Dalbergia stevensonii in Golden Stream Corridor Preserve and Maya Mountain North Forest Reserve

Summary of Ya'axché Conservation Trust's 2013-2019 research and monitoring under the Global Trees Campaign Project, "Supporting Rosewood Conservation in Belize"

Prepared for the Belize Forest Department
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List of Acronyms

ANOVA	Analysis of Variance
CAI	Current Annual Increment
CITES	Convention on International Trade in Endangered Species
GSCP	Golden Stream Corridor Preserve
MAI	Mean Annual Increment
MMNFR	Maya Mountain North Forest Reserve
GTC	Global Trees Campaign
CAP	Conservation Action Plan
DBH	Diameter at Breast Height

1.0 Acknowledgements

Much appreciation is given to the Ya'axché Conservation Trust ranger team, without whom the data presented in this report would not be available. Special thanks goes to the research and monitoring ranger team members Anignacio Makin, Octavio Cal, Andres Chen, Gerasimo Coc, and Rosendo Coy for their increased interest in rosewood research since 2016. Ya'axche staff and consultants, past and present, who have contributed to our knowledge of rosewood in the MGL includes Nick Wicks, Gail Stott, Steven Brewer, Said Gutierrez, and Jean Linsky. Thanks to Dr. Percival Cho for sharing his survey data for the Maya Mountain North Forest Reserve with Ya'axché in order to facilitate conservation and sustainable forest management in Belize.

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2.0 Introduction

Honduran rosewood, *Dalbergia stevensonii*, has long been a valuable cultural, environmental, and economic resource for Belize. Though the Belize government established a moratorium on its harvest in 2012, high demand of the multipurpose timber continues to make rosewood vulnerable to overexploitation, both illegally and legally if/when the moratorium is lifted. *D. stevensonii*, is further threatened by its limited geographical range, "pulse" recruitment, high levels of seed abortion, and limited seed viability (CITES, 2013). A critical factor for sustaining its populations is the establishment of appropriate, biologically relevant management plans by conservation and forest management organizations.

2.1 Ya'axché Protected Areas

Ya'axché manages or co-manages 2 protected areas in which *D. stevensonii* occurs. Its 15,000-acre private protected area, the Golden Stream Corridor Preserve (GSCP), is primarily comprised of "broken ridge" forest on inner coastal plain alluvium, the preferred habitat of *D. stevensonii*. It is likely one of the last strongholds of the species in the Toledo District (Figure 1). Threats to the reserve include incursions along the boundary lines and the harvest of various timber species.

The southern region of the 36,000-acre Maya Mountain North Forest Reserve (MMNFR) contains lowland broadleaf forest with seasonally swampy, waterlogged soil. The reserve was previously the site of a long-term forest concession and may hold that role again in the future, stressing the importance of documenting and monitoring existing *D. stevensonii* populations there. A 2014 timber survey done partly under the Darwin Initiative project "Biodiversity Conservation through poverty alleviation: enabling sustainable forestry in Belize" and shared with Ya'axche by Dr. Percival Cho indicated that the average density of *D. stevensonii* greater than or equal to 5cm diameter at breast height (DBH) is 2.22 stems/ha across the lowland broadleaf forest area. This translates to roughly 5,225 individuals in the sampled region. The density of commercial individuals (those greater than or equal to 25cm DBH) is 0.54 trees/ha, or approximately 1275 trees in the same region. This indicates that extraction from the reserve has skewed the size distribution of the population remaining in favour of smaller stems. Further, trees have a patchy distribution across the southern portion of the reserve. Ya'axché rangers have documented illegal logging of rosewood in the reserve since patrols began there in 2013. Proper management and protection against illegal extraction within the borders of MMNFR is of primary concern, as is increased research in support of conservation action.

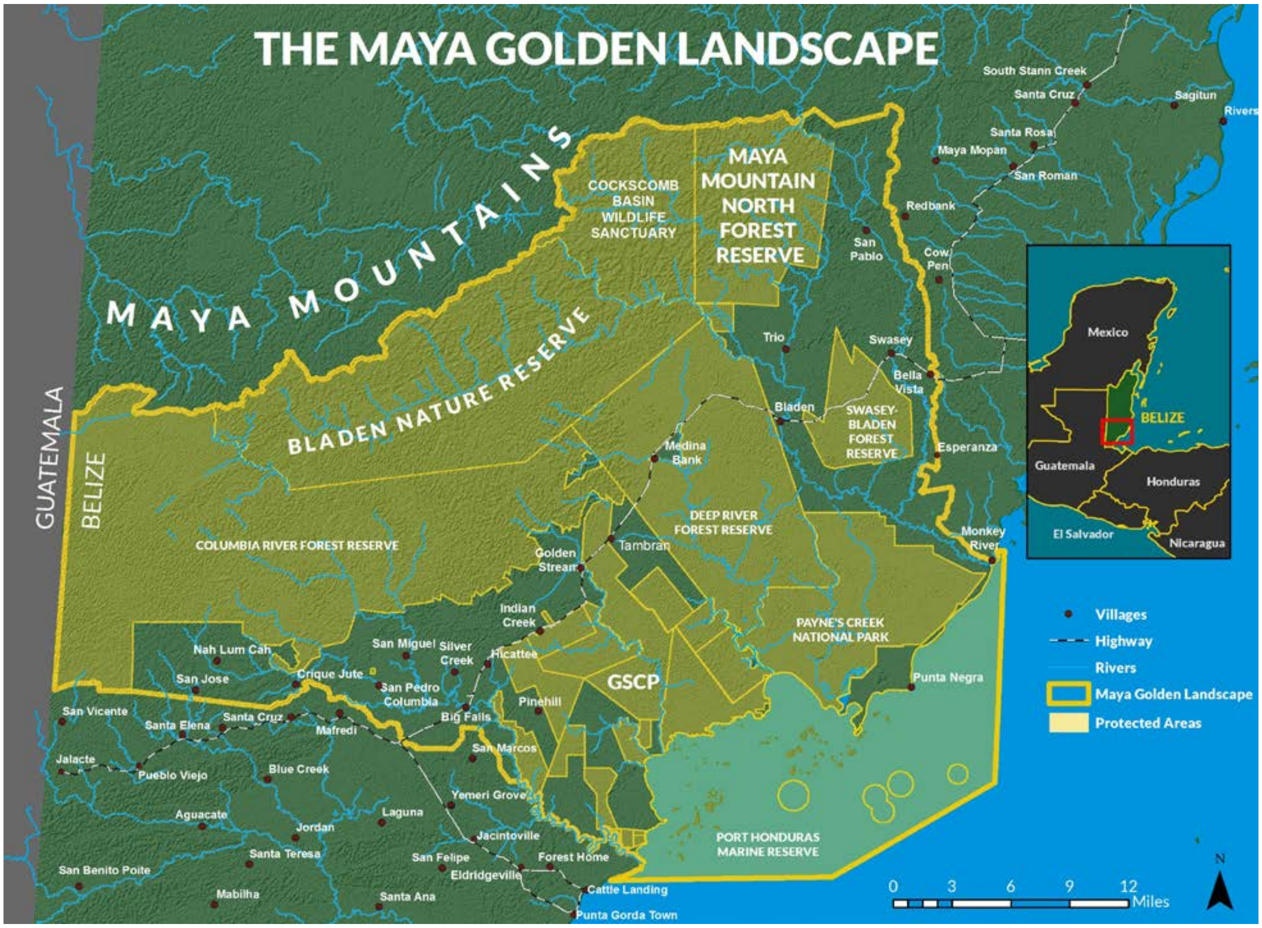


Figure 1. Map of the Maya Golden Landscape of the Toledo District in which Ya'axché works, including two reserves where *D. stevensonii* occurs, Golden Stream Corridor Preserve (GSCP) and Maya Mountain North Forest Reserve (MMNFR)

2.2 Rosewood Research and Monitoring at Ya'axché

In 2013, Ya'axché implemented long-term phenology monitoring of 100 *D. stevensonii* trees in GSCP and began capacity building for management organizations to recognize and protect threatened trees, including *D. stevensonii*. In July 2016, Ya'axché partnered with the Global Trees Campaign (GTC) to begin a project entitled, "Supporting Rosewood Conservation in Belize." This project was intended to build from Ya'axché's prior rosewood work to continue protection and research as well as increase national awareness and community education of the issues faced by *D. stevensonii*. In 2016, under this same GTC project, Ya'axché implemented further research into *D. stevensonii* biology, with the overall goal of supporting the Belize Forest Department in developing a sustainable management plan for the species.

Specifically, Ya'axché implemented studies of tree growth, stump regeneration, and vegetative propagation to complement its ongoing phenology monitoring. In combination with tree phenology patterning, growth rate data contribute valuable information on long-term reproductive patterns and population processes that, at the time of implementation in 2016, were still undetermined for this hardwood species. In addition, evaluating re-growth success from stumps provides valuable information on the regenerative capacity of the species and is crucial for identifying the amount of time it takes for the regrowth to reach commercial size.

During the course of the project and its research, Ya'axché has documented additional information on seed predators of the species (Dorgay 2017). Due to increasing difficulty with sourcing viable *D. stevensonii* seeds, Ya'axche turned to vegetative propagation options to produce seedlings. The results of the *D. stevensonii* vegetative propagation trials, along with the growth, phenology, and stump regeneration studies since 2013 are presented in this report.

3.0 Methodology

3.1 Study Sites and Trees

In 2013, 100 individuals of *D. stevensonii* were tagged and geolocated in 4 different sites in GSCP: Hope Creek, Behind Greenhouse, Opposite Field Station, and Downstream (HC, BGH, OFS, and DS, respectively). These sites are mapped in Figure 2 below.

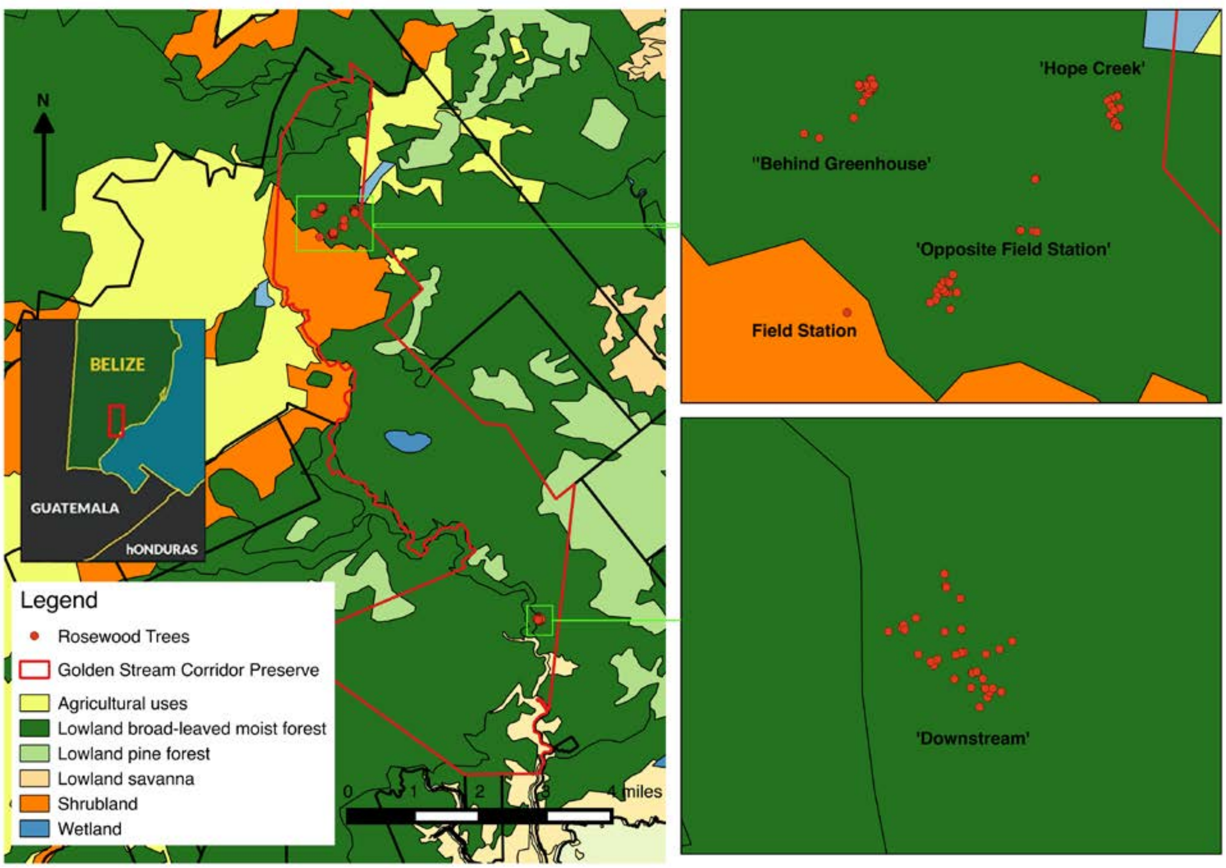


Figure 2. Location of 100 *D. stevensonii* trees used in analysis (Golden Stream Corridor Preserve, Toledo District, Belize)

For all trees in GSCP, DBH of the main stem for each tree was measured at 1.3m with diameter tape to the nearest 0.1cm. Diameters range from 7.9cm to 45cm at breast height. The trees were classified into size classes of the following groups: 5-9.9cm DBH, 10-19.9cm DBH, 20-29.9cm DBH, 30.0-39.9cm DBH, 40.0-49.9cm DBH, 50.0-59.9cm DBH, and 60.0-69.9cm DBH (Figure 3).

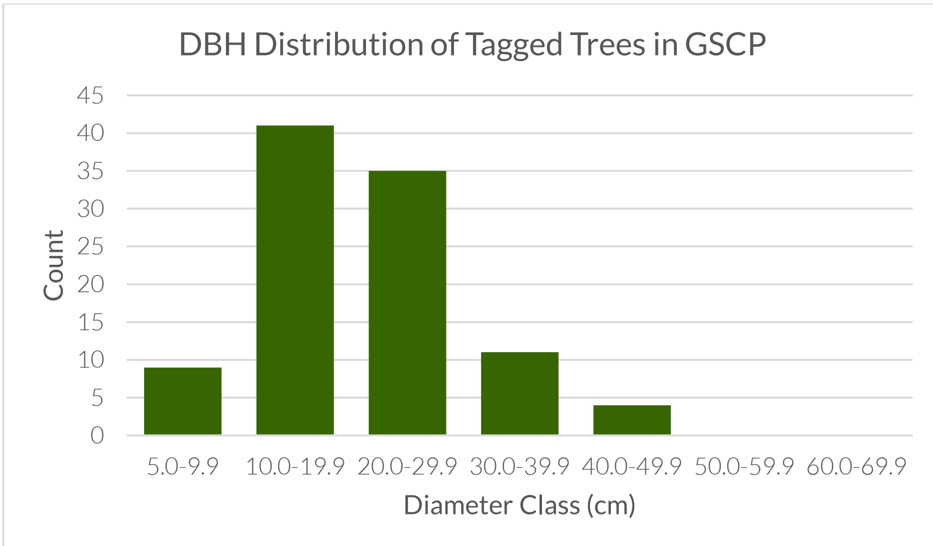


Figure 3. 2013 Diameter distribution of 100 *D. stevensonii* trees used in analysis

In March 2017, Ya'axché with GTC geolocated and tagged 18 *D. stevensonii* trees in southern MMNFR in order to replicate the phenology and growth study in Golden Stream Corridor Preserve. The trees are distributed near the boundary of the reserve, which is a relatively accessible site for Ya'axché's rangers to monitor regularly (Figure 4).

Of the 18 trees tagged in MMNFR, the DBH ranges from 7.5cm to 53cm. The trees selected for the study are more evenly distributed on either side of the 25cm commercial cutting diameter than would be expected for the entire population according individuals recorded during Dr. Cho's survey (see Figure 5).

In June 2017, 15 stumps at a separate site in MMNFR were tagged and geolocated for long-term regeneration monitoring. The starting location for the stump mapping activity was guided by ranger knowledge and 2013 incident reports of rosewood extraction along the western MMNFR/southeastern Cockscomb Basin Wildlife Sanctuary boundary line. The team followed an existing patrol route, BNR trail 6, to meet this area where stumps were known to occur. The locations of these individuals can be found in Figure 4.

As it is common for rosewood trees to take multiple forms, including heavily leaning trunks and multiple stems, Ya'axche encountered stumps remaining from such trees. All forms of stumps with regrowth were tagged and incorporated into the study. During the search for suitable stumps, only one stump was found to have no regrowth at all. This stump was excluded from the sample and no data were recorded. Every other stump encountered had some measurable amount of regrowth and was tagged, measured, and recorded. One of the original trees had a double trunk and each of the two stems were recorded as separate stumps. The diameter at the point of cutting was recorded (Figure 6).

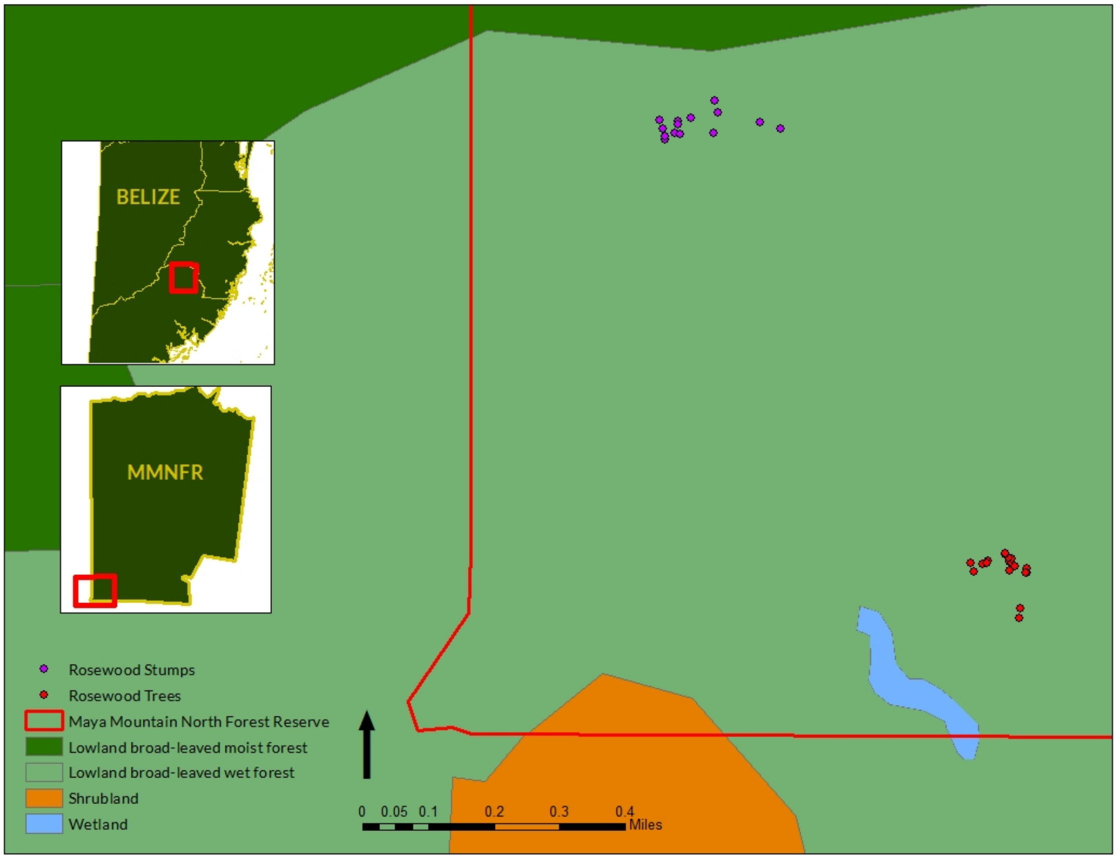


Figure 4. Location of tagged *D. stevensonii* trees and stumps.

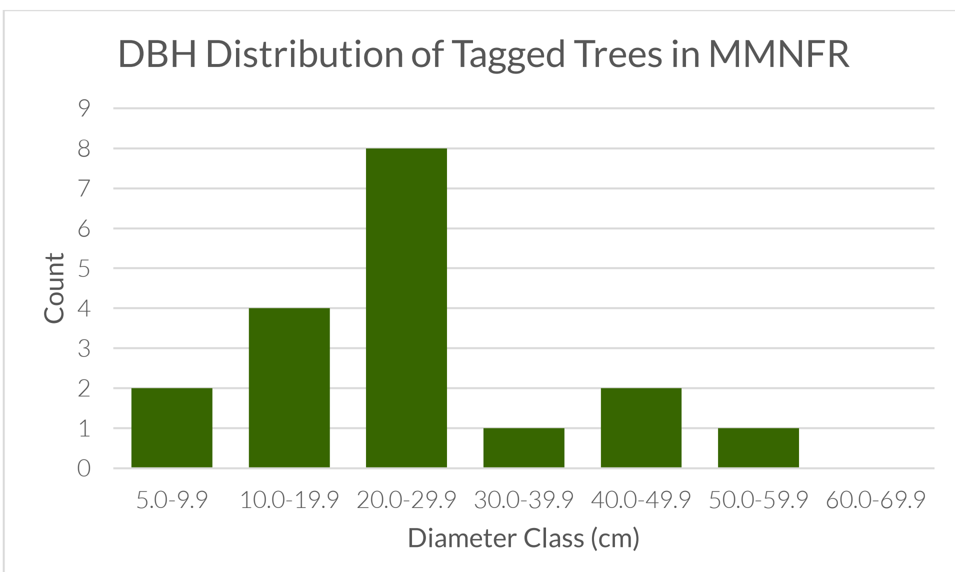


Figure 5. Distribution of 18 tagged MMNFR *D. stevensonii* trees in each DBH class, 2017

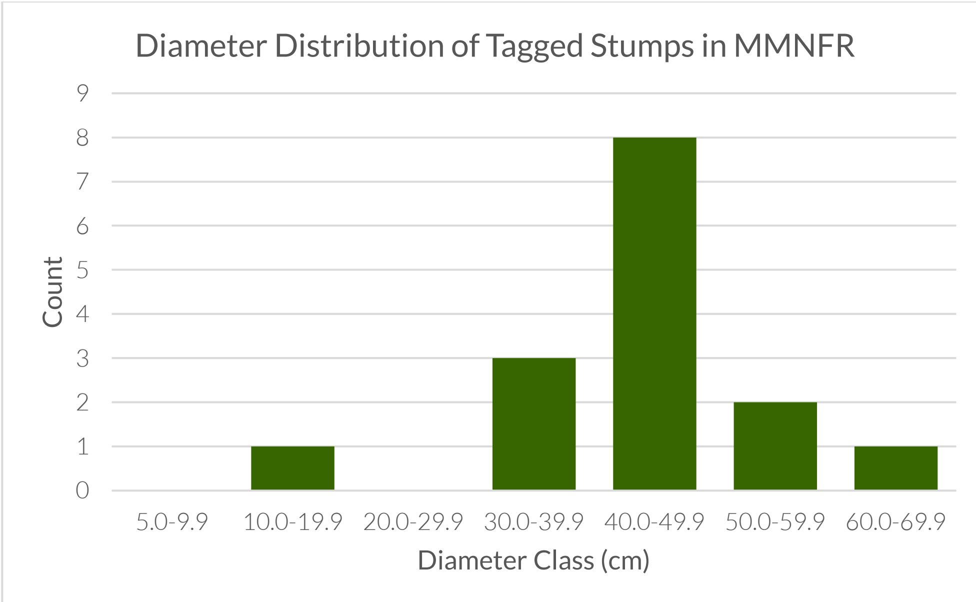


Figure 6. Distribution of 15 MMNFR *D. stevensonii* stumps by size class, based on diameter at cut surface, 2017

3.2 Growth Rate Assessment

3.2.1 Data Collection

In GSCP in 2013, ocular height in meters was recorded for each of the 100 trees. The same researcher estimated ocular height within each site (though not necessarily between sites) to minimize discrepancies in measurements. DBH of the main stem was measured at 1.3 m using diameter tape. Measurements were recorded to the nearest 0.1cm. Where trees had fallen and resprouted, the number of resprouts were documented.

In 2016, all GSCP trees were remeasured for DBH and height. In both visits, data sheets were used to record DBH, height, and notes on each tree's health and condition (i.e. broken crowns, dead branches, multiple stems, and leaning trunks).

3.2.2 Data Analysis

The data were transferred to an Excel spreadsheet and analyzed for general trends in tree growth. Growth rates were calculated overall and for each size class of D. stevensonii.

3.3 Phenology Monitoring

3.3.1 Data Collection

Phenology monitoring began in GSCP in October 2013, and 3 of the 4 sites were visited once a week on a rotating basis (i.e. Week 1: Site A; Week 2: Site B, Week 3: Site C; Week 4: Site A, etc.). Trees at the 'Downstream' location were not monitored on the regular schedule due to the distance required for access. Therefore, these trees were only monitored 2-3 times per year. Between 2017 and 2019, data collection efforts improved, and the Downstream site was visited roughly once per month. During each visit a data sheet was filled out (see Figure 7) to answer “yes” or “no” to questions relating to the phenological phase of each individual. Flowering and fruiting conditions were recorded since October 2013. Rangers began recording leaf loss in June 2014. When a tree was determined to be dead, a suitable nearby replacement tree was identified and incorporated into the long-term monitoring rotation.

Date Monitoring Carried Out:							
Ranger Names:							
		Is the tree losing its leaves?	Does the tree have flower buds (very small, green, hanging on ends of branches)?	Does the tree have open flowers on the branches or on the ground (look for pale yellow petals)?	Does the tree have unripe pods (bright green, hanging in clusters) on the branches?	Does the tree have ripe pods (brown) on the branches?	Are there pods on the ground?
		(yes or no)	(yes or no)	(yes or no)	(yes or no)	(yes or no)	(yes or no)
	Tag #						
	1						
	2						
	3						
	4						

Figure 7. Data collection sheet for *D. stevensonii*.

Monitoring began in MMNFR in March 2017. The same data sheet from Figure 7 was used to record the phenological condition of the trees at the MMNFR site. Efforts were made to visit the trees monthly between 2017 and 2019.

3.3.2 Data Analysis

Data were analysed in Excel for general trends in flowering, fruiting, and leaf loss. For each monthly site visit, trees were counted as “flowering” if a “yes” was recorded for the tree having either flower buds or open flowers. Trees were counted as “fruiting” if they had either unripe or ripe pods on the branches. They were counted as “leafless” if they were recorded as losing their leaves.

Comparisons of the proportion of observed flowering and fruiting individuals between size classes of *D. stevensonii* were made. Patterns in the length and frequency of annual flowering and fruiting events during the monitoring period were described.

3.4 Stump Regeneration Rate Assessment

3.4.1 Data Collection

The first stump data were recorded in June 2017. For each stump, the number of living resprouts was recorded. The height (m) and DBH (cm) of the tallest resprout were recorded, as was the length (cm) of the smallest resprout. The diameter (cm) of the cut surface and height (m) of the stump were also noted. The stumps were revisited in April 2018 and the resprout parameters were recorded again. Stumps will continue to be revisited and data collected yearly.

3.4.2 Data Analysis

Resprouts were assessed for percent survival and current annual increment (CAI) between 2017 and 2018 and for mean annual increment (MAI) since 2013 using Excel. Pearson product-moment correlation coefficients were computed to assess the relationship between stump and resprout parameters using PAST software (Hammer et. al 2001).

3.5 Vegetative Propagation

3.5.1 Experimental Design

In June 2018, Ya'axche began a vegetative propagation trial for *Dalbergia stevensonii* at the Golden Stream Field Station's nursery. The trial was guided by evidence from two 2017 pilot trials, in which the following observations were noted:

1) Season matters. Shoots cut and struck in the dry season while the plant was dormant successfully produced leaves, while wet season cuttings were not observed to do so
2) In standard soil mix, cuttings produced leaves but didn't establish roots, suggesting that nursery soil alone provides suboptimal rooting conditions
3) Cuttings successfully produced leaves from mother trees at DBH size 7.5, 22, and 47.5cm
4) Cuttings that successfully produced leaves were taken from lower positions on the trunk or from larger shoots near base of the main trunk, though few mature trees have enough growth from the lower trunk to support a trial
5) Cutting lengths of 46-60cm and with 4-6 nodes produced leaves successfully

Given the above conditions, a trial was designed to explore whether branch cuttings can establish roots, the optimal concentration of rooting hormone (to inform input cost), and whether inoculation with soil microbial associants is necessary for establishment (to inform effort needed for production).

Since Ya'axche works with 8 buffer communities around its protected areas, the trial was designed to be as low-tech as possible so any positive results could be replicated by community members wanting to grow rosewood on their lands. To meet this goal, a non-mist propagator was built to house the cuttings following Leakey's design, which is meant to be affordably built and used without a water supply or electricity (Leakey et. al 1990).

A randomized experimental design was used with two treatments and three factor levels each as follows:

	Treatment	Factor1	Factor2	Factor3
1st level	Inoculation with microbial associants	AMF soil	AMF + sand	standard nursery soil
2nd level	Root-inducing hormone	1st %	2nd %	none

Where AMF (arbuscular mycorrhizal fungi) soil is that collected from the roots of mature D. stevensonii in the nearby Golden Stream Corridor Preserve. The root inducing hormone used was applied at 1st concentration = 0.03%, 2nd concentration = 0.3%, or not at all. Four replicates were used per treatment, and 10 cuttings per replicate, for a total of 360 cuttings planted.

Cutting survival, root presence, callus formation, and evidence of sprouting were recorded once per month for four months.

3.5.2 Propagator Preparation

The Leakey non-mist propagator was built according to the FAO handbook, manual 1: "Rooting cuttings of tropical trees" (Longman 1993). The propagator was divided into three 1mx1m sections so that three different soil types could be tested (standard nursery soil, forest soil with microbial associants, and forest soil + sand for drainage). Nursery soil was sieved through a screen on site at the field station as per standard nursery procedure. Forest soil was collected from the roots of mother trees 72, 78, and 83 at the Opposite Field Station site. This soil was broken up with spades and stirred to homogenize. Large leaves were removed, but otherwise all pieces of roots and organic material were left in the soil. A portion of the forest soil was used in the forest + sand mixture at a 1:1 volume:volume ratio. Sand was sieved through the nursery screen and then again through #10 soil sieves prior to mixing with forest soil. None of the soil used was sterilized, and no fungicides or insecticides were used; this was done first to save costs for any community member replicating the procedure, second out of environmental concerns, and third because it would kill the microbial associants in the AMF soil.

3.5.3 Cutting Preparation and Planting

The experiment began with the harvest of branches during the beginning of the rainy season, June 24, 2018. Leafy branches were collected from two parent trees that were healthy and had accessible branches (tag numbers 72 and 86 at the OFS site). The distal ~10 feet of mature branches were cut, capturing all parts of the branch considered to be softwood according to the USDA Nursery Manual for Native Plants (Dumroese et. al 2009).

Branches were processed at the field station during the same day. All leaves were removed. The apical 4 nodes were also removed; after counting 4 nodes from the apex of the branch, the branch was cut into 10cm lengths until reaching semi-hardwood. Because cutting length rather than the number of nodes was used to standardize the cuttings, the number of nodes was not recorded. As branch cuttings retain polarity, the cutting orientation was tracked by cutting the basal end at an angle and the apical end straight. Cuttings were placed in labelled bags, sprayed liberally with water, and sealed for planting the following day.

An uneven number of cuttings were collected from the two mother trees, so care was taken to ensure that the same proportion of cuttings from each mother tree were used across treatments. Fewer cuttings were available for tree 86, so 14 per treatment were used compared to 26 cuttings per treatment from tree 72. All cuttings destined for each treatment group were then mixed together, so mother trees were not necessarily divided evenly among replicates (i.e. mother tree was not a factor in this experiment). 10 cuttings per replicate (40 per treatment) were planted in the non-mist propagator using a random number generator from randomizer.org to assign locations.

Rooting hormone Hormex #3 was diluted to 300ppm (0.03%) and 3000ppm (0.3%) using tap water. Cuttings receiving the hormone were dipped in the solution and briefly air dried before planting. Those receiving the control were dipped in tap water. Holes were made in the soil with a small stick to a 2cm depth, then cuttings were placed in and gently covered with soil.

3.5.4 Data Collection

Every four weeks, root growth was assessed by gently prying up each cutting with a small, flat board. The propagator was also weeded during these checks. The planted ends of cuttings were sprayed with water during the assessment to see root growth more clearly. Cuttings were considered rooted when they had roots reaching 0.5 cm or longer. The presence of leaves and calluses on the planted surface were recorded. Dead cuttings were recorded and removed at each check.

After four months, surviving rosewood cuttings were transplanted into nursery bags filled with 1:1:1 by volume nursery soil: sand: rice trash. Bags were then placed inside clear plastic bags and sealed to maintain moist propagator conditions for 1.5 weeks while still under nursery shade.

3.5.5 Data Analysis

Data were entered into Excel and transferred to PAST for analysis. A 2-way Analysis of Variance (ANOVA) with replication was used to test for differences between treatment means and interactions between factors.

4.0 Results

4.1 Growth Rate Assessment

Between 2013-2016, one tree in the 20.0-29.9cm DBH class died and was excluded from this analysis.

4.1.1 Diameter Growth

Averaged across all sites, the rate of diameter growth varied greatly by size class. Trees in the 30.0-39.9cm size class had the fastest average DBH growth rate (0.71 cm/yr), followed by trees in the 5.0-9.9cm size class (0.46 cm/yr). Overall, trees in size class 20.0-29.9cm had the slowest growth rate at 0.24 cm/yr (see Figure 8 below).

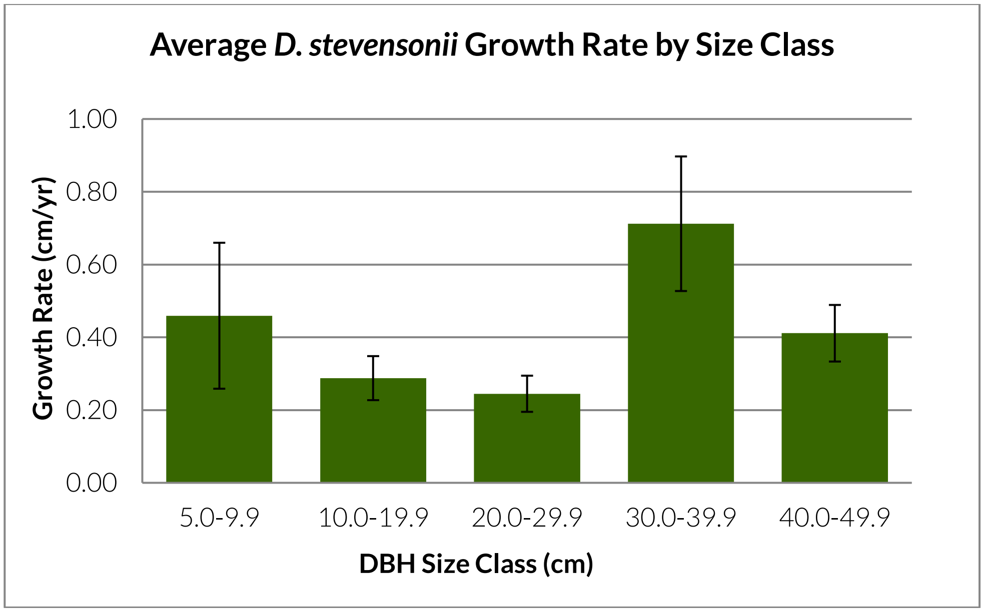


Figure 8. Average diameter growth rates with standard error over three years of 99 sampled trees in GSCP according to their diameter size class

By site, trees at Hope Creek had the fastest average growth rate, at 0.58 cm/yr, compared to the slowest rate of 0.17 cm/yr Behind Greenhouse. Growth rates were variable among trees of the same size class across the four sites (see Figure 9). Trees in the smallest size class grew at the fastest rate at the Opposite Field Station site. Trees in size class 10.0-19.9cm grew fastest at Hope Creek. Mean growth rates were not appreciably different between sites for trees in size classes 20.0-29.9cm and 30.0-39.9cm.

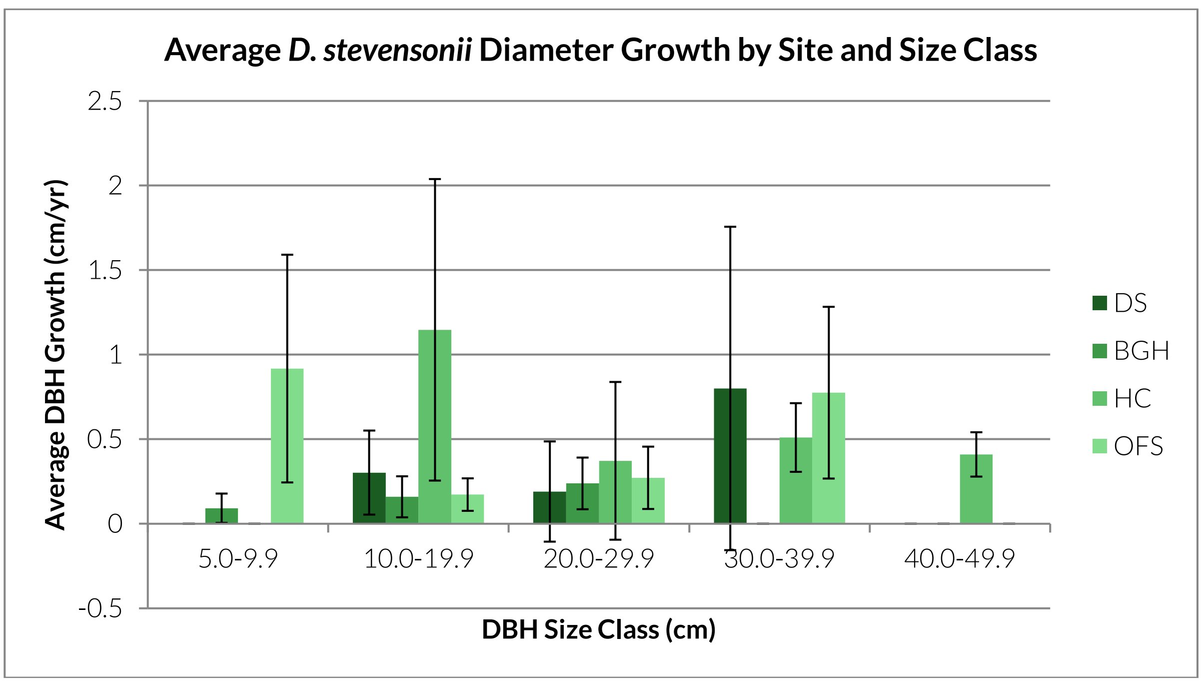


Figure 9. Average growth rates and standard deviation over three years for 99 trees, according to their diameter size class and across four sites in GSCP

4.1.2 Height Growth

Four trees were excluded from the following height analysis due to incomplete data from one or both years. The remaining 96 trees are characterized as follows:

Average tree height increased the fastest for trees in the smallest size class (1.25 m/yr) and slowed as trees increased in diameter (see Figure 10). Trees in intermediate size class 30.0-39.9cm averaged a much slower rate of height increase compared to the previous size class. Trees in the largest size class experienced an average loss of 0.08 m/yr in height over the three-year timespan, though standard error for this class is high.

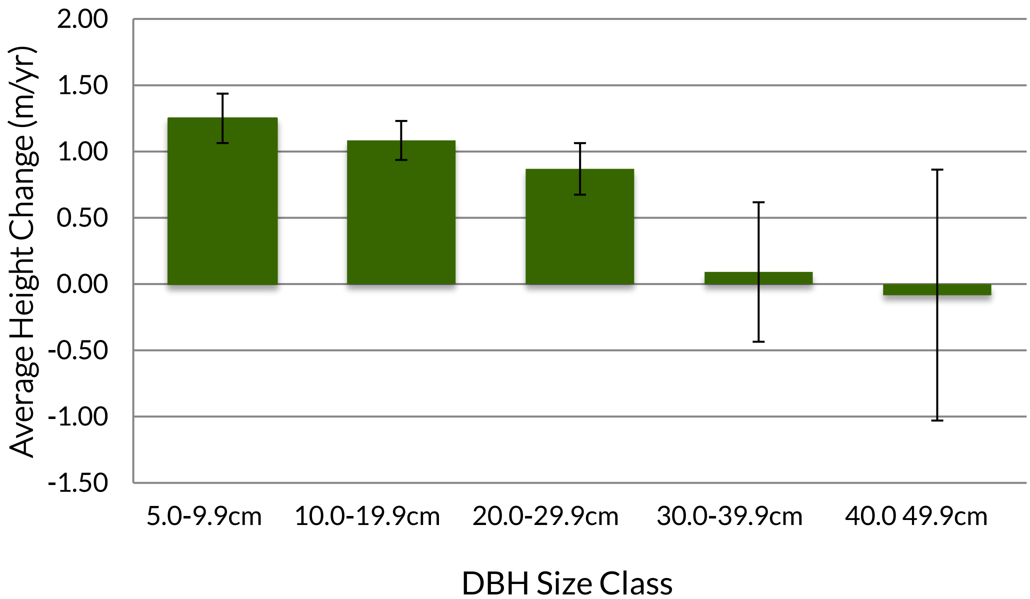


Figure 10. Average change in height with standard error over three years for 96 trees in GSCP according to their diameter size class

As with diameter growth, variability in tree height growth exists between sites over the three-year timespan. Trees in all size classes had the greatest average increase in height at the Downstream site over three years. Trees at Hope Creek experienced lesser rates of height increase compared to the other three sites. See Figure 11 for a breakdown of tree height growth by size class and site.

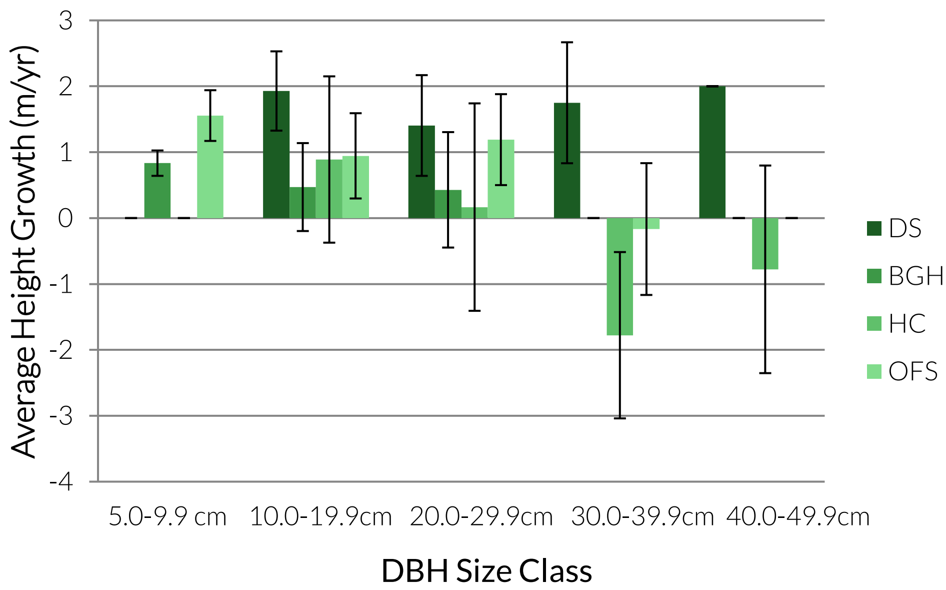


Figure 11. Average change in height and standard deviation over three years for 96 trees, according to their diameter size class and across four sites in GSCP

4.1.3 Tree Health and Condition

Broken crowns and crown dieback were common during the three-year monitoring period. Trees with notably broken crowns make up 19% of trees Opposite Field Station, 24% of trees Downstream, 35% of trees Behind Greenhouse, and 42% of trees at Hope Creek.

4.2 Phenology Monitoring

4.2.1 Phenology Patterns in GSCP and MMNFR

The 100 *Dalbergia stevensonii* trees in GSCP were monitored between October 2013 and May 2019. During that time, data were recorded during 54 monthly visits at the Behind Greenhouse site, 57 visits at Opposite Field Station, 58 visits at Hope Creek, and 31 visits Downstream.

Since monitoring in GSCP began, *D. stevensonii* leaf loss has been consistent yearly, with most trees shedding their leaves between April and July (Figure 12). Flowering begins at the peak of the leafless period, and its ending coincides with the time the trees begin regaining leaves. Flowering events for the species are narrow and occur for approximately one month each year between May and July. Fruits are observed after peak flowering, though the period of fruiting is less well-defined. Fruits are first formed in July, with few trees still holding on to mature fruit into March of the following year.

Though on average, roughly 30% of the trees are observed to flower each year, at most only 15% of the trees are observed to have fruit at any time of the year.

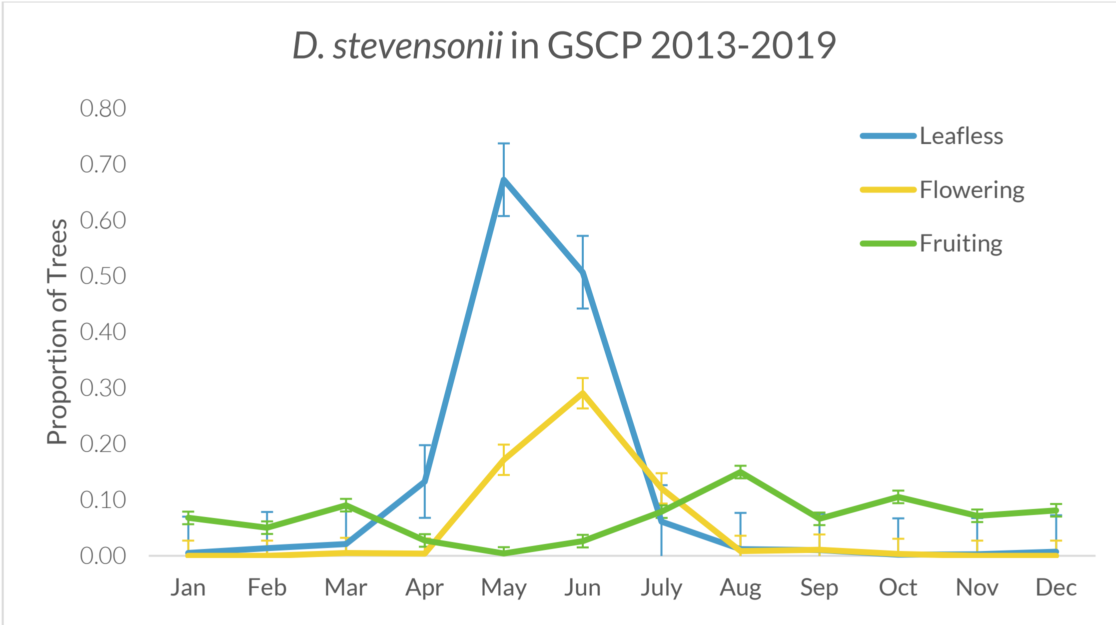
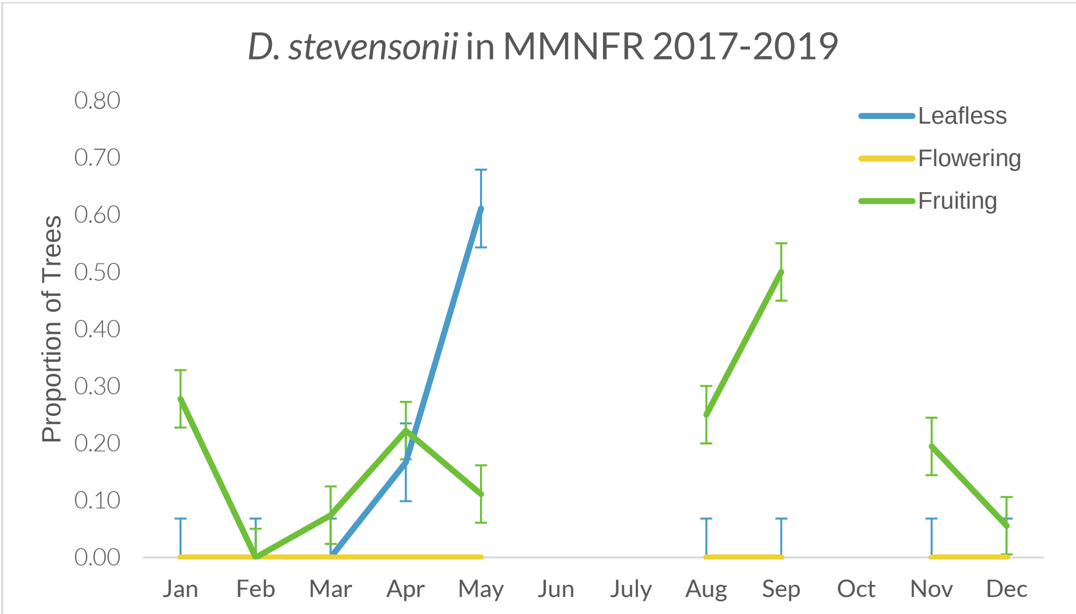


Figure 12. Phenological patterns of 100 D. stevensonii trees in GSCP since October 2013. Monitoring of leaf loss began in June 2014. Averages each month plus standard error are shown.

The 18 *D. stevensonii* trees in MMNFR were visited 14 times between March 2017 and March 2019. Data were not collected during June, July, or October during that time, as the site became inaccessible due to flooding of the river at the access point to the site. The proportion of trees in MMNFR observed flowering, fruiting, and losing leaves each month are shown in Figure 13 A. The summary of phenological conditions of all GSCP trees during the same time period can be found in Figure 13 B. for comparison.

The timing of leaf loss in MMNFR *D. stevensonii* corresponds closely to that seen in GSCP. Leaves are shed beginning in April, and leaf loss increases sharply in May. As no data have been recorded in June or July, no estimate of the extent of flowering or leaf loss can be made during that time. Though as no flowers were observed during any other months of the year, it can cautiously be assumed that the narrow flowering window for trees in MMNFR occurs during June and July. This is roughly a month later than the flowering window in GSCP. Fruits have been observed on the MMNFR trees in August through January in the months recorded, with some trees holding onto fruits until at least May of the following year. Compared to 30% of trees in GSCP, at least 50% of trees in MMNFR were observed to have fruit during the year.

A.



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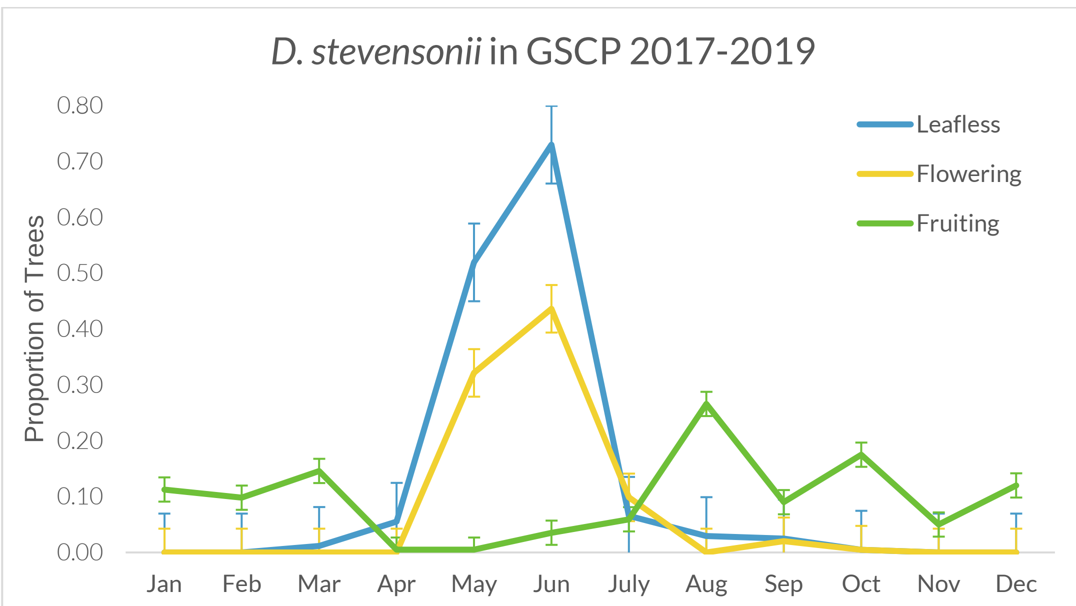

Figure 13 A & B. Phenological patterns of A. 18 trees in MMNFR and B. 100 D. stevensonii trees in GSCP between March 2017 and March 2019. Weather conditions prevented the collection of phenology data in MMNFR during the months of June, July, and October. Averages each month plus standard error are shown.

4.2.2 Reproductive Condition and Size Class

In terms of reproductive condition of the trees based on size class, 75 of the 100 trees in GSCP were observed to have flowers or fruit at least once during the monitoring time period. The proportion of trees observed with unripe or ripe fruit generally increased with increasing size class (see Figure 14). 100% of trees in the largest size class produced fruit at least once during the monitoring period, compared to 65% of trees meeting the commercial cutting diameter of 25cm DBH or larger.

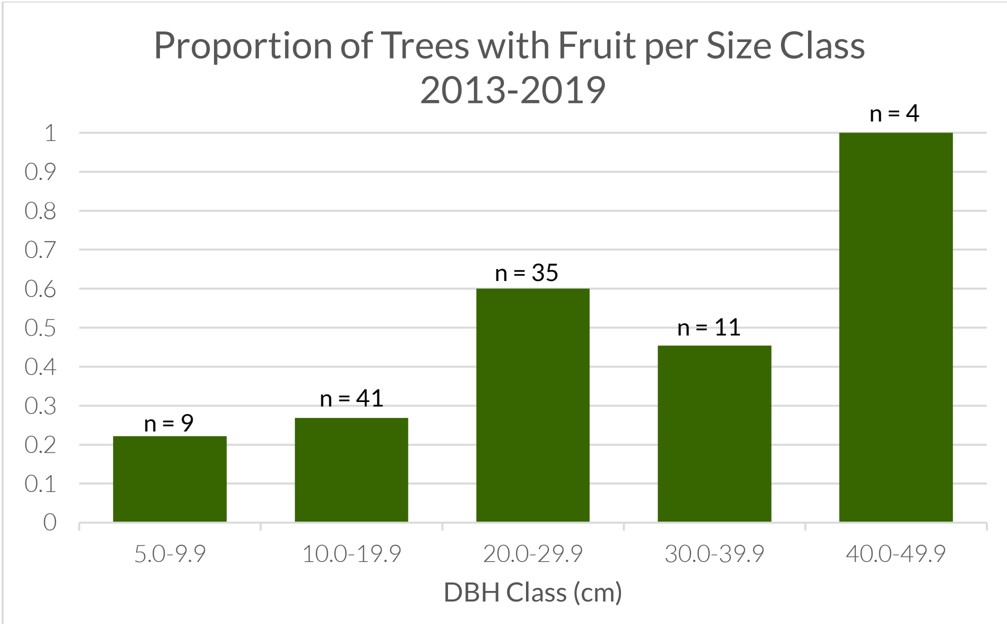

Figure 14. Proportion of GSCP *D. stevensonii* in each size class observed to have unripe or ripe fruit at any point between October 2013 and May 2019.

The year 2017 had the most consistent data coverage with all 100 trees visited during 9 of the 12 months of the year. In 2017, the proportion of trees observed with flowers increased with increasing DBH size class until reaching roughly 75% for trees at least 20.0cm in diameter. Trees in the smallest size class were not observed to have any fruit (Figure 15). Unripe fruits were observed in trees at least 10.0cm in diameter; the proportion of trees with unripe fruits increased with increasing size class. Ripe fruits were observed in trees at least 20.0cm in diameter and increased with increasing size class, though even in the largest diameter class (40.0-49.9cm), only 25% of trees were observed to have ripe fruit.

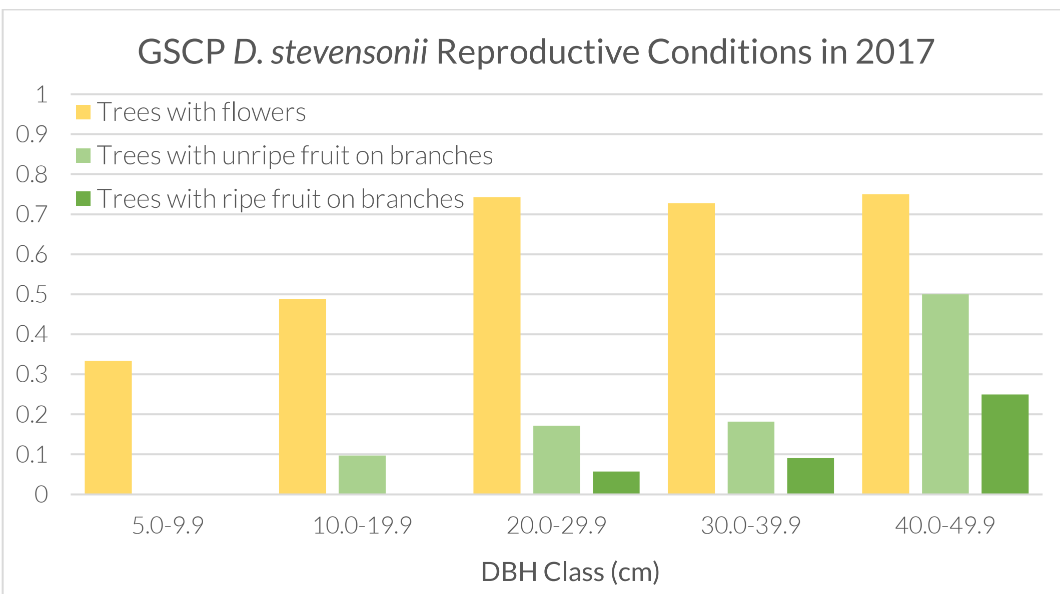

Figure 15. Proportion of GSCP *D. stevensonii* in each size class observed to have flowers or fruit in 2017.

4.3 Stump Regeneration Rate Assessment

The 15 stumps identified are estimated to have been cut in September 2013, according to ranger incident reports. The regrowth since that time has taken many forms (see Photos 1 and 2 below).

Photos 1 and 2. Examples of stumps with varying amounts of regrowth in MMNFR

The diameters of the stumps at their cut surfaces range from 17.3cm to 69.7cm. The number of resprouts from these stumps after 4 years ranged from 1 to 28 stems, with an average of 11.6 stems. The estimated height of the regrowth ranged from 1.5m to 6.5m and averaged 4.36m.

Results of growth between 2017 and 2018 show that 78% of the original shoots had survived, and nearly every stump had lost an average of 3 shoots. The largest surviving shoots had an average CAI of 0.2cm in diameter and 0.9m in height. Average MAI between 2013 and 2018 was 0.7cm/year for diameter and 1.1m/year for height.

There was a strong negative correlation between the diameter of the stump and the diameter CAI of the largest resprout (Pearson's $r(13) = -0.73$, $p = 0.002$). Increases in stump diameter were correlated with decreases in diameter increment of the largest resprout between 2017 and 2018, though the relationship between stump diameter and MAI since time of cutting is weakly negative (not significant, $r(13) = -0.04$, $p=0.88$).

Conversely, there are moderately strong positive correlations between stump height and largest resprout DBH, diameter MAI, largest resprout height, and height MAI ($r(13) = 0.56$, $p = 0.03$; $r(13) = 0.58$, $p=0.02$; $r(13) = 0.60$, $p = 0.02$; and $r(13)=0.59$, $p = 0.02$, respectively). As the cutting height of the stump increases, so does the diameter and height of the largest resprout. In addition, as the cutting height of the stump increases, so does the rate of increment of diameter and height of the largest resprout.

4.4 Vegetative Propagation

Of 360 cuttings planted, 16 cuttings successfully rooted (producing roots 0.5cm or greater) after four months. Analysis of variance for the rooting parameters evaluated showed there was a significant interaction between the effects of soil type and rooting hormone concentration on rooting capacity ($F = 3$, $p = 0.03599$), but there was no significant effect of soil type or rooting hormone concentration on rooting capacity of the cuttings.

General trends show that the forest (AMF) soil + sand mixture performed the best: 8 rooted cuttings were in forest (AMF) soil + sand, 5 were in forest (AMF) soil, and 3 were in standard nursery soil. Of the 8 surviving cuttings in the forest + sand soil, 5 cuttings had no hormone applied. Hormone application did not produce any clear trends in the other soil types.

5.0 Discussion

The information presented above serves as a primary analysis of growth rates, phenology, stump regeneration, and vegetative propagation of *Dalbergia stevensonii* in the Maya Golden Landscape. Insight into growth and reproductive patterns can provide recommendations for management issues such as sustainable harvest sizes and rates as well as contribute to hypotheses regarding limitations to species persistence.

5.1 Growth Strategy

As a species with extremely dense timber, *Dalbergia stevensonii* has been thought to grow at very slow rates. Results from 3 years of growth of the 100 monitored trees in Golden Stream Corridor Preserve confirm this belief. Annual growth rates vary by diameter, but are on average quite slow at 0.32cm per year. Diameter and height growth appear to be faster in the smallest trees (5.0-9.9cm DBH), indicating that young trees invest energy into outcompeting other new saplings for available light.

Trees 10.0cm DBH and larger maintain a slower state of horizontal growth until reaching approximately 30 cm in diameter. At this point, horizontal growth becomes emphasized again, which is likely when the tree reaches the upper canopy and competition for light becomes less important.

General trends in tree height show that height increased more slowly with increasing diameter size class. With high standard error, height is a less reliable growth metric than DBH. This is likely influenced by crown dieback, which could also partially explain why trees in the largest size class decreased in height over three years' time.

5.2 Site Variability

Rates of growth in diameter and height for each size class were variable by site, indicating site-specific influences to tree growth. This is not unusual; individual trees of *D. sissoo* among other species experience high degrees of variation in growth and height attributed to inherent genetic factors as well as environmental conditions (Sharma and Bakshi 2014; Gera et al. 2001). Variability exists between the four sites in GSCP, especially in the level of disturbance caused by Hurricane Iris in 2001. More trees at the Behind Greenhouse, Hope Creek, and Opposite Field Station sites are leaning or downed from this event compared to those Downstream.

5.3 Size and Reproductive Condition

The larger size classes, starting at 10.0cm DBH, all show more than 45% of trees in a reproductive state at least once between 2013 and 2019. This indicates the importance of maintaining standing individuals of a larger sizes to act as seed trees for natural regeneration. In the greatest class size found in GSCP, 40.0-49.9cm DBH, 100% of the monitored trees were observed fruiting and flowering. While the sample size for this group is small (n=4), the high proportion of reproductive individuals may be indicative of the importance of large trees as reproductive individuals. Continued monitoring of the reproductive success of frequently fruiting trees of various size classes is recommended to further understand the reproductive biology, particularly in a genus known for mass flowering and high levels of seed abortion. An investigation into whether size class plays a role in the production of viable seeds would be useful in determining harvestable size limits.

5.4 Management Implications

While specific forest management practices can't be recommended from the preliminary analyses presented here, the general trends in tree growth are important. Based on the average diameter growth rates per size class of trees in GSCP, any *D. stevensonii* tree beginning at 5.0cm DBH in year 1 would take roughly 65 years to reach 25cm DBH, or 115 years to reach a DBH of 45cm, the minimum cutting diameter (MCD) previously set at the Chiquibul Forest Reserve logging concession. This is consistent with the growth rates of other species of *Dalbergia* and *Pterocarpus*, which commonly take more than 100 years to reach merchantable size (Winfield et al. 2016).

A MCD of 45cm falls within one of the largest size classes (40.0-49.9cm) of trees monitored by Ya'axché. Ya'axché phenology research has also identified this to be a critical size class for *D. stevensonii* reproductive activity. Between October 2013 and May 2019, 100% of the trees in this class experienced at least one fruiting and flowering period. In comparison, only 37% of trees in size classes between 10.0cm-39.9cm were found to be in a reproductive state during that time. While the sample size for the largest class is small (n=4), the high proportion of reproductive individuals indicates of the importance of maintaining large seed trees for natural regeneration (Linsky, 2016), especially given that other species in the genus experience high levels of flower and seed abortion in fruit-producing trees (Bawa & Webb, 1984) and seed predation (Dorgay, 2017).

6.0 Recommendations

The survey results indicate a large presence of *D. stevensonii* in MMNFR, with the population distribution skewed toward smaller individuals. This is hopeful news for the reproduction and recruitment potential of the species. However, patterns produced from phenology monitoring in Golden Stream Corridor Preserve show that all trees greater than 40.0cm DBH produced fruits between 2013 and 2019, 65% of trees in all size classes larger than the commercial cut off 25cm DBH produced fruits during that same time, and only 31% of trees with DBH between 5.0cm and commercial size produced fruits. Individuals in this smallest category are most abundant in the reserve, which indicates the importance of protecting the largest, commercially desirable trees as seed trees. In addition, monitoring of the MMNFR population should continue to determine if the reproductive patterns are consistent between locations.

Ya'axche should continue monthly patrols in the southwestern region of the reserve. Though this region has many stumps, the team also identified several mature, unharvested rosewood trees in close proximity to the stumps. Monthly phenological monitoring of the rosewood trees at the other site will serve as a patrol in that region.

Ya'axché Conservation Trust's Conservation Action Plan (CAP) for *Dalbergia stevensonii* has been updated to include recommendations for monitoring and patrols based on the results presented in this document. The CAP is available upon request.

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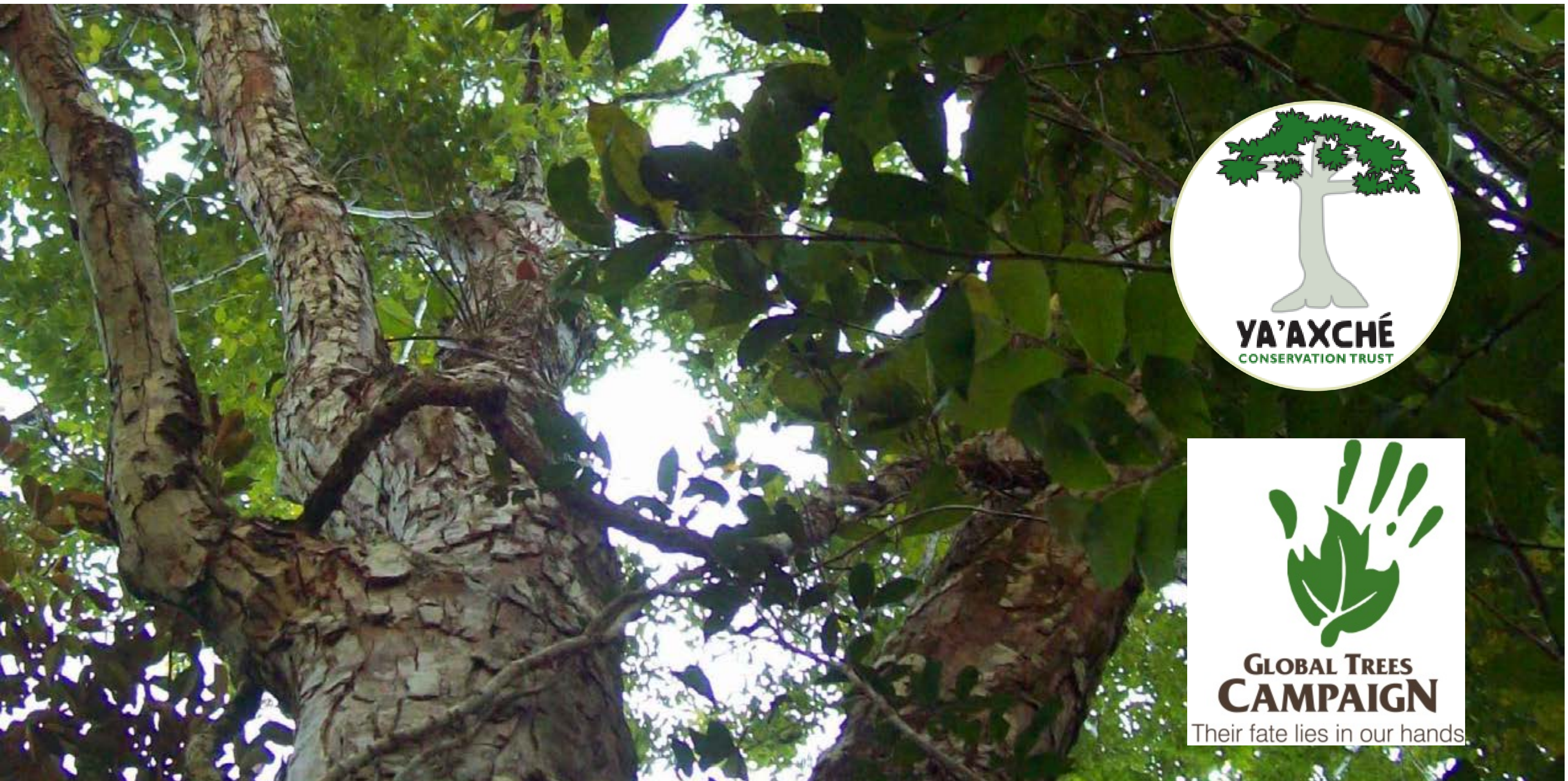

Dalbergia stevensonii in Golden Stream Corridor Preserve and Maya Mountain North Forest Reserve

Summary of Ya'axché Conservation Trust's 2013-2019 research and monitoring under the Global Trees Campaign Project, "Supporting Rosewood Conservation in Belize"

Prepared for the Belize Forest Department
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