CHAPTER 2

Literature Review

2.1 Forest issues

Forests provide many benefits for humans and wildlife. They supply not only products, but also ecosystem services, such as maintenance of biodiversity, climate and water regulation, and they play a major role in carbon storage (Davies *et al.*, 2013; Percy *et al.*, 2003). More than 4 billion hectares of world's terrestrial area is covered by forests, which constitutes an enormous carbon sink, via photosynthesis and soil storage (Percy *et al*., 2003; Sedjo, 2001) Because of human population growth and economic development, human activities, such as burning fossil fuels and deforestation emit enormous quantities of CO_2 into the atmosphere, which contributes significantly to rising global temperatures (Sedjo, 2001). Furthermore, demand for land and natural resources has increased, leading to deforestation and depletion of forest resources (Table 2.1) especially in Africa and South America (Chakravarty *et al*., 2012).

Table 2.1 Global forest cover 1990 to 2010

Regions	Total forest cover		
	1990	**2000**	**2010**
	Million Hectares		
Africa	749	709	674
Asia	576	570	593
Europe	989	998	1,005
North and Central America	708	705	705
Oceania	199	198	191
South America	946	904	864
World	**4,168**	**4,085**	**4,033**

Source: Compiled by Earth Policy Institute from U.N. Food and Agriculture Organization, Forest Resources Assessment 2010: Global Tables (Rome, 2010), www.fao.org/forestry/fra/fra2010/en/.

In the 2000s, around 30% of Earth's land area was covered by forest. More than 50% of forest is in the tropics and the rest is distributed across the boreal region, sub-tropics and temperate regions (Percy *et al*., 2003). From the 1990s to the 2000s, forest cover in the tropics declined by 14.2 million hectares, whilst non-tropical forests increased (FAO, 2001).

In Southeast Asia forest cover declined from 268.0 million hectares in the 1990s to 236.3 million hectares in 2010s (FAO, 2017; Stibig *et al*., 2014). The major cause of deforestation in Southeast Asia is agriculture expansion, which contributes to high biodiversity loss with the predicted extinction of 13 – 42 percent of terrestrial plant and animal species by the 2100s (FAO, 2017). Mining and urban development are also major threats to forest and biodiversity in South Asia, East Asia and Pacific (FAO, 2017). However, forest cover for the Asia-Pacific region as a whole actually increased from 731.1 million ha in 2000 to 734.2 m in 2005 at 0.09 percent of annual change rate, because of large reforestation campaigns in China (Figure 2.2) (FAO, 2005).

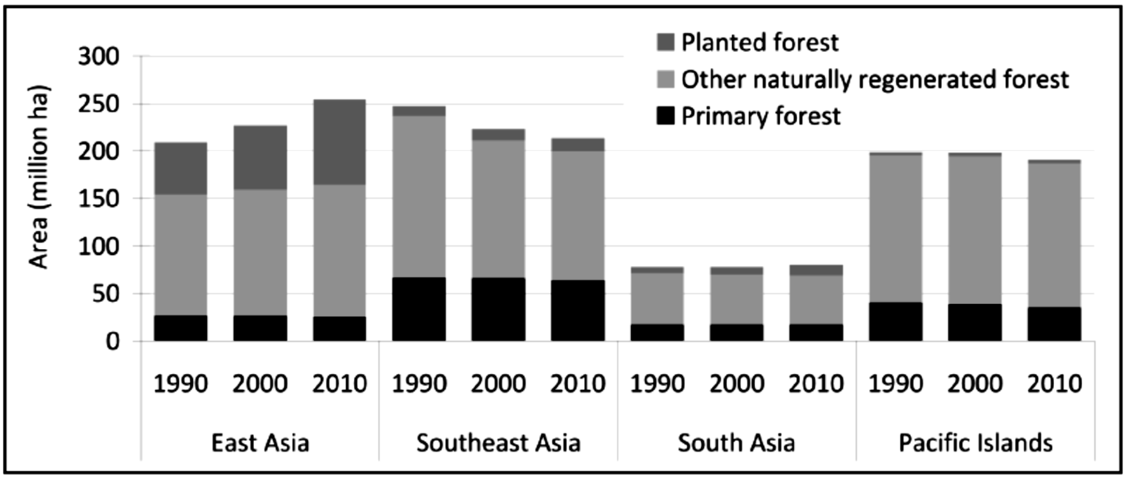

Figure 2.1 Category of forest area in Asia-Pacific sub region during 1990s to 2010s. (FAO, 2017; http://www.fao.org/asiapacific/forestry-outlook)

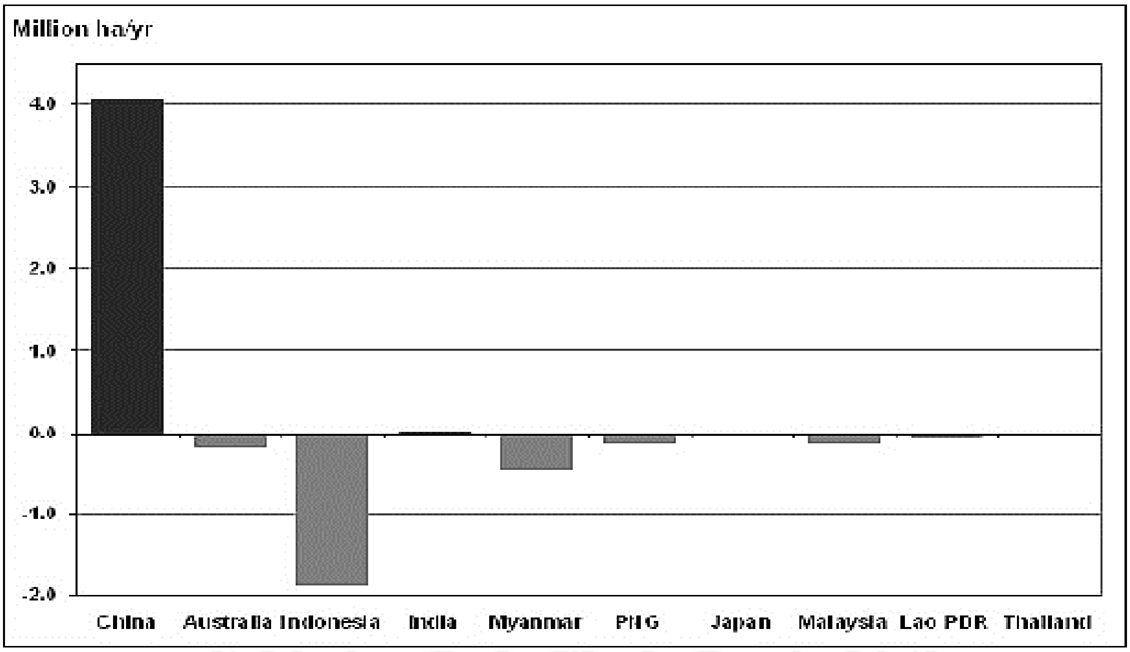

Figure 2.2 Annual change of forest area in ten largest forest area countries in Asia-Pecific (FAO, 2017; http://www.fao.org/docrep/011/i0627e/I0627E05.htm).

Focusing on Thailand, deforestation is one of main environmental issues. Thailand's forest cover declined from 53.33 percent to 25.13 percent of contry's total land area from 1961 to 1998 (Lakanavichian, 2001), appeared to increase suddenly to 32.66 percent in 2004 due to higher resolution satellite images being used to assess forest cover (RFD, 2004). The most rapid deforestation occurred from the late 1970s to early 1980s (Lakanavichian, 2006). In 2015, total forest cover was reported at 32.1 percent of total country area (Trading Economics, 2017). The main cause of forest destruction is agricultural expansion and logging. The logging and commercial timber product ban in 1989 helped to slowdown net forest change in Thailand (Lakanavichian, 2006).

Forest destruction negatively affects living organisms both directly and indirectly. Wildlife loss their habitats and provisions. It is estimated that more than 100 plant and animal species in tropical forests go extinct every day (Aerts and Honnay, 2011; Secretariat of the Convention on Biological Diversity, 2010). In addition, forests lose their ability to provide ecosystem services and forest ecosystem functioning, for example, decomposition of organic matter and water regulation (Aerts and Honnay, 2011; Duffy, 2009). Forest cover loss reduces rainfall in dry season (Delang, 2002). Runoff regulation declines, leading to more intense floods in the rainy season (Aerts and Honnay, 2011). Climate change and global warming are also included amongst the negative effects of deforestation (Stocker *et al*., 2013).

2.2 Forest restoration

Whilst deforestation is largely human-caused, forest recovery on degraded areas can be natural or human-assisted or managed (Lakanavichian, 2006). Natural forest recovery differs in pattern and dynamics, depending on the history and severity of disturbances (Breugel, 2007; Holl, 2012). Recovery of natural processes can be slow, because of limiting factors, such as lack of a seed bank, microclimatic conditions, soil degradation, competition with exotic grasses and herbaceous weeds, seed and seedling predation and lack of a soil seed bank of forest trees (Aide and Cavelier, 1994; Holl, 2012). So, forest restoration is an essential key to accelerate forest recovery (Aerts and Honnay, 2011).

The first step of any restoration project should be the identification of goals and specific objectives (Figure 2.3). Evaluation of the stage of degradation helps with plans to identify seed resources, and plan costs, labor and processes to support a successful restoration project (Holl, 2012). Normally, reforestation is measured in terms increases in biomass, structural complexity, biodiversity and ecological functioning. The main goal of forest restoration is to bring back a forest community where the aforementioned 4 parameters are similar the pre-disturbance condition (Fukami and Lee, 2006; Holl, 2012). The recovery of complex forest ecosystems leads increased biodiversity recovery and increased ecosystem functioning including carbon storage, nutrient cycles and watershed services (Palmer *et al*., 1997; Lamb *et al*., 2005; Gamfeldt *et al*. 2008; Isbell *et al*., 2011; Aerts and Honnay, 2011). Many organizations have achieved effective techniques to restore forests (i.e. International Tropical Timber Organization (ITTO) and IUCN) (Lamp *et al*., 2005). The restoration technique applied should be selected according to the severity of forest degradation (i.e. the level of degradation as in Elliott *et al*. 2013).

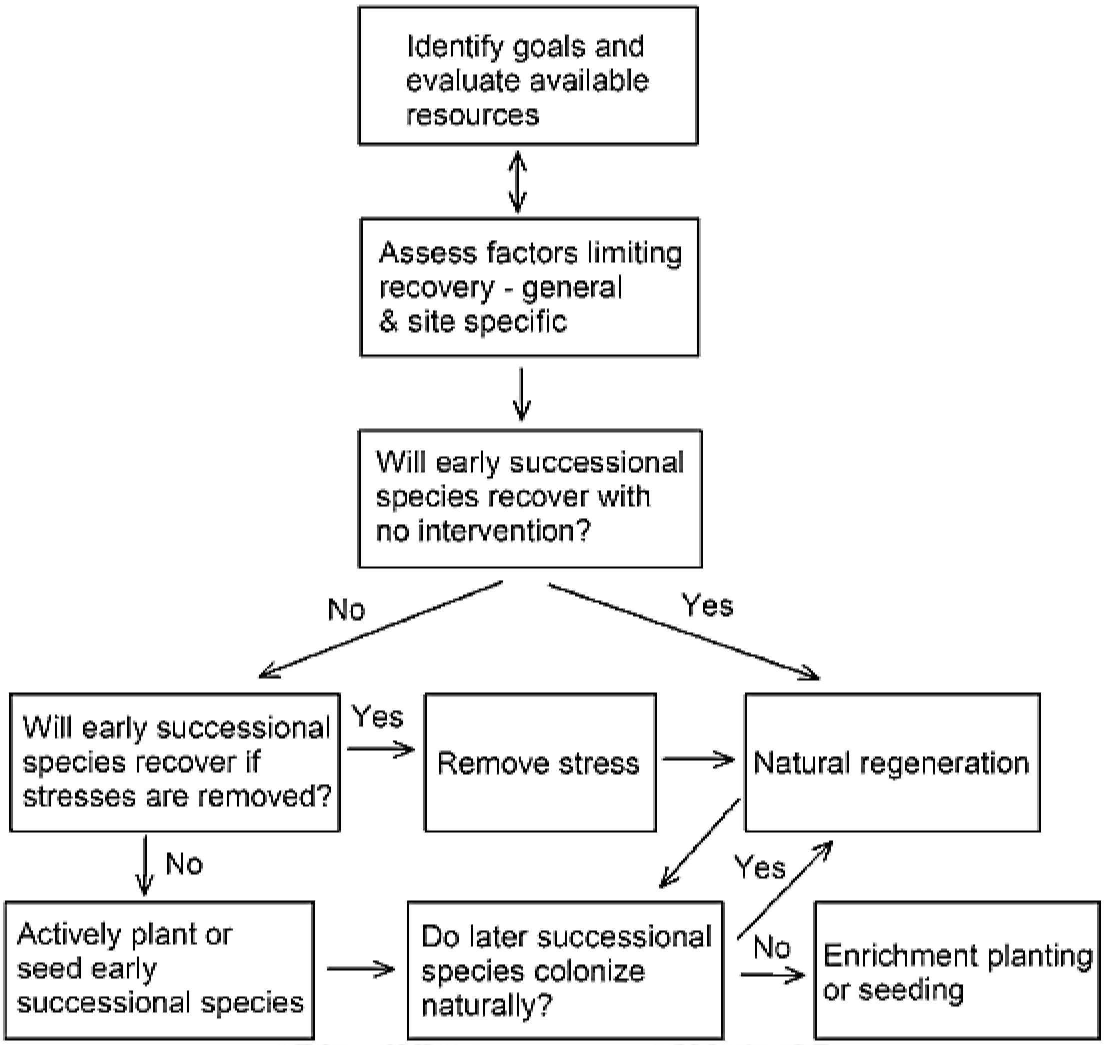

Figure 2.3 The selection process for tropical forest restoration techniques (Diagram from: Holl, 2012).

Forest restoration by planting indigenous tree species is recommended (FORRU 2006), especially those with broad dense crowns to shade out weeds and those which encourage seed dispersal by birds and improve the soil (Holl, 2012). Farwig *et al.* (2008) found that planting a mixture native tree species attracts birds and the species composition of the bird community in restored areas becomes similar to that in nearby natural forest. In contrast, bird species diversity in monocultures and exotic plantations is usually less than that in natural forest. Monocultures and exotic plantations support different bird species than natural forests do. To restore forest ecosystems, selecting mixtures of native tree species is recommended rather than exotic species. Forest restoration by planting non-native tree species contributes to new colonizing community, leading to change the original forest processes and ecological functioning and affects plant or animal specialist species in the areas (Magura *et al*., 2002)

The Miyawaki method of forest restoration originated in Japan in the 1970s and has been applied successfully in every region of Japan, South-East Asia, China and South America. This method is used when degradation is severe enough to prevent incoming seed dispersal. The process includes vegetation and soil survey and selects native tree species for planting at the high densities (Miyawaki, 2004). Degraded sites can be transformed into fully functioning forest in about 15-20 years using this method, which involves planting multiple tree species.

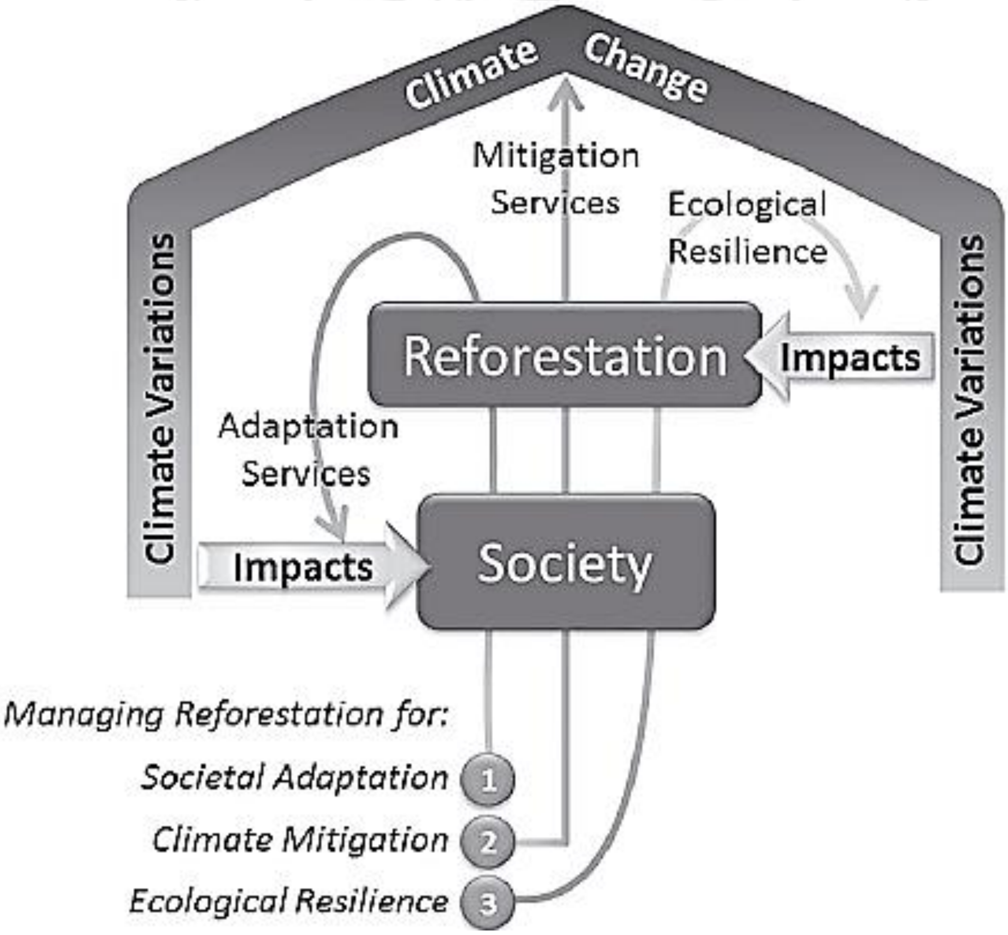

Figure 2.4 Climate-smart reforestation idea for forest restoration management (Locatelli *et al.*, 2015).

The framework species method is used to restore slightly less degraded sites where natural seed dispersal is still possible. It involves planting multiple indigenous forest tree species, including both climax and pioneer species to encourage rapid growth, shade out weeds and attract animal dispersers (Aerts and Honnay, 2011; Elliott *et al*., 2002). Reforestation by native species depends on species selection, site plan and management to attract dispersers and to reduce stresses conditions (Cunningham *et al*., 2015). The selection of native species following their functional group requires knowledge about traits, their reproductive biology, phenology and propagation (Thomas *et al*., 2014). Moreover, genetic variation and inbreeding between species in small population size should be considered for forest restoration by native species (Thomas *et al*., 2014).

Forest restoration can both mitigate global climate and is affected by it (Wright *et al*., 2009). Climate change affects tropical forest structure and their dynamics; for example, increasing temperature may affect biological processes in plants and plant-soil relations (Lewis *et al*., 2004). Moreover, reduced precipitation, resulted from climate change, limits plant growth and forest regeneration (Lewis *et al*., 2004). So, climate-smart reforestation should be encouraged at the aim for forest migration and adaptation in climate situation and future direction (Locatelli *et al*., 2015). Species selection for reforestation should be high resilient and can adapt to climate change situation (Figure 2.4).

Forest restoration is time-consuming and expensive. Before planting trees, seeds must collected usually from natural forest. Seeds are germinated and seedlings raised in tree nurseries. (Lamb *et al*., 2005; FORRU, 2006; Bruel *et al*. 2010). Seedling production requires building and maintaining a tree nursery. In addition, seedlings in nurseries require constant care by highly skilled nursery staff (FORRU, 2006). Therefore, the construction, maintenance and labor costs of conventional tree planting are costly and time-consuming (FORRU, 2006; Bruel *et al*. 2010).

2.3 Direct seeding

Direct seeding involves sowing seeds directly into the substrate of restoration sites (Ochsner, 2001; NRCS, 2009, Birkedal, 2010). This method is commonly used to grow most annual crops (Balasubramanian and Hill, 2000) and more rarely to promote biodiversity recovery in natural forests and for reclamation of limestone mines (Kumar and Ladha, 2013; Hossain *et al*., 2014). Direct seeding has been successfully used to restore broadleaved woodland (Willoughby *et al.*, 2004), coniferous forests (Nilson and Hjältén, 2003), Beech and Oak forests (Birkedal, 2010), pasture land (Douglas *et al*., 2007) and limestone mines (Barton *et al*., 2015).

Direct seeding can result in trees with higher performance than those from conventional tree planting (Tunjai, 2005; NRCS, 2009). Seedlings from direct seeding are stronger, taller, more robust, have broader crowns and higher survival rates compared with planted nursery-raised seedlings (Tunjai, 2005; NRCS, 2009). The method is about 20 – 50 percent cheaper than tree-planting (Willoughby *et al*., 2004; Birkedal, 2010). There are no nursery costs and transporting seeds is easier than seedlings (Birkedal, 2010; Farlee, 2013). However, weed removal costs may be higher for the direct seeding to ensure survival of the very small seedlings just after germination (Tunjai, 2011).

Douglas *et al*. (2007) suggested that appropriate tree species for direct seeding in pasture land are (1) native, (2) adaptable, (3) with wide environmental tolerance, (4) highly competitive with grasses, (5) with high germination and growth rates and (6) suited to the soil microbial status. It is necessary to select characteristic of tree species to increase the probability of seedling establishment (Lamb, 2005). Rapid seed .germination is preferable to minimize seed predation (Lamb *et al.*, 2005; FORRU, 2006; Tunjai and Elliott, 2011). Moreover, species should have dense spreading crowns to shade out weeds and provide resources, such as flowers and fruits, early in life to attract seed-dispersing animals (FORRU, 2006). In addition, seed traits are important because some are related to seedlings survival e.g. seed size, shape and moisture content all affect seedling establishment (Tunjai and Elliott, 2012). Previous studies show that large-seeded species have higher establishment rates than small seeded species (Doust *et al*., 2008, Tunjai and Elliott, 2011).

Site preparation is also important for the success of direct seeding (Douglas *et al.*, 2007). Weeds must be removed before sowing to reduce competition (Ochsner, 2001) and to reduce the habitat for seed or seedling predators (Birkedal, 2010). Site preparation can be done by mechanical treatments (Birkedal, 2010). Ploughing and herbicide spraying are options for weed control (Aleksandrowicz-Trzcińska *et al.*, 2014; Doust *et al*., 2006; Ochsner, 2001). Although herbicide is effective for weed control, its is not very practical since it kill natural regeneration, and affect environment and human (FORRU, 2006). Burning is not recommend because fires can destroy natural regenerants in the sites.

In some cases, soil testing should be done to determine nutrient levels. Soil manipulation helps to provide suitable microhabitats for seed sowing and to provide better conditions for direct seeding (Doust *et al*., 2006).

In general, seeds are usually collected from mother trees in natural habitat (Willoughby *et al*., 2004; FORRU, 2006; Doust *et al*., 2008). To restore degraded areas, local tree species from forest nearby the degraded site are selected. The Forest Restoration Research Unit (FORRU-Chiang Mai University) recommends phenology studies (time for flowering, fruiting and leafing) to determine the optimal seed collection time and to understand the ecological status of tree species in their natural habitats. Genetic variability should be also maximized by collecting seeds from many parent trees (FORRU, 2006; Doust *et al.*, 2008).

Seed storage behavior can also be important if direct seeding is carried out outside the fruiting period of the species being planted. The practical dimension to seed storage behavior contrasting patterns belong to (1) the effect of desiccation on viability and (2) seed longevity response to the storage condition (Hong and Ellis, 1996) (Figure 2.5). Furthermore, seed behaviors can also be predicted by seed coat ratio (SCR), using the proportion of dry seed coat and dry seed mass. Large seeds with low seed coat ratio tend to be recalcitrant and sensitive to dry conditions (Dawns *et al*., 2006). Three categories of seed storage behavior include orthodox, intermediate and recalcitrant.

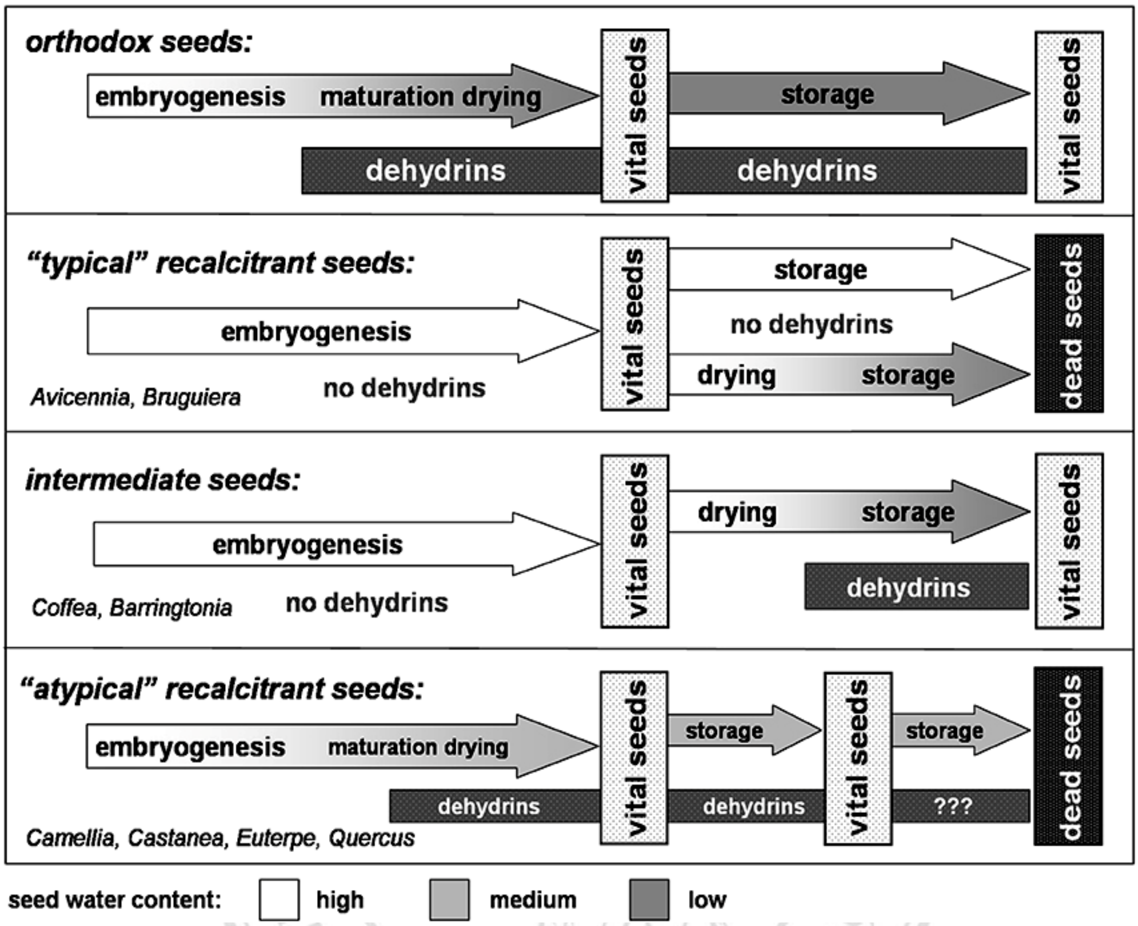

Figure 2.5 The dehydrin expression and maturation drying–an adjustment to the chain of seed behavior events (Radwan *et al.*, 2014).

Orthodox seeds can be stored in dry condition much longer than recalcitrant seeds can (Mag'omba, *et al.*, 2007). The seed longevity increases with decrease in moisture content and temperature of seed storage in a quantifiable and predictable way (Radwan *et al.*, 2014; Roberts, 1973) (Figure 2.5). The germination will be happen in fully hydrated, this can be prevented by storage seeds in dormant condition (Hong and Ellis, 1996). However, if need to use some long dormancy-orthodox seed immediately after collecting from mother trees, seed pretreatments can be used to shorten the dormancy period and increase percent germination (Willoughby *et al.*, 2004). Effective pretreatments vary among tree species, depending on seed characteristics. For example seed testa removal increased germination of *Uapaca kirkiana*seeds to 100% (Mag'omba, *et al.*, 2007).

Recalcitrant seeds cannot be dried without damage (Roberts, 1973). Seed viability losses in dry seed storage environments, which reduced seed moisture content (Hong and Ellis, 1996) (Figure 2.5). There is still no method to preserve the viability of recalcitrant seeds over long term due to they cannot be dried and are sensitive to subzero temperature (Hong and Ellis, 1996). This means that recalcitrant seeds can only be used for direct seeding during or very shortly after the seed are collected from the mother trees (Mag'omba, *et al*., 2007). Nevertheless, short-term storage under specialized conditions is possible for recalcitrant seeds (Hong and Ellis, 1996).

Intermediate species have seed strong behaviors between those of recalcitrant and orthodox species (Figure 2.5). The intermediate category was subdivided and introduced more recently to complete the loosely gap in classification between recalcitrant and orthodox categories (Hong and Ellis, 1996). These seeds are known to have high water content level and tolerance to dehydration (Mag'omba *et al*., 2007). Intermediate seed may be appropriate for direct seeding.

Sowing time influences seedling establishment. For example, Doust *et al*. (2008) reported higher seedling establishment for seeds sown late in the wet season (Doust *et al*., 2008). Seedlings from seeds that were sown in early rainy season had lower development root systems (Doust *et al*., 2008). However, another study suggested different sowing time. Brikedal, 2010 reported that sowing in early rainy season enabled better root system because of longer time to grow. Weed competition is an important limitation when implementing early sowing, whereas water supply is limiting for late sowing in rainy season (Doust *et al*., 2008).

Additionally, site preparation and intensive site maintenance contribute to increased seeding growth and deeper root systems (Lof and Birkedal, 2009). Seeds should be sown two weeks after weed removal by herbicide for site preparation. Small-seeded species are usually sown at higher densities than large-seeded species (Doust *et al*., 2008). Burying seeds at an appropriate depth reduces seed predation (Doust *et al*., 2006, Farlee, 2013). In addition, weeding is usually done two months after direct seeding to reduce competition with herbaceous weeds (Doust *et al*., 2008; St-Denis *et al*., 2013). Fertilizer is applied after weeding. Both weed control and fertilizer application are needed for site maintenance for at least three rainy seasons in tropical areas before the trees can begin to close canopy and shade out weeds (FORRU, 2006).

2.4 Limitations/failures of direct seeding

Direct seeding can often be more successful than conventional tree planting (Lamb, 2005), but there are challenges in wet tropical environments (Holl *et al.*, 2000), such as environment conditions (Douglas *et al*., 2007), competition with herbaceous weeeeds (Douglas *et al*., 2007; Doust *et al*. 2008) and seed and seedling predation (Fricke *et al*., 2014; Hau, 1997; Orrock *et al*., 2006).

This study focuses on effect of natural enemies on seeds and seedlings. Seeds can be killed when animal predators completely consume or partially damage the seeds (Janzen, 1970). The destruction of seeds leads to low seed availability and loss of germination and/or growing ability (FORRU, 2006). For seedlings, being completely or partially consumed by animals lead to loss of growing ability and death. Consequently, attacks by seed and seedling predators may lead to failure of forest restoration by direct seeding method (Farlee, 2013).

2.5 Seed removal and seed predation

Seeds may be removed by secondary seed dispersers and/or predators. If seeds are removed by secondary seed dispersers, they are not killed but are transported to new areas. Seed predation is the consumption or destruction of seeds by granivorous animals (Vander Wall *et al*., 2005). Seed predation usually occurs on the ground (Vander Wall *et al*., 2005). In the direct seeding context, seed removal from the target area reduces the number of seeds available for seedling establishment on the restored site. In this study, seed removal is used as a proxy to estimate seed predation.

The major group of invertebrate predators is insects, including beetles (Coleoptera), ants and wasps (Hymenoptera), flies (Diptera), caterpillars of butterflies and moths (Lepidoptera), and thrips (Thysanoptera) (Zhang *et al*, 1998). In some degraded areas, ants are major seed predators (Wood and Elliott, 2003). Of the vertebrates, mammals, such as rodents, are most commonly associated with seed predation and seed loss (Birkedal *et al*., 2010; Wood and Elliott, 2003). Large seeds are lost to rodents but small seeds are not destroyed. At the post-dispersal stage, both vertebrates and invertebrates are major seed predators.

The intensity of seed predation varies, according the predator communities that are present in different forests types or degraded areas (Wells and Bagchi, 2005), which is related to availability of food resources (Doust *et al*., 2006). Seed predation have been recorded high rate in open woodland area (Nilsson *et al*. 1996; Farlee, 2013). In degraded grassland and shrub lands in Hong Kong, a high percent seeds are lost (11 from 12 seeds species were completely removed) due to predation by rats (Hau, 1997). In contrast, seed predation occurs at lower seed removal in abandoned agricultural lands in northern Thailand (Woods and Elliott, 2003).

The intensity of seed removal and seed predation depends on predators' body sizes relative to seed size (Wells and Bagchi, 2005). Small-seeded species suffer less predation than bigger seeded species (Ferreira *et al*., 2011). In addition, the relationship between seed size and predation rate also depends on habitat type, the searching ability of seed predators and whether seeds are on the soil surface or buried (Moles and Westoby, 2006). Seeds with soft seed coats are significantly more attractive to seed predators on degraded hillside than those with harder seed coats (Hau, 1997). Therefore, the intensity of seed predation depends on a combination of many factors that should be considered case by case.

2.7 Seedling predation (Herbivory)

In tropical forests, the majority of damage by herbivores occurs on young leaves (Kursar and Coley, 2002). Young leaves are attractive to herbivores, because they lack structural carbohydrates, which make the leaves tough and less digestible (Coley, 1983). Seedlings have a low investment in defensive chemical because of limited photosynthetic ability and root biomass (Boege and Marquis, 2005). Herbivory reduces seedling growth and survival, their competitive ability against weeds (Mills, 1983).

After germination, seedlings are usually attacked by invertebrates, particularly insects (Doust *et al*., 2008; Fricke *et al*., 2014). Total plant biomass is mostly reduced more by invertebrates than by vertebrates (Gurevitch *et al.*, 1992; Meiners *et al*., 2000). Invertebrates attack both above- and below-ground plant parts. Leaf-feeding herbivores affect plant growth by reducing photosynthetic capacity and by decreasing carbohydrate reserves (Wahungu *et al*., 2002). In the case of sap-feeding insects, they can kill seedlings without obvious damage to the leaves and/or stems (Meiners *et al*., 2000). Insects can also heavily damage germinating seeds and young seedlings below ground (Meiners *et al.*, 2000)

Herbivory by small mammals also affects seedling survival and establishment (Birkedal *et al*., 2010; Wahungu *et al*., 2002). Small mammals (rodents) can significantly reduce seedling survival (Zhang *et al*., 2017). Rodents can kill seedlings by clipping their shoots and removing their cotyledons. In direct seeding trials, few studies have been done on seedling predation by vertebrates (Birkedal *et al*., 2010). The effects of rodents on seedling survival may be reduced by site preparation and management (Birkedal *et al*., 2010).

2.8 Methods used for studying predators

Many studies of post-dispersal seed predation published in natural forests (Cramer *et al*., 2007; Ferreira *et al*. 2011; Wahungu *et al*., 2002), grasslands (Bricker *et al*., 2010; Pufal and Klein, 2013) degraded forests (Hautier *et al*., 2010), agriculture lands and abandoned agricultural areas (Rocha-Ortega *et al*. 2016; Pufal and Klein, 2013; Wood and Elliott, 2003). One way to determine the intensity of seed and seedling predation is to exclude predators from sample plots and then compare seed loss with control plots exposed to predators. For example, Fricke *et al*. (2014) studied the effects of natural enemies on tree survival and density-dependent mortality. The experiments included an insecticide treatment to exclude insects, fungicidal treatment to prevent fungal infection and enclosure to protect seeds from small mammals (Fricke *et al*., 2014). The experiments allowed comparisons among treatments, to determine the cause of density-dependent mortality. Effect of pesticide (fungicide or insecticide) on seedling germination, survival and growth usually test on crop plants (e.g. Onemli, 2004; Udaiyan et al., 2001). A few work was done in tree seedling. For example, Rolando (2006) claim that insecticide supported survival of pine species during regeneration period. However, the violence of insecticide depends on chemical types, concentration and plant species treat by insecticide (Robinson, 1985)

Knowing the species of seed and seedling predators helps in managing sites to prevent predation (Birkedal, 2010). Animal surveys are the primary steps used to identify species and their roles in plant-animal interactions. Different groups of animals require different survey methods.

Camera trapping has been widely used for monitoring wildlife diversity, activity patterns and population dynamics. It is also a standard sampling technique for some rare species (McDonald *et al*., 2015). Camera trapping has been effective in determining abundance of animals and their activity patterns in nature reserve (Liu *et al*., 2013). Kukielka *et al*. (2013) successfully used camera traps to monitor interaction between wildlife and livestock at water bodies during the dry season. In Central Panama, Meyer *et al*. (2015) used camera traps to estimate species richness, evenness and community structure of forest mammals. Camera traps have been used to detect medium to large animals, as well as small animals including rodents (De Bondi *et al*., 2010; McDonald *et al.*, 2015; Melidonis and Peter, 2015).One advantage of the technique is that of animals can be observed continuously, allowing more accurate estimates of animal abundance. De Bondi *et al*. (2010) surveyed small mammals by live trapping and compared abundance estimated that obtained with camera trapping. Camera trapping recorded more animal species than live trapping did. Camera traps can continue working long periods and are effective at capturing undisturbed animal activities.

However, camera trapping is not suitable for some species (Pollock *et al*., 2002). Camera sensors can detect animals by motion when they are passing the detection zone. In addition, camera sensors detect differences between body temperature and ambient temperature (Rovero *et al*., 2013). If an animal has similar body temperature as the environment such as reptiles and amphibians, the cameras may not be triggered animals.

Camera trapping is not a good method for insect surveying. Insects are too small to trigger motion sensor and their body temperature is similar to ambient temperature. Other insect sampling method include netting (sweep net method), flight intercept trapping, pitfall trapping, light trapping, sticky trapping, etc. (Upton and Mantle, 2010).

Sticky traps used to collect insects in forest and farmland (Atakan and Canhilal, 2004). They have been used in agricultural lands to estimate insect pest (Silvanderson, 2015) and for studies the population dynamics of parasitoids on crop plants (Qiu and Ren, 2006). However, sticky trap mostly capture abundant flying insect species. Whereas, studies of ground-dwelling insects mostly use pitfall traps (Upton and Mantle, 2010). Such trap are constructed by placing a plastic cup into the soil with alcohols or detergent and protecting from rain by a cover (Gadagkar *et al*., 1990). Therefore, different traps have different effective to collect insect group. The target insect group should be considered before trapping selection.