TÍTULO

ANALYSIS OF REGENERATION BY COPPICING OF *DALBERGIA STEVENSONII* IN BELIZE

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"Analysis of Regeneration by Coppicing of *Dalbergia stevensonii* in Belize"

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Contents

LIST OF ACRONYMS

APO	Annual Plan of Operations
BERDS	The Biodiversity and Environmental Resource Data System of Belize
CBD	Convention on Biological Diversity
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CoP	Conference of the Parties
DBH	Diameter at breast height
BFD	Belize Forest Department
GDP	Gross Domestic Product
IUCN	International Union for the Conservation of Nature
MAFFESD	Ministry of Agriculture, Fisheries, Forestry, the Environment and Sustainable Development
MA	Management Authority
NBSAP	National Biodiversity Strategies and Action Plans
NDF	Non-detriment findings
NPAS	National Protected Areas System
SA	Scientific Authority
UNEP	United Nations Environment Programme
UNODC	United Nations Office on Drugs and Crime
WCMC	World Conservation Monitoring Centre
WWF	World Wildlife Fund

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ABSTRACT

Dalbergia stevensonii is a tropical timber species with a limited distribution range. Its unsustainable harvest for the musical industry and furniture production has led to a reduction of 55% of the commercial stock in Belize. The species is protected by the CITES and its research is needed to have an effective Non-detriments findings process. In order to ensure its sustainable trade, research on its regeneration is needed. Coppicing is one mechanism but has been understudied for this species. The aim of this research is to investigate if regeneration by coppicing is an important source of recruitment for the species. A total of eight inventory plots assessed for coppicing during the 2014 population assessment in the Toledo District were reassessed. Results showed no significant relationship between resprouting viability and stump height and diameter. Survival of the most dominant resprout per stump varied. Although no significant effect of light on resprout growth was observed, high mortality of resprouts and a decrease in the heights of the most dominant resprouts per stump, when compared to the 2014 assessment data, was evident. Long-term monitoring of resprouts by long term licensees and the Belize Forest Department is recommended in order to determine if coppicing is a major source of regeneration for this commercially important species.

Keywords: *Dalbergia stevensonii* Regeneration Coppicing

1.0 INTRODUCTION

Belize has long been known for its natural beauty and high biological diversity. Its location in Central America and the Mesoamerican Biodiversity Hotspot contributes to the high levels of biological diversity as it provides habitat for North and South American species (Belize Forest Department (BFD), 2014; see Figure 1). Among the most recognized species are *Alouatta pigra* (Yucatán black howler monkey) (Ministry of Agriculture, Forestry, Fisheries, the Environment and Sustainable Development (MAFFESD, 2016), an endemic of the Yucatan Peninsula, and *Harpia harpyja* (harpy eagle) (MAFFESD, 2016) a species associated mainly with South America with only a small population still existing in Central America. The black howler monkey is categorized as “Endangered” on the International Union for Conservation of Nature (IUCN) Red List of Threatened Species (Marsh, Cuaron, Cortes-Ortiz, Shedden, Rodriguez-Luna& de Grammont, 2008) and the harpy eagle is categorized as “Near Threatened” (BirdLife International, 2017). Deforestation is among the main threats to both species.

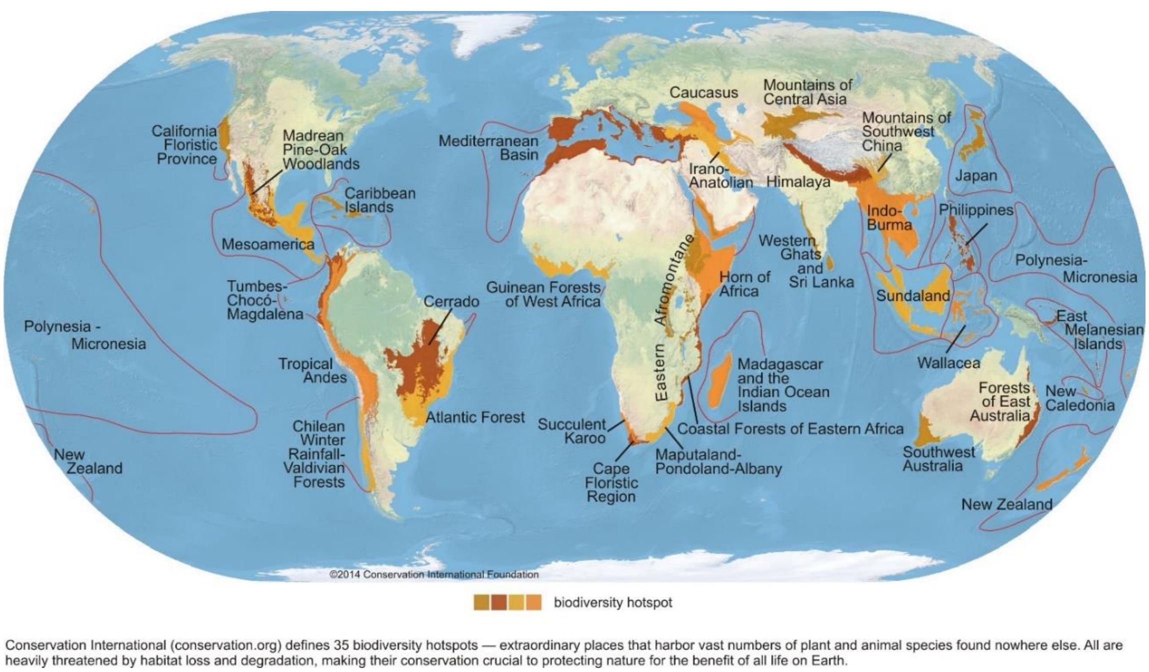

Figure 1. Biodiversity Hotspots as defined by Conservation International. Adapted from Biodiversity Hotspots, in Penn State’s College of Earth and Mineral Sciences, n.d.; Web; January 3rd, 2019.

Belize has experienced the lowest deforestation rate in Central America and as of 2013, retained approximately 61.1% of its forest cover intact. The low deforestation rates have enabled the country to sustain high wildlife biodiversity by providing habitat for approximately 105 imperiled species (with 11 critically endangered, 31 endangered, and 63 vulnerable species, according to the IUCN) and 40 endemic plant species, mainly in the pine savannah and sinkhole ecosystems (BFD, 2016). As reported by the Belize Forest Department (2010), the critically endangered species include *Dermatemys mawii* (Central American river turtle), (known locally as the hicatee), *Epinephelius itajara* (Goliath grouper), and the *Eretmochelys imbricata* (Hawksbill turtle). Endangered species include the *Ateles geoffroyi* (Spider monkey), *Tapirus bairdii* (Tapir) and the *Amazona oratrix* (Yellow-headed parrot). The *Trichechus monatus* (West Indian manatee), the *Crax rubra* (Great curassow), and the *Rhinocodon typus* (Whale shark) are considered vulnerable.

In addition, approximately fourteen endemic vertebrates are found in the mainland, including the *Poecilia teresae* (a freshwater fish), *Tantilla hendersoni* (Petén centipede snake), and the *Rana juliani* (Maya Mountains frog)—all which are only found in the Maya Mountain Massif (BFD, 2014). Furthermore, Belize is considered one of the last remaining strongholds in the region for the globally threatened *Dermatemys mawii* (Central American river turtle), *Amazona oratrix* (yellow-headed parrot), *Trichechus manatus manatus* (West Indian manatee), *Alouatta pigra* (black howler monkey), *Epinephelus itajara* (Atlantic goliath grouper), *Tayassu pecari* (white-lipped peccary) (BFD, 2016). Balick, Nee & Atha (2000) note several endemic plant species in Belize, some of those being *Koanophyllon sorensenii (Asteraceae* family), *Hypericum aphyllum (Clusiaceae* family*) Syngonanthus hondurensis (Eriocaulaceae* family), *Pleurothallis duplooyi (Orchidaceae* family), *and the Schippia concolor (Arecaceae* family), a cycad native to both Belize and Guatemala.

Belize is also home to a variety of timber species including *Haematoxylum campechanium* (logwood), *Swietenia macrophylla* (bigleaf mahogany), as well as *Dalbergia stevensonii* (rosewood), the subject of the present research.

Although Belize has a small footprint, approximately 60.3% forest cover remains (BFD, 2014), within three large tracts of forests along the Maya Mountain Massif, the Selva Maya in the west (connected to the Guatemalan Selva Maya), and the Shipstern and Fireburn tract in the northeast (BFD, 2016). These forested tracts maintain both national and regional biodiversity. Presently, approximately 35.8% of the forest cover is under protection through the National Protected Areas System (NPAS), exceeding global protection targets for most of its ecosystems (See Figure 2). In addition, Belize is home to two RAMSAR sites, Crooked Tree Wildlife Sanctuary and the Sarstoon Temash National Park. Due to its location, the Sartston Temash National Park possesses a variety of ecosystems including basin mangrove forests, riverine mangrove forests, evergreen broadleaf lowland forests, tropical evergreen swamp forests, among others (Meerman, Herrera & Howe, 2003). There are fourteen broad natural ecosystems in Belize, including lowland broad-leaved forests, sub-montane broad leaves forests, and lowland pine savannas.

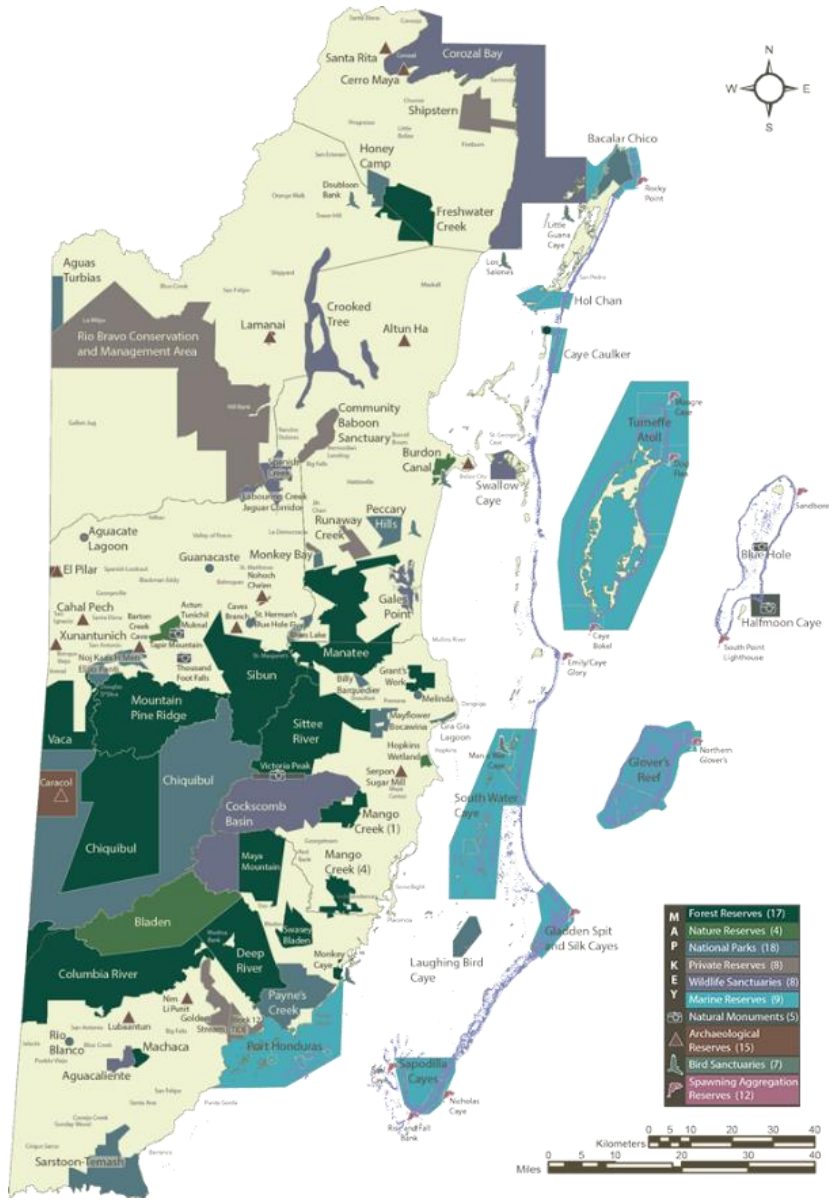

Figure 2 Protected Areas of Belize. Adapted from National Protected Areas System, 2014; Web; January 5th, 2019. Retrieved from: http://protectedareas.gov.bz/largemap/

According to Belize's Fifth National Report to the Convention on Biological Diversity (BFD, 2014), the deforestation rate for Belize was close to 1% (see Figure 3). The BFD (2016), reports that 6.4% of the deforestation that occurred between the period of 2010-2012 occurred in those protected areas near the western border and is a result of land clearing for *milpas*[1], illegal logging

[1] A crop growing system usually planted with maize, beans and other products.

and the illegal extraction of Non-timber forest products (NTFP's) due to transboundary incursions. Escaped fires lead to ecosystem degradation and most of the time, especially in Southern Belize, forest fires are a result of escaped agricultural fires (Centella, Bezanilla, Vichot & Joslyn, 2017). Hurricane damage is also considered a cause of deforestation. For instance, for the period of 2010-2012, it is estimated that approximately 33,129 hectares of forest sustained damages due to fire and hurricane damage (Cherrington, Cho, Waight, Santos, Escalante, Nabet & Usher, 2012) with further land clearing occurring as a result of increased access to those affected areas. Cherrington *et al*. (2012), note that with the increasing deforestation rates, it is estimated that Belize would have a 50% forest cover within a period of 29 years.

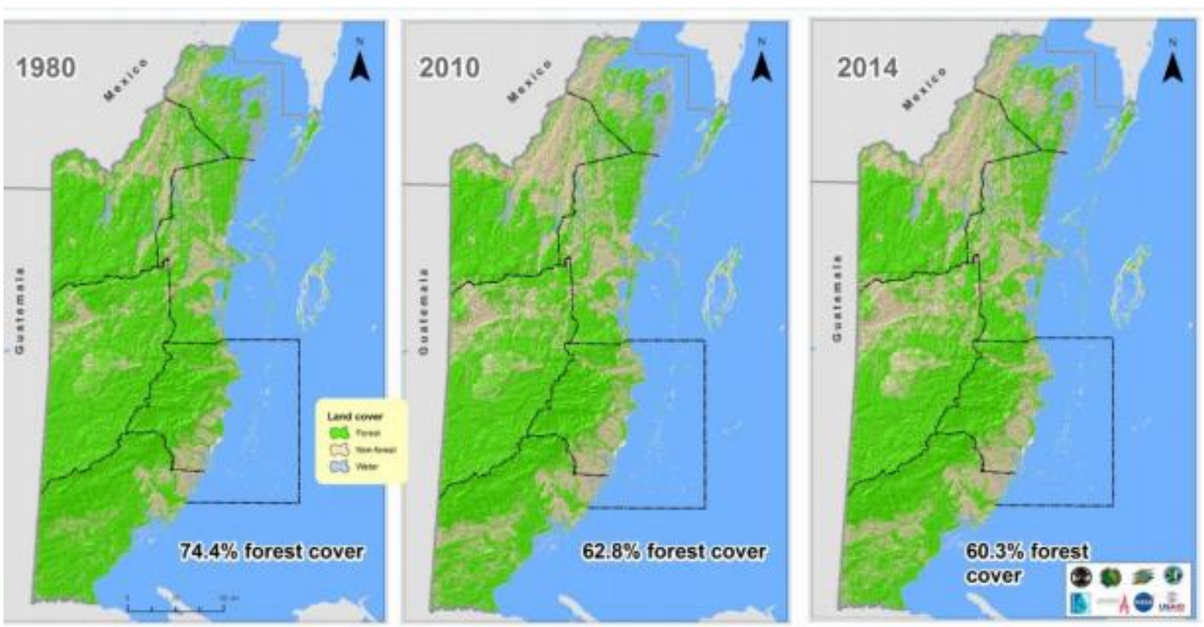

Figure 3. Belize Forest Cover for the period 1980-2014. Adapted from Forest Cover and Deforestation in Belize: Cherrington *et al*. 2010; Web; December 4th, 2018.

As of 2012, 13% of Belize's economy was based on the primary sector, which includes the agriculture, fisheries and forestry sectors (Statistical Institute of Belize, 2017). Historically, Belize's economy has been built through the harvesting of timber, with records going as far back as 1680, with the settlement of the British. This is considered an anomaly as other British Caribbean colonies economies were mostly based on agriculture and not timber extraction

(Camille & Espejo-Saavedra, 1996). Although agriculture plays a vital role in the country's economy, it is still the main cause of land use change due to agricultural expansion (BFD, 2016). Unsustainable harvesting of natural resources, such as illegal logging and the illegal extraction of NTFP's, increases as a result of land clearing as it opens roads for easier access to forests.

Since Belize's economy is nature-based agriculture, fisheries, forestry, and tourism (Walker & Walker, 2013), the country has enacted stringent legislation for the protection of its natural resources. As of early 2017, the government amended the Forests Act for the implementation of higher penalties on forest offences. The Protection of Mangroves Act, amended on June 2018, emphasizes on the conservation and management of mangroves especially in critical areas and strengthens fines and penalties associated with mangrove offenses.

Although Belize's economy is not solely based on timber extraction, it is still one of the main exports, being below the exportation of marine products and agricultural products (sugar, molasses, orange and grapefruit concentrate and bananas). In 2015, the timber industry accounted for $5.3 million Belize Dollars in gross domestic product per capita and approximately $6.68 million Belize Dollars in exports for 2016 (Statistical Institute of Belize, 2017). The exported timber species are *Swietenia macrophylla* (big leaf mahogany), *Dalbergia stevensonii* (rosewood), and *Cedrela odorata* (red cedar).

Swietenia macrophylla has a wide distribution, from the eastern states of the Yucatan and Quintana Roo in Mexico, south through Central and South America to Peru, Bolivia, and Brazil (Navarro-Martínez, Ellis, Hernandez-Gomez, Romero-Montero, & Sanchez-Sanchez, 2018; WCMC 1998). The species has an exotic distribution range and is found in Malaysia, Sierra Leone, Sri Lanka, India, among others. According to Orwa, Mutua, Kindt, Jamnadass, Anthony (2009), the species exists in all forest types, ranging from pine savannahs, to riverbanks and rainforests. Orwa *et al.* (2009) note that although the species is shade tolerant when young, optimal growth is achieved with full access to light and side protection. Locally, its lumber is used for indoor furniture, but in India, its resin is used. In Belize, this species can be found country-wide, and is locally used for handicrafts but exported for furniture as well.

Cedrela odorata also has a wide distribution, occurring along the coasts of Mexico and south to Argentina and including the Caribbean Islands (Mark & Rivers, 2017). The species also has an exotic distribution range including Fiji, Kenya, Indonesia, Uganda, South Africa, among others.

Orwa, Mutua, Kindt, Jamnadass & Anthony (2009) note that *C. odorata* is found in primary and secondary evergreen to semi-deciduous lowland or lower montane rainforests. The species is light demanding, with open canopies encouraging regeneration. Although it can tolerate soils with high calcium levels, growth is best on free draining weakly acidic soils (Orwa, *et al.*, 2009). Like *S. macrophylla, C. odorata* is also commonly used by locals for indoor furniture.

Unlike *S. macrophylla* and *C. odorata*, *Dalbergia stevensonii* is limited to a few countries, those being Belize, Guatemala and Mexico. The species is limited to broadleaf evergreen swamps forests, further restricting its habitat in its geographic range. Carmenates (2010), notes that although the species is commonly known as Honduras Rosewood, it is not present in Honduras. The species is mainly found in Belize, which was known as British Honduras until 1973. For the purpose of this research, the species will be referred to by its local name, rosewood. In Belize it is locally used in handicrafts but on the international market, it is used for the production of furniture and musical instruments.

The export of *S. macrophylla*, *C. odorata*, and *Dalbergia stevensonii* is regulated by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). The CITES is an international agreement amongst governments of member countries, referred to as Parties, which ensures that international trade of wild flora and fauna is not detrimental to their survival. Presently, there are 183 parties to the convention. Belize has been a Party to CITES since 1976, originally as part of the United Kingdom of Great Britain and Northern Ireland and as an independent nation on 21 September 1981.

In this Convention, the trade of species is regulated using three Appendices, those being Appendix I, II and III. Appendix I includes species that are threatened with extinction, whose trade is permitted only in exceptional cases. Appendix II species are those species which are not threatened with extinction but whose trade should be regulated to in order to avoid overutilization. Appendix III species are those which are protected in one or more countries and who have asked other CITES Parties to assist in regulating trade. Presently, Belize has species listed in all three Appendices with *Caretta caretta* (Loggerhead sea turtle), *Tapirus bairdii* (Baird's tapir), and *Ara macao* (Scarlet macaw) in Appendix I, and *Amazona albifrons* (White-fronted parrot), *Encyclia alata* (Orchid). *Swietenia macrophylla*, *Dalbergia stevensonii* (rosewood) are listed as Appendix II. *Cedrela odorata* and the *Nasua narica* (white-nosed coatimundi) are currently Appendix III species.

Ecuador has proposed the listing of the entire *Cedrela* genus to Appendix II but this will be deliberated at Conference of the Parties 18 in May-June 2019 (CoP 18, Proposal57).

Species may be proposed for inclusion in Appendices I or II based on a set of scientific criteria that demonstrates its level of endangerment. The CITES Parties review and adopt such proposals at their regular meetings called the CITES Conference of the Parties (CoP), which occur every 2-3 years. *Swietenia macrophylla* was included in Appendix II in 2003 at CoP12. Although only the population of *Dalbergia stevensonii* in Guatemala was included in Appendix III in 2008, due to alarming rates of illegal harvesting, the species was included in Appendix II in 2013 at CoP16 (UNEP-WCMC, 2019). CITES regulation is done by each signatory country and is regulated and enforced by a CITES Management Authority (MA) and a CITES Scientific Authority (SA), along with enforcement authorities. The Management Authorities for Belize are the Belize Forest Department and the Belize Fisheries Department, which are tasked with the issuance of permits whilst the Scientific Authority provides scientific advice as to whether the proposed harvest and export will be detrimental to the survival of the species in the wild.

1.1 Rosewood in Belize

In Belize *Dalbergia stevensonii* Standl mainly occurs in Southern Belize, where it is relegated to only small patches (Cho, 2016). The increased demand of *D. stevensonii* during the period of 2010-2013 led to the over harvesting of the species and population decline. This raised concerns because, unlike *S. macrophylla* and *C. odorata*, *D. stevensonii* has a limited range in the southern region of Belize (Cho, 2012).

Before 2010, rosewood was mainly used for subsistence construction and small-scale handicrafts by the indigenous communities in the Toledo District (Ya'axche Conservation Trust, 2013). The Belize Forest Department records demonstrate a rise in exports since 1996, peaking in 2012 with the majority being exported to China for the production of high-end furniture. The species has a high international demand due to its density, making it ideal for the production of musical instruments such as xylophones, claves, fingerboards for violins and even knife handles (Flynn, 1994).

According to internal communications with the Chief Forest Officer (W. Sabido, personal communication, May 25th, 2018), the majority of *D. stevensonii* extracted during the period of 2009-2012 was done outside of the legal permitting system and outside of the legally established girth limits[2]of 35cm diameter at breast height (DBH). It was mostly extracted only with the permission of the village councils[3] and Alcaldes[4] from the surrounding villages, but not in compliance with the national Forest Department permitting system. Import data for the period of January 2010 to March 2012, demonstrate that more than 2.6 million board feet (6135.3 cubic meters; m^3) of rosewood from Southern Belize was exported to China (Wainwright & Zempel, 2017).

Due to the extent of illegal logging of rosewood, the Belize Forest Department initiated an assessment of the remaining rosewood populations in 2012 but was discontinued (P. Cho, MAFFESD, personal communication, March 17, 2019). A proper population assessment was undertaken in 2014 (February to June) by the BFD with the support of the Darwin Initiative Sustainable Forestry Project. Since, illegal logging continued even when the 2012 population assessment was being carried out, the Government of Belize imposed a moratorium which took effect on the 16 March 2012. Not only did this prohibit the harvesting of the species but also maintained the integrity of the data being collected during the first aborted and later the second successful assessment. Preliminary results prior to the establishment of the moratorium indicated drastic harvesting of the mature sized classes, that is above 30 cm DBH, with the smaller diameter size classes being left almost intact (Cho, 2016). This was not odd as illegal loggers targeted the larger trees due to their value.

Illegal harvesting continued even after the establishment of the moratorium that the Belize Forest Department saw the need to propose the inclusion of the species in CITES Appendix II in 2013. Even with the inclusion, the illegal harvest of rosewood continued, and the Government of Belize decided to put into effect an amnesty period (8-26 April 2013) after which a strict moratorium would be enforced. During the amnesty period, people declared the rosewood in their possession

[2] A measure of the distance around the tree trunk which is measured at Diameter at Breast Height (1.3m).
[3] Village councils consist of a chairperson and six councilors, who are elected by registered villagers to advise the national government on the affairs of the community.
[4] A local magistrate who has judicial and administrative roles. This form of local governance is practiced in Mayan (indigenous) communities in Belize.

to the BFD for the setting of a ‘pre-convention’ quota (Wainwright & Zempel, 2017). Wainwright & Zempel (2017) note that the media documented illegal harvest even during the amnesty period. This continued illegal harvest was borne out in the import data which showed a boom in China’s rosewood imports in late 2013, those being over 2 million board feet (4719.5 cubic meters) of rosewood originating from Belize. The Environmental Investigation Agency (2014) note that the import numbers contain approximately 1.6 million board feet (3775.6 cubic meters) in excess from the 400,000 board feet (943.9 cubic meters) of rosewood established in the ‘pre-convention’ quota.

In 2015, following a population assessment of the species and the development of the sustainable yield, the moratorium was partially lifted so as to allow extraction only from lands under an approved sustainable forest management plan; this was done to accommodate initiatives by indigenous communities to transition into sustainable forest management (W. Sabido, Chief Forest Officer, personal communication, May 27, 2018). An export quota for the species was also developed in that same year (P. Cho, MAFFESD, personal communication, March 17, 2019).

At the end of 2016, the illegal harvesting of *D. stevensonii* subsided following a bust of over 30,000 board feet of illegal lumber in the possession of a local timber exporter. The illegal harvesting of the species has since been in check and today all exports are fully determined to be both legal and sustainable (P. Cho, MAFFESD, personal communication, March 23, 2019). Presently, rosewood is extracted from long term community forestry groups who implement sustainable forest management practices. As opposed to short term licenses, which are valid for a period of one-two years the most, long term licensees operate for a longer period of time and implement best management practices such as reduced impact logging methods. In addition, long term licensees need to develop sustainable management plans and annual harvest plans which are submitted to the BFD for approval.

Like other sustainable logging operations in Belize, the forest management unit is divided into production and protection areas. An inventory of tree species in the production area is done to determine the prospects for sustainable yield of each species inventoried. A yield model is used to determine whether or not a sustainable yield for each timber species is possible. This assists in preventing overharvesting of the species and is thus considered an important aspect in the non-detriments findings (NDF) process. The NDF process is a science-based assessment which evaluates whether the trade of the species will be detrimental to its survival in the wild. An NDF is needed for the trade of CITES-listed species in Appendix I and II and its export is monitored by the country's Scientific Authority.

As highlighted in CITES Resolution Conf. 16.7 (Rev. CoP17) on *Non-detriment findings*, the NDF methodology should take into consideration but may not be limited to: (1) species biology and life history characteristics; (2) species range (historical and current); (3) population structure, status and trends; (4) threats; (5) historical and current species specific levels and patterns of harvest and mortality from all sources combined; (6) management measures currently in place and proposed, including adaptive management strategies and considerations of levels of compliance; (7) population monitoring; and (8) conservation status. As mentioned by Cho (2016), the NDF process is a continuous process whereby steps are repeated every certain time periods. This allows for the consideration of new data that may have recently been obtained therefore improving the NDF.

2.0 PROBLEM STATEMENT

Records on the international export of *D. stevensonii* go as far back as 1888, when clarinetist, John Calhoun Deagan, replaced the use of *Platymiscium yucatanum* (granadillo) with *D. stevensonii* in the production of xylophone keys (Carmenates, 2010). Carmenates (2010) notes that logs from trees as old as 1,000 years of age were extracted from Belize and shipped to Chicago, US. By the 1920's the mature tree population had been depleted and harvesting moved to younger trees. Another spike in the demand of rosewood from Belize occurred during the period of 2010-2013 with the principal importer being China (Wainwright & Zempel, 2017). The unregulated supply of species in the *Dalbergia* genus has led to population declines (United Nations Office on Drugs and Crime, UNODC; 2016).

The dramatic decrease of rosewood stocks should be of interest to its range governments not only due to its economic importance but also due to its role in the ecosystem. In addition, in order to be able to comply with CITES obligations of properly assessing whether or not trade of the species is detrimental or not, one must investigate biological aspects of the species. Such information is integral for making a non-detriment finding to satisfy CITES permitting obligations with regard to this Appendix-II species.

Information suggests that recruitment and regeneration from seeds is low for *Dalbergia* species. Literature for the genus *Dalbergia* suggests that its seeds have a high mortality rate due to predation and a low viability period leading to the assumption that reproduction is more successfully achieved through vegetative methods (see Species Biology, below). Over the past years, Ya'axche Conservation Trust (YCT), a non-governmental organization (NGO) in Belize has conducted research on rosewood regeneration from seeds. The research is ongoing, but preliminary results demonstrate a high mortality rate of planted rosewood seeds (S. Gutierrez, YCT, personal communication, February 19, 2019).

Presently, there is little research on coppicing of *Dalbergia* species, with much of it being concentrated on *D. sissoo*, a species endemic to India and Southern Iran. In the case of *D. stevensonii*, no literature in regard to regeneration by coppicing could be found. Furthermore, *D.*

stevensonii has a small range, making it one of the less researched *Dalbergia* species in the Americas.

Like *Dalbergia sissoo*, *D. stevensonii*, has the ability to resprout after a disturbance, with some sprouts growing into large trees. It has been observed that even a few months after felling, stumps are able to produce numerous resprouts which rapidly grow in height.

Since this research is the first of its kind, it aims to provide baseline information on the regenerating method of stool coppicing (stump resprouting) through the assessment of its scope as a form of regeneration and the survival, mortality and growth (in numbers) of stump resprouts. Findings of this research will provide an insight of current resprout survival in the *D. stevensonii* population.

In addition, the results will assist and facilitate decision making for the BFD. For instance, this research might inform on the magnitude at which rosewood stumps should may be dug up for export. Furthermore, if regeneration from resprouting is shown to be an effective method to facilitate harvest recovery and increase timber production in this species, this research will highlight some of the management measures that may be adopted in order to facilitate regeneration to mature sized trees.

3.0 RESEARCH QUESTIONS

Since this research is based on comparative aspects of resprouting after felling, such as the mortality, survival, and growth (in numbers), it is necessary to revisit the data on resprouts that was collected during the rosewood population survey which took place in the Toledo District during the period of February to June 2014 (Cho, 2014).

The 2014 population assessment was aimed at rosewood and included a general inventory of other commercial trees in the study location. All trees 25cm DBH and above were identified and recorded, except for *Dalbergia stevensonii* and *Swietenia macrophylla*, for which a minimum inventory diameter of 10 cm DBH was applied. In order to estimate the rosewood population size before logging, rosewood stumps were also assessed. Stump diameter, the number of resprouts present in the stump, and the height of the most dominant resprout per stump were recorded. A more detailed description of the methodology used in the 2014 population assessment can be seen in the Methodology section of this research. The aim of this research is to provide preliminary information on the scope of regeneration of the species to mature diameters through the specific method of vegetative reproduction known as stool coppicing.

In order to be facilitate the gathering of preliminary information on coppicing of *D. stevensonii* in Belize, a series of research questions have been highlighted and are outlined below:

1. What is the percent survival rate of resprouts in the *D. stevenosonii* population in the Toledo District?
2. What is the mean increase of resprouts in the *D. stevenosonii* population in the Toledo District?
3. What is the percentage mortality rate of resprouts in the *D. stevenosonii* population in the Toledo District?
4. To what degree are resprouts of *D. stevensonii* stumps a major source of regeneration?

Since it is unknown whether regeneration by resprouts after coppicing, or in this case felling is a viable and efficient method of regeneration or merely a response to disturbance, it is important to estimate if it is a major source of regeneration for the species. In order to do so, the following research questions will be answered:

1. What is the mean percentage mortality in resprouts in the assessed population, that is, between 2014 and 2018?
2. What is the mean height of the leading resprout/stump and how did this change between 2014 and 2018?
3. What is the mean number of resprouts per stump in 2014 and 2018?

3.1 Hypotheses

The various hypotheses assessed in this research are categorized as null and alternative hypotheses. A null hypothesis, represented as H_0, shows that no variation exists between variables. On the other hand, an alternative hypothesis, represented as H_a, is a hypothesis that is contrary to the null hypothesis, showing that there is variation between the two variables being tested. As previously mentioned, since this research compared data obtained in 2014 and in 2018, such data will be represented as T_0 and T_1 respectively.

Hypotheses are outlined below:

Null hypothesis: Coppicing is not a major source of regeneration in the *D. stevensonii* population.

Alternate hypothesis: Coppicing is a major source of regeneration in the *D. stevensonii* population.

Null hypothesis: Resprout survival in T_0 is equal to resprout survival in T_1.

Alternate hypothesis: Resprout survival in T_0 is not equal to coppice survival in T_1.

Null hypothesis: Height of leading resprout/stump in T_0 is equal to height of leading resprout/stump in T_1.

Alternate hypothesis: Height of leading resprout/stump in T_0 is not equal to height of leading resprout/stump in T_1.

Null hypothesis: The mean number of resprouts/ stump in T_0 is equal to the mean number of resprouts/stump in T_1.

Alternate hypothesis: The mean number of resprouts/ stump in T_0 is not equal to the mean number of resprouts/stump in T_1.

4.0 LITERATURE REVIEW

This literature review is divided into two sections, the first section concentrates on the available information for *Dalbergia stevensonii* such as physiological aspects, range, and its illegal harvest in Belize. The second section concentrates on a review of the available literature on regeneration by coppicing. Since during the time of the writing of this manuscript, no information on the regeneration by coppicing of *D. stevensonii* was found, available information on the related species, *D. sissoo* (*Dalbergia* genus) are highlighted. In addition, since the genus *Dalbergia* belongs to the *Fabaceae/Leguminosae* family, the literature was reviewed for information on regeneration by coppicing for other species in this family, such as *Leucaena leucocephala* and *Acacia auriculformis*.

Finally, since regeneration by resprouting is not confined to species in the *Fabaceae/Leguminosae* family, a literature review is also presented pertaining to resprouting in other species, such as those in the *Sapindaceae* and the *Lauraceae* families.

Species Taxonomy

Kingdom: Plantae

Class: Magnoliopsida

Order: Fabales

Family: *Leguminosae (Fabaceae)* Juss. 1789

Genus: *Dalbergia stevensonii* Standl. (Standley 1927)

Common names: Rosewood, Honduras Rosewood

4.1 *Dalbergia* Genus Overview

The *Dalbergia* genus is composed of over 250 species and includes small to medium sized trees, shrubs and lianas in the pea family (Vasudeva, Vats, Sharma & Sardana, 2009). The genus has a distribution that is limited to the tropics and subtropics and is present in 102 countries including the Asian, African and Central and South American continents (Vaglica, 2004). The species in this genus are normally sought after for their decorative lumber to make furniture that is considered to be of a high social status in China. For this reason, the illegal harvest of species in the *Dalbergia* genus around the world increased to alarming levels as the lumber harvested came from the wild populations (UNODC, 2016). Furthermore, due to its density and acoustic properties, the lumber is highly valued in the musical instrument industry. Apart from its economic value, species in this genus possess medicinal properties, ranging from anti-inflammatory activities, as obtained from *D. sissoo* leaves (Hajare, Chandra, Sharma, Tandan, Lal, Telang, 2000), to antifertility activities, as obtained from the roots of *D. saxatilis* (Vasudeva *et al.*, 2009).

Belize may be home to two species of *Dalbergia*: *D. stevensonii* and *D. tucerensis*. Although literature such as the UNEP-WCMC (2015) and Wiemann & Ruffinatto (2012) mention that Belize provides a habitat for *D. tucerensis*, up to this date, only plant specimens of *D. stevensonii* have thus far been collected in Belize (G. Lopez, BFD, personal communication, March 18, 2018). *Dalbergia tucerensis* has been confirmed in Costa Rica, El Salvador, Guatemala, Honduras, Mexico and Nicaragua (UNEP-WCMC, 2018).

4.2. *Dalbergia stevensonii* Species Range

Dalbergia stevensonii is one of the approximately 80 *Dalbergia* species present in the Central American and South American region. The Asian and African continents contain approximately 119 and 116 species, respectively (CITES, CoP17, Proposal 55). The range of *D. stevensonii* is restricted to three countries in Central America: Belize, Guatemala, and Mexico (Meyrat, 2017) (See Figure 5). Even within those countries, its range is limited to specific habitats. For instance, in Belize, *D. stevensonii* is found in waterlogged lowland swamp forests which is characteristic of the Southernmost district in Belize.

In Mexico, the species can be found in the state of Chiapas. In Guatemala, only four (4) populations ranging from 44 to 800 trees have been observed in the area referred to as "Fuente Transversal Norte" (Belteton, 2016). According to Cho (2016), Belize holds the majority of the *D. stevensonii* population, most of which are found between the Sarstoon and Monkey Rivers in the Toledo

District (Cho & Quiroz, 2005). Small populations are also observed in drier areas such as the Chiquibul and Columbia Forest Reserves in the Cayo and Toledo Districts respectively (CITES CoP16 Prop. 62). The restricted habitat makes it more susceptible to declining populations as a result of its illegal extraction. Illegal harvest, compounded by deforestation due to land use change heavily, impact its wild populations in Belize.

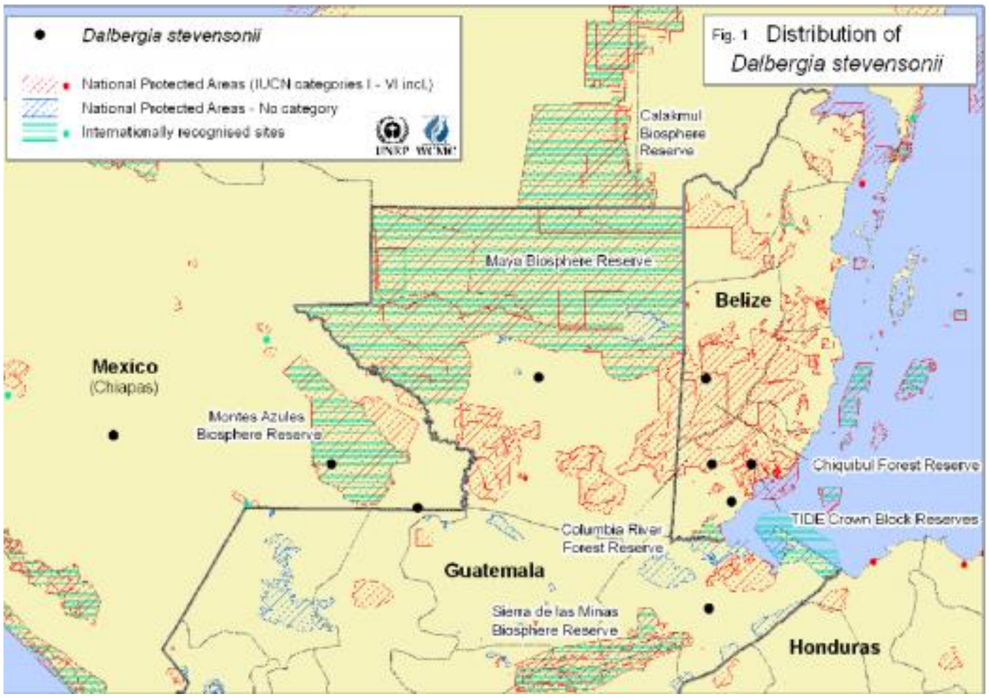

Figure 4 Image showing *D. stevensonii* range in Belize, Guatemela and Mexico. Adapted from the CITES CoP16 Proposal 62.

4.2.1 Species Biology

D. stevensonii is a deciduous hardwood tree which can reach a height of up to 30 meters, up to 60 centimeters in diameter (Cho, 2016) and is usually 6 to 11 meters to the first branch (Herrera *et al.*, 2016). The species has grayish, smooth bark when young with irregular plates developing as it matures. Its leaves are pinnate dark green with 5-7 elliptical leaflets, rounded at the apex (See Figure 5).

Figure 5 Leaf formation in a young and mature *D. stevensonii* tree. Adapted from Manual Para La Descripcion Botanica Y De La Madera De Las Especies Forestales De Guatemala Incluidas En El Listado II De CITES in Herrera, *et al.* 2016.

Variation in the periods of flowering and seeding have been observed for the species in different sites. In Guatemala, *D. stevensonii* flowers can be observed during the period of April to July, with fruits appearing during the months of June to November and seeds being shed during the months of October to December (Herrera *et al.*, 2016). In Belize, flowering and seeding differs depending on the elevation that the species is found. According to Cho (2016), its yellow flowers can be observed during the months of January to May in the dry mountainous areas and from June to August in the wet, lowland areas. Flowers are mainly pollinated by bees and even though the species in the *Dalbergia* genus exhibit mass flowering, seeds exhibit high levels of seed abortion and low seed viability (CITES CoP17, Proposal 54). In addition, mass flowering does not guarantee a high fruit yield, as observed in *D. miscolobium* which has very few fruits reaching maturity (Gibbs & Sassaki,1998). Furthermore, many species in the genus demonstrate self-incompatible and hermaphroditic reproductive traits. Possessing self-incompatible traits prevents self-fertilization as the individual is able to recognize and reject its own pollen (Wright & Barrett, 2010). It is not known if *D. stevensonii* exhibits those same traits, but Winfield, Scott & Grayson (2016) note that several similarities are shared within species in the *Leguminosae* family.

In Belize, seeding occurs during the months of March to May in the mountainous areas and from August to September in the lowlands (Cho, 2016). Although trees as small as 15 centimeters DBH have been observed flowering and seeding, the age or size at which it reaches maturity is still not known. The genus exhibits slow growth, reaching a commercial harvestable heartwood diameter at approximately 70 years of age (Winfield, *et al.*, 2016). Cho (2016) notes that although growth of *D. stevensonii* is very slow, averaging 4mm per year, the species experiences periods of rapid growth as a result of increased availability of resources. Although there is little information on the role of the species in the ecosystem, it plays a role in the enhancement of soil fertility through the formation of nitrogen-fixing nodules (CITES, CoP16. Prop. 62).

4.2.2 Properties of Wood

The valuable timber produced by species in the genus *Dalbergia* is found in the heartwood, resulting in high timber loses once the sapwood is removed. Furthermore, since it is the straight grain lumber that is used in the musical industry, it results in high log wastage (See Utilization and Trade, below). *Dalbergia stevensonii* is characterized by its brown to dark brown with reddish stripes colour. Lumber colour varies from species to species, for instance *D. tucurensis* is red in color whilst *D. calycina* is dark brown.

The CITES CoP16 Proposal 62 refers to Titmus & Patterson (1988), who mention that the wood has an average weight of 960kg/m3 when dry. It is very heavy and has a density of 0.75h/cm3. Its heartwood is hard, heavy and of brown colour with black or dark brown growth rings which overtime become obscure due to oxidation processes.

The sapwood on the other hand, is whitish in colour but becomes creamy or yellowish when exposed to the environment (after felling or any other disturbance). Standley & Record (1936) make reference to Stevenson (1927) who described the growth rings of the sapwood as not clearly marked (as opposed to those of the heartwood) and which rapidly decay once in contact with the ground. In addition, recently cut wood is characterized by a sweet rose like odor which diminishes when drying (CITES, CoP16, proposal 62).

Dalbergia stevensonii is a straight-grained, fine-textured wood with luster in both the radial and tangential sections. According to Herrera, *et al.* (2016), its fine texture is attributed to the presence of narrow xylem vessels, measuring 125.88±30.39 micrometers. The species also has a vessel frequency of 3-6 per mm^2 and paratracheal vasicentric to aliform and confluent parenchyma (Wiemann & Ruffinatto, 2012). Although the species shares many anatomical similarities with

Dalbergia tucurensis, maximum vessel diameters differs between the two species. For instance, *Dalbergia stevensonii* has a maximum vessel diameter of 350 micrometers whilst *Dalbergia tucurensis* has a maximum vessel diameter of 450 micrometers. In the tangential section, *Dalbergia stevensonii* rays are storied. When it comes to the transverse view of the wood, the distribution of the vessels can be semi-circular to diffuse, vessels are solitary and in multiples of 2-3 with some containing crystallized substances inside. Parenchyma rays are abundant and narrow with 1-3 rows of cells. The axial parenchyma can be of various types; narrow banded, diffuse and diffuse in aggregate, this being less abundant and faintly narrow and confluent. In some rare instances, the parenchyma is faintly lozenge aliform and variably marginal (Wiedenhoeft, 2011 & Herrera, *et al.*, 2016).

4.2.3 Population Distribution and Status

The boom in demand for species in the genus *Dalbergia* for international and domestic purposes has caused population declines. Its rampant illegal harvest along with the species high seed mortality and low seed viability further affects the existing wild populations. Winfield, *et al.* (2016) note that regeneration rates of the *Dalbergia* genus are very low, even in protected areas. This may be attributed to higher browsing intensities due to larger populations of wildlife present in protected areas (Winfield, *et al*, 2016).

In the case of *D. stevensonii*, Belize contains most of the species in its range, with Mexico and Guatemala containing only small populations (Carmenates, 2010 & Cho, 2016). Its limited range, the alarming rates of illegal extraction, and the fact that little is known on its population status, harvest, management, and research on the species, raises concerns with the relevant authorities in Belize. In addition, although in 2010, the Toledo District retained more than 70% of its forest cover (Cherrington, *et al.*, 2010) slash and burn agriculture has opened roads that has allowed greater access for logging purposes (Carmenates, 2010).

During February to June 2014, the Belize Forest Department conducted a rosewood population assessment in all areas where the species is known to occur in its range, that is, the Toledo District. This assessment included a general inventory, with a total of 389 rosewood trees and stumps being assessed. Results showed that rosewood had an occurrence rate of 4% with most of them existing in small patches surrounding some of the villages in the Toledo District (Cho, 2014) (See Figure 6).

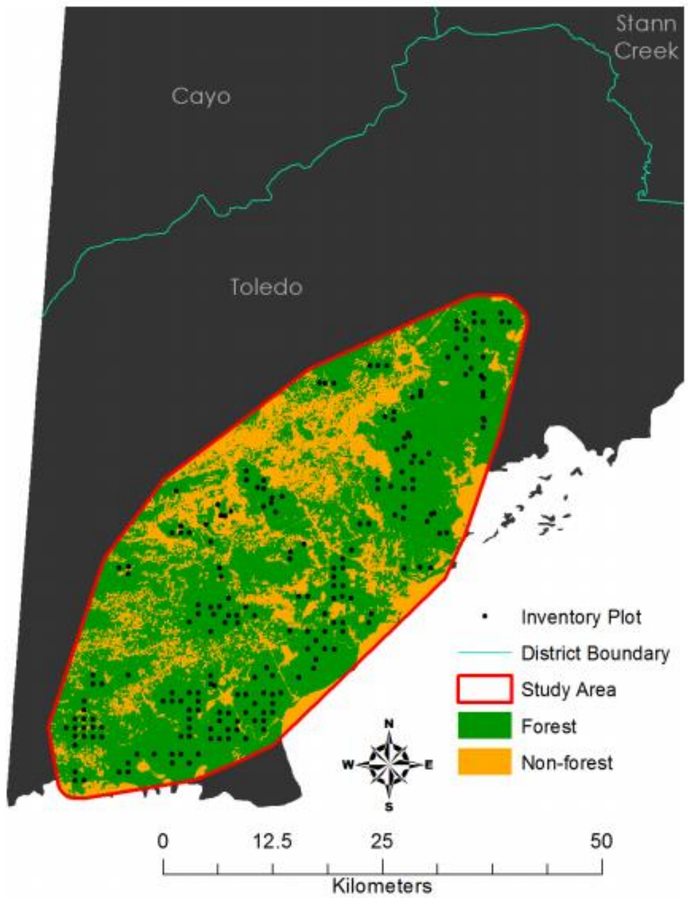

Figure 6 Location of plots during the rosewood inventory. Adapted from Report on the Findings from the Rosewood Inventory in the Toledo District by Cho, P. (2014). Belize Forest Department Internal Document.

Results demonstrated that rosewood trees 30 cm DBH and above had been targeted by illegal and legal logging over the years, leading to a reduction of approximately 55% of the original stock. Trees smaller than 30cm DBH were not heavily targeted due to their small size and the quality of the wood. From the stump data and trees assessed, the population of the species in the Toledo District was estimated and is represented in Figure 7 below.

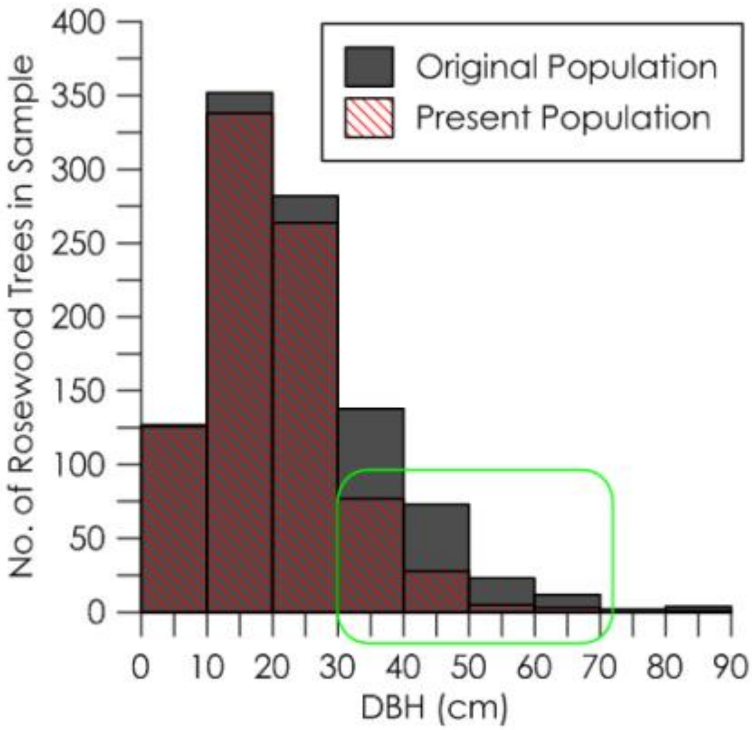

Figure 7 Distribution of original and present population of rosewood in the Toledo District. Adapted from Report on the Findings from the Rosewood Inventory in the Toledo District by Cho, P (2014). Belize Forest Department Internal Document.

Even though approximately 100,720 rosewood trees with a DBH of 30cm and more were estimated to have been harvested in recent years, trees under 30 cm in DBH are still considered to be common in the forests of the Toledo District (Cho, 2014).

4.2.4 Threats

The UNODC 2016 World Wildlife Crime Report mentions that illegal logging is one of the most destructive wildlife crimes as it affects entire habitats. According to Carmenates (2010) the main threats to *D. stevensonii* are habitat loss and destructive harvesting methods. Carmenates (2010) and Cho (2016) consider the principal threat to this species as deforestation due to land use change (slash-and-burn and large-scale agriculture). Illegal uncontrolled logging also threatens the species, especially during the period of 2008-2013 with the surge in demand from the Chinese markets. Forest fires, although small and slow moving, can cause damage, especially in times of prolonged dry season (Carmenates, 2010). Damage caused by fire can range from the destruction of ground vegetation, seedlings, and young trees to landscape changes, such as the establishment of grasslands (WWF, 2016).

4.2.5 Utilization and Trade

Dalbergia stevensonii has been internationally used in the production of musical instruments due to its density (Flynn, 1994), brilliance and durability (Carmenates, 2010). During the 1920's and 1930's, percussion companies targeted the oldest available trees of *D. stevensonii* for harvest, as age and density increased its value (Carmenates, 2010). The species is still being used to produce bars for xylophones, claves, guitars, flutes, fingerboards for violins and even knife handles. Kline (1980) mentions that there is wastage of approximately 70-80% of lumber is as only the finest straight grain parts of the log are used in the production of marimba bars.

Before 2010, rosewood was mainly used locally as subsistence construction (fence posts), especially by members of the Mennonite community of Pine Hill (Toledo District) and for small-scale handicrafts, such as small souvenirs, picture frames by the indigenous communities in the Toledo District (Ya'axche Conservation Trust, 2013). The Belize Forest Department records demonstrate a rise in exports since 1996, peaking in 2012 with the majority being exported to China for the production of high-end furniture.

Figure 8 Rosewood bowl as being sold on online stores. Retrieved from https://beckalar.com/product/belizean-rosewood-bowl/#iLightbox[product-gallery]/0

The parts mainly used are the stem, burls[5] and large to medium sized branches. Burls are used for souvenirs and bowls, with branches being turned into blanks for knife handles and flutes (Cho, 2016) (see Figure 8). Important to note is that small souvenirs and bowls are produced in-country, whilst other products are produced oversees, thus raw lumber and semi-finished products such as marimba keys are exported from Belize to manufacturing countries.

4.2.6 International Trade

Due to its alarming rates of harvest, in 2013 Belize proposed the inclusion of *D. stevensonii* on Appendix II. The listing means that although its export is allowed it is regulated to prevent its unsustainable extraction. After the March 2013 Appendix-II CITES listing, China imported over 2 million board feet (4719.5 cubic meters) of rosewood directly from Belize, which is 1.6 million board feet (3775.6 cubic meters) in excess of the established “pre-convention” export quota of 400,000 board feet (943.9 cubic meters); (Environmental Investigation Agency, 2014).

CITES trade data for rosewood in Belize go as far back as 2008, when it was still listed as an Appendix III species. According to the CITES trade database, as an Appendix-III species, rosewood was imported from Belize by China and Germany in 2008. China imported 13.59 cubic meters of wild sourced rosewood (sawn wood) for commercial purposes; Germany imported 6.929 cubic meters of wild-sourced rosewood (sawn wood) originating from Belize. Germany also reported importing 24.31 and 18.83 cubic meters of wild-sourced rosewood (sawn wood) in 2011 and 2012, respectively (Figure 9). From the CITES trade data it can be noted that only one export occurred in 2012, presumably exported prior to implementation of the 2012 moratorium.

According to the UNEP-WCMC (2018) exports in 2013, total to approximately 965.16 cubic meters of assorted sources, including pre-convention, wild and confiscated lumber exported from Belize to China, Germany and the United States (US). A total of 13.21 cubic meters of pre-convention timber was also exported to Germany. Belize exported approximately 898.62 cubic meters of logs, sawn wood and timber to China. However, a discrepancy is noted in one export heading to China whereby Belize reports exporting 2.16 cubic meters of wild sourced timber but

[5] A tree growth in which the grain has formed in a deformed manner. It is a small knot from dormant buds.

China reports importing just 0.3 cubic meters. The importing volume as reported by China was taken into account for the approximate total of 965.16 as reported above.

Of the 898.63 cubic meters exported to China, approximately 803.82 cubic meters were pre-convention lumber, presumably from the stock reported during the amnesty period. In addition, in the same year 13.35 cubic meters of wild sourced rosewood was exported to Germany. An additional, 53.2 cubic meters of rosewood was exported to the US in the same year, 2013. Of those 53.2 cubic meters, 43.2 cubic meters were wild sourced, with 0.004719 cubic meters being pre-convention lumber. The remaining 10 cubic meters were sources as "confiscated".

In 2014, approximately 211.98 cubic meters of lumber was exported, with the majority being classified as pre-convention lumber and just one export coming classified as being wild sourced. Further breakdown for the data for 2014 demonstrates that Belize exported 146.8 cubic meters of rosewood to China, of which all was pre-convention lumber. In addition, Netherlands imported 51.09841 cubic meters of pre-convention lumber from Belize. The remaining 14.085 cubic meters of rosewood was exported to the US with 14 cubic meters of such being wild sourced.

In 2015, approximately 77.300 cubic meters of rosewood was exported. 21. 01 cubic meters of the total amount was exported to Spain and was wild sourced. A total of 56.27 cubic meters was exported to Netherlands and was labelled as being pre-convention lumber. The remaining 0.011327 cubic meters was exported to the US and was categorized as pre-convention.

In 2016, approximately 23.71 cubic meters of wild sourced sawn wood was exported. Of that total amount, 8.71 cubic meters of the exported rosewood to the Netherlands and the remaining 15 cubic meters to the US (Figure 10).

Overall, it can be noted that for the period of 2013-2015, the export of rosewood has mainly been from 'pre-convention' sourced lumber, which was sourced out after the implementation of the amnesty period in 2012. As of 2016, the export of wild sourced rosewood recommenced. Although from Graph 2 it can be noted that 2016 exports are very minimal when compared to 2013 and 2014 exports, it is still similar to exports made during 2008, 2011 and 2012. Furthermore, according to the CITES Trade database, the majority of the legally exported lumber is imported from Belize by the US and is followed by China and Netherlands (Figure 11) (UNEP-WCMC, 2018). According to the Belize Forest Department CITES permits records, approximately 28.1 cubic meters of rosewood was exported in 2016 and none in 2017. For the year 2018, as of August approximately 35.4 cubic meters of rosewood had been exported.

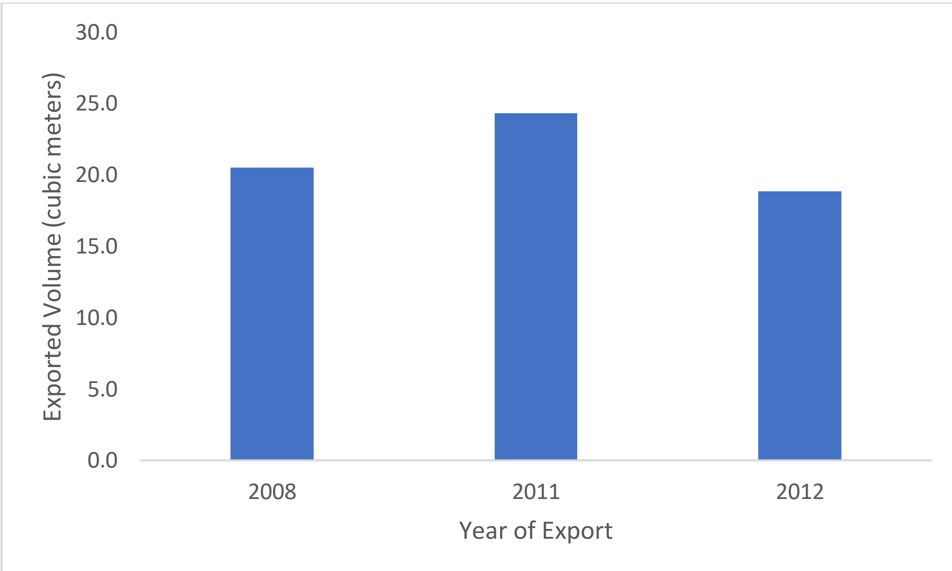

Figure 9 Exports for the period of 2008, 2011 and 2012

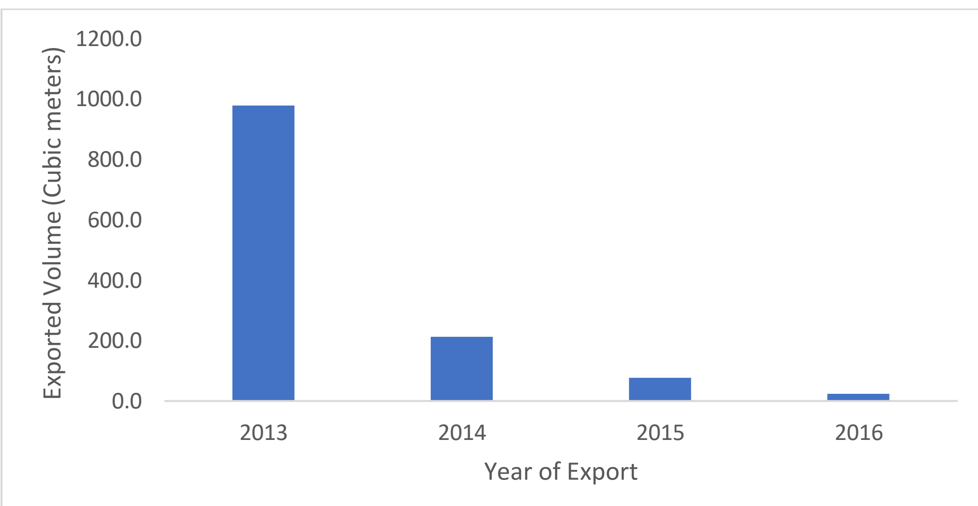

Figure 10 Rosewood exports for the period 2013-2016

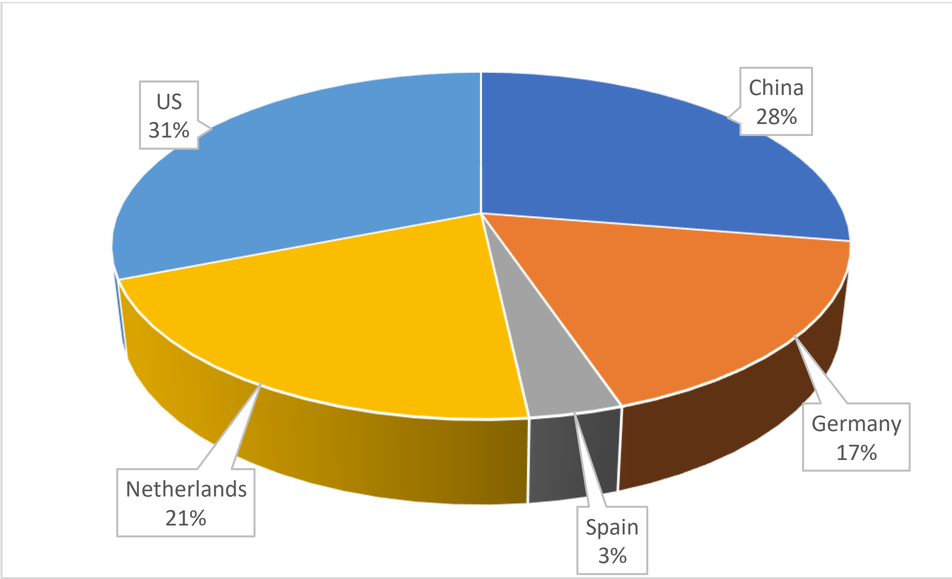

Figure 11 Pie chart showing importing counties of *D. stevensonii* originating from Belize

4.2.7 Illegal Harvest

Mulligan (2015) notes that illegal logging accounts for up to approximately 50%-90% of harvested volumes in key tropical countries, with global illegal logging having an approximate economic value of US$30-US$100 billion dollars annually (Chudy, 2016). Mulligan (2015) also refers to a study which estimated the value of the illegal harvests of mahogany, cedar and rosewood in the Toledo District and the Chiquibul National Park for the period of 2010-2012 and estimated it at a monetary loss of approximately $USD 490,177 for that two-year period.

In addition, authors such as Young (2008) and Carmenates (2010) note that illegal logging is a major issue in Belize's logging industry. Young (2008) noted that approximately 60% of harvested lumber in Belize is illegally acquired. Although illegal logging is described as the handling of logs without licenses. Illegal extraction of lumber does not necessarily mean that it is done without the acquisition of legal documents but also entails the over-allowing of export quotas, logging outside the permitted concession area and even mixing legal with illegal lumber during transportation (Mulligan, 2015). Although the illegal logging of rosewood in Belize is poorly documented, there is anecdotal data that shows that rosewood was extracted during the night (Wainwright & Zempel, 2017). This occurred in contravention to the Forest Act[6] and during the period when a moratorium for the species was in place (Wainwright & Zempel, 2017).

Wainwright & Zempel (2017) conducted interviews in some of the Mayan[7] communities, where Maya men reportedly felled rosewood trees with chainsaws and then shaped the trunks into flitches (squared logs). Flitches were hauled from the forest to the roadside with the help of a mule, horse and sometimes even a bicycle. There, the buyer would meet the logger at the roadside where the purchase would be made and then transported and stored in shipping containers.

Internal data from the Belize Forest Department for the period of November 2012 to February 2013 demonstrate that approximately 1,246 fletches, 488 round logs and 69 burls were intercepted. Interestingly, 544 flitches were found in Belize City, which according to the BFD report, was presumed to have been loaded in containers in Northern Belize. Suspects that were caught transporting the rosewood were charged at court, and the material was seized. Such material was transported to the nearest forest station for its safe keeping. On one occasion though, a total of 39 flitches were stolen from the Machaca Forest Station.

A partial lifting of the moratorium occurred in 2015, with the condition that rosewood was to only be extracted from approved concession areas with approved sustainable management plans. Despite this pre-condition, there is evidence that illegal extraction continued. In the period of December 2016 and January 2017, two major confiscations were made: 31,000 ft3 (73.2 m^3) in the Cayo District of western Belize and 1,000 ft3 (2.3 m^3) in the Toledo District of southern Belize, where no proper documentation for such could be produced ("Rosewood Busted in South and West; Stiffer Penalties for Offenders?, 2017").

[6] Parent act (Chapter 213) governing the use of Belize's forests.
[7] Indigenous people of Belize.

4.2.8 National and International Legislation/Protection

Prior to 1992, the raw export of rosewood was prohibited, with only finished and semi-finished products being allowed for export (CITES, CoP17. Prop. 54). CoP17, Prop. 54 also notes that in 1996, legislation was changed to allow the export of raw timber, this being at an opportune time when the Chinese demand started increasing.

The increasing demand from the Chinese market led to a period of rampant illegal harvesting of rosewood in Belize (Environmental Investigation Agency, 2014). In order to minimize illegal extraction, a moratorium was put into effect, this serving some sort of protection to the species (W. Sabido, BFD, personal communication, June 2, 2018). Furthermore, in 2013, *D. stevensonii* was placed in CITES Appendix II, with exports only being allowed once the material was not illegally harvested. In 2015, a partial lifting of the moratorium went into effect which allowed the harvesting of rosewood from approved concession areas with sustainable management plans (W. Sabido, BFD, personal communication, January 3, 2019).

In 2017, the Government of Belize approved an amendment to the Forests Act, this which allows for the implementation of stiffer penalties depending on the species volume, market price and scarcity ("Forest Department enforces new amendments for Forest Offenses, 2017"). Presently, rosewood is the species with the highest penalties in relation to forest offences committed in contravention to the Forests Act.

4.2.9 Current Forest Management of *D. Stevensonii*

The Food and Agriculture Organization of the United Nations (FAO) (2018) defines forest management as the implementation of practices for the use of forests to meet environmental, economic, social and cultural objectives. More specifically, forest management should take into account several key technical factors such as species reproduction, natural regeneration, growth, seed dispersal, management and others (Hartshorn, 1995). In Belize, forest management is regulated by various acts including the Forests Act (Chapter 213), the Private Forests (conservation) Act (Chapter 217) and the Forest Fire Protection Act (Chapter 212), among others. The principal act governing the management of timber species in Belize is the Forests Act Chapters 213 and 213s (substantive and subsidiary laws). The Forest Act highlights the administrative, legal, economic and technical aspects of forest management. The technical aspect of the Forest Act highlights the girth limits for the harvesting of specific timber species. The Act does not establish a commercial DBH for rosewood, but it is presently being harvested at a DBH of 35 centimeters. Presently, silvicultural processes, such as liana liberation, are applied to trees with 20 cm DBH and above.

As per the partial lifting of the moratorium, the harvest of rosewood is to only be harvested from areas with an approved sustainable forest management plan (SFMP). Furthermore, the approved export quota is derived from such operations. The SFMP includes information such as the division of the license area, stands, harvesting methods, silvicultural treatments and standards for infrastructure. The total area to be managed under the duration of the long-term license is divided into production and protection areas. The production area is the area where the harvest will occur and is inventoried for its population status and structure. This inventory will determine whether a sustainable harvest for the species will be possible. Furthermore, the production area is divided into annual blocks which are further subdivided into production and protection zones. Each annual production area is inventoried for commercial species with 25 cm DBH and above, whilst *D. stevensonii* and *Swietenia macrophylla* are inventoried at 10 cm DBH and above.

Data from the inventory is not only used to produce the 5-year period SFMP but is also used to produce an annual plan of operations (APO). Both documents, the SFMP and the APO, are requirements for the approval of harvests by the BFD. Not only does the APO plan out the projected harvest trees but is also a plan for the road network and the location of the barquadiers[8] in the area. In order to determine if a sustainable yield for a specific species is possible, data collected from each annual block is entered into the sustainable yield model. Each tree is designated a certain category before it is exported to the yield model. Tree designations include: Future trees, Crop (harvest) trees (50cm-89.9cm), Reserve, Preserve, and Seed trees (G. Lopez, BFD, personal communication, March 12, 2019). Each category is designated depending on certain parameters such as crown form, log grade and DBH classes. The yield model estimates the population at the next cutting cycle through the consideration of general growth and mortality patterns.

[8] Log landings in the concession area

Presently rosewood is extracted by three indigenous community groups in the Toledo District, those being the Q'iché Há Group, Boom Creek Lumber Production Association and Rax Mú QÍ Ché. Typically, such long-term sustainable logging operations have a duration of 40 years, as is the case of Bull Ridge Limited (privately-owned company operating in the Chiquibul Forest Reserve and harvests rosewood at a minimal scale) but can also be for a shorter period as in the case of the community forestry groups. For instance, in the case of Q'iché Há Group, the license is for a period of 24 years, Boom Creek Lumber Production Association on the other hand is for a period of 20 years, whilst in the case of Rax Mú QÍ Ché it is for a period of 19 years.

Like big leaf mahogany, rosewood has an export quota depending on harvests. The community forestry licensees do not directly export the rosewood, but the material is rather sold to an exporter. For the year 2016, Boom Creek Lumber Production Association had an export quota of 26, 577 board feet (62.7 m^3). Of those 62.7 cubic meters of rosewood, a total of 28.08 cubic meters was exported, leaving a balance of approximately 34.7 cubic meters. No quota was issued in 2017 since none of the companies harvested rosewood. For 2018, the export quota was at a total of 98,046 board feet (231.4 m^3) which was divided amongst three companies. Those three companies being from 2 community forestry groups, Q'iché Há Group, Rax Mú QÍ Ché and one privately owned company, Bull Ridge Limited. As of August 2018, only two exports had been made from rosewood totalling 35.4 cubic meters and leaving a balance of approximately 195.9 cubic meters of *D. stevensonii*.

4.3 Management by Coppicing

In this section, a review of literature associated with the vegetative reproduction of coppicing is highlighted. Since there is little research on *Dalbergia stevensonii* and none on its coppicing abilities being found during the writing of this thesis, a review of available journals on coppicing in the same *Fabaceae/Leguminosae* family is presented. In addition, this literature review also contains information on coppicing in other families.

In forestry, regeneration is the process whereby forests are re-stocked of trees either by natural or artificial means. Natural regeneration can be achieved through various methods, those being through seed development, resprouts or root suckers from previously established trees. On the other hand, artificial regeneration is achieved through the planting of seedlings in a specific area (Upadyay, 2008). Typically, planted seedlings are derived from seeds collected in the wild and grown under specific conditions in a nursery.

Artificial regeneration can also include propagation by cuttings. Upadhyay (2008) notes that although trees regenerate by seeds, some species have the ability to regenerate through its vegetative parts, that is, through roots, branches and stems. Even though, there are many methods of vegetative regeneration, coppices and root suckers are the two methods which can be applied when wanting to achieve natural regeneration. Reproduction through coppicing can be achieved in any of three ways, those being, seedling coppice, stool coppice and pollard shoot.

In seedling coppicing, the shoots climb from seedlings that have been cut or burnt. In the case of stool coppicing, the shoots rise from living stumps. With this form of regeneration, shoots may either rise from the near the base of the stump or from the top of the stump. In the "pollarding" method, the tree is pruned at the top, generally at 1 to 1.25 meters, so that it produces a flush of new shoots from the surface of the cut (Upadhyay, 2008).

Figure 12 Image depicting Stool Coppicing. Adapted from Forestrypedia; Web; October 23, 2018

Since the purpose of the present research is to assess whether or not stool coppicing is a major form of regeneration in rosewood stumps, from here on this literature review will focus on the regeneration method of stool coppicing.

Mostacedo, *et al.* (2008) refers to Bond & Midgley (2001) who mention that resprouting capacity in tropical woody plants is a response to disturbances such as hurricanes, fires and logging. The ability to coppice allows plants to grow and recover leaf area after disturbances making resprouting an integral part of plant life history (Poorter, Kitajima, Mercado, Chubina, Melgar & Prins, 2009). In tropical dry forests, seedlings tend to grow at a slower rate than resprouts. The advantages of regeneration by coppicing as compared to seedling is that resprouts are not affected by the lack of seed dispersers or the presence of impoverished soils. Thus, successful regeneration depends in large part of the condition of the stumps and roots (Mwavu & Witowski, 2007).

Mwavu & Witowski, (2007) and Upadhyay (2009) mention that coppicing ability is dependent on the species in question. Conifers do not coppice after disturbances but species such as those in the *Fabaceae/Leguminosae* family do have coppicing ability. Species in the *Dalbergia* genus in particular are considered to be strong coppicers (Upadhyay, 2009) and are capable of growing into large-sized trees (Cho, 2016).

Coppicing ability is not solely dependent on the species being assessed but is also as a result of numerous physical factors. Various authors have noted that the age of the tree at the time of harvest plays an important role in its coppicing intensity (e.g., Solomon & Blum, 1967; Matilo, Akouehou & Sinsin, 2017). Typically, old bark as observed in mature trees prevents the emergence of dormant buds, therefore younger trees have a higher coppicing intensity when compared to mature trees (Upadhyay, 2009).

Although in some species coppicing ability is higher in taller stumps, in general it is the lower stumps that have more coppicing power. Since, the stump is lower, the coppice is less affected by wind, and trampling resulting in straighter shoots than those produced from seeds (Felker & Patch, 1996). Since resprouts can develop a root system, its survivability does not solely depend on the health of the stump, as stumps tend to dry over time. Upadhyay (2009) notes that stumps are generally kept at a height of 15-25 cm to maximize coppicing survivability.

Light availability is a major factor in coppicing intensity as resprouts/coppices are strong light demanders. Like other timber species, the availability of light and space accomplished through a canopy opening leads to rapid re-growth (Cho, 2013). Interestingly, coppice regeneration often decreases the opportunities of seedling growth as resprouts rapidly close the canopy opening (Stocker, 1981).

In addition to the factors mentioned above, coppicing effectiveness is also affected by physical factors such as the method of felling, presence of splits in the stump, the creation of slight slopes in the stump (when felling) and the removal of climbers. Water may make its way inside the stump through splits/cracks therefore rotting the stump. This greatly affects resprout survival, especially if resprouts have not produced a root system of its own and are dependent on the stump root system.

In order to prevent the accumulation of water both inside and on top of the stump, fellers are recommended to create a slight slope in a direction when felling the tree. This will prevent or at least minimize rotting of the stump. The removal of climbers, other resprouts (different to the species) and even eliminating some of the competing resprouts will increase resprout survivability. In general, it is recommended that stumps be limited to one resprout each, which depending on the species may result in poles with diameters of 5cm-7cm after 2-3 years of felling (Felcker & Patch, 1996).

Coppicing is a complex process involving many inter-relationships between the stump and the resprout. In his study of *Acer rubrum* stump sprouts, Wilson (1968), reported on the growth habit from sprout origin to its first year. There is an initial rapid response to disturbance, described as high resprouting vigor, with rapid growth from external and buried buds. Once the resprout has leaves of its own, it is able to produce hormones which will act as a sink for materials such as carbohydrates and water moving from the stump and root system and into the resprout. Even though such movements of material are regulated by the leaves, its high growth rates are attributed to the increased flow of material from the already-developed stump and root system. Not taking advantage of the available resources, can prove costly to the resprout in terms or carbohydrate storage and energy needs. Since it is the leaf that produces the growth regulators, exposing the resprout to shade leads to a decreased growth. This decreased growth is often observed after the first year, when surrounding pioneer species or more dominant resprouts have closed the canopy gap that had been created after felling.

Regeneration through coppicing is common in neotropical forests (Evans, 1992). This coppicing ability of species can be used to reforest degraded areas due to its rapid growth, improved wood quality and resistance to diseases when compared to seed origin plantations (Bailey & Harjanto, 2004). Furthermore, regeneration through stump coppicing is important, especially in slow growing species as it can maintain the species in the forest for a period of time (Hartshorn, 1989). Since, vegetative regeneration is important in species with high seed mortality, browsing of resprouts should be controlled in order to reach maturity. The ability to coppice can be used to alleviate pressures exerted by international market demands especially on species with declining populations.

4.3.1 Coppicing in *Fabaceae/ Leguminosae*

The *Fabaceae*/*Leguminosae* family is the third largest family of angiosperms, after the *Orchidaceae* and the *Asteraceae*. It consists of more than 700 genera and approximately 20,000 species of trees, vines, herbs and shrubs. The family is characterized by its fruits, being legumes or pods, which open as it dries, thus releasing the seeds (Encyclopedia Britannica, 2019).

Species in the *Dalbergia* genus are considered to be strong coppicers. In a study of coppicing ability of *Dalbergia sissoo*, Goel & Singh (2008) observed coppicing in 98% of the assessed stumps during the first year of felling. A decrease in the mean number of resprouts was also noticed during the study period, where 4.59±1.65 resprouts/stump being observed during the first year and only 2.2±1.00 resprouts per stump were observed five years after felling. The authors attributed the decline in live resprouts per stump due to drying of the same as a result of competition for sunlight.

Even within the same species, coppicing ability can vary. In contrast to the results obtained by Goel & Singh (2008), Naugraiya & Sisodia (2015) assessed coppice growth of *D. sissoo* in India and noted a decrease in resprouts numbers from the coppiced stumps. From the study area, only 42% of stumps were able to produce resprouts. After six months stumps contained a mean of 4.95 resprouts per stump. The authors do not postulate the reason for the low coppicing intensity of the stumps, however, their research may suggest that coppicing is influenced by factors other than species, stump height, and diameter (age of tree prior to harvesting), and grazing by wild and domestic animals, as observed in some species (Olckers, 2011).

A similar case of strong coppicing ability can be noted in other species of the *Leguminosae* family. For instance, Olckers (2011) refers to the high coppicing power of *Leucaena leucocephala*, noting that its ability to resprout even after a fire or frost is key to its nature as an invasive species and that stumps need to be treated with diesel or herbicides to prevent it from coppicing. Strong coppicing ability can also be observed in the *Calliandra* genus, an ornamental tree in which stumps are cut at a height of 20-50 centimeters and resprouts are observed to reach a height of up to 3 meters within 6 months of felling (National Research Council, 1983).

Other studies suggest that species in the *Leguminosae* family have a strong coppicing ability. For instance, Mostacedo *et al* (2008) assessed root and stump resprouts in 31 species in a logged dry forest in Bolivia. The results demonstrated that out of the 31 species assessed, 27 resprouted, with species in the *Fabaceae* family being the most frequent stump and root resprouters. Furthermore, the results reaffirmed the general tendency of a negative relationship between the number of resprouts per stump and increasing stump height and diameter.

Similar results were obtained by Matilo, Akouehou & Sinsin (2017) for *Acacia auriculformis* in the Benin Republic. Even though the general tendency is for resprout numbers to decrease after the first year, results showed that resprout numbers increased after the first year for *A. auriculformis*. The authors note that the increase in resprout number is a result of the species not being able to complete its resprouting cycle in one season growth. A negative correlation between the stump diameter and resprout height was also evident and can be attributed to the stump physiological changes, with resprout mortality increasing in stumps with a diameter larger than 35 centimeters. Groover (2017) discusses such physiological and morphological changes, trees undergo with age. For instance, bud breaking is influenced by age, with the younger trees budding earlier and being more amenable to the development of adventitious roots than mature trees. Due to this ability, vegetative reproduction is highest during the juvenile stages.

The importance of sunlight to resprout growth and survival has also been noted by authors such as Solomon & Blum (1967), Felker & Moss (1996) and Cho (2013). Fast resprout growth especially in light-demanding species such as those in the *Dalbergia* genus, is essential for survival as resprouts need to reach a certain height before the canopy gap closes (Van Breugel, 2007). Luoga, Witkowski & Balkwill (2002) studied resprouting in response to light availability following land use change for the African tree species *Julbernardia globiflora (Fabaceae), Pterocarpus angolensis (Fabaceae*), *Combretum molle* (*Combretaceae*), and *Spirostachys africana (Euphorbiaceae)*. In this study, the authors assessed stumps in 64 plots, 34 being in a forest reserve and 30 in public lands. Results showed that overall species' response to coppicing was higher in the public lands than in the reserve, with 90% and 83% of stumps resprouting in the public lands and forest reserve, respectively. The same trend was observed when calculating mean number of resprouts per stump, with 5.1±1.9 (Standard error; S.E.) shoots in the public lands and 3.2±1.7 (S.E.) in the forest reserve. The authors note that although one might assume that regeneration and coppicing effectiveness would be higher in forest reserves, its increased effectiveness in public lands results from increased exposure to sunlight due to the greater number of canopy openings and to less grazing by wild animals.

4.3.2 Coppicing in Other Families

Stool coppicing is also an effective method of regeneration in other tree species. In contrast to the general tendency in studies seen above, in a study of hardwoods, Solomon & Blum (1967) noted that resprout production is at its highest at an intermediated stump diameter, with fewer resprouts being observed in smaller and larger stump diameters. In their study, Solomon & Blum (1967) investigated stump resprouting on four northern hardwoods: *Betula alleghaniensis* and *B. papyrifera* (*Betulaceae* family), and *Acer saccharum* and *A. rubrum* (*Acereaceae* family). In the case of *A. rubrum*, the number of resprouts per stump increased until the stump reached a diameter of 9 inches (22.86 cm) and resprout numbers started declining. A decline in mean height of resprouts was also noted in those stumps which had a higher number of resprouts and this is attributed to competition amongst them. In the case of *A. saccharum* a decline in resprout numbers was noted once the stump diameter increased over 6-ins. (15.24 cm), leading to the assumption that in some species coppicing effectiveness is highest at a specific stump diameter range.

A similar study was conducted by Rijks, Malta & Zagt (1998) who compared differently-aged resprouts of *Chlorocardium rodiei* (*Lauraceae* family) stumps that had been logged at different times (1, 5, 8 and 20 years ago) in Guyana. The authors assessed resprout numbers per stump and found that over 70% of the stumps in the 1, 5 and 8-year old sites had resprouts whilst in the 20-year-old site only 55% of the stumps had resprouted. Rijks *et al,* (1998) also note that the highest mean in number of live resprouts (10 resprouts) per stump was observed in the 5-year-old site, this which decreased in the 20-year-old site, indicating that resprouts undergo a self-thinning process.

Similar results were obtained by Wendel (1975), who assessed resprout growth in *Quercus rubra* (*Fagaceae* family*)*, *Quercus alba* (*Fagaceae* family), *Liriodendron tulipifera* (*Magnoliaceae* family),and *Prunus serotina* (*Rosaceae* family) in a forest in West Virginia. This research involved clear-felling of the above-mentioned species in two one-acre plots, to a stump height of 6-ins (15.24 cm). Resprouts were monitored at three different times: 5, 7 and 10 years after felling. Results demonstrated that the number of resprouts per stump decreased with increasing time, with only 3 to 7 resprouts of 21 to 42 resprouts remaining after the tenth year. The author also noted that resprouts underwent high mortality rates during the first five years, with 75-90% of resprouts drying by the tenth year. Wendel (1975) found no correlation between the height of the tallest resprout and stump diameter and reports a mean resprout height of 37.7-ins. (11.49 meters; m) at the tenth year for *P. serotina* and 19.6 feet (5.97m) in the case of *Q. alba.* In addition, resprout diameter growth was also observed with the most dominant resprouts having a mean DBH of 4.1 ins. (10.41cm) in *L. tulipifera* and 2.4 ins. (6.1cm) in *Q. alba.*

As previously mentioned, the harvesting method of the parent tree also influences resprout dynamics. Ducrey & Turrel (1992) studied the effects of four different cutting methods, “chainsaw at ground level,” “chainsaw at 15cm height,” axe, and “saut du piquet” (stump breaking) on *Quercus ilex* coppices in France. Results showed that four years after felling, there was no significant difference in resprout parameters (such as numbers, heights and diameters) between the axe and “chainsaw at ground level” methods. Interestingly, resprout mortality was the highest in stumps that were felled using the “saut du piquet” with resprout numbers, height and diameters decreasing when compared to the other methods. However, the authors note that this method can harm the stump physiology and weaken it. Although there was not much difference in the mean resprout height in those stumps cut with “chainsaw at 15cm” and those cut with “chainsaw at ground level” an increase in resprouts with small diameters was observed in those stumps cut at a 15cm height with a chainsaw.

Fire can also have an influence on resprout growth and overall resprout effectiveness. Stocker (1981) assessed the regeneration of commercial trees through coppicing after a fire in a forest reserve in Australia. The majority of the stumps assessed were observed with resprouts 23 months after a fire, with the *Lauraceae*, *Sapotaceae*, and *Myrtaceae* stumps presenting resprouts. Observations showed that after the fire it was mostly the stumps 20cm and under that readily resprouted as opposed to the larger stumps thus leading to the assumption that those younger stumps have the ability to regenerate in a vegetative manner even after a major disturbance such as a fire.

The effects of light on resprout growth in a *Quercus nigra* plantation was assessed by Gardiner & Helmig (1996). In this study, stumps in a heavily thinned area (60% basal area removal) and a lightly thinned area (40% of basal area removed) were assessed. Results demonstrated that after the 7th year, resprout survival in the heavily thinned site was of 76%, 23% higher survivability than those resprouts in the lightly thinned area. Although, it may be assumed that resprout self-thinning after a period of time is due to the availability of light, it is rather as a result of intra-sprout competition.

Similar thinning treatments were given to *Quercus pagoda* stumps in the Mississippi alluvial valley, where stumps were exposed to heavy (50-55% stocking removal) and light thinning (20-25% stocking removal). Results obtained by Lockhart & Chambers (2006) demonstrated no statistical difference in resprouting vigor between the two treatment areas. Although resprout numbers decreased with time, no statistical difference was found in stumps in the two treatment areas. The authors also observed an increasing resprout height with increasing stump diameter, regardless of the thinning treatment.

Interestingly, O’Hara & Berrill (2009), assessed resprout development of *Sequoia sempervirens* (a conifer capable of resprouting) at different light environments. Growth of the tallest of the sprout clumps was assessed 5 years after thinning (with the thinning having occurred in 2003 and measurements in 2007). Results demonstrated that there is a rapid decrease in resprout growth with decreasing light. In addition, although the species rapidly resprouts after felling, having up to 100 resprouts per stump, self-thinning increases in shaded or poorly lighted environments. The authors also note that since, self-thinning is part of the resprout survival process, self-thinning occurring in lighted conditions is a result of competition amongst the resprouts unlike self-thinning occurring in limited light environments which is a result of resprout weakening, resulting in the possible death of all resprouts. In addition, the study demonstrated high mortality rates of resprouts, with 85% resprout mortality after 4 years of thinning, with complete mortality of approximately 50% of resprout clumps. In conclusion, the authors mention that although stump age directly affects resprouting vigor, it is the availability of light that ultimately affects resprout growth and mortality.

Although in general, resprouting intensity decreases with increasing stump diameter, studies have found that in some instances and species, resprouting intensity is highest at an intermediate stump diameter. The number of resprouts tend to be the highest during the first year of felling and is marked by rapid growth of the same. The rapid growth is a result of competition for sunlight whilst the canopy gap is still open. Once the canopy is closed, resprouts tend to dry, leading to the high mortality rates experienced after the first year of felling.

4.3.3 Management of Coppiced Forests

Coppicing is the oldest form of silvicultural treatment (Matula, Svatek, Kurova, Uradnicek, Kadavy & Kneifl (2012). It entails felling trees in order to stimulate coppice growth from the remaining stump. Sprouting usually occurs immediately after the tree is felled with stumps having anywhere from 10-30 sprouts (Bane, 1999) and even 100 in the case of *Sequoia sempervirens* (O'hara & Berrill, 2009).

Over time, coppiced forests have been able to supply a variety of products such as timber, honey and (Buckley, 1992) charcoal whilst maintaining forested areas. Bane (1999), notes that coppicing, prolongs the life span of trees up to four times due to the same stump being used by resprouts. Diseased, or slow growing species, were typically used for fuelwood. According to Bane (1999), thinning of the overstory is an integral part of coppice management as it allows for sunlight to penetrate. Poles and timber were grown to the size needed in Pre-industrial Europe in order to decrease the wastage of lumber.

The interest on coppiced woodlands has greatly decreased over the past years, resulting in coppiced forests that have not been harvested for the past forty to fifty years (Buckley, 1992). Even though mature trees dominate the coppice forests canopy, in some species resprouting vigor is still high.

Matula, *et al.* (2012) assessed resprouting vigor on a coppice forest which was abandoned during the period of 1902-1920. Four hectares of the high forest were harvested in 2009. Results demonstrated that even though, the coppice forest had not been active for several years, coppicing ability was still high in the mature trees. Matula *et al,* (2012) note that even though coppicing ability varied amongst the assessed species, sessile oak (*Quercus petraea*), small-leaved lime (*Tilia cordata*) and European hornbeam (*Carpinus betulus*), all three species produced resprouts.

It has been noted however that resprouts undergo self-thinning after a period of time. In some species, such as *Dalbergia sissoo,* evidence of self-thinning was noted after 5 years (Goel & Singh, 2008) and even decades in the case of Coast Redwood *(Sequoia sempervirens)* (O'hara & Berrill, 2009). O'hara & Berrill (2009), refer to other research (e.g., Cole, 1983) that showed sprouts that have naturally self-thinned produce smaller-sized stems when compared to those sustained when artificial thinning is done. Beck (1977) assessed the effects of natural and artificial thinning on *Liriodendron tulipifera* (*Magnoliaceae* family), limiting thinned stumps to 1 resprout after 6 years after felling. Although the results showed a slight greater growth in DBH of resprouts in the artificially thinned stumps, it was not significant. Furthermore, the author notes that after 24-years, naturally thinned stumps contained a mean of 2.1 resprouts per stump leading to the assumption that due to its rapid natural thinning rates, artificial thinning of *L. tulipifera* is not necessary. However, Beck (1977) notes that early pre-commercial thinning of the *L. tulipifera* is recommended as it reduces the incidences of butt rots and limits the stump to 1 resprout prior to heartwood formation. However, in the case of *Tilia americana* (*Malvaceae* family), Godman (n.d) notes that artificial thinning should be undertaken as early and before resprouts reach a DBH of 3 ins (7.62cm) or more. Ducrey & Toth (1991) assessed the effect of thinning intensity on *Quercus ilex* and reported a positive relationship between thinning and repsprout DBH. The authors note that young resprouts had a mean annual growth of 6mm in control areas whilst the ones exposed to heavy thinning had a mean annual DBH growth double the size.

In their study of vegetative propagation, Nilum & Verma (1995) assessed vegetative reproduction of *Dalbergia sissoo* and *Acacia catechu* from branch cuttings and coppice (stump) shoots of *Prosopis cineraria*—all in the family *Fabaceae/Leguminosae.* Branch cuttings were categorized as 'softwood' and 'hardwood', softwood being green cuttings and the latter being brown and woody cuttings. Overall, *D. sissoo* rooted very well, with no need for the use of auxin, a growth regulating substance. Contrary to *D. sissoo*, *A. catechu* and *P. cineraria* auxins were applied in order to initiate rooting but had a success rate no larger than 50% and 25% respectively. In addition, this research demonstrates no rooting success in the 'hardwood' cuttings of *A. catechu* and coppices in the case of *P. cineraria*. The differences in the results can be attributed to the physiological nature of the cuttings. Although the general literature suggests that young shoot cuttings root easier, the authors observed minimal rooting success for *A. catechu* and *P. cineraria* even with the application of auxin.

The rooting ability of cuttings of *Populus alba* (*Salicaceae* family) was assessed by Harfouche, Baoune & Merazga (2007). Results show that rooting ability of cuttings from root suckers was the highest (97% rooting) and was followed by 96% from cuttings from sticklings. Ninety one percent of stump sprout cuttings displayed rooting ability. Although all cuttings were subject to hormonal treatment, IBA hormone, it showed little effect on the cuttings. For instance, evidence showed that although it facilitated root initiation it had little effect on root development.

4.3.4 Sprouting and Non-Sprouting Species

Since resprout regeneration is only possible in some species, authors such as Bond & Midgley (2003) and Poorter & Kitajima (2007) believe that there is a tradeoff to that ability. According to Bond & Midgley (2003), although faster seedling growth is evident, reduced tree height and fewer seed numbers are characteristics of species capable of resprouting. In addition, stumps experience carbohydrate loss when resprouts succumb to self-thinning, limiting the stump to 1 resprout regardless of the initial number of resprouts that were present in the stump. In addition, Knox & Clarke (2005) note that the root mass ratio is higher in resprouters than in obligate seeders with leaf mass ratio decreasing in resprouters.

Another tradeoff concerns the allocation of starch reserves within the plant. Carbohydrate storage also differs between sprouting and non-sprouting species, where large amounts of non-structural carbohydrates are found in the roots of resprouting species. Varma, Catherin & Sankaran (2018), notes that the ability to resprout after a fire as seen in some savannah tree seedlings is a result of the species ability to allocate belowground and in-root carbohydrate reserves.

In general, resprouting species tend to be capable of storing starch in their roots, whereas non-resprouters accumulate little to no starch on its roots. This accumulation of carbohydrate reserves by resprouting seedlings occurs at the expense of shoot and root growth (Bond & Midgley, 2003). Husen (2008) notes that the formation of shoots before roots in *D. sissoo* may be attributed to the carbohydrate reserves which facilitate the movement of auxin to the lower part of the cutting thus initiating the process of root formation, reiterating the importance of carbohydrate storage in coppicing species.

4.3.5 Coppiced and Non-Coppiced Lumber

Since sprouts grow from the root system of a previous tree, it may be assumed that coppiced wood shares the same characteristics (density, hardness, quality, appropriateness of use, among others) as non-coppiced wood or seed origin lumber.

According to Zobel (1992), silvicultural methods such as pruning, coppicing and others may influence the wood properties of the trees. However, in a research undertaken by Sharma *et al* (2005) the authors noted very few anatomical differences between coppiced and non-coppiced timber of Eucalyptus trees *(Myrtaceae* family) in India. Although the anatomical features of coppiced and non-coppiced lumber were similar (Figure 8), vessel frequency varies between the two.

Table 1 Wood quality of coppiced *Eucalyptus tereticornis*. Adapted from Wood Quality of Coppiced *Eucalyptus tereticornis* for Value Addition by Sharma, *et al* (2005).

	Non-Coppiced Wood	**Coppiced Wood**
Weight	Heavy	Heavy
Hardness	Very Hard	Very Hard
Porosity	Diffuse	Diffuse
Vessel Frequency	9-10	8-9

Similarly, Antwi-Boasiako, Anthonio & Frimpong-Mensah (2017) researched the mechanical properties of coppiced and non-coppiced *Pterocarpus erinaceus* (*Fabaceae*/*Leguminosae*), a species of rosewood native to the African continent, and noted several similarities between the coppiced and non-coppiced lumber. For instance, the Modulus of Elasticity,[9] Modulus of Rupture,[10] and strength properties of both coppiced and non-coppiced lumber are comparable—meaning that like un-coppiced lumber, coppiced lumber can be used for construction/engineering purposes.

In contrast, Zobel & Buijetenen (1989) make reference to Sesbou (1981) who noted a difference in the wood density of coppiced *Ecalyptus camaldulensis* (*Myrtaceae* family) when compared to the parent tree. Wood defects may be encountered in coppiced trees (this is evident in the Eucalyptus, Quercus and Fraxinus genera) as a result of multiple resprouts per stump. Since the stems lean away from each other with limbs occur on one side, tension builds up on one side of the tree, therefore causing defects (Zobel & Buijetenen, 1989). In the case of *Tectona grandis* (*Lamiaceae* family), commonly known as teak, Wang (2013) notes that the production and quality of coppiced wood is better than seed-origin teak. However, a drawback to this is that coppicing productivity decreases after several rotations.

[9] Ratio of stress placed compared to the strain exhibited along the length of the lumber
[10] Measure of strength before rupture

5.0 MATERIAL AND METHODS

5.1 Study Area

Belize is a Central American country bordered on the northwest by Mexico, on the east by the Caribbean Sea and on the south and west by Guatemala. Belize has an area of 22,800 square kilometers and is divided into six districts. The terrain is relatively low and flat in coastal and northern areas. The central and southern regions are characterized by mountainous areas with the highest point being Doyle's Delight at 1,124 meters.

Belize has two major seasons, dry and wet. The dry season is from December to May with April being the driest month, whilst the wet season is from June to November. Variability in precipitation is also experienced in country, with the southern part receiving the highest mean precipitation with an annual rainfall of approximately 4064mm. The lowest precipitation is received in the northern part of the country with an approximate rainfall of 1524mm (National Meteorological Service of Belize, 2019).

Due to its location in Central America and the Caribbean Sea, hurricanes and tropical storms often threaten the country. For the period of 2000-2016, a total of nine hurricanes and four tropical storms have affected the country (Consejo Belize, 2019).

According to the 2017 Statistical Institute of Belize census, the country has a population of 387, 879. Belize is divided into six administrative districts (see Figure 13). As of 2017, the most populated district was the Belize District with a population of 117, 196 and the least populated district being the Toledo District with 36,695 persons and having an unemployment rate of 3.9. Perhaps not coincidentally, as the sparsely populated Toledo District is also the least developed district in the country, in terms of physical infrastructure, and the poor income obtained from agriculture (Kairi Consultants Ltd, 2002). Furthermore, it is considered to be the poorest district in the country as 60% of its population falls below the poverty line (Wainwright & Zempel, 2017). Furthermore, as opposed to other countries, administrative districts are governed by national law, with laws being the same in all districts.

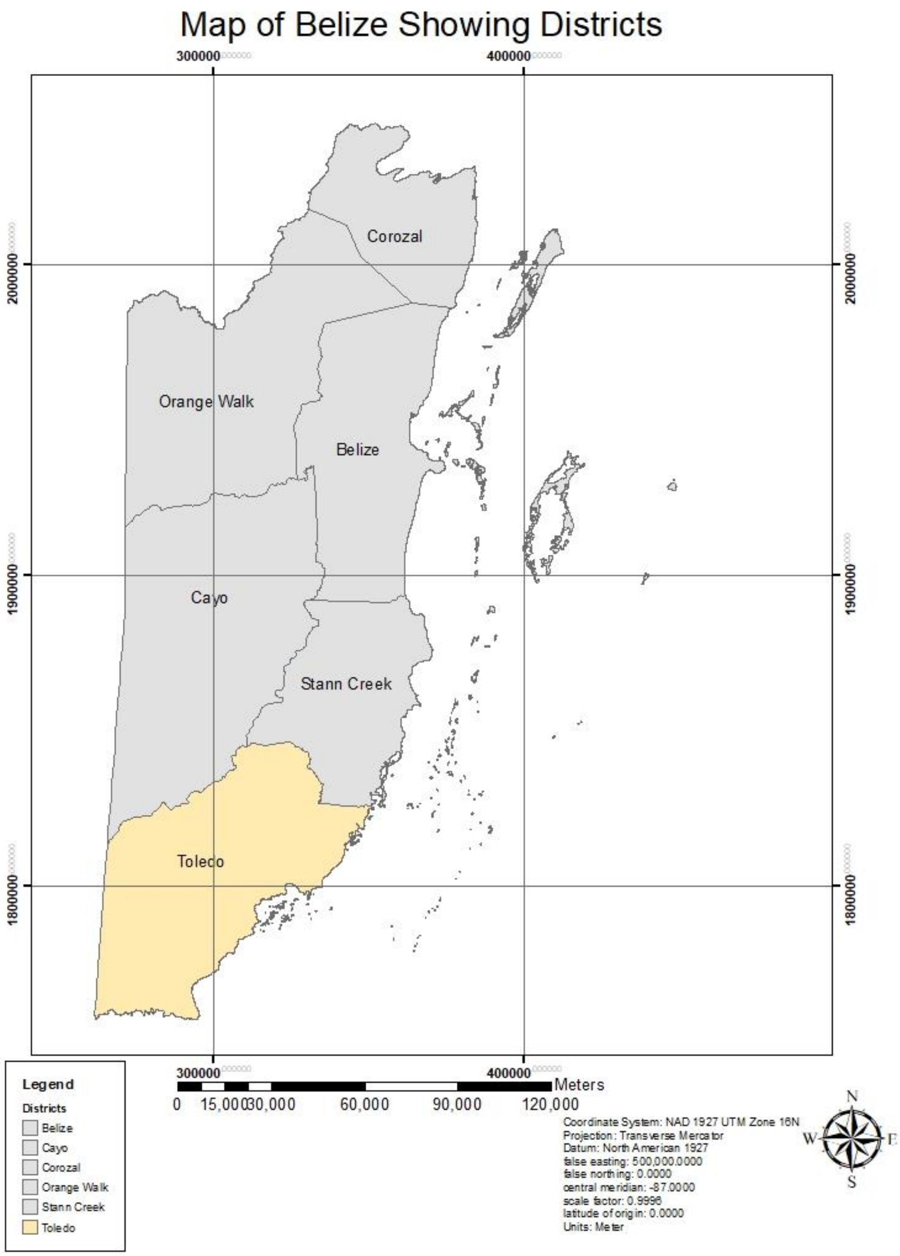

Figure 13 Map Showing Belize Districts, with the Toledo District being highlighted.

5.2 Data Collection

Since this research is based on a reassessment of the stump and coppicing aspect of the 2014 population status of *Dalbergia stevensonii*, it was necessary to re-collect data from the previous inventory plots. During the 2014 population assessment data was collected during the period of February to June 2014. During this research, data on coppicing was collected during a one-week period, that being October 8-12, 2018. Since, inventory plots were already established and coordinates were readily available, data collection was more efficient.

For the purpose of this research, a total of eight inventory plots were re-assessed and were chosen due to the availability of stumps (see Figure 14). Inventory plots run due west and measure 250m by 20m. Plots were then subdivided into ten subplots, each measuring 50m by 20m. During the 2014 population assessment, all trees were identified, with their respective height and DBH measured. Grade and crown forms were also assessed. Encountered stumps were also assessed and parameters such as stump diameter, number of coppices and height of all resprouts were measured.

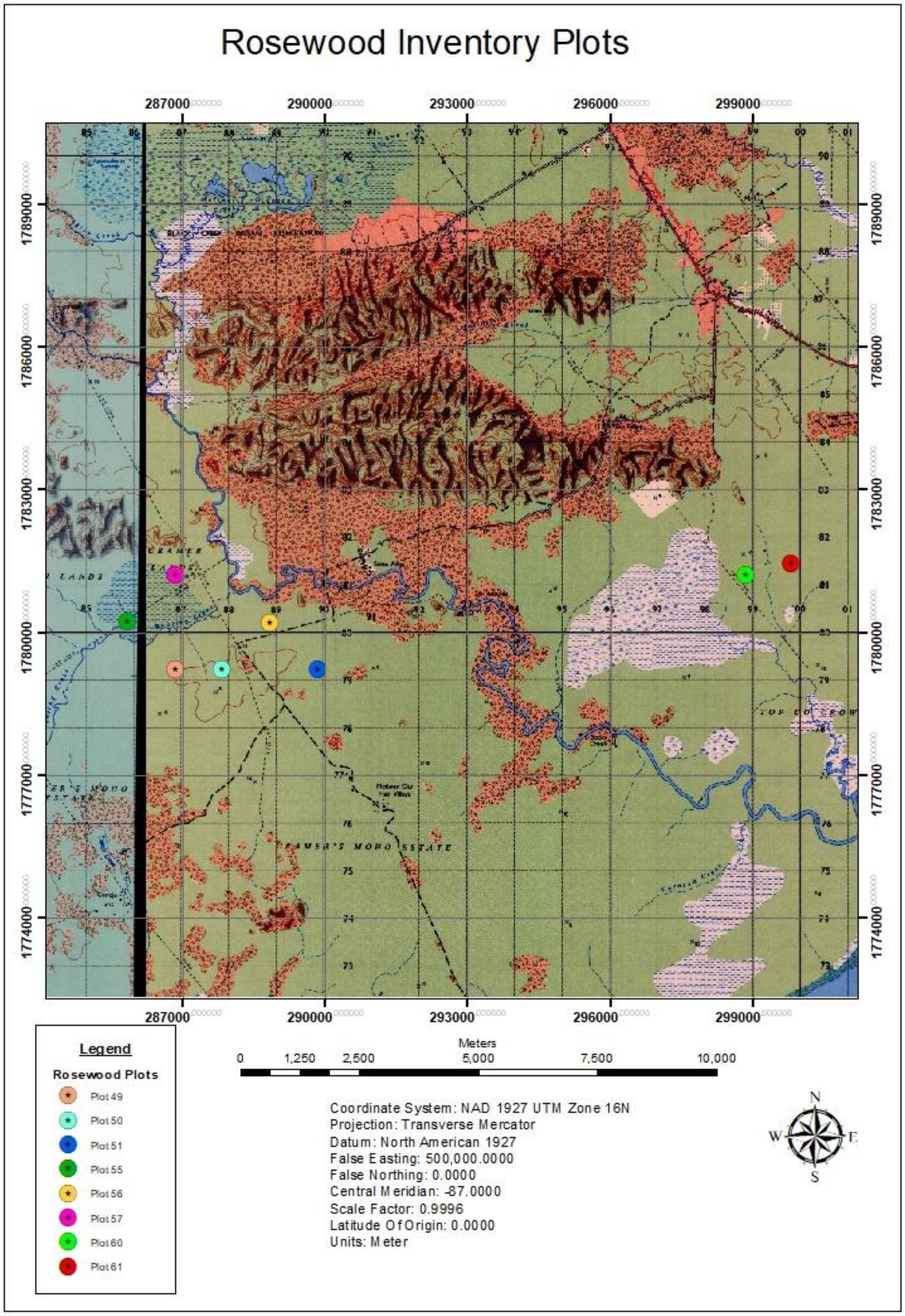

Figure 14 Topographic Map showing Rosewood Inventory Plots in the Toledo District

Once in the field, the exact location of the 250 x 20-meter inventory plot had to be located in order to assess the same stumps that were encountered during the 2014 population assessment (see Figure 15). This was done by searching for old markers and even trees that were recorded as being on the edges of the plots or in close proximity to the stumps.

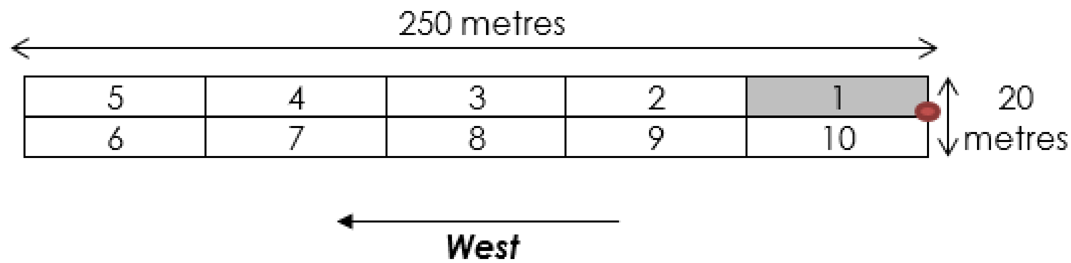

Figure 15 Image showing layout of rosewood inventory plots. Adapted from Job Control Document, Cho, P. (2014). Belize Forest Department Internal Document.

Since stumps were not tagged in the forest, a copy of the 2014 population assessment data was obtained in order to facilitate the identification of stumps through the identification of trees in close proximity. Stump diameter was also an effective parameter in the identification of stumps although in some instances, although it was noted that stump diameter in some cases was greater than those recorded during the 2014 assessment. This increase in stump diameter is attributed to cracks and even holes in the middle of the stump as a result of rotting.

Once the stump was located, stump diameter and stump height were measured. Two measurements were taken to obtain the stump diameter (Figure 16) those of the longest and shortest lengths of the stump cross section, inclusive of bark. Due to the fact that the trees were harvested four years (2014) or even more, little bark was present on the stumps. Overall stump diameter (measured as cm) was calculated as the mean of both measurements. In order to measure stump height (Figure 17) the leaf litter around the stump was removed and two different measurements around the stump were taken with a measuring tape. Two measurements were especially taken on stumps where one height was visibly higher than the other. Mean stump height (measured in cm) was calculated as the mean of the two measurements.

Figure 16 Stump Diameter Measurement
(Photograph taken by Mercedes Valdez)

Figure17 Stump Height Measurement
(Photograph taken by Mercedes Valdez)

In addition to stump height and diameter, the stump was assessed for resprouts. The number of live and dry resprouts with their respective heights (in meters) recorded. Furthermore, descriptions such as “High Forest”, “Low Forest” and “Swamp Forest” were used to describe the site.

5.3 Data Analysis

Data analysis was done with IBM SPSS[11] Statistics for Windows, Version 25.0. Stump frequency was tallied into various stump diameter size classes varying from 10.1-20.0 to70.1-80.0 cm and the data represented in a bar graph (Figure 18). The mean number of resprouts, both dead (dry) and live were tallied into various stump diameter size classes of <15, 15.0-24.9 to 65.0+ cm (Figures 19-20). Green and woody resprouts were categorized as living whilst dry resprouts regardless of the size were considered to be dead. Number of live and dead resprouts per stump were recorded in order to calculate percentage mortality of resprouts. Percent mortality was calculated using the following formula:

[11] Statistical Package for the Social Sciences

(Initial resprouts - Surviving resprouts)/Initial resprouts * 100%

The mean number of living resprouts per stump size diameter class was represented using a box plot (Figure 20). This was necessary in order to determine whether different stump diameter size classes sustain different mean number of live resprouts per stump. Although, from the box plot slight differences in mean numbers of live resprouts per stump diameter size classes were observed, a One-Way Analysis of Variance (ANOVA) was performed to determine whether differences were statistically significant.

Since some of the literature reviewed suggests some relationship between the mean number of resprouts per stump diameter and height, linear regressions were performed to test those parameters. When performing the linear regressions, entries with a "0" number of resprouts in both 2014 and 2018, were omitted to avoid skewing of the data. Linear regressions were performed for the following:

- Resprout height vs. stump height (Figure 21)
- Resprout heights vs. stump diameter (Figure 22)
- Percentage survival of resprouts vs. Number of total resprouts/stump (Figure 24)
- Percentage survival of resprouts vs. Stump diameter (Figure 25)
- Percentage survival of resprouts vs. Stump height (Figure 26)
- Percentage survival of resprouts vs. Resprout height (Figure 27)
- Percentage survival of resprouts vs. Height of dominant resprout (Figure 28)
- Number of live resprouts 2018 vs. Number of live resprouts in 2014 (Figure 30)
- Height of dominant resprout 2018 vs. Height of dominant resprout in 2014 (Figure 31)
- Mean resprout height 2018 vs. Mean resprout height 2014 (Figure 32)

In addition, a two-way ANOVA was used to test percentage survival of resprouts/stump in 2018 with light exposure and the presence of splits in the stump. This two-way Anova test was replicated in order to test the independent variables with the height of the dominant resprout in 2018.

6.0 RESULTS AND DISCUSSION

6. 1 Frequency of Stumps Per Diameter Size Classes

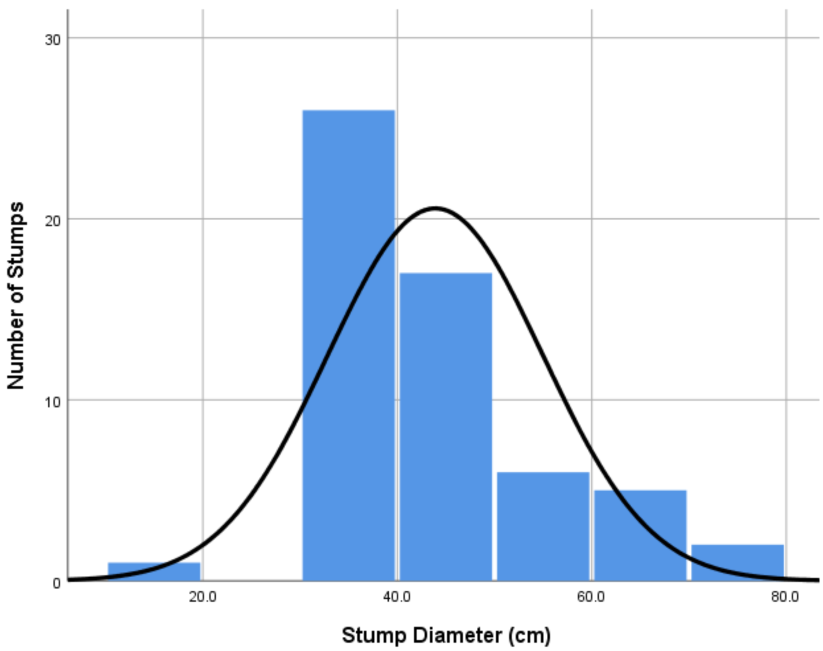

Figure 18 Graph showing frequency of stumps per stump diameter size class

A total of fifty-seven *D. stevensonii* stumps were assessed for the presence of resprouts. Since, stool coppicing entails stump resprout, it was assumed that the majority of the stumps encountered would be those of commercial size. Fifty-six of the stumps assessed had diameters above 30cm with one stump being less than 20cm in diameter. This was not unusual as in Belize, *D. stevensonii* is considered to be commercially sized at a diameter size of 30cm and above. In addition, the smaller diameter size classes do not have enough heartwood to be used for commercial purposes and are therefore spared by loggers. Cho (2016) notes that age can be determined by the growth rings, however this was not possible as stump growth rings were not visible. The assessed population was not that of a typical bell-shaped curve but rather an inverse J curve (see Figure 18). This inverse J curve is typical of natural forests (Njepang, 2015) and is indicative of an uneven-aged forest where younger trees grow under the shade of older trees (Wittwer, Anderson & Marcouiller, 1990). As a result, it is mostly the shade tolerant species that thrive in such forests.

Since the number of resprouts per stump is an indicator of the coppicing effectiveness/viability of each stump, it was necessary to plot the mean number of resprouts per stump diameter size class (see Figure 19). The mean number of resprouts plotted is inclusive of both live and dead resprouts. Dead resprouts are those which during the data collection were observed as dry and whose numbers were taken into account in order to be able to estimate the percentage survival of resprouts per stump, for the year 2018. Results demonstrated that the highest mean number of resprouts per stump, 3.83 ± 2.2 (standard error (S.E.)), n=12 was observed in the 45.0-54.9 cm diameter class. On the other hand, a mean number of resprouts, of 1.25 ± 1.25 (S.E.), n=8, were noted in stumps with a diameter of 55.0 centimeters and above. The results obtained differ from what has been observed by Stocker (1981) and Upadhyay (2009), who mention that in general resprout effectiveness, that is the number of resprouts per stump, decreases with increasing age due to the existence of old bark. Interestingly, the results demonstrate that resprouting effectiveness is highest at an intermediate stump diameter of 45.0 – 54.9 centimeters. This is similar to resprouting effectiveness found in other families, such as the *Sapindaceae* (Solomon & Blum, 1967).

To determine the extent of resprout survival, the mean number of live resprouts was calculated and plotted against diameter size class (Figure 20). The descriptive statistics are reported in Table 2 below. Results demonstrated similar mean numbers of live sprouts giving the impression that there is no significant relationship between resprout survival and stump diameter. The largest mean live number of resprouts/stumps, 1.25± 1.25 (S.E.) is sustained at the 55.0-64.9 cm and 65cm and above stump diameter size classes.

In general, when compared to the other smaller size classes, the higher diameter size classes, 45.0-65+ centimeters had the most live resprouts/stump (Figure 20) even though they had contained fewer overall number of resprouts (live and dead). The results support the idea that resprout survival is highly dependent on the number of resprouts competing in the stump. Poor resprout survival as observed in the smaller diameter size classes was also observed by Khan & Tripathi (1989) who assessed several species in burnt and unburnt environment and who attribute poor resprout growth to the few nutrient reserves present in the smaller diameter stumps.

6.2 Mean Number of Resprouts by Stump Diameter Size Class

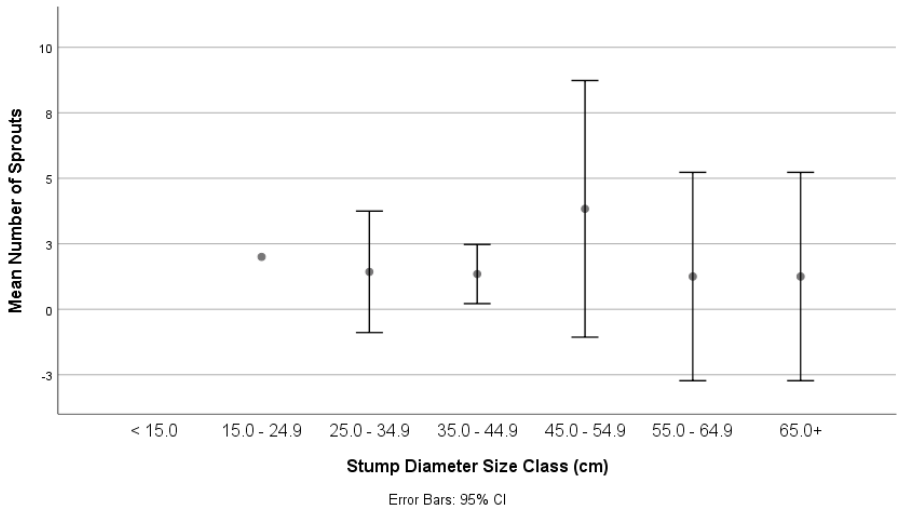

Figure 19 Mean number of resprouts (live and dead) per Stump Diameter Size Class

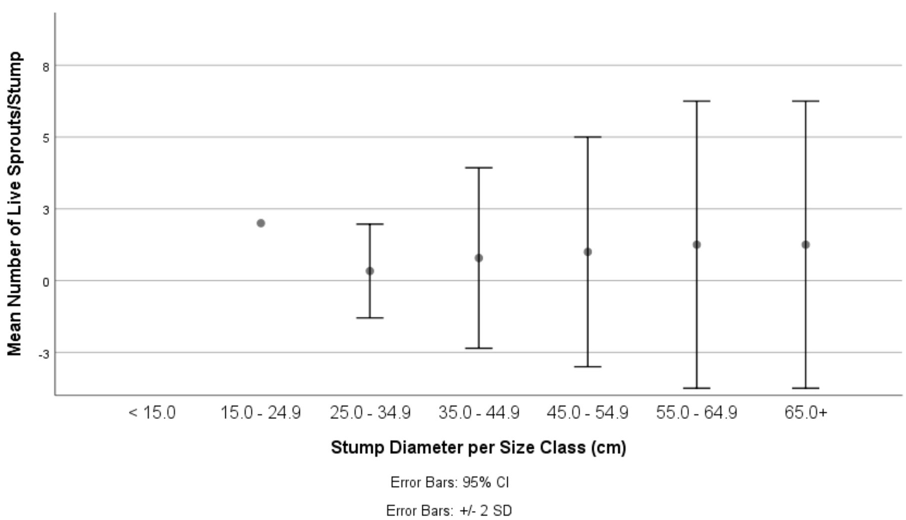

Figure 20 Mean Number of Live resprouts per Stump Diameter Size Class

A One-Way ANOVA with a Tukey test was performed to indicate whether or not there is any statistical difference among the mean number of live resprouts in each diameter size class (Figure 20). Although poor resprout survival was observed in small diameter size classes, the ANOVA test, F (5, 49) = 0.29, p = 0.91, indicated that there is no significant difference amongst the mean number of live resprouts per stump diameter size class.

Table 2. Descriptive statistics for number of live resprouts per stump diameter size class

	N	***M***	***SD***
15.0-24.9	1	2.00	-
25.0-34.9	6	0.33	0.816
35.0-44.9	28	0.79	1.57
45.0-54.9	12	1.00	2.00
55.0-64.9	4	1.25	2.50
65.0+	4	1.25	2.50

6.3 Relationships between Resprout Height and Stump Height and Diameter

Literature such as MacDonald & Powell (1983) and Khan & Tripathi (1989) mention a significant relationship between resprout heights and stump height and diameter. Plotting resprout height and stump height demonstrate dominant resprouts with heights of up to seven meters in stump heights between 20-30cm (Figure 21). A dramatic decrease in height of the dominant resprout is observed in stump heights larger than 30cm (Figure 21). Taller resprouts as observed in the lower stump heights coincides with Felker & Patch (1996) who mention that resprouts from lower stumps have straighter shoots due to it being less affected by physical factors such as wind and trampling.

Interestingly, a dominant resprout of more than 6m is observed on a stump height of 150 cm (one stump with that height in the assessed sample). This resprout can be considered an outlier as it was the only stump height above a 100cm that was encountered. On the other hand, it may also indicate that resprout heights are highest at the lower stump heights, decreasing at an intermediate stump height and again increasing at around the 75 cm and above stump heights. There is some research to support this theory. Stocker (1998) refers to Crist *et al*. (1983) who mention that taller stumps have higher food reserves and a larger area for the presence of dormant buds, thus explaining the increase in dominant resprout height in the taller stump heights. This however would not explain the decrease in resprout heights in the intermediate stump heights.

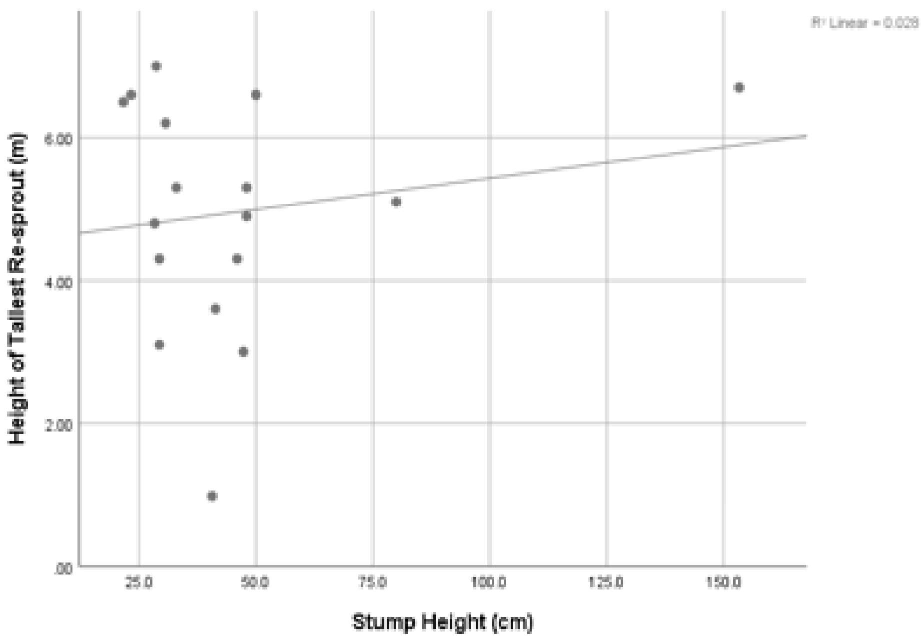

Figure 21 Graph showing height of dominant resprout vs stump height

A simple linear regression was conducted to predict the effect of stump height on resprout height and a weak positive relationship was found, b = 0.166, t (15) = 6.21, p = 0.523, with an R^2 of 0.028 indicating that there is no significant relationship between stump height and the height of the tallest resprout.

Results obtained contrast those obtained by Khan & Tripathi (1989) who assessed the effect of stump diameter and height on *Quercus* species and concluded that both parameters, those being, stump diameter and height have a positive correlation with the elongation rates of resprouts. Although results of the present research show that stump height is not a factor in the height of the dominant resprout, such resprouts are influenced by the time of felling and the availability of light. The effect of the availability of light on height of the most dominant resprout was assessed in Figure 23 below.

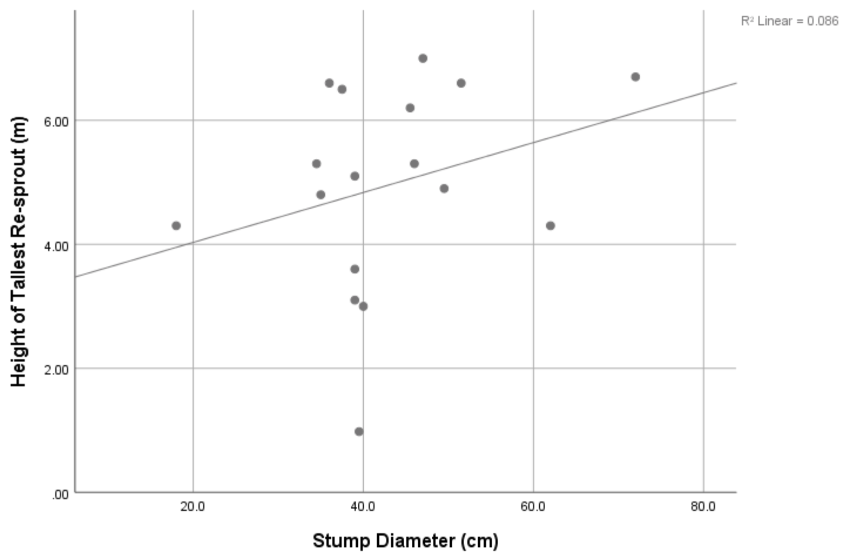

Figure 22 Graph showing height of tallest resprout vs stump diameter

Plotting the height of the tallest resprout against stump diameter (Figure 22) demonstrated that height increases with increasing stump diameter. An increase in the height of tallest resprouts was noted for stumps with diameters between 35.0-55.0 cm. A decrease in resprout height to under 5 meters is noted on a stump with a diameter larger than 60cm, with an increase in resprout height noted on a stump with a diameter larger than 65cm. This bimodal relationship is similar to that found by MacDonald & Powell (1983) in *Acer saccharum* in which they attribute the relationship to the phase change of the resprout but could still not explain a second increase in heights associated with larger stump diameters.

Poor growth in smaller size classes, that is, resprouts on the 30-40 cm diameter stamps can be attributed of the lack of nutrient supplies in the stump whilst in the stump above 60cm a decrease in growth can be attributed to the hormonal imbalances that come as a result of tree age. In their study of coppicing potential in *Eucalyptus nitens*, Little, van der Berg & Fuller (2002) note that aside from stump diameter, felling season, bark damage, seed origin and a reduction in starch reserves before felling greatly affect coppicing ability.

A linear regression showed that there is a weak positive relationship between height of the tallest resprout and stump diameter, b = 0.293, t (15) = 2.14, p = 0.254, with an R^2 of 0.086 thus showing that there is no significant relationship between height of the tallest resprout and stump diameter.

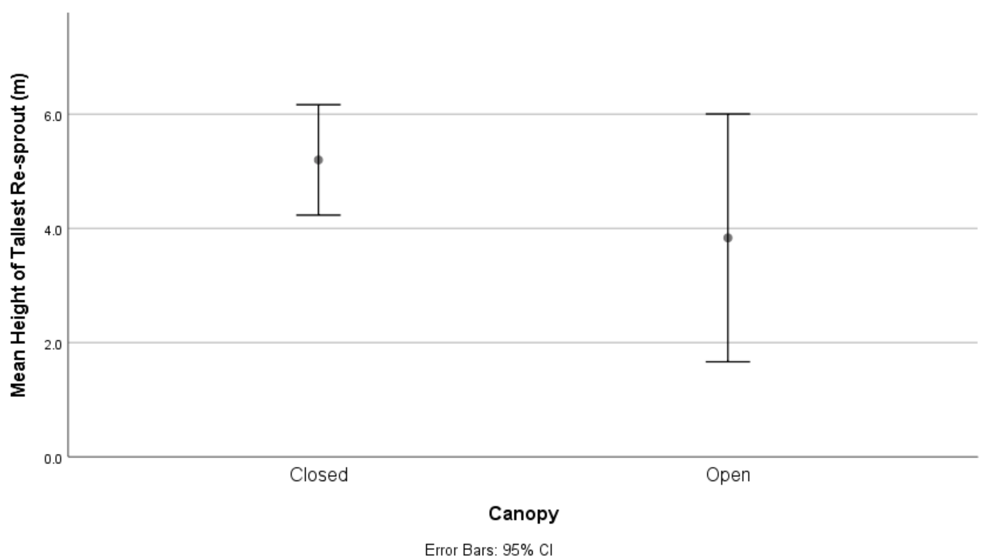

Figure 23 Graph showing the mean height of most dominant resprout plotted against canopy

Goel & Singh (2008), note that sunlight is an important aspect of resprout survival, with resprouts exhibiting rapid growth before the canopy closes. A simple linear regression was conducted to see if there is any relationship between height of the tallest resprout and the availability of light, that being an open or closed canopy. In this research, canopies with more than 50% canopy coverage were considered as closed canopy as it is already restricting the availability of light. The results are summarized in the simple error bar graph (Figure 23) where not much difference can be observed between the two categories of canopy cover. The mean height achieved by the tallest resprout under open canopy was of 3.96±1.63 (S.D.) and of 5.2±1.68 (S.D.) in closed canopy.

A linear regression analysis demonstrated that there is a medium negative relationship between the mean height of the tallest resprout and the canopy cover, b = - 0.329, t (15) = 12.22, p = 0.198, therefore there is no significant relationship between mean height of tallest resprout and canopy cover. Although, literature shows that in general light is a limiting factor in resprout growth, the results here demonstrate that the differences obtained per canopy cover is not significant. Moreover, in their study of *Sequoia sempervirens,* O'Hara & Berrill (2009) note a decrease in resprout heights with decreasing light availability after a period of 5 years. The results obtained can therefore be due to the time period (4-years) thus not having much influence on resprout growth or may be due to the sampling intensity, whereby six plots and 14 stumps were found under closed canopy whilst only two plots and 3 stumps were found under an open canopy.

A scatter plot was used to show the relationship between the percentage survival of resprouts against the total number of resprouts (live and dead) that were observed per stump (Figure 24). Results demonstrated a percentage survival of 71% ±39.6 % with a mean number of resprouts of 5.35±5.91 per stump. A dramatic decrease in resprout survival is observed in stumps with 5 resprouts and more and is a result of self-thinning. This decrease is attributed to the strong competition for light and nutrients especially at the seedling stage.

The Pearson correlation resulted in a significant negative relationship between the percentage of survival of resprouts and the number of resprouts, $b = -0.630$, $t(18) = 9.701$, $p = 0.003$, with an R^2 of 0.396. In general, there is a decrease in the number of resprouts over time. For instance, Goel & Singh (2008), note a decrease from 4.59±1.65 resprouts in *D. sissoo* at the first year after felling to 2.2±1.00 after five years. In addition, Upadhyay (2009) recommends artificial thinning of competing resprouts. Results obtained by this research show that stumps should be thinned after a period of not less than 4 years, limiting each stump to no more than 4 of the most dominant resprouts. If in the case that excess resprouts are still viable and have not succumbed to the self-thinning process, those can be tested for rooting ability.

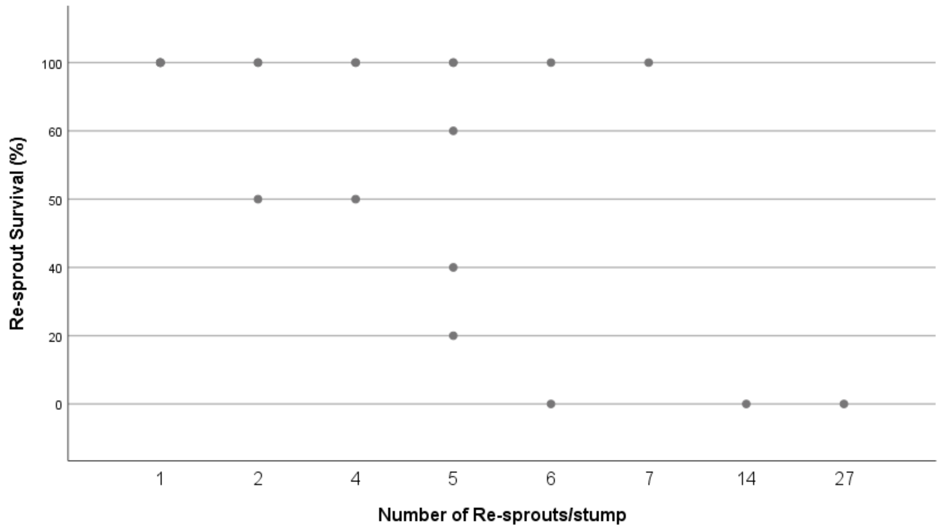

Figure 24 Graph showing percentage of resprout survival plotted against the number of resprouts per stump

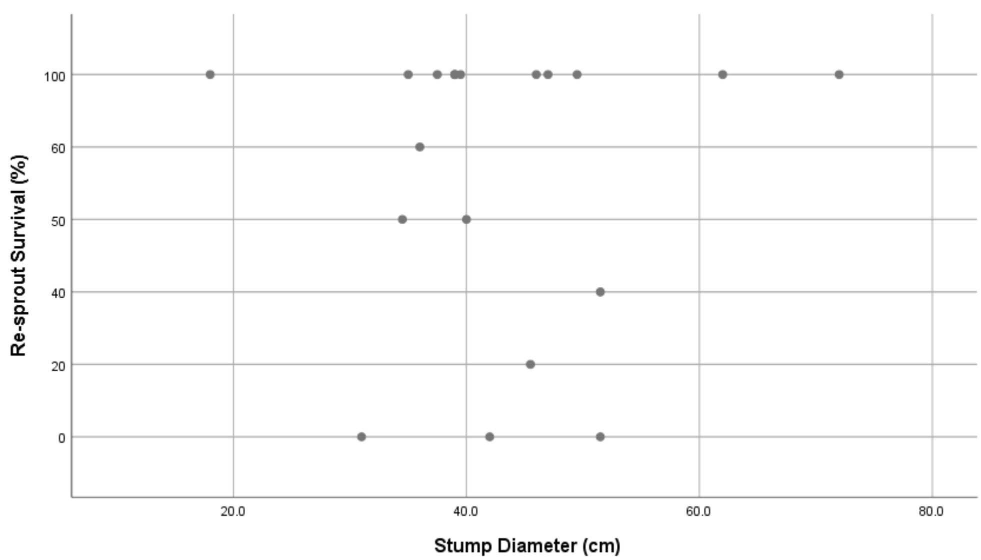

Figure 25 Graph showing percentage resprout survival plotted against stump diameter

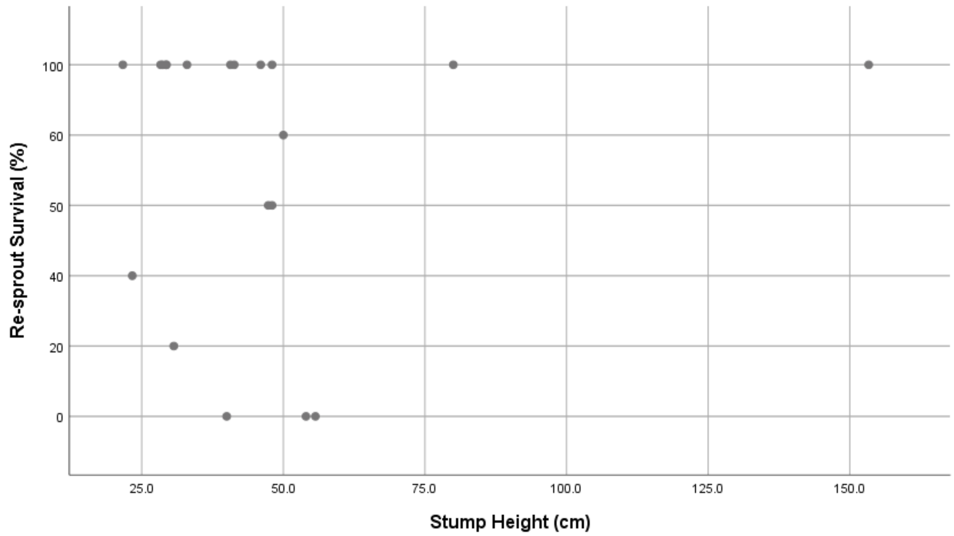

Figure 26 Graph showing percentage resprout survival plotted against stump height

Stumps undergo physiological changes as a result of increasing age (Khan & Tripathi, 1986), therefore it may be assumed that those differences affect resprout survival. From Figure 25, it can be observed that resprout survival can be variable throughout the different stump diameter size classes. According to the data, 100% of resprout survival (live and dead resprouts) can be attained regardless of the stump diameter (Figure 25) leading to the assumption that more than 4-years is needed before differences in resprout survival are evident. A decrease in percentage of resprout survival is more pronounced between the stump diameters of 40.0-55.0cm but this may be due to the majority of the sample size being in between those stump diameters.

A Pearson correlation was conducted to see the relationship between resprout survival and stump diameter and resulted in a weak positive and non-significant relationship, b = 0.054, t (18) = 1.75, p = 0.821 with an R^2 of 0.003. This demonstrates that even though stump diameter is not a factor influencing resprout survival, other factors such as the number of resprouts per stump affect resprout survival (as seen on graph Figure 24).

The mean percentage survival of resprouts was of 71% ±39.60 (S.D.) with a mean stump height of 46.4±28.67 (S.D.) (Figure 26). No statistically significant relationship was obtained when a linear regression was used to test the relationship between resprout survival and stump height, b = 0.062, t (18) = 3.806, p = .794 with an R^2 of 0.062. Again, resprout survivability varies, suggesting that it is influenced by external factors, such as the number of resprouts, and nutrient and light availability. Although literature suggests that resprout survivability increases with an increased stump height as it decreases the probabilities of grazing, the results show there is no relationship between the two variables. For this research, no evidence of resprout grazing was observed, yet its absence cannot be ruled out as data specifically for grazing was not collected. In addition, as survival is variable, the assumption that low cut stumps are often subject to microbial decay (Khan & Tripathi, 1986) causing resprout mortality cannot be adopted either. Reason to this being that this research showed no statistical difference in resprout survival and stump height. In addition, resprout mortality due to microbial decay cannot be completely ruled out as few stumps presenting minimal decay were observed but were not at an advanced stage to be able to cause resprout mortality.

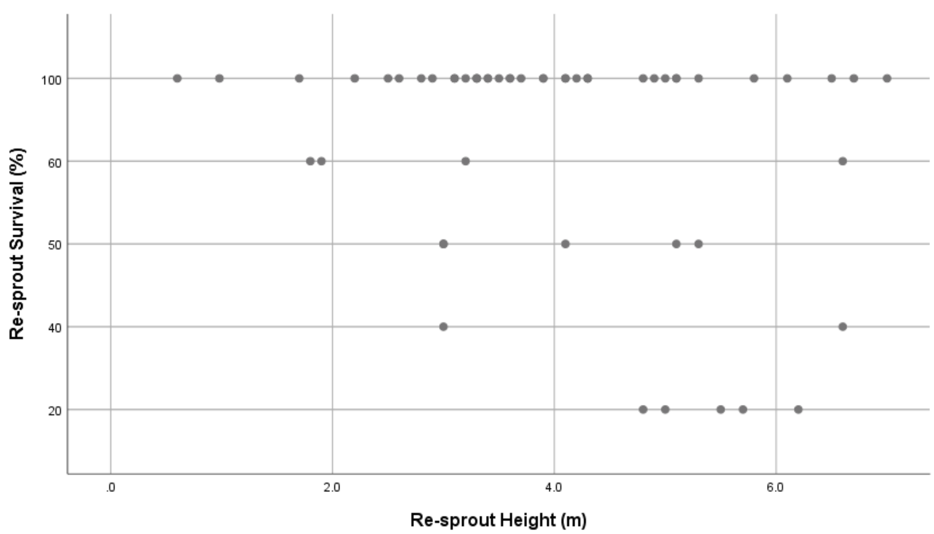

Figure 27 Graph showing resprout survival percent vs resprout height

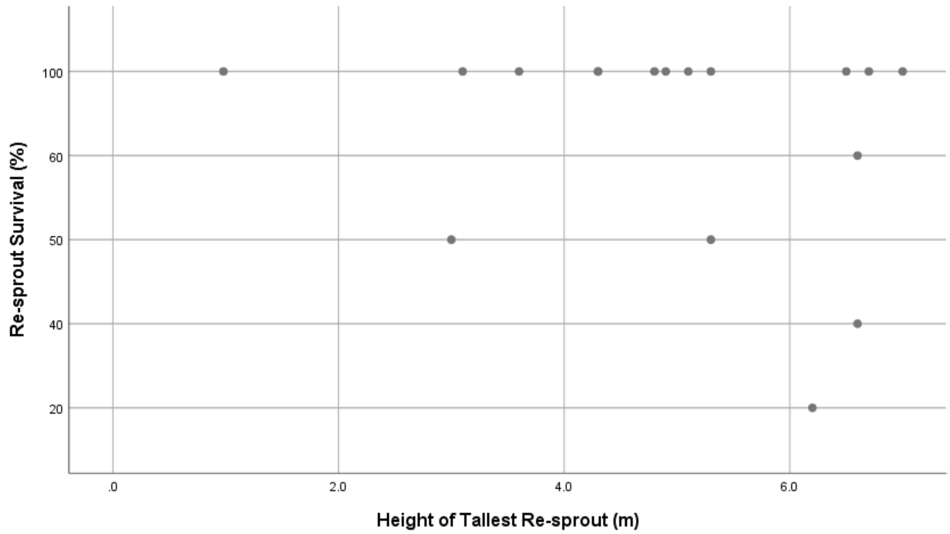

Figure 28 Graph showing percent of resprout survival vs height of the most dominant resprout

Plotting resprout survival against resprout height (Figure 27), demonstrates that survival is at a 100% on resprouts with a height of one meter. Percentage survival then varies anywhere from 50%-100% in resprouts with heights between 1 and 3 meters.

A notable decrease in resprout survival is evident in those resprouts with a height larger than three meters. Interestingly, a 100% resprout survival was noted in those resprouts with a height between 0.5m to 6.7m supporting the assumption that after a period of time, self-thinning occurs. A simple linear regression was conducted to test the relationship between the two variables and resulted in a weak negative correlation, b = -0.243, t (53) = 9.382, p = 0.073 with an R^2 of 0.059.

Literature suggests that the most dominant resprouts are the most likely to survive. That assumption was evident when survival was plotted against the dominant resprout (Figure 28) resulting in 100% survival. Although the data shows that most surviving resprouts were dominant (with a height of six meters and above), there was still some evidence demonstrating mortality of dominant resprouts. This implies that although a resprout is the most dominant, it may still be affected by external factors such as the decreased flow of nutrients from the stump and root system. The dominant resprout may also be subject to herbivory. A simple linear regression test of the two variables resulted in a weak negative relationship, b = -0.256, t (15) = 4.810, p = 0.322 with an R^2 of 0.256.

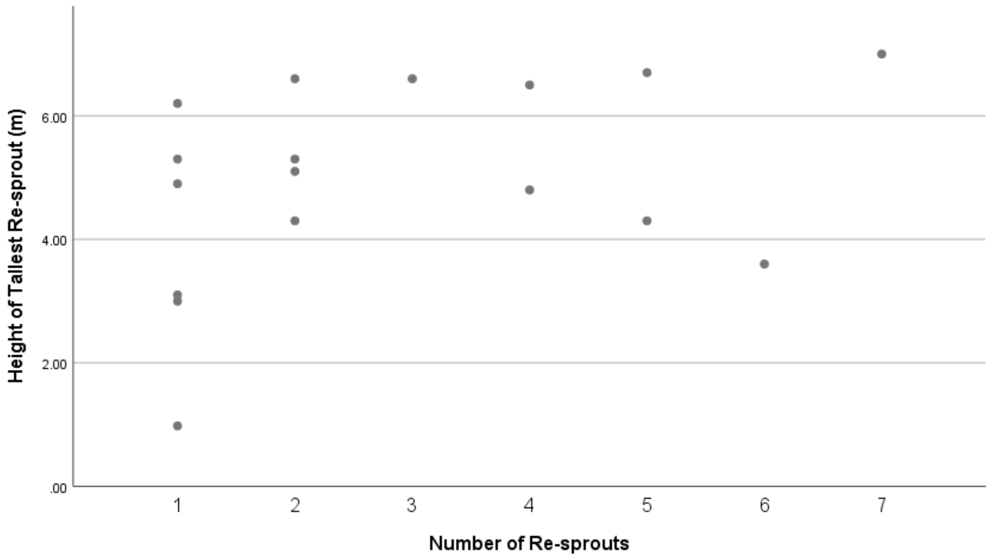

Figure 29 Graph showing height of the tallest resprout plotted against the number of resprouts per stump

Since the literature notes that resprout growth is highest during the initial stages as a response to competition for sunlight, the height of the tallest resprout was plotted against the number of resprouts present in the stump (Figure 29). The descriptive analysis denoted a mean height of the tallest resprout to be 4.96±1.63m (S.D.) with a mean number of 2.82±1.98 (S.D.) resprouts per stump.

The data demonstrates that the height of the tallest resprout can vary when the stump has only one live resprout, with that resprout height being between 1.0 to 6.0 meters. This may be as a result of the lack of competition the resprout undergoes when multiple sprouts are present. The height of the most dominant resprout can either increase or decrease in stumps with 4 or more resprouts. This might be indicative that resprouts are at thinning stage, whereby some succumb while other thrive. Similarly, looking at overall survivability of resprouts in this research, maximum height of the most dominant resprout is approximately at 6 meters with an optimal number 4 resprouts per stump.

A simple linear regression between the height of the tallest resprout and the number of resprouts was done and resulted in a medium positive correlation with b = 0.363, t (15) = 6.06, p = 0.153, resulting in a non-significant relationship between the two variables.

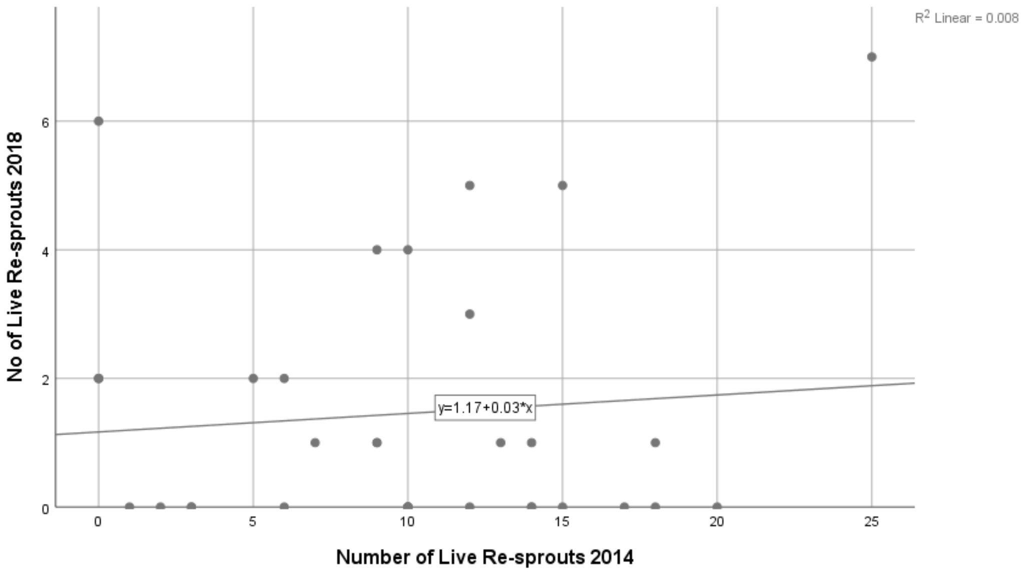

Figure 30 Graph showing number of live resprouts 2018 vs number of live resprouts in 2014

In general, the number of resprouts declines after a period of time. During the population assessment (2014), stumps had a mean of 9.97 ±6.21 (S.D.) resprout, this number which dramatically decreased to 1.45±2.0 (S.D.) during the reassessment in 2018 (Figure 30). This trend is similar to research by Moreno & Oechel (1991) and Catry, *et al*. (2010), who observed that although coppicing ability may be high during the initiating phases, many of the resprouts do not survive. Although resprout mortality can be attributed to light competition, according to Pausas (1997) it may also as a result of other factors such as the parent tree size and the presence of nutrient and carbohydrate stocks at the time of resprout recruitment.

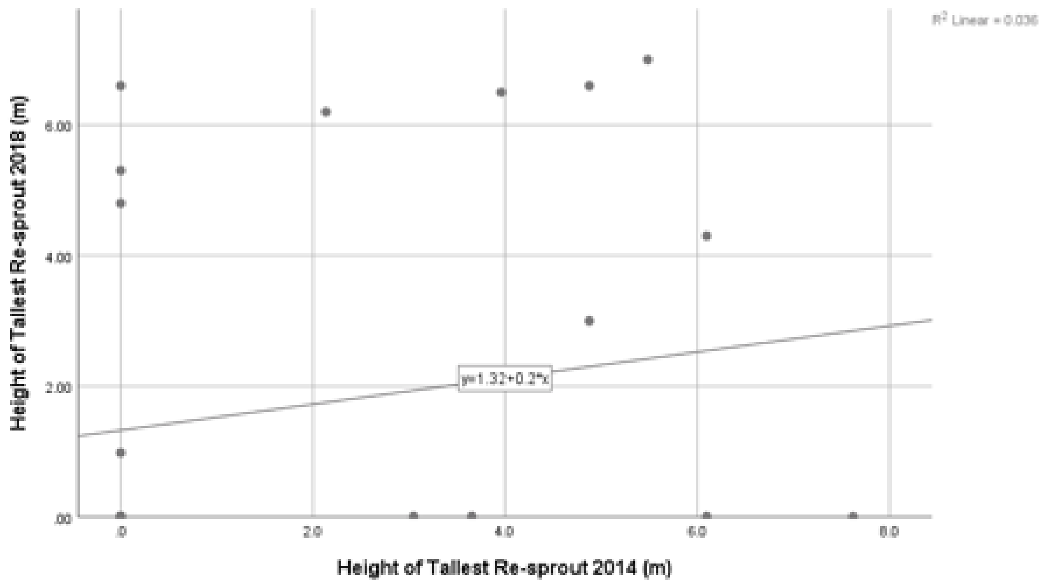

Figure 31 Graph showing height of most dominant resprouts in 2014 and 2018

Plotting the heights of the most dominant resprouts in 2014 and those in 2018, there is a notable decrease, but not statistically significant, in mean number of resprouts from the 2014 assessment was noted (Figure 31). The scatter graph depicts more variable heights of the most dominant resprouts in 2018 when compared to 2014. At the same time, the descriptive statistics demonstrate that the most dominant resprouts in 2014 had a mean height of 2.22±2.5 (S.D.) meters and a mean height of 1.76±2.7(S.D.) meters in 2018, indicating a decrease in resprout heights. This decrease in height was expected as resprouts undergo rapid growth during the first months in order to obtain sunlight before a canopy closure. A simple linear regression was conducted to see if the height of the dominant resprout in 2014 influenced the height of the dominant resprout in 2018 but resulted in a weak positive relationship with, $b = 0.189$, $t(27) = 1.98$, $p = 0.327$ thus, a non-statistically significant relationship. Interestingly, few stumps which possessed zero resprouts in 2014, experienced resprout growth with heights reaching up to six meters in 2018. An increase in resprout number at the second re-measurement was also noted by Matilo, Akouehou & Sinsin (2017) after assessing *A. auriculformis* who suggested that the species was not able to complete its resprouting cycle in one season growth.

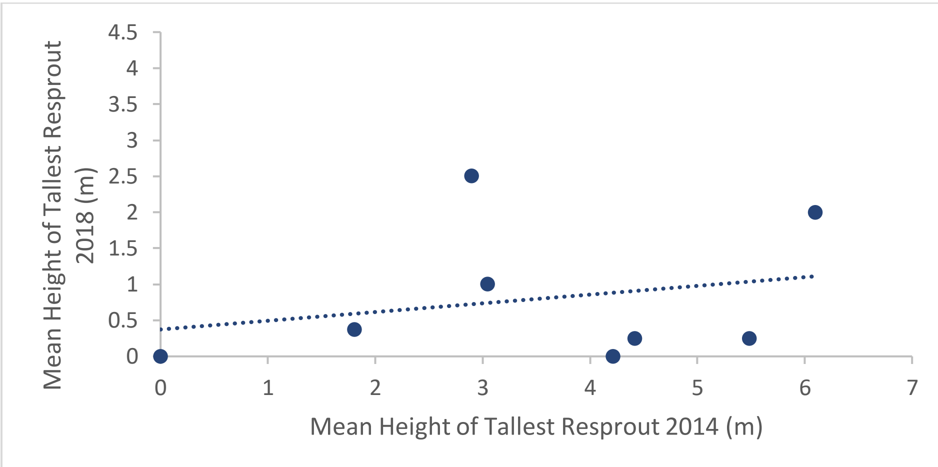

Figure 32 Graph showing mean heights of most dominant resprouts in 2014 and 2018

Similar results were obtained when the mean height of the dominant resprouts in 2014 and 2018 were plotted against each other (Figure 32). A mean height of 0.79 ±0.95 (S.D.) meters is observed in dominant resprouts in 2018 and a mean height of 3.4±1.99 (S.D.) meters during the 2014 assessment.

According to the literature, high initial resprouting vigor does not guarantee survival of those resprouts. For instance, authors such as Moreira *et al*, (2012) note that despite having a high number of resprouts during the initial stages, the majority of those will not survive due to the lack of sunlight. Even those that do survive, undergo through a stage of self-thinning after a period of several years in order to decrease competition amongst them.

High mortality for resprouts is expected due to the inter-competitions amongst them. In addition to competition, resprouts are subject to trampling, grazing and herbivory from wildlife. O'Hara & Berrill (2009) note that self-thinning is part of the resprout survival process. They note that self-thinning in environments with limited light as a result of weakening whilst those in lighted environments undergo self-thinning as a result of light suppression from taller resprouts. In addition, Felcker & Patch (1996) recommend that stumps be limited to one resprout in order to avoid competition and promote growth of the same. Natural and artificial self-thinning results in high mortality of the resprouts. In this study, resprouts did not show signs of human disturbance thus the assumption that natural thinning occurred. During the 4-year period (2014-2018), the mean percentage mortality of the resprouts is estimated to be at approximately 88.58% ±15.78% (S.D.) resulting in approximately 11.42% survival rate of resprouts. Although the low survival rate may give the impression that resprout is not an effective form of regeneration, one must take into account that according to the literature only one or two resprouts per stump are needed for successful regeneration to occur. Even so, as in the case *of Eucalyptus camaldulensis*, the presence of two resprouts on the stump greatly affect its lumber by producing defects as a result of leaning stems (Zobel & Buijetenen, 1989).

As previously mentioned, some species are not able to finish resprouting in one season growth. Although, the studies on the *Dalbergia* genus that were reviewed mention no such increase in numbers, the feature is noted in *Acacia auriculformis (Fabaceae* family). Very few instances of increases in resprout numbers per stump were encountered when the 2018 data was compared to the 2014 data. The analysis showed a mean increase in numbers of 0.19 ± 0.90 (S.D.) resprouts for the 4-year period. The increase in resprout numbers was observed in stumps which in 2014 had no resprouts. The increase after the 4-year period may be due to the few numbers of buds or even small nutrient reserves in the stump root system.

7.0 CONCLUSIONS

In general, it was noted that effective regeneration by coppicing is probable but additional research is needed, especially in the long-term monitoring of resprout growth to mature trees. Long-term monitoring is needed for the species especially due to the fact that there is little information on the biology of the species and therefore growth rates cannot be efficiently estimated.

Results have shown that although initial resprouting vigor is high it does not guarantee survival of all the resprouts. Resprout mortality further increases given the fact that self-thinning occurs in order to decrease competition amongst resprouts. No significant difference was noted in the number of live resprouts per stump diameter size class, suggesting that stump diameter is not a predictor of the number of resprouts a stump can sustain.

Although literature suggests that the height of resprouts increases with decreasing stump height, the data demonstrates this to be partly true for the species, where resprout heights increased in the lower stump heights, but decreased at the intermediate stump heights and again increased with the taller stumps. A similar bimodal relationship was observed for the height of the most dominant resprout and stump diameter, although the relationship between the two variables was not significant. In regard to the effect of light on resprout growth, this research showed that there was no significant relationship between resprout growth and the availability of light. Those results may be due to the sampling intensity where by most stumps were found under closed canopy or due to the short period of time (4-years) following presumed felling.

Although the percentage survival of resprouts varied, resprout survival generally decreased with an increase in the number of resprouts present in the stump. No relationship was found between resprout survival and stump height and diameter. In addition, a weak negative relationship between resprout survival and resprout height was found. Survival of the most dominant resprouts varied, suggesting that those are still subject to external factors such as nutrient and light availability and even herbivory as has been observed in other species. Importantly, the data demonstrated that the height of the dominant resprout greatly varied when it is the only resprout in the stump.

In general, mean resprout numbers per stump for 2018 decreased when compared to the stump data obtained during the 2014 assessment. The same applies for the height of the most dominant resprout in 2014 and 2018, where height of the most dominant resprout was greater in 2014. Overall, when comparing resprout survival in 2014 and again in 2018, it was noted that there is high resprout mortality. This was expected given that literature makes mention of self-thinning and encourages limiting stump to one resprout in order to promote faster growth and an increase in resprout DBH.

An increase in the number of resprouts was also observed in a few cases, although it was minimal. The increase suggests that although coppicing vigor of a stump is minimal immediately after felling, resprout growth in numbers may still occur after a period of time. Further replication of this research, especially in the long term is needed in order to determine if resprout survival and its subsequent growth to mature trees is possible.

8.0 RECOMMENDATIONS

As previously mentioned, the aim of this research is to provide baseline information on resprout survival in the *D. stevensonii* population in the Toledo District. Results have shown that continuous monitoring of resprout growth is needed, especially in those harvested in community concession areas. Results demonstrate that stump height and diameter do not influence resprouting vigor, with resprouting occurring even in those stumps lower than commercial DBH.

In addition, since resprouts go through a process of self-thinning, artificial thinning is recommended to commence at approximately 4 years after harvesting by limiting stumps to no more than 4 resprouts. Although the best approach is to limit resprout numbers to one per stump, (that one resprout being the most dominant sprout) the optimal number recommended is of 4 resprouts as extensive research is needed to determine survival probabilities of even the most dominant resprouts. Not only will artificial thinning increase survival of resprouts but will also increase resprout diameters. Since the maximum resprout height achieved during the time of this research has been 6m, it is suggested that resprouts under 6m heights be subject to artificial thinning.

Furthermore, although assessing stump shoot (resprouts) was not in the scope of this research, the reviewed literature suggests that resprouts are capable of initiating rooting once it is cut from the stump, but again extensive research is needed to verify if this is possible in *D. stevensonii* resprouts. It is therefore recommended that in the case that green shoots are obtained when artificial thinning is carried out, that such resprouts be tested for rooting capabilities.

Additional literature suggests that lighted environments enhance resprout growth and survival. It is therefore recommended that some thinning of the canopy occurs especially after artificial thinning of resprouts has occurred. *D. stevensonii* is a light demanding species, giving the impression that even after initial growth, resprouts are highly dependent on light. When resprout growth was assessed against the available light, results showed that there was no significant difference between the obtained results but may be due to the sample size being larger in closed canopy areas. In addition, results obtained may be as a result that a longer time period is needed to determine the effects of light on resprouts. If replication of this research occurs, it is recommended that attention is given to assessing similar sample sizes in open and closed canopy environments. It is also important that both environment types, that is open and close canopies, be properly distinguished from each other. In addition, attention must be given to microbial decay in stumps and its effect on resprout survival. During the course of this research, minimal decay was evident in a few stumps.

The need for continuous monitoring and ongoing research is again reiterated, especially since there is minimal research on the species in Belize. Due to its rarity, commercial value and ecological role, special attention should be given to investigating its regeneration. The needed monitoring can be undertaken with the assistance of the community forestry groups, which should have at their best interest, the successful regeneration of rosewood.

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Proposal: Inclusion of 13 timber species in the *Dalbergia* genus in Appendix II. Convention on the International Trade in Endangered Species of Wild Fauna and Flora (CITES). Proponent: Mexico. CoP 17 Prop. 54

Proposal: Inclusion of *Cedrela* genus in Appendix II. Convention on the International Trade in Endangered Species of Wild Fauna and Flora (CITES). Proponent: Ecuador. CoP 18 Prop. 57

Proposal: Inclusion of *Dalbergia* genus in Appendix II with exception to the Species included in Appendix I. Convention on the International Trade in Endangered Species of Wild Fauna and Flora (CITES). Proponents: Argentina, Brazil, Guatemala and Kenya. CoP 17. Prop. 55

Proposal: Inclusion of *Dalbergia stevensonii* in Appendix II. Convention on the International Trade in Endangered Species of Wild Fauna and Flora (CITES). Proponent: Belize. CoP 16. Prop. 62

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ANNEX A

Rosewood Stump Data Sheet

Recorder _________ Easting _________ Plot No ___________

Date _________ Northing _________

Subplot No	Stump No	Species	Stump Diameter	Stump Height	No of resprouts	No of live sprouts	Resprout height	Resprout diameter	Comments

Description of forest ______________________________