CHAPTER 2

Literature review

2.1 Montane forest ecosystem

Montane forest ecosystems are commonly found above 1,000 m elevation (Santisuk, 2006). It is predominant across most of Thailand's critical water catchments. Such ecosystems play an important role in the hydrologic cycle, due to its ability to prevent run-off after heavy downpours, ensuring continuous stream flow to lower-lying areas and protection against soil erosion (Ateroffa and Rada, 2000; Khamying et al., 2003). Montane forest ecosystems contain high biodiversity, some families that are commonly found e.g. Magnoliaceae, Theaceae, Lauraceae, Moraceae and Fagaceae (Santisuk, 2006; FORRU, 2006).

During the past few decades of rapid economic development, Thailand's natural resources have been severely degraded (ICEM, 2003). Montane forest ecosystems have been modified by various types of land-use, particularly shifting cultivation (Delang, 2002). Since the last century, people have illegally settled in the mountain chains of the North, altering the natural montane vegetation (Santisuk, 2006), and increasing the intensity of land use which has been driven by economic development and population growth (Santisuk, 2006; ICEM, 2003). Deforestation in northern Thailand caused by land encroachment, agricultural expansion, intensive shifting cultivation and fire disturbance (ICEM, 2003; Ongprasert, 2011). Although patches of trees can be found on northern mountains land degradation might have caused heavy soil erosion, siltation, flash floods etc. Continuingly, these events have become serious problems of the country (Maxwell and Elliott, 2001).

Another major cause of montane forest degradation is fire (Ongprasert, 2011). Due to high annual humidity in montane forest ecosystems, forest fire is naturally less frequent compared to other ecosystems in lower elevation (Santisuk, 2006; Hoffman, 2003; FORRU, 2006; Bruijnzeel et al., 2011). However, using fire to control weeds in highland agricultural areas is a major cause of fire disturbance in this ecosystem (Bruijnzeel et al., 2011). Furthermore, climate change could cause some areas to become drier, and therefore increase fire severity in the montane forests (Cochrane, 2003, Bruijnzeel et al., 2011).

2.2 Forest restoration in high elevation

SER (2004) proposed that ecological restoration is the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed. The term restoration could be translated into different meanings or levels of practices in the context of Thailand. Forest restoration is a specialized form of reforestation. Elliott et al. (2013) defined forest restoration as re-instatement an ecological process, which accelerates recovery of a forest's structure, ecological functioning and biodiversity levels, towards those typical of a climax forest.

Reforestation in northern Thailand began in 1906 in province of Phrae. Its goal was to replant teak trees in logging concession areas, and was later expanded to include planting more tree species in the watershed areas (Royal Forestry Department, 2009). This same period of time, the Royal Forestry Department focused on planting few species of high value timber, such as teak (Tectona grandis) and rose wood (Xylia xylocarpa) (Royal Forestry Department, 2009). Later in 1941, they changed their strategy from planting high value timber species to fast growing species (Kiianmaa, 2005), such as eucalyptus (Eucalyptus oblique) and pine (Pinus kesiya). Most reforestation programs focused on montane forest ecosystem, such as in Doi Inthanon National Park (Werner and Santisuk, 1993). Another species that had been planted widely was Leucaena leucocephala. It is used in many plantations because it helps to improve soil fertility and survives well in drought condition (Frois et al., 2008). The use of pioneer species, either exotic or native species in reforestation projects, is mainly to reduce the incidence of weeds and prevent soil erosion.

Planting few tree species can bring back green cover and some ecological functions but does little for biodiversity. A restoration technique called framework species method was first coined in Queensland, Australia, and later adopted in Thailand by the Forest Restoration Research Unit, Chiang Mai University (FORRU-CMU). It has been scarcely tested in northern Thailand, since 1997 (FORRU, 2006). This technique calls for planting a mixture of 20-30 indigenous tree species, to encourage the re-establishment more balance in the ecosystems (FORRU, 2006) (Figure 2.1). This technique encourages seed dispersers from nearby intact forests such as birds, squirrels and civets by providing resources such as fruits and suitable habitats. Its results showed a high level of biodiversity recovery in less than 10 years after planting (Elliott et al., 2013).

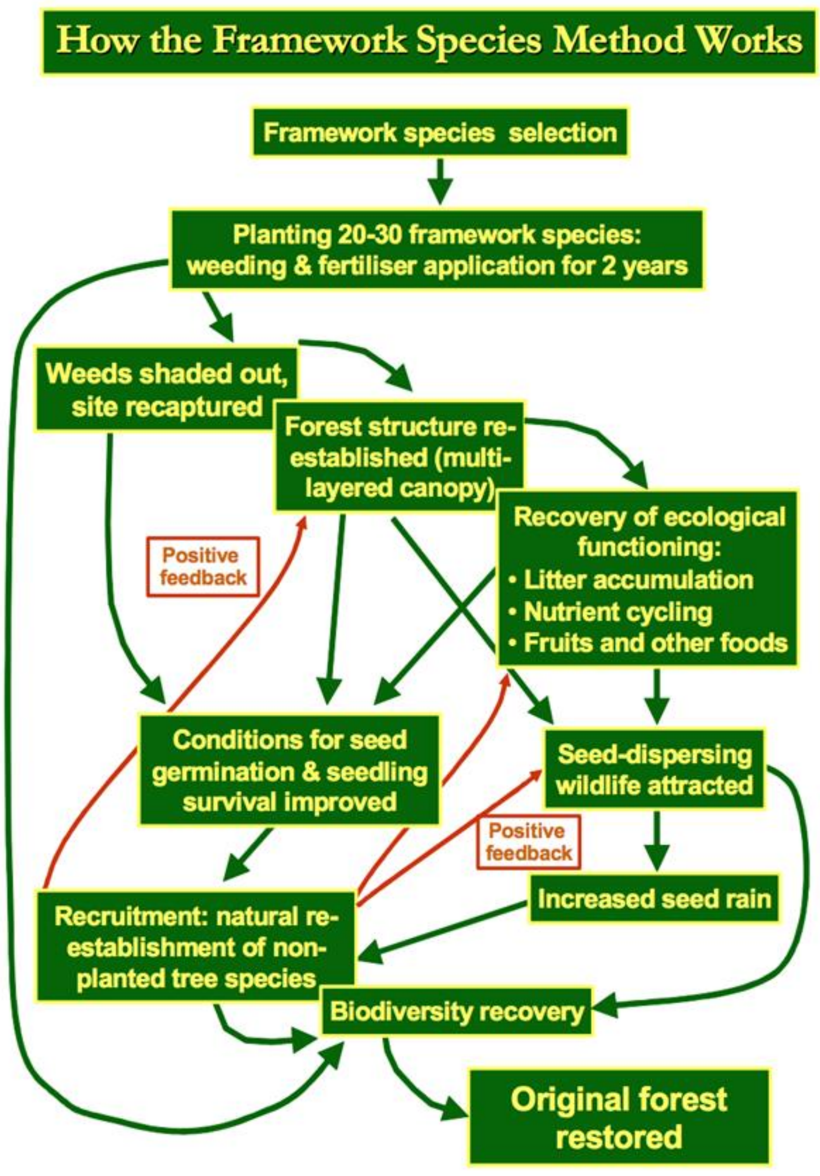

Figure 2.1: Concept of framework species method (FORRU, 2006)

2.3 Fire disturbance in montane forest ecosystem

For successful restoration in northern Thailand, fire prevention has been widely emphasized. An ecosystem, affected by fire, has decreased in ecosystems dynamics (Hoffman, 1996; Schmoldt et al., 1999), ecosystem functionality (Attiwill, 1994), plant species diversity and plant abundance (Attiwill, 1994; Vaidhayakarn and Maxwell, 2010).

In many tropical forest ecosystems, fires damage mature vegetation (Maxwell and Elliott, 2001), affect ecosystem regeneration, and destroy the soil seed bank (Maxwell and Elliott, 2001; Nieuwstadt et al., 2001; Lentile et al., 2007). Ground flora dominated by fire resistant-grasses are proliferated and therefore can obstruct forest recovery (Maxwell and Elliott, 2001; Setterfield, 2002; Lentile et al., 2007).

In Thailand, fire disturbance is common in deciduous forests, and sparsely occurs in evergreen forests which contains high moisture biomass content (Junpen et al., 2013). Fire occurs during dry season (December to May), which peak in March (Junpen et al., 2013). The Forest Fire Control Division of the Royal Forestry Department (FFCD) (2011) reported that all fires are human-caused with various reasons (% of incident) including gathering of forest non-timber products (39%) such as mushroom, hunting (24%), agriculture residue burning for land clearing before the next crop (19%), incendiary fire (10%), illegal logging (2%) and other (6%).

Junpen et al. (2013) reported fire hotspot mainly occurs in upper northern, western, upper northern eastern, and east side of the northeastern regions in Thailand. The study of fire hot spots in Thailand during 2005 - 2009 found the intensity of fire hotspot in 2007, which El Nino occurred in this year (Junpen et al., 2013) (Figure 2.2). Furthermore, Cochrane (2001) reported that climate change is one of major causes of drier and higher temperatures in the dry season, which can contribute to higher intensity and frequency of fire disturbance in terrestrial ecosystems. Climate change may increase the likelihood of fire disturbance in montane forest ecosystem where fires are less frequent (Hoffman, 2003; FORRU, 2006; Bruijnzeel et al., 2011). Therefore, plants in this ecosystem that barely evolved along with frequent fires, are more likely to disappear after a fire (Hoffman, 2003; Conchrone, 2003; ICEM, 2003; Marrinan et al., 2005).

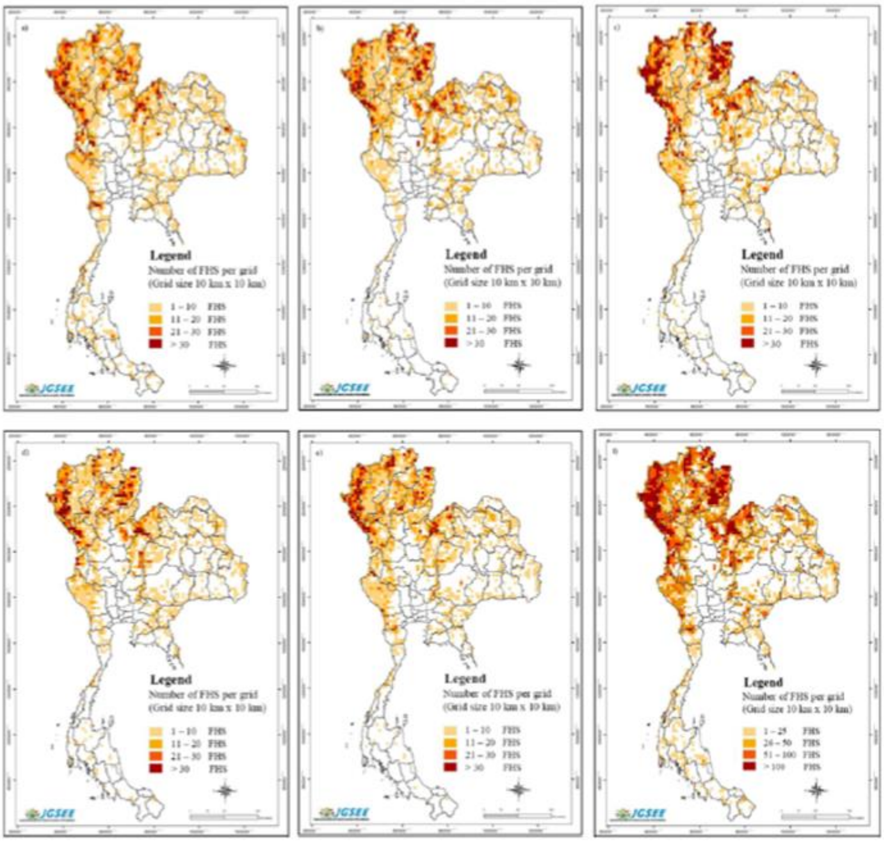

Figure 2.2: Forest fire hotspots density distribution on yearly scale for (a) 2005, (b) 2006, (c) 2007, (d) 2008, (e) 2009, and (f) cumulative forest fire hotspots density distribution during 2005 - 2009 (Junpen et al., 2013)

2.4 Factors affecting survival after fire disturbance

Fire kills trees by destroying the cambium during burning. However, post-fire mortality is a consequence of stem necrosis (Dickinson et al., 2004; Bova and Dickinson, 2005) and stem deformation (Michaletz et al., 2011). Stem necrosis is a cause of preventing downward translocation of photosynthate, trees will survive until root starvation (Nobel, 2005). Stem deformation is another cause of post-fire mortality. In normal stages, lignin, hemicellulose and cellulose polymer in the conduit wall are hard and glassy, but soft in high temperature. Heating softens cell walls and sap surface tension. These components become permanently deformation in cooler stages after a fire, and results in permanent disruption of xylem flow and reduce hydraulic conductivity (Michaletz et al., 2011).

Many studies reported that post-fire survival is correlated with bark thickness (Pinard et al., 1999; Hoffmann et al., 2003; Midgley et al., 2010; Lawes et al., 2011a; Lawes et al., 2011b; Xaub et al., 2013), that protect epicormic buds, cambium, hydraulic system and stem injury. Bark slows the heat transfer to cambium, that prevents stem necrosis (Bova and Dickinson, 2005), deformation (Michaletz et al., 2011) and failure of the hydraulic system (Midgley et al., 2010). Several studies in tropical forests showed positive relationship between bark thickness and stem diameter in tropical species (Bova and Dickinson, 2005; Midgley et al., 2010; Lawes et al., 2011a). Therefore, bigger trees have thicker bark and higher survival ability after fire. Forest species require considerably greater stem diameter to ensure stem survival during a burn (Hoffmann et al., 2003).

2.5 Factors affecting resprouting ability after fire disturbance

Resprouting is the response of initial growth from buds follow disturbance; this response implies the potential for repeated vegetative regeneration from a source of protected buds and meristem (Clarke et al., 2012). This trait is important for achieving persistence at the species level and can survive diverse disturbances (Marrinam et al., 2005; Vesk and Westoby, 2004; Clarke et al., 2012). Resprouting is also resilient to severe disturbances at the community level, which might have caused consequences on vegetation dynamics, community composition, and species coexistence (Poorter et al., 2010; Clarke et al., 2012).

The influences and consequences of resprouting from individuals to communities are discussed in several publications (Figure 2.3). Clarke et al. (2012) proposed a new conceptual framework for resprouting theory, the buds-protection-resources (BPR) scheme. This concept considered resprouting as a plant functional trait based on bud location, their protection, and resourcing of regrowth, in response to disturbance (Clarke et al., 2010; Lawes and Clarke, 2011; Hoffmann et al., 2012) (Figure 2.3).

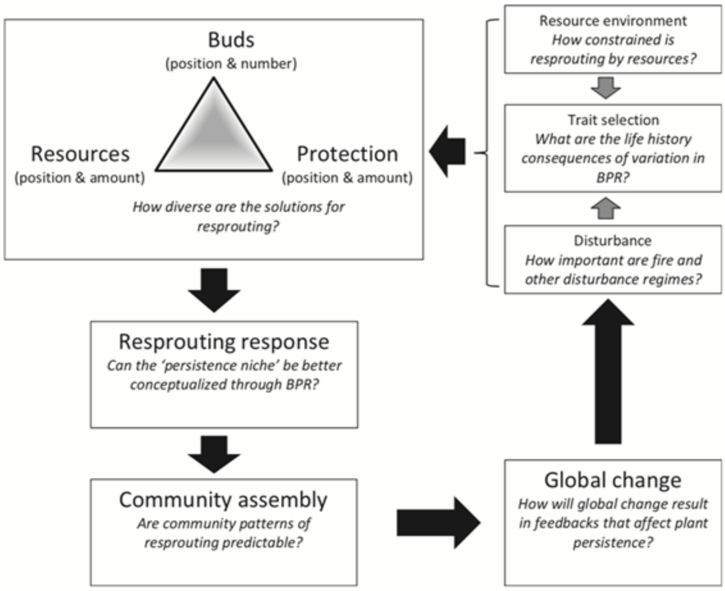

Figure 2.3: The influences and consequences of resprouting from individuals to communities (Clarke et al., 2012)

Protecting buds from scorching flames is an important factor for resprouting (Kauffman, 1991; Marrinam et al., 2005). Clarke et al. (2012) summarized that this factor contains 4 mechanisms; there are growing rapidly, a thicker stem, thick bark and special protection. First, rapid growth helps plants to reach an escape height which allows buds in the crown to escape being scorched. Secondly, thicker stem helps to buffer the xylem against hydraulic failure. Thirdly, thick bark protects xylem and phloem from fire damage; however in a forest ecosystem where fire is less selective, bark thickness inhibits resprouting by hindering epicormic bud emergence. Special protection is the last mechanism that depends on species, such as deeply embed meristems protection of Eucalyptus.

When a plant loses above ground biomass from a disturbance, resources allocation to stem and root is a potential source to support resprouting (Clarke et al., 2012). Carbohydrate reserve was reported as the important resource (Bond and Midgley, 2001; Shibata et al., 2016), which correlated with the root size (Shibata et al., 2016). Clarke et al. (2012) also reported that in more fire-prone system, allocation of resources to roots is increased.

Furthermore, bud senescence also affects resprouting ability, but decreases with age. Bud senescence involves with genetics, physiological and anatomical change (Clarke et al., 2012). Bond and Midgley (2001) found that resprouting ability is more common in juveniles than adults. The study in a tropical forest in Malaysia by Kauffman (1991) found the significant inverse relationship between resprouting and stem diameter, bigger trees have lower resprouting ability. Similarly, failure rate of resprouting was observed in older oak tree with thicker bark (Johnson et al., 2002).

2.6 Fire resilience of indigenous tree species in montane forest ecosystem

Ecological resilience is defined as an amount of disturbance that an ecosystem could withstand without changing self-organizing processes and structures (Gunderson, 2000). Each ecosystem has a certain ability to absorb changes, hold, maintain stability and return to the equilibrium state after a disturbance (Holling, 1973). In any ecosystem, there is a disturbance threshold, a critical point at which an ecosystem could switch to another state (Standish et al., 2014). Small disturbances might cause ecosystem shift, if resilience is lacking. On the other hand, an ecosystem with high resilience can withstand a high intensity disturbance. The stability of any ecosystem depends on two factors; level of disturbance and ecosystem resilience (Standish et al., 2014).

Nieuwstadt et al. (2001) who studied burned forest of east Kalimantan in Indonesia, suggested 4 main processes to recover after burnt; they were tree survival, resprouting of damaged trees, germination of seeds from seed bank and the seed rain. Resprouting after fire disturbance is an effective persistence mechanism after a fire disturbances (Marrinam et al., 2005) by a shorten time to recovery with a rapid regrowth (Kauffman, 1991; Marrinam et al., 2005; Lawes et al., 2011a) and a greater capacity for exploitation of limited resources in tropical forest (Kauffman, 1991). Four factors affecting on resprouting ability including intensity of disturbance, size, resources allocation and post neighboring vegetation (Bond and Midgley, 2001; Vesk and Westoby, 2004).

Knowledge of fire resilience of indigenous tree species in montane forest ecosystem is essential for restoration. Forest restoration which is aiming to recover this forest type ought to be concerned about planting native tree species with fire resilient characteristics (FORRU, 2006). Only one study on fire resilience of native tree species from montane forest ecosystem exist; Elliott et al. (2003) reported that by three growing seasons after planting (trees were 33 months old), most framework tree species are large enough to recover well after fire, whereas younger trees (21 months old) showed greater variability in their response. However, no statistical analysis was performed to explain this interesting finding.

2.7 Restoring a resilient ecosystem in changing climate

Fire severity may increase with dryness due to climate change (Cochrane, 2003, Bruijnzeel et al., 2011). The highest intensity of fire hotspots reported in 2007 when El Nino occurred (Junpen et al., 2013). Climate change has become more obvious and caused serious consequences currently. Therefore, restoring biodiversity and ecological processes might not be enough to withstand this change. Restoring ecosystem resilience may be an effective way to build adaptive capacity to climate change (Padgham, 2014).

Bernhardt and Leslie (2013) reported mechanisms that enhancing the resilience: diversity, connectivity and adaptive capacity. Biodiversity is increasing the likelihood of some species and/or functional groups that they are resistant to disturbance, to compensate some species within community and facilitate ecological processes. Multiple forms of connectivity can stabilize ecosystems and enhance recovery following a severe disturbance. Adaptation to climate change is an important trait to survive new condition.

In ecosystems with resistance species or species that are able to recover quickly following disturbance, these are able to maintain ecosystem processes that sustain function and lack of loss in productivity (Padgham, 2014). In the planning process of forest restoration, diversity of native tree species, connectivity between species and /or family, and species with fire adaptation, is needed to create fire resilient systems: this should be integrated holistically.