CHAPTER 2

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2.1 Tropical deforestation:

Tropical forests have the highest biodiversity of any terrestrial ecosystems on Earth, but they are being rapidly degraded and destroyed by habitat conversion (de Lacerda & Nimmo, 2010; Laurance *et al*., 2011).The main reason for deforestation is land conversion to agriculture and infrastructure development. Around 13 million hectares of forest were converted to other uses or lost through natural causes each year in the last decade (FAO, 2010).

Like many rapidly developing tropical countries, Thailand has experienced extensive deforestation. Whilst, a ban on commercial logging, since 1989, has helped to slow the rate of destruction in Thailand, it may also have put more pressure on the forests of neighboring countries (FORRU, 2000). Despite the logging ban, forest cover has shrunk alarmingly since 1973. Duangsathaporn (2013) reported that Thailand's forest cover declined 480, 0000 ha (30.9 million rai) of land from 1973 to 2009.

The top eight types of infrastructure construction projects, responsible for most forest destruction are (in declining order of forest area impacted): Dams, Man-made canals, Road and Highway construction, Mining, Power Generating infrastructure, Telecommunication infrastructure, Soil Excavation and Sand dredging, Rock Blasting activities.

(http://www.bangkokpost.com/lifestyle/family/374915/clearing-the-way).

The productive forest Area in Thailand was 58% of the total land area in 1959 (Bhumibhamon, 1986). Between 1976 and 1980, Thailand had the second highest rate of forest depletion in Asia, next to Nepal (Dankelman and Davidson, 1988).

Thailand has forested area about 37.1% or 18,972,000 ha of land. At the same time 35.5% (6,726,000 ha) is classified as primary forest, the most bio-diverse and carbon-dense form of forest. Change in Forest Cover: Between 1990 and 2010, Thailand lost an average of 28,850 ha or 0.15% per year. In total, between 1990 and 2010, Thailand lost 3.0% of its forest cover, or which is around 577,000 ha (FAO, 2005 & 2010).

In 1991, the Thai Government set a national forest policy, which declared that the country's forest cover should be around 40%, with 25% as conservation forest and 15% as production forest. However, this action angered Thailand's mining industry, which sought to exploit mineral reserves, located within the country's parks.

(http://rainforests.mongabay.com/20thailand.htm)

2.2 The need for forest restoration on mines:

Economic development is a major driver of deforestation. As the Thai economy has expanded, electricity consumption has increased and is expected to continue to do so (Sivavong and Limkitisupasin, 2005). Intarapravich (1991) reported that coal accounts for 13 percent of the commercial primary energy demand, because of its relative low price. It is used as a cheap fuel, because of huge domestic reserves and stable international price. Since 1987, the Exploration & Assessment Project (CEP) set under Mineral Fuels Division has assessed the coal resources throughout Thailand in more than 70 Tertiary basins. The work covered detailed geological investigations, a high-resolution seismic reflection survey and drilling with well logging. Most of the coal is classified in Lignite - Sub bituminous, with a few deposits being Anthracite. Remaining reserves are estimated to be around 1,354 million tons in 16 districts in northern Thailand. The highest coal reserve is 1,140 million tons at the Mae Moh Mine, Lampang Province and the third largest reserve is at the Mae Than Mine also in Lampang Province (Sivavong and Limkitisupasin, 2005).

However, Intarapravich (1991) also stated that, coal exploitation carries with it substantial environmental degradation such as land surface degradation, dust emissions, waste disposal and so on. Land surface disturbance includes the open pit method, which is used for mining coal. It removes the top soil and overburden is normally moved from the pit. As a result, it changes topography, vegetation and streams.

The measure to deal with land surface disturbance from coal mining varies among mines. The ONEB stipulates a set of conditions for work operations to minimize environmental disturbance and the danger to the public and to ensure the safety of the personnel. Land reclamation is a legal requirement (Intarapravich, 1991).

2.3 Progress with mine-site rehabilitation:

Coal mining has great impact on ecosystems with disruption being greater with surface mining than with deep mining. In the past, the only concern was the efficient production of coal and the detrimental effects on the environment were often ignored. However, now coal mining companies are required to run mitigation programs and they try to recapture the site with some standards (Coal mine site reclamation, 2013).

In areas degraded by mining or petroleum exploration activities, the processes of natural regeneration are generally slower compared to natural tree fall gaps due to the removal of the surface and partial sub-surface soil layers. Soil removal and exposure of the less fertile sub-surface layers induces changes in the physical, chemical, and biological characteristics of the soil (e.g. changes in pH, cation exchange capacity, quantity of organic material, compaction, reduction in microbial activity)and ecosystem disturbance (King, 1988; Gonzalez-Sangregorio *et al*., 1991; Parrotta *et al*., 1997; Parrotta and Knowles, 1999).

Fast growing native vegetation that colonizes abandoned areas, in the absence of intense land-use (Uhl *et al*., 1988) and fire Zarin *et al*., (2005), has the capacity to rebuild carbon and nutrient stocks (Johnson *et al*., 2001; Feldpausch *et al*., 2004), leaf area and stand structure (Feldpausch *et al*., 2005). In addition, forest plantations can facilitate and accelerate the processes of natural regeneration (Uhl, 1988; Lugo, 1992; Parrotta *et* *al*., 1997a; Nichols *et al*., 2001). The lack of knowledge, however, concerning physiological characteristics of native species related to the capture and utilization of primary resources such as nutrients and light has become a limiting factor in determining the success of forest plantations in strongly impacted environments. The use of fast-growing species has been a strategy adopted in many forest plantations to altered areas, with the goal of rapid accumulation of biomass in the vegetation and the surface soil horizons. In the edaphic environment, the accumulation of biomass is important for the stabilization of soil physical and chemical properties, as well as an increase in the quantity of organic matter. This results in an enhanced soil capacity to retain water and nutrients, improving the environment for the establishment of native species from natural or artificial regeneration (Fisher, 1995; Lugo, 1997; Mapa, 1995; Parrotta, 1999; Singh *et al*., 2002).

2.4 Direct seeding:

Direct seeding is often used when mine-spoils are being vegetated in order to control erosion in the short term and provide forest products in the long term. For example, in northern Australia, direct seeding of mine-spoils was carried out using aerial seeding of a mixture of 30 native tree species and fertilizer (Foster & Dahl, 1990). Herb seeds could be subsequently added in order to provide ground cover, as found in a field trial in India (Jha & Singh, 1993). However, direct seeding for mine rehabilitation can be somewhat hit and miss if not carefully planned and implemented, or when unpredictable weather conditions follow seed spreading. A number of important aspects need to be taken into account to increase the chances of success when seeding, such as seed supply, seed treatment, ecosystem succession, seeding rate, seed spreading, timing of seeding and spreading vegetation (Mine Rehabilitattion Working Group, 2006).

In the EU, North America, Australia and New Zealand, mining permits are only granted if a full mine plan is provided, covering the cradle-to-grave lifetime of the mine. This must take into consideration the surrounding environment (land, soil, water, ecosystems) and also the local heritage and community. In some cases, mining bonds must be set aside to cover the costs of reclamation and these will not be released until the mine site has been closed, reclaimed and restored to minimum standards (Coal mine site reclamation, 2013).

In Thailand, energy demand has increased by 4% per since 2001 (Chungsangunsit *et al*., 2004). In 2001, nearly 81% of total energy was derived from fossil fuels, 2% from hydropower and biomass resources accounted for16.2% (Wibulswas & Chungpaibulpatana, 1996). As fossil fuel has a lot of benefits in the energy sector, at the same time it has caused serious impacts on environment. Global warming is one of the issues, which are the result of emission of CO_2, SO_2 and NO_X (Chungsangunsit *et al*., 2004).

As a result, the Electricity Generating Authority of Thailand (EGAT), which controls most of the coal reserves in Thailand, has on-going projects for land reclamation about 1,095 rai or 175.20 ha. of the Mae Moh Mine and 2,135 rai or 314.6 ha of the Krabi mine are planned to be rehabilitated for diversified post mining land use. Though land reclamation of private mine has not yet shown much progress, the areas required reclamation are minimal (Intarapravich, 1991).

2.5 Methods used in Forest restoration:

A generally accepted definition of forest restoration is "to re-establish the presumed structure, productivity and species diversity of the forest originally present at a site, with ecological processes and functions of the restored forest closely matching those of the original forest" (Gilmour *et al*., 2000).

Ecological restoration is a broad concept that can encompass several kinds of ecological repair after some kind of damage (SERI 2004). Full ecosystem restoration is expected to return the complete set of native species (plants, animals, fungi and microbes) to a site, in the proportions and roles observed for them in undamaged ecosystems. Some restorative activities can have more specific and less ambitious objectives, including re-vegetation (establishment of plant cover), reforestation (accelerated establishment of trees after timber harvesting or other disturbance), afforestation (establishment of trees after a prolonged period of cover by other vegetation), reclamation (returning industrial land to a forested, agricultural, or other productive state), or rehabilitation (redirecting existing ecosystem composition or structure towards a more desired state) (Burton & Macdonald, 2011).

Various forest restoration methods have been developed e.g. assisted natural regeneration (ANR) (Jansen and Pfeifer,1989), the framework species method (Goosem and Tucker,1995) and the accelerated pioneer climax series method (APCS) (Sou, 2000).

Goosem and Tucker (1995) proposed that two major types of tropical rainforest restoration could be adopted in Australian systems: the framework species method (FSM) and the maximum species diversity method (MSDM). They reported that forest restoration using framework species was first developed in Queensland, Australia in 1980. Twenty to thirty selected species were planted in degraded areas, which resulted in 80 woody species colonizing planted sites. The major advantages of this technique are 1) it needs only a single planting and 2) it is self-sustaining. However, the framework species method is suitable only where native vegetation is located near. In the maximum species diversity method, a larger percentage of species are from the mature phase and primary promotes are generally avoided. The major disadvantage is the slower growth rate of many mature phase forest species, which requires longer and more intensive post planting management.

The idea of assisted natural regeneration or ANR was discussed firstly in the Philippines and has developed continually for the past 20 years. This idea is flexible, depending on limiting factors of succession in each area and overcoming these factors is the goal to restore biodiversity and limiting factors in Philippines are forest fire and weed competition which interfere seedling and coppicing dispersion (Dalmacio, 1987). ANR methods include cutting or pressing the weeds around existing naturally established seedlings, protecting the area from fire and planting with desired species if necessary (Hardwick *et al.*,1997).

Hardwick *et al*. (1997) describes part of a 2-year project in Northern Thailand on assisting natural processes in degraded seasonal evergreen forests and reported that seed germination of *Beilschmiedia* sp. was sharply reduced by lack of rainfall and the seedling were highly susceptible to scorching by direct sunlight. Raising seedlings in nurseries and planting them out in degraded areas under the shade of existing herbaceous vegetation may be a suitable method to accelerate the regeneration. Seedling recruitment of *Prunus cerasoides* in the clearing was limited mainly by insufficient dispersal of its seeds into the cleared area. Under experimental conditions seeds germinated and seedlings established readily, so direct seed sowing in degraded areas may be appropriate. *Engelhardia spicata* seeds were widely dispersed by wind and weeds appeared to be a limiting factor. This barrier could be overcome by cutting back weeds or by shading them out with nursery trees.

Framework species are indigenous forest tree species which are i) are fast growing, ii) shade out weeds rapidly and iii) produce resources (fruits or nectar) which attract seed-dispersing animals. Moreover, they must be easily propagated in the nursery. The height of healthy seedlings planted is usually about 50-60cm. They are planted spaced about 1.6-1.8m apart at the beginning of rainy season. Usually planted trees are weeded and given fertilizer in the first two rainy seasons after planting and the trees usually grow and shade out weeds efficiently. Framework tree species can re-establish basic eco systems structure and function, whilst other aspects of ecosystem integrity return naturally. Biodiversity is restored by seed dispersing wildlife attracted to the planted trees (FORRU, 2008).

The major groups of framework species for Northern Thailand, recommended by the Forest Restoration Research Unit FORRU, 2000 are tree species in the family's Moraceae (fig trees), Leguminosae and Fagaceae (Oaks and Chestnuts). Fig trees fruits are eaten by many species of birds. Legume trees can fix nitrogen in the soil, so these trees are particularly suitable for planting where soil degradation has occurred. Although the members of Fagaceae grow slowly, they develop dense crowns, shading out the weed efficiently and providing food sources for wildlife, as well as humans.

Reforestation plays a key role in the long term of restoration of landscape functioning, as well as economic and social development. It catalyzes natural forest succession (Parrotta, 2000). In addition, target areas, that are either close to intact forest or which retain an abundance of animals, have a high chance for successful restoration, by accelerated biodiversity recovery in the first stage of succession (Parrotta, 2000).

2.6 Direct seeding as an alternative method to tree planting:

Most forest restoration projects involve planting nursery raised tree seedlings, but this is the most labor and capital intensive method of forest restoration. Seed collection, raising seedling in a nursery, planting and maintaining planted saplings until they can establish and become independent all require substantial labor inputs (Hardwick et al., 2000). Furthermore, root deformities caused by seedling outgrowing their containers and those caused by careless transplanting techniques can reduce sapling survival in the field (Zangkum, 1998).

The potential advantages of direct seeding over the plantation establishment techniques(i.e. planting of nursery grown seedlings, wilding or rooted cuttings)include cost savings associated with nursery care and planting, as well as the possibility that tress established by this means may develop more naturally and quickly than would transplanted seedlings or cuttings (Engel and Parrotta,2001).The significant advantages of direct seeding that can outweigh these disadvantages include low germination survival percentages, resulting in either inadequate plantation stocking and increased seed costs to compensate for poor germination and survival; lack of daily care compare to the nursery raised seedlings and increased seedling mortality, associated with weed competition in addition to increased susceptibility to poor weather conditions Evans, 1982. In addition, the major problem is that failure is more common than with tree planting, because of the vulnerability of very young seedlings to climatic extremes, disease, grazing animals and insect attack (www.netc.net.au, 2004).

The Eden project in Niger recommends direct seeding as an appropriate method of establishing trees, (Eden Foundation, 2000). It is claimed that nursery plants use precious irrigation, whereas direct seeding carried out prior to or during the rainy season does not need irrigation. They further maintain that plants established by direct seeding tend to produce an extensive root system, whereas the above ground shoots grow more slowly. In contrast, seedlings raised in nurseries tend to produce large shoots and must be irrigated to prevent high mortality, whereas plants established through direct seeding are more likely to be able to reach moisture remaining in the soil after rainy season (Ochsner, 2001). This was quantified in Senegal by Samba (1992) who sowed the seeds of *Faidherbia albida*at the same time as planting nursery raised plants. Four months after sowing direct seeded plants were about twice as tall and had a mean dry root mass 25 times higher than that of the nursery raised plants.

Steven (1991) reported that the results of direct seeding are affected by several factors, including species, soil conditions, site preparation and techniques for seed germination.

Thomson (1992) and Applegate et al. (1993) stated that the potential cost savings associated with direct seeding, particularly for species whose seeds are readily available and applicable for this method of establishment, could overweigh its disadvantages and offer a more economical means for re-establishing forest cover over large areas of degraded lands.

2.7 Direct seeding for mine site rehabilitation:

In many developed countries, direct seeding is often used when mine spoils are being re-vegetated to control erosion in the short term and provide forest products in the long term. In the tropics, direct seeding on mine spoil has only been reported from India and Australia, but the practice may be used in other places without having been reported in available literature (Ochsner, 2001). Mine spoils are a poor medium for establishing plant growth of any kind. As a growing medium, mine spoils are characterized by being completely without organic material and hence also lacking a natural seed bank.

In northern Australia, direct seeding of mine spoils was applied using aerial seeding of a mixture of 30 native tree species and fertilizer (Foster and Dahl, 1990). In addition herb seeds were added to the mixture on certain types of mine spoils in order to provide ground cover.

On the northeast coast of South Africa, mining entails the removal of the dune forest in 1977. Then the area is sown with a mixture of seeds, consisting mainly of rapidly germinating species (e.g., *Helianthus annuus, Sorghum* spp., *Pennisetum americanum, Crotalaria juneea).*This mix act as a nurse crop that protects the slower germinating indigenous species. After this nurse crop died off, the vegetation became dominated by the major pioneer species e.g. *Acacia karoo*, (Camp and Weisser, 1991).

In India, a field trial on coalmine spoils investigating several species of trees, grasses and herbs found seedling emergence between 20 and 85% (Jha and Singh, 1993). In some situations, the concentration of plant available heavy metals may be low enough to allow the direct establishment of commercially available plants onto tailings without resultant phyto-toxicity. This is an attractive option, as direct seeding with agricultural seed mixtures is a very economical re-vegetation technique. Organic matter (e.g. Sewage sludge) would normally be applied as thin surface covering to improve the physical structure of the substrate and to provide the nutrients in a slow-release form to encourage sward establishment. Once established, legumes such as *Lotus corniculatus* and *Trifoliumrepense* supply the sward with N by atmospheric fixation. A self-perpetuating system can therefore develop, although the application of P-rich fertilizer may be needed. This technique was also used to establish vegetation on abandoned metalliferous fluorspars dams in Derbyshire, UK (Jhonson *et al*., 1976).

2.8 Success with direct seeding- Literature case studies:

A rehabilitation program, of bauxite mines in the Jarrah (*Eucalyptus marginata*) forests of Western Australia, evolved from sustained research which aimed to establish a self-sustaining Jarrah forest ecosystem, which close resembles the native forest. Restoration of the Jarrah forest, was augmented by a seed mix containing up to 60 species, sown by hand, together with fertilizer. From this mix, 39 species established (Ward and Koch, 1994). Subsequently, Ward and Koch (2005) studied the growth and form of 13-year-old Jarrah (*Eucalyptus marginata*) trees, established from seed and planted seedlings and subjected to various fertilizers, understory seed and spacing treatments. Seeded Jarrah had a mean establishment density of 2,662 stems per hectare and density of 2,300 stems per hectare after 13 years, a survival rate of 86%. Sixty two percent of the seeded trees developed into saplings (>1.5m tall). The saplings had a mean height of 9.0m and db hob 14.4cm after 13years. The mean density of potential saw logs (trees with a single stem to at least 2m) was 1297 stems per hectare after 13years. It has also high establishment variability (the range across the experiment site was 1104 to 5829 per hectare).

Planted Jarrah, growing in arboreta in Western Australia has also shown poor form Abbott and Loneragan, (1986), while survival of Jarrah has been satisfactory from broadcast seed compared with planted as seedlings Ward and Koch, (1995).

An innovative approach to increasing the germination of both broadcast seed and seed held in the replaced soil is the use of smoke. Collaborative research between Alcoa of Australia Limited and researchers at Perth's Kings Park and Botanic Garden identified why bush fires are necessary for the regeneration of many Australian native species (Dixon et al., 1995). Although the seeds of some species respond to these elements, it is the smoke which is the main catalyst for increasing germination. Additionally, treatment of field sites increases the number of seedlings from the seed bank in replaced top soil by over 50%.

2.9 Soil Conditioners:

The type, mix, and amounts of soil amendments will vary from site to site in response to the local mix of site contaminants, soil conditions, and type of desired vegetation. The first and most essential components of any soil amendment strategy are an accurate assessment of existing site soil conditions and knowledge of the range of target soil conditions appropriate for the re-vegetation species of interest. Post-revitalization land use also is an important consideration in choosing soil amendments and remedial strategies. Additionally, it is essential that potential soil amendments be carefully characterized for all important physical, chemical and microbiological properties.

2.9.1 Biosolids:

One of the potential advantages of biosolids application is an increase the site quality through higher organic matter and nutrients (Henry et al., 1994). It is well known that biosolids increase plant growth (Tapper and Sabey, 1986; Wong and Ho, 1940). After 5 years, tree height improved by as much as 50 percent and diameter by 85 percent Kelly,2006.Other research on biosolids, such as that in the Hunter Valley, Australia(Pearce, 1991; Rawlinson & Lane, 1992; Logan, 1993;Phillips, 1993; Newton & Whitehead, 1998) has shown that addition of biosolids at rates of 50-150dt/ha, produced more plant and tree biomass than ordinary fertilizer applications, despite problems such as drought and weed infestation,. Parker and Grant (2001) found that application of biosolids in open-cut coal mining rehabilitation in the Hunter Valley, Australia increases growth of native and exotic grass species (Kelly, 2006).

2.9.2 Compost:

The key advantage of compost application is the replenishment of organic matter in the soil. Banerjee et al. (1999) reported that seeds sown in 1:2 spoil compost combinations increased tree height growth by 364.9% and root collar diameters by 63.9%. Similarly, biomass also increased. The most beneficial combination was equal proportions of spoil, compost and urea at 150 ppm N.

2.10 Identifying gaps in the knowledge:

Direct seeding has often used because of low cost. From initial work on more than 350 native tree species in Doi Suthep-Pui National Park, FORRU identified a number of potential framework species.

However, nobody has adequately tested direct seeding as a viable method of forest restoration in mine site rehabilitation program in Northern Thailand, using these framework species. Therefore, this study investigated the effectiveness of direct seeding for forest restoration in severely degraded land is necessary to fill the gaps in knowledge that have been identified above.