https://doi.org/10.26525/jtfs2018.30.1.3948

EFFECTS OF GAP SIZE AND LOCATIONS ON THE REGENERATION OF *CASTANOPSIS KAWAKAMII* IN A SUBTROPICAL NATURAL FOREST, CHINA

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Submitted February 2017; accepted August 2017

Castanopsis kawakamii is an endangered tree species due to its low population in the middle stage of development and low percentage of seedlings in natural conditions. The present study explored whether a forest gap has the potential to promote the regeneration of *C. kawakamii* seedlings, and examined favourable locations for seedling regeneration within the gap. Nine sampling gaps were classified into small, medium and large sizes. The number of *C. kawakamii*, their basal areas and height at four stages (tree, sapling, shrub and seedling) in five locations within the gap (center, south, east, north and west) were determined during the growing season. A significant positive relationship was found between the number of *C. kawakamii* and gap area (r = 0.815, p = 0.007), with higher numbers in large gap size (p = 0.031) compared with small gap size. The number of *C. kawakamii* was predicted by a linear regression model: Number of *C. kawakamii* = 0.124 × gap area + 10.597, R^2 = 0.664. Moreover, the number and size of seedlings in the center of the gap were significantly different (p = 0.041, p = 0.017) from other locations within the gap. Management for *C. kawakamii* should move forward to provide suitable conditions for regeneration by focusing on the centre and large gap areas.

Keywords: Forest gap, seedling regeneration, micro-environment, location within gap

INTRODUCTION

Forest gap created by forest disturbance is important in maintaining forest diversity. Gap creates a micro-environment different from that of a closed canopy forest, and it is important for species regeneration (Yamamoto 2000). Inside the gap area, the micro-environment, such as light (Gray et al. 2002), temperature, vapor pressure deficit, litter moisture (Matlack 1993), soil water content (Wang et al. 2013) and soil chemical properties (Özcan & Gökbulak 2015) differed with the gap size and the location within the gap. Gap sizes and locations within the gap have an effect on plant composition and traits, which is dynamic over time (Kern et al. 2012). The higher survival rate of chestnut (*Castanea dentata*) in North American forest was found in gap area, than under the canopy (Dalgleish et al. 2015). The quantity demand of resources for each species differ, therefore, micro-environmental heterogeneity within the gap encourages species diversity and supports species regeneration and growth (Veblen 1989, Barik et al. 1992, Svenning 2001, Muscolo et al. 2014).

Castanopsis kawakamii, a member of the Fagaceae family, is an endemic species of southeast China, particularly in Fujian, Guangdong and Jiangxi Province. It is also a native species that is widely distributed in Taiwan and north Vietnam. The *C. kawakamii* is categorised as lower risk/near threatened in The IUCN Red List of Threatened Species (IUCN 1998). Research on the population dynamics of this species noted that the period of seed and growth were highly sensitive to disturbances, and the population mainly exist in matured stages (Liu & Hong 1999). The lack of middle stage *C. kawakamii* causes a decline of the entire population structure (Liu et al. 2011), which may soon disappear. As mentioned above, the effect of forest gap on species regeneration has encouraged many researchers to study *C. kawakamii* in a natural forest reserve area.

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Studies on *C. kawakamii* in Sanming City Natural Forest Reserve showed that size and development stage of the gap affected the index which had an effect on species diversity in regeneration layers (Liu et al. 2003 & He et al. 2012). Studies of microclimate in forest gaps have noted that the air temperature, soil temperature and relative humidity in different gap sizes were highly significant, which were higher than canopy area (He et al. 2012a). The higher regeneration niche width of *C. kawakamii* in gaps, than under-canopy, shows the improvement of *C. kawakamii* regeneration (He et al. 2012b). Studies have shown that microclimates differ by gap size and location within the gap, and clearly affects *C. kawakamii* regeneration. However, studies on the most suitable site within the gap for *C. kawakamii* regeneration is still lacking. Relatively, little is known about favorable locations within the gap for *C. kawakamii* regeneration. Thus, the objectives of this study were 1) to estimate the gap size for *C. kawakamii* regeneration and 2) to examine suitable sites within the gap area for *C. kawakamii* regeneration in the *Castanopsis kawakamii* Natural Forest Reserve in Sanming City, Fujian Province, China. We expected that 1) gap size may affect the number of *C. kawakamii* and 2) the number of *C. kawakamii* will be different in different locations within the gap due to micro-environmental heterogeneity. The results from this research will help to develop a better understanding of gap micro-environmental effects on *C. kawakamii* regeneration, conservation and management in the *C. kawakamii* Natural Forest Reserve.

MATERIALS AND METHODS

Site descriptions

The *C. kawakamii* Natural Forest Reserve in Sanming City, Fujian Province, China, was select as the study site. It is located at 26° 10'–26° 12' N and 117° 26'–117° 28' E. Wuyi Mountains is the boundary on the northwest, while the southeast of the site adjoins Daiyun Mountains. This area comprises the evergreen broad-leaf forest of *C. kawakamii* species, with a middle subtropical monsoon climate. The average annual temperature is 19.5 °C, of which the lowest temperature is -5.5 °C and the highest is 40 °C. The mean annual relative humidity is 81%, and the average annual rainfall is 1,749 mm. Most of the rainfall (79%) occurs from March to August (Liu et al. 2009). This *C. kawakamii* forest in the National Nature Reserve comprises large areas (approximately 700 ha) of highly pure stands of *C. kawakamii* (> 80%)), with an average tree age of approximately 150 years (Lin & Qiu 1986, Zhang 1993).

Gap areas and environmental factors measured

The naturally formed forest gaps were selected using the following sampling method. The mother tree distances were controlled, i.e. every selected gap or under canopy area were approximately at a similar distance from the mother tree. The gap area was measured by taking a photo from the center of each gap, using a fish-eye-lens camera, and calculating the area by using a computer software (Adobe Illustrator CC 2014). Two hemispherical photographs (THP) method was used to calculate the gap areas (Hu & Zhu 2009). The under-canopy areas were selected and plot sizes of 15 m × 15 m were established. Tree heights around the gaps were approximately 15 to 30 meters. The nine gap areas were classified into three sizes: small, medium and large. The topographical factors and features of each gap are shown in Table 1. In each gap, after measuring the width and length of the gap, a grid (3 m × 3 m) system was made to cover the entire gap and canopy areas (Figure. 1). At every point, the environmental factors (air temperature, air humidity and light intensity) were measured. The air temperature and air humidity were measured using TES-1360A handheld digital thermo-hygrometers. The light intensity was measured using a light-intensity meter. The soil temperature and soil water content were measured by using a 6300-needle soil thermometer and a TZS-IIW soil moisture and temperature measuring instrument. A soil sample was collected from each point at 0–20 cm depth for soil chemical properties analysis. A core-soil-sampling with a capacity of 200 cm^3 was used to collect soil samples for analysis of physical properties. The soil samples were preserved in a sealed plastic bag and sent to the laboratory for analysis. All samples were collected in the growing season (July 2014).

Table 1 Topographical factors and features of each forest gap at the study site

Gap no factor	Small gap size			Medium gap size			Large gap size		
	1	5	6	3	7	8	2	4	9
Topographical									
slope	30°	10°	28°	32°	32°	30°	33°	34°	21°
Altitude (m asl)	236.4	226.7	246.9	275.4	300.0	262.3	249.5	283.7	226.8
Slope direction	E→W	N→S	S→N	S→N	S→N	N→S	E→W	E→W	E→W
Gap feature									
Gap area (m^2)	34.78	30.28	48.52	81.25	72.84	81.50	216.72	182.56	198.59
Gap maker	Branch fall	Branch fall	Branch fall	Tree fall	Tree fall	Tree fall	Trees fall	Trees fall	Trees fall
Gap stage [a]	Early	Medium	Later	Medium	Early	Later	Medium	Later	Early

[a] = secondary data (He 2012)

Castanopsis kawakamii population investigation

In each gap, plots sizes of 5 m × 5 m were set in five directions (center, south, east, north and west) (Figure 1). The *C. kawakamii* plants were classified into four stages based on their height and diameter at breast high (DBH): tree (> 2 cm DBH, height 5–15 m), sapling (< 2 cm DBH, height 2–5 m), shrub (height < 2 m) and seedling (height < 0.5 m). The *C. kawakamii* plants in each plot were counted, and the height and DBH of the trees and saplings were collected. The basal diameter (BD) and height of the shrubs and seedlings were measured. Data were collected in the growing season (July 2014).

Soil analysis

The soil acidity (pH) was determined using a pH meter on 1:1 soil suspensions (Jackson 2005). Organic matter content (OM) was determined by the Walkley and Black Rapid Titration Method (Walkley & Black 1934). Available nitrogen was calculated as the sum of ammonium nitrogen (NH_4-N) and nitrate nitrogen (NO_3-N). Available phosphorus (AP) was extracted using 0.5 Mol L^{-1} $NaHCO_3$ solutions, determined by the Mo-Sb calorimetry method. Available potassium (AK) was extracted with ammonium acetate and measured by flame atomic absorption spectrometry. Total nitrogen and carbon were measured using a CN Machine Model Vario Max CN Element Analyser (GmbH). The value is expressed in percentage (%) of N and C, and CN^{-1} ratio. Total phosphorous and potassium were calculated by digesting the soil using H_2SO_4–$HClO_4$ method and measuring the level as described in AP and AK. The soil physical properties were measured based on the forest soil analysis reference (Zhang et al. 1999). All samples were analysed in triplicates.

Data analysis

The variation of the number of *C. kawakamii* among and between three groups of gap sizes and gap directions was conducted by one-way ANOVA, and multiple comparisons by Tukey post-hoc test method ($p < 0.05$). The relationship among the numbers of *C. kawakamii* and the gap area was estimated by linear regression. The Pearson correlation was used to analyse the relationship between each variable (Steel & Torrie 1980). The stepwise multiple regression models were used to analyse the relative importance of environmental factors and soil variables for the numbers of *C. kawakamii* in each gap size. The environmental factors and soil variables in each forest gap were divided into five directions: center, south, east, north and west. The total number, number of trees, number of saplings, number of shrubs and number of seedlings of *C. kawakamii* were dependent variables. The environmental and soil factors were independent variables. The average, maximum and minimum values of the data were processed using SPSS for Windows Version 16.0.

RESULTS

Gap area, gap position and numbers of *Castanopsis kawakamii*

The average values of environmental factors in each gap size and under-canopy areas are shown in Table 2. The total number of *C. kawakamii* was

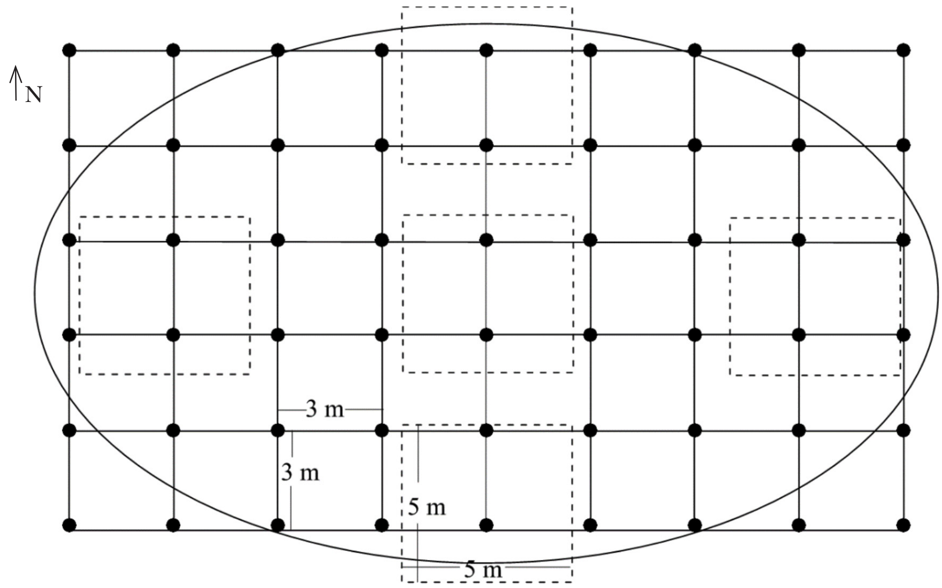

Figure 1 Grid system (3 m ×3 m) in each forest gap and under-canopy areas for investigation of soil and climate factors; oval = gap area, black dots = climate soil sampled points and dashed square = plant collecting plots in five directions

Table 2 The average value of environmental factors in each gap size and under-canopy areas

Gap size	Average value of environment factors				
	Light intensity (lux)	Soil temperature (°C)	Soil water content (%)	Air temperature (°C)	Air relative humidity (%)
Small	871.21	27.14	26.93	29.33	77.91
Medium	1529.67	27.39	34.84	30.03	79.41
Large	1655.19	28.68	31.66	30.55	77.40
Under-canopy	729.64	26.58	31.50	29.40	70.84

investigated in four stages in each forest gap. The total number and size of *C. kawakamii* are shown in Table 3. A strong positive significant correlation was found between total number of *C. kawakamii* and gap area (r = 0.815). Gap area had a positive significant correlation with the number of shrubs (r = 0.587) and seedlings of *C. kawakamii* (r = 0.762), whereas a negative significant correlation with the number of *C. kawakamii* trees (r = -0.595), where maximum number of trees were found in under-canopy areas.

The strong correlation between number of *C. kawakamii* and area of a gap prompted us to predict the number of *C. kawakamii* by gap areas (Figure 2). To conduct this model, linear regression was used to predict the number of *C. kawakamii* with area of the gap. The following equation shows the relationship between gap area and number of *C. kawakamii*.

Number of *C. kawakamii* = 0.124 × gap area + 10.597, $R^2 = 0.664$, $p = 0.007$.

The effect of gap size on the number of *C. kawakamii* showed that the average number of *C. kawakamii* had statistically significant differences between the three groups of gap sizes, as the bar graph shown in Figure 3a. At the center of the gap, the number and size (BD) of *C. kawakamii* seedling were significantly different between the three groups of gap sizes, as the bar graph shown in Figure 3b.

Castanopsis kawakamii and micro-environment within the gap

In small gap size, the total number, number of trees, saplings and seedlings of *C. kawakamii* were significantly correlated with capillary water capacity (CWC), minimum water-holding

Table 3 The total number and total size [(DBH or BD (cm)] of *C kawakamii* at each stage of the *Castanopsis kawakamii* Natural Reserve Forest in Sanming City, Fujian Province, China

Gap size	Numbers/ DBH or BD (cm) of *Castanopsis kawakamii* at each stage				
	Tree	Sapling	Shrub	Seedling	Total
Small	6/154.2	10/8.9	4/12.55	23/5.8	43/181.45
Medium	3/128	19/30.2	12/12	30/7.05	64/177.25
Large	1/80	36/12	8/33.4	61/21.55	106/146.95
Under-canopy	9/253.4	1/3.2	2/2.5	0/0	12/259.10

DBH = diameter at breast high, BD = basal diameter

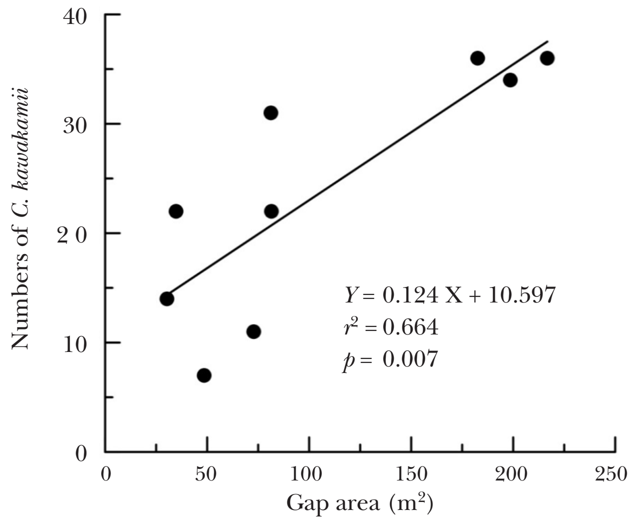

Figure 2 Correlation between gap area and number of *C. kawakamii* expressed as: number of *C. kawakamii* = 0.124 × gap area + 10.597, R^2 = 0.664, p = 0.007, n = 9

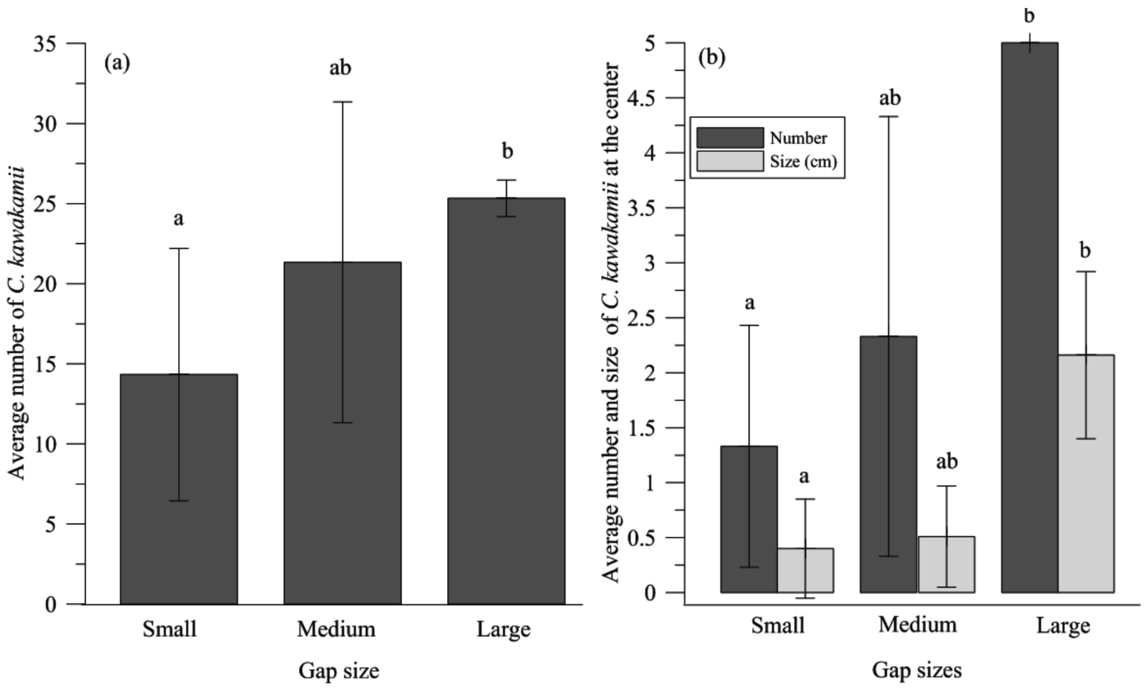

Figure 3 Bar graph and statistical analysis of (a) average number of *C. kawakamii* in each gap size and (b) average number and size of *C. kawakamii* at the center (ANOVA, Tukey's post-hoc test, p < 0.05); error bar shows the standard deviation value; different letters over error bars indicate statistically significant results

capacity (MWHC), relative humidity (RH), nitrogen content (N), soil volumetric moisture content (SVMC), soil total porosity (STP) and soil water mass content (SWMC). In medium gap size, the number of shrubs and seedlings were significantly correlated with available phosphorous (AP), available potassium (AK) and STP. The results of large gap size revealed that the number of trees, saplings, shrubs and seedlings of *C. kawakamii* were significantly correlated with soil temperature at 5 cm, STP, pH, SWMC, maximum moisture capacity (MMC), enzyme phosphatase activity (PA), AP, AK, air temperature (AT), RH, CWC and the soil aeration degree (SAD). Equations to predict dependent variables are shown in Table 4. In under-canopy areas, no significant correlation was found between number of *C. kawakamii,* in the four stages, and environmental factors and soil variables.

DISCUSSION

Gap areas and number of *Castanopsis kawakamii*

The results showed that the number of *C. kawakamii* was affected by gap area, similar to a study on bamboo, *Fargesia denudata,* in which higher numbers were observed in large gap size (Kang et al. 2015), as high light levels in large gap size activates plant growth. The percentage of seedling survival of *Castanea dentata* in eastern North American forests was higher in gaps than in non gaps (Dalgleish et al. 2015). Sapkota and Odén (2009) studied the effect of gap characteristics on woody species in a dry *Shorea robusta* forest, and the results indicated that *Terminalia alata* seedling density was significantly and positively correlated with gap area. Large gap size supplies a convenient environment for plant establishment, as noted in a study of seedling establishment in a northern temperate forest, where highest density of plant species in the seedling layer was found in large gap size (Willis et al. 2015).

The seedling and shrub stages of *C. kawakamii* preferred the environment in large gap size over small gap size. The large gap size allowed sunlight to reach the ground than small gap size. In this study, the average light intensity in large gap size was 2363.74 lux, whereas 1658.27 lux in small gap size. Light is clearly important, as it promotes the germination of *C. kawakamii* seeds, and the best temperature for *C. kawakamii* seed germination is 40 to 50 °C (He et al. 2012c). Temperatures lower or higher than this range decreased the

Table 4 Results of stepwise multiple regression models for environmental and soil variables, and number of trees, saplings, shrubs and seedlings of *C. kawakamii*, at *C. kawakamii* Natural Reserve Forest, Sanming City, Fujian Province, China

Gap size	Number	Regression equation	F	r^2	p
Small	Total	y = - 16.445 + 0.046 (CWC)	16.97	0.57	0.001
	Tree	y = -34.533+0.041(MWHC) + 0.286(HR) - 18.673(N) + 0.172(SVMC)	21.07	0.89	0.000
	Sapling	y = -2.297 + 0.054(STP)	21.59	0.62	0.000
	Seedling	y = -7.033 + 0.22(SWMC)	6.14	0.32	0.028
Medium	Shrub	y = -1.910 + 0.576(AP)	7.06	0.35	0.020
	Seedling	y = 29.063 - 0.069(AK) - 0.337(STP)	7.62	0.75	0.007
Large	Tree	y = 17.598 - 0.530(ST5) - 0.542(pH) - 0.002(SWMC) + 0.001(MMC) - 0.026(PA) + 0.006(AP)	330.97	0.99	0.000
	Sapling	y = -11.49 + 1.215(AT) + 0.169(HR) -1.434(ST5)	104.68	0.97	0.000
	Shrub	y = -11.584 + 0.034(CWC)	5.38	0.29	0.037
	Seedling	y = 6.930 - 0.069(AK) + 0.262(SAD)	16.80	0.86	0.000

Data were derived from sample size (n = 15) for each gap size; AT = air temperature, RH = air relative humidity, CWC = capillary water capacity, MWHC = minimum water-holding capacity, SVMC = soil volumetric moisture content, SWMC = soil water mass content, STP = soil total porosity, MMC = maximum moisture capacity, SAD = soil aeration degree, ST5 = soil temperature at 5 cm, N = nitrogen content, AP = available phosphorous, AK = available potassium, PA = enzyme phosphatase activity percentage of seed germination. Most of the studies on seedling growth of *Castanopsis sp.* indicated that higher growth of seedlings is found in high light conditions compared with low light conditions (Hiroki & Ichino 1998, Du & Huang 2008, Hubbard 1974). A significant negative correlation is found between number of trees and gap area, with highest number of trees in under-canopy areas, as *C. kawakamii* is a shade-tolerant species. In the tree stage, it prefers to grow in shade more than high sunlight, thus showing a negative relationship between number of trees and gap size. Thus, large gap size may increase plant growth in the early stage but decrease it in the mature stage (Fraver et al. 1998).

The number of seedlings of *C. kawakamii* in large gap size was higher than small gap size due to reasons, as discussed below.

(1) The distance from the mother tree had an effect on the number of seedlings. The nearest mother tree produced higher number of seedlings than distant mother tree. In this study, the selected gaps controlled the distance of the mother tree.

(2) The percentage of seeds that reached the forest ground increased with gap size. A previous study in the same area noted that the percentage of seed rain, at the peak stage in forest gap, was 77. 13%, whereas in under-canopy area was 74.5% (He et al. 2012d). Moreover, studies of seed arrival and dispersal confirmed that percentage of seeds increased with gap size (Puerta-Piñero et al. 2013).

(3) Seed germination was promoted by gap size. In this study, it was found that large gap size had the highest soil temperature (28.68 °C), compared with medium (27.39 °C) and small (27.14 °C) gap size. Consequently, large gap size with higher temperature promoted seed germination better than small gap size.

(4) The environment within large gap size is more suitable for seedling growth and survival (Collet et al. 2002). In this study, the micro-environment within the gap showed that large gap size had a more significant correlation, compared with small and medium gap size. The competition for environmental resources is weaker in large gap size than small gap size, and/or in under-canopy, thus the seedling establishment is likely to be higher in the large gap size than small gap size (Bullock 2000). In addition, a previous study on seed regeneration in this area found that density of seeds and seedlings of *C. kawakamii* was higher in the gap than in under-canopy areas (He et al. 2012d).

Location within gap for *Castanopsis kawakamii* regeneration

In the center of the gap, the number and the size of seedlings of *C. kawakamii* were significantly different between the three groups of gap size. The results indicated that the direction within the gap had an effect on *C. kawakamii* regeneration. The study showed that both, the number and the size of seedlings at the center of a gap, were significantly different from those in other directions. This finding is supported by the study on *Quercus michauxii* regeneration, in the Atlantic Coastal Plain (Collins & Battaglia 2002), which found that seedling growth and survival after establishment were higher at the center of large gaps. The seedling establishment was higher at the center of a gap due to the convenience of resources, especially light and temperature. The longest period of time to receive the sunlight available during a day usually occurs at the center of the gap, compared with other locations.

Results from this study were similar to other findings on the effect of gaps on seedling regeneration. Yan and Cao (2008) studied the seedling growth in Xishuangbanna tropical seasonal rainforest and noted that the growth of seedlings at the center was greater than the edge or under-canopy. The regeneration density of *Schima superba* increased with gap size and mostly occupied the center of the gap (Ge et al. 2013). However, the result was inconsistent with a study at the north of Serra San Bruno, which found that seedlings of the silver fir (*Abies alba*) were more numerous in small gaps than large gaps (Albanesi et al. 2008). Similarly, studies conducted at the Apalachicola National Forest in northwestern Florida showed that seedlings of the longleaf pine were fewer in gaps (Gagnon et al. 2004). An experiment on Douglas-fir regeneration in British Columbia forest noted that this species prefers the medium gap size for regeneration rather than the small or large gap size (Zustovic 2015). The likely explanation for these differences is the environmental requirement of the species. Different species need different quantity of resources, and the main function of the gap is to allow different species to coexist and thus maintain the species diversity of the forest ecosystem (Pulliam 2000).

Castanopsis kawakamii and micro-environment within gaps

The number of *C. kawakamii* at the four stages, and environmental factors and soil variables, differed across gap sizes, indicating that the interaction between species recruitment and environmental gradient is complex. Explanations for these differences are discussed below.

(1) The ontogenetic growth stages requirements of a species for resources shifts constantly during its lifespan (Poorter et al. 2005). A study presented clear evidence that the resource requirement for seedling stage differed from adult stage (Máliš et al. 2016). The present study showed that the tree stage in both, small and large gaps required more resources than other stages. This observation is similar to an experiment conducted in a forest in France, which reported that nutrient requirement was higher in the tree stage than seedling stage (Bertrand et al. 2011). The observation was supported by Eriksson (2002), who mentioned that niche shifts are more influential in the adult stage than juvenile stage. The relationship between number of *C. kawakamii* and gap areas, in the seedling and tree stage were inverse, suggesting that the resource requirement of *C. kawakamii* showed uncoupling (Eriksson 2002).

(2) Resource requirement varied in different gap sizes within the same stage. The resource partitioning in each gap is individual because the micro-environment can vary both spatially and temporally (Brown 1993). The environmental gradient changes with gap size, with greater variation occurring in large gap size than small gap size (Bianchini et al. 2001). Plant species has to adapt to the environmental variation for regeneration and survival. The same species had to adapt to a different environment. The failure to adapt may cause the species to disappear from the ecosystem. The mission of ecologists and foresters is to protect and conserve the remaining species.

Castanopsis kawakamii species management and conservation

Management of *C. kawakamii* should move forward to provide suitable conditions for regeneration by focusing on large gap areas, especially at the center of the gap. Forest ecologists should manage the gap area by cutting the trees around the small and medium gaps to make the space larger, thus promoting *C. kawakamii* regeneration. The disadvantages of large gap size must be considered, such as extreme light may harm the small seedlings (Spittlehouse & Stathers 1990), and invasive species that can easily arrive in the large gap size, causing species competition. More research on disadvantages is needed to provide information for *C. kawakamii* species management and conservation. Forest ecologists should consider the environmental gradient, which varies both spatially and temporally, because seed germination in neutral conditions was limited (Brown 1993). Forest ecologists are able to germinate seeds in a nursery by providing optimum conditions and planting them in a suitable location within the gap (He et al. 2012c). A vigorous and strong seedling will increase the rate of establishment.

CONCLUSIONS

The results from this study showed that *C. kawakamii* regeneration was greater in large gap size than small or medium gap size, and the environment at the center of the gap was preferable for seedling regeneration, compared to other locations within the gap. The relationship between the number of *C. kawakamii* and gap area provided a model to predict the total number of the species. This information is useful for *C. kawakamii* species management and conservation. The effect of micro-environmental factors on *C. kawakamii* leads the way to future research on ontogenetic shift in resource requirement of the species, which is currently unknown. However, the queries that need to be addressed are, what is the pattern of the ontogenetic shift of *C. kawakamii and w*hat are the factors that drive the ontogenetic shift in each stage of the lifespan? Knowledge on ontogenetic shift is most useful for *C. kawakamii* species management and conservation because it provides the resource requirement and recruitment behavior at each growth stage, which enables the well management of *C. kawakamii.*

ACKNOWLEDGEMENTS

The authors would like to thank LX Qi, R Tang, KJ Kuang, JH Huang, YH Zhan and SS Zhou for field and laboratory work. Thanks to Sanming

C. kawakamii Nature Reserve for permitting to conduct the study on their site. The authors also appreciate anonymous reviewers for valuable suggestions.

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