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DePaul Discoveries

Volume 8 | Issue 1 Article 8

2019

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Acknowledgements

I would like to thank Dr. Christie Klimas for providing her constant insight and knowledge throughout this project, and I look forward to working more with her in future projects. I would also like to acknowledge the financial support of an Undergraduate Research Assistant Program (URAP) grant from DePaul University's College of Science and Health. This project is only possible due to strong collaborations. We want to thank Patricia da Costa for her work leading this collaborative effort and Lúcia Helena de Oliveira Wadt for leading the collaboration that preceded the current one. We are grateful to Ana Cláudia Lira Guedes, Carolina, Volkmer de Castilho, and many field technicians and students for data collection and compilation. This project would not be possible without the efforts of many.

Comparing *Carapa guianensis* Seed Production in 3 Amazonian Forests

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ABSTRACT This paper is the first part of a project that has the purpose of creating models that help us better understand variation in seed production in *Carapa guianensis,* a species in the mahogany family. The goal of this paper is to visualize seed production patterns to inform species management. When this study is completed, it will aid local communities harvesting *Carapa* in projecting revenue from the oil produced from the seeds. *Carapa* is a masting species, which means it has an intermittent synchronous production of large seed crops. The major suspected causes of variation in seed production are resource acquisition and allocation, while some trees may use masting as a defense mechanism against predators. We compiled data from 2005-2017 in three forests in Brazil, Acre, Amapá, and Roraima, and by using statistical computing language R, we found that *Carapa* did not have consistent seed production in these forests. In Acre, masting years 2005, 2008, 2011, and 2013 had medians of 73.15, 328.54, 134.80 and 235.90 kg seeds, respectively (Appendix A). In Amapá, the medians from 2012-2016 were 1,481.52, 276.62, 573.52, 1,467.67, and 1135.12 kg, respectively, and those years were the only recorded. In Roraima, masting years 2006, 2007, 2008, 2009, 2011, and 2012 had medians of 312.80, 1016.60, 1919.81, 164.22, 469.20, and 316.71 kg, respectively, with zero median production in 2010 and 2017. These data have variation between years, and in the future, we will work to see what causes this variation and how we can model seed production for revenue projections.

INTRODUCTION

The Amazon is seeing land-use change, specifically deforestation, due to logging, cattle ranching, and increasing urbanization (Fearnside, 2005). Since all tropical forests combined contain about 25 percent of the world's carbon, with the Amazon basin storing up to 140 billion tons (127 billion metric tons) (Rainforest Trust, 2017), deforestation is playing a major role in decreasing a vital carbon sink. The Amazon Rainforest comprises about 40% of Brazil's total area, occupying the drainage basin of the Amazon River and its tributaries, covering an area of 2,300,000 square miles (Britannica, 2017).

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Research Completed in Fall 2018/Winter 2019

Throughout the diverse Brazilian landscape, *Carapa guianensis*, a species in the Mahogany family, plays an important role in local economies and communities. Valuing the Amazon for resources other than its timber widens the scope of the forest's economic use. For example, Andiroba oil, a product produced from the seeds of *Carapa guianensis*, is utilized for therapeutic, beauty, and medical purposes, as well as lamp fuel. Andiroba oil populates the cabinets of many South Americans, for the applications are multiple. While some utilize the oil for moisturizers and soap, others make candles and pest repellant, swearing by its ability to ward off mosquitos and other disease-carrying insects (Miot et al., 2004).

The history, use, and benefits of Andiroba oil are the subjects of much research although species in the mahogany family, like *Carapa*, are often valued more for their timber (Miot et al., 2004).

Carapa guianensis is valued for its high-quality timber as well as its seed oil, making it a multi-use tree species (Panayotou et al., 1992; Salick et al., 1995). Forest management for multiple products, using multi-use species or a mix of different species, has the potential to help meet the needs of those living in or near tropical forests and to help make the standing (intact) forest more valuable than its absence (Wahlen, 2017).

A challenge of working with *Carapa guianensis* is that it is a masting species, which means it has an intermittent synchronous production of large seed crops (Isagi et al., 1997). Masting species have years of high production and years of low production, which may be caused by variation in resource acquisition and allocation (Crone et al., 2009). This is a challenge for those who depend on *Carapa* seed oil for economic revenue. If these patterns are predictable, this information can be used to facilitate management. Visually illustrating high and low years of production may help with long-term forest management and allow oil producers to better plan for high years or expect low years.

The goals of supporting Andiroba oil production as opposed to timber production are not to dismiss the value of timber, but to offer alternatives within the industry, expanding the uses of *Carapa guianensis*. Communities that collect *Carapa* seeds and produce andiroba oil may be able to supplement their income via proper species management. The study goal is to visually portray patterns of seed production to help illustrate challenges and potential management opportunities for *Carapa guianensis* seeds. We hypothesize that seed production will differ by year and location (Acre, Amapá, and Roraima). Our null hypothesis is that masting years will be consistent across our three locations. Our alternate hypothesis is that mast years will not be consistent across the three locations.

The long-term objective of this study is to create models that explain seed production so producers can use them to project revenue. In further research, we will find the relationship between trees with a DBH >=75cm² and variation in seed production by year and location. We hypothesize that DBH and crown size will significantly affect seed production. Published work (Snook et al., 2005) found this relationship to be significant, and we will test this in the future.

METHODS

In Acre, data was collected and compiled throughout 2005-2009, 2011, and 2013-2015. In Amapá, data was collected throughout 2012-2016. In Roraima, data was collected throughout 2006-2012, and 2017.

Detailed seed collection methodology for the Acre site can be found in a series of publications (Klimas et al., 2007, Klimas et al., 2012). There were 39 trees monitored for seed production in Acre in 2005. This increased to 104 by 2007-2008 but was reduced to 98 trees by 2015 due to death of some individuals. In brief, trees were randomly selected to follow for seed production, excluding conspecific individuals with overlapping canopies. Researchers visited these trees weekly during the period of seed production (which ranged from 5 to 34 weeks) and continuously from 2007-2009, 2010-2011, and 2014-2015.

Similar tree selection methods were used in Roraima with trees visited once or twice a month from April or May to July or August to collect, dry and weigh seed production. There were 138 trees monitored for seed production in Roraima.

In Amapá, trees occurred in flooded, varzéa, forest. Sixteen trees were surrounded by nets to capture all seed production. Seeds were collected, dried, and weighed throughout the seed production period and summed for total seed production.

The seed wet weight in grams in Acre (for 2011 and beyond) was converted by a factor of 0.674 to get seed dry weight. This factor was based on a calculated conversion factor based on measurements from 2004-2009. In Amapá, from 2006-2012 and 2017, wet and dry weight were both measured, and the conversion factor was 0.890. The average of the conversion factors for Amapá and Acre was 0.782, which was used to convert seed wet weight to dry weight in Roraima.

We used R to make the boxplots (R Core Team, 2018), importing data from Excel. For comparison, the boxplots are graphed on top of each other (Appendix B). We also used R functions mean, standard error, median, minimum, and maximum.

RESULTS

This study adds to the information available to producers. Based on our data, we see evidence of zero median production in Acre in 2006, 2007, 2009, 2014, and 2015. We have missing values in 2010, 2012, 2016, and 2017. Masting years 2005, 2008, 2011, and 2013 had medians of 73.15, 328.54, 134.80 and 235.90 kg seeds, respectively (Appendix A). The means of these years were 263.74, 111.86, 92.12, 1877.31, 7.62, 1815.55, 2674.90, 1010.32, and 210.45, respectively.

In Amapá, we have data from 2012-2016. The medians these years were 1,481.52, 276.62, 573.52, 1,467.67, and 1135.12 kg (Appendix A). The means of these years were 2,445.14, 1008.95, 1246.29, 3529.50, and 1010.33.

In Roraima, we have missing values in 2005 and 2013-2016. We see zero median production in 2010 and 2017. Masting years 2006, 2007, 2008, 2009, 2011, and 2012 had medians of 312.80, 1016.60, 1919.81, 164.22, 469.20, and 316.71 kg, respectively (Appendix A). The means of these years were 3390.11, 4546.73, 9210.30, 4132.92, 4869.84, 7046.42, and 2979.93.

The seed dry weight data have no obvious linear relationship from year to year in each location. In some years, such as 2011 and 2013 in Acre, there are higher seed dry weight values, which means higher seed production (Appendix B). Conversely, there are years with little or no production. While missing data make it difficult to compare across the three sites, there does not appear to be consistency in high production years across locations, though 2011 may be an exception for Acre and Roraima. Zeros in the data table, illustrating years with no seed production, have important implications for revenue.

DISCUSSION

Our hypothesis stated that seed production would differ by year and location that masting years would be consistent across our three locations. From our data, we can conclude that *Carapa guianensis* did not have consistent seed production in these forests by neither year nor location. There are significant correlations between seed production and year as well as location. Variation between years showed evidence of masting. In addition, we did not find consistent high seed production at all locations in the same year.

Another similar study found inconsistent inter-annual fruit production per tree, which creates complications for consistent tree regeneration (Snook et al. 2005). Analyzing yearly variation in seed production can help communities plan for lower production years. If some years are predicted to have lower seed production than others, harvesters may choose to save oil from a higher production year, keeping the supply constant across multiple years.

This work is the first step in a longer-term study to model seed production with a goal of better understanding the factors that are important in predicting high seed production years. We detail some of our next steps in this discussion.

We are still testing whether similar DBH and crown size means similar seed production and whether the relationship between DBH and production is consistent between the three study regions. A previous study on the *Carapa guianensis* population in Acre found that *Carapa* was most productive for trees with DBH >=75cm² (Klimas et al., 2012). In similar species, such as *Swietenia macrophylla*, commonly known as mahogany, seed production showed obvious trends in correlation with DBH. Trees below 75 cm DBH usually produced close to zero fruits, while trees larger than 75 cm DBH rarely produced zero fruit. Variability was higher in trees larger than 75 cm DBH than trees lower than 75 cm DBH (Snook et al. 2005). Larger crown heights also indicated higher production, leading to higher projected revenue. This study suggests that good years for growth are also good years for fruit production, a pattern known as resource matching in masting species, which means production may directly correlate with environmental variation of resource availability (Snook et al., 2005; Kelly, 1994). Further investigation on this data set may indicate similar results for *Carapa*.

It follows that high production by certain trees is of interest for oil management. Focusing collection on high producers may be an opportunity to increase oil production with less effort (visiting fewer trees).

However, reasons for fruit production are not solely based on resource matching, DBH, or tree height. Deciduous trees can fruit copiously in consecutive seasons, demonstrating that there is not necessarily an energetic trade-off between reproduction and growth, nor are individuals constrained to non-reproduction as a result of resource depletion following a bumper crop season (Wesołowski et al., 2015). A bumper crop season defines a season with an uncharacteristically productive harvest. Masting in oak trees can produce massive acorn production, which allows acorns to sprout and become seedlings, ensuring future populations (Miller, 2015).

This pattern of periodic high production can be challenging for management. Some seedlings, such as mahogany, grow better after regenerative preparatory treatments such as fire or machine-clearing (Snook et al., 2004). In regeneration methods that rely solely on natural seed fall, clearing may not be the best for regeneration. Harvesting seeds for future use assures future growth, particularly in species with high inter-annual variability (Snook et al., 2005). However, managing only one tree species in a diverse forest is problematic, for species richness is vital to resilience of both flora and fauna (Lohbeck et al., 2016).

Despite the challenges of working with an economically important species that has high and low production years, we hope that visually portraying seed production, and later exploration of tree attributes that affect seed production, will help local communities better manage *Carapa guianensis*.

ACKNOWLEDGEMENTS

I would like to thank Dr. Christie Klimas for providing her constant insight and knowledge throughout this project, and I look forward to working more with her in future projects. I would also like to acknowledge the financial support of an Undergraduate Research Assistant Program (URAP) grant from DePaul University's College of Science and Health. This project is only possible due to strong collaborations. We want to thank Patricia da Costa for her work leading this collaborative effort and Lúcia Helena de Oliveira Wadt for leading the collaboration that preceded the current one. We are grateful to Ana Cláudia Lira Guedes, Carolina, Volkmer de Castilho, and many field technicians and students for data collection and compilation. This project would not be possible without the efforts of man.

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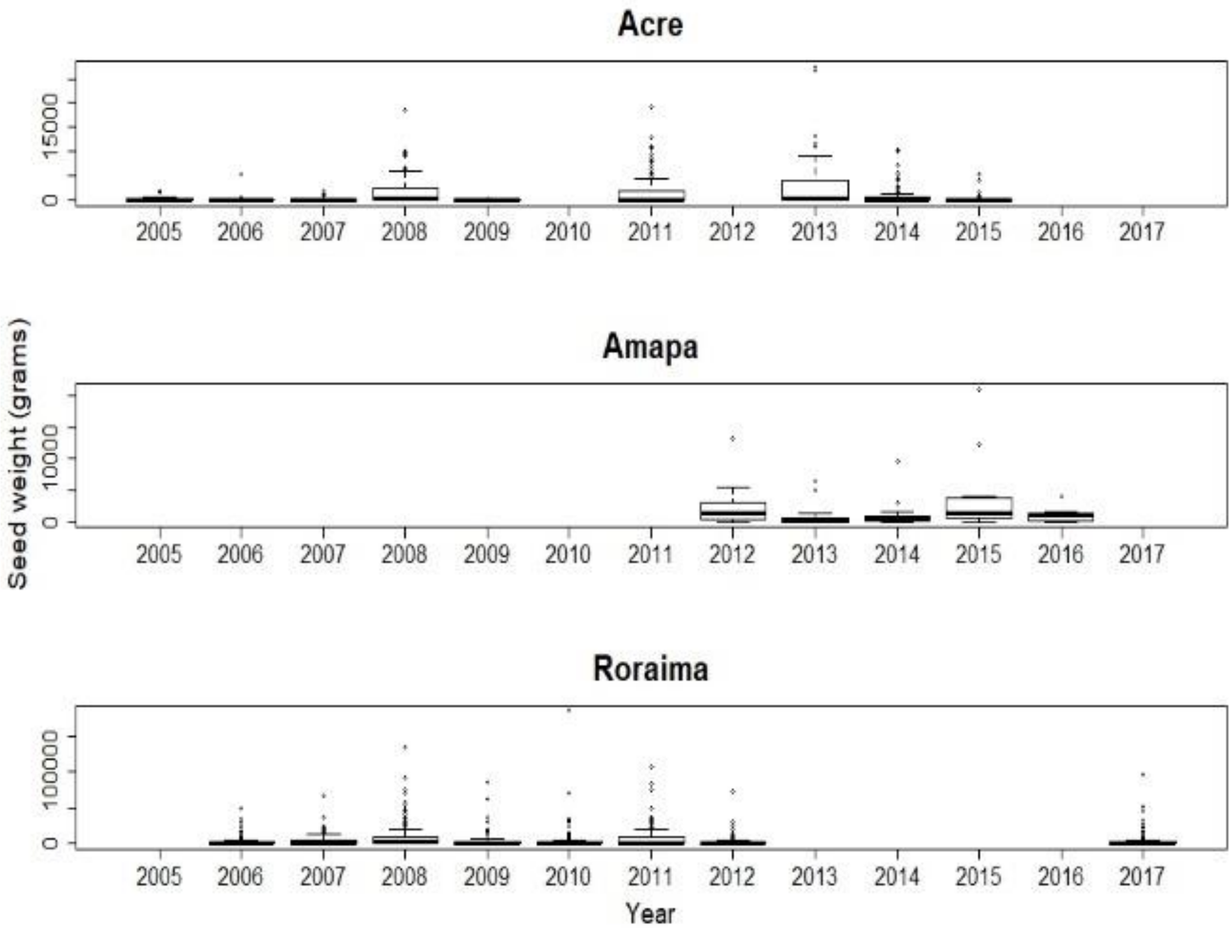
APPENDIX A

	Mean	St. Error	Median	Min	Max	Mean	St. Error	Median	Min	Max	Mean	St. Error	Median	Min	Max
2005	263.74	66.37	73.15	0	1829.82	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
2006	111.86	98.43	0	0	5288.04	NA	NA	NA	NA	NA	3390.11	642.99	312.80	0	49,969.80
2007	92.12	45.14	0	0	1784.67	NA	NA	NA	NA	NA	4546.73	704.44	1016.60	0	67244.18
2008	1877.31	301.26	328.54	0	18458.73	NA	NA	NA	NA	NA	9210.30	1577.00	1919.81	0	134402.20
2009	7.62	4.50	0	0	342.40	NA	NA	NA	NA	NA	4132.92	866.63	164.22	0	84518.56
2010	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	4869.84	1505.64	0	0	184512.90
2011	1815.55	325.38	134.80	0	19074.20	NA	NA	NA	NA	NA	7046.42	1285.69	469.20	0	105867.20
2012	NA	NA	NA	NA	NA	2445.14	815.59	1481.52	0	13127.18	2979.93	677.57	316.71	0	73445.44
2013	2674.90	490.87	235.90	0	27398.10	1008.95	476.78	6554.70	0	6554.7	NA	NA	NA	NA	NA
2014	1010.32	266.95	0	0	10279.50	1246.29	586.60	573.52	0	9554.59	NA	NA	NA	NA	NA
2015	210.45	71.84	0	0	5324.60	3529.50	1456.67	1456.67	0	21080.93	NA	NA	NA	NA	NA
2016	NA	NA	NA	NA	NA	1010.33	257.10	1135.12	0	4144.45	NA	NA	NA	NA	NA
2017	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	3438.19	921.00	0	0	95138.12

Appendix A. Appendix A includes the mean, standard error, median, minimum, and maximum for seed dry weight for each of the three studied locations. NAs are years with no data collection for that location.

APPENDIX B



Appendix B. Appendix B shows the seed dry weight in grams for Acre, Amapá, and Roraima throughout 2005 - 2017 in boxplots.