

# Relative importance of various regeneration recruits in different recovery stages of *Quercus variabilis* forest after selective logging

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## Abstract

*Aim of study:* *Quercus variabilis* (Chinese cork oak) reproduces asexually and sexually. This study aimed to determine the status and growth of asexual and sexual recruits of *Q. variabilis* in different forest recovery stages.

*Area of study:* Three selective logged stands and one unlogged stand in *Q. variabilis* forest, Shaanxi Province, China.

*Material and methods:* Origin, number, basal diameter, height and size structure of *Q. variabilis* shoots (height  $\leq 200$  cm) were investigated in the plots of 5, 10, and 20-years post-logging stands and unlogged stand. Effects of recovery stage on the density and growth of the three original recruits (stump sprouts, stem base sprouts and true seedlings) were analysis by One-way ANOVA.

*Main results:* Sprouts dominated logged stands, whereas true seedlings dominated unlogged stand, stem base sprouts only existed in 20-years post-logging and unlogged stands. Stump sprout density and sprout number per stump both declined with extended post-logging time. True seedlings density increased from 7 to 20 shoots/100 m<sup>2</sup> as the post-logging time extended, and peaked in unlogged stand (94 shoots/100 m<sup>2</sup>). An ongoing size structure was observed in true seedlings in all stands. Stump sprouts were taller and greater than true seedlings.

*Research highlights:* Stump sprouts contributed more to *Q. variabilis* forest recovery in the early stage after disturbance. The contribution of true seedlings was limited in the same stage, but they were beneficial for population long-term development. Stem base sprouts were most likely to be a survival strategy rather than a reproductive strategy.

**Key words:** asexual reproduction; true seedling; post-logging time; Chinese cork oak.

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## Introduction

The natural recovery of disturbed (logged, burned, slashed, and damaged by hurricane) forests may be initiated through sexual and asexual mechanisms. For some species, sexual reproduction is the dominant mechanism, but the pattern may be reverse for other species. Moreover, numerous plant species can reproduce through both ways. Sexual and asexual recruits are both essential in forest recovery, but differ in individual survival and growth rate, dispersal distance, phenology of offspring production, and establishment (Winkler and Fischer, 2002; Beaudet and Messier *et al.*, 2008). Germinated seeds in soil seed bank, suppressed seedlings, and sprouts from existing roots or stems may be initial recovery recruits (Hoffmann, 1998; Kammesheidt, 1998, 1999; Yamada

and Suzuki, 2004; Simões and Marques, 2007; Ky-Dembele *et al.*, 2007). Sprouts grow fast but their dispersion is limited by the parent plant, whereas true seedlings can disperse far (Hoffmann, 1998; Winkler and Fischer, 2002). Sexual reproduction provides greater genetic variability than asexual reproduction (Simões and Marques, 2007). Asexual sprouting may result in several individuals (clones) originating from one parent plant and occupying its niche persistence, thereby improving individual survival and resistance (Miller and Kauffman, 1998; Bond and Midgley, 2001; Beaudet and Messier *et al.*, 2008).

The relative importance of these two regeneration mechanisms during forest recovery was determined by species composition and biology of disturbed forest, and the origin and intensity of disturbance (Kennard *et al.*, 2002; Ky-Dembele *et al.*, 2007). The regeneration of some forests after disturbance, such as burning, is dominated by asexual recruits (*e.g.*, sprouts) rather than shoots established from seeds

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(Hoffmann, 1998; Kennard *et al.*, 2002). In other forests, such as the Nazinon forest, sexual reproduction is the predominant mechanism after selective cutting (Ky-Dembele *et al.*, 2007). Less intense disturbances, such as canopy opening, may stimulate more seeds to germinate (Vázquez-Yanes and Orozco-Segovia, 1993). The time elapsed after disturbance may also influence the contribution of the two regeneration mechanisms to forest recovery (Kammesheidt, 1999). Therefore, developing a management plan for target forest recovery and maintenance requires understanding of the status changes in different regeneration recruits during forest recovery.

Chinese cork oak (*Quercus variabilis* Bl., Fagaceae) is a common deciduous broadleaf tree in East Asia (24-42°N, 96-140°E, mainly in China, Korea, and Japan). In China, this species is important for the socio-economic development of some regions because of its dominant status (accounting for more than 70% of basal area) in local forests and abundant products. Chinese cork oak is the primary source of cork and tannin extract in China, but the quality and content of these two products in Chinese cork oak are lower than those in *Quercus suber* L., which is distributed in the Mediterranean Basin and North Africa (Pausas, 1997; Zhou *et al.*, 2010). Chinese cork oak supplies excellent timber, firewood, and raw material for cultivating edible fungi (Zhang and Lu, 2002; Zhou *et al.*, 2010; Kang *et al.*, 2011). Continuously cutting and stripping bark within the recovery phase (usually 9 years; Zeng, 2001) is the main disturbance for a Chinese cork oak forest; this disturbance impairs individual growth and degenerates the forest to a secondary forest or coppice, which is characterized by reduced ecological function and low productivity (Zhang and Lu, 2002).

Chinese cork oak reproduces both sexually and asexually (Xue *et al.*, 2012, 2013). Asexual reproduction in Chinese cork oak primarily involves sprouts arising from the stem base, stump, and root, similar to *Quercus nigra* L., *Quercus pagoda* Raf., *Detarium microcarpum* Guill. & Perr., *Acacia dudgeoni* Craib ex Holland, *Fagus grandifolia* Ehrh., and *Quercus liaotungensis* Koidz (Gardiner and Helmig, 1997; Lockhart and Chambers, 2007; Ky-Dembele *et al.*, 2007; Beaudet and Messier *et al.*, 2008; Rong *et al.*, 2013). To develop a management plan for Chinese cork oak forest recovery, understanding which reproduction is predominant in different forest recovery stages is necessary. This study aimed to: (1) determine the predominant reproduction mechanism

of Chinese cork oak in selective logged and unlogged stands by investigating the density and size structure of different original recruits; (2) detect whether the status of different original recruit changes during recovery; and (3) assess the similarity between the development of true Chinese cork oak seedlings and that of sprouts.

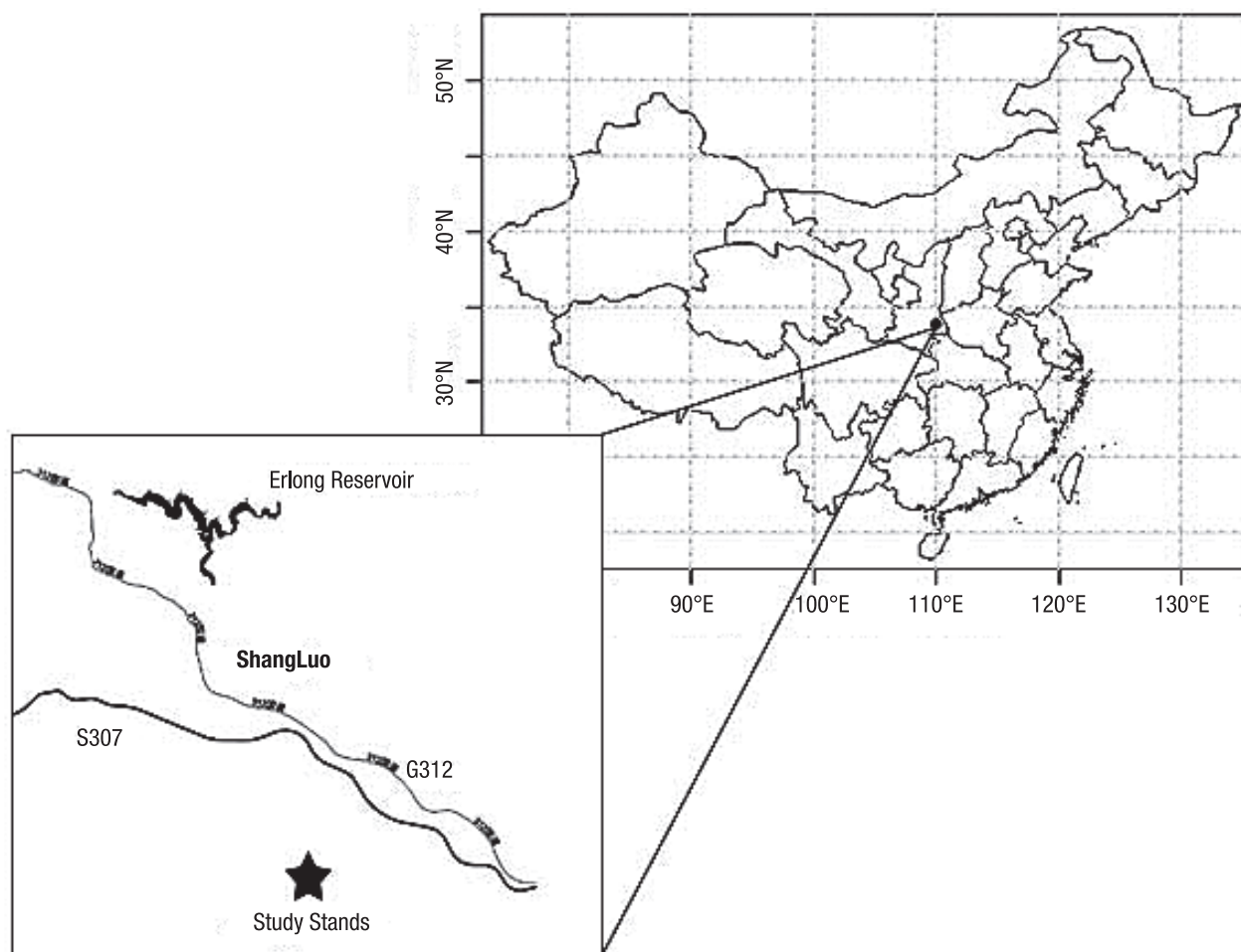
## Material and methods

### Study site

This study was conducted using four Chinese cork oak stands in Shangzhou District, Shangluo City, Shaanxi Province, China (109.93°E, 33.87°N, Fig. 1). This region is located in the southern part of Qinling Mountains, which is the center of the Chinese cork oak distribution area. The area is characterized by a typical warm temperate climate. The area has a mean annual temperature of 12.9°C and mean annual precipitation of 725.5 mm. Rainfall between July and September accounts for more than 50% of the annual amount of precipitation. The altitude ranges between 600 and 1800 m a.s.l. The soil of the stand is yellow-brown earth, which has neutral to weak acidity (pH 5 to 7.5). The growing season lasts from the end of March to the end of October (Han and Shan, 2005; Zhao, 2010). The Chinese cork oak forest is located at 1200 m a.s.l. to 1800 m a.s.l. in this region, and Chinese cork oak covers over 80% of the stand basal area.

### Plot set up

In September 2010, survey plots were established in four stands (25 ha total), which were similar in origin, species composition, stand age (all about 50 years old), and site conditions. The stands comprised one control stand (10 ha) and three logged stands (5 ha each) with different post-logging times (prior to 2010). Logged stands defined as: 5-years post-logging stand was logged in 2005, 10-years post-logging stand was logged in 2000, and 20-years post-logging stand was logged in 1990. The three stands were logged selectively by cutting 50% of the total basal area, and the cut trees were greater than 5 cm in diameter at breast height (DBH). The control stand was not logged.



**Figure 1.** Location of study stands of Chinese cork oak in Southern China.

Five square plots ( $20 \times 20$  m for each) were established in each stand. The distance between plots was at least 40 m. Five quadrats ( $5 \times 5$  m for each) were set up in the center and four corners of each plot. The quadrats served as shoot survey areas. A total of 100 quadrats (5 quadrats  $\times$  5 plots  $\times$  4 stands) were laid out for the collection of Chinese cork oak recruit data, and 25 quadrats were used as replicates for data analysis of each stand.

### Plot inventory

The plot inventory had two parts. The first part was implemented within the plot. The objects were trees taller than 200 cm, and data included species name, height, DBH, and coordinates (x, y). We also recorded the number of Chinese cork oak trees with acorns (seed tree). The features of each stand based on this inventory are shown in Table 1.

The second part of plot inventory was conducted within the quadrat. The targets were Chinese cork oak shoots with a height of up to 200 cm irrespective of the recruit origin. To identify the origin of shoot, the underground part of each shoot was carefully excavated to determine its connection with the stump, stem, or root system. The shoots were divided into three origins based on this investigation and previous descriptions from other studies on Chinese cork oak and other species (Johnson, 1993; Ky-Dembele *et al.*, 2007; Simões and Marques, 2007; Xue *et al.*, 2012, 2013). The three origins of Chinese cork oak recruit were (1) true seedlings originating from acorn germination, (2) stump sprouts arising from severed stem of tree in response to logging or non-logging disturbances, and (3) stem base sprouts from the base of an existing and living tree. Diameter at soil level (basal diameter) and height of each recruit, and sprout number per stump were recorded. For stump sprouts

**Table 1.** Plot number, quadrat number and four stand characteristics in 2010

Stands	Plot number	Quadrats number	Height (m)	DBH (cm)	Tree density (per 100 m <sup>2</sup> )	Seed tree density (per 100 m <sup>2</sup> )
5-years post-logging	5	25	6.46 ± 0.13 b	7.55 ± 0.30 b	14.59 ± 1.75 b	10.45 ± 1.34 b
10-years post-logging	5	25	6.73 ± 0.12 b	8.57 ± 0.36 b	18.67 ± 2.10 b	15.73 ± 2.15 b
20-years post-logging	5	25	6.63 ± 0.07 b	8.08 ± 0.19 b	32.00 ± 4.01 a	17.90 ± 1.84 b
Control	5	25	11.12 ± 0.19 a	11.73 ± 0.30 a	19.86 ± 2.47 b	22.56 ± 0.95 a
F <sub>3,16</sub>			173.886	39.991	6.433	7.955
p			<0.001	<0.001	<0.05	<0.01

Note: Results of height, DBH and tree density based on the data of the trees taller than 200 cm in each plot. Seed tree density presented the density of Chinese cork oak with acorns. Data were Mean ± SE. The different letters followed SE indicated significant difference at 5% level among four stands after One-way ANOVA and Tukey's test.

and stem base sprouts, basal diameter was measured at the point of sprouting, and height was measured from the point of origin.

## Data analysis

Shoot number was computed using the recruit origin from each quadrat. The density of each recruit origin (number per 25 m<sup>2</sup>) for each quadrat was obtained, and the unit of shoot density was transformed to number per 100 m<sup>2</sup>. The mean density of each recruit origin for each stand was gathered from 25 quadrats. Meanwhile, height and basal diameter of each recruit origin, as well as sprout number per stump, were averaged within each quadrat. The mean height and basal diameter of each recruit origin, as well as mean sprout number per stump for each stand, were collected from 25 quadrats.

One-way ANOVA followed by Tukey's post-hoc comparison tests were performed using SPSS 13.0 (SPSS Inc., Chicago, USA) to test the influence of origin and post-logging time, respectively, on recruit density, height, and basal diameter. The effects of post-logging time on the stand characteristics and sprout number per stump were also tested. An alpha level of 0.05 was used to determine significant differences.

To examine the size structure of Chinese cork oak recruits, shoots from each origin within each stand were grouped into four height classes with intervals of 50 cm (≤50 cm, 51 cm to 100 cm, 101 cm to 150 cm, and 151 cm to 200 cm) and four basal diameter classes (≤1.0 cm, 1.1 cm to 2 cm, 2.1 cm to 3 cm, and 3.1 cm to 5 cm). The density of shoots grouped according to basal diameter and height per recruit origin was calculated, and used to plot graphs in two figures using

software Origin 8.0 (Origin Lab Corporation, Northampton, MA, USA).

## Results

### Regeneration mechanism of Chinese cork oak

For 100 quadrats of 25 m<sup>2</sup> in the four stands, 11,354 Chinese cork oak shoots were recorded, corresponding to a density of 454 shoots/100 m<sup>2</sup>. True seedlings, stump sprouts, and stem base sprouts accounted for 50.0%, 48.5%, and 1.5% of Chinese cork oak regeneration at our study site, respectively. True seedlings and stump sprouts were both observed in all stands, and stem sprouts were only found in the control and 20-years post-logging stands (Table 2).

### Density of different regeneration shoots

The shoot density of true seedlings and stump sprouts significantly varied between the logged stands and control stand. The density of stump sprouts decreased from 164 shoots/100 m<sup>2</sup> in the 5-years post-logging stand to 42 shoots/100 m<sup>2</sup> in the control stand, and true seedlings displayed the opposite pattern. No significant difference in the density of stem base sprouts was observed among the four stands (Table 2).

The statuses of different original recruits varied among the four stands. In the logged stands, stump sprouts were the primary dominant recruits compared with true seedlings and stem base sprouts. The densities of stump sprouts were 23.4, 2.7, and 2.5 times

**Table 2.** Mean density, height and basal diameter of Chinese cork oak shoot recorded per original recruit and per stand in Southern China

Stands	Mean density (shoots/100 m <sup>2</sup> )				Mean height (cm)				Mean basal diameter (cm)			
	True seedling	Stump sprout	Stem base sprout	F <sub>2,72</sub> p	True seedling	Stump sprout	Stem base sprout	F <sub>2,72</sub> p	True seedling	Stump sprout	Stem base sprout	F <sub>2,72</sub> p
5-years post-logging stand	7.0 ± 4.7 <sup>b</sup> <sub>C</sub>	163.8 ± 7.1 <sup>a</sup> <sub>A</sub>	0 <sup>c</sup> <sub>A</sub>	356.51 <0.001	35.6 ± 14.3 <sup>b</sup> <sub>A</sub>	128.6 ± 5.2 <sup>a</sup> <sub>A</sub>	0 <sup>c</sup> <sub>B</sub>	21.40 <0.001	0.3 ± 0.1 <sup>b</sup> <sub>A</sub>	1.2 ± 0.1 <sup>a</sup> <sub>A</sub>	0 <sup>c</sup> <sub>A</sub>	10.24 <0.01
10-years post-logging stand	18.6 ± 9.3 <sup>b</sup> <sub>B</sub>	50.7 ± 10.9 <sup>a</sup> <sub>B</sub>	0 <sup>c</sup> <sub>A</sub>	9.55 <0.01	64.5 ± 13.5 <sup>b</sup> <sub>A</sub>	105.1 ± 15.3 <sup>a</sup> <sub>A</sub>	0 <sup>c</sup> <sub>B</sub>	22.16 <0.001	0.7 ± 0.4 <sup>a</sup> <sub>A</sub>	1.4 ± 0.3 <sup>a</sup> <sub>A</sub>	0 <sup>a</sup> <sub>A</sub>	2.46 >0.05
20-years post-logging stand	20.6 ± 4.4 <sup>b</sup> <sub>B</sub>	52.7 ± 16.7 <sup>a</sup> <sub>B</sub>	2.0 ± 2.0 <sup>c</sup> <sub>A</sub>	6.51 <0.01	55.7 ± 11.5 <sup>ab</sup> <sub>A</sub>	78.5 ± 4.6 <sup>a</sup> <sub>B</sub>	36.1 ± 5.9 <sup>b</sup> <sub>A</sub>	3.57 <0.05	0.5 ± 0.1 <sup>a</sup> <sub>A</sub>	0.7 ± 0.1 <sup>a</sup> <sub>B</sub>	0.2 ± 0.0 <sup>a</sup> <sub>A</sub>	0.98 >0.05
Control stand	93.8 ± 21.1 <sup>a</sup> <sub>A</sub>	42.2 ± 11.2 <sup>b</sup> <sub>C</sub>	2.5 ± 0.8 <sup>c</sup> <sub>A</sub>	10.99 <0.01	45.3 ± 2.9 <sup>b</sup> <sub>A</sub>	83.8 ± 5.2 <sup>a</sup> <sub>B</sub>	77.4 ± 22.1 <sup>ab</sup> <sub>A</sub>	24.24 <0.001	0.5 ± 0.04 <sup>a</sup> <sub>A</sub>	0.7 ± 0.1 <sup>a</sup> <sub>B</sub>	0.7 ± 0.4 <sup>a</sup> <sub>A</sub>	0.89 >0.05
F <sub>3,96</sub>	3.70	8.97	0.45		0.87	17.68	3.25		0.73	15.71	1.90	
p	<0.05	<0.01	>0.05		>0.05	<0.001	<0.05		>0.05	<0.001	>0.05	

Note: Data were displayed by Mean ± SE. The column named as F<sub>2,72</sub> and lower case letters on the up corner after SE presented the results of One-way ANOVA and Tukey's test implemented in each stand, recruit origin was taken as factor, and different letters indicated significant difference at 5% level among recruit origins within one stand. The row named as F<sub>3,96</sub> and capital letters on the down corner after SE present the results of One-way ANOVA and Tukey's test conducted to one recruit origin among four stands, and different letters indicated significant difference at 5% level among four stands for one original recruit.

greater than that of true seedlings in the three logged stands, respectively. True seedlings were the most common recruits in the control stand (Table 2).

### Patterns of size-class distribution

The height of Chinese cork oak shoots ranged from 3 cm to 200 cm. The mean shoot height among the three original recruits significantly differed. Stump sprouts were the tallest, followed by true seedlings or stem base sprouts (Table 2).

The density of true seedlings and stem base sprouts declined with increasing height class in both the logged and control stands. For stump sprouts, the height class distribution pattern varied between the logged and control stands. In the control stand, the density of stump sprouts decreased with increasing height class. In the 5- and 10-years post-logging stands, more sprouts were found in the third and fourth height classes (100 cm to 200 cm). In the 20-years post-logging stand, the largest density of stump sprouts was found in the second height class (51 cm to 100 cm) (Fig. 2).

The basal diameter of recruits was between 0.1 and 5.0 cm. Stump sprouts had the greatest mean basal diameter, followed by true seedlings or stem base sprouts in all stands. A significant difference in the basal diameter among the three original recruits was

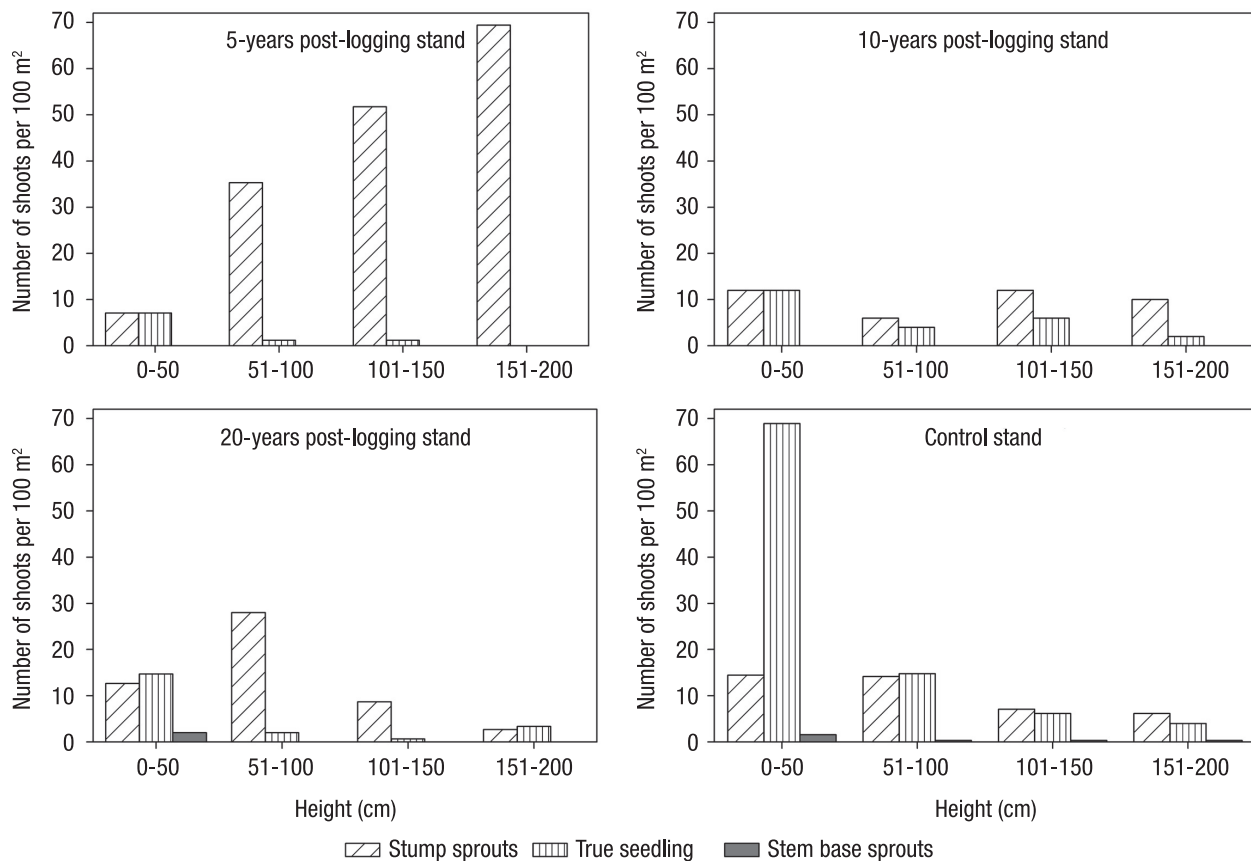
only observed in the 5-years post-logging stand (Table 2). For all types of recruits, abundant shoots were all observed in the lowest basal diameter class (0 cm to 1.0 cm), and the recruit density declined with increasing basal diameter class (Fig. 3).

### Number of sprouts per stump

The sprout number per stump ranged from 1 to 17, and was significantly different among different stands (F<sub>3,96</sub> = 4.31, p < 0.01). The mean number of sprouts per stump was greatest in the 5-years post-logging stand (4.71 ± 0.77 sprouts per stump), and this parameter in the remaining stands was almost equal (2.22 ± 0.40, 2.55 ± 0.27, and 2.91 ± 0.31 sprouts per stump) (Fig. 4).

### Discussion

Shoots from sexual (true seedlings) and asexual origin (stump sprouts and stem base sprouts) can be found in both disturbed and undisturbed forests (Kammesheidt, 1998, 1999; Ky-Dembele *et al.*, 2007). However, the statuses of sexual and asexual recruits in forest recovery vary in different habitats and recovery stages (Simões and Marques, 2007; Ky-Dembele *et al.*, 2007). In the present study, both true seedlings and

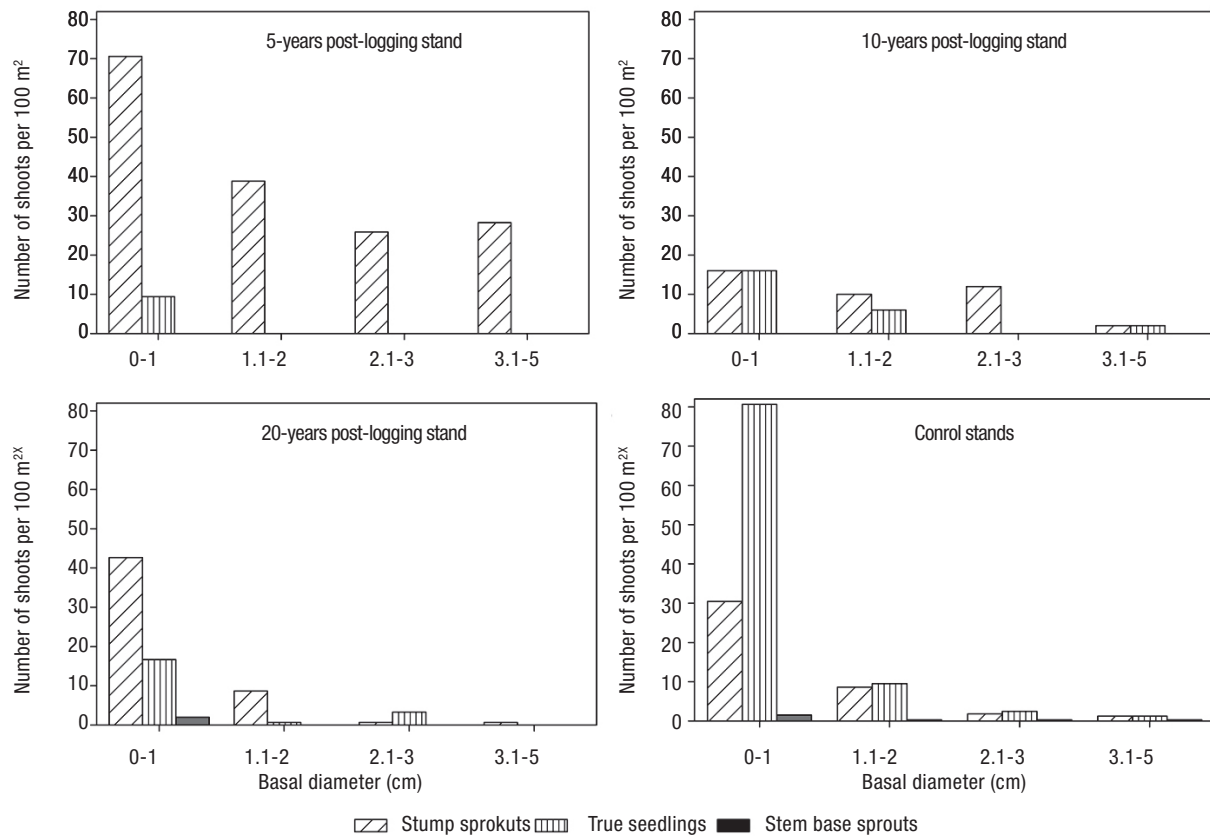


**Figure 2.** Height class distributions of Chinese cork oak recruits per stand for true seedlings, stump sprouts and stem base sprouts in Southern China.

asexual recruits (stump sprouts and stem base sprouts) of Chinese cork oak were found in the logged and unlogged stands. Sprouts (mainly stump sprouts) were the predominant recruits in the logged stands, whereas true seedlings dominated the unlogged stand. According to the model of Bellingham and Sparrow (2000), asexual recruits are favored over sexual shoots in disturbed forests, but this preference is reversed when the disturbance is moderate and rare. Wu *et al.* (2001) reported that the Chinese cork oak population recovers mainly through asexual regeneration under intense disturbance. Our results in the present study were consistent with those from previous studies because 50% logging is an intense disturbance for a forest.

The dominant status of stump sprouts declined with the extension of post-logging time for Chinese cork oak. However, opposite results were reported in the study of Kammesheidt (1999), who focused on other species, in which the proportion of sprouts from the youngest logged stand (5 years old) to the oldest logged stand (19 years old) and mature forest slightly in-

creases from 10% to 16% and 17% in Venezuela. This increasing trend was explained by the removal of many stumps from the ground immediately after logging. By contrast, the stands in our study were completely protected after logging, and all stumps remained in the stands. Stump sprouts have long been considered as important natural recruits in disturbed forests because of their abundant number and rapid growth (Gardiner and Helmig, 1997; Hoffmann, 1998; Miller and Kauffman, 1998; Silla *et al.*, 2002; Luoga *et al.*, 2004; Lockhart and Chambers, 2007). However, the production of stump sprouts depends on the formation of stumps, which are affected by disturbances, such as logging, naturally fallen trees, animal injury, and fire. In the early stage after disturbance, numerous stumps formed, followed by a period of abundant stump sprouts. However, as the time after disturbance increased, some stumps became rotten or died, and the sprouting capability of live stumps decreased because of vitality loss associated with aging (Kaupi *et al.*, 1988, Rong L *et al.*, 2013; Xue *et al.*, 2013). Thus, the

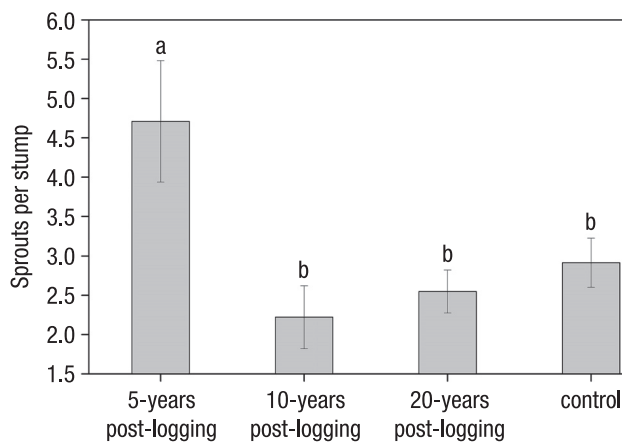


**Figure 3.** Basal diameter class distributions of Chinese cork oak recruits per stand for true seedlings, stump sprouts and stem base sprouts in Southern China.

number of stump sprouts declined, and their dominant position was gradually replaced. In our study, the abundance of stump sprouts in the middle and higher height classes, as well as the decreasing density of small sprouts in the logged stands, suggests the decline in stump sprouting capability and sprout survival rate of Chinese cork oak with increased post-logging time. This result was consistent with other studies those focused on *Ilex pedunculosa* Miq., *Rhododendron arboreum* Smith, *Q. liaotungensis* and *Q. variabilis* (Imanishi *et al.*, 2010; Ashish *et al.*, 2010; Rong *et al.*, 2013; Xue *et al.*, 2013). The height structure of sprouts in Chinese cork oak also indicated that the contribution of stump sprouts to forest recovery was important and indispensable in the early stage after disturbance.

Density and size structure of true seedlings affected their status in the forest recovery process. The density of true seedlings may be affected by numerous factors, such as mature seed tree density, seed dispersal and predation, and soil and climate conditions related to seed germination and survival (Miller and Kauffman, 1998;

Côté *et al.*, 2003; Ky-Dembele *et al.*, 2007; Ma *et al.*, 2010). In the present study, true seedlings were the primary Chinese cork oak recruits in the unlogged stand (94 shoots/100 m<sup>2</sup>), and the density of true seedlings increased with increasing post-logging time in the logged stands (7 shoots/100 m<sup>2</sup> to 21 shoots/100 m<sup>2</sup>). The low density of true seedlings in the stands in the early stage after logging could be explained by the low density of Chinese cork oak with acorns (seed tree) in these stands compared with the unlogged and logged stands in the late stage of recovery. Moreover, high seed predation by small animals and seed rot caused by disease in the logged stand also reduced the available acorn number in the soil seed bank, as observed by Ma *et al.* (2010), who investigated a Chinese cork oak forest in Qinling Mountains. Ma *et al.* (2010) reported that soil drought stress caused by loss of overstory trees may result in low seed germination rate or high sapling mortality for Chinese cork oak in logged stand or forest gap. Size structure may also be associated with the contribution of recruits (Zhang *et al.*, 2003). In the



**Figure 4.** Sprout number per stump of different stands in Southern China. The different letters above error bars indicated significant difference at 5% among stands after One-way ANOVA and Tukey's test. Bars were Mean  $\pm$  SE.

present study, the height and basal diameter distributions of true seedlings in all stands showed the same trend, in which the increase in size led to the decrease in density of true seedlings. Most of the true seedlings (>80%) were classified into the lowest class, and this ongoing size structure was also observed in other species (Teketay, 1997; Ky-Dembele *et al.*, 2007). Thus, the contribution of true seedlings to Chinese cork oak forest recovery may be limited in the early stage after disturbance caused by low seed tree density and high mortality of sapling, but ongoing size structure will benefit long-term development and consistency in the group of true seedlings.

Stem base sprouting occurs in uncut stems (Kammesheidt, 1999), and was observed and recorded in some species (*i.e.*, *Burkea Africana* Hook., *A. dudgeoni*, and *D. microcarpum*) in the savanna woodland in Burkina Faso, called as water sprouts (Ky-Dembele *et al.*, 2007). Simões and Marques (2007) pointed out that stem base sprouting is associated with stem damage. Observations in our study area suggested that damage of Chinese cork oak was caused by falling neighboring trees and overstory branches and mammalian behavior (including human damage). Stem sprouts were only observed in the 20-years post-logging stand and control stand. This result may be due to the risk of damage by fallen branches of overstory trees and herbivores in these stands, which were much higher because of high density canopy overstory trees and understory plants in the stands. The same phenomenon was also observed by Guariguata (1998) and Paciorek *et al.* (2000) in other forests. In our study, the stem base sprouts had

no competitive advantage compared with true seedlings and stump sprouts because of their lower density, smaller mean height, and basal diameter. Therefore, sprouting from a damaged part of Chinese cork oak tree may occur, but it is regarded as an accidental event and most likely to be a survival strategy rather than a reproductive strategy. The advantage of stem base sprouts is that they can replace the parent tree immediately once the parent stem falls or dies, thereby occupying its niche.

The difference in the development between stump sprouts and true seedlings has been reported by numerous studies (Hoffmann, 1998; Miller and Kauffman, 1998; Winkler and Fischer, 2002). In our study, stump sprouts of Chinese cork oak were taller and bigger than true seedlings in both the logged and unlogged stands; this result was consistent with those of previous studies. The greater height and basal diameter of stump sprouts caused by rapid development could be attributed to the established root system, which could offer more surface area for water and nutrient uptake (Cruz *et al.*, 2002; Kennard *et al.*, 2002), thereby providing sprouts a competitive advantage for occupancy, survival, and dominant regeneration position in forest recovery (Lockhart and Chambers, 2007). The lower height development of true seedlings may be explained by the fact that seedlings invest great nutrition and energy to develop a completed root system first, whereas repeated shoot dieback caused by herbivores can result in lower heights (Ky-Dembele *et al.*, 2007). High mortality caused by less light, drought stress, and herbivores during establishment (Ma *et al.*, 2010) can also lower the mean height of true seedlings. In the present study, the difference in mean height between stump sprouts and true seedlings shrank as the post-logging time increased. The rapid development of stump sprouts was more obvious in the early stage after logging, which was confirmed by other studies on other oaks (Lockhart and Chambers, 2007; Xue *et al.*, 2013; Rong *et al.*, 2013). Stump sprouting is a process that consumes energy and resources, as reflected by the sharp decline in starch content in the root system of the stump after sprouting (Bowen and Pate, 1993; Bell and Ojeda, 1999), and decrease in carbohydrate and nutrients in the stump and root system with increasing harvesting age (Lockhart and Chambers, 2007). Midgley (1996) proposed a trade-off between sprouting and height growth for stump sprouts; the production of new sprouts may influence the height increment of old



sprouts. This trade-off was also reported in *Q. liaotungensis* (Rong *et al.*, 2013).

## Conclusions and recommendations for management

This study revealed the presence of both asexual (stump sprouts and stem base sprouts) and sexual (true seedling) regeneration recruits for Chinese cork oak in the southern area of Qinling Mountains. Asexual shoots (mainly stump sprouts) were the predominant recruits of Chinese cork oak in the logged stands, whereas true seedlings were predominant in the unlogged stand. The dominant position of stump sprouts declined as the post-logging time increased, so their contribution to forest recovery may be more important in the early stage after disturbance. Stem base sprouts had no competitive advantage compared with true seedlings and stump sprouts, and were most likely to be a survival strategy rather than a reproductive strategy. Low density and high mortality of true seedlings limited their contribution to forest recovery in the early stage after disturbance, but the ongoing size structure of this type of recruit will benefit their long-term development and consistency. The development of true seedlings was slower than that of stump sprouts, so more emphasis should be given to protect true seedlings from further disturbance. From the perspective of maintaining sufficient genetic variation in selectively logged stands, the amount of true seedlings should be maintained at a reasonable level by protecting seedlings and/or increasing the sowing density when implementing artificial regeneration. Nevertheless, further studies should be carried out to: 1) examine how long the stump can produce new sprouts, 2) determine if a trade-off exists between sprouting and seed product of clone individuals, and 3) investigate whether the persistent niche of stump sprouts will reduce species richness and natural succession of a Chinese cork oak forest.

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