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Assessment and Management of Oak Coppice Stands in Shangnan County, Southern Shaanxi Province, China

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Contents

1 Introduction

The People's Republic of China is the world's fourth largest country in terms of total area. The diverse geographic environment and the complex climatic conditions have created a great variety of forest types. From the north to south, China's major forest types are cold-temperate & temperate mountain coniferous forest, temperate coniferous forest, subtropical coniferous forest, mixed coniferous and broad-leaved forests, temperate deciduous broad-leaved forest, subtropical evergreen broad-leaved forest, tropical rain forest and monsoon forest, and bamboo forest (Dai *et al.*, 2011). Various forest types, together with the biological communities in these forests, and environmental factors, constitute China's rich forest ecosystems. China has 11,405 woody species, belonging to 1,175 genera and 170 families, of which, 6,735 (59.5%) are shrubs, belonging to 754 genera and 142 families; 3,165 species (27.8%) are trees, falling under 498 genera and 107 families; and 1,035 (9.1%) are woody vines, falling under 176 genera and 49 families; and 470 are bamboos, falling under 33 genera and 1 family (Fang *et al.*, 2011).

It is recorded that the forest resources in ancient China were rich. However, the forest resources decreased gradually because of such factors as nature, war, social productivity, and accelerating population growth (Li *et al.*, 2004). By 1948, before the founding of the People's Republic of China, the country had few remaining forests. According to Li *et al.* (2004) the forest coverage was only 8.6%. These forest resources further decreased during the collectivization period (1958-1982), especially during the Great Leap Forward and the Cultural Revolution (Démurger *et al.*, 2009). The deforestation was exacerbated at the beginning of the 1980s because of the economic reform. The rapid economic growth during the reform period led to a surge in demand for forest products (Démurger *et al.*, 2009). Due to the deterioration of forest ecosystems and reduction in biodiversity, caused by this over-exploitation of forest resources, China has faced a series of hazards and disasters including soil erosion, floods, and desertification.

According to the seventh National Forest Inventory (NFI) released in 2009, China's forested area covers 195 million ha with the forest stocking volume at 13,721 million m^3 (Department of Forest Resource Management, 2010). The forest coverage increased to 20.36 percent of the country's total land area from 18.21 percent in 2003. Although China has maintained an increase both in forested area and stocking volume, it can still be considered as a country with a shortage of forest. The forest area per capita is only 0.145 ha, less than one fourth of the world average; the forest stock per capita is only 10.151 m^3, one seventh of the world average (Department of Forest Resources Management, 2010). Furthermore, long-term ignorance of forest management has resulted in low quality of forest resources. Despite the flourishing economic situation and the growth of the human population, the existing forest resources are not able to meet the country's needs for economic and social development. The huge demands on forest products are met through imports from abroad. For example, the volume of imported logs in 1999 was 11.37 million cubic meters and it soared to 37.13 million cubic meters in 2007, representing an increase of 226.5% (Nie *et al.*, 2010). The amount of imported wood pulp has increased by 300% in 2003, compared with that in 1997 (Cheng and Liu, 2006).

Oak forest is the largest part in China's forest resources. According to the seventh NFI report, oak species is the most frequent species with 16.10 million hectare in area and 1,208 million m^3 of stock volume, accounting for 10.35% of forest area and 9.04% of forest stock volume (Department of Forest Resource Management, 2010).

Due to the discrepancy on the morphological classification, the number of *Quercus* species still is controversial in China. Xu and Ren (1998) reported that the number of *Quercus* species in China is 51. However, Huang (1999) stated that there are only 35 species. Peng *et al.* (2007) classified the *Quercus* in China into five groups using specimens: Section *Aegilops*, Section *Quercus*, Section *Brachylepides*, Section *Engleriana* and Section *Echinolepides.* Deciduous oak is the main tree species in deciduous needle-leaf forest and deciduous broadleaved forest. The main tree species of defoliation oak are *Quercus accutissima*, *Quercus variabilis, Quercus mongolica, Quercus liaotungensis*, *Quercus dentate* and *Quercus glandulifera*. The natural distribution of deciduous oak covers 26 provinces in China, within 98°-134.3°E and 18.5°-53.5°N (The research group of the deciduous oaks, 1988). Among all oak species, *Q. accutissima*, *Q. variabilis* and *Q. dentata* are the most widely distributed species in China, ranging from the northeast to the southwest.

The large area of oak forest plays an important role in water and soil conservation. Wang *et al.* (1997) found that the soil permeability and water storage capacity of *Q. mongolica* in the eastern mountainous area of Liaoning province are higher than other species, such as larch and pine. *Quercus* species is the first option in reforestation owing to its large root systems. In addition, *Quercus* species is an important timber species; it is widely used as the material in the production of flooring material and furniture. In many rural areas in China, oak trees also are used as the materials for planting mushrooms and for energy (fuelwood) resources.

However, degradation of oak forest has happened because of over exploitation. The oak forest had sharply decreased in quantity and quality. There are only a small number of natural oak forests or natural secondary oak forests, which grow in high mountainous area (Li *et al.*, 2001b). Zhang and Li (1989) have reported that the oak stock volume decreased from 0.31 million m^3 in 1984 to 0.13 million m^3 in 1988 in Ankang area, Shaanxi province. In Shaanxi Province, the quantity of oak consumed for planting fungus and *Gastrodia elata* (a Chinese herb medicine), and used as charcoal, is more than 2 million m^3 per year, which means that 33,000 hm^2 of oak trees are cut down (Li *et al.*, 2001b). The long-term ignorance of management also accelerates the degradation of oak forest. The lacking of cutting plans resulted in an unreasonable cutting. For instance, to get the high timber production, big trees were cut in the tending management. As a result, large areas of oak forests located near residential regions, became open forest or useless stands. As well, the regeneration after harvesting had received even less attention (Liu *et al.*, 2003). All these factors give rise to strong pressure on the need for sustainable forest development.

Quercus variabilis (Chinese cork oak) is considered one of the major tree species in the warm-temperate deciduous broad-leaved forest and subtropical evergreen broad-leaved forest. It is widely distributed in Asian countries, including Japan, Korea and China. In China, the Qinling Mountain in the Shaanxi Province and the Dabieshan Mountain in the Anhui Province are the major distribution areas (Wu, 1998). *Q. variabilis* can be found in these areas at an elevation ranging from 500 to 1600 m above sea level. In Shaanxi Province, *Q. variabilis* forests distribute widely in the low mountainous area of the Qinling Mountains and northern Bashan Mountains. However, most of *Q. variabilis* forests in low altitude areas have been seriously damaged because of intensive use. As a result, these stands have become coppiced stands. Repeated sprouting has resulted in low stand quality and low yield. Coppice stands usually are young and the stocking volume is about 30 m^3 ha^{-1} on average (Zhang, 1986). A small part of *Q. variabilis* forests in areas of high altitude (more than 1300 m above sea level) are high forests. Compared to the coppice stands, stand quality, age, and stocking volume in high forests are higher. The stocking volume of high forest is more than 120 m^3 ha^{-1} on average (Zhang, 1986)

As *Q. variabilis* was considered as an important reforestation tree species, attention has been given to silvicultural techniques that improve its survival rate in open fields (Wang, 1975; Zheng *et al.*, 1990; Zhang, 1992). Management systems to improve stand stability and productivity in North China were recommended by Zhang (2000) and Lu (2007). Zhao *et al.* (2008) recommended the selection of potential crop trees for the management of cork oak plantations. However, few studies regarding the management and regeneration ability of oak forests were carried out in the Shaanxi Province. In addition, most of the studies dealing with *Q. variabilis* focused on basic research rather than management aspects.

Quercus acutissima (sawtooth oak), a deciduous broad-leaved tree, is an important forest element in hillsides in warm temperate area. Similar to the *Q. variabilis* forest, the *Q. acutissima* forests are widely distributed in China. Because of high resistance to drought and the adaption to poor soil condition, it is commonly planted in the mountainous and hilly areas for soil and water conservation and wood production. However, compared to the *Q. variabilis*, the demands on water and heat for *Q. acutissima* are higher. Therefore, in the Qinling Mountains and Dabashan mountains, *Q. acutissima* forests occur in the lower elevation area below 1,000 m above sea level and located within the distribution area of *Q. variabilis* forests (Zhang, 1986). Similar to the *Q. variabilis* forest, the *Q. acutissima* forest in low-elevation areas has been converted to coppice stands.

Energy sources in rural areas are lacking (Chen and Zhang, 2009). China's rural population accounts for 80% of total population and the demand of fuelwood is 657 kg per person each year. However, according to the stocking volume of fuelwood, there is only 146 kg per person available each year, accounting for only 1/5 of the demand. The ratio of households with serious shortage of fuelwood has reached 47.7% of rural population (Chen and Zhang, 2009). Therefore, fuelwood forests play a vital role in the rural energy crisis. Although researchers as well as forestry authorities have noted shortage problems of fuelwood and made some suggestions (Hu and Wu, 2001; Zhang, 2006; Chen and Zhang, 2009), studies on management of fuelwood forest are scarce.

As the economic, ecological and social demands on the forest resources will grow with the economy growth, the improvement of living standards, and the improvement of environmental awareness (Li, 1998), it is necessary to combine socioeconomics with forest management and utilization. This can be done by socio-economic surveys which are a useful tool since they provide information not only on socio-economic condition, but also information about the use of forest products (timber or non-timber products). Studies dealing with forest use and socio-economic issues have been conducted recently (Gavin and Anderson, 2007), especially in developing countries, where a strong relationship between the local socio-economic situation and forest management and utilization exists (Faham *et al.*, 2008; Mcelwee, 2008). Masozera and Alavalapati (2004) considered that forest management must be consistent with socio-economic development.

The study area Shangnan County is located in the southern Shaanxi Province, China (33°06'-33°44' N and 110°24'-111°01' W). As one of the upriver areas of Danjiang River, it plays an important role in ecosystem conservation. The implementation of the South-North Water Diversion Project brings even more attention to this area. *Q. variabilis* and *Q. acutissima* trees are two main broad-leaved species in this area. Therefore, study on oak coppice in Shangnan could be helpful not only in understanding the potential of wood production and regeneration but also in providing management recommendations to local people.

The current study was conducted within the framework of the Sino-German project "Rehabilitation of degraded land ecosystems in the mountainous area of the Southern Shaanxi Province, China" (El Kateb *et al.*, 2008). The objective of this study is to provide recommendations for sustainable management of oak coppice stands. This will be achieved i) by a scientific investigation of the potential of the wood production and stand regeneration in coppice stands and ii) by a socio-economic survey on people's use of the coppice forests and the assessment of the degree of acceptance by the local inhabitants to change the present use of the forest resources.

2 Research questions

The study is addressing two aspects of forest management in the research area, i) questions concerning the characteristics of oak coppice forests and ii) questions concerning the people's use of local forests.

(1) Questions concerning the characteristics of coppice forest

- What are the stand characteristics of coppice stands in the study area (density, basal area, stocking volumes and growth)?
- What are the single tree characteristics of coppice stands (crown class, stem type, vitality class)?
- How is the stand regeneration (species, density and height of understory seedlings?

(2) Questions concerning the people's use of the coppice forests in the local area

- What are the socio-economic conditions in the study area (energy resources, status of forest resources, and use of the forest resources)?
- Are the local inhabitants willing to change the present use of the forest resources (communication between farmers and local forest authorities, acceptance degree of new change)?

In the end, the present study should enable recommendations on how to introduce sustainable forest management methods in the coppice stands.

3 Literature review

3.1 Studies on coppice stands and management

Coppice forests, which are characterized by sprouting stems from stumps, are widely distributed in the world. Oaks (*Q. cerris*, *Q. pubescens*, *Q. ilex*), sweet chestnut (*Castanea sativa*), hazel (*Corylus avellana*), and ash (*Fraxinus excelsior*) are the most common species that have been developed into coppice forest in European countries (Ciancio *et al.*, 2006). In China, the majority of coppice stands are comprised of a variety of oak species (*Q. variabilis, Q. aliena, Q. Liaotungensis*) or *Robinia pseudoacacia.* One of these species can form a pure coppice stand or they can occur together to develop a mixed coppice stand. Coppice is a significant component of the woodland resource in many countries (Ningre and Doussot, 1993). The coppice forestry system have been used in central European since the Middle Ages (Szymura, 2010). Many advantages of coppice forests, such as simplicity of management, ease and rapidity of natural regeneration, fast growth of new stands, shorter rotation and more frequent income than high forest, have led to the successful development of coppice systems (Ciancio *et al.*, 2006).

Sprouting is the main mechanism to regenerate coppice stands. However, the vigor of the coppice tends to decline with the frequency of coppicing. Management of coppice stands could assist in increasing the regrowth rate or number of coppice shoots produced. The growth and vitality of sprouting stems are strongly affected by stump size. Boivin-Chabot *et al.* (2004) pointed out that there were significant differences in coppice-shoot height and number of new coppice shoots among some provenances of *Calycophyllum spruceanum* Benth. The average diameter of the leading shoots decreased significantly with increasing shoot densities (McLaren and McDonald, 2003). The number of shoots per stump was most frequently related to cutting height for twelve savanna species (Shackleton, 2000). However, Debell and Alford (1972) found that the height of stump and angle of cut had no significant effect on the vigor, size, or number of sprouts produced by *Populus deltoides*. Due to the competition between shoots on the same stump and competition between stumps for environmental resource, the radial growth differed among shoots (Cartan-son *et al.*, 1992). Compared to the seed-origin plantation, the mean height and diameter of trees in coppiced teak (*Tectona grandis* L.) plantation were both significantly greater at ages 3, 8, and 13 years (Bailey and Harjanto, 2005). The wood production and quality of coppiced teak plantations were better than seed-origin plantations. However, the growth and productivity of coppiced stems generally decline with the increasing of rotation. For example, Harrington and DeBell (1984) found that the greatest yields of black cottonwood and red alder were usually obtained at the first or second coppice harvest; red alder yields declined substantially between the third and fourth harvests.

Coppice can be managed in a number of different ways according to the desired end products. For example, sawlogs, firewood, pulpwood, posts and poles can be produced from trees with two or three coppice stems, whereas sawn timber is produced by reducing the stem number to one or two (Department of Primary Industries, 2000). To improve the growth of coppiced trees, thinning becomes one of the key silvicultural treatments. The heaviest thinning treatment (50% of basal area removed) produces the largest values of basal area and biomass for the mean tree; however, no differences were found between different thinning treatments for overall stand yield (Canellas *et al.*, 2004). Thinning management also has a strong influence on the density and total number of stems per stump (Gracia and Retana, 1996). In addition, moderate grazing has been shown to improve tree growth and provide significant wood production during the management period in a deciduous oak coppice forest (Ainalis *et al.*, 2010).

Short rotation coppice management for biomass production has been the traditional silvicultural practice for many centuries. A variety of papers have discussed the growth, woody biomass, and productivity of coppice stands with short rotation management (Kauter *et al.*, 2003; Liberloo *et al.*, 2004). However, this management system has been questioned due to the demand of high-quality wood production (Cutini, 2001), and the decrease in use in firewood and charcoal as energy sources (Adame *et al.*, 2008). As a result, new management systems such as the adoption of long rotation periods or the conversion into high forest, which aim to produce more wood products have been adopted in the 18th and 19th century (Cutini, 2001).

However, with the appearance of the recent global energy crisis, the development of renewable energy sources (like biomass) to satisfy the demand for energy, heat and fuel, becomes a new focus. With the biomass option, short rotation coppice has the potential to become an important source of renewable energy because of high biomass yields, good combustion quality as a solid fuel, and low costs on biomass production (Kauter *et al.*, 2003). Beside, coppice management is an important conservation tool for maintaining both typical forest herbs and herbs with affinity for more open habitats, especially in intensively managed landscapes (Van Calster *et al.*, 2008) and it is a suitable contribution to regional CO_2 mitigation and carbon sequestration under possible climate change (Lasch *et al.*, 2010). Hölscher *et al.* (2001) concluded that frequent disturbance of soil and stand structure by cutting and burning apparently accelerates the nutrient turnover, as a result, there is a higher storage of Ca, K, Mg and N in the mineral topsoil. Through phytoremediation (a technology that involves the use of plants to remove metals from contaminated soil), waste products that previously have been a burden for society can be used a-s valuable resources to increase short-rotation willow biomass production (Mirck *et al.*, 2005).

The rotation of coppice stands is different according to the end-product for the wood and the biological characteristics of tree species. Generally, 3-4 coppice rotations can be harvested before full-scale replanting need be considered (Evans, 1992). In India, Jacobs (1981) reported the *Eucalytus globulus* has been coppiced successfully in the Nilgiri Hills on 10-year rotations for more than 100 years. Kauter *et al.* (2003) studied rotations of poplar and aspen coppice for solid fuel use, and 6-7 years of short rotation for poplar and 11-12 years for aspen were recommended. Abbot and Lowore (1999) proposed the typical firewood species of central Malawi, such as *Combretum apiculatum*, *Pericopsis angolensis* and *Combretum molle* be managed for domestic firewood on a coppice rotation of 5 years upwards and recommended that national policies for fuelwood production should develop mechanisms for incorporating the rural woodland users into the management process. Qi and Chen (2008) studied the growth and biomass accumulation of *Q. variabilis* and suggested that 6 years rotation was appropriate in terms of fuelwood production and economic benefit. Cutini (2001) suggested that a cultivation system based on a long rotation period (35 years) and heavy thinning was a valid alternative for those stands characterized by a good productivity on abandoned or traditionally over-exploited chestnut coppice stands.

Large areas of coppice stand have occurred in China because of the shortage of forest resources and the unreasonable use of forest resource. To improve the quality and productivity of coppice forests, much attention has been paid, especially on the oak coppice in northeast of China and *Robinia pseudoacacia* coppice in Loss Plateau (Cai *et al.*, 1995; Guo *et al.*, 1998; Wang and Wang, 2002). Sun *et al.* (2002) found that the young oak forest in Heilongjiang Province are characterized by low productivity (the average stocking volume less then 20 m^3 per ha), single species and bad wood quality. Management methods, such as tending and stand reconstruction by strip-cut are recommended to improve the productivity of oak coppice (Cai *et al.*, 1995; Li and Bi, 2002). Shi *et al.* (2004) demonstrated in detail the management of oak coppice for providing material for cultivating mushrooms, including soil preparation, cultivation and cutting. They suggested that strip clear-cutting should be adopted to ensure sustainable use.

Robinia pseudoacacia is regarded as a drought-resistant species, and has been planted widely in northern China since the 1950s, especially in the Loss Plateau region. It plays an important role in water soil conservation and vegetation rehabilitation. However, long-term unreasonable cutting and management led to the plantations being converted to coppice stands. With the shortage of water and soil nutrition and high density, these coppice stands had a low productivity (Guo *et al.*, 1998). Peng *et al.* (2001) concluded that the stems with poor quality in the coppice stands took more than half in the Weibei Loss Plateau. On the other hand, many advantages also have been realized from coppice stands. For instance, Sun *et al.* (1993) found that a *R. pseudoacacia* sprout stand had a higher biomass than the seedling plantation. The site condition could be improved by coppicing as well (Sun *et al.*, 1993). Developing *R. pseudoacacia* coppice stands is very helpful to increase the local people's income in Loss Plateau regions (Ma, 1995).

3.2 Understory regeneration of oak

Regeneration is considered as an important factor that affects the sustainable development of forests. Sexual regeneration is a process involving acorn production, germination and seedling establishment, and finally, growth to mature trees (Schupp, 1990; cited in Pons and Pausas, 2006). A lot of studies have reported that many oak species have a problem with sexual regeneration. Usually, there are not enough young seedlings becoming established or even if the number of seedlings is sufficient, they can not grow into mature trees. For instance, few seedlings in *Quercus lobata* community in central coastal California were found, moreover, under deer and rodent-browsing conditions, seedlings could not become saplings (Griffin, 1976). Similar results were found on brown oak (*Quercus smemecarpifolia*) above 2400 m in the Himalaya (Singh *et al.*, 1997). Predation by small mammals and birds prevented the production of seedlings of sessile oak (*Quercus petraea*) in North Wales (Shaw, 1968). The failure of sexual regeneration of sessile oak is also caused because the environmental conditions in the wood are unfavorable to growth and survival of oak seedlings (Shaw, 1968).

Another important mechanism of oak regeneration is sprouting, i.e. the production of sprouts from buds on stumps or roots. Sprouting regeneration is a helpful means to maintain the population over long periods, which compensates for sparse seedling regeneration (Kubo *et al.*, 2005). Sprouting has several advantages compared to seeding regeneration: first, since no acorns are involved, there is less risk of damage from insects, rodents or birds (Mccreary *et al.*, 1991); second, sprouting seedlings promote their survival under a variety of stressful condition including suppression by canopy trees, herbivory, site exposure and desiccation (Del Tredici, 2001); finally, the initial growth of sprouts should be greater than that of seedlings (Mccreary *et al.*, 1991; Department of Primary Industries, 2000). Many of oak forests accomplish their regeneration by sprouting or with the help of sprouting. At one extreme, oaks of the arid south-western USA may regenerate almost exclusively by sprouting (Johnson *et al.*, 2009). For *Q. variabilis* populations in Shaanxi Province, China, because of low number of seedlings, the development of the population needed the supplement of sprouting seedlings (Han *et al.*, 2004a). Merz and Boyce (1956) found that 74% of the oak seedlings they sampled were of sprout origin (n=100). Suh and Lee (1998) found that among the seedlings of *Q. mongolia*, more than 70% originated from sprouts, which showed a higher growth potential than seedlings. But even when regeneration is largely dependent on sprouting, some new seedlings eventually must be produced to replace the trees and rootstocks that are inevitably lost to mortality, if a species is to persist (Johnson *et al.*, 2009).

A number of factors have an influence on regeneration. Site quality, such as the position in the slope, is a key factor on size differentiation of sprouting holm oak individuals (Gracia and Retana, 2004). Soil properties, such as temperature, type (Dzwonko and Gawronski, 1994) and compaction (Bejarano *et al.*, 2010) have direct effects on seedling roots. In addition, the number of oak seedlings and saplings significantly depend on stand density (Gracia and Retana, 2004) and the growth of seedlings is affected by the canopy cover (Dobrowolska, 2008). Thus, reducing overstory density is a commonly recommended method of increasing the regeneration potential of oak (*Quercus*) forests (Larsen *et al.*, 1997). An inverse relationship between the stump diameter and the number of sprouts was found on black oak, chestnut oak and white oak (Sands and Abrams, 2009). Weigel and Peng (2002) reported that sprouting and competitive success probabilities of five oak species in southern Indiana decreased with increasing parent tree age and diameter at breast height. The competition with ground vegetation was considered as one limiting factor to restrict the seedlings growth. Humphrey and Swaine (1997) suggested that effective control of dense *Pteridium aquilinum* is necessary to promote the successful regeneration of *Quercus petraea* and *Q. robur*. However, Buckley *et al.* (1998) stated that the positive effects of removing potential competitors on seedling growth may be compromised by simultaneous negative effects of browsing and frost damage. Shrubs can also facilitate the establishment of tree regeneration. Shrubs improved the *Q. humilis* regeneration by protecting individuals from grazing (Rousset and Lepart, 1999). Additionally, Arthur *et al.* (1998) described that periodic prescribed fire may reduce regeneration of non-oak species sufficiently to promote oak sprout regeneration.

3.3 Studies on *Quercus variabilis*

3.3.1 Morphological character

Quercus variabilis (Chinese cork oak) is a deciduous trees belonging to the Fagaceae family. It can grow to a height of 25-30 m with an open crown (Northwest Institute of Botany, 1974). The bark has thick cork with deep fissures. Leaves are broad-lanceolate, 8-12 cm in length, and 2-5 cm in width. The obverse side of leaves is dark-green and the reserve side is grey-white, densely covered with pubescence. The edge of leaf, also known as the leaf’s margin, is finely-toothed. It is a monoecious plant and flowers in May. The seed matures in October.

The morphological character also is affected by habitat. Han *et al.* (2004a) reported that the petiole length, leaf length and cork thickness had a second-degree polynomial relationship with latitude while the leaf width and seed width had a significantly positive linear correlation with latitude. Zhang *et al.* (2003) demonstrated that the cork of *Q. variabilis* distributed in different regions in Shaanxi differed in color, thickness, and cracking form.

3.3.2 Geographic distribution

Q. variabilis has a broad geographic distribution between 19°-42° N and 97°-140° E (Wang et al, 2009b). In addition to the mainland of China, it is found in Taiwan, Japan and North Korea (Fig. 1). The climate type in the distribution area covers the temperate zone, warm-temperate zone, north subtropical zone and south subtropical zone. In China, it grows in an area with average annual temperature of 7.2-23.6 ℃ and average annual precipitation of 411-2000 mm (Wang et al, 2009b). The Qinling Mountains in the Shaanxi Province and the Dabieshan Mountains in the Anhui Province are the major distribution areas (Wu, 1998). *Q. variabilis* can be found in these areas at an elevation ranging from 500 to 1600m above sea level. The *Q. variabilis* high forests in Qinling Mountains are distributed between 1200 and 1600 m above sea level, while the large areas of *Q. variabilis* coppice forests are formed in the low mountainous areas at an elevation between 500 and 1300 m (Zhang, 1986).

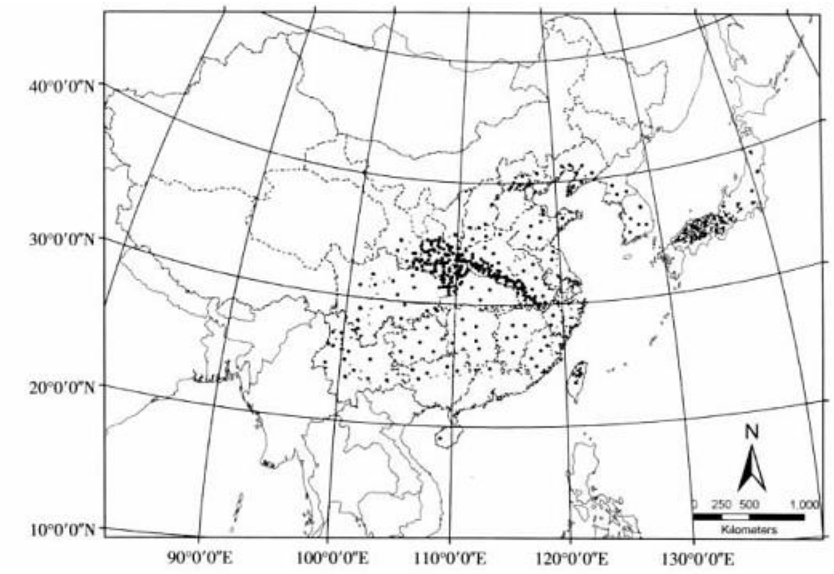

Fig. 1: The geographic distribution of *Q. variabilis* in East Asia (from Wang *et al.*, 2009b)

3.3.3 Ecological characteristics of *Q. variabilis*

Q. variabilis forest has important ecological effects in terms of improving soil fertility (Ye *et al.*, 1995), absorbing heavy metal elements from the atmosphere (Cai *et al.*, 2001), and decreasing soil erosion (Song *et al.*, 2001). Recently, a large amount of research work related to the *Q.*

variabilis population has been carried out. Population dynamics and species spatial distribution pattern were studied in different regions of the Shaanxi Province (Zhang *et al.*, 2002; Han *et al.*, 2004a; Han *et al.*, 2004b). Zhang and Lu (2002) classified the *Q. variabilis* communities in the Shaanxi Province into six types, for each, the species' diversity was investigated. Some models were developed to describe the dynamic of the age structure of *Q. variabilis* population (Han *et al.*, 2004b). Furthermore, the impact of climate change on the physiological characteristics of seedlings was investigated (Zhang *et al.*, 2004; Yi *et al.*, 2008). Zhang *et al.* (2004) found significant difference in drought resistance in four *Q. variabilis* provenances. Yi *et al.* (2008) demonstrated that the photosynthesis of the cork oak was negatively affected under water-logging condition.

3.3.4 Silviculture of *Q. variabilis*

As *Q. variabilis* was considered as an important reforestation species, attention was paid to the cultivation of seedlings (Cai and Cai, 2007; Wang *et al.*, 2008; Jiao, 2009; Chen, 2009) and the afforestation techniques in the open field (Wang, 1975; Zheng *et al.*, 1990; Zhang, 1992; Zhang, 2009b). Wang *et al.* (2008) found that the germination rate of *Q. variabilis* seed, planted in the field where maize has been harvested, could reach up to 90%. The thickness of soil is the most important factor that influences the survival rate of seeds in field forestation (Zheng *et al.*, 1990). Meanwhile, the biomass of oak stands has been widely discussed (Bao *et al.*, 1984; Liu *et al.*, 1998b; Wu *et al.*, 2000). To get the maximum biomass, the rotation of *Q. variabilis* coppice stands was investigated (Qi and Chen, 2008). To improve stand stability and rehabilitate stand productivity, different management systems are being practiced in North China (Zhang, 2000; Lu, 2007). Zhao *et al.* (2008) recommended that trees with straight stems should be selected as potential crop trees in cork oak plantations managed as close-to-nature forests.

3.3.5 Utilization of *Q. variabilis*

Q. variabilis have provided a wide variety of uses to human beings over centuries. Demands on *Q. variabilis* have increased with social and economic development. The timber of *Q. variabilis* is widely used as material for furniture, floorboard, pillars, and shipping. The bark of *Q. variabilis*, characterized with soft and thick cork, is an important industrial material. It can be used for many cork products, such as cork stoppers, floorboard, cork decorative panels, and rafts. The seeds of *Q. variabilis* are used as animal feed because of its rich starch, and the stems can also be used as material for planting mushrooms (Fig. 2). Further, Zhang *et al.* (2009a) reported that around 12.5 kg of tannin could be extracted from 50 kg acorns of *Q. variabilis.* The seeds and branches of *Q. variabilis* are also used in Chinese medicine (Chang *et al.*, 1999; Zhou *et al.*, 2000).

Fig. 2: *Q. variabilis* used for planting fungus: *Auricularia auricula* (left) and *Lentinula edodes* (right)

3.3.6 Regeneration of *Q. variabilis*

Natural regeneration of *Q. variabilis* can be conducted both by seeding and sprouting. Sprouting, characterized with sprout seedlings from the stool, plays an important role in the development of *Q. variabilis* populations. However, multiple sprouting events reduce the growth of sprout seedlings. Human activities also have an impact on regeneration. Wu *et al.* (1999) reported that human disturbances accelerated the sprouting of *Q. variabilis*. Zhang *et al.* (2008) found that the *Q. variabilis* population from sprouting regeneration is in recession while the population from seeding regeneration is sustainably developing. Zhang and Lu (2002) also pointed out that sexual reproduction was the essential method to maintain the genetic diversity of *Q. variabilis*.

The introduction of *Q. variabilis* trees in terms of mophological characters, distribution, ecological characeters, and utilization, was described preciesely in German by Peng (2001).

3.4 Studies on *Quercus acutissima*

3.4.1 Morphological character

Quercus acutissima (sawtooth oak) is another deciduous species belonging to the Fagaceae family. The tree height can reach up to 25-30 m with a trunk up to 1.5 m diameter. The bark is dark grey and deeply furrowed. The leaves are 8-18 cm long and 2-5 wide, having slightly hairy scale edges. Twigs are slender and red to gray-brown with buds that are triangular in shape. Sawtooth leaves are similar to those of the cork oak but are longer and greener on reserve side (see the photos in Appendix). The flowers bloom in May and the seeds mature in October. A detailed introduction of *Q. acutissima* is given by Gilman and Watson (1994).

3.4.2 Geographic distribution

Quercus acutissima (sawtooth oak) is an important forest element in hillsides with warm temperate climates. It is native to eastern Asia, in China, Japan, and Korea. It was introduced to the eastern United States around 1920, as a food source for wildlife or as a landscape tree (Whittemore, 2004). In China, it is distributed broadly in North China and East China. There are also sawtooth oaks growing in south-western regions, such as Guizhou and Yunnan Province. The sawtooth oak occurs both in the south face and north face of the Qinling Mountains, however the amount of sawtooth oak growing in the south face is greater than in the north. Nevertheless, compared to the cork oak, the sawtooth oak in Qinling regions is less abundant.

Q. acutissima has almost the same requirements on the environment as *Q. variabilis.* However, compared to *Q. variabilis*, the demands on water and heat for *Q. acutissima* are higher. Therefore, in Qinling Mountains and Dabashan Mountains, *Q. acutissima* forests occur in the lower area below 1,000 m above sea level within the distribution area of *Q. variabilis* forests (Zhang, 1986).

3.4.3 Ecological characteristics of *Q. acutissima*

Q. acutissima is a shade-intolerant species. It has high resistance to drought and is well-adapted to poor soil conditions (Yang *et al.*, 1997). However, trees grow best in well-drained soil in the full sun. Elevated carbon dioxide was shown to cause an increase in photosynthesis of *Q. acutissima* leaves, instantaneously (Xie *et al.*, 2002). *Q. acutissima* is able to grow under salt stress condition, but the ability of salt tolerance varied among *Q. acutissima* provenances (Wang *et al.*, 2009a).

Q. acutissima stands play an effective function in terms of water conservation through the roles of interception and absorption of the canopy layer, litter layer and soil layer. Xu (2010) reported that pure *Q. acutissima* stands and stands of *Q. acutissima* mixed with pine had a great capacity for water and soil conservation (the amount of water-holding in the litter layer in a 8-year-old *Q. acutissima* stands reached 34.48 t/ha).

3.4.4 Silviculture of *Q. acutissima*

Because of the high resistance to drought and the adaption to poor soil condition, the *Q. acutissima* is considered to be an important afforestation species. The tree growth is affected by many site factors. Guo *et al.* (2003) found that the biomass and productivity of *Q. acutissima* stands with south-facing aspect were greater than that with a north-facing aspect. The shortage of nutrient content in soil is also one limitation influencing the tree growth (Tang *et al.*, 2010). But

Q. acutissima had a higher total biomass than *Pinus massoniana* on sites with poor nutrient quality (Tang *et al.*, 2010). Fertilization in *Q. acutissima* plantations in poor sites could be used to promote tree growth.

Different silvicultural methods are used according to the purpose of the stands. Thinning was helpful to the enhancement of carbon storage in the *Q. acutissima* plantations in Jianghuai hilly lands, and 30% thinning could be best (Cheng *et al.*, 2012). Short-term rotation of *Q. acutissima* of about 8-10 years was suggested for fuelwood production by Chen *et al.* (2004). To get the maximum efficiency of the fuelwood, they also proposed the time for cutting as when the percentage of trees >8 cm DBH in stands accounted more than 30%. The experiment on fuelwood production of *Q. acutissima* conducted in hilly area of east of Anhui Province found that the biomass yield could reach 9 000-10,500 kg ha^{-1} on *Q. acutissima* stands aged 10 years old (Yu *et al.*, 2009). In addition, Liu *et al.* (2009) found that the energy accumulation (such as gross caloric value, ash free caloric value and ash content) in regeneration by sprouting was greater than afforestation by planting. Therefore, developing the fuel forest on the sawtooth coppice stands seems a sound practice.

3.4.5 Utilization of *Q. acutissima*

Because of its high resistance to drought and the adaption to poor soil conditions, *Q.acutissima* is commonly planted for soil and water conservation and wood production (Yang *et al.*, 1997; Yang and Jiang, 2001). Meanwhile, because of its strong sprouting ability, it is used broadly as fuelwood by coppicing in rural areas (Li *et al.*, 2001a; Jiang *et al.*, 2005). *Q. acutissima* forests (Kunugi forests) are managed for production of bed-logs for shiitake mushrooms and cow-calf farming in the Aso District of Kyushu Island in southwest Japan (Matsumoto *et al.*, 1999).

The timber of *Q. acutissima* is strong, hard-wearing, decay and shock resistant. It is excellent for railway ties, mine props, carts, boats, agricultural tools and furniture. The foliage can be used for feeding silkworms; the acorns have a starch content of approximately 50% and can be used to produce methanol, or as animal feed. Mushrooms can be grown on the twigs and small timber, as well as black fungus (*Auricularia auricula*) and silver fungus (*Tremella fuciformis*). The wood burns with a bright flame and no smoke, and is widely used for charcoal (Needham *et al.*, 1996).

3.4.6 Regeneration of *Q. acutissima*

The studies on the regeneration of *Q. acutissima* are scarce. Zhang (1986) reported that the *Q. acutissima* stands in south slope of Qinling Mountains and in Dabashan Mountains had good regeneration. The number of seedlings in the understory is 5100 individuals per ha. The seedlings in these regions are distributed evenly in the stand and mainly consist of *Q. acutissima,* *Q. variabilis, Q. aliena* var. *acuteserrata and Platycarya strobilacea.* Toshinori *et al.* (1999) considered that forest clearance should be avoided, and heavy thinning would be recommended for considerable growth of the planted *Q. acutissima* seedlings in the Red-pine forest floor.

Seedlings established by sprouting had a high survival rate and fast growth. A cutting on seedlings developed from seeding or planting is recommended after 2-3 years to promote the regeneration success (Lu *et al.*, 2003). The length and basal collar diameter of seedling sprouts decreased with increasing of number of sprouts and height of stump (Cao, 2009). The leaves of *Q. acutissima* seedlings respond to different habitats with phenotypic plasticity of morphology is an important mechanism for seedlings to adapt to broader ecological amplitudes (Xu *et al.*, 2008).

3.5 Socio-economic studies

Forestry is always related to the economic development and population growth. Nowadays, with the flourishing economic situation and the growth of the human population, the demands on forests are increasing. However, forest resources worldwide are declining gradually. The total net change in forest area in the period 2000-2010 is estimated at -5.2 million hectares per year, an area slightly bigger than the size of Costa Rica, or equivalent to a loss of more than 140 km^2 of forest per day (FAO, 2010). Therefore, appropriate management on remaining forests is a critical issue for all foresters. Study on socioeconomics affecting forest conservation and utilization is an effort to find ways to manage the forests sustainably and to satisfy the local inhabitants' demand on forests. In addition, it may help to improve the policy planning and execution.

Few studies dealing with forest development and socio-economic issues have been conducted recently, especially in developing countries, where there is a strong relationship between the local socio-economic situation and forest management and utilization. For instance, Singh and Sharma (2010) found that long-term security tenure can provide greater incentives for local people for the protection and sustainable use of forest resources in Gujarat state, India. By using the socio-economic questionnaires, Cai *et al.* (2007) found that the most important information needed by local farmers in Fujian Province, southern of China, are techniques on forest management (71.4%), and information on forest products (61.3%). In addition, 75.4% of farmers wanted to get guidance from forestry authority on technical assistance for afforestation and 52.4% of farmers wanted to get advice on pest control. The farmers also hoped that the local forest department would provide training programs. In Zhejiang Province, farmers preferred to plant cash crops in their own forestland for the purpose of economic benefits (Li *et al.*, 2004). The sale of forest products and harvest quota are two factors that affect farmers' choice of management patterns on private timber forest (Huang, 2008). Additionally, the communication between the local inhabitants and forest authorities is also important for making and implementing forest policy. Lack of communication between the forest officials and local people creates negative attitudes towards the forest management (Obua *et al.*, 1998).

To improve the sustainable development of forest resources, more and more people realized that involving local inhabitants in forest management is an effective measure (Yuan and Lang, 2002; Springate-Baginski *et al.*, 2003; Ellis and Porter-Bolland, 2008). Participation of the community is another recommendation to decrease forest destruction (Aregu and Demeke, 2006). Socio-economic factors (such as age, level of literacy, information source, household size, economic and social motivation) had a significantly influence on forest dwellers' participation in reforestation and development of forest areas (Faham *et al.*, 2008). The implementation of collective forest tenure reform considerably improves the farmers' initiative on forest management. However, the incomplete and unstable forest tenure system, heavy forest taxes, and the low economic benefits, hindered the development of farmers' participation in forest management (Liu *et al.*, 2000).

Several factors may affect household utilization of available forest resources. Türker and Kaygusuz (1995) found that in rural area of Turkey, there was a statistically positive relationship between the fuelwood consumption and the altitude of village, the distance between town centre and village and a negative relation between fuelwood consumption and the population density of the village, the distance between the forests and villages, and the number of people per household. A higher level of formal schooling is associated with less forest cutting (Godoy and Contreras, 2001). Forest resource utilization is positively related to the age of the head of household until a peak of physical strength is reached and children move away (Piland, 1991, cited in Mamo *et al.*, 2007). Total household income (and wealth) is often found to have a nonlinear relationship with forest resource extraction (Mamo *et al.*, 2007).

4 Materials and methods

4.1 Introduction of study area

4.1.1 Geographic location

Shangnan County is located in the southern part of Shaanxi Province (33°06'-33°44' N and 110°24'-111°01' W) in the eastern section of the southern slope of the Qinling Mountains (Fig. 3). The total area of Shangnan is 2314.87 km^2, stretching 72 km from south to north and 58 km from east to west.

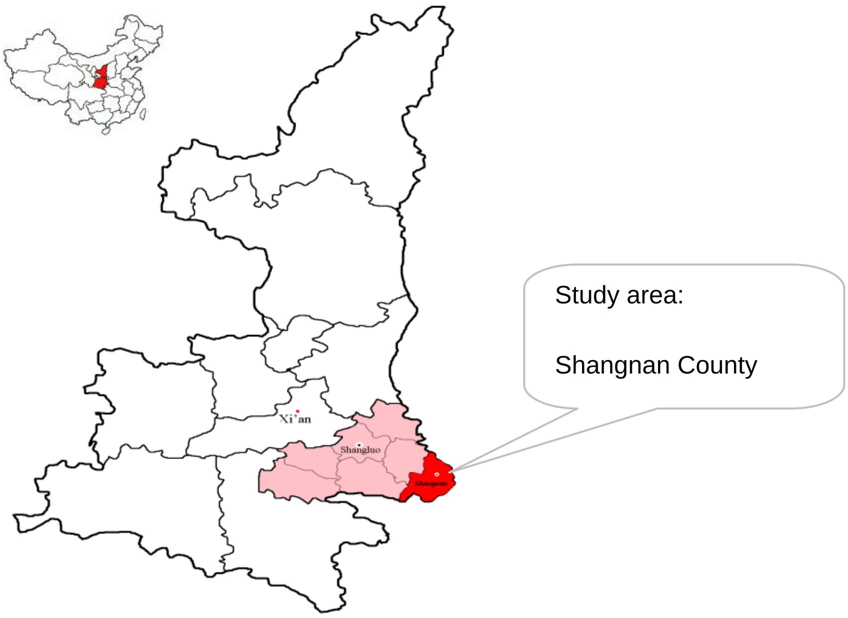

Fig. 3: Location of study area

4.1.2 Topography

In Shangnan, 70% of land area is low mountainous area or hillsides. The height above sea level is high in the north and southwest and low in the southeast and middle, varying from 216-2057 m in altitude. The Danjiang River, which is a branch of the Hanjiang River, is the largest watershed in this county. It divides the whole county from the middle into two parts: the north part and the south part. In the north, the parent material of mountains is mainly made up of quartzite; while the parent material in the south consists of crystalline limestone, slate, phyllite, and schist. Flat area is formed on the banks of Danjing and its branch watersheds, such as Xian and Qingyou River. The area below 800 m above sea level is dominated by yellow-brown soil with texture of clay loam or clay, while the soil in the region at more than 1000 m above sea level is mainly composed of brown forest soil or yellow-brown forest soil.

4.1.3 Climate

Shangnan County is located in the transitional area between the subtropical zone and the warm temperate zone, characterised by warm climate, abundant rainfall and four distinct seasons. Mean annual temperature varies between 10.7-15.0℃. The average sunlight time is 1973 hours, and the frost-free period lasts 216 days. The mean annual rainfall is 800 mm, concentrated in July, August and September. Disastrous flooding occurs frequently in July and August.

4.1.4 Vegetation

The vegetation resource is rich in Shangnan. There are 2000 plant species, belonging to 218 families. The number of woody plants reaches 700, including 316 tree species, 314 shrubs, and 82 woody vines. The different forest types are formed according to the different climate zones. Forests in warm temperate zone are mixed with deciduous broadleaved and needle species, such as *Q. variabilis*, *Q. acutissima*, *Q. dentata*, *Ulmus pumila*, *Pistacia chinesis, Pinus massoniana, Pinus tabulaeformis.* Forests in the subtropical zone consist of evergreen broadleaved and needle species, such as *Cinnamonum camphora, Pteroceltis tatarinowii, Q. phillyraeoides, Vernicia fordii, Cunninghamia lanceolata.*

4.1.5 Forest resources

The forested area in Shangnan is 129,915.2 ha and the forest coverage is 56.1% (Northwest Institute of Forest Inventory, Planning and Design, 2009). The average stocking volume is 28.6 m^3 per ha, which is equivalent to 33.3% of national average stocking volume (85.8 m^3 per ha according to report of seventh NFI) (Fang, 2011). The Natural Forest Conservation Program, conducted since 1999, has an essential impact on local vegetation reconstruction (Ye, 2008). However, with the implementation of the conservation program, many problems have appeared. Because of cutting limitation, the tending measures in the young stands could not be carried out; as a result, because of the high density and the unfavourable stand structure, the growth is slow and the quality is poor (Ye, 2008).

Oak forests are the biggest part of Shangnan's forest resources in terms of area and stocking volume. The area of oak forest in Shangnan is 90,073 ha, with a stocking volume of 2.590 million m^3, accounting for 70.9% of forested area and 71.3% of stocking volume (Northwest Institute of Forest Inventory, Planning and Design, 2009). Oak is also an important timber forest species. The area and the stocking volume of oak timber forest are 45,868 ha and 1.412 million m^3, respectively. It means that oaks are covering 72.9% of timber forest area and are contributing to 68.1% of the timber volume. However, the ignorance of management and over-exploitation on the oak forest has resulted in degradation and low quality of the stands (Qu *et al.*, 1990).

The existing timber forest resource can not satisfy the wood demand of local people in Shangnan County. According to the forest resource inventory in 2006, the young and middle-aged timber forest area account for 93.7% of the total timber forest area, whereas the mature forest is only 6.3 % (or 3927.4 ha). The amount of annual wood production for timber forest is 26,000 m^3, far less than the amount of actual demand (40,000 m^3 per year) (Ye, 2008). Moreover, fuelwood resources are scarce in Shangnan. There are only 728.2 ha of fuel-wood forest, accounting for 0.6% of forested area (Ye, 2008). Although some new energy technology, like biogas, has been applied in some villages, the most frequently used energy resource is still fuelwood, especially for the households who live in the mountainous area. The shortage of fuelwood intensifies the conflict between the environment and economic development.

4.1.6 Social economic condition

Shangnan County consists of 16 towns, 164 villages and 3 communities (the county town is divided as communities while the other towns as villages). The total population was 238,500 at the end of 2006. There are 209,400 farmers, accounting for 88.8% of total population. The arable land in Shangnan is only 13,000 ha, and the arable land per capita is about 600 m^2. Corn, wheat, and peanut are main crops in this area. Planting tea and mushrooms has become one of the main sources of income. In 2009, the farmer's average annual income was 2998 Yuan (Shangnan Statistic Bureau, 2009).

4.2 Oak stands survey

4.2.1 Sampling

The assessment of oak coppices is based on 30 sample stands in the Shangnan County. These stands were randomly selected within an area of a size of 20 km × 20 km (33°26'27″-33°37'15″N and 110°43'22″-110°56'10″E), which include two main branches of the Danjing River (Qingyou and Xian River). Using a topographic map, watersheds within the 400 km^2 area were identified, and larger watersheds were partitioned in smaller units not exceeding 4 km^2. In total, 72 watersheds were identified. From these, ten were randomly selected for field investigation. Each selected unit was identified using GPS (global positioning system) in the field. One of the eight cardinal directions was selected at random as a starting direction for the selection of three stands within each watershed. The stand occurring first in the selected direction was identified the first one for sampling. Following the same direction, providing there was a separation distance of at least 200 m, the next two stands were also selected for sampling. This sampling procedure was appropriate in order to avoid too long walking distances.

In each selected stand, a plot of 20 m × 20 m in size was established for the data collection of mature stands. Each plot includes an inner plot of 10 m x 10 m, on which 16 circle sample plots of a size of $1m^2$ were systematically installed. These were used to collect information about the stand regeneration and the ground vegetation. The layout of a plot is presented in Fig. 4.

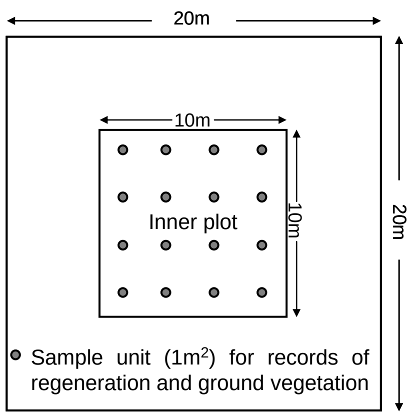

Fig. 4: Layout of a plot

4.2.2 Data collection

The data were collected in summer 2008. A brief description of the investigated parameters is presented in Table 1.

Table 1: Measured parameters in the coppice stands

Measured parameters	Sample Size
Elevation, longitude, latitude, and slope direction	Elevation of the plot centre, and slope direction of the most frequent aspect in a plot
Slope steepness	5 systematically distributed samples on each plot
Soil characteristic including soil type, soil thickness	One soil profile on each plot
Tree species, DBH (diameter at breast height) and height of all single-stem trees, DBH and height of the main stem of multiple-stem trees*, stand age, origin of each individual tree whether sprout or not, number of sprouts, crown class[1], vitality[2], quality[3], damage[4]	All trees ≥ 2 m height within the whole plot (20 m × 20 m)
DBH and height of all stems of multiple-stem trees; Crown width and crown length of all single-stem trees; Crown width and crown length of the main stem of multiple-stem trees;	All trees ≥ 2 m height within the inner plot (10 m × 10 m)
Regeneration: species, number of seedlings, root collar diameter, height, origin of seedlings	16 circles with 1 m^2 in size on each plot
Understory vegetation: total coverage, average mean height, coverage and mean height of different life forms (grass, herb, shrub, tree)	16 circles with 1 m^2 in size on each plot

* The main stem is defined as the thickest stem of multiple-stem trees. For multiple-stem trees, the definition of crown class, vitality, quality, damage is based on the main stem.

1. Classification of crown class (four levels):
   - Dominant (Crown fully free)
   - Co-dominant (Crown less than 1/3 suppressed)
   - Intermediate (Crown between 1/3 and 2/3 suppressed)
   - Suppressed (Crown more than 2/3 suppressed)
2. Classification of tree vitality (three levels)
   - Vigorous(healthy, densely foliated),
   - Moderate(reasonably healthy, fairly foliated)
   - Weak(unhealthy or poorly foliated)
3. Classification of tree quality (three levels)
   - High (straight trunk, free of fork, well formed crown)
   - Satisfactory (slightly crooked central leader, slight forked, fairly formed crown)
   - Unsatisfactory (sharply crooked leader, strongly forked, badly formed crown)
4. Classification of damage degree (three levels)
   - Undamaged
   - Slightly damaged
   - Severely damaged

The tools and methods that used to measure the parameters were:

Site factors

- Elevation, longitude, and latitude were recorded using GPS.
- Slope direction was measured with compass.
- Slope steepness was measured with Vertex IV. We recorded at least three times at different points in one plot. The average of these values is the slope steepness of plot.

Tree parameters

- Diameter at breast height (DBH): DBH was measured using a diameter tape at the height of 1.3 m.
- Tree height: tree height was measured from the tree base to the top or the tallest live portion of crown with Vertex IV.
- Crown length: crown length is the distance between the crown base and the top of the tree. It was measured with Vertex IV as well.
- Crown width: crown width was determined by averaging two crown diameter measurements at 90 degrees to each other.
- Tree age: was measured by using tree cores that extracted with increment borer.
- Stand age: stand age was determined by the average age of five individual trees per plot.

Regeneration & vegetation

- Root-collar diameter: was measured with calliper on each seedling.
- Height of seedlings: was measured with folding rule.
- Coverage of vegetation: it was estimated as the percentage of area covered by vegetation within 1m^2 circle area.
- Height of vegetation: was measured by folding rule.

4.2.3 Data analysis

1. Data analysis on stand level

1). Calculation of stand parameters

The **tree number** (N) and **stem number** (N), used as density of trees/stems, is the number of trees/stems per hectare.

The **arithmetic mean diameter** ($\bar{d}$), is calculated from the individual diameter values.

$$\bar{d} = \frac{d_1 + d_2 + ... + d_N}{N} = \frac{1}{N} \times \sum_{i=1}^{N} d_i \qquad \text{(4.1) (Pretzsch, 2010)}$$

where d_i is the diameter at breast height of individual i, N is the total number of stems in the plots.

The **arithmetic mean height** ($\bar{h}$), is calculated from the individual height values.

$$\bar{h} = \frac{h_1 + h_2 + ... + h_N}{N} = \frac{1}{N} \times \sum_{i=1}^{N} h_i \qquad \text{(4.2)(Pretzsch, 2010)}$$

where h_i is the height of individual.

The **quadratic mean diameter** (d_q), or diameter of the mean basal area tree (stem) is calculated from the arithmetic mean of the basal area of all stems at breast height $ba_{1.3}$ in a stand:

$$\overline{ba} = \frac{\sum_{i=1}^{N} ba_i}{N} \qquad \text{(4.3) (Pretzsch, 2010)}$$

This mean basal area of all stems is used then to obtain d_q:

$$d_q = 2 \times \sqrt{\frac{\overline{ba}}{\pi}} \qquad (4.4)(\text{Pretzsch, 2010})$$

The **mean height** (h_q) is the mean height of three (or more) stems with DBH closest to the quadratic mean diameter.

The **slenderness** (h_q/d_q), is calculated by quadratic mean height divided by quadratic mean diameter.

The **mean diameter of dominant trees** (d_{100}), is the mean of DBH of dominant trees. Dominant trees are the 100 thickest trees per hectare. Here, it means the 100 largest stems per hectare (In coppice stands, single-stem trees and multiple-stem trees exists altogether. The main stem of multiple-stem trees also could be the thickest one). Furthermore, we calculated these values only for the main species in stands. Only the main species belonging to the group of the 100 thickest trees per ha were included in the calculations according to the recommendations of Zingg (1994) and Commarmot *et al.* (2005) for mixed species forests.

The **dominant height** (h_{100}), is the mean height of dominant trees.

The **slenderness of dominant trees** (h_{100}/d_{100}), is the ratio of dominant height and dominant diameter.

The **basal area** (BA) is calculated as the sum of cross-sectional area of stems at the 1.3 m height.

$$BA = \frac{\sum_{i=1}^{N} ba_i}{A} = \frac{\sum_{i=1}^{N} \frac{d_i^2 \times \pi}{4}}{A} \qquad (4.5)(\text{Pretzsch, 2010})$$

where ba_i is the cross-sectional area of stem i , A is the plot size in ha.

The **volume** (V) is calculated as the sum of volume of standing trees per plot area. The volume of standing trees was obtained from volume tables (compiled with DBH and height). The volume table of oak species in Northwest of China (Forestry Administration of China, 1978) was used to estimate the volume of oak, and the volume table of broadleaved species in Northwest of China is used to calculate the volume of other broadleaved species (Forestry Administration of China, 1978).

The calculation of BA and V of single-stem trees are based on the samples of whole plot (20 m × 20 m). However, for the multiple-stem trees, the DBH and height of the main stem (the thickest one) were measured in whole plot (20 m × 20 m) while the DBH and height of the secondary stems (the other stems except the main stem) were measured in inner plot (10 m × 10 m). Therefore, the calculation of BA and V of the main stem of multiple-stem trees are based on the samples in whole plot (400 m^2) and the BA and V of the secondary stems are based on the sample s in inner plot (100 m^2). Thus, the BA and V of all stems of multiple-stem trees were obtained as the sum of values of the main stem and values of the secondary stems (Equation 4.6 and Equation 4.7).

$$\begin{aligned}\mathrm{BA}_{\text{multiple-stem tree}} &= \mathrm{BA}_{\text{main stem}} + \mathrm{BA}_{\text{secondary stem}} \\ &= \frac{\sum_{i=1}^{N} \mathrm{ba}_{i(\text{main stem})}}{400} + \frac{\sum_{i=1}^{N} \mathrm{ba}_{i(\text{secondary stem})}}{100}\end{aligned} \quad (4.6)$$

$$\begin{aligned}\mathrm{V}_{\text{multiple-stem tree}} &= \mathrm{V}_{\text{main stem}} + \mathrm{V}_{\text{secondary stem}} \\ &= \frac{\sum_{i=1}^{N} \mathrm{V}_{i(\text{main stem})}}{0.04} + \frac{\sum_{i=1}^{N} \mathrm{V}_{i(\text{secondary stem})}}{0.01}\end{aligned} \quad (4.7)$$

The BA and V of all stems in a stand, i.e., the stand basal area and stand volume, are calculated by adding the values of single-stem trees and the values of multiple-stem trees together.

The **number of species** is recorded as the number of tree species which appeared on the whole plot.

Simpson's index of diversity (4.8) and **Shannon-Wiener index** (Peet, 1974) (4.9) were calculated as follows:

$$\mathrm{D}=1-\frac{\sum n_i(n_i-1)}{N(N-1)} \quad (4.8)$$

where D is the value of Simpson's index of diversity, n_i is the number of individuals in species i, N is the total number of tree species. The Simpson's index of diversity ranges from 0 to 1, and the greater the value is, the greater the sample diversity.

$$\begin{aligned}H' &= -\sum_{i=1}^{n} p_i \ln(p_i) \\ p_i &= \frac{n_i}{N}\end{aligned} \quad (4.9)$$

where H' is the value of Shannon-Wiener index, p_i is the proportion of the individuals in tree species i, n_i is the total number of species i, N is the total number of all species. The maximum value for the Shannon-Wiener index occurs when the proportions are equal over all tree species. The minimum value of index is 0, when there is only one tree species.

2). Calculation of parameters of stand regeneration

The **number of species** is presented as the number of seedlings appeared on 16 circles of 1m^2 in size on each plot.

The **density** is the number of seedlings per hectare.

The **average height** is the mean of seedling height.

The **average root-collar diameter** is the mean value of regeneration root-collar diameter.

The **diversity** of regeneration species is represented using **Simpson's index** of diversity (4.8) and **Shannon-Wiener index** (4.9).

The **frequency** of occurrence of species (%): is calculated as the percentage of plots with the occurrence of the specified species to total number of plots (Geldenhuys, 1997).

3). Calculation of parameters of understory vegetation

The **coverage of understory vegetation** is calculated as the sum of coverage of 16 circles (1m^2 in size) divided by 16.

The **average height of understory vegetation** is the average of height of understory vegetation in 16 circles.

The **coverage of different life forms** (grass, herb, shrub, trees <2 m) in the understory are calculated respectively by averaging the coverage of each life form in 16 circles.

The **average height of different life forms** (grass, herb, shrub, trees <2 m) in the understory are calculated respectively by averaging the mean height of each life form in 16 circles.

When the value of stand parameters were recorded, we made the scatter diagram of stand density (number of stems) with stand age as well as the scatter diagram of stand mean diameter with stand age, respectively. We found that the stand density and stand mean diameter were different between the stands with same age, and all stands could be classified into two groups according to their distribution on the diagram. One group is characterised with a higher stand density and lower mean diameter compared with to the other one at the same stand age. Due to the wide use of oak coppice, rapid growth of stem, strong sprouting ability, and low cost in stocking growth in the study area, these oak stands have been coppiced one or more times. It is known that frequent coppicing results in lower stand mean diameter and higher stem densities. For instance, when a stand is coppiced frequently, there can be problems with obtaining good regrowth, particularly if stands have been neglected for some while (Fuller and Warren, 1993) and Strong (1989) also documented that the average shoot height and diameter decreased with each successive cycle. Therefore the coppicing frequency can be derived from the stem density and mean stand diameter. Based on this knowledge and the preliminary results, we classified all stands into two stand use types based on coppicing frequency: 1) stands with moderate use and 2) stands with intensive use. Besides, we found that none of site factors had an impact on stands because 1) the stand management or use is the most important factor that eclipses all other factors and 2) the number of the combinations of the site factor levels is too large for the 30 plots. The classification of plots with different types of uses and the site characteristics of each plot are presented in Table 2.

Table 2: Site characteristics, main species, and forest stand use type of 30 coppice stands

Plot no.	Main species	Stand age (year)	Elevation (m)	Slope steepness (°)	Slope direction*	Soil thickness*	Soil type	Use type
3	*Q.variabilis*	11	740	35	S	Shallow	Silty sand	Moderate use
13	*Q.variabilis*	12	500	42	SE	Deep	Sandy silt	Moderate use
15	*Q.variabilis*	12	500	41	S	Shallow	Loamy silt	Moderate use
14	*Q.variabilis*	14	500	38	S	Intermediate	Loamy silt	Moderate use
18	*Q.variabilis*	15	452	37	E	Shallow	Silty sand	Moderate use
28	*Q.variabilis*	15	671	27	S	Deep	Loamy silt	Moderate use
27	*Q.variabilis*	16	520	31	SW	Shallow	Silty sand	Moderate use
25	*Q.variabilis*	17	540	24	E	Deep	Loamy silt	Moderate use
22	*Q.variabilis*	19	495	41	NE	Shallow	Sandy silt	Moderate use
1	*Q.variabilis*	20	716	35	E	Intermediate	Loamy sand	Moderate use
16	*Q.variabilis*	20	445	40	N	Shallow	Sandy silt	Moderate use
26	*Q.variabilis*	20	553	46	S	Intermediate	Silty sand	Moderate use
19	*Q.variabilis*	21	517	33	NE	Shallow	Silty sand	Moderate use
29	*Q.variabilis*	25	671	34	SE	Shallow	Sand	Moderate use
24	*Q.variabilis*	25	524	37	SE	Shallow	Sand	Moderate use
4	*Q.variabilis*	11	449	39	E	Shallow	Silty sand	Intensive use
5	*Q.variabilis*	10	405	34	NW	Intermediate	Silty sand	Intensive use
6	*Q.variabilis*	11	398	39	S	Shallow	Silty sand	Intensive use
30	*Q.variabilis*	12	720	33	SW	Intermediate	Silty loam	Intensive use
17	*Q.variabilis*	14	446	39	N	Shallow	Silt	Intensive use
11	*Q.variabilis*	16	460	26	SW	Shallow	Silty sand	Intensive use
9	*Q.variabilis*	17	435	34	E	Shallow	Silty sand	Intensive use
7	*Q.variabilis*	20	440	39	SE	Shallow	Silty sand	Intensive use
12	*Q.variabilis*	21	460	35	SE	Shallow	Silty sand	Intensive use
23	*Q.variabilis*	25	520	35	E	Shallow	Loamy sand	Intensive use
20	*Q.acutissima*	7	535	28	N	Intermediate	Silty sand	Moderate use
21	*Q.acutissima*	17	496	34	NW	Intermediate	Loamy silt	Moderate use
2	*Q.acutissima*	8	710	32	W	Shallow	Sand	Moderate use
8	*Q.acutissima*	27	426	26	S	Deep	Silty loam	Moderate use
10	*Q.acutissima*	18	435	42	N	Shallow	Sand	Intensive use

*Slope direction: south (S), north (N), east (E), west (W), southeast (SE), southwest (SW), northeast (NE), northwest (NW); *Soil thickness: shallow (soil thickness<30 cm), intermediate (soil thickness between 30 to 60 cm), deep (soil thickness>60 cm)

Comparing regression analyses was used to test the difference of stand parameters among stands and among stand usage. Relationships between stand variables (density, basal area, volume and quadratic mean diameter, quadratic mean height and slenderness) with stand age were estimated using regression analyses as well. Further, the stands regeneration and understory vegetation of different stands were analyzed by comparing regression analyses.

Different regression models (linear, exponential or power) were developed according to the goodness of fit for equation which determined by examining *p*-values, the mean square of the error (MSE) and the coefficient of determination (adjusted r^2). Regression lines (curves or liner) on graphs indicated the output from the regression model. Different patterns of regression line were used according to the result of difference test among stands (Table 3). All comparing regression analyses were conducted using the programme "HK_WB Rehabilitation Southern Shaanxi, China - Oak coppice, 2011 ©" (El Kateb, 2011), developed in SAS programming language based on SAS for windows, version 9.2. It should be noted these non-linear or linear regressions were applicable to the range of size or ages examined.

Table 3: Patterns of regression line in different types of stands

Stand type	Patterns of regression line
Stands with moderate use	
Stands with intensive use	
Q. variabilis stands	
Q. acutissima stands	
Q. variabilis stands, moderate use	
Q. variabilis stands, intensive use	
Q. acutissima stands, moderate use	
All stands	

2. Data analysis on individual tree parameters

According to the origin of trees (seeds or sprouts) and the number of stems per tree, the following classification of stems was used to differentiate individual stems.

Classification of stems:

Main stem:

1): non-coppiced, single stem (the stem of trees origin from natural or planted seedlings)

2): coppiced, single stem (the stem of trees from coppicing, only one stem per tree)

3): coppiced, multiple stem (the thickest stem of multiple-stem trees)

Secondary stem:

4): coppiced, multiple stem (except the main stem, the rest of stems of multiple-stem trees)

The study on the characteristics of *Q. variabilis* and *Q. acutissima* on tree level was conducted on the main stem. Therefore, three types of stems were defined: (1) non-coppiced, single stem; (2) coppiced, single stem; (3) coppiced, multiple stem. All damaged trees (induced by biotic, abiotic or other factors) were excluded. We classified the single trees based on the stem type and the crown class. The relationships among variables of single tree (DBH, height, slenderness) and the relationships between crown variables and DBH or height were explored. The correlation coefficient (R^2) was used to detect the degree of correlation. The arithmetic means of DBH, height, slenderness, crown width, crown length and crown ratio of different types of stem in each crown class were calculated to compare the growth of stem within the same vitality class.

4.3 Socio-economic survey

4.3.1 Sampling

A socio-economic questionnaire was conducted in summer 2009 on randomly selected 175 households from 11 villages (15-16 households in each village). These villages were located within the Shangnan County. The furthest one was 19 km and the nearest one was 5 km away from the county centre.

4.3.2 Data collection

The questionnaire consisted of open-ended and closed-ended questions. Questions were explained to the interviewee to avoid any misunderstanding and to improve efficiency of answers during the interview. To measure the quality of the answers, the reliability was assessed at the end of the interview by surveyor according to the people's response in answering the question (such as certain, uncertain, or careless). It was found that 97% of questionnaires were largely reliable or reliable.

The first part of questionnaire contained the socio-economic parameters (Table 4). The main part of questionnaire was a list of questions which were related to the following objectives:

- Forest resources
- Energy sources
- Usage of forest resources
- Efficiency of collaboration with local authorities
- Acceptance by the local inhabitants to change the present use of the forest resources

Table 4: Socio-economic dimensions in questionnaires

Name of socio-economic variables	Unit
Number of inhabitants in village	person
Gender	-
Marital status	-
Age	year
House size	m^2
Household size	person
Number of children	person
Economic situation	-
Full or part time farmer	-
Practiced land use type	-

4.3.3 Data analysis

Data analysis for the socio-economic study was conducted in two sections, descriptive and inferential statistics. In descriptive statistics, the values such as mean, standard deviation, minimum and maximum value, were used for the quantitative variables. For all nominal variables as well as all the class of interval variables, the percentage of samples in each class was calculated to describe the distribution of sample. The hypothesis test of distribution of classification of variables was detected using One-sample Binomial test (two categories) or One-sample Chi-square test (more than two categories) (Larson-Hall, 2009; Bryman and Cramer, 1990). Inferential statistics were applied to explore the correlations among the variables. Analysis of variance (ANOVA) was used to determine whether there were significant differences in the quantitative variables among different classes. However, in our case, the majority of variables in questionnaire are nominal (categorical). Thus, non-parametric statistics methods were used. The Chi-Square test (χ^2-Test) was one of non-parametric statistics that used to test whether or not there is a relationship between two nominal variables (David and Sutton, 2004). Fisher's Exact Test is an alternative to the χ^2-Test when the minimum expected count for any cell in a contingency table is less than 5. To test the strength of such relationships we use correlation-like measures such as the *Phi coefficient*, the *Cramer´s V* (Morgan *et al.*, 2011; UNESCO, 2011). Analysis of the data from socio-economic investigation was done with the IBM SPSS statistics 19.

5 Results

Part 1 Results of oak stands

5.1 Description of stands

5.1.1 Main stand

5.1.1.1 All trees

25 stands of the selected 30 coppice stands, which accounted 83% of the total coppiced oak stands, were mixed stands dominated by *Quercus variabilis*. The age of these 25 stands varied from 10 to 25 years. The remaining 5 stands (accounted 17% of all coppiced oak stands) were dominated by *Quercus acutissima*, with ages from 7 to 27 years.

The stem density varied from 1275 to 9175 stems ha^{-1} belonging to 1275 to 6150 partly multi-stemmed trees ha^{-1} in *Q. variabilis* dominated stands (Table 5). The range of the arithmetic mean diameter ($\bar{d}$) was 3.8 to 12.5 cm and the range of the arithmetic mean height ($\bar{h}$) was 4.3 to 11.5 m. Compared to the $\bar{d}$ and $\bar{h}$, the quadratic mean diameter (d_q) and height of quadratic mean diameter (h_q) varied from 5.0 to 13.2 cm and 4.8 to 12.0 m, respectively. The lowest slenderness of stem (h_q/d_q) was 94 and the highest was 137. The basal area of all stems (stand basal area) varied between 10.6 and 26.6 m^2 ha^{-1} and the stocking volume of all stems (stand stocking volume) ranged from 47.5 to 152.7 m^3 ha^{-1}.

In *Q. variabilis* dominated stands, 32 woody species were found. *Q. variabilis* was the main species, and its density ranged from 1150 to 5225 trees ha^{-1} with comprising 32.2-99.0% of all trees (Table 5, Table 6). The basal area of all stems of *Q. variabilis* ranged from 6.1 to 26.6 m^2 ha^{-1} with comprising 38.3-99.9% of all trees (Table 5, Table 7). Another two oak species, *Q. acutissima* and *Q. dentata*, were observed in *Q. variabilis* stands. *Q. dentata*, occurred in half of the stands with a low number (25-175 trees ha^{-1}) and a low basal area, whereas *Q. acutissima* appeared only in some older stands (>20 years) with a relatively high basal area. *Pinus massoniana* was the only coniferous species that frequently occurred in *Q. variabilis* stands (it was recorded in 64% of all investigated *Q. variabilis* stands). The density of *P. massoniana* ranged from 25 to 575 trees ha^{-1} while the basal area of *P. massoniana* was the largest among the accompanied species. Some native species, such as *Dalbergia hupeana*, *Robinia pseudoacacia*, *Pistacia chinensis,* and *Albizzia julibrissin*, were recorded frequently in *Q. variabilis* stands. *D. hupeana* had a high variation on density from 25 to 1675 trees ha^{-1}, however, the basal area was around 0.1 m^2 ha^{-1} in most of the stands (the largest was 0.4 m^2 ha^{-1}). Also *P.*

chinensis frequently appeared in *Q. variablis* stands. The density ranged from 25 to 700 trees ha^{-1} and the basal area ranged from <0.1 to 1.7 m^2 ha^{-1}. The other woody species were observed occasionally with a very small number, including *Paulownia tomentosa*, *Morus alba*, *Acer pashanicum*, *Populus davidiana*, *Ulmus pumila*, *Castanea mollissima*.

We recorded 15 tree species in 5 *Q. acutissima* dominated stands. The density of all trees ranged from 1375 to 5050 trees ha^{-1} and the density of all stems ranged from 1575 to 5475 stems ha^{-1}. Although the d_q and h_q of all stems had no apparent increase with the stand age, the basal area and volume of all stems in *Q. acutissima* stands showed an increase trend. The slenderness of stem varied from 87 to 149.

Q. acutissima was the main species in *Q. acutissima* stands, and its density ranged from 825 to 4025 trees ha^{-1} with comprising 57.1-79.7% of all trees. The basal area of all stems of *Q. acutissima* ranged from 9.2 to 23.0 m^2 ha^{-1} with comprising 57.2-96.4% of all trees. *Q. variabilis* accompanied in *Q. acutissima* stands frequently, with a mean density of 269 trees ha^{-1}, ranged from 25 to 325 trees ha^{-1}. However, the basal area of *Q. variabilis* in *Q. acutissima* dominated stands was very small (only 0.1 m^2 ha^{-1}). *R. pseudoacacia* occurred frequently in *Q. acutissima* stands as well, ranged from 50 to 250 trees ha^{-1} in density. *P. massoniana* was found also in *Q. acutissima* stands, accounted the largest basal area among accompanied species.

Table 5: Characteristics of all trees in 30 oak coppice stands. Abbreviation: N= number of trees, N= number of stems, $\bar{d}$ = arithmetic mean diameter of all stems, $\bar{h}$ = arithmetic mean height of all stems, d_q=quadratic mean diameter of all stems, h_q= mean height (height of quadratic mean diameter) of all stems, h_q/d_q = slenderness (h_q : d_q) of all stems, BA= basal area of all stems, V=stocking volume of all stems, N% of main sp= the ratio of number of trees of the main species to number of all trees, BA%= the ratio of basal area of all stems of the main species to basal area of all stems

Plot no.	Main species	Age (yrs)	N (trees ha^{-1})	N (stems ha^{-1})	$\bar{d}$ (cm)	$\bar{h}$ (m)	d_q (cm)	h_q (m)	h_q /d_q	BA (m^2 ha^{-1})	V (m^3 ha^{-1})	N% of main sp	BA% of main sp
5	*Q. variabilis*	10	5900	9125	4.0	4.3	4.7	4.7	100	15.9	73.7	54.7	38.3
3	*Q. variabilis*	11	5025	8525	4.5	5.5	5.4	6.5	121	19.4	87.0	62.7	95.5
4	*Q. variabilis*	11	5175	7075	4.6	5.8	4.6	5.9	129	11.7	47.5	99.5	99.6
6	*Q. variabilis*	11	4225	6550	5.3	5.5	5.2	5.3	101	14.1	63.3	92.9	96.8
13	*Q. variabilis*	12	4350	5950	6.1	7.0	6.2	7.7	124	18.0	88.1	89.1	97.1
15	*Q. variabilis*	12	5325	7075	6.0	7.5	6.3	8.0	128	21.8	105.4	98.1	95.4
30	*Q. variabilis*	12	3950	5775	5.2	6.0	5.6	6.4	114	14.3	72.6	84.8	95.8
14	*Q. variabilis*	14	4850	5975	5.6	6.2	6.1	6.7	110	17.3	87.4	88.7	66.5
17	*Q. variabilis*	14	6150	8950	3.8	4.8	4.2	5.8	137	12.7	63.0	84.6	96.9
18	*Q. variabilis*	15	3975	4100	7.7	9.2	8.4	10.8	128	22.7	122.8	96.2	88.1
28	*Q. variabilis*	15	3050	4325	7.1	8.3	7.8	9.5	121	20.8	106.3	89.3	89.2
27	*Q. variabilis*	16	4650	5275	7.2	8.9	7.6	10.8	141	24.2	127.6	84.9	66.9
11	*Q. variabilis*	16	3925	4450	4.2	5.2	5.5	5.9	107	10.6	62.2	45.9	88.8
25	*Q. variabilis*	17	3525	4375	6.5	7.4	7.9	9.7	123	21.5	119.2	70.2	64.4
9	*Q. variabilis*	17	4800	6400	5.6	6.4	6.2	7.2	115	19.6	93.0	69.3	69.0
22	*Q. variabilis*	19	3175	3350	8.6	9.3	9.5	11.1	117	23.5	136.7	81.9	83.7
1	*Q. variabilis*	20	2400	3000	10.0	10.0	10.6	12.8	120	26.6	160.6	92.7	98.7
16	*Q. variabilis*	20	2675	3075	6.2	6.5	7.7	7.3	95	14.4	84.8	68.2	88.9
26	*Q. variabilis*	20	2375	3950	7.8	8.2	8.0	9.8	123	19.8	110.5	72.6	85.4
7	*Q. variabilis*	20	3225	5275	5.6	5.7	6.2	7.3	118	15.8	78.2	49.6	62.0
19	*Q. variabilis*	21	2275	2700	10.0	10.7	11.1	13.4	121	26.1	149.6	85.7	83.7
12	*Q. variabilis*	21	3575	4900	5.5	6.2	7.0	8.4	120	19.0	117.8	32.2	60.7
29	*Q. variabilis*	25	2450	2975	9.5	10.2	10.7	11.7	110	26.6	152.7	99.0	99.9
24	*Q. variabilis*	25	1275	1275	12.5	11.5	13.0	12.2	94	16.9	107.1	96.1	96.0
23	*Q. variabilis*	25	3100	3675	7.0	7.7	8.6	10.2	118	21.4	122.9	62.9	68.7
20	*Q. acutissima*	7	3325	4150	5.7	6.3	5.9	6.9	117	11.3	54.8	75.9	81.2
2	*Q. acutissima*	8	3325	4925	5.5	6.3	5.8	7.4	128	12.8	70.6	57.1	81.5
21	*Q. acutissima*	17	1725	2100	10.0	9.0	10.2	8.9	87	17.2	104.0	59.4	57.2
10	*Q. acutissima*	18	5050	5475	5.5	7.2	6.6	9.8	148	18.8	101.7	79.7	90.1
8	*Q. acutissima*	27	1375	1575	11.1	11.7	13.9	16.9	122	23.9	207.7	60.0	96.4

Table 6: Species composition of 30 oak coppice stands by tree density (trees ha^{-1})

Plot no.	Age (yrs)	Tree density (trees ha^{-1})									
		Total	*Q. variabilis*	*Q. acutissima*	*Dalbergia hupeana*	*Robinia**	*Pinus**	*Pistacia**	*Q. dentata*	*Albizzia julibrissin*	*Other species**
5	10	5900	3225	-	775	1050	425	100	-	150	175
3	11	5025	3150	-	1675	-	25	-	150		25
4	11	5175	5150	-	-	-	-	25	-	-	-
6	11	4225	3925	-	75	-	-	-	-	50	175
13	12	4350	3875	-	-	-	-	300	25	-	150
15	12	5325	5225	-	-	-	50	-	-	25	25
30	12	3950	3350	-	275	-	-	25	125	125	50
14	14	4850	4300	-	50	50	100	75	50	150	75
17	14	6150	5200	-	-	-	75	300	-	125	450
18	15	3975	3825	-	-	-	100	-	-	-	50
28	15	3050	2725	-	25	-	25	75	25	-	175
27	16	4650	3950	-	-	150	200	-	-	75	275
11	16	3925	1800	-	1025	625	50	150	125	125	25
25	17	3525	2475	-	175	50	275	275	-	-	275
9	17	4800	3325	-	150	575	375	25	100	-	250
22	19	3175	2600	-	-	-	75	225	175	-	100
1	20	2400	2225	-	50	-	25	-	100	-	-
16	20	2675	1825	25	-	-	575	75	-	-	175
26	20	2375	1725	-	-	-	-	450	100	-	100
7	20	3225	1600	575	125	25	25	600	25	75	175
19	21	2275	1950	-	-	-	250	-	75	-	-
12	21	3575	1150	400	825	225	125	450	75	125	200
29	25	2450	2425	-	-	-	-	-	-	-	25
24	25	1275	1225	25	-	-	-	25	-	-	-
23	25	3100	1950	75	325	-	250	325	-	50	125
20	7	3325	275	2525	-	75	75	200	25	75	75
2	8	3325	325	1900	775	-	-	-	300	-	25
21	17	1725	25	1025	-	225	325	75	-	-	50
10	18	5050	-	4025	850	50	75	-	-	-	50
8	27	1375	50	825	-	250	-	50	-	-	200

Robinia= Robinia pseucdoacacia, Pinus*= Pinus massoniana, Pistacia*= Pistacia chinensis*

** Sabina chinensis, Armeniaea sibirica, Prunus davidiana, Paulownia tomentosa, Ailanthus altissima, Morus alba, Acer pashanicum, Platycladus orientalis, Malus pumila, Populus davidiana, Ulmus pumila, Castanea mollissima, Sapium sebiferum, Toona sinensis, Diospyros kaki, Cupressus funebris, Q. serrata, Broussonetia papyrifera, Pterocarya insignis, Toxicodendron vernicifluum, Lindera glauca, Rhamnus utilis, Juglans cathayensis*

Table 7: Species composition of 30 oak coppice stands by basal area (m^2 ha^{-1})

Plot no.	Age (yrs)	basal area (m^2 ha^{-1})									
		Total	*Q. variabilis*	*Q. acutissima*	*Dalbergia hupeana*	*Robinia**	*Pinus**	*Pistacia**	*Q. dentata*	*Albizzia julibrissin*	*Other species**
5	10	15.9	6.1	-	0.2	0.9	8.3	0.1	-	0.1	0.2
3	11	19.4	18.5	-	0.4	-	<0.1	-	0.4		0.1
4	11	11.7	11.6	-	-	-	-	0.1	-	-	-
6	11	14.1	13.7	-	<0.1	-	-	-	-	0.2	0.2
13	12	18.0	17.4	-	-	-	-	0.3	0.1	-	0.2
15	12	21.8	20.8	-	-	-	1.0	-	-	<0.1	<0.1
30	12	14.3	13.7	-	<0.1	-	-	<0.1	0.3	0.1	0.2
14	14	17.3	11.5	-	0.1	0.1	4.0	0.2	0.1	0.9	0.4
17	14	12.7	12.3	-	-	-	0.2	0.1	-	<0.1	0.1
18	15	22.7	20.0	-	-	-	2.1	-	-	-	0.6
28	15	20.8	18.5	-	<0.1	-	1.5	<0.1	<0.1	-	0.8
27	16	24.2	16.2	-	-	1.9	2.1	-	-	0.6	3.4
11	16	10.6	9.4	-	0.2	0.4	0.1	0.4	0.1	<0.1	<0.1
25	17	21.5	13.9	-	0.1	0.4	5.3	0.2	-	-	1.6
9	17	19.6	13.5	-	0.1	0.4	5.4	<0.1	0.1	-	0.1
22	19	23.5	19.7	-	-	-	0.8	0.6	1.8	-	0.6
1	20	26.6	26.3	-	<0.1	-	<0.1	-	0.3	-	-
16	20	14.4	12.8	<0.1	-	-	0.7	0.1	-	-	0.8
26	20	19.8	16.9	-	-	-	-	1.7	0.4	-	0.8
7	20	15.8	9.8	3.1	0.2	0.2	0.6	1.4	<0.1	<0.1	0.4
19	21	26.1	21.9	-	-	-	3.5	-	0.7	-	-
12	21	19.0	11.5	4.1	0.4	0.6	0.8	0.4	0.2	0.1	0.9
29	25	26.6	26.6	-	-	-	-	-	-	-	<0.1
24	25	16.9	16.2	0.5	-	-	-	0.2	-	-	-
23	25	21.4	14.7	0.9	<0.1	-	4.4	1.3	-	<0.1	<0.1
20	7	11.3	<0.1	9.2	-	0.1	1.2	0.2	<0.1	0.1	0.5
2	8	12.8	0.1	10.5	0.2	-	-	-	0.9	-	1.1
21	17	17.2	0.1	9.9	-	0.3	6.7	0.2	-	-	<0.1
10	18	18.8	-	16.9	0.3	0.1	1.4	-	-	-	0.1
8	27	23.9	<0.1	23.0	-	0.5	-	<0.1	-	-	0.4

Robinia= Robinia pseucdoacacia, Pinus*= Pinus massoniana, Pistacia*= Pistacia chinensis*

5.1.1.2 Dominant trees

The mean diameter of dominant trees (d_{100}) of *Q. variabilis* stands varied between 8.5 and 22.4 cm and the dominant height (h_{100}) from 7.1 to 16.2 m (Table 8). Both the d_{100} and h_{100} increased with higher age. The slenderness of dominant trees was 69 to 103. The basal area and volume of dominant trees increased with the increase of stand age as well. The lowest basal area and volume of dominant trees was 0.5 m^2 ha^{-1} and 2.4 m^3 ha^{-1} at the age of 11 years and the largest was 3.9 m^2 ha^{-1} and 27.2 m^3 ha^{-1} at the age of 20 years.

The d_{100} and h_{100} of 5 *Q. acutissima* stands also increased with the stands age. When the age of stand increased from 7 to 27 years old, the basal area of dominant trees increased from 1.0 to 6.2 m^2 ha^{-1} and the volume increased from 7.2 to 60.6 m^3 ha^{-1}, respectively.

Table 8: Characteristics of dominant trees in 30 oak coppice stands. Abbreviation: d_{100}=mean diameter of dominant trees, h_{100}= dominant height, h_{100}/d_{100}= slenderness of dominant trees, BA=basal area of dominant trees, V=stocking volume of dominant trees

Plot no.	Main species	Age (yrs)	Dominant trees (100 thickest stems of the main species per hectare)				
			d_{100} (cm)	h_{100} (m)	h_{100}/d_{100}	BA (m^2 ha^{-1})	V (m^3 ha^{-1})
5	*Q. variabilis*	10	8.5	7.1	84	0.6	2.4
3	*Q. variabilis*	11	11.3	11.4	101	1.0	6.1
4	*Q. variabilis*	11	8.4	7.8	93	0.5	2.4
6	*Q. variabilis*	11	10.6	9.0	85	0.9	5.6
13	*Q. variabilis*	12	13.2	10.9	83	1.4	8.9
15	*Q. variabilis*	12	12.8	11.9	93	1.3	8.3
30	*Q. variabilis*	12	14.8	11.6	78	1.7	12.2
14	*Q. variabilis*	14	12.5	9.8	78	1.2	7.4
17	*Q. variabilis*	14	16.4	13.2	80	2.1	13.2
18	*Q. variabilis*	15	14.6	15.0	103	1.7	10.5
28	*Q. variabilis*	15	12.7	11.1	87	1.3	7.4
27	*Q. variabilis*	16	14.1	14.6	104	1.6	9.6
11	*Q. variabilis*	16	16.0	15.1	94	2.0	13.2
25	*Q. variabilis*	17	14.9	13.4	90	1.7	11.4
9	*Q. variabilis*	17	12.5	11.5	92	1.2	7.4
22	*Q. variabilis*	19	15.7	14.5	92	1.9	14.3
1	*Q. variabilis*	20	19.7	15.3	78	3.1	21.2
16	*Q. variabilis*	20	22.4	15.8	71	3.9	27.2
26	*Q. variabilis*	20	19.0	13.0	68	2.8	21.2
7	*Q. variabilis*	20	12.5	11.8	94	1.2	7.4
19	*Q. variabilis*	21	20.1	16.2	81	3.2	22.6
12	*Q. variabilis*	21	18.7	14.5	78	2.7	18.8
29	*Q. variabilis*	25	17.3	14.0	81	2.4	16.7
24	*Q. variabilis*	25	18.2	13.8	76	2.6	17.5
23	*Q. variabilis*	25	16.3	14.8	91	2.1	13.2
20	*Q. acutissima*	7	11.5	9.5	83	1.0	7.2
2	*Q. acutissima*	8	15.7	12.8	82	1.9	14.5
21	*Q. acutissima*	17	17.0	14.2	84	2.3	18.4
10	*Q. acutissima*	18	16.3	17.1	105	2.1	15
8	*Q. acutissima*	27	28.2	23.0	82	6.2	60.6

5.1.1.3 Single-stem trees

In stands dominated by *Q. variabilis*, the number of single-stem trees ranged from 1275 to 4575 trees ha^{-1} accounting 53.2-100% of all trees (Table 9). The d_q and h_q of single-stem trees were 3.7-13.0 cm and 5.2-13.4 m, respectively. The highest slenderness of single-stem trees was 149 and the lowest was 80. The basal area of single-stem trees varied greatly among stands, from 2.9 to 22.4 m^2 ha^{-1} comprising 15-100% of all trees. Similar to the basal area, the volume of single-stem trees ranged considerably, from 12.4 to 121 m^3 ha^{-1}.

For stands dominated by *Q. acutissima*, the proportion of single-stem trees reached to more than 75% of all trees in number and 70% of all trees in basal area. With the increase of stand age, the basal area and volume of singe-stem trees showed an increase trend.

Table 9: Characteristics of single-stem trees in 30 oak coppice stands. Abbreviation: N= number of single-stem trees, d_q=quadratic mean diameter of single-stem trees, h_q= mean height (height of quadratic mean diameter) of single-stem trees, h_q/d_q= slenderness of single-stem trees (h_q:d_q), BA = basal area of single-stem trees, V= stocking volume of single-stem trees, N%= the ratio of number of single-stem trees to number of all trees, BA%= the ratio of basal area of single-stem trees to basal area of all trees

Plot no.	Main species	Age (yrs)	Single-stem trees							
			N (trees ha^{-1})	d_q (cm)	h_q (m)	h_q/d_q	BA (m^2 ha^{-1})	V (m^3 ha^{-1})	N%	BA%
5	*Q. variabilis*	10	3750	6.2	6.2	100	11.4	56.4	63.6	71.5
3	*Q. variabilis*	11	2700	3.7	5.4	146	2.9	12.4	53.7	15.0
4	*Q. variabilis*	11	3500	4.8	6.0	125	6.2	26.4	67.6	53.5
6	*Q. variabilis*	11	2500	5.5	5.6	102	6.0	26.4	59.2	42.4
13	*Q. variabilis*	12	3000	6.8	8.6	126	10.8	53.1	69.0	59.9
15	*Q. variabilis*	12	3800	6.6	9.1	138	13.2	64.6	71.4	60.5
30	*Q. variabilis*	12	2500	5.8	6.6	114	6.6	32.5	63.3	46.3
14	*Q. variabilis*	14	3925	6.8	7.7	113	14.4	74.7	80.9	83.3
17	*Q. variabilis*	14	4575	5.5	6.2	113	11.0	56.3	74.4	86.7
18	*Q. variabilis*	15	3850	8.6	11.5	134	22.4	121.0	96.9	98.5
28	*Q. variabilis*	15	2025	7.9	8.1	103	10.0	53.4	66.4	47.9
27	*Q. variabilis*	16	4075	8.1	10.5	130	21.0	112.2	87.6	86.9
11	*Q. variabilis*	16	3550	6.0	7.8	130	10.2	60.0	90.4	95.6
25	*Q. variabilis*	17	2950	8.0	9.2	115	14.7	84.5	83.7	68.3
9	*Q. variabilis*	17	3200	6.6	9.8	148	10.8	51.1	66.7	55.3
22	*Q. variabilis*	19	3000	9.4	11.1	118	20.6	119.5	94.5	87.8
1	*Q. variabilis*	20	1875	10.2	10.7	105	15.2	91.1	78.1	57.1
16	*Q. variabilis*	20	2475	8.3	8.8	106	13.3	79.2	92.5	92.5
26	*Q. variabilis*	20	1500	9.1	10.5	115	9.8	57.4	63.2	49.3
7	*Q. variabilis*	20	2025	6.9	5.5	80	7.6	38.0	62.8	48.3
19	*Q. variabilis*	21	1875	11.1	13.4	121	18.0	103.6	82.4	68.8
12	*Q. variabilis*	21	3025	8.3	7.3	88	16.4	103.2	84.6	86.6
29	*Q. variabilis*	25	1950	10.3	11.7	114	16.3	94.7	79.6	61.1

24	*Q. variabilis*	25	1275	13.0	12.2	94	16.9	107.1	100.0	100.0
23	*Q. variabilis*	25	2725	9.7	11.4	118	20.1	115.3	87.9	93.8
20	*Q. acutissima*	7	2525	6.4	8.2	128	8.1	39.7	75.9	71.8
2	*Q. acutissima*	8	2575	6.7	6.4	96	9.0	52.1	77.4	70.5
21	*Q. acutissima*	17	1525	11.6	8.9	77	16.0	96.4	88.4	93.1
10	*Q. acutissima*	18	4675	6.9	9.4	136	17.3	92.6	92.6	92.0
8	*Q. acutissima*	27	1200	14.7	17.6	120	20.3	177.0	87.3	84.7

5.1.1.4 Multiple-stem trees

In stands dominated by *Q. variabilis*, the number of multiple-stem trees varied from 0 to 2350 trees ha^{-1} and the number of stem varied from 0 to 5825 stems ha^{-1} (Table 10). The d_q of the main stem of multiple-stem trees ranged between 3.2 and 14.5 cm while the h_q ranged between 4.5 and 14.4 m. The slenderness of the main stem of multiple-stem trees varied from 94 to 146. Meanwhile, the d_q and h_q of all stems of multiple-stem trees were smaller than that of the main stem. The basal area and volume of all stems of multiple-stem trees varied greatly among stands, ranged 0-16.5 m^2 ha^{-1} and 0-74.6 m^3 ha^{-1}, respectively.

For stands dominated by *Q. acutissima*, the number of multiple-stem trees decreased from 800 trees ha^{-1} at the age of 7 years to 175 trees ha^{-1} at the age of 27 years. The number of all stems of multiple-stem trees declined at the same time. Except one stand by age 18, the d_q and h_q of the main stem of multiple-stem trees increased with the increasing age and the slenderness was about 110. The d_q and h_q of all stems of multiple-stem trees were smaller than these of the main stem whereas the slenderness was greater. The basal area of multiple-stem trees in *Q. acutissima* stand was low, ranged from 1.2 to 3.8 m^2 ha^{-1}, while the volume of multiple-stem trees varied from 7.6 to 30.7 m^3 ha^{-1}.

Table 10: Characteristics of multiple-stem trees in 30 oak coppice stands. Abbreviation: N= number of multiple-stem trees, N= number of stems of multiple-stem trees, d_q(m)=quadratic mean diameter of the main stem of multiple-stem trees, h_q(m)= mean height (height of quadratic mean diameter) of the main stem of multiple-stem trees, h_q/d_q(m)= slenderness of the main stem of multiple-stem trees (h_q: d_q), d_q(a)=quadratic mean diameter of all stems of multiple-stem trees, h_q(a)= mean height (height of quadratic mean diameter) of all stems of multiple-stem trees, h_q/d_q (a)= slenderness of all stems of multiple-stem trees (h_q(a):d_q(a)), BA= basal area of all stems of multiple-stem trees, V= stocking volume of all stems of multiple-stem trees

Plot No.	Main species	Age (yrs)	Multiple-stem trees									
			N (trees ha^{-1})	N (stems ha^{-1})	d_q(m) (cm)	h_q(m) (m)	h_q/d_q (m)	d_q(a) (cm)	h_q(a) (cm)	h_q/d_q (a)	BA (m^2 ha^{-1})	V (m^3ha^{-1})
5	*Q. variabilis*	10	2150	5375	4.3	4.5	106	3.3	3.8	116	4.5	17.3
3	*Q. variabilis*	11	2325	5825	6.7	7.8	117	6.0	6.6	110	16.5	74.6
4	*Q. variabilis*	11	1675	3575	5.1	6.6	129	4.4	6.2	141	5.4	21.1
6	*Q. variabilis*	11	1725	4050	6.4	7.1	110	5.1	5.5	109	8.1	36.9
13	*Q. variabilis*	12	1350	2950	6.8	8.5	125	5.6	5.9	106	7.2	35.0
15	*Q. variabilis*	12	1525	3275	6.8	8.5	126	5.8	7.8	135	8.6	40.8
30	*Q. variabilis*	12	1450	3275	6.7	7.1	106	5.5	5.9	108	7.7	40.1
14	*Q. variabilis*	14	925	2050	5.9	6.3	107	4.2	5.5	130	2.9	12.7
17	*Q. variabilis*	14	1575	4375	3.2	4.8	149	2.2	3.8	172	1.7	6.8
18	*Q. variabilis*	15	125	250	5.9	8.6	146	4.2	4.6	111	0.3	1.8
28	*Q. variabilis*	15	1025	2300	8.2	9.7	119	7.8	9.7	125	10.8	52.9
27	*Q. variabilis*	16	575	1200	7.2	10.1	140	5.8	8.4	145	3.2	15.4
11	*Q. variabilis*	16	375	900	3.9	5.4	138	2.6	3.8	148	0.5	2.2
25	*Q. variabilis*	17	575	1425	8.5	9.4	110	7.8	10.1	129	6.8	34.7
9	*Q. variabilis*	17	1475	3200	7.0	7.5	107	5.9	7.0	119	8.7	41.9
22	*Q. variabilis*	19	175	350	12.3	12.1	98	10.2	11	108	2.9	17.2
1	*Q. variabilis*	20	525	1125	14.5	14.4	99	11.4	11.8	104	11.4	69.5
16	*Q. variabilis*	20	200	600	6.0	6.9	115	4.8	6.2	129	1.1	5.6
26	*Q. variabilis*	20	875	2450	9.7	9.1	94	7.2	9.1	126	10.0	53.1
7	*Q. variabilis*	20	1200	3250	6.7	7.0	105	5.7	5.2	92	8.2	40.2
19	*Q. variabilis*	21	400	825	10.5	11.2	106	11.2	11.9	106	8.2	46.1
12	*Q. variabilis*	21	550	1875	5.5	7.3	134	4.2	6	144	2.5	14.7
29	*Q. variabilis*	25	500	1025	11.0	11.6	106	11.3	11.6	102	10.4	58.1
24	*Q. variabilis*	25	0	0	-	-	-	-	-	-	0	0
23	*Q. variabilis*	25	375	950	5.8	5.5	96	4.2	5.5	130	1.3	7.6
20	*Q. acutissima*	7	800	1625	6.6	7.2	109	5.0	6	120	3.2	15.1
2	*Q. acutissima*	8	750	2350	7.1	8.0	113	4.5	5.6	124	3.8	18.5
21	*Q. acutissima*	17	200	575	8.7	10.1	116	5.1	6.8	133	1.2	7.6
10	*Q. acutissima*	18	375	800	6.0	7.9	131	4.9	6.4	131	1.5	9.1
8	*Q. acutissima*	27	175	375	14.5	17.0	117	11.1	13.9	125	3.6	30.7

5.1.2 Regeneration & understory vegetation

5.1.2.1 Regeneration

In all studied *Q. variabilis* stands, 17 different woody species were found in the understory (Fig. 5). Many of these species are of ecological and economic importance, as *Q. variabilis*, *Q. dentata*, *Dalbergia hupeana*, *Pistacia chinensis*, and *Rhus chinensis*. The average number of the regeneration species in was 3.3±0.3 in 16 m^2. The average density of the natural regeneration in a stand was high being 18,875±3,338 individuals ha^{-1} with an average height of 35±3.0 cm. The average height of the different regeneration species in the study area is indicated in Fig. 5b. *Q. variabilis* was the most abundant species in the understory with the average density of 8,675±2,000 trees ha^{-1} and an average height of 27.3±1.5 cm. The frequency occurrence of *Q. variabilis* was 92% (Fig. 5c). In addition, the seedlings of *D. hupeana* were numerous in *Q. variabilis* coppice stands. The average density of *D. hupeana* was 6,925±1,835 individuals ha^{-1} (accounted 36.4% of all woody species in density) with an average height of 45.4±2.6 cm. The frequency occurrence of *D. hupeana* was high as well, reached up to 68%.

Nine woody species were observed in the natural regeneration of the *Q. acutissima* coppice stands (Fig. 6). The average number of the regeneration species was 4.4±0.4 in 16 m^2. The average density of the natural regeneration was 25,500±6,618 individuals ha^{-1} with an average height of 46.6±3.0 cm in *Q. acutissima* stands. Compared to *Q. variabilis* stands, the average density and average height of seedlings in *Q. acutissima* stands were higher. *D. hupeana* was the most abundant species in *Q. acutissima* stands with an average density of 18,250±6,093 individuals ha^{-1} (accounted almost 72% of all species) and an average height of 48.2±3.6 cm. The average density of *Q. acutissima* was only 3,750±948 individuals ha^{-1} with an average height of 36.3±6.5 cm. Both, *Q. acutissima* and *D. hupeana* were found in all investigated *Q. acutissima* stands (the frequency of occurrence reached to 100%).

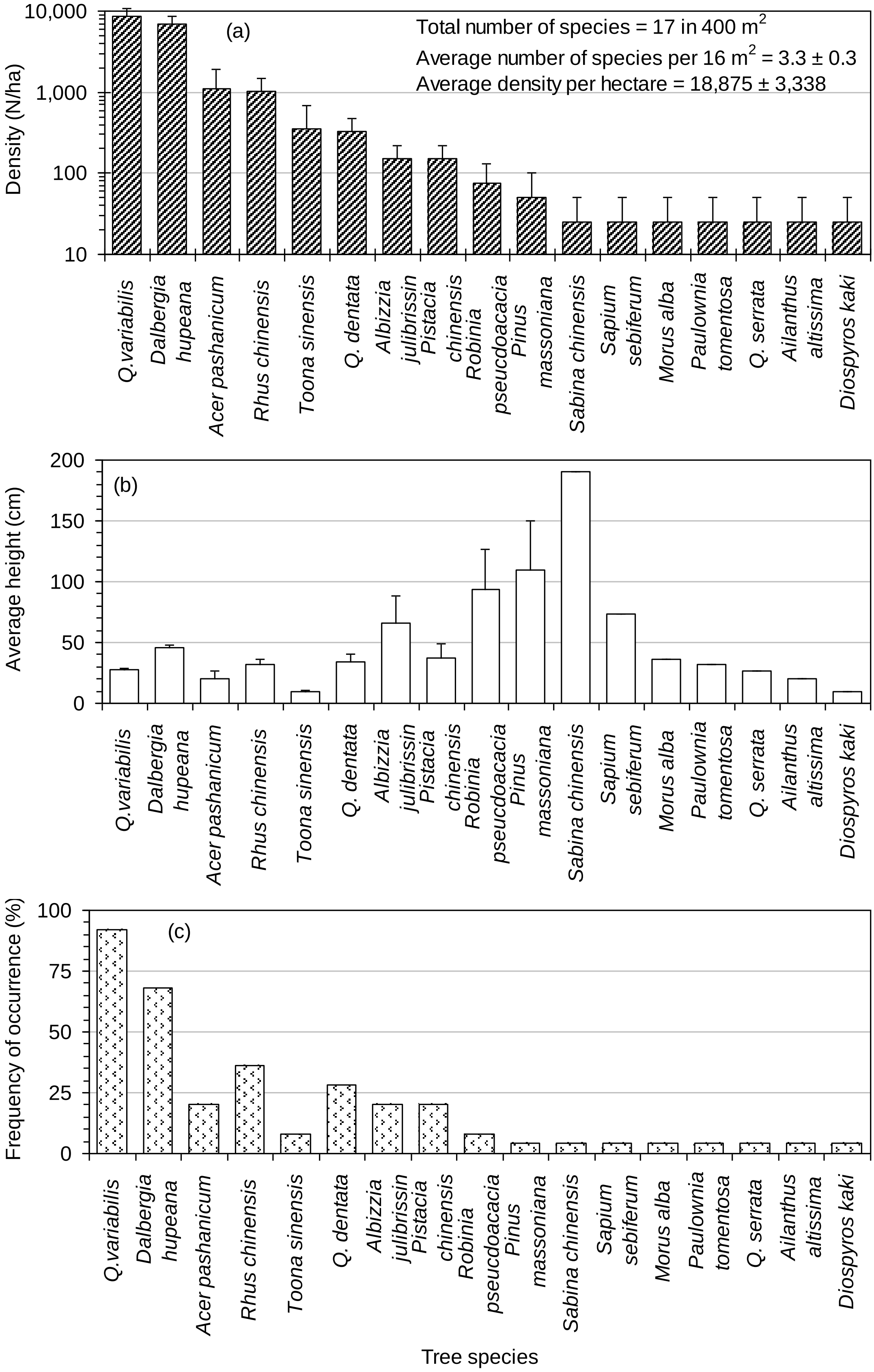

Fig. 5: Density (a), average height (b) and frequency of occurrence (c) of regeneration species in *Q. variabilis* coppice stands

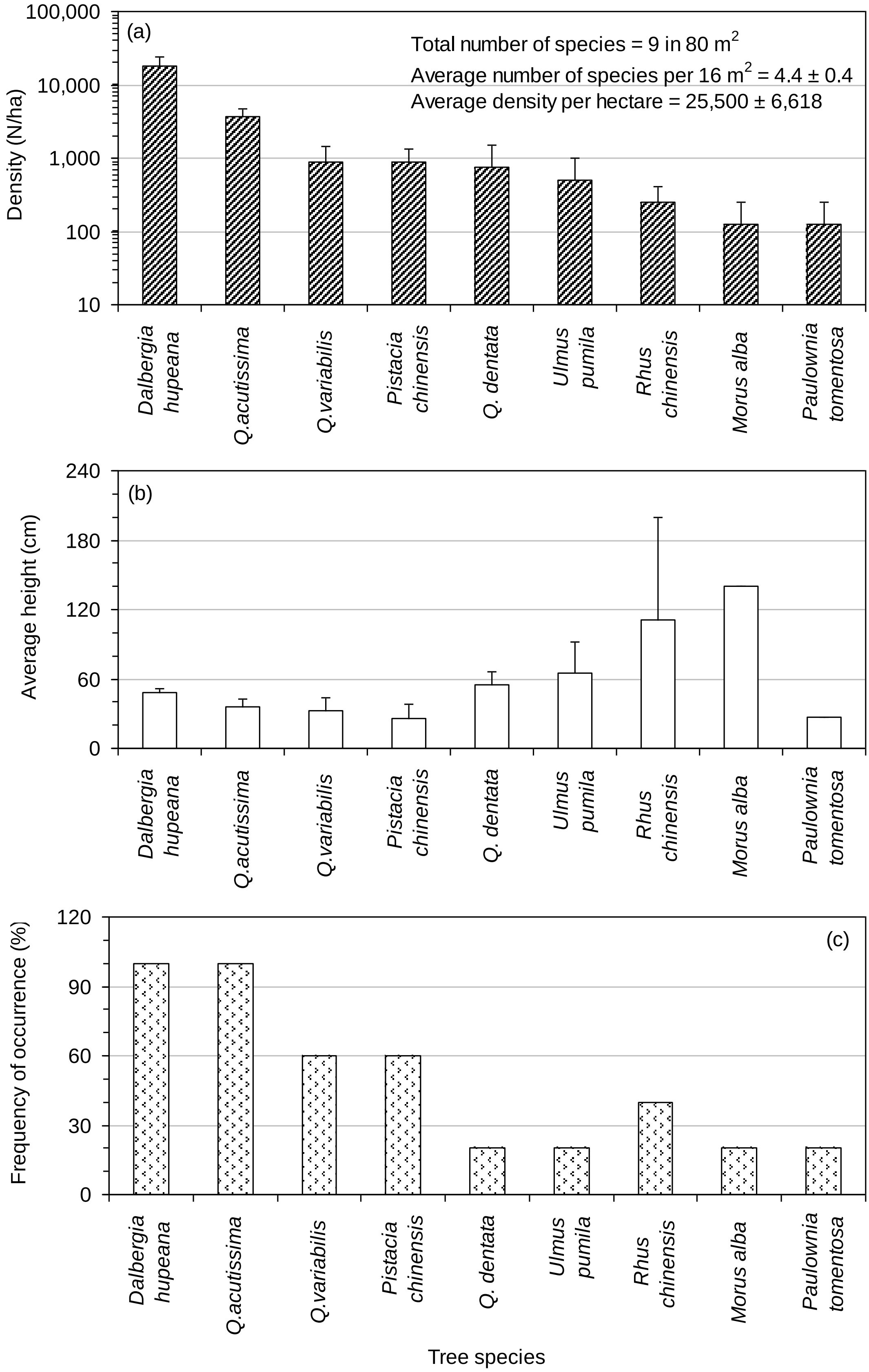

Fig. 6: Density (a), average height (b) and frequency of occurrence (c) of regeneration species in *Q. acutissima* coppice stands

5.1.2.2 Understory vegetation

In *Q. variabilis* stands, the whole coverage of understory vegetation was 10.1±1.3% on average (ranged from <1% to 20%) and the average height was 23.8±1.6 cm (ranged from 8 to 41.2 cm). In *Q. acutissima* stands, the average coverage of understory vegetation was 25.5±4.4% (ranged from 14% to 39%) and the average height was 37.6±6.1 cm (ranged from 20.3 to 53.3 cm). When the understory vegetation was analyzed by different life forms, we found that the grass, herb, and shrub were scarce, especially in the *Q. variabilis* stand, where the coverage of grass, herb and shrub was all less than 3% (Fig. 7a). In *Q. acutissima* stand, both the coverage of grass and the coverage of herb was around 7% (Fig. 7a) with the average height of 29.1 cm and 22.7 cm, respectively (Fig. 7b). In both *Q. variabilis* stands and *Q. acutissima* stand, the shrub had the lowest coverage and the greast average height compared to other vegetation types, while the regeneration seedlings (small trees <2 m in height) had the greatest coverage. We also found that the herbs and the seedlings occurred in all *Q. variablis* stands, while 88% of *Q. variablis* stands had grass and 68% had shrub in the understory. However, grass, herb, shrub, and regeneration seedlings appeared in all investigated *Q. acutissima* stands.

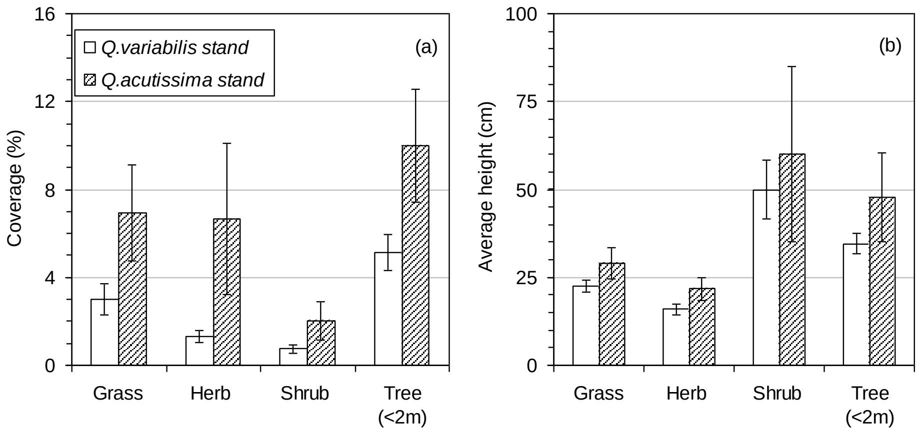

Fig. 7: Understory vegetation in *Q. variabilis* and *Q. acutissima* coppice stands: (a) coverage and (b) average height (Note: tree means the seedlings in the understory that the height is <2 m)

5.2 Forest stand use and stand structure

5.2.1 Main stand

5.2.1.1 All trees

Species diversity

The number of tree species per plot (400 m^2), the Simpson's index and the Shannon-Wiener index had no relationship with the age of stand (Fig. 8). However, the average number of tree species per plot was higher in stands with intensive use (7.9 species) in comparison to stands with moderate use (5.4 species). No differences in the number of species were detected between *Q. variabilis* stands and *Q. acutissima* stands (Fig. 8a). *Q. variabilis* stands with intensive use have higher values of the Simpson's index and the Shannon-Wiener index. For stands with intensive use, the mean value of Simpson's index and Shannon-Wiener index was 0.548 and 0.569 while in stands with moderate use was 0.244 and 0.313, respectively (Fig. 8b-8c). But, in *Q. acutissima* stands, the values of the two indexes were same between two types of forest stand use and equal to the values of *Q. variabilis* stands with intensive use.

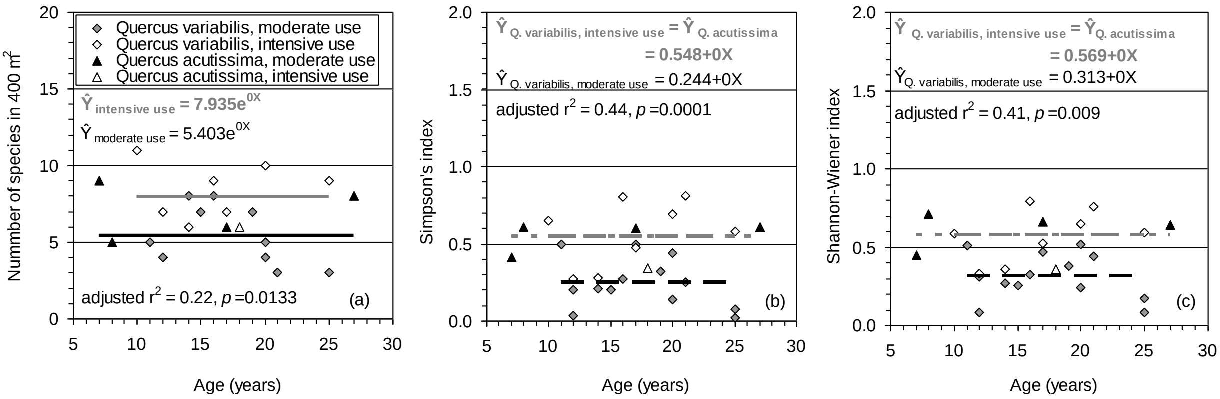

Fig. 8: Species diversity of standing trees in *Q. variabilis* and *Q. acutissima* coppice stands: (a) number of species, (b) Simpson's index, (c) Shannon-Wiener index. (The points are observed data in different types of stands and the curves or liners indicate the output from regression model. Regression equations, adjusted r^2, and *p*-value are given in graphs as well. The same meaning and pattern are used in following graphs.)

Density, basal area, volume

The number of all stems of all species in *Q. variabilis* stands and in *Q. acutissima* stands decreased with increasing of age, irrespective of types of use (Fig. 9a). Stands with intensive use have a higher stand density (none of the stands with intensive use had the number of stems less than 3,600 per ha) than stands with moderate use. Additionally, the difference in number of stems of all species between the two types of use increased with stand age. Compared to the density of stems in *Q. variabilis* stands with moderate use, the density of stems in *Q. acutissima* stands with moderate use was lower. The difference decreased with increasing stand age. The basal area (basal area of all stems of all species) of stand increased with increasing stand age, irrespective of stand use type (Fig. 9b). Moreover, the basal area of *Q. variabilis* stands with moderate use was always higher than that with intensive use. The difference in basal area between the two types of forest stand use became greater in older stands. For example, the basal area of stands with moderate use was 4.5 m^2 ha^{-1} higher at 11-year-old stands and almost 6.9 m^2 ha^{-1} higher at 25-year-old stands. The stocking volume of *Q. variabilis* stands (volume of all stems of all species) with moderate use was also higher than of stands with intensive use (Fig. 9c). The difference in stocking volume between different forest stand use types was greater in older stands

(23.3 m^3 ha^{-1} higher in 11-year-old stands and 49.0 m^3 ha^{-1} higher in 25-year-old stands). Even so, the stocking volume of intensively used stands still reached 126.4 m^3 per ha at stand age 25. In *Q. acutissima* stands, difference in basal area and stocking volume was not found between two types of forest stand use. Additionally, under moderate use, although the number of stems of all species in *Q. acutissima* stands was less than the number of stems of all species in *Q. variabilis* stands, the stocking volume was similar between two oak stands.

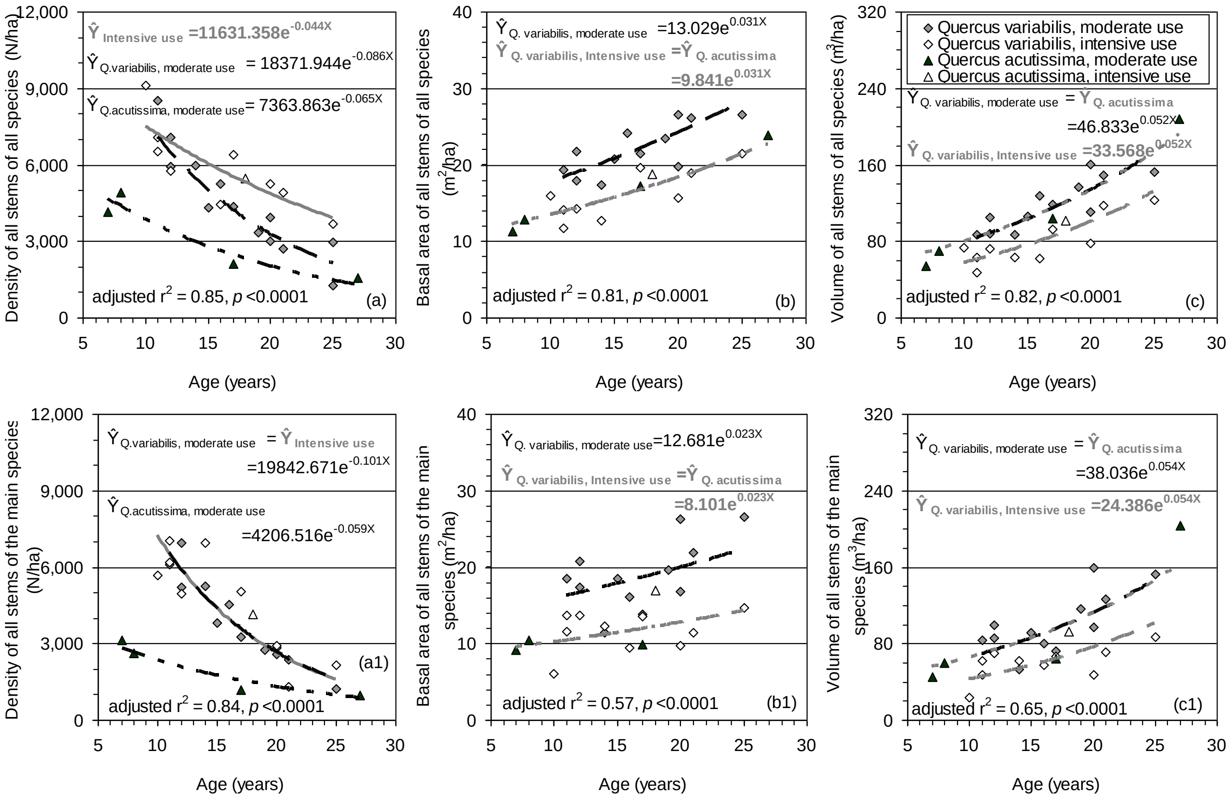

Fig. 9: Density, basal area, and volume of all stems of all species and of the main species in *Q. variabilis* and *Q. acutissima* coppice stands

Different intensity of use on stands had no effect on the density of all stems of the main species (*Q. variabilis*) in *Q. variabilis* stands, whereas the intensive use led to a higher number of the main species (*Q. acutissima*) in *Q. acutissima* stands (Fig. 9a1). The basal area and volume of all stems of the main species in *Q. variabilis* stands with moderate use was higher than these with intensive use (Fig. 9b1-c1). In *Q. acutissima* stands, the forest stand use had no influence on the basal area and volume of all stems of the main species.

Quadratic mean diameter, mean height, slenderness

The quadratic mean diameter (d_q) and mean height (h_q) of all stems of all species were remarkably different between forest stand use types (Fig. 10). They were always lower in stands with intensive use in comparison with stands with moderate use. Moreover, the d_q of all stems of all species in *Q. acutissima* stands with moderate use was higher than these in *Q. variabilis* stands with the same forest stand use (Fig. 10a). No difference in the h_q of all stems between *Q. variabilis* stands and *Q. acutissima* stands was observed (Fig. 10b). The slenderness of all stems of all species remained constant along with the increase of age, and was not influenced by the forest stand use (Fig. 10c).

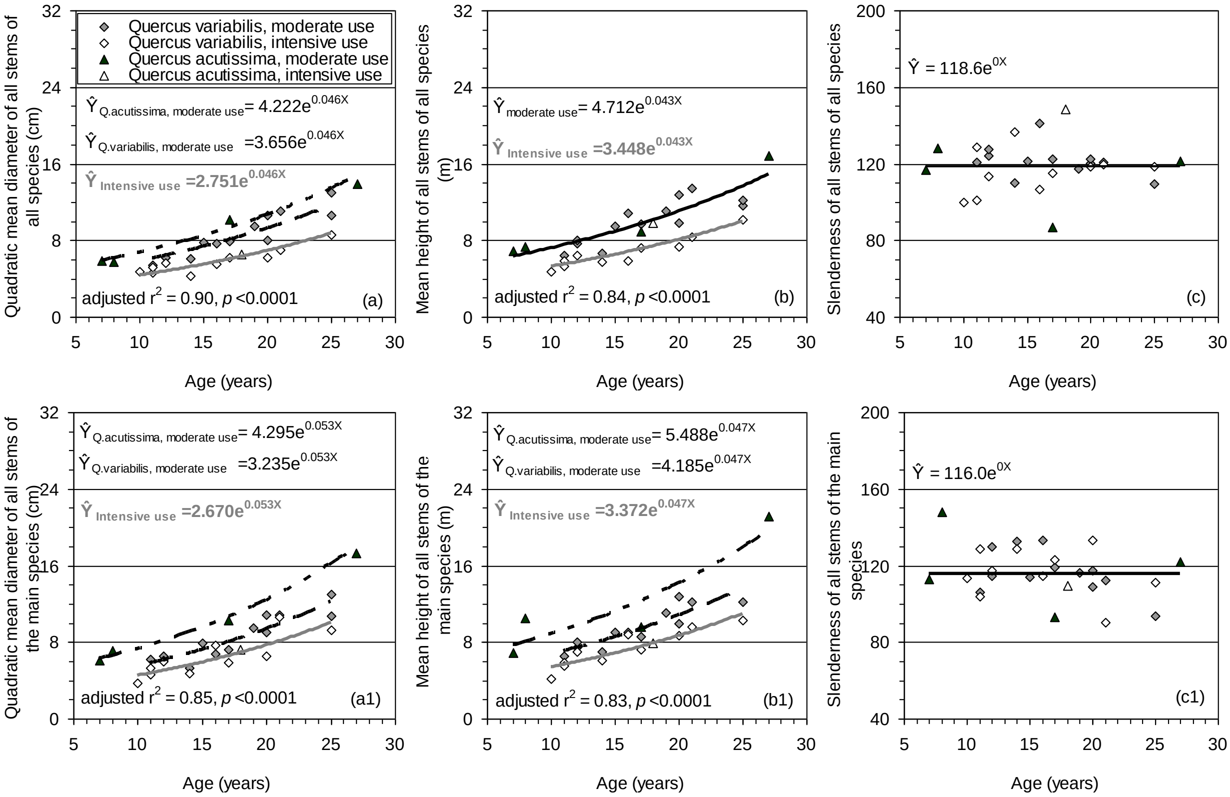

Fig. 10: Quadratic mean diameter (d_q), mean height (h_q), and slenderness (d_q/h_q) of all stems of all species and of the main species in *Q. variabilis* and *Q. acutissima* coppice stands

All stems of the main species in stands with moderate use had a higher d_q and h_q compared to that with intensive use (Fig. 10a1-b1). The d_q and h_q of all stems of the main species (*Q. acutissima*) in *Q. acutissima* stands with moderate use was always greater than these of all stems of the main species (*Q. variabilis*) in *Q. variabilis* stands under moderate use. The mean slenderness of all stems of the main species in *Q. variabilis* stands and in *Q. acutissima* stands was 116, irrespective of the forest stand use and the stand age (Fig. 10c1).

Proportion of the main species

The percentage of the main species' number in *Q. variabilis* stands and the percentage of the main species' number in *Q. acutissima* stands remained constant with increasing stand age (Fig. 11a). The intensive use decreased the percentage of the main species' number in *Q. variabilis* stands (the proportion of *Q. variabilis* in stands with moderate use was almost 21% higher than that in stands of intensive use). But, the percentage of the main species' number in *Q. acutissima* stands was not affected by forest stand use (the *Q. acutissima* trees accounted 62.6% of all trees). However, when the percentage of the main species was calculated in basal area and volume, no relationships with age or types of use were observed (Fig. 11b-c). But, the diagram showed that all investigated stands assembled in two groups: the first group, the average ratio of basal area and average volume of the main species was 89.5% and 93.3%, respectively; and the second group, the average ratio of basal area and average volume of the main species was lower, 64.4% and 63.9%, respectively. The further analysis about the difference between two groups found that some big *P. massoniana* trees grew in second group stands that resulted in a lower proportion the main species.

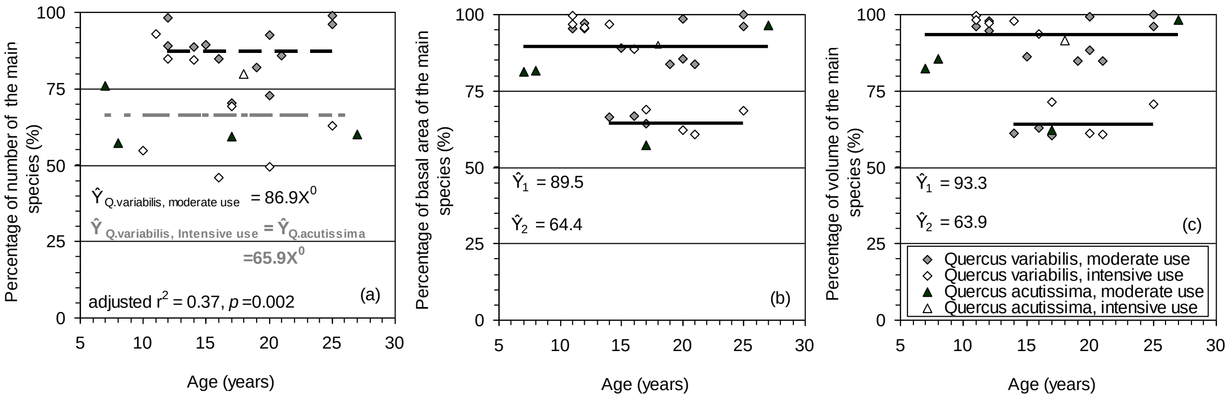

Fig. 11: Percentage of the main species in number, basal area and volume in *Q. variabilis* and *Q. acutissima* coppice stands

Tree quality

The quality of trees in *Q. variabilis* stands was influenced by forest stand use (Fig. 12). For stands aged >15 years, the percentage of trees with high quality (straight trunk, free of fork, well formed crown) in moderately used stands was about 16% greater than that in intensively used stands (Fig. 12a). Only 3.6% of the trees, on average, had a high quality in intensively used stands. A higher percentage of trees with satisfactory quality (slightly crooked central leader, slightly forked, fairly formed crown) was found in moderately used stands, around 10% greater than that in intensively used stands(Fig. 12b). On the contrary, a higher percentage of trees with unsatisfactory quality (sharply crooked leader, strongly forked, badly formed crown) was found in intensively used stands (Fig. 12c). More than the half of the trees had an unsatisfactory quality in the intensively used *Q. variabilis* stands. For younger stands (<15 years), the percentage could reach up to more than 75%. Along with the increase of stand age, the proportion of trees with unsatisfactory quality in both types of forest stand use declined gradually.

However, the forest stand use had no effect on tree quality in *Q. acutissima* stands (Fig 8a-c). Trees with unsatisfactory quality accounted the largest part (56.8 to 78.9%) while trees with high quality took the smallest part, 3.6% on average, ranged from 0 to 11.6%.

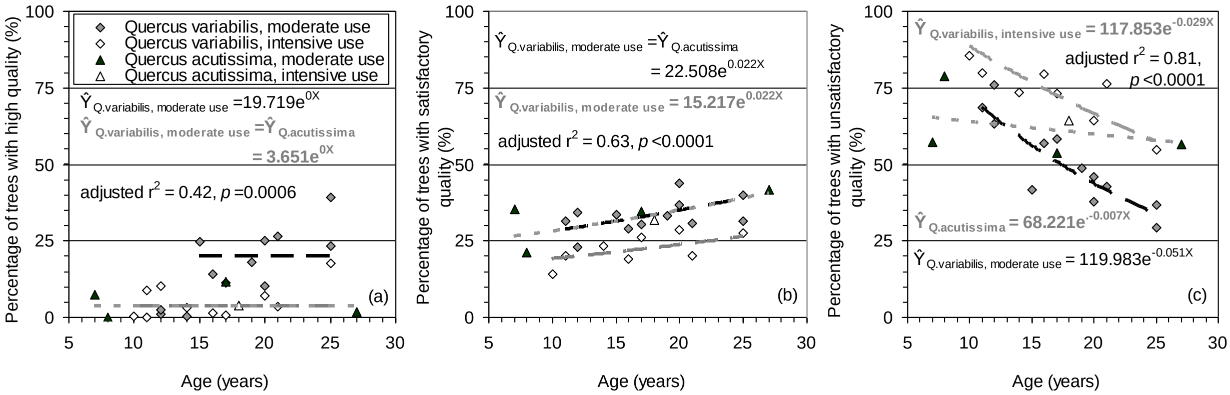

Fig. 12: Percentage of trees in different quality classes (high, satisfactory, and unsatisfactory) in *Q. variabilis* and *Q. acutissima* coppice stands. For the multiple-stem trees, the quality is defined according to the main stem

5.2.1.2 Dominant trees

Only the main species in stands belonging to the group of the 100 thickest stems per ha were considered as the dominant trees.

Basal area and volume

The basal area and volume of dominant trees increased with the stand age (Fig. 13). Different types of forest stand use had no effect on the basal area and volume of dominant trees in both *Q. variabilis* stands and *Q. acutissima* stands. However, the basal area and volume of dominant trees differed between *Q. variabilis* stands and *Q. acutissima* stands. At a same stand age, the dominant trees in *Q. acutissima* stands always had a greater basal area and volume than that in *Q. variabilis* stands.

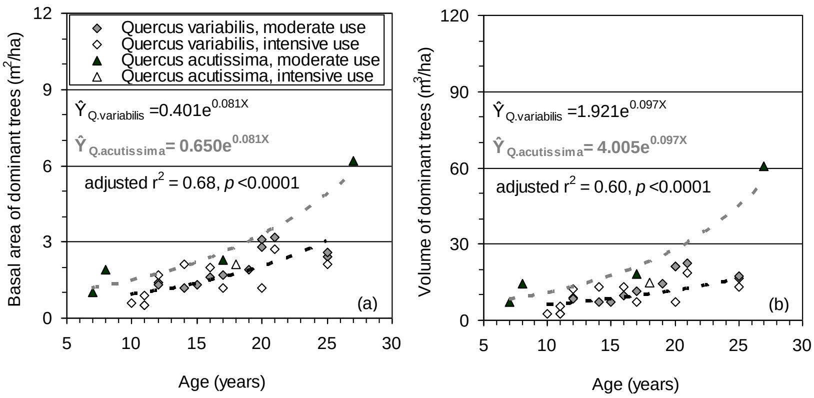

Fig. 13: Basal area and volume of dominant trees in *Q. variabilis* and *Q. acutissima* coppice stands

Mean diameter, mean height, and slenderness

Mean diameter of dominant trees (d_{100}) and dominant height (h_{100}) were positively related to stand age (Fig. 14). The forest stand use had no influence on the mean diameter of dominant trees and dominant height in *Q. variabilis* stands as well as these in *Q. acutissima* stands. In addition, dominant trees in *Q. acutissima* stands always had a higher mean diameter and mean height compared to dominant trees in *Q. variabilis* stands. However, no differences in the slenderness of dominant trees were found between stands or forest stand use. The mean slenderness of the dominant trees was 86.6, remained constant with the increase of age.

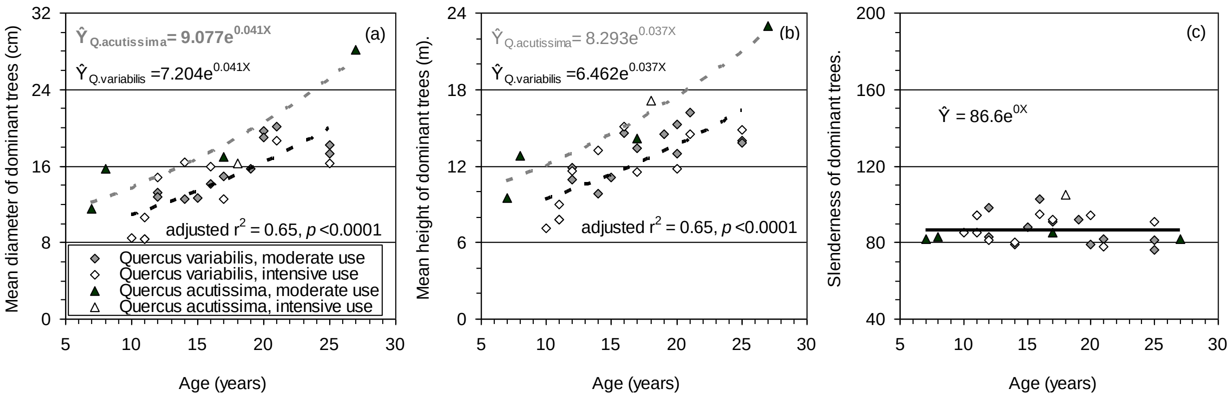

Fig. 14: Mean diameter, mean height, slenderness of dominant trees in *Q. variabilis* and *Q. acutissima* coppice stands

5.2.1.3 Single-stem trees

Density, basal area, volume

The density of single-stem trees of all species in *Q. variabilis* stands differed between stands with moderate use and stands with intensive use (Fig. 15a). The difference increased with growing stand age. For instance, at stand age 10, the density of single-stem trees of all species in intensively used stands (3,508 trees ha^{-1}) was nearly similar with this in moderately used stands (3,565 trees ha^{-1}). However, the number of single-stem trees of all species in stands by age 25 was 2,680 trees ha^{-1} in intensively used stands and 1,584 trees ha^{-1} in moderately used stands, respectively. Compared to *Q. variabilis* stands in moderate use, the density of single-stem trees of all species in *Q. acutissima* stands with moderate use was lower. The basal area and volume of single-stem trees of all species in *Q. variabilis* stands with intensive use were always lower than in stands with moderate use, while the basal area and volume of single-stem trees of all species in *Q. acutissima* stands were the same irrespective of stand use (Fig. 15b-c). Nevertheless, both the basal area and volume of single-stem trees of all species increased with growing stand age.

We found that different forest stand use did not affect the density of single-stem trees of the main species (*Q. variabilis*) in *Q. variabilis* stands. The density of single-stem trees of the main species (*Q. acutissima*) in *Q. acutissima* stands with intensive use was considerably higher than that in moderately used stands (Fig. 15a1). Although there was no difference in density of single-stem trees of the main species in *Q. variabilis* stands between the types of use, the basal area and volume of single-stem trees of the main species in moderately used stands were always greater than that in intensively used stands (Fig. 15b1-c1). However, the basal area and volume of single-stem trees of the main species in *Q. acutissima* stands was similar between two types of forest stand use.

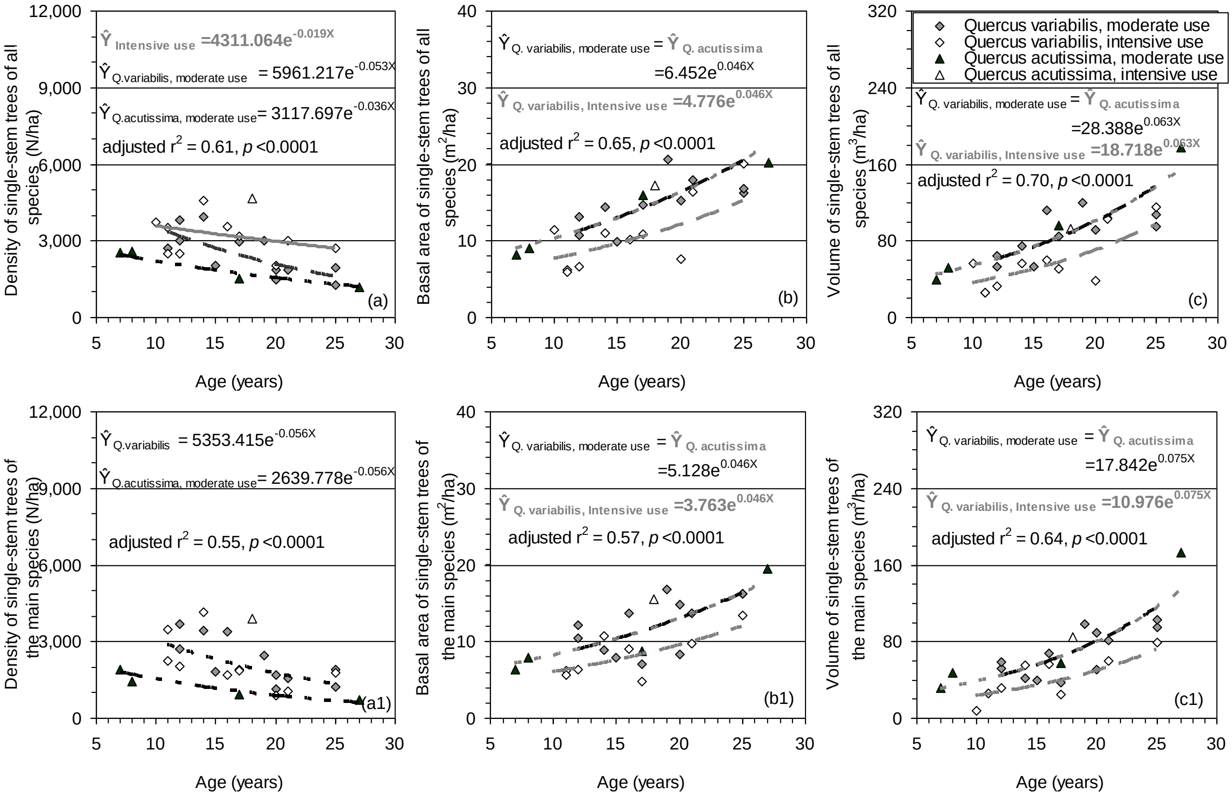

Fig. 15: Density, basal area, and volume of single-stem trees of all species and of the main species in *Q. variabilis* and *Q. acutissima* coppice stands

Quadratic mean diameter, mean height, slenderness

An exponential equation could be used to properly describe the relationship between the quadratic mean diameter (d_q) of single-stem trees of all species and stand age (adjusted r^2=0.91) (Fig. 16a). The d_q and h_q of single-stem trees of all species varied between the different types of stand use (Fig. 16a-b). The intensively used stands had a lower d_q and h_q in both *Q. variabilis* and *Q. acutissima* stands. We also found that the d_q of single-stem trees of all species in *Q. acutissima* stands were higher than the d_q of single-stem trees of all species in *Q. variabilis* stands. However, there was no difference in the h_q of single-stem trees of all species between *Q. acutissima* stands and *Q. variabilis* stands. The slenderness of single-stem trees of all species was 113.2 on average, and no relationship between slenderness and age was observed (Fig. 16c).

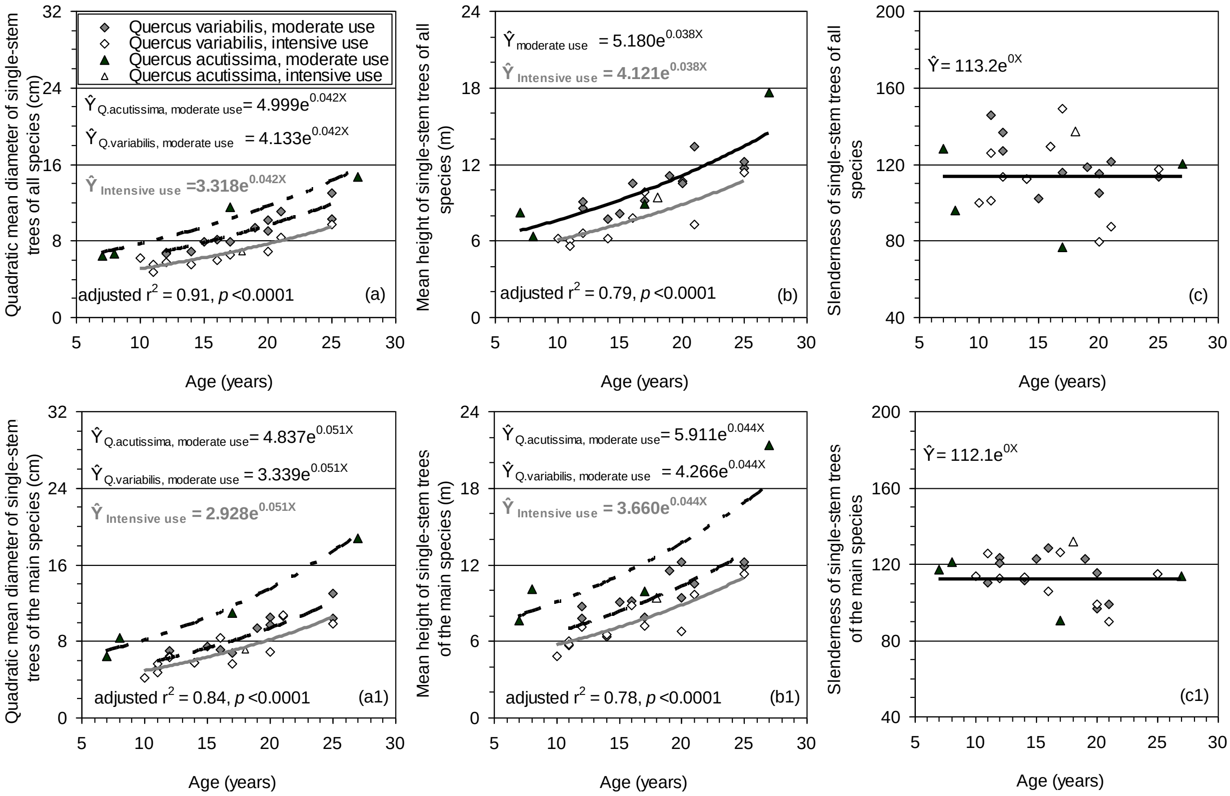

Fig. 16: Quadratic mean diameter (d_q), mean height (h_q), and slenderness (d_q/h_q) of single-stem trees of all species and of the main species in *Q. variabilis* and *Q. acutissima* coppice stands

A higher d_q and h_q of single-stem trees of the main species were observed in the moderately used stands (Fig. 16a1-b1). Under the moderate use, the d_q and h_q of single-stem trees of the main species (*Q. acutissima*) in *Q. acutissima* stands were greater than that of single-stem trees of the main species (*Q. variabilis*) in *Q. variabilis* stands at a given stand age. The mean slenderness of single-stem trees of two main species was 112.1 and had no relationship with the stand age (Fig. 16c1).

Proportion of single-stem trees

Different forest stand use had no influence on the ratio of density of single-stem trees to density of all trees in *Q. variabilis* stands and that in *Q. acutissima* stands (Fig. 17a). The ratio of density of single-stem trees of all species was positively correlated with the stand age, although a high variation was found among stands in same age. In addition, the proportion of single-stem trees in *Q. acutissima* stands was greater than that in *Q. variabilis* stands in younger stands. This difference declined with increasing of stands age. However, no difference in percentage of basal area and percentage of volume of single-stem trees of all species was found between forest stand use types and between *Q. variabilis* and *Q. acutissima* stands (Fig. 17b-c). The average percentage of basal area of single-stem trees of all species was 69.4%, ranged from 46.3% to 100.0%, and the average percentage of volume of single-stem trees of all species was 70.3%, ranged from 44.7% to 100.0%.

For the main species in coppice stands, the ratio of density of single-stem trees to density of all trees was not affected by forest stand use as well (Fig. 17a1). The proportion of single-stem trees of the main species (*Q. acutissima*) in *Q. acutissima* stands was relatively greater than that of the main species (*Q. variabilis*) in *Q. variabilis* stands in younger stands. But, the difference declined with the increase of stand age. Additionally, with the increase of stand age the proportion of single-stem trees of the main tree species also increased. There was no difference in percentage of basal area and percentage of volume of single-stem trees between forest stand use types and between *Q. variabilis* and *Q. acutissima* stands (Fig. 17b1-c1). The average ratio of basal area of single-stem trees of the main species was 63.4%, ranged from 33.0% to 100.0%, while the average ratio of volume of single-stem trees of the main species was 63.8%, ranged from 31.9% to 100.0%.

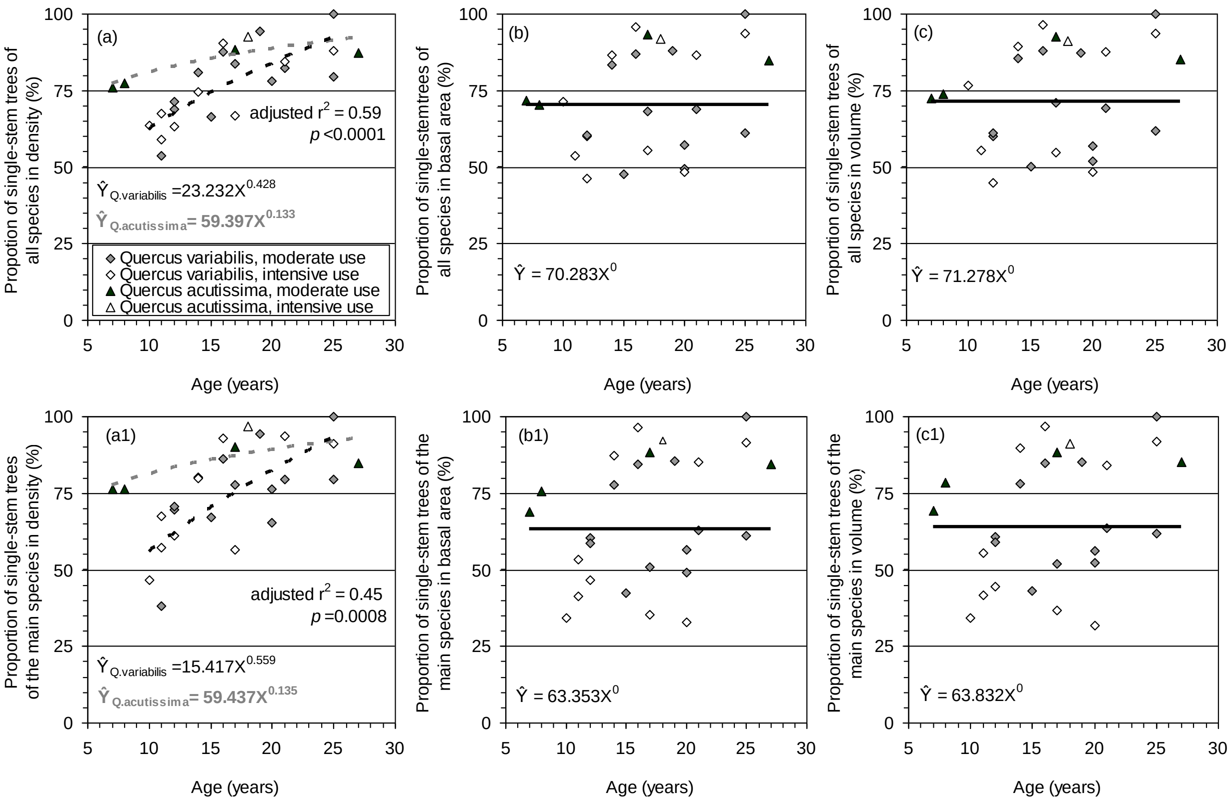

Fig. 17: The proportion of single-stem trees of all species in density, basal area, and volume (a-c) and the proportion of single-stem trees of the main species in density, basal area and volume in *Q. variabilis* and *Q. acutissima* coppice stands (a1-c1)

Crown parameters

The average crown width (Crd) and average crown length (Crl) of single-stem trees of all species in *Q. variabilis* stands and in *Q. acutissima* stands could be described by a linear function (Fig. 18a-b). In *Q. variabilis* stands, different forest stand use did not influence the average Crd of single-stem trees of all species, but it influenced the average Crl (the crown length of single-stem trees in intensively used stands was always 0.45 m lower than in moderately used stands). In *Q.*

acutissima stands, the average Crd and the average Crl of single-stem trees of all species in intensively used stands differed greatly from these in moderately used stands (Fig. 18a). Moreover, we found that the average values of Crd and Crl of single-stem trees of all species in *Q. acutissima* stands with moderate use were always greater than these in *Q. variabilis* stands. The average crown ratio (Cr%) of single-stem trees of all species in both *Q. variabilis* and *Q. acutissima* stands remained constant (36.2% on average) and no difference was found between the two forest stand use types as well as between the two stand types (Fig. 18c).

The forest stand use had no effect on the average of Crd, Crl, and Cr% of single-stem trees of the main species in *Q. variabilis* stands. However, the mean value of Crd, Crl and Cr% of single-stem trees of the main species in intensively used *Q. acutissima* stands varied considerably with these in moderately used stands (Fig. 18a1-c1). The average Crd and average Crl of single-stem trees of the main species had a linear relationship with the stand age (adjusted r^2>0.8) while the average Cr% remained constant with growing stand age, except these single-stem trees in intensively used *Q. acutissima* stands. In addition, the single-stem trees of the main species in moderately used *Q. acutissima* stands always had higher average values of Crd, Crl, and Cr% than single-stem trees of the main species in *Q. variabilis* stands.

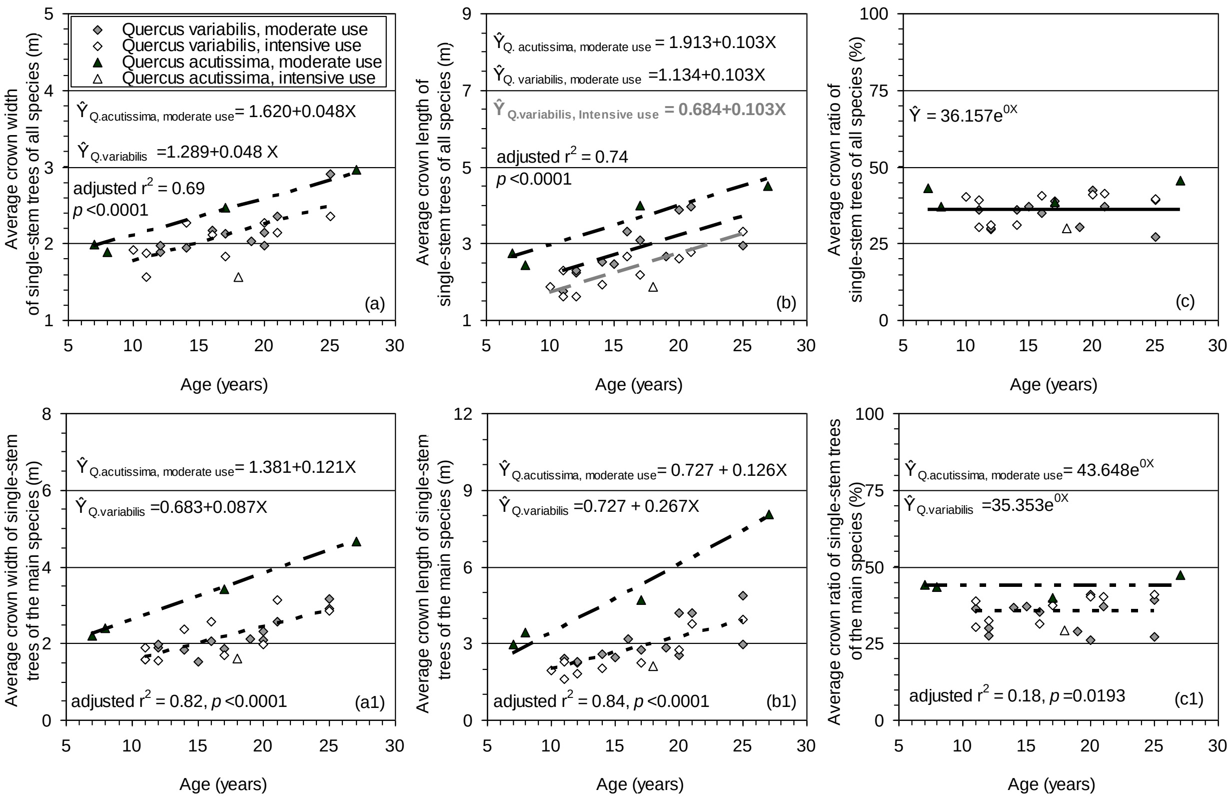

Fig. 18: Average of crown width, crown length, and crown ratio of single-stem trees of all species and of the main species in *Q. variabilis* and *Q. acutissima* coppice stands

The average crown width to diameter ratio (Crd-DBH) of single-stem trees of all species varied between forest stand use types (Fig. 19a). It remained constant (mean 48.6) in intensively used stands while it was negatively related to the stand age in moderately used stands. Furthermore, the average value of the Crd-DBH ratio of single-stem trees of all species in intensively used stands was always greater than that in moderately used stands. No difference in the average Crd-DBH ratio of single-stem trees of all species was found between *Q. variabilis* and *Q. acutissima* stands. There was no correlation between crown width to tree height ratio (Crd-H ratio) and height of single-stem trees of all species in both forest stand use types (Fig. 19b). The intensive use on *Q. variabilis* stands resulted in a greater Crd-H ratio. The average of crown width to crown length ratio (Crd-Crl) of single-stem trees of all species in *Q. variabilis* stands was affected by the forest stand use (the average value of the Crd-Crl ratio in intensive use was about 0.2 greater than that in moderate use) (Fig. 19c). However, no difference in the average Crd-Crl ratio of single-stem trees of all species in *Q. acutissima* stands was detected between two types of stand use (mean 0.873).

We found that the intensive use still led to a greater average value of the Crd-DBH ratio of single-stem trees of the main species (Fig. 19a1). And, there was a negative correlation between Crd-DBH ratio and stand age in stands with moderate use as well as in stands with intensive use. The intensive use resulted in a greater average of Crd-H ratio of single-stem trees of the main species in *Q. variabilis* stands (Fig. 19b1). The forest stand use had no influence on the average of Crd-Crl ratio of single-stem trees of the main species in *Q. variabilis* and in *Q. acutissima* stands. The mean value was 0.875, irrespective of stand age (Fig. 19c1).

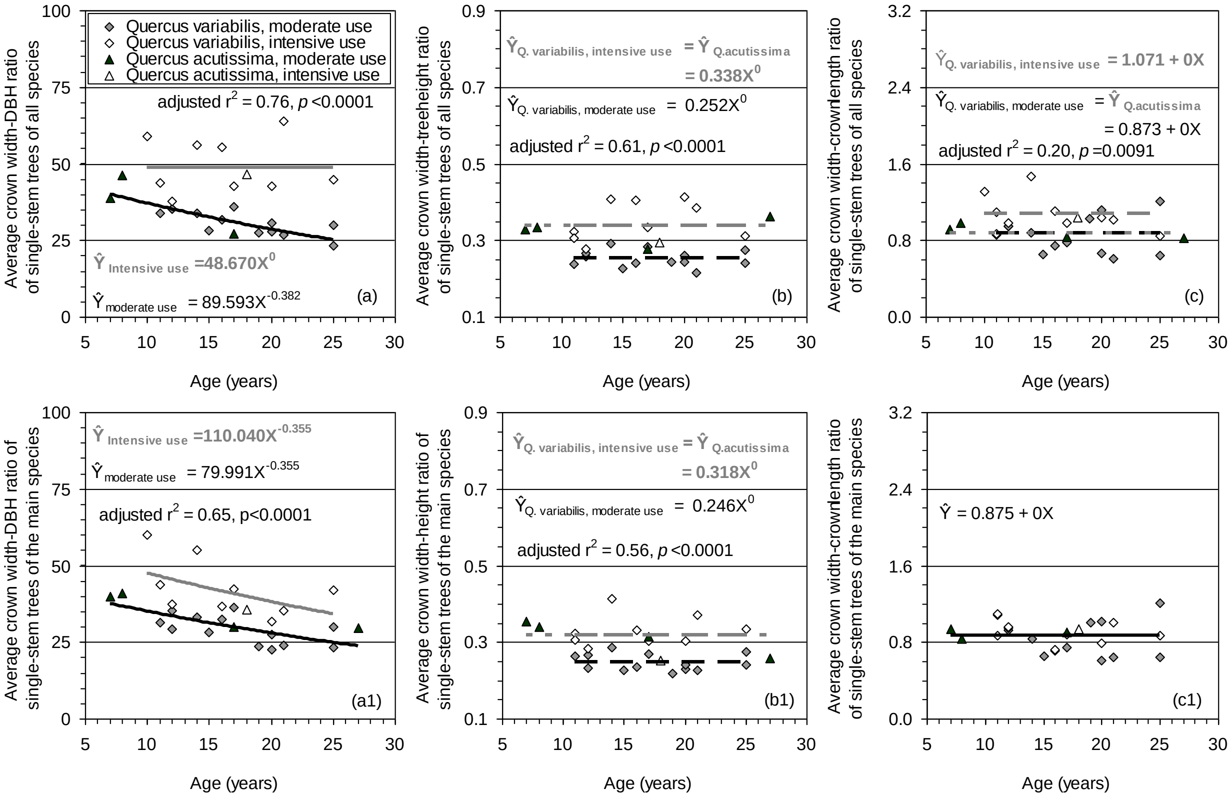

Fig. 19: Average of crown width-DBH ratio, crown width-tree height ratio, and crown width-crown length ratio of single-stem trees of all species and of the main species in *Q. variabilis* and *Q. acutissima* coppice stands

5.2.1.4 Multiple-stem trees

Density, basal area, volume

In *Q. variabilis* stands, the intensive use increased the number of all stems of multiple-stem trees of all species (Fig. 20a). But, in *Q. acutissima* stands, the forest stand use did not affect the density of all stems of multiple-stem trees of all species. Nevertheless, the density of all stems of the multiple-stem trees of all species decreased gradually with the age development of the stands. The basal area of all stems of multiple-stem trees of all species in *Q. variabilis* stands and in *Q. acutissima* stands remained constant with the increase of stand age, irrespective of forest stand use type (Fig. 20b). But, the multiple-stem trees of all species in *Q. variabilis* stands with moderate use always had a greater basal area than that with intensive use (4.1 m^2 ha^{-1} higher). The volume of all stems of multiple-stem trees of all species had no increase with the development of stands as well (Fig. 20c). For *Q. variabilis* stands, the stands with moderate use still had a higher volume of multiple-stem trees of all species compared to the stands with intensive use (21.2 m^3 ha^{-1} higher). However, no differences in the volume and basal area of multiple-stem trees of all species in *Q. acutissima* stands were found between the forest stand use types.

Different forest stand use had no effect on the density of all stems of multiple-stem trees of the main species in *Q. variabilis* stands and in *Q. acutissima* stands (Fig. 20a1). The basal area and volume of multiple-stem trees of the main species remained constant in two stand types (Fig. 20b1-c1). In *Q. variabilis* stands, they were greater in moderately used stands (6.8 m^2 ha^{-1} and 35.4 m^3 ha^{-1} on average, respectively) compared to that in intensively used stands (2.7 m^2 ha^{-1} and 14.3 m^3 ha^{-1} on average, respectively). However, no differences in the basal area and volume of multiple-stem trees of the main species in *Q. acutissima* stands were detected between the forest stand use types.

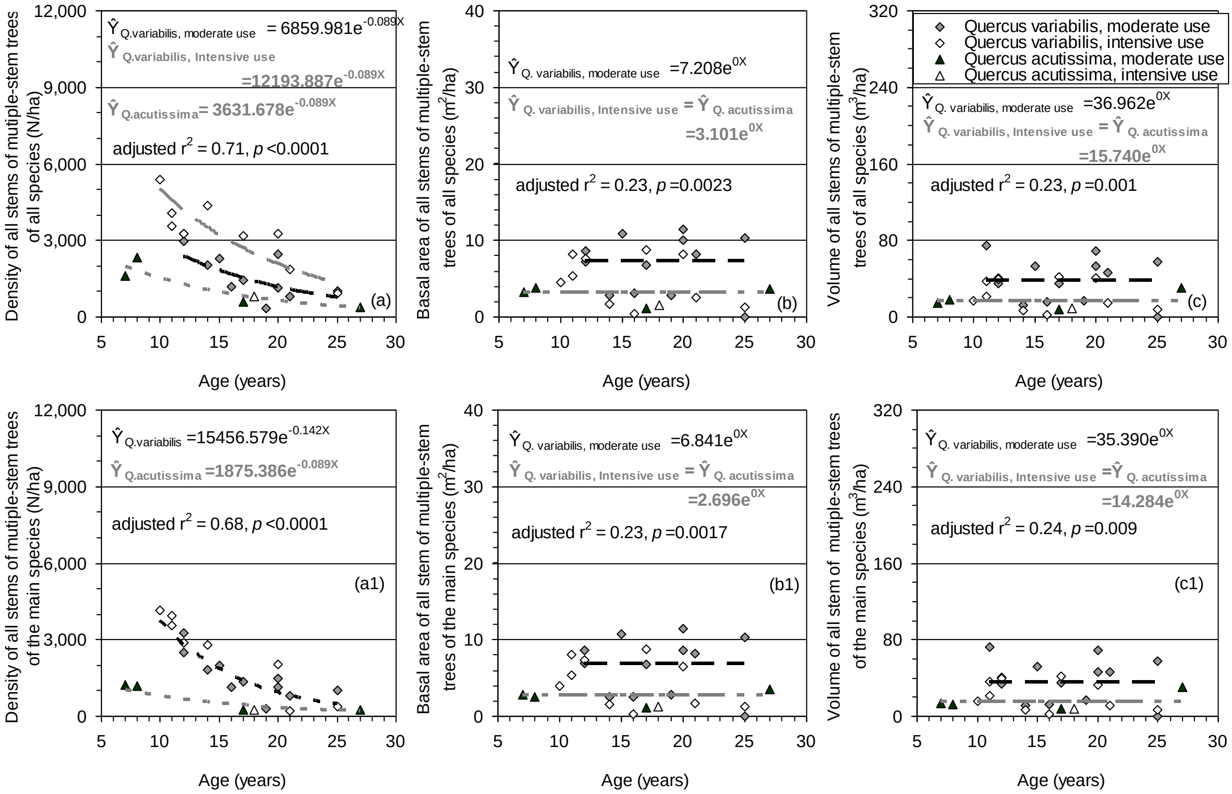

Fig. 20: Density, basal area, and volume of all stems of multiple-stem trees of all species and of the main species in *Q. variabilis* and *Q. acutissima* coppice stands

Quadratic mean diameter, mean height, slenderness

The d_q and h_q of all stems of multiple-stem trees of all species varied between stands with moderate use and stands with intensive use. But no differences in the d_q and h_q of all stems of multiple-stem trees of all species were detected between the *Q. variabilis* and *Q. acutissima* stands (Fig. 21a-b). The d_q and h_q of all stems of multiple-stem trees of all species in moderately used stands increased with growing stand age, while they remained constant in intensively used stands (4.1 cm and 5.1 m, respectively). As a result, for multiple-stem trees of all species, the difference in the d_q of all stems and the difference in the h_q of all stems between two types of forest stand use increased with older stand age. The slenderness of all stems of multiple-stem trees of all species had no relationship with stand age. It was not affected by the forest stand use with the mean value of 120.9 (Fig. 21c).

The d_q and h_q of all stems of multiple-stem trees of the main species varied also between moderately used stands and intensively used stands. Within the same forest stand use, multiple-stem trees of the main species (*Q. variabilis*) in *Q. variabilis* stands had the same d_q and h_q as multiple-stem trees of the main species (*Q. acutissima*) in *Q. acutissima* stands (Fig. 21a1-b1). The intensive use still decreased the d_q and h_q of all stems of multiple-stem trees of the main species. However, unlike the d_q and h_q of all stems of multiple-stem trees of all species, the d_q and h_q of all stems of multiple-stems trees of the main species increased with the stand age even in intensively used stands (Fig. 21a1-b1). The slenderness of all stems of multiple-stem trees of the main species had a slightly negative relationship with stand age and no difference was found between forest stand use types or between *Q. variabilis* stands and *Q. acutissima* stands (Fig. 21c1).

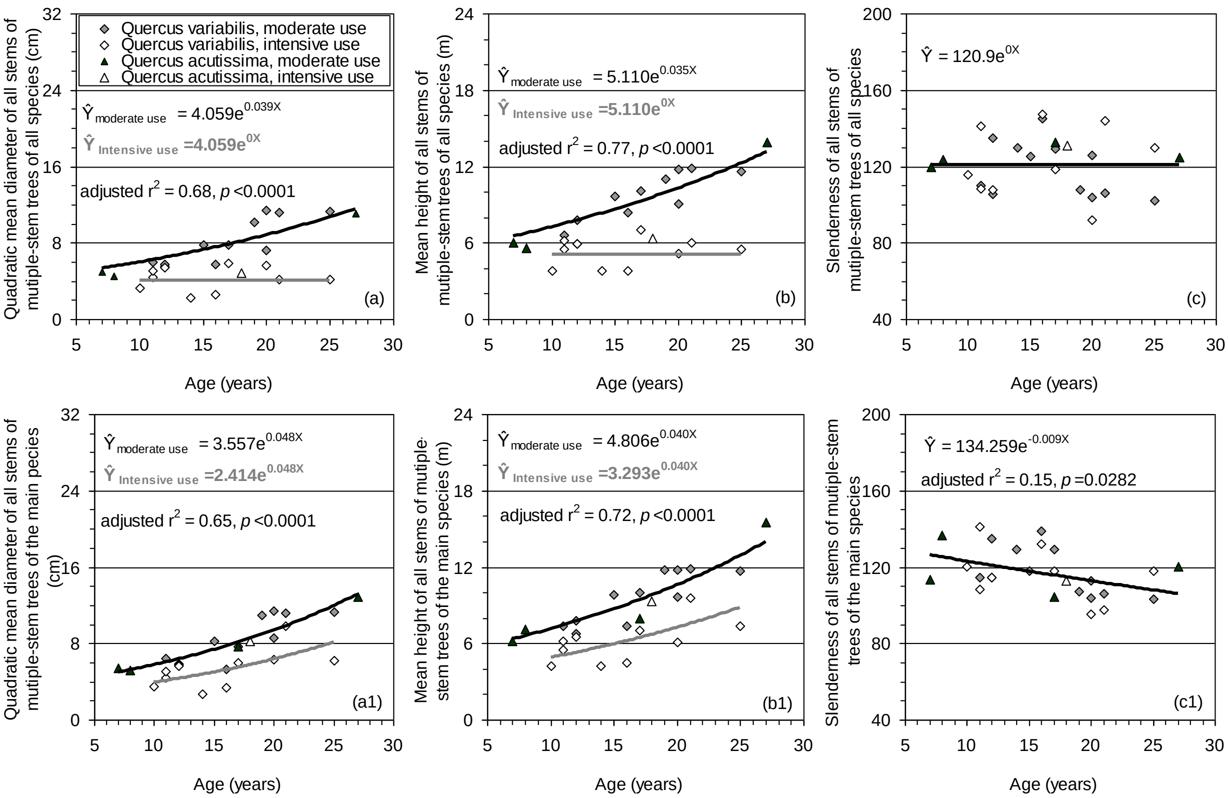

Fig. 21: Quadratic mean diameter (d_q), mean height (h_q), and slenderness (d_q/h_q) of all stems of multiple-stem trees of all species and of the main species in *Q. variabilis* and *Q. acutissima* coppice stands

The growth of the main stem of multiple-stem trees of all species varied between the moderately used stands and the intensively used stands (Fig. 22). The d_q and h_q of the main stem of multiple-stem trees of all species in stands with moderate use increased gradually with increasing age, while the d_q and h_q of the main stem of multiple-stem trees of all species in intensive use remained constant (5.2 cm and 6.2 m, respectively) (Fig. 22a-b). The slenderness of the main stem of multiple-stem trees of all species retained constant (mean 114.5). We also found that the d_q and h_q of the main stem of the multiple-stem trees of the main species in moderately used stands was always higher than in intensively used stands (Fig. 22a1-b1). But, compared to the multiple-stem trees of all species, the d_q and h_q of the main stem of the multiple-stem trees of the main species increased with the higher stand age, irrespective of forest stand use. Additionally, a poor negative relationship was found between the slenderness of the main stem of multiple-stem trees of the main species and stand age (Fig. 22c1). The slenderness of the main stem of multiple-stem trees of the main species was not influenced by forest stand use or the main species.

No difference was found between *Q. variabilis* stands and *Q. acutissima* stands in terms of the d_q and h_q of the main stem of the multiple-stem trees of all species and of the main species.

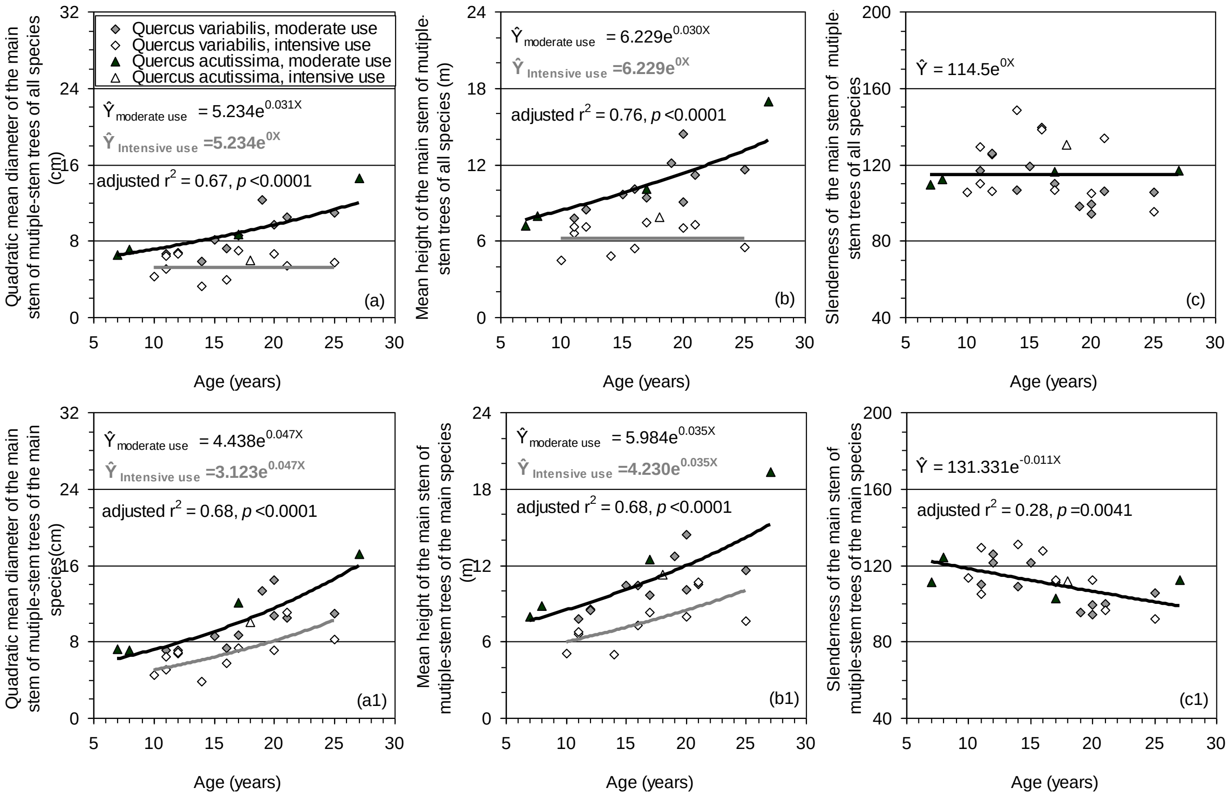

Fig. 22: Quadratic mean diameter (d_q), mean height (h_q), and slenderness (d_q/h_q) of the main stem of multiple-stem trees of all species and of the main species in *Q. variabilis* and *Q. acutissima* coppice stands

5.2.2 Regeneration & understory vegetation

5.2.2.1 Regeneration

Species diversity

The number of regeneration species, the Simpson's index and the Shannon-Wiener index had no correlation with stand age (Fig. 23). Different forest stand use also had no effect on the number of regeneration species and diversity indices. The average number of regeneration species was 3.3 per plot (sample area per plot = 16 x 1 m^2)(Fig. 23a), and the average Simpson's index and average Shannon-Wiener index were 0.505 and 0.848, respectively (Fig. 23b-c).

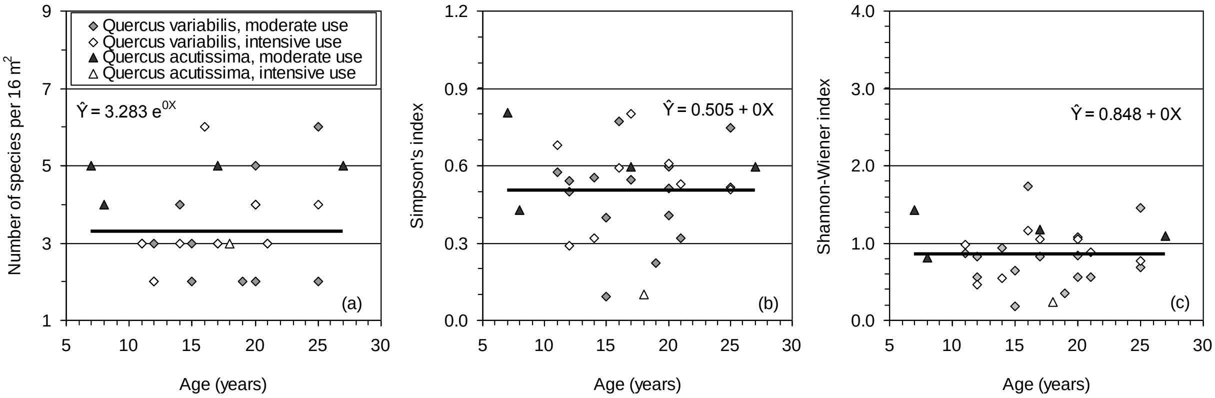

Fig. 23: Species diversity of the regeneration in *Q. variabilis* and *Q. acutissima* coppice stands: (a) number of species, (b) Simpson's index, (c) Shannon-Wiener index

Density, average height, average root-collar diameter

The density of the regeneration was 18,188 individuals ha^{-1} on average (ranged from 2,500 to 40,000) and was not related to stand type, forest stand use, and stand age, respectively (Fig. 24a). However, there was a clear indication that the intensive use on stands stimulated the growth of regeneration (Fig. 24b-c). Regardless of stand age, the average height and the average root-collar diameter of all woody regeneration in intensively used stands were always about 14 cm and 0.12 cm, respectively, higher than that in moderately used stands. The stand age had no effect on the average height and the average root-collar diameter of the regeneration (Fig. 24b-c). No relationships between the regeneration density and the average height or the average root-collar diameter were found (Fig. 24e-f). The average height had a close relationship with the average root-collar diameter for all woody regeneration (adjust r^2=0.87), irrespective of forest stand use (Fig. 24d). In addition, no differences in the average height and average root-collar diameter of the regeneration were found between *Q. variabilis* stands and *Q. acutissima* stands. The stand density (number of standing trees) had no effect on the density, average height and average root-collar diameter of the regeneration (Fig. 25).

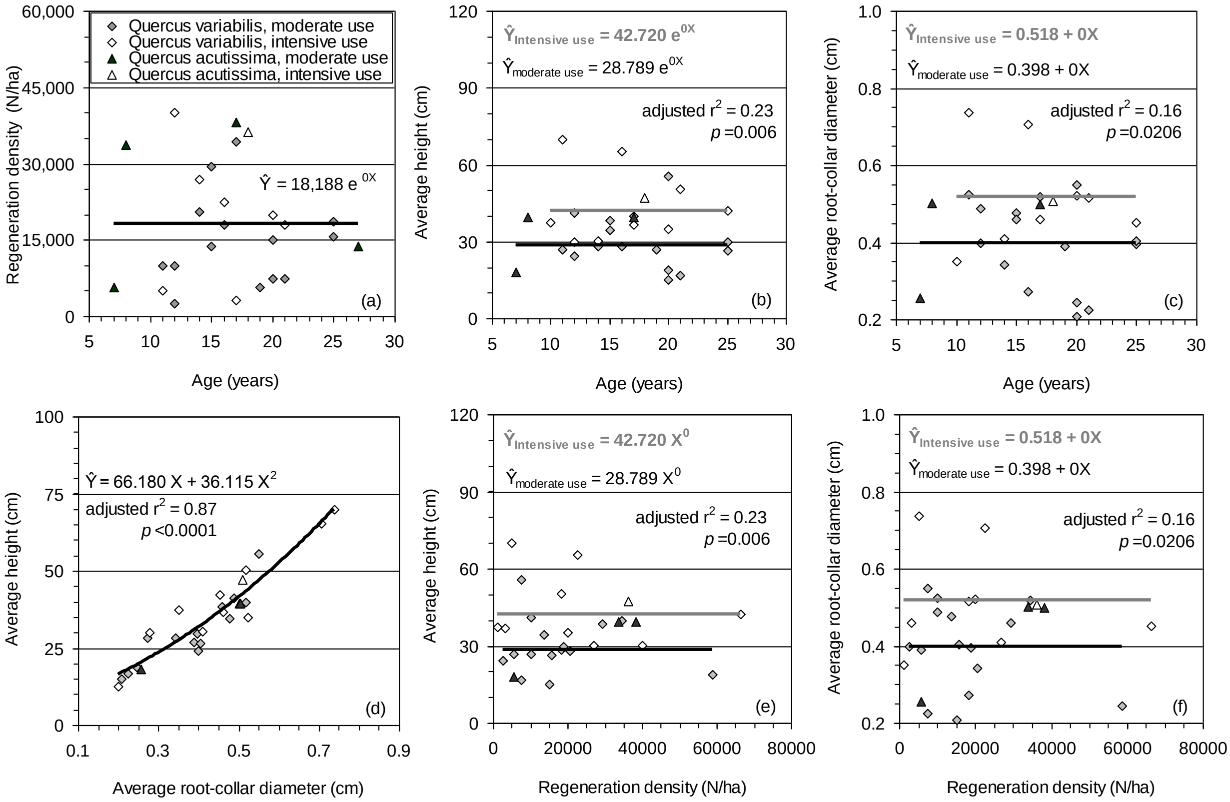

Fig. 24: Characteristics of the regeneration in *Q. variabilis* and *Q. acutissima* coppice stands: (a) density, (b) average height, (c) average root-collar diameter of regeneration, (d) relationship between average height and average root-collar diameter, (e) relationship between average height and density, (f) relationship between average root-collar diameter and density

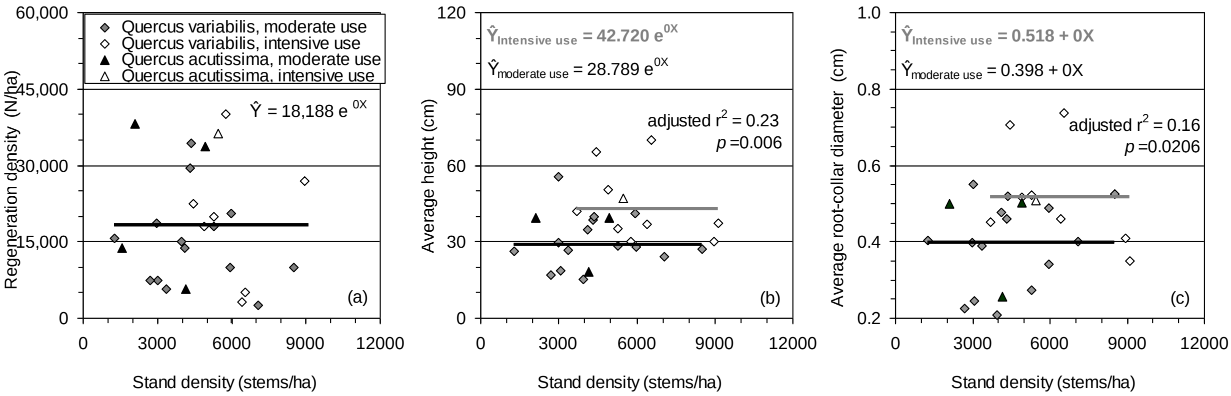

Fig. 25: Relationships between stand density and the regeneration of *Q. variabilis* and *Q. acutissima* coppice stands: (a) density, (b) average height, (c) average root-collar diameter

Regeneration of the main species

The regeneration of *Q. variabilis* had the highest density (8,675±2,000 individuals ha^{-1}) compared to other species in the *Q. variabilis* stands (Fig. 26). However, we found that the high density is mainly caused by three stands (points noted by a bigger size in Fig. 26a). Within these three stands, the density of *Q. variabilis* reached 35,625 individuals ha^{-1} in one moderately used stand, 21, 875 individuals ha^{-1} and 38,125 individuals ha^{-1} in two intensively used stands. Except these three stands, we found that the regeneration density of the main species was affected by the forest stand use. The intensive use reduced the number of seedlings of the main species. About 5910 individuals ha^{-1} on the average were recorded in moderately used stands and 2766 individuals ha^{-1} on the average were recorded in intensively used stands, respectively. The regeneration density of *Q. acutissima* in *Q. acutissima* stands was similar with the density of *Q. variabilis* in *Q. variabilis* stands within the same forest stand use type. The forest stand use had no influence on the average height and average root-collar diameter of the regeneration of the main species (25.0 cm and 0.35 cm, respectively) and no difference was detected between the *Q. variabilis* and *Q. acutissima stands* (Fig. 26b-c). The stand age also had no correlation with the regeneration density, the average height and average root-collar diameter of the main species.

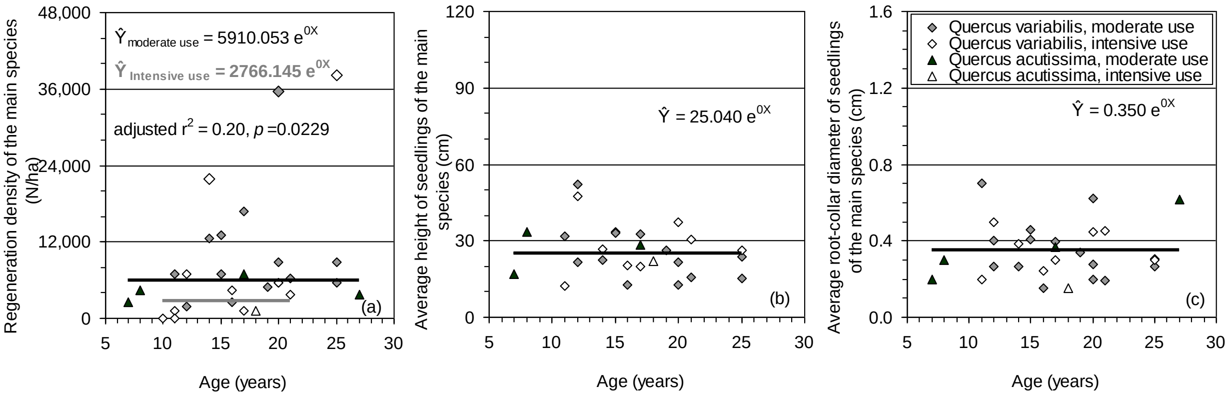

Fig. 26: Regeneration of the main species in *Q. variabilis* and *Q. acutissima* coppice stands: (a) density, (b) average height, (c) average root-collar diameter

Regeneration of *Dalbergia hupeana*

The regeneration of *D. hupeana* was very abundant both in the understory of *Q. variabilis* and *Q. acutissima* stands with an average density of 11,875 individuals ha^{-1}, ranged from 625 to 34,375 individuals ha^{-1} (Fig. 27a). No correlation was found between the number of *D. hupeana* and forest stand use. However, the intensive use of stands stimulated the height growth of *D. hupeana* seedlings (Fig. 27b). The average height of *D. hupeana* in intensively used stands was almost 20 cm higher than in moderately used stands (54.6 cm and 34.8 cm, respectively). But, no difference in root-collar diameter (mean 0.49 cm) of *D. hupeana* seedlings was found between the forest stand use types (Fig. 27c).

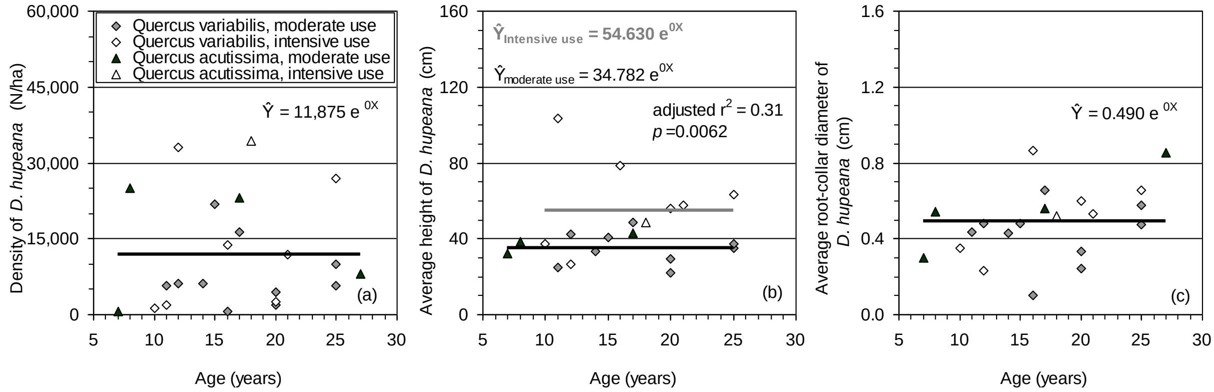

Fig. 27: Regeneration of *Dalbergia hupeana* in *Q. variabilis* and *Q. acutissima* coppice stands: (a) density, (b) average height, (c) average root-collar diameter

5.2.2.2 Understory vegetation

The coverage and average height of understory vegetation were not affected by the forest stand use in both *Q. variabilis* and *Q. acutissima* stands (Fig. 28). They were positively related to the stand age. However, the coverage and average height of ground vegetation was different between *Q. variabilis* stands and *Q. acutissima* stands. The average coverage of ground vegetation in *Q. acutissima* stands was 17.4% greater than that in *Q. variabilis* stands (Fig. 28a), while the average height of understory vegetation in *Q. acutissima* stands was 10.8 cm higher than that in *Q. variabilis* stands (Fig. 28b). The average height and coverage exhibited a power relationship, which was not affected by forest stand use and stand type (Fig. 28c).

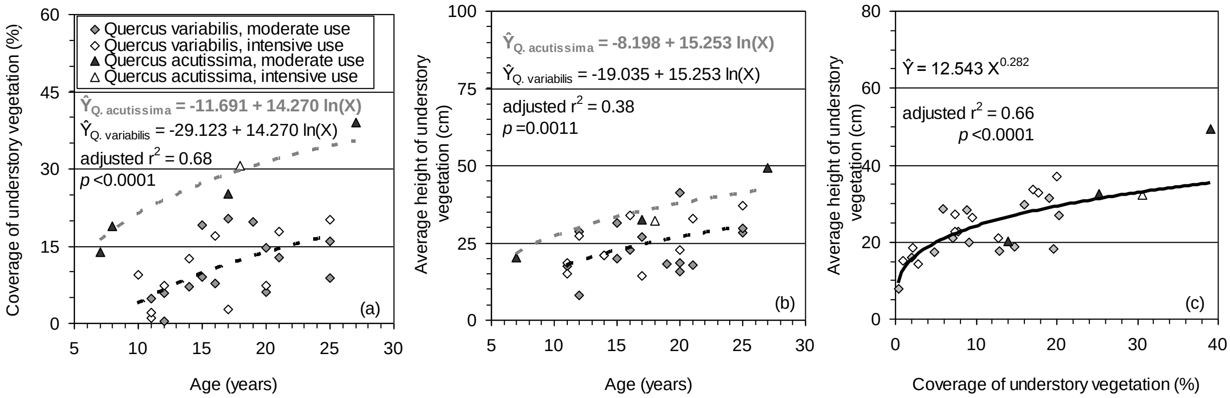

Fig. 28: Understory vegetation in *Q. variabilis* and *Q. acutissima* coppice stands: (a) coverage, (b) average height, (c) relationship between the average height and coverage

5.3 Characteristics of *Q. variabilis* and *Q. acutissima* on tree level

The study on the characteristics of *Q. variabilis* and *Q. acutissima* on tree level was conducted on the main stem, i.e., all single-stem trees and the main stem of multiple-stem trees. Three types of stems were classified according to the main stem types: (1) non-coppiced, single stem; (2) coppiced, single stem; (3) coppiced, multiple stem.

5.3.1 Allometric relationships

Quercus variabilis

Fig. 29 shows the height-DBH relationship and slenderness-height relationship of *Q. variabilis* in different crown classes (dominant, co-dominant, intermediate and suppressed). All three stem types had a similar height-diameter relationship and similar slenderness-height relationship in all crown classes. Tree height was strongly correlated with DBH in all crown classes (all had R^2>0.7). And a polynomial equation was fit well to describe the relationship between height and DBH. The slenderness of *Q. variabilis* remained constant, irrespective of height. However, with the decrease of crown class, the slenderness increased gradually (from 107.9 in dominant class to 142.7 in suppressed class). Trees in suppressed class had a high variation of slenderness, especially for small trees, for instance, the slenderness ranged from 42.4 to 227.7 for trees with heights of 2 to 3 m.

A positive linear relationship exists between crown width (Crd) and DBH for *Q. variabilis* in all crown classes (Fig. 30). However, the Crd was more related to DBH for trees in the dominant crown class (R^2=0.636) in comparison with trees in other classes (none had R^2>0.3). The Crd-DBH relationship was similar regardless of the stem type in the four crown classes. When considering the relationship between crown length (Crl) and height (H), a stronger correlation was found in the dominant crown class compared to that in other classes (Fig. 30). Additionally, the Crl-H relationship of trees with non-coppiced, single stem differed from that with coppiced stem in the dominant crown class, while the trees in other classes, irrespective of the stem type, had a similar Crl-H relationship.

The crown ratio (Cr%) had no relationship with height in all crown classes except the crown ratio of non-coppiced trees had a positive correlation with height in the dominant crown class (Fig. 31). With the decrease of crown class, the average crown ratio of individual trees also declined. Additionally, apart from the dominant class, no difference in crown ratio was observed among tree types in other crown classes. The relationship between the ratio of Crd-DBH and DBH had no difference among stem types in all crown classes as well. However, the relationship between the ratio of Crd-DBH and DBH varied among crown classes. For trees in the dominant crown class, the ratio of Crd-DBH had a weak and negative correlation with DBH (a relative smooth curve). But for the trees in other crown classes, the ratio of Crd-DBH was negatively related to the DBH.

The stem type had no influence on the relationship between the ratio of Crd-H and H as well as the relationship between the ratio of Crd-Crl and DBH in all crown classes (Fig. 32). But, the relationship between the ratio of Crd-H and H was different among crown classes. For trees in the dominant crown class, the ratio of Crd-H had no correlation with H (mean of 0.283). But for the trees in other crown classes, the ratio of Crd-H was slightly negatively related to the height. The ratio of Crd-Crl had no relationship with DBH in all crown classes (ranged from 0.759 in dominant class to 1.017 in intermediate class)(Fig. 32).

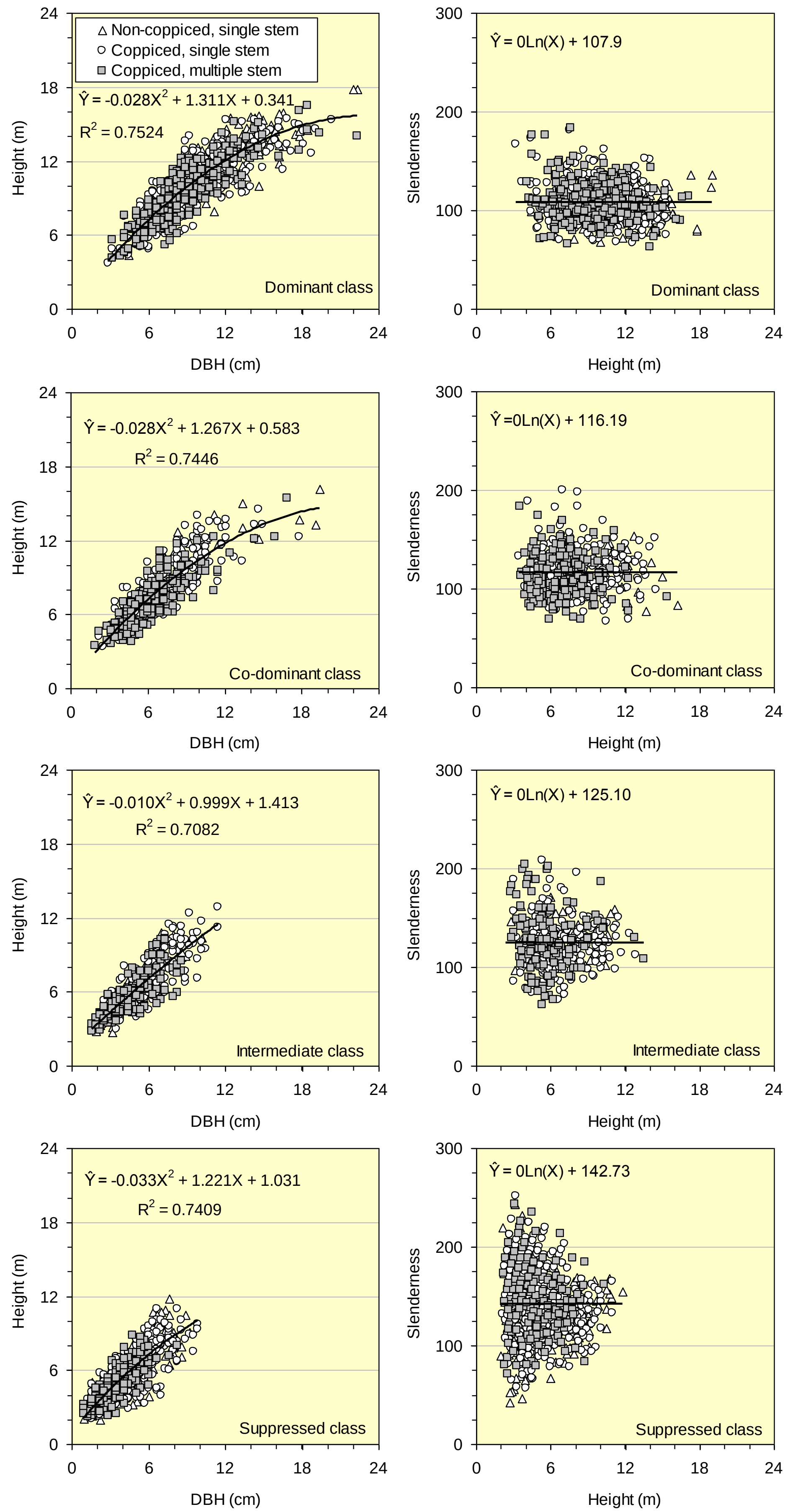

Fig. 29: Relationship between height and DBH, slenderness and height of *Q. variabilis* for different stem types and crown classes

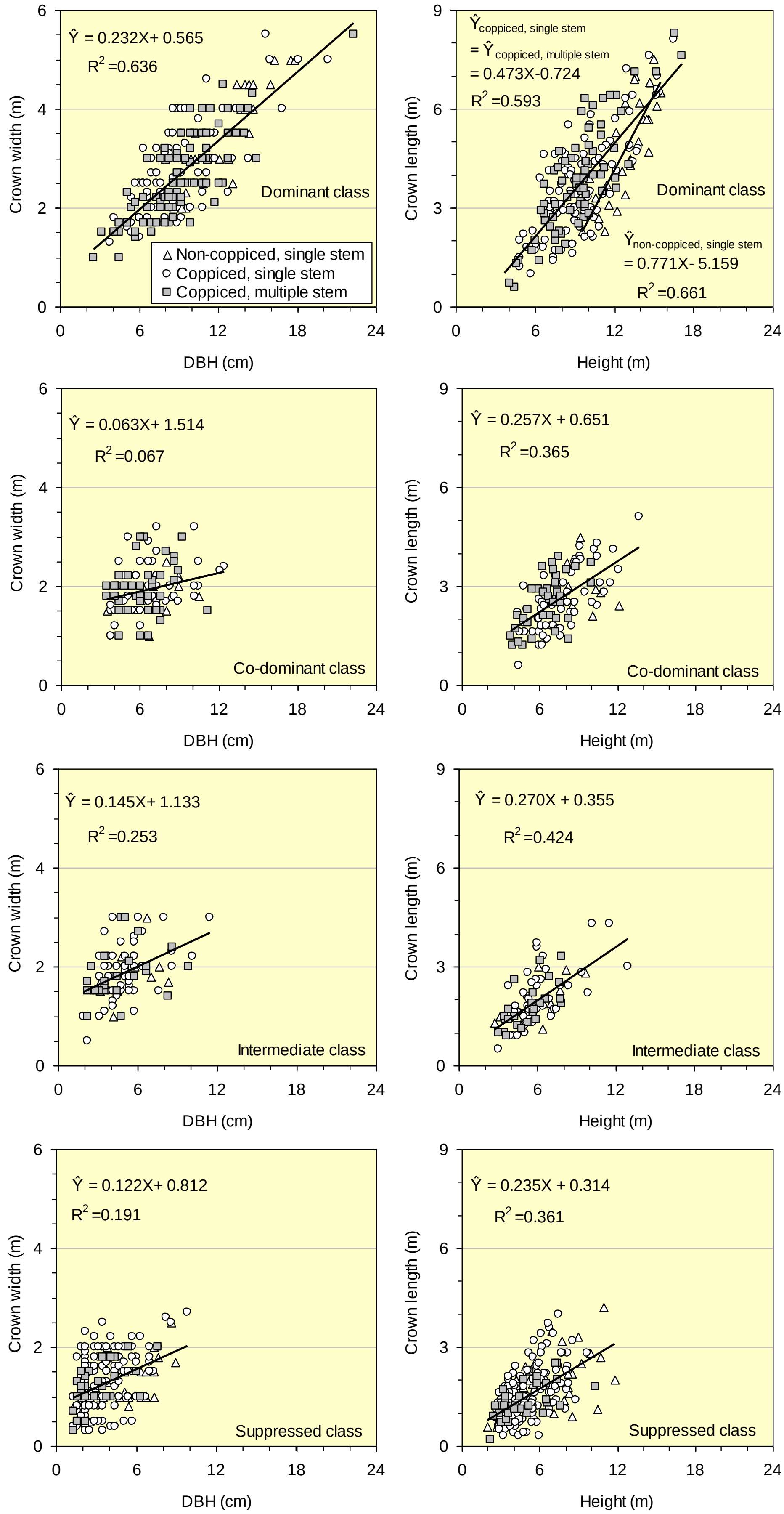

Fig. 30: Relationship between crown width and DBH, crown length and height of *Q. variabilis* for different stem types and crown classes

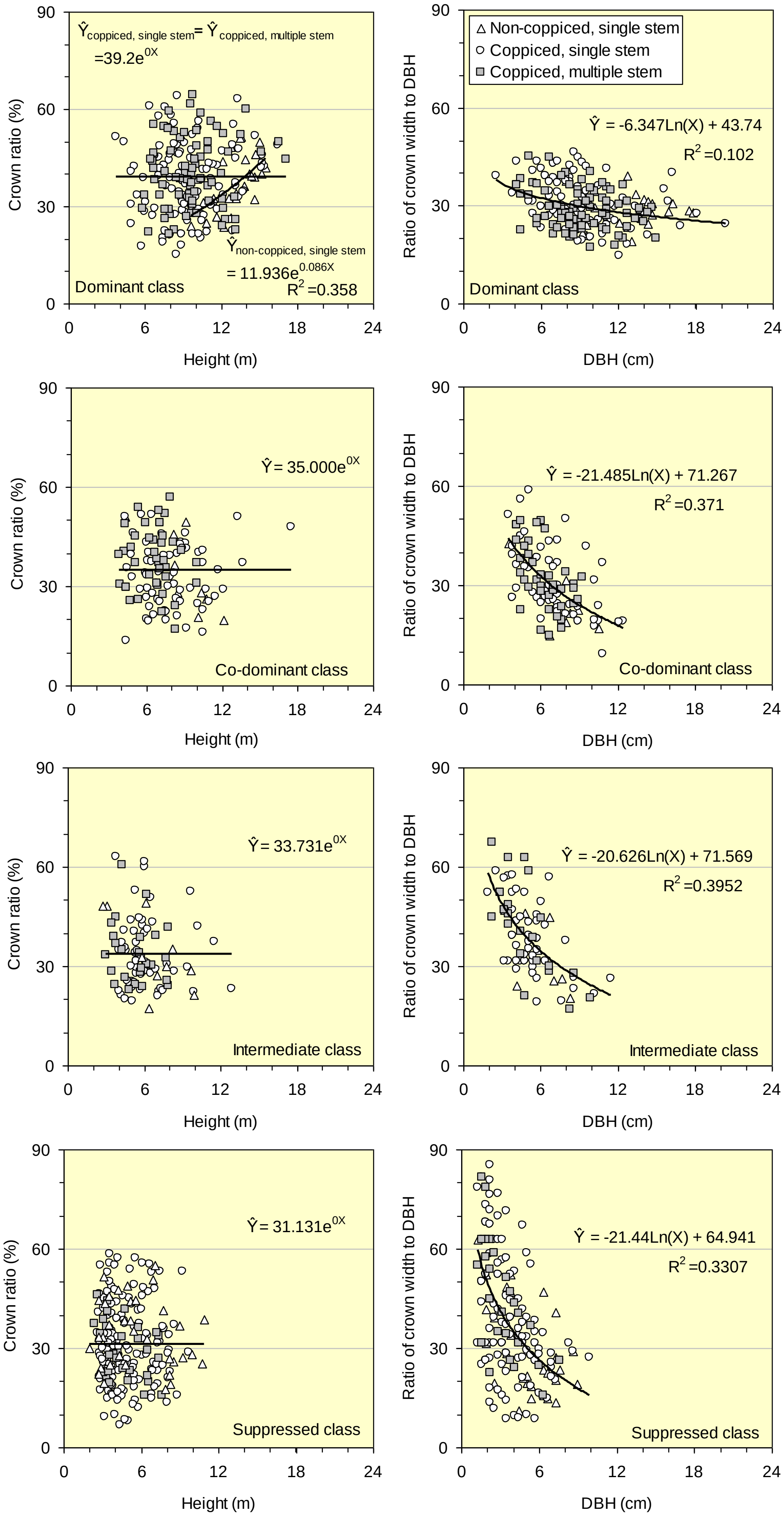

Fig. 31: Relationship between crown ratio and height, ratio of crown width-DBH and DBH of *Q. variabilis* for different stem types and crown classes

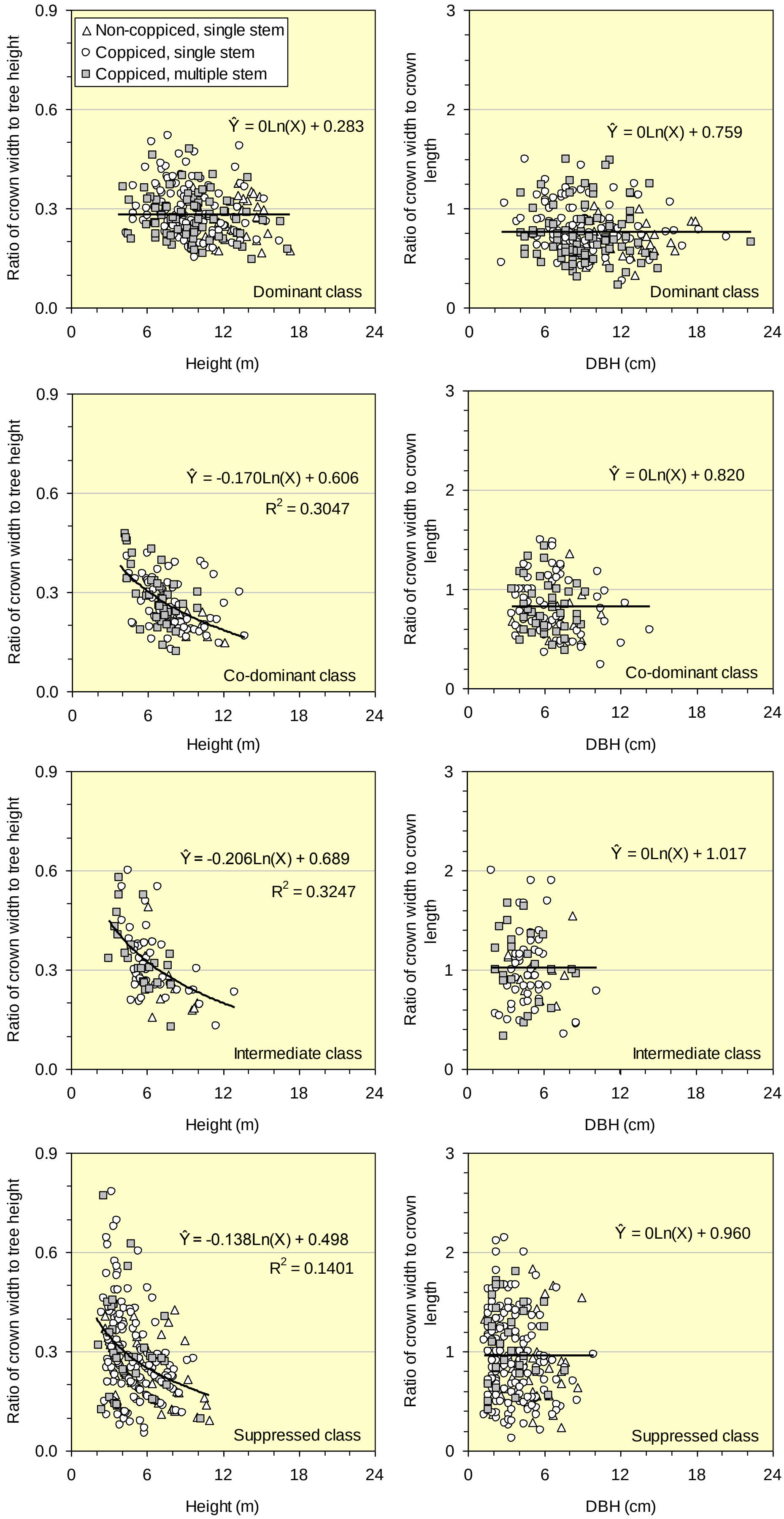

Fig. 32: Relationship between ratio of crown width-height and height, ratio of crown width-crown length and DBH of *Q. variabilis* for different stem types and crown classes

Quercus acutissima

There were very few *Q. acutissima* with non-coppiced, single stem type in the investigated stands. The number of *Q. acutissima* with coppiced, multiple stem was also sparse. Most of *Q. acutissima* in study area were coppiced trees with single stem (Fig. 33). A polynomial relationship was found between tree height and DBH in all crown classes. With the decrease of crown class, the coefficient of correlation decreased as well. No relationship between slenderness and height was observed in all crown classes. However, the average slenderness of trees increased with the decrease of crown class. Height-DBH relationship as well as the slenderness-height relationship of *Q. acutissima* was similar between the coppiced, single-stem trees and coppiced, multiple-stem trees.

Due to insufficient data on the crown parameters, the relationships between the crown parameters and DBH or height of *Q. acutissima* were not analyzed.

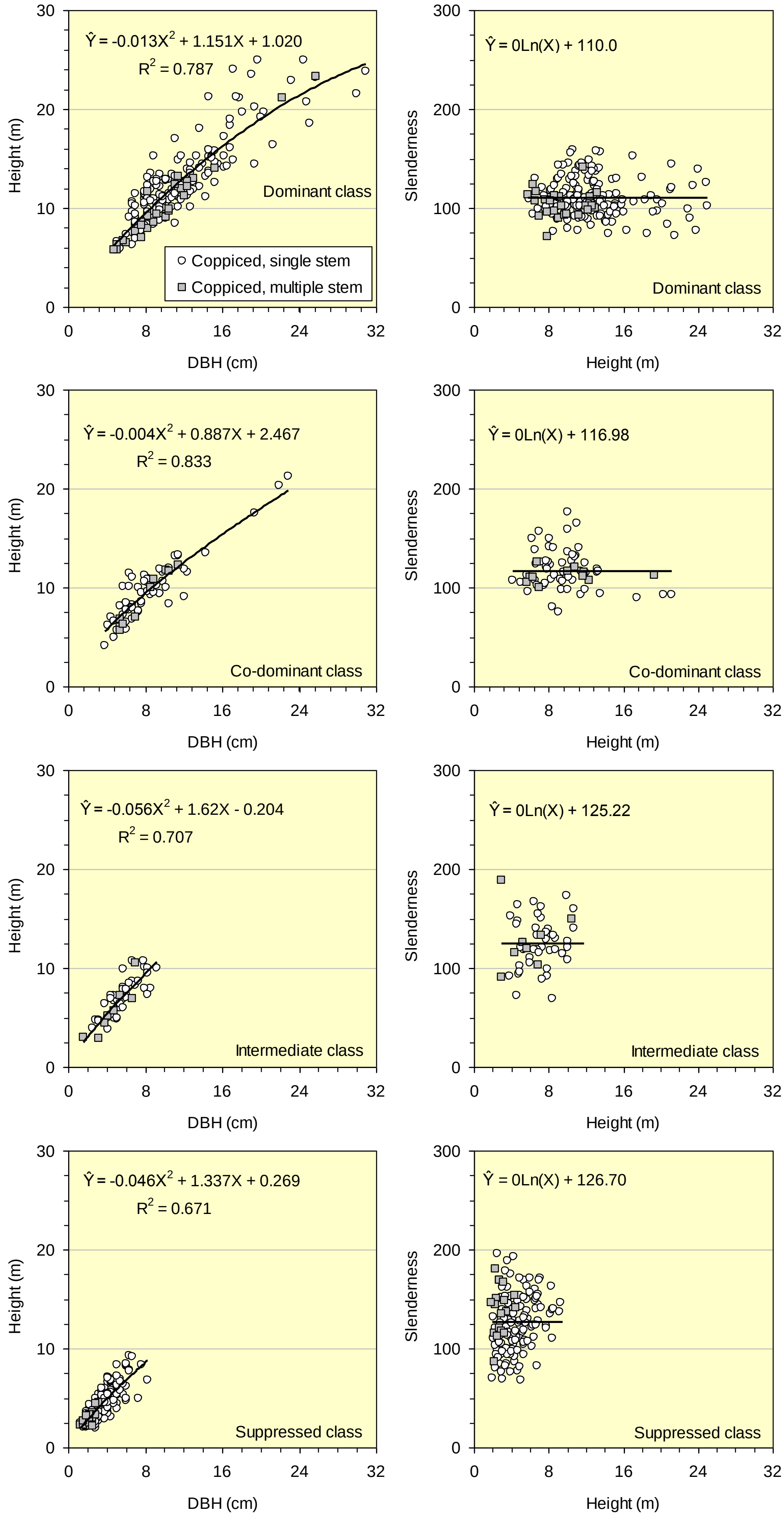

Fig. 33: Relationship between height and DBH, slenderness and height of *Q. acutissima* for different stem types and crown classes

5.3.2 Vitality

In this chapter the tree structure is analyzed for the vitality classes: vigorous vitality (healthy, densely foliated), moderate vitality (reasonably healthy, fairly foliated), and weak vitality (unhealthy or poorly foliated).

Quercus variabilis

Among all investigated *Q. variabilis* trees (n=2950), the percentage of trees with vigorous vitality, moderate vitality and weak vitality was 21.4%, 60.9% and 17.7%, respectively. Hence, the majority of *Q. variabilis* (82.3%) had a high or moderate vitality in the study area.

Vigorous vitality

Table 11 shows the means of diameter at breast height (DBH), height (H), slenderness, crown length (Crl), crown width (Crd) and crown ratio (Cr%) of *Q. variabilis* with vigorous vitality. Nearly half of the *Q. variabilis* trees had a coppiced, single stem (48.7%), while *Q. variabilis* with non-coppiced, single stem accounted the smallest proportion (22.3%). Among trees with the same stem type, the number of trees in the dominant crown class was remarkably greater than these in other crown classes. Most of the vigorous trees had a dominant crown. Both the average DBH and average height decreased with the decrease of crown class, in contrast, the average slenderness increased.

The crown characteristics were studied only for dominant and co-dominant trees since the data was lacking for trees in intermediate and suppressed class. For trees with coppiced-single stem, the average Crl in dominant class (4.5±0.2 m) was slightly greater than that in co-dominant class (3.7±0.6 m), while the average Crd was almost similar. For trees with coppiced-multiple stem, the average Crd and average Crl of trees in dominant class was greater than that in co-dominant class.

Among vigorous trees in the dominant crown class, non-coppiced, single-stem trees had a higher average DBH and average height than coppiced trees. No differences were observed between coppiced single-stem trees and coppiced, multiple-stem trees. However, the slenderness of trees with different types of stem was same. The average Crl and average Crd of non-coppiced, single-stem trees were also higher than coppiced trees. No differences were found between coppiced, single-stem trees and coppiced, multiple-stem trees. The average crown ratio of trees with different types of stem in dominant class was almost similar (around 40%). Because of the number of trees in the other crown classes was too small, the comparison among trees with different types of stems was not conducted.

Table 11: Average ± S.E. of diameter at breast (DBH), height (H), slenderness, crown length (Crl), crown width (Crd), crown ratio (Cr%) of *Q. variabilis* with vigorous vitality

Vigorous vitality (n=632, 21.4% of all trees)								
Stem type	Crown class*	n	DBH (cm)	Height (m)	Slenderness	Crl (m)	Crd (m)	Cr%
Non-coppiced, single stem (n=141, 22.3%)	Do.	128	13.4±0.3	13.2±0.2	101.2±1.4	5.7±0.3	4.0±0.2	41.1±1.8
	Co-do.	3	12.6±2.7	12.3±1.6	101.8±14.3			
	Inter.	3	8.8±0.9	10.6±0.3	123.3±17.7			
	Supp.	7	5.4±1.1	5.4±0.7	116.9±15.5			
Coppiced, single stem (n=308, 48.7%)	Do.	256	10.7±0.2	10.9±0.2	104.3±1.1	4.5±0.2	3.1±0.1	40.4±1.3
	Co-do.	35	8.6±0.5	9.4±0.5	112.5±3.4	3.7±0.6	3.0±0.4	50.3±3.6
	Inter.	11	5.9±0.6	7.1±0.7	120.2±3.5			
	Supp.	6	5.3±0.6	6.8±0.8	135.5±8.8			
Coppiced, multiple stem (n=183, 29.0%)	Do.	153	10.4±0.3	10.6±0.2	104.4±1.3	4.6±0.2	3.2±0.1	42.6±2.0
	Co-do.	24	6.8±0.5	7.7±0.5	119.4±4.6	3.0±0.3	2.3±0.3	43.6±2.5
	Inter.	3	6.1±0.6	7.5±1.6	122.5±12.2			
	Supp.	3	3.7±1.4	4.6±0.9	171.8±65.9			

Crown class*: Do.= Dominant, Co-do.= Co-dominant, Inter.= Intermediate, Supp.= Suppressed. The same abbreviation of crown class is used in following tables in this chapter.

Moderate vitality:

For *Q. variabilis* with moderate vitality, 58.2% of trees were coppiced, single-stem, compared to 30.0% of coppiced, multiple-stem and 11.9% of non-coppiced, single-stem (Table 12). Irrespective of the stem type the crown classes were more even distributed in comparison to the vigorous ones. With lower crown classes, the average DBH and height decreased, in contrast, the average slenderness increased. The average crown width, crown length and crown ratio also exhibited a declining trend with the decrease of crown class.

Within the same crown class, the average DBH and the average height of trees with three types of stem ranked as follows: non-coppiced, single-stem > coppiced, single-stem > coppiced, multiple-stem; while the mean slenderness was almost similar among the different stem types. In the dominant crown class, the means of Crl, Crd and Cr% among trees with three stem types ranked as follows: non-coppiced, single-stem > coppiced, single-stem > coppiced, multiple-stem. But, no differences in terms of the means of Crl, Crd and Cr% among stem types were observed in co-dominant, intermediate and suppressed class.

Table 12: Average ± S.E. of diameter at breast (DBH), height (H), slenderness, crown length (Crl), crown width (Crd), crown ratio (Cr%) of *Q. variabilis* with moderate vitality

Moderate vitality (n=1797, 60.9% of all trees)								
Stem type	Crown class*	n	DBH (cm)	Height (m)	Slender ness	Crl (m)	Crd (m)	Cr%
Non-coppiced, single stem (n=213, 11.9%)	Do.	44	11.3±0.6	11.2±0.3	103.7±3.1	5.7±0.7	3.9±0.7	43.5±4.5
	Co-do.	48	8.7±0.4	10.1±0.3	119.5±2.7	2.8±0.3	1.9±0.2	33.2±3.7
	Inter.	36	5.9±0.3	7.1±0.4	128.9±3.5	2.3±0.2	1.9±0.2	32.2±3.6
	Supp.	85	4.4±0.2	6.0±0.3	144.3±3.7	2.2±0.2	1.7±0.2	31.9±2.7
Coppiced, single stem (n=1045, 58.2%)	Do.	218	8.3±0.1	9.2±0.1	113.3±1.2	3.3±0.2	2.5±0.1	37.8±1.4
	Co-do.	231	7.0±0.2	8.0±0.2	119.3±1.7	2.6±0.2	2.0±0.1	32.6±1.2
	Inter.	224	5.6±0.1	6.7±0.1	123.2±1.6	2.1±0.1	2.0±0.1	34.5±1.6
	Supp.	372	4.2±0.1	5.5±0.1	141.3±1.8	1.8±0.1	1.6±0.1	33.5±1.4
Coppiced, multiple stem (n=539, 30.0%)	Do.	150	7.6±0.2	8.4±0.2	113.8±1.7	3.1±0.2	2.2±0.1	36.6±1.8
	Co-do.	158	6.6±0.2	7.1±0.2	112.6±1.8	2.5±0.2	2.0±0.1	36.3±1.7
	Inter.	131	5.1±0.2	6.0±0.2	125.6±2.7	1.9±0.2	1.9±0.1	33.4±1.9
	Supp.	100	3.7±0.2	5.0±0.2	143.0±3.8	1.4±0.1	1.6±0.1	30.4±2.0

Weak vitality:

The percentage of trees with coppiced, single stem accounted the most part (68.7%) among *Q. variabilis* with weak vitality (Table 13). And the percentage of trees with non-coppiced, single stem and trees with coppiced, multiple stem was almost similar (15.7% and 15.5%, respectively). Trees in suppressed crown class were much more abundant than trees in other crown classes for all stem types. With the decrease of the crown class, the average DBH and average height decreased for coppiced, single-stem trees and coppiced, multiple-stem trees, while the average slenderness increased. Average Crd and average Crl also decreased with the decrease of the crown class.

The number of non-coppiced trees in the suppressed class was greater than the coppiced trees in terms of means of DBH, Crl, Crd and Cr%, whereas the slenderness of non-coppiced trees was smaller. The mean values of these variables were almost similar between trees with coppiced, single stem and trees with coppiced, multiple stem.

Table 13: Average ± S.E. of diameter at breast (DBH), height (H), slenderness, crown length (Crl), crown width (Crd), crown ratio (Cr%) of *Q. variabilis* with weak vitality

Weak vitality (n=521, 17.7% of all trees)								
Stem type	Crown class*	n	DBH (cm)	Height (m)	Slenderness	Crl (m)	Crd (m)	Cr%
Non-coppiced, single stem (n=82, 15.7%)	Do.							
	Co-do.							
	Inter.							
	Supp.	82	4.2±0.2	5.1±0.3	137.2±5.3	1.8±0.2	1.2±0.1	33.8±2.6
Coppiced, single stem (n=358, 68.7%)	Do.							
	Co-do.	6	6.1±0.3	7.1±0.4	116.6±3.0	2.6±0.8	1.9±0.4	38.8±12.7
	Inter.	21	4.6±0.3	5.6±0.3	126.5±5.1	1.3±0.1	1.4±0.2	25.9±1.4
	Supp.	331	3.3±0.1	5.5±0.1	147.6±2.1	1.2±0.1	1.0±0.0	28.7±1.3
Coppiced, multiple stem (n=81, 15.5%)	Do.	2	9.4±2.1	9.7±1.6	104.1±6.4			
	Co-do.	4	5.2±0.5	5.9±0.4	114.9±5.0	2.3±0.6	1.3±0.2	37.5±6.7
	Inter.	6	3.9±0.5	4.9±0.5	134.6±19.3	2.1±0.5	1.2±0.3	41.3±6.5
	Supp.	69	3.0±0.2	4.3±0.2	153.4±4.3	1.2±0.1	1.0±0.1	27.5±3.1

Quercus acutissima

Among all recorded *Q. acutissima* trees (n=492), the percentage of trees with moderate vitality was the highest (62.6% of all trees). The trees with vigorous and weak vitality accounted 21.3% and 16.6%, respectively.

Vigorous vitality:

For vigorous trees, the trees with coppiced, single stem and trees with coppiced, multiple stem accounted 69.5% and 25.7%, respectively, and only 4.8% was non-coppiced, single-stem trees (Table 14). The majority of vigorous *Q. acutissima* were in the dominant crown class. From the dominant to co-dominant class, the average DBH and height decreased while the average slenderness increased. Compared to the coppiced, multiple-stem trees, the coppiced, single-stem trees had higher means of DBH, height, crown width, and crown length in the dominant class. But they had the similar average slenderness and average crown ratio.

Table 14: Average ± S.E. of diameter at breast (DBH), height (H), slenderness, crown length (Crl), crown width (Crd), crown ratio (Cr%) of *Q. acutissima* with vigorous vitality

Vigorous vitality (n=105, 21.3% of all trees)								
Stem type	Crown class*	n	DBH (cm)	H (m)	Slenderness	Crl (m)	Crd (m)	Cr%
Non-coppiced, single stem (n=5, 4.8%)	Do.	5	14.7±0.9	12.6±0.9	86.6±7.4			
	Co-do.							
	Inter.							
	Supp.							
Coppiced, single stem (n=73, 69.5%)	Do.	65	12.1±0.5	11.9±0.4	100.6±1.5	6.5±0.7	3.5±0.3	56.7±2.6
	Co-do.	6	7.6±0.5	8.5±0.9	110.6±4.8	4.4±0.4	3.0±0.3	52.3±2.4
	Inter.	2	8.3±0.0	9.8±0.3	117.8±3.0			
	Supp.							
Coppiced, multiple stem (n=27, 25.7%)	Do.	21	8.8±0.6	8.9±0.5	103.4±2.7	5.1±0.7	2.9±0.1	56.7±4.1
	Co-do.	4	5.5±0.1	6.0±0.2	109.3±1.4			
	Inter.							
	Supp.	2	3.7±0.5	4.5±0.0	125.0±16.3			

Moderate vitality:

For *Q. acutissima* in moderate vitality, coppiced, single-stem trees accounted the largest part (87.3%) and 10.1% were coppiced, multiple-stem trees (Table 15). With the decrease of crown class, the average DBH and height of all stem types decreased gradually and the average slenderness increased. The average Crl also declined with crown class. However, for coppiced, single-stem trees, the average Crd of trees in dominant and co-dominant crown class was same (mean 3.0 m), while the average Crd of trees in intermediate or suppressed classes was the same and smaller than that in dominant and co-dominant crown classes. For coppice, multiple-stem trees, the average Crd decreased with the decrease of the crown class.

The comparison among different stem types was not analyzed because both the number of trees with coppiced, multiple stem and the number of trees with non-coppiced, single stem were too low (less than 10 in each crown class).

Weak vitality:

Q. acutissima trees with weak vitality accounted 16.6% of all trees. Among these trees, no trees were of non-coppiced, single stem type. The majority was coppiced, single-stem trees with a suppressed crown (89.9%) and trees with coppiced, multiple stem took about 10.1% (Table 16).

Table 15: Average ± S.E. of diameter at breast (DBH), height (H), slenderness, crown length (Crl), crown width (Crd), crown ratio (Cr%) of *Q. acutissima* with moderate vitality

Moderate vitality (n=308, 62.6% of all trees)								
Stem type	Crown class*	n	DBH (cm)	H (m)	Slenderness	Crl (m)	Crd (m)	Cr%
Non-coppiced, single stem (n=8, 2.6%)	Do.							
	Co-do.	4	8.4±1.2	10.3±0.5	126.6±10.6			
	Inter.	2	6.5±1.4	8.4±1.3	130.0±9.4			
	Supp.	2	3.5±0.0	5.0±0.7	141.3±18.6			
Coppiced, single stem (n=269, 87.3%)	Do.	99	15.1±0.5	13.1±0.4	118.4±2.1	4.9±0.5	3.0±0.2	41.0±2.8
	Co-do.	53	7.9±0.3	9.3±0.3	120.1±3.5	4.2±0.7	3.0±0.3	41.4±3.9
	Inter.	40	5.7±0.3	6.9±0.3	125.4±4.3	2.5±0.4	1.7±0.1	37.0±4.1
	Supp.	77	4.2±0.2	5.2±0.2	128.5±4.0	1.8±0.3	1.8±0.1	35.2±2.8
Coppiced, multiple stem (n=31, 10.1%)	Do.	8	14.2±2.3	14.2±1.8	104.3±6.1	7.4±1.6	5.3±1.3	51.1±8.9
	Co-do.	7	9.8±1.4	11.1±1.6	114.0±3.2	5.2±0.8	2.6±0.9	59.4±3.8
	Inter.	7	4.7±0.7	5.9±1.0	130.1±12.1	2.8±0.8	2.0±0.4	43.3±5.4
	Supp.	9	2.1±0.2	2.8±0.1	135.2±6.4			

Table 16: Average ± S.E. of diameter at breast (DBH), height (H), slenderness, crown length (Crl), crown width (Crd), crown ratio (Cr%) for *Q. acutissima* with weak vitality

Weak vitality (n=79, 16.6% of all trees)								
Stem type	Crown class*	n	DBH (cm)	H (m)	Slenderness	Crl (m)	Crd (m)	Cr%
Coppiced, single stem (n=71, 89.9%)	Do.							
	Co-do.							
	Inter.	4	5.8±1.1	9.3±0.8	140.2±11.4	4.3±0.5	2.5±1.0	48.5±3.6
	Supp.	67	3.3±0.2	4.0±0.2	127.4±4.3	1.3±0.2	1.2±0.1	30.9±1.9
Coppiced, multiple stem (n=8, 10.1%)	Do.							
	Co-do.							
	Inter.							
	Supp.	8	2.1±0.2	3.0±0.3	143.9±12.9			

Part 2 Results of socio-economic study

5.4 Characteristics of socio-economic conditions

5.4.1 Description of socio-economic parameters

There were 175 people from 12 villages involved in the socio-economic investigation. The average distance between the village and the county centre was 12.8±2.0 km (range 5-26 km) (Table 17). Based on the distance from village to county centre, the households were grouped into three categories (<10, 10-19, 20-29 km) (Table 18). The number of households distributed in these three categories was equal (no significant difference was detected)(Table 20). The average number of inhabitants of villages was 1504±164 persons (range 742-2864 persons). Three categories of inhabitants were defined (700-1200, 1200-1700, >1700 persons). The households from village sized 1200-1700 persons accounted 51.4% of all households, which was significantly greater than households from village size of 700-1200 and >1700 persons (Table 20).

The average size of household is 4±1.3 persons, ranging from 1 to 10 persons (Table 17). More than half of households (56.0%) had 3-4 members. The households of 1-2 persons and of >7 persons are very rare in the study area, account only 4.0% and 5.1%, respectively (Table 18). The average number of children for each household was 2±0.8 persons. Almost 80% of families have 1-2 children, significantly higher than these with 3-4 children (16%) and these do not have any child (4.5%)(Table 18, Table 20). The mean house size was 125.8±2.3 m^2, ranging from 35 to 220 m^2 (Table 17). The households had a house in size between 100 and 150 m^2 took the largest part (72.0%) (Table 18).

Table 17: Description of socio-economic parameters (interval variables)

Socio-economic parameters	Unit	Median	Mean	S.E.	Min.	Max.	S.D.
Location of village (Distance from the village to county centre	km	10.5	12.8	2.0	5	26	7.0
Inhabitants of village	person	1390.5	1504.3	164.2	742	2864	569.0
Age of interviewee	year	45	45.9	0.9	18	80	12.5
House size	m^2	130	125.8	2.3	35	220	30.4
Household size	person	4	4	0.1	1	10	1.3
Number of children	person	2	2	0.1	0	4	0.8

S.E.= standard error, S.D.= standard deviation

Table 18: Classification of socio-economic parameters (interval variables)

Socio-economic parameters	Unit	Categories	Frequency	Percent (%)
Village location (distance from the village to county centre)	km	<10	65	37.1
		10-19	62	35.4
		20-29	48	27.4
		Total	175	100.0
Inhabitants of village	person	700-1200	45	25.7
		1200-1700	90	51.4
		>1700	40	22.9
		Total	175	100.0
Age of interviewee	year	≤35	33	18.9
		>35≤50	82	46.9
		>50≤65	50	28.6
		>65≤80	10	5.7
		Total	175	100.0
House size	m^2	<100	14	8.0
		≥100<150	126	72.0
		≥150<200	29	16.6
		≥200<250	6	3.4
		Total	175	100.0
Household size	person	1-2	7	4.0
		3-4	98	56.0
		5-6	61	34.9
		≥7	9	5.1
		Total	175	100.0
Number of children	person	0	8	4.5
		1-2	139	79.5
		3-4	28	16
		Total	175	100.0

The age of interviewees ranged from 18 to 80 years, with the median age of 46 years old (Table 17). The largest proportion of interviewees was in the 35 to 50 year age class (accounted 46.9% of all interviewees); while people aged 65 to 80 years only accounted 5.7% (Table 18). Among 175 interviewees, the number of males sampled was a little higher (51.4%), but not significantly than the number of females interviewed (48.6%) (Table 19, Table 20).

Half of the head of households (50.3%) had completed middle education (5 years education in primary school and 3 years education in middle school; Table 19). While 17.1% were illiterate, 29.1% had basic education (only 5 years study in primary school), and 3.4% had higher education (graduated from high school and college). The distribution of the number of the head of households in four education classes was significantly unequal (Table 20). The majority of the head of households are married (97.1%), significantly higher than single ones (Table 19, Table 20). In terms of occupation, 89.7% of the heads of households are full-time farmers, while 10.3% are part-time farmers (Table 19).

Concerning the economic situation of households, 16.6% of households were considered well-off and 43.4% were in the middle level. The households which were in poor and poverty stricken economic situations accounted for 29.7% and 10.3% of all household sampled, respectively (Table 19). In total, 197 responses were received from 175 interviewees when the practiced land use type was surveyed. Agriculture was the practiced land use for the most of households (85.3%), greatly higher than other practiced land use types (Table 21).

Table 19: Description of socio-economic parameters (nominal and ordinal variables)

Socio-economic parameters	Category	Frequency	Percent (%)
Gender of interviewee	Female	85	48.6
	Male	90	51.4
	Total	175	100.0
Economic situation	Well-off	29	16.6
	Average	76	43.3
	Poor	52	29.7
	Poor stricken	18	10.3
	Total	175	100.0
Marital status of the head of household	Married	170	97.1
	Single	5	2.9
	Total	175	100.0
Occupation of the head of household	Full-time farmer	157	89.7
	Part-time farmer	18	10.3
	Total	175	100.0
Education level of the head of household	High education	6	3.4
	Educated	88	50.3
	Basic educated	51	29.1
	Illiterate	30	17.1
	Total	175	100.0

Table 20: Results of frequency test of categories of socio-economic parameters

Socio-economic parameters	Test method	*p*
Village location	One-sample Chi-square test	0.244
Inhabitant	One-sample Chi-square test	0.000
House size	One-sample Chi-square test	0.000
Age	One-sample Chi-square test	0.000
Gender	One-sample Binomial test	0.762
Economic situation	One-sample Chi-square test	0.000
Educational level	One-sample Chi-square test	0.000
Marital status	One-sample Binomial test	0.000
Full or part time farmer	One-sample Binomial test	0.000
Household size	One-sample Chi-square test	0.000
Children number	One-sample Chi-square test	0.000

The significance level is 0.05. We assumed that the proportion of categories of variable is equal. If the *p* value is equal to or less than 0.05, then we reject the assumption.

Table 21: Percentage of households in different practiced land use type

Practiced land use type by the household	Responses		Percent of Cases (%)
	N	Percent (%)	
Agriculture	168	85.3	96.0
Forestry	10	5.1	5.7
Agriforestry	4	2.0	2.3
Other	15	7.6	8.6
Total	197	100.0	112.6

Responses percent was calculated by number of responses in each class divided by total responses (N=197); percent of cases was calculated by number of responses in each class divided by total cases (n=175)

5.4.2 Relationships among socio-economic parameters

Table 22 shows the significance test on the correlation of socio-economic parameters. The economic situation of household was slightly related with the village location (*Cramer´s V*=0.230, $p<0.01$) as well as the house size (*Cramer´s V*=0.26, $p<0.05$). A weak, but significant correlation between the educational level of the head of household and economic situation was found (*Cramer´s V*=0.207, $p<0.01$). In addition, the household size had a slightly significant correlation with house size (*Cramer´s V*=0.169, $p<0.01$). Household size was significantly correlated with marital status of head of household (*Cramer´s V*=0.555, $p<0.01$). More than 95% of households with single householder had 1-2 family members, while the size of household with a married householder varied from 1-2 to 6-7 family members.

The number of children in each household was strongly and significantly related to the marital status (*Cramer´s V*=0.699, $p<0.001$) and household size (*Cramer´s V*=0.769, $p<0.001$). The farmer type (part-time or full-time farmer) of householder had a weak, but significant relationship with house size (*Cramer´s V*=0.248, p<0.05), economic situation (*Cramer´s V*=0.230, p<0.05), and education level (*Cramer´s V*=0.238, p<0.05). The practiced land use type of household was weakly but significantly related to the village location (*Cramer´s V*=0.176, p<0.05) but moderately related to farmer type (part-time or full time) (*Cramer´s V*=0.433, p<0.01). Part-time famers who engaged in agriculture and forestry were fewer in comparison with these with full-time farmer; in contrast, more part-time farmers worked on other practiced land use type (Fig. 34).

Table 22: Results of correlation test between socio-economic parameters

Correlation coefficient (*Cramer´s V*)	Village location	Village size	House size	Economic situation	Educational level	Marital status	Household size	Children number	Full or part time	Practiced land use type
Village location	1	-0.034	0.185	0.230**	0.086	0.094	0.148	0.114	0.124	0.176*
Village size		1	0.142	0.126	0.106	0.104	0.107	0.086	0.084	0.169
House size			1	0.261**	0.133	0.115	0.169**	0.132	0.248*	0.150
Economic situation				1	0.207**	0.099	0.158	0.162	0.230*	0.153
Educational level					1	0.091	0.113	0.062	0.238*	0.156
Marital status						1	0.555***	0.699***	0.200	0.099
Household size							1	0.769***	0.054	0.072
Children number								1	0.126	0.141
Full or part time									1	0.433**
Practiced land use type										1

(* significance at p<0.05, ** significance at p<0.01, *** significance at p<0.001)

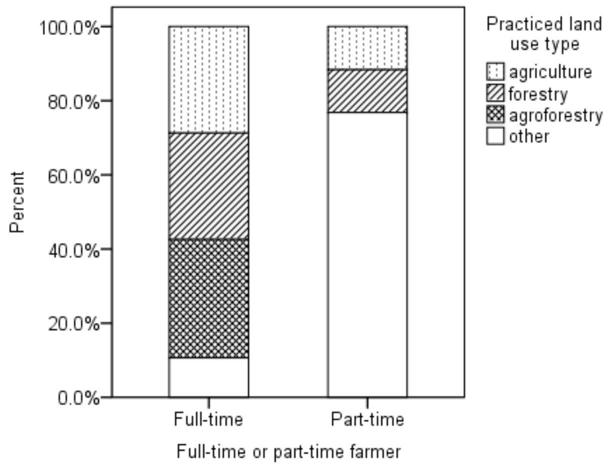

Fig. 34: Percentage of households with different practiced land use type according to farmer type of the head of household

5.5 Energy sources and use of fuelwood

When surveying about the main source of energy for the household in the local area, 237 responses were received from the 175 interviewees. The majority of households regarded the fuelwood as their main energy source (68.8%) (Table 23). Meanwhile, about 60% of household chose the fuelwood as the only energy source (not displayed here). Beside fuelwood, the other energy sources, such as biogas, coal gas, were the main resources for 16.5% of households.

Table 23: Energy source of households and percentage of households using different energy sources

Energy source	Responses		Percent of cases (%)
	N	Percent (%)	
Fuelwood	163	68.8	93.1
Electricity	22	9.3	12.6
Coal	13	5.5	7.4
Other	39	16.5	22.3
Total	237	100.0	135.4

Responses percent was calculated by number of responses in each class divided by total responses (N=237); percent of cases was calculated by number of responses in each class divided by total cases (n=175)

The households that do not use fuelwood at all accounted for 6.9% of respondents. These households have stopped using fuelwood 1-4 years ago, either because of the appearance of a new energy resource (41.7%), no time for cutting (25.0%), high cost of buying fuelwood (8.3%), or attempt to save time (25.0%).

For the households that considered fuelwood as the main energy source, the majority of them obtain the fuelwood from their own woodland (63.2%) (Table 24). Others got the fuelwood from the collective forest (20.7%), or by purchase (15.5%). Cooking was the main purpose for using fuelwood (88.0%) (Table 25). Only 7.7% of households used fuelwood for heating and 3.8% of households for mushroom business.

The average amount of fuelwood consumption was 1417.8±55 kg per year per household, ranging from 250 to 5000 kg (Table 26). If we divided the consumption by the household size, the consumption of fuelwood per capita was 350.4±14 kg per year, varying between 56 and 1000 kg. Most households (70.1%) consumed around 1000-1500 kg fuelwood and only 3.8% of household consumed more than 2500 kg fuelwood each year (Table 27).

Table 24: Different ways to obtain fuelwood and percentage of households in different ways

From where obtain the fuelwood	Responses		Percent of cases (%)
	N	Percent (%)	
Collective-owned forest	36	20.7	22.1
Farmers' own woodland	110	63.2	67.5
Purchase	27	15.5	16.6
Other	1	0.6	0.6
Total	174	100.0	106.7

Responses percent was calculated by number of responses in each class divided by total responses (N=174); percent of cases was calculated by number of responses in each class divided by total cases (n=163)

Table 25: The main purpose for using fuelwood and percentage of households in different purposes

Main purpose for using the fuelwood	Responses		Percent of cases (%)
	N	Percent (%)	
Heating	14	7.7	8.6
Cooking	161	88.0	98.8
Mushroom business	7	3.8	4.3
Other	1	0.5	0.6
Total	183	100.0	112.3

Responses percent was calculated by number of responses in each class divided by total responses (N=183); percent of cases was calculated by number of responses in each class divided by total cases (n=163)

Table 26: Amount of fuelwood consumption

Variable	Unit	Mean	S.E.	Min.	Max.	Range	S.D.
Amount of fuelwood consumption (kg.year-1)	household	1417.8	55.17	250	5000	4750	691.29
	person	350.4	13.7	56	1000	944	171.2

Table 27: Percentage of households in different fuelwood consumption classes

Variable	Unit	Classification	Frequency	Percent (%)
Amount of fuelwood consumption	household	<1000	15	9.6
		1000-1500	110	70.1
		1501-2000	18	11.5
		2001-2500	8	5.1
		>2500	6	3.8
		Total	157	100.0

With respect to the species and size of fuelwood, the majority of households do not have specific demand (85.3% of household had no preference on species and 95.1% of households had no preference on the size). For 14.7% of households who selected a specific size, the small trees, trees with crooked trunk and low vitality or tree branches are the most choice for them (95.8%).

5.6 Household forests

We found that 79.4% of households had their own forestland in the local region, significantly higher than the number of who don't (p<0.001) (Table 28, Table 29). The area of household forests varied considerably, ranging from 0.01 to 1.33 ha. Approximately half of the households surveyed (51.9%) had forest lands of than 0.1 ha (Fig. 35). A very small part (7.5% of household) had the forest land larger than 0.5 ha. The household who considered the quality of their forest was high and medium, accounted for 36.0% and 36.7%, respectively and the rest of household (27.3%) thought the forest quality was low (Table 28). No significant difference in percentage of farmers with different evaluation on the quality of their forests was found (Table 29). With respect to the management on forestland, most of households (94.2%) did not get any advice from the local authority (Table 28).

Table 28: Description of variables of household forests

Variables	Category	Frequency	Percent (%)
Households have own forestland or not	Yes	139	79.4
	No	36	20.6
	Total	175	100.0
Evaluation on quality of own forest	High	50	36.0
	Middle	51	36.7
	Low	38	27.3
	Total	139	100.0
Get the advice on management or not	Yes	8	5.8
	No	131	94.2

	Total	139	100.0

Table 29: Results of frequency test of categories of variables of household forests

Variables	Test method	*p*
Households have own forest land or not	One-sample Binomial test	0.000
Evaluation on quality of own forest	One-sample Chi-square test	0.323
Get the advice or not	One-sample Binomial test	0.000

The significance level is 0.05. We assumed that the proportion of categories of variable is equal. If the *p* value is equal to or less than 0.05, then we reject the assumption.

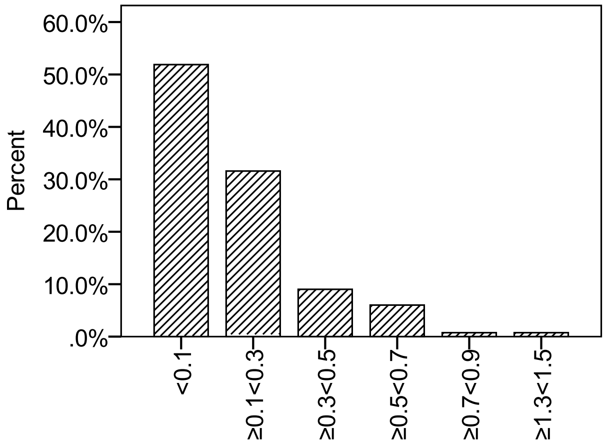

Fig. 35: Percentage of household in different forestland area classes

5.7 Farmers' view on the current forest

Farmers' view on the current forest was classified to four categories: good (29.7%), moderate (44.0%), bad (21.1%), and unknown (5.1%) (Table 30). It was the opinion of the farmers that decrease on cutting (36.5%) and good growth (32.7%) were the main reasons to improve the status of the forest. However, 21.1% of people considered that the poor growth (18.9%), overcutting (18.9%), and bad site condition (18.9%) resulted in a bad situation. The percentage of people who gave a moderate evaluation on forest status was significantly greater than other evaluation (p<0.001) (Table 31). We also found that 64.6% of people thought that the coppice stands need to be improved compared to the 19.4% of people, who see no need for improvement, and 16% people with no idea (Table 30). However, about a quarter of the interviewees (26.6%) didn't know how to improve it. Paying more attention on the coppice management (34.5%) and no cutting or appropriate cutting (11.5%) became the main choices for the local farmer to improve the stands.

Table 30: Description of variables of farmers' view on current forest

Variables	Category	Frequency	Percent (%)
Evaluation on forest status	Good	52	29.7
	Moderate	77	44.0
	Bad	37	21.1
	Unknown	9	5.1
	Total	175	100.0
A need for improvement on coppice stands or not	No	34	19.4
	Unknown	28	16.0
	Yes	113	64.6
	Total	175	100.0

Table 31: Results of frequency test of categories of variables of farmers' view on current forest

Variables	Test method	*p*
Evaluation on the forest status	One-sample Chi-square test	0.000
A need for improvement on coppice stands or not	One-sample Chi-square test	0.000

The significance level is 0.05. We assumed that the proportion of categories of variable is equal. If the *p* value is equal to or less than 0.05, then we reject the assumption.

5.8 Communication between households and local forest authority

5.8.1 Present situation of communication

The percentage of households who feel a need for communication with the local forest authority was not significantly different (52.6%) from those who did not (47.4%). (Table 32, Table 33). Meanwhile, 42.9% of people, which accounted the largest part, considered that the communication which had happened before was bad. The people who thought the communication would get an excellent and good effect accounted 25.7% and 24.0%, respectively.

The majority of households (61.1%) had no idea on how to improve the communication with the local forest authorities (Table 34). The proportion of people who suggested that the local forest authorities should play an important role on improving the communication accounted 37.7%. Suggestions included: the local forest authorities should come to the village more often and communicate with farmers (11.4%), make an appropriate policy (6.3%), provide technique guidance (5.7%), and help farmers resolve the difficulties and problems (4.6%). In addition, a few people (1.1%) advised from the farmers' side, e.g., the farmers should give suggestions to local authorities and a good leader in village, to improve the communication.

Concerning the quality of the advice of local forest authority, nearly half of the people (48.0%) felt that the advice was good, while 11.4% of people thought the advice was of no help to them

(Table 32). Meanwhile, 27.4% of households had no idea about the quality of the advice. The percentage of households with different opinions on the quality of the advice was significantly different (p<0.001) (Table 33). Most farmers would accept advice from the local forest authority always (66.9%), remarkably higher than the people who not always accept (10.3%) and never accept (10.3%) (Table 32, Table 33).

Table 32: Description of variables of communication between households and local forest authority

Variables	Category	Frequency	Percent (%)
A need for communication or not	No	83	47.4
	Yes	92	52.6
	Total	175	100.0
Assessment on the communication	Bad	75	42.9
	Excellent	45	25.7
	Good	42	24.0
	Unknown	13	7.4
	Total	175	100.0
Evaluation on the quality of advice	High	84	48.0
	Low	20	11.4
	Middle	23	13.1
	Unknown	48	27.4
	Total	175	100
Acceptance degree	No	18	10.3
	Not always	18	10.3
	Unknown	22	12.6
	Yes	117	66.9
	Total	175	100.0

Table 33: Results of frequency test of categories of variables of communications

Variables	Test method	p
A need for communication or not	One-sample Binomial test	0.545
Assessment on the communication	One-sample Chi-square test	0.000
Evaluation on the quality of advice	One-sample Chi-square test	0.000
Acceptance degree of advice	One-sample Chi-square test	0.000

The significance level is 0.05. We assumed that the proportion of categories of variable is equal. If the p value is equal to or less than 0.05, then we reject the assumption.

Table 34: Opinions to improve the communications between households and local forest authority and the percentage of interviewees with different opinions (case number=175)

What could be made to improve the communications between the households and local forest authority?	Items	Percent (%)	Total
Have no idea		61.1	61.1
The local forest authority should…..	Come to the village more often and communicate with farmer	11.4	
	Help farmers to resolve the problems and difficulties	4.6	
	Do more practical things	2.9	
	Listen more opinions	1.7	
	Provide suggestions and information	3.4	
	Provide technique guidance	5.7	
	Make appropriate policy	6.3	
	Execute the policy correctly	1.7	37.7
The farmers should …..	Give suggestions to authorities	0.6	
	Have a good village leader	0.6	1.1
			100.0

5.8.2 Relationships among variables of communication

Table 35 shows that whether a communication between the farmers and authorities is needed was significantly related to the result of the communication ($p<0.001$), the quality of advice ($p<0.05$), and the acceptance degree of advice ($p<0.01$). Communication result had a high correlation with requirement of communication (*Cramer´s V*=0.681), while a weak relationship with the quality of advice and acceptance degree (correlation coefficient was 0.247 and 0.248, respectively). There was more excellent and good communication happened among the people who wanted to communication than these who didn't (Fig. 36). On the contrary, among people who did not want to communicate, most of them considered that the communication was bad or had no opinion on communication.

Additionally, we found that farmers' assessment on the communication results had a poor relationship with the quality of advice (*Cramer´s V*=0.211, $p<0.01$) and the acceptance of new advice (*Cramer´s V*=0.201, $p<0.05$).

Table 35: Results of correlation test among variables of communication

Correlation coefficient (Cramer´s V)	A need for communication	Assessment on communication result	Evaluation on quality of advice
A need for communication	1.000		
Assessment on communication result	0.681***	1.000	
Evaluation on quality of advice	0.247*	0.211**	1.000
Acceptance of new advice	0.278**	0.201*	-

(* significance at $p<0.05$, ** significance at $p<0.01$, *** significance at $p<0.001$). Correlation between acceptance degree and evaluation on the quality of advice can not be tested.

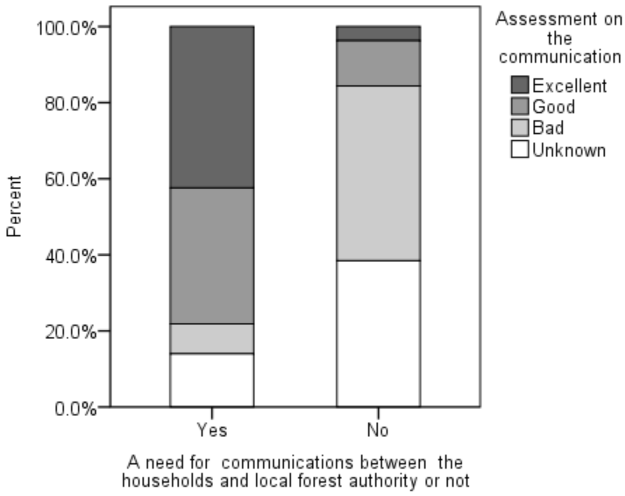

Fig. 36: Percentage of people with different assessments on communication according to whether a communication is needed by them

5.9 Relationships between socio-economic parameters and use of fuelwood

The significance test on the correlation between the socio-economic parameters and usage of fuelwood is presented in Table 36. It showed that the main energy source of household was weakly but significantly related to the number of residents of a village (*Cramer´s V*=0.201, $p<0.01$). The way to obtain the fuelwood also significantly related to the number of residents of a village (*Cramer´s V*=0.343, $p<0.001$). With the increase of village size, the percentage of household who obtained the fuelwood from own farm considerably decreased (Fig. 37). In a small village (700-1200 inhabitants), 61.5% of households obtained the fuelwood from their own woodland compared to 3.7% of households in a bigger village (>1700 inhabitants). Since about half of households (51.2%), live in village with >1700 inhabitants, they need other way to obtain the fuelwood. The main purpose of fuelwood had a very weak correlation with the house size (*Cramer´s V*=0.18, $p< 0.05$).

The amount of fuelwood that is consumed per capita was affected by economic situation, household size, and number of children (Table 37). With the decrease of economic situation, the amount of fuelwood consumption per capita increased. The households in poverty-stricken consumed the most fuelwood (435 kg fuelwood per person per year) (Fig. 38). On the other hand, with the increase of the number of household, per capita fuelwood consumption decreased. For a household with 1-2 members, the consumption of fuelwood reached to an average of 607 kg per year, which was considerably higher than these consumed by a bigger household (3-4 or 5-6 members) (Fig. 38). The other socio-economic factors, such as location of village, size of village, educational level of the head of household, and type of farmer (full or part time), had no correlation to the consumption of fuelwood.

Table 36: Results of correlation test between socio-economic parameters and energy sources, usage of fuelwood

Correlation Coefficient (*Cramer´s V*)	Main energy source	From where obtain the fuelwood	Main purpose for using the fuelwood
Village location	0.159	0.182	0.152
Village size	0.201**	0.343***	0.095
House size	0.169	0.131	0.180*
Economic situation	0.170	0.159	0.068
Educational level	0.119	0.127	0.138
Household size	0.106	0.104	0.116
Children number	0.077	0.116	0.095
Full or part time farmer	0.170	0.103	0.121

(* significance at p<0.05, ** significance at p<0.01, *** significance at p<0.001)

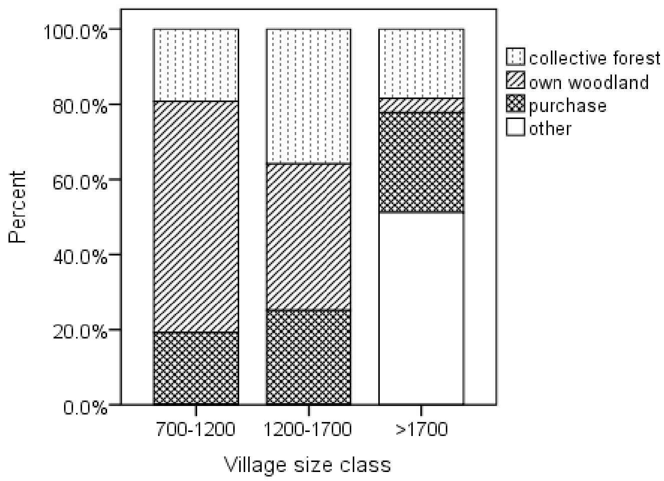

Fig. 37: Percentage of households that get the fuelwood from different way in different village size classes

Table 37: Results of one-way analysis of variance (ANOVA) for socio-economic parameters versus amount of fuelwood consumption

Dependant variable	Independent variable	Source of variance	d.f.	F	*p*
Amount of fuelwood consumed per capita per year (kg)	Village location	Between groups	2	1.150	ns
		Within groups	154		
	Village size	Between groups	2	1.391	ns
		Within groups	154		
	House size	Between groups	3	1.054	ns
		Within groups	153		
	Economic situation	Between groups	3	3.785	*
		Within groups	153		
	Educational level	Between groups	3	0.526	ns
		Within groups	153		
	Household size	Between groups	3	12.158	***
		Within groups	153		
	Children number	Between groups	2	8.958	***
		Within groups	153		
	Full or part time farmer	Between groups	1	0.010	ns
		Within groups	155		

(Significant level: ns: non-significant, * significance at p<0.05, ** significance at p<0.01, *** significance at p<0.001)

Table 38: Results of correlation test between socio-economic parameters and efficiency of communication

Correlation Coefficient (*Cramer´s V*)	A need for communication or not	Communication result	Quality of advice	Acceptance of new advice
Village location	0.187*	0.103	0.187	0.150
Village size	0.168	0.100	0.211*	0.153
House size	0.087	0.091	0.172*	0.163
Gender	0.007	0.060	0.050	0.161
Age	0.199	0.167	0.142	0.187
Economic situation	0.259**	0.136	0.169*	0.106

(* significance at p<0.05, ** significance at p<0.01, *** significance at p<0.001)

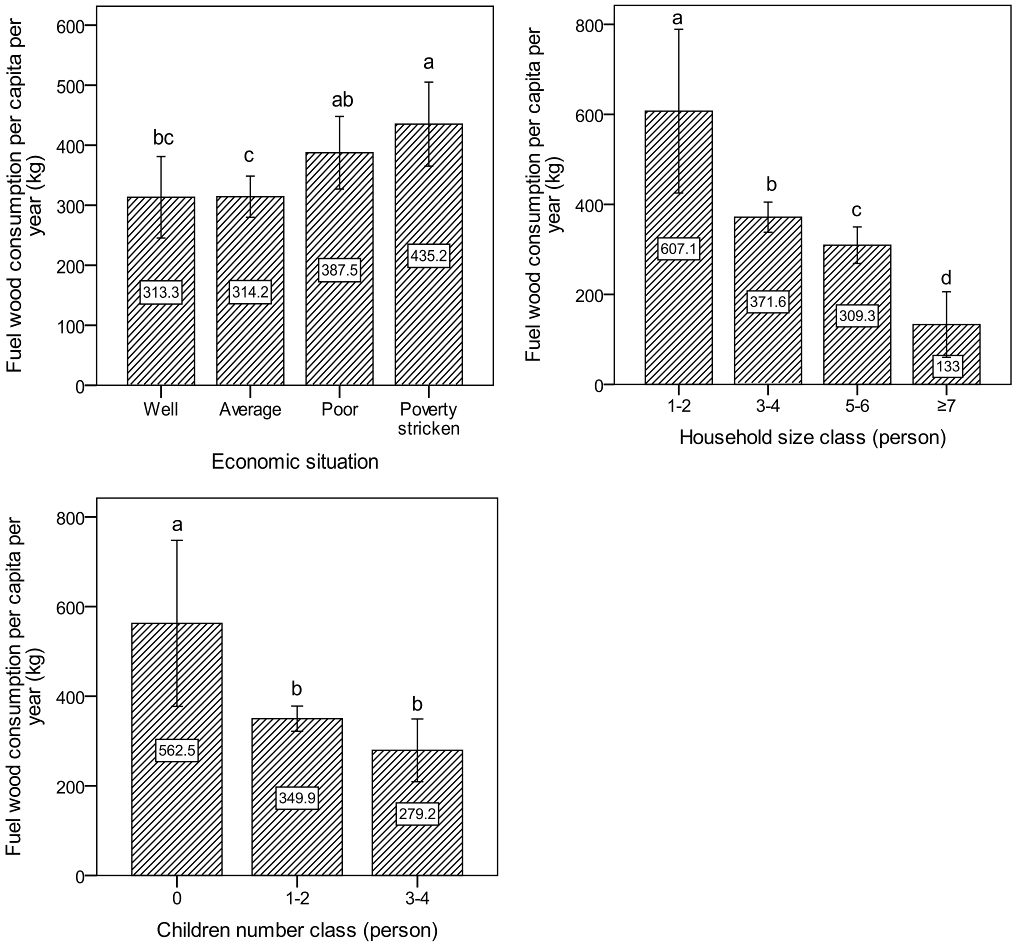

Fig. 38: Fuelwood consumption per capita per year in different economic situation, household size and children number classes (person). The same letters indicate no significant difference (LSD test, p=0.05)

5.10 Relationships between socio-economic parameters and efficiency of communication

A need for communication between the local people and forest authority was correlated to village location (*Cramer´s V*=0.187, p<0.05) and economic situation of household (*Cramer´s V*=0.259, p<0.01). There were no relationships between the personal socio-economic conditions and the quality of communication result. The assessment on the quality of advice provided by forest authority, was weakly correlated to village size (*Cramer´s V*=0.21, p<0.05) and house size (*Cramer´s V*=0.172, p<0.05). Besides, the economic situation was also correlated to the assessment on the advice quality (*Cramer´s V*=0.169, p<0.05) (Table 38). No correlations were found between the socio-economic parameters and the acceptance of new advices.

6 Discussion

6.1 Discussion of the results of coppice assessment

6.1.1 Assessment of coppice stands

Oak forest is the largest part in China's forest resources. It has provided a wide variety of uses to human beings in terms of wood product, energy resource, and water and soil conservation. Due to the intensive cutting and ignorance on silviculture, many oak forests become the coppice stands. Many scholars considered that these oak coppices are degraded and have a low productivity due to frequently coppicing (Wu, 1998; Zhang *et al.*, 2008; Zhou *et al.*, 2010).

Oak coppice stands in Shangnan County, Southern Shaanxi Province, are mainly composed of *Quercus variabilis* stands (accounted 83% of total coppice stands). The remaining 17% of oak stands are dominated by *Quercus acutissima.* A total of 32 tree species were recorded in *Q. variabilis* stands, indicating a rich species composition. Coppicing of trees led to a high stand density, especially for younger stands. For instance, 9175 stems per hectare were recorded in a 10-year-old stand. The largest stocking volume was 152.7 m^3 ha^{-1} in a stand aged 25 years and the smallest stocking volume was 47.5 m^3 ha^{-1} in an 11-year-old stand. Our results on stocking volume of *Q. variabilis* coppice stands in the study area were higher compared to other stands, for instance, Qu *et al.* (1990) reported that the stocking volume of a 10-year-old *Q. variabilis* coppice forest in southern Shaanxi was only 15.0-22.5 m^3 ha^{-1}; Zhang (1986) demonstrated the average stocking volume of young *Q. variabilis* coppice stands in the lowlands of the Qinling region was only 30 m^3 ha^{-1}.

Regeneration potential refers to the ability of trees to contribute to stand regeneration through sexual or vegetative reproduction (McShea and Healy, 2002). Many researchers have reported that the natural regeneration of *Q. variabilis* stands is weak. Zhang *et al.* (2008) reported that *Q. variabilis* populations located in lower altitudes of the northern Bashan Mountains had insufficient regeneration because the number of seedlings was low and most of the regeneration developed only from sprouting. At higher elevations (600-1200m) a high density of *Q. variabilis* regeneration (8600 individuals ha^{-1}) was observed in Qinling-Bashan area (Lu, 2002). Zhang (2009b) investigated the potential of *Q. variabilis* regeneration in Baotianman Nature Reserve and found that it was hard to conduct natural regeneration in this area because there was little disturbance happened in reserve region. The dense canopy resulted in a low light condition in the understory which restricted the growth of seedlings. In this study 17 different woody species were found in the understory of 25 sampled *Q. variabilis* stands. Many of these species are of ecological and economic importance, for example, *Q. variabilis*, *Q. dentata*, *Dalbergia hupeana*, *Pistacia chinensis*, and *Rhus chinensis*. Regeneration of tree species in *Q. variabilis* stands is abundant with average density of the regeneration 18,875±3,338 individuals ha^{-1}. These stands are located closed to the villages and frequently disturbed by farmers for collecting the fuelwood. An open gap which was produced randomly by cutting some trees in stands would promote the regeneration of trees. In the 5 sampled *Q. acutissima* stands, 9 woody species were observed in the stand regeneration. The average density of the natural regeneration reached up to 25,500±6,618 individuals ha^{-1}. Therefore, the regeneration in both *Q. variabilis* stands and *Q. acutissima* stands is sufficient in terms of species and number.

The ground vegetation in the investigated coppice stands was very scarce, especially in *Q. variabilis* stands, where the whole coverage of ground vegetation was 10.1±1.3% on the average, and the coverage of grass, herb, and shrub was all less than 3%. The coverage of ground vegetation in the study area is much less than other investigated *Q. variabilis* stands. For example, Zhang and Lu (2002) recorded the shrub cover was 40-50% and the grass cover was 10-20% in the understory of *Q. variabilis* stands that are distributed in Qinling-Bashan area within an elevation range of 400-1100 m. Cheng and Xiao (1998) documented that the shrub and grass coverage of the *Q. variabilis* community in the Baotianman region reached more than 70% and 20%, respectively. The investigated coppice stands of this study had a very dense overstory and were subjected to frequent disturbance in the understory by people for the purpose of collecting branches or weak trees. In this case, it is difficult for grass, herb, and shrub exist in the understory.

6.1.2 Assessment of the effects of forest stand use on forest stand parameters, regeneration and understory vegetation of coppice stands

Stand parameters

The basic feature of a coppiced wood is that it is cut periodically and the trees are allowed to regrow from the cut stumps, which are termed *stools* (Fuller and Warren, 1993). Many advantages of coppice forests, such as simplicity of management, ease and rapidity of natural regeneration, fast growth of new stands, shorter rotation and more frequent income than high forest, have led to the successful development of coppice systems (Ciancio *et al.*, 2006). The regrowth from the cut stools can be remarkably fast. From the first coppice the rate of shoot growth can be expected to be around 10-20% faster than that of original trees (Department of Primary Industries, 2000).

Large areas of oak coppice forests in the study area have formed since 1980s (Qu *et al.*, 1990). Due to the importance of oak trees in all aspects of people's lives and the strong sprouting ability, these stands have been coppiced one or more times. When a stand is coppiced frequently, there can be problems with obtaining good regrowth, particularly if stands have been neglected for some while (Fuller and Warren, 1993). Strong (1989) also documented that average shoot height and diameter decreased with each successive cycle. Based on this knowledge and the difference in stand mean diameter between stands with same age, we classified all investigated stands into two types based on coppicing frequency: 1) stands with moderate use and 2) stands with intensive use. The variation of most stand parameters could be explained by the forest stand use. We also found that none of the site factors had an influence on the forest stand structure.

Stands classified as intensively used stands have a higher stand density (stems per hectare) and a lower quadratic mean diameter (d_q) and mean height (h_q). The density of the main species in *Q. variabilis* stands was not affected by the forest stand use, while the d_q and h_q of the main species in moderately used stands were higher than in intensively used stands. Therefore, the number of accompanied species in *Q. variabilis* stands is increased by intensive use. We found that the stand basal area and stocking volume of the stand as well as the basal area and volume of the main species in moderately used stands were always higher than these in intensively used *Q. variabilis* stands. The difference in basal area between two forest stand use types became greater on the older stands than the younger ones. The vigour of the coppice from subsequent crops tends to decline. For example, Harrington and DeBell (1984) found that the greatest short-rotation yields of black cottonwood and red alder were usually obtained at the first or second coppice harvest for all treatments (irrigation or application of pulp-sludge), and declined over time. In this study, coppice stands with intensive use are characterised by relatively lower growth. These intensively used stands could be cut many times and the repeated coppice decreased the growth of sprouting shoots.

However, it is surprising that the stocking volume of stands could reach up to 120 m^3 ha^{-1} (80 m^3 ha^{-1} of *Q. variabilis*) on average at the age of 25 years old even after frequent cutting. The stocking volume of *Q. variabilis* stands in moderately used sites was around 170 m^3 ha^{-1} by age 25. All these findings indicate that the oak coppice stands in Shangnan area still have high growth potential. Although no difference in basal area and stocking volume between the two forest stand use types on *Q. acuttissima* stands was found, the d_q and h_q of all species or the d_q and h_q of the main species in moderately used stands was always greater than in intensively used stands. The high density of intensively used *Q. acuttissima* stands may contribute to the improvement of the stand basal area and stocking volume. The stocking volume of *Q. acutissima* stands could also reach up to 170 m^3 ha^{-1} by age 25, indicating a high potential of stand growth as well.

The tree quality refers to the trunk form, free of fork or forked and the form of crown. It is an important parameter that should be considered in forest management. For *Q. variabilis* stands, the intensive use lowered the tree quality. For stands aged > 15 years old, on the average, only 3.6% of trees in intensively used stands had a high quality (straight trunk, free of fork, well formed crown) compared to 19.7% of trees in moderate use. More than half of the trees in intensively used stands had a poor quality and the ratio of trees with poor quality was higher in younger stands. Therefore, if the stands are used for producing timber, practices should be applied to improve the tree quality.

The dominant trees are represented by the 100 thickest stems per hectare; it represents the most stable part of the stand and should be less influenced by treatment (Slodicak and Novak, 2006). The dominant height (average height of dominant trees) is also considered as an indicator of site quality (Philip, 1994). The forest stand use had no effect on the growth of dominant trees. Our results showed that the mean diameter (d_{100}), dominant height (h_{100}), basal area, and volume of dominant trees were the same between the forest stand use types. The difference on dominant trees only appeared between *Q. variabilis* and *Q. acutissima* stands. At the same age, the dominant trees in *Q. acutissima* stands always had a greater d_{100}, h_{100}, basal area and volume than that in *Q. variabilis* stands. From the aspect of ecological characteristics, *Q. acutissima* demands on water and heat are higher than *Q. variabilis* (Zhang, 1986) and it is inferior to *Q. variabilis* in the tolerance to the dry and poor soil (Li *et al.*, 1989). A higher value on dominant height indicated a better site quality of *Q. acutissima* stands.

The coppice stands are composed of trees with single stem and trees with multiple stem together. The proportion of single-stem trees of all species and of the main species in number was not affected by forest stand use but it was positively correlated with stand age. However, neither forest stand use nor stand age had a correlation with the proportion of single-stem trees in terms of basal area and volume.

Both the single-stem trees and the multiple-stem trees of all species in *Q. variabilis* stands with moderate use had higher values on the d_q, h_q, basal area, and volume in comparison with these under intensive use. However, for the single-stem trees of all species, all these parameters showed an increase with increasing stand age in two types of stand use; for the multiple-stem trees of all species, only the d_q and h_q in moderately used stand had an increase while the d_q and h_q in intensively used stand remained constant. Meanwhile, due to the decrease of number of stems, the basal area and volume of multiple-stem trees of all species, even the basal area and volume of multiple-stem trees of the main species had no increase with stand development irrespective of stand use types. The competition between shoots on the same stump and competition between stumps for environmental resource resulted in a different radial growth among shoots (Cartan-son *et al.*, 1992). For multiple-stem trees in investigated stands, especially these under intensive use, the strong competition among stems (higher stem density) and repeated coppicing decreased the growth of individual stem. Cao and Peters (1998) also found that the stem growth declined with the increase of stem size in the multi-stemmed beech (*Fagus engleriana* Seem.*)* but not in single-stemmed *Fagus hayatae* Palibin ex Hayata. Therefore, the multiple-stem trees should be cut or the number of stems per tree should be reduced, since there is no increase on the d_q, h_q, basal area, and volume.

Only one intensively used *Q. acutissima* stand was found in this investigation. Although the d_q and h_q of single-stem trees of all species and of the main species in the intensively used stand was lower than in the moderately used stands, no difference in basal area and volume of all species or of the main species were found between the stand use intensity. This is because the high density of single-stem trees in intensively used stands contributed to the increase of basal area and volume. The same pattern was obtained on the multiple-stem trees in *Q. acutissima* stands. Unfortunately, the number of *Q. acutissima* stands was limited in this survey. Further studies on *Q. acutissima* stands should increase the number of plots.

In our study, we found a greater d_q and h_q of the main species in *Q. acutissima* stands (*Q. acutissima*) in comparison with that of the main species in *Q. variablis* stands (*Q. variablis*) in moderately used stands at a given age. *Q. acutissima* has the same approximate requirements on the environment as *Q. variabilis.* However, it prefers to grow in areas with deep soil and full light. Xie (2002) found that the photosynthetic capacity of *Q. acutissima* was higher than that of *Q. variabilis* in same light condition. The greater growth of *Q. acutissima* can partly be attributed to its biological characteristics. As well, the lower stand density reduces the competition for resources. Moreover, we also found that the greater growth of *Q. acutissima* only occurred on the single-stem trees. But, for the multiple-stem trees, no differences in the d_q and h_q between two species were found. This finding suggests that the further study on the tree growth among coppiced trees should consider the form of coppicing, i.e., the number of shoots per stump.

Standard analysis incorporates the calculation of slenderness to characterise the stability of the trees. Slenderness values usually fall within the range 50-150; slenderness values below 80 are generally an indicator of adequate individual tree stability (Pretzsch, 2010). The results showed that the value of slenderness of dominant trees was the lowest (86.6 on average), while the slenderness of all stems or of the all single stem fell into the range 110-120 and they were not affected by the forest stand use.

The crown structure is determined both by the biological characteristics of a species and the growing conditions. Study on the crown structure provides lots of critical information, such as tree growth (Maguire *et al.*, 1998), timber production (Ford, 1985) and forest productivity (Stenberg *et al.*, 1994). The stand density also has an important influence on the development of crown size (Jack and Long, 1991; Zhang *et al.*, 2009b). Our results showed that the average crown width and average crown length of single-stem trees of all species and of the main species in both *Q. variabilis* and *Q. acutissima* stands displayed a linear increase along with the stand age. The forest stand use had no effect on the average crown width of single-stem trees of all species in *Q. variabilis* stands, but it did affect the average crown length. The intensive use increased the density of stands and the high density limits the light condition of low branches and causes the death of these branches (Zhang *et al.*, 2009b). But, if we focus on the average crown width and average crown length of the main species in *Q. variabilis* stands, no difference was found between the forest stand use types. Therefore, the lower average crown length in intensively used stands is induced mainly by the small crown lengths of the accompanied species. On the other hand, althouth no difference on the average crown width as well as on the average crown length of the single-stem of the main species between two forest stand use types was found, the greater d_q and h_q of single-stem trees in moderaterly used stands implied a greater growth. The single-stem trees of all species and single-stem trees of the main species in moderately used *Q. acutissima* stands always had a greater crown size than these in *Q. variabilis* stands. The greater crown size properly resulted in a greater d_q of single-stem trees in *Q. acutissima* stands than that in *Q. variabilis* stands.

The results showed that the average crown ratio of single-stem trees of all stands was 36.2% and remained constant with increasing age. We found no difference in average crown ratio between different forest stand use types. However, the average crown ratio of single-stem trees of the main species in moderately used *Q. acutissima* stands was almost 8% higher than single-stem trees of the main species in *Q. variabilis* stands. This is because the low density of moderately used *Q. acutissima* stands provides more space to develop the tree crown.

The ratio of Crd-DBH is applied in silviculture to regulate the stand density at a given diameter. Generally, the ratio of Crd-DBH decreased with the increase of tree diameter, and it is different among tree species within the same site condition (Dai *et al.*, 2009). For *Q. variabilis* stands, a higher average ratio of Crd-DBH of all species and of the main species in intensively used stands was found. This result implies that in intensively used stands, at a given diameter, the average crown width of trees is greater than that in moderately used stands. Therefore, the stand density should be decreased for intensively used stands to get the same diameter as the moderately used stands. The ratio of Crd-Crl represents the relationship between crown width and its length. In our study, the intensively used stand decreased the average crown length while it had no influence on the crown width; as a result, the ratio of Crd-Crl in intensively used stands was around 0.2 higher than that in moderately used stands. But, the ratio of Crd-Crl of the main species did not influence by the stand use type.

Regeneration

Regeneration ability is influenced by many factors, such as tree species, site position, soil properties, overstory density, and human activity. Many investigations have documented that the number of oak seedlings and saplings significantly depend on stand density (Gracia and Retana, 2004) and the growth of seedlings is affected by the canopy cover (Dobrowolska, 2008). Reducing overstory density is a commonly recommended method of increasing the regeneration potential of oak (*Quercus*) forests (Larsen *et al.*, 1997). Our results showed that although the intensive use led to a higher number of standing tree species and a greater stand density, the density of regeneration, species number and diversity did not differ between the stands with moderate use and the stands under intensive use. Meanwhile, no correlation between the numbers of seedlings with stand density was found for *Q. variabilis* stands or for *Q. acutissima* stands. On the other hand, we found the intensive use of stands promoted the growth of the tree seedlings. The average height and average root-collar diameter of woody tree seedlings in intensively used stands were always about 14 cm and 0.12 cm, respectively, higher than in moderately used stands. The intensive use improves the transmission of light to the understory and thus helps the growth of the seedlings.

The density of the main species in the regeneration was influenced by forest stand use. Compared to the moderately used stands, the seedlings of the main species in intensively used stands were less (only 2766 individuals ha^{-1} on average were recorded). This means that there is more chance for other tree species to establish and survive in intensively used stands. Nevertheless, the average height and average root-collar diameter of the main species was not affected by forest stand use. This finding also suggests that attention should be paid on the regeneration of oak seedlings, especially for stands with intensive use, to maintain the sustainable development of oak stands.

We found that in intensively used stands, the density of of *D. hupeana* seedlings is very high (the average density reached 11,875 individuals ha^{-1}). The average percentage of *D. hupeana* accounted for half of all woody regeneration (50.8%), although the variation was very large, ranging from 3.4% to 100.0%. Moreover, the intensive use stimulated the height of *D. hupeana* seedlings. The majority of *D. hupeana* trees was suppressed in oak coppice stands and have a moderate or weak vitality and a small size (basal area <0.1 m^2 ha^{-1}, average diameter <1.7 cm and mean height <3.1 m). *D. hupeana* is one species that occurs in the subtropical zone or in the transitional zone between subtropical and warm temperates, and mainly grows in forest or among shrubs in mountain areas. Zhang and Lu (2002) and Li *et al.*, (2005) also recorded that *D. hupeana* distributed in *Q. variabilis* stands as an accompanied species in small size and formed the *Q. variabilis-D. hupeana-Carex lanceolata* community.

Usually, the number and composition of seedlings vary with stand development. However, no relationships between the seedling parameters (number, average height, and average root-collar-diameter) and stand age were found in this study. This is because the age of investigated stands ranged from 7 to 27 years old; within this period it is likely that the stands are in same development stage. Another possibility is that the irregular human disturbance on stands also affects the number of regeneration.

Understory vegetation

Many studies have examined the impacts of various factors on understory vegetation. Human disturbances, management practices or canopy closure are well known to be related to the understory vegetation. In our study, although the intensive use on stands promoted the number of overstory trees, it had no influence on the coverage and average height of ground vegetation. These stands are closed to the village and frequently disturbed by farmers for collecting fuelwood. Frequent disturbances may cause the decrease of soil organic matter, soil microbes and soil stable aggregates (Zhou and Shangguan, 2005). As the result, low vegetation cover was recorded in the understory, and no differences in coverage were found between forest stand use types. However, compared to *Q. acutissima* stands, ground vegetation was less in *Q. variabilis* stands. A denser, more productive overstory yields a less diverse or less productive understory because of limited resources, particularly understory light availability (Oliver and Larson, 1996). At a given stand age, *Q. acutissima* stands with moderate use always had a lower stand density than *Q. variabilis* stands. The lower number of standing tree produces a better light condition in the understory, which contributes to the growth of the understory vegetation. The coverage and average height of the vegetation increased gradually with stand age. This is explained by the reduction of stand density as well as the reduction of disturbances (farmers prefer to collect fuel wood in young stands).

6.1.3 Assessment of growth parameters of coppice stands on tree level

Relationships between growth parameters

Crown classification, a subjective assessment grouping trees into dominant, co-dominant, intermediate and suppressed class, is used as a common way to express the competitive position of a tree in a stand (Marquis, 1991). The crown classes not only reflect the tree's height relative to its competing neighbours in the crown canopy but also indicate the proportion of the tree's crown that receives the sunlight for tree growth (Marquis, 1991). Generally, trees in the dominant class intercept the most sunlight from top and along the sides of the upper branches. With the increase of suppression, trees intercept less sunlight.

Resource allocation of the stem is a trade-off between diameter and height growth (Aiba and Kohyama, 1996). The height-DBH relationship is closely related to environmental factors, such as temperature (Wang *et al.*, 2006), light (King, 1996) and water resources (Li *et al.*, 2011). The strong height-DBH relationship of *Q. variabilis* and *Q. acutissima* can be described with a second-degree polynomial equation. In the same crown class, trees with different types of stems (non-coppiced-single stem; coppiced-single stem; coppiced-multiple stem) had a similar height-DBH relationship. This is, the stem type had no effect on resource allocation for height growth or diameter growth. Additionally, no relationship between the slenderness and tree height was found. But, with the decrease of crown class, the average slenderness increased gradually. This is because the trees in lower story had more competition for light than top trees with dominant crown. Under competition, diameter growth is more restricted than height growth (Lanner, 1985).

The relationship between the crown width and diameter as well as the relationship between the crown length and tree height also varied with different crown status. Francis (1986) reported that the crown class significantly influenced the slope or intercept of the linear relationship of Crd-DBH for Green ash, Nuttall oak and Overcup oak. Krajicek *et al.* (1961) found a very strong relationship (R^2=0.98) between DBH and crown width of open-grown white oak (*Quercus alba*), red oaks (*Q. velutina* and *Q. rubra*), and shagbark hickory (*Carya ovata*). The results of our study also support that the trees in the dominant crown class (more free crown) had a stronger correlation between crown width and diameter (R^2=0.64) than trees in other crown classes (none had R^2>0.3). The same effect of crown class on the relationship between the crown length and tree height was found.

Different crown classes determine the percentage of live crown length to total tree height (the crown ratio). Maintaining crown ratio at 40% or greater is considered desirable for sustainable vigorous growth (Harrington *et al.*, 2009). Larger crown ratios are generally associated with healthier, faster growing trees. For trees in dominant crown class, the average crown ratio of coppiced trees was 38% and remained constant with the increase of tree height. However, the crown ratio was positively related to the tree height for non-coppiced trees. For trees in other crown classes, the crown ratio had no relationship with tree height and no difference was found among different types of trees. With the decrease of crown class, the average crown ratio declined to 31% in suppressed class.

The crown class also had an effect on the relationship between the ratio of Crd-DBH and DBH as well as the relationship between the ratio of Crd-H and H. Trees in the dominant crown class always varied with these in other crown classes. This is because trees in the dominant class have a free and open crown that capture plenty of lights used to develop the crown size as well as tree height and diameter simultaneously; for trees in suppressed position, the development of crown is always hindered, because of the lacking of space and light, and allocate resource to height growth to get more light. A relatively small difference in the value of the ratio of Crd-Crl among four crown classes was observed (mean value ranged from 0.8 to 1.0), indicating that the crown shape did not change obviously in different crown classes.

Apart from the difference among stem types on the Crl-H relationship and the Cr%-H relationship in the dominant crown class, three stem types had the same relationships between growth parameters. Crown ratio and crown length reflect the potential of a tree to use the available resources such as increased growing space and therefore are useful indicators of tree vigour, wood quality, stand density, competition and survival potential (Acharya, 2006). Based on our results, for small trees, the coppiced trees had a higher crown length and crown ratio than non-coppiced trees. The increase of crown length is closely related the growth of tree height. Therefore, it seems that the non-coppice trees in dominant class have more growth potential than coppiced one. In addition, our results indicated that the difference in relationships between growth parameters exists among crown classes. Decreasing the number of trees with bad growth in suppressed class could be used to reduce the competition on resources.

Comparisons of growth of individual tree classified by vitality

The crown's vitality had an essential role on the tree growth. A better crown condition is positively correlated to the ability of the tree to accumulate biomass in the main stem (Drobyshev *et al.*, 2007). A relatively high vitality also implies that trees have a great capacity to resist to external stress (such as disease, drought or flooding) (Dobbertin, 2005). In all investigated *Q. variabilis*, more than 80% of all trees were healthy and foliated, indicating a good vitality. *Q. acutissima* trees with vigorous and moderate vitality also accounted 84% of all trees.

Regardless of which vitality class a tree was in, the means of DBH and height decreased with the decrease of crown class, in contrast, the average slenderness increased. The means of crown width, crown length and crown ratio also exhibited a declining trend with the decrease of crown class.

Most of vigorous trees occur in the dominant crown class. These vigorous trees outstrip their neighbours, occupy superior positions in the crown canopy, and normally have the best chance of surviving competition in the future (Florence, 2004). The moderate trees were distributed in all crown classes while most of weak trees had a fully suppressed crown.

In addition, our results also showed that *Q. variabilis* trees with non-coppiced stem showed a greater DBH and height than these with coppiced stem in the same vitality and crown class. Non-coppiced trees are scattered in the coppiced stands with a small number. These trees originated from planting by farmers or regeneration by seedlings. The greater DBH and height of non-coppiced trees also implies that they have a higher competition ability compared to coppiced trees.

6.2 Discussion of the results of socio-economic study

The results of socio-economic study indicate that the economic situation is poor in study area. The households in a poor and poverty stricken economic situation accounted for 40% of the sample. We also found that the economic situation has a slight correlation with the location of village to the city of Shangnan, the educational level and the farmer type (full or part time) of the head of household. The education level of the head of the household is low as well. The illiterate heads of the household accounted for 17.1% of the sample, while almost 30% of the heads of household had only completed the basic education (5-year study in primary school). In our sample, 89.7% of the heads of households are full-time farmers, only 10.3% are part-time farmers. Agriculture is the practiced land use type for most of households, remarkably higher than other practiced land use types, such as forestry and agroforestry. Only 5% of households practice forestry.

Fuelwood plays an important role in the people's daily life in Shangnan County. The majority of households (68.8%) regard fuelwood as their main energy sources. Recently, in order to decrease the demand on fuelwood, local government has encouraged farmers to build biogas digesters. However, because of the lack of materials for producing biogas, many biogas digesters have been abandoned. This attempt to switch away from fuelwood did not resolve the energy resource problem in rural area.

A weak relationship between the village size (the number of residents) and the choice of the main energy source was found. The possible reason is that the forest area per capita in a larger village is less; therefore, the shortage of forest resource forces households to choose other energy sources. We also found that the village size affected the way people obtain fuelwood. With the increase of village size, the percentage of households who obtained the fuel wood from their own forestland considerably decreased.

Hu and Wu (2001) reported that 7,000 households faced a fuelwood shortage problem in Shangnan County. Our results show that there exists a huge demand on fuelwood in the local rural area. The average amount of fuel wood consumption per household was 1417.8±55 kg per year and the average amount of fuelwood consumption per capita was 350.4±13 kg per year. There are 209,400 farmers in Shangnan County, accounting for 88.8% of total population. When the sample is projected to the whole county, it means that around 70.000 tons fuelwood is consumed each year. Ma (1994) reported that the biomass yield of fuelwood forest in Santai and Suining, Sichuan Province was 10-20 tons ha^{-1} $year^{-1}$. Shangnan has a similar climate, topography and tree species as Santai and Suining. According to the statistics, the area of fuelwood forest in Shangnan is 728.8 ha (Ye, 2008). Therefore, the fuelwood yield is only 7-14 million kg per year, which is far less than the demand. Although the farmers always cut branches or trees with low vitality as fuelwood, the shortage of fuelwood still exists.

The amount of fuelwood that is consumed by households was affected by the village location (classified as the distance between villages to county centre) and household size. The further away the villages are, the more fuelwood is consumed by a household. Türker and Kaygusuz (1995) found that, in rural areas of Turkey, there was a statistically positive relationship between the fuel wood consumption and the distance between town centre and village. Usually, the remote village is inconveniently located and economically undeveloped. Therefore, the households in these rural villages rely mainly on fuelwood as the energy resource.

Only 6.9% of households do not use fuelwood at all. These households have stopped the use of fuelwood 1-4 years ago, because of the appearance of the new energy resource, no time for cutting, high cost on buying the fuelwood, or the attempt to save the time. Most of the households had no specific demand on species and size of fuelwood. Usually, they cut young trees, trees with bad quality or branches, irrespective of tree species. Cooking was the main purpose for using fuelwood.

In spite of the high demand for fuelwood, the farmers' own forest resources are not abundant. 79.4% of households had own forestland in the local region, however, nearly half the households (51.9%) had forestland of less than 0.1 ha and only a very small proportion (7.5%) had forestland larger than 0.5 ha. Despite the limited resources the majority of the households (63.2%) obtain the fuelwood from their own woodland (63.2%). Others get fuelwood from the collective forest (20.7%), or by purchase (15.5%). Farmers managed their own forestland by themselves and almost did not get any guidance from the local forest authority. Therefore, developing a reasonable management strategy and education to improve the yield is an alternative approach that could relieve the shortage of fuelwood to some extent.

Our result found that farmers thought the forest have improved recently because of the prohibition of cutting and rapid tree growth. At the same time, 64.6% of the people thought that the coppice forests still need to be improved. The local people have realized that more attention should be paid to stand management. Cai *et al.* (2007) also found by a questionnaire survey that the most important information needed by farmers in Fujian Province, Southern China, are techniques on forest management (71.4%).

The quality of advice determines the farmers' acceptance. However, we found that the proportion of people who thought that the advice proposed by local forest authority is good was less than half (48.0%). This low evaluation was induced by the failure of previous attempts by the forest authority to offer guidance. For example, the local authority encouraged farmers to plant medical plants a few years ago; however, but there was no market for these plants and the farmers did not get any profits. One of the most interesting results is that the majority of the farmers (67% of the total households) would accept an advice from the local forest authority to change traditional land use, providing that it enhanced their economic situation.

Good communication between farmers and the local forest authority is needed before implementing a new policy. Lack of communication between the forest officials and local people creates negative attitudes towards the forest management (Obua *et al.*, 1998). However, in our investigation, we found an insufficient communication between farmers and the local forest authority. We found that 42.9% of people considered that the communication which had happened before was bad. Consequently, about half of the famers were reluctant to communicate with local authorities in the future. The investigation results also showed that 61.1% of the farmers had no idea how to improve the communication with the local forest authority, while 37.7% suggested that the local forest authorities should play a leading role. Therefore, promotion of communication between the households and local forest authority is necessary in the study area and more responsibility should be taken by the forest authority.

7 Conclusions

7.1 Conclusions of the results of coppice assessment and the results of socio-economic study

In this study, the oak coppiced stands in Shangnan County, Southern Shaanxi Province were assessed both in terms of stand growth and stand regeneration. These stands are not degraded severely by coppicing and still had a high potential for growth. We suggest that in *Q. variabilis* stands, especially these under intensive use, the multiple-stem trees should be cut or have the number of shoots on a stump reduced since there was no increase on the mean diameter, basal area, and volume with the increase of stand age. In addition, most of trees in the coppice stands were of poor quality, especially in younger stands. The low quality of trees will decrease the timber value. Therefore, if the stands are used for producing timber, strategies should be applied to improve tree quality.

The forest stand regeneration is sufficient in terms of density and consists of diverse valuable native species. However, seedling density had a great variation among stands. Neither stand age nor stand use types had an influence on the seedling density. More investigations need to be done to explore the great variation of the regeneration density. Although different stand use types had no influence on the seedlings density, the density of the regeneration of the main species decreased by intensive use. The intensive use on coppice stands improves the chance for other species to establish in the oak coppice stands. The attention should be paid on the regeneration of the main species, especially for stands under intensive use, to maintain the sustainable development of oak stands. The understory vegetation was scarce, and these coppice stands are mainly located on the hillsides. Thus, the coppice function to retain water and soil runoff is decreased. Consequently, the opening of the dense canopy should be used to promote the growth of the understory vegetation.

The different stem types (non-coppiced, coppiced-single, coppiced-multiple) of *Q. variabilis* and of *Q. acutissima* trees had a similar allocation pattern between diameter and height growth. The diameter and height growth were more correlated with the crown size for trees in dominant crown class. However, we also found that within the same vitality and the same crown class, *Q. variabilis* originated from seedlings showed more growth potential than trees from coppicing.

A questionnaire survey about the socio-economic condition and the use of forest products was a useful tool since it provided a great deal of practical information for forest management and practice. The majority of households in Shangnan County regarded fuelwood as their main energy sources. Management on oak coppice stands should focus on the high demand for fuelwood and the sustainable development of coppice stands. The local people have realized that more attention should be paid on stand management to improve the coppice stands. A new and practical forest management could be implemented because we found most of farmers would like to accept an advice from the local forest authority.

The analyses of the status of forests and the socio-economic survey are helpful to the development of recommendations not only to improve the environmental situation and the land use management, but also to satisfy the desires of the local rural residents, in particular to their economic income, and subsequently improving their living standards.

7.2 Management recommendations

The results indicate that the oak coppices stands in the study area have a high productive potential. The different intensity of the practiced coppice treatments have no influence on the growth of dominant trees. The forest stand regeneration is sufficient in density and consists of diverse valuable native-species. This provides the possibilities for many options that can be practiced towards a sustainable management of these stands. The following forest systems are appropriate for the prevailing situation in the study area.

Coppice: Coppicing is the cutting of trees back to ground level on a regular short rotation (Buckley, 1992). Where the stands are not degraded, which means the re-growth of the coppiced trees is still rapid and not diminished by overharvest or due to root aging, the traditional management of coppice can be practiced. Coppice is essentially a system for the production of fuelwood and small or medium-sized material, but not for the production of large timber (Matthews, 1991).

Coppicing has been practiced since the early medieval times in Western Europe (Werf, 1991). Most broadleaved species, such as oak, eucalypt, and maple, are suitable for coppicing. In comparison to other forestry systems, the advantages of the coppice system are (Matthews, 1991):

- It is simple in operation and can be applied on small areas as well as on larger areas.
- It is a flexible system. If an existing species or cultivar is surpassed in health, yield, and quality it can be replaced. The size of product can be adjusted to suit changes in harvesting and processing
- Because of the short rotation only small amount of costs are tied up in the growing stock and early returns are obtained.

- Where there is a market for small diameter wood products, coppice works with a shorter rotation period than most other forestry systems due to the generally, rapid initial growth of coppice stem (Department of Primary Industries, 2000).
- The application of the coppice system is a reasonable way to meet the fuelwood demands in the study area.

Although the intensive use (frequently coppicing) decreased the growth of diameter, height, basal area and stand volume compared to the moderate use, the stocking volume of the stands are still high even after frequent cutting. This finding also illustrates that the coppice stands in the study area are not degraded and had a good re-growth of the coppice stems. Therefore, the coppice system is one appropriate option for oak stands in study area. Further studies on coppice rotation length and productivity on biomass are needed.

Coppice with standards: is a combination of coppice with older and larger trees (standards) that originated from seed (Sands, 2005). Fig. 39 shows one stand, which is managed as coppice with standards in Iphofen, Germany. It is an appropriate option to form two-story, uneven-aged forests, where sufficient standards or large trees with good quality are available in the coppice stands (Machar, 2009; Gross and Konold, 2010). The standards are selected and spaced out to stimulate their growth until they grow into the desired large timber dimensions. It can be the same species as those grown as coppice sprouts or different species. The timber of the standards can be used for construction and furnishing. The cuttings of small trees to promote the growth of the standards are used as fuelwood or material for other uses, such as growing mushroom, silk production, fencing, or making baskets. In the open patches that arise by the cutting of the small trees, the growth of the understory regeneration is stimulated by the available light and, thus, the production of timber and non-timber products is substantially supported. The number of standards is different depends on the species and purpose of management. Hopkison (2008) recommended that the standards should be retained at a density of about 30-100 per hectare with 10-18 m spacing, while Elevitch (2004) considered the retention of at least 8-20 large trees per acre are required to ensure the diversity and productivity of the forest.

Photo by Lei Deng, in Iphofen, Germany

Fig. 39: *Quercus petraea* stands managed by coppice-with-standards system. Coppicing trees used as fuelwood grow in the understory, while the standards managed for timber production occupy the overstory.

This traditional two-story woodland management system was developed over the past thousand years in Western and Northern Europe to sustain both permanent forest cover and a continuous flow of a wide range of forest products (construction timber, fencing and furniture parts, fruits and wild game) (Lassauce *et al.*, 2012). Moreover, it also played an important role in enhancing ecosystem diversity and wildlife habitat (Bane, 2004; Mosandl *et al.*, 2010). A typical coppice with standards system is oak standards over hazel or sweet chestnut. Since the decrease in firewood demand due to development of fossil fuels, coppice with standards has been converted into high forest for getting more timber products (Mosandl *et al.*, 2010; Lassauce *et al.*, 2012). However, the interest on this forestry system has arisen again, because of the development of multifunctional forests and the development of wood biomass as a renewable energy source.

Coppice with standards system has been adapted to other regions around the world. In Australia, coppice with standards has been used for the treatment of eucalypt forests (Department of Primary Industries, 2000). In Korea, a system called “sunchon” is used for growing pine standards between rows of locust (*Robinia* sp.) coppiced for fuel wood (Bane, 2004). In India, sal (*Shore robusta*) is grown over teak to provide frost protection during cool winter months for teak which is more sensitive to frost (Bane, 2004). However, this system has rarely been used in China.

Trees reserved as standards are of natural or planted seedlings origin. In our investigation, the non-coppiced, single-stem trees are scattered in the coppice stands, irrespective of stand use intensity. These trees with dominant crown exhibited a greater growth of DBH and height than these with coppiced stems. Therefore, these trees could be retained as standards. Even for intensively used stands, the dominant trees could be chosen as standards because of its high potential for growth. In addition, the regeneration in coppice stands was also high. Therefore, there is no limitation to develop the standards at present and the high density of seedlings also can be a source for future standards.

As the importance of fuelwood in rural area increases, coppice with standards will contribute to the production of fuelwood as well. On the other hand, new forest policy in China has reduced the area of timber forest (Démurger *et al.*, 2009), and timber production has decreased. However, the demand of timber still is increasing because of economic development. To satisfy the growing demand for timber, the imports of logs, sawn wood, wood chips as well as fibreboard has surged dramatically (Démurger *et al.*, 2009). In regard to the shortage of timber product as well as fuel woods, the coppice with standards management is a good option to combine timber and fuel wood production on the same area. This makes it interesting also for small scale forestry in rural areas.

Coppice with standards also has an essential role in the enrichment of the ground vegetation by regular intervention. Its usually high species diversity contributes to humus decomposition, preservation of soil fertility and also ecological stability (Utinek, 2004). Recently, because of serious soil erosion problems in the local area, vegetation restoration has attracted more attention. Many studies have been shown that the lack of understory vegetation could lead to soil erosion in woodland (Wang *et al.*, 2006; Zhou *et al.*, 2006; He *et al.*, 2011). In our study, we found that the high tree density in coppice stands caused a low coverage of ground vegetation especially in *Q. variabilis* stands. Low coverage of ground vegetation is one of the reasons, which reduce the ability of woodland for soil and water conservation. The transfer of coppice to coppice with standards will contribute to the restoration of the ground vegetation in coppice stands and consequently will reduce the soil erosion in the study area.

All the above-described management options maintain a continuous forest cover, which supports the objectives of soil and water conservation. The recommendation of Zhang *et al.* (2008) to protect the *Q. variabilis* stands at low altitudes is not valid for our study area due to the high demand for fuel wood by the local residents and the ecological as well as the economic benefits of managing those coppice stands in a sustainable way.

Summary

The study area Shangnan County is located in the southern Shaanxi Province, China. As one of the upriver areas of Danjiang River, it plays an important role in ecosystem conservation. The implementation of the South-North Water Diversion Project brings even more attention to this area. Oak forests are the biggest part of Shangnan's forest resources in terms of area and stocking volume. It has provided a wide variety of uses to local residents in terms of wood product, energy resource, and water and soil conservation. However, the long-term ignorance of management accelerates the degradation of oak forest. The lacking of cutting plans resulted in an unreasonable cutting. As well, the regeneration after harvesting had received even less attention. All these factors give rise to strong pressure on the need for sustainable forest development. Therefore, study on oak stands in Shangnan could be helpful not only in understanding the potential of wood production and regeneration but also in providing management recommendations to local people.

The current study was conducted within the framework of the Sino-German project "Rehabilitation of degraded land ecosystems in the mountainous area of the Southern Shaanxi Province, China". The study is addressing two aspects of forest management in the research area, i) questions concerning the characteristics of oak coppice forests and ii) questions concerning the people's use of local forests. The objective of this study is to provide recommendations for sustainable management of oak coppice stands. This will be achieved i) by a scientific investigation of the potential of the wood production and stand regeneration in coppice stands and ii) by a socio-economic survey on people's use of the coppice forests and the assessment of the degree of acceptance by the local inhabitants to change the present use of the forest resources.

Methods

The assessment of oak coppices is based on 30 sample stands in the Shangnan County. These stands were randomly selected within an area of a size of 20 km × 20 km. Using a topographic map, watersheds within the 400 km^2 area were identified, and larger watersheds were partitioned in smaller units not exceeding 4 km^2. In total, 72 watersheds were identified. From these, ten were randomly selected for field investigation. Each selected unit was identified using GPS (global positioning system) in the field. One of the eight cardinal directions was selected at random as a starting direction for the selection of three stands within each watershed. The stand occurring first in the selected direction was identified the first one for sampling. Following the same direction, providing there was a separation distance of at least 200 m, the next two stands were also selected for sampling. In each selected stand, a plot of 20 m × 20 m in size was established for the data collection of mature stands. Each plot includes an inner plot of 10 m x 10

m, on which 16 circle sample plots of a size of 1 m^2 were systematically installed. These were used to collect information about the stand regeneration and the ground vegetation.

A socio-economic questionnaire was conducted on randomly selected 175 households from 11 villages (15-16 households in each village). These villages were located within the Shangnan County. The furthest one was 19 km and the nearest one was 5 km away from the county centre. The questionnaire consisted of open-ended and closed-ended questions. Questions were explained to the interviewee to avoid any misunderstanding and to improve efficiency of answers during the interview. The first part of questionnaire contained the socio-economic parameters. The main part of questionnaire was a list of questions which were related to the forest resource, energy resource, and use of forest resource.

Results

Oak coppice stands

The results showed that oak coppice stands in study area are mainly composed of *Q. variabilis* stands (accounted 83% of total coppice stands). The remaining 17% of oak stands are dominated by *Q. acutissima.* A total of 32 tree species were recorded in *Q. variabilis* stands, indicating a rich species composition. Coppicing of trees led to a high stand density, especially for younger stands. The age of *Q. variabilis* stands varied from 10 to 25 years while the stand basal area varied between 10.6 and 26.6 m^2 ha^{-1} and the stand stocking volume ranged from 47.5 to 152.7 m^3 ha^{-1}.

We found all investigated stands could be classified into two types based on coppicing frequency: 1) stands with moderate use and 2) stands with intensive use. The variation of most stand parameters could be explained by the forest stand use. We also found that none of the site factors had an influence on the forest stand structure.

Stands classified as intensively used stands have a higher stand density (stems per hectare) and a lower quadratic mean diameter (d_q) and mean height (h_q). The intensively used *Q. variabilis* stands are characterized with lower basal area and stocking volume compared to the moderately used stands at a given age. However, it is surprising that the stocking volume of stands could reach up to 120 m^3 ha^{-1} (80 m^3 ha^{-1} of *Q. variabilis* trees) on average at the age of 25 years old even after frequent cutting. The stocking volume of *Q. variabilis* stands in moderately used sites was around 170 m^3 ha^{-1} by age 25. All these findings indicate that the oak coppice stands in Shangnan area still have high growth potential. Although no difference in basal area and stocking volume between the two forest stand use types on *Q. acuttissima* stands was found, the d_q and h_q of all species or the d_q and h_q of the main species in moderately used stands was always greater than in intensively used stands.

However, the forest use type had no effect on growth of dominant trees. Our results showed that the mean diameter, dominant height, basal area and volume of dominant trees were same between different types of forest use. This result implies that coppice stands in intensive use still had high potential on productivity as these in moderate use. The dominant trees in *Q. acutissima* stands also showed a greater growth in comparison with the dominant trees in *Q. variabilis* stands.

The coppice stands are composed of trees with single stem and trees with multiple stem together. The proportion of single-stem trees in number was not affected by forest stand use but it was positively correlated with stand age. However, neither forest stand use nor stand age had a correlation with the proportion of single-stem trees in terms of basal area and volume.

For the single-stem trees of all species, the d_q, h_q, basal area, and volume showed an increase with increasing stand age in two types of stand use; for the multiple-stem trees of all species, only the d_q and h_q in moderately used stand had an increase while the d_q and h_q in intensively used stand remained constant.

We found a greater d_q and h_q of the single-stem trees of the main species in *Q. acutissima* stands (*Q. acutissima*) in comparison with that of the main species in *Q. variablis* stands (*Q. variablis*) in moderately used stands at a given age. However, no differences in d_q and h_q were found between the multiple-stem trees of two main species. This finding suggests that the further study on the tree growth among coppiced tree species should consider the form of coppicing, i.e., the number of shoots per stump.

Regeneration & understory vegetation

In this study 17 different woody species were found in the understory of 25 sampled *Q. variabilis* stands. Many of these species are of ecological and economic importance, for example, *Q. variabilis*, *Q. dentata*, *Dalbergia hupeana*, *Pistacia chinensis*, and *Rhus chinensis*. Regeneration of tree species in *Q. variabilis* stands is abundant with average density of the regeneration 18,875±3,338 individuals ha^{-1}. In the 5 sampled *Q. acutissima* stands, 9 woody species were observed in the stand regeneration. The average density of the natural regeneration reached up to 25,500±6,618 individuals ha^{-1}. Therefore, the regeneration in both *Q. variabilis* stands and *Q. acutissima* stands is sufficient in terms of species and number.

Our results showed that although the intensive use led to a higher number of standing tree species and a greater stand density, the density of regeneration, species number and diversity did not differ between the stands with moderate use and the stands under intensive use. But, the intensive use of stands promoted the growth of the tree seedlings. The density of the main species in the regeneration was influenced by forest stand use. This finding also suggests that attention should be paid on the regeneration of oak seedlings, especially for stands with intensive use, to maintain the sustainable development of oak stands.

The ground vegetation in the investigated coppice stands was very scarce, especially in *Q. variabilis* stands. The forest stand use had no influence on the coverage and average height of ground vegetation.

Growth of single trees

In the same crown class, trees with different types of stems (non-coppiced-single stem; coppiced-single stem; coppiced-multiple stem) had a similar height-DBH relationship. This is, the stem type had no effect on resource allocation for height growth or diameter growth for *Q. variabilis* and *Q. acutissima* single trees. However, the relationship between the crown width and diameter as well as the relationship between the crown length and tree height also varied with different crown status.

In all investigated *Q. variabilis*, more than 80% of all trees were healthy and foliated, indicating a good vitality. *Q. acutissima* trees with vigorous and moderate vitality also accounted 84% of all trees. In addition, our results also showed that *Q. variabilis* trees with non-coppiced stem showed a greater DBH and height than these with coppiced stem in the same vitality and crown class.

Socio-economic study

The fuelwood plays an important role in people's daily life in Shangnan County. The majority of households (68.8%) regarded the fuelwood as the main energy sources. The average amount of fuelwood consumption per household was 1417.8±55 kg per year and the average amount of fuelwood consumption per capita was 350.4±13 kg per year. In spite of the demand of fuelwood is high, the farmers' own forest resources in local area are not abundant.

The local people have realized that more attention should be paid on stand management to improve the coppice stands. A new and practical forest management could be implemented because we found the majority of the farmers (67% of the total households) would accept an advice from the local forest authority to change the present use of the forest resources.

Management recommendation

Management on oak coppice stands should focus on the high demand for fuelwood and the sustainable development of coppice stands. Coppice and coppice-with-standards system are two recommended management options that not only maintain a continuous forest cover, which supports the objectives of soil and water conservation, but also to satisfy the high demand for fuel wood by the local residents as well as the economic benefits of managing those coppice stands in a sustainable way.

Zusammenfassung

Die Untersuchungen wurden im Landkreis Shangnan im Südlichen Teil der Provinz Shaanxi durchgeführt. Das Gebiet befindet im oberen Einzugsgebiet des Danjiang Flusses und hat daher eine bedeutende Funktion für die Realisierung des South-North Water Diversion Projektes. Die Waldzusammensetzung im Untersuchungsgebiet ist sowohl im Hinblick auf die Fläche als auch des Holzvorrates von Eichenwald geprägt. Der Wald dient der Landbevölkerung zur Befriedigung des Bedarfs an Holzprodukten und Brennholz sowie für den Wasser- und Bodenschutz. In den Wäldern ist eine zunehmende Degradation durch eine unzureichende Bewirtschaftung der Eichenwälder zu beobachten. Kennzeichnend hierfür sind ungeregelte Nutzungen auf Grund fehlender Einschlagsplanungen und die Vernachlässigung der Waldverjüngung nach Hiebsmaßnahmen. Infolgedessen ist es notwendig in diesem Gebiet die nachhaltige Waldentwicklung zu fördern. Die hier vorgestellte Studie soll hierzu einen Beitrag leisten und das Potential der Holzproduktion und Waldverjüngung erforschen, um daraus Empfehlungen für die Waldbewirtschaftung für Landbevölkerung zu entwickeln.

Die Studie wurde im Rahmen des deutsch-chinesischen Projektes "Rehabilitation of degraded land ecosystems in the mountainous area of the Southern Shaanxi Province, China" durchgeführt. Die Untersuchung i) beschreibt die Merkmale des Eichenniederwaldes und ii) die Nutzung des Waldes durch die Landbevölkerung. Das Ziel ist es, Empfehlungen für die nachhaltige Bewirtschaftung des Eichenniederwaldes bereitzustellen. Dies wird erreicht durch i) die waldbauliche Untersuchung der Potentiale für Holzproduktion und Waldverjüngung im Eichenniederwald sowie durch ii) die Befragung der lokalen Landbevölkerung zur aktuellen Nutzung des Niederwaldes und zur Bereitschaft die gegenwärtige Praxis der Waldnutzung zu verändern.

Methoden

Die Untersuchung des Eichenniederwaldes erfolgte auf Grundlage von 30 Beständen im Landkreis Shangnan. Die Bestände wurden zufällig in einem Testgebiet von 20 km × 20 km Größe ausgewählt. In diesem 400 km^2 großen Gebiet wurden Wassereinzugsgebiete mit Hilfe einer topographischen Karte ausgeschieden. Die größeren Wassereinzugsgebiete wurden in kleinere Einheiten kleiner gleich 4 km^2 weiter unterteilt. Insgesamt wurden 72 Wassereinzugsgebiete gebildet. Daraus wurden 10 Raumeinheiten für die Feldaufnahmen zufällig ausgewählt Jede ausgewählte Einheit wurde mit Hilfe von GPS (global positioning system) im Feld eingemessen. Innerhalb einer Raumeinheit wurde dann zufällig eine von acht Himmelsrichtungen ausgewählt, um in dieser Richtung drei für die Aufnahme geeignete Eichenniederwaldbestände innerhalb der Raumeinheit zu finden. Der Bestand, welcher in der

gewählten Richtung als erstes gefunden wurde, bildete den ersten Untersuchungsbestand. Die nächsten beiden Bestände wurden dann in derselben Richtung gesucht, wobei ein Mindestabstand von 200 m zwischen den Untersuchungsbeständen einzuhalten war. In jedem der ausgewählten Bestände wurde eine Parzelle von 20 m x 20 m für die Aufnahme des Altbestandes angelegt. Jede Aufnahmefläche beinhaltete eine innere Parzelle von 10 m x 10 m, in welcher 16 Probekreise mit einer Größe von 1 m^2 systematisch angeordnet wurden. In den Probekreisen wurde die Waldverjüngung und die Bodenvegetation aufgenommen.

Die Befragung wurde in 175 Haushalten in 11 Gemeinden durchgeführt. Jedes Dorf hatte 15 bis 16 Haushalte. Die Dörfer lagen in einer Entfernung von 5 bis 19 km vom Zentrum des Landkreises Shangnan entfernt. Die Befragung umfasste offene und geschlossene Fragen. Die Fragen wurden den an der Studie teilnehmenden Personen erläutert, um Missverständnisse zu vermeiden und die Effizienz der Beantwortung während des Interviews zu verbessern. Der einführende Teil der Befragung beinhaltete Fragen zu sozioökonomischen Parametern. Der Hauptteil der Befragung befasste sich mit den Themen Wald- und Energieressourcen sowie der Waldnutzung.

Ergebnisse

<u>Eichenniederwald</u>

Die Ergebnisse zeigen, dass es sich bei den untersuchten Niederwaldbeständen vorwiegend um *Q. variabilis* Bestände handelt (83% der Bestände). Die übrigen Bestände sind von *Q. acutissima* dominiert. Insgesamt wurden 32 Baumarten aufgenommen, was auf eine hohe Baumartenvielfalt hinweist. Die Bewirtschaftung der Eiche im Niederwaldbetrieb führt zu höheren Stammzahlen insbesondere in jüngeren Beständen. In den *Q. variabilis* Beständen betrug die Spreitung des Alters 10 bis 25 Jahre, der Grundfläche 10.6 bis 26.6 m^2 ha^{-1} und des Holzvorrates 47.5 bis 152.7 m^3 ha^{-1}.

Die untersuchten Bestände konnten anhand der Häufigkeit des Einschlages in zwei Klassen eingeteilt werden: 1) Bestände mit mäßiger Nutzungsintensität und 2) Bestände mit intensiver Nutzungsintensität. In der Auswertung konnte die Variation der meisten Bestandeswerte durch die Nutzungsintensität erklärt werden. Für die untersuchten Standortsfaktoren war hingegen kein Einfluss nachzuweisen.

Die intensiv genutzten Bestände haben insgesamt eine höhere Stammzahlen sowie geringere Kreisflächenmitteldurchmesser und Mittelhöhen. Die intensiv genutzten *Q. variabilis* Bestände besitzen im Vergleich zu gleichaltrigen mäßig genutzten *Q. variabilis* Beständen niedrigere Grundflächen und Vorräte. Trotz der häufigen Eingriffe erzielen im Mittel 35-jährige Bestände 120 m^3 ha^{-1} Gesamtvorrat bzw. 80 m^3 ha^{-1} bezogen auf *Q. variabilis*. Der Vorrat 25-jähriger mäßig genutzter Bestände betrug 170 m^3 ha^{-1}. Die Ergebnisse zeigen, dass Eichniederwald im Landkreis Shangnan ein hohes Wachstumspotential besitzt.

In *Q. acuttissima* Beständen waren Grundfläche und Vorrat in beiden Nutzungsklassen vergleichbar. Die Kreisflächenmitteldurchmesser und die Mittelhöhen aller Baumarten einschließlich der Hauptbaumart waren bei mäßiger Nutzungsintensität größer als in den intensiv genutzten Beständen.

Generell hatte die Nutzungsintensität keinen Einfluss auf die Entwicklung der dominanten Bäume. Die Ergebnisse zeigen, dass der Mitteldurchmesser, die Höhe, die Grundfläche und der Vorrat der dominierenden Bäume in Beständen unterschiedlicher Nutzungsintensität gleich sind. Daraus kann gefolgert werden, dass intensiv genutzter Niederwald eine vergleichbare Produktivität wie Bestände mit mäßiger Nutzungsintensität hat. In *Q. acutissima* Beständen wiesen die dominanten Bäume ein besseres Wachstum auf als in *Q. variabilis* Beständen.

Niederwälder setzen sich aus Bäumen mit einem Stamm und Bäumen mit mehreren Stämmen zusammen. Der Anzahl einstämmiger Bäume wurde nicht durch die Nutzungsintensität beeinflusst, war aber positiv mit dem Bestandesalter korreliert. Bezogen auf die Grundfläche und den Vorrat war der Anteil der Einzelstämme jedoch nicht mit der Nutzungsintensität oder dem Bestandesalter korreliert.

Bei allen Baumarten konnte für die Einzelstämme festgestellt werden, dass der Kreisflächen Mitteldurchmesser und die Höhe mit dem Bestandesalter bei beiden Nutzungsintensitäten anwuchs. Bei allen Baumarten nahm für die mehrstämmigen Bäume der Kreisflächenmitteldurchmesser und die Höhe in mäßig intensiv genutzten Beständen zu während diese Parameter bei intensiver Nutzung konstant blieben.

Der Kreisflächenmitteldurchmesser und die Mittelhöhe einstämmiger Bäume der Hauptbaumart war bei mäßiger Nutzung und vergleichbarem Alter in *Q. acutissima* Beständen höher als in *Q. variablis* Beständen. Keine Unterschiede zwischen Kreisflächenmittendurchmesser und Mittelhöhe wurden zwischen den mehrstämmigen Bäumen der beiden Hauptbaumarten gefunden. Die Ergebnisse zeigen, dass bei weiteren Untersuchungen des Wachstums im Niederwaldbetrieb die Art der Eingriffe, z.B. die Anzahl der Sprosse je Stumpf, berücksichtigt werden sollte.

<u>Verjüngung und Bodenvegetation</u>

Im Rahmen der Studie wurden 17 verschiedene holzartige Pflanzen in den untersuchten 25 *Q. variabilis* Beständen gefunden. Viele dieser Arten sind von ökologischer und ökonomischer Bedeutung. Beispiele hierfür sind *Q. variabilis*, *Q. dentata*, *Dalbergia hupeana*, *Pistacia chinensis*, and *Rhus chinensis*. Die Verjüngung ist in den *Q. variabilis* Beständen mit einer durchschnittlichen Dichte von 18,875±3,338 Pflanzen ha^{-1} dominant. In den 5 untersuchten *Q. acutissima* Beständen wurden 9 Gehölzarten in der Verjüngung beobachtet. Die durchschnittliche Dichte der Naturverjüngung betrug dort 25,500±6,618 Pflanzen ha^{-1}. Infolgedessen war die Verjüngung sowohl in den *Q. variabilis* Beständen als auch *Q. acutissima* Beständen im Hinblick auf die Baumartenvielfalt und Dichte zufriedenstellend.

Die Ergebnisse zeigen, dass intensivere Nutzung zu einer größeren Anzahl an Baumarten und Stämmen führen, die Verjüngung jedoch im Hinblick auf Pflanzendichte, Artenanzahl und Diversität keine Unterschiede zwischen den beiden Nutzungsintensitäten aufweist. Bei intensiver Nutzung wurde jedoch das Wachstum der Verjüngung gefördert. Die Dichte der Hauptbaumart in der Verjüngung wurde durch die Nutzungsintensität beeinflusst. Aus den Ergebnissen kann abgeleitet werden, dass auf die Verjüngung der Eiche - insbesondere in intensiv genutzten Beständen zu achten ist, um eine nachhaltige Entwicklung der Eichenbestände zu gewährleisten.

Bodenvegetation war in den untersuchten Niederwaldbeständen kaum vorhanden, insbesondere in den *Q. variabilis* Beständen. Die Nutzungsintensität hatte keinen Einfluss auf den Bedeckungsgrad und die mittlere Höhe der Bodenvegetation.

Entwicklung von Einzelbäumen

Innerhalb der gleichen sozialen Klasse haben Bäume mit unterschiedlicher Stammklasse (einzelstämmige Kernwüchse, einzelstämmiger Stockausschlag, mehrstämmiger Stockausschlag) ein vergleichbares Verhältnis von Brusthöhendurchmesser zu Baumhöhe. Die Stammklasse hat offensichtlich keinen Einfluss auf die Allokation in Bezug auf Höhen- und Durchmesserwachstum bei *Q. variabilis* and *Q. acutissima*. Jedoch variiert das Verhältnis Kronenbreite zu Brusthöhendurchmesser und das Verhältnis von Kronenlänge und Baumhöhe in Abhängigkeit von der sozialen Stellung des Baumes.

Von *Q. variabilis waren 80 %* der Bäume gesund und voll belaubt und hatten damit eine vitalen Gesundheitszustand. *Q. acutissima waren* zu 84 % von guter oder mäßiger Vitalität. Weiterhin war zu beobachten, dass Kernwüchse von *Q. variabilis* bei gleicher Vitalität und sozialer Stellung größere Brusthöhendurchmesser und Baumhöhen aufwiesen.

Sozioökonomische Studie

Brennholz spielt im Alltag der Landbevölkerung im Kreis Shangnan eine bedeutende Rolle. Für die Mehrzahl der Haushalte (69%) ist Brennholz die Hauptenergiequelle. Im Durchschnitt liegt der jährliche Brennholzverbrauch bei 1417.8±55 kg je Haushalt und 350.4±13 kg je Einwohner. Trotz des hohen Bedarfs an Brennholz besitzt die Landbevölkerung nur geringe eigene Waldressourcen.

Zusammenfassung

Die lokale Bevölkerung hat erkannt, dass der waldbaulichen Behandlung höhere Aufmerksamkeit geschenkt werden muss, um den Niederwald zu verbessern. Neue praxisorientierte waldbauliche Verfahren könnten eingesetzt werden, da die Mehrheit der Bauern (67% der Haushalte) sowohl gegenüber der Beratung durch die lokalen Forstbehörden als auch dem Wechsel der gegenwärtigen Waldnutzung aufgeschlossen sind.

Waldbauliche Empfehlungen

Die waldbauliche Behandlung des Eichenniederwaldes sollte auf die Deckung Brennholzbedarfes und die nachhaltige Entwicklung ausgerichtet werden. Niederwald und Mittelwald können als Betriebsform empfohlen werden, da sie nicht nur zu einer kontinuierlichen Waldbedeckung führen, welche dem Boden- und Wasserschutz dient, sondern auch den hohen Brennholzbedarf der lokalen Landbevölkerung decken als auch nachhaltig ökonomische Vorteile erbringen.

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Appendix

Appendix 1: Table of stand parameters

Parameters	Abbreviation	Unit
Age	Age	year
Number of tree species		
Diversity index		
Density		Trees/stems ha^{-1}
Basal area	BA	m^2 ha^{-1}
Volume	V	m^3 ha^{-1}
Arithmetic mean diameter	$\bar{d}$	cm
Arithmetic mean height	$\bar{h}$	m
Quadratic mean diameter	d_q	cm
Mean height	h_q	m
Slenderness	h_q/d_q	
Dominant height	h_{100}	m
Mean diameter of dominant tree	d_{100}	cm
Slenderness of dominant tree	h_{100}/d_{100}	
Average crown width		m
Average crown length		m
Average crown ratio		%
Average crown width-DBH ratio		
Average crown width-height ratio		
Average crown width to crown length ratio		

Appendix 2: Table of single tree parameters

Parameters	Abbreviation	Unit
Diameter at breast height	DBH	cm
Height	H	m
Slenderness		
Crown length	Crl	m
Crown width	Crd	m
Crown ratio	Cr%	
Crown width to diameter ratio	Crd-DBH ratio	
Crown width to tree height ratio	Crd-H ratio	

Crown width to crown length ratio	Crd-Crl ratio

Appendix 3: Socio-economic questionnaires (part 1)

Item	Answers
Name of surveyor	
Date and time of interview	
Name of the village	
Number of inhabitants in the village	
Estimation of the house size (m^2)	
Estimation of the interviewee age (year)	
Gender of the interviewee	☐ male ☐ female
Estimation of the economic situation of the household by the surveyor at the end of the interview.	☐ well ☐ average ☐ poor ☐ poverty-stricken
How does the surveyor assess the quality of the interviewee answers at the end of the interview?	☐ reliable ☐ largely reliable ☐ varying ☐ unreliable
Educational level of the head of the household	☐ higher education ☐ educated ☐ basic education ☐ illiterate
Marital status of the head of the household	☐ married ☐ single ☐ divorced ☐ widowed
Size of the household (persons)	
Of which children (number)	
Is the head of the household full or part time farmer?	☐ full time ☐ part time
Practiced land use type by the household	☐ agriculture ☐ forestry ☐ agroforestry ☐ other

Appendix 4: Socio-economic questionnaires (part 2)

Item	Answers
What is the main source of energy for your household?	☐ fuel wood ☐ electricity ☐ coal ☐ other
If fuel wood, not mentioned above: Do you use fuel wood at all for your household?	☐ yes ☐ no
If no: Since when does not your household use fuel wood?	☐ since ever ☐ years(specify)
If no: What is the reason for not using fuel wood anymore?	
If yes: From where you obtain the fuel wood?	☐ forest ☐ own farm ☐ purchase ☐ other
If yes: For which main purpose do you use the fuel wood?	☐ heating ☐ cooking ☐ mushroom business ☐ other

If yes: How much fuel wood do you use per year?	
If yes: Do you prefer a specific size of logs?	☐ yes ☐ no
If yes: Which size do you prefer?	
If yes: Do you prefer a specific species?	☐ yes ☐ no
If yes: Which are the most favourable tree species for your household?	
If yes: Why do you prefer these species?	
How do evaluate the current status of the forest?	☐ high ☐ mid ☐ low ☐ do not know
If evaluated: Which reasons do you think support your evaluation?	
Do you think that the coppice stands need to be improved?	☐ yes ☐ no ☐ don't know
If yes: What do you think it must be made to improve the stands?	
Do you think there is a need for communications between the households and local forest authority?	☐ yes ☐ no
If communications are in place, how do you assess the communication between the head of the household and the local forest authority?	☐ excellent ☐ good ☐ bad ☐ don't know
What on your opinion could be made to improve the communications between the households and local forest authorities?	
How do you evaluate the quality of the advice of local forest authorities?	☐ high ☐ mid ☐ low ☐ do not know
Does the household accept an advice from the local forest authorities?	☐ yes ☐ not always ☐ no ☐ do not know
Do you have the coppice stand?	☐ yes ☐ no
If yes: How much size (m^2)	
If yes: How do you evaluate the quality?	☐ high ☐ mid ☐ low
If yes: Are there some advices from the local forest authorities on management?	☐ yes ☐ no

Appendix 5: Pictures of trees and stands

1. Leaves of *Q. variabilis* (obverse side)

2. Leaves of *Q. acutissima* (obverse side)

(photo by Yayu)

3. Leaves of *Q. variabilis* (reverse side)

(photo from CFH: Chinese Field Herbarium)

4. Leaves of *Q. acutissima* (reverse side)

(photo by Yayu)

5. Acorns of *Q. variabilis*

6. Acorns *of Q. acutissima*

7. Trunk of *Q. variabilis*

8. Trunk of *Q. acutissima*

9. 11-year-old *Q. variabilis* coppice stand

10. 7-year-old *Q. acutissima* coppice stand

11. Trees with different types of stems (from left to right): non-coppiced, single stem; coppiced, single stem; coppiced, multiple stem (n=2); coppiced, multiple stem (n>2)

<u>Appendix 6</u>: Pictures of socio-economic study

12-13. Fuel woods stored by farmers

14-15. Questionnaire survey

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