) to the highest peak (3,105 m), there are three vegetation zones (Ban et al. 1995) successively distributed along the altitude, namely mixed evergreen and deciduous broadleaved forest zone (400-1,800 m), coniferous and broadleaved forest (1,800-2,600 m) and Taiga forest (2,600-3,105). The figure (left) presents the vertical spectrum of the vegetation as sub-zones. The soil-vertical spectrum (middle) is presents as soil types after Zheng (1987): Yellow forest soil (400-600 m), yellowish-brown forest soil (600-1,500 m), brown forest soil (1,500-2,200 m), dark-brown forest soil (2,200-2,600 m), meadow soil (2,400-3,000 m), and brownish dark forest soil (3,000-3,100 m). The climate spectrum based on the temperature variation is showed in the figure (right) as five sub-zones following Zhu and Song (1999): Northern sub-tropics (400-800 m), warm temperate (800-1,200 m), temperate (1,200-2,200 m), cold temperate (2,200-2,600 m), and frigid temperate (2,600-3,105 m).

4) Dark-brown forest soil, a cold-temperate zonal soil formed under the conifer forest, is distributed on the mountain peaks over 2,900 m in Shennongjia, where the mean annual temperature is about 0-1 ºC and total annual precipitation is over 2,500 mm with a high air humidity. The representative profile at the highest summit, Shennongding (3,105 m), is presented in Figure 2.4(V). The plants occurring on the brown coniferous soil are dominated by the farges fir (*Abies fargesii*), umbrella bamboo (*Fargesia murielae*), fragrant cypress (*Sabia sino-alpina*), and several rhododendrons (*Rhododendron spp.*). Umbrella bamboo plays a key role in the vegetation structure and covers over 30-50 % of the area in this mountain belt (Ban et al. 1995).

5) Mountainous meadow soil does not form a closed belt along the elevation in Shennongjia, but mosaics that are distributed within other soil zones, extending from 1,700-3,100 m. Meadow soil supports at least three kinds of plant communities over the mountain ranges. One is the community of dwarf shrub thickets and grasses distributed on the south-facing slopes between 2,300-2,600 m. The dominating species are light-loving grasses such as *Festuca rubra*, *Deyeuxia henryi* and *Trisetum* sp., associated with *Geranium henryi*, *Polygonum suffultum*, *Allium pratii*, *Fragaria orientalis*, and *Poa* sp.. Some dwarf shrubs, such as *Rhododendron fargesii*, *R. concinuum*, *Sorbus huphensis* and *Dasiphore fruticoca*, are mixed sporadically with the grasses or occupy particular habitats to form mosaic communities. Another community is the true meadow occurring on the open mountaintops or gentle slopes over 2,500 m. The third one is the swamp in the open valleys between 1,800 m and 2,100 m, where the aboveground water is difficult to drain. Meadow soil developed due to seasonal water accumulation supports the species from the genera of *Carex*, *Junicus*, *Eleocharis* and *Polygonum* (Ban et al. 1995).

2.4 History

According to oral legend, Shennongjia was the place where the Chinese Agricultural God (Shennong) built his ladder for collecting medical grasses. In 686 DC of the Tang Dynasty, Prince Li Xian was banned to Shennongjia from the capital city of Changan (now Xi'an) by his mother, Wu Zetian, the only female emperor in Chinese history. Li Xian lived in Shennongjia for about 20 years and went back to Changan in August 705

to succeed his mother as emperor. Following Li Xian, a number of people moved to the Shennongjia ranges and established themselves as farmers combining agriculture with cattle and goat breeding (Cui 1996). Until the 1960s, the population in the Shennongjia region was under 20,000, with a population density of 5.8 inhabitants km^{-2}.

The earliest Western scientist to conduct plant studies in Shennongjia was Augustine Henry (1857-1930), an Irish physician and plant collector. From 1882-1900, Henry was employed as an officer in the Maritime Customs Service of the Empire of China located at Yichang, a city near Shennongjia. Over a period of twenty years (1880-1900), he collected approximately 150,000 plant specimens. In 1888, he also journeyed to Lao Junshan, the highest summit in eastern part of the reserve, to collect plant samples (Cui 1996). After Henry, Ernest H. Wilson, an American horticulturist, visited China four times between 1900 and 1910 to collect plant specimens, seeds, and lily bulbs. He devoted himself to collecting specimens in the mountains of Western Hubei, including the Shennongjia ranges from February 1900 to April 1902. Among his valuable collections, 2 new genera, 225 new species and 162 new varieties of woody plants were described in "*Plantae Wilsonianae* (Volume 1-3)" (Sargent 1913-1917), published in Cambridge.

During the establishment of the Peoples' Republic of China from 1949 to 1979, political upheavals prevented further connections between Shennongjia and the Western world. In 1980, with the falling of the political curtain in China, Shennongjia reopened and hosted a milestone botanical expedition: the Sino-American Botanical Expedition (Spongberg 1993). During the expedition, about 25,000 herbarium specimens, and over 500 collections of different seeds and other propagules were collected. Following this botanical research, Zheng et al. (1980) published "Plants in Shennongjia", which recorded over 1,900 species of vascular plants. Two years later, in 1982, a reserve was established and botanical investigations then led to a regular monitoring of the biodiversity.

2.5 Fauna and flora

2.5.1 Fauna

There are 75 species of mammals in the reserve belonging to 53 genera in 22 families. The species make up 69 % of the mammal fauna of Hubei and 15 % of that of China.

Among them, 14 species are state-protected wildlife, including three species in Category I (first priority endangered species), *viz*. golden monkey (*Rhinopithecus roxellane*), southern Chinese tiger (*Panthera tigris amoyensis*) and golden-dotted leopard (*Panthera pardus fusca*). A recent survey (Zhu and Song 1999) recorded 308 bird species in the reserve ranges, which count for 68 % of the bird fauna in Hubei or 26 % in China. Among the bird fauna, 51 species are state-protected birds including two species, golden vulture (*Aquila chryaetos*) and white crane (*Ciconia ciconia*), in Category I. There are 23 amphibian species in Shennongjia in 11 genera of 7 families. Two species, the giant salamander (*Andrias davidianus*) and the tiger frog (*Rana tigrina rugulosa*), are the key state-protected wildlife in Category II. Up to 1999, 40 species of reptiles were discovered in the reserve, including 23 snake species. There are 47 species of fish originally occurring in the reserve, including 5 newly recorded species in Hubei. Since the reserve is located in the middle reaches of the Yangtze River and upper reaches of the Han River, the fish species occur in the two river systems as follows: 15 species in the Yangze River system, 21 species in the Han River system, and 9 species in both. Up to now, 560 species of insects have been identified in the reserve, of which three species, *Luehdorfia chinensis huashanensis*, *Bhutanitis thaidina*, and *Carabus lafossei*, are key state-protected wildlife in Category II.

Table 2.2: Species richness of vertebrate animals in Shennongjia (Data source: Zhu and Song 1999). ND = No data.

	Area (km²)	Mammals	Birds	Reptiles	Amphibious	Fish
Shennongjia	704.67	75	308	40	23	47
Hubei	180000	109	454	ND	ND	175
China	9600000	499	1186	376	279	2804
% of Hubei	0.39	68.81	67.84	ND	ND	26.86
% of China	0.0073	15.03	25.97	10.64	8.24	6.24

2.5.2 Flora

There are 2,762 species of vascular plants belonging to 872 genera in 193 families in the reserve, among which 297 species of 75 genera in 34 families are ferns, 30 species of 18 genera in 6 families are gymnosperms, and 2,435 species of 779 genera in 159 families are angiosperms (Zheng 1993; Zhu and Song 1999). The geographical distribution pattern of the flora is complex: 34 % species belong to the global

distribution type, 19 % to the tropical and subtropical type, 17 % to the tropical to temperate zone type, 18 % to the holo-temperate type, and 0.3 % of the species are endemic to China, including 42 species endemic to Shennongjia (Ge et al. 1997).

Table 2.3: Species richness of vascular plants in the Shennongjia National Nature Reserve (Data source: Ge et al. 1997).

	Ferns			Gymnosperms			Angiosperms			Total		
	Fam.	Gen.	Spec.	Fam.	Gen.	Spec.	Fam.	Gen.	Spec.	Fam.	Gen.	Spec.
Shennongjia	34	75	297	6	18	30	159	779	2435	199	872	2762
Hubei	41	97	370	9	31	100	191	1324	5550	241	1450	6020
China	62	204	2600	10	34	190	291	2946	25000	363	3184	27790
% in Hubei	82.9	77.3	80.3	66.7	58.1	30.0	83.2	58.8	43.9	82.6	60.1	45.9
% in China	54.8	36.8	11.4	60.0	52.9	15.8	54.6	26.4	9.7	54.8	27.4	9.9

The reserve holds 34 species of nationwide protected plants, which count for 54.8 % of the total number of protected plants in Hubei, and 8.7 % in those in China (Ge et al. 1997). Among them are dove tree (*Davidia involucrate*), ranked in Category I, and another 15 species including the famous Ginkgo tree (*Ginkgo biloba*), goose-palm tree (*Liriodendron chinense*) and lotus tree (*Cercidiphyllum japonicum*) in Category II. In addition, the local flora comprises 150 species of wild fiber plants, 208 species of wild oil-bearing plants, 190 species of wild starch and carbohydrate plants, 180 species of wild perfume plants, 160 species of wild vegetables, 253 species of wild flowers, and over 1600 species of wild medical plants (Zhan 1994).

Most of the moss species in the reserve remained unknown until 1990, since only five species had been recorded until then (Cui 1996). A recent survey (Liu 1999) preliminarily documented 135 species of mosses in the reserve and most of them are new records in Hubei. So far, 735 species of fungi and 191 species of lichens have been recorded in the reserve, including 10 new species, 5 new varieties, and 113 new records in China.

2.6 Vegetation

Shennongjia has a rich flora and diversity of habitats, which result in a complex mosaic of vegetation types and plant communities. According to China's vegetation zoning, the zonal vegetation in Shennongjia belongs to the eastern fringe of the evergreen and

deciduous *Quercus spp-Pinus armandii* vegetation area of the northern sub-tropical evergreen and deciduous broadleaved forest belt (Ban et al. 1995). However, a refined survey shows that in Shennongjia there are six major vegetation types: 1) Coniferous forest, 2) Broadleaved forest, 3) Bamboo forest, 4) Shrub thickets, and 5) Meadow.

The most extensive conifer forest is the farges fir *(Abies fargesii*) community, which distinctively stretches across most of the upper mountain areas above 2,500 m, and dips down into the deciduous broad-leaved forest at lower elevations. It is a monotonous forest, with crowded trees of modest stature, and low species diversity in the overstorey and understorey. Umbrella bamboo (*Fargesia murielae*) and rhododendrons (*Rhododendron* sp.) are common associates in the understorey and form the pure bamboo or shrub communities when the fir has been logged. Within the fir forest without bamboo and shrub thickets, a ground layer of dwarf shrubs, grasses, ferns and mosses can reach 100 % cover, which is a two-layered community. The second extensive conifer forests, the *Pinus armandii* and *Pinus henryi* communities, occur in the areas from 850-2,700 m. Other coniferous forests such as *Abies chinsiensis*, *Tsuga chinensis* and *Pinus massoniana* exist as mosaic communities within or mixed with the broadleaved forest, but they are not dominant.

Shennongjia has two basic kinds of broadleaved forest, *viz*. deciduous and evergreen, which are based on elevation. At middle and high elevations from 1,500-2,600 m mostly deciduous forests occur, which are typically leafless during the winter. Evergreen areas only extend from the mountain feet (400 m) up to 800 m in some habitats on the south-facing slopes. There is an area of mixed evergreen and deciduous forest from 800-1,500 m. Different species occupy specific elevations to form an altitudinal diversity of communities over the mountain ranges, e.g., *Betula albo-sinensis* occurring from 1,500 m up to 2,800 m, *Fagus engleriana* from 1,500-2,400 m, *Quercus glandulifera* var. *brevipetiolata* from 1,200-1,900 m, *Q. variabilis* from 400-1,500 m, while *Machilus ichangensis* and *Phoebe neurantha* only occur under 900 m, and *Q. acrodonta* occurs from 900-1,400 m. Due to selective logging in the 1970s, the degraded broadleaved forest consists mainly of deciduous and evergreen trees of little or no commercial value, which are now more common than they used to be. However, the secondary forest shows a much higher species diversity, and the structure of subdominant canopy layers is more complex.

There are three kinds of bamboo forest in Shennongjia: *Phyllostachys nigra* var. *henonis*, *Ph. bambusoides*, and *Fargesia murielae* forests. *Phyllostachys nigra* var. *henonis* and *Ph. bambusoides* are man-made forests introduced and cultivated by farmers below 1,400 m around the farmhouses or tea yards. Umbrella bamboo (*F. murielae*) communities are naturally distributed at 2,400-3,100 m, where it is foggy and rainy in summer and autumn and windy all the year round, leading to a moist environment. Umbrella bamboo forms a dense understorey under the forests, but where the overstorey was burned or cut down, it forms a pure bamboo community.

There are three stable shrub thickets in Shennongjia: *Sabina pingii* var. *wilsonii* in the sub-alpine areas above 2,700 m, *Chimonanthus praecox* from 500-800 m, and *Coriaria sinca* from 800-1,100 m. *Sabina* is only about 50 cm in height and is associated with *Rhododendron fargesii* and *Potentilla fruticosa* var. *alboicans*. Since both *Sabina pingii* and *Chimonanthus praecox* are famous garden plants in China, the original communities have degraded very rapidly due to human impacts.

Meadows play a key role in the subalpine areas above 2,500 m in Shennongjia. The community consists mainly of *Trisetum clarkei* and *Festuca rubra*, but many dwarf tree and shrub species such as *Malus kansuensis, Sorbus koehneana, Lonicera nervosa, Potentilla fruticosa, Salix polyclona*, *Rosa omeiensis, Fargesia murielae* and *Rhododendron fargesii* occur within the community. In the catchment basins, there are swamp communities in the southwest of the reserve at elevations from 1,700-2,100 m. The upper layer is dominated by *Sanguisorba officinalis* var. *longifolia* and *Sagittaria sagittifolia*, and the ground layer consists of species such as *Juncus bufonius, J. alatus, Iris wilsonii, Geum aleppicum*, and *Clintonia udensis*.

Along the elevational gradients, there are considerable vegetation shifts, which are shown in Figure 2.5. The Taiga evergreen coniferous forest zone extends from 2,600-3,100 m, and is dominated by three kinds of vegetation, i.e., fir (*Abies fargesii*) forest, bamboo (*Fargesia* murielae) forest and mountainous meadow (*Trisetum clarkei* and *Festuca rubra*). A warm-temperate coniferous forest and deciduous broadleaved forest zone occurs in the section between 1,800 m and 2,600 m and consists of two major vegetation types. One is the *Abies fargesii*, which includes deciduous species such as *Betula albo-sinensis*, *B. utilis*, *Sorbus kansuensis*, *Populus wilsonii*, and *Acer sp.*. The other is *Pinus armandii* mixed with *Acer davidii*, *Quercus aliena* var.

acuterrata, and *Tilia oliveri*. The mixed evergreen and deciduous broadleaved forest zone occurs from the mountain feet at 420 m up to 1,800 m. This zone is quite complex and can be roughly subdivided into a deciduous broadleaved forest sub-zone with an evergreen broadleaved forest (800-1,500 m) and a deciduous broadleaved forest sub-zone with evergreen broadleaved trees. The low mountain areas in the mixed evergreen and deciduous forest zone also contain some man-made forests cultivated by local farmers, mainly dominated by *Cunninghamia lanceolata*, *Pinus massoniana*, and *Toxicodendron succedoneum*.

3 INVENTORY OF BAMBOO DIVERSITY

Summary: Diversity and distribution of mountain bamboos were investigated in the Shennongjia National Nature Reserve, Central China. The taxa checklist documents the bamboo species occurring in this region. A total of 11 bamboo species was identified based on the morphological recognition of approximately 110 collections. Of these, 4 species (*Phyllostachys nigra* var. *henonis*, *Ph. heteroclada*, *Ph. nidularia* and *Ph. bambusoides*) have monopodial rhizomes, 4 species (*Indocalamus latifolius, I. longiauritus, I. wilsoni* and *I. tessellatus*) amphipodial rhizomes, and 3 species (*Fargesia spathacea, F. murielae* and *Yushania confusa*) sympodial rhizomes. All bamboo species occurring in Shennongjia are native to China. *Fargesia murielae* is endemic solely to Shennongjia, while 3 other species (*F. spathacea, Y. confusa,* and *I. wilsoni*) are endemic to Central China with Shennongjia as their distribution center. From the mountain feet (400 m) towards the summit (3,100 m), bamboo species richness decreased corresponding to the increase in altitude, which significantly ($P < 0.01$) follows a linear model: $Y = 7.5 - 0.21X$, where Y indicates the number of species and X the altitude step in 100 m. Within the climatic spectrum along the altitude (400-3,100 m), monopodial-rhizome bamboos occur in low mountains (400-1,800 m), namely the warm-temperate and mid-temperate belt; amphipodial-rhizome bamboos prefer moderate elevations (500-2,500 m), growing in the warm-temperate, mid-temperate and cold-temperate belt; sympodial-rhizome bamboos are able to survive from moderate slopes up to mountaintops (1,200-3,100 m), occurring in the mid-temperate, cold-temperate and frigid temperate belt. Of the bamboos in Shennongjia, 3 species (*F. spathacea, F. murielae* and *Y. confusa*) are the preferred food of the giant panda, and, based on aerial photographs, approximately cover 12 %, 8 % and 3 % of the mountain ranges, respectively. The latest gregarious flowering of *F. murielae* occurred in 1996-2000, *I. wilsoni* in 1997-1999, *Ph. nigra* var. *henonis* in 1993, *F. spathacea* in 1984-1988. Flowering of *Ph. nidularia* follows a sparodic pattern. Most bamboos occurring in Shennongjia have already appeared in Western gardens, e.g., *F. murielae, F. spathacea, Ph. nigra* var. *henonis* and *Ph. bambusoides*. So far *I. wilsoni* and *Y. confusa* have not been introduced.

3.1 Checklist of bamboo taxa occurring in Shennongjia

3.1.1 Introduction

The richness of the bamboo taxa in Shennongjia was unknown before the 1980s. In 1976-1979, an extensive plant inventory in Shennongjia was conducted by the Wuhan Institute of Botany (Cui 1996; Zhu and Song 1999), which reported about 2,000 species of vascular plants (Zheng et al. 1980). Of these, 9 species of bamboo (Table 3.1) were recorded (Zheng et al. 1980). Since this inventory was not designed specifically for bamboos, the inventory results may not present a real picture of the bamboo diversity, as there might have been difficulties and errors in the identification of species. Correspondingly, this investigation aims to make a comprehensive understanding of the bamboo diversity in this region.

3.1.2 Methods

The inventory of bamboo species was conducted between June 2000 and August 2001 along seven survey routes covering the mountain ranges of the Shennongjia National Nature Reserve (Figure 3.1). Specimen collection was restricted to the wild and naturalized bamboos. Garden bamboos were not included. A total of 110 bamboo specimens was collected. Species identification was carried out in the Hubei University Herbarium (HUBUH) in Wuhan, China. Initial identifications were made using taxonomic keys and manuals, which include: Flora Republicae Popularis Sinicae, Tomus 9(1) (Keng and Wang 1996), Compendium of Chinese Bamboo Species (Zhu et al. 1994), Compendium of Bamboos in Sichuan (Yi 1997), and The Plants of Shennongjia (Zheng et al. 1980). Nomenclature of taxa principally followed Keng and Wang (1996). Verification of the identified taxa was carried out by comparing the collected specimens with the voucher collections in Wuhan University Herbarium (WHUH), Central China Normal University Herbarium (CCNUH), and the specimens in the Shennongjia National Nature Reserve. Morphological descriptions were made for each taxon based on my own specimens. For the common species, the important characters were illustrated, showing how to distinguish them from closely-related species. For the complex taxa, detailed descriptions were made, showing how to define the boundary of the species.

A checklist of bamboo species was developed in terms of: 1) Accepted name;

2) Synonyms; 3) References for the accepted name; 4) Morphological features; 5) Taxonomic status and current treatment; 6) Ecological and phytogeographical status. Of these, 'Taxonomic status and current treatment' forms a discussion section that aims to outline the nomenclature changes of the relevant taxon and to explain the classification treatment in this research. The section of 'Ecological and phytogeographical status' is set up to represent the status of the relevant taxon in the flora of Shennongjia, i.e. endemic (= if distribution does not extend beyond Shennongjia), native, naturalized, or cultivated.

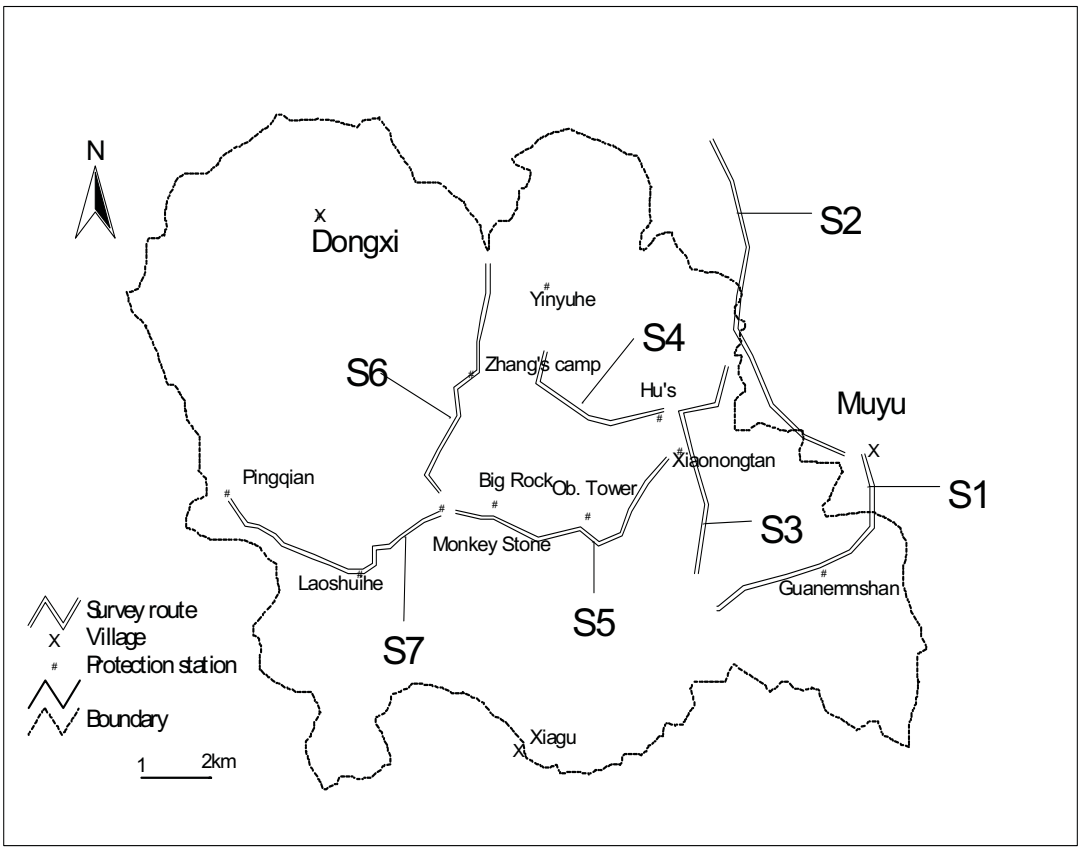

Figure 3.1: Survey routes of the mountain bamboos in the Shennongjia National Nature Reserve, Central China. Survey route 1 (S1): alt. 800-2,200 m; estimated length 15 km; surveyed in September 2000 and May 2001. S2: 1,200-1,930 m; 20 km; April 2001. S3: 1,860-2,700 m; 15 km; June and July 2000. S4: 2,100-2,750 m; 8 km; July 2000. S5: 2,100-3,100 m; 20 km; September 2000 and July 2001. S6: 2,500-2,700; 15 km; September 2000 and July 2001. S7: 600-2,600 m; 20 km; October 2000 and July 2001.

3.1.3 Treatment of accepted taxa

The result of the bamboo taxa inventory summarized in the following checklist shows that there are 11 bamboo species occurring in the mountain ranges of Shennongjia. Of these, 4 species are in the genus of *Phyllostachys* Sieb. et Zucc., 4 species in *Indocalamus* Nakai, 2 species in *Fargesia* Franchet, and 1 species in *Yushania* Keng f.. A comparison between local botanical records (Zheng et al. 1980) and this inventory is presented in Tab. 2.1.

Table 3.1: Nomenclature treatment of bamboo species in Shennongjia, Central China.

Local records (Zheng et al 1980)	This treatment	Notes
Phyllostachys nigra var. *henonis* (Bean) Stapf. ex Rendle.	*Phyllostachys nigra* var. *henonis* (Mitford) Stapf. ex Rendle.	Confirmed
Phyllostachys congesta Rendle	*Phyllostachys heteroclada* Oliver	Name changed
Phyllostachys nidularia Munro	*Phyllostachys nidularia* Munro	Confirmed
Phyllostachys bambusoides Sieb. & Zucc.	*Phyllostachys bambusoides* Sieb. & Zucc.	Confirmed
No record	*Indocalamus wilsoni* (Rendle) C.S. Chao et C.D. Chu	New record
Indocalamus latifolius (Keng) McClure	*Indocalamus latifolius* (Keng) McClure	Confirmed
Indocalamus longiauritus Hand.-Mazz.	*Indocalamus longiauritus* Hand.-Mazz.	Confirmed
Indocalamus tessellatus (Munro) P. C. Keng	*Indocalamus tessellatus* (Munro) P. C. Keng	Confirmed
Sinarundinaria nitida (Mitf.) Nakai	*Fargesia murielae* (Gamble) Yi	Name changed
Sinarundinaria sparsiflora (Rendle) Keng f.	*Fargesia spathacea* Franch.	Name changed
No record	*Yushania confusa* (McClure) Z.P. Wang et G.H. Ye	New record

Bamboo checklist in Shennongjia, Central China

I. *Phyllostachys* Sieb. et Zucc.

(1) *Phyllostachys nigra* var. *henonis* (Mitford) Stapf ex Rendle, J. Linn. Soc., Bot. 36(254): 442-443. 1904 = *Phyllostachys henonis* Bean, Gard. Chron., ser. 3, 15: 238. 1894 = *Sinarundinaria henonis* (Bean) Ohwi ex Mayeb., Fl. Austro-Higo. 86. 1931.

= *Bambusa puberula* Miq., Ann. Mus. Bot. Lugduno-Batavum 2: 285. 1866 = *Phyllostachys puberula* (Miq.) Munro, Gard. Chron. 6: 773-774. 1876 = *Phyllostachys nigra* var. *puberula* (Miq.) Fiori, Bull. Tosc. Ort. 42: 97, f. 3, 4, 6. 1917.

= *Phyllostachys fauriei* Hack., Bull. Herb. Boissier 7(9): 718. 1899.

(= *Phyllostachys henonis* Mitford, Bamb. Gard. 47: 149-151. 1895).

= *Phyllostachys nevinii* Hance, J. Bot. 14: 295. 1876.

= *Phyllostachys nevinii* var. *hupehensis* Rendle, J. Linn. Soc., Bot. 36(254): 442. 1904.

= *Phyllostachys montana* Rendle, J. Linn. Soc., Bot. 36(254): 441. 1904.

= *Phyllostachys henryi* Rendle, J. Linn. Soc., Bot. 36(254): 440-441. 1904.

References: Keng and Wang 1996; Zhu et al. 1994; Zheng et al. 1980.

Morphological features: Open, sometimes tuft, spreading bamboo. Rhizomes monipodial. Culms erect, straight, 4-10 m tall, 2-6 cm in diameter, wall 3-6 mm thick, green when young, golden-yellow when older. Internodes 15-30 cm long, white powdery waxy when young, pith white membranaceous; wall 3-6 mm thick. Nodes prominent, lower (sheath) annuli slightly convex, subglabrous, brownish, upper (culm) annuli extremely convex, much higher than sheath annuli, white ciliated when young, segments between two nodes 5-9 mm. Each culm node carrying one bud, bud adnate to culm, purplish yellow, ovate, 1.2-4 cm long, 0.8-2.1 cm wide. Branches paired each node, unequal in thickness, thicker one 60-130 cm long, thinner one 30-80 cm long, internodes of the thick branch 3-10 cm long, solid. Culm sheaths coriaceous, long-triangular in shape, purplish brown, 16-31 cm long, 3-6 (8) cm wide, apex arched, brown bristles sparely on lower of the sheath, but heavier on upper part; longitudinal veins prominent, crossveins prominent on upper part, margins densely ciliated, cilia brownish; sheath auricles typically prominent, 6-12 mm long, 3-5 mm wide, sheath shoulders and upper margins bearing bristles, bristles 8-14 mm, ciliated; sheath ligules truncated, 3-6 mm high, 12-20 mm wide, top margins serrated, slightly ciliated; sheath blades triangular, erect, brownish green when young and brown later, subglabrous, 5-9 cm long, 0.8-1.4 cm wide, longitudinal veins visible, crossvein poor, margins bearing bristles. Branchlet usually bearing two leaves, leaf sheathes 1.8-3.6 cm long, greenish yellow, glabrous or sparsely ciliated on upper part, longitudinal veins and central ridge prominent; auricles tiny or absent, sheath mouth and auricle margins finely ciliated, each sheath should bearing 2-5 gray bristles; ligules

truncated, 2-3.6 mm high, top margins serrated; leaf petioles 4-8 mm long, leaf blades lanceolated, papyraceous, 5-11 cm long, 0.6-1.2 cm wide, green, slightly covered with white ciliates, leaf tip aristiform, side-veins 5 pairs, crossveins prominent, one side-margin bearing tiny teeth, the other entire.

Inflorescence terminal, panicle, bearing 3-7 spikelets and some bracts, 2.5-3 cm long, 0.8-1.6 cm wide; richilla and pedicel puberculent; spikelet-stalks 1.5-2 mm long, greenish, puberculent; glumes 1-3, lemmas purplish-green, papery, ovoid, 15-19 mm long, 3-4 mm wide, 7-9 nerved, with dense cilia on outer surface, inner surface glabrous, apex aristiform; paleas shorter than lemmas, brownish-green, papery, ovoid, 10-12 mm long, 2-3 mm wide, inner-surface glabrous, with a central keel and 2-3 pairs of nerves, apex bearing 2 serrated teeth; lodicules 3, triangular shaped, greenish white, membranous, 2-4 mm long, 1.5-2.5 mm wide, glabrous, upper margins ciliated; ovaries lageniform, base enlargements semi-globular, 1-1.5 mm high, 1.1-1.5 mm in diameter, yellowish brown, glabrous, specular, cervical parts oblate, 4-5.5 mm long, 0.8-1.3 mm wide; stigma 1, stamens 3; fruit not present.

Taxonomic status and current treatment: Treatment of this taxon was based on specimen *Li2031* (deposited in HUBUH). *Phyllostachys nigra* var. *henonis* is a naturalized bamboo in Shennongjia. It is widely cultivated in China and Japan. This species was the most popular bamboo in Japan until the middle of the 18th century and from Japan it was introduced in the West by Dr. Henon as an ornamental plant (Cao 1989; Bezona and Rauch 1997; Linvill et al. 2001). In 1887, Augustine Henry collected a specimen of this taxon in West Hubei (*Henry 6338*), which was described as the new species: *Phyllostachys henryi* Rendle, but synonymied with *Phyllostachys nigra* var. *henonis* by later authors. In 1907, Ernest Wilson collected this taxon (*Wilson 3904*) again in West Hubei, but Rendle (in Sargent 1913) treated this sample as *Phyllostachys puberula* Munro. Now the accepted name for this taxon is *Phyllostachys nigra* var. *henonis* (Keng and Wang 1996). When Zheng et al. (1980) surveyed the plants in Shennongjia, they also accepted the name of *Ph. nigra var. henonis*. The variety *henonis* differs from the nominal species (*Phyllostachys nigra* (Lodd. ex Lindl.) Munro) in its culm, which does not turn dark purple and the

mature culm is far taller and thicker. *Ph. nigra* var *henonis* is similar to *Ph. sulphurea* (Carr.) A. et C. Riv. in the color and structure of its culm, but the culm sheath of *Ph. sulphurea* does not have auricles. The yellow culm can distinguish this species from other large bamboos in Shennongjia.

Status: Naturalized and cultivated.

(2) ***Phyllostachys heteroclada*** Oliver, Hooker's Icon. Pl. 23(4): pl. 2288. 1894.

= *Phyllostachys congesta* Rendle, J. Linn. Soc., Bot. 36(254): 438-439. 1904.

= *Phyllostachys purpurata* McClure, Lingnan Univ. Sci. Bull. 9: 43. 1940 = *Phyllostachys heteroclada* fo. *purpurata* (McClure) T.H. Wen, Bull. Bot. Res., Harbin 2(1): 78. 1982.

References: Keng and Wang 1996; Zhu et al. 1994.

Morphological features: Open spreading bamboo. Rhizomes monopodial. Culms separated, erect, 1.5-5 m tall, 0.8-1.2 cm in diameter; internodes 8-23 cm long, branching side flatted in upper nodes, unusually with a prominent ridge in the center of flattened side, hollowed, green in color, subglabrous, whiter powdery when young, ribbed striates prominent, walls 1-2.5 mm thick, pith membranous, stick to inner-wall, white in color. Sheath nodes prominent, annuli grayish brown, glabrous; culm annuli swelled, higher than sheath annulus, brownish, glabrous, specular; node segments 2-4 mm long, green, glabrous, scabrous. Each culm node carrying one bud, bud greenish, long ovate, 1-3 cm long, 0.5-1.2 cm wide. Main branches 2, unequal in thickness, usually with an accessory branch between two main branches; thicker main branches 45-70 cm long, 3-5 mm in diameter, with 8-11 nodes, branching side flatted, hollowed with a tiny hole or solid; thinner main branches 25-40 cm long, 1.5-2.5 mm in diameter, with 3-9 nodes, solid; accessory branches usually 2-6 cm long, with 2-6 short nodes. Culm sheaths caduceus, triangular in shape, subcoriaceous, green purplish, 8-12 cm long, 1-2.1 cm wide, apex vaulted, 3-5 mm wide; abaxial surface subglabrous, scabrous, longitudinal striates prominent, crosslets visible in middle and upper parts of the sheath, margins bearing yellowish gray ciliates; approximate surface purplish, glabrous; sheath auricles small but visible, 1-1.5 mm long, 0.5-1.5 mm wide; sheath ligules truncated at top, subglabrous, brownish, 1-1.5 mm high; sheath

blades initially erect, side sedges enrolled, forming a boat ship, 0.8-2.5 cm long, 0.3-1.0 cm in wide at base, longitudinal veins visible, abaxial surface glabrous, approximate surface bearing dense short flosses. Branchlet usually bearing 2-3 foliage leaves, leaf sheath purplish green, glabrous, 2-3.5 cm, longitudinal veins prominent, central ridge visible in upper part, upper margins ciliated, auricles absent, ligules truncated at top, 0.7-1.1 mm high, 2.6-3 mm wide; sheath apex bearing 4-6 oral setae, setae greenish white, 2-5 mm long; foliage blades linearly lanceolate, greenish, papery, 6-13 cm long, 8-14 mm wide; abaxial surface puberculent, approximate surface slightly ciliated at lower part; lateral veins 5-6 pair, crossveinlets visible, both sides serrated. Flower and fruit not present.

Taxonomic status and current treatment: Treatment of this taxon was based on specimen *Li2097* (HUBUH). *Phyllostachys heteroclada* is a fast-growing bamboo (Zhu et al. 1994). In about 1888, Augustine Henry collected the type specimen of this species (*Henry 8833*) from West Hubei (East Szechuan?). It was introduced in the United States by F. A. McClure in 1928 from Eastern China under the name of *Phyllostachys purpurata* McClure (Young 1991; McClure 1993). Zheng et al. (1980) selected the name *Phyllostachys congesta* Rendle for this taxon. Now *Ph. congesta* is accepted as a synonym of *Ph. heteroclada* (Keng and Wang 1996; Zhu et al. 1994). In Shennongjia, this species is similar to *Phyllostachys nidularia* Munro, having green culms and long internodes. However, the auricles of its culm sheath are tiny, much smaller that those of *Ph. nidularia*. Generally, it is easily to recognize *Ph. heteroclada* by its culm sheath blades - they are enrolled into a boat form.

Status: Native.

(3) ***Phyllostachys nidularia*** Munro, Gard. Chron., n.s., 9: 773-774. 1876.

References: Keng and Wang 1996; Zhu et al. 1994; Zheng et al. 1980.

Morphological features: Open spreading bamboo. Rhizomes monopodial. Culm erect, apex bending, 1.5-5 m tall, 1-2 (5) cm in diameter, greenish. Internodes 10-20 cm long, down nodes heavily white powdery waxy when young. Branches paired, branchlet bearing one leaf (initially having 2-3 leaves, but only one left, the others fallout soon). Culm sheath 10-18 cm long, deciduous,

light greenish yellow with white ribbed straights, thickly white powdery, ciliated at base part; sheath blade triangular, erect; ligules 1-2 mm high, brownish, apex truncate; auricle typically prominent, clasping culm together with the extended base of sheath blade. Leaf blade lanceolate, 5-10 cm long, 3-8 mm wide, apex bending abaxially to hook-like. Flower and fruit not present.

Taxonomic status and current treatment: Treatment of this taxon was based on specimen *Li21183* (HUBUH). The type specimen (*Fenzi 4*) of *Phyllostachys nidularia* was from the cultivated plants in Italy, from material originally collected in Japan in 1868 (Yi 1997). This species is very easy to recognize, as its mature branchlet carries only one leaf. Another distinctive feature is that its culm sheath auricles enlarge to clasp the culm. The leaf sheaths also make this species easy to recognize as they have whitely ribbed straights. Ernest Wilson collected this species in West Hubei (*Wilson 3407*) in 1907 (Sargent 1913). *Ph. nidularia* is an easily recognized species without nomenclatural confusions.

Status: Native.

(4) ***Phyllostachys bambusoides*** Sieb. & Zucc., Abh. Math.-Phys. Cl. Königl. Bayer. Akad. Wiss. 3(3): 746, pl. 5, f. 3. 1843.

= *Bambusa castilloni* Marliac ex Carrière, Rev. Hort. 58: 513. 1886 = *Phyllostachys castillonis* (Marliac ex Carrière) Mitford, Bamb. Gard. 47: 3. 1895 = *Phyllostachys bambusoides* var. *castillonis* (Marliac ex Carrière) Makino, Bot. Mag. (Tokyo) 14: 63. 1900 = *Phyllostachys bambusoides* var. *castillonis* (Marliac ex Carrière) Makino ex Shiras., Icon. Bamb Jap. pl. 2, f. 1-4. 1912 = *Phyllostachys bambusoides* fo. *castillonis* (Marliac ex Carrière) T.P. Yi, J. Bamboo Res. 12(4): 47. 1993 = *Phyllostachys quilioi* var. *castillonis* (Marliac ex Carrière) J. Houz., Bambou (Mons) 1: 29. 1906 = *Phyllostachys nigra* var. *castillonis* (Marliac ex Carrière) Bean, Bull. Misc. Inform. Kew 1907: 232. 1907 = *Phyllostachys reticulata* var. *castillonis* (Marliac ex Carrière) Makino, Bot. Mag. 26: 21. 1912.

= *Phyllostachys castillonis* var. *holochrysa* Pfitzer, Mitt. Deutsch. Dendrol. Ges. 14: 60. 1905 = *Phyllostachys reticulata* var. *holochrysa* (Pfitzer) Nakai, J. Jap.

Bot. 9: 34. 1933 = *Phyllostachys bambusoides* var. *castilloni-holochrysa* (Pfitzer) J. Houz., Act. Congr. Int. Bot. Brux. Actes 2: 228. 1912.

= *Phyllostachys quilioi* var. *castillonis-holochrysa* Regel ex J. Houz., Bambou (Mons) 1: 118. 1906.

= *Phyllostachys sulphurea* (Carrière) Rivière & C. Rivière, Bull. Soc. Natl. Acclim. France 5: 773. 1878 = *Phyllostachys reticulata* var. *sulphurea* (Carrière) Makino, Bot. Mag. (Tokyo) 26: 24. 1912.

= *Phyllostachys bambusoides* var. *sulphurea* Makino ex Tsuboi, Illustr. Jap. Sp. Bamboo 7, t. 5. 1916.

= *Phyllostachys sulphurea* var. *viridis* Rob. A. Young, J. Wash. Acad. Sci. 27: 345. 1937.

= *Phyllostachys marliacea* Mitford, Bamb. Gard. 158. 1896.

= *Phyllostachys reticulata* fo. *geniculata* Nakai, J. Jap. Bot. 9: 34. 1933.

References: Keng and Wang 1996; Zhu et al. 1994; Zheng et al. 1980.

Morphological features: Open spreading bamboo. Rhizomes monopodial. Culm erect, straight, 4-8 m tall, 2-5(8) cm in diameter, wall 3-7 mm thick, green when young, light green to yellowish when old. Internodes 10-25 cm long, glabrous, smooth, polished, with waxy ring below the nodes. Branches usually paired in the mid-culm part, unequal in thickness. Culm sheath 10-15 cm long, promptly deciduous, light orange-yellow, abaxial surface conspicuously purplish-brown or black spot and blotches; sheath blade lanceolate, 1-4 cm long, erect or spreading; auricles usually 2, usually unequal two sides, sickleform to ovoid, sometimes only one or entirely lacking with bristles; ligules 1-3 mm high, long ciliate at apex; Leaf blade lanceolate, 5-12 cm long, 5-10 mm wide, glabrous. Flower and fruit not present.

Taxonomic status and current treatment: Treatment of this taxon was based on specimen *Li21178* (HUBUH). *Phyllostachys bambusoides* is one of the large bamboos in China (Zhu et al. 1994). It is similar to another large bamboo *Phyllostachys pubescens* Mazel ex J. Houz., both species being large and having black spots and blotches on the culm sheaths. However, the culm sheaths of *Ph. bambusoides* are usually glabrous and smooth, while culm sheaths of *Ph. pubescens* are covered with dense brownish hairs. The species

can be distinguished from *Ph. nigra* var. *henonis* by numerous black spots on the culm sheaths. In Japan, *Phyllostachys bambusoides* contributed about 75 % of bamboo stands before 1960. However, simultaneous flowering during the 1960's and 1970's caused a shrinking of this species (Watanabe 1994). Due to long history in cultivation, many varieties appeared in different countries, which enhance the difficulty in classification of this species.

Status: Cultivated.

(II) *Indocalamus* Nakai

(5) *Indocalamus wilsoni* (Rendle) C.S. Chao et C.D. Chu, J. Nanjing Techn. Coll. For. Prod. 1981(3):43. 1981 = *Arundinaria wilsonii* Rendle, J. Linn. Soc. Bot. 36: 437. 1904 = *Sinarundinaria wilsonii* (Rendle) P. C. Keng, Techn. Bull. Nat. For. Bur. China. No.8: 14. 1948.

= *Sasa nubigena* P.C. Keng, Act. Phytotax. Sin. 6(4): 357. Pl. 56. 1957 = *Indocalamus nubigenus* (P.C. Keng) Yi ex H.R. Zhao & Y. L. Yang, Act. Phytotax. Sin. 23(6): 465. 1985.

= *Indocalamus shimenensis* B.M. Yang, Nat. Sci. J. Hunan Norm. Univ. 12(4): 334. 1989.

Reference: Keng and Wang (1996); Zhu et al. (1994); Yi (1997).

Morphological features: Semi-running bamboo. Rhizomes amphipodial. Spreading rhizomes yellowish, internodes 2.5-4 cm long, 3-5 mm in diameter, glabrous, longitudinal striates prominent, hollowed, pith scobicular, wall 0.8-1.2 mm thick; each node bearing 2(3) roots. Culm necks (clumping rhizomes) short, 6-11 mm long, with (4)5 nodes, yellowish, glabrous, slightly scabrous, ribbed striates visible. Culms separate, erect, 60-90(110) cm tall, 2-4 mm in diameter; with 7-11 nodes; internodes usually 6-18 cm long, cylindrical, greenish yellow to yellow, scabrous, slightly pruinate when young, internodes hollowed, culm wall 1.8-2.5 mm thick. Sheath nodes slightly convex, scabrous; culm nodes plain to slight convex, glabrous; node segments between two annuli 0.5-1.2 mm, glabrous. Culm buds long-ovate, one on each node, 1.1-1.5 cm long, 1-3 mm wide, grayish yellow, adnating to culm, glabrous. Branch one, as thick as culm, erect, pruinate, pubescent. Culm sheaths persistent, clasping culm, long-triangular, papery, shorter than culm internodes, 2-4 cm long, 4-8 mm

wide at base, top margin truncated, 3-5 mm wide; abaxial surface light purplish, slightly bearing brownish bristles, longitudinal nerves prominent, crossveinlets visible in the upper part; approximate surface purplish, glabrous; auricles and oral setae usually absent; ligules short, brownish, apex truncated, 0.2-0.8 mm high; sheath blades outwards or erect, long-triangular to linear, 3-9 mm long, 1-3 mm wide, abaxial surface bearing dark cilia, approximately glabrous. Branchlet bearing 3-5 foliage leaves, leaf sheaths 2-6 cm long, yellowish green, chartaceous, glabrous, upper margins ciliated, longitudinal nerves visible; leaf auricle and oral setae usually absent; leaf ligules very prominent, purplish, usually unequal in two sides, 1.5-6 mm high; leaf petioles 2-3 mm long, purplish, glabrous; leaf blades elliptical lanceolate, papery, crinkled curved when dry, 6-17 cm long, 1.5-4 cm wide, apex acuminated, base obtuse; approximate surface green, glabrous; abaxial surface grayish green, slightly pubescent; lateral veins 4-6(8) pairs, cross veinlets visible, side margins smoothly; leaves wavy curved when dry.

Flowering branches 8-25 cm long. Inflorescences panicle, 3-9 cm long, 1-2 cm wide, enlarged leaf sheaths at base; each spiketlet 1.5-3 cm long, carrying 3-7 floretlet; rachilla segments 3-5 mm long, dense pubescent; glumes 2, chartaceous, lanceolate, the first glume 2-5 mm long, 1-3 mm wide, 3 nerved; the second glumes 3-5 mm long, 2-3 mm wide, 5-7 nerved; lemmas ovoid-lanceolated, greenish yellow, chartaceous, apex acuminated or aristiform, abaxial surface slightly pubescent, 9-12 mm long, 3-4 mm wide, 7-9 nerved; paleas shorter than lemmas, grayish green, thin papery, 6-9 mm long, 3-5 mm wide. Fruit not present.

Taxonomic status and current treatment: Treatment of this taxon was based on specimen *Li2026* (HUBUH). *Indocalamus wilsoni* is a rare species endemic to Central China (Keng and Wang 1996). It can be easily recognized by the leaf blades which are crinkled-wavy when dry. This feature is similar to another two species *Indocalamus hispidus* H.R. Zhao et Y.L. Yang and *Indocalamus auriculatus* (H.R. Zhao et Y.L) Y.L. Ynag, but *I. hispidus* is much taller (1.5-3.5 m), and its leaf sheath ligules are much shorter (1-3 mm), while the culm sheath of *I. auriculatus* has auricles. Zheng et al. (1980) did not record this

species during their inventory. I treat this taxon as *I. wilsoni* according to Keng and Wang (1996).

Status: Native.

(6) ***Indocalamus latifolius*** (Keng) McClure, Sunyatsenia 6(1): 37. 1941 = *Arundinaria latifolia* Keng, Sinensis 6(2): 147, 153. f. 1. 1935 = *Sasamorpha latifolia* (Keng) Nakai ex Migo, J. Shanghai Sci. Inst. III. 4(7): 163. 1939.

= *Sasamorpha migoi* Nakai ex Migo, 1. c.. 163. 1939 = *Indocalamus migoi* (Nakai) Keng f., Clav. Gen. et Sp. Gram. Prim. Sin. App. Nom. Syst. 152. 1957.

= *Indocalamus lacunosus* Wen, J. Bamb. Res. 2(1): 70. f. 21. 1983.

References: Keng and Wang 1996; Zhu et al. 1994; Yi 1997.

Morphological features: Semi-running bamboo. Rhizomes amphipodial. Spreading rhizomes yellowish, internodes 3.5-6 cm long, 5-8 mm in diameter, glabrous, hollowed, pith scobicular; each node bearing 2 roots. Culm necks (clumping rhizomes) 2-4 cm long, 7-13 mm thick, with 5-9 nodes, yellowish, glabrous, solid. Culms separate to clumping, erect, 1.2-2.5 m tall, 8-12 mm in diameter; with 7-11 nodes; internodes usually 18-25 cm long, 30 cm as maximum, cylindrical, greenish, scabrous, slightly pruinate when young; hollowed, well 2.5-3 mm thick; pith white, scobicular. Sheath nodes slightly convex, purplish, culm nodes convex, higher than sheath node; node segments between two annuli 4-6 mm, greenish, glabrous. Culm buds ovate-triangular, one on each node, 9-12 mm long, 5-7 mm wide, grayish yellow to purplish, margins ciliated. Branch usually one, top nodes sometimes bearing 2-3 branches, erect; 60-120 cm long, with 5-9 nodes, pruinate, pubescent. Culm sheaths persistent, tightly clasping culm in down nodes, long-triangular, coriaceous, shorter than culm internodes, 4-8 cm long, 12-18 mm wide at base, top margin arched; abaxial surface purplish green, usually bearing brown setae; sheath ligules brownish, 1-2 mm high, top truncate, top margins ciliated; sheath auricles usually absent; sheath blades lanceolate to linear, erect, purplish green, 5-8 mm long, 2-4 mm wide. Branchlet bearing 2-4 giant leaves, leaf sheaths 6-9 cm long, greenish when young, purplish later, coriaceous, initially pubescent, longitudinal nerves visible; leaf auricle absent, leaf ligules truncate, brownish, glabrous, 2-4 mm high; leaf petioles 4-7 mm long, greenish, finely

pubescent; leaf blades elliptical lanceolate, thick papery, 18-40 cm long, 3.5-7 cm wide, apex acuminated, base obtuse; approximate surface green, glabrous; abaxial surface grayish green, slightly pubescent; lateral veins 6-12 pairs, cross veinlet visible, side margins serrated. Flower and fruit not present.

Taxonomic status and current treatment: Treatment of this taxon was based on specimen *Li21031* (HUBUH). *Indocamlamus latifolius* is a species of giant-leaved bamboo widely growing in subtropical and warm-temperate China (Keng and Wang 1996). Its giant leaves have long been used in China for wrapping Chinese tamales, or making rainproof hats and boat covers, while culms are processed as the holder of the Chinese writing brush. In recent years, leaves of *I. latifolius* are in great demand by both the chemical industry and traditional food makers. This species is best distinguished from other *Indocalamus* species by the top nodes carrying 2-3 branches. It can be distinguished quickly from *Indocalamus tessellates* (Munro) Keng f., another common species with which it is often found, by the absence of hairs on the leaf.

Status: Native.

(7) ***Indocalamus longiauritus*** Hand.-Mazz. Anzeig. Akad. Wiss. Math. Naturw. Wien 62: 254. 1925 = *Arundinaria longiaurita* (Hand.-Mazz.) Hand.-Mazz. Sym. Sin. 7: 1271. 1936.

References: Keng and Wang (1996), Zhu et al. (1994).

Morphological features: Semi-running, sometimes densely tufted bamboo. Rhizomes amphipodial. Culms 1.3-3 m high, 5-10 mm in diameter. Internodes usually 10-15 cm long, cylindrical, glabrous or subglabrous, brownish ciliates forming a ring below node. Culm sheaths persistent, brownish green when young, 8-10 cm long, ciliated in mid and down parts; sheath ligules 1-2 mm high, top transacted to slightly arched, apex ciliated; sheath auricles typical prominent, sickleform, margins bearing radial hairs, hairs 4-8 mm long, slightly curved; sheath blades triangular, erect. Branchlet bearing 2-3 giant leaves, leaf blades long-lanceolate, thickly papery, 10-30 cm long, 2-6 cm wide; abaxial surface slightly ciliated. Flower and fruit not present.

Taxonomic status and current treatment: Treatment of this taxon was based on specimen *Li2101* (HUBUH). *Indocalamus longiauritus* is one of the most common *Indocalamus* species in South and Central China (Keng and Wang 1996). It is similar to *Indocalamus herklotsii* McClure but can easily be distinguished by having auricles on the culm sheath. The radial hairs on the margin of culm sheath auricles distinguish it from the other *Indocalamus* species in Shennongjia, i.e., *I. latifolius* and *I. tessellatus*.

Status: Native.

(8) ***Indocalamus tessellatus*** (Munro) P. C. Keng, Clav. Gen. Sp. Gram. Prim. Sin. App. Nom. Syst. 152. 1957 = *Bambusa tessellata* Munro, Trans. Linn. Soc. London 26(1): 110. 1868 = *Sasa tessellata* (Munro) Makino & Shibata, Bot. Mag. (Tokyo) 15: 27. 1901 = *Sasamorpha tessellata* (Munro) Koidz., Acta Phytotax. Geobot. 10(1): 75-76. 1941.

= *Arundinaria ragamowskii* Pfitzer, Mitt. Deutsch. Dendrol. Ges. 1902: 96. 1902.

References: Keng and Wang 1996; Zhu et al. 1994; Zheng et al. 1980

Morphological features: Semi-running bamboo. Rhizomes amphipodial. Culms 1-2 m high, 4-7 mm in diameter. Internodes usually 20-30 cm long, cylindrical, greenish, hollowed, well 2-3 mm thick. Nodes plain, upper (culm) node slightly higher than the down (sheath) node. Culm sheaths persistent, longer than the internode, clasping culm tightly in down culm but loosely in upper culm, glabrous; sheath ligules brownish, 1-2 mm high, top transacted to arched, abaxial face brownish ciliated; sheath auricles absent; sheath blades lanceolate, deciduous easily. Branchlet bearing 2-4 giant leaves, leaf blades elliptical to long-lanceolate, thickly papery, 20-45 cm long, 4-8 cm wide; approximate surface green, glabrous; abaxial surface grayish green, covered with short flosses; ciliates rowed in one side near the main vein; lateral veins 8-16 pairs, cross veinlet prominent. Flower and fruit unknown.

Taxonomic status and current treatment: Treatment of this taxon was based on specimen *Li21023* (HUBUH). *Indocalamus tessellatus* is a common giant-leaved bamboo in South China (Keng and Wang 1996). The first description of this species (*Indocalamus tessellatus* Munro) was derived from leaves used to wrap parcels of Chinese tea sent to England by Munro in 1868 (Stapleton

2000). It is similar in size to *I. latifolius* but it can be distinguished by a row of hairs on the distal surface of the leaves.

Status: Native.

III. *Fargesia* Franchet

(9) *Fargesia murielae* (Gamble) T.P. Yi, J. Bamb. Res. 2(1): 39. 1983 = *Arundinaria murielae* Gamble, Bull. Misc. Inform. Kew 1920(10): 344-345. 1920 = *Sinarundinaria murielae* (Gamble) Nakai, J. Jap. Bot. 11(1): 1-2. 1935 = *Thamnocalamus murielae* (Gamble) Demoly, Bull. Assoc. Franc. Bot. 13: 10. 1990.

References: Keng and Wang 1996; Zhu et al. 1994.

Morphological features: Clumping bamboo. Rhizomes sympodial. Culms erect, 2.0-4.5 m tall, 8-14 mm in diameter; internodes 15-25 cm long, cylindrical, green and pruinate when young, yellow and glabrous when older; ribbed-striates prominent, hollowed, wall 1.8-2.5 mm thick, pith white, debris. Sheath nodes prominent, annuli glabrous, sheath scares gray to darkish brown, scabrous; culm nodes slight convex or plain, glabrous; node segments between two annuli 3-5 mm, greenish yellow, glabrous. Culm buds long ovate, adnate to culm, pubescent, margins thickly ciliated, cilia yellowish gray. Branches (3)5-9(11) each node, oblique erect, 8-45 cm long, with 5-8 nodes, branch internodes 0.5-8 cm long, 1-2 mm in diameter, solid, glabrous, longitudinal striates visible. Culm sheaths persistent, elongated with round apex, coriaceous, shorter than culm internodes, 12-18 cm long, 1.8-3.2 cm wide at base, 1.3-2.5 cm wide at top; abaxial surface vinaceous, glabrous, upper margins bearing yellowish gray ciliates, longitudinal veins prominent, crossveinlets visible in the upper part; approximate surface light purplish, glabrous; auricles and oral seta usually absent; ligules short, brownish, apex arched, 0.5-1 mm high, 0.6-1.5 mm wide; sheath blades outwards, long-triangular, apex acuminated, 5-8 cm long, 2-6 mm wide, longitudinal striates prominent, side margins inrolled. Branchlet bearing (2)3-4 foliage leaves, leaf sheaths 2.5-3.5 cm long, light purplish, chartaceous, glabrous, upper margins slightly ciliated, longitudinal nerves prominent, transverse veinlets inconspicuous; leaf auricle absent, each sheath humerus bearing 1-5 setae; leaf ligules yellowish brown, subglabrous, apex truncated, 0.3-0.8 mm high; leaf

petioles 3-5 mm long, yellowish green, glabrous, slightly scabrous; leaf blades long-lanceolate to lanceolate, papery, glabrous, 7-11 cm long, 0.9-1.4 cm wide, apex acuminate, obtuse at base; approximate surface green, abaxial surface grayish green, initially slightly pubescent, late glabrous; lateral veins 3-4 pairs, cross veinlets visible, one side serrated, the other smoothly.

Flowering branches 5-35 cm long, each branch node carrying 1-2 branchlets; leaf sheaths enlarged as spathes towards the tip; spathes 3-5, purplish, papery, step-wisely larger; inflorescence racemose terminal, lateral exerting from pathes, 1.5-2.5 cm long, 5-11 mm wide; each influence bearing 7-11 spiketlets, arranged a spikeform on the rachilla; pedicels 1-1.5 mm long, brownish, glabrous, usually with one bract at base; bract long-triangular, central striate prominent, veins inconspicuous; spikelet bearing 1-3 florelets, 8-10 mm long, 0.8-1.2 mm wide; rachilla segments 1.2-1.8 mm long, glabrous; glumes 2, chartaceous, lanceolate, upper part slightly pubescent, apex mucronated; the first glume 10-15 mm long, 0.9-1.2 mm wide, 5 nerved; the second glumes 11-13 mm long, 2-2.5 mm wide, 7 nerved; lemmas ovoid-lanceolated, chartaceous, apex acuminated or aristiform, abaxial surface slightly pubescent, 10-12 mm long, 3-3.5 mm wide, 7-9 nerved; paleas shorter than lemmas, narrowed, abaxially manicated, 2 keeled, each having a acuted tooth; lodicules 3, narrowly ovoid, membranous, longitudinal veins visible; ovary ellipsosome, 1.5-2 mm long, 0.6-0.9 mm in diameter at middle, style 1, stigmas 3. Fruits caryopsis, long-ellisosome, purplish dark, scabrous, 6-8 mm long, 1.5-1.8 mm in diameter, abdominal groove prominent, with a ridge along groove center, flowering style usually persistent.

Taxonomic status and current treatment: Treatment of this taxon was based on specimen *Li20113* (HUBUH). On 17 April 1907, Ernest Wilson (1876-1930) collected "one of the most beautiful Chinese bamboos" (*Wilson 1462*) from Shennongjia in western Hubei of Central China. Rendle (in Sargent 1913) did not describe this new species, but titled it as an uncertain taxon "*Arundinaria sp*". In 1920, this bamboo was named *Arundinaria murielae* after Wilson's daughter, Muriel, by Gamble (Keng 1987). Later it was assigned to a newly established genus *Sinarundinaria* Nakai in 1935 (Li 1996). Presently it is in

the genus of *Fargesia* Franchet (e.g., Yi 1988; Stapleton 1995; Keng and Wang 1996). *F. murielae* was introduced to Kew Gardens in the early 20th century and all plants in European countries are the vegetative offspring of this clone (Eberts 1996; Gielis 1999). It is the most successful and widely grown ornamental bamboo in the West; however, there is no species name *F. murielae* mentioned in the Shennongjia botanical accounts (e.g., Zheng et al. 1980; Ban et al. 1995; Zhu and Song 1999).

Before the late 1970s, *F. murielae* did not appear in any authoritative taxonomic books in China, e.g., "Iconographia Comorphytorum Sinicorum" (Beijing Botanical Institute 1976). Therefore, when Zheng et al. (1980) compiled "The Plants in Shennongjia", they treated the species as *Sinarundinaria nitida* (Mitf.) Nakai. In this book, they noted “it is difficult to identify these two species (indicating *Sinarundinaria nitida* and *Sinarundinaria sparsiflora*), further work is needed to distinguish them” (Zheng et al. 1980). My morphological study shows that this species is certainly the *Fargesia murielae,* rather than the fountain bamboo *Sinarundinaria nitida* (now renamed as *Fargesia nitida*).

There are obvious differences between *F. murielae* and *F. nitida*, i.e., the culm sheath of *murielae* is relatively shorter than the internodes and with a round top, while the culm sheath of *nitida* is longer than the internodes and with a triangular top. Furthermore, *F. nitida* growing in western Sichuan and southern Gansu simultaneously flowered in the 1980s (Keng and Wang 1996; Yi 1997), while *F. murielae* endemic to Shennongjia flowered in the 1990s. Since currently most bamboo taxonomists agreed to merge *Sinarundinaria* with the genus *Fargesia* (Yi 1985; Keng 1987; Stapleton 1997), *murielae* received the full name *Fargesia murielae* (Gamble) Yi.

Status: Endemic.

(10) ***Fargesia spathacea*** Franch., Bull. Mens. Soc. Linn. Paris 2: 1067. 1893 = *Arundinaria spathacea* (Franch.) D.C. McClint., Garden (London 1975+) 105(7): 298. 1980 = *Thamnocalamus spathaceus* (Franchet) Soderstrom. Brittonia 31(4): 495. 1979 = *Thamnocalamus spathaceus* (Franch.) C.D. Chu & C.S. Chao, Bamb. Res. Asia 1: 5. 1981.

= *Arundinaria sparsiflora* Rendle, J. Linn. Soc. Bot. 36:436. 1904.

References: Keng and Wang 1996; Yi 1997; Yi 1988.

Morphological features: Clumping bamboo. Rhizomes sympodial. Culms erect, with 18-32 culm nodes, 2-4(6) m tall, 10-15 mm in diameter; internodes 15-25 cm long, cylindrical, green and pruinate when young, yellowish green and glabrous or dark-foedated when older; ribbed-striates prominent, hollowed, wall 1.2-2 mm thick, pith white, scobicular. Sheath nodes convex, annuli slightly pruinate, scares purplish yellow to purplish, glabrous; culm nodes plane or slight convex, approximately as high as sheath annuli, glabrous; intranodes glabrous, 2-3.5 mm high, glabrous. Culm buds presenting in middle and upper nodes, long ovate, adnate to culm, purplish yellow, 12-15 mm long, 4-7 mm wide, abaxial surface pubescent, margins ciliated. Branches (4) 7-13 each node, clustered, 20-35 cm long, with 5-11 nodes; branch internodes solid or near so, glabrous, usually 5-8 cm long. Culm sheaths persistent or late deciduous, long-triangular, as long as culm internodes or slightly shorter in upper nodes and longer in low nodes; coriaceous, 6.5-22 cm long, 1.8-3.5 cm wide at base, apex truncated, 4-6 mm wide; abaxial surface greenish to purplish, initially bearing brists, later subglabrous, upper margins bearing grayish white ciliate, longitudinal veins prominent, crossveinlets visible in the upper part; approximate surface light purplish, glabrous; auricles usually absent; each humerus initially bearing 4-6 setae, later fallout, ligules brownish, apex truncated or silted in low nodes, 0.3-0.7 mm high, top margins ciliated; sheath blades outward or erect, long-triangular to lanceolate, 5.8 cm long, 2-6 mm wide, longitudinal striates prominent, side margins inrolled. Branchlet bearing 2-3 foliage leaves, leaf sheaths 2.5-3.5 cm long, light purplish, chartaceous, glabrous, upper margins slightly ciliated, longitudinal nerves prominent, transverse veinlets inconspicuous; leaf auricles small or sometimes absent, purplish, each bearing 5-7 setae; leaf ligules brownish, glabrous, 0.8-1.2 mm high; leaf petioles 1-2 mm long, yellowish green, glabrous, slightly scabrous; leaf blades linearly lanceolate, papery, glabrous, 6-10 cm long, 5-8 mm wide, apex acuminate, obtuse at base; approximate surface green, glabrous, abaxial surface grayish green, glabrous, lateral veins 3-4 pairs, cross

veinlets visible, one side serrated, the other smoothly. Flower and fruit not present.

Taxonomic status and current treatment: Treatment of this taxon was based on specimen *Li2095* (HUBUH). *Fargesia spathacea* was first described by Franchet in 1893, based on a specimen (*Farges 567*) from Sichuan in China (Keng 1987; Yi 1988, 1997). In 1988, Augustine Henry collected a specimen from Shennongjia (*Henry 6938*). This specimen was cited by Soderstrom as the lectotype of *Thamnocalamus spathaceus* (Soderstrom 1979); however, Yi (1988, 1997) argued that it should be back to *Fargesia spathacea* Franch., since its flower certainly belongs to the *Fargesia* type. Thus, I treat *Thamnocalamus spathaceus* as a synonym of *Fargesia spathacea* Franch.

There is no species which previously was identified as *Fargesia spathacea* or *Thamnocalamus spathaceus* in the local botanical accounts in Shennongjia. However, Zheng et al. (1980) recorded this taxon as *Sinarundinaria sparsiflora* (Rendle) Keng f., a synonym of the species *Fargesia spathacea*. It is very similar to the fountain bamboo (*F. nitida*), but its leaf sheath has visible auricles and oral setae. In the habitats of the giant panda in Sichuan, a staple food species of the giant panda had long been known as *F. spathacea* (e.g., Campbell and Qin 1983; Schaller et al. 1985; Taylor and Qin 1988; 1991). Campbell and Qin (1983) first doubted the taxonomic treatment of this species. Then, after a detailed morphological comparison, Yi (1988) separated this taxon from *F. spathacea* as a new species *Fargesia robusta* Yi. *Fargesia spathacea* can easily be distinguished from *F. robust* by its culm sheathes, which are much longer than the internodes.

Status: Native.

IV. *Yushania* Keng f.

(11) *Yushania confusa* (McClure) Z.P. Wang et G.H. Ye. J. Nanjing Univ., Nat. Sci. Ed. 1981(1): 92. 1981 = *Indocalamus confusa* McClure, Lingnan Univ. Sci. Bull. 9: 20. 1940.

= *Arundinaria nitida* Mitford ex Stapf. Bull. Misc. Inform. Kew, 109: 20. 1896.

References: Keng and Wang 1996; Zhu et al. 1994.

Morphological features: Semi-spreading bamboo. Rhizomes sympodial. Culm necks 20-35 cm long, 4-8 mm thick, with 4-9 nodes, glabrous, solid. Culms erect, 1.5-3 m tall, 3-9 mm in diameter; with 18-28 nodes; internodes usually 16-25 cm long, 35 cm as maximum, cylindrical, initially greenish, slightly purinate, later greenish yellow, glabrous, frequently darkish foedated, minute longitudinal striates visible; hollowed with tiny inner diameter, culm wall 2-3.5 mm thick; pith white or purplish white, scobicular or sponge-form in upper nodes. Sheath nodes prominent, annuli convex, glabrous, sheath scars brownish, scabrous; culm nodes plain or slightly convex, usually lower than sheath nodes, glabrous, specular; intranode segments 2-4 mm high. Culm buds ovoid to long-ovoid, one bud on each node, 6-21 mm long, 4-12 mm wide, light purplish to yellow to purplish, adnate to culm, surface pubescent, margins ciliated. Branch usually (1)3-5 each node, obliquely erect, 15-35 cm long, with 4-10 nodes; internodes 1-8 cm long, 1-2 mm thick, greenish yellow to purplish, branching side slightly flatted, solid or near so. Culm sheaths persistent or late deciduous, elongate-triangular, coriaceous, shorter than culm internodes, 8-12 cm long, 2.5-3 cm wide at base, top margin grayish ciliated; abaxial surface glabrous, longitudinal nerves prominent, crossveinlets visible in upper part; approximate surface specular, glabrous; auricle absent; both humerus initially bearing several grayish setae, later fallout; ligules brownish, apex truncated, 0.5-1 mm high, glabrous; sheath blades outward, linear-triangular, sedges inrolled, 2.5-6 cm long, 2-4 mm wide, longitudinal veins distinct, apex acuminate. Each branchlet bearing 3-5 foliage leaves; leaf sheaths 2.1-5 cm long, yellow to purplish, longitudinal nerves prominent, central striate prominent in upper part, margins slightly ciliated; leaf auricle usually absent; both humerus bearing 3-7 grayish setae either, setae 2-5 mm long, slightly curved; leaf ligules darkish brown, apex truncated, glabrous, 0.8-1.2 mm high. Petioles 2-3 mm long, brownish, pubescent. Leaf blades lanceolate, papery, 4-10 cm long, 6-11 mm wide, apex acuminated, base obtuse; approximate surfaces greenish, glabrous; abaxial surface grayish green, albus downy; lateral veins 3-5 pairs, cross veinlet vivid, tessellated. Flower and fruit not present.

Taxonomic status and current treatment: Treatment of this taxon was based on specimen *Li21020* (HUBUH). This taxon (*Henry* 6832) was first collected by Augustine Henry (1857-1930) in Shennongjia in 1888 (Keng 1987; Yi 1988; Stapleton 1995, 1997; Li 1996). When Otto Stapf described the fountain bamboo *Arundinaria nitida*, he was actually describing material from two collections (Keng 1987; Stapleton 1995; Li 1996): one was from the living plants raised from bamboo seeds collected by Berezowski in south Gansu Province of China in 1886; the other was the fertile specimen *Henry 6832* (Keng 1987). Later, the vegetative collection was cited by Nakai (1935) as the type specimen, together with *F. murielae*, for establishing the new genus of *Sinarundinaria*. Plant collection *Henry 6832* was separated from *F. nitida* by McClure as a different species *Indocalamus confusus* (McClure 1940; Keng 1997), newly combined as *Yushania confusa* (McClure) Z.P. Wang & G.H. Ye (Keng and Wang 1996). My inventory successfully collected this species on the southern slope of Shennongjia. It is difficult to clearly distinguish species of *Yushania* from species of *Fargesia* in their vegetative form. However, the rhizomes of these two genera are different. A typical rhizome of *Fargesia* bamboo is usually thicker than the culm, solid without air channels, and both ends are thicker than its middle part, while a rhizome of *Yushania* bamboo is slender and longer, usually with a caliber and many air canals, and both ends are not thicker than the middle part.

Status: Native.

3.2 Field key for species identification

The taxonomy of bamboos is quite complicated, and has long been neglected (Liese 1985; Campbell 1987). For a long time, taxonomists thought that the flowers were essential for identification, but now it is accepted that vegetative parts of the bamboo are also important (Stapleton 1994). As some species may not flower for 120 years (Janzen 1976), vegetative features make it much easier to identify the different species. Morphological descriptions in this study allow a positive identification in the field from vegetative material alone. The following field key was compiled to enable the general

investigators to classify the underlying bamboo taxa into genus and species in Shennongjia.

Field key for bamboos in Shennongjia, Central China

1 Rhizomes amphipodial. Culm node carrying only one branch, branch usually as thick as culm. Some with giant leaves --- **(I)** ***Indocalamus*** Nakai

2 Culm height less than 1 m. Leaf blades crinkled-wavy when dry --- ***Indocalamus wilsoni*** (Rendle) C.S. Chao et C.D. Chu [Appendix 2]

2 Culm higher than 1 m. Leaf blades plain when dry.

3 Culm sheath blades triangular with a narrowed base. Sheath auricles prominent --- ***Indocalamus longiauritus*** Hand. –Mazz.

3 Culm sheath blades linear to lanceolate. Sheath auricles absent.

4 Culm sheath leathery and longer than internode. Abaxial surface of the leaf blade bearing a row of dense hairs near main vein --- ***Indocalamus tessellatus*** (Munro) Keng f.

4 Culm sheath papery and shorter than internode. Leaf blade glabrous --- ***Indocalamus latifolius*** (Keng) McClure [Appendix 1]

1 Rhizomes monopodial or sympodial. Each culm node bearing two or more branches, branches obviously thinner than culms. Leaf sizes normal.

5 Rhizomes monopodial. Main branches paired at each culm node, one of them thicker and the other thinner. The internodes with a sulcate throughout the branching side --- **(II)** ***Phyllostachys*** Sieb. et Zucc.

6 Culm sheath with brownish dots and blotches. Internodes of the culm without white powder --- ***Phyllostachys bambusoides*** Sieb. & Zucc.

6 Culm sheath without dots or scars. Internodes of young culm white-powdery.

7 Mature branchlet bearing only one leaf. Leaf sheath with white ribbed striations --- ***Phyllostachys nidularia*** Munro

7 Mature branchlet bearing 2-5 leaves. Leaf sheath not whitery ribbed.

8 Culms usually yellowish when older. Culm sheath auricles prominent, falcate, sheath blades lanceolate --- ***Phyllostachys nigra*** **var.** ***henonis*** (Mitford) Stapf. ex Rendle [Appendix 3]

8 Culms greenish, sheath auricles small but visible, sheath blades inrolled to boat form --- ***Phyllostachys heteroclada*** Oliver [Appendix 4]

5 Rhizomes sympodial. Each culm node bearing 3 or more branches. Internodes usually cylindrical.

9 Culm necks thick and short, usually solid without air channels, both ends of neck thicker than middle part --- **(III)** ***Fargesia*** Franch.

10 Culm sheath elongated with a round top, shorter than the internode (around 4/5). Leaf auricles absent --- ***Fargesia murielae*** (Gamble) Yi [Appendix 5]

10 Culm sheath triangular with a narrow top, slightly longer than, or as long as internode. Leaf auricles visible --- ***Fargesia spathacea*** Franch. [Appendix 6]

9 Culm necks slender and longer, usually with a caliber and many air canals, both ends not markedly thicker than the middle portion --- **(IV)** ***Yushania*** Keng f. – ***Yushania confusa*** (McClure) Z.P. Wang et G.H. Ye [Appendix 7]

3.3 Distribution of bamboo species in Shennongjia

3.3.1 Introduction

The natural world is extremely dynamic, due to both intrinsic ecological factors and increasing human influences. In such complex natural systems, setting priorities is a necessary prerequisite for effective biodiversity conservation. The judgment of conservational priority in plants usually depends on the status ranks of the individual taxon. Many bamboo species are endemic to Central and Western China (Yi 1997), covering the upper reaches of the rivers. Protecting the endangered bamboo species is an important issue for the biodiversity conservation in China. In Shennongjia, since available information for the bamboo species is rare, the targeting conservation towards bamboo requires a sound understanding on the species distribution.

Furthermore, understanding the distribution of the bamboos is an essential step to assess the possibility of introducing the giant panda *(Ailuropoda melanoleuca)* back to Shennongjia (Ref. to Chapter 1). Bamboo availability is one of the key factors that determine the survival of the giant panda in a given region (O'Brien and Knight 1987; Taylor et al. 1991; Fong and Li 2001), since over 99 % of the food of giant pandas consists of bamboo (Schaller et al. 1985). This availability contains two basic issues: if there are suitable species or not; if yes, how many animals the forage species can

support. Therefore, a sound understanding is needed on the distribution of the bamboo species which may comprise the staple diet of the giant panda.

3.3.2 Methods

Investigation on the distribution of the bamboo species was conducted in terms of altitudinal range, land coverage and ground coverage in Shennongjia. Here, land coverage indicates the %-percent cover of the bamboo stands (plant communities in which bamboo occurs) in a given area, while ground coverage indicates the %-percent cover of bamboo clumps (bamboo plants which grow in the plant community) in the bamboo stand. Land coverage was estimated by using aerial photographs that are stored in the Shennongjia National Nature Reserve. Species recognition was based on the field records in which the species were marked on a 1:50,000 topographical map.

Ground coverage was given for the two most dominant species, *F. spathacea* and *F. murielae*. A total of 31 bamboo stands was surveyed (11 for *F. spathacea* and 20 for *F. murielae*). The bamboo stands were classified into vegetation types following Ban et al. (1995): conifer forest, broadleaved forest, shrubland, mountain meadow, and pure bamboo community. In each stand, a quadrat was set up (20-200 m^2) to measure the ground coverage of the bamboo clumps. Paired samples correlation analysis was applied to test the relationship between bamboo ground-coverage and environmental variables.

For clarifying the distribution range of bamboo species, the distribution map was developed for each species based on field investigations. The map indicates where the species could be found. For conservation priorities to be set at local as well as range-wide scales, ranking on each species was carried out at three status levels: endemic to Shennongjia, endemic to Central China (with Shennongjia as the distribution center), and endemic to China. These ranks allow local priorities to be set within a wide context to protect the bamboo diversity. For emphasizing such priorities, bamboo flowering was investigated, since some bamboo species simultaneously flower and then die back, which may threaten the survival of the species on population level. Flowering investigations were conducted by both of interviewing the local farmers and checking the yearly pattern of the rhizome structures of the bamboo seedlings.

Table 3.2: Summary of distribution and flowering of the bamboos in Shennongjia, Central China. In the table, *Ph = Phyllostachys, I = Indocalamus, F. = Fargesia, Y = Yushania*. Flowering types follows Dransfield and Widjaja (1995): Gregarious = a whole population flowers over a period of 2-3 years and then dies; Sporadic = the individuals flower seasonally or occasionally, and only the flowering culms die afterwards, while the rhizomes continue to live.

Species	Elevation range (m)	Land coverage	Flowering type	Recent flowering
Ph. nigra var. *henonis*	500-1,800	1-2 %	Gregarious	1993
Ph. heteroclada	500-1,400	<1 %	Gregarious	1958
Ph. bambusoides	500-1,300	<1 %	Gregarious	Unknown
Ph. nidularia	500-1,200	<1 %	Sporadic	Frequently
I. latifolius	500-1,200	<1 %	Unknown	Unknown
I. wilsoni	1,700-2,400	1-2 %	Sporadic	1997-1999
I. longiauritus	500-1,300	<1 %	Unknown	Unknown
I. tessellatus	500-1,000	<1 %	Sporadic	Unknown
F. spathacea	1,200-2,600	12 %	Gregarious	1984-1988
F. murielae	2,400-3,100	8 %	Gregarious	1996-2000
Y. confusa	1,200-2,300	2-3 %	Gregarious	1976-1979

3.3.3 Results

The results of the investigation are shown in Table 3.2. In Shennongjia, bamboos occur from the mountain feet (ca. 500 m) up to the summit (3,100 m). However, each species has a specific elevation range (Table 3.2), which results in altitudinal changes in bamboo diversity. The species richness declined significantly ($P < 0.05$) with the increase in altitude (Figure 3.2). A linear model, $Y = 7.5 - 0.21X$ (Y indicating the number of species and X the altitude step in 100 m), is adequate to describe this relationship.

Land-coverage estimations show that 2 species, namely *F. spathacea* and *F. murielae* were the dominant bamboo and covered 12 % and 8 % of the mountain ranges, respectively. There were 3 species (*Y. confusa*, *I. wilsoni*, and *Ph. nigra* var. *henonis*) frequently occurring in the mountain ranges and each covering 1-3 % of the land. The other 6 species, namely *Ph. heteroclada, Ph. bambusoides, Ph. nidularia, I. longiauritus, I. latifolius*, and *I. tessellatus,* were the rare species in Shennongjia and each covered less than 1 % of the land. The distribution is mapped in Figure 3.4-3.14, in which the distribution range for each species is indicated.

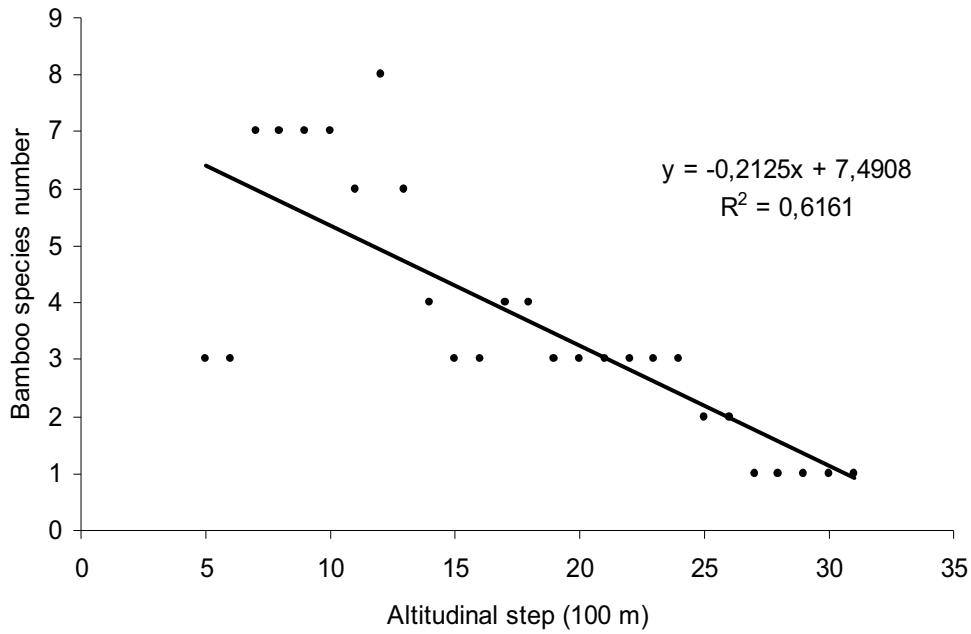

Figure 3.2: Relationship between species richness of bamboo and altitudinal changes in Shennongjia, Central China. In the equation, y = number of species and x = altitudinal step in 100 m.

The ground-cover investigation was given for two dominant species: *F. spathacea* and *F. murielae*. In overall scales, the bamboo clumps of these two species covered 40 ± 18 % and 72 ± 20 % of the ground of their own bamboo stands, respectively. This means that *F. murielae* covered the ground much more efficiently than *F. spathacea* did. The paired samples correlation analyses show that the ground coverage of bamboo was not strongly affected by the altitude (*F. murielae*: r = 0.116, n = 20, P = 0.627; *F. spathacea*: r = 0.403, n = 11, P = 0.219), but certainly related to the associated vegetation. In the broadleaved forests (i.e., forests of *Quercus spinosa*, *Fagus engleriana, Acer davidii*, *Populus davidiana*, *Tilia oliveri*, and *Betula utilis*), *F. spathacea* covered 41 ± 16 % of the forest floor. However, in the coniferous forest (forests of *Abies chensiensis*, *A. fargesii, Pinus henryi,* and *P. armandii*), this ground coverage increased to 50 ± 26 %. *Fargesia murielae* shared the same pattern of *F. spathacea*: under the coniferous forest (*Abies fargesii*), it covered 77 ± 21 % of the ground, while in the broadleaved forests, the coverage reduced to 73 ± 4 %.

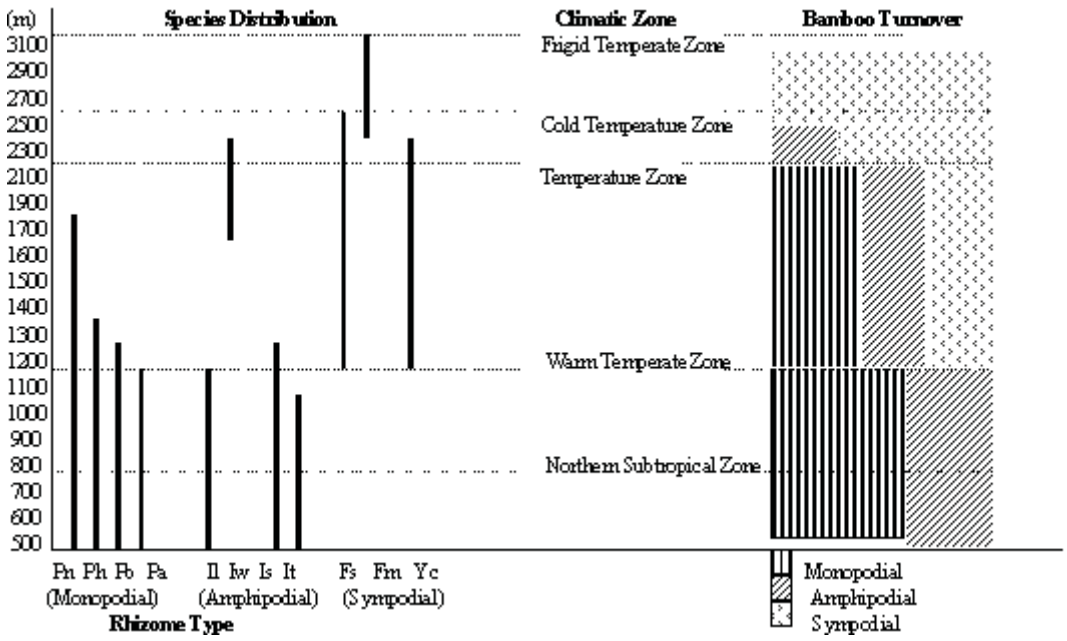

Figure 3.3: Altitudinal turnover of bamboo species in Shennongjia, Central China. In the figure, Pn = *Phyllostachys nigra* var. *henonis,* Ph = *Ph. heteroclada,* Pb = *Ph. bambusoides*, Pa = *Ph. nidularia*, Il = *Indocalamus longiauritus*, Iw = *I. wilsoni*, Is = *I. latifolius*, It = *I. tessellatus*, Fs = *Fargesia spathacea,* Fm = *F. murielae*, Yc = *Yushania confusa.* In the "Bamboo Turnover" section, width of the columns indicates the relative dominance of bamboo species assembled by the rhizome types.

A total of 7 species was recorded flowering or flowered recently in Shennongjia (Table 3.2). From 1996 to 2000, *Fargesia murielae* gregariously flowered and died back on population level. A large number of seeds were produced and seedlings appeared in most of the old stands. *Indocalamus wilsoni* flowered in a secondary forest (N31°23.345', E110°24.500', alt. 1990 m) in 1997-1999. Soon after flowering, the flowered culms died and non-flowering culms remained alive. New shoots continuously emerged from the ground in the flowering years. It seems as if the flowering of *I. wilsoni* follows a sporadic pattern. *Phyllostachys nidularia* in a bamboo grove beside a river (N31º23.831', E110º33.409', alt. 630 m) flowered in 2000 and 2001. In the bamboo clumps, a few culms flowered and died; however, the non-flowering culms remained alive and continued to produce new shoots. A grove of *Phyllostachys nigra* var. *henonis* (N31º27.965', E110º23.680', alt. 1,250 m, area: 0.2 ha)

simultaneously flowered in 1993 and all culms then apparently died without seeding. In the second year, new culms appeared from the ground; however, culms in the old stand again flowered and some short slender culms in the margins grew up without flowering. The next set of short slender culms formed the new generation. Gradually the culms grew and reached a normal size and shape. This bamboo stand was restored in about 6-7 years.

3.3.4 Discussion

The species richness of mountain bamboos in Shennongjia follows a general tendency: decline with the increase in altitude. However, the altitudinal pattern of the bamboo species is highly related to rhizome types of the species assemble (Figure 3.3). Within the altitudinal spectrum of climatic belts, monopodial-rhizome bamboos (*Ph. nigra* var. *henonis, Ph. heteroclada, Ph. nidularia, and Ph. bambusoides*) occur in low mountains (400-1,800 m), namely in the warm-temperate and mid-temperate belt; amphipodial-rhizome bamboos (*I. latifolius, I. longiauritus, I. tessellates,* and *I. wilsoni*) prefer moderate elevations (500-2,500 m), which belong to the in warm-temperate, mid-temperate and cold-temperate belt; sympodial-rhizome bamboos (*F. spathacea, F. murielae*, and *Y. confusa*) are able to survive from moderate slopes to mountaintops (1,200-3,100 m), namely in the mid-temperate, cold-temperate and frigid temperate belt. Particularly, species of *Indocalamus* (i.e. *I. longiauritus*, *I. latifolius*, and *I. tessellates*) growing in the low mountains usually have giant leaves, while the bamboo in high elevations (i.e., *I. wilsoni*) bears normal-sized leaves.

According to their distribution ranges, all bamboos occurring in Shennongjia are native Chinese species (Zhu et al. 1994). Of these, *F. murielae* is endemic solely to Shennongjia, and *F. spathacea, Y. confusa,* and *I. wilsoni* are endemic to Central China with Shennongjia as their distribution center (Table 3.3). Taxonomic confusions caused misunderstandings of some rare bamboos in Shennongjia. For instance, *F. murielae* was wrongly treated as a popular species *F. nitida*, which resulted in the “loss” of this rare species. Consequently, in the past decades, no protective support and scientific research has been given to this endemic species. This situation calls for more taxonomic work on the bamboo taxa in this region. My investigation, in fact, only presented the bamboo diversity within the Shennongjia National Nature Reserve in an area covering about

60,000 ha. Many other species undoubtedly will remain undiscovered outside the reserve, considering that the Shennongjia Mountains cover an area of 3,200 km^2 (Cui 1996).

Table 3.3: Status ranks and introductory situation of the bamboo species in Shennongjia, Central China. Here Central China indicates an area covering Hubei, Hunan, Henan, Eastern Sichuan, and South Shaanxi.

Species	In Shennongjia	In Central China(1)	In China(1)	In USA and Europe
Ph. nigra henonis	Naturalized	Native	Native	Introduced(2)
Ph. heteroclada	Native	Native	Endemic	Introduced(2)
Ph. nidularia	Native	Native	Endemic	Introduced(2)
Ph. bambusoides	Cultivated	Native	Native	Introduced(2)
I. wilsoni	Native	Endemic	Endemic	Non
I. latifolius	Native	Native	Endemic	Introduced(3)
I. longiauritus	Native	Native	Endemic	Introduced(3)
I. tessellatus	Native	Native	Endemic	Introduced(3)
F. murielae	Endemic	Endemic	Endemic	Introduced(3)
F. spathacea	Native	Endemic	Endemic	Introduced(3)
Y. confusa	Native	Endemic	Endemic	Non

Notes: (1) Zhu, S.L., Ma, L.S. and Fu, M.Y. 1994. Compendium of Chinese bamboo species. China Forestry Press, Peking.
(2) Young, S.M. 1991. Bamboos in American botanic gardens, past, present and future. Journal of American Bamboo Society, 8: 97-116.
(3) Shor, G. 2002. Bamboo species source list, No. 22. the American Bamboo Society, Portland.

Plant introduction is probably one of the best ways to conserve the bamboo species, since most bamboos can be planted in home gardens. Most bamboos occurring in Shennongjia have already appeared in Western gardens, e.g., *F. murielae, F. spathacea, Ph. nigra* var. *henonis, Ph. heteroclada, Ph. nidularia* and *Ph. bambusoides*. However, 2 species (*I. wilsoni* and *Y. confusa*) have not yet been introduced in the West. Of these, *I. wilsoni* is a dwarf bamboo with spreading rhizomes that are able to cover the ground very quickly, which may be suitable for recovering degraded land in temperate regions.

According to the list of bamboo species forming the panda's diet (Yi 1985), of the 11 bamboo species in Shennongjia, 3 species (*F. spathacea, F. murielae*, and *Y. confusa*) are the preferred food of the giant panda, while *Ph. heteroclada, Ph. nidularia,* and the *Indocalamus* bamboos belong to the accepted food. In 1990s,

F. murielae simultaneously flowered all over the world. This is the first mass flowering since Ernest Wilson recorded and introduced it in the West in 1907. Considering *F. murielae* was in fully vegetative phase in 1907 (Sargent 1913) and *Fargesia* bamboos usually need about 20 years for rebuilding the bamboo stands after flowering death (Taylor and Qin 1993), I assume that flowering interval of *F. murielae* may be as long as 110 years (1886-1996). *Yushania confusa* flowered in around 1888 (sample *Henry 6832* in Kew). After that it flowered again in 1976-79, which indicates that the flowering interval of this bamboo is about 88 years. Latest flowering of *Fargesia spathacea* occurred in 1984-88 and the flowering prior to this time was around 1949, from the local elders. Thus I assume the flowering interval of *F. spathacea* as 35 years. The possible relationship between bamboo and the giant panda in Shennongjia will be discussed in a following chapter.

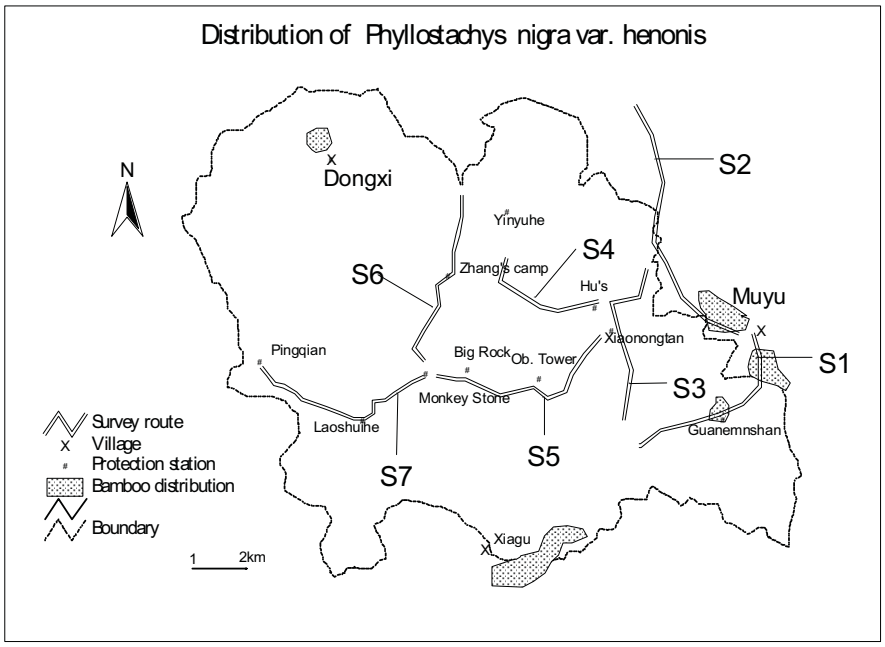

Figure3.4: Distribution of *Phyllostachys nigra* var. *henonis*, naturalized in Shennongjia.

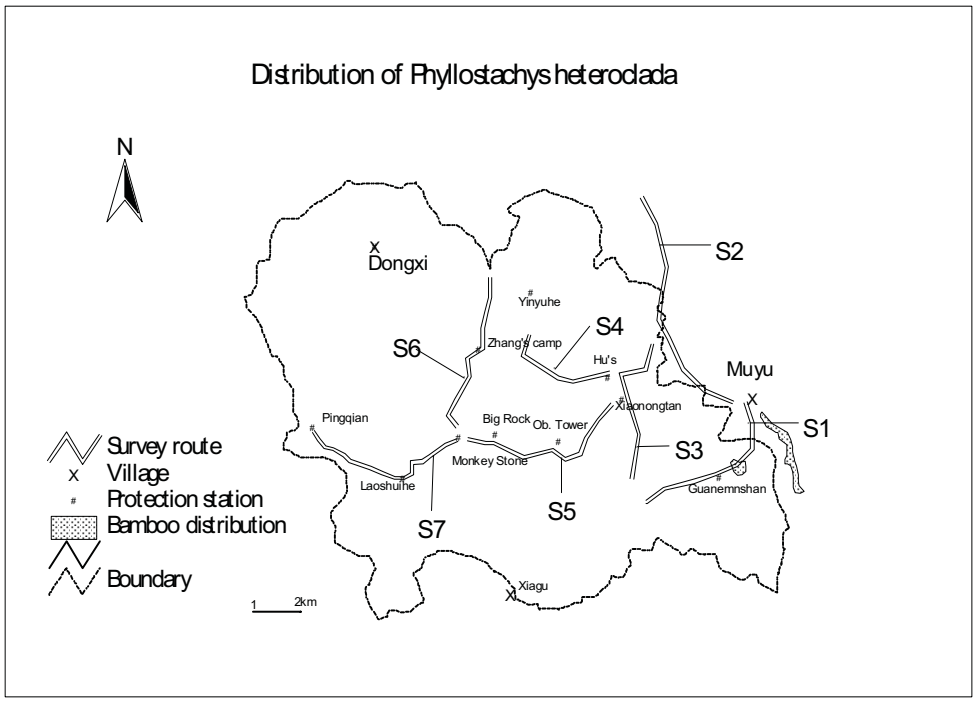

Figure 3.5: Distribution of *Phyllostachys heteroclada*, native in Shennongjia.

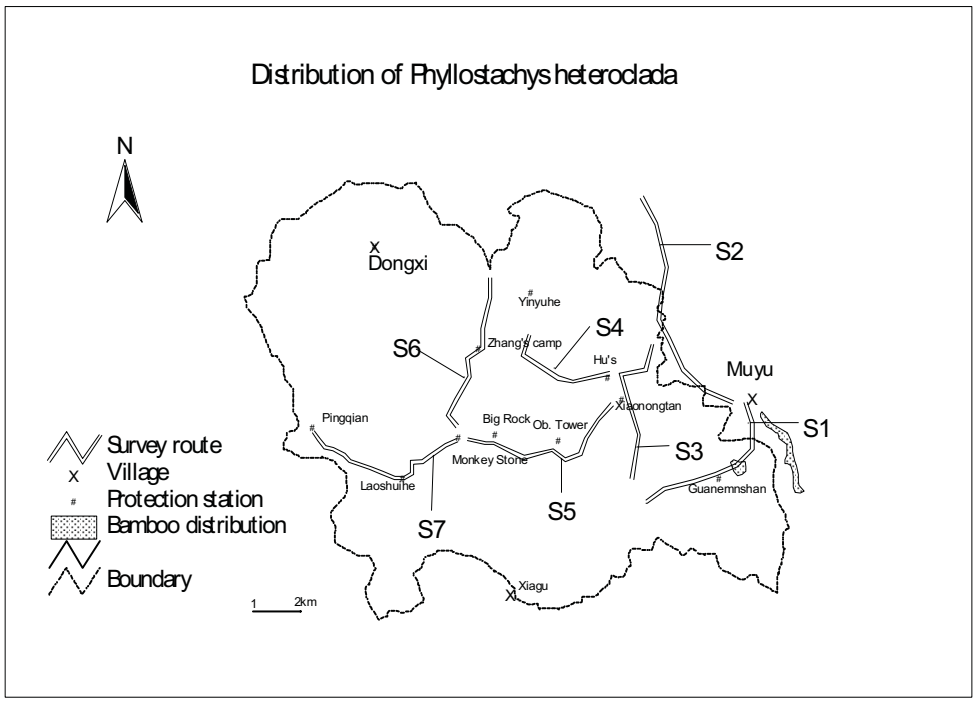

Figure 3.6: Distribution of *Phyllostachys nidularia*, native in Shennongjia.

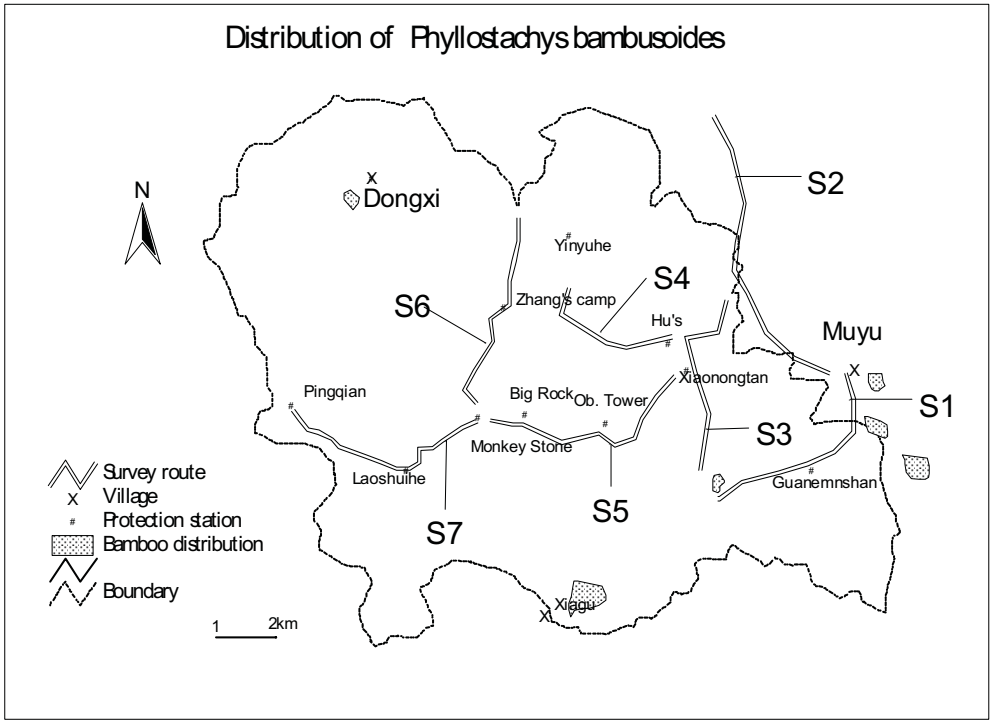

Figure 3.7: Distribution of *Phyllostachys bambusoides*, cultivated in Shennongjia.

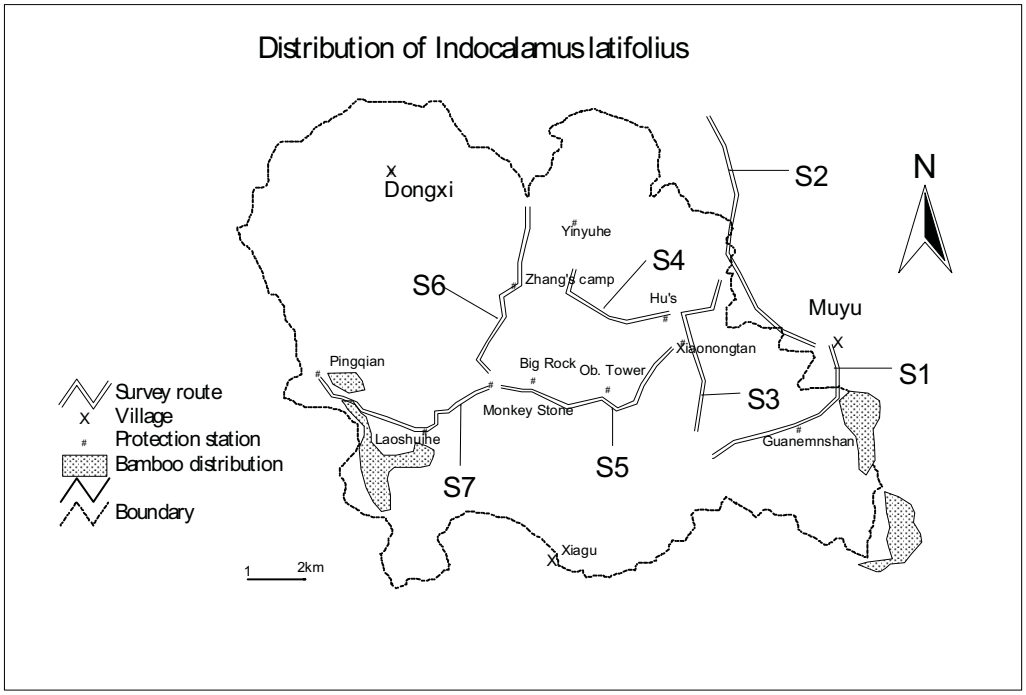

Figure 3.8: Distribution of *Indocalamus latifolius*, native in Shennongjia.

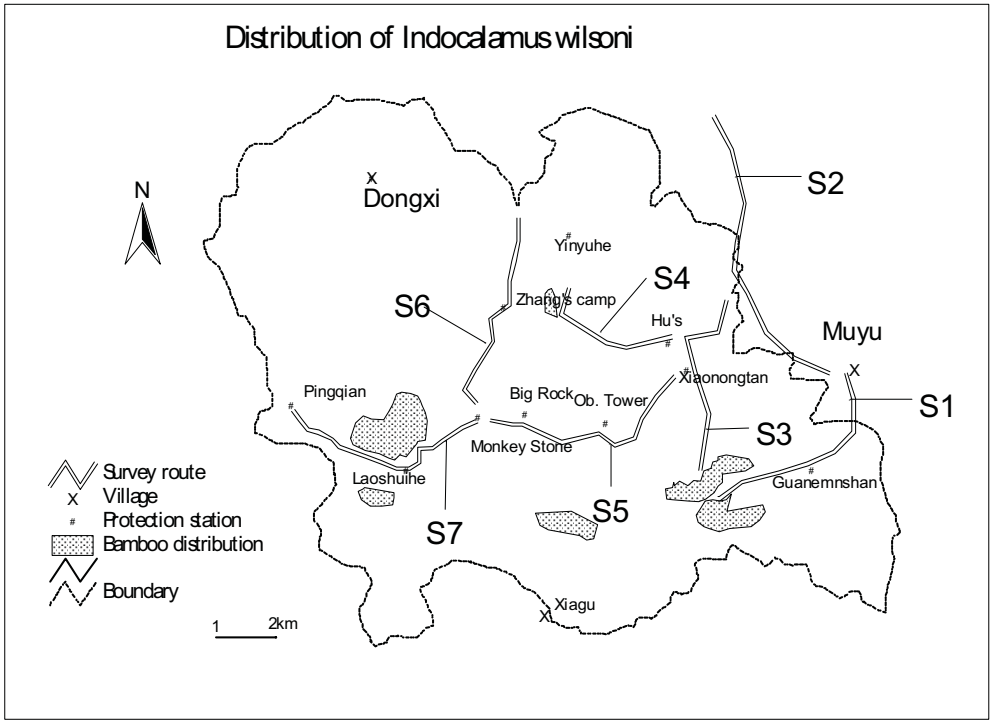

Figure 3.9: Distribution of *Indocalamus wilsoni,* native in Shennongjia.

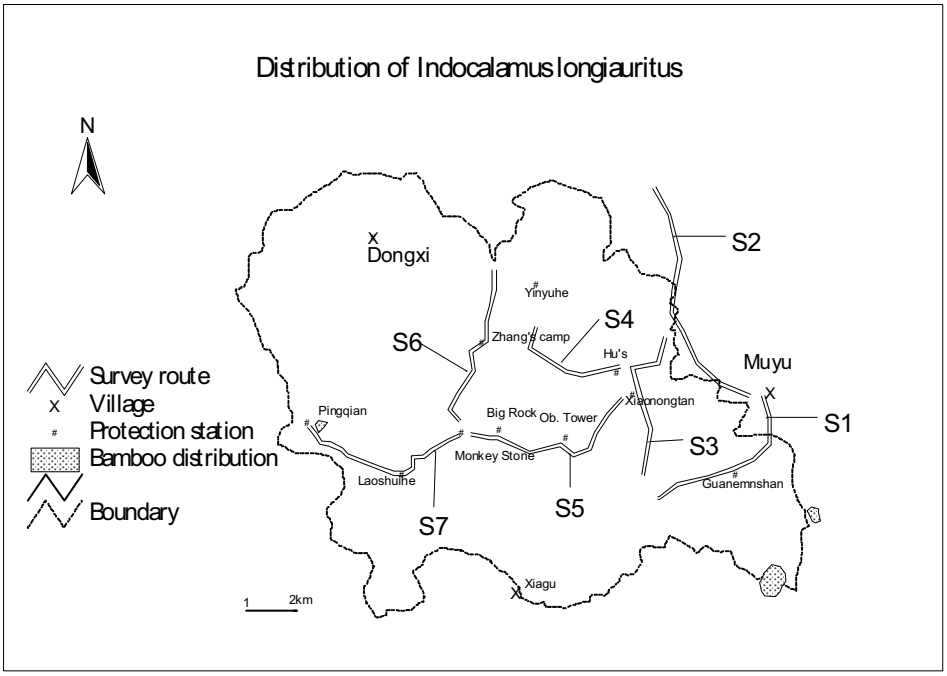

Figure 3.10: Distribution of *Indocalamus longiauritus*, native in Shennongjia.

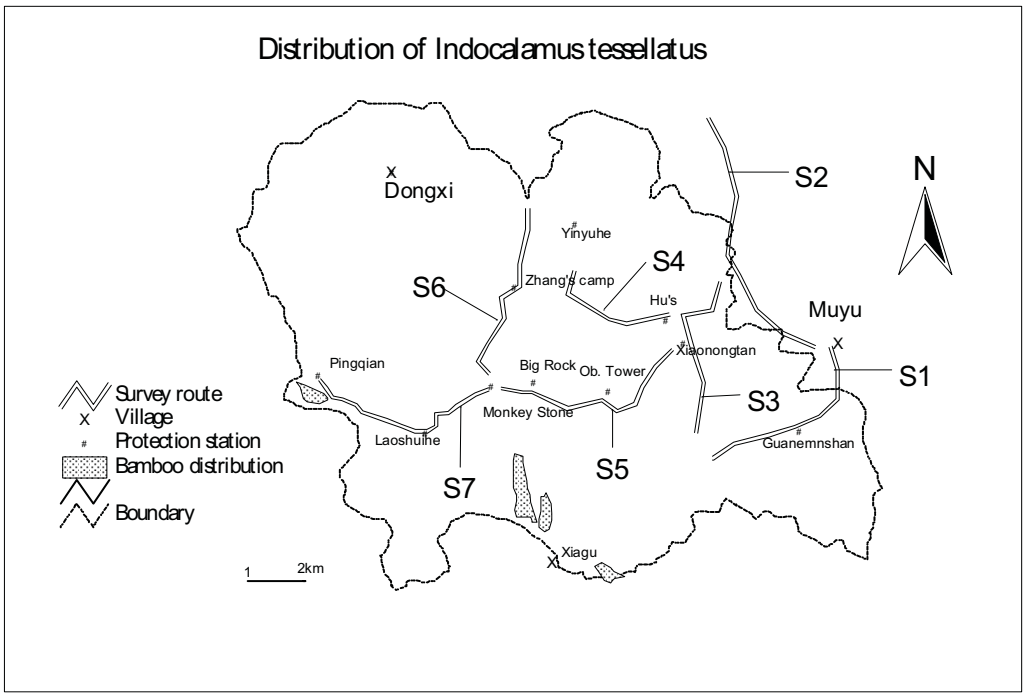

Figure 3.11: Distribution of *Indocalamus tessellatus*, native in Shennongjia.

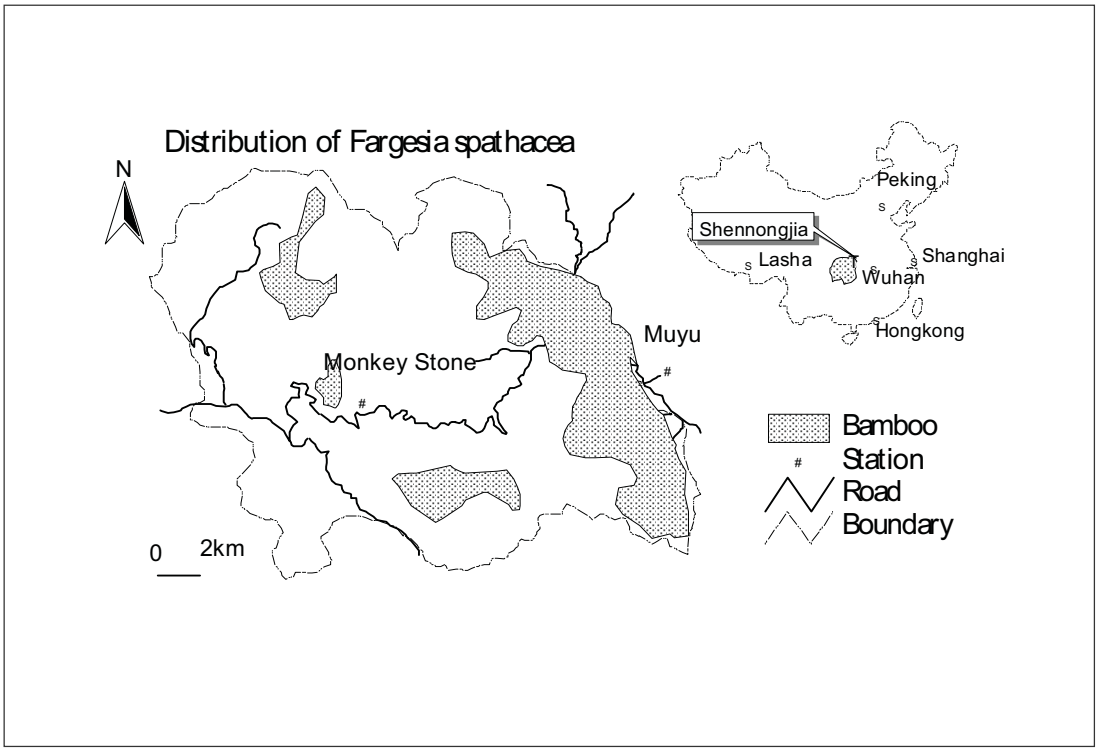

Figure 3.12: Distribution of *Fargesia spathacea*, native in Shennongjia.

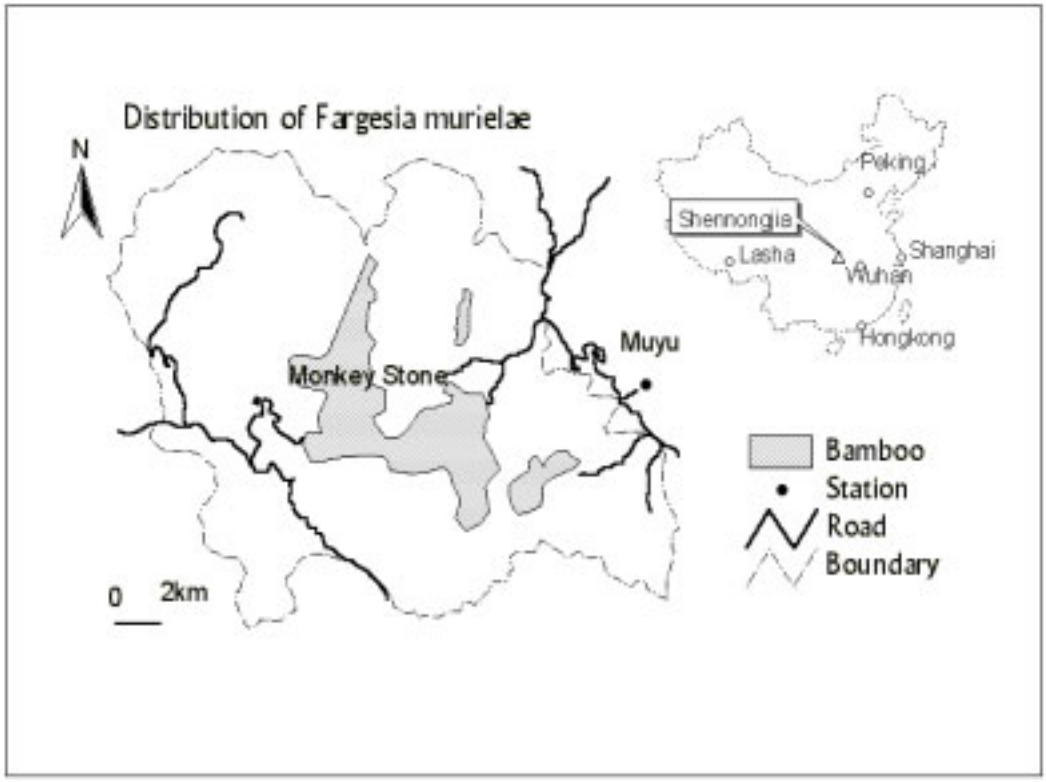

Figure 3.13: Distribution of *Fargesia murielae*, endemic to Shennongjia.

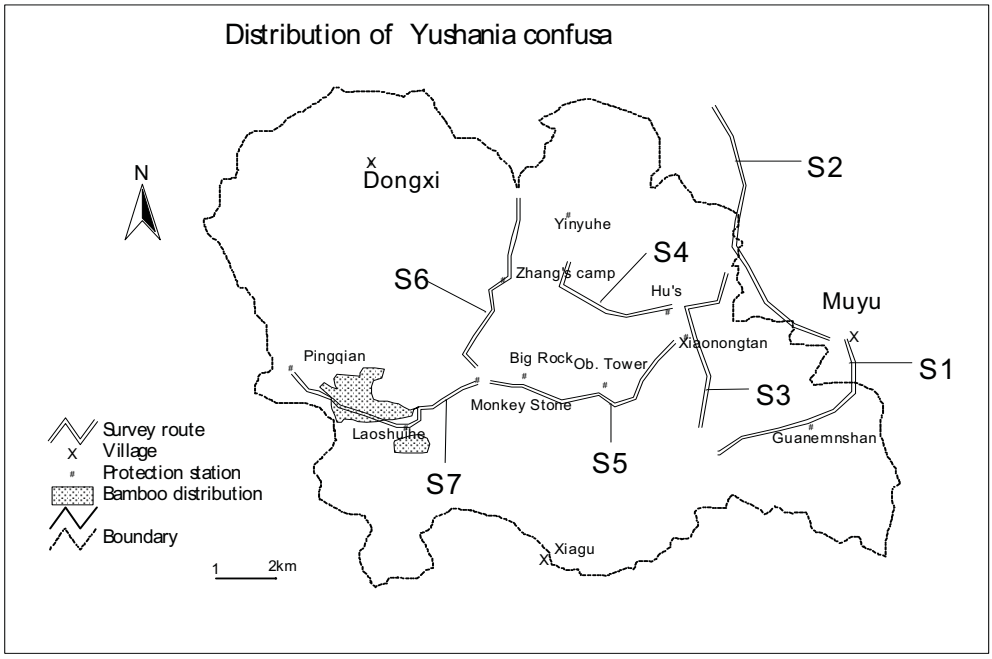

Figure 3.14: Distribution of *Yushania confusa*, native in Shennongjia.

4 VEGETATIVE GROWTH OF BAMBOO

Summary: A study was conducted in the Shennongjia National Nature Reserve (Shennongjia in brief), Central China, to assess the vegetative growth of three bamboo species: henon bamboo (*Phyllostachys nigra* var. *henonis* (Bean) Stapf. ex Rendle), tamale bamboo (*Indocalamus latifolius* (Keng) McClure), and arrow bamboo (*Fargesia spathacea* Franchet). Henon bamboo was selected to represent the growth pattern of the monopodial bamboos in Shennongjia. The studies on its vegetative growth were focused on sprouting, survival, and height growth of the new shoots. New shoots reached an average density of 2.7 ± 0.9 [± S.D.] shoots m^{-2} within a sprouting phase of 16 ± 2 days in 2001. The shoot emerging rate throughout the sprouting phase presented a slow-fast-slow sequence. An average of 31.8 ± 4.7 % of bamboo shoots died back before maturity. Insect damage, malnutrition death, and rodent predation were responsible for 57 %, 29 % and 14 % of total shoot mortality, respectively. New shoots reached an average height of 400 ± 23 cm in 34 ± 2 days. The daily growth varied from 1 to 56 cm with an average rate of 12.4 ± 0.9 cm day^{-1}. Height growth in cumulative percentage (*Ph*) during the vegetative period (*T*, in days) significantly ($P < 0.0001$) followed a logistic model: $Ph = 1 / (1 / 100 + 1.039 \times 0.779^T)$. Shoot production was positively related to the density of standing culms ($r = 0.938$, $P < 0.01$), but negatively to the coverage ($r = -0.458$) and height ($r = -0.904$) of herb layers.

Tamale bamboo is a small bamboo with giant leaves that represents the growth pattern of amphipodial bamboos. In seven plots at altitudes ranging from 510 m to 1,150 m asl, new shoots sprouted between late March and mid May, and reached an average density of 8 ± 2 newly sprouted shoots m^{-2} within a sprouting phase of 22 ± 3 days. Altitude has a significant influence on the beginning and end of the sprouting phase. The sprouting phase began 1.5 days later and ended 1.4 days later with each 100 m increase in altitude. A total of 17.9 % of the newly sprouted shoots died back before maturity; among these 56.4 % were damaged by insects and 16.2 % by rodents. Shoots grew to the full height of 191 ± 23 cm within 98 ± 3 days. The logistic model $Pt = 1 / (1 / 100 + 0.1978 \times 0.9303^T)$ describes significantly the relative accumulative growth of the new shoots during the first growing season. It is estimated that the annual economic potential of the leaves of *Indocalamus latifolius* may reach US$ 2,500 – 4,800 per

hectare, and a 0.3-hectare plantation can support a household by providing an income that is about average for the region.

Arrow bamboo is a medium-sized bamboo that represents the growth pattern of the sympodial bamboos. Investigations were conducted on the sprouting of new shoots along an altitudinal gradient from 1,200 to 2,600 m in Shennongjia. New shoots reached an average density of 9.9 ± 2.2 shoots m^{-2} within a sprouting phase of 25 ± 4 days. Elevation has a strong influence on the sprouting phase in terms of beginning, end and duration. The beginning of the sprouting phase was progressively delayed by 2.7 days with each 100 m increase in altitude, and the end delayed by 1.6 days correspondingly, which resulted in a shortening of the phase by 0.8 day 100 m^{-1}. The initial temperature for sprouting was around 8 ºC, although the arrow bamboo survives between -7.8 and 23.1 ºC.

The comparison of bamboo growth shows that bamboos with different rhizome types have different vegetative growth habits. In the Shennongjia region, shoots of monopodial bamboos usually emerge in late spring and early summer within a short sprouting phase, and the emerged shoots rapidly elongate and grow into the canopy of the stand, while clumping (sympodial and amphipodial) bamboos usually have a relatively long sprouting phase and height-growth period. Nevertheless, the environmental conditions such as temperature and rainfall may affect the starting and duration of the sprouting phase.

4.1 Introduction

Bamboo, as one of the most important minor forest products, provides food, raw material, shelter and even medicine for millions of people around the globe (Austin et al. 1983; Liese 1985, 1991, 2001; McClure 1993). In recent years, bamboos have gained increased attention as an alternative crop with multiple uses and benefits (Diver 2001; Liese 2001). However, the actual importance and the research efforts spent on bamboo are highly imbalanced compared with that of other agricultural crops (Gielis and Doves 2001; Liese 2001). For instance, knowledge of the growth, particularly of shoot sprouting and culm production, of bamboo species is important to assess the species that can be planted commercially. As yet, few species have been investigated.

The study on bamboo growth was conducted against the background that a number of mountain bamboos in Central and Western China are fed on by giant pandas. Bamboo comprises 99 % of the giant panda's diet (Schaller et al. 1985), but of more than 500 species of Chinese bamboos (Zhu et al. 1994; Keng and Wang 1996), the panda prefers only about 15 species (Campbell and Qin 1983; Yi 1985; Taylor et al. 1991; Carter et al. 1999). Most of these bamboos (e.g., *Fargesia spathacea*, *F. robusta, F. denudata* and *Bashania fangiana*) are monocarpic and flower simultaneously at estimated intervals of 30-100 years, depending on the species (Campbell and Qin 1983; Campbell 1987; Taylor et al. 1987, 1993). From the early 1970s to the mid 1980s, several bamboo species flowered simultaneously and died in panda habitats in West Sichuan, resulting in widespread starvation of giant pandas (Taylor et al. 1991). Consequently, the Chinese government proposed moving a number of starving giant pandas from Sichuan to one of the animal's historical habitats, Shennongjia, where bamboo supplies are plentiful and human impacts relatively low (Cui 1996). However, such a radical conservation program of reintroduction is a complex, risky, and multi-dimensional task (Reading et al. 1998). One essential aspect is the supply of food for the panda in the respective region (Schaller 1998), including the growth pattern of fresh shoots.

Since most of the bamboos are monocarpic and flower at intervals of 30-120 years (Janzen 1976), the sustainability and expansion of bamboo stands are mainly achieved through the yearly sprouting and subsequent growth of new shoots. The vegetative growth of new bamboo is in at least three successive phases, i.e., shoot sprouting, height growth, and branch spreading. The first phase starts with new shoots emerging from the ground. New shoots are produced annually mostly from the youngest rhizomes, thus developing near the culms of the previous year (Chaturvedi 1990; Dransfield and Widjaja 1995; Li et al 1998). This period is called the sprouting phase (or shooting season). The second phase is the height growth of the new shoots, i.e., emerged shoots elongate and grow to full height. During this phase, the internode length increases from the base towards the middle part of the new shoot and then further upwards (Liese 1985; Dransfield and Widjaja 1995). The third phase is the development of branches. This phase usually begins after the shoot has reached its full size. Most bamboos spread branches at the end of height growth during the first growing season

(e.g., *Phyllostachys* spp.), but others, especially the alpine bamboos such as *Fargesia nitida* (Mitford ex Stapf) Keng f. ex T. P. Yi and *Bashania fangiana* (A. Camus) Keng f. et Wen, produce the shoot in the first year and develop branches in the second year to avoid winter damage (Yi 1997). To enable a general understanding of the vegetative growth of the bamboos in Shennongjia, three species, namely henon bamboo (*Phyllostachys nigra* var. *henonis* (Bean) Stapf. ex Rendle), tamale bamboo (*Indocalamus latifolius* (Keng) McClure), and arrow bamboo (*Fargesia spathacea* Franchet) were selected for observing the recruitment and growth of new shoots during the growing season in 2001.

4.1.1 Overview of henon bamboo

Henon bamboo (*Ph. nigra* var. *henonis*) is a species native to China and of great economic importance (McClure 1966; Keng and Wang 1996). In China and Japan it has been widely cultivated for poles and edible shoots for more than a thousand years (Yi 1997; Zhu et al. 1994). Until the middle of the 18th century, it was the most common bamboo in Japan, and was introduced in the West by Dr. Henon in 1895 as an ornamental plant (Cao 1989; Bezona and Rauch 1997; Linvill et al. 2001). In recent years, small-scale growers in the USA have successfully created shoot-orientated plantations of henon bamboo (Lewis 1998; Miles et al. 2000), and its agroforestry use has also been proposed (Diver 2001).

In China, henon bamboo is one of the most common bamboos dominating in the mountainous areas in central and southern China, and is an alternative to *Phyllostachys pubescens* Mazel ex J. Houz., the most popular and useful bamboo in China, in higher elevations and/or northerly areas (Keng and Wang 1996). Henon bamboo differs from the original variety, black bamboo (*Phyllostachys nigra* (Lodd. ex Lindl.) Munro), in the culm, which never turns dark purple and is far taller and thicker. Mature culms of henon bamboo often reach more than 5 m, sometimes up to 10 m, and diameters at breast height (DBH) range from 2-6 cm. Culms are commonly used for handles of farm equipment, and as sunning poles, punt-poles and building material (Zhu et al. 1994). Strips from henon bamboo are pliable and tough and good for weaving (Yi 1997), and the shoots are edible. Each year, mainly in autumn and winter, most old culms (> 5 years) are selectively harvested. New shoots, tightly wrapped with brown

sheaths, emerge annually from lateral buds on rhizomes that are below the ground surface at a depth of about 0-30 cm.

In Shennongjia, henon bamboo is one of the most widely cultivated bamboos (Ban 1995). It was selected for this study for the following reasons: 1) It is the largest bamboo in the study area; 2) It is the most important cash-bamboo in the region that produces both poles and edible shoots; 3) It represents the growth behavior of the monopodial bamboo in the study.

4.1.2 Overview of tamale bamboo

Leaves of the tamale bamboo (*Indocalamus latifolius*) have been used for wrapping Chinese tamales for more than 2,000 years (Zhu et al. 1994; Xiao et al. 1999). Chinese tamales consist of sticky rice with strongly spiced, finely-chopped pork, chicken, beef or vegetable, which is wrapped in bamboo leaves for steaming and serving. The Chinese, Japanese and Vietnamese traditionally eat tamales during the Dragon Boat Festival at the beginning of May on the lunar calendar to memorize the Chinese poet Quyuan (340 – 278 B.C.). However, with more than 100 varieties, Chinese tamales are becoming an all-year popular food all over China and other Asian countries. Moreover, biochemical analyses have shown that the leaves of *Indocalamus* bamboo contain not only a considerable amount of nutritional components such as carbohydrates, amino acids, vitamins, and mineral nutrients (Lai and Ma 1995), but also 47 volatile substances, including 12 aldehydes and 8 carboxylic acid compounds, which can serve as additives for the food industry (Wang and Mao 2001). Benefiting from its nutrients and fragrance, a large variety of *Indocalamus* bamboo-based products such as bamboo juice, bamboo beer and bamboo fragrant rice have been developed in China (Wu and Wu 1998).

There are 22 bamboo species and 6 varieties in the genus of *Indocalamus* Nakai in China (Keng and Wang 1996), but only few species such as *I. latifolius*, *I. tessellates* (Munro) Keng f., and *I. longiauritus* Hand.–Mazz. produce leaves longer than 25 cm that are large enough for wrapping tamales. The rapidly increasing demand for wrapping leaves provides income opportunities for Chinese farmers. However, so far there is no *Indocalamus* under cultivation (Ma 2001) and the leaves have to be collected from natural bamboo stands. For example, in Shangzhi, a mountainous county

in southern China, in 1993 there were about 1,330 ha of undisturbed natural *Indocalamus* stands. But since then, with the expanding market, over 5,000 tons (dry weight) of bamboo leaves have been harvested from these natural stands, and a local export company is at present recruiting about 2,000 field workers for collecting and processing the bamboo leaves. Facing this situation, the increasing demand may lead to the degradation and loss of natural *Indocalamus* stands, unless plantations are established to meet the needs of the expanding market.

Indocalamus latifolius is the most popular tamale-wrapping bamboo in Central China. It has a high potential to be cultivated either as an intensive crop or as small clumps in house gardens, along riverbanks or field boundaries. Bamboo clumps usually occur in two different forms due to the respective rhizome types (Liese 1985; Janssen 1991): either as single-stemmed culms apart from each other (monopodial rhizome system, such as *Phyllostachys* spp.) or as dense clumps (sympodial rhizome system, such as *Fargesia* spp.). *Indocalamus latifolius*, however, has an amphipodial rhizome system with both continuous leptomorph and congested pachymorph rhizomes. This mixed underground system gives *I. latifolius* the flexible ability to either rapidly occupy an open habitat by spreading rhizomes or to tightly hold a suitable niche with congested rhizomes.

Before contemplating the cultivation of any natural bamboo species, it is essential to understand its growth behavior. However, so far little is known about *Indocalamus* species (Ma 2001). Tamale bamboo was selected for this study for the following reasons: 1) It has a high potential to be cultivated as a new bamboo crop in China; 2) It is one of small bamboos in the study area; 3) It is distributed in low mountains; 4) It represents the growth behavior of amphipodial bamboos in the study.

4.1.3 Overview of arrow bamboo

Arrow bamboo (*Fargesia spathacea*) is a mountain bamboo native to Central China (Keng and Wang 1996). It was introduced to Europe and the United States as an ornamental plant in the late 19th century (Bezona and Rauch 1997; Judziewicz et al. 1999). Culms of *F. spathacea* are erect, unbranched, and, on average, 3-4 m in height. Its rhizome is a bulb-shaped pachymorph with short and compact internodes. The tip of the rhizome is thicker and often oriented upward from where the bamboo culm arises,

being thinner than the bulb. Each year a rhizome can produce one culm in spring and two new rhizome buds in autumn. This rhizome system connects emerging shoots and adjacent culms to form a dense bamboo clump. In Shennongjia, *F. spathacea* is a common species occurring between 1,200 and 2,600 m, forming a dense understorey of the forests.

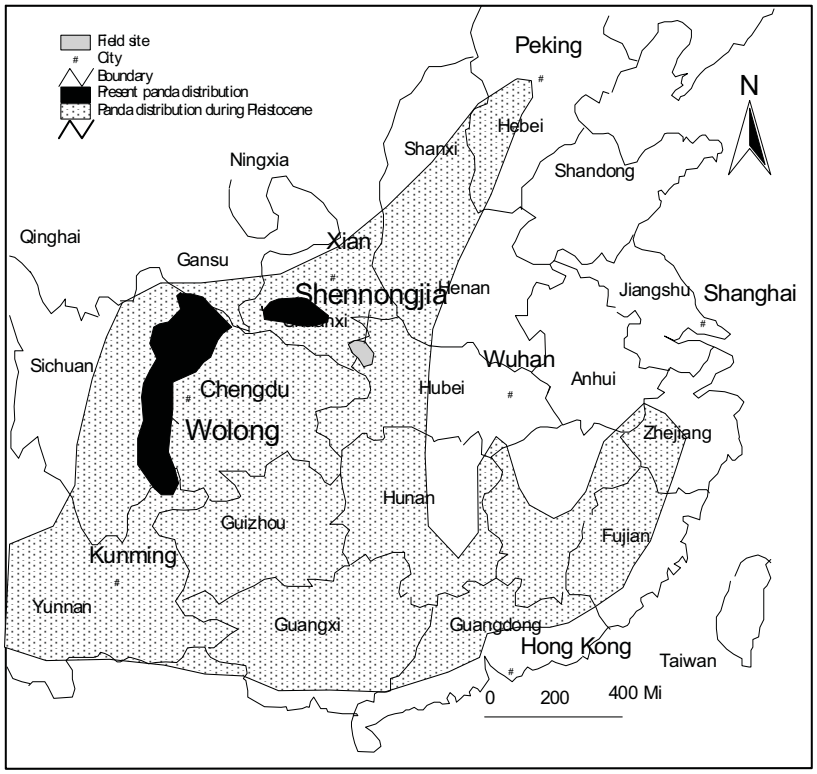

Figure 4.1: Distribution of the giant panda habitats and location of Shennongjia in China.

Until the early 19th century, giant pandas were to be found in the Shennongjia region (Loucks et al. 2001; Li and Denich 2001). There are 11 species of mountain bamboos in Shennongjia, but of these, only three species, i.e., arrow bamboo (*F. spathacea*), umbrella bamboo (*Fargesia murielae* (Gamble) Yi), and *Yushania confusa* (McClure) Z.P. Wang et G. H. Ye are favored by the giant panda, according to the list of panda bamboos (Yi 1985). Previous researches in panda habitats on the Qionglai Mountains reported the phonology and biology of several bamboo species including one species under the name of *F. spathacea* (i.e., Campbell and Qin 1983; Schaller et al. 1985; Taylor and Qin 1987; Reid and Hu 1991). However, there is a

considerable taxonomic confusion over the mountain bamboos in China (Campbell 1991; Keng 1987). Recent taxonomic researches show that *Fargesia spathacea* Franchet is endemic only to Western Hubei, Southern Shaanxi, and Eastern Sichuan, with Shennongjia as the distribution center; the taxon on the Qionglai Mountains in Western Sichuan is a different species - *Fargesia robusta* Yi (Keng and Wang 1996; Yi 1997). On the other hand, Shennongjia is over 1,000 km east of the Qionglai Mountains, which makes it doubtful whether the existing data can be cited for assessing the food availability, even if it is the same species.

Arrow bamboo was selected for the study for the following reasons: 1) It was the staple food of the giant panda in the study area, so the sprouting pattern of bamboo shoots along an altitudinal gradient was studied for predicting the food supply for a possible giant panda population; 2) It is distributed in higher mountains (1,200-2,600 m); 3) It is of medium size compared with henon bamboo (larger) and tamale bamboo (smaller); 4) It represents the growth behavior of sympodial bamboos in the study.

4.2 Material and methods

4.2.1 Field sites

The study on henon bamboo was carried out between March and August 2001 within a 0.25 ha semi-wild henon bamboo stand (N31º28'762", E110º23'127", alt. 1,290-1,310 m asl) near the town of Muyu (Plot H1, Table 4.1). The local climate in this area is warm-temperate with warm, rainy summers and cool, dry winters. The mean annual temperature is 11.2 ºC, with a monthly maximum of 22.8 ºC in July and a monthly minimum of 0.7 ºC in January. Annual precipitation is about 1,150 mm, with 86 % of rainfall during the growing season from April to October (Zhu and Song 1999). The bamboo grove is located on a gentle south-facing slope. A soil profile from the bamboo stand shows that the organic fraction of horizon Ao (0-4 cm) was dominated by bamboo leaves (> 70 %). Horizon A (4-18 cm) was formed by grayish-yellow loam with moderate acidity (pH 6.0), while horizon B (18-45 cm) consisted of a more acid (pH 5.5) clayey-loam, purplish-yellow in color. Horizon BC occurred below 45 cm and was reddish-yellow in color.

The study on tamale bamboo was carried out in seven altitudinal plots (Plot T1-7, Table 4.1). In Shennongjia, *Indocalamus latifolius* naturally occurs at altitudes

from 500-1,240 m, where the average annual temperature declines from 14.5 ºC to 10.2 ºC along the altitudinal gradient, while the mean annual precipitation increases from about 900-1,300 mm. For regular observation of shoot sprouting and dieback, three permanent plots (T1, T2, T3) and four temporary 2×2 m^2 plots (T4, T5, T6, T7) were set up in early March of 2001 (Table 4.1).

Table 4.1: Bamboo plots in Shennongjia, Central China.

Plot	Size (m^2)	Altitude (m)	Latitude (N)	Longitude (E)	Density (culms m^{-2})	Associated vegetation
Henon bamboo (*Phyllostachys nigra* var. *henonis*) plot						
H1	5×10	1,260	31º 28.762'	110º 23.127'	7	Bamboo forest
Tamale bamboo (*Indocalamus latifolius*) plots						
T1	10	1,150	31º26.849'	110º25.006'	71	Riverside farm field
T2	15	810	31º23.674'	110º28.790'	33	Disturbed forest
T3	10	510	31º23.831'	110º33.409'	48	Broadleaved forest
T4	2×2	600	31º21.831'	110º33.409'	42	Disturbed forest
T5	2×2	720	31º21.682'	110º36.110'	80	Riverside grassland
T6	2×2	890	31º27.031'	110º25.904'	52	Broad leaved forest
T7	2×2	1,050	31º27.243'	110º24.362'	64	Broad leaved forest
Arrow bamboo (*Fargesia spathacea*) plots						
A1	2×2	1,230	31º 26.502'	110º 24.316'	47	Broad-leaved forest
A2	4×2	1,350	31º 26.183'	110º 24.220'	77	Broad-leaved forest
A3	2×2	1,420	31º 26.023'	110º 24.247'	53	Mixed forest
A4	4×2	1,510	31º 26.541'	110º 24.260'	69	Broad-leaved forest
A5	4×2	1,640	31º 28.674'	110º 22.490'	73	Broad-leaved forest
A6	4×2	1,750	31º 31.583'	110º 20.167'	65	Mixed conifer forest
A7	2×2	1,870	31º 30.583'	110º 20.596'	77	Mixed conifer forest
A8	4×2	2,050	31º 29.453'	110º 21.367'	82	Broad-leaved forest
A9	4×2	2,230	31º 28.082'	110º 17.639'	88	Open shrubs
A10	2×2	2,530	31º 27.403'	110º 11.603'	64	Mountain meadow

The study on arrow bamboo was carried out in ten altitudinal plots (Plot A1-10, Table 4.1). The plots were set up to cover the altitudinal range of *F. spathacea* from the lowest elevation (1,200 m) up to highest limitation (2,600 m) in early March of 2001.

As far as possible, I chose sites with a similar bamboo structure (i.e., culm density, culm height, and upper canopy cover), although in some cases this was impossible due to the variation of the associated vegetation and topographical conditions.

The location of the plots, including longitude, latitude, and altitude was measured by GPS receptor. The associated vegetation was classified into community types following Ban et al. (1995). Community features such as bamboo density were measured and the canopy cover was estimated.

4.2.2 Data collection

During the sprouting phase in 2001, shoot emergence was monitored in all plots in two-day intervals on the tamale bamboo and arrow bamboo plots and daily on the henon bamboo plot. Shoots were considered sprouted when they were higher than 3 cm. The individual shoot was tagged and its emerging date, initial height, and base diameter were recorded. Shoot survival was continuously monitored in the permanent plots (H1, T1, T2, T3, A1) beyond the sprouting phase. Three criteria were established to classify the dieback reasons: (1) damage by animals (rodents), (2) damage by insects, and (3) unknown reason (i.e. death caused by malnutrition or/and virus).

The growth measurements were carried out in Plot H1 for henon bamboo and Plot T1 for tamale bamboo. For each species, ten shoots were selected and their height growth was measured daily from the shoot emergence until full height. Measurement of the henon bamboo was carried at about 8.00 a.m. from 10 May to 10 July, while the tamale bamboo was measured at around 6.00 p.m. from 12 April to 20 July. Measurement of height growth on arrow bamboo was not consistent as the sample shoots (in Plot A1) were destroyed or eaten by wild boars and monkeys during the observation period.

To illustrate the relationship between parent culms and the new shoots, a community investigation was conducted on henon bamboo in Plot H1, where five 2×5 m^2 quadrats were established in the bamboo stand in early March 2001. The bamboo features in terms of culm density, culm height, culm DBH, number of culm nodes, and culm age were measured in each plot in March. Height and coverage of the herb layer under the bamboo were measured in late April when the herbs were well developed.

These community features were used to predict the influence of the parent culms on the recruitment of new shoots in the bamboo stands.

Additionally, to demonstrate the economic potentials of tamale bamboo, leaf production was measured in Plot T2 within a 1 × 1 m^2 quadrat. All bamboo culms with leaves were harvested in late August. The culms were classified according to their age (i.e., 1-year-old culms, 2-year-old culms, 3-year-old and older culms), and the respective leaves were classified as new leaves (leaves of the current year) or mature leaves. To compare the sprouting habits of the bamboos in Shennongjia, a phenological observation was additionally carried out for three species: *Phyllostachys heteroclada*, *Yushania confusa,* and *Fargesia murielae*. Their sprouting phases were recorded as starting day, end day, and the shoot density at the end of the phase.

4.2.3 Data analysis

Sprouting on the time scale was expressed as both daily emergence and cumulative emergence of bamboo shoots. A logistic model was adapted to describe cumulative sprouting. In the logistic model, the upper boundary is replaced by the maximum relative number of sprouting, i.e., 100 %. The model is as follows: $S = 1 / [1 / 100 + a \times b^T]$, where S is the relative percentage of cumulative sprouting; a and b are fitted parameters; and T is the time expressed in days.

Temporal sprouting was analyzed by means of linear regression to assess the variation of the sprouting phase at different altitudes. In this analysis, the starting day, ending day and duration of the sprouting phase, respectively, were related to the altitude. The starting day and ending day in the plot at the lowest altitude (Plot T3 for tamale bamboo, 510 m; Plot A1 for arrow bamboo, 1,230 m) were defined as reference days to which the phenological observations from the other plots were related.

Linear models were adapted to determine the relationship between shoot thickness (base diameter) and shoot emerging time, as well as the relationship between base diameter of the shoot in spring and height of the culm in autumn. The model is as follows: $Y = a + bX$, where a and b are fitted parameters, Y and X indicate different variables in different cases. These analyses were only carried out for henon bamboo.

The height growth was expressed relative to the final height recorded in the field. The cumulative growth was described by the logistic model: $P = 1 / [1 / 100 + a \times$

b^T], where *P* indicates the relative cumulative height (%). Pair samples analysis was used to test the effects of bamboo community features on shoot production and shoot survival. All calculations were carried out with SPSS for Windows 10.0.

Table 4.2: Community features of henon bamboo (*Phyllostachys nigra* var. *henonis*) in Shennongjia, Central China. Features were measured in March 2001, except for the coverage and height of ground herbs, which were measured in late April when the plants were well developed. Each plot covers an area of 10 m^2.

	Plot A	Plot B	Plot C	Plot D	Plot E	Mean ± S.D.
Age structure						
Culms	69	103	43	64	89	74±23
1-year culms	11	22	9	14	29	17 ± 8
2-year culms	23	21	14	19	20	19 ± 3
3-year culms	18	33	11	20	26	22 ± 8
4- + year culms	17	27	9	11	14	16 ± 7
Culm feature						
Mean height (m)	3.7	4.1	3.2	5.2	4.4	4.1 ± 0.7
Base cover (%)	0.2	0.3	0.04	0.2	0.2	0.2 ± 0.1
Mean DBH (mm)	14.1	15.7	10.1	15.8	14.5	14.0 ± 2.3
Mean nodes	25.0	24.0	18.0	26.0	25.0	23.6 ± 3.2
Herb layer						
Coverage (%)	7.0	21.0	34.0	23.0	20.0	21.0 ± 9.6
Height (cm)	15.0	10.0	20.0	15.0	10.0	14.0 ± 4.2

4.3 Results

4.3.1 Results of henon bamboo study

The henon bamboo in the study site was planted 45 years ago. Management only consisted of annual shoot harvesting and pole cutting, which results in a semi-natural community. The bamboo culms were 4.1 ± 0.7 [± S.D.] m high and 14 ± 2 mm thick (DBH). The vertical structure of the bamboo community was quite simple: pure bamboo as the upper canopy and herbs as the ground layer. The bamboo layer was 3-5 m high and covered 80-100 % of the stand, with an average density of 7.4 ± 2.3 culms m^{-2}. The herb layer was relatively weak and covered only 7-35 % of the ground. Community features and age structure of bamboo culms in each plot are presented in Table 4.2.

In five 2×5 m^2 quadrats of Plot H1, a total of 137 bamboo shoots sprouted from 9 to 27 May (Figure 4.2). The sprouting phase lasted 16 ± 2 days, and shoots reached a density of 2.7 ± 0.9 shoots m^{-2} at the end of the sprouting phase. Daily emergence of new shoots was not even through the sprouting phase, but significantly followed a Normal distribution with a single peak (mean = 7.21, S.D. = 5.85, *d.f.* = 18, t = 5.37, $P < 0.001$).

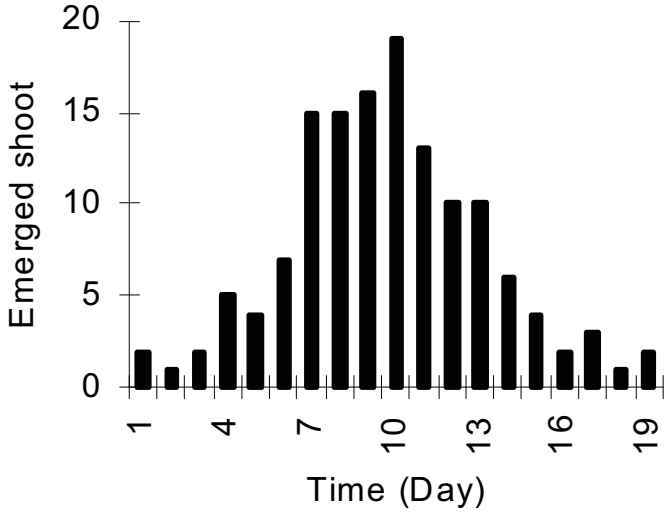

Figure 4.2: Daily sprouting of henon bamboo (*Phyllostachys nigra* var. *henonis*) during the sprouting phase in 2001 in Shennongjia, Central China. Sprouting rate through the time significantly ($P < 0.001$) follows a Normal distribution pattern (n = 19, mean = 7.21, S.D. = 5.85).

The sprouting process can be roughly divided into three successive stages: initial phase (a period with a sprouting rate lower than the mean value at the beginning), full phase (a period with a sprouting rate higher than the mean value), and final phase (a period with a sprouting rate lower than the mean value at the end). The initial phase lasted 6 days (9-14 May) and contributed 15.3 % of the newly emerged shoots; the full phase lasted 7 days (15–21 May) and contributed 71.5 %; the final phase lasted 6 days (22-27 May) and contributed 13.1 %. Percentage cumulative sprouting was significant ($P < 0.001$) following a logistic model (Figure 4.3): $S = 1 \div (1 / 100 + 1.62 \times 0.5679^{T})$ ($r^2 = 0.920$, F-value = 195.58, $P = 0.000$).

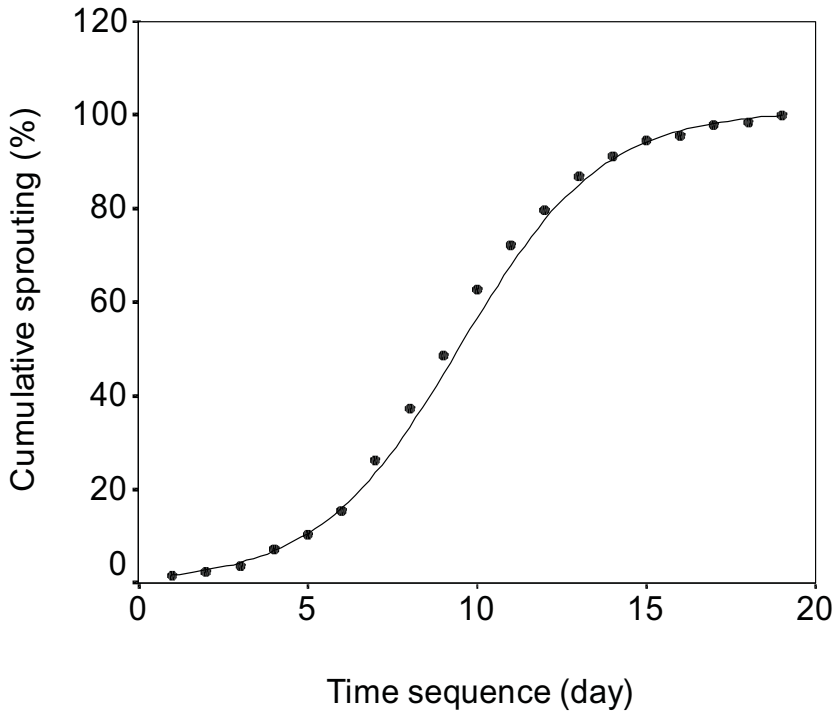

Figure 4.3: Percentage cumulative sprouting of henon bamboo (*Phyllostachys nigra* var. *henonis*) during the sprouting phase in 2001 in Shennongjia, Central China. Logistic model $S = 1 / (1 / 100 + 1.62 \times 0.5679^{T})$ can significantly describe this sprouting process ($r^2 = 0.920$, F-value = 195.58, $P = 0.000$).

The shoot diameter (i.e., base diameter) was strongly ($r = -0.938$, $P < 0.001$) related to its emerging date (Figure 4.4). The early shoots were usually thicker than the later ones. This relationship can be described by a linear model: $Y = 25.58 - 0.6565X$ ($P < 0.001$), where Y indicates the base diameter of the shoot in mm and X its emerging day with the first sprouting day of the stand = 1. This might imply that the bigger buds had gathered more nutrients from the rhizomes before they emerged, so that during the sprouting phase they could grow more quickly than the small ones. The thickness of bamboo shoots in spring significantly ($r = 0.902$, $P < 0.001$) determines the height of new culms in autumn (Figure 4.5). The relationship followed a linear equation: $Y = 164.51 + 11.08X$ ($d.f = 39$, F-value = 119.10, $P < 0.001$), where Y indicates the height of new culms in cm in autumn and X the base diameter of shoots in mm in spring.

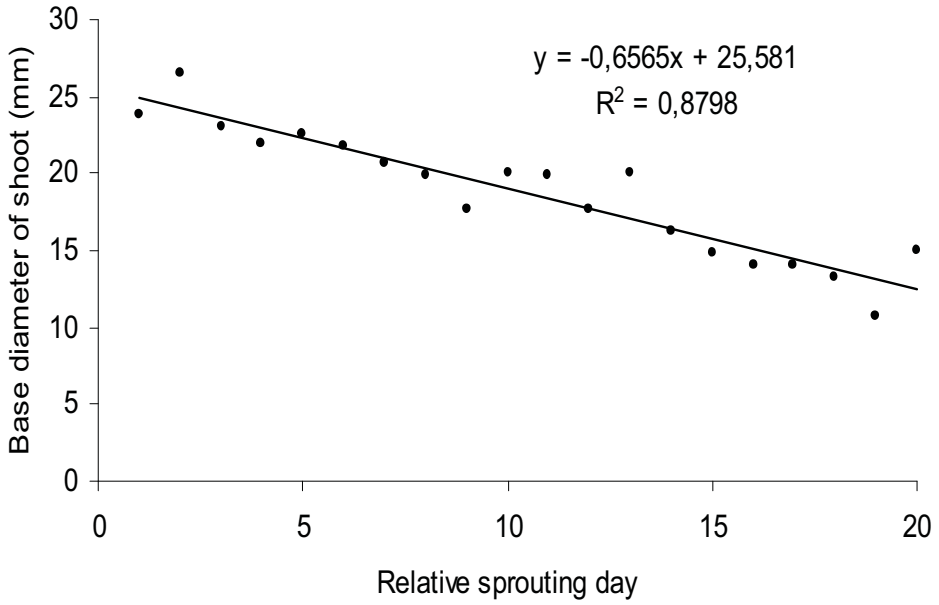

Figure 4.4: Relationship between base diameter and emerging day of shoot of henon bamboo (*Phyllostachys nigra* var. *henonis*) in Shennongjia, Central China. In the equation, *Y* indicates base diameter and *X* indicates underlying sprouting day (*d.f.* = 17, *F*-value = 153.18, $P < 0.001$).

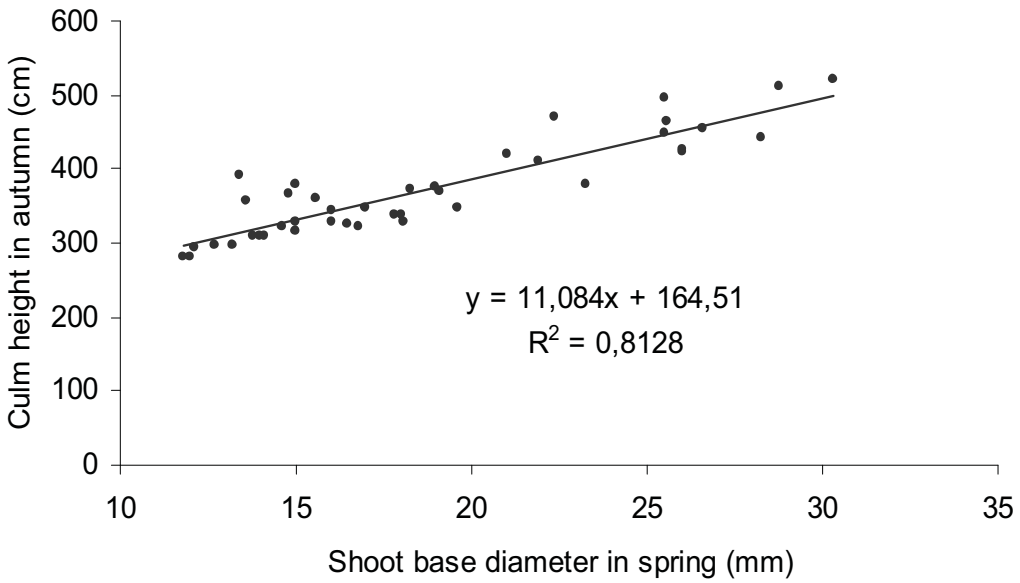

Figure 4.5: Relationship between base diameter of henon bamboo in spring and culm height in autumn in Shennongjia, Central China. In the equation, *Y* indicates culm height and *X* indicates shoot base diameter (*d.f.* = 39, *F*-value = 119.10, $P < 0.001$).

Table 4.3: Emergence and survival of new shoots of henon bamboo (*Phyllostachys nigra* var. *henonis*) in Shennongjia, Central China during the vegetative season of 2001.

Plot	A	B	C	D	E	Total	Mean±S.D.
Plot area (m²)	10	10	10	10	10	50	10.0
New shoot number	28	37	18	19	35	137	27.4±8.8
Shoots lost number	9	11	7	6	9	42	8.4±2.0
Insect damage	5	6	5	4	4	24	4.8±0.8
Malnutrition	3	2	2	0	5	12	2.4±1.8
Rodent predation	1	3	0	2	0	6	1.2±1.3
Survival rate %	68	70	61	68	74	69	68.2±4.7

The survival rate of new shoots did not differ significantly between the plots; it was around 64 ± 5.4 % (Table 4.3). Insect damage, malnutrition death, and rodent predation were responsible for 57 %, 29 % and 14 % of the total shoot loss, respectively. The new shoots were mostly susceptible to rodents during the first two weeks, and to insects (weevils) during the first six weeks. Malnutrition death mainly occurred over the shoots that emerged during the final sprouting phase. The thinner shoots had a higher mortality rate. The mortality rate of shoots with a base diameter below 16 mm was 56.4 %, while that of shoots with a base diameter above 18 mm was 19.5 %.

The shoots reached an average height of 400 ± 23 cm (n = 40) in 34.4 ± 2.0 days (n = 10). The daily growth varied from 1 to 56 cm day^{-1} with an average growth rate (AGR) of 12.4 ± 0.9 cm day^{-1}. Observations show that height growth presented a slow-fast-slow sequence, which was identified by plotting AGR against time during the growing season. The initial slow-growth phase lasted 10 ± 1 days with AGR of 5.02 ± 0.63 cm day^{-1}. Thereafter, growth accelerated to a fast phase, which lasted 21 ± 2 days with AGR of 20.87 ± 2.07 cm day^{-1}. At the end of the fast-growth phase, culm sheaths at the base nodes began to fall and branches started to spread, which made growth slow down. The final slow-growth phase lasted 8 ± 2 days with AGR of 5.12 ± 1.05 cm day^{-1}. The relative cumulative growth of bamboo shoots followed a logistic model: $Ph = 1 / (1 / 100 + 1.039 \times 0.779^{T})$, where Ph indicates the percentage of cumulative height of henon bamboo and T indicates the time in days (r^2 = 0.993, $d.f.$ = 34, F-value = 4685, P < 0.001, Figure 4.6). When all culm sheaths have fallen and all branches have unfolded

their leaves, the new culm has developed. Thereafter, height, diameter and volume of the culms are stable and do not change noticeably.

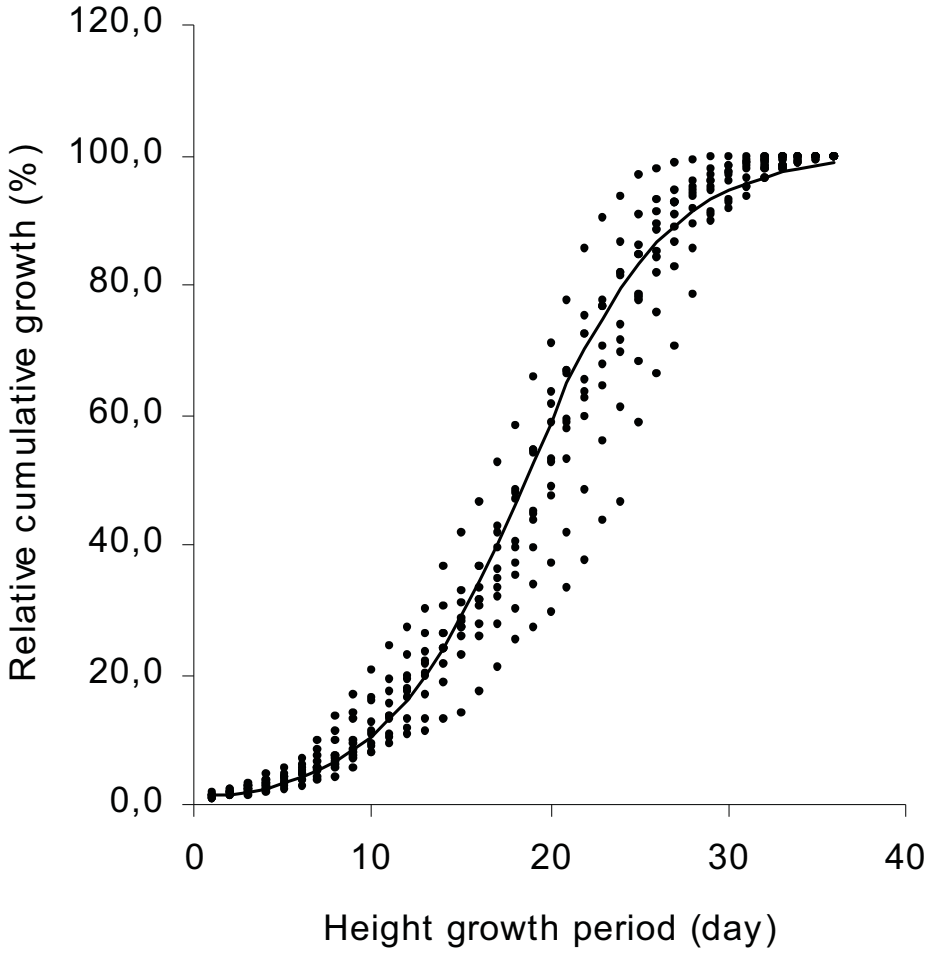

Figure 4.6: Percentage accumulative growth of henon bamboo from shoot emergence till full height of young culm. In the model, $Ph = 1 / (1 / 100 + 1.039 \times 0.779^{T})$, *Ph* indicates the percentage cumulative growth of bamboo shoot and T the time in days ($r^2 = 0.993$, *d.f.* = 34, *F*-value = 4685, $P < 0.001$)

4.3.2 Results of tamale bamboo study

Distribution and growth of *Indocalamus latifolius* were strongly affected by the associated vegetation and the underlying site conditions. Bamboo clumps occurring in undisturbed broadleaved forests usually cover several hectares forming a dense understorey, while the clumps occurring in disturbed sites were usually observed as small patches covering 8 to 106 m^2 ($n = 15$).

Shoots of *I. latifolius* sprouted from late March to mid May. In the seven study plots, the average duration of the sprouting phase was 22 ± 3 days. Altitude had a significant influence on beginning, end and duration of the sprouting phase (Table 4.4). Linear regressions show that the sprouting phase tends to begin 1.5 days later, relative to the onset of the sprouting phase at the lowest plot, with each 100 m increase in altitude. Correspondingly, the end of the sprouting phase was postponed by 1.4 days.

Table 4.4: Linear regression and correlation between altitude (*X*, 100 m) and beginning (*Y*1), end (*Y*2) and duration (*Y*3) of the sprouting phase of *Indocalamus latifolius* along an altitudinal gradient from 500 – 1,200 m in Shennongjia, Central China (*** = P < 0.001 and * = P < 0.05).

	Fitted equation	d.f.	F-value	R^2	P
Beginning	Y1 = -6.084 + 1.466X	1,6	429.091	0.994	***
End	Y2 = -6.598 + 1.39X	1,6	115.998	0.979	***
Duration	Y3 = 29.785 – 0.77X	1,6	7.617	0.777	*

Table 4.5: Shoot emergence during the sprouting phases of *Indocalamus latifolius* in Shennongjia, Central China.

Plot	Duration (days)	Shoot (Shoots m^{-2})	Mean (Shoot day^{-1})	Initial phase		Full phase		Final phase	
				Day	Sprouting	Day	Sprouting	Day	Sprouting
1	21	9.7	0.46	5	8%	8	80%	8	11%
2	25	8.3	0.33	7	15%	12	71%	6	14%
3	23	8.5	0.37	5	9%	12	79%	6	12%

Table 4.6: Dieback of bamboo shoots during the vegetative period of *Indocalamus latifolius* in Shennongjia, Central China (*n* = number of lost shoots; % = number of lost shoots relative to total number of sprouted shoots per plot).

	Plot T1		Plot T2		Plot T3		Total	
	n	%	n	%	n	%	n	%
Insects	6	6.2	10	8.0	15	17.6	31	10.1
Rodents	3	3.1	0	0	6	7.1	9	2.9
Others	5	5.2	7	5.6	3	3.5	15	4.9
Total	14	14.4	17	13.6	24	28.2	55	17.9

At the end of the sprouting phase, the density of newly sprouted culms reached 8 ± 2 shoots m^{-2}, but the sprouting rate was not uniform through the time. The temporal variation of the sprouting rate was found to follow a normal distribution (Figure 4.7).

Accordingly, the sprouting process can be divided into three successive phases: one phase (full phase) in the mid-sprouting phase with a sprouting rate (expressed as shoots day^{-1}) higher than the mean value, and two phases, respectively, at the beginning (initial phase) and the end (final phase), with sprouting rates lower than the mean value. In my plots, the full phase lasted 8-12 days and represented 70-80 % of the newly sprouted culms, whereas the initial and final phase lasted 5-7 days and 6-8 days, representing 8-15 % and 11-14 % of the bamboo shoots, respectively (Table 4.5).

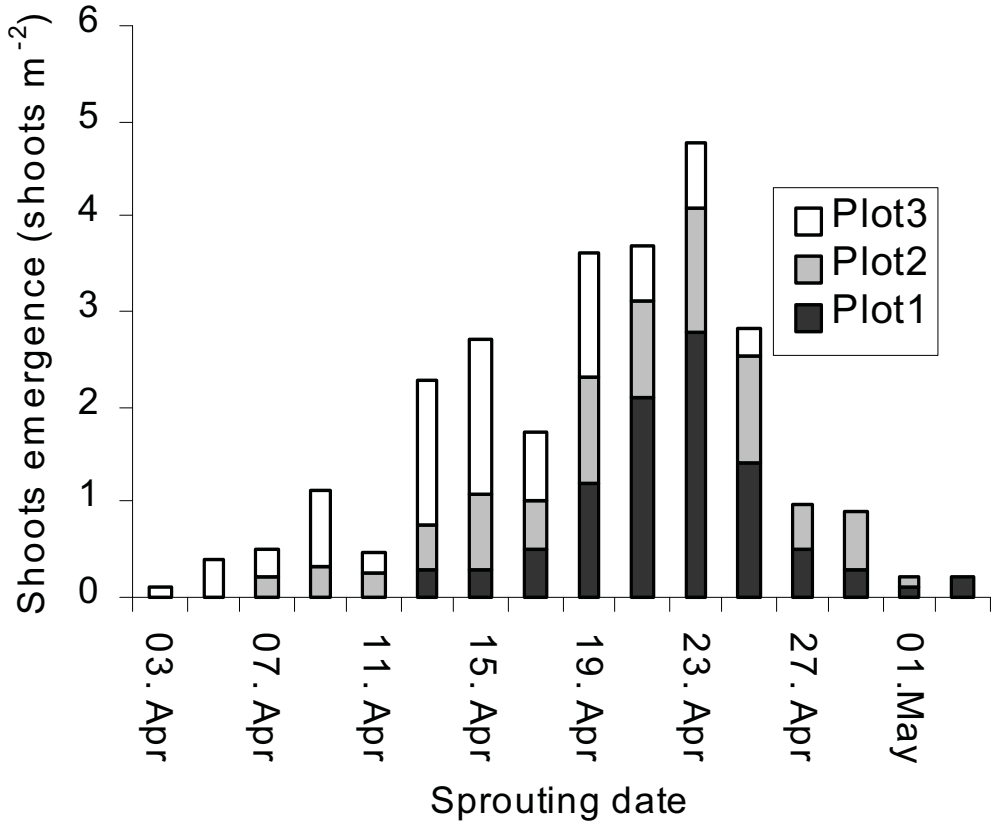

Figure 4.7: Pattern of newly sprouted shoots of *Indocalamus latifolius* during the sprouting phase in Shennongjia, Central China at different altitudes (Plot T1 = 1,150 m asl, Plot T2 = 810 m asl, Plot T3 = 510 m asl).

During the sprouting phase and the subsequent growing phase, a total of 17.9 % of the bamboo shoots were lost (Table 4.6). Field observations showed that the damage to shoots of *I. latifolius* by rodents took place mainly during the first four weeks

after the emergence of the shoots. Insects (mainly stem-boring weevils and larvae of shoot flies) damaged the shoots during the whole sprouting phase and the early phase of height growth, for as long as nine weeks. Additionally, 4.9 % of the shoots died for unidentified reasons. The associated vegetation affects the survival of the bamboo shoots. In the deciduous broadleaved forest (Plot T3), 28.2 % of the bamboo shoots died before growing to full height. In the disturbed forest next to farmland (Plot T2), only 13.6 % of the bamboo shoots died before maturity, which is similar to the bamboo clumps on the riverside with full sun (14.4 %, Plot T1).

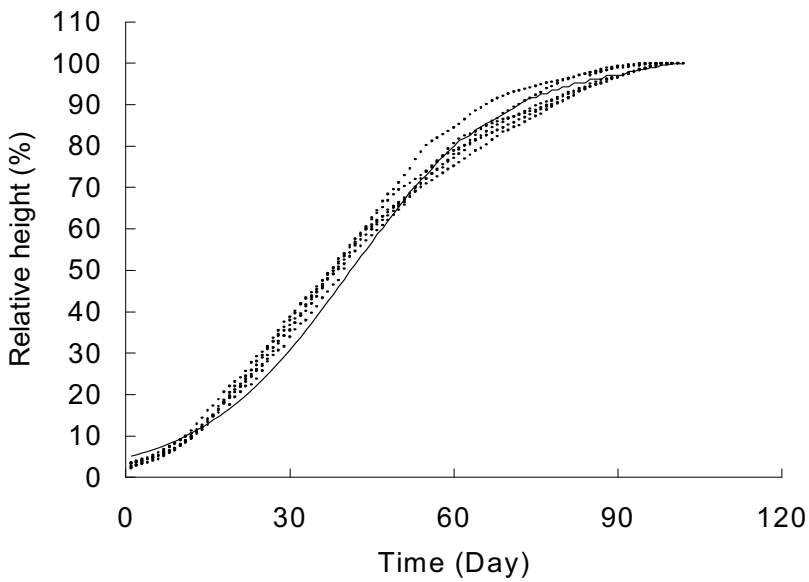

Figure 4.8: Relative cumulative growth of *Indocalamus latifolius* from shoot emergence till full height of young culms. $Pt = 1 / (1/100 + 0.1978 \times 0.9303^{T})$ ($r^2 = 0.985$, $n = 97$, $P < 0.0001$).

After emerging, the *Indocalamus* shoots in Plot T1 (1,150 m asl) grew to their full height of 191 ± 23 cm within 98 ± 3 days. Three growth phases (Liese 1985; Tewari 1993) i.e., initial slow growth, fast growth and final slow growth, can be identified by plotting the daily growth rate against the time of height growth (see Figure 4.8). The initial slow growth was observed from the emergence of the shoots to about 20 days after shoot emergence (DAE) (0.5 to 2 cm day^{-1}), which contributed about 14.6 ± 5.2 % of the full height, while the phase with fast growth (2 to 3 cm day^{-1}) occurred during 20-70 DAE and contributed 74.5 ± 11.5 % of the full height. During the final phase of slow growth, the growth rate slowed down between 70 DAE and about 95-102 DAE (2 to 0.2 cm day^{-1}). The final phase contributed only about 10.9 ± 7.3 % of the height growth.

A logistic growth model fits best the sigmoid curve of the height growth. Based on the relative height growth of the *Indocalamus* shoots, the logistic growth model is defined as follows: $Pt = 1 / (1/100 + 0.1978 \times 0.9303^{T})$, where Pt indicates the relative accumulated height of tamale bamboo and T the time in days (Figure 4.8). The newly sprouted culms reached full height at the end of July, and after that, height did not increase no matter how long the culm survived.

Table 4.7: Leaf production of *Indocalamus latifolius* in Shennongjia, Central China. *Culms of 3 years and older cannot be distinguished from each other.

Culm age (year)	Culms m^{-2}	Number of new leaves	Number of mature leaves	Total leaf number
1	11	43	0	43
2	8	49	52	101
>2 *	29	117	176	293
Total	48	209	228	427

In the final phase of the height growth, leaves begin to develop at branch and culm apices. The young leaves are tender even at the end of the growing season (6-16 cm long, 1.8-2.7 cm wide). They grow bigger (20-38 cm long, 4-10 cm wide) and become tougher during the second year. After that they are suitable for wrapping Chinese tamales. A newly-sprouted culm usually produces 3-5 leaves in the first year and 6-9 leaves in the second year. The life span of a leaf is about three years. Counting in Plot 2 revealed 209 new leaves m^{-2} in the growing season and 228 mature (2 to 3-year-old leaves) leaves m^{-2} (Table 4.7).

4.3.3 Results of arrow bamboo study

Shoots of *Fargesia spathacea* sprouted from late March in lower altitude valleys (Plot A1) till late May in the higher mountains (Plot A10). Over ten observed plots, the average length of the sprouting phase was 25 ± 4 [± S.D.] days. At the end of the sprouting phase, shoots achieved a density of 9.9 ± 2.2 shoots m^{-2} (Table 4.8). However, sprouting was neither uniform through the time nor synchronous through the elevation. Figure 4.9 shows that sprouting against time presented a bell-shaped curve with a single peak.

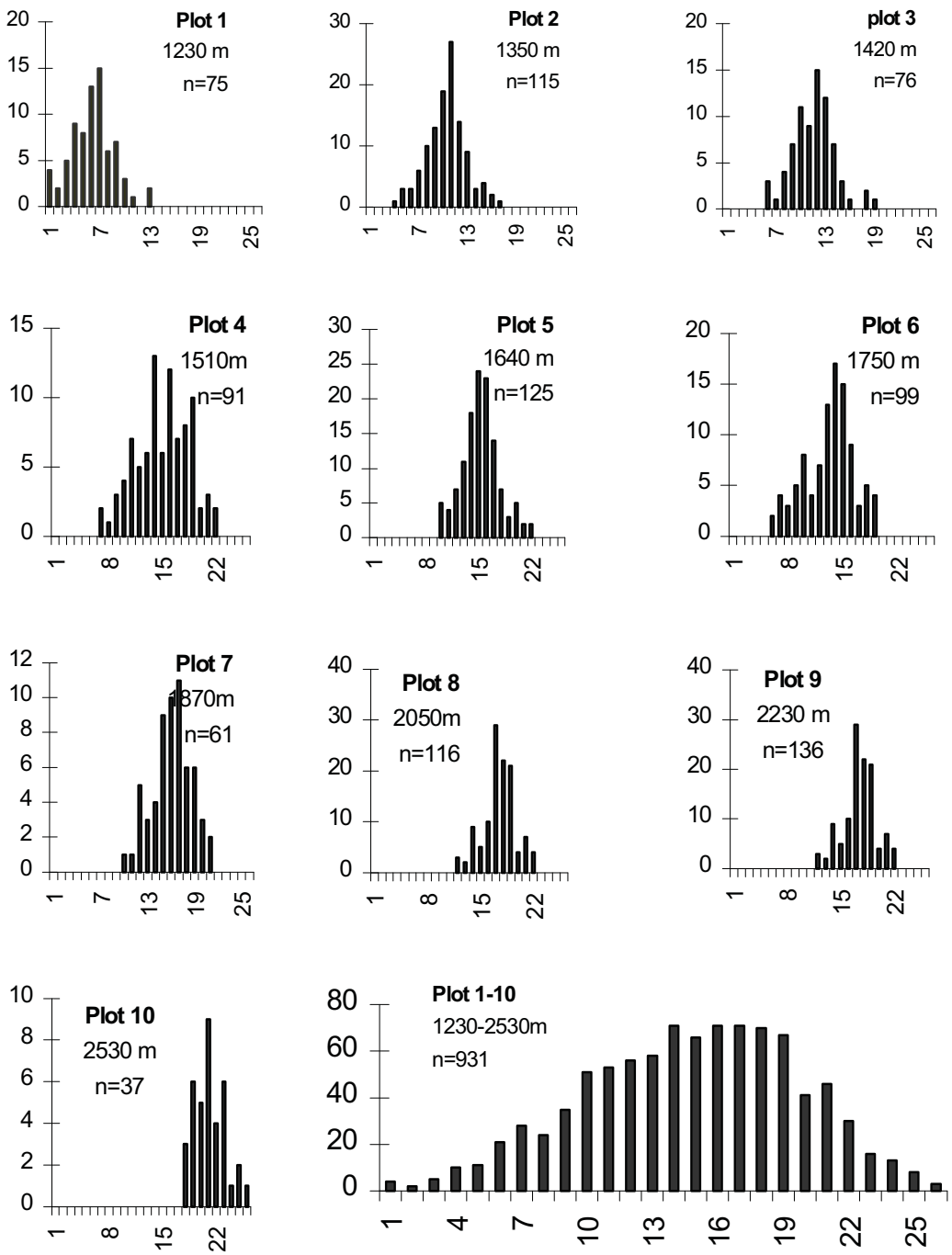

Figure 4.9: Shoot sprouting patterns of umbrella bamboo (*Fargesia spathacea* Franchet) at ten plots along an altitudinal gradient from 1,200 to 2,600 m in Shennongjia, Central China. X-axis indicates the time scale expressed as every two days. Starting day of the sprouting phase in Plot A1 (29-30 March) was defined as the base time (= 1) on a time axis. Y-axis indicates shoot emergence in numbers.

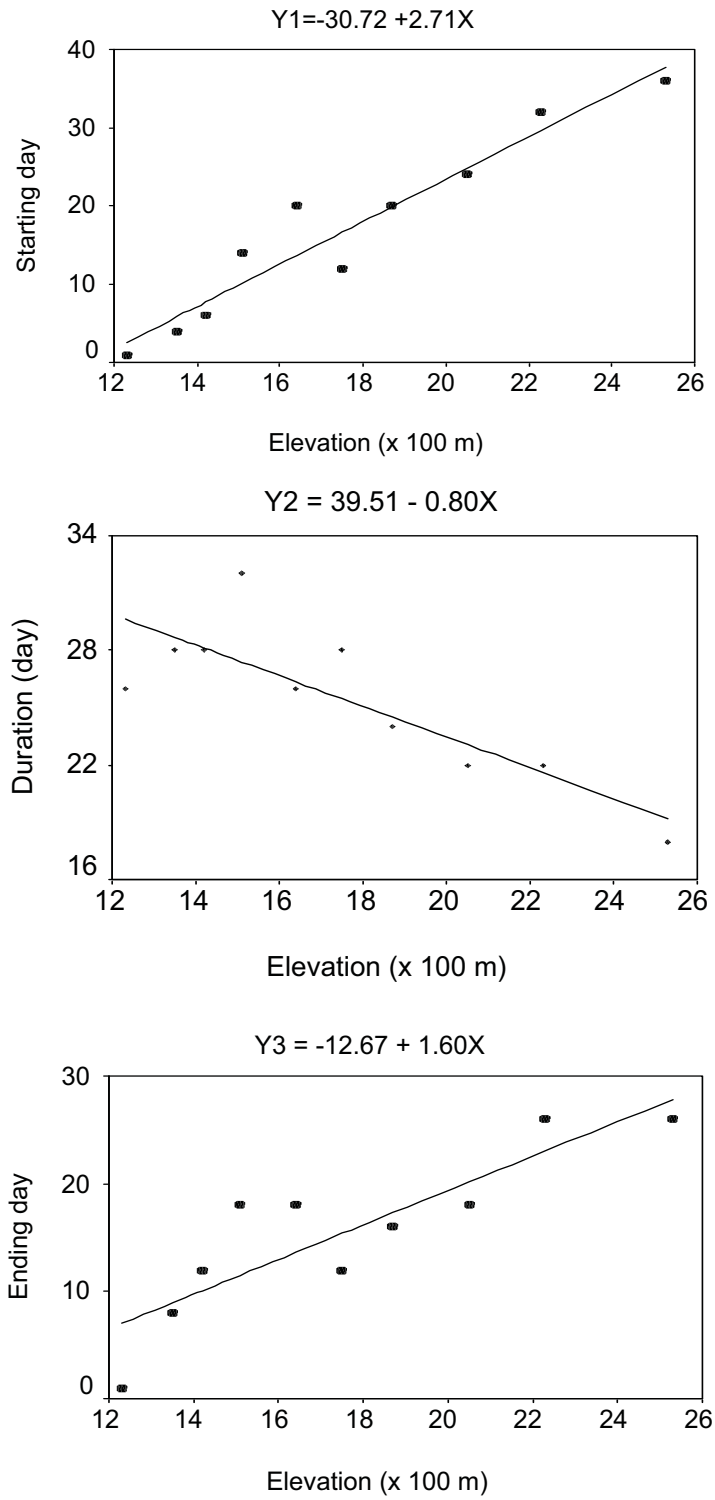

Figure 4.10: Linear regressions between elevation (X, 100 m) and beginning (Y1, *d.f.* = 8, *F*-value =96.41, *r* = 0.923, P < 0.001), length (Y2, *d.f.* = 8, *F*-value = 24.11, r = 0.751, P < 0.001) and end (Y3, *d.f.* = 8, *F*-value = 17.98, *r* = 0.692, P < 0.005) of the sprouting phase of umbrella bamboo (*Fargesia spathacea* Franchet) along an altitudinal gradient from 1,200-2,600 m in Shennongjia, Central China.

Table 4.8: Shoot sprouting of umbrella bamboo (*Fargesia spathacea* Franchet) at 10 altitudinal plots in Shennongjia, Central China.

Plot	Onset of sprouting	End of sprouting	Sprouting duration (Day)	Number of emerged shoots	Number of aborted shoots	Shoot survival rate (%)	Shoot density (m^{-2})
A1	29 Mar	23 April	26	75	22	70.7	13.3
A2	8 April	6 May	28	115	43	62.6	9.0
A3	14 April	10 May	28	76	39	48.7	9.3
A4	16 April	18 May	32	91	41	54.9	6.3
A5	22 April	18 May	26	125	37	70.4	11.0
A6	10 April	8 May	28	99	19	80.8	10.0
A7	22 April	16 May	24	61	25	59.0	9.0
A8	26 April	18 May	22	116	13	88.8	12.9
A9	4 May	26 May	22	135	35	74.3	12.7
A10	8 May	26 May	18	37	8	78.4	7.3

Table 4.9: Daily sprouting rate and cumulative emergence of bamboo shoots during the sprouting phase over ten altitudinal plots of umbrella bamboo (*Fargesia spathacea* Franchet) in Shennongjia, Central China. Daily sprouting rate was expressed as daily percentage relating to total emerged shoots during a sprouting phase. *t*-Test was used to check the temporal pattern of the sprouting rate through the time. The logistic model $S = 1 / (1/100 + a \times b^T)$ was adapted to describe the relationship between the cumulative percentage of shoot emergence and time over the sprouting phase. In the model, *S* means relative percentage sprouting, *T* indicates time, and *a* and *b* are fitted parameters.

Plot	t-test (sprouting rate)					Cumulative sprouting				
	N	Mean	S. D.	t	Sig.	a	b	r^2	F-value	Sig.
A1	13	7.69	6.09	4.55	0.001	0.4108	0.5125	0.996	1785	0.000
A2	14	7.16	6.70	4.00	0.002	0.6769	0.4750	0.991	753	0.000
A3	14	7.15	6.30	4.24	0.001	0.5690	0.5152	0.994	1117	0.000
A4	16	6.25	4.03	6.12	0.000	0.6574	0.6106	0.988	593	0.000
A5	13	7.69	6.22	4.46	0.001	0.5291	0.4980	0.998	3399	0.000
A6	14	6.75	4.30	5.88	0.000	0.4850	0.6138	0.957	157	0.000
A7	12	8.33	5.61	5.15	0.000	0.9470	0.5053	0.987	545	0.000
A8	11	9.09	7.91	3.81	0.003	0.9276	0.4669	0.989	639	0.000
A9	11	9.35	5.86	5.29	0.000	0.5071	0.4758	0.990	718	0.000
A10	9	11.15	7.24	4.62	0.002	0.3396	0.3751	0.928	90	0.000

In the distribution range of arrow bamboo from 1,200 to 2,600 m, altitude had a significant effect on the beginning (r = 0.96), end (r = 0.87) and length (r = 0.83) of the sprouting phase. Linear regressions (Figure 4.10) showed that the beginning of the phase tended to be delayed by 2.7 days (F-value = 96.41, $d.f.$ = 8, $P < 0.001$) per 100 m increase in altitude, and the end by 1.6 days correspondingly (F-value = 24.11, $d.f.$ = 8, $P < 0.001$). Meanwhile, the duration of the sprouting phase declined by 0.8 day 100 m^{-1} (F-value = 17.98, $d.f.$ = 8, $P < 0.005$). Pair-correlation analysis (Table 4.10) also showed that, with the increase in altitude, shoot mortality was reduced (r = 0.60) and consequently the shoot survival rate increased (r = 0.56). However, shoot density was less affected by the altitude (r = 0.36) than by the density of parent culms (r = 0.59).

Table 4.10: Paired-samples analysis between plot features and shoot survival of umbrella bamboo (*Fargesia spathacea* Franchet) in Shennongjia, Central China.

	Emerged shoot		Aborted shoot		Survival rate		Shoot density	
	Corr.	Sig	Corr.	Sig.	Corr.	Sig.	Corr.	Sig.
Elevation	-0.150	0.679	-0.596	0.069	0.562	0.091	-0.042	0.908
Culm density	0.585	0.076	0.113	0.756	0.299	0.402	0.105	0.772

4.4 Discussion

4.4.1 Resource management of henon bamboo

The sprouting phases vary depending on the species and environmental conditions (Liese 1985; Dransfield and Widjaja 1995). *Phyllostachys nigra* var. *henonis* in Shennongjia grows from the mountain feet (ca. 500 m) up to 1,840 m, adapting to environmental conditions with an annual average temperature ranging from 7-14 ºC and average annual precipitation from 700-1,700 mm (see Table 2.1). It seems that this species can be introduced in most temperate regions, e.g., south and west Europe. However, the sprouting phase will vary according to the underlying environmental conditions. For instance, in China, *Phyllostachys pubescens* has an observed sprouting phase of 28 days (Zhang 1995), while in South Carolina, USA, its sprouting phase is as long as 44 days (Lee and Addis 2001).

The structure of the bamboo community may strongly affect the production of new shoots, since the mature culms are the only nutrient source for the new shoots (Liese 1985). The annual production of bamboo shoots strongly depends on density (r =

0.938,) and base-area coverage (r = 0.826) of the standing culms (Table 4.11). The results seem to confirm the nourishing role of the mother culms. Mother culms contribute to the vegetative growth of the clump through the photosynthesis in their leaves. The nutrients they synthesize are partly consumed by the culms themselves, but the greater proportion is transported to the rhizomes (Fu 1989, 1992; Qiu et al. 1992; Isagi et al. 1997). Here it is stored as energy, which is converted into the next year's growth of new shoots. As a result, the bamboo farmers to are often faced with a problem: how many shoots should be left on their bamboo stands. If all shoots are harvested, the bamboo clumps will lose vigor and timber; if all shoots are left, the farmers will lose money and food.

This problem has been discussed for *Phyllostachys pubescens* in Japan (Mumata 1979; Watanabe 1994) and China (e.g., He 1993; Zheng et al. 1998) for many years. He (1993) suggested an age-rotation model for maintaining shoots in the timber-oriented clumps as follows: 1-year culm: 2-year culm: 3-year culm: 4-year (+) culm = 1: 1: 1: 1, while Zheng et al. (1998) modified the ratio as 1: 1.6: 1.6: 1.5 for the shoot-oriented clump. In my plots, the age structure was 1: 1.14: 1.27: 0.92 in 2000, approximately following the optical age rotation for the timber-oriented plantation. Considering that the age-based density in my site was 1.9 culms m^{-2} $year^{-1}$, and the density of emerged shoots was 2.7 shoots m^{-2}, the average shoot yield of this timber-orientated stand may be expected as 0.8 shoot m^{-2}. Of course, farmers can adjust the harvest ration of bamboo shoots according to market variation and stand condition.

Various kinds of diseases and damage affect bamboo shoots during their different growth phases. In the plots, damage through animal predation and disease rotting was mostly spread over the early shoots, whereas malnutrition mainly affected the later shoots. High damage incidence and mortality were recorded in emerging shoots of 10-35 cm in height. Corresponding to this mortality pattern, both early and late shoots should be harvested before they become degraded. The shoots must be harvested as soon as they emerge. Even waiting a day will make them too tough and unsavory for eating, since exposure to sunlight causes the production of chemicals that are bitter and that hasten shoot elongation by stimulating the development of a very woody base (Lewis 1998). Meanwhile, if symptoms of dying are displayed, the shoots should be harvested immediately. Symptoms of approaching death of the new shoots are, for

example, no guttation on the tips of sheaths covering the emerging shoot, loosening sheaths, and termination of height growth.

Table 4.11: Pair-samples analysis between new sprouting (density and survival) and community features of henon bamboo (*Phyllostachys nigra* var. *henonis*) in Shennongjia, Central China. Significance level is defined as: * $P < 0.05$, ** $P < 0.01$.

	Shoot density	Shoots lost	Insect damage	Malnutrition	Rodent predation	Survival rate
Age structure						
Total culms	0.938**	0.823	0.304	0.361	0.532	0.836
1-year	0.805	0.538	-0.143	0.594	0.069	0.878*
2-year	0.645	0.580	0.124	0.254	0.434	0.704
3-year	0.867*	0.752	0.309	0.212	0.631	0.787
4-+ year	0.801	0.905*	0.745	0.113	0.717	0.447
Culm feature						
Mean height	0.064	-0.233	-0.544	-0.305	0.426	0.580
Base cover	0.826	0.690	0.221	0.156	0.673	0.834
Mean DBH	0.511	0.327	-0.72	-0.123	0.706	0.769
Mean nodes	0.424	0.192	-0.317	0.034	0.442	0.800
Herb layer						
Coverage	-0.458	-0.427	-0.031	-0.300	-0.199	-0.535
Height	-0.904*	-0.705	-0.071	-0.428	-0.413	-0.939**

Observations show that the herbs in terms of ground cover and mean height negatively affected shoot production and shoot survival (Table 4.11). Herb height strongly reduced the shoot production ($r = -0.904$, $P < 0.05$) and shoot survival rate ($r = -0.939$, $P < 0.01$). The effects from herb coverage were not as strong as from herb height, although herb coverage also negatively influenced shoot production ($r = -0.458$) and survival ($r = -0.535$). Generally, weeds consume nutrients intended for the bamboo, shade the ground, lower soil temperature and thus retard shoot emergence (Fu 1994). In the field, the negative effects were enhanced by the higher herbs that might have competed for nutrients in the deeper soil, where the bamboo roots absorb the water and nutrients. Therefore, high herbs with deep roots should be removed from the bamboo stands.

4.4.2 Cultivation potentials of tamale bamboo

Bamboo flowering is considered an economic setback in bamboo cultivation (Liese 1985). In China and India, it has long been assumed that of many bamboo species all individuals flower simultaneously at intervals of 3-120 years (Janzen 1976), after which they all die and are replaced by seedlings. Among the bamboo species, there are, however, three different flowering patterns (Dransfield and Widjaja 1995): gregarious (a whole population flowers and then dies); sporadic (individuals flower and then die; the rhizomes survive); and continuous flowering (individuals produce flowers all year round but do not die). Among these three types, the gregarious pattern is the main threat to bamboo plantations (Liese 1985), because the flowering stands can only be restored by a sexual regeneration process, which usually takes more than ten years (Taylor et al. 1995). However, my observations on the flowering pattern and regeneration process of another *Indocalamus* species (*I. wilsoni* (Rendle) Chao et Chu) in Shennongjia showed that bamboos of the genus *Indocalamus* might follow the sporadic flowering pattern, rather than the gregarious (Li and Denich 2001). In a flowering site (at 1,750 m asl), about 70 % of the bamboo culms of *I. wilsoni* flowered and died in 1997-1999, but the culms that did not flower are still alive. Further observations on their rhizome system showed that although pachymorph rhizomes under the flowered culms had died and decayed, the leptomorph rhizomes had survived and continued to produce new shoots. Since *I. latifolius* has a similar rhizome structure to *I. wilsoni,* and if it follows the same flowering pattern of *I. wilsoni*, the flowering threat to plantations might be reduced.

During one vegetative period, about one fifth of the bamboo shoots died back. Compared to other bamboo species such as *Fargesia spathacea* (31-66 %; Taylor and Qin 1987), *Fargesia denudata* (45 %; Wang et al 1991), and *Phyllostachys nidularia* (63 %; Zhang et al. 1995), the mortality of *I. latifolius* is relatively low. In the study region, shoot-dieback was mainly caused by insects (43-62 % of the lost shoots) and rodents (22-25 %). Therefore, pest control will be an indispensable management measure in future cultivation.

Height growth of *I. latifolius*, as with all other bamboos, depends entirely on the elongation of the internodes (Tewari 1993; McClure 1993). However, the height growth process lasts as long as 90-100 days, much longer than other common bamboo species such as *Phyllostachys heteroclada* (28-41 days; Jing et al. 1999), *Ph. nidularia*

(30-40 days; Zhang et al. 1997), *Ph. nigra* (22-24 days; Zhang et al. 1997), *Ph. pubescens* (30-40 days; Li et al. 1997), *Chimonobambusa utilis* (60-70 days; Zhang et al. 1998), and *Indocalamus barbatus* (67 days; Zhang et al. 1997). So far, no other bamboo species has been reported from China with a height growth phase longer than that of *I. latifolius*. The maximum daily growth of *I. latifolius* observed in the field was, on average, 4.3 cm, while that of *Phyllostachys pubescens* may be more than 100 cm day^{-1} (Li et al. 1997).

Although the leaf production of *I. latifolius* reached 437 leaves m^{-2} (209 new leaves m^{-2} + 228 mature leaves m^{-2}), only the mature leaves are suitable for wrapping Chinese tamales. Every year, a vital culm can produce 3-9 leaves, depending on its age. Leaves continue to age and die; therefore, a portion of the leaves can be harvested through selective collection. However, sufficient photosynthetically active leaves must remain to maintain the productivity of the clumps. Considering the life span of the bamboo leaves of three years, I assume that one third of the mature leaves might be harvested without impairing the sustainability of leaf production. Thus, the marketable production of *Indocalamus* leaves may reach 70-80 mature leaves m^{-2}. The market price of tamale bamboo leaves in China is around YMB 0.03-0.05 per leaf (personal investigation in January 2002). A one-hectare bamboo plantation can thus generate YMB 21,000 – 40,000 per year, equivalent to US$ 2,500 – 4,800 per hectare and year. As the average annual income of a local household in Shennongjia is around US$ 816 – 1,400 (Zhu and Song 1999), a 0.3-ha bamboo plantation will be sufficient to support a rural family in the region.

Moreover, *I. latifolius* can be integrated into agroforestry systems. In mountainous Central China, there are at least two options: (1) deciduous broadleaved trees + bamboo and (2) bamboo together with edible fungi. The first system can be established by either converting semi-natural bamboo stands or by planting new ones under secondary forest. Since *I. latifolius* usually occurs together with various trees along the upper reaches of rivers, such systems may not only generate economic benefits by producing bamboo leaves, but also play an important role in soil and water conservation. The second option can be realized when *I. latifolius* is cultivated as an intensive crop. There are a large number of edible fungi regarded as natural food rich in vegetable proteins. Among these, *Dictyophora tomentosa*, *Pleurotus ostreatus* and

Auricularia auriculajudoe can be cultivated in bamboo stands (Fu and Banik 1995), which satisfy the fungi's needs for humidity, shade and a fertile bed.

4.4.3 Arrow bamboo as the food supply of the giant panda

The panda habitat falls within the temperate forests in Central China with bamboos at altitudes between 1,100 m and 3,300 m, and sometimes as high as 4,000 m (Schaller 1985, Fong and Li 2001). Pandas move up and down in elevation during different seasons in order to select certain bamboo species and seasonal habitats (Schaller 1985). In winter, they generally depend on areas at lower altitudes, between 1,200 to 2,000 m, where they also mate and give birth. In summer, they live in higher elevations above 2,200 meters. In such a habitat range, the most important variables closely related to bamboo distribution and panda migration may be temperature and precipitation. In the Wolong reserve, the giant panda consumes 8.1-24.3 % of *F. spathacea* (now named *Fargesia robusta* Yi) shoots (Campbell and Qin 1983; Schaller et al. 1985; Taylor and Qin 1987; Reid and Hu 1991). From November to March, pandas eat both bamboo stem and leaves; from March to June they eat bamboo shoots; and from July to October they concentrate on leaves (Schaller et al. 1985). This feeding pattern shows that the sprouting time of forage bamboo plays a key role in food supply since culms and leaves are available all year. Moreover, once the shoots are fully grown they become tough and fibrous and pandas move to where emerging shoots of other species are available. A number of studies (e.g., Deng et al. 1981; Pan et al. 1988; Wei et al. 1996; Hu et al. 2000) report that in summer the giant panda prefers to feed on shoots thicker than 10 mm and higher than 50 cm (at least 15 days after emergence). Under the above criteria, my investigations confirm that in Shennongjia, *F. spathacea* can produce bamboo shoots suitable for the giant pandas from early April till mid June along the altitude from low mountains (1,200 m) to the subalpine belt (2,600 m). After June, the pandas may move upward in elevation to feed on the shoots of *F. murielae* that sprout later than those of *F. spathacea*.

Both temperature and precipitation patterns in Shennongjia are similar to those of the current panda habitats in Sichuan, e.g., Wolong (Ouyang et al. 2000) and Emei (Tang and Ohsawa 1997). In the case of arrow bamboo in Shennongjia, the winter temperature (January) at the upper limitation (2,600 m) may indicate the lowest

boundary, and the summer temperature (July) at its lower limitation (1,200 m) may indicate the highest boundary. The result derived from temperature gradients (Table 2.1) predict that *F. spathacea* can naturally survive within a temperature spectrum ranging from coldest -7.8 ºC to hottest 23.1 ºC. The average annual growing temperatures for *F. spathacea* range from 3.2-10.2 ºC. Temperature also appears to be the principal environmental factor controlling the onset of shoot sprouting (Stoller and Woolley 1983; Satorre et al. 1996; Li et al. 2000). In my case, shoots of *F. spathacea* first sprouted in late March at the lowest plot (1,230 m), when the daily air temperature increased to 8.2 ºC. Gradient-based estimation indicated that the shoots in the highest plot (2,530 m) started to sprout when temperatures reached 7.7 ºC in early May. The results show that 8 ºC may be the initial air temperature for the natural sprouting of *F. spathacea*. Of course, temperature is one important factor determining the sprouting phase of bamboo, but not the sole one.

Table 4.12: Sprouting phases of bamboo species in Shennongjia, Central China. Data on *Phyllostachys nigra* var. *henonis, Indocalamus latifolius,* and *Fargesia spathacea* is the result of regular observation of the plots, while data on *Phyllostachys heteroclada, Fargesia murielae* and *Yushania confusa* is general data taken from the area outside the plots.

Species	Rhizome types	Start day	End day	Duration (days)	Shoot density (m^{-2})
Phyllostachys heteroclada	Monopodial	11 May	7 June	27	2.4
Ph. nigra var. henonis	Monopodial	9 May	17 May	19	2.7
Indocalamus latifolius	Amphipodial	3 April	5 May	33	8.8
Fargesia spathacea	Sympodial	29 March	26 May	59	9.9
Fargesia murielae	Sympodial	12 June	20 July	39	7.0
Yushania confusa	Sympodial	10 May	24 June	46	4.7

Climate change has in the past led to shifts in vegetation patterns; in a future, warmer climate due to enhanced greenhouse-gas concentrations, vegetation is also likely to be highly responsive to such warming (Vedyushkin 1997). Mountain regions are considered to be particularly sensitive to such changes (Keller 2000). The species that prefer low thermal conditions move out of the plots. In my case, if the distribution range of *F. spathacea* strictly responds to the temperature change, the altitudinal boundary may rise 100 m with each 0.506 ºC increase in the mean annual temperature (see Chapter 2). In the past five centuries, the temperature has increased about 1.1 ºC in

the northern hemisphere (Titus and Narayanan 1995), which may have resulted in a 200 m-increase of the lower boundary of this bamboo. With the disappearance of bamboos in low elevations, the closed bamboo vegetation then moved to higher mountains, leading to disjunctive patterns. Such disjunctive bamboo mountains then may separate the involved panda population. When forage bamboos simultaneously die in one "island", the giant pandas will probably be unable to cross wide, bamboo-less, low mountains to reach another "island", which may lead to the extinction of pandas. Of course, a number of reasons are responsible for the decline of the wild panda population, but an assessment of the effect of the climate on the survival of the giant panda will be helpful to understand the relationship between panda and bamboo.

4.4.4 Comparison of bamboo growth

In seasonal climates, plants usually grow in a regular time pattern of annual cycles. In bamboos, this cycle results an annual growth of the new culms involved in three phases: sprouting, height-growing, and branch-spreading (Table 4.12). New shoots are produced annually from the youngest rhizomes, but the growth patterns are different. The new shoots of monopodial bamboos (i.e., *Phyllostachys nigra* var. *henonis* and *Phyllostachys heteroclada*) come from the lateral buds, while shoots of sympodial bamboos (i.e., *Fargesia spathacea*, *Fargesia murielae* and *Yushania confusa*) come from distal ends of the rhizomes. In sympodial bamboos, lateral buds produce only rhizomes. The new shoots of amphipodial bamboos (i.e., tamale bamboo *Indocalamus latifolius*) come from both kinds of buds. The shoot density of monopodial bamboos is very low (2.4-2.7 shoots m^{-2} in Shennongjia), leading to a spreading bamboo stand with a low culm density. Relatively, both sympodial and amphipodial bamboos have high shoot density (4.7-9.9 shoots m^{-2}), forming dense bamboo clumps.

Comparisons of the duration of the sprouting phase and height growth period over documented Chinese bamboo species (Table 4.13) shows that the monopodial bamboos sprout and grow much quicker than the sympodial and amphipodial bamboos. Shoots of *Phyllostachys* (monopodial bamboos) usually emerge in the spring and early summer within a short sprouting phase averaged 31±10 days. Emerged shoots rapidly elongate and grow into the canopy of the stand within 40 ± 16 days. Clumping bamboos (from the genera of *Fargesia*, *Dendrocalamus*, *Indocalamus* and *Bashania*) usually

have a relatively long sprouting phase (117 ± 48 days) and growing period (94 ± 36 days).

Henon bamboo is one of the rapidly sprouting (19 days) and fast growing (32-36 days) bamboos. The local farmers appreciate the growth behavior of henon bamboo, since it means that each year they need spend only two weeks harvesting shoots in May and another two weeks weeding and cutting old culms. Arrow bamboo is one of the slowly growing plants, with a long sprouting phase (59 days) and height growing period (110 days). The giant panda prefers this bamboo because it can provide fresh shoots for a long period.

Table 4.13: Duration of sprouting phase and height growth of selected Chinese bamboos. In the table: Mono = Monopodial-rhizome bamboo, Sym = Sympodial-rhizome bamboo, Amph = Amphipodial-rhizome bamboo.

Species	Rhizome type	Location	Sprouting phase (d)	Height growth (d)	Reference
Spreading bamboo					
Phyllostachys pubescens	Mono	S. China	31	NA	Zheng et al. 1998
Ph. pubescens	Mono	E. China	28	33	Zhang 1995b
Ph. pubescens	Mono	USA	44	70	Lee and Addis 2001
Ph. nigra	Mono	E. China	27	24	Zhang et al. 1997
Ph. makinoi	Mono	E. China	25	32	Huang and Ma 1994
Ph. heteroclada	Mono	E. China	45	39	Jin et al. 1999
Ph. nidularia	Mono	W. China	20	45	Zhang et al. 1995
Ph. nigra var. henonis	Mono	C. China	19	34	This research
Clumping bamboo					
Fargesia robusta	Sym	W. China	80	70	Qin et al. 1993
Fargesia denudata	Sym	W. China	90	163	Wang et al. 1991
Dendrocalamopsis oldhami	Sym	S. China	120	80	Gao et al. 2000
Dedrocalamus latiflorus	Sym	E. China	180	90	Zhou 1999
Fargesia spathacea	Syn	C. China	59	110	This research
Indocalamus barbatus	Amph	E. China	67	66	Zhang 1995b
Bashania fangiana	Amph	W. China	170	95	Mu and Shi 1991
Indocalamus latifolius	Amph	C. China	22	102	This research

Comparisons of the growth of new shoots show that the height growth of the bamboos follows the same pattern. When a young shoot emerges from the ground, it

consists essentially of a short, massive, little-differentiated stem packed with nutrients and protected by numerous sheaths. This new shoot develops slowly at first, then elongating rapidly and forming a new culm. The cumulative growth of bamboo shoots can be described with logistic models, although different bamboos have different growing seasons of different durations.

Due to bamboo's contribution and great potential to social, economic, environmental and rural development, on the global level there is an increasing interest to develop bamboo plantation (Liese 2001). From a bamboo area, ripe culms can be harvested each year. In case of wood, one has to wait for some ten or twenty years, after which the area is cleared, with the risk of deforestation and erosion. In a bamboo plantation only the ripe culms are removed, while the younger culms remain in place. Moreover, a village community can easily grow bamboo. A small plantation of just one hectare yields enough bamboo culms each year to build several houses and to create some jobs. More researches are needed to make a detailed understanding of bamboo biology and ecology from species to species.

5 FLOWERING OF *FARGESIA MURIELAE*

Summary: Simultaneous flowering of umbrella bamboo (*Fargesia murielae* (Gamble) Yi) was studied in terms of flowering pattern, seedling establishment, and fire effect in Shennongjia, Central China. Over 95 % of bamboo stands simultaneously flowered and died in 1996-2000, extending from lower elevations to the higher mountains along the altitude and from southwest to northeast along the mountain settings. Bamboo seedlings emerged after simultaneous flowering, reaching an average density of 5,460 seedlings m^{-2} in the autumn of the first year after flowering. After a high mortality rate throughout the first winter, seedling density remained stable in following 2-4 years (1,130-1,230 seedlings m^{-2}). However, seedling densities varied from vegetation to vegetation type, with a positive relation to the coverage of parent bamboos and a negative relation to the coverage of herb layers. Investigation on the post-fire regeneration shows that wildfires might be a driving force which synchronizes the bamboo flowering. In a burned site, bamboo clumps reached an average density of 99 ± 22 culms m^{-2} and a mean height of 166 ± 15 cm ten years after the fire, which were 34 % denser but 35 % shorter than those in the unburned clumps. The fire influence was extent as a critical effect on seed regeneration. Over 70 % of the flowered bamboo clumps in the burned site did not produce seedlings after simultaneous flowering in 1998-2000. The loss of age diversity may result in a synchronous flowering of the monocarpic bamboos.

5.1 Introduction

The life history of many bamboo species is characterized by an unusual flowering habit. They often flower and die simultaneously over wide areas after vegetative regeneration at intervals of a few years to up to 120 years (Janzen 1976; Campbell 1985; Young 1985; Taylor et al. 1988, 1991, 1992; Abe et al. 2001). Several hypotheses exist concerning the causes of flowering. One explanation is that of external controls on physiological processes by available resources such as rainfall (e.g., Campbell 1991; Hu et al. 1997). Another is a widely accepted theory proposed by Janzen (1976), which assumes that irregular fruiting cycles are sufficient disequilibria to inhibit seed predators from maintaining populations large enough to decimate a “mast year” of fruiting. Recently, Keeley and Bond (1999, 2001) proposed a “fire cycle hypothesis”, arguing that lightning-ignited wildfire has synchronized flowering by creating the conditions for

monocarp reproduction of clones at long intervals and delaying of reproduction. However, all these hypotheses lack of field evidence. One reason is that the flowering cycle of many bamboo species may be 30-70 years or more, much longer than the active professional life of a researcher, so that one person does not usually have the opportunity to observe a full cycle or conduct relevant experiments. Therefore, recording the simultaneous flowering of particular species is an essential aspect for understanding the bamboo flowering behavior.

During the life history, bamboo can reproduce in two ways: clonal regeneration during the vegetative period and seed regeneration after simultaneous flowering. Clonal regeneration is expressed as a yearly recruitment of new culms from the rhizomes (Liese 1985; McClure 1993). Seed regeneration occurs after simultaneous flowering and is expressed as a recruitment of bamboo seedlings. Fire disturbance plays an important role in the life history of many plant species (Bond and van Wilgen 1996; Ne'eman et al. 1999; Kennard et al. 2001; Ramsey et al. 2002). Most plant species survive fire by using one or both of two basic mechanisms: one involving resprouting of damaged plants, the other a range of responses which result in new plants being established from seed (del Barrio et al. 1999; Eshel et al. 2000; Hiers et al. 2000). Considering the life history of bamboo, a fire may affect the regeneration of bamboo in two ways: an immediate effect that influences clonal growth, and a postponing effect, which may affect the sexual regeneration by influencing seed production. Nevertheless, little is known about the effect of fire on the simultaneous flowering and regeneration of bamboo species.

Umbrella bamboo (*Fargesia murielae* (Gamble) Yi) is the most popular and widely grown bamboo in the colder areas of Europe and North America (Eberts 1996; Keng and Wang 1996). It is a native Chinese bamboo endemic to the Shennongjia National Nature Reserve (N31º21'-37', E110º03'-34', alt. 420-3105.4 m asl, Shennongjia in brief) of Central China (Zhu et al. 1994; Keng and Wang 1996), covering the ground of subalpine forests from ca. 2,400 m to the summit of 3,100 m (Ban 1995). From 1993 to 1998, *F. murielae* plants simultaneously flowered and died in the European gardens; this was the first simultaneous flowering since 1907 when the species was introduced in the West by Ernest Wilson (Eberts 1996; Gielis et al. 1999; Shannik 1999). In Shennongjia, this species also simultaneously flowered in the late 1990s, which

provided a centurial opportunity for observing the flowering pattern and seedling establishment of this species, and for assessing the flowering hypotheses including the fire-cycle theory.

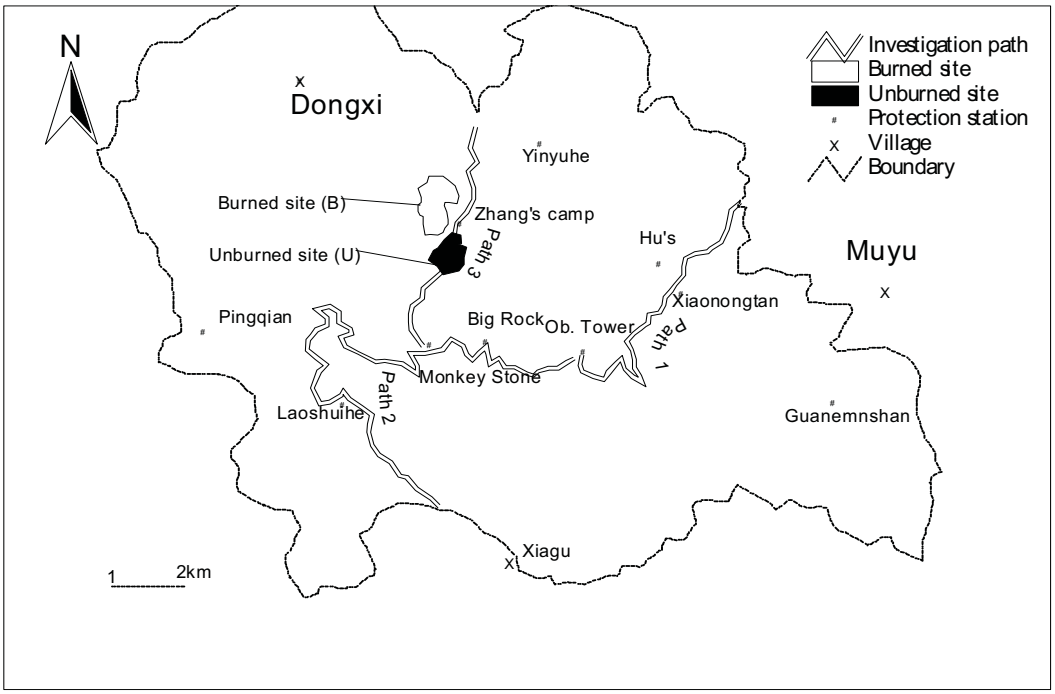

Figure 5.1: Study sites and survey paths in the Shennongjia National Nature Reserve.

5.2 Materials and methods

The study was conducted in Shennongjia (Figure5.1), the only natural habitat of umbrella bamboo (*F. murielae*) in the world (Zhu et al 1994; Keng and Wang 1996). Here, the climate is transitional from subtropical to temperate, allowing rich forest cover and a high diversity of bamboo species (Ban et al. 1995). Umbrella bamboo occurs from 2,400 m to the mountaintop at 3,100 m asl. In this mountain section, the annual precipitation ranges from 2,200-2,700 mm and mean annual temperatures from 1-4 ºC. Because of the high elevation, the habitats of *F murielae* are usually subject to strong, cold winter winds so that the associated vegetation is characterized by plants that have a cold-temperate affinity. In bamboo habitats at lower elevations (2,400-2,700 m), farges fir (*Abies fargesii*) co-occurs with broadleaved deciduous trees such as *Betula albo-sinensis, Acer mono,* and *Populus davidiana*, forming coniferous and broadleaved mixed forests. On the upper mountains (2,700-3,100 m), broadleaved trees give way to

A. fargesii, forming a pure coniferous forest. Umbrella bamboo usually occurs in the forests as a dense understorey; however, it also survives in the degraded forest habitats such as in open shrub communities and mountainous meadows.

5.2.1 Investigation on flowering pattern and seedling establishment

Fieldwork on the investigations of flowering pattern and seedling establishment was carried out from June to October 2000. Features of bamboo flowering, structures of bamboo-associated vegetation, and density of bamboo seedlings were surveyed along three mountain paths across the umbrella bamboo ranges (Figure 5.1). Path 1 (16 km) was from the northern-east boundary of the reserve (Yaziko, N31º30'920", E110º20'127", alt. 1,820 m) up to the mountain peak (Observation Tower, N31º27'069", E110º16'040", alt. 2,930 m), representing the flowering pattern on northern slopes. Path 2 (21 km) was from the southern-west boundary (Gangou, N31º17'611", E110º09'720", alt. 1,250 m) towards the Observation Tower, representing the flowering pattern on the southern slopes. Path 3 (12 km) started at the Monkey Stone (N31º27'403", E110º12'039", alt. 2530 m) and ended at the Southern Gate (N31º25'190", E110º10'413", alt. 268 m), representing the flowering pattern along the mountain ridges. In all, 59 stands were surveyed along the three paths, at intervals of about 500 m along the paths across the umbrella bamboo range. In each stand, a quadrat (area varied from 20-200 m^2) was set up and the underlying plant community classified into community types following Ban et al. (1995): (1) conifer forest, (2) conifer mixed forest, (3) deciduous broadleaved forest, (4) open shrubs, and (5) meadows. The dominating species were recorded and %-cover was estimated for each story (i.e., canopy layer, bamboo layer, and herb layer).

In each quadrate, several 1×1 m^2 sub-quadrats were set up to exam the flowering year of the bamboo stand. Two criteria were applied to determine the flowering year: one based on the appearance of parent culms and the other based on the number of culmlets of the bamboo seedlings. The parent culms in the first year after simultaneous flowering still had intact branches, complete inflorescences, and a fresh yellow color; in the second year, inflorescences withered, branches were yellowish-dark and broken, culms darkish-yellow; and in the third year, most of the branches decayed, and culms were dark. However, it is very difficult to determine the age of the culms

after three years. Some researchers (e.g., Cheung et al. 1984; Qin et al. 1989, 1993) suggest another way to determine the flowering year of the parent bamboo clumps: *Fargesia* bamboo seeds tend to germinate synchronously in the year following the flowering. The new seedlings may reach full height in the first year of growth, and in the following years, a *Fargesia* seedling usually produces one new culm each year in its young phase (up to 5-7 years of age). Thus, counting the culmlets of the seedlings can deduce the flowering year of their parent culms. Surveys on bamboo seedlings were conducted in each stand within several 10 × 10 cm^2 quadrates in which the density of seedlings was determined.

5.2.2 Investigation on post-fire regeneration

Since the establishment of the Shennongjia National Nature Reserve in 1982, the habitat of umbrella bamboo has been well protected and fire is strictly forbidden. Inventories and inquiries over the reserve finally identified a burned bamboo site in the central part of the reserve, where a wildfire accidentally occurred on 5 December 1989, burning about 30 ha of vegetation (Cui 1996), including 15 ha of an umbrella bamboo community.

Fieldwork on the investigations of post-fire regeneration was conducted in August 2000 and July 2001. A burned bamboo site (31º29'15"N, 110º10'53"E, alt. 2,510-2,680 m), covering an area of approximately 15 ha, was selected. A contrasting site with intact vegetation was set up on an unburned slope nearby (31º28'64"N, 110º10'93"E, alt. 2,550-2,630 m). These two sites (Figure 5.1) had a similar topographical structure and the same vegetation (bamboo mosaics in a meadow). The climate in this elevation falls in the mountain belt of the cold-temperate, with rainy, warm summers and windy, cold winters (Ban et al. 1995; Zhu and Song 1999). Average annual precipitation is around 2,200-2,500 mm, with a relatively dry period from November to April and wet conditions during the rest of the year. Snowfall starts in November during the dry period, the snow covering the ground until the following March, considerably reducing the risk of fire. However, in some years, there is not enough snow to cover the ground; the vegetation is then in danger of ignition.

Two transects were respectively established across the burned site (B) and the unburned site (U) in August 2000. Transect B (ca. 230 m long) encompassed 15

bamboo clumps and Transect U (ca. 150 m long) included 10 clumps. In each clump, one 1 × 1 m^2 plot was set up. Here, bamboo height, density, and flowering year were recorded in 2000. Bamboo seedlings were counted in 2001 in all plots. The flowering year was defined as the year of simultaneous flowering on a clump level; sporadic flowering on a culm level was excluded. One bamboo clump in the burned site was dug out and the age of each culm identified by checking its location on the rhizome system. Then an age-based sequence of culm height was developed to predict the height recovery model of the vegetative regeneration. All statistic analyses and modeling were carried out on SPSS for Windows.

5.3 Results

5.3.1 Flowering pattern

Observation carried out in 59 bamboo stands shows that a total of 56 stands (95 %) completely flowered in 1996-2000. All flowered bamboo clumps died back without exception, showing that the flowering of umbrella bamboo belongs to the simultaneous (gregarious) type. In 1996, flowering occurred only on the bamboo stands below 2,700 m where about 10 % (6 of 59) of the bamboo stands flowered. In 1997-98, flowering extended up to 2,800 m, here about 40 % (24 of 59) of bamboo stands bloomed. In 1999, simultaneous flowering covered all altitudinal ranges and here another 40 % of the stands flowered. Flowering in 2000 only occurred on the mountaintops above 2,800 m and 10 % (6 of 59) of the bamboo stands flowered (Figure 5.2).

Flowering duration in low elevations was longer than that in high mountains. In the bamboo stands below 2,800 m, all bamboo stands took four to five years to flower, while stands above 2,800 m took only two years (Figure 5.2). The relationship between flowering duration and elevation can be described by a linear model: $Y = 18.8 - 0.57X$ ($r^2 = 0.612$, $F = 6.32$, $P < 0.05$), where Y indicates the flowering duration in years and X indicates the altitudinal step in 100 m. Different slopes had different flowering durations: on the northern facing slopes (Path 1), flowering lasted only three years (1998-2000), while on southern facing slopes (Path 2) and mountain ridges (Path 3) it lasted five years.

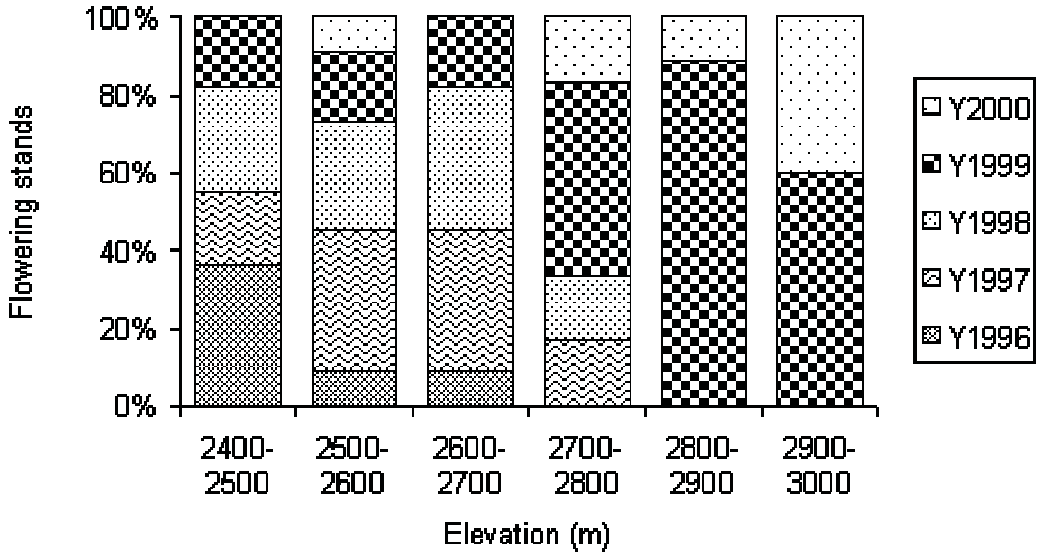

Figure 5.2: Altitudinal flowering pattern of *Fargesia murielae* on a time scale in Shennongjia between 2,400 and 3,000 m asl.

Table 5.1: Summary of one-way ANOVA analysis on the relationship between flowering year of *Fargesia murielae* and the environmental factors in Shennongjia

	Path 1			Path 2			Path 3e			Over all		
	d.f.	F	Sig.	d.f.	F	Sig.	d.f.	F	Sig.	d.f.	F	Sig.
Spatial location												
Altitude	2,17	4.68	0.026	9,30	15.53	0.000	2,9	0.34	0.841	9,58	10.572	0.000
Latitude	2,17	0.84	0.449	9,30	5.20	0.003	2,9	0.85	0.548	9,58	0.907	0.466
Longitude	2,17	8.06	0.004	9,30	10.13	0.000	2,9	0.16	0.949	9,58	4.790	0.002
Vegetation cover												
Canopy	2,17	0.35	0.708	9,30	3.98	0.012	2,9	0.35	0.833	9,58	3.703	0.010
Bamboo	2,17	1.23	0.319	9,30	3.10	0.033	2,9	4.96	0.054	9,58	1.495	0.217
Herb	2,17	0.22	0.804	9,30	2.96	0.038	2,9	1.16	0.425	9,58	2.294	0.071

A one-way ANOVA analysis (Table 5.1) shows that the flowering of umbrella bamboo tends to extend from lower elevations to the higher mountains along the altitudinal scale ($P < 0.001$), and from southwest to northeast along the mountain settings. Specifically, on the northern slopes (Path 1), flowering significantly extended from west to east and approximately from low elevation to higher altitudes ($P < 0.005$), but was not affected by the latitude ($P > 0.05$). On the southern slope (Path 2),

flowering time strongly related to altitude ($P < 0.001$), latitude ($P < 0.005$), and longitude ($P < 0.001$). However, flowering along the ridge (Path 3) at a similar altitude seems to have no connection with the geographical location ($P > 0.05$, Table 1). This implies that the latitudinal and longitudinal effects may be a topographical influence derived from the geographical setting of the mountains. The associated vegetation did not strongly affect the spatial pattern of the flowering time, since the canopy and bamboo cover contributed very little to determining the flowering time (Table 5.1).

Table 5.2: Bamboo seedling density (seedlings 100 cm^{-2}) in 2000 after simultaneous flowering in 1996-1999. In the table: NA = not applicable, CB = conifer-bamboo forest, DB = deciduous broadleaved tree-bamboo forest, PB = pure bamboo forest, SB = shrub-bamboo community, and BM = bamboo-meadow community.

Flowering year	1996	1997	1998	1999
Path 1	NA	NA	13.9±11.1	72.8±55.3
Path 2	14.0±4.1	12.8±13.7	11.2±9.1	63.3±41.8
Path 3	2.0±0	6.0±1.4	3.0±0	16.8±30.3
Total	12.0±6.2	12.3±12.3	11.3±10.1	54.6±48.0
CB	15.4±4.1	7±1.4	9.6±7.4	71.1±50.3
DB	10.0±0	NA	19.3±12.3	7.0±0
PB	NA	16.0±13.7	3.0 ±0	44.0±29.8
SB	NA	3.0 ±0	NA	NA
BM	2.0±0	NA	3.0±0	2.5±2.1

5.3.2 Bamboo seedling

After simultaneous flowering, the parent clumps die back and the recovery of the bamboo stands totally depends on the establishment and growth of bamboo seedlings (Taylor et al. 1988, Makita 1992). The investigations show that most of the bamboo seedlings emerged in the year following the simultaneous flowering. The density of the bamboo seedlings, on an average level, was as high as 5,460 ± 4,800 seedlings m^2 in the autumn of 2000 in the bamboo stands which flowered in 1999, while that was about 1,130 ± 1,000 seedlings m^2 in the bamboo stands which flowered in 1998. This indicates a high mortality during the first winter. Through 2-4 years of age, the seedling density was seemed relatively stable (Table 5.2), as the mortality of the older seedlings was compensated by the newly emerged ones. Although the community structures did

not affect the flowering time of underlying bamboo clumps, it strongly related to the early establishment of bamboo seedlings. Bamboo coverage tended to positively affect the seedling density (r = 0.372, P < 0.01), probably due to denser bamboo clumps, which produce more seeds and shade the floor more efficiently. Meanwhile, herb coverage significantly obstructed the seedling density (r = -0.392, P =< 0.01), mainly due to competition.

Seedling density varied from stand to stand, but strongly related to the associated vegetation types. On average level, the conifer - bamboo community usually carried the highest seedling density (3,980 ± 4,750 seedlings m^2), followed by the pure bamboo community (2,490 ± 2,470 seedlings m^2) and the deciduous tree - bamboo community (1,570 ± 1,110 seedlings m^2). Shrub-bamboo and bamboo-meadow communities were relatively poor in bamboo seedlings.

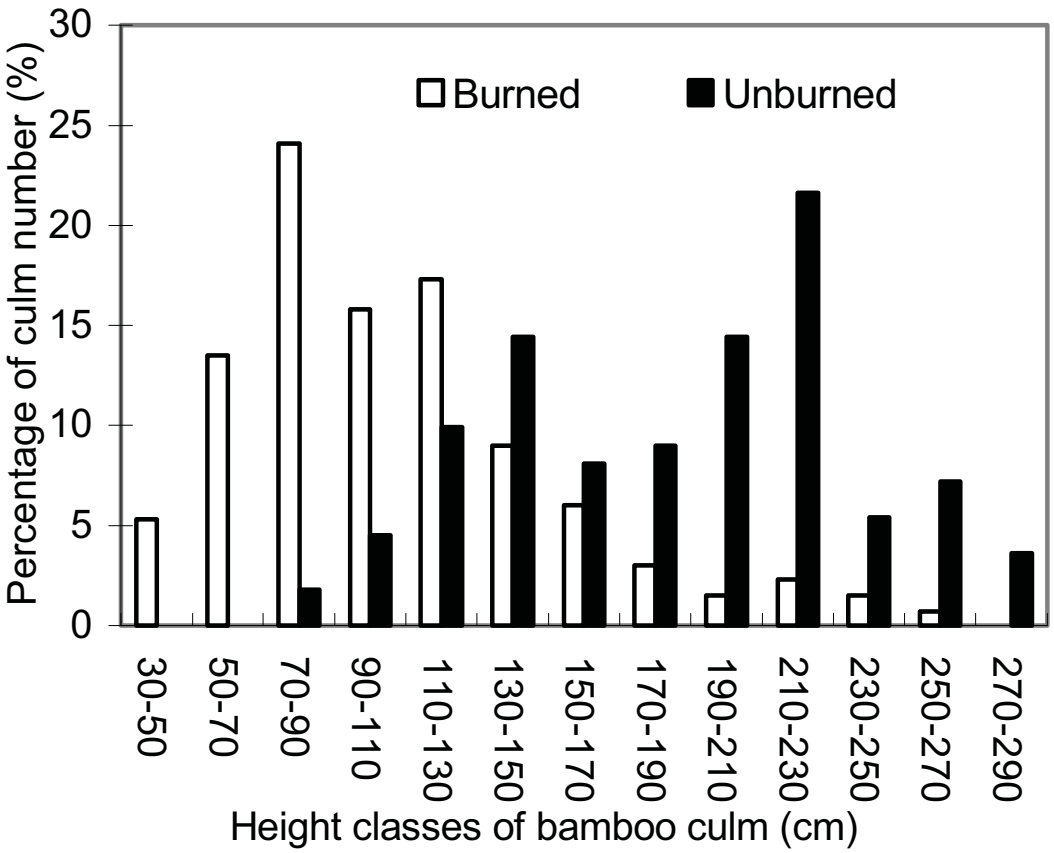

Figure 5.3: Height distribution of bamboo culms from a burned (1.2 m^2) and an unburned clump (1.3 m^2) of *Fargesia murielae* at Shennongjia in Central China.

5.3.3 Fire effects

Measurements show that 10 years after the fire, bamboo density in the burned clumps reached 99 ± 22 culms m^{-2}, which was about 34 % denser than in the unburned plots (64 ± 16 culms m^{-2}), indicating that the fire might have stimulated vigorous resprouting of bamboo culms. However, the culm height on the burned plots was only 166 ± 15 cm, about 35 % shorter than that in unburned plots (255 ± 22 cm). Height distributions (Figure 5.3) of bamboo culms from a burned clump (covering an area of 1.2 m^2) and an unburned clump (covering an area of 1.3 m^2) showed different patterns. In the unburned clump, culms in height grades strictly obeyed a normal distribution (t = 4.401, $d.f.$ = 13, P = 0.001), while a considerable fraction (19 %) of very short (< 70 cm) culms appeared in the burned clump, resulting in a lower significant (t = 3.613, $d.f.$ = 13, P = 0.004).

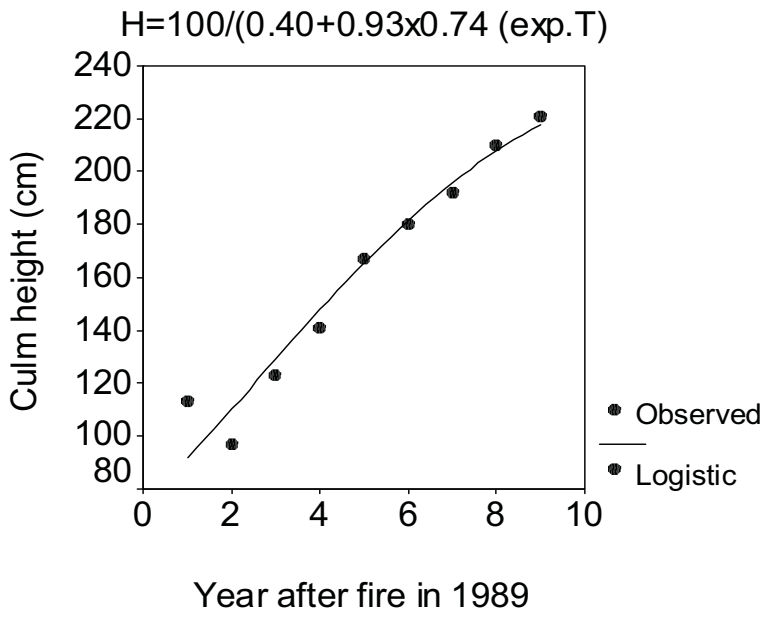

Figure 5.4: Post-fire recovery of bamboo height in a burned clump after the fire in 1989. In the model, H indicates the expected height and T means the time in years (r = 0.96, $d.f.$ = 7, F-value = 177.73, P < 0.001).

The age-based sequence of culm height in a burned bamboo clump illustrates the process of post-fire regeneration. The fire killed all aboveground culms, but the underground rhizomes survived and continued to sprout new culms every year. At first, the newly recruited culms were relatively short (113 cm in 1990), but during the course of time, the newly recruited shoots became progressively higher, e.g., culms emerging

in 1998 averaged 221 cm. Shoot sprouting in the bamboo clump ceased in 1999 and the clump flowered simultaneously in 2000. A logistic model (Figure 5.4): $H = 100 / (0.40 + 0.93\times0.74^{T})$ can significantly describe this recovery process ($r = 0.96$, $d.f. = 7$, F-value = 177.73, $P < 0.001$, H is the expected height, T the time in years). Considering the mean height of bamboo culms in the unburned plots was 255 cm, it is assumed, derived from the logistical model above, that the umbrella bamboo needs at least 13 years to return to its former height.

The influences of the fire were accumulated as a critical effect on the sexual regeneration after simultaneous flowering. From 1998 to 2000, all bamboo clumps in burned and unburned sites simultaneously flowered and died, all following a similar time pattern (Appendix 13). However, over 70 % (9 of 15) of clumps in the burned site flowered and died without producing seedlings. Seedling density over the burned plots in 2001 averaged 1.3 ± 2.3 seedlings m^{-2}, with the highest density being 7 seedlings m^{-2}. In contrast, all flowered clumps in the unburned site produced seedlings, with a mean density of 29.4 ± 15.2 seedlings m^{-2}. After simultaneous flowering, the bamboo clumps died in the succeeding years and the recovery of the bamboo stands then totally depended on the establishment and growth of seedlings (Taylor and Qin 1995). In the burned site, the lack of seedlings may trigger an extinction of underlying burned clumps.

5.4 Discussion

5.4.1 Flowering interval

All *Fargesia murielae* plants in the Western world were propagated vegetatively, starting with one plant from Shennongjia in 1907. In Europe and North America, this species flowered in 1993-1998 (Eberts 1996; Gielis et al. 1999; Shannik 1999). Considering this is the first simultaneous flowering since 1907, its flowering interval was estimated as being about 90 years (Shannik 1999). However, I should be cautious to accept this estimation because this species was introduced in the West as a vegetative clone, rather than as seeds or young seedlings.

Anecdotal evidence from a number of local elders indicated that the umbrella bamboo did not simultaneous flower between the "establishment of new China" (the Peoples' Republic of China) in 1949 and 1996, but the elders could not recall the last

flowering prior to 1996, which left a long gap between 1907 and 1949. In April 1907, Ernest Wilson recorded that this bamboo (specimen *Wilson 1462*) was “2-4 m tall, stems golden, without flowers” (Sargent 1913). In 1922 and 1926, the Chinese pioneer botanists H. R. Cheng and R. Cheng respectively visited Shennongjia; however, they neither recorded nor collected this bamboo species. I assume that the bamboo did not flower when they were there, as they would otherwise have had a flowering collection. The first record of this species in China is probably the vegetative specimen collected by Chang H. Zhou in 1935 (in Herbarium of Wuhan University, "*Arundinaria sp.*"). In 1943, another Chinese botanist Zhan Wang visited the umbrella bamboo ranges on the mountaintop. His colleague, the local governor Wen Z. Jia, described the umbrella bamboo stands as “bamboo like a sea and fir shading the sky”. Thus, we can assume that umbrella bamboo did not flower between 1907 and 1996 in Shennongjia.

However, I cannot confirm that the flowering interval of umbrella bamboo is 89 years (1907-1996), because Wilson’s field record indicated that umbrella bamboo was in the vegetative phase (2-4 m high, without flowers), rather than in the phase of seed or seedling at the beginning of its life history. Considering that *Fargesia* seedlings need about 20 years to reach the full height of the bamboo community prior to flowering death (Taylor and Qin 1993), I estimate that flowering interval of umbrella bamboo may be as long as 110 years, or more.

5.4.2 Flowering pattern

Flowering of the whole *Fargesia murielae* population over the mountain ranges in Shennongjia takes about five years. However, flowering was not randomly across the habitat: Observations indicate a temporal sequence during the flowering period. On the same slope, higher elevation pitches tended to delay and decrease the duration of simultaneous flowering. The altitudinal delay of simultaneous flowering is a common phenomenon over the mountain bamboos. Yi (1997) records that the simultaneous flowering of *Fargesia nitida* on Mount Jiuzhaigou in West Sichuan from 1982-1985 obviously extended from a lower elevation (started in 1982 below 2,700 m) to the mountaintop (started in 1985 over 2,800 m). Taylor et al. (1991) report that in the Wolong Giant Panda Reserve, West Sichuan, such a delay had led to the survival of *Bashania fangiana* in high altitude sites (above 3,000 m) for several years. Documented

evidences on the flowering of cultivated *F. murielae* indicate a latitudinal delay. All plants scattered in Europe are the ramset of the same genet from Shennongjia, mostly from an elevation between 2,400 and 2,600 according to Wilson's possible collecting route in 1907. Genetically, all plants may flower during the same period; however, the flowering process lasted six years from 1993 to 1998. In Europe, simultaneous flowering started in Germany and Britain, then extended to Switzerland, and finally arrived in Denmark in 1998 (Eberts 1996, Gielis et al. 1999). In North America, flowering started in USA in about 1995, and in Nova Scotia in Canada, simultaneous flowering was delayed until 1998 (Shannik 1999). In any case, the environmental variables can only affect the flowering sequence during the flowering period on a spatial scale, rather than determine the flowering cycles.

In Shennongjia, the spatial pattern that puzzled us was that in some places the yearly boundary of simultaneous flowering was too clear to be explained by either "available resource theory" or "mast year hypothesis". For example, in a bamboo stand (N31º26'936", E110º14'436", alt. 2,690-2,720 m, 30 ha) on the north-facing slope (Path 1), a flowering boundary strictly separated the stand into two parts, one (ca. 26 ha) completely flowering in 1997 and the other (ca. 4 ha) in 1999. Absolutely, this boundary was not determined by the topographical variation or "resource availability", since environmental conditions and vegetation were similar over the stand. I assume that this marked boundary must have been caused by a fire. After simultaneous flowering, the widespread death of bamboos makes them vulnerable to intensive fire because of the accumulated fuel load. When a wildfire occurs across a flowered stand, underlying bamboo seedlings will be killed and new seedlings may appear the following year from the soil seed bank. The new seedlings may genetically delay the flowering of a burned stand, compared with unburned stands. If one stand has been partially burned, a sharp flowering boundary will appear between the burned and unburned sites during the subsequent flowering period.

5.4.3 Seedling density

Makita (1992) divides the early regeneration process of bamboo after simultaneous flowering into three phases: establishment, stable density, and thinning phases. In the life history of bamboos, the seedling is most vulnerable shortly after germination

(Taylor and Qin 1988). The field data (Table 5.3) suggest that the seedling population suffered from a high mortality during the first year after simultaneous flowering. Under the fir-bamboo forest, bamboo seedling density fell from 7,110 seedlings m^{-2} in the first year to 960 seedlings m^{-2} in the second year after flowering, with a death rate above 85%. However, the seedling density was stable in years 2 to 4, maintaining about 1,130-1,230 seedlings m^{-2}. This initial result indicates that there is a very high mortality of the one-year old seedlings, but a stable phase between 2 and 4 years. When and how the seedlings pass through the self-thinning phase needs further observation.

The seedling density in two vegetation types, shrub-bamboo forest and bamboo-meadow, showed an average 200-300 seedlings m^{-2}, near that of *Fargesia scabrida* in West Sichuan eight years after the simultaneous flowering (Qin 1985). Deciduous forest, shrubs and meadow over the bamboo ranging between 2,400 m and 3,100 m have long been considered as secondary vegetation of the local climax of the fir (*Abies fargesii*) forest (Ban et al. 1995). Low seedling density in such secondary communities may indicate that human disturbances (i.e., burning and logging) may negatively influence the regeneration of natural bamboo stands. Taylor et al. (1993) studied the dynamic of bamboo density of *Bashania fangiana* in clear-cut and closed forest. The results suggest that although at first seedlings appeared in both the closed and clear-cut forest after simultaneous flowering, finally the seedlings in a closed forest rebuilt the bamboo community, while the seedlings on clear site lost vigor and were unable to restore the bamboo stand. Further studies are needed to assess whether *Fargesia murielae* follows the regeneration pattern of *Bashania fangiana* or not.

5.4.4 Fire effects

In both burned and unburned sites, all bamboo clumps flowered in 1998-2000, regardless of age, height, and density of the culms. It appears that environmental disturbances, including intensive fire, may not change the flowering cycle. Actually, all culms in an independent clump might be derived from the same genetic source: a single seed. Based on this concept, a clump represents a genet and culms are thus the ramet of this genet. When fire killed aboveground culms, the underground rhizomes ensured the survival of the genet. The life of the genet began when the bamboo seed germinated, rather than at the time of disturbance through the fire. When the life of the genets in

both burned and unburned sites begins at the same time, they may flower simultaneously.

Burned bamboo clumps flowered simultaneously with the unburned clumps; however, burned clumps failed to produce offspring. Rhizomes can maintain the genetic information of the genet, but cannot produce energy. All energy comes from the culms through the photosynthesis in their leaves. This energy is partly consumed by the culms themselves but the greater proportion is transported to the rhizomes (Isagi et al. 1997). When the genet flowers simultaneously, all energy goes towards flower production (Liese 1985). Simultaneous flowering makes the seeds plentiful, which is necessary to ensure restocking of a bamboo area after simultaneous flowering (Janzen 1976). For this reason, certain time is necessary for accumulating the energy for flowering and seeding. When the fire occurs such that the plant has sufficient time for the production and storage of energy before flowering, the flowering clumps might produce full seeds. However, when the fire occurs without providing sufficient time for energy storage, bamboo clumps might fail to seed after flowering. This recovery time may vary from species to species and is not yet known. For the species of *F. murielae,* the height recovery model suggests that new clumps need at least 13 years to reach the height they had prior to the fire. More time may be needed for the community to mature. The fire in the study site occurred in 1989, and the bamboo flowered in 1998-2000, meaning only 9-11 years for vegetative recovery and energy saving, even less than the minimum time for height recovery. Thus, when the genet matures to flowering, the ramets are still young. These immature ramets cannot support the mature genet in full seeding after flowering.

5.4.5 Flowering hypotheses

In the Plant Kingdom, grasses including bamboo belong to the seed plants. Flowering and seeding are necessary for reproduction and new generations. Flowering of some bamboos is cyclic (e.g. every 30 or 100 years), but for most bamboos flowering is unpredictable. Towards the end of the 1990s *Fargesia murielae* flowered in Europe, North America, and China. During this worldwide flowering event, nearly all plants of this species simultaneous flowered without any exception. Of 11 mountain bamboo

species in Shennongjia, all clumping bamboos, such as *F. murielae, F. spathacea, Y. confusa* flowered simultaneously at the end of their own life cycle (Table 3.2).

The myth is that why bamboo is able to flower periodically all over the world at the same time. To date, at least three explanations for such simultaneous flowering, i.e., external controls, predator satiation, and fire cycle hypothesis. Observations on the simultaneous flowering of *F. murielae* could not support the "external controls". *Fargesia murielae* grows in a diverse environments all over the world, from warm California to frigid Scot Nadia in North America, from frosted Denmark to sunny France in Europe, and from broadleaved forests in temperate belt to taiga in frigid temperate in Shennongjia. Over such scales, available resources including temperature, rainfall, soil nutrient are certainly different. However, all bamboos scattered in different environments flowered simultaneously without any exceptions. Furthermore, I comprised the flowering patterns between a burned and the unburned bamboo stands in Shennongjia. Results suggest that in the burned site, wildfire killed all aboveground parts of the bamboo in 1989, however the burned clumps simultaneously flowered in 1998-2000, following the same time pattern of the unburned stands in that area. Even the fire, one extensive natural force, could not change the flowering cycle of the bamboo. This phenomenon suggests that the external environments are not the driving force to control the flowering cycle of the bamboo, which may be determined by the internal genetic force. However, along altitudinal gradient in Shennongjia, *F. murielae* in lower elevations flowered earlier, while in the higher mountains flowering was successively delayed. I am not sure whether this is an environmental modification or genetic performance.

“Predator satiation” suggests that a long interval and simultaneous flowering is a survival technique. The seeds, which are a delicacy to rodents, must be produced to a saturation point. Only by devoting a grove’s entire resources to producing seed will there be enough for foraging animals and to establish new generation. However, the observation in Shennongjia did not universally agree with this theory. One obvious fact is that several species in Shennongjia belong to the simultaneous flowering group (Table 3.2), i.e. *Fargesia spathacea* (flowered in 1984-1988), *F. murielae* (in 1996-2000), *Yushania confusa* (in 1976-1979). According to the “predator satiation” hypothesis, I assume that comparing to the dominated species (*F. murielae* and

F. spathacea), the simultaneous flowering of rare species (*Y. confusa*) is just a minor flowering. For an evolutional run, minor species may have to simultaneously flower with dominated species, otherwise it would become extinct under the predators. Actually in Shennongjia, predator satiation is unable to explain why rare bamboo species can hold its own flowering cycle, without synchronizing with the predominated species.

On the other hand, the survey on post-fire regeneration of *F. murielae* in Shennongjia suggests that fire might have played a key role in synchronizing the flowering of bamboo species. Fire has two kinds of effects on the regeneration of bamboo: one is an immediate effect that influences the clonal growth; the other is an extending effect, which affects the sexual regeneration by influencing the seed production. The study presented that the wildfire did not threaten the vegetative survival of *F. murielae*. But, fire influence extending as a critical effect on the seed regeneration after simultaneous flowering: over 70 % of flowered bamboo clumps in the burned site produced no seedlings. We can assume that at the very beginning, one bamboo community contains several clumps with different ages. When a wildfire burned the bamboo on community level, some young clumps have enough vegetative time to accumulate energy for seeding, but old clumps may not have sufficient time for storing energy. So the old clumps flowered without full seeding, resulting in the disappearance of this age group. The space would be occupied by the young clumps which were still alive. Generation after generation, the age diversity of bamboo community reduced to its lowest, and a simultaneous flowering then was formed. This hypothesis allows different species carrying different flowering intervals.

6 EFFECT OF *FARGESIA MURIELAE* ON PLANT DIVERSITY IN FIR FOREST

Summary: Simultaneous flowering caused a gregarious dieback of umbrella bamboo (*Fargesia murielae* (Gamble) Yi) all over the world in 1993-2000. This catastrophic death is troublesome on bamboo plantation in European gardens, but provides an infrequent opportunity for the tree regeneration and species recovery in its associated forests in Central China. Mount Shennongjia is the native home of *F. murielae*, where the bamboo dominates the understorey of the farges fir (*Abies fargesii*) forest between 2,400 and 3,100 m asl, covering the ground for more than one century before a periodically flowering death. Data from 20 quadrats along a vegetation sequence present that the density, coverage, and height of umbrella bamboo negatively affected the species richness, diversity, and evenness of vascular plants in the bamboo associated vegetation. Local climax community of fir-bamboo was the poorest in species diversity, while the bamboo-free communities (i.e. shrubs and meadows) were bearing a higher species diversity. The simultaneous dieback of umbrella bamboo is a necessarily ecological release, which can periodically promote the plant diversity in the fir forest.

6.1 Introduction

Umbrella bamboo (*Fargesia murielae* (Gamble) Yi) is one of the most popular and widely grown garden bamboos in Europe and North America (Keng and Wang 1996, Gielis et al. 1999). It was introduced in the West by Ernest H. Wilson (1876-1930) from Central China in 1907 (Sargent 1913, Eberts 1996). All plants of umbrella bamboo scattered in Europe are the ramets of the same genet from the Kew Gardens (Gielis et al. 1999). From 1993 to 1998, umbrella bamboo simultaneously flowered and then died all over the world (Renvoize 1993, Eberts 1996, Shannik 1999), resulting in a gregarious demise of this garden plant. However, the ecological performance of this species in its natural habitats is unknown yet.

Mount Shennongjia (N31º21'-37', E110º03'-34', alt. 3,105 m asl) is the native home of umbrella bamboo (Zhu et al. 1994, Keng and Wang 1996), where it occurs between 2,400 and 3,100 m asl, predominating in the understorey of farges fir (*Abies fargesii*) forest (Ban et al. 1995). In 1996, umbrella bamboo started to flower at low elevations, and then successively extent to higher mountains. Until 2000, over 95 % of

bamboo clumps simultaneously flowered and died back. This is the first intensive flowering since Ernest Wilson recorded it as a "most beautiful Chinese bamboo" (specimen *Wilson 1462*) in 1907 (in Sargent 1913).

During their vegetative period, mountain bamboos usually form a single strain, covering the ground of their associated forests for several decades, and shading the forest floors more effectively than canopy trees (Taylor and Qin 1992, Wada 1993, Taylor et al. 1995, 1996, Gratzer et al. 1999). The dense understorey of bamboo, not only competes against other species for light, water, nutrients and facilitation (e.g., Nakashizuka 1988, Holmgren et al. 1997, Gratzer et al. 1999), but also carpets the forest floors and leads to pulses of resource availability for tree regeneration. It is recognized that the simultaneous flowering and subsequent dieback of the bamboo can promote tree regeneration of its associated forests (e.g., Nakashizuka 1988, Taylor et al. 1996). Nevertheless, how does the bamboo affect the plant diversity in its associated vegetation is not certainly concerned. This study is aimed at assessing the relationship between umbrella bamboo and the plant diversity in its associated fir forest therefore to appraise the ecological importance of bamboo in the local ecosystem.

6.2 Materials and methods

6.2.1 Study site

The fieldwork was conducted in a fir forest near the Observation Tower (N31º27'069", E110º16'040", alt. 2,930 m) in the Shennongjia National Nature Reserve, West Hubei in Central China (Figure 6.1). Here tectonic uplift and fluvial erosion have produced a deep incised topography in the landform. Slopes are steep (30-65º), but the mountaintops are relatively plain. Climate is characterized by cool raining summers and cold windy winters due to its high elevation. According to the meteorological records at the Observation Tower in 1997-1998, the mean annual temperature is around 2.2 ºC, with the monthly maximum of 8.1 ºC in July and monthly minimum of -9.4 ºC in January. The annual precipitation is about 2,330-2,780 mm. Snowfall normally starts at the end of October and covers the land until next April. The landscape is mainly covered by farges fir (*A. fargesii*) forest, with a few coexistent broadleaved trees from the genera of *Betula* and *Acer*.

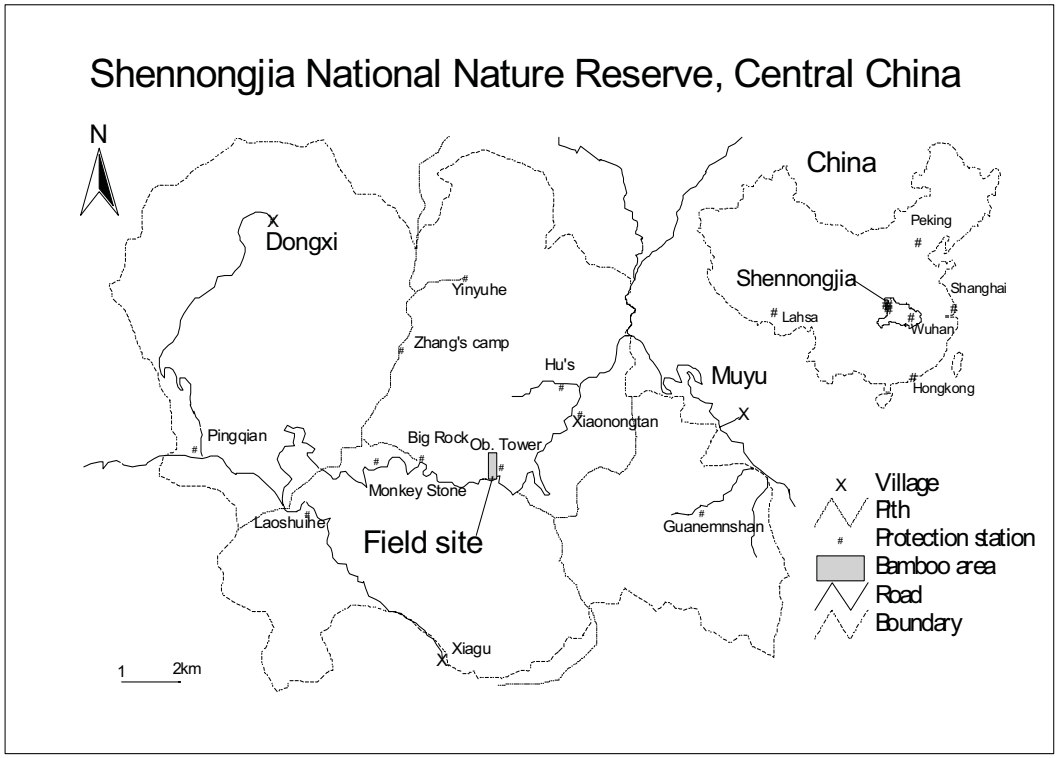

Figure 6.1: Location of field site in the Shennongjia National Nature Reserve, Hubei Province, China.

6.2.2 Data collection

Field data were collected in July-August 2000, when the herb layers were fully developed. A transect was set up in a vegetation sequence from an open valley (N31º27'142", E110º16'122", alt. 2,890 m) up to the mountaintop (N31º27'090", E110º16'083", alt. 2,932 m). Along the transect 20 quadrats were established, each 5 × 5 m^2 in size. An inventory of plant species and measurements of coverage, dominance, density and height were carried out for each species. Seedlings from woody species were also recorded. The field records were then synthesized as a cover-abundance rating for each species on a 5-point sociability index (Moore and Chapman 1986): 1- Single plant; 2- Grouped or tufted; 3- Troops, small patches or cushions; 4- Small colonies, in extensive patches or forming carpets; 5- Large crowds or pure populations. Mosses and lichens were excluded. In each quadrat, one 1 × 1 m^2 sub-quadrat was set up for measuring the height, density, and flowering year of the bamboo culms. Bamboo

seedlings were measured in July 2001, since some clumps had flowered in 2000 and seedlings only emerge the following year.

6.2.3 Data analysis

Species richness, diversity, and evenness were calculated for all 20 quadrats. Species richness (*S*) was considered as the number of species, since all quadrats were of the same size. Species diversity was calculated as the Shannon-Wiener Index (Ludwig and Reynolds 1988):

$$H' = -\left[\sum (Pi)(Ln(Pi))\right]$$

where *H′* is the Shannon-Wiener Index; *Pi* indicates the sociability index of *i*th species; and *Ln(Pi)* means natural log of *Pi*. The evenness index (*J′*) was derived from the Shannon-Wiener Index (*H′*) and species richness (*S*) with the formula:

$$J' = \frac{H'}{Ln(S)}$$

The Diverse Hierarchical Cluster Analysis (S-Plus 2000) was used to classify the quadrats into community types, based on the sociability index of the species in different quadrats. Paired Samples Correlation (SPSS for Windows 10.0) was used to examine the relationship between species variables and bamboo features.

6.3 Results

6.3.1 Species diversity on plot level

A total of 32 species of vascular plants were found over the 20 quadrats along the transect, including one tree species (*Abies fargesii*), four species of shrubs (*Sorbus huphensis*, *Malus kansuensis*, *Acer maximowiczii*, and *Crataegus wilsonii*), one species of bamboo (*Fargesia murielae*), and 26 species of grasses and forbs (Appendix 14). Species richness (*S*) over the individual quadrats varied between 4 and 12 species (Table 6. 1), with an average level of 8 ± 2 [± S.D.] species quadrat^{-1}. Pair samples analysis shows that species richness was negatively affected by density (r = -0.581, P =

0.007), sociability (r = -0.505, P = 0.023), height (r = -0.493, P = 0.027), and coverage (r = -0.485, P = 0.03) of the bamboo. Species diversity (H') varied from 1.31 to 2.34, with a mean value of 1.85 ± 0.32. It positively related to the species richness (r = 0.968, P = 0.000), but negatively to density (r = -0.689, P = 0.001), sociability (r = -0.633, P = 0.003), coverage (r = -0.610, P = 0.004), and height (r = -0.609, P = 0.000) of the bamboo. Species evenness varied between 0.84 and 0.99, with a mean value of 0.93 ± 0.04. It positively related to species diversity (r = 0.556, P = 0.009), but showed little relation to species richness (r = 0.374, P = 0.104). Evenness also negatively related to coverage (r = -0.708, P = 0.000), sociability (r = -0.682, P = 0.001), height (r = -0.641, P = 0.002), and density (r = -0.624, P = 0.003) of the bamboo.

Table 6.1: Summary of species diversity of vascular plants and bamboo features over 20 quadrats along a vegetation transect near the Observation Tower in Shennongjia, Central China.

Quadrat	Plant species features			Bamboo features			
	Richness (S)	Diversity (H′)	Evenness (J′)	Sociability index	Density (Culm m^{-2})	Mean height (m)	Cover (%)
V1	7	1.79	0.92	5	98	4.2	80
V2	11	2.22	0.93	5	92	3.5	70
V3	10	2.21	0.96	0	0	0	0
V4	5	1.41	0.88	5	114	3.3	80
V5	12	2.34	0.89	0	0	0	0
V6	8	2.02	0.97	0	0	0	0
V7	7	1.87	0.96	0	0	0	0
V8	8	2.06	0.99	0	0	0	0
V9	6	1.65	0.92	4	132	3.5	50
V10	6	1.63	0.91	5	121	3.5	70
V11	5	1.49	0.93	0	0	0	0
V12	7	1.80	0.93	0	0	0	0
V13	6	1.50	0.84	5	64	3.8	60
V14	9	2.10	0.96	0	0	0	0
V15	10	2.20	0.96	0	0	0	0
V16	4	1.31	0.94	5	142	3.6	60
V17	10	2.21	0.96	0	0	0	0
V18	7	1.74	0.89	5	93	3.2	100
V19	5	1.37	0.85	5	187	2.9	100
V20	8	1.98	0.95	0	0	0	0

6.3.2 Plant diversity on community level

The vegetation type in the study area was classified as a farges fir (*A. fargesii*) forest (Ban et al. 1995). However, cluster analysis (Figure 6.2) suggests that vegetation here can be classified as four communities in two groups. Group I is the original vegetation - fir (*A. fargesii*) forest, which includes two communities (clusters): Cluster 1 (V1, V9, V10, V19, V18, V2, V4, V20, V13, V16) represents the fir-bamboo community and Cluster 2 (V6, V11) the fir-herb community. Group II is the disturbed vegetation, which also includes two communities (clusters): Cluster 3 (V3, V7, V14, V15, V8) represents the herb community and Cluster 4 (V5, V17, V12) the shrub community. Bamboo-associated community (Cluster 1) showed poor species richness (7 ± 2), lower diversity (1.7 ± 0.3), and weaker evenness (0.90 ± 0.03), while bamboo-free communities (Cluster 2, 3, 4) showed relatively high species richness (9 ± 2), diversity (2.0 ± 0.3), and evenness (0.95 ± 0.02).

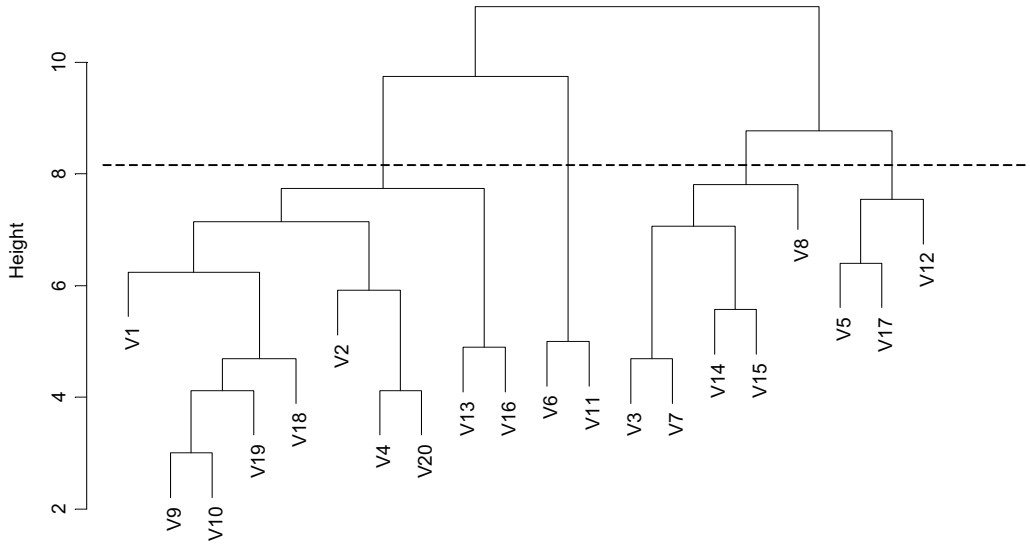

Figure 6.2: Cluster diagram of plant quadrats along a vegetation transect of the fir (*Abies fargesii*) forest in Shennongjia at Central China. The quadrats can be classified into 4 clusters, which are interpreted as 4 communities based on the field observations: Cluster 1 (V1, V9, V10, V19, V18, V2, V4, V20, V13, V16): Fir-bamboo community; Cluster 2 (V6, V11): Fir-herb community; Cluster 3 (V3, V7, V14, V15, V8): Herb community; Cluster 4 (V5, V17, V12): Shrub-herb community.

Different communities presented different species patterns. The shrub community (Cluster 4) showed the highest species richness (10 ± 3), which was slightly higher than that of the herb (Cluster 3; 9 ± 1), but significantly (P = 0.003) higher than that of the community of fir with bamboo (Cluster 1; 7 ± 2). The variation of species diversity (H') over four communities followed a pattern similar to that of species richness: shrub community (2.1 ± 0.3) > herb community (2.0 ± 0.1) > fir-herb community (1.8 ± 0.4) > fir-bamboo community (1.7 ± 0.3). However, species evenness showed a different pattern: Herb community had the highest species evenness (0.97), followed by fir-herb community (0.95), shrub community (0.92), and fir-bamboo community (0.90).

6.3.3 Bamboo flowering

A total of eight bamboo clumps were encountered on the study site. The clump sizes varied from 12-50 m^2. All bamboo clumps fully flowered between 1998 and 2000. One clump flowered in 1998, five clumps in 1999, and two clumps in 2000. Pair samples analysis showed that the flowering year of bamboo clumps revealed little relationship with the background communities, e.g., correlation coefficient between bamboo flowering year and canopy coverage from *A. fargesii* is -0.048 (P = 0.750). Nevertheless, the flowering time had significantly affected the coverage of the herb layer (r = 0.535, P = 0.000). The earlier flowering quadrats had higher species richness and diversity. It indicated that the species tended to invade the bamboo stands when the bamboo plants had withered.

6.4 Discussion

6.4.1 Bamboo effects on species diversity

The concept of species diversity, as a central theme in community ecology (Magurran 1988), embodies two notions: Richness, which indicates the number of different species, and evenness, which indicates the relative importance (e.g., abundance) of the species (Ludwig and Reynolds 1988). The results show that the bamboo layer negatively affected the species diversity with regard to both richness and evenness in its associate vegetation. I assume that in the fir forest, bamboo acts as an ecological filter during its vegetative period. For example, in order to reach the overstorey canopy, all seedlings of

canopy trees and high shrubs must become established in and grow through the bamboo layer. However, only few species can grow through such dense bamboo layers, since bamboo intercepts much of the light, thus altering light quality and reducing light quantity. The denser the bamboo layer, the poorer the light conditions beneath the canopies, which results in a negative relationship between the bamboo features (i.e., density, coverage and height) and the species diversity of its associate vegetation.

In fact, umbrella bamboo vegetatively reproduces itself for about one century through underground rhizomes, forming a dense group - sometimes carpeting a forest floor for many square meters persisting for a species' specific period of time before flowering and dying. Furthermore bamboo rhizomes are able to survive the extreme conditions, i.e., a thick snow cover in the study site may kill tree seedlings and weak forbs during the winter, but protect the bamboo rhizomes from frost damage. The bamboo rhizomes spread year after year to new sites to create a bamboo-uniform habitat. Loss of microhabitat diversity may cause the decrease of species diversity in the bamboo-dominated communities.

Historically, the giant panda might have been a major force for controlling the monopolization of bamboo in Shennongjia. The giant pandas thrived in Shennongjia for thousands of years until the late 19th century when they became extinct (Reid and Gong 1998, Fong and Li 2000, Li and Denich 2001). Bamboo comprises 99 % of a giant panda's diet (Schaller et al. 1985). In Shennongjia, according to the list of bamboos forming the giant panda's diet (Yi 1985), *F. murielae* was the bamboo most preferred by the panda. An adult giant panda consumes about 4,500 kg of bamboo per year, amounting to an estimated 466,000 shoots and culms (Schaller et al. 1985). Considering that the bamboo density in the standing clumps under the fir forest site was around 130 culms m^{-2} (Table 6. 1), one panda could produce 3,580 m^2 (0.36 ha) bamboo margins per year. In other words, during the life history of *F. murielae*, one giant panda is able to generate 0.3-0.4 km^2 of space for other species. However, after the giant panda became extinct a century ago, the flowering death became the only force preventing the invasion of bamboo and promoting the recovery of species diversity of the fir forest. Thus, if the umbrella bamboo were not to die back, the fir forest would consequently suffer from a loss in species diversity.

6.4.2 Effect of bamboo on community diversity

Fir forest is the most dominant and stable vegetation in the high mountains of Shennongjia (Ban et al. 1995). Farges fir (*A. fargesii*) is the only tree species in the study site. Under its canopy (Figure 6.3), where umbrella bamboo occurred as understorey, conditions were generally cool and moist. Under the bamboo, only grew a number of shade-tolerant herbs, such as *Oxalis griffithii*, *Rubia cordifolia*, and *Polygonum viviparum*. The canopy cover from the farges fir was about 60 %, while umbrella bamboo covered 70-90 % of the forest floor. A thin herb layer covered 10-20 % of the ground. This community is very poor in species diversity, due to high bamboo coverage.

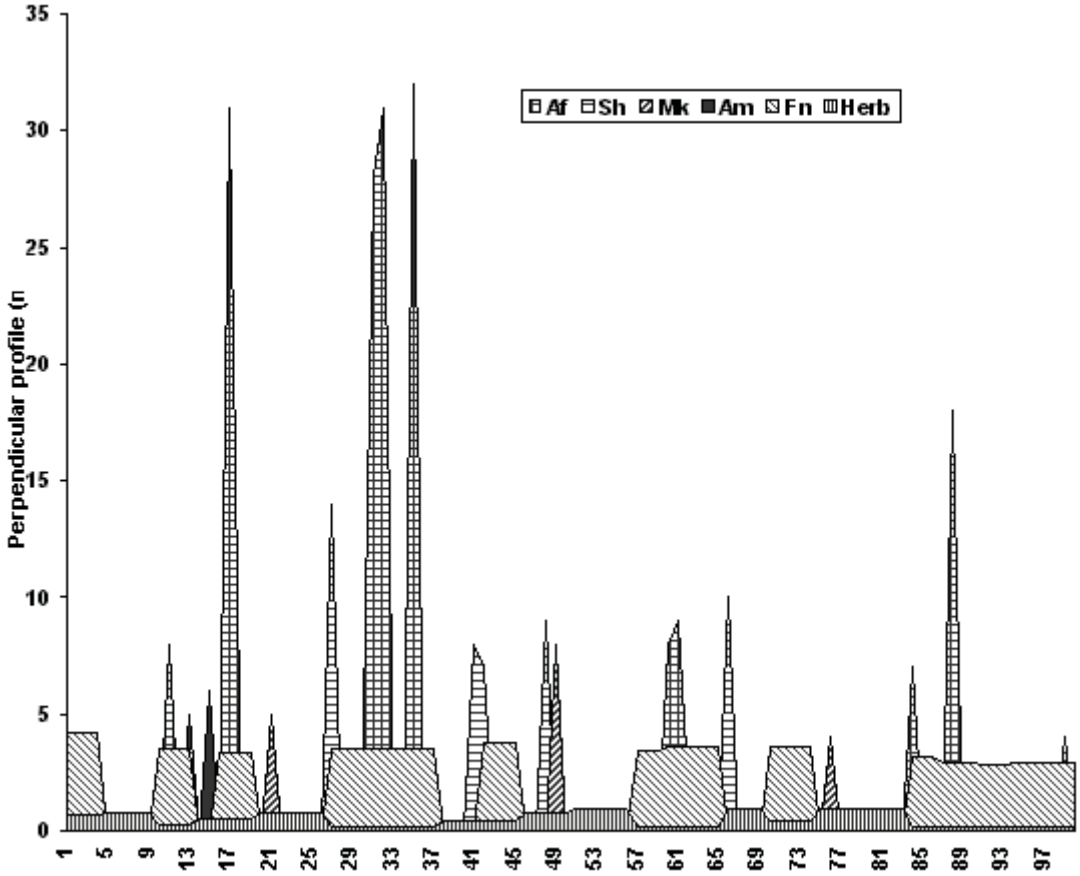

Figure 6.3: Diagram of perpendicular profile of a fir forest along a strip transect on Mount Shennongjia in Central China. Transect is 100 m long with 5 m in wide. In the diagram, Fn = *Fargesia murielae*, Herb = vascular herbaceous plants, Mk = *Malus kansuensis*, Sh = *Sorbus huphensis*, Am = *Acer maximowiczii*, and Af = *Abies fargesii*.

When fir forest is disturbed or burned, species diversity rapidly increases. Wildfire is usually considered to be the major disturbance of the local vegetation in

Shennongjia (Ban et al. 1995, Zhu and Song 1999). It usually kills *A. fargesii*, but the resprouting species, e.g., shrub species such as *S. huphensis* and *M. kansuensis*, and the bamboo *F. murielae*, survive. In the burned sites, the microclimate is warmer and dryer, and grasses rapidly occupy the ground. Consequently, the degraded vegetation tends to gain species during the course of succession. However, umbrella bamboo is also a sprouting species that efficiently survives the fire by producing new plants from the underground rhizomes. The existence of bamboo limits the invasion of new species, but provides shelter for the shade-tolerating fir seedlings. Therefore, bamboo can also negatively affect the community diversity in the fir forest habitats.

Many bamboos differentiate them from other members of the grass family by simultaneously flowering (Liese 1985, McClure 1993). But After growing by rhizome and branch production for a species-specific period of 3-120 years, nearly all the members of one species in one area produce wind-pollinated flowers, set large quantities of seed and die (Janzen 1976). Although the cues that trigger simultaneous displays are not well understood (Liese 2001), the effects of bamboo on the tree regeneration are widely recognized (Nakashizuka 1997, Taylor et al. 1988, 1992, 1995, Gratzer et al. 1999). In the study quadrats, there were six woody species, but only four different seedlings were discovered: *A. fargesii*, *C. wilsonii*, *S. huphensis*, and the bamboo *F. murielae*. Bamboo seedlings grew densely on all quadrats except in the herb community. Individual seedlings of *A. fargesii* occurred over the site except in the herb community. The shrub seedlings *C. wilsonii* and *S. huphensis* only grew under the parent plants where bamboo did not exist. The age structure of *A. fargesii* presented a pyramidal model: Adult tree (higher than 20 m): young tree (6-19 m): established seedling (0.5-5 m) = 1 : 2 : 2. Because shrub seedlings such as *C. wilsonii* and *S. huphensis* never occurred inside the bamboo clumps, it seems that the flowering death of umbrella bamboo may not strongly affect the growth of the seedlings from these species. On the other hand, seedlings and saplings from *A. fargesii* were common in the bamboo clumps, which indicates that the seedling establishment of *A. fargesii* was not dependent on the sim ultaneously dieback of the bamboo. This phenomenon was also observed in *Yushania* bamboo associated fir (*Abies densa*) forest in central Bhutan Himalayas (Gratzer et al. 1999). Nevertheless, the dieback of bamboo may release light and available resources to the *Abies* seedlings. *Fargesia* bamboos usually need 15-21

years for developing from seed germination to a stable community (Tian 1991, Taylor et al. 1992). During the course of two decades, fir saplings and seedlings can develop to an upperstorey and meanwhile some other species also invade the old bamboo stands, resulting in an increase of species richness. Thereafter, with the successively growth of bamboo, the plant diversity may tend to decrease until next simultaneous flowering of the bamboo.

7 GENERAL DISCUSSION AND CONCLUSION

7.1 Bamboo and giant panda in Shennongjia

Fossil evidence has demonstrated that the giant panda was once widespread in southern and eastern China and in neighboring Myanmar and North Vietnam (Schaller et al. 1985; Taylor et al. 1991; Reid and Gong 1998; Loucks et al. 2001). However, by 1800 the giant panda likely occurred only in two isolated mountain regions (Figure 7.1): one is on the east slope of the Tibetan plateau in central Sichuan and southern Gansu, stretching east to the Qinling Mountains of south-central Shaanxi; the other is in a hilly country in southern Shaanxi, eastern Sichuan, western Hubei, and north western Hunan, with Shennongjia as the highest peak and distribution center (Fong and Li 2001). By 1900, pandas were apparently extinct over the eastern region including Shennongjia (Schaller et al. 1985; Reid and Gong 1998). Why the giant panda became extinct from Shennongjia has not been fully understood yet.

Bamboo availability has long been considered as a key factor that affects the survival of the giant panda (O'Brien and Knight 1987; Taylor et al. 1991; Fong and Li 2001). In the mid-1970s, three species of *Fargesia* bamboos flowered and died within a few years in the Min Mountains. Consequently, a total of 138 giant pandas were found dead, mainly due to starvation (Schaller et al. 1985). In the early 1980s, *Bashania fangiana*, the preferred sub-alpine bamboo in the Qionglai Mountains, simultaneous flowered (Reid et al. 1989). Another 141 pandas were found dead (Fong and Li 2001). In fact, wild pandas rapidly declined in China from about 2,000 animals in the 1960s to less than 1,200 in the 1990s (Li and Denich 2001). Considering the serious problems of bamboo flowering and environmental degradation in panda habitats in Sichuan, the Chinese government proposed to remove the starving giant pandas to one of its historical habitats, Shennongjia in Central China (Figure 2.1). This proposal has not been put into practice, due to many reasons. One of the essential problems is that the availability and carrying capacity of the food bamboos in Shennongjia is unknown.

7.1.1 Bamboo availability

A total of 11 bamboo species were recorded during the investigation in Shennongjia (Table 3.1). According to the panda diet list (Yi 1985), *F. spathacea, F. murielae,* and

Y. confusa are the preferred food, while *Ph. heteroclada, Ph. nidularia* and *Indocalamus* bamboos are the acceptable food of the panda. *Fargesia spathacea* and *F. murielae* are the predominant species that comprise the staple food of the giant panda.

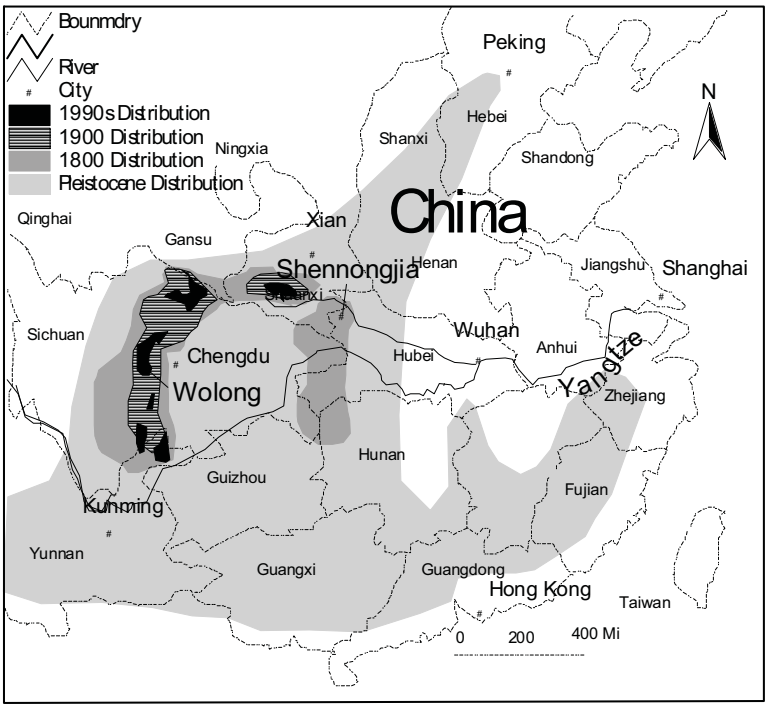

Figure 7.1: Distribution of the giant panda in China during Pleistocene (50,000 years ago), 1800, 1900, and 1990s (adapted from Fong and Li 2001).

Pandas select certain bamboo species on a seasonal basis, and consequently undergo altitudinal migration in certain seasons. Key factors inducing these movements are availability of bamboo shoots, and severity of winter weather (Schaller et al. 1985). For example, in Wolong Reserve, giant pandas spend most of the year feeding on leaves and stems of *Bashania fangiana* bamboo, from 2,600 to 3,400 m in the sub-alpine conifer forest. In May, most pandas move down-slope to feed almost exclusively on emerging shoots of *Fargesia robusta*, which only grows below 2,600 m under a mixed canopy forest. By late June, when shoots are fully grown and fibrous, the pandas move back upslope to feed on *B. fangiana* again (Campbell and Qin 1983; Schaller et al. 1985; Reid et al. 1989). Apart from during the sprouting season, pandas feed on *F. robusta* when winter snow makes foraging more difficult in the conifer forests

(Schaller et al. 1985), or soon after a die-back of the dominant *B. fangiana* (Reid and Hu 1991).

In Shennongjia, altitudinal distribution of two major food species, *F. spathacea* (1,200-2,600 m) and *F. murielae* (2,400-3,100 m), follows the same pattern of *F. robusta* (1,800-2,600 m) and *B. fangiana* (2,600-3,400 m) in Wolong. *Fargesia spathacea* starts sprouting new shoots in late March in the low elevations and the sprouting phase lasts until late May in upper mountains, providing the panda with fresh shoots from early April to June. When shoots of *F. spathacea* become fibrous, the panda can move to upper mountains to feed on newly growing shoots from *F. murielae*, which produces available shoots from late June to July (Table 4.12). Beside these two staple food species, *Y. confusa* and *Ph. heteroclada* may provide the giant panda with an additional choice. Therefore, in Shennongjia, bamboo is available to the giant panda in terms of species availability, diet combination, and fresh shoot supply.

Table 7.1: Panda carrying capacity of three preferred bamboo species in Shennongjia.

Species	Coverage	Area (km^2)	Carrying capacities (no. of pandas)	
			(3.8 km^2 $panda^{-1}$)	(3.3 km^2 $panda^{-1}$)
Fargesia spathacea	12 %	384	101	116
Fargesia murielae	8 %	256	67	76
Yushania confusa	3 %	96	25	29
Total	23 %	736	193	223

7.1.2 Carrying capacity

An adult giant panda consumes 12-15 kg of food per day when feeding on bamboo leaves and stems. However, when feeding on new bamboo shoots, they are capable of eating up to 38 kg day^{-1}, which is about 40 % of their average body weight (Schaller et al. 1985), which results in a low density of the panda over the habitats. On average, within the 6,000 km^{-2} panda habitats in China, an area of 9.3-10.7 km^2 can support a panda. But in the bamboo-covered stands, an area of 3.3-3.8 km^2 is sufficient to feed a panda (Schaller et al. 1985).

Shennongjia has an area of 3,200 km^2, in which 23 % of the land is covered with three preferred forage bamboos, *F. spathacea* (12 %), *F. murielae* (8 %), and *Y. confusa* (3 %) (Table 3.2). This habitat area, on the average level, could support 300-

344 pandas. On the other hand, preferred bamboos could feed 193-223 pandas. It is accepted that 30 individuals can form a viable effective giant panda population (Hu 1998). So the carrying capacity of both the mountain ranges and food supply was high enough to support an effective population.

7.1.3 Bamboo flowering risk

In Shennongjia, *Fargesia murielae* simultaneously flowered in 1996-2000. This is the first mass flowering since Ernest Wilson recorded it in 1907. The flowering interval of *F. murielae* was as long as ca. 110 years (1886-1996). *Yushania confusa* once flowered around 1888 (sample *Henry 6832* in Kew). After that it flowered again in 1976-79, which indicates that the flowering interval of this bamboo is about 88 years. The latest flowering of *F. spathacea* occurred in 1984-88 and the flowering prior to this time was around 1949. Thus, the flowering interval of *F. spathacea* is assumed as 35 years.

Historically, panda populations have obviously survived thousands of flowering events without any help from humans. When one bamboo species had flowered, pandas would normally switch to other species, or expand their home ranges to access areas where bamboo had not flowered. However, the panda habitat has been fragmented into isolated areas by human activities in recent centuries, and migration to other areas where bamboo is still plentiful is thus obstructed. During the flowering death of bamboo species in the Min Mountains in the 1970s, bamboo species' richness significantly reduced the mortality. In the area with only one bamboo species, between 30 and 80 % of the pandas died, while in the area with two or more, few animals died (Schaller et al. 1985). Therefore, when a substantial standing crop of at least one alternative bamboo is available, the threat to the giant panda is greatly reduced.

Normally, forage bamboos in Shennongjia could support a panda population of 193-233 animals. When one or even two species die back, other bamboo species can support the underlying population throughout the hard time. Such food shifting is a common strategy of the giant panda for surviving the bamboo flowering, e.g., when *B. fangiana* flowered in the Qionglai in the 1980s, for a short period, pandas cropped more culms from the remaining un-flowered clones than these clones replaced with new shoots (Reid et al. 1989). After a few years they changed their winter food habits, and began to eat more of the alternative lower elevation bamboo (Reid et al. 1989).

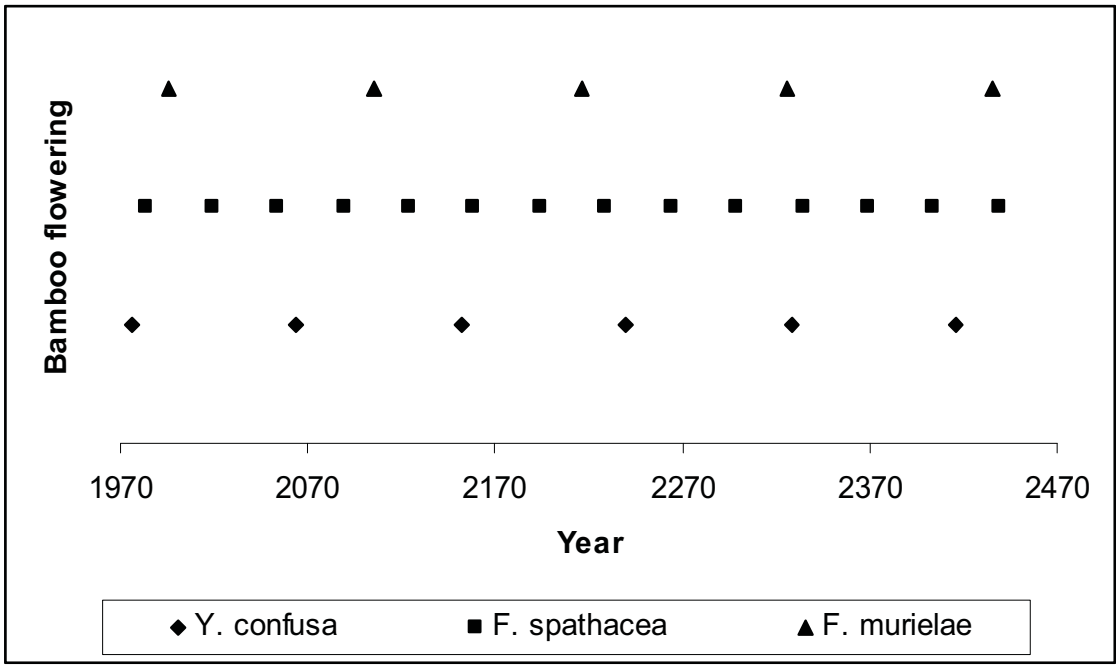

Figure 7.2: Prediction on synchronous flowering of three bamboo species in the coming 400 years in Shennongjia, Central China.

However, this may be desirable when multi-species flowerings are nearly synchronous. In Shennongjia, three preferred food species, *F. murielae*, *F. spathacea,* and *Y. confusa* have their own flowering intervals, i.e., 110, 35, and 88 years, respectively. Under the assumption that the intervals are genetically fixed, in the past four centuries (1600-2000), *F. murielae* flowered 4 times (1666, 1776, 1886, and 1996), *F. spathacea* 11 times (1634, 1669, 1704, 1739, 1774, 1809, 1844, 1879, 1914, 1949, 1984), and *Y. confusa* 5 times (1616, 1704, 1792, 1880, 1888, 1976). The staple food species *F. murielae* and *F. spathacea* might have synchronously flowered twice in the past four hundred years: 1666 (*murielae*) - 1669 (*spathacea*) and 1774 (*spathacea*) - 1776 (*murielae*), but *Y. confusa* might have carried some pandas over this hard time. An intensive flowering occurred in 1879-1888: during less than ten years, three species flowered and died back one after another. In this case, the pandas had to migrate to other habitats where suitable bamboos were available. Historically, this migration was a normal way to maintain the population, and even a method to eliminate the weaker and sick individuals.

Geographically, Shennongjia is separated from the northern panda habitats of Qinling by the Hanshui River and from southern panda habitats in northern Hunan by the Yangtze River. In the east, Shennongjia faces an extensive low-land area: Jianhan Plain, one of the most famous agricultural regions in China. This plain has an agricultural history going back 3,700 years ago and as early as the Song Dynasty (960-1279), being completely occupied by humans (Cheng et al. 1995). So when the bamboos died back in Shennongjia, the affected giant pandas mostly moved to western habitats, i.e., panda habitats in central and western Sichuan. However, since the Qing Dynasty (1616-1912), millions of people, called by the government, had migrated to the Sichuan basin, an event named "Filling Sichuan". Shennongjia was successively separated from the western panda habitats by the well-populated Sichuan basin. Consequently, Shennongjia became an isolated panda island. When three preferred species synchronously died in 1879-1888, starvation might have caused the extinction of the pandas in Shennongjia.

A prediction (Figure 7.2) on the flowering of these three species shows that in the coming 500 years (2000-2500), three multi-species flowering will occur in Shennongjia. The most serious flowering will occur in 2436-2439, when two staple food species, *F. spathacea* and *F. murielae* may synchronously flower and die. On this prediction, moving the giant panda to Shennongjia is a risky task, as the bamboos in Shennongjia also regularly flower and die, without any exception.

7.2 Conclusions

1) There are 11 bamboo species occurring in the mountain ranges of Shennongjia. Of these, three species, i.e., *Fargesia murielae, Fargesia spathacea*, and *Yushania confusa* are the preferred forage bamboos of the giant panda. These three species currently cover 12 %, 8 %, and 3 % of the land area of Shennongjia, respectively.

2) New shoots of the bamboo emerge from the ground once a year. About 18-32 % of new shoots from three observed species (*Phyllostachys nigra* var. *henonis*, *Indocalamus latifolius*, and *Fargesia spathacea*) died back before maturity, due to insect and virus damage, malnutrition death and animal predation. The shoots grew to their full height within 34-92 days in the first vegetative year. Thereafter, their height, diameter and volume were stable and did not change noticeably. Bamboo species with monopodial

rhizomes usually have a short sprouting phase and growth period, while those with sympodial or amphipodial rhizomes have a relatively long sprouting phase and growth period.

3) Shennongjia is the native home of *Fargesia murielae*. Here this species gregariously flowered and died back in 1996-2000, after about 110 years' vegetative regeneration. Bamboo seedlings achieved a high density in the autumn of the first year after flowering, but over 80 % of emerged seedlings died back in the first winter. Thereafter, seedling density tended to stable in following 2-4 years.

4) The density, coverage, and height of *F. murielae* negatively affected the richness, diversity, and evenness of vascular plants in its associated fir forest. However, the tree canopy could not determine the growth and flowering of the bamboo. Consequently, periodical flowering and dieback of the bamboo is a necessary ecological release for recovering the plant diversity and promoting the tree regeneration in its associated vegetation.

5) Three forage bamboo species of the giant panda (*F. spathacea, F. murielae*, and *Y. confusa*) currently can feed 194-223 giant pandas. On a seasonal basis, *F. spathacea* is able to provide the panda with fresh shoots from early April to June, and *F. murielae* from June to July. However, all these species have a gregarious flowering habit. If all forage species flowered and died back simultaneously, the underlying pandas may face a shortage of food. Considering Shennongjia had already been separated from other panda habitats by densely populated agricultural zones, reintroducing the giant panda to this isolated habitat is not without risks.

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9 APPENDICES

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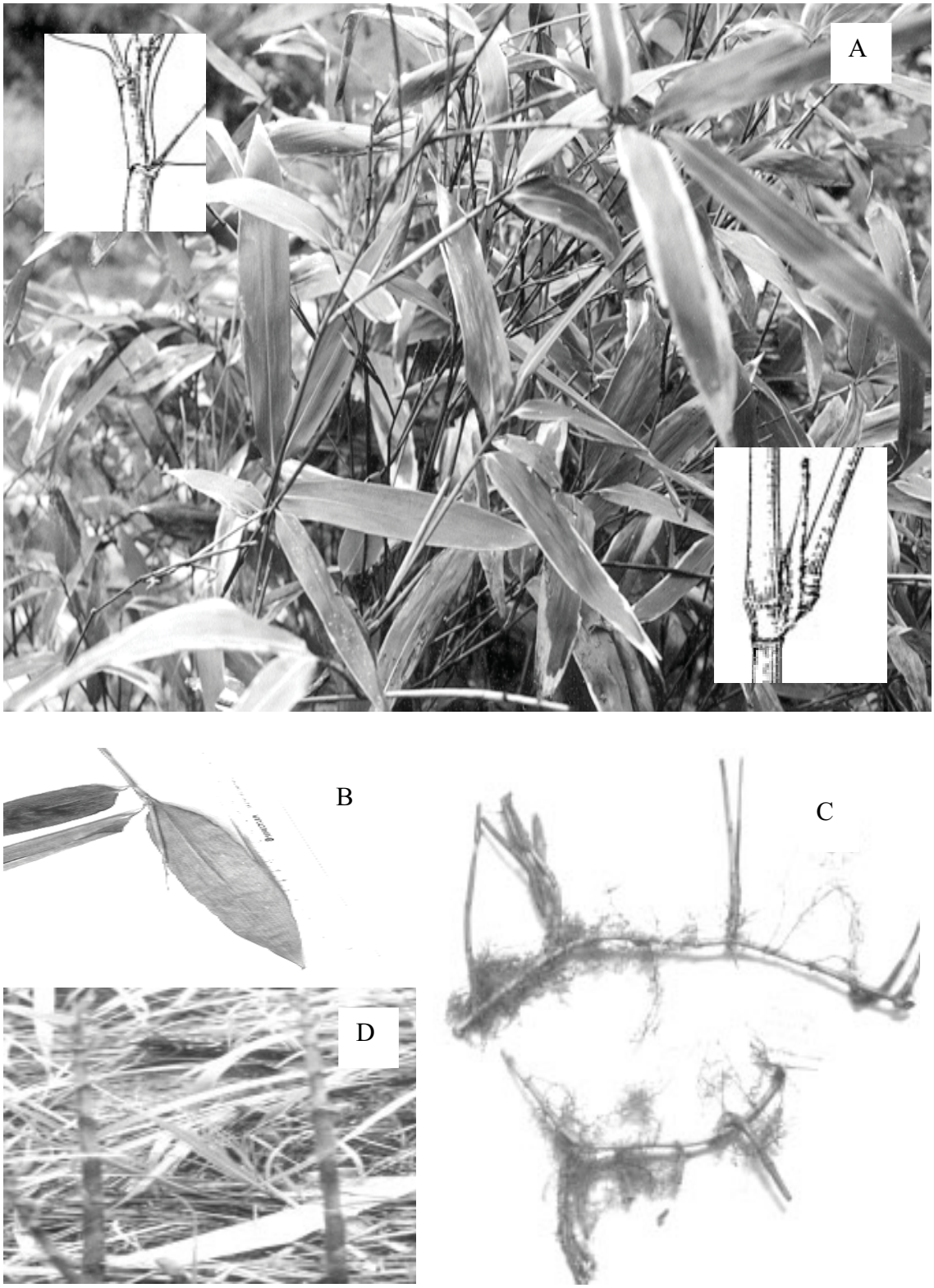
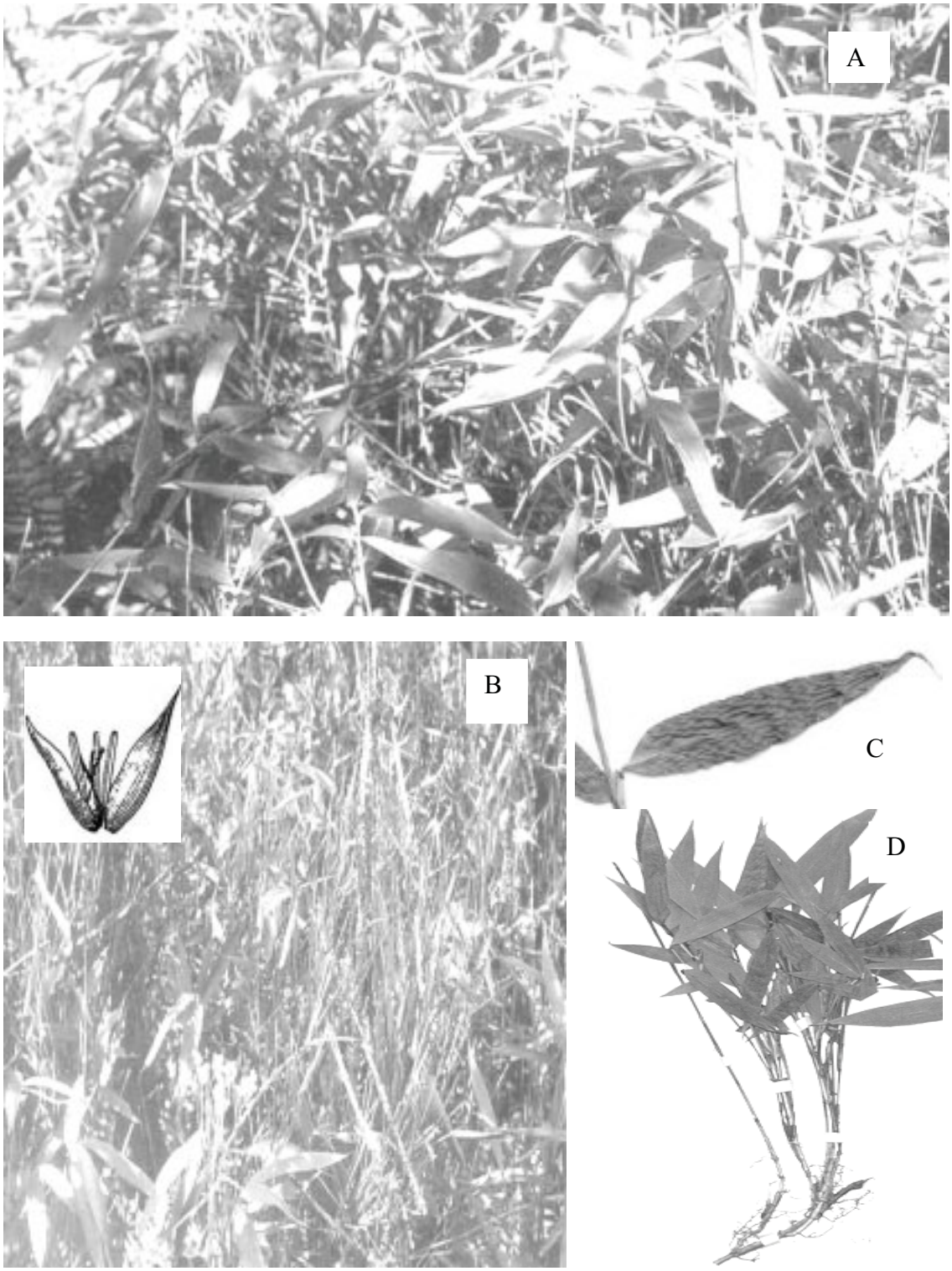


Appendix 1: Tamale bamboo *Indocalamus latifolius* (Keng) McClure. (A) Bamboo Figure 2.3: Climate diagram based on data gathered from 1975 to 1990 by the meteorological station at Songpei (altitude 930 m), capital town of the Shennongjia Foclump. (B) Dry leaf. (C) Amphipodial rhizome. (D) New shoots.



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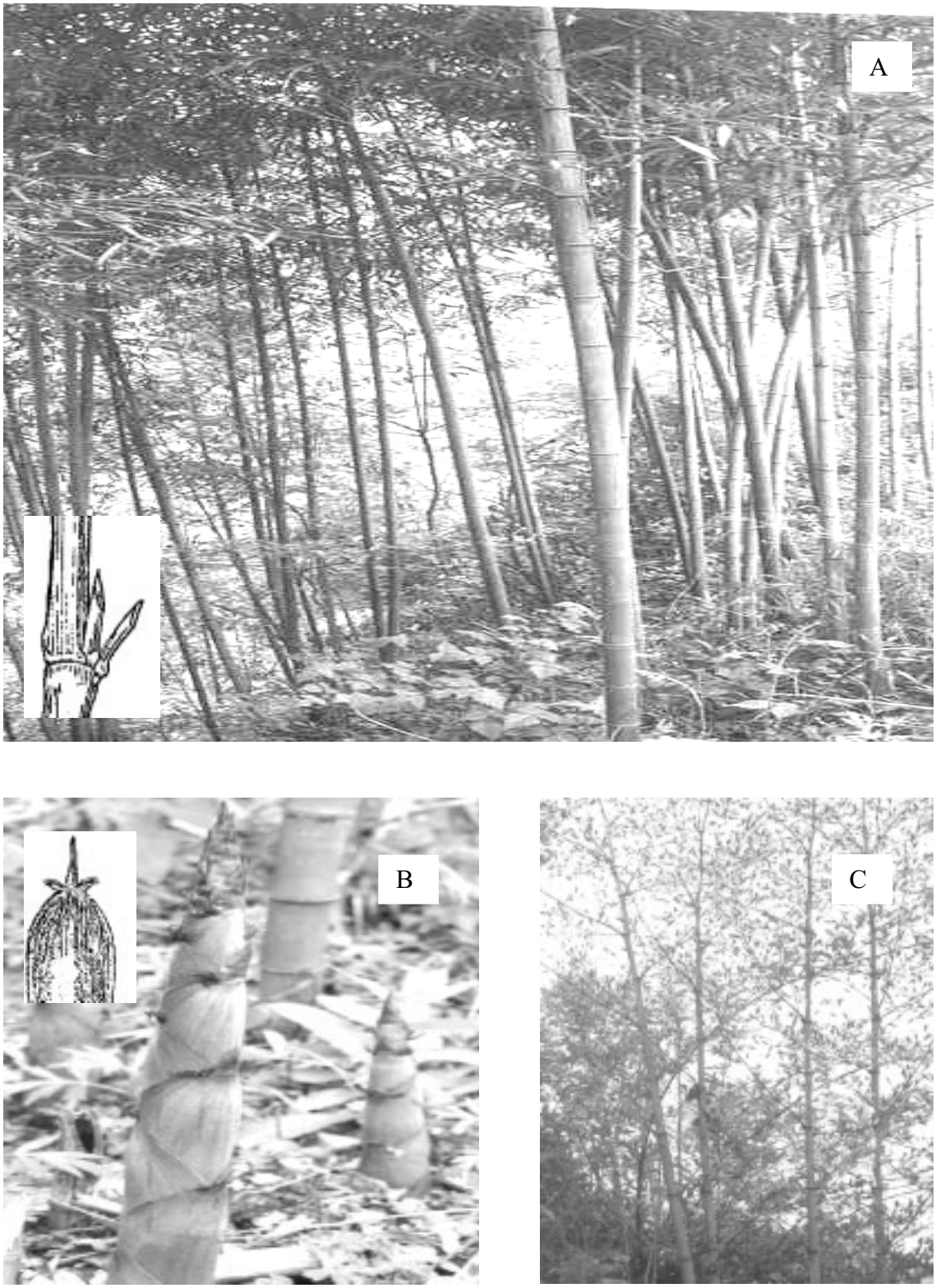

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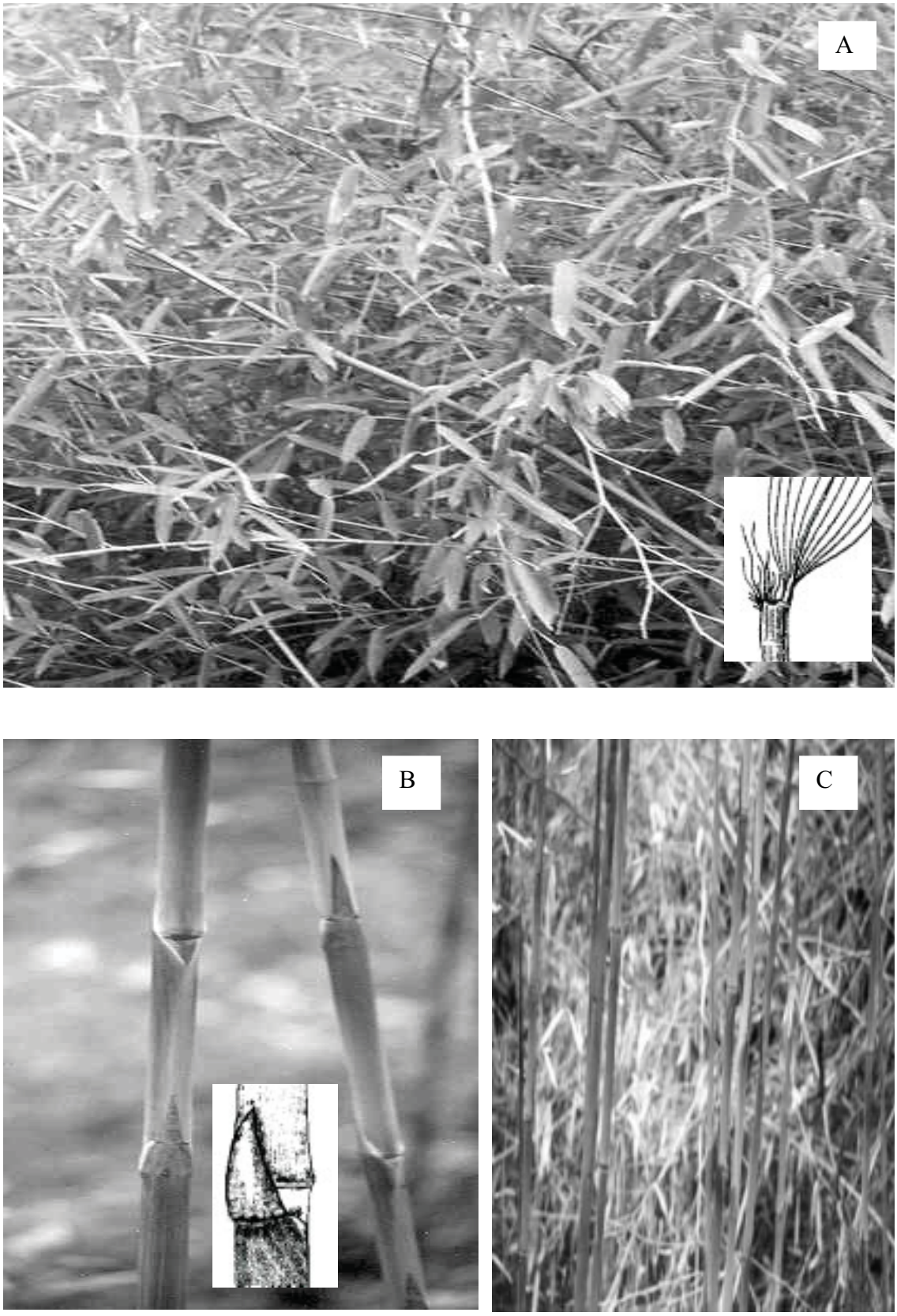

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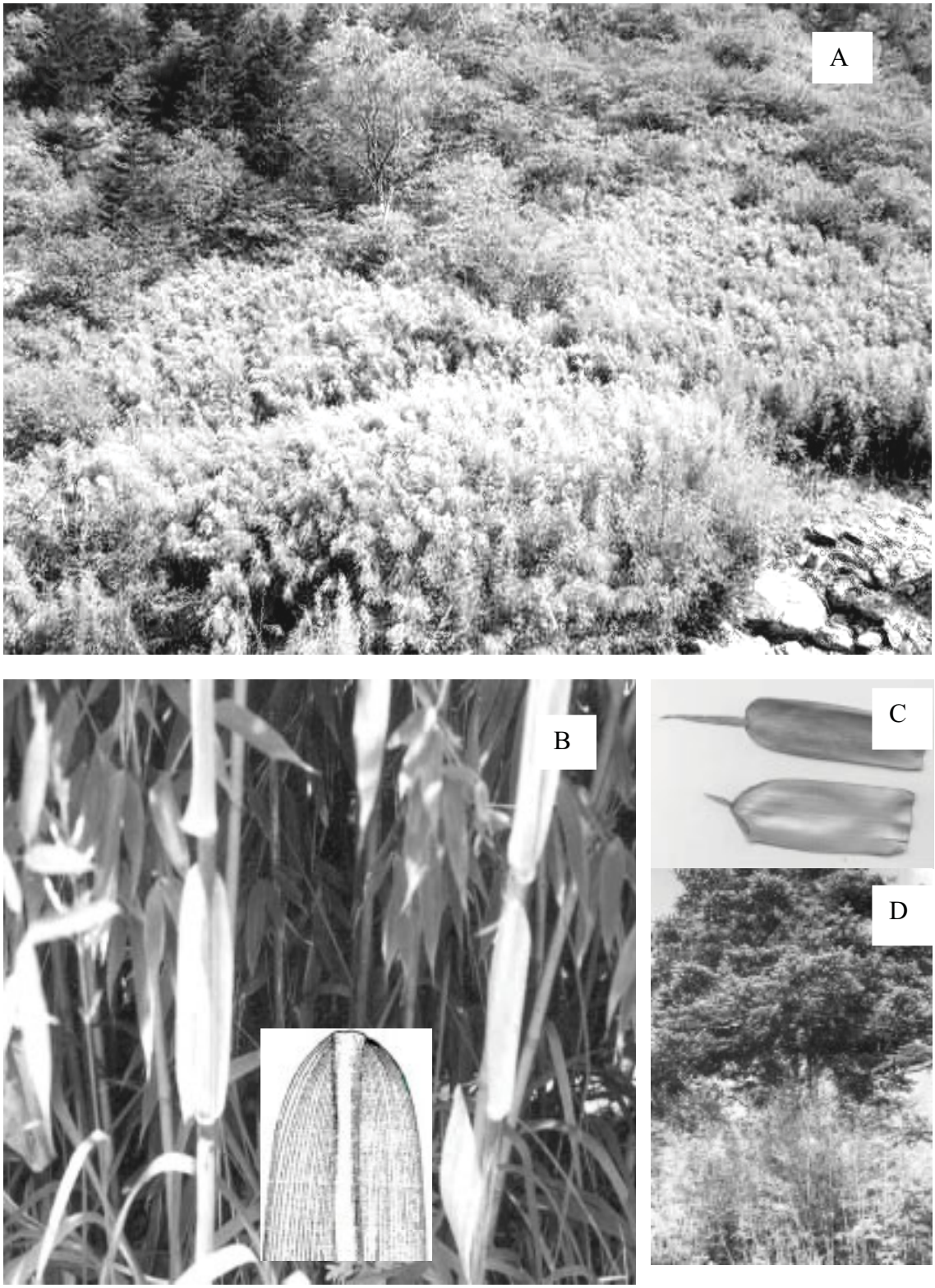

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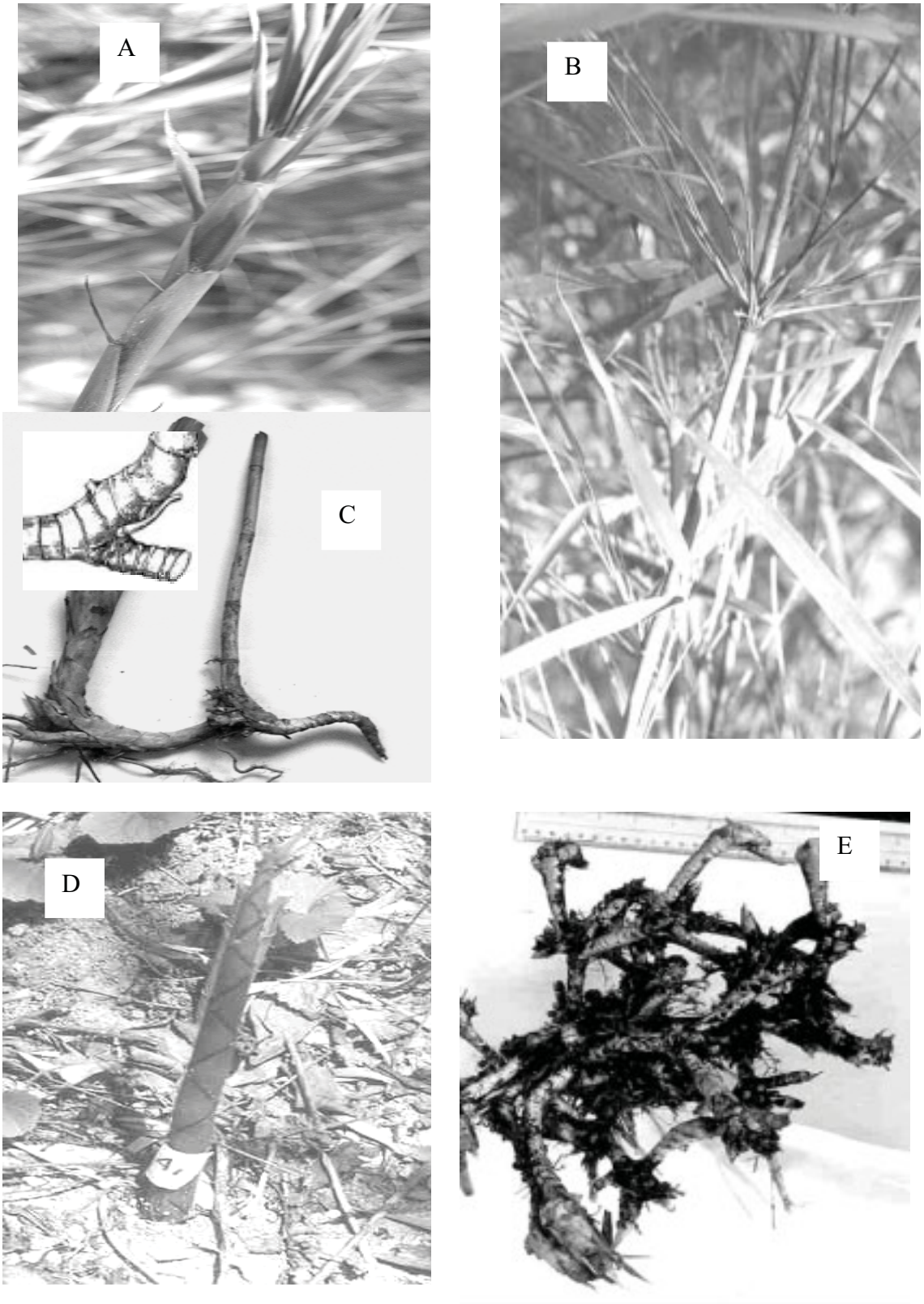

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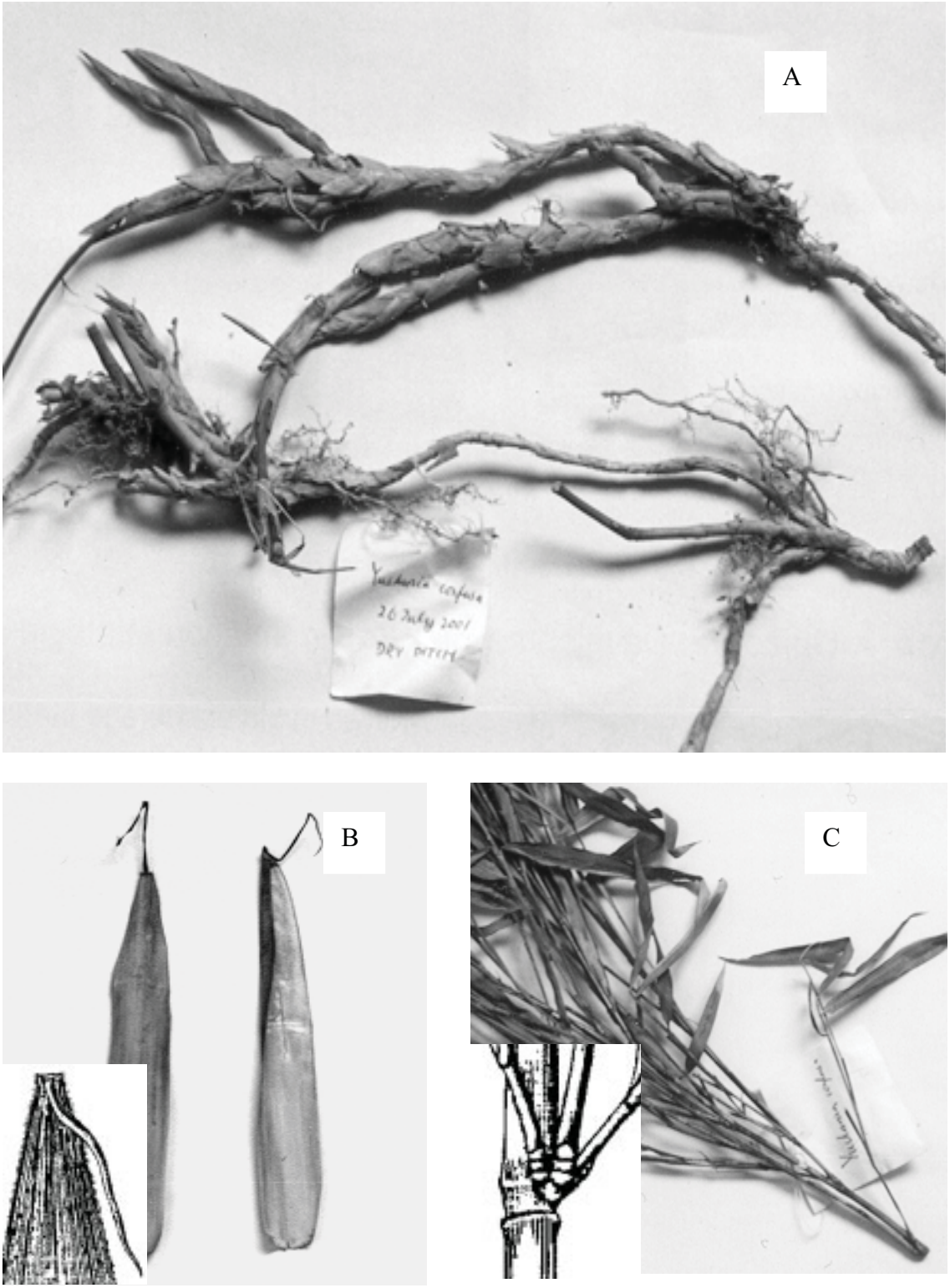

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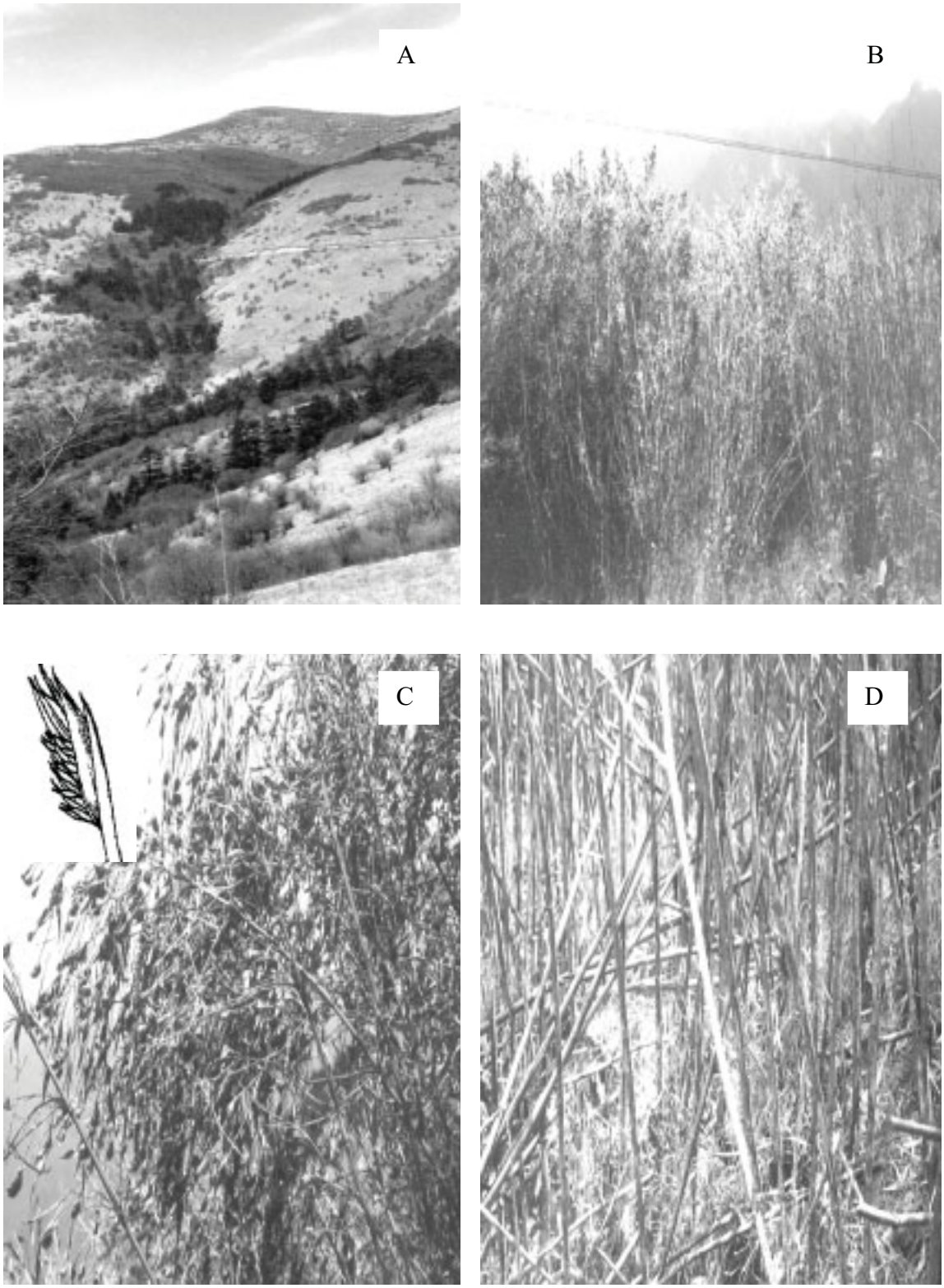

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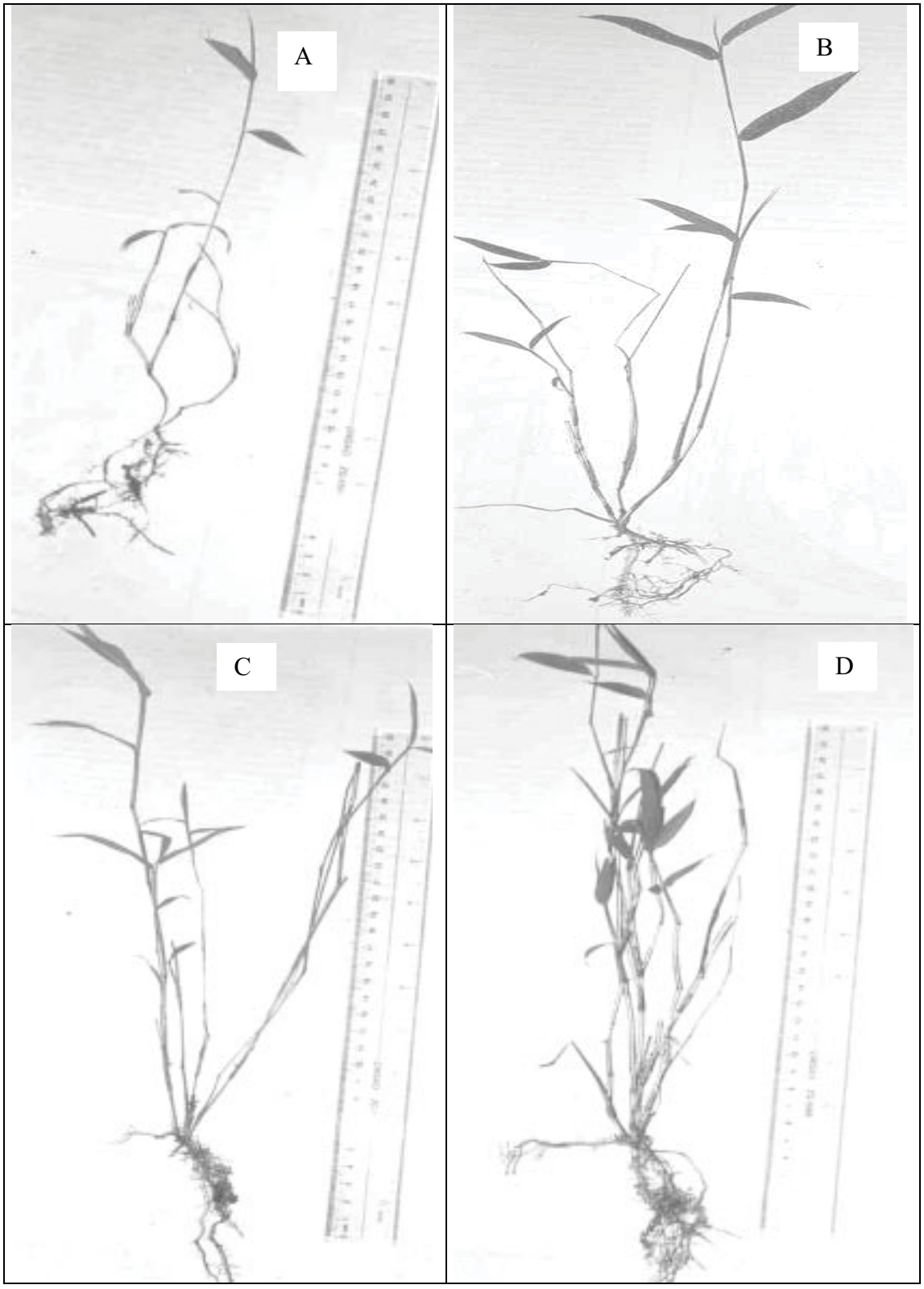

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Appendix 12: Community features and flowering of *Fargesia murielae* along three paths in Shennongjia, Central China. In the table: CB = conifer-bamboo forest, DB = deciduous broadleaved tree-bamboo forest, PB = pure bamboo forest, SB = shrub-bamboo community, and BM = bamboo-meadow community.

Plot	Altitude (m asl)	Latitude	Longitude	Associated vegetation	Canopy cover (%)	Bamboo cover (%)	Herb cover (%)	Flowering year	Seedling Density (-100 cm^{-2})
Path 1									
P1-1	2950	31°27.115'	110°16.334'	CB	60	100	30	2000	0
P1-2	2930	31°27.069'	110°16.122'	CB	30	100	40	1999	173
P1-3	2900	31°27.069'	110°16.122'	CB	40	100	40	2000	0
P1-4	2890	31°27.090'	110°16.083'	PB	0	90	90	2000	0
P1-5	2900	31°27.132'	110°16.019'	CB	30	80	60	1999	126
P1-6	2840	31°26.809'	110°16.019'	CB	20	60	70	1999	43
P1-7	2800	31°26.565'	110°16.428'	PB	0	100	70	1999	76
P1-8	2780	31°26.827	'110°16.601'	CB	10	100	30	1999	55
P1-9	2750	31°26.973'	110°16.800'	CB	80	100	20	1999	83
P1-10	2710	31°27.217'	110°16.878'	BD	70	100	30	1998	21
P1-11	2700	31°27.217'	110°16.945'	DB	60	90	40	1998	33
P1-12	2650	31°26.805'	110°17.120'	DB	50	80	50	1998	20
P1-13	2600	31°26.672'	110°17.295'	CB	60	70	40	1998	9
P1-14	2610	31°26.638'	110°17.380'	PB	0	100	70	1998	3
P1-15	2550	31°26.084'	110°17.154'	CB	30	90	60	1998	8
P1-16	2500	31°27.337'	110°17.139'	DB	60	90	20	1998	3
P1-17	2450	31°27.728'	110°17.202'	CB	70	40	30	1999	19
P1-18	2420	31°27.922'	110°17.332'	DB	60	20	40	1999	7
Path 2		'	.						
P2-1	2400	31°27.299'	110°10.144'	DB	40	70	80	1998	5
P2-2	2410	31°27.182'	110°10.431'	SB	20	90	100	1997	3
P2-3	2420	31°27.147'	110°10.505'	CB	40	30	50	1988	7
P2-4	2420	31°27.152'	110°10.506'	CB	40	90	70	1996	12
P2-5	2430	31°27.263'	110°10.725'	DB	50	80	30	1996	10
P2-6	2440	31°27.265'	110°10.823'	CB	30	50	80	1997	6
P2-7	2450	31°27.243'	110°10.931'	CB	20	50	80	1996	18
P2-8	2480	31°27.107'	110°11.058'	CB	50	40	30	1996	11
P2-9	2490	31°27.067'	110°11.201'	CB	40	50	40	1998	2
P2-10	2500	31°27.011'	110°11.492'	CB	100	80	20	1998	22
P2-11	2540	31°27.455'	110°11.466'	CB	70	100	30	1996	19

Plot	Altitude (m asl)	Latitude	Longitude	Associated vegetation	Canopy cover (%)	Bamboo cover (%)	Herb cover (%)	Flowering year	Seedling Density (-100 cm^{-2})
P2-12	2540	31°27.722'	110°12.534'	PB	0	100	90	1997	2
P2-13	2560	31°27.579'	110°12.842'	SB	20	100	80	1997	3
P2-14	2570	31°27.503'	110°12.131'	CB	30	90	40	1997	8
P2-15	2580	31°27.468'	110°12.314'	PB	0	60	90	1999	38
P2-16	2610	31°27.544'	110°13.372'	BM	0	90	90	1999	4
P2-17	2580	31°27.671'	110°13.378'	SB	10	30	80	2000	12
P2-18	2620	31°27.310'	110°13.382'	PB	0	100	60	1997	15
P2-19	2630	31°27.187'	110°13.523'	PB	0	50	80	1997	7
P2-20	2650	31°27.278'	110°13.647'	PB	0	100	80	1997	39
P2-21	2690	31°27.003'	110°14.214'	PB	0	100	90	1997	33
P2-22	2700	31°26.936'	110°14.436'	PB	0	100	80	1997	20
P2-23	2720	31°27.934'	110°24.608'	CB	20	80	60	2000	0
P2-24	2760	31°26.982'	110°14.915'	CB	60	90	30	1999	36
P2-25	2790	31°26.938'	110°15.105'	CB	70	100	20	1999	115
P2-26	2810	31°27.022'	110°15.287'	CB	80	100	10	1999	137
P2-27	2820	31°27.044'	110°15.433'	CB	70	100	20	1999	95
P2-28	2830	31°26.942'	110°15.555'	CB	30	90	40	1999	78
P2-29	2860	31°27.040'	110°15.883'	CB	30	100	20	1999	44
P2-30	2870	31°27.055'	110°15.989'	PB	0	70	80	1999	31
P2-31	2900	31°27.003'	110°15.204'	CB	40	100	40	1999	55
Path 3									
P3-1	2680	31°27.352'	110°11.122'	BM	0	10	100	1996	2
P3-2	2780	31°27.783'	110°11.156'	PB	0	70	80	1997	5
P3-3	2810	31°27.925'	110°11.145'	PB	0	90	70	1999	4
P3-4	2780	31°28.041'	110°11.185'	PB	0	100	60	1999	71
P3-5	2690	31°28.247'	110°11.111'	CB	30	80	70	1999	5
P3-6	2580	31°29.103'	110°10.452'	BM	0	60	100	1999	1
P3-7	2510	31°28.947'	110°10.729'	PB	0	100	30	1997	7
P3-8	2640	31°28.654'	110°10.933'	BM	0	50	100	1998	3
P3-9	2700	31°28.652'	110°10.933'	CB	60	90	40	1999	3
P3-10	2790	31°28.132'	110°11.167'	BM	0	80	100	2000	0

Appendix 13: Community features and flowering of *Fargesia murielae* on a burned and unburned site in Shennongjia in Central China.

Plot	Mean height (cm)	Culm density (culms m^{-2})	Flowering year	Seedling density (seedlings m^{-2})
Burned Site (B)				
B-1	147	132	1998	1
B-2	186	118	1999	0
B-3	155	88	1999	0
B-4	173	93	2000	0
B-5	161	132	1999	0
B-6	184	87	1999	7
B-7	176	73	1999	0
B-8	165	116	2000	3
B-9	155	57	1999	1
B-10	177	96	1998	6
B-11	181	88	1998	0
B-13	146	131	1999	0
B-13	137	107	1999	0
B-14	167	68	1999	2
B-15	181	113	2000	0
Unburned Site (U)				
U-1	247	83	1999	16
U-2	255	41	1999	28
U-3	239	48	1998	22
U-4	285	61	2000	14
U-5	277	73	1998	33
U-6	236	57	1999	26
U-7	260	71	1998	52
U-8	228	91	1999	29
U-9	234	52	1998	15
U-10	287	66	1998	59

Appendix 14: Sociability index of plant species along a transect near the Observation Tower in Shennongjia, Central China.

Species / Quadrat	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Abies fargesii	0	0	0	1	0	1	0	0	0	2	1	0	0	0	0	3	0	3	1	2
Acer maximowiczii	0	0	0	0	1	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0
Sorbus huphensis	0	0	0	0	0	0	0	0	1	0	0	0	1	1	0	0	1	0	0	0
Crataegus wilsonii	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0
Malus kansaensis	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0
Fargesia murielae	5	5	0	5	0	0	0	0	4	5	0	0	5	0	0	5	0	5	5	5
Impatiens noli-tangere	0	0	2	0	2	0	4	3	0	0	0	0	0	0	1	0	0	0	2	0
Heracleum moellendorffii	0	0	0	0	2	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
Geranium henryi	0	0	1	0	4	0	0	0	0	0	0	2	0	0	0	0	3	0	0	2
Trisetum sp.	1	1	2	0	2	2	2	3	0	0	0	0	0	0	2	0	2	2	0	0
Polygonum uncinatum	0	1	0	0	1	0	0	0	0	0	0	2	0	0	2	0	0	0	0	0
Polygonum viviparum	2	2	3	0	2	2	2	2	2	2	4	4	1	2	4	0	3	1	0	0
Setaria glauca	0	0	0	0	2	0	0	2	0	0	0	0	0	0	0	0	2	0	1	2
Cystopteris fragilis	2	0	2	2	3	0	0	0	0	1	0	3	1	0	0	2	0	0	0	2
Cirsium henryi	0	0	1	0	1	0	3	0	0	0	0	0	0	0	0	0	1	0	0	0
Bupleurum longicaule	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rubia cordifolia	2	2	3	0	0	2	3	3	0	0	0	1	2	2	0	0	0	0	0	1
Polygonatum hookeri	3	0	0	0	0	3	0	0	2	2	3	0	0	0	0	0	0	0	0	0
Actaea asiatica	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Calanthe fimbriata	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Rubus sp.	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Saussurea dutaillyana	0	3	2	2	0	2	0	0	0	0	0	0	0	0	1	0	3	0	0	3
Thalictrum przewalskii	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Arisaema heterophyllum	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Triosteum himalayanum	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxalis griffithii	0	0	0	0	0	3	0	3	3	2	3	0	0	0	0	2	0	2	3	0
Crisium japonicum	0	1	2	0	1	0	3	0	0	0	0	0	0	2	3	0	2	0	0	1
Pedicularis decora	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0
Saxifraga sp.	0	0	0	0	0	0	0	2	1	0	2	2	2	2	0	0	0	1	0	0
Carex sp.	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0
Aconitum lonchodontum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	2
Plantae asiatica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0

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