CHAPTER 2

Literature Review

2.1 Global View

2.1.1 Deforestation: Causes and Consequences

Forests play vital roles in human livelihoods. They provide many goods and services through i) supporting soil formation, photosynthesis and nutrient cycles ii) regulating air quality, climate, water purification and soil erosion iii) provisioning of food, medicine, fresh water and raw materials and iv) cultural services in spiritual and religious values, recreation and ecotourism and mental and physical health (WWF, 2016). They are also crucial in carbon storage. Globally, about 645 Pg C[1] is stored in the vegetation and about 1,567 Pg C in the soil across all biomes (Prentice et al., 2001). The net rate of carbon accumulation in all forest biomes is about 1–3 Pg C/year, of which 0.4 Pg C/year is added to forest soils (Lal, 2005). Unfortunately, world forest cover has dramatically declined especially in the tropics. In 2015, forests covered 3,999 million hectares or 30.6 percent of Earth's total land area. Although, the annual global rate of net forest loss declined slowly from 1990s, it remains high at about 3.3 million hectares per year (2010-2015, (FAO, 2015).

In the tropics, forest degradation is driven by various factors; agriculture (commercial and subsistence), surface mining and urban expansion (Hosonuma et al., 2012). Agriculture (small and large scale) is the main driver, which caused more than 80% of deforestation across the Africa America and Asia continents (Figure 2.1). In tropical countries, large-scale commercial and local subsistence agriculture accounted for 40% and 33% of deforestation respectively (FAO, 2016).

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[1] Petagram (Pg) of Carbon – One Pg =10^{15} grams = one billion metric tonnes

In addition, tropical countries exhibited net forest loss of 7 million hectares per year, whereas agricultural land were increased of 6 million hectares per year from 2000-2010 (Figure 2.2, FAO, 2016). In Southeast Asia for example, forest cover was estimated at 268 million hectares in 1990 and dramatically decreased to 236 million hectares by 2010. Land conversion to cash crop plantation and selective logging were the main drivers (Stibig et al., 2014).

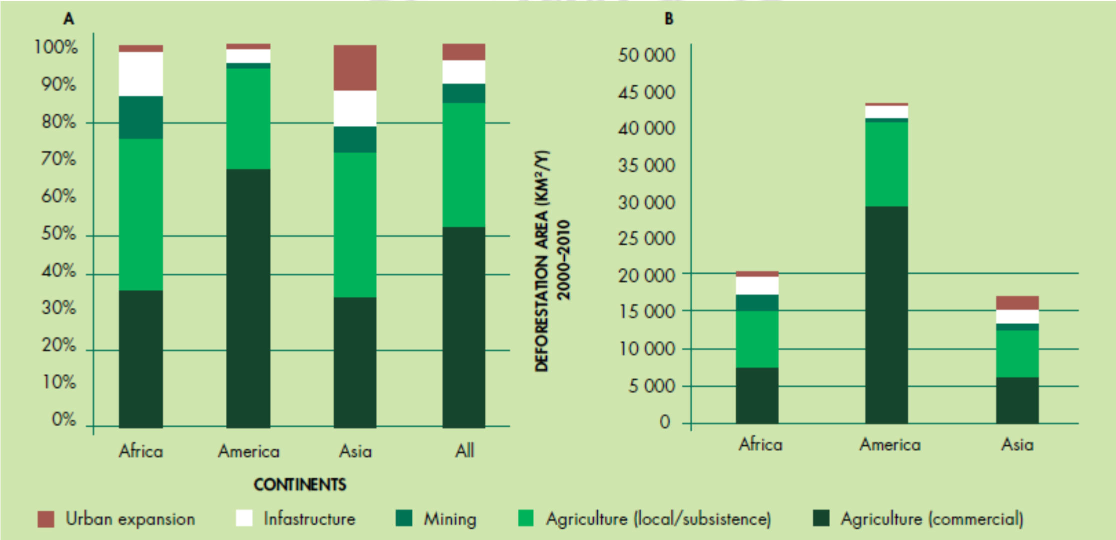

Figure 2.1 Estimate of (A) proportion of total area of land-use change associated with various proximate drivers of deforestation, and (B) Absolute net forest area change associated with proximate drivers of deforestation, by region, 2000-2010 (FAO, 2016)

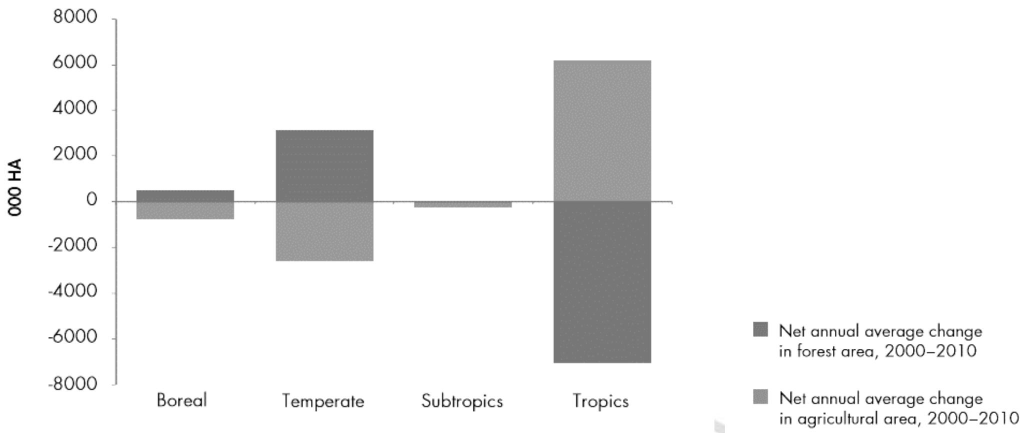

Figure 2.2 Net annual average change in forest and agricultural land by climatic domain 2000-2010 (FAO, 2016).

Deforestation and forest degradation lead to habitat loss and consequently biodiversity decline. From 1970-2012, the living planet index (LPI) of vertebrates declined by 58 % of overall population abundance (WWF, 2016). More than 5,520 mammal, bird, amphibian and insect species are threatened with extinction due to habitat loss and degradation, overexploitation, pollution, invasive species, diseases and global warming (WWF, 2016). In Indonesia, for example, a biodiversity hotspot, forests have declined by 47,600 hectares per year, amounting to 6.02 million hectares lost over 12 years (2000 to 2012) (Margono et al., 2014).

Concentrations of atmospheric greenhouse gasses are increasing. Carbon dioxide concentrations have increased by 40% since pre-industrial times (IPCC, 2013), of which deforestation and forest degradation have contributed about one third of the global anthropogenic carbon emission (Denman et al., 2007). Emissions from tropical countries (including the draining and burning of peat swamps in South East Asia) over the twenty years of 1990-2010 averaged 1.4 Pg C/year (Houghton, 2012). This has caused global temperature to rise by 0.85 °C from 1880–2012. The Ocean is warmer than in past century by 0.11 (0.09-0.13) °C. Sea level rose by an average of 0.19 m from 1901 to 2010, due to thermal expansion of the oceans, combined with the melting of polar ice caps and glaciers (IPCC, 2013).

Global temperature seems set to increase much more, substantially changing ecosystem components, so mitigation actions need to be substantial, to bring about a sustained reduction of greenhouse gas emissions (IPCC, 2013). Forests are net carbon sinks where carbon is sequestered in biomass (particularly tree trunks and roots) both above and below ground and as dead organic matter in the soil.

2.1.2 Reforestation

The United Nations Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries (UN-REDD) was launched in 2008. It drew upon the technical expertise of the Food and Agriculture Organization of the United Nations (FAO), the United Nations Development Programme (UNDP) and the United Nations Environment Programme (UNEP). The UN-REDD Programme has 3 main tasks: i) design and implement REDD+ programmes at national levels, ii) support national REDD+ action plans and iii) support technical capacity building. The goal of the programme is to "*reduce forest emissions and enhance carbon stocks in forest, while contributing to national sustainable development*".

In 2011, the Bonn Challenge committed from governments, organizations, communities and individuals to share in the common goal of "*restoring the world's degraded and deforested lands*". The Challenge targeted the restoration of 150 million hectares of degraded forest by 2020. It appears that this goal is being achieved faster than expected, according to world leaders who gathered at the UN Climate Summit in New York in 2014. They agreed on an even more ambitious target for global reforestation in the New York Declaration on Forests "… *at least halve the rate of loss of natural forests globally by 2020 and strive to end natural forest loss by 2030. Support and help meet the private-sector goal of eliminating deforestation from the production of agricultural commodities such as palm oil, soy, paper and beef products by no later than 2020, recognizing that many companies have even more ambitious targets. Significantly reduce deforestation derived from other economic sectors by 2020. Support alternatives to deforestation driven by basic needs (such as subsistence farming and reliance on fuel wood for energy) in ways that alleviate poverty and promote sustainable and equitable development. Restore 150 million hectares of degraded landscapes and forestlands by 2020 and significantly increase the rate of global restoration thereafter, which would* *restore at least an additional 200 million hectares by 2030...*" (UN Climate Summit, 2014). Organizers of the challenge claim that 148.38 million hectares have already been restored, sequestering 15.1 Gigaton of Carbon dioxide and injecting 46,595 million US Dollars into the economies of the participating countries (Bonn Challenge, 2017).

2.1.3 National Examples

Brazil serves as a good example. It is rich in biodiversity, being classified as one of the world's megadiverse countries (CBD, 2017a). However, deforestation rates are very high, 0.2% or 984,000 hectares per year, ranking it among the top ten countries in terms of annual forest loss, 2010-2015 (FAO, 2015). Fragments of Atlantic forest along the country's eastern coastline are small (more than 80% are less than 50 ha) and widely separated (averaging 1440 m apart, Ribeiro et al., 2009). The Atlantic Forest Restoration Pact (AFRP). AFRT is collaborative programme, with more than 260 stakeholders from the government, private sector, NGOs and researchers. It aims to restore 15 million ha of degraded and deforested lands by 2050 (Pinto et al., 2014). The AFRT is part of The Bonn Challenge, committed 12 million ha goal by 2030 (Bonn Challenge, 2017). In addition, the AFRT is attempting to add economic value, less expensive and profitable, to the restoration project (Pinto et al., 2014).

China launched a similar large-scale programme called Grain for Green Programme (GGP) in 1999, to restore forest to the central and western parts of the country, principally to control soil erosion. The GGP has already restored over 20 million ha of forest on formerly agricultural land, with a budget of USD 40 billion. This programme has increased soil organic carbon accumulation at different soil depths (Song et al., 2014) and has sequestered a total of 12.3 tC ha−1 in above- and below-ground biomass over 10 years, equivalent to 14% of China's total carbon emissions in 2009 (Persson et al., 2013).

2.2 Forest Status in Thailand

Thailand covers an area of 513,115 km^2 in South East Asia. The country has several unique ecosystems, both terrestrial and aquatic, which support very a high biodiversity. For example, more than 10,000 species of vascular plants, belonging to 275 families of spermatophytes and 36 families of pteridophytes, have been recorded (DNP, 2017). Vertebrate species number at least 4,722 (Table 2.1) and invertebrates, 124,526 representing 5% and 12% of world species record, respectively (ONREP, 2014). Seven vertebrate species have gone extinct and 555, or 11.75%, are “threatened” (Table 2.1). In particular, several megafauna species are very rare, e.g. only 50-70 wild water buffalo remain and 200-500 tigers, whilst both the Javan and Sumatran rhinos have been extirpated (CBD, 2017b).

Table 2.1 Number of vertebrate species found in Thailand and threaten status (ONREP, 2014)

Classification	Species found in Thailand	Threatened species	
		Numbers (kinds)	percentage
Mammals	336	118	35.12
Birds	1,010	168	16.63
Reptiles	394	49	12.44
Amphibians	157	18	11.46
Fishes	2,825	202	7.15
Total	4,722	555	11.75

The country’s rich biodiversity has been decreasing as economic growth and population growth have been increasing. Forest lands, wildlife habitat, were converted to agricultural land and other land uses to support economic development, with an average loss of 162,200 km^2 per year, from 2008 to 2014 (ONREP, 2014). The first forest survey in 1961, carried out by aerial photography, found that just over half the country remained forested (53.33%), but by 1989, just over half of the original forest remained (27.95% cover) due to intensive logging and land conversion. Faced with huge loss of biodiversity and forest land, the Thai government canceled all forest concessions in that year.

The Thai government established a policy to maintain 40% of the country under forest in 1985, including 25% economic forests and 15% protected forests. Following the logging ban, less land was required for economic forests, so in 1992, the government swapped these goals to 25% protected forest and 15% economic forests in the Seventh National Economics and Social Development Plan B.E. 2535-2539 (NESDB, 1992).

Surprisingly, forest cover suddenly increased in 1998 from 25.28% to 33.15 in 2000 (Figure 2.3). This may have been an artifact of increasing satellite imaging resolution used for forest assessments from 1:250,000 to 1:50,000 scale. Consequently, more tiny forest patches could be included into the country report (Seub Foundation, 2016). Consequently it appears that forest cover has increased, since forest concessions were cancelled, reaching 31.60% in 2015 (Figure 2.3). Many former logging concession areas were merged with the 238 protected areas that now cover 19% of the country (DNP, 2017).

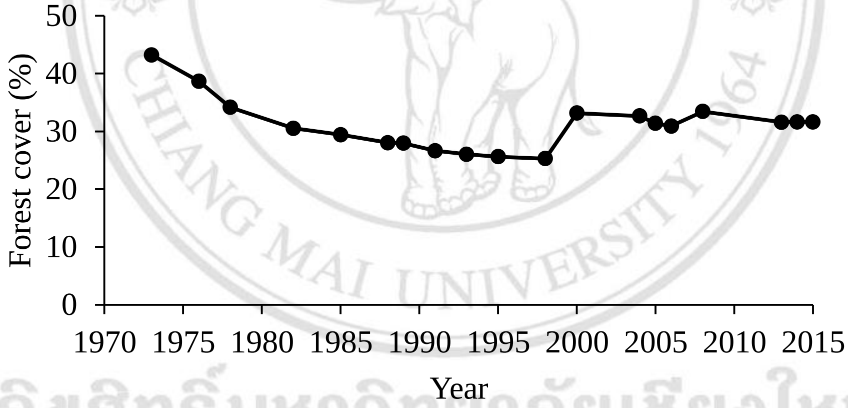

Figure 2.3 Forest cover in Thailand during 1973-2015 (modified from RFD, 2015).

2.3 Forest Restoration

The Society for Ecological Restoration (SER, 2002) defines ecosystem restoration generally as “the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed”. FAO stated that the main purpose of forest restoration is “to re-establish the presumed structure, productivity and species diversity of the forest originally present at a site” (Sustainable Forest Management Toolbox (SFM), FAO, 2017). All these definitions share the goal of restoring degraded land to its original pre-degradation state. The definition of tropical forest ecosystem restoration used as the basis of this study is “Directing and accelerating ecological succession towards an indigenous target forest ecosystem of the maximum biomass, structural complexity, biodiversity and ecological functioning that can be self-sustained within prevailing climatic and soil limitations.” (modified from Elliott et al., 2013)

Understanding the initial level of site degradation is key to success. It enables strategies or techniques to be selected, which are suited to the conditions prevalent at any particular degraded site. There are five levels of degradation that determine restoration approach. They are determined by 3 site (restoring site) and 3 landscape (surrounding area) degradation thresholds. For site-critical thresholds, it is necessary to consider the density of natural regenerants[2], weed competition and soil degradation. Whilst, landscape-critical thresholds include proximity of climax forest, abundance of seed dispersers and fire risk. For instance, stage-1 degradation follows selective logging where tree cover remains dense enough to suppress herbaceous weeds, natural regenerants are common and soils mostly remain fertile. Large remnants of climax forest are nearby, seed-dispersing animals remain common and fire risk is low to medium. The recommended restoration strategy for such areas is protection; prevention of encroachment, cattle, fire and hunting of seed dispersers. In contrast, stage-5 degradation refers to sites that are highly disturbed, have no tree cover, few or no natural regenerants and eroded soils. Remnant climax forest patches are remote and seed dispersing animals have mostly been hunted out. Fire risk is low initially (due to low fuel loads), but increases as weeds recolonize. In such areas, soil

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[2] *i.e.* seedlings, saplings, trees and live tree stumps, capable of coppicing

quality must first be improved before planting of nurse tree species and subsequent re-introduction of more diverse species of tree seedlings (Table 2.2, Elliott et al., 2013).

Table 2.2 Simplified guide to choosing a restoration strategy (from Elliott et al., 2013)

Landscape-critical thresholds			Site-critical thresholds			Suggested restoration strategy
Forest in landscape	Seed-dispersal mechanism	Fire risk	Vegetation cover	Natural regenerants	Soil	
Remnant forest remains within a few km of the restoration site	Mostly intact, limiting the recovery of tree species richness	Low to medium	Tree canopy cover exceeds herbaceous weed cover	Natural regenerants exceeds 3,100/ ha with more than 30** common tree species represented	Soil does not limit tree seedling establishment	Protection
		Medium to high	Tree crown cover insufficient to shade out herbaceous weeds			Protection + ANR*
		High	Herbaceous weed cover greatly exceeds tree crown cover	Natural regenerants sparser than 3,100/ ha with fewer than 30** common tree species represented		Protection + ANR + Planting Framework tree species
Remnant forest patches very sparse or absent from the surrounding landscape	Seed-dispersing animals rare or absent such that the recruitment of tree species to the restoration site will be limited				Soil degradation limits tree seedling establishment	Protection + ANR + Maximum diversity tree planting
		Initially low (soil conditions limit plant growth); higher as the vegetation recovers	Herbaceous weed cover limited by poor soil conditions			Soil amelioration + Nurse tree plantation, followed by thinning and gradual replacement of maximum diversity tree planting

* ANR Accelerate Natural Regeneration

** Or roughly 10% of the estimated number of tree species in the target forest, if known

Species selection plays the vital role in ecosystem restoration. Native species have been widely used for ecological restoration to complement natural regeneration (Miyawaki, 1998; Miyawaki, 2004; Elliott et al., 2013). The diversity of tree species planted depends on degradation stage (Table 2.2). Restoration may require planting only a few native trees or the maximum number of species possible. The Miyawaki method is one of the most successful restoration techniques for severely degraded sites with low or absent incoming seed dispersal. The method involves vegetation and soil surveys and the planting of as diverse a range of native tree species for planting species as possible at very high densities. Mulching is initially applied after planting, to maintain soil moisture, suppress weed growth and prevent soil erosion. Weeding is essential over the first 3 years, cut weeds serve as additional mulching (Figure 2.4) This method was first applied in Japan in the 1970s and was introduced globally to South-East Asia, China and South America (Miyawaki, 2004).

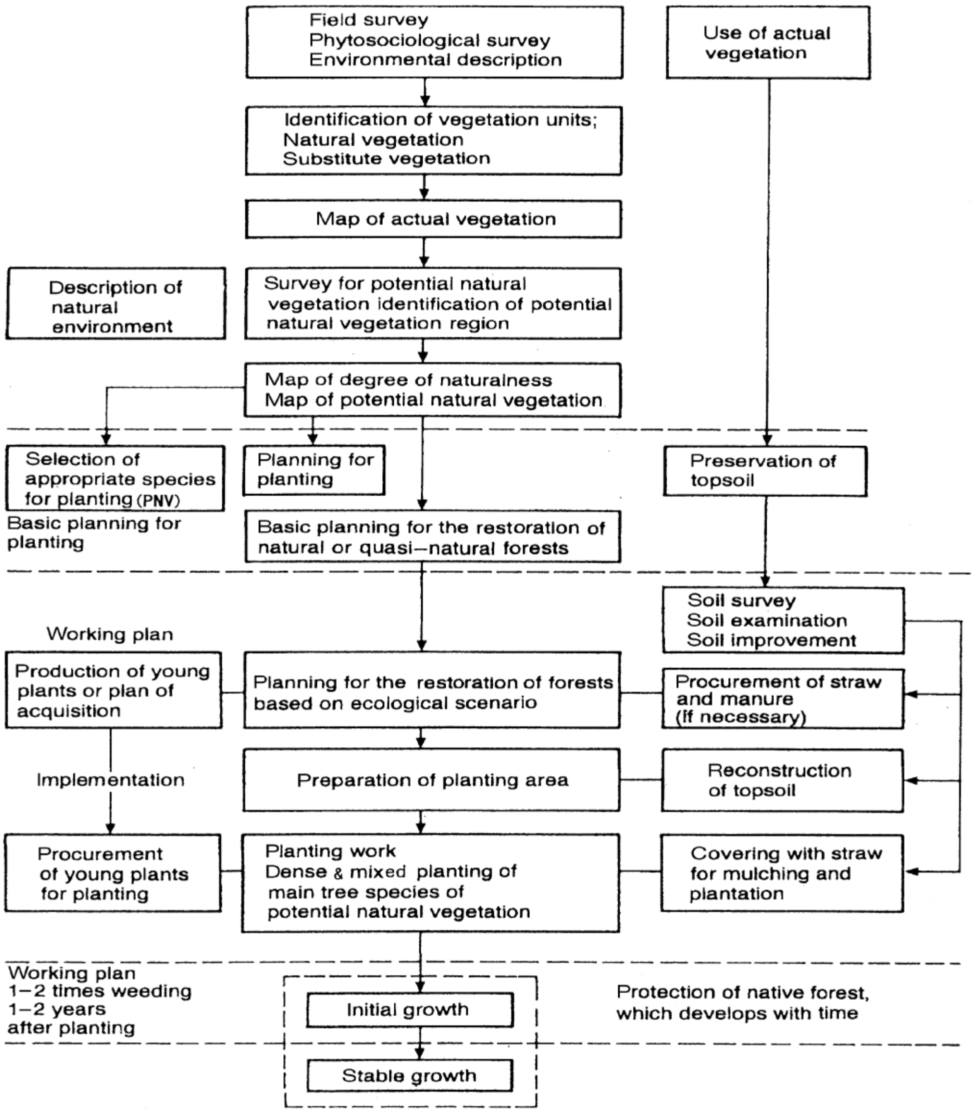

Figure 2.4 The Miyawaki method summarized as a flow chart (Miyawaki, 2004)

In the Mediterranean environment, the Miyawaki method successfully restored Italian forest with higher biodiversity compared with conventional techniques (planting *Pinus pinaster* Aiton (maritime pine), *Pinus halepensis* Miller (Aleppo pine), *Cedrus atlantica* (Endl.) Carrie`re (Atlas cedar), *Quercus suber* L. (cork oak), *Quercus pubescens* Willd. (downy oak), and *Castanea sativa* Miller (sweet chestnut), new plant community was able to re-establish without support (Schirone et al., 2011). In Shanghai, China, the Miyawaki concept was applied to urban ecosystem reconstruction by restoring climax to the city and coining the new term: Near-Natural Method of Afforestation (Da, and Guo 2014). Although the method showed promised restoring results, labour and planting costs were very high due to the high plant diversity required (Schirone et al., 2011).

Accelerated or Assisted Natural Regeneration (ANR) is cost-effective and requires low labour input (Table 2.3). The lack of need for a nursery considerably reduces the cost of this technique (Shono et al., 2007). The technique involves reducing the barriers to natural regeneration including: low site resources (soil quality), ongoing disturbances (fire, cattle grazing), competition with weeds and low regenerant density (Hardwick et al., 2004). ANR could be integrated broadly into various restoration regimes for various purposes from biodiversity recovery to economic plantations (Shono et al., 2007). However, this technique is limited where the level of degradation is high (Table 2.2).

Table 2.3 Various reforestation approaches and their merits (Shono et al., 2007)

Reforestation Approach	Costs (Labour and Capital)	Biodiversity	Time for Forest Development	Research Input Required
Commercial monoculture plantation	High[a]	Low	Fast	Low
Monoculture of commercial nurse trees	High[b]	Low to medium	Fast[c]	Low
ANR without enrichment planting	Low	Low to medium	Slow to medium	Low
ANR with enrichment planting	Low to medium	Medium	Medium	Low to medium
Framework species method	Medium to high	Medium	Medium	High
High-density planting of forest trees	High	High	Fast	High

[a] The high establishment and operational costs are generally recovered by profits.
[b] Some of the establishment cost may be recovered by harvesting of nurse trees.
[c] Nurse trees grow fast, but understory develops slowly.

2.4 The Framework Species Method

Forest restoration has been studied worldwide and practical methods have been developed to increase its effectiveness. The framework species method has rapidly become accepted as an effective and practicable way to restore tropical forests, largely due to the work of Goosem and Tucker (1995) and Chiang Mai University's Forest Restoration Research Unit (FORRU-CMU) (Elliott et al., 2013). It was conceived to restore tropical forest in Queensland, Australia (Goosem and Tucker, 1995) and involves planting saplings of 20-30 native forest tree species, including both pioneers and climax species (Figure 2.5). Framework species are defined by the following criteria; high field performance (i.e. high rates of survival and growth), ability to shade out herbaceous weeds with dense broad crowns and the provision of resources, which attract seed-dispersing animals at a young age. The method has been applied to seasonally dry tropical forest in northern Thailand and researched extensively by FORRU-CMU. The unit has published many books and papers on tropical forest restoration, based on field and nursery research results (FORRU, 2006; FORRU, 2008; Elliott et al., 2013).

This method rapidly recovers biodiversity and restores forest ecosystems to degraded land. It promotes recruitment of non-planted tree species into restoration plots, mostly via seed dispersal by birds (Wydhayagarn et al., 2009). Best-performing framework tree species have been identified (Elliott et al., 2003) and optimal silvicultural treatments determined (FORRU, 2006). Canopy closure can now be achieved within 3 years after planting (with a planting density of 3,100 trees per hectare). Rapid biodiversity recovery was also achieved. Sinhaseni (2008) reported that 73 non-planted trees species re-colonized the plots within 8–9 years. When combined with the 57 planted framework tree species, the total tree species richness in the sampled plots amounted to 130 (85% of the tree flora of the target evergreen forest). The species richness of the bird community increased from about 30 before planting to 88 after 6 years, including 54% of the species found in the target forest (Toktang, 2005).

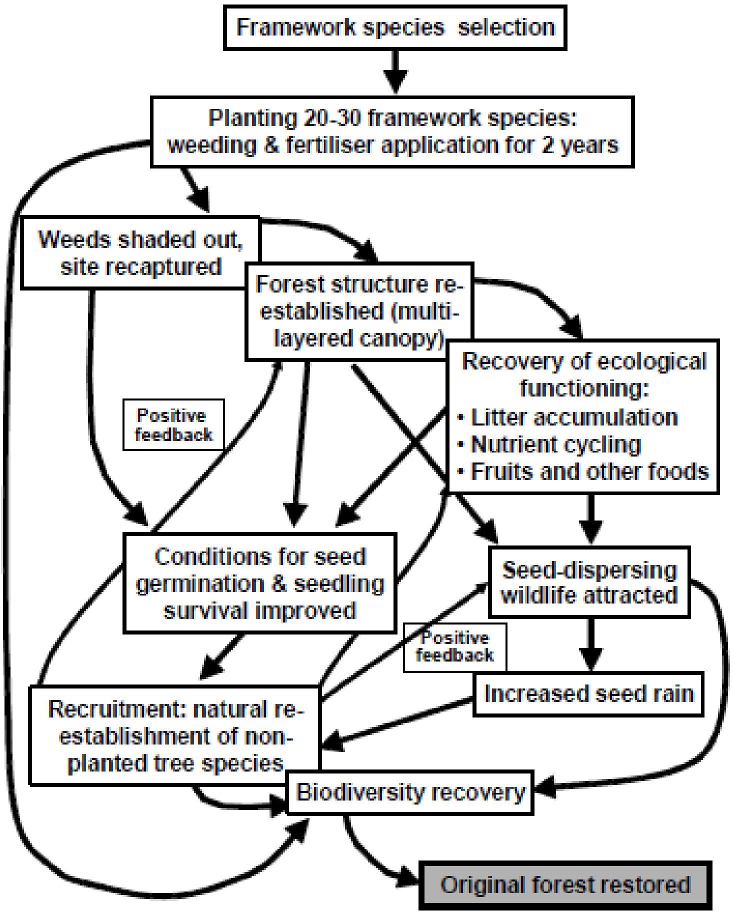

Figure 2.5 Concept of framework species method (FORRU, 2008)

2.5 Direct seeding

Direct seeding – as the name suggests – is replacing tree planting with sowing seeds directly into the soil of the restoration site. The method is low cost since nursery production of planting stock, a major cost of conventional restoration, is not required. Its successfulness depends on various factors, including seed traits, physical factors and controlling seed predation. Seed traits, including seed size or mass, shape and seed coat thickness, play vital roles in seedling establishment success. Large-seeded species usually have higher rates of germination (Figure 2.6) (Ceccon et al., 2015; Palma and Laurance, 2015) and seedling establishment (Doust et al., 2006; Doust et al., 2008; Tunjai and Elliott, 2012). Seedlings growing form small seeds fail to survive the early stages of development. For example, *Ficus* species seedlings have more than 90% mortality, mostly due to damping-off diseases within a month and those that do avoid disease are all killed during the first dry season (Kuaraksa and Elliott, 2013). In southern Thailand lowland forest, large to intermediate-sized seeds, which were round or oval and had low to medium moisture content had higher seedling survival rates than species with other seed characteristics (Tunjai and Elliott, 2012).

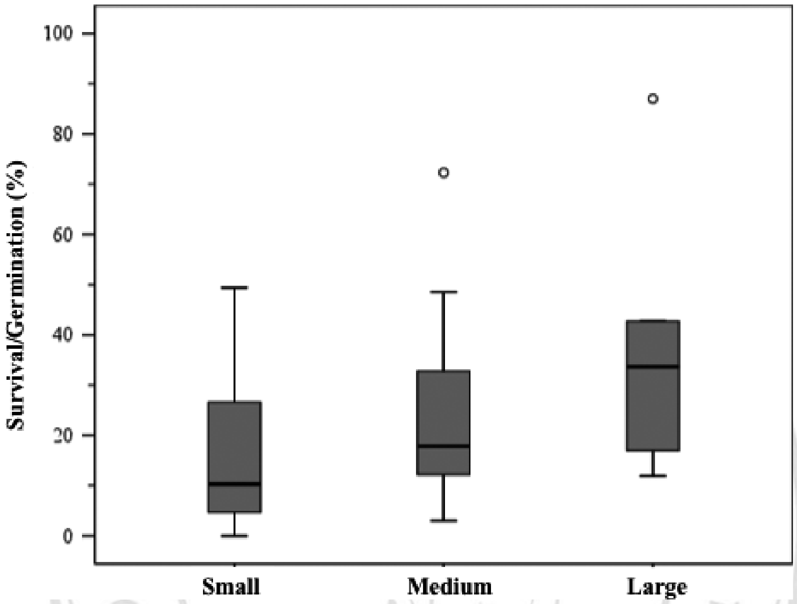

Figure 2.6 Survival/germination according to seed size (mass) in direct seeding experiments. Seed mass categories: Small: seeds 0–99 mg (n = 29); Medium: 100–2000 mg (n = 14); Large: >2000 mg (n = 6). ANOVA; F = 5.0 df = 2, P < 0.01. The tick line represents the median, the outer limits of the box the first and third quartiles. Whiskers extend to cover any data point <1.5 times the interquartile range. Circles represent outliers (Palma and Laurance, 2015).

Physical factors (light, moisture) have a great influence on direct seeding success. For example, when four canopy species were planted into primary dry forest in Jamaica, seedling survival rates were lower in non-shaded than in shaded plots (McLaren and McDonald, 2003). Regeneration guild (early or late successional status) may affect seedling establishment and seeds of tree species in different guilds may require different germination conditions (Engel and Parrotta, 2001; Cole et al., 2011). In addition, different times of sowing present different weed competition conditions (Doust et al., 2008).

Seed predation severely reduces seedling establishment. For example ants destroyed seeds in abandoned agricultural land in northern Thailand (Woods and Elliott, 2004) and cattle may also be a cause of seedling predation (FORRU, 2006). Rodents are the major seed predators in various type of restoration site (Hau, 1997; Hau, 1999; Birkedal et al., 2009; Castro et al., 2015). Rats, including *Niviventer fulvescens* and *Rattus rattus flavipectus*, were the main seeds predator in a shrub-land restoration project in Hong Kong. Seeds of 11 out of 12 species studied were removed from the restoration site within 60 days. However, rodents removed few *Choerospondias axillaris* and *Elaeocarpus sylvestris* seeds probably because they have thick or tough seed coats (Hau, 1997). Coating seeds or protecting them physically might help to reduce seed predation during direct seeding projects for forest restoration (Castro et al., 2015).

Further studies are needed to incorporate direct seeding into tropical forest restoration protocols around the world. Greater understanding is needed about the time frame of the method from seed collection preparation to the establishment of a closed canopy forest. The costs-effectiveness of direct seeding should be more widely compared with that of other restoration techniques and the likely effects of climate change on direct seeding success (both in terms of species selection, seed germination and seedling establishment) should be explored (Palma and Laurance, 2015). In addition, more tree species should be tested for direct seeding to improve our understanding in this method and identify situation when direct seeding alone is enough to restore forest ecosystems and when it should be complemented with ANR or conventional tree planting (Silva et al., 2015). Cost-effectiveness is one of the main benefits of using this technique. However, this is not true for all species. The high mortality of small-seeded species such as *Ficus* spp resulted in very high cost of per plant established compared with planting nursery-raised seedlings and planting stock from vegetation propagation (Kuaraksa and Elliott, 2013).

2.6 Seed Storage

In tropical forests, trees produce seeds in all months of the year. For example, in Doi Suthep-Pui National Park, 43% of wind-dispersed tree species mainly produce seeds during the mid to late dry season, whilst animal-dispersed species tend to produce seeds in late rainy season (FORRU, 2006). The optimum seed-sowing period is the beginning of the rainy season, so direct seeding may be limited to only those tree species that fruit just before that period. Such a limitation considerably reduces the ability of direct seeding to replicate high tree species richness at the start of a restoration project. Therefore, efficient seed storage, from fruiting time to the optimum direct seeding time, could play a major role in making direct seeding technique a more attractive restoration tool (Guarino and Scariot, 2014).

Seed storage and longevity behavior can be classified as orthodox, recalcitrant or intermediate (Hong and Ellis, 1996; Schmidt, 2007). It depends on the ability of seeds to tolerate desiccation, chilling and the duration of storage. The viability of orthodox seeds can be maintained *ex situ* for long periods. They tolerate both chilling and drying. Recalcitrant seeds are desiccation-sensitive. They cannot survive chilling and/or drying. Short-term storage can be possible, but only under specialized conditions. Intermediate species are half way between orthodox and recalcitrant. Chilling may prolong viability to some extent either wet or dry. Medium-term storage is possible, when storage conditions are well-defined and controlled. For direct seeding, intermediate species may be suitable if the time from seed collection to direct seeding is not too long. Thus, knowledge of storage behaviour is essential for defining suitable storage environments and knowing the likely longevity of tree seeds both for restoration and for species conservation projects (Hong and Ellis, 1996).

Storage behaviour can also be identified by probabilistic models, which are based upon the dry seed mass and the seed coat ratio, SCR, is the proportion of dry seed coat and dry seed mass. These parameters have been found to be reliable predictors of storage behaviour. Large seeds with relatively low SCR (thin seed coats) are usually desiccation-sensitive (Daws et al., 2006).

Seed storage behaviour has been studied worldwide in different plant families. In Sri Lanka, a hundred species of Fabaceae, both native and introduced species, were classified into 94 orthodox species and 6 non-orthodox (Jayasuriya et al., 2013). In Vietnam, Hong and Ellis' Protocol was tested on 51 native and 9 introduced tree species, of which 34 were orthodox, 13 intermediate and 13 recalcitrant (Ellis et al., 2007). A similar trend was found in Brazilian Amazon rainforest, where orthodox species were the most common. Sixty-seven tree species were tested, of which 38 were orthodox, 23 recalcitrant and 6 intermediate (De et al., 2014).

2.7 Hydrogels

Hydrogels or hydrophilic gels are hydrophilic crosslinked polymers. These polymers can be classified into three different groups, according to their synthetic process. Firstly, naturally occurring polymers are essential for life components, such as proteins, polysaccharides and other starch derivatives. These polymers are normally used in the food industry as thickening agents. Natural gums (including Arabic gums and guar gum) and agar are other examples of natural polymers. Secondly, semi-synthetic polymers are combinations of natural polymers (cellulose) and petrochemical derivatives, such as cellulose ethers. Thirdly, synthetic polymers or hydrogels are synthesized from monomers of petrochemicals, including cross-linked polyacrylamide (PAM) $(\text{-CH}_2\text{CHCONH}_2\text{-})_n$, hydroxyethyl methacrylate and polyvinyl alcohol $(\text{-CH}_2\text{CHOH-})_n$ (Mikkelsen, 1994). Hydrogels have been used for different purposes, such as biomedical products, biotechnologies, pharmaceuticals, separation technologies, electro-conduction and biosensors, contact lenses, food packaging, cosmetics, oil-spill recovery and agriculture (reviewed in Ullah et al., 2015).

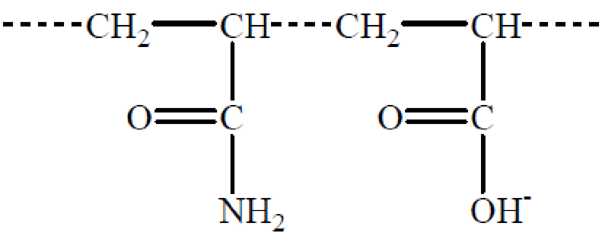

Figure 2.7 Molecular structure of anionic polyacrylamide (Green and Stott, 2001).

Polyacrylamide (PAM) is a well-known hydrogel. Commonly used as a super-absorbent, it can absorb more than 400 to 1,500 times its dry weight of water (Figure 2.7, Landis and Haase, 2012). PAM is a soil conditioner, which stabilizes soil aggregation and flocculate suspension. PAM has been used to help prevent soil erosion especially in furrow irrigation, on steep slopes during construction projects and in other disturbed areas, as well as for improving soil and water quality (Green and Stott, 2001). PAM has been greatly used in agriculture, both in nurseries and after out-planting. Although PAM can retain a lot of water close to large seeds and aid their germination, it may also inhibit germination, particularly of smaller seeds by reducing aeration and oxygen supply. Moisture supplied to seedling roots from PAM promotes fine root development by preventing desiccation. It may also promote production of natural polymeric mucilage from healthy roots (Figure 2.8). PAM is, therefore, often are mixed into growing media to increase water-holding capacity and reduce moisture stress (Landis and Haase, 2012).

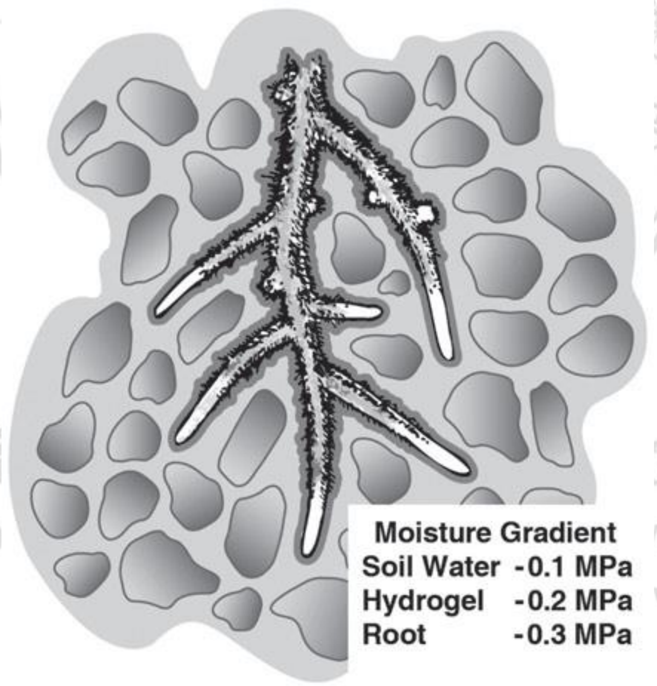

Figure 2.8 When hydrogels are applied as root dips, they function like the mucilage that is naturally produced by healthy roots and improve water uptake, by increasing root-to-soil contact and filling in air spaces (Landis and Haase, 2012)

Hydrogels have been studied, both in nurseries and in the field, especially for economic species. Numerous studies have shown that gels reduce drought stress. For example, *Pinus halepensis* seedlings perform better (shoot and root growth) in gels than in control growing media, when subjected to drought conditions (Hüttermann et al., 1999). Gels enhanced the drought tolerance capacity of *Conocarpus erectus* in arid and semi-arid areas (Al-Humaid and Moftah, 2007). Furthermore, media mixed with gel increase water-holding capacity (Akhter et al., 2004; Chirino et al., 2011) and seedling survival of *Quercus suber* (Chirino et al., 2011) and arable crops (wheat and barley) (Akhter et al., 2004) in field although it they had no effect germination of the latter (Akhter et al., 2004). In contrast, overdoses of hydrogel can cause mortality of pine seedlings, two years after planting. Hence, application rate must be carefully determined based on species and environmental variables (Sarvaš et al., 2007). Although the applications of hydrogel have been well explored for economic species, few forest and native tree species have been tested in nurseries and during direct seeding (Landis and Haase, 2012). Therefore, in the study presented below, I tested the effects of hydrogel on seed germination and seeding establishment both in the nursery and in the field during direct seeding.

2.8 Fertilizer Application

Mineral nutrients play key roles in plant growth and development, especially in physiological processes. Plants normally store nutrients in the seed for use during germination. External nutrient sources are important after seedling emergence. Plants naturally uptake nutrients from growing media (Jacobs and Landis, 2014). Therefore, providing sufficient nutrient is essential for plant growth. Mineral nutrients are often provided to plants in the nursery and during out-planting as fertilizer (FORRU, 2006; Hasse et al., 2014). Fertilizer application depends heavily on plant stage (seedling, sapling or adult) and nutrient availability in growing media.

Synthetic fertilizers can be categorized as soluble or controlled-release. Soluble fertilizers rapidly dissolve in water. Their main advantages are low cost and simple adjustment of nutrient rate of supply and ratio. However, since they dissolve fast, they drain rapidly from the system, so a lot of fertilizer fails to be up taken by the plants and they may cause pollution from leaching into water bodies (eutrophication). Controlled-release fertilizers are combined into pellets with less-soluble materials such as sulfur or a polymer. The slow break down of the pellet regulates fertilizer release rate. This ensures more of the nutrients are taken up by the plants and less leaches into the environment (Table 2.4).

Table 2.4 Comparison of advantage and disadvantages of two majors types of synthetic fertilizers used in tropical plant nurseries (Jacobs and Landis, 2014)

Factor	**Soluble fertilizer**	**Controlled-release fertilizer**
1. Nutrient release rate	Very fast	Much slower-dependent on type and thickness of coating, as well as temperature and moisture
2. Number of application	Multiple-must be applied at regular intervals	Usually once per season, but additional top-dressing is an option
3. Uniformity of application	Good, but dependent on irrigation coverage	Can be variable if incorporated, resulting in uneven growth
4. Adjusting nutrient rates and ratios	Easy and quick	Difficult
5. Nutrient uptake efficiency	Poorer	Better
6. Leaching and pollution potential	Higher	Lower
7. Potential for fertilizer burn (salt toxicity)	Low if applied properly	Low, unless prills damaged during incorporation or following high temperatures
8. Product cost	Lower	Higher
9. Application cost	Higher	Lower

Controlled-release fertilizers have been used for native tree seedling production. FORRU-CMU recommends around 0.3 g of Osmocote, a slow release fertilizer, is applied at potting time and at 3-month intervals thereafter, to promote growth and ensure that the saplings are large enough by the optimum plating time (mid-June in northern Thailand) (FORRU, 2006). This amount and brand of fertilizer have been used since the unit was established (on the advice received during training in Australia). New coating technology is currently being developed, to reduce manufacturing costs and increase controlled-release efficiency. The National Nanotechnology Center (NANOTEC) is currently applying Nanotechnologies to produce new coating systems using a polyurethane modified alkyd resin. It controls nitrogen release for up to 36 days while, uncoated fertilizer dissolves in water in only 5 minutes (Sitthisuwannakul1 et al., 2014). The product shows positive results in the laboratory, but it has not been tested on plants under more natural conditions and never with forest tree species. Consequently, one of the aims of the study described here was to test this new kind of fertilizer and compare its performance with that of FORRU-CMU's conventional fertilizer regime.

2.9 Preparing for Automated Restoration

The aim of the New York Declaration (described above), to restore forest to 350 million hectares of degraded land; an area large than India, by 2030 is hugely ambitious. A major limitation to achieving it is that sites available for restoration are often remote from access and are situated on steep, rugged terrain. Supportive technologies are, therefore, essential for restoring such enormous remote areas. Current aerial technologies are being developed to solve this problem. Lightweight Unmanned Aerial Vehicles (UAVs) or “drones” are being widely used for remote photography, surveys, logistics (Prime Air, new delivery system of AMAZON company by Drone, AMAZON, online, 2017) and can potentially be applied for restoring forest ecosystems (Elliott, 2016).

Drones could possibly be installed with equipment capable of carrying out various restoration tasks such as GPS, high-resolution cameras and tools to collect or deposit seeds or collect plant specimens, or to deliver fertilizer or spray pesticides (Elliott, 2017). Drones are highly cost-effective, being able to carry out tasks rapidly in remote rugged or dangerous locations, regardless of access problems and without employment of a lot of labour. Drones are becoming more and more affordable. Communities with limited funds can use this technology to enhance their ability in forest management and conservation (Paneque-Gálvez et al., 2014). Open access software such as “Ecosynth UAV” can effectively measure forest structure and complexity across landscapes using ordinary digital camera without the need for specialized sensors (Zahawi et al., 2015). Furthermore, in riparian forest, drones have been used to identify dead wood, canopy mortality and vegetation units via computer-aid visual images identification (Dunford, et al., 2009). Drones are now recommended as a useful component of ecologists' toolboxes, complementing traditional field tools (Zhang et al., 2016).

The latest imaging technologies allow drones to identify forest structure remotely. For forest restoration, they may become useful for various tasks, such as site preparation, planting, weed control, fertilizer application and monitoring etc. (Elliott et al., 2013; FORRU, 2006). However, use of drone technology is currently a huge knowledge gap. Native tree species have traditionally been used for conventional forest restoration because they have evolved to suite local ecosystem conditions (Elliott et al., 2013). However, which native tree species may be suitable for forest restoration by aerial seeding is still unclear. Transitioning from planting seedlings to dropping seeds from drones will require a quantum shift in forest restoration research. Firstly, testing which species to determine which may be suitable for aerial restoration is a high priority. The factors involved in ensuring survival of planted trees and those to ensure seed germination and early seedling establishment are very different. The first step is to test the relative performance of species during direct seeding, before taking the next step of testing them with aerial seeding. Direct seeding tests can be used to suggest which species would do well if dropped by drones. Dropping seeds in biodegradable "bombs" or encasing them in pelleting materials provides opportunities to greatly enhance germination and early seedling establishment. Media in bombs or pellets could include combinations of forest soil (to provide essential microbes) mixed hydrogels (to preserve moisture), predator repellants (to deter rats etc.) and fertilizer (to boost seedling growth immediately after germination. Testing all the "seed enabling technologies" will be essential to develop effective aerial seeding for forest restoration (Elliott, 2017).

All components of the study described below are, therefore, aimed at paving the way for a transition from traditional tree planting to aerial seeding by drones, seen as an essential step if large scale restoration is to be achieved in remote, rugged areas with the minimum of human intervention.