TREE DIVERSITY, COMPOSITION AND STAND STRUCTURE ACROSS POST-LOGGED LOWLAND TROPICAL FOREST ON SANTA ISABEL, SOLOMON ISLANDS.

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ABSTRACT

The rate of deforestation in the Solomon Islands is alarming with more than half of the nation's primary commercial forest resource having already been subject to timber harvesting leaving behind extensive areas of degraded forest without current management. This study aims to determine the species composition, tree species diversity and stand structure of the post-logged lowland tropical forest on Isabel Island, Solomon Islands. In this study, I compared the species composition, tree diversity and stand structure of the understory saplings and canopy trees in an unlogged forest and forests that were logged 3-years and 20-years ago to assess the recovery dynamics of these forest after selective timber harvesting.

A total of 168 different tree species from 92 genera and 43 families were identified in all the forest categories. The total number of species identified across the three forest types were 95, 110 and 116 in the 3-year-old forest, the 20-year-old forest and the unlogged forest, respectively. This study determined that even 20-years after timber harvesting, the tree community composition in the post-logged forests has not recovered for both the saplings and canopy vegetation. Tree diversity for saplings and canopy trees in the 3-year-old logged forest was significantly lower than the unlogged forest. Tree species richness was significantly higher for the saplings but considerably lower for the canopy vegetation in the 3-year logged forest. However, tree species diversity and richness for the sapling and canopy vegetation in the older 20-year-old logged forest were more similar to the unlogged state.

In terms of stand structure, there is rapid regeneration of pioneer trees dominated by *Macaranga* species in the newly logged (3-years) forest which has a considerably high stem density and basal area in the understory saplings compared to the saplings of the old logged (20-years) forest and the unlogged forest. Stem density for the canopy vegetation of the 3-year-old logged forest was significantly lower while the 20-year-old forest stem density did not differ to that of the unlogged forest. With increasing diameter class, the stem density reduced for the mature commercial tree species in the 20-year-old logged forest compared to the unlogged forest. This study shows that stem density for mature trees DBH ≥ 60 cm in the two logged forest was considerably reduced. Basal area of the canopy trees in the logged forest was also significantly lower compared to the unlogged forest. This highlights that timber harvesting has dramatically reduced the commercial tree species and timber stocking in the lowland forest in Isabel Island, which requires more than two decades for the forest to replenish for another commercial crop.

Managing the forest resources for the logged and unlogged forest is crucial for continuous provision of forest goods and services. I suggest that communities and resource owners can

utilise and manage their forest through a number of management strategies such as land-use planning, small-scale sawmilling and enrichment planting. Land-use planning ensures resource owners properly assess the forested land and its potential for various land uses. Emphasis on allowing ample time for the forest to recover after initial logging before the next harvesting is paramount to ensure restocking and the continuous supply of timber. Small-scale sawmilling and enrichment planting are equally vital for sustainable harvesting of timber and to established mature-phase and diverse tree species that support resilient forest communities.

CHAPTER 1: INTRODUCTION

1.1 Background

Extractive timber harvesting had an adverse effect on the species composition, diversity and the structure of the tropical forest in the Tropical South Pacific. Even 50-years after timber harvesting, tree species composition and diversity have not recovered to pre-harvest level on the logged-over forest in the Solomon Islands (Katovai et al., 2016). However, the post-logging responses of forest tree species remain understudied in the lowland tropical rain forest in the Solomon Islands, with minimal information available on the recovery dynamics of logged forest. Thus, further research is necessary to understand the forest succession pattern after selective logging.

Even though species diversity, composition and forest recovery after selectively logged have been widely studied, there is very little information on this subject in the Solomon Islands. Understanding the recovery dynamics of the logged forest can help the government, communities and forest managers to make an informed decision on managing post-logged forest recovery and to ensure more resilient and sustainable forest. The restoration of degraded sites due to timber harvesting can help improve the quality of forest habitat, increase forest productivity by producing both timber and non-timber products and establish the mature-phase tree species, which is vital to ensuring resilient and long-lived forest communities (Forbes et al., 2020).

Human activities are the driving force in biodiversity alteration and disturbance of tropical forest ecosystem processes (Martínez-Ramos et al., 2016), including the tropical forest of Solomon Islands. In the Solomon Islands, more than 50% of the primary forests have already been harvested, and an estimated 475,800 ha of former logging concession is without current management (Clifton et al., 2012). The rate of natural forest timber harvesting in the Solomon Islands has far exceeded the maximum sustained yield (Katovai et al. 2015). Timber harvesting by commercial logging at an unsustainable rate has depleted the timber stock and left behind large areas of degraded forest. Loss of biodiversity, ecosystem functions and important native tree species will be costly for the Solomon Islands if no management intervention is put in place. Selective logging on Isabel Island has modified the forest composition, diversity and structure by creating fragments of forest and causing disturbances on both the understorey and canopy vegetation which impact the biodiversity and forest wildlife. Therefore, research is required to understand succession patterns and restoring tree species composition and for improving regrowth of forests with diverse tree species, including species that can benefit future local communities (e.g. for through sustainable timber harvesting).

1.2 Research questions

It is imperative to understand both the understory sapling and canopy vegetation composition and diversity when planning and designing practical conservation and sustainable management plans for these degraded forests (Montagnini & Jordan, 2005). There is limited information on logged forest recovery, and there is a need to explore more about the recovery dynamics of logged-over forest in the Solomon Islands and the state of the forest concerning diversity, composition and stand structure. Increase in tree species diversity is vital for forest stability and resilience due to climate change. Therefore, understanding the process of forest recovery of the tropical forest after extractive timber harvesting is vital in the management of the logged-over forest. This study was conducted on Isabel Island, Solomon Islands and aimed to assess tree species composition, diversity, and structure of the post-logged lowland tropical forest. The objectives of the study will be determined by answering the following questions.

i. How are forest composition and structure affected by time since logging and by the intensity of the original logging?

Subsequent sub-questions are;

ii. What is the community composition and tree species diversity after selective logging?

iii. What are the stand density and basal area of the forest in relation to the intensity of logging and the period since logging?

1.3 Research objectives

This study aimed to evaluate the tree species composition, diversity and structure of post-logged forest at a different successive stage on Isabel Island, Solomon Islands. The specific objectives of the study were:

i. To determine tree species diversity and composition on the post-logged forest.
ii. To determine the forest structure and distribution of tree species across the post-logged forest.
iii. To make recommendations for future management

The findings from this study will contribute to information and add value to the understanding of forest recovery pattern of logged forest in the Solomon Islands. It will also be used as baseline information for future studies of forest biodiversity and ecology in the Solomon Islands. Finally, the findings of this study will inform resource owners on the tree species composition and biodiversity values in these degraded forests. The study will provide suggestions on the way forward and approach for community and landowners to manage their land and the forest resources for a more resilient and sustainable forest in the face of growing population pressure, the demand for hardwood timber and climate change issues in the Solomon Islands.

The thesis structure includes the following: Chapter 2 literature review which highlights the tropical forest and its importance in global biodiversity and how tropical forest exploitation through anthropogenic activities is a global threat to the ecosystem, the forest ownership/land tenure system in the Solomon Islands, the different types of forest in the Solomon Islands, selective logging, logged forest and opportunity for conservation, the implication of logging in the Solomon Islands and forest succession following logging or other disturbances on the tropical forest in the Solomon Islands and other tropical forest regions.

Chapter 3 of the thesis describes the study area and the location, and the methods used in conducting the study which includes: data collection, data processing, data/statistical analysis on the species composition, species diversity and forest structure in the three treatments.

Chapter 4 presents the results of the study with regards to the tree species composition in terms of the family, genera and species, the species importance value index (IVI), the species diversity index (Shannon-Wiener index, species richness and Pielou’s evenness) and the stand structure by determining the density and the basal area of each forest stand.

This is followed by Chapter 5, which discusses the results of the species composition, tree species diversity, forest stand structure. This chapter also states the limitation of the study that can be improved in any future investigations.

Chapter 6 outlines the values associated with these logged forests and implications to the resource owners. These values include soil and water conservation, carbon sequestration, economic importance, biodiversity values and other values that are equally important the landowners.

Chapter 7 presents some recommendation on the way forward on how the resource owners can better manage their forest for a sustainable and resilient future forest.

Chapter 8 draws conclusions from the overall study and outlines the study’s contribution to the post-logged forest recovery in Isabel Island, Solomon Islands.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

The tropical forests are one of the richest terrestrial ecosystems which cover less than 10% of the global land area yet likely harbour more than half of all species and sustain vast global biodiversity on Earth (Shi & Singh, 2002; Testolin et al., 2016). Ifo et al. (2016) stress that the tropical regions comprise an extensive area of the total global forest, and they are recognized to be the most significant areas in terms of biodiversity. In many tropical countries, overexploitation of the forest, including unregulated harvesting by industrial logging results in forest deforestation and degradation (Katovai et al., 2015; Montagnini et al., 1997; Tigabu et al., 2010). Forest deforestation and degradation is an ongoing serious environmental concern in many tropical countries and needs proper management to minimize its impact hence there is a need for more robust approach to tackle the problem of forest deforestation and degradation as a result of selective timber harvesting.

Forest recovery and succession patterns after extractive timber harvesting on lowland tropical rain forest across the Pacific region are yet to be fully understood (Katovai et al., 2016; Yosi et al., 2011). Keppel et al. (2010) highlighted that much of the research on the evolution and ecology of lowland tropical rain forest are from Amazonia and Southeast Asia. Katovai et al. (2016) pointed out that regenerations of late succession commercial tree species in the post-logging areas are hindered by several factors and needs further investigation in the Solomon Islands. Katovai et al. (2016), argued that findings from tropical mainlands or continental land bridge islands could not be generalised to isolated archipelagos such as the Solomon's since succession patterns and processes are not the same. Thus, continuous forest inventory is required to determine an appropriate management approach and understanding of forest dynamics and recovery process on the post-logging forest or degraded sites that are in need of restoration. (Kuswandi & Murdjoko, 2015; Matthew E. Simmons et al., 2012).

2.2 Forest ownership in the Solomon Islands

In the Solomon Islands, the land tenure system is mainly customary meaning that forested land is under customary ownership by local communities. Tribal group communally owns about 90% of the land in the Solomon Islands. This often limits Government participation to negotiate for environmental protection because of limited jurisdiction over customary land. Customary Land Tenure is a significant factor that connects the people to the land and the resources within the land. Land ownership is connected to a tribal group which are believed to have common ancestral descendants. Relationships to the land are a fundamental part of their connection with each other (Burt, 1994). The traditional land tenure system of land ownership provides a welfare safety net for the vast majority of Solomon Islanders (Pauku, 2009).

In the Solomon Islands, the native people consider the land as a treasure and as their identity. Pauku (2009), pointed out that there are two types of land tenure system in the Solomon Islands. They are the customary land tenure systems and the alienated (registered) land tenure systems. With the traditional land tenure systems, the land is not surveyed and marked for registration, yet it is recognised by law. In many cases, this often results in a land dispute between land-owning groups or with the people because the land boundary is often not demarcated and appropriately marked. For that reason, the customary ownership is often regarded as the main hindrance to major development such as infrastructure development and also a setback in the prerequisite to obtain a felling license and the right to log the forest (Pauku, 2009).

2.3 Solomon Islands forest types

The Solomon Island forests are classified into different types. The forest classification is based on the Solomon Islands National Forest Resources Inventory (MoNR, 1995) and the Solomon Islands National Forest Reference Level report (MoFR, 2018). The Solomon Islands Ministry of Forest through the consultative workshop in 2017 and 2018 developed the Solomon Islands National Forest Reference Level where forest classification aligned with the FAO Global Ecological Zones for forest reporting. The six basic forest types that were identified are described in Table 1.

Table 1. The forest type in the Solomon Islands (Source: The Solomon Islands National Forest Reference Level, 2018)

Forest Type	Description
Freshwater swamp and Riverine Forest	Forest occurred on land with minimal relief and obstructed drainage. Undisturbed forests are those with no apparent indications of anthropogenic activities and ecological disturbance while those that are disturbed have visible signs of human disturbances.
Saline Swamp Forest	Mangrove forest that occurs along with the coastal saline areas and subject to tidal influences. The intact mangrove forests show no signs of human disturbances while the degraded sites show visible indication of human activities.
Lowland Rainforest	Forest on level or nearly level land below 200 meters above sea level. Has a complex structure and composition. The lowland forests are either intact or degraded. Intact lowland forest has no apparent indications of human activities and ecological disturbance Degraded lowland forests are forest that has visible indications of human disturbance. E.g. logging
Hill Forest	The forest between 200-600 meters above sea level. This forest is either intact or degraded. Intact forest occurs on well-drained soils with no apparent indications of human activities and ecological disturbances. Has a complex structure and composition. Degraded hill forests have visible indications of human disturbance. E.g. logging
Montane Forest (Upland Rainforest)	Forest on higher altitude ridge tops, generally above 600 meters above sea level. The forest is either intact or degraded. The intact montane forest has no clear indications of human activities and ecological disturbance while the degraded montane forest has visible signs of human disturbance.
Plantation Forest (Industrial Plantation and Community Woodlots)	More extensive commercial plantations mainly Eucalyptus, Teak and Gmelina >3000 trees Small scale plantation with 250 to 3000 stems. Mainly Teak, Mahogany and Eucalyptus.

2.4 Selective logging

Selective logging is the widely used practice of extractive timber harvesting in the natural forests in the tropics (Pamoengkas et al., 2018) including the Solomon Islands. Generally, selective logging involves harvesting the tree species that are commercially valuable (T. Whitmore, 1984). These commercial trees are only about 3 to 7 % of all the trees (Heydon & Bulloh, 1997). If well planned and executed, selective timber harvesting is an important part of forest management intended to promote sustainable timber yields. Regrettably, logging activity in the tropics has been all too often carried out in a manner not favourable for the sustainability of the timber stocking and other forest resources (Robinson et al., 2001). Rist et al. (2012) pointed out that the tropical forests are exploited both by logging operation for commercial purposes and by the communities who are dependent on non-timber forest products. Despite the fact that only a fraction of the trees is harvested by selective logging, the associated damage during the harvesting operation destroys up to 50% of the trees (Johns, 1988).

The Pacific region in the Eastern Melanesian islands has recently recorded an increase in logging activities as timber stocking in neighbouring Southeast Asia has been depleted (Katovai et al., 2015). Nearly all the Solomon Island's timber is exported to mainland China. The Solomon Islands is, in fact, the second biggest exporter of tropical logs to China, after Papua New Guinea, with about half of China's tropical log imports coming from these two Melanesian countries (Yin, 2018). Despite the many negative impacts of selective logging, the timber industry is one of the significant contributors to the economy of these countries. The forest industry is the largest export industry in the Solomon Islands, accounting for around 20% of national Government revenue (PHAMA, 2020). The Solomon Islands nationwide forest inventory in 1995 revealed that commercial timber harvesting occurs on many islands in the Solomon Islands with the level of deforestation proceeding much faster than reforestation or natural regeneration.

The 1995 forest inventory in Solomon Island found that there is a possibility for recovery of the forest after selective timber harvesting as long as the harvesting operations minimize soil compaction and the canopy openings that allow too much light (MoNR, 1995). This is supported by the recovery of logged forest in Temotu (Vanikoro Island) and Western (Bagha) part of the Solomon Islands. However, there is strong evidence that heavily logged forest in Kolombangara Island has not been able to recover or form another commercial crop 30 years after harvesting which is in contrast to the logging in Bagha (Olsen & Turnbull, 1993). The national forestry inventory concluded that selective logging produced forest gaps that are too large as well as soil compaction that delayed logged forest recovery thus slowing down the time frame that allows for the forest to recuperate to another commercial crop.

2.5 Logged forest important for conservation

The tropical rain forests in the Solomon Islands have been heavily logged over the past century (Burslem and Whitmore, 1999) with more logged forest land than unlogged forest. Logged forests are degraded but still serve as an important provision of ecosystem services. These forests may continue to supply timber, small-diameter trees and other forest products, mostly for local communities whose livelihoods depend on the forests. Although logged forests may slowly recover, most will take some time to do so. Tulod et al. (2019), stated that the establishment of late-successional (mature forest) species could take a very long time in the highly disturbed forest due to competition. The condition of degraded forest, including the lack of suitable conditions for regeneration coupled with a lack of seed sources or regenerating materials often hindered the succession of mature forests tree species (Zhao et al., 2012). Consequently, secondary successions in the logged forests are often characterised by the prevalence of seral tree species that have low commercial value (Tigabu et al., 2010).

With the ever-increasing human population, conserving the remaining forest and their biodiversity and function may not be sufficient. It is of great significance not only to preserve but also to restore the degraded logged forest ecosystems (Aerts & Honnay, 2011). Restoration provides opportunities to increase native biodiversity and thus providing a range of benefits to the ecosystem and the local communities. Cardinale et al. (2012), pointed out that the diversity of plants and animals in the ecosystems are proportional to the amount and stability of services the ecosystems provide to the people. Basey et al. (2015), concluded that the restoration of degraded lands, including logged forests is crucial in biodiversity recovery, wildlife conservation, soil improvement, and improved water quality and climate change mitigation.

Yosi et al. (2011) pointed out that forest regeneration after extractive timber harvesting is a significant problem for tropical forest managers and communities. Katovai et al. (2015) highlighted that there is a need for restoration and conservation of logged areas in the Solomon Islands. They raised concerns about whether repeated logged forests that are highly degraded can return to a pre-logging condition via natural regeneration, or whether post-logged human intervention is required. Harrison and Swinfield (2015) pointed out that the availability of source populations on forests that have been degraded by logging may benefit in retaining a significant proportion of their original diversity. Paquette et al. (2009), however, argued that although logged forests may have lost many of their ecological functions, they still provide elements of biodiversity conservation or are important for other environmental services. For instance, logged forests still store a significant amount of carbon (Putz et al., 2012) and maintain hydrological cycles in a similar manner to what primary forests do. While logged forest cannot replace mature unlogged forests, there is excellent potential for logged forests to boost conservation at a landscape and regional scales, for example through acting as buffers around protected sites and enhancing forest connectivity (Edwards & Laurance, 2013). Makana and Thomas (2006), argued that secondary forests, that are impacted by selective timber harvesting might have significant conservation and economic potential if appropriately managed and prevented from further disturbances.

2.6 The Implication of Logging in the Solomon Islands

The rate of deforestation in the Solomon Islands is alarming with over half (475,800 out of 800,500 ha) of the nation's primary commercial forest resource having already been subject to timber harvesting (Clifton, Andrewartha et al. 2012). The majority of the population in the Solomon Islands are heavily reliant on the forest for survival, with the 1999 population census in the Solomon Islands emphasising the ongoing reliance of local communities on forest ecosystem services (Peterson et al., 2012). For example, more than 90% of all housing materials are sourced locally from the forest, including fuelwood which is the primary source of cooking energy in the communities (Peterson et al., 2012). Although timber harvesting is a source of income for communities and the Government, Yosi et al. (2011) highlighted that it is identified as the main contributor of deforestation and degradation of the tropical forest.

The Solomon Islands in recent years have relied heavily on timber harvesting from the natural forests to provide export income mainly through log exports. The National log export volumes have increased from about 600,000-800,000 cubic meters (m^3) per year (pre-2006) to more than 1.5 million cubic meters (m^3) per year in 2010 and 2011 (Clifton et al., 2012). Moreover, since 1995 total log exports are estimated to have exceeded 16.4 million m^3. According to Clifton et al. (2012), the annual log exports have exceeded the estimated yearly sustained yield of Solomon Islands forests by more than twice the estimated amount over that entire period (Clifton et al., 2012). Lamb (2011) pointed out that with such rate of timber harvesting, the commercially viable natural forest will soon be logged and export incomes will then tumble. There are few alternatives available for Government and community revenue; hence such a change will be abrupt when it occurs (Lamb, 2011).

In one recent study, it was estimated that the sustainable harvest rate for the Solomon Islands is 325,000 m^3 per year. In contrast, the actual harvest rates were more than double the sustainable harvest rate at 700,000 cubic meters per year (Clifton et al., 2012). Lineback (1998) pointed out that, logging licences issued by the Government was 4,000,000 cubic meters per year. This is about twelve times the sustainable rate. In a review, Katovai et al. (2015) pointed out that the country's timber stock was intensely harvested at a highly unsustainable level in the past two decades. In a recent summit Ricky Hou, the then Prime Minister of Solomon Islands, addressed the New Zealand Institute of International Affairs in Wellington. He pointed out that logging activity in the Solomon Islands has increased in recent years, which was about 10 to 15 times higher than the recommended sustainable rate for logging. It was highlighted that such a scale could considerably deplete the Solomon Island's forests. Although it may not feature in the spectrum of global news, harvesting of the natural resources unsustainably, including the forests is a fundamental global issue since deforestation is related to climate change, food security and biodiversity loss (Sevilla, 2013).

One option to address this issue is through strengthening protection laws and the restoration of degraded forests in order to prevent further deforestation and thus increase the biodiversity and abundance of the high value native commercial species that have been lost mainly due to logging and shifting cultivation (Tigabu, Savadogo et al. 2010). According to Keefe et al. (2012), often there is a lack of valuable species in the secondary forest. Rehabilitation to increase the value of the forest is, therefore, a vital forest management goal. Millet et al. (2013) suggested in their study that restoration may offer a means of mitigating degraded logged forest while also sustaining biodiversity values. Increasing the concentration of commercially valuable local tree species by assisted regeneration or planting seedlings for future harvest as a strategy for boosting natural forests' commercial value can be achieved with artificial regeneration (Keefe et al., 2012). However, lack of adequate knowledge and information relating to the costs and benefits may discourage landowners from exploring and engaging in restoration activities (Martínez-Garza & Howe, 2003; Millet et al., 2013).

2.7 Forest succession following logging/disturbances on the tropical forest

For the past several decade's little research has been done to understand forest dynamics after logging in the Solomon Islands. Despite a long history of silvicultural practices managing the tropical forests, there is limited knowledge of the natural succession processes and success of different treatments for restoring logged forests (Harrison & Swinfield, 2015). Katovai et al. (2015) suggest that enrichment planting, direct seeding and use of artificial perches are practical options to restore the logged forest in the Solomon Islands. Enrichment planting is one option that can speed up succession processes. It also enhances the quality of a secondary forest by promoting economically and ecologically valuable tree species (Weber et al., 2008). Human intervention plays a significant role to regenerate the mature-phase tree species within the degraded forest in cases where natural or human disturbances restrict their recruitment and natural regeneration (Forbes et al., 2020).

The recovery of the post-logging forest depends on several factors. A recent study by Katovai et al. (2016) in the Solomon Islands examines factors that affect tree species communities across logged forests (10, 30 and 50 years) on Kolombangara Island. Results of that study showed that there was little evidence that the composition of tree-communities is converging towards that of a pre-logged forest even 50 years after logging. They pointed out that the persistence of the pioneer species *Campnosperma brevipetiolata* has been hindering the recovery of later successional (including mature forest) tree communities in logged forest. According to (T. Whitmore, 1969), the prevalence of pioneer *C. brevipetiolata* in the forest is evidence of past human disturbance as observed in previous human settlements in Isabel Island and other parts of the Solomon Islands. Other studies on secondary forest succession in Southeast Asia have indicated that the presence of long-lived pioneer species contributed to the slow recovery of secondary forest (Chua et al., 2013). However, (Harrison & Swinfield, 2015; Matthew E Simmons et al., 2012), proposed that thinning of pioneer species eliminate the competition of pioneer trees and helps attain consistent light improvement for the understory saplings of mature-phase tree species. Katovai et al. (2016), concluded that thinning of long-lived pioneer species *Campnosperma brevipetiolata* could improve the growth of later succession species and help speed up the recovery of logged forest.

Katovai et al. (2016) used linear mix effect model (LMMs) to investigate the response of tree species richness and diversity to selected predictor variables. Their study established that the distance to logging roads and unlogged forest have the most influence on post-logging recovery. Results show that distance to logging roads and unlogged forest had various degree of impact on tree species richness across the recovery period. For instance, both had a positive effect on a more recently logged forest (10 years) while a negative effect on 30-year-old and 50-year-old logged forest. However, distance to the unlogged forest had no pronounced effect on the recently logged forest despite a positive trend on the prediction model. Their study revealed that tree species richness of the three logged forests and the unlogged forest did not differ significantly. This is an indication of similarity in species richness across recovery time.

They also determined the species diversity between the forest class types, by calculating the Shannon diversity index and then compared the means of Shannon diversity index. Their result shows that there is a significant difference in the diversity between the logged and unlogged forest. Although diversity differs significantly, the result indicates that logged forest become more diverse with time. For example, 30 and 50-year post-logged forest have higher diversity compared to the 10-year-old post-logged forest. The low diversity in the 10-year-old post-logged forest is an indication of low species abundance in the recently cut forest. The composition of forest classes implies that even though there was little indication of tree community composition on post logged forest converging towards that of the unlogged forest after a half-century, 30 and 50-year post-logged forest begin to show some resemblance to the unlogged forest compared to the 10-year-old forest which shows the importance of time in the recovery process.

In Papua New Guinea, Whitfeld et al. (2014) conducted one of the first studies in an attempt to document successional changes in New Guinea's lowland tropical forests aged between 3 years to 50 years after disturbance. The result shows that species composition differed strongly between mature and secondary forests. However, functional diversity was highest in mature forests, even after accounting for differences in stem and species diversity. This is similar to the pattern of succession in post logged forest in the Solomon Islands (Katovai et al., 2016). In another study, Yosi et al. (2011), analysed data collected by the PNG Forest Research Institute (PNGFRI) in unlogged and logged forest measured over 15 years in permanent sample plots distributed across the country in lowland forest. The results show that the Shannon–Wiener Index for the unlogged forest was higher than in the selectively harvested forest.

Until recently, the Tropical South Pacific (TSP) lowland forest have received very little attention comparatively, with the exception of Polynesian Islands like Tonga and Samoa, although there are several biodiversity hot spots and high endemism in this region (Keppel et al., 2010). A study conducted in Tonga on the rain forest composition and patterns of secondary succession concludes that secondary forest begins to resemble mature remnant forest in 30-50 year in terms of structure and native species richness (Franklin et al., 1999). The study infers that the most significant environmental factor affecting successional changes in the composition of the plant species was the coastal and maritime influence. However, proximity to the source population has a significant effect on the species composition and diversity in tropical lowland forest (Chazdon, 2003) which is also supported by a strong correlation between geographic distance and floristic similarity (Keppel et al., 2010). Keppel et al. (2010), highlighted that proximity to source propagules was important along with other factors such as age, disturbance frequency and area, in affecting community composition and diversity. According to Franklin et al. (2006), early successional species dominate the secondary forests while the disturbances and environmental factors explain the variations in the composition of late-successional, lowland forest in Tonga. Whitmore (1990) also highlighted that the variation in biogeography, habitat and disturbance determine how tree species diversity in the tropical forest varies from one place to another.

Studies in Southeast Asia tropical forest indicate some similarity in the recovery pattern of post logged forest in the Solomon Islands. For instance, in Borneo, a study on the effect of selective logging on tree diversity show that species richness did not differ significantly amongst forest types (Verburg & van Eijk-Bos, 2003). However, unlike in the Solomon Islands where diversity differs significantly between the logged forest and the unlogged forest, the findings in Borneo revealed that logging had no significant effect on tree diversity in a recently logged forest and a 20-year-old logged. This can be explained by the intensity of the harvest in Solomon Island in comparison to Borneo, as highlighted by Katovai et al. (2016) in their study. The cut limit in Borneo is 60 cm and 40 cm diameter at breast height (DBH) for first and second harvest respectively while the cut size limit in the Solomon Islands is 30 cm DBH. In another study conducted in Indonesia (Brearley et al., 2004) comparing structure and floristics of a 55-year-old secondary rain forest with primary forest found a similar pattern of succession as described by Katovai et al. (2016) in the Solomon Islands. Brearley et al. (2004), concluded that although the basal area, tree height and biomass of the old secondary forest approached that of the primary forest, there were significant differences in the species diversity for the old secondary rain forest to that of primary forest.

Moreover, in the selectively logged forest in Malaysia, 40 years is not sufficient for selectively logged forest to recover its species diversity and composition to the original state. This study estimated that it requires more than 40 years for the species diversity to recover in a selectively logged forest (Shima et al., 2018). Another study comparing the species diversity and composition of four different succession stage of secondary forest in northern Amazon have found that diversity and composition increase over time (Villa et al., 2018). The study concludes that age, along with environmental factors such as soil, determines the diversity along the successive gradient. However, Katovai et al. (2016), found that soil N does not have any significant effect on diversity across recovery time in the Solomon Islands.

Finally, tropical forests are the richest biological communities and known to harbour a significant amount of global biodiversity (Naidu & Kumar, 2016). Chua et al. (2013) highlighted that since secondary tropical forest constitutes an increasing proportion of tropical landscapes, understanding the structure and diversity of the forests is vital. Species diversity is important indices to assess the successional changes in the disturbed secondary forest over time (Villa et al., 2018). The succession patterns tend to have similarity across forest types in the Pacific, and Southeast Asia as reported from the studies reviewed here. Most of the studies reported that there was no significant difference in species richness over recovery time. Some studies have reported showing significant differences in tree diversity, which is similar to findings in the Solomon Islands while other studies reveal no significant differences in tree diversity among the forest class types. The intensity of logging is one major factor that determines the differences in diversity as reported. But with time, diversity increases but at different rate depending on the extent and nature of the previous disturbances. Therefore, the constant monitoring and management of both primary and secondary forest are necessary, particularly in promoting successional processes in maintaining species and habitat diversity.

CHAPTER 3: METHODOLOGY

This chapter describes the location of the study sites, which include the vegetation types, soils and, and the climate. The section also outlines the sampling method, data collection, data processing and the analysis of the data sets.

3.1 Study site

The Solomon Islands are situated east of New Guinea and north-east of Australia. They are located in the southwest Pacific and lie between 115^o 30′ and 170^o 30′ W longitude and 5^o 10′ and 12^o 45′ E latitude. The Solomon Islands lie 12^o south of the equator and comprise an archipelago consisting of seven major islands and over 900 smaller Islands. The total land area is around 28,800 $km^{2,}$ of which about 89% is occupied by natural forests and forest plantation (MoFR, 2019).

The study was conducted on Isabel Island (Figure 1). Isabel Island is located north-west of the capital of Solomon Islands, Honiara and can be accessed either by boat or plane. Isabel Island (also known as Santa Isabel or Bugotu) is one of the large islands and the longest of the Solomon Islands covering 4,095 km2 (Mayr et al., 2001). Santa Isabel mainland stretches to about 200 km and extends up to about 35 km with Barora Fa and neighbouring islands at the westerly end. The study sites are in Bansokeo, Eguegu and Mablosi in Isabel Island. The unlogged forest was situated in Bansokeo, the 20-year-old logged forest was in Bansokeo/Eguegu, and the 3-year-old logged forest was in Mablosi.

3.1.1 Vegetation

The Solomon Islands are mainly covered with tropical rain forest with small patches of grasslands and heaths in regions with seasonal climate. About 80% of the total land area in the Solomon Islands is covered with a tropical forest of which one third is considered to be a commercial forest. Western, Isabel and Choiseul provinces comprise the largest areas of commercial natural forests. However, industrial and smallholder plantations are mainly confined to the Western region. For example, the two largest industrial plantation companies, Kolombangara Forest Plantation Limited and Eagon Plantation are based in the Western Province.

According to T. Whitmore (1969), the non-forested grassland patches and heaths in parts of Solomon Islands seemed to have been maintained by fire and are probably the result of anthropogenic activities. This occurs in the San Jorge Islands in Isabel, parts of the Guadalcanal province and the Central islands. The islands of the Solomon archipelago are mostly of lowland and hill forest although only a few of the islands have hill forest that extends up to more than 1000 m in elevation (T. Whitmore, 1969; Wilramanayake et al., 2002). The lowland rain forest with an uneven canopy is the most widespread vegetation type in the Solomon Islands (Wikramanayake et al., 2002). The forests in Isabel Island are mostly of low elevation tropical rain forest with a small area consisting of the mossy montane forest above 1000 meter in the south of the island on the Kubonitu-Sasari massif (DeCicco et al., 2019).

There is a distinct forest type in specific areas in Isabel and San Jorge Island dominated by *Casuarina* species and *Xanthostemon melanoxylon* on the high nickel ultrabasic soil. The latter is a species endemic only to parts of Isabel Islands and Choiseul Island in the Solomon Islands (MoNR, 1995).

3.1.2 Map of the Solomon Islands and sampled area in Solomon Island

Figure 1 and *Figure 2* below shows the map of the study area in the Solomon Islands and the sampling site in Isabel Island where the forest categories are indicated in blue, red and green colour.

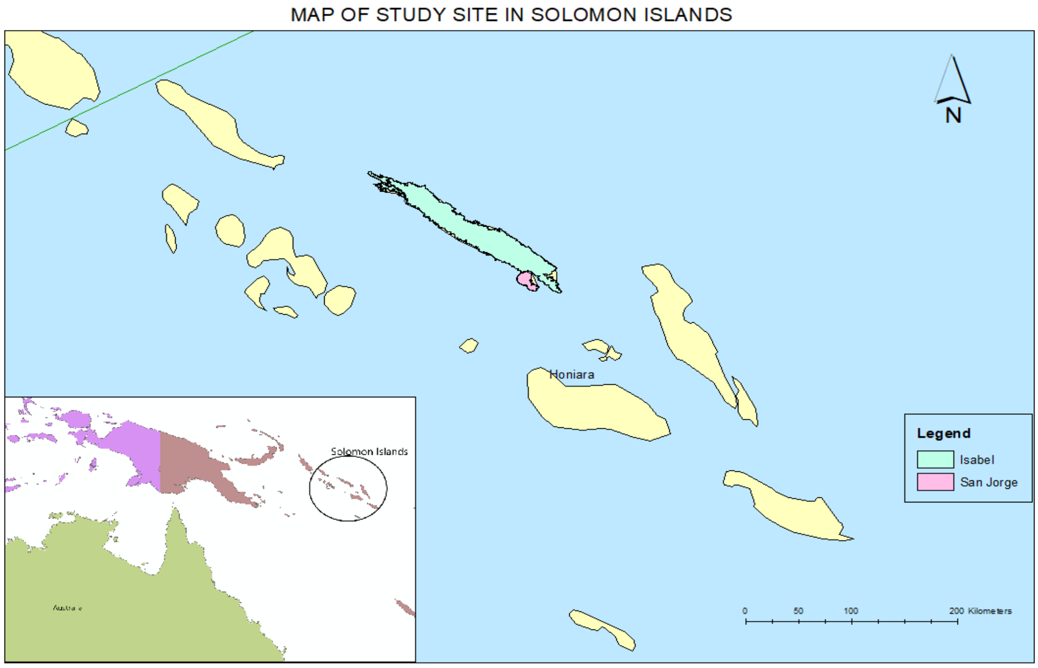

Figure 1. Map of Solomon Islands and the location of the study site.

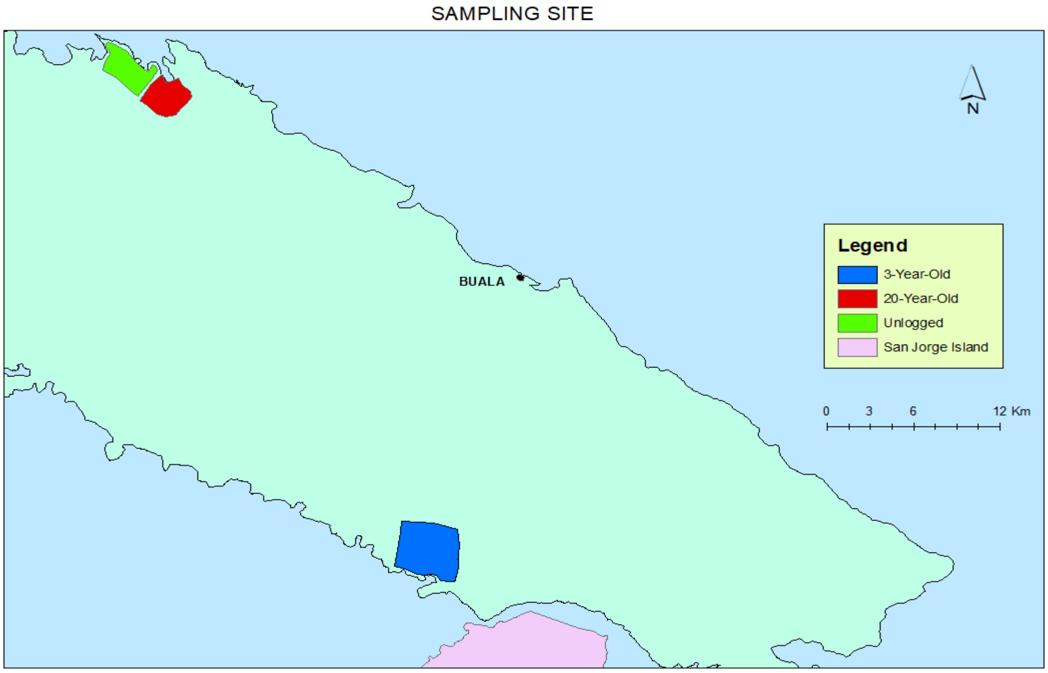

Figure 2. Map of the sampling sites

3.1.3 Soils and Topography

The soil of the Solomon Islands varies widely between and within the islands. The fertility ranges from fairly infertile and slightly toxic soils to very high fertile soils in specific locations resulted from the extrusion residue of volcanic activities and alluvial deposits. The Solomon soils are somewhat related to comparable soils in countries like Hawaii, New Caledonia, New Zealand, Australia, the West Indies and south-east Asia. Very little evidence can be seen on the relationship between soils and vegetation except in areas that are dominated by *Casuarina papuana* in which the soils are derived from serpentine (Lee, 1969)

Isabel Island mainly comprises low rounded hills and ridges with steep sides and crests. Some are flat with mild to gradual slopes. Most upper land soils are well structured, but either deficient with one or more significant nutrients or have a substantial nutrient imbalance (PHCG, 2008).

3.1.4 Climate

The climate of the Solomon Islands is tropical wet with a mainly dry and rainy season similar to that of other Pacific Island countries (Wilramanayake et al., 2002). There is a lot of sunshine and a high temperature throughout the country. The Solomon Islands is characterised by relatively high uniform humidity and with the daytime temperature around 25°C to 32°C. However, there is rarely extreme temperatures due to the cooling effect of the winds blowing off the surrounding seas. The temperatures in the Solomon Islands are heavily associated with the fluctuations in the surrounding ocean temperature (Lavery et al., 2016). The mean annual rainfall in most of the islands is 3,000 to 5,500 mm. During the year, rainy seasons and dry seasons occurs between November to April and June to October, respectively.

3.2 Site selection

To assess the diversity, composition and structure of the post logged forest in Isabel Island, two logged forest, and an unlogged forest was selected for the study. The study was conducted in the lowland forest as classified in the Solomon Islands National Forest Reference Level (FRL) for the United Nations Framework Convention on Climate Change (UNFCCC) Technical Assessment (MoFR, 2019). The lowland forest defined in the FRL report as the forest range at 0 – 200 m elevation. It is important to note that the lowland forest classified in Solomon Islands Forest Reference Level report is based on FAO Global Ecological Zones for forest reporting. However, based on the Solomon Islands National Forest Resources Inventory report (1995), forests within the 0-200 m.a.s.l zone but occurred on hills (0-200 m) are referred to as lowland forest on a hill, mixed species composition (MoNR, 1995).

There were three different study area and were classified as logged and unlogged forest. The three-forest categories include: (1) Forest logged 3-years ago, (2) Forest logged 20-years ago and (3) unlogged mature forest. The sample plots were located at an elevation range between 30 to 160 meters above sea level (a.s.l). The forest type on this study is the “Mixed Species Composition Lowland Rainforest” (Table 1) based on the 1995 Solomon Islands National Forest Resources Inventory report and Forest Reference Level report (MoFR, 2019; MoNR, 1995). The forests are considered to be similar across the three study sites. It was not possible to locate study sites any closer together because harvested sites at the desired ages were not available in the same areas. It was planned to sample unlogged forest adjacent to the 3-year old logged forest and to establish further sample plots on the 3-year and 20-year harvested site, but because of the Covid-19 pandemic, it was not possible to return to the Solomon Islands to undertake this sampling.

The main classes of forest under the lowland rainforest in the Solomon Islands are listed in Table 2 below (Source: Solomon Islands National Forest Resources Inventory, 1995).

Table 2. The lowland forest type in Isabel Islands, Solomon Islands.

LOWLAND FOREST	
LB	Lowland beach forest
LC	Casuarina dominated lowland forest
LL	Logged lowland rainforest
LK	Campnosperma dominated forest
LM	Lowland rainforest, mixed species composition
LN	Degraded lowland rain forest

3.2.1 The three forest classes

Below are the images of the three forest classes that were evaluated in this study. *Figure 3*, *Figure 4* and *Figure 5* are the 3-year-old logged forest, 20-year-old logged forest and the unlogged forest, respectively.

Figure 3. The 3-year-old logged forest with a highly dense understory

Figure 4. The 20-year-old logged forest with scattered mature trees

Figure 5. The unlogged forest with mature trees

3.2.2 Plots and Sample Size

An initial survey was conducted with the locals to gain a good insight and overview of the forest. I then used stratified random sampling to determine the location of the sample study areas. There were 51 sample plots of 20m x 20m (0.04 ha) established across the three treatments. Twenty sample plots were established and sampled in the unlogged forest, 16 and 15 sample plots were established and sampled at the 20-year-old and 3-year-old logged forest, respectively. All tree size DBH ≥ 10cm were identified, and the diameter at breast height measured.

We also assessed the understory saplings at the three sites. Thirty-seven plots were randomly selected from the 51 sample plots and sampled for saplings. In the 37 plots, all understory saplings 2≤ DBH<10 cm was identified and enumerated. Again, it was planned to complete the sapling sampling on the second field visit, which was not possible because of the Covid-19 pandemic travel restrictions.

All sample plots were kept constant at below 10% slope across the plots. The coordinate and elevation of each plot were determined with Global Positioning System (Garmin GPSMAP 64x). The establishment of the sample plots was done using Suunto clinometer and compass to determine the slope and direction, respectively. 50-meter measuring tapes were used for measurement around the perimeter of the sample plots.

3.3 Data collection

3.3.1 Stakeholder and community consultation

Initial consultation was carried with the Ministry of Forestry in Honiara and their provincial office in Isabel province. This was done to acquire information about active and inactive logging concession areas and obtain information on old logging sites. After the initial consultation with the Ministry of Forestry, community consultation was followed through with the community leaders and the resource owners at the study sites. The consultation with the landowners was to seek permission to access the forest sites to conduct the study and also to obtain information on the forest and history of logging activities on the sites.

3.3.2 Fieldwork

The consultation and fieldwork were conducted between July and December 2019. The fieldwork team comprised representatives of the landowners, forestry field officers, a botanist and myself. The botanist assisted with species identification and recording, while one compass person took the bearings, three establishment personnel moved around the plot perimeter placing pickets with flagging tape as markers, and one tree measurer measured the tree diameter.

Figure 6 below show the marking of the plot with flagging tape and measuring of the plots by establishment personnel.

Figure 6. Marking and plot establishment

3.3.3 Species Identification

A botanist who is an expert in Solomon Island flora was engaged for tree species identification. All trees in each plot were identified to genus or species level. Where tree species cannot be identified, voucher specimens or parts of leaf, flower, bark or fruit of the tree were collected and taken to the national herbarium for verification. Locals were also engaged for identification and confirmation of species in the local dialect and common names.

Figure 7 show the identification and recording of tree species by the botanist, an expert in the Solomon Islands flora assisted by a local person.

Figure 7. Tree species identification and recording

3.3.4 Tree measurement

The diameter at breast height (DBH) for all saplings and canopy trees were measured in each plot. Saplings sizes are stems with diameter 2 cm ≤ DBH < 10 cm while canopy trees are those with the diameter at breast height greater or equal to 10 centimetres (DBH ≥ 10 cm). All stems both saplings and canopy trees are counted and recorded in the sample plots. DBH of the trees were measured at 1.3 meters from the base of the stem. The DBH for trees with buttresses were measured at 30 cm above the buttresses. Diameter tape and measuring tape were used for measuring the DBH of the trees.

Figure 8 shows the tree diameter (DBH) measurement. The image on the left indicated the measurement of diameter above the tree buttress, and the image on the right shows the measurement of tree diameter without buttress.

Figure 8. Tree diameter (DBH) measurement

3.3.5 Data recording and processing

The tree species identification was recorded on a data recording template in the field. The field data were then manually entered into Microsoft excel sheet. The tree species are sorted and categorized into either sapling (2 cm ≤ DBH < 10 cm) or canopy trees (DBH ≥ 10 cm). The species spellings are cross-checked with online databases to confirm the correct name and spelling. The raw data are then sorted in a pivot table by species identity, plot numbers, and species abundances per plot. The Excel file was then converted to a comma-separated value (CSV) file before imported to R for analyses.

3.4 Data analyses

I performed the analysis of the diversity, composition, and structure at each site separately for saplings and canopy trees. In this study, saplings were categorised as 2cm ≥ DBH < 10cm and canopy trees DBH ≥ 10cm. The most common species with the highest percentage of stem density will be reported to describe the species composition in each of the forest types. Additionally, the importance value index, which is a measure of the most dominant species in the three forests, was calculated to quantify the ten dominant species. The Shannon index, richness and Pielou's evenness shows the estimated measure of the diversity in the three sites. Finally, the structures of the forest will be recorded in terms of the stem density, the basal area, and the diameter (DBH) class distribution in the three treatment sites

3.4.1 Species composition

Examination of the species composition was conducted across different successional stages. I identified and recorded the number of species per plot and the abundance of each species at each plot. This data was then used to determine the species composition in each of the treatment sites. Analysis based on the non-metric multidimensional scaling was performed to determine the difference in the community composition at each location.

3.4.2 Importance value index (IVI)

The importance value index (IVI) of the trees were determined by the sum of relative frequency (R.F), relative density (R. Den), and relative dominance (R.D) (Katovai et al., 2016; Naidu & Kumar, 2016).

- Relative density = $\frac{\text{Number of individuals of the species}}{\text{Number of individuals of all the species}} \times 100$

- Relative frequency = $\frac{\text{Number of occurrences of the species}}{\text{Number of occurrences of all the species}}$ X 100

- Relative dominance = $\frac{\text{Total basal area of the species}}{\text{Total basal area of all the species}}$ X 100

$$Importance\ Value\ Index\ (IVI) = RDen + RF + RD$$ Equation 1. Importance value index

3.4.3 Species richness and diversity

Diversity was assessed using the Shannon Wiener index, species richness, and Pielou's evenness at each sample plot. The analysis of Shannon Wiener index species richness and Pielou's evenness was performed using the R Vegan package (Oksanen et al., 2019). The mean at each site was calculated and was used to determine the differences in the diversity between the three sites. The Shannon-Wiener index was selected in this study because of its sensitivity to the presence of rare species especially in selectively logged forests where some species are scarce and may have been eliminated or reduced in density (Nagendra, 2002).

The one-way analysis of variance (ANOVA) was performed to examine how the means of species Shannon Wiener index, species richness and Pielou’s evenness differed among age-classes for logged and unlogged forest and then followed by Tukey's post hoc tests. Saplings and canopy trees were analysed separately. Bar plots of the means and standard error were created with excel to show the results.

Diversity indices

The species richness, Shannon diversity and Pielou’s evenness were determined as follows.

- Species richness (S) = Species richness is the number of species recorded per plot.

$$Shannon\ diversity = H' = -\sum_{i=1}^{s} pi\text{In}pi$$ Equation 2. Shannon diversity

Where S - is the number of species and

pi - is the proportion of species i.

$$Pielou's\ Evenness(J) = \frac{H'}{\log(s)}$$ Equation 3. Pielou’s evenness

Where H'- Shannon index, s – number of species

3.4.4 Stand density and basal area of the stand

The forest structure is essential to evaluate the stocking of a forest stand. Two parameters that can easily be captured to estimate the stand structure are density and basal area. Stand density is the number of stems per hectare and was calculated by converting the mean abundance of stems per plot to per hectare basis. Basal area is the cross-sectional area of the tree diameter at breast height (DBH). The calculation for stand density and basal area are performed using Microsoft excel.

$$Stand\ density = \frac{Stem\ density\ per\ plot}{area\ of\ plot\ in\ hectare}$$ Equation 4. Stand density

Where stand density – stems per hectare

Stem density per plot - is the number of trees per 400 m^2

$$Basal\ Area = 0.0000785\ x\ (DBH)^2$$ Equation 5. Basal area

Where 0.0000785 is a constant calculated by π / 40,000 as conversion ratio to square meters

DBH – Diameter at breast height and the unit is centimetres (cm)

A one-way analysis of variance was performed to examine how the means of stem density differed among age-classes for logged and unlogged forest followed by Tukey's post hoc tests. Similarly, ANOVA was performed to examine how the means of basal area differed in among the forest categories. Saplings and canopy trees were analysed separately.

3.4.5 Distribution of diameter at breast height class (DBH Distribution)

The structural composition was analysed by comparing the distribution of diameter class for the logged forest and unlogged forest. The examination of the distribution of the diameter class represents the stand structure. (Brearley et al., 2004). Histogram constructed with Microsoft excel was used to compare the size class diameter distribution at each forest category.

3.4.6 Ordination

Ordination was performed with the Vegan package in R software (Oksanen et al., 2019). The non-metric multidimensional scaling was run with the procedure of metaMDS function in the R software. An output graph of the community composition for sapling abundance and canopy basal area matrices was produced. For the sapling's abundance matrices, species with less than ten stems were removed before the analysis.

3.4.7 Analysis of similarity (ANOSIM)

To test for the differences in composition, I performed an analysis of Similarity (ANOSIM) based on Bray–Curtis similarity matrices of occurrence and abundance across the different forest age-classes (Katovai et al., 2016). ANOSIM was also performed for canopy trees community composition based on the basal area matrices. R vegan package was used for the analysis of similarity. (Oksanen et al., 2019). The procedure was performed using the non-metric multidimensional scaling (NMDS) to examine the differences in the community composition.

CHAPTER 4: RESULTS

This section presents the results of the data analyses at the three treatment sites: (1) 3-year-old logged forest, (2) 20-year-old logged forest and (3) unlogged forest. The species composition, diversity and the forest structure were compared between the three sites. The understorey vegetation with stems 2cm≤DBH<10cm and the canopy vegetation with stems DBH≥10cm were compared and evaluated to see the regeneration and succession pattern of the two logged forests in comparison to the mature unlogged forest in terms of their composition, diversity and structure.

4.1 Species composition

The overall result revealed a total of 2996 individuals in the unlogged and logged forests. These were sorted into 168 morphospecies belonging to 43 families and 92 genera. Out of the total 168 species, 115 were identified to species level, 51 to genus level and 2 were unidentified species. The total number of species combined for the understory saplings 2≤DBH<10 and canopy trees DBH≥10cm identified in the unlogged forest were 116 species, the 20-year-old logged forest comprised 110 species, and the 3-year-old logged forest consisted of 95 species (*Table 3*). Twenty-six species were found only in the 3-year-old logged forest compared to 16 species found only in the 20-year-old logged forests while 22 species were found only in the unlogged forests. A total of 49 species were common in all the three forest categories. The 20-year-old logged forest had 50% similarity in the species composition to the unlogged forest compared to the 3-year-old logged forest and the unlogged forest with 35.1% similarity in the species composition

4.1.1 Species

A total of 78 species were reported for the understory sapling in the 3-year-old logged forest, 94 species were identified for the saplings of the 20-year-old logged forest and 85 species were found in the unlogged forest. In contrast, the number of species found in the canopy vegetation at each site includes 55 species were identified in the 3-year-old logged forest, 76 species were found in the 20-year-old logged forest and 87 species were identified in the unlogged forest (*Table 3*). These results showed that the occurrence of species in the sapling phase was highest in the secondary forest 20-years after felling operations as oppose to canopy phase vegetation where the species composition was found to be highest in the unlogged forest. The results also revealed that recently logged 3-year-old forest showed the lowest number of species in each of the forest categories for both the sapling and the canopy vegetation.

4.1.2 Genera

The number of genera in the sapling vegetation was found to be highest in the 20-year-old logged forest with a total of 55 genera compared to the 3-year-old logged forest and the unlogged forest with 52 genera each. In contrast, the highest number of genera for the canopy vegetation was highest in the unlogged forest with a total of 53 genera followed by the 20-year-old logged forest with 48 genera, and lowest was observed in the 3-year-old logged forest with only 38 genera (*Table 3*).

4.1.3 Families

The highest number of the family for the sapling vegetation was found in the 3-year-old logged forest with 33 families while the lowest was found in the unlogged logged forest with 30 families. The 20-year-old logged forest recorded a total of 31 families for sapling vegetation. In contrast, the unlogged forest was found to have the highest number of the family with 31 families in the canopy vegetation followed by the 20-year-old logged forest with 28 families, and the lowest was observed in the 3-year-old forest with 26 families (*Table 3*).

Table 3 presents the number of species found in the three forest classes for both the sapling vegetation and the canopy vegetation and the total combined number of species found in each forest.

Table 3.Summary of the number of families, genera and species of unlogged forest and logged forests for both the saplings and canopy trees.

Forest class	Group	No. of families	No. of genera	No of species	Total no Species
Logged 3 years	Saplings	33	52	78	95
	Canopy tress	26	38	55	
Logged 20 years	Saplings	31	55	94	110
	Canopy tress	28	48	76	
Unlogged	Saplings	30	52	85	116
	Canopy tress	31	53	87	

The values in the next two tables (Tables 4 & 5) show the stem density, basal area, and importance value index of the top ten species for the understory saplings and the canopy trees respectively, as described in Section 4.2.

Table 4. Composition, stem density, basal area and importance value index (IVI) of the top10 sapling species at 3-year-old (L3), 20-year-old (L20) and unlogged (UL) forest.

Species	Density ha^{-1}	Basal area ha^{-1}	IVI (%)
3-YEAR- OLD LOGGED FOREST			
Macaranga dioica	1528.6	3.08	33.1
Macaranga tanarius	164.3	0.43	4.8
Pometia pinnata	117.8	0.24	3.4
Cryptocarya solomonensis	85.7	0.27	3.0
Campnosperma brevipetiolata	103.6	0.22	2.9
Brownlowia argentata	92.9	0.14	2.8
Diospyros sp.	42.9	0.15	2.3
Melicope solomonensis	64.3	0.04	1.9
Litsea perglabra	42.9	0.07	1.9
Dendrocnide rechingeri	78.6	0.09	1.8
20-YEAR OLD LOGGED FOREST			
Dendrocnide salomonense	183.3	0.34	10.4
Litsea perglabra	143.8	0.13	6.7
Dysoxylum sp.	104.2	0.11	5.7
Pometia pinnata	62.5	0.16	4.9
Elaeocarpus floridanus	66.7	0.10	4.2
Litsea sp.	45.8	0.07	3.1
Diospyros sp.	37.5	0.04	3.0
Syzygium sp.	31.3	0.08	3.0
Flueggea flexuosa	54.2	0.05	2.9
Dendrocnide sp.	50.0	0.09	2.9
UNLOGGED FOREST			
Dysoxylum sp.	93.8	0.15	8.0
Pometia pinnata	47.9	0.12	5.2
Barringtonia sp.	62.5	0.07	4.9
Syzygium sp.	52.1	0.10	4.9
Elaeocarpus floridanus	37.5	0.07	4.1
Canarium salomonense	39.9	0.08	3.9
Canarium vitiense	31.1	0.09	3.5
Maniltoa sp.	35.4	0.05	3.4
Celtis philippensis	41.7	0.06	3.4
Dysoxylum caulostachyum	29.2	0.04	2.8

Table 5. Composition, stem density, basal area importance value index (IVI) of the top 10 canopy tree species at 3-year-old (L3), 20-year-old (L20) and unlogged (UL) forest.

Species	**Density ha^{-1}**	**Basal area ha^{-1}**	**IVI (%)**
3-YEAR- OLD LOGGED FOREST			
Pometia pinnata	16.7	0.84	7.3
Brownlowia argentata	20.0	0.35	5.9
Dysoxylum excelsum	13.3	0.49	4.8
Dysoxylum sp.	8.3	0.60	4.2
Macaranga tanarius	11.7	0.11	3.7
Endospermum medullosum	5.0	0.82	3.6
Endospermum formicarum	1.7	0.82	3.2
Macaranga dioica	15.0	0.14	3.0
Aglaia sp.	5.0	0.36	2.7
Cryptocarya solomonensis	11.7	0.17	2.7
20-YEAR OLD LOGGED FOREST			
Terminalia sepicana	28.1	4.40	9.1
Pometia pinnata	48.4	2.27	8.6
Macaranga dioica	28.1	1.54	5.1
Terminalia complanata	12.5	1.73	3.8
Dysoxylum excelsum	15.6	0.71	3.3
Endospermum formicarum	7.8	1.66	3.2
Melicope sp.	4.7	2.16	3.1
Elaeocarpus floridanus	10.9	1.23	2.9
Terminalia calamansanai	7.8	1.30	2.8
Elaeocarpus sphaericus	9.4	1.17	2.8
UNLOGGED FOREST			
Pometia pinnata	41.3	12.33	11.9
Terminalia sepicana	31.3	3.20	6.0
Terminalia brassii	2.5	8.19	5.3
Canarium salomonense	22.5	2.94	4.7
Parinari glaberrima	22.5	1.73	3.3
Terminalia complanata	16.3	2.10	3.2
Endospermum formicarum	11.3	3.10	3.2
Canarium asperum	15.0	0.78	2.6
Vitex cofassus	2.5	3.62	2.6
Myristica fatua	15.0	0.52	2.5

4.2 Importance Value Index (IVI)

Table 4 and *Table 5* represents the ten most important species in the sampling area at the three forest categories for both the understory saplings 2cm ≤DBH< 10cm and canopy trees DBH ≥10 cm, respectively. The top ten saplings in the 3-year-old logged forest accounted for more than half the total importance value index at the site with 57.9%. Conversely, the ten most important sapling species in the 20-year-old logged forest, and the unlogged forest accounted for 46.8% and 44.1% of the importance value index at each site, respectively. In terms of the basal area, the top ten sapling species at the 3-year-old logged forest accounted for 76.1%, while the top ten saplings species at the 20-year-old logged forest accounted for 55.1% and the unlogged forest top ten sapling species made up 50.6% of the basal area. The results showed that the importance value index for the top ten saplings made up more than half of the total IVI in the 3-year-old logged forest compared to the 20-year-old forest and the unlogged forest which made up less than half of the total IVI. Similarly, the basal area of the saplings in the recently logged forest was higher than the 20-year-old logged forest and the unlogged forest (*Table 4*).

In contrast, the top ten canopy tree species in the 3-year-old logged, the 20-year-old logged, and the unlogged forest contributed 41.1%, 44.7% and 45.3% of the importance value index at each site, respectively. In terms of the tree basal area, the unlogged forest recorded the highest while the lowest was recorded in the 3-year-old logged forest. The top ten canopy tree species in the 3-year-old logged forest contributed 49.5% whereas the top ten trees in the 20-year-old logged forest and the unlogged forest contributed 60.9%, and 72.3% of the basal area at each of the sites, respectively. The results revealed that the top ten canopy trees in the unlogged forest recorded the highest IVI and lowest IVI was recorded in the 3-year-old logged forest. The basal area of the top ten species also revealed that the highest basal area was recorded in the unlogged forest, whereas the lowest was recorded in the 3-year-old logged forest (*Table 5*).

The most dominant sapling species at each successive site varied among sites, although with some similarities. The species *Macaranga dioica* in the family *Euphorbiaceae* was found to be the most dominant for the sapling vegetation in the 3-year-old logged forest with the importance value index of 33.1%. The dominant species reported for the sapling vegetation in the 20-year-old post logged forest was *Dendrocnide salomonense* with the importance value index of 10.4%. In comparison, *Dysoxylum* species was the most dominant sapling species in the unlogged forest with an importance value index of 8% (*Table 4* and *Figure 9*).

Pometia pinnata was found to be the most dominant canopy tree species in the 3-year-old logged forest and the unlogged forest with the importance value index of 7.3% and 11.9%, respectively. In contrast, *Terminalia sepicana* was recorded as the dominant canopy tree species for the 20-year-old logged forest with an importance value index of 9.1%. The results revealed that though the density of *Terminalia sepicana* (28.1) was lower than *Pometia pinnata* (48.4*)* in the 20-year-old logged forest, *T. sepicana* had higher basal area hence reported as the most dominant species in the 20-year-old logged forest (*Table 5* and *Figure 10*).

Figure 9 and *Figure 10* below display the bar chart of the top ten species in each of the three forest types for both the understory saplings and canopy trees, respectively.

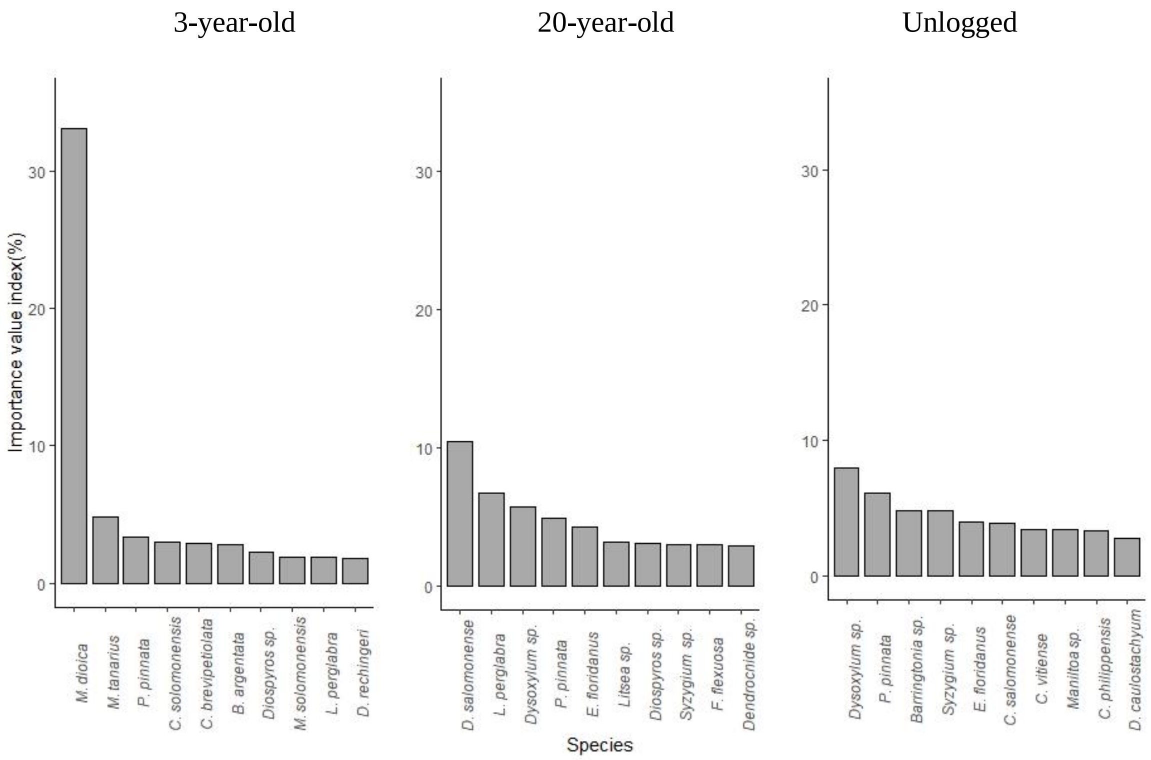

Figure 9. Importance value index of the top ten sapling species in all the three forest classes

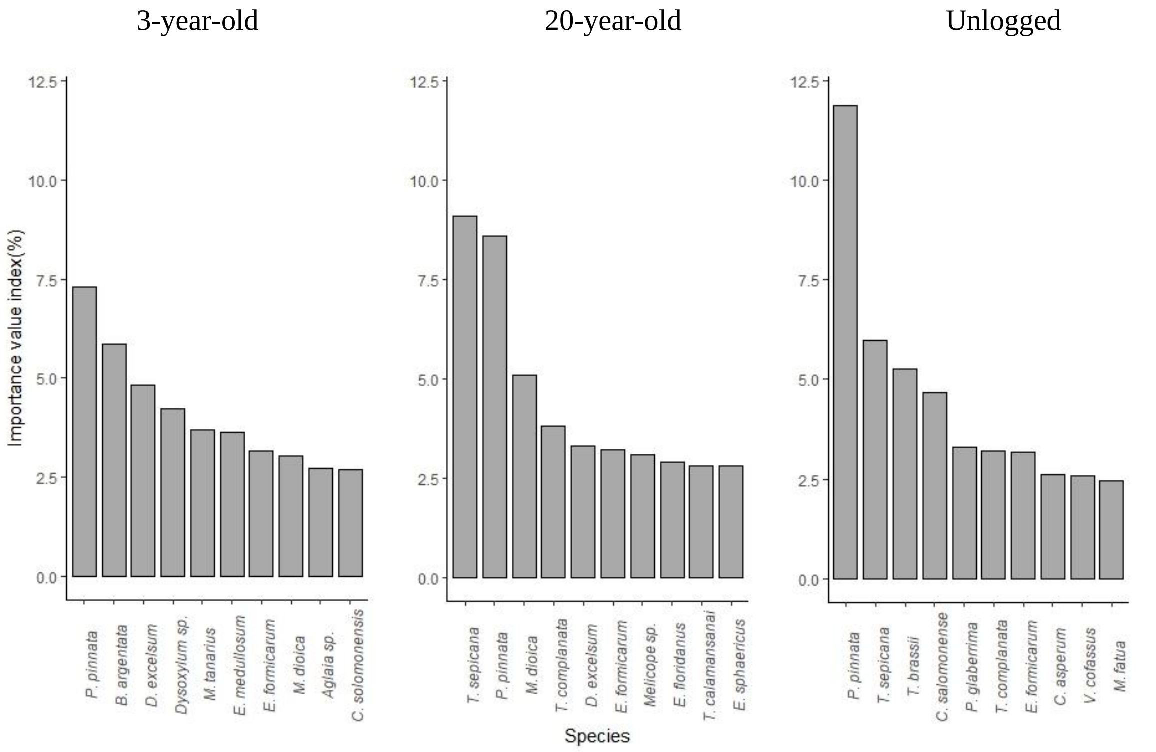

Figure 10. Importance value index of the top ten canopy tree species in the three forest classes

4.3 Species richness and diversity

The estimates of the Shannon Wiener index, species richness, and evenness varied for each forest type. This section presents the result of the species diversity at the three forest categories for saplings 2≤DBH<10 and the canopy trees DBH≥10cm. The summary of the Shannon index, Species richness and Pielou's evenness in the sampling areas are presented in *Table 6*.

Table 6. Summary of tree diversity of unlogged forest and logged forests for both the saplings and canopy trees. Shannon Wiener index, richness and evenness estimates are the sample mean± standard deviation

Forest class	Group	Shannon-Wiener index	Richness	Pielou's evenness
Logged 3 years	Saplings	2.25±0.711	26.4±4.35	0.682±0.196
	Canopy tress	1.82±0.520	7.47±3.52	0.975±0.027
Logged 20 years	Saplings	2.51±0.374	19.8±7.21	0.863±0.087
	Canopy tress	2.23±0.295	11.3±3.36	0.940±0.027
Unlogged	Saplings	2.74±0.276	18.8±5.98	0.949±.043
	Canopy tress	2.34±0.237	12.2±3.08	0.949±0.029

The bar graph of the means (±SE) below illustrates the significance level for the Shannon Wiener index, species richness, and Pielou's evenness for the saplings and canopy in the three forest classes.

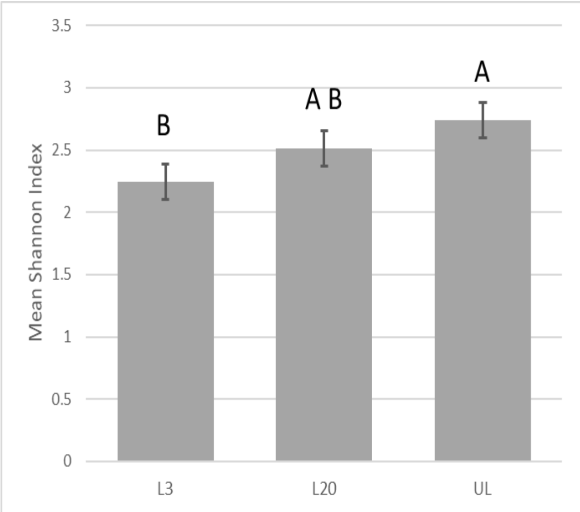

Figure 11. Mean (±SE) Shannon diversity of saplings (2≤DBH<10) across the 3 treatments. Tukey's post-hoc test indicated means are significantly different where letters are not shared.

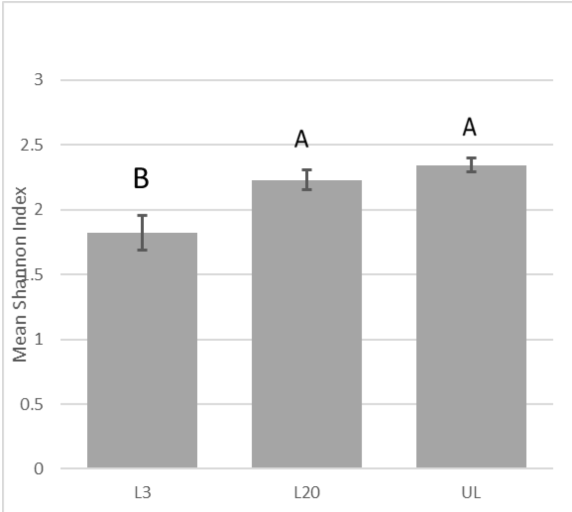

Figure 12. Mean (±SE) Shannon diversity of canopy trees DBH>10) across the 3 treatments. Tukey's post-hoc test indicated means are significantly different where letters are not shared.

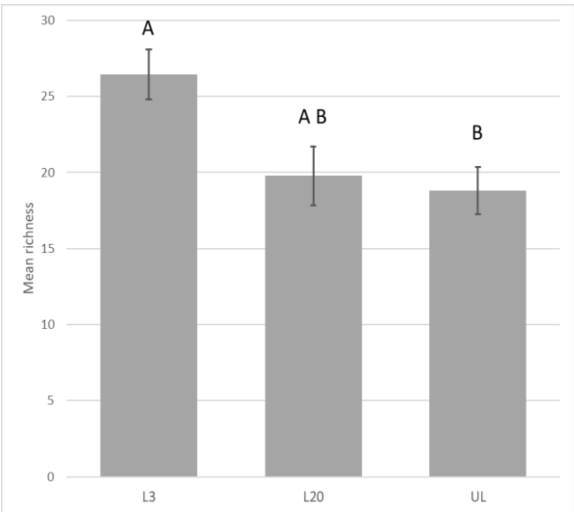

Figure 13. Mean (±SE) species richness of saplings (2≤DBH<10) across the 3 treatments. Tukey's post-hoc test indicated means are significantly different where letters are not shared.

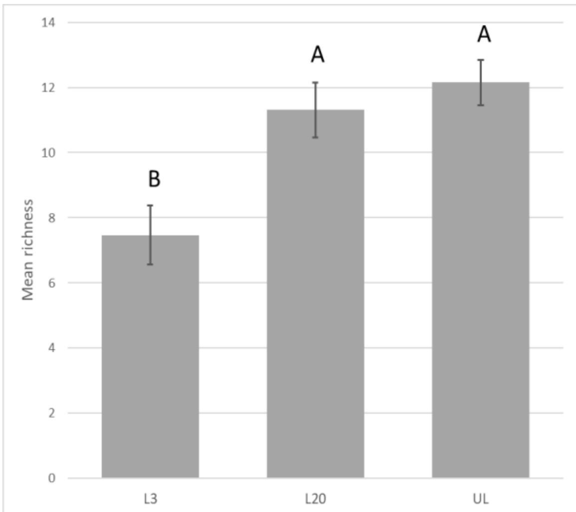

Figure 14. Mean (±SE) species richness of canopy trees across the 3 treatments. Tukey's post-hoc test indicated means are significantly different where letters are not shared.

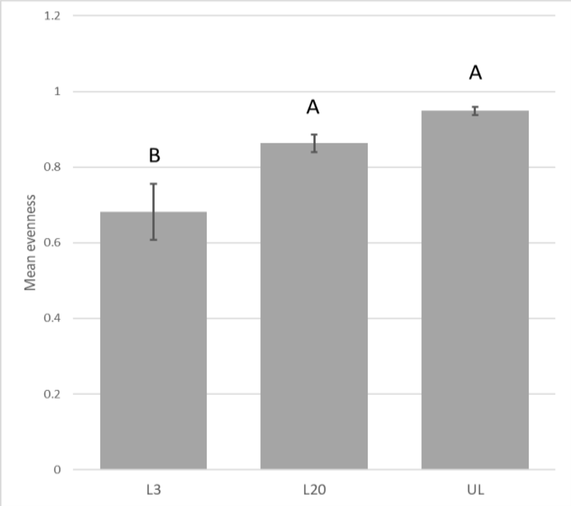

Figure 15. Mean (±SE) species evenness of saplings (2≤DBH<10) across the 3 treatments. Tukey's post-hoc test indicated means are significantly different where letters are not shared.

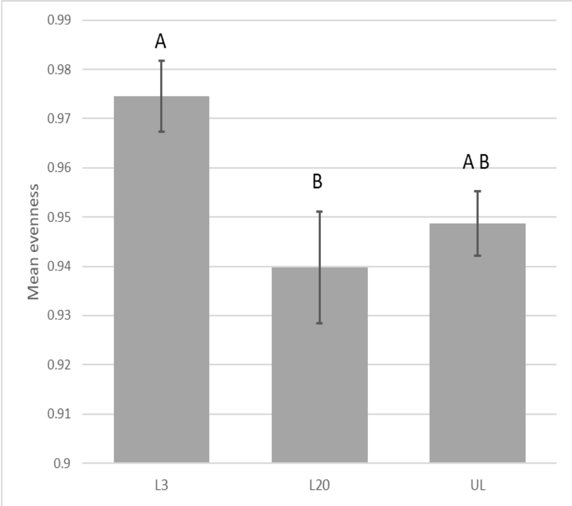

Figure 16. Mean (±SE) species evenness of canopy trees across the 3 treatments. Tukey's post-hoc test indicated means are significantly different where letters are not shared.

4.3.1 Shannon diversity

The Shannon index was found to be highest in the unlogged forest saplings with the Shannon index of 2.74 compared to the 20-year-old logged forest with the Shannon index of 2.51 and Shannon index of 2.25 at the 3-year-old logged forest (*Table 6*). The one-way analysis of variance in the means of the Shannon diversity index between the three sites revealed that the means were significantly different. Tukey's post-hoc test indicated that the Shannon diversity index in the 3-year-old logged forest was significantly lower than the 20-year-old logged forest and the unlogged forest (*Figure 11*).

In contrast, the Shannon index for the canopy trees (DBH ≥ 10cm) was found to be highest in the unlogged forest with the Shannon index of 2.34, in comparison to the 20-year-old logged forest with the Shannon index of 2.23 and the 3-year-old logged forest with the Shannon index of 1.82 (*Table 6*). One-way ANOVA test indicated that the means of the Shannon index at each site differs significantly. Post-hoc Tukey's test showed that the Shannon diversity in the 3-year-old logged forest was significantly lower than the site 20-year-old logged forest and the unlogged forest (*Figure 12*).

4.3.2 Species richness

The species richness for saplings per plot ranges from 10 species to 32 species per plot. All forest types recorded 32 species as the highest number recorded per plot. The lowest number of species per plot found at each site were 18, 11 and 10 species at the 3-year-old logged forest, the 20-year-old logged forest and the unlogged forest, respectively. The estimated mean of species richness for saplings was found to be highest in the 3-year-old forest with 26.4 species followed by the 20-year-old logged forest with 19.8 species, and lowest mean richness was observed in the unlogged forest with 18.8 species, respectively (*Table 6*). The one-way analysis of variance revealed that the mean of saplings richness differs significantly among the saplings of the three sites. Tukey's post hoc test revealed that only the mean of sapling richness in the 3-year-old logged forest, and the unlogged forest was significantly different (*Figure 13*).

The richness for canopy vegetation varied between the three sites. Species richness ranges from 2 to 13 species per plot in the 3-year-old logged forest compared to the 20-year-old logged forest with the species richness of 6 to 18 species and the unlogged forest with the richness of 9 to 22 species per plot. The mean richness was found to be highest in the unlogged forest (12.2 species), and lowest in the 3-year-old logged forest (7.47 species) as shown in Table 4. One-way ANOVA revealed that there was a significant difference in the mean richness among the sites. Tukey's post-hoc test indicated that means of species richness was significantly lower in the 3-year-old logged forest (*Figure 14*).

4.3.3 Evenness

The Pielou's evenness index of the sapling vegetation was reported to be highest in the unlogged forest with the evenness index of 0.949, followed by the 20-year-old logged forest with the evenness index of 0.863 and the lowest evenness was found in 3-year-old logged forest with the evenness index of 0.682 (*Table 6*). One-way ANOVA revealed that the means of evenness index between the forest categories differ significantly. Tukey's post-hoc test indicated that the evenness of sapling vegetation in the 3-year-old logged forest was significantly lower than the 20-year-old logged forest and the unlogged forest. (*Figure 15*).

In contrast, the estimated Pielou's evenness index for canopy trees was revealed to be highest in the 3-year-old logged forest, whereas the lowest evenness index was observed in the 20-year-old logged forest. The means of the evenness index were 0.97, 0.94 and 0.949 in the 3-year-old logged forest, 20-year-old logged forest and the unlogged forest, respectively (*Table 6*). There was a significant difference observed in the means of the evenness index between the logged forest and unlogged forest. The post-hoc test, however, revealed that the means of evenness index was significantly different only between the 20-year-old and the 3-year-old logged forest (*Figure 16*).

4.4 Structure

The structure of the forest stand was compared on the basis of the stem density, basal area and the diameter class distribution at each of the forest categories.

4.4.1 Stand density and basal area

Table 7. Summary statistics of stem density and basal area for saplings and canopy trees at each treatment site.

Forest class	Group	Mean number of stems per 400 m^2	No. of stems ha^{-1}	Mean basal area per 400 m^2	Basal area (m^2 ha^{-1})
Logged 3 years	Saplings	133±39.2	3325	0.249±0.083	6.25
	Canopy tress	10.06±5.18	251	0.412±0.336	10.3
Logged 20 years	Saplings	50.41±31.4	1258	0.085±0.044	2.14
	Canopy tress	17.6±7.47	439	1.19±0.478	29.8
Unlogged	Saplings	36.4±23.0	911	0.077±0.0258	1.9
	Canopy tress	19.05±5.13	476	2.27±1.26	56.78

The bar graph of the means (±SE) below illustrates the significance level for the density and basal area for the saplings and canopy in the three forest classes.

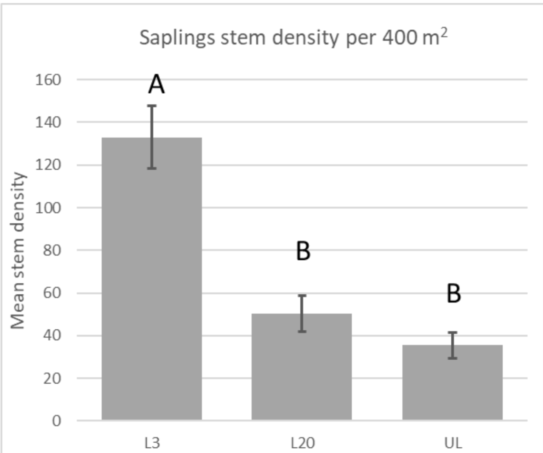

Figure 17. Mean (±SE) stem density of saplings (2≤DBH<10) per 400 m^2 across the 3 treatments. Tukey's post-hoc test indicated means are significantly different where letters are not shared.

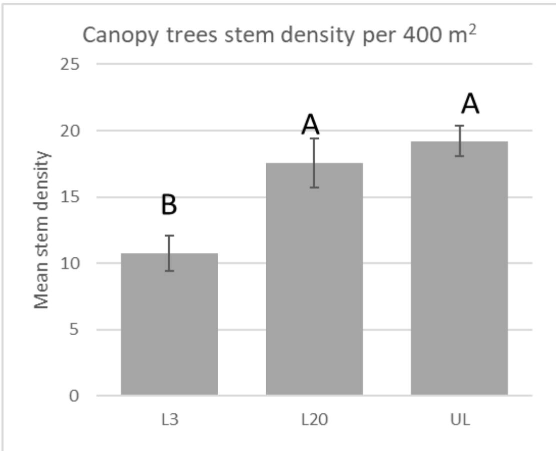

Figure 18. Mean (±SE) stem density of canopy trees (DBH>10) per 400 m^2 across the 3 treatments. Tukey's post-hoc test indicated means are significantly different where letters are not shared.

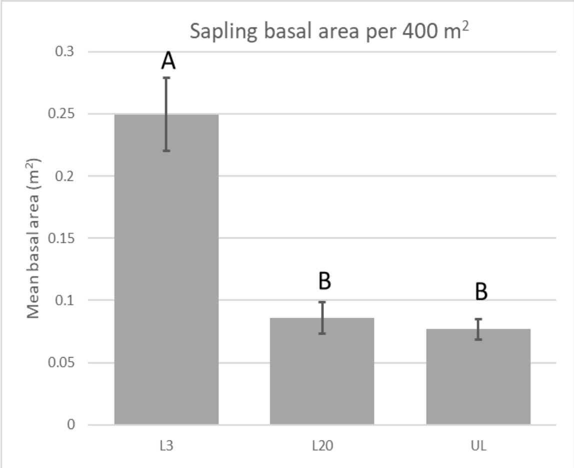

Figure 19. Mean (±SE) basal area of saplings (2≤DBH<10) per 400 m^2 across the 3 treatments. Tukey's post-hoc test indicated means are significantly different where letters are not shared.

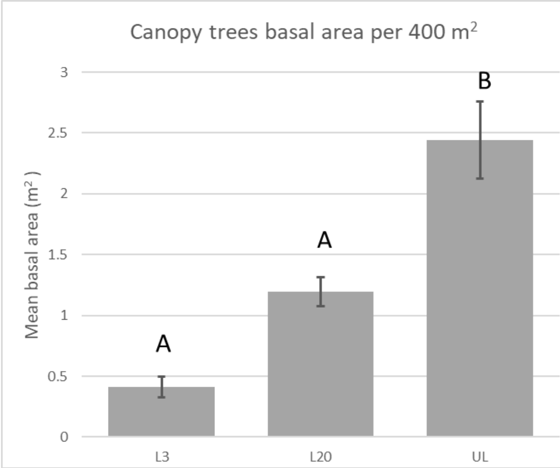

Figure 20. Mean (±SE) basal area of canopy trees (DBH>10) per 400 m^2 across the 3 treatments. Tukey's post-hoc test indicated means are significantly different where letters are not shared.

Stand density

The highest stem density for understory saplings was reported in the 3-year-old logged forest followed by the 20-year-old logged forest and then the unlogged forest. The recorded stem density for each site was 3325 stems/ha, 1258 stems/ha and 911 stems/ha at the site 3-year-old logged forest, the 20-year-old logged forest and the unlogged forest, respectively (*Table 7*). The results revealed that the 3-year-old logged forest recorded more than double the stem density in the 20-year-old logged forest and almost four times the density in the unlogged forest. These results showed that the regeneration of saplings in the two logged forests was higher compared to the unlogged forest with the recently 3-year-old logged forest recorded the highest regenerations. One-way analysis of variance showed that the means of stem density for the sapling vegetation at the three sites were significantly different. Tukey's post-hoc test revealed that the means of stem density for understory saplings was significantly higher in the 3-year-old logged forest compared to the 20-year-old and unlogged forest (*Figure 17*)

In contrast, the canopy vegetation with the highest stem density per hectare was observed in the mature unlogged forest (476 stems/ha), whereas the lowest stem density was observed in the 3-year-old logged forest (251 stems/ha). The 20-year-old logged forest recorded a density of 439 stems/ha. (*Table 7*). One-way ANOVA showed that the mean density of the canopy vegetation differs significantly between the three forest classes. Tukey's post-hoc test indicated that the mean density of canopy trees in the 3-year-old logged forest was significantly lower than the mean density in the 20-year-old logged and the unlogged forest. There were no significant differences observed between the 20-year-old logged and the unlogged forest (*Figure 18*)

Stand Basal Area

The basal area of the sapling vegetation varied considerably between the three forest categories. The 3-year-old logged forest was reported to comprise the highest basal area with 6.25 m^2/ha, and the lowest basal area was reported at the unlogged forest with 1.9 m^2/ha. The 20-year-old logged forest showed a moderate basal area with 2.14 m^2/ha (*Table 7*). Test for the differences in the basal area of the sapling vegetation, using the one-way analysis of variance revealed that there was a significant difference between the three forest categories. Tukey's post-hoc test, however, revealed that the means of basal area in the 3-year-old logged forest was significantly higher than the 20-year-old logged forest and the unlogged forest (*Figure 19*).

In comparison, the highest basal area for the canopy vegetation was observed in the unlogged forest (56.78 m^2/ha) followed by the 20-year-old logged forest (29.8 m^2/ha) and then the 3-year-old logged forest (10.3 m^2/ha) as shown in *Table 7*. One-way ANOVA in the means of basal area for the canopy vegetation was significantly different between the logged and unlogged forest. Tukey's post-hoc test showed that the mean of basal area in the 3-year-old logged forest was significantly lower than the means of basal area in the 20-year-logged forest and the mature unlogged forest (*Figure 20*).

4.4.2 Distribution of density-diameter at breast height (DBH Distribution) and basal area

Table 8 below presents the summary of the diameter distribution of density-diameter and basal area for the understory saplings in each of the diameter class for the three forest categories.

Table 8.Summary distribution of the stem density and basal area per hectare of understory sapling.

	L3		L20		UL	
DBH class (cm)	Stems ha^{-1}	Basal area (m^2 ha^{-1})	Stems ha^{-1}	Basal area (m^2 ha^{-1})	Stems ha^{-1}	Basal area (m^2 ha^{-1})
2-4	1639.3	1.22	870.8	0.49	600	0.36
4-6	917.9	1.66	293.8	0.50	295	0.52
6-8	567.9	2.03	145.8	0.52	127.5	0.47
8-10	200	1.32	91.7	0.55	95	0.57

The stem density and basal area for the sapling vegetation at each of the diameter class varied considerably at the three sites. Most saplings fell into the 2 – 4 cm diameter class whereas the lowest saplings stem density was observed in the diameter class range from 8 – 10 cm. The distribution of the saplings density in the diameter class reduced with the increased diameter in all the forest types. The highest basal area observed in the 3-year-old logged forest fell in the 6 – 8 cm DBH class whereas the lowest was observed in the 2-4 cm. The basal area in the 20-year-old logged forest, and the unlogged forest reported similar results where the highest and lowest basal area fell in the DBH 2 – 4 cm and 8 – 10 cm, respectively (*Table 8*).

The table below shows the summary distribution of the stem density and basal area per hectare within each diameter class for the canopy vegetation in the three forest classes.

Table 9. Distribution of the stem density and basal area per hectare of canopy size trees

	L3		L20		UL	
DBH class (cm)	Stems ha^{-1}	Basal area (m^2 ha^{-1})	Stems ha^{-1}	Basal area (m^2 ha^{-1})	Stems ha^{-1}	Basal area (m^2 ha^{-1})
10-20	176.7	2.47	225.0	3.35	218.75	3.80
20-30	28.3	1.33	89.1	4.41	93.75	4.63
30-40	25.0	2.37	62.5	5.70	60	5.78
40-50	18.3	2.99	32.8	5.15	31.25	4.97
50-60	1.7	0.33	10.9	2.57	16.25	4.05
60-70	0.0	0.00	4.7	1.60	16.25	5.33
70-80	1.7	0.82	7.8	3.25	17.5	7.45
80-90	0.0	0.00	4.7	2.55	10	5.35
90-100	0.0	0.00	0.0	0.00	2.5	1.68
>100	0.0	0.00	1.6	1.25	6.25	13.74
Total	251	10.3	439	29.8	472.5	56.79

The density and basal area for the canopy tree for each of the diameter classes in the three forest categories varied. The DBH of most canopy trees in all the forest categories fell into 10 – 20 cm diameter class while the highest observed basal area in the 3-year-old logged, 20-year-old logged and the unlogged forest fell into the diameter classes of 40 – 50 cm, 30 – 40 cm and DBH > 100 cm respectively (*Table 9*).

The unlogged forest basal area was found to be highest in all the diameter classes except in the 40-50 cm diameter class where the basal area was the highest in the 20-year-old logged forest. My result revealed that the highest diameter class trees found in the 3-year-old logged forest fell in the DBH class 70 – 80 cm. In contrast, the highest diameter class trees in the canopy of the 20-year-old logged forest, and the unlogged forest fell in the diameter class DBH > 100 cm.

The bar chart below *Figure 21* and *Figure 22* shows the percentage contribution of the stem density for the sapling and canopy vegetation in the three forest categories for each diameter class. The bar chart in *Figure 22* was on a logarithm scale.

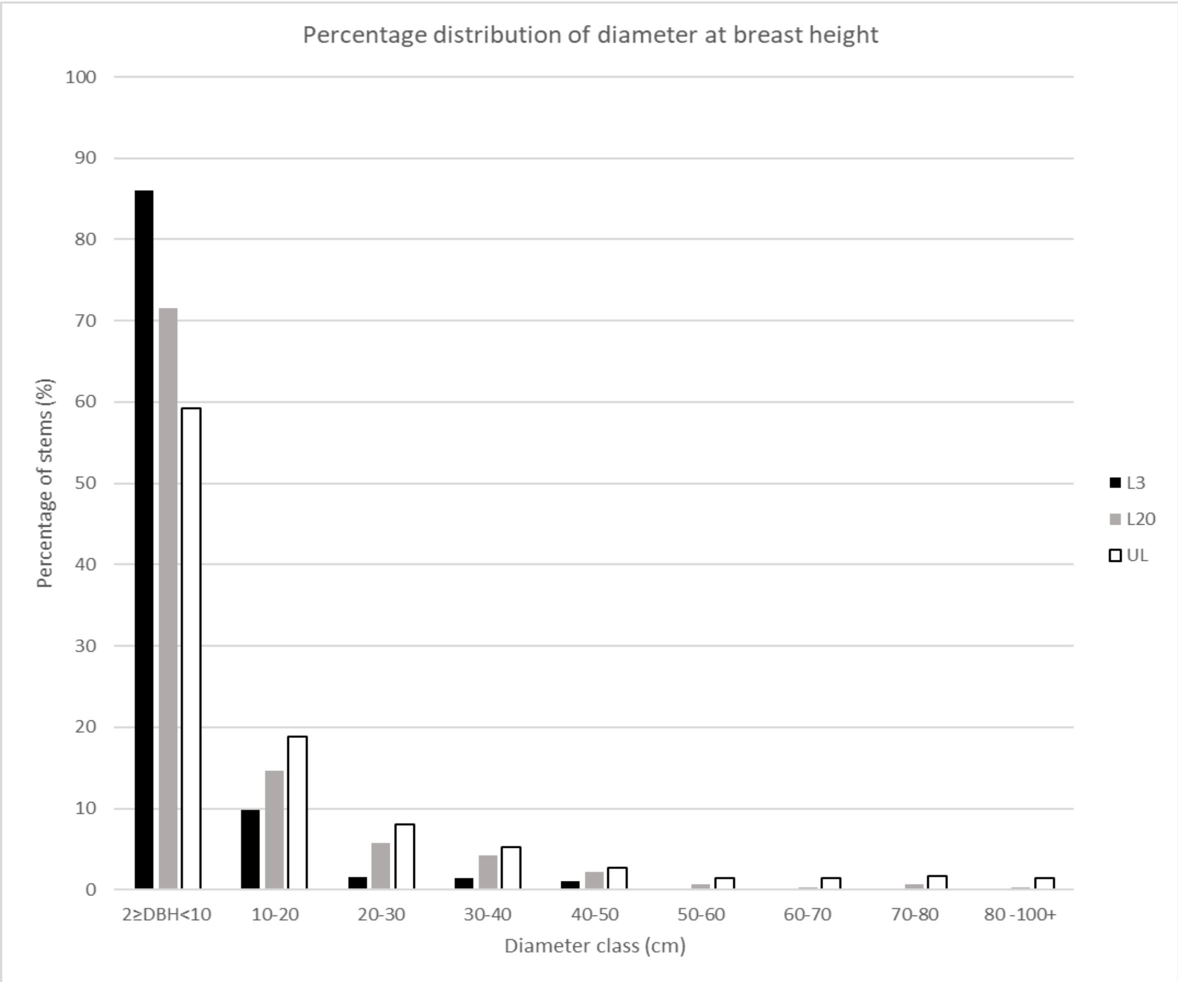

Figure 21. Percentage of stems in different diameter class (non-log scale)

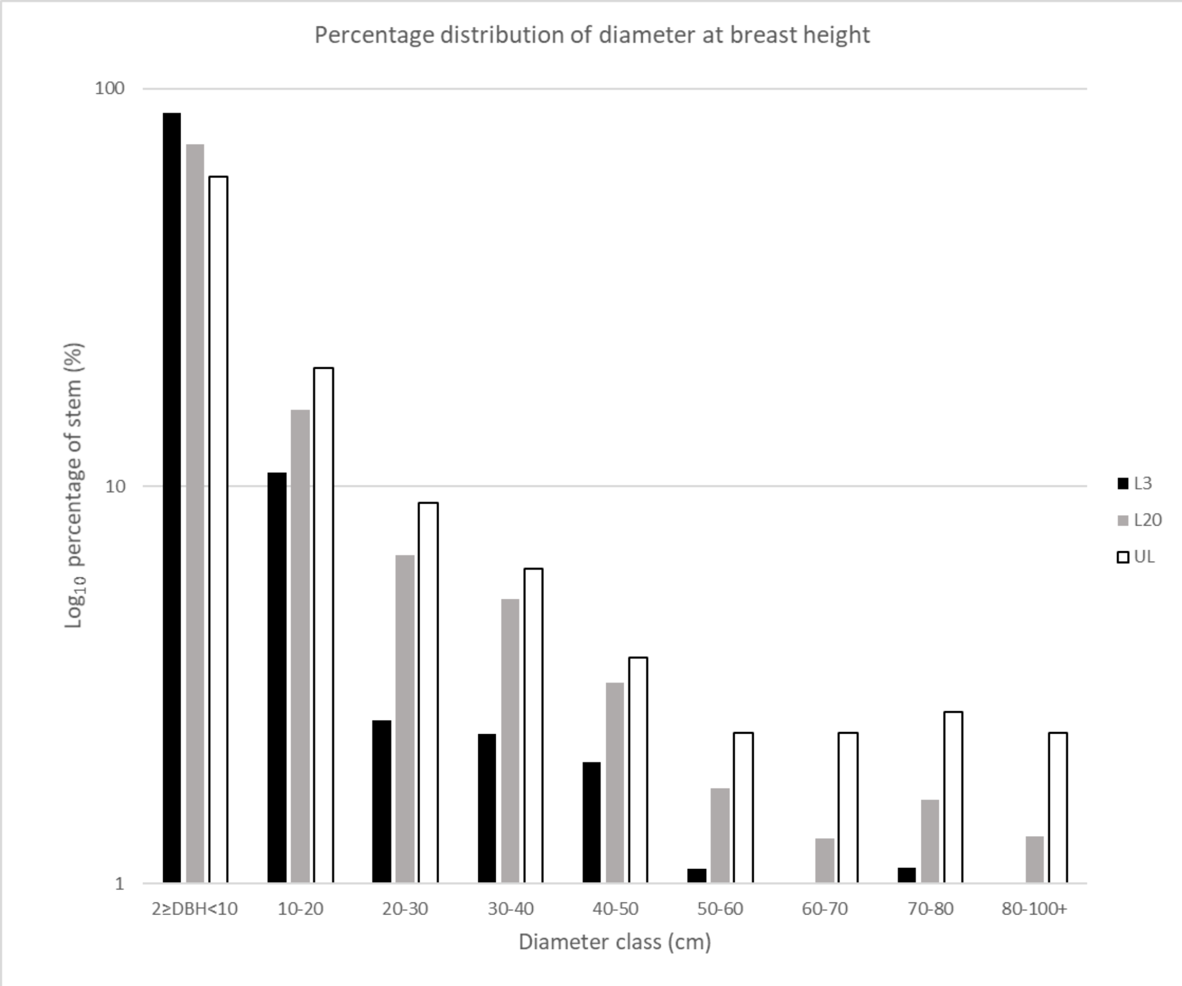

Figure 22. Logarithm scale percentage of stems in different diameter class

The results show that the stem density of the understory saplings in the 3-year-old logged forest accounted for 86% of the total stems compared to only 14% for the canopy trees. For the 20-year-old logged forest, the stem density of the saplings accounted for 71.5% while the canopy trees accounted for only 28.5% of the total stem density. Moreover, in the unlogged forest, saplings accounted for 58.9 %, whereas the canopy trees comprised 41.1% of the total density.

The trend indicated in *Figure 21* and *Figure 22* showed that stem density reduced as diameter size increased. The graph shows that the proportion of stem density in the unlogged forest was highest for the canopy vegetation at each of the diameter sizes compared to the two logged forest. However, the saplings proportion was observed to be highest in the 3-year-old logged forest compared to the 20-year-old logged and the mature unlogged forest

Furthermore, *Figure 21* and *Figure 22* shows that there were no trees found within the diameter class 60 – 70 cm and 80 – 100+ cm in the 3-year-old logged forest. The results also revealed that the stem density in the two logged forests from diameter class 50 – 60 cm and above recorded either no trees or less than 1% in the total density of each forest compared to the unlogged forest which was found to be much higher. This showed that the two logged forest comprised of fewer individuals for the larger diameter trees compared to the unlogged forest.

4.4.3 Trees per hectare of commercial timber species

Table 10 shows the commercial timber species density in the three forest categories in two size classes.

Table 10. Commercial timber species per hectare in the 3 forest classes

Forest class	Diameter Classes	
	30 - 59 cm	> 60 cm
3-year-old	33	2
20-year-old	75	13
Unlogged	76	49

Diameter class 30 – 59 cm includes trees that could form another commercial crop. Diameter class DBH > 60 cm are the commercial trees that are now mature. However, based on the results collected here, trees within the size class 30 – 59 cm have been harvested for timber by logging companies from the 3-year old forest even though they are yet to reach the mature size. Mature trees (DBH > 60 cm) are at low densities in the two logged forests. The results show that commercial tree species in the size class 30 - 59 cm are recovering for the 20-year-old logged forest. Despite the recovery of the next commercial crop size class, 30-59 cm in the 20-year-old logged forest, my findings show that the basal area for the canopy trees is significantly lower for both the logged forests (*Figure 20*).

4.5 Ordination

Figure 23 and *Figure 24* below revealed the graphical representation of the ordinations in the composition of sapling and canopy vegetation between the logged forests and the unlogged forest. The code L3, L20 and UL represents 3-year-old logged, 20-year-old logged and unlogged forest, respectively.

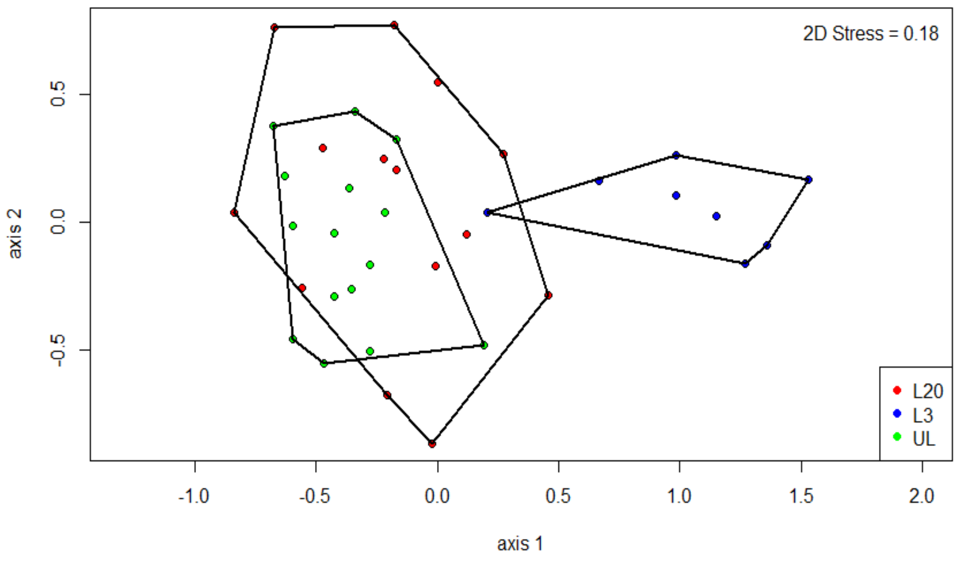

Figure 23. Non-metric multidimensional scaling of sapling species abundance composition of saplings

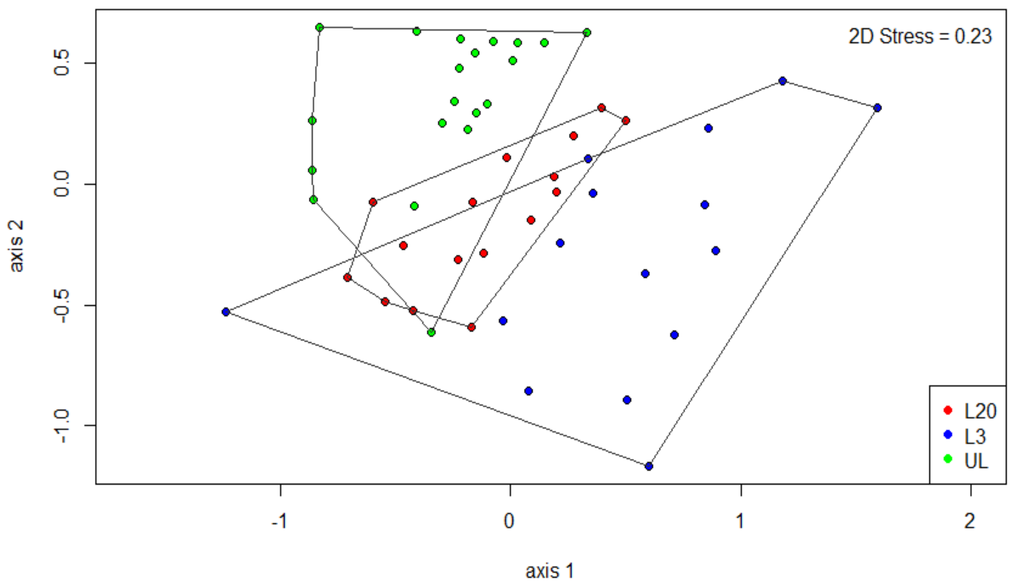

Figure 24. Non-metric multidimensional scaling of canopy tree species composition

The plotted NMDS ordination graph indicated that there are differences in the community composition for the sapling vegetation. The differences in the composition are characterised by the dispersion of plot locations between the sites. The further apart the points, the greater the differences in composition between sites. However, overlaps between the sites indicating some similarities among and within the sites. Figure 23 and Figure 24 shows that the 20-year-old logged forests and the unlogged forests are more similar to each other while the 3-year-old logged forest is very different.

Figure 24 presents the examination of the community composition of the canopy vegetation based on the basal area matrices. Results of the ordination revealed that sample sites between the unlogged and the 20-year-old logged forest are more similar to each other. The 3-year-old logged forest sample sites are scattered, which suggests that they are more diverse, and less similar to the unlogged and 20-year old sites. However, there is some overlap which indicates some similarity in the composition between groups.

Despite having similarity in the composition among the saplings and canopy vegetation, ANOSIM test revealed that sapling species composition differed significantly across the three forest classes ($R = 0.563$, $P < 0.001$). Similarly, results for the ANOSIM test for canopy tree species composition revealed that there was a significant difference among the three forests classes ($R = 0.363$, $P < 0.001$).

Notwithstanding the differences in plot location on different sides of Isabel Island, these results show a marked compositional difference between the 3-year-old logged forest and the 20-year-old or the unlogged forest. They also show that this effect is much stronger with the sapling vegetation than with the canopy vegetation.

CHAPTER 5: DISCUSSION

5.1: Introduction

The present analyses of the three forest classes in the lowland tropical rain forest of Isabel Island have shown varied patterns along the forest chronosequence. The effects of selective harvesting on tree diversity, composition and structure were assessed in the 3-year-old logged forest, the 20-year-old logged forest and the unlogged forest. The variations in the species composition, the diversity and the structure between the three forests categories are due to several factors. The nature (or magnitude) of the site disturbance influence the pattern of vegetation establishment and regrowth soon after logging (Baxter & Norton 1989). This was the case in the present study, where selective logging strongly affected a number of forest attributes including the composition, diversity and structure of the forest, with the effects are most evident in the recently logged forest.

The forest age, harvest history, proximity to the source population, the presence of residual trees and geographical location are factors supported in various studies that have been shown to influence species composition and diversity. For instance, Keppel et al. (2010), stated that proximity to source propagules, age, disturbance frequency and area affect community composition and diversity in comparable forests to those studied here from PNG to Fiji. Chazdon (2003) also found that proximity to the source population has a profound effect on the species composition and diversity in harvested tropical lowland forest. These factors play a vital role in the recovery process in the logged-over forests on Isabel Island. Studying post-logged forest composition and diversity can help understand the recovery dynamics of logged forests and can play a vital role in forest management planning and restoration processes (Katovai et al., 2015) which is a key driver to promoting diversity and other forest-associated taxa (Ampoorter et al., 2020).

5.2 Species Composition

Across the three forest treatments at the study site on Isabel Island, I found a total of 168 species. This finding is comparable to a study conducted in Kolombangara, Solomon Islands, where 173 species were identified (Katovai et al., 2016). The results from Kolombangara were, however, from much larger sample size and focused only on the canopy vegetation (DBH $\geq$ 10 cm). A survey on the tree species diversity in the tropical South Pacific Island by Keppel et al. (2010) highlighted that forest in the Solomon Islands is comparable to some of the highest species richness regions like the New Guinea (135 and 164 species per hectare). The study by

Keppel et al. (2010), found that the Island of Lauru, Tetepare and Kolombangara in the Western Solomon Islands comprises of 131, 85 and 82 species per hectare, respectively.

In this study, I found a total of 87 tree species (DBH≥10cm) in 0.8 hectares and 85 saplings (2≤DBH<10) in 0.6 hectares of mature unlogged forest in Isabel Island (*Table 3*). This result in the lowland forest in Isabel, therefore, reflects the considerable diversity in the lowland tropical forest in the Solomon Islands. Husch et al. (2002), stated that species composition and richness are significant indicators for measuring biodiversity and supports the high diversity of these forests.

5.3 Comparing sapling and canopy vegetation composition across forest class

This study found that selective logging greatly affects tree species composition across the chronosequence of the lowland tropical rain forest at the study sites. There is a considerable reduction of species composition in the canopy vegetation in the recently logged 3-year-old forest. Similarly, fewer tree species were observed in the canopy vegetation of the 20-year-old logged forest compared to the unlogged forest (*Table 3*). This is because selective logging focuses on the harvesting of the larger diameter stems in the canopy vegetation, (Bischoff et al., 2005) hence primarily affects the composition in the canopy vegetation. The species composition will be greatly altered in the canopy vegetation as harvesting are more focus on mature tree species. However, understorey vegetation is equally affected in instances where no proper harvesting plan is in place. Often the understorey trees and vines are cleared before felling, and the skidding of log usually damages small-diameter trees and seedlings. In the Solomon Islands, the leading cause of delay in the recovery of the logged forest is the creation of large canopy openings and soil compaction associated with harvesting (MoNR, 1995).

The understory saplings in the 3-year-old logged forest also show a decrease in species composition. Despite no felling operation in the understory vegetation, Johns (1988), pointed out that the extent of damage by logging is spread across all taxa and size classes and therefore affect the tree species composition in the understory. Furthermore, the dominance of only a few species in the sapling vegetation can exclude other species from establishing. However, the 20-year-old logged forest showed an increase in the number of species in the sapling vegetation compared to the unlogged forest. This suggests that over time (20 years), the understorey saplings of the 20-year-old logged forest continue to recover through the succession process hence the gradual increase in the number of species. The occurrence of more species in the understory vegetation of the 20-year-old logged forest is the result of the regeneration of pioneer and late succession species due to canopy openings by tree felling (*Table 3*). This result is comparable with the work of Deb et al. (2015), who showed that species diversity increases in the regenerative phase 20-years after logging due to the creation of canopy gaps that facilitate the colonization of both early and later succession species.

The difference between the 3-year-old logged forest, and the 20-year-old logged, or unlogged forest is stronger between the sapling vegetation than with the canopy vegetation (*Figure 23* and *Figure 24*). These results indicate that the canopy vegetation does show some similarity despite the 3-year-old forest having been logged recently because residual canopy trees are still present. But the regeneration patterns of saplings are highly varied in the young, logged stand compared to the older logged (20 years) or unlogged forest. The findings imply that the effects of logging 20 years ago are now (20 years later) having less impact on species composition and these forests may be heading towards a form similar to the original forest.

Despite there being a greater similarity in the composition between the 20-year-old logged and the unlogged forest (*Figure 23* and *Figure 24*), analysis of similarity (ANOSIM) reveals that community composition was significantly different between the logged forests and the unlogged forest for both the sapling vegetation ($R = 0.563$, $P < 0.001$) and the canopy vegetation ($R = 0.363$, $P < 0.001$).

Katovai et al. (2016), observed a similar pattern in Kolombangara Island, Solomon Islands. They reported that even though the composition begins to converge towards that of the unlogged forest, species composition is still significantly different 50 years after logging compared to unlogged forest. Similar studies conducted in Papua New Guinea (Ifo et al., 2016; Testolin et al., 2016) also found that tree species composition is significantly different between the logged and the unlogged forest for trees with DBH ≥ 10 cm. A related study also conducted in Papua New Guinea in lowland secondary forest 3 to >50 years since disturbance shows that species composition differed significantly between secondary and mature forests (Whitfeld et al., 2014). The lowest compositional similarity was between the recently logged forest and the unlogged forest.

Field observation in the 20-year-old logged forest study site indicate that it was low-intensity logging with little subsequent disturbance since the harvesting area was mostly flat and the diameter of the stumps harvested are greater than DBH > 60 cm, as opposed to the timber harvesting on Kolombangara Island where trees were harvested to about DBH ≥ 30 cm (Katovai et al., 2016). Although the species composition between the two logged forest and the unlogged forest are significantly different, they share some of the most common species present in the lowland forest of Isabel Island such as *Pometia pinnata*, *Endospermum formicarum*, *Diospyros*, *Canarium* and *Dysoxylum* (*Table 4 and Table 5*).

5.4 Diversity

My analysis confirmed that the Shannon-Wiener diversity and species richness increase with time in the canopy vegetation of the two logged forest in Isabel Island. At the study sites, the 20-year-old logged forest, and the unlogged forest barely differed in the Shannon-Wiener diversity, species richness and evenness index for both the sapling and canopy vegetation. Findings in Kolombangara Island (Solomon Islands), show similar results in terms of species richness; however, it was the opposite for the Shannon diversity (Katovai et al., 2016). These results suggest that the Shannon diversity in the canopy vegetation of the 20-year-old logged forest appears to have recovered to a pre-cut level in the forest on Isabel Island. The diversity in the logged forest (10, 30, 50 years) in Kolombangara does not recover to pre-cut level as opposed to the results in the older logged forest (20 years) in Isabel Island. The different outcome may be due to variation in logging intensity and the degree of the disturbances between the study sites. However, the study by Katovai et al. (2016) used plots of size 50 m x 20 m and cover forest area up to an elevation of 422 m which are important factors to consider in comparing the results between the two Islands.

Sapling species richness in the 3-year-old logged forest increased significantly while the Shannon index and evenness are substantially lower compared to the unlogged forests. I also found that the Shannon index and species richness decreases considerably in the canopy vegetation of the recently logged forest (*Table 6*, *Figure 12* and *Figure 14*) with great variation in the tree diversity at each sample plot of the 3-year-old logged forest. The high variation in the tree diversity in the 3-year-logged forest confirms the irregularity in harvesting due to species selection and diverse distribution of timber species in the tropical rain forest on Isabel Islands.

In comparison, the evenness of the canopy vegetation in the recently logged forest increases while the Shannon-Wiener diversity and richness decreases in the canopy vegetation of the 3-year-old forest. High evenness in the canopy trees in the unlogged forest is due to a few remaining stems with more equitable number of different species. Species richness and evenness may respond differently following disturbance (Yeboah et al., 2016). This is in contrast to findings by (Katovai et al., 2016), which indicated that evenness is lower in the 10-

year-old logged forest in the Solomon Islands. Even though there is high evenness in the canopy vegetation of the 3-year-old logged forest, species richness is considerably low which also reflects on the low Shannon wiener index.

It is interesting to note that despite having been logged recently, the mean species richness or the rate at which species occur per plot for the sapling vegetation in the recently logged 3-year-old forest is highest in all the forest categories. The high number of species occurrence per plot in the sapling vegetation of the 3-year-old logged forest is likely the result of rapid regeneration of light-demanding trees after harvesting (*Figure 13*). Fast-growing early successional species that colonized the gaps created after the harvesting operation may have influenced the high species richness in the sapling vegetation per plot as described by Brokaw and Scheiner (1989). I found that both the pioneer and non-pioneer species were present as understory saplings in the 3-year-old logged and 20-year-old logged forests in Isabel Island. Egler (1954), has stressed that pioneer and non-pioneer species are likely to occupy the forest recovering after timber harvesting simultaneously. Katovai et al. (2016), further highlighted that progressive mixing of long-lived pioneers and mid-successional species occupy higher disturbance area in the logged forest of Kolombangara Island in the Solomon Islands.

In my study, pioneer species such as *Macaranga dioica, Macaranga tanarius, Campnosperma brevipetiolata and Dendrocnide rechingeri* as well as climax species like *Pometia pinnata* were all colonizing the sapling vegetation of the 3-year-old logged forests. Katovai et al. (2016), found that *M.dioica and C.brevipetiolata* are two pioneer species that dominated post-logging forest in the Solomon Islands with the latter, a long-lived pioneer species which can dominate the forest even up to 50 years post logging. The regeneration of saplings of some climax species in the recently logged 3-year-old forest may have been from seeds that are already present on the forest floor prior to harvesting, seedlings that have survived the harvesting operation, or from re-spouting. This is supported by Brokaw and Scheiner (1989), who suggest that there is simultaneous colonization of pioneers and climax species which survived the disturbance of the felling operation.

5.5 Structure

5.5.1 Density and DBH distribution

Forest stand structure, as illustrated by the histograms for the frequency distribution of tree DBH is typical in forestry (Pond & Froese, 2015). The most apparent effect of selective timber harvesting is the increasing canopy openness (Uhl & Vieira 1989, Webb 1997) which impacts the different attributes of the forest structure. In my research, selective logging appears to have a long-term effect on the structure (Density and DBH distribution) of the logged forest, especially on the canopy vegetation (DBH ≥ 60 cm) where timber harvesting mainly focuses. Stem density reduces considerably in the canopy vegetation of the logged forest as diameter increases with the recently logged forest (3 years) showing significantly lower stem density. The canopy vegetation of the 3-year-old logged forest had hardly any stems in the diameter class DBH ≥ 60cm while older logged forest (20 years later) comprised few individuals but gradually decreases in the stem density in each of the diameter class between 60cm to >100cm (*Table 9*). It is evident in this study that the logged forests comprised less stem density of the mature trees than the mature unlogged forest.

The density distribution of the diameter size class in the canopy vegetation indicated that stem density of young logged forest in the DBH class 10 – 20 cm and older logged forest stem density in the diameter class from 10 cm – 60 cm is showing signs of recovery to that of the mature unlogged forest. However, larger trees became relatively more frequent in the unlogged forest compared to the two logged forest. A similar pattern was observed in New Guinea on the succession of secondary forest in relation to the mature forest (Whitfeld et al., 2014).

Additionally, sapling density is considerably higher in the understory of the two logged forest with the 3-year-old logged forest shows a significant increase in the stem density. The stem density of the sapling in the 20-year-old post logged forest decreases by 62.1% compared to the recently logged forest. For instance, sapling density in the 3-year-old logged forest is 3325 stems/ha while the 20-year-old logged forest comprised 1258 stems/ha (*Table 7*). Usually, within 3 to 6 years, tree densities within the gaps created by logging begin to decline as tree sizes increases (Schnitzer et al., 2000). The increase in the stem density of saplings in the two logged forest is primarily due to the rapid early response of undergrowth vegetation after disturbance to such time competition results in self-thinning (Baxter & Norton, 1989).

My results show that the understory saplings species in the 3-year-old logged forest and 20-year-old logged forest is dominated by light-demanding pioneer species of *Macaranga* and *Dendrocnide,* respectively. The increased of canopy openness as a result of timber harvesting can encourage the regeneration of light-demanding pioneer species (Holdsworth & Uhl, 1997). Often the climax (non-pioneer) species occur in successive forest cycles where gaps created is small. However, when the forest gaps that are created are large as a result of tree felling, pioneer and non-pioneer species co-exist, usually non-pioneer regenerate from sucker shoots or are they are growing from juveniles surviving the previous mature forest (Brokaw & Scheiner, 1989).

The findings presented here show that fast-growing pioneer species of *Macaranga* dominate the sapling vegetation, contributing over half (50.1%) of the total stem density in the understorey of the 3-year-old logged forest (*Table 4*). The prevalence of *Macaranga* species in the understory of the 3-year-old logged forest would take at least a couple of decades before it can be expected to transition into canopy vegetation. This is observed in the canopy vegetation of the 20-year-old logged forest where *Macaranga* species is still one of the top ten dominant species (*Figure 10*). This pattern is similar to the results of research conducted in Kolombangara, Solomon Islands by Katovai et al. (2016), in PNG by Testolin et al. (2016) and in Borneo by Imai et al. (2019).

Similarly, in the understorey of the 20-year-old logged forest pioneer species *Dendrocnide* comprises 18.5% of the total stems (*Table 4*). Pioneer species dominating the understorey could slow down the succession process by suppressing the regeneration of later succession species as highlighted by Katovai et al. (2016) and Chua et al. (2013). Despite the light-demanding pioneer species dominating the understory saplings of the two logged forests, climax species *Pometia pinnata* were present in both the 3-year-old logged forest and the 20-year-old logged forest, suggesting that eventually, they will establish the new canopy.

5.5.2 Basal Area

The recovery of the basal area in the canopy vegetation of the logged forests to a pre-logged state would take several decades or more. The basal area of the canopy vegetation in the 3-year-old logged forest and 20-year-old logged forest are significantly lower than the unlogged forest (*Figure 20*). The timber cutting size (DBH ≥ 60 cm) for the two logged forest would take time to recover. This is because only a few large diameter timber tree species remain in the canopy vegetation of the logged forests after the felling operation. This finding can be comparable to studies conducted in the tropical forest in Papua New Guinea (Testolin et al., 2016; Yosi et al., 2011). A study in Indonesia comparing a 55-year-old secondary forest and primary forest show that the basal area (BA) of the old secondary forest approached that of the primary forest (Brearley et al., 2004). In the tropical forest in Myanmar, a study on tree species composition under different disturbances levels showed that density and basal area decreased with recently disturbed forest in the canopy vegetation (DBH ≥ 10 cm) (Htun et al., 2011) which is comparable to this study. Recovery, however, will occur first in terms of the floristic composition before the changes to the structural attributes of the forest (Baxter & Norton, 1989).

Basal area for sapling vegetation in the 3-year logged forest is, however, significantly higher than in the 20-year-old logged forest and the unlogged forest (*Figure 19*). The pattern of sapling basal area is opposite to that of the basal area of the canopy trees (*Figure 19* and *Figure 20*). In each diameter class for the saplings, the basal area of the recently logged forest (3-years) is twice that of the older logged forest and the unlogged forests (*Table 8*). This can be directly related to the high stem abundance of mainly fast-growing pioneer species that occupy the understory saplings in respond to the disturbance and canopy openings as described earlier. Self-thinning will eventually take place as competition increases, and the gradual succession process takes place with the replacement of mid-succession and later succession species (Baxter & Norton, 1989; Katovai et al., 2016).

5.6 Summary discussion of species composition, diversity and stand structure

I observed in the sapling phase that there is a gradual shift in the light-demanding species to shade-tolerant species at each successive stage. Based on the Intermediate Disturbance Hypothesis (IDH), a newly disturbed or logged forest would comprise mainly early successional species (Yeboah et al., 2016). Even though the older logged forest showed recovery in the sapling and canopy vegetation, the community composition still differed from the unlogged forest. The findings in the logged forest show that the young forest stand (3 years) consist of early succession species, the older stand forest (20 years) consist of both early and late-succession and the mature unlogged species comprise mainly of the late-succession species. Pioneer *Macaranga* species persist in the canopy of older logged forest (20-years) which indicate that the older logged forest is still in intermediate succession stage.

Diversity and richness of the recently logged forest differ significantly to that of the unlogged forest. Even though richness was higher in the sapling of the young forest stand compared to the unlogged forest, pioneer species dominate the understorey, which is the result of immediate vegetation response after disturbance. The Shannon diversity and species richness in the older logged forest appear to have already recovered to the pre-logged state. Recovery of tree species diversity and the species richness at the 20-year-old logged forest site could be due to the low-intensity logging and disturbances; therefore, the stand tends to recover faster than an intensely logged forest. These outcomes show that over time, tree diversity and species richness can recover to pre-cut level with low-intensity logging and minimal disturbance in the understorey sapling vegetation. However, in this study, it is not clear whether the tree diversity and species richness in the 3-year-old logged forest will recover 20 years later since the timber harvesting in the 3-year-old logged forest appear to be more intense than the 20-year-old logged forest.

The study showed that even though the older logged forest appears to have regained stem density comparable to that of the unlogged forest, the relative density for the harvestable size for timber (diameter class ≥ 60 cm) is still very low in the two logged forest as shown in *Table 10*. It may take a relatively extended period for the two logged forest to recover to the harvestable tree size in the diameter class (DBH ≥ 60 cm). The findings showed that in the two logged forest types, canopy tree basal area is significantly lower than in the mature unlogged forest. This show that the volume of the canopy tree is yet to reach the timber volume that is available in the mature unlogged forest. The capacity of the forest stand to respond to disturbance can be influenced through active management by manipulating the forest structure, which in turn affects the stand dynamics (Oliver et al., 1996).

In order to have any immediate significant impact on the recovery of the two logged forest, an appropriate silvicultural management regime needs to be in place to which any human-induced disturbance should be eliminated in the logged forest. Therefore, understanding how human disturbances such as selective timber harvesting influences patterns of community composition and the underlining interactive processes that structure communities is vital to alleviate threats to biodiversity (Gray et al., 2018; Martínez-Ramos et al., 2016).

5.7 Limitations of this study

This section highlights the limitation of the research, which can be considered for improvement when conducting a similar study in the logged forest in Isabel Island. The limitations include the absence of older logged forests, location of the 3-year-old site and the sample size.

5.7.1 Absence of older logged site

Absence of older logged forest is one of the limitations to this study. Attempt to identify the older logged sites (>20 years) for the study was not possible as the older logged forest within my study area on Isabel island had been re-entered by logging companies undertaking repeated timber harvesting. With older secondary forest (50 years or even more), research can evaluate the succession time frame and better understanding the recovery pattern for the young forest, mid-age forest and old age logged forest.

5.7.2 Location of 3-year-old logged site

The 3-year logged forest in this study was located on the other side of the Island *Figure 2*. Even though all plots slope was kept constant (below 10%) and situated within the same lowland forest category (0- 200 m) as defined in the Solomon Islands forest reference level, the island side effect may have some influence on the forest condition and composition in the 3-year-old logged forest due to the location. It had been planned to establish unlogged forest plots adjacent to the 3-year old harvest sites, but this was not possible because of travel restrictions associated with the Covid-19 pandemic.

5.7.3 Sample size

Another limitation of the study was the sampling size. The final trip to conduct sampling of the additional plots was postponed due to border restrictions associated with the Covid-19 pandemic. The additional sample plots may have helped better illustrate the patterns discussed here.

CHAPTER 6: WHAT ARE THE VALUES ASSOCIATED WITH THESE LOGGED FORESTS AND IMPLICATIONS TO THE RESOURCE OWNERS?

The values that forest provide are vast and immeasurable. The landowners are the direct beneficiaries from the forest in terms of financial returns from the timber harvesting. However, other benefits in the form of ecosystem goods and services not only provide immense benefits to the resource owners but to other communities who rely on the forest and also other living organisms. Timber harvesting by logging may have provided revenue to the landowning group, yet there are downsides of timber extraction to the environment and the native people who own the land. This section discusses some of the values/benefits of the forest, including extractive timber harvesting and its implications of timber harvesting to the values and benefits.

6.1 Soil and water conservation

One of the primary importance of the forest is the conservation of soil and water resources. Forest productivity is a crucial aspect of the economic and environmental sustainability of the forest ecosystem (López-Vicente & Wu, 2019). Trees and other plants species in the forests play a significant role in the preservation of soils and watershed resources in Isabel Island. The communities who own the forest at the study site rely primarily on the forest for their water source. There was no storage dam or water supply infrastructure in the communities at the study site, and the people rely very much on streams and springs for water. However, during an extended dry period, the supply of water is low, and it is challenging for the communities if there is no rain for a long time (Fakale, 2019).

The conservation of soil productivity and hydrological stability of the forest maintains the yield of the forest for timber and other human necessities which is one of the goals of sustainable forest management of natural forest in the tropics (Montagnini & Jordan, 2005). Timber harvesting has a considerable impact both within the forest and the downstream coastal marine systems, which include the mangrove forest along the coastal shoreline at the study sites. Waste and sediments are washed into streams and the ocean from logging operations and harvesting debris and muddy coastal seawater dominate the shoreline in the vicinity of the logging sites and log landings. However, in this study, there was no data collected to quantify the extent to which timber harvesting influence the condition of streams flowing through and from forests, the impacts of soil erosion on the streams and the in-shore marines system, or impacts on the mangrove forest ecosystem. This study has able to verify that the communities and the resource owners rely heavily on the mangrove forest to obtain food (crabs, mangrove shells and fruit), poles for houses and medicinal necessities; thus any effects on the mangrove forest may have a considerable impact on the livelihood of the communities.

The forest vegetation cover has an umbrella effect that slows down the kinetic energy of rain droplets which helps prevent soil erosion and surface runoff (Zuazo & Pleguezuelo, 2009). The forest vegetation and the root system protects water catchment and supports in sustaining hydrological cycles, regulating and stabilising water runoff and acts as a cushion against natural calamities like flood and drought (Nepstad et al., 1994). Reports have revealed that the Solomon Islands experienced one of the worst dry periods during an El Nino in 1997 (Times, 2009). The forest facilitates the percolation of water into the ground, thus helping in the maintenance of the groundwater table. Selective logging is a significant cause of deforestation in Isabel Island, which is one of the primary causes of the lowering of the groundwater table. The risk of drought is high in logged over sites due to vegetation removal, and if natural phenomena like El Nino do occur, it may affect forest productivity, wildlife and the peoples' livelihood.

6.2 Carbon sequestration

Forest ecosystems in the Solomon Islands play several vital roles, including carbon sequestration. According to Poorter et al. (2015), the tropical forest stored about 25% of the total world carbon. Forest comprising diverse tree and plant species are significant sinks of greenhouse gasses such as carbon dioxide. The regulation of carbon cycles at global and regional scales is an essential function of the tropical forest because of its rich biodiversity (Sullivan et al., 2017). Deforestation and forest degradation due to selective logging and other anthropogenic activities are characterized as a substantial source of greenhouse gas emissions and therefore contribute to global warming (O'Connor, 2008). Hence, there is increasing importance in the valuation of intangible benefits such as carbon both at national and international level (Lette & De Boo, 2002) to provide an incentive for forest conservation as climate amelioration.

The composition of diverse tree species in the tropical forest of Isabel Island provides an important reservoir of carbon storage. Diversity has a positive effect on the above-ground biomass, which increases carbon storage in the tropical forest (Poorter et al., 2015). Findings by Huang et al. (2018) suggest that tree diversity is directly related to forest productivity and carbon build-up. My study found that timber harvesting reduces the diversity and structural attributes in the two logged forest. This implies that the logged forest accumulates less carbon compared to the mature forest because logged forests are less diverse and are structurally not intact. Recovery of the logged forest with various species could promote biodiversity restoration and climate change mitigation (Huang et al., 2018). Thus, biologically diverse forest ecosystem plays a vital role in the sequestration of carbon in the forest and helps in the mitigation of climate change as a result of global warming. In the Solomon Islands, the UN REDD+ initiative has gain popularity as an incentive for resource owners to gain monetary benefits by preserving the natural forest to protect carbon stock guard emission from the forest through forest deforestation and degradation. Recently a pilot study was conducted in Choiseul Island in the Solomon Islands as part of the REDD+ initiative to estimate the standing carbon stock (Henderson, 2015).

6.3 Direct economic value

Timber is currently the most sought-after product by logging companies from the forested land in Isabel Island and other parts of the Solomon Islands. There are direct economic returns that the communities and resource owners have gained from their forests through the timber harvesting. Income earned from logging by landowners is mainly from royalty payments, levy payments and employment opportunities from the logging companies. Indigenous landowners gain a smaller financial return from the logs than the government. Regardless of the smaller returns they receive, the fast money gain from logging is attractive and considered as a lucrative business by the landowners to earn income (Kabutaulaka, 2000).

However, reports are claiming that the levy paid to the Government for reforestation purposes on the logged out areas have not been fully utilised by the National Government (Times, 2008). This study found that the two logged forests that were evaluated showed a decline in the timber species. The decrease in timber stocking shows that the commercial value falls considerably after timber harvesting. I found that even 20 years after the harvesting operation, the basal area of the canopy vegetation, especially trees with DBH $\geq$ 60 cm is still significantly lower compared to the unlogged forest. This indicated that timber volume from the post-logged forest would need more than 20-years to recover after the logging operation from the study sites in Isabel Island. Olsen and Turnbull (1993), found that even 30 years after selective timber harvesting, the logged forest in the Solomon Islands have not recovered to commercial crop.

The results in this study show that the major timber species have already regenerated in the two logged over forests. The regeneration of the leading timber species from the logged-over forest will increase in the market value of the forest in the future. How long the logged forest will yield another commercial crop comparable to that of the pre-logged condition is, however, unclear but will not be anytime soon. The main commercial timber species that have regenerated in the logged forests includes *Pometia pinnata, Calophyllum, Terminalia, Planchonella, Palaquium, Celtis, Canarium, Campnosperma, Parinari, Burckella, Dysoxyllum, and Maranthes.* However, analysis of tree species composition has revealed that the species composition of the post-logged forests has not recovered to the pre-cut level 20 years after the harvesting. This is because regeneration of these timber species, in the two logged forest, are mostly in low abundances compared to the unlogged forest. The pioneer species occur in high density and dominate the understorey of the understorey sapling phase of the two logged forest.

6.4 Biodiversity values

The Solomon Islands are considered among the most biologically diverse archipelagos on earth (Lavery et al., 2016). The tropical forest vegetation in Isabel Island comprises rich species diversity which plays an essential function in the protection of habitats for both plants and animals, soil formation and conservation, nutrient cycling, hydrological cycle, carbon storage and maintaining ecological balance. This study recorded a total of 95, 110 and 116 tree species at the 3-year-old logged forest, the 20-year-old logged forest and the unlogged forest, respectively. These numbers reflect the diversity in the recently logged forest, the old logged forest and the mature forest at the study area in Isabel Island. High diversity forest also means it is harbouring more biodiversity. The more diverse the forest is, the more resilient the forest. That means the ecosystem is more robust and can better adapt to sudden or dramatic changes in the environment (Folke et al., 2004).

The Solomon Island tropical forest includes many ecologically valuable species that are either threatened or at risk of extinction. Based on the threatened species identified by the International Union for Conservation of Nature (IUCN) red list, 17 plant species are determined to be threatened in the Solomon Islands (SPREP, 2020). Of these 17 species, three species, *Pterocarpus indicus, Instia bijuga* and *Gonystylus macrophyllus,* were present in my study sites. In my research, the density of *Pterocarpus indicus, Instia bijuga* and *Gonystylus macrophyllus* at the study sites are 7, 3 and 5 stems respectively in all the forest categories. The risk of these species declining in density or become locally extinct due to logging is high since they occur in very low abundance. *Pterocarpus indicus* and *Instia bijuga* are two high-value timber species which are restricted to be exported as round logs. Locals often target these two species for sawn timber production either for building house or selling at the domestic market. Harvesting of such species should be restricted and protected from further harvesting. By eliminating the human-induced disturbances, the logged forest can be protected from further alteration, thus promoting the regeneration of rare and valuable species which can gradually recover most of its biodiversity. And as the plant diversity recovers, so also will animal diversity which I was not able to assess.

6.5 Presence of other values to the local community

Countless benefits are provided for by the forest to the customary landowning group in Isabel Island. The resource owners and the communities at the study site had benefited from the forest for food, fibre, fuelwood, water, building material, traditional herbal medicine, hunting ground, and numerous other goods and ecosystem services provided for by the forest over the centuries. The dependence on forest resources and subsistence agriculture to sustain livelihood is still very much the norm for more than 80% of the people in the Solomon Islands who live mainly in rural areas. The current customary land tenure system offers welfare security for most Solomon Islanders, including the forest resource owners in Isabel Island. The customary land tenure system also supports the people's robust rural-based subsistence agriculture in Isabel (Pauku, 2009). However, this often has repercussion to the forest ecosystem since the practice of farming the land requires removing the forest vegetation and its accompanying biodiversity (Foale et al., 2016).

Furthermore, the forest has played an essential role in sustaining the community livelihood and the environment that surround the communities. Communities with their forest resources provide an avenue and opportunity for forestry research and education that could contribute to biodiversity conservation. The alteration of the forest by extractive timber harvesting has destroyed not only the trees but have threatened the function of the ecosystem, including destruction to taboo sites. Culturally, the indigenous people of Isabel Islands and other parts of the Solomon Islands has had a special connection to the forest with traditional beliefs and spiritual connections (Burt, 1994). Various trees, vines or shrubs are used for custom ceremonies, traditional costumes and are also used as remedy and treatment of sicknesses as well as illness believed to have been caused by evil spirits. Artefacts such as jewellery and weapon are often put as a landmark to signify the ownership of the land by certain tribal groups. Such values are profound and of great importance to the traditional norms and beliefs to the indigenous people of the Island. Needless to say, the existence of such important values is under threat with the ongoing exploitation of the forest by logging companies in Isabel Islands.

CHAPTER 7: RECOMMENDATIONS

This chapter will focus on the practical ways that the local community and landowners can adopt to better manage their forest in a more resilient and sustainable approach. The following are the recommendation for the resource owners, land-use planning, small-scale sawmilling and enrichment planting.

7.1 Land-Use planning.

In a highly polarized context of the Solomon Islands where land is mostly customary owned and where land allocation can be a source of conflict, it is vital to have proper land-use planning. The community should prepare a simple land-use plan as part of managing their forest for current and future use where they can identify zones for existing and proposed land uses. In forestry, this will involve assessment of the forested land and its potential for various land uses. This requires planning and demarcation of boundaries for timber harvesting and areas to be preserved for aesthetic values, wildlife habitat, and biodiversity values. It should also include guidance on subsequent harvesting with consideration being given to allowing enough time for the forest to recover after initial logging. Land-use planning should address environmental, social and economic needs of the local population. The land-use plan should demarcate the land by identifying and allocating, sustainable forest management area, future gardening sites, propose new and village expansion and coconut plantation. This can be done through a participatory approach where landowners could identify and discuss boundaries for land ownership and land use.

7.2 Small-Scale milling

Small-scale sawmilling can ensure landowners benefit more from their forest in a manageable and sustainable way. Landowners should engage in small scale milling instead of allowing logging companies to do extensive and damaging timber harvesting. With proper land-use planning, landowners can ensure no conflict arises among themselves for any business activity like the small-scale sawmilling. Small-scale sawmilling can improve income for resource owners with substantially reduced impacts on tree species composition and diversity by working within the frameworks of the land use plan for the forest that the local community was involved in developing.

7.3 Enrichment planting

Enrichment planting for forest restoration is an effective method that undoubtedly enhances and supplement the natural regeneration of degraded sites that lacks diverse species. Although the process is long term and will take some time before forest structure and composition to recover fully, the objective to achieve ecological, social and cultural benefits is particularly beneficial (Forbes et al., 2020). Such intervention is of importance and desirable if communities whose forest has been degraded as a result of timber harvesting and other anthropogenic disturbances. As described by Forbes et al. (2020), restoration such as enrichment can establish the mature-phase tree species, which is vital to ensuring, diverse, resilient and long-lived forest communities.

Landowners should be empowered and mobilised to carry out enrichment planting on the logged-over forest through the forestry extension programs of the Solomon Islands Ministry of Forestry. Species selection is a crucial part of the enrichment planting. The choice of species should follow criteria that include commercially valuable native species and those that are important for biodiversity. The importance of enrichment planting is to facilitate and accelerate forest succession processes. Timber harvesting and construction of logging roads by logging companies have resulted in forest degradation and deforestation. As a result, an extensive area of forests is reduced to smaller patches and fragments of forest which divide the population of plant and animals in the forest ecosystem. Enrichment planting can connect the forest fragments, which promotes connectivity for wildlife and therefore increases the biodiversity and the commercial value of the forest.

CHAPTER 8: CONCLUSION

This study has determined the species composition, tree species diversity and the stand structure of the forest in Isabel Island at the different successive stage, the newly logged forest (3 years later), the older logged forest (20 years later) and the unlogged mature forest. The study shows that timber harvesting affects the species composition, the diversity and the structure of the forest. However, with time the species composition, diversity and structure start to converge towards of the pre-logged state after extractive timber harvesting, which was similar to the findings of other studies conducted in the Solomon Islands and other tropical regions like Papua New Guinea and South-east Asia.

This study revealed that after 20-years of selective harvesting tree diversity and richness for the saplings and canopy trees have recovered to that of the unlogged forest. While the species diversity and richness have recovered to that of the unlogged forest, the species composition and stand basal area have not recovered 20-years after timber harvesting. The analysis of the species composition using ordination techniques showed that the tree community composition in both the sapling and canopy trees are significantly different across the three treatments. However, there was overlap in sapling composition and some overlap for the canopy vegetation between the 20-year-old logged forest and the unlogged forest. These overlaps suggest that 20-years later after selective logging, the logged forest is converging towards that of the unlogged state. However, the recovery trajectory might take more than 50 years.

The slow recovery of the species composition and the basal area highlights the adverse impact of selective logging on the timber species and timber stocking in the lowland forest in Isabel Island. The recovery of species diversity does not mean that species community has recovered to that of the pre-logged state. Instead, it only shows the number of species present (richness) and equity of the species in the logged-over forest. This was also shown in the study where mature trees in the diameter class (DBH $\geq$ 60 cm) is considerably lower in the logged forests because most of the timber species have been extracted during the timber harvesting operation. This signifies that logged over forests in Isabel Island will require more than 20-years to have a commercial crop for timber harvesting.

In this study, the determination of species composition, diversity and structure will be useful for the future management of post-logged forest in Isabel Island. Planning and executing adequate conservation strategies and sustainable forest management approach require a better understanding of the forest composition and tree species diversity. Information on the forest composition assemblage and tree species diversity and the pattern of secondary forest recovery and succession are vital for any forest restoration activities. Forest restoration goals are often aimed at ecosystem recovery, biodiversity and or increasing commercial value of forest by planting high-value timber species. In this study, I recommend that that land-use planning and restoration (enrichment) planting can restore the biodiversity, ecosystem functions and increase the commercial value of the logged-over forest. Despite the ability of the logged forest to gradually recover naturally over time, the nature of the disturbances, especially soil compaction which prevents seed germination and plant growth and large canopy opening that promote fast-growing pioneers, often delays the recovery of the logged forest as highlighted in the 1995 National forest inventory. Thus, in such a situation, human intervention is important to fast track the recovery process of deforested and degraded forest due to timber harvesting.

Conservation has been increasingly crucial for logged-over forests worldwide for both biodiversity and climate change mitigation. With ongoing deforestation and degradation of the tropical forest by timber harvesting and subsistence agriculture, the tropical forest in the Solomon Islands has been altered and modified which impact the regeneration of valuable timber species, biodiversity useful plant and wildlife and disrupt the ecological balance of the forest ecosystem. The disruption of ecological balance in the forest ecosystem also has an adverse impact on the coastal marine ecosystem. Continuous exploitation of the forest by timber harvesting results in a vulnerable and less resilient forest. This is a threat to food security, wildlife conservation, soil and water conservation and imbalance of the ecological processes that regulate the ecosystem. Logged over forests are degraded but still important and with post-logging intervention, logged forest can be restored to boost economic and environmental resilience for the community and the resource owners.

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APPENDICES

Species lists

The species table below shows the total number of species present in the forest categories. The tree species are present in only one forest class, present in two of the forest categories or are present in all the forest class. Numbers 1 or 0 indicate whether the species is present or not present. I.e. 1 = Present and 0 = Not present.

Table 11. List of species found in all the forest categories arrange in alphabetical order.

No	Species Name	3-Year-old	20-Year-old	Unlogged
1	*Actinodaphne sp.*	0	1	0
2	*Actinodaphne ziziphus*	0	1	1
3	*Aglaia ganggo*	1	1	1
4	*Aglaia sp.*	1	1	1
5	*Alstonia scholaris*	1	0	1
6	*Alstonia spectabilis*	1	0	0
7	*Amoora cucullata*	0	1	1
8	*Artocarpus sp.*	1	0	0
9	*Artocarpus vriesianus*	1	0	0
10	*Atuna racemosa*	0	1	1
11	*Barringtonia sp.*	1	1	1
12	*Brownlowia argentata*	1	1	1
13	*Buchanania arborescens*	0	1	0
14	*Burckella obovata*	1	1	1
15	*Burckella sp.*	1	1	1
16	*Calophyllum paludosum*	0	1	0
17	*Calophyllum peekelii*	0	1	1
18	*Calophyllum sp.*	1	0	1
19	*Calophyllum Vitiense*	0	0	1
20	*Campnosperma brevipetiolata*	1	1	0
21	*Cananga odorata*	1	0	0
22	*Canarium asperum*	0	1	1
23	*Canarium indicum*	0	1	1

24	*Canarium salomonense*	1	1	1
25	*Canarium sp.*	1	0	1
26	*Canarium vitiense*	0	0	1
27	*Celtis latifolia*	1	1	1
28	*Celtis philippensis*	1	1	1
29	*Celtis sp.*	0	1	1
30	*Commersonia bartramia*	1	0	0
31	*Crostylus sp.*	1	0	0
32	*Cryptocarya solomonensis*	1	0	1
33	*Cryptocarya Sp.*	1	1	1
34	*Cryptocarya sp1*	0	0	1
35	*Cryptocarya sp2*	0	1	1
36	*Cyathocalyx petiolatus*	1	0	0
37	*Dendrocnide inerme*	0	1	1
38	*Dendrocnide rechingeri*	1	1	1
39	*Dendrocnide salomonense*	0	1	1
40	*Dendrocnide sp.*	0	1	0
41	*Dillenia crenata*	1	0	0
42	*Dillenia solomonensis*	1	0	1
43	*Diospyros sp.*	1	1	1
44	*Dysoxylum caulostachyum*	1	1	1
45	*Dysoxylum excelsum*	1	1	1
46	*Dysoxylum sp.*	1	1	1
47	*Dysoxylum sp1*	0	0	1
48	*Dysoxylum sp2*	0	0	1
49	*Elaeocarpus floridanus*	0	1	1
50	*Elaeocarpus sp.*	1	1	1
51	*Elaeocarpus sphaericus*	1	1	1
52	*Endospermum formicarum*	1	1	1
53	*Endospermum medullosum*	1	1	0

54	*Euodia sp.*	0	1	0
55	*Fagraea racemosa*	1	1	0
56	*Ficus chrysochaete*	1	1	1
57	*Ficus copiosa*	0	1	1
58	*Ficus longifolia*	1	1	0
59	*Ficus obracteatus*	0	0	1
60	*Ficus septica*	0	1	0
61	*Ficus sp.*	1	1	1
62	*Ficus variegata*	1	1	0
63	*Ficus wassa*	1	1	1
64	*Finschia chloroxantha*	1	1	1
65	*Finschia sp.*	0	0	1
66	*Flueggea flexuosa*	0	1	1
67	*Galearia celebica*	0	1	0
68	*Garcinia sessilis*	1	1	1
69	*Garuga floridanus*	1	0	0
70	*Gironniera sp.*	1	1	1
71	*Gmelina moluccana*	1	1	1
72	*Gnetum gnemon*	0	1	1
73	*Gomphandra sp.*	1	0	0
74	*Gonystylus macrophyllus*	0	1	1
75	*Haplolobus sp.*	0	0	1
76	*Heritiera Solomonensis*	0	1	1
77	*Hernandia nymphaeifolia*	0	1	0
78	*Homalanthus sp.*	1	0	0
79	*Horsfieldia sp.*	1	0	0
80	*Horsfieldia spicata*	0	1	1
81	*Inocarpus fagifer*	0	1	1
82	*Intsia bijuga*	0	1	1
83	*Leea indica*	1	1	1

84	*Leucosyke sp.*	1	0	0
85	*Litsea perglabra*	1	1	1
86	*Litsea sp.*	1	1	1
87	*Macaranga choiseuliana*	1	0	0
88	*Macaranga dioica*	1	1	1
89	*Macaranga similis*	1	0	0
90	*Macaranga sp.*	1	0	0
91	*Macaranga tanarius*	1	1	0
92	*Mangifera indica*	0	0	1
93	*Maniltoa sp.*	0	1	1
94	*Maranthes corymbosa*	0	1	1
95	*Melastoma novae-georgiae*	1	0	0
96	*Melicope denhamii*	1	1	0
97	*Melicope elleryana*	0	1	0
98	*Melicope solomonensis*	1	1	0
99	*Melicope sp.*	1	1	1
100	*Melicope triphylla*	1	1	0
101	*Mellastoma affine*	0	0	1
102	*Micromelum minutum*	0	1	1
103	*Myristica fatua*	1	1	1
104	*Myristica irya*	1	1	1
105	*Myristica sp.*	1	1	1
106	*Neonauclea orientalis*	0	1	1
107	*Neonauclea sp.*	0	1	1
108	*Osmoxylon novo-guineensis*	0	0	1
109	*Palaquium firmum*	0	1	1
110	*Palaquium salomonense*	0	0	1
111	*Palaquium sp.*	1	1	1
112	*Pangium edule*	0	1	0
113	*Paratocarpus venenosa*	0	0	1

114	*Parinari glaberrima*	1	1	1
115	*Parinari nonda*	1	0	1
116	*Parinari Solomonense*	0	1	1
117	*Parinari sp.*	0	1	1
118	*Phyllanthus ciccoides*	0	1	0
119	*Phyllanthus sp.*	1	1	0
120	*Pimelodendron amboinicum*	1	1	1
121	*Pimelodendron sp.*	0	1	0
122	*Pipturus argenteus*	1	0	0
123	*Planchonella firma*	1	1	1
124	*Planchonella sp.*	1	1	1
125	*Planchonella thyrsoidea*	0	0	1
126	*Pleomele angustifolia*	0	1	0
127	*Plerandra sp.*	0	1	1
128	*Polyscias angustifolius*	0	1	0
129	*Polyscias guilfoylei*	0	1	1
130	*Polyscias sp.*	1	1	1
131	*Pometia pinnata*	1	1	1
132	*Premna corymbosa*	1	0	0
133	*Psychotria solomonensis*	0	1	1
134	*Psychotria sp.*	0	1	0
135	*Pterocarpus indicus*	1	1	1
136	*Pullea sp.*	0	1	1
137	*Rhus taitensis*	1	0	0
138	*Sarcolobus sp.*	1	0	0
139	*Saurauia sp.*	1	0	0
140	*Schefflera sp.*	1	0	0
141	*Semecarpus forstenii*	0	1	1
142	*Sloanea insularis*	0	0	1
143	*Sterculia conwentzii*	1	1	1

144	*Sterculia parkinsonii*	0	1	1
145	*Sterculia sp.*	0	1	1
146	*Syzygium aqueum*	0	1	1
147	*Syzygium cinctum*	1	0	1
148	*Syzygium nemorale*	1	1	1
149	*Syzygium onesima*	0	0	1
150	*Syzygium sp.*	1	1	1
151	*Syzygium tierneyanum*	1	0	0
152	*Teijsmanniodendron ahernianum*	1	0	1
153	*Terminalia brassii*	1	0	1
154	*Terminalia calamansanai*	1	1	1
155	*Terminalia complanata*	1	1	1
156	*Terminalia fatua*	0	0	1
157	*Terminalia sepicana*	1	1	1
158	*Terminalia sp.*	1	1	1
159	*Timonius sp.*	1	1	1
160	*Timonius timon*	1	0	1
161	*Toxicaria sp.*	0	0	1
162	*Trema orientalis*	1	0	0
163	*Trichospermum psilocladum*	0	1	0
164	*Unidentified sp1*	1	0	0
165	*Unidentified sp2*	0	0	1
166	*Vitex cofassus*	0	0	1
167	*Xanthophyllum sp.*	0	0	1
168	*Zizyphus angustifolius*	0	0	1
	Total	**95**	**110**	**116**

Data recording template

Date: ______________ Location: _________________ Recorder: ________________

Elevation: __________ Plot#: _________________ Coupe Age: ______________

Slope (%): __________ Sheet#: _________________

Table 12. Datasheet template for field data collection

DBH (cm)	Height (m)	Local name	Scientific Name	Remarks