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ABSTRACT

Background

Forest fire is a natural phenomenon that is very important to afforestation in the secondary succession process. Approximately 349.7 M ha yr^{-1} of forest had been lost due to forest fire in the world. In Republic of Korea, the forest fires occur at a rate of approximately 400 events yr^{-1}, and burned areas are mainly located on the eastern coast. In the eastern coastal region, pine forest is widely distributed, and pine forest is changed to oak forest through stump sprout regeneration following forest fires. However, there is a lack of research on oak competition during regeneration in burned areas. Therefore, this research was conducted to evaluate the effects of species composition and the survival ratio of *Quercus serrata, Quercus variabilis,* and *Quercus mongolica* in burned areas. The investigation plots were set to investigate tree growth, survival, and composition in Goseong-gun, Republic of Korea.

Results

The mean tree heights of *Q. serrata* and *Q. variabilis* were approximately 9.8 m and 9.1 m, respectively, which were higher than the approximately 5.8 m heights of *Q. mongolica* stands 18 years after a forest fire, and the trend for tree diameter at breast height was the same for all three species. In the early stage of regeneration, the survival probability of the *Q. serrata* sprouts rapidly decreased at a rate 1.7-2.0 times higher than that of other oak species in the *Q. serrata*-dominant stands. The median survival time of *Q. variabilis* sprouts in the *Q. variabilis*-dominant stands was approximately 10.1 years, which was similar to *Q. se rrata*-dominant stands. However, the dominant stand of *Q. mongolica* was different from that of other dominant stands due to different topography and soil environments located in the ridge and the upper part of the mountain.

Conclusion

Dominant species decision seems to be determined by the survival and occurrence of sprouts during the early stage in postfire regenerated oak forests. Therefore, it would be more desirable to coppice sprout for dominant species productivity and rapid dominance after a forest fire.

Key words: Survival analysis, Viability, Burned area, Oak forest, Sprout coppices

Background

During 15 years (1997-2011), approximately 348 M ha yr^{-1} of the forest had been lost due to forest fire, and burned area decreased by 1% yr^{-1} for this period in the world (Giglio et al., 2013). However, the characteristics of forest fire occurrence and areal extent differ among regions. For example, the frequency of forest fire in Equatorial Asia, Boreal Asia, and Boreal North America are characterized by high coefficient of variance. And the forest fire damaged area in African continent from 1998 to 2012 is more than half of the total area burned globally (Giglio et al., 2013). Recently, forest fire occurrence was decreased while the burned area or suppression cost was increasing in developing and advanced country such as Republic of Korea, Canada and United States of America from 1970 to 2015 (Calkin et al., 2005; Doerr and Santín, 2015; Korea Forest Service, 2018) In the temporary ecosystem, forest fires are a major cause of disturbance in forest ecosystems due to their influence on the forest and its environment, and fires are known to be a main cause of secondary succession (Barnes et al., 1994; Korea Forest Research Institute, 1999). Especially in temperate pine forests, the metamorphosis into oak-dominant forests is attributed to forest fire occurrence (Fulé et al., 2000). In the Republic of Korea, there are pine trees (*Pinus densiflora, P. thunbergii*, and etc.) before forest fires and oaks, such as *Quercus mongolica, Q. variabilis, Q. serrata,* and *Q. acutissima*, after forest fires.

In the Republic of Korea, approximately 440 forest fires have occurred, and approximately 2,650 hectares have been burned annually during the last 16 years (2000-2016) (Korea Forest Service, 2016; Korea Forest Service, 2018). Considering that an average of 237 forest fires occurred in the 1980s (1,100 ha of damage) and an average of 336 forest fires occurred in the 1990s (1,400 ha of damage), annual occurrence has increased over time (Lee et al., 2012; Korea Forest Service, 2020). It seems to be related to household income and leisure time growth. Because of the forest fire mostly due to accidental fire by human activity (90s: 82.2%, 00s: 87.4%) (Kim and Lee, 2013; Korea Forest Service, 2018). In particular, the East Coast region has relatively higher winter temperature and lower spring humidity than other regions in Korea due to topographical and climatic factors such as Föhn phenomenon and oceanic climate. Also, many areas of the region consist of pine (*P. densiflora*) forests in crown layer, and *Quercus* spp. in understory layer, which are likely to lead to large forest fire damage (Lim, 2000; Lee et al., 2009).

The Goseong region is located in the East Coast region of Korea. In the Goseong region, the pine forest was mainly consisted by *P. densiflroa* that species are sensitive more than other species (*Quercus* spp.). It cause of thin bark, high volatile compound content, flammability and evergreen species (Kim and Shin, 2005; Shan et al., 2008; Korea Forest Research Institute, 2012a; Patra et al., 2015). As a result, policy support and technical research have been continuously carried out to predict and prevent large-scale forest fires. From 2012 to September 2018, the number of large-scale forest fires was only 6 cases (Korea Forest Service, 2018). However, there are ecosystem changes and succession processes that occur postfire. In addition, studies on the prediction of forest fires and prevention of forest fires have been conducted; however, studies of the forest ecosystem changes and succession processes after forest fires are lacking (National Science and Technology Information Service, 2019).

The forest fire-damaged area was changed from pine forest to various postfire ecosystems that are naturally regenerated stands and plantations, and the soil chemical properties were altered (Certini 2005; Ryu et al., 2017). In the Republic of Korea, the natural regeneration was performed in areas that prioritized diversity and ecological management, and artificial regeneration was performed mainly in areas aimed at economic feasibility through forestry production, soil erosion control, and landslide prevention (Korea Forest Research Institute, 2010). Following past forest fire disasters, most burned areas have been restored by focusing on pine afforestation. Although interest in natural regeneration after the forest fire disasters in 1996 and 2000 has increased, most of them were restored through artificial regeneration. There is a lack of detailed research on the survival of natural oak and forest vertical structures to prevent secondary damage, such as landslides.

Quercus spp. is widely distributed in not only Korea but also in other northern hemisphere countries that including China, Japan, Indonesia, Mexico, South-eastern USA, and South-western Europe (Denk et al., 2017). In case of Korea, high abundance is related to naturally regenerated *Q. acutissima*, *Q. mongolica*, *Q. variabilis*, *Q. serrata*, *Q. dentate*, and *Q. aliena*. after forest fires. These species are deciduous broadleaf tall trees that dominate temperate forests in Northeastern Asia (Dolezal et al., 2009; Korea Forest Research Institute, 2012b). In the Republic of Korea, most deciduous *Quercus* species are widely distributed in the middle and northern regions as small pure forest or mixed forest with other deciduous or conifer trees. However, *Q. mongolica* could make relatively large pure forest at some areas of high altitude (Korea Forest Research Institute, 2012b). Although the vertical distribution of the *Quercus* spp. varies with latitudinal position, the average distribution altitude of *Q. mogolica* in Koera is about 700 m above sea level (ASL) while *Q. variabilis* and *Q. serrata* are about 400 m ASL. *Q. mongolica* generatlly fits ridge or upper slope with higher altitude than *Q. variabilis* and *Q. serrata* whilst *Q. variabilis* prefers middle or upper slope (Korea Forest Research Institute, 2012b; Lee, 2012).

The forest consisted of oak species in the overstory, and its natural regeneration is inhibited by the growth of various species such as *Phyllostachys edulis, Liquidambar formosana*, *Prunus brachypoda*, and *Cyclocarya paliurus* in the understory and by high rodent densities and high acorn removal rates beneath the oak canopies (Da et al., 2009; Ryu et al., 2017). *Q. mongolica* and *Q. variabilis* can be described as long-lived pioneer species because they often require large stand disturbances, such as forest fire, landslides and thinning, to regenerate successfully from seeds (Wang et al., 1996; Xu et al., 2015). Otherwise, stump sprouts mainly occur in degraded land, such as silviculturally thinned area and forest fire-damaged areas in secondary succession processes. Stump sprouts are important in *Quercus* spp. reforestation in burned area; however, the sprouts have growth limitations (Xue et al., 2013; Ryu et al., 2017).

The competition of naturally regenerated *Quercus* spp. is divided into between-individual and within-individual. In the case of between-individual competition, oak outcompete *Pinus densiflora* except in barren areas, such as ridges. Oak can grow under the canopy of red pine; however, red pine is shade intolerant (Lee et al., 2004; Dey et al., 2012). In the case of multiple sprouts from a tree, a within-individual relationship occurs in the oak species. Stump sprout is a secondary reboot in oak species. Some studies have shown that resprouts in the early stage of forest development after a disturbance gain a competitive advantage by utilizing the stump (Liu et al., 2011) and hence grew disproportionately more height than sprouts emerging from seeds (Mostacedo et al., 2009). However, in the later stages of forest development, the resprouts grow disproportionately less than single-stem sprouts because they experience more intense competition with dense polycormons (Kauppi et al., 1988; Pytte et al., 2013). As the previous study, the coppice management of multiple stump-sprouts are influenced to improvement of volume, height growth and survival (Canellas et al., 2004; Lim et al., 2009). In particular, vertical position is important because of species composition and growth; as the upper layer develops, the depth of the middle and lower vegetation decreases (Swaim et al., 2016). In other words, biotic factors mainly consist of competitions between-species or between-individuals and relationships with microbes.

The objective of this study was to understand regeneration characteristics of naturally regenerated oak forest in the eastern coast of Korean peninsula during 19 years after forest fire. Specifically, to figure out and which *Quercus* species were dominant in the oak forest as time passed, sprouting patterns including overstory composition, growth, and development of the major oak species in the study sites were monitored. Since most of fire burned areas in Republic of Korea has been restored through artificial regeneration, it will help not only to understand post-fire regeneration processes in these oak forests but also to develop alternative post-fire management options for these regions.

Material and methods

Study site description and survey to tree growth

<Fig. 1>

Fig. 1 The geographic location and the study site.
White filled squares, *Quercus mongolica* dominant stand; Black filled squares, *Quercus variabilis* stand; Gray filled squares, *Quercus serrata* dominant stand

In the Goseong region on the eastern coast of Republic of Korea, many forest were lost by the "Goseong forest fire (3,834 ha)" in 1996 and the "Eastern coast forest fire (23,794 ha)" in 2000. These due to accidental fire by human. In the Goseong region, the annual average temperature was approximately 12.2 degrees Celsius, and the annual average precipitation was 1,402.2 mm from 1981 to 2010 by the table of climatological standard normals (Korea Meteorological Administration, 2011). The altitude of the study sites ranged from 51 to 166 meters. And in this region, pine forest is widely distribution, and many pine forests are consisted of mainly *Pinus densiflora* in overstory (crown layer) and broadleaf tree such as *Q. mongolica*, *Q. variabilis*, *Q. serrata, Q. dentata, Alnus japonica, Fraxinus rhynchophylla and Castanea crenata etc.* in understory on unburned area (Lee et al., 2009). In contrast, the overstory of the study sites was composed of naturally regenerated *Quercus* spp., which was mainly *Quercus mongolica* Fisch. Ex Ledeb., *Quercus variabilis* Blume, *Quercus serrata* Murray, *Quercus acutissima* Carruth., etc. on natural regenerated stand in burned area (Song et al., 2017). This experiment was performed for confirm the overstory dominant and competition of species in naturally regenerated stands after two forest fire (1996 and 2000).

The three study sites were selected to exclude exposed area or rocky area for monitoring the growth of naturally regenerated plants as soon as forest fire occurrence. One study site consisted of five-square survey plots (10×10 m, 100 m^2 $plot^{-1}$). Initially, the five survey plots were located in the valley, but one survey plot in the valley was turned into a mountain stream three years later because of change in the waterway due to landslide. Finally, a total of 14 survey plots sites has been remained (Fig. 1; valley: 4 plots, mountainous facing: 5 plots, ridge: 5 plots).

The number of individual oaks (stump sprouts per ground area) was measured ten times (2001, 2002, 2003, 2004, 2005, 2006, 2008, 2010, 2010, and 2018) from 2001 to 2018. And sprout height, root collar diameter (RCD), and diameter at breast height (DBH) of *Quercus* spp. were measured only 2 and 18 years after forest fire (2002 and 2018) in 14 study plots during the fall season (from September to November). In each survey plot, the dominant species was determined by the number of sprouts, that were consist of forest crown after 18 years from the forest fire. The criteria for the survival ratio were based on a study after forest fire damage (Xue et al., 2013). The survival and composition ratio were calculated by stump sprout number through elapsed time after forest fire. For example, the composition ratio was calculated to specified species per total sprout number of *Quercus* spp. by equation (1) and (2)

$$Survival\ ratio\ (SR) = \frac{SN_{sp\ yr}}{SN_{sp\ 2001}} \tag{1}$$

$$Compoistion\ ratio\ (CR) = \frac{SN_{sp\ yr}}{SN_{total\ yr}} \tag{2}$$

$SN_{sp\ yr}$: Sprouts number of each species and each year within plot
$SN_{sp\ 2001}$: Sprout number of each species at 2001
$SN_{total\ yr}$: Sprouts number of total each year within plot

Analysis

Each subpopulation and the time-series viability data of each *Quercus* spp. were analyzed by Kaplan-Meier survival analysis and Gehan-Breslow methods. Gehan-Breslow tests is a non-parametric test using chi-square test. And it assumes that early survival times are known more accurately than later survival times, and that required samples that is less than logrank and Tarone-Ware method (Kortet and Hedrick, 2007; Ahnn and Anderson, 1998). We selected to this method because the change of survival was important in initial stage after forest fire.

Multiple comparisons of survival curves among oak species were confirmed by the Holm-Sidak adjustment method (Sidak, 1967) using Sigmaplot 12.5 (SYSTAT Inc., USA). The probability density function was calculated as the survival function multiplexed by the hazard function. And the differences of tree growth and tree density among dominant-species were verified by non-parametric methods (Kruskal-Wallis test and Dunn-Bonferroni method). All data analysis used SPSS 18.0 (IBM, USA), except for survival analysis.

Results

Sprout growth and composition over time

Eighteen years after a forest fire, the mean tree heights of the dominant species in each stand (Table 1). The *Q. serrata*- and *Q. variabilis*-dominant stands were similar at 9.8 (Standard deviation, SD: 3.8) and 9.1 (SD: 4.3) m height, however these values were higher than 6.0 (SD: 2.8) m height in *Q. mongolica* ($p<0.05$, H-value=28.703). The mean DBH of *Q. serrata* was the highest at 14.3 (SD: 4.1) cm, followed by *Q. variabilis* at 11.6 (SD: 4.3) cm and *Q. mongolica* at 5.9 (SD: 2.5) cm ($p<0.05$, H-value=63.364). According to Korean yield table (Korea Forest Research Institute, 2012c) the DBH of *Q. mongolica* ranged from 8 to 15 cm at 20 years old, that is higher than the growth of *Q. mongolica* in study site. Otherwise, the tree density of the dominant species was approximately 20,300 sprouts ha^{-1} in the *Q. mongolica* stand, which was the highest, followed by approximately 9,100 sprouts ha^{-1} in the *Q. serrata* stand and approximately 8,700 sprouts ha^{-1} in the *Q. variabilis* stand ($p<0.05$, H-value=8.409)). In the trees above 2 m height, the composition ratio of dominant species occupying approximately 0.781 was *Q. mongolica*, followed by 0.371 in *Q. serrata*, and 0.216 in *Q. variabilis*. Low occupancies and high tree height are presented to show significant changes in vertical distribution composition.

Table 1. The growth of oak in naturally regenerated stands during 18 years after forest fire.

Stand	Species	Tree height, m	Mean DBH, cm	Tree density, trees ha^{-1}
Quercus variabilis	*Quercus variabilis*	9.1 (4.3)$_a$	11.6 (4.3)$_b$	870$_b$
	Quercus mongolica	4.5 (2.9)	5.4 (2.4)	670
	Quercus serrata	4.7 (2.9)	4.1 (3.0)	1,370
	Quercus dentate	1.9 (0.6)	2.2 (0.8)	120
Quercus mongolica	*Quercus mongolica*	6.0 (2.8)$_b$	5.9 (2.5)$_c$	2,030$_a$
	Quercus variabilis	4.9 (2.0)	7.1 (3.2)	130
	Quercus serrata	3.6 (3.9)	5.0(5.9)	200
	Quercus dentate	2.4 (0)	2.5 (0)	30
Quercus serrata	*Quercus serrata*	9.8 (3.8)$_a$	14.3 (4.1)$_a$	910$_b$
	Quercus variabilis	4.1 (3.1)	4.9 (2.3)	670
	Quercus mongolica	2.9 (2.4)	3.8 (2.9)	330
	Quercus dentate	2.1 (1.5)	2.3 (1.3)	170
	Quercus acutissima	3.4 (3.3)	3.7 (3.4)	200
Kruskal-Wallis H-value[1]		28.703	63.364	8.409

[1]Comparison of among growth and tree density of dominant species.
*Different subscript with number indicated to significantly difference between groups by Dunn-Bonferroni test at 0.05 levels.
**When the tree height is more than 2 m .

***Value: Mean (Standard deviation)

<Fig. 2>

Fig. 2 Change to vertical distribution of *Quercus* spp. in *Q. serrata* stand as time passed. (a) 2 years after forest fire; (b) 18 years after forest fire. Error bar means standard error.

In the year following the forest fire, most study sites began stump sprouting of oak species (*Q. mongolica*, *Q. variabilis*, and *Q. serrata*) at a rate of more than two hundred per plot, although the composition ratio was different among species. More than 90% of oak sprouts were in the range from 10 to 160 cm height after 2 years. At 9 years after the forest fire, the number of *Q. variabilis* sprouts rapidly decreased from 4 to 8 years, more than in other oak species (Fig. 3). In total, the relative growth of *Q. variabilis* height was 1.1 m per year at 9 years after, which is higher than the 0.7 m of *Q. serrata* and 0.3 m of *Q. mongolica* $p<0.01$).

<Fig. 3>

Fig. 3 The survival ratio and composition ratio of *Quercus variabilis* (a) and *Quercus serrata* (b) during the 18 years after a forest fire

Survival analysis of oak sprouts

The sprout survival ratio (SSR) of *Quercus variabilis* was the highest (0.025-0.061) in the five *Q. variabilis*-dominant plots, followed by *Q. mongolica* (0.014) and *Q. serrata* site (0.004) 18 years after the forest fire. In *Q. variabilis*-dominant stands, the estimated survival probability of *Q. variabilis* sprouts ranged from 0.974 at 2 years to 0.0378 at 18 years, with a decrease of approximately 0.5 points during the first 8 years after forest fire. The total censored percentage of this species was 0.038 over 18 years since forest fire. The mean survival time of sprouts was approximately 10.062 (9.575-10.550 95% CI) years in *Q. variabilis*, the lowest of the oak species, followed by approximately 12.875 (12.479-13.271 95% CI) years in *Q. mongolica* and approximately 13.070 (12.858-13.283 95% CI) years in *Q. serrata* ($p<0.01$).

In the case of *Quercus serrata*-dominant stands, the SSR of *Q. serrata* was the highest (0.013) in the four *Q. serrata*-dominant sites, followed by *Q. variabilis* (0.008) and *Q. mongolica* (0.005) 18 years after the forest fire. The survival probabilities of *Q. serrata* sprouts decreased by approximately 0.7 points during the first 8 years after forest fire (0.95-0.27). The total censored percentage of this species was 0.038. The mean survival time of *Q.*

serrata sprouts was approximately 10.062 (9.575-10.550 95% CI) years, which was the lowest of the oak species ($p<0.01$). The sprout survival probability in *Q. serrata*-dominant stands was the same as in *Q. variabilis*-dominant stands.

Meanwhile, in *Q. mongolica*-dominant stands, the SSR of *Q. mongolica* was 0.362 higher than the 0.132 in *Q. serrata*. The mean survival times of *Quercus* spp. sprout were approximately 14.402 (14.171-14.633 95% CI) years in *Q. mongolica*, approximately 14.186 (13.693-14.680 95% CI) years in *Q. variabilis*, and approximately 15.093 (14.228-15.958 95% CI) years in *Q. serrata*. Furthermore, the sprout survival probability in *Q. mongolica*-dominant stands was different than that in *Q. variabilis*- and *Q. serrata*-dominant stands, which were caused not only by sprouts of *Q. serrata* occurring in only one site but also by the number of *Q. serrata* sprouts occurring in *Q. mongolica*-dominant stands 18 years after the forest fire (see Fig. 2). In addition, the *Q. mongolica*-dominant stand was located on the ridge and upper part of the mountain, and the soil physical and chemical properties were more substandard than found at other sites.

<Fig. 4>

Fig. 4. Sprout survival and density probability of each *Quercus* spp. in natural regenerated forest. (a), *Quercus variabilis*-dominant stand; (b), *Quercus serrata*-dominant stand; (c), *Quercus mongolica*-dominant stand. In left two figures, the gray color means 95% confidence interval of dominant species. In right two figures, the dark gray color means interval with high density probability of dominant species and light gray means interval with high density probability non-dominant species.

Discussion

In *Q. variabilis*-dominant stands, the average height of sprouts of *Q. variabilis* 18 years after the forest fire was approximately 9.1 m, it is higher than other species; however, tree density was approximately 870 sprouts ha^{-1}, lower than *Q. serrata* (1,370 sprouts ha^{-1}). According to Korean yield table (Korea Forest Research Institute, 2012c; National Institute of Forest Science, 2016), the average tree height of *Q. variabilis* and *Q. serrata* are range from 8.4 to 12.4 m (*Q. variabilis*) and 6.8 to 8.5 m (*Q. serrata*) at 20 years old, that are similar this results. However, tree height of *Q. mongolica* (average: 6.0 m) is lower than yield table that is range from 8.2 to 10.8. In the initial stage, the sprout number of *Quercus* spp. was the highest at approximately 9,870 sprouts ha^{-1} in *Q. serrata*, followed by *Q. mongolica* and *Q. variabilis*. During the first 8 years after the forest fire, the tree survival ratio of *Quercus* spp. rapidly decreased, which was fastest in *Q. variabilis*, followed by *Q. serrata*, and *Q. mongolica*. In the case of *Q. serrata*-dominant stands, the *Q. serrata* sprouts had within-individual competitions during the first 8 years; as a result, the tree height growth of *Q. serrata* was higher than that of other species. *Q. serrata* covered an overstory 15 years after the forest fire. The density probability consisted of survival probability multiplied by hazard probability. Thus, the density probability means snapshot probability at a specific point in time. In addition, density changes hazard and survival, which are less sensitive than hazards (see Fig. 4). The high increase of density function means high hazard at a specific time. Thus, the SSR of the dominant species rapidly decreased in the early stage (before 10 years), while the SSR of the suppressed trees rapidly changed after 10 years.

The height growth in low density stump sprouts was higher than that in high density (Dinh et al., 2019). In addition, the coppice management effect in the early stage before few after thinning on *Q. variabilis* forest increased productivity more than in the later stage (Wang, 2013). In particular, the growth of suppressed trees rapidly decreased 10 years after the forest fire in *Q. variabilis*- and *Q. serrata*-dominant stands, which appears to be caused by the fact that the dominant trees formed the overstory. Consequently, it seems resources such as water, light and nutrients were not sufficiently supplied to all sprouts of suppressed trees (Staaf and Stjernquist, 1986; Peri et al., 2008). In addition, the precipitation levels were 1,264 mm and 1,283 mm in 2007 and 2010, respectively, owner than the climatological normal (1,402 mm, 1981-2010) which corresponded to the period of rapid decrease in the number of sprouts of suppressed trees. The previous study showed that the quantity of oak sprouts was rapidly reduced when resources were not supplied properly (Keim et al., 2006; Khan and Tripathi, 1989). Meanwhile, the tendency of *Q. mongolica*-dominant stands was different than that of *Q. serrata* and *Q. variabilis* stands. The height and DBH growth in *Q. mongolica*-dominant stand were lower than documented in the Korean yield table (National Institute of Forest Science, 2016), smaller stature and smaller DBH may be due to geographical location. The *Q. mongolica*-dominant stands were located on the ridge or upper part of the mountain. Considering the Keim *et al*. (Keim et al., 2006), these topographical features and soil conditions may have negative effects not only on stump sprouting but also on the height growth of other *Quercus* spp. with low competition.

It has been reported that *Q. variabilis, Q. acutissima* and *Q. serrata* are rapidly selected as the main sprouts rather than *Q. mongolica* and *Q. dentate*, and the dynamics are inversely correlated (Brevik et al., 2004; Ebihara et al., 2005). Additionally, topography is a major factor in the growth of *Quercus* species that are dependent on dominant coverage (Son et al., 2002). In this process, the difference in sprouting ability of each oak species was affected by geographical location which is consistent with previous articles (Swaim et al., 2016; Dinh et al., 2019). In the case of *Q. mongolica* forest after forest fire, the tree density of *Q. mongolica* was continuously the highest. This result is similar to that in a California black oak forest where after disturbances, stump sprouts regenerated more rapidly than other sprouts, and seeds generated 13 years after the forest fire (Hammett et al., 2017). The mean tree height of the *Q. mongolica* stand was lower than that of the other stands, and it was difficult for certain species and individuals to grow vertically. The diameter before thinning was affected not only by the growth limitation of stump sprouts but also by the relative growth rate after thinning in the oak forest (Korea Forest Research Institute, 2012c; Lim et al., 2009), and clump growth and survival of *Quercus nigra* were increased with overstory thinning intensity in a 28-year-old *Q. nigra* forest (Gardiner and Helmig, 1997). Stump sprouts have a low occurrence because oak trees growing are slow to grow and strive for survival compared to inter-individual competition (Pytte et al., 2013). Then, the high density of sprouts was reduced due to competition, but after the determination of the dominant relationship with the competition pressure, the growth increased (Liu et al., 2011; Mostacedo et al., 2009). In the case of the *Q. mongolica* stand, competition between individuals was sufficient, and the growth was not good due to the soil inferiority; so that vertical differentiation seemed to be reduced. However, many studies have shown that oak growth caused by stump sprouting has marginal growth. Therefore, further studies and analysis of stump sprouting is needed.

Conclusion

The stump sprouting of oak is a common phenom and nature regeneration process in the Republic of Korea. after forest fire. The space available to each individual stump sprout influences not only the intensity of inter- and intra- specific competition but also the growth of oak sprouts during regeneration process (Khan and Tripathi, 1989; Gardiner and Helmig, 1997). For this reason, this study was performed to determine the relationship between sprout density and species dominance in natural regeneration. The authors confirmed that high mortality due to competition in the first 8 years are associated with dominance later in the burned area. As a result, when natural sprouting occurred at an early stage in *Q. serrata* and *Q. variabilis*, they appeared to dominate. Therefore, the first 8 years after forest fire would be more desirable to sprouting for dominant species productivity and rapid dominance after the forest fire. These results were used to predict stand change, which was natural domination selection and sprout growth through oak sprout viability in the early stage. Meanwhile, this result was not considered an environmental condition, such as topography, terrain location, and soil properties. Therefore, further research is needed to define these conditions.

Abbreviations

DBH: Diameter at breast height

RCD: Root collar diameter

SSR: Sprout survival ratio

Declarations

Ethics approval and consent to participate: Not applicable

Consent for publication: Not applicable

Availability of data and material

This data that support the findings of this study are available from in National Institute of Forest Science, Korea Forest Service but restriction apply to the availability of these data, which were used under license for the current study, and so are not publicly available. Data are however available from the corresponding author upon reasonable request and with permission of Korean National Institute of Forest Science, Korea Forest Service.

Competing interests

The authors declare that they have no competing interests.

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Author's contribution

JK was responsible for study design, data analysis, and drafting this manuscript. JHL was responsible for initial design, and supervised the field survey. MS and SHH was responsible for field data collection, providing feedback and revision to manuscript. WK was responsible for initial design and provided a major contribution to securing funding support, and providing feedback and revision to manuscript drafts. All authors read and approved the final manuscript.

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Figures

Figure 1

The geographic location and the study site. White filled squares, Quercus mongolica dominant stand; Black filled squares, Quercus variabilis stand; Gray filled squares, Quercus serrata dominant stand

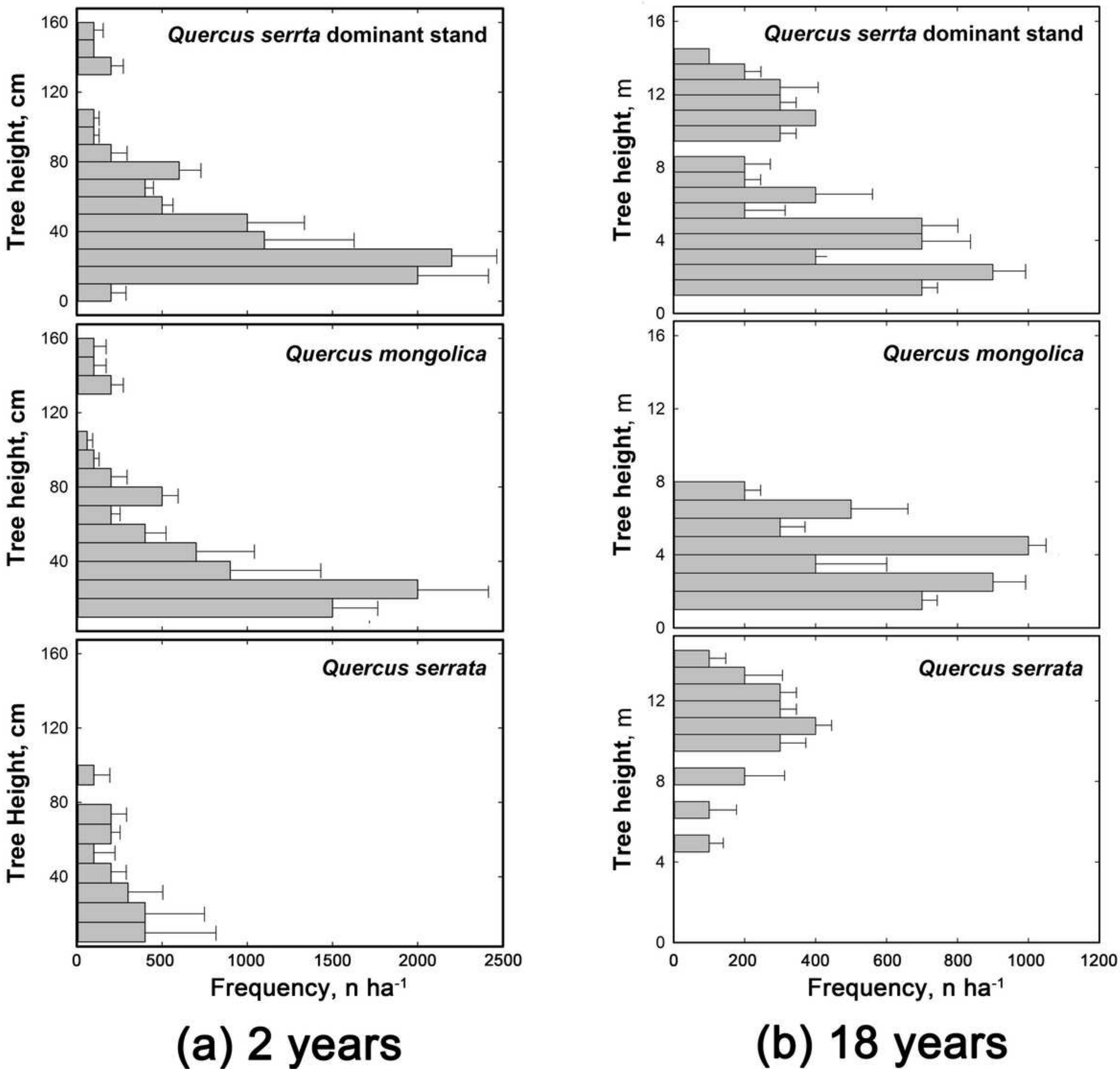

Figure 2

Change to vertical distribution of Quercus spp. in Q. serrata stand as time passed. (a) 2 years after forest fire; (b) 18 years after forest fire. Error bar means standard error.

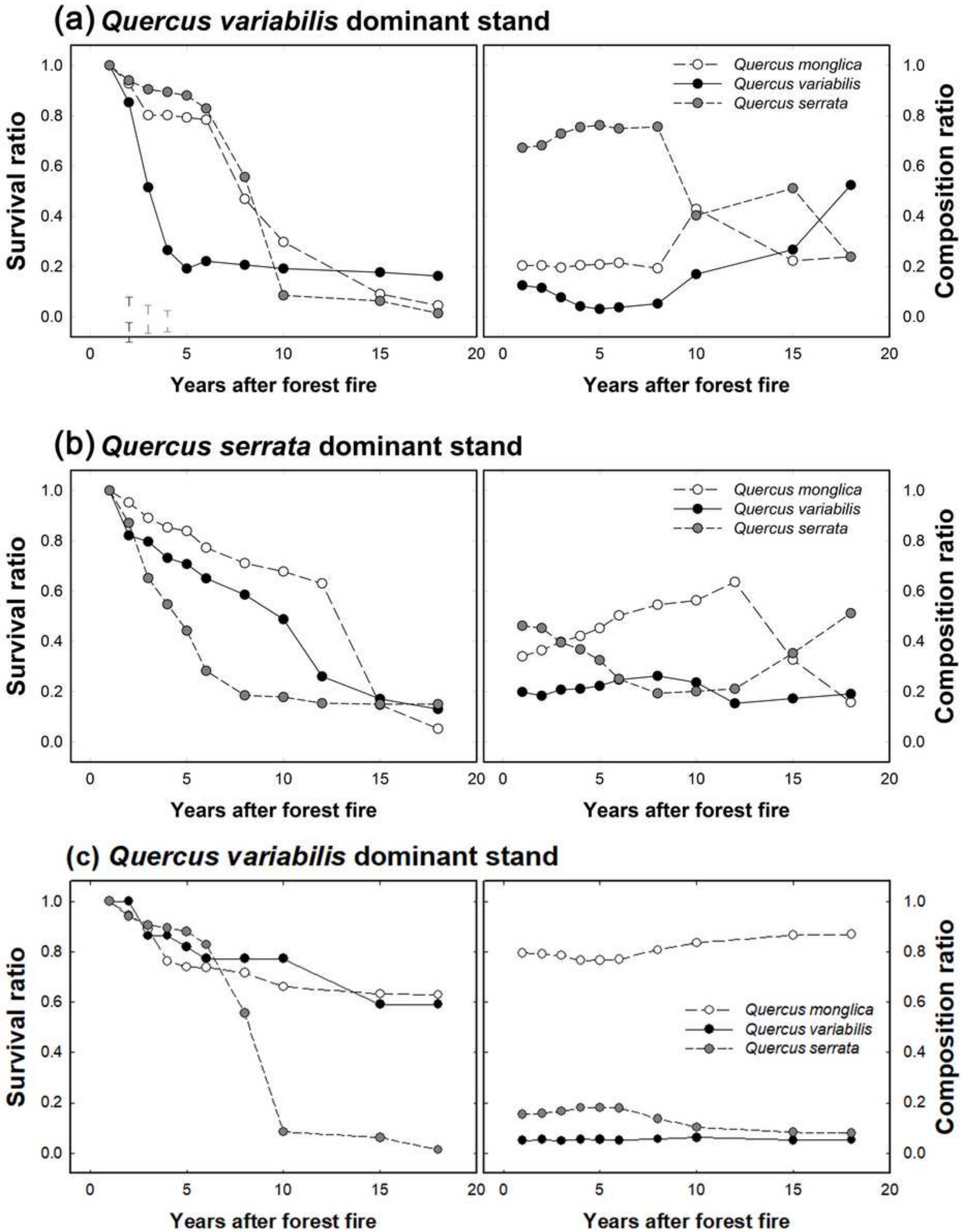

Figure 3

The survival ratio and composition ratio of Quercus variabilis (a) and Quercus serrata (b) during the 18 years after a forest fire

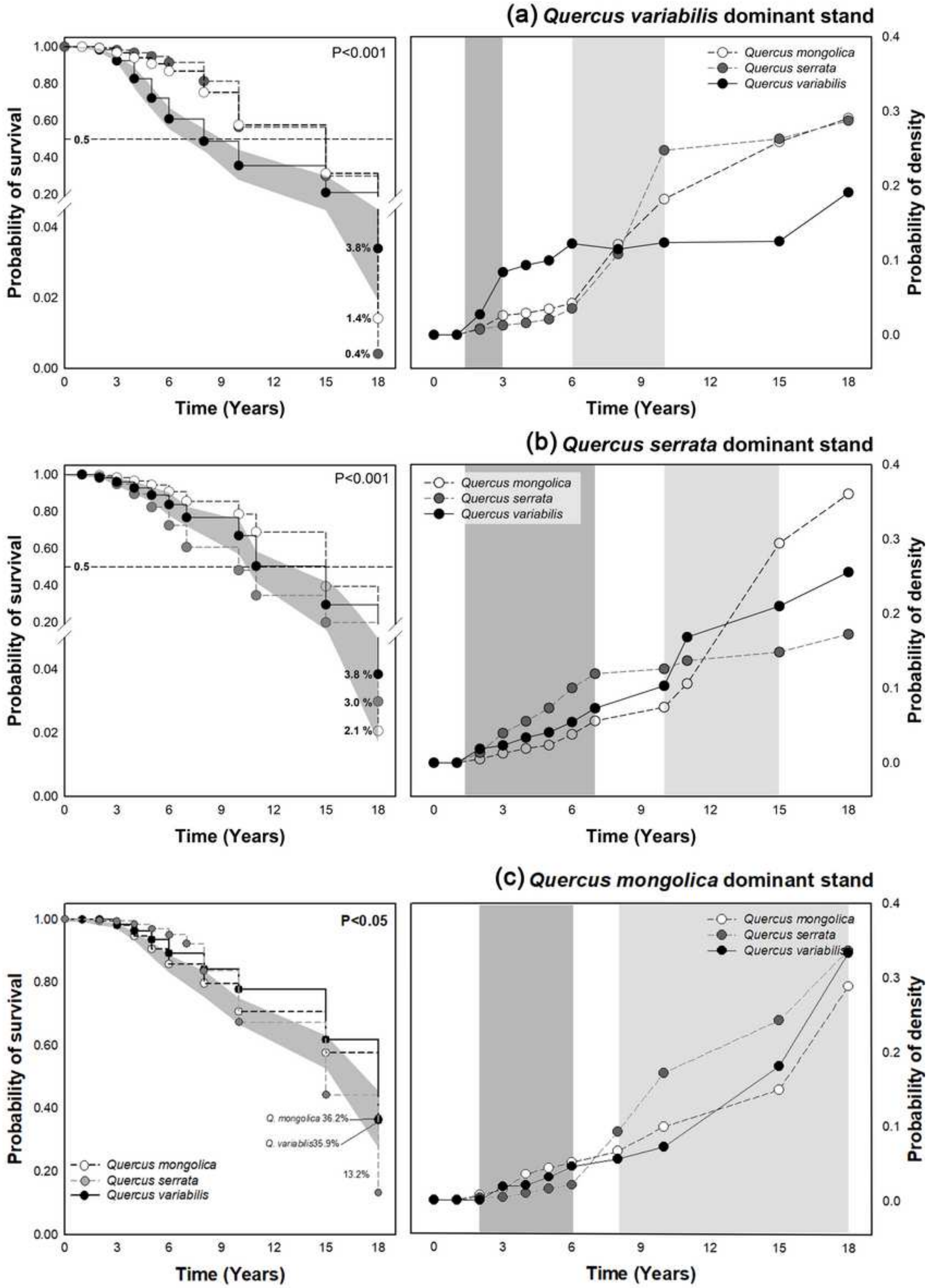

Figure 4

Sprout survival and density probability of each Quercus spp. in natural regenerated forest. (a), Quercus variabilis-dominant stand; (b), Quercus serrata-dominant stand; (c), Quercus mongolica-dominant stand. In left two figures, the gray color means 95% confidence interval of dominant species. In right two figures, the dark gray color means interval with high density probability of dominant species and light gray means interval with high density probability non-dominant species.