Comparison of tree sprouting in three regeneration stages of an evergreen broadleaved forest in a karst landscape, SW China

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ABSTRACT

Little is known about the role of tree sprouting in the regeneration of karst forest communities. In Shilin Stone Forest Geographical Park, southwestern China, all genets with the largest stem ⩾3 cm DBH (diameter at breast height) and/or stumps ⩾3 cm BD (basal diameter) were identified and number of sprouts counted in 10 transects (10 m × 100 m) in each of three evergreen broadleaved forest stands representing three regeneration stages (about 10, 20, and 30 years old). Species with >10 genets accounted for 72.4% of the 76 species, and all of them showed evidence of sprouting. One-third to two-thirds of the genets in the three forests were sprouting, with an average of 4.0–5.7 sprouts per sprouting genet. Sprouting capability (sprouting genets/total genets) and intensity (sprouts per sprouting genet) differed significantly among the three forest stages. More than 90% of the damaged genets were sprouting. The number of sprouts in a non-damaged genet was determined by intrinsic sprouting ability, and the number of sprouts in damaged genets was determined by stump size. As the forest developed, percentage of damaged genets increased, the portion of shoots ⩾3 cm DBH co-existing in a genet decreased, and the portion of shoots <3 cm DBH sprouted from damaged genet increased. Thus the role of sprouting changed from contributing recruitment in the young stage to persistence in the later stage.

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1. Introduction

Trees have two modes of regeneration: sexual reproduction by seedlings and vegetative recruitment by sprouts. Sprouts grow much faster than seedlings and can quickly re-occupy their own gaps when a tree is blown over or damaged because of the already established and functioning root system [1]. In contrast, some species with apparently non-damaged trees have a sprout bank independent of disturbance, and these trees are replaced by their sprouts [2,3]. Sprouting ability can have a major impact on plant populations by reducing turnover of genets [4,5] and minimizing effects of disturbance [6,7] via recruiting new sprouts; and increasing *in situ* persistence [5]. The study of sprouting has been recommended as a means of extending our understanding of plant traits and functions in forest communities [3,5,8]. However, most existing observations are based on damaged or coppiced genets, and the other genets, which may play different functional roles, have been excluded. Consequently, the status and functional role of sprouting in forest dynamics are uncertain.

Sprouting is a result of the species' intrinsic abilities combined with specific environmental cues. In a particular environment, some species/individuals will never sprout, while others have a strong tendency to sprout [9]. Sprouters tend to be more numerous in harsh, unstable conditions [10,11] and in less-productive sites [12]. The incidence of sprouting species varies greatly with forest types and environmental variation [13–16]. Sprouting intensity is largely determined by amount of carbohydrates stored in the roots [1] and by frequency and severity of disturbance [9,10]. On a continuum of forest development from the early stage toward the climax stage, forests differ in species composition, structure, and function [17], and individual trees, whether sprouters or not, will experience different biotic and abiotic environments and be subjected to different ongoing disturbances. Thus, incidence and intensity of sprouters, together with the functional role of their sprouts may vary. However, few of studies have focused on sprouts' contributions to this process [3,18].

Karst landscapes and hydrological systems on limestone and other soluble rocks, which are distributed widely throughout the world [19], are highly fragile environments, and they are vulnerable to a variety of disturbances. Thus they should be suitable sites for sprouting studies. In a typical karst slope, soil and water are easily lost into the epikarst and deeper underground, where they are routed through caves to the springs at the regional boundaries.

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As a result of this, a rocky and stony land surface with bedrock pinnacles is formed. Plants growing on the remaining shallow soil in between these pinnacles may be stressed by shortage of water and soil nutrients, which cause them to die [20–22]. Thus, a karst environment may induce high frequency and low intensity of tree sprouting. Many karst areas have been densely populated by humans and thus heavily impacted for hundreds of years. Not surprisingly, modification by human activities will strongly impact regeneration of forest and water/soil runoff features. Forest regeneration after human modification of the landscape is a long process, and it consists of several stages. The vulnerable abiotic karst environment may vary greatly from one stage to the other and thus have a strong influence on sprouting capability and intensity. However, there have been relatively few studies done on sprouting regeneration by trees in such sites.

The karst area in southern China is one of the largest in the world, covering more than 500,000 km^2 [23]. Various types of evergreen broadleaved forests grow in this karst area across a wide range of climate conditions [20]. Although sprouting is known to occur often in karst forests in SW China [24–28], the importance of this method of regeneration has not been quantified at the community level. Thus, we studied three karst forests in different regeneration stages in a typical karst area in southern China. Evidence of sprouting of each genet in which the main stem was ≥3 cm DBH (diameter at breast height) and /or the stump ≥3 cm BD (basal diameter) and number of sprouts were documented and analyzed to compare the capability and intensity of tree sprouting in these forests. The purposes of our study were to: (1) determine sprouting capability and intensity of each tree species; (2) compare role of sprouting in the three stages of forest regeneration; and (3) compare sprouting in forests of southwest China to that in forests in other parts of the world.

2. Material and methods

2.1. Study sites

The study was carried out in Shilin Stone Forest Geographical Park (SGP) (24°38́–24°58́N, 103°11́-103°29́E), a karst geo-park famous for its various stone forest landforms. The climate is subtropical and semi-humid. Mean annual temperature is 16.2 °C, mean maximum temperature of the warmest month (July) is 20.7 °C, and mean minimum temperature of the coldest month (January) is 8.2 °C. Average annual precipitation is 967.9 mm, 80% of which falls between May and October [29]. The moderate temperature period from late spring to early autumn coincides with the rainy season and this favors plant growth [20]. Dissolution on the exposed limestone bedrock surface produces both soil and bare rock outcroppings at the surface of upland terraces. The small size of rock gaps, rock ditches, small rock caves, and rock slots are typical surface forms on the ground, and soil is distributed in or between these various rock surface forms [29]. Water and nutrients are the main limiting factors for plant growth in these shallow soil patches, especially during the dry season.

The zonal vegetation type on this karst land is semi-evergreen broadleaved forest dominated by *Cyclobalanopsis glaucoides*, *Olea yunnanensis*, and *Neolitsea homilantha* [20,30]. Historically, agricultural practices were rudimentary, with subsistence cultivation in SGP. Rapid growth of the human population in this area resulted in intensive clearing of forests, especially in the last century. Forest cutting for fuel wood and burning to clear land for cultivated crops and pastures occurred in this area. However, in the past decades, under the efforts of the SGP authority, local government and villagers living within SGP, some mountains and hills were closed and then forest patches regenerated naturally. Three forests (SF1, SF2,

SF3) with different closing and regenerating time schedules were selected for this study. The three forests have very similar abiotic environments. The altitude of the three sites is about 1900 m, slopes are 10°–20°, and soil surface/rock surface ratio is 2:3. SF3 is about 30 years old and contains two tree strata, canopy height is 5.1 m and average DBH 8.0 cm. SF2 is about 20 years old and contains only one canopy stratum; canopy height is 3.5 m and average DBH 5.7 cm. SF1, which has been generating for about 10 years, has a canopy height of 3.3 m and an average DBH of 4.1 cm. Shen et al. (2005) described the floristic composition and community structure of SF3 and SF2 in detail [31]. The SGP authority declared that while these three forest stands were strongly preserved, removal of dead and broken tree trunks was allowed, leaving the stumps in place. This natural dying or breaking of stems was treated as damage to the genets in this study.

2.2. Sprouting survey and statistical analysis

Ten transects 10 m in width along the slope were established in each of the three forest stands and each transect was divided into 10 quadrats (10 m × 10 m) with plastic lines. Sprouting surveys were carried out in each of those quadrats.

We refer to each individual plant as a genet, even if it had only one stem, and each stem in a genet as a shoot (ramet). All shoots of the genet originated from a seed, and they were morphologically connected by roots. In a genet with multiple shoots, shoots that generated other shoots are referred to as the main shoot and the others as sprouting shoots. Once the main shoot was damaged or dead below breast height, we considered it to be a stump. In each quadrat, genets with the main shoot ≥3 cm DBH and/or with the stump ≥3 cm BD were carefully checked, DBH or BD measured, and number of sprouts counted. Connection of shoots by roots was checked by excavation whenever there was any uncertainty. If a sprouting genet was recorded for a species in the forest, this species was considered "able to sprout"; otherwise, it was "unable to sprout". Since sprouting was strongly influenced by disturbance regimes and varied among study sites, a species that sprouted in one forest might not sprout in the others. For consistency, once a species sprouted at one of the three forests, we considered it "able to sprout" in all three of them.

The sprouting rate (SR) was calculated as number of sprouting genets/total number of genets to indicate the sprouting capability of a species and forest stand. To assess the intensity of sprouting, average sprouts per genet was calculated and compared among the three forests, and then genets were divided into five categories: 0, 1–5, 6–10, 11–15, ≥16 sprouts per genet to check the distribution pattern. Presence of a stump was taken as an indicator of damage, and then all genets were categorized into two groups: damaged genets with stumps and non-damaged genets without stumps. Sprouting rates and intensities were compared between these two groups. Some genets may be capable of sprouting, yet left no sign of it during the survey. Therefore, we might have underestimated some sprouting rates. It was difficult to distinguish sprouts and resprouts, especially in genets that had both shoots and stumps. Thus, we treated all of them as sprouts.

One-way ANOVA followed by Duncan's Post Hoc Tests were used to test for differences in capability and intensity of sprouting among the three forest types. Differences in capability and intensity of sprouting among species were tested with likelihood-ratio Chi-square tests. All the sprouting genets that were not damaged (751) were selected and grouped into six classes to evaluate the relationship of DBH of the main shoots and average number of spouts *via* ANOVA. To assess effects of stump size on sprouting intensity, all genets with stumps (654) were selected and then divided into seven BD classes. One-way ANOVA followed by