CHAPTER 4

Results and discussion

4.1 Percent survival after fire between old and young plot

Figure 4.1 presents survival following fire. By the 3^{rd} monitoring (30 weeks after fire), the percent survival of trees in the 1-, 2-, 14- and 17-year-old plots was 42.8, 39.8, 95.3 and 98.6 respectively. Inspection of the trees in the 14- and 17-year old plots revealed no immediate mortality due to fire (so 1^{st} monitoring survival was 100%), whereas pre-fire surveys in the younger plots was used to calculate immediate mortality as a result of the fire.

Trees in the older plots (14- and 17-year-old plots) survived well (mean survival across species 95.3% and 98.58% respectively). These remaining trees can be seed source for post-fire ecosystem recovery. Furthermore, forest structure remained largely intact, retaining shady conditions. This result agreed with those of Swaine (1992), who also found that standing trees remaining after fire provide seed sources and shady conditions in dry forest in western Africa.

In contrast, tree survival after burning in the 1- and 2-year-old plots was much lower (mean across species 42.9% and 39.8, respectively) which shows the greater susceptibility of small trees to fire mortality. Fire opened up the younger plots, reducing canopy cover and allowing grasses and herbs to re-invade the sites. This result was similar to that obtaining in Australian tropical forest by Setterfield (2002) who also reported that grass and forb ground cover increased after fire. Such invasion by grasses and vines after fire has also been reported in the Amazonia rain forest (Cochrane, 2003).
Invasion by grasses can increase flammability and increase the subsequent fire risk (Pinard *et al*., 1999; Bond and Keane, 2017).

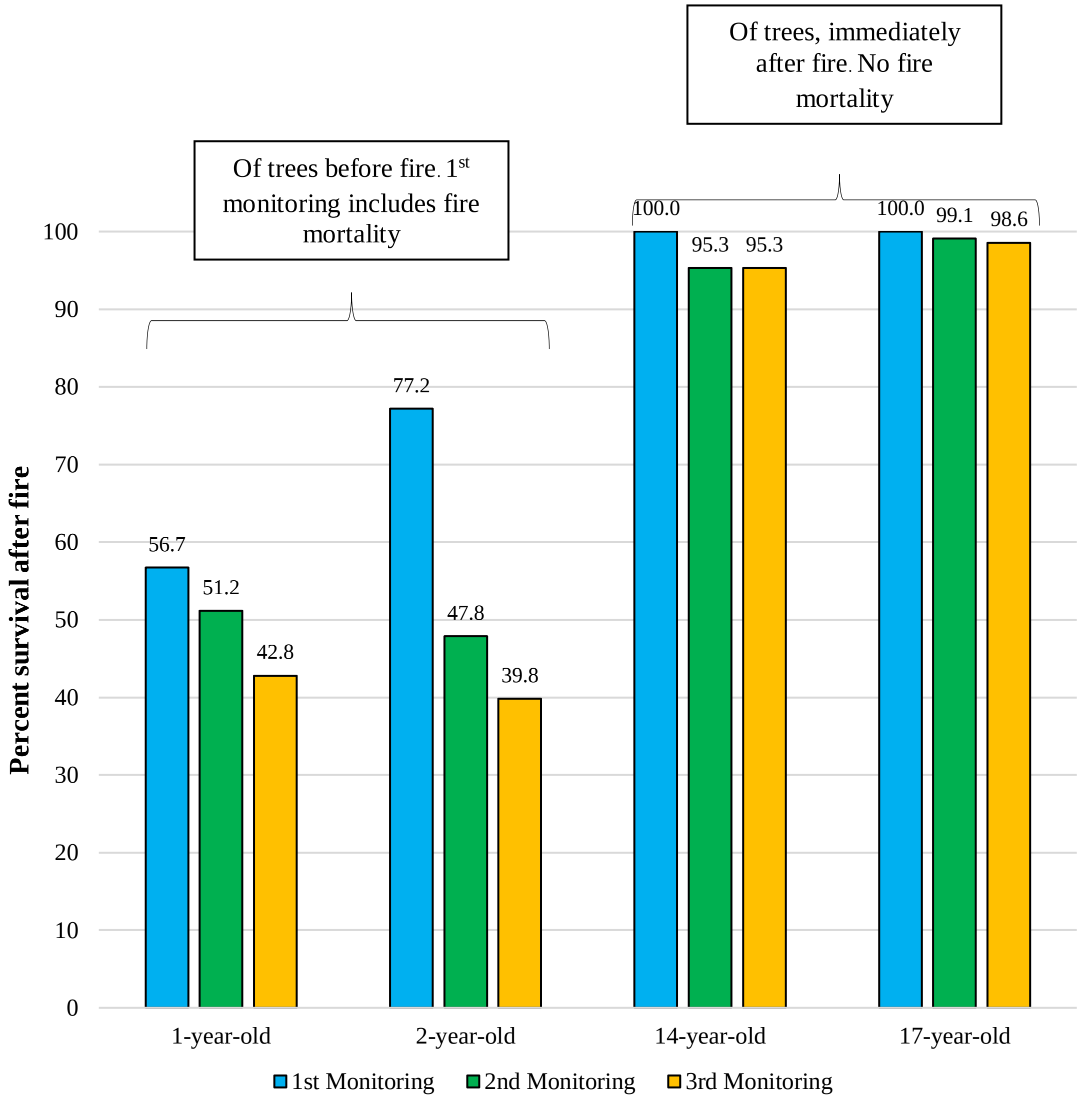


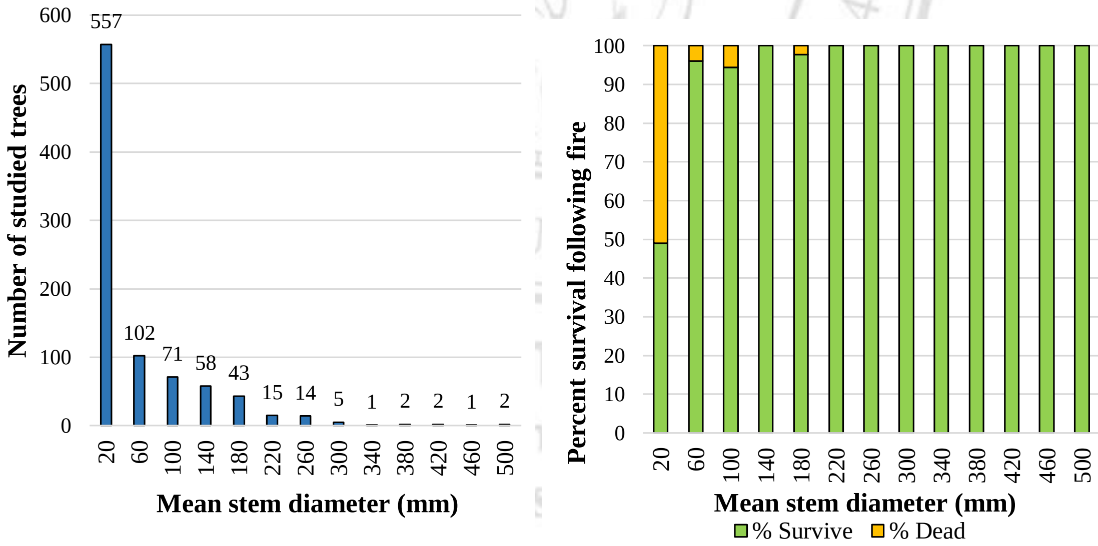
Figure 4.1: Survival percentage of native tree species at 1st, 2nd and 3rd monitoring after fire in each plot

4.2 Percent survival after fire between monitoring

In the younger plots, mortality continued to occur throughout the 30 weeks of the study whereas in the older plots very little additional mortality occurred after the 2nd monitoring (Figure 4.1).

Throughout monitoring, survival percentage of younger trees in this study was more rapidly decreased than older trees, assuming that younger trees faced cambium injury which could cause tree mortality within weeks (Michalet *et al.*, 2011). In Amazonian forest, fire damage continued to kill the trees during 1 and 3-years post fire due to death of the cambium (Barlow *et al.*, 2003). A similar phenomenon was reported in West African forest up to 2 – 4 years die back after fire (Swaine, 1992). Therefore, cambium die-back after fire is an important cause of tree mortality in montane forest ecosystems in northern Thailand, if fires become more frequent or more severe.

Apart from cambium die back, heat is also an important cause of xylem and phloem deformation. Heat reduces xylem conductivity by deform conduit wall, and later become permanent deformation at lower temperature (Michalet *et al.*, 2011). Unlike younger trees, several older trees might not die from cambium die back but facing conduit deformation. With tree conduit deformation, the trees can survive longer period until store carbon reserves are deplete (Michalet *et al.*, 2011).



(a) (b)

Figure 4.2: Number of studied trees (a) and percent survival after fire (b) of 13 classes, stem diameters were classified with 40 mm in each class

4.3 Effects of tree size on survival after fire

Thirteen classes of burned trees were categorized by stem diameter (40 mm interval). The size before burning was used for 1- and 2-year-old plot, whereas data from 1st monitoring was used for 14- and 17-year-old plot. In figure 4.2 (a), mean stem diameter represents each size class, the smallest size class (stem diameter ≤40 mm; mean = 20 mm) consists of the highest number of studied trees, while smaller numbers are in bigger size classes.

Figure 4.2 (b) shows percent survival after fire of trees in each size class, smaller trees were more vulnerable to fire than large ones were. This figure shows that trees larger than 40 mm stem diameter had a 94-100% chance of survival, where as those <40 mm stem diameter had a more or less equal chance of dying or surviving (51% chance of dying).

4.3.1 Chi-square test

Looking more closely at the smallest size class (stem diameter ≤40 mm) (Fig. 4.3), a steady increase in survival with size class can clearly be seen from 29% for the smallest trees to 100% for the largest. A chi-square test was performed to examine the relation between stem diameter and survival after fire. I separated trees into 8 groups by the stem diameter, 5 mm in each class. And I grouped trees that not significant between group, 4 groups were interesting; they were 1.0 – 9.9 mm, 10.0 – 24.9 mm, 25.0 – 34.9 mm and 35.0 – 40.0 mm. Chi-square tests revealed that increases in survival from DBH size classes 1.0 – 9.9 mm to 10.0 – 24.9 mm (X^2 (1, N = 487) = 3.841), from 10.0 – 24.9 to 25.0 – 34.9 mm (X^2 (1, N = 330) = 3.481) and from the latter to 35.0 – 40.0 mm (X^2 (1, N = 70) = 3.481) were highly significant (p = 0.05). Increasing stem diameter significantly increased survival.

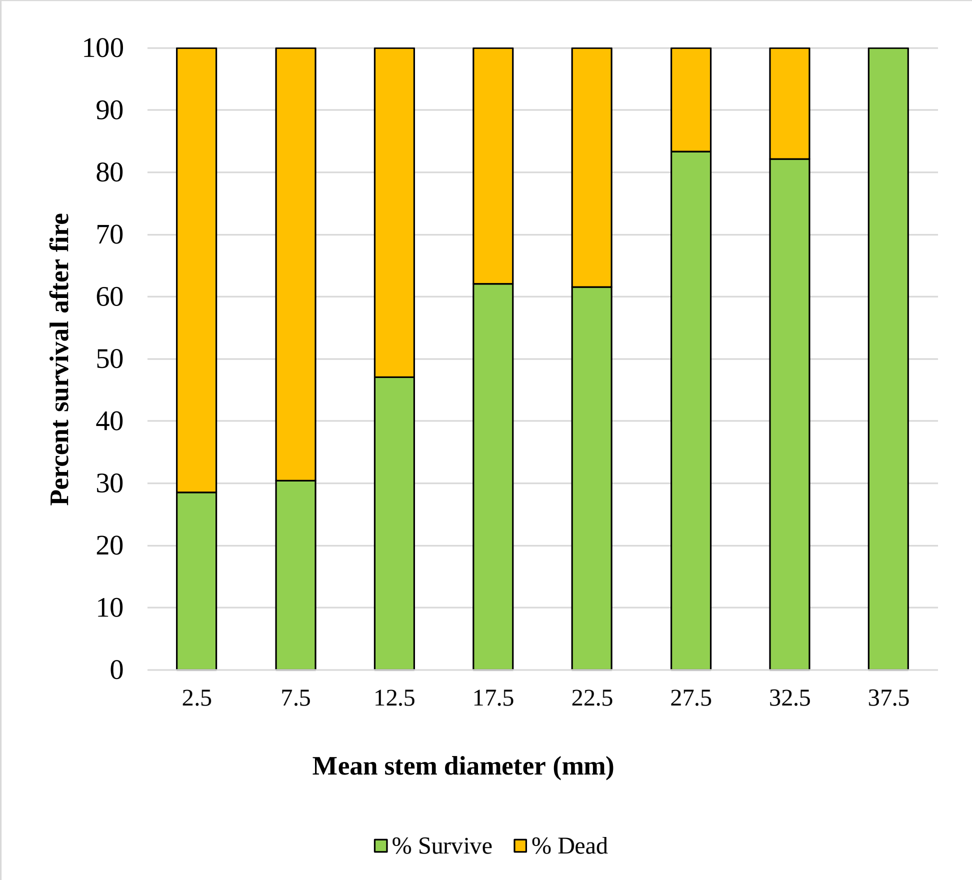


Figure 4.3: Survival and mortality percentage after fire of native tree species in class 1 (1.00 – 39.99 mm), 8 sub-class were classified with 5 mm in each class

4.3.2 Simple linear regression

Figure 4.4 shows a linear relationship between mean stem diameter and percent survival after fire. The results of the regression indicated a positive significant effect between stem diameter and survival (R^2 = 0.9634, p = 1.59 x 10^{-6}). It was found that significantly predicted tendency (β_1 = 2.064, p = 0.002), as did agreeableness (β_0 = 20.609, p = 1.59 x 10^{-6}).

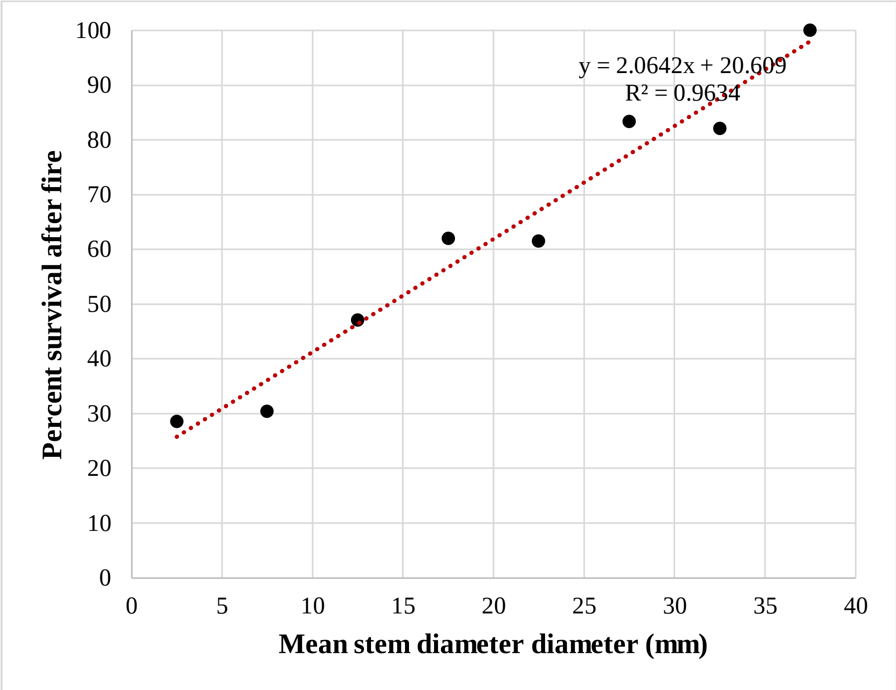


Figure 4.4: Linear relationship between mean stem diameter and percent survival after fire

4.3.3 GLMMs

GLMMs was carried out, to test the effects of stem diameter on survival, after fire. Only small trees (stem diameter ≤50 mm) were focused on this section. Figure 4.5 shows a significantly positive relationship between stem diameter and survival chance (co-efficient estimate ± SE = 0.10 ± 0.01, $z = 6.90$, $p = 5.3\text{x}10^{-12}$), increasing of stem diameter contributed to higher chance of survival after fire. In montane forest, the trees with stem diameter bigger than 40 mm tend to survive better (Figure 4.5).

This trend is similar to that reported in studies in the tropical forests in South America and Asia. In tropical Amazon forest, Xaub *et al*. (2013) reported that survival of trees (>10 cm DBH) after fire was between 79-92%, while similar survival percentage observed in bigger trees from sub-humid tropical forest in eastern Bolivia (84% from trees with DBH > 40 cm) (Pinard *et al*., 1999). In Eastern Kalimantan, Indonesia showed wide range of survival percentage after fire among species (20-95%) of the trees that have DBH > 30 cm (45% survival in average)

(Nieuwstadt *et al.*, 2001). Unsurprisingly, smaller trees with DBH <5-10 cm, showed lower survival percentage after fire, broader range (1-40%) had been reported from tropical Asian forest (Slik and Eichhorn, 2003; Nieuwstadt and Sheil, 2005) compared to 26% from tropical Amazon forest (Pinard et al., 1999).

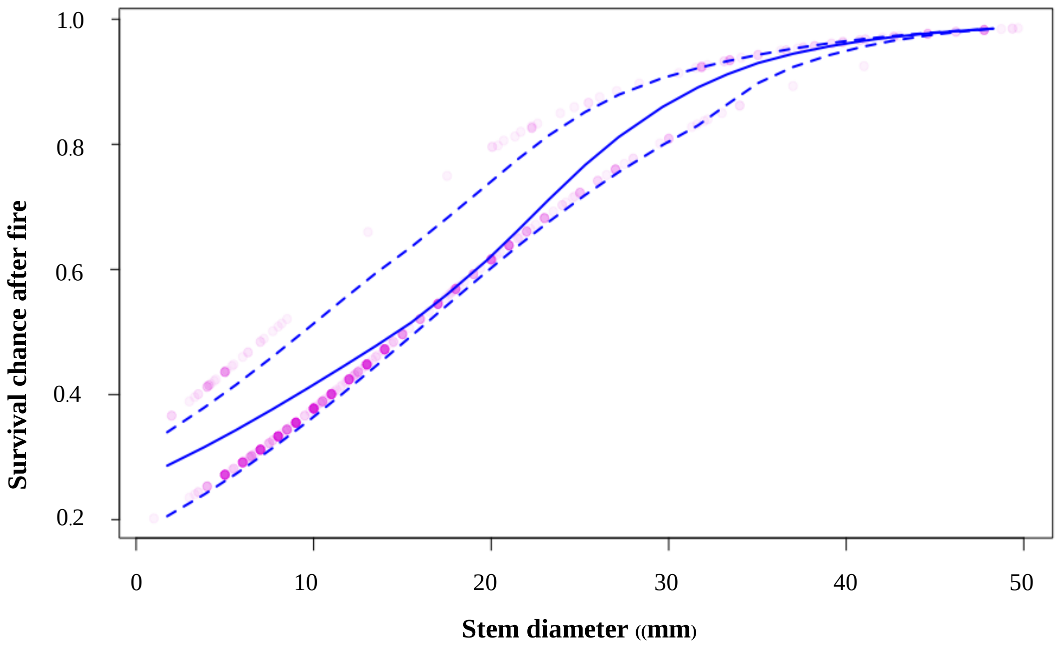


Figure 4.5: Relationship between stem diameter size and chance of tree survival after fire predicted by GLMMs, pink dot is observed value, blue line is predicted line and dash line is 95% interval for the regression line

The studies from Amazonian tropical forests reported high survival chance after fire of trees with a minimum of 10 cm DBH for (Xaub *et al*., 2013), especially trees with double size stem (DBH ≥ 20 cm) can protect cambium tissue from fire (Cochrane *et al.*, 1999). Fire transfers heat to tree stem that causes stem necrosis (Bova and Dickinson, 2005; Midgley *et al*., 2010) and stem deformation (Michalet *et al.*, 2011), both affect survival after fire. Stem necrosis from fire prevents the downward supply of photosynthates and causes of hydraulic system failure (Midgley *et al.*, 2010). In addition, fire reduces xylem conductivity because of vessel deformation and changing in sap surface tension (Michalet *et al.*, 2011). Both intensity of stem necrosis and deformation correlated to the bark thickness, which corresponds to a stem diameter (Bova and Dickinson, 2005; Midgley *et al.*, 2010). Thick bark prevents heat transfer to vascular cambium, so, thicker bark trees had higher percent survival after fire.

In an ecosystem with frequent fire, in resources are allocated to the bark as a defense component to fire, such as *Pinus* species which inhabit in frequently burned area (Jackson *et al.*, 1998). However, the studies of relationship between tree bark and stem size in tropical forests in south central Brazil (Hoffmann *et al.*, 2003) and Australia (Lawes *et al.*, 2011a) showed positive relationship between bark thickness and stem diameter in tropical tree species, bigger tree usually comes with thicker bark.

Bark thickness was considered as a strong strategy to prevent stem from fire (Pinard *et al.*, 1999; Hoffmann, 2003; Xaub *et al.*, 2013; Lawes *et al.*, 2011a; Lawes *et al.*, 2011b). In savanna ecosystems, with annual fires, bark thickness is an important component to prevent the cambium from burning (Hoffmann *et al.* 2003, 2003; Lawes *et al.*, 2011a). Even in tropical forest in Amazonian where fires are rare, the thicker bark tree showed higher ability to survive after fire than the thin bark (Cochrane *et al.*, 1999).

Therefore, bigger trees in this study assumed to have thicker bark that provided a fire defense component, which showed in the results of higher survival percentage in bigger trees in montane forest ecosystem, northern Thailand.

4.4 Percent survival of native tree species in each plot

From 4.3, bigger stems had increased chance of survival. However, different species might contain different traits to survive after fire. Therefore, looking into the species level could contribute to better understanding about this relationship between stem size and survival after fire. The size of the largest tree that died and the smallest tree that survived of each species can provide useful guidance to restoration practitioners.

4.4.1)1-year-old plot

Figure 4.6 shows the survival percentage of six species in 1-year-old plot after fire in May 2015. Three species showed good survival performance (>50%); they were *C. tribuloides*, *C. longiopetiolatum* and *P. cerasoides*. While three other species expressed low survival percentage (<40%); *A. kurzii*, *Q. semiserrata* and *A. fraxinifolius*. According to Elliott *et al*. (2003), percent survival after fire has been suggested as one of the criteria for selecting framework species in northern Thailand (Elliott *et al*., 2003). With this standard, *C. tribuloides* was the only one that could be categorized as "excellent" (75% survival), while *C. longiopetiolatum* and *P. cerasoides* were "acceptable" (50% survival), and the rest were rejected due to low survival percentage after fire.

When considering the largest tree of each species that died after fire, the size of the largest tree of *C. tribuloides (*only one species in the excellent group*)* was the smallest among all species *(*4.5 mm*)*. Not much different with other 2 species in the acceptable group, the largest tree of *C. longiopetiolatum* and *P. cerasoides* was 5.4 and 5.0 mm respectively. For these 3 species, the average of smallest stem that survived and the largest stem that died were 3.0 and 5.0 mm respectively. Unclear relationship between stem size and survival ability was found in this plot.

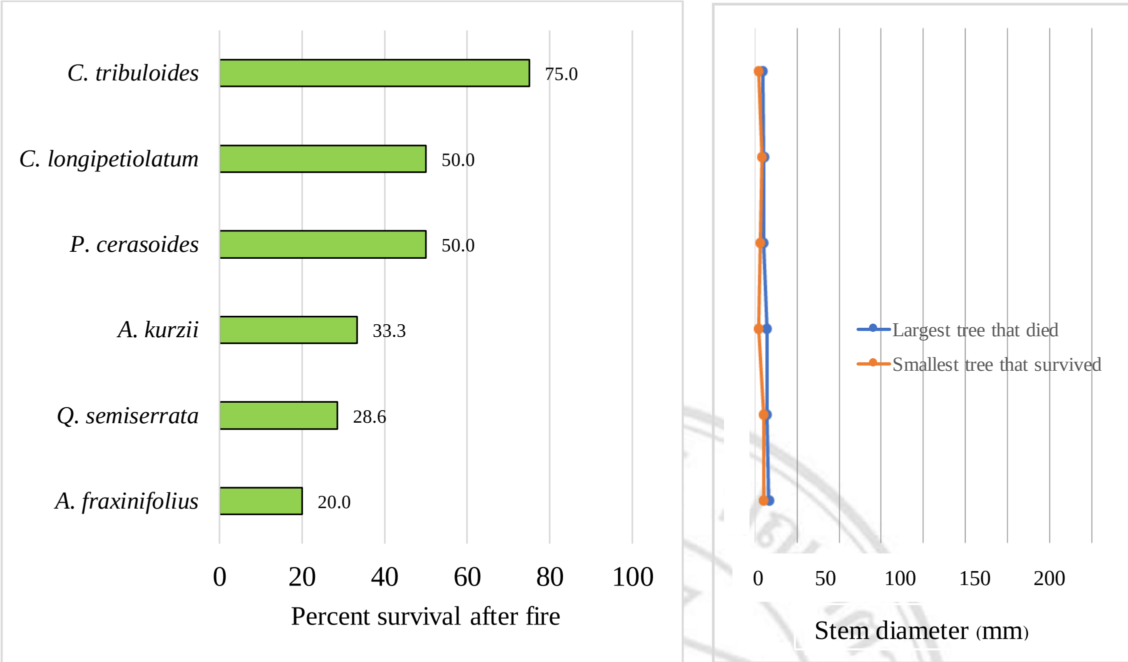


Figure 4.6: Survival percentage and stem size of the largest tree that died and the smallest tree that survived in 1-year-old plot (planted in 2014)

Jackson *et al.* (1998) found that oak species tend to have thicker bark in more frequent fire-prone habitat. Compare to other plots, fires were more frequent in 1-year-old plot as the evidences from burning were commonly found on the standing trees and rocks in this plot. Bark of *C. tribuloides* is thick (FORRU, 2006), even in young saplings this trait could help on protecting an injury from fire.

A trait of *C. longiopetiolatum* was never studied. However, *Cinnamomum caudatum*, which was the same genus of this species, was studied before. Survival and growth rate of *C. caudatum* at 17 months old was unacceptable (37.5% survival and height shorter than 1.25 m), but percent survival after fire at 21 months old was 60% (Elliott *et al.*, 2003). The results from Elliott *et al.* (2003) showed better survival after fire.

Percent survival of 1- year-old *P. cerasoides* was slightly lower (50%) than 21-month-old (60%), compared with Elliott *et al.* (2003)'s. Moreover, FORRU (2006) reported rapid growth of this species that could contribute to larger stem and thicker bark.

4.4.2) 2-year-old plot

Figure 4.7 shows the survival percentage after the plot was burned in April 2015. Using the minimum field performance standard for selecting framework tree species in evergreen forest sites in northern Thailand (Elliott *et al.*, 2003), four categories have been proposed according to percent survival after fire. Excellent performance (>70%) included *M. garretii* (83.3%), *B. javanica* (78.4%) and *F. auriculata* (70.0%). Acceptable performance (50 – 69%) included *P. serratum* (61.5%), *P. cerasoides* (59.1%) and *H. trijuga* (56.7%). Four species in marginal performance group (45 – 49%); they were *H. dulcis* (48.6%), *F. hispida* (48.3%), *S. arboreum* (47.8%) and *F. callosa* (47.1%). The remaining 13 species were in rejected group (< 45%).

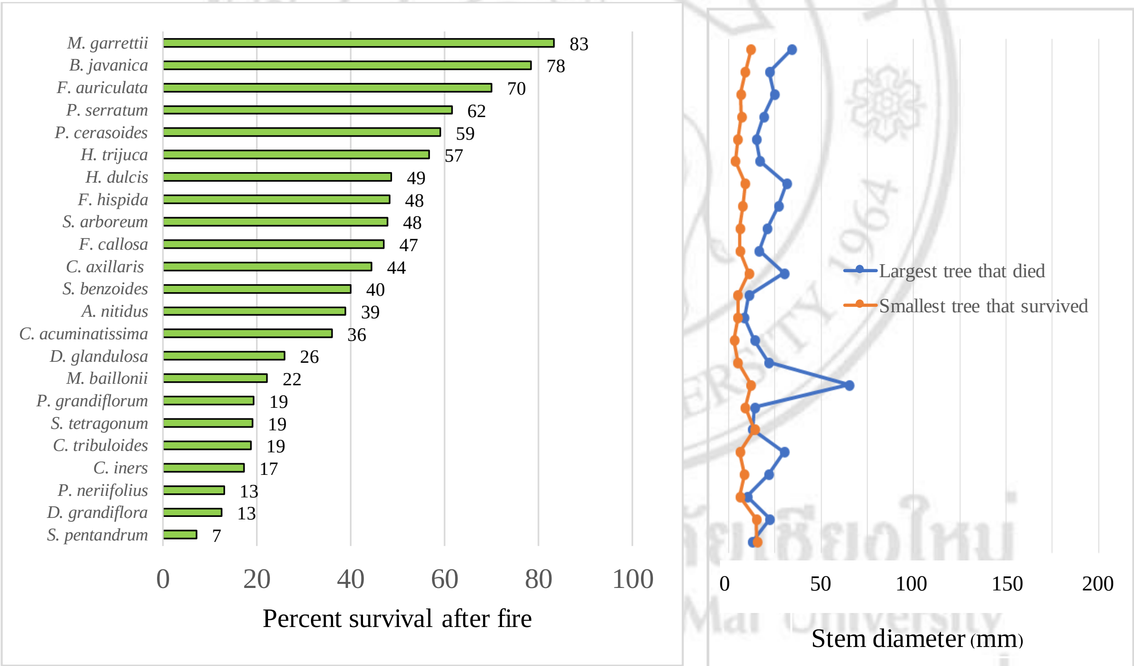


Figure 4.7: Survival percentage, the largest tree that died and the smallest tree that survived in 2-year-old plot (planted in 2013)

The species in excellent (*M. garretii*, *B. javanica* and *F. auriculata*) and acceptable (*P. serratum*, *P. cerasoides* and *H. trijuga*) groups are interesting to investigate further for future implementation. Seedlings of *M. garrettii* and *F. auriculata* grow well in the restoration sites (FORRU, 2006), this characteristic could contribute to larger stem and therefore thicker bark. This relationship has been commonly reported in tropical forests (Hoffmann *et al*., 2003; Lawes *et al.*, 2011a). In addition to rapid growth, *F. auriculata* can grow dense root system which able to help increasing the size of protection structure *(* e. g. bark*)* and containing high carbohydrate, which therefore increasing the ability to resprout (Shibata *et al*., 2016) and survive after fire. The last species in this group, *B. javanica* showed positively fire resilient performance after fire. Higher percent survival found in older saplings, 87% at 33 months old in Elliott *et al*. (2003)'s study, and 78.4% at 24 months old in this study.

In the acceptable group, *P. serratum* had the highest percent survival after fire among other species (61.5%), whereas no existing data to compare elsewhere. Next on the list was *P. cerasoides*, their saplings showed similar survival percent after fire (about 59-60%) in this study and Elliott *et al.* (2003)'s. Similar to *B. javanica* in the previous group, *H. trijuca* showed higher percent survival when the saplings were older (67.0% at 33 months old) in Elliott *et al*. (2003)'s compared to this study (56.7% at 24 months old). It is still unclear why this species performed better among other studied species, however rapid growth has been emphasized to be an important characteristic of the species with fire resilience (e.g. *P. cerasoides).*

The mean stem diameter of biggest tree that died of these 6 species was 22. 0 mm. And the mean stem of smallest tree that survived was 7.2 mm. Among all six species in both excellent and acceptable groups, the biggest difference between the largest tree that died (30 mm) and the smallest tree that survived (6 mm) was found in *P. cerasoides*. Apart from the size of stem diameter, fire intensity (Slik and Eichorn, 2003) and duration of heating (Lawes *et al.*, 2011) were an important cause of survival. Therefore, the bigger trees with higher fire intensity and/or longer duration of heating might lower chance of survival than the smaller trees with lower fire intensity and shorter heating duration.

4.4.3) 14-year-old plot

Figure 4.8 shows percent survival in 14-year-old plot, the smallest trees that survived were presented for all species, whereas the largest trees that died were presented only for the species that had percent survival less than 100. According to

Elliott *et al.* (2003), all species in this plot were classified as excellent species based on their survival percent after fire. Eight species had 100% survival, they were *C. axillaris*, *Q. semiserrata*, *M. stipulata*, *F. subulata*, *S. tetragona*, *S. albiflorum*, *C. acuminatissima* and *B. javanica*. The rest of the species had more than 80% survival; they were *P. cerasoides* (96.4%), *A. nitidus* (94.4%), *S. arboretum* (90.0%), *M. baillonii* (86.7%), *H. trijuca* (83.3%) and *C. diversifolia* (83.3%).

For eight species that had 100% survival after fire, the range of their smallest trees that survived is between 20.1 – 141.7 mm. When considering all species in this plot, the smallest size of trees that survived also varies between 20.1 - 141.7 mm, while the largest tree that died is between 22.6 - 117.8 mm. Mean stem diameter among species of the largest tree that died was 68.4 mm, mean stem diameter of the smallest tree that survive was 44.7 mm. The largest tree that died in this plot had 117.8 mm of stem size (*C. diversifolia* - 83.33 % survival). The smallest tree that survived had 20.1 mm of stem size (*C. acuminatissima* and *M. stipulate* - both were 100% survival).

Similar to the 2-year-old plot, fire intensity and heating duration (Slik and Eichorn, 2003; Lawes *et al*., 2011a) are affected to stem injury, that can cause mortality after fire. Bigger trees might have a lower chance of survival in the higher fire intensity and/or longer heating duration.

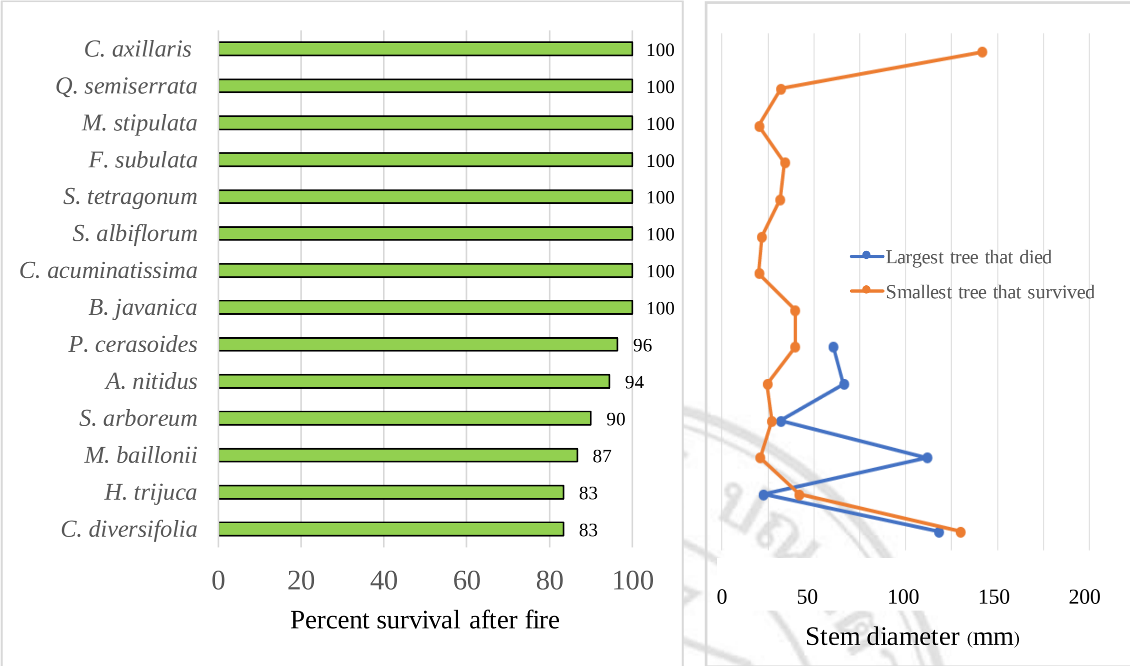


Figure 4.8: Survival percentage, the largest tree that died and the smallest tree that survived in 14-year-old plot (planted in 2001)

4.4.4) 17-year-old plot

Figure 4.9 shows percent survival, stem size of the largest trees that died and the smallest trees that survived in 17-year-old plot (planted in 1998). Most species at this age can survive fire disturbance. Only 3 species had survival percentage less than 100; they were *B. javanica* (97.6%), *C. axillaris* (95.0%) and *M. azedarach* (81.8%). All of them were classified into the excellent group of fire resilience performance (> 70% survival after fire) (Elliott *et al.*, 2003). Mean stem diameter of the largest tree that died was 113.9 mm, while, mean stem diameter of the smallest tree that survived was 53.6 mm. The largest tree that died was *M. azedarach* (181.5 mm) with 81.8% survival. The smallest tree that survived after fire in this oldest plot was *G. mckeaniana* (13.1 mm) with 100% survival.

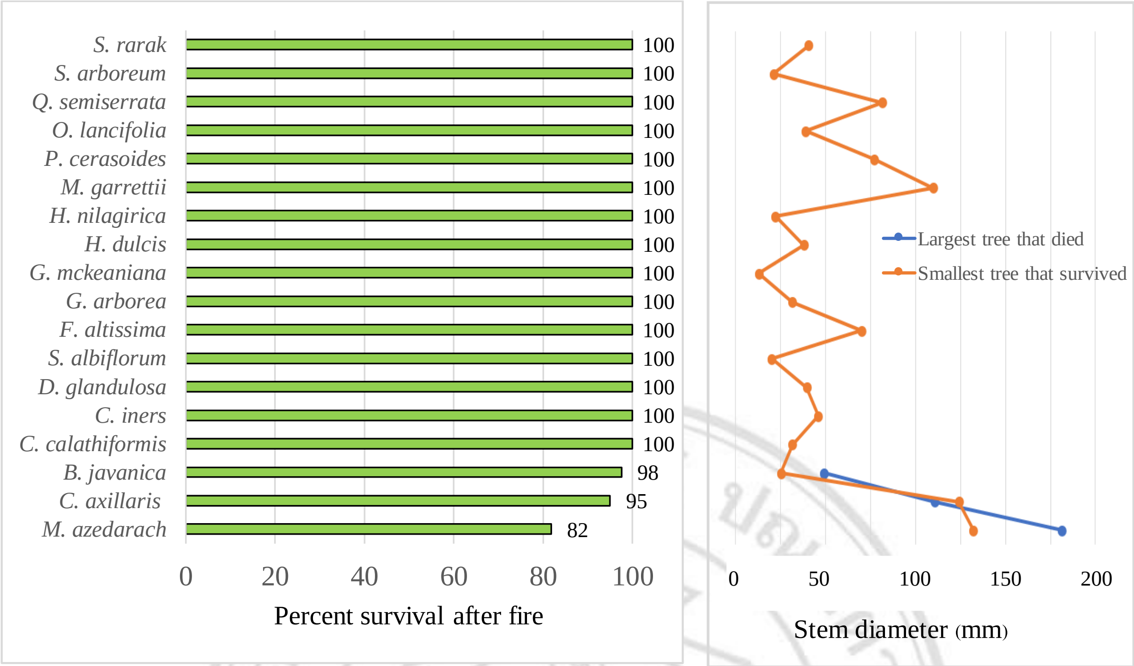


Figure 4.9: Survival percentage, the largest tree that died and the smallest tree that survived in 17-year-old plot (planted in 1998)

Planted trees 14 and 17-year-old plot were big enough to survive after fire. Nieuwstadt and Sheil (2005) studied in the tropical forest in Kalimantan, Indonesia, they found survival of burnt trees were decreased in stem size less than 10 cm and increased in stem size bigger than 70 cm. Another studied in tropical forest at eastern Bolivia (Pinard *et al*., 1999) was found percent survival of small tree (73% survival of 10 – 40 cm) was lower that large trees (84% survival of tree bigger than 40 cm). Survived of big trees were not only persist pre-fire ecosystem, but also valuable for source of seed and shade providing (Swaine, 1992) and decrease ability of un-wanted species (such as grass) to grow after burnt.

Mean stem diameter of the largest trees that died was increased in older plot (6.2, 22, 68.4 and 113.9 mm in 1-, 2-, 14-, 17-year-old plot). Mean stem diameter of the smallest trees that survived was also increased in older plot (6, 7.2, 44.7 and 53.7 mm in 1-, 2-, 14- and 17-year-old plot). Although bigger tree is contribute thicker bark and larger stem, fire intensity and duration of heating also affected to survive of burnt trees. Moreover, habit of tree was probably affected to the survival ability after fire. Three species that percent survival less than 100% in 17-year-old plot

(*M. azedarach*, *C. axillaris* and *B. javanica*) were categorized as pioneer species (Maxwell and Elliott, 2001). Pioneer species was mature early and die back in 15-20 years (Elliot *et al*., 2013), this senescence probably a cause of more sensitive to fire disturbance and decrease survival ability when get older.

4.5 Resprouting ability after fire disturbance

At 30 weeks after burning, the smallest size tree class (0-30 mm) produced the highest number of resprouting shoots. From this study, the number of shoots decreased when the stem size increased until it reached 90 mm, then the numbers fluctuated until the stems were bigger than 210 mm. Very few resprouting shoots were observed from the trees in big size classes (210 - 510 mm) (Figure 4.10).

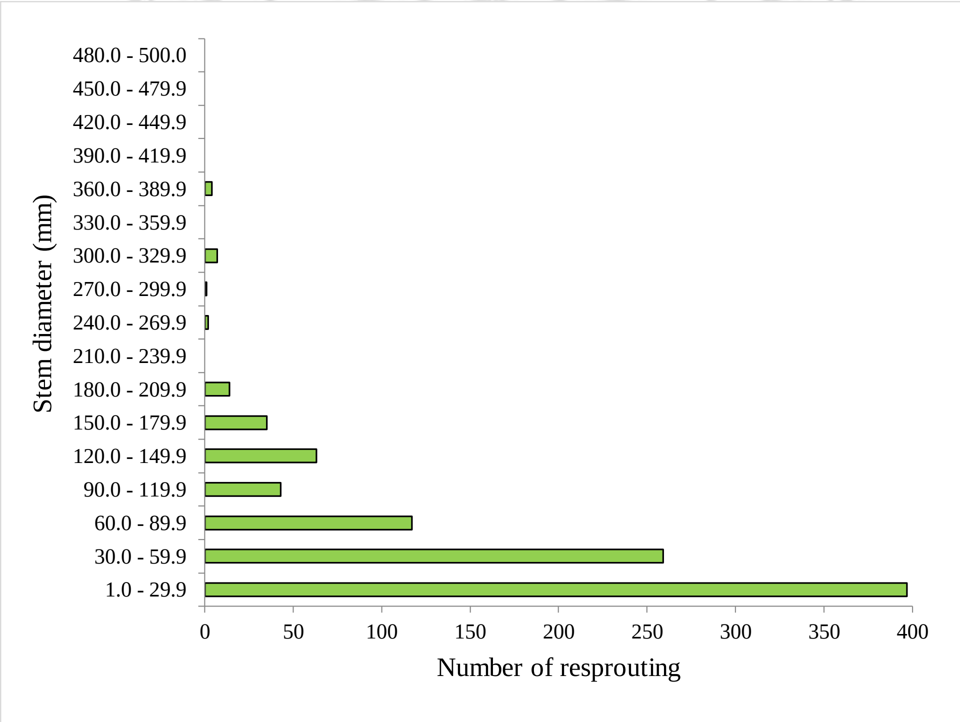


Figure 4.10: Number of resprouting shoots of the trees survived at 30 weeks after burning (30 mm interval)

To examine this closer, only the trees with DBH <210 mm were focused (10 mm range in each size class). The number of resprouting shoots was high (58-193) in smaller class sizes (0-60 mm). The trees that survived after burning tended to produce less number of resprouts (31 or less) if they were bigger than 90 mm. Only few resprouting shoots were observed from the trees of DBH > 190 mm (Figure 4.11).

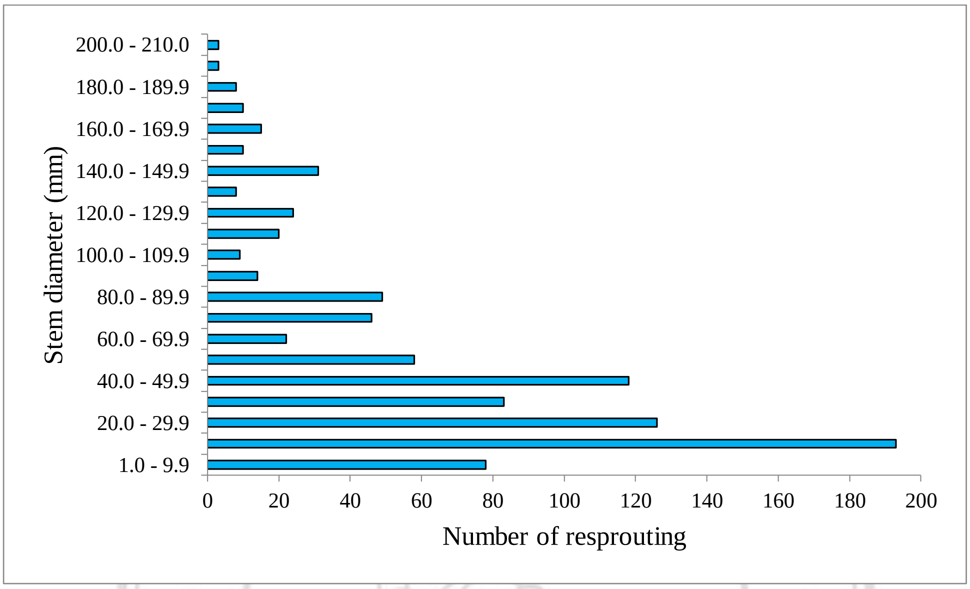


Figure 4.11: Number of resprouting shoots of the trees survived at 30 weeks after burning (10 mm interval)

4.6 Effects of tree size on resprouting ability after fire

Only the trees with a DBH <210 mm were included in GLMMs analysis in this section. Figure 3 shows negative significant between stem diameter and the number of resprouting shoots (co-efficient estimate ±SE = -0.006 ± 0.001, z = 6.01, p = 1.86×10^{-9}). Trees with larger stem diameters significantly resprouted less after fire in montane forest ecosystem of northern Thailand. Similar to studies in tropical forests in Malaysia by Kauffman (1991), who reported that resprouting ability was decreased in bigger tree.

According to the positive correlation of stem diameter and bark thickness (Lawes *et al.*, 2001a; Hoffmann *et al.*, 2003), bigger trees could possibly have thicker bark. Although bark thickness can prevent cambium necrosis from fire, but thick bark also inhibiting resprouting because it hinders epicormic bud emergence (Clarke *et al.*, 2012). The study in oak species confirmed a failure rate of resprouting in oaks with thick bark (Johnson *et al.*, 2002).

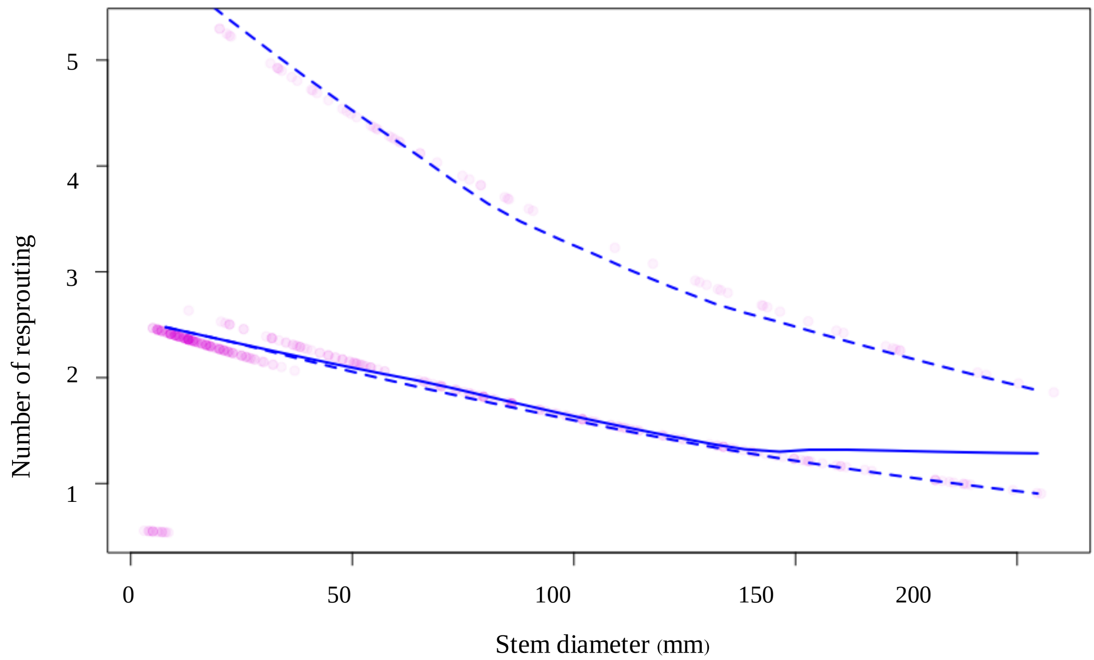


Figure 4.12: Predicted values for number of resprouting: an interaction between number of resprouting and stem diameter (DBH<210 mm), pink dot is observed value, blue line is predicted line and dash line is 95% interval for the regression line

From Figure 4.12, the number of resprouting shoots were high (58-193) in smaller class sizes (0-60 mm). Therefore, the trees in these small class sizes were included in GLMMs analysis to quantify the effects of stem size on resprouting ability after a fire. Differently, Figure 4.13 shows positive significance between stem diameter and resprouting ability of small trees with a DBH <60.0 mm (co-efficient estimate ± SE = -0.009 ± 0.004, z = 2.07, p = 0.04). Trees with a larger stem in these categories showed a significantly amount of resprouted shoots after they were burned. Pinard *et al*. (1999) confirmed that trees smaller than 100 mm DBH in a tropical Amazonian forest were relatively common on resprouting ability, but uncommon for bigger trees than 100 mm DBH. In addition, Shibata *et al*. (2016) found that resprouting ability increased with bigger stem of woody species in a temperate forest.

There was a positive relationship between stem diameter and resprouting ability of trees with DBH <60 mm. Inside this range, larger trees could have better bud protection and resource reserver. Clarke *et al*. (2012) reported that thicker stem helps to protect buds from burning, buffer xylem against hydraulic failure, and prevent phloem and xylem necrosis from the heat transfer through cambium. In addition, bigger stems are associated with resource storage (Shibata *et al*., 2016), which shows higher ability to resprout shoots than smaller stems.

Consistent with stem diameter and the age of the tree (mean stem diameter was 5.0, 13.2, 101.7, 124.1 mm in 1-, 2-, 14- and 17-year-old trees respectively), its resprouting ability decreases: this might be linked to bud senescence. The study of functional trait of resprouting by Clarke *et al*. (2012) found that this occurring was possibly arise from combination of genetic, physiological and related anatomical changes. Bond and Migdley (2001) confirmed that resprouting ability increases with size until the trees reach an adult stage and losing the capacity to resprout.

Resprouting is a tolerant trait to persist at the plant level, resilient to severe disturbance at community level (Clarke *et al*., 2012), and shortens the time to recovery (Lawes *et al*., 2011b). Therefore, smaller trees that were mostly killed by fire resprout after the fire disturbance to restore their photosynthesis capacity (Lawes *et al*., 2011b) and persist in a site (Vask and Westoby, 2004). Conversely, trees that were big enough to escape fire damage lost their capacity to resprout due to their remaining photosynthesis structure (Bond and Midgley, 2001).

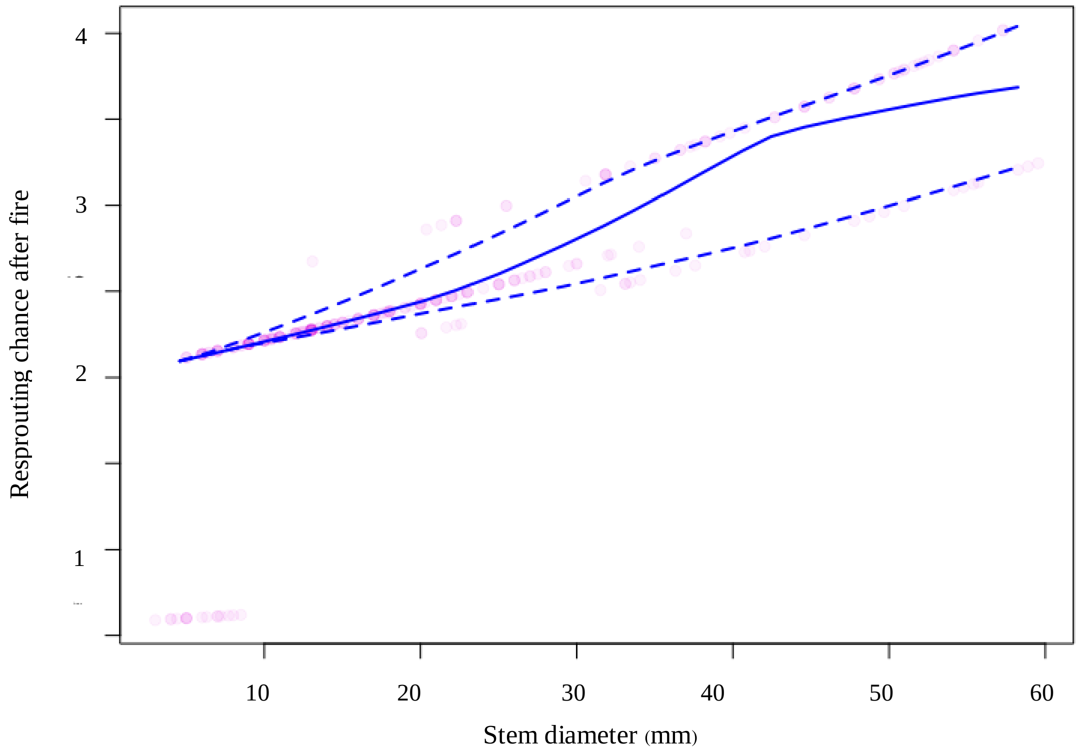


Figure 4.13: Predicted values for resprouting: an interaction between the number of resprouting and stem diameter (DBH<60 mm), a pink dot is the observed value, the blue line is the predicted line and the dash line is the 95% interval for the regression line.

4.7 Potential tree candidates for restoring fire-prone montane forest

Most trees in 14- and 17-year-old plot (planted in 2001 and 1998, respectively) were big enough to survive a fire disturbance in the summer of 2015 (April – May). Here I particularly focused on the trees that survived in the young plots; the 1- and 2-year-old plot (planted in 2014 and 2013, respectively), using survival data from the 3rd monitoring at 30 weeks after the fire. According to Elliott *et al.* (2003), tree species with a percent survival (after burning) that were lower than 45% were rejected, a total of 12 species were therefore selected to calculate the suitability index for this study. Only *P. cerasoides* has two values calculated from both 1- and 2-year-old plot (Table 4.1).

I propose 3 classes of suitability based on the scores calculated from 3 parameters (survival percentage, RGR and resprouting ability); excellent (>75), acceptable (60-75), and marginal (<60). High growth rate correlated with both survival and resprouting ability in juvenile trees (Hoffmann, 2003). From 12 species (10 families), there were three species (*F. auriculata*, *F. hispida* and *F. callosa*) from Moraceae that were available for this calculation. *Ficus* was selected because of its fire resilience, rapid growth after burning and its root system penetrates deep underground (FORRU, 2006), which can prevent it from being burned.

Three species were categorized into as "excellent" (rank suitability score >75); they were *M. garrettii*, *B. javanica* and *F. auriculata*. These three native tree species had been recommended as potential framework tree species (FORRU, 2006) for restoring forest ecosystems in northern Thailand where fires are prone. Elliott *et al*. (2003) confirmed that *B. javanica* was resilient to fires (87 % survival after a fire at 33-month-old), and resprouted well after fire (FORRU, 2006). Apart from fire resilient characteristics, *B. javanica* and *F. auriculata* have been reported by FORRU (2006) that these species can produce fruits within 6 years after planting. They have the ability of attracting wildlife in the early stage of restoration. Even though *M. garrettii* cannot produce fruit within 7 years, but seeds of this species attract birds and squirrels. Moreover, *M. garrettii* develops broad leaves and dense crown which effectively shade out weeds (FORRU, 2006). For restoring in montane forest where fire disturbance is common, these 3 species were highly recommended.

Seven species were grouped in the "acceptable" (rank suitability score 60-75); *F. hispida*, *H. trijuca*, *P. cerasoides* (2-year-old), *C. tribuloides*, *P. serratum*, *S. arboreum* and *H. dulcis*. Six out of 7 species were recommended as potential framework tree species for montane forest in northern Thailand (FORRU, 2006), except *P. serratum*. Among six potential framework tree species, *C. tribuloides* was reported to resprout rapidly, while *F. hispida* and *H. dulcis* were mentioned to have >70% survival after a fire. Although *S. arboreum* is a slow growing tree species but it showed high survival and rapidly resprouting characteristic. With similar percent survival after fire, *H. trijuca* and *P. cerasoides* were identified into acceptable category in both Elliott *et al*. (2003) and in this study.

During the 3rd monitoring, *C. tribuloides*' seedlings were found in both 1- and 2-year-old plots, however only those in the 1-year-old plot (ML) survived >45%. In temperate forest, *Pinus* and *Quercus* that grow in an area with high frequency of fire tend to have thicker bark (Jackson *et al.*, 1998) and this trait could possibly be inherited to next generation. Local seed source could help to maximize possibility that seedlings will survive and adapt to local disturbance (e.g. fire). *C. tribuloides*' seedlings in the 1-year-old plot (ML) produced from local seed source, whereas those planted in the 2-year-old plot (BMSs) propagated from another location (FORRU, 2014 - unpublished paper).

Due to a rank suitability score of < 60%, 3 species were categorized as "marginal"; *F. callosa*, *P. cerasoides* (1-year-old) and *C. longipetiolatum*. Two out of 3, *F. callosa* and *P. cerasoides* were recommended as potential framework tree species (FORRU, 2006), whereas *C. longipetiolatum* had never been studied before. Interestingly, older seedlings of *P. cerasoides* (2- year-old) expressed better resilient performance compared to those younger seedlings in the 1-year-old plot. For those trees DBH <60 mm, trees with larger stems have better bud protection and resource reserve. *P. cerasoides*' trees in the 2- year-old plot produced 8 times more resprouting shoots than those in the 1- year-old plot. As mentioned in 4.6 that a bigger stem is associated with resource storage, it has more of the ability to produce resprouting shoots than smaller stems (Shibata *et al*., 2016).

All species in Table 1 should be considered during species selection process for restoring montane forest in northern Thailand. Nine out of the 12 species are potential framework tree species which can provide resources for wildlife and shade out weeds effectively within 3 - 5 years after planting. Planting these 9 framework tree species with 3 additional species (*P. serratum*, *F. callosa* and *C. longipetiolatum*) can help to increase species richness and also ecosystem resilience simultaneously

Table 4.1: Suitability index of native tree species in northern Thailand for restoring montane forest

No.	Scientific name	Plot age (year)	Survival (%)[a]	Largest tree that died (mm)	Smallest tree that survived (mm)	RGR (%/year)[b]	No. of resprouting shoot/tree[c]	Standardized suitability score[d]	Rank suitability score
1	*M. garrettii*	2	100.0	34.0	12.0	42.9	100.0	342.9	100.0
2	*B. javanica*	2	94.1	22.0	9.0	37.2	70.2	295.5	86.2
3	*F. auriculata*	2	84.0	24.7	6.4	24.4	69.8	262.2	76.5
4	*F. hispida*	2	57.9	27.0	7.5	100.0	35.5	251.3	73.3
5	*H. trijuca*	2	68.0	17.0	3.5	65.8	49.0	250.8	73.1
6	*P. cerasoides**	2	70.9	15.0	5.0	38.3	66.8	246.9	72.0
7	*C. tribuloides**	1	90.0	4.5	2.0	45.2	12.2	237.4	69.2
8	*P. serratum*	2	73.8	19.0	7.0	35.8	43.3	226.8	66.1
9	*S. arboreum*	2	57.4	21.0	6.1	29.8	76.7	221.3	64.5
10	*H. dulcis*	2	58.4	31.3	9.0	55.8	33.1	205.7	60.0
11	*F. callosa*	2	56.5	16.5	6.0	37.3	30.3	180.5	52.6
12	*P. cerasoides**	1	60.0	5.0	3.0	50.8	8.2	179.0	52.2
13	*C. longipetiolatum*	1	60.0	5.4	4.1	17.9	16.3	154.2	45.0

*Native tree species that were planted in both 1- and 2-year-old plot
[a,b,c] Standardized by converting the maximum value to 100, then adjusted other values proportionately
[d] Standardized suitability score = 2a + b + c

43