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What Can Native Trees Provide in Revegetating Tropical Degraded Land? An Experience of Man-Made Dipterocarp Forest in Indonesia †

Henti Rachmat [1,*], Kirsfianti Ginoga [1], Yunita Lisnawati [1], Asep Hidayat [1], Rizki Fambayun [1], Kusumadewi Yulita [2] and Arida Susilowati [3,*]

[1] Forest Research and Development Center – Indonesia Ministry of Environment and Forestry; hendalastuti@gmail.com
[2] Research Centre for Biology, Indonesian Institute of Sciences; yulita.kusumadewi@gmail.com
[3] Department of Silviculture, Faculty of Forestry – Universitas Sumatera Utara; arida_iswanto@yahoo.co.id
* Correspondence: hendalastuti@gmail.com; Tel.: +62-252-8334314 (R.H.H.); arida_iswanto@yahoo.co.id; Tel.: +62-061-8201920 (A.S.)
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Abstract: The benefits of revegetation provided by the successful growth of planted vegetations. This paper described a successful initiative on revegetation of tropical degraded land using native trees. More than 250 hectares of intact landscape in Gunung Dahu, West Java - Indonesia have been successfully revegetated using 32 Dipterocarp species. The success of this 20-years-old revegetated landscape was revealed by timber volume, natural regeneration, soil characteristics, ectomycorrhiza occurrence, and ecotourism potential. The results showed that the average diameter and height were varied from 12 - 43 cm and 10 - 23 m; diameter mean annual increment were at 0.6 - 2.1 cm year^{-1}; standing stock per hectares were at 10 – 220.84 m^3 ha^{-1}. The variations might be caused by different planted species, spacing distance and planting technique. The natural regeneration success was observed by the offspring's occurrence from six *Shorea* species and supported by mycorrhiza fruiting bodies predominantly by the genus *Rusula*. Planted trees also improved the availability of organic materials to the soils as described by good total soil porosity (51,06%-52,32%) and infiltration rate 120-155,33 mm hour^{-1} at the site. The landscape also provided springs with continuous water supply and allowed tourists to experience the serenity of the tropical forest. Hence, revegetation using native tree is prospective and proven to deliver wider benefit in ecological, economic, and social aspect.

Keywords: landscape restoration, indigenous tree, Shorea, standing stock,

1. Introduction

Land degradation and deforestation are among the major threat to both environment and human-wellbeing due to significant effect in losing biodiversity, causing soil degradation and contributing to significant greenhouse gas emission [1]. Rehabilitation of degraded tropical forest has been an important issue in both regional and global scale [2,3]. Planting of native indigenous trees for rehabilitating degraded tropical forest is considered to provide multiple benefits such as timber, medical product, food, and ecosystem services [4–8].

Dipterocarps are the major commercial trees of the tropics especially is Southeast Asia rain forest [9,10]. The Dipterocarps family growing naturally in Indonesia spread throughout the islands of Sumatera, Kalimantan, Java, Sulawesi, Nusa Tenggara, Moluccas and Papua and consists of at least 8 genera and 155 species [11]. The trees are ecologically important and significant commodities of

tropical economies. Considering many Indonesia dipterocarps population are now in danger [12,13] nationwide movement for conserving the species is needed [14–16]. Planting dipterocarps for forest rehabilitation and restoration has also been widely adopted in Indonesia [17,18] and several of them haven been determined to have faster growth among other such as *Shorea leprosula, S. parvivolia, S. johorensis* and *S. platyclados* [19–21].

Gunung Dahu Research Forest (GDRF) located at 06^{0}36'30"- 06^{0}37'00" and 106^{0}34'00" - 106o35'30" and was a revegetated area that first established in 199 by planting Dipterocarpd originated both from shoot cutting and wildings. Objective of this paper is to review how revegetation of degraded tropical land using dipterocarp trees can bring long-term multiple benefit as revegetated landscape can provide timber stock, enrich soil characteristics, water and sanitation, ecosystem services, create biological interdependent and natural regeneration capacity that resembles those in natural forest.

2. Methodology

The first step in the development of this review was a search of peer-reviewed publications followed by the search of another web-based "grey" literature (guidebooks, and conference proceedings). Local searches were carried out for less visible publication specific to the targeted site of revegetated Gunung Dahu landscape (unpublished data, village and other similar data record, institution report, project reports, modules,). The lists of literature were then compiled; literatures were selected according to their relevancy on specific section of discussion. Other literatures on similar works were also added to our list as for further comparison and discussion. When available, open-publicly data were analyzed using similar tools those stated on referred literatures to provide similar value for comparison and discussion. The literature is relatively recent and specific on the site, a few examples from the similar project site within other tropical zone are included where these experiences might translate into broader context of comparison and discussion.

3. Good Performance of Native Trees in the Man-Made Dipterocarps Forest Brings the New Insight

Measurement result to all planted dipterocarp showed that their average diameter at breast height were ranged at 12 – 43 cm, average height at 10 – 23 m, and Diameter Mean Annual Increment (DMAI) at 0.6 – 2.1 cm year-1. Based on their DMAI, the planted species might categorized into four growth rate [22] those were: very fast (*S. platyclados, S. leprosula, S. ovalis, S. smithiana*), fast (i.*e S. platyclados, S. leprosula, S. balangeran, H. gregaria, Anisoptera sp*), normal (i.e *S. leprosula, S. selanica, S. pinanga, S. palembanica, S. macrophylla, S. stenoptera, S. guisso, H. bancana, V. sumatrana, H. dryonbalanoides, S. johorensis, S ribrera, D aromatica, D. oblongifolia, D. lanceolata, S. laevis*) and moderately slow (i.e *S. mecisopterix, S. multiflora, S. curtisii, P. lucida, P. aptera, S. falcifera, S. seminis, A. marginata*). The highest DMAI value was showed by *S. platyclados* (2.1 cm year^{-1}). The same species may come to different category of DMAI rate depend on planting distance and silvicultural treatment [23]. More spacious planting diatance allowed higher DMAI value.

The calculations of volume standing stock were ranged at 10 – 220.84 m3 ha-1. With the highest volume was reached for *S. platyclados* at 4 m x 8 m planting distance. On the other hand, *S. leprosula* with 3 m x 3 m of planting distance also had relatively high volume per hectare (215.412 m3 ha-1). More planting distance would yield in higher DBH and height growth but result in lower volume per hectare due to the lower number of trees per hectare [12]. In accordance with the result of *S. leprosula*, the higher number of individual trees resulted in high value of volume per ha. That result will support the effort of stocking carbon where more individual tress will be preferred. The volume standing stock for many species in the revegetated study area was relatively high compared to the standing stock potency in the logged over area/LOA (35 to 40 m^3 ha^{-1}) in Indonesia[24].

That result proved dipterocarps in the man-made dipterocarps forest has better performance as they could reach the same value in the younger age. Hence, good performance of dipterocarps species became an indicator that it could grow well outside its natural habitat and very prospective to be

planted as the restoration commodity in the study areas and the other areas with almost similar condition.

4. Natural Regeneration Capacity as a Key Indicator of Self-Sustaining Native Forest: Case Study from Prospective Species of *Shorea leprosula, S. pinanga* and *S. platyclados*

Forest sustainability is closely related to the potential for natural regeneration in forests. Observations and measurements on regeneration of this plantation forest were made on three model species, i.e *S. leprosula*, *S. pinanga* and *S. platyclados* in 2018 [25,26] and monitored again earlier in 2020 using the same method. The three red meranti from this revegetated site started flowering at 16 years for *S. leprosula* and *S. pinanga*, and 15 years for *S. platyclados*. The age of the first flowering for these red meranti is therefore in between the common plantation and natural forest. *S. platyclados* showed the most abundant natural regeneration (>23.000 seedlings) than *S. leprosula* (>11.000 seedlings) and *S. pinanga* (>450 seedlings). Observation made on offsprings density showed that the number of seedlings was higher than those of saplings.

Comparing to other three model species, the other three Shorea, namely *S. selanica*, *S. macrophylla* and *S. stenoptera*, showed less reproductive capacity as seen by the absence of survived seedlings for *S. macrophylla* and *S. stenoptera* and only 5 seedlings found for *S. selanica*. Considering the age at first flowering, this three Shorea species also flowered at older age compare to others species. However, their reproductive ability could be determined successful as many others species in the area have not yet shown their reproductive ability.

It can be concluded that in during the twenty years of revegetation six species planted in the landscape has capacity to develop natural regenerations in different scale. *S. platyclados* showed the best natural regeneration with two flowering patterns that rarely found in nature, i.e. annual and irregular flowering with high number of survived offspring. *S. pinanga*, *S. leprosula*, *S. selanica*, *S. macrophylla* and *S. stenoptera* showed less capacity of natural regeneration. It is recommended that artificial interventions are required for seedlings survival and establishment to enhance the natural regeneration capacity.

5. Soil Characteristics, Land Productivity and Potential Hydrological Value

Slopes also affects tree growth. Different slope gradients are known to have different impact on stand performance [23]. Gentle sloping class provides better growth for both the diameter and tree height. Gentle-sloping area has thicker litter (11.7 cm) than other slope classes (6.3 – 7.9 cm), while litter thickness is thought to be the main factor in producing greater diameter growth and tree height.

The function of litter is essential, it will increase nutrient content in the soil through the process of mineralization into organic material which is assisted by soil organisms, including soil fauna and flora. Chotimah et al. [27] reported that soil fauna under *S. leprosula* stands in revegetated landscape is dominated by ants and worms. Various ant species were found in the revegetated forest include Odontomachus denticulata, Anoplolepis gracilipes, Monomorium pharaonis, and Pheidole dentata. Meanwhile, earth worms found under the *S. leprosula* stands was Lumbricus terrestris and was found in almost all planting distance. Litter is considered to be the best food source for earthworms because of its relatively high carbohydrate content and low lignocellulose content.

Soil solum depth is also a major determinant in determining land productivity. The soil solum at revegetated area was categorized as deep (>100 cm) as well as the effective root depth of around 90 cm that allows plants to grow well. The impact of more than 20 years of revegetation activities in Gunung Dahu can also be measured in the context of improvement on soil physical properties. Nutrient cycle has been established in revegetated site through the fallen litter of planted dipterocarp trees and converted into available nutrient and minerals by the help of soil microorganism.

Saputra [28] conducted observations of soil physical properties and found that bulk density value was considered under high criterion and characterized by high clay content that has high cohesiveness, enabling the increase in soil density [29]. The value of total pore space belongs to "good" criterion (51.06 – 52.32%), thus in turn were directly affect the infiltration rate that categorized [30] as rather fast at *S. leprosula* stand (120 mm hr^{-1}) and fast at *S. selanica* stand (155.33 mm hr^{-1}).

Higher infiltration rate at *S. selanica* stand was strongly influenced by soil physical properties, namely high porosity and the presence of soil cover from understorey plants and litter. Correlation matrix showed that infiltration rate in *S. selanica* stands positively correlated (0.643) with the value of slow drainage pores.

6. Ectomycorrhizal fungal association marks of how man-made dipterocarp forests have grown to resemble its natural one

Revegetation activities using dipterocarps trees carried out 20 years ago have changed the landscape of Gunung Dahu Forest. None of planted were inoculated with Ectomycorrhiza (ECM). However, the planted seedlings have grown and developed into forest stands and revegetation activities have transformed the degraded landscape into lush and productive man-made dipterocarp forest.

Research have been conducted to several experimental plot in this revegetated site and identified the occurrence of ECM family included Amanitaceae, Boletaceae, Hydnangiaceae, Russulaceae, and Schelodermataceae. The diversity index of ectomycorrhizal fungi in all planting plot was medium, while the richness index and evenness index of ectomycorrhizal fungi were low. The ECM fruiting bodies showed a random distribution pattern and distributed evenly, with the most common species being the genera Russula and Boletus. Similar microclimate and soil characteristic may be the causing factor for the similarity of ECM found at each observation plot. The abiotic factor that was slightly varied was the different light intensity values between *S. leprosula* and *S. selanica* stands with composition of ECM fungi in *S. selanica* was higher (103 individu ha^{-1}) than in *S. leprosula* (69 individu ha^{-1}) stands [27,31].

Not to surprising that on unplanted land adjacent to those which were planted by dipterocarp species, ECM individual was not found [27]. From this condition, it is clear that the presence of ectomycorrhizae is highly correlated with the formation of man-made dipterocarp forest that was established as the result of revegetation success of more than 20 years ago. The success of restoration vegetation was followed by the development of the edaphic ectomycorrhizal community at the site.

7. Revegetated landscape deliver environmental services value and support community livelihood

Gunung Dahu man-made dipterocarp forest have been transformed from almost bareland area with few old pine trees into densely planted forest landscape. This 20-years old revegetated area have brough many benefits in form of socio economic and also environment services. Aboveground tree biomass carbon stocks have been calculated and were varied depend on silvicultural technique applied. *S. leprosula* stand at a spacing distance of 2 m x 2 m, 3 m x 3 m, 4m x 4m, has aboveground carbon stocks of 73.4 tonnes C ha^{-1}, 85.6 tonnes C ha^{-1}, and 45.4 tonnes C ha^{-1} respectively; while potential carbon stock of *S. selanica* species at a spacing of 2 m x 2 m, 3 m x 3 m, 4 m x 4 m, respectively, are 66.9 tonnes C ha^{-1}, 49.4 tonnes C ha^{-1}, and 30.9 tonnes C ha^{-1} [32].

Not only increasing the carbon stock, revegetation activities has also changed the landscape characteristics. Thus, no wonder that this man-made forest has been established as a popular spot for ecotourism. Based on actual visitor record [33], the visit intensity divided into 3 phases, those were: booming (June 2017 – December 2018), steady (January 2019 – March 2020) and pandemic or closure period (April 2020 – present). In two active phases of booming and steady, the peak for the visit happens during the weekend with the average numbers of visitor were 250 - 300 person day^{-1} and 40-70 person day^{-1} respectively, while weekday visits for both periods were 30-50 person day^{-1} and 15 – 30 person day^{-1}. Covid-19 breakout also gave significant impact on this aspect as the site was closed for public visiting since April 2020. Numbers of visitor coming to enjoy the scenery have created multiplier effect for surrounding community by generating new income from selling food, goods and services which in turn it supported community livelihood. There were more than 30 food counters opened at the site during booming period that generating income for the seller of about 600.000 IDR (equal to around US$ 42) and IDR 300.000 (equal to around US$ 21) day^{-1} during weekend and weekdays.

Five springs have been identified inside the forest, namely Cikutu, Gunung Menteng, Cilame, Pondok, and Legok Gintung springs [34]. The existence of revegetation program to established a man-made forest receive positive assessment from community living surrounding the forest. To their perception, the successful revegetation activities gave positive implication that forested landscape delivered important role in water management by providing more continuous water supply and greater discharge from existing springs than that before the revegetation took place.

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