Biomass of *Mauritia flexuosa*: a Study on Deforestation and Carbon Emissions with Focus on the Aguaje Palm

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Introduction

What is the average biomass of *Mauritia flexuosa*, also known as aguaje, in an aguajal, within a given area, and what can we use this information for? The project site is located in the Madre de Dios region in Southeastern Peru. *Mauritia flexuosa*, in Peru commonly known as aguaje, is a palm tree native to The Amazon, and is abundant in this area. Aguaje is found primarilly in wetlands and is believed to be one of the most common plant species in the Amazon basin. Aguaje is a popular plant both among animals and humans. Fish, monkeys, birds and tapirs eat the palm, and various insects also live in it. People harvest it for its fruits, used for food, oils and more, and use the leaves and stem for handicrafts, hats, houses and everything in between, leading to a rising demand for aguaje based products. Instead of climbing up the tree and harvesting its fruits sustainably, often the whole tree is cut down. This is a cause for increasing concern, as many animals and people rely on the species.

The purpose of this project is to measure the biomass of aguaje (*Mauritia flexuosa*), an important palm species in the Amazon rainforest. This will be done in three 5 by 40 meter plots and nine 2 by 20 meter transects in an aguaje swamp. This knowledge will be usefull in understanding the impacts the degradation of aguaje peat swamps has on the environment and, with the biodiversity of aguaje swamps in mind, give an indication of the distruction size cutting down one tree has.

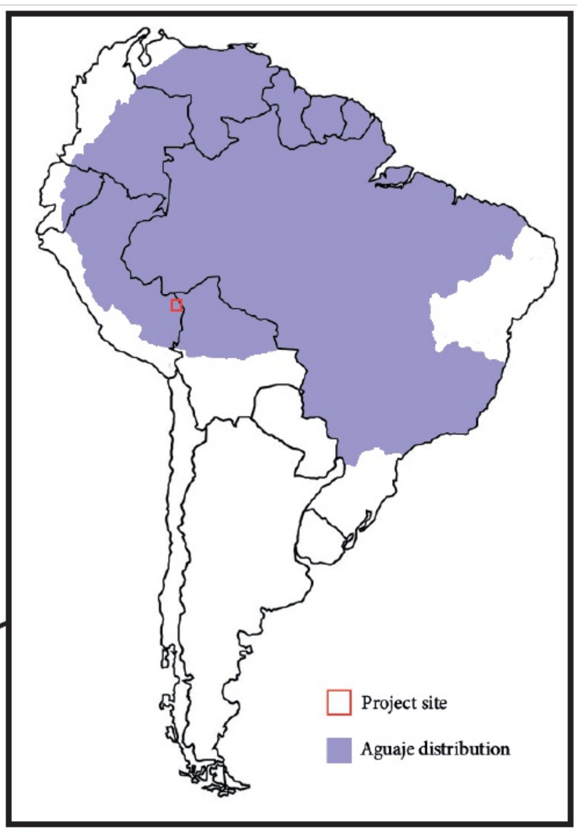


Figure 1: Map of aguaje habitat

By looking at the location of the plots and their environments, this will also tell how or where possible reforestation of aguajeswamps could be beneficial.

Aguaje morphology

Aguaje is a palm tree that can reach up to 35 meters. The leaves are big, round and can get to a size of 2,5 x 4,5 meters. Its flowers are yellow-orange and placed in big inflorescences. Aguajes are dioecious which means that there are plants with only male flowers and plants with only female flowers. Both of these are needed for reproduction of aguaje to happen. The aguaje fruits are around 2,5 x 4,5 cm in size, with red-brown scales, growing around December until June. Female plants can start producing fruits when they are 14 years old.

Figure 2: Aguaje palm illustration

Pollination

Pollen from aguaje is wind-dispersed which makes the pollination within a population more difficult. The further the distance of the aguajes in an area are, the more difficult it will be for the pollen to reach the right tree species. Furthermore there are male aguajes and female aguajes, this also contributes to a lower chance of pollination as a male tree has to be in the wind direction and right distance of a female aguaje palm.

Habitat

Aguaje grows in hydromorphic soils, meaning soils where there is an excess of water. *Mauritia flexuosa* is therefore most often found in aguaje peat swamps, called aguajales. Because aguaje grows in wetlands, the aguaje swamps also serve as carbon sinks, storing a lot of carbon in a thick layer of organic material consisting mostly of fallen leaves and old roots. The big leaves of the aguaje provide important shade on the wet soil underneath them, which helps minimize the heating and evaporation of the of the water in the swamp. This is important to maintain a habitat for the animals and plants that live in this environment. These swamps are some of the most carbon-dense places in the world, thus making them very important to preserve. But they are sensitive to deforestaion, overexploitation and climatic changes.

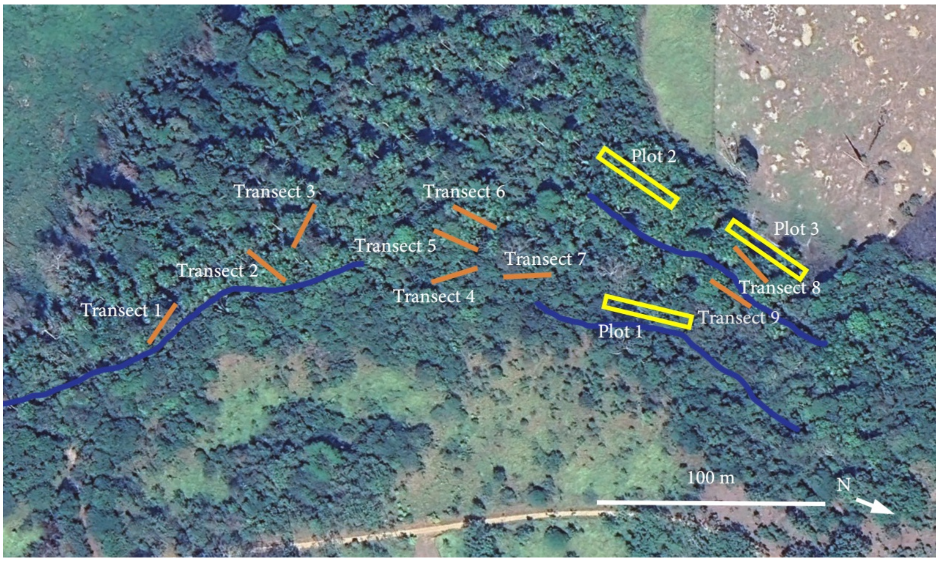
Picture 1. Showing aguaje growing in water.

Picture 2. Leaf coverage of aguaje.

Peat swamps

The water in peat swamps creates anaerobe conditions, and prevents oxygen from reaching the biological matter, such as fallen leaves and old roots, in the swamps. When swamps are drained, the stored biological matter gets exposed to the atmosphere's oxygen and microorganisms are able to start decomposing this organic material. When the biological material decomposes, the carbon in it is released into the atmosphere, where it will react with oxygen and turn into CO2. When the trees are cut, the sun will dry out the swamp, making the water level decrease and the decomposition of the organic material stored in the swamp begins. When a tree is cut down the same process happens when microorganisms start decomposing the tree. If a tree is burned, the carbon is also emitted into the atmosphere, but it happens much quicker.

Figure 3. Map of research area with location of transects and plots. Three plots measuring 5 by 40 meters. Nine transects measuring 2 by 20 meters. Blue line represents the stream.



Methods

In this report I will measure and calculate the above ground biomass, AGB, of aguaje in three plots measuring 5 by 40 meters and nine transects measuring 2 by 20 meters.

The plots are located in a swamp area, where there is an excess of water and therefore there will always be water available for the aguaje palms. This area is dominated by aguaje palms and called an aguajal. The research areas will resemble the average environments within the aguajal at Finca Las Piedras. These areas will be chosen by eye, and will not necessarily be the exact average. The location of the three plots will be chosen by different criterias in the aguajal:

1. Constant water table above ground.
2. Non-constant water table above ground.
3. Edge of swamp, next to a field.

These three plots with different criterias are made so they will give an indicatin of the average amount of aguaje and their height in this area. With different environments and with larger plots, it is easier to be nonbiased. The plot size of 5 by 40 meters is chosen because it makes it easier to have larger plots, where all the palms meet the criterias within each category. The same is done in the nine transects measuring 2 by 20 meters. The locations of these are more randomly chosen. The average of these transects can then be compared to the larger plots, to check for potential biases.

Picture 3. Aguaje in its habitat.

After the research is collected, the above ground biomass, AGB, will be calculated based on allometric models by Goodman et al. measuring the biomass of woody palms (Goodman et al. 2013). This study is based on field work and by cutting down the trees and measuring their dry weight. The formula for measuring AGB of *Mauritia flexuosa* is:

$$ln(AGB) = 2,4647 + 1,3777 \cdot ln(H_{stem})$$

Where H_{stem} is the height of the aguaje stem from ground to leaves. In this formula it is assumed that the diameter of aguaje is around the same of all trees and therefore it is not a part of the equation.

The stemheight was measured by placing a stick of 1 meter next to each tree and then, at a distance, counting how many of this stick it would be possible to place on top of each other until the top of the tree was reached.

Results

1. Constant water table above ground

This plot was located along a stream in the aguajal. This was the place with the densest vegetation of the three plots.

Table 1. Results of plot number 1.

	Trunk height	Above ground biomass	dbh
1	11,5 m	340, 3 kg	45,2 cm
2	7 m	171,7 kg	36,3 cm
3	11 m	320,0 kg	39,2 cm
4	9,5 m	261,6 kg	36,3 cm

Number of trees: 4

Total biomass: 1093,5 kg

Average biomass: 273,4 kg

Average dbh: 39,2 cm

Picture 4. Vegetation in plot number 1.

Picture 5. Aguaje palm with no bark.

2. Non-constant water table above ground

The primary plant here is aguaje and it is easier to walk around. Mixed in between the aguaje are also other bigger trees. There is a lot of leaf litter on the ground beneath the aguajes.

3. Next to a field

Here there are no bigger trees besides the aguaje trees in this study. There are a few smaller bushy plants, but nothing taller than 1,5 meters. Soil is wet, a big part of the ground is bare. A couple of trees are missing their bark.

Table 2. Results of plot number 2.

	Trunk height	Above ground biomass	dbh
1	13 m	402,9 kg	40,4 cm
2	12 m	360,8 kg	40,7 cm
3	10,5 m	300,2 kg	47,1 cm
4	11,5 m	340,3 kg	44,6 cm
5	12 m	360,8 kg	32,8 cm
6	10,5 m	300,2 kg	37,9 cm
7	9 m	242,7 kg	38,5 cm
8	11,5 m	340,3 kg	37,6 cm
9	11 m	320,0 kg	31,2 cm
10	11 m	320,0 kg	29,7 cm
11	10 m	280,7 kg	44,6 cm
12	4,5 m	93,4 kg	28,6 cm

Number of trees: 12
Total biomass: 3662,2 kg
Average biomass: 305,2 kg
Average dbh: 37,8 cm

Table 3. Results of plot number 3.

	Trunk height	Above ground biomass	dbh
1	10 m	280,7 kg	42 cm
2	9 m	242,7 kg	47,8 cm
3	11 m	320,0 kg	41,4 cm
4	10,5 m	300,2 kg	39,8 cm
5	12,5 m	381,7 kg	39,5 cm
6	10,5 m	300,2 kg	43,0 cm

Number of trees: 6
Total biomass: 1825,5 kg
Average biomass: 304,2 kg
Average dbh: 42,2 cm

Transects

- Transect 1: Along the stream. Soil moist, but not wet.

Height	AGB	dbh
8 m	206,4 kg	33,7 cm
10 m	280,7 kg	38,2 cm
11 m	320,0 kg	37,6 cm
11,5 m	340,3 kg	42,0 cm
11,5 m	340,3 kg	37,6 cm

- Transect 2: Along the stream. Dense

Height	AGB	dbh
12 m	360,8 kg	33,1 cm
10 m	280,7 kg	36,0 cm

- Transect 3: 25 steps further into the aguajal, away from the stream. Soil moist but not wet.

Height	AGB	dbh
11 m	320,0 kg	34,7 cm

- Transect 4: Dense vegetation, but plants are taller, so less of an understory.

Height	AGB	dbh
5,5 m	123,2 kg	33,1 cm
8,5 m	224,4 kg	39,2 cm
11,5 m	340,3 kg	37,6 cm
9 m	242,7 kg	43,6 cm

- Transect 5: Along the stream. Soil moist, but not wet.

Height	AGB	dbh
5,5 m	123,2 kg	33,1 cm
8,5 m	224,4 kg	39,2 cm
11,5 m	340,3 kg	37,6 cm
9 m	242,7 kg	43,6 cm

- Transect 6: Very wet, no aguajes in sight.

- Transect 7: Less wet. Closer to the main trail than transect 6. Dense forest and understory.

Height	AGB	dbh
10 m	280,7 kg	32,8 cm
10,5 m	300,2 kg	26,7 cm

- Transect 8: A little bit further in than plot 3, but still next to the field. Very wet. Not many other plants than aguaje, some smaller ferns.

Height	AGB	dbh
8 m	206,4 kg	34,7 cm
10 m	280,7 kg	35,7 cm
10,5 m	300,2 kg	48,5 cm
11 m	320,0 kg	37,6 cm
6,5 m	155,0 kg	31,5 cm
9,5 m	261,5 kg	46,2 cm
8,5 m	224,4 kg	37,6 cm

- Transect 9: Where the area next to the field with not many small plants meet the part of the forest that is denser in vegetation, theres a small belt with water and a lot of smaller aguajes. Transect 9 is in this area, on the other side of the stream from the field.

Height	AGB	dbh
8 m	206,4 kg	42,7 cm
8 m	206,4 kg	24,2 cm
9,5 m	261,5 kg	42,4 cm

Summary

Plots:

	Number of trees	Total biomass	Average biomass	Average dbh	Average height
1. constant water table above ground	4	1093,5 kg	273,4 kg	39,2 cm	9,8 m
2. Non-constant water table above ground	12	3662,2 kg	305,2 kg	37,8 cm	10,5 m
3. Next to a field	6	1825,5 kg	304,2 kg	42,2 cm	10,6 m
All	22	6527,2 kg	296,7 kg	41,2 cm	10,4 m

Transects:

Transect	Trees	Total biomass	Average biomass	Average dbh	Average height
1	5	1487,6 kg	297,5 kg	37,8 cm	10,4 m
2	2	641,5 kg	320,7 kg	34,5 cm	11 m
3	1	320,0 kg	320,0 kg	34,7 cm	11 m
4	4	1066,3 kg	266,6 kg	39,0 cm	9,6 m
5	4	930,5 kg	232,6 kg	38,4	8,6 m
6	0	-	-	-	-
7	2	580,8 kg	290,7 kg	29,8 cm	10,3 m
8	7	1748,1 kg	249,7 kg	38,8 cm	9,1 m
9	3	674,3 kg	224,8 kg	36,4 cm	8,5 m
All	28	7449,1 kg	266,1 kg	37,2 cm	9,3 m

Plots and transects:

Total area: 960 m²

Total biomass: 13.976,3 kg

Average biomass: 279,5 kg

Sources of error

Because most of the trees are placed in a dense forest area, it is not possible to see the whole tree, if you are far away, and when collecting the data, it was necessary to find the right angle where the whole tree was visible. The most common mistake to have occurred during the measuring process for this project is therefore a varying distance to the tree combined with the measuring method. Using this method, a certain angle within your vision is your given meter. Standing closer to the tree, one meter will be a bigger angle and therefore, when looking up at the tree and trying to measure its height with this method, the tree will become shorter, than if you are further away.

Because the distance to all the measured trees was not the same, this has possibly contributed to uneven measurements within the tree heights. This was a source of error that was clear already when the data was collected and therefore the heights of multiple neighboring trees were compared, and it was decided to have height intervals of 0,5 meters. As stated earlier human mistakes has probably also been a big source of error but, it is assumed, that these will be evened out as this would have led to both taller and shorter measurements than the real height.

Discussion

Plot 1, 2 and 3

The only plot where the average biomass sticks out is plot 1, *Constant water table above ground*. Because there are only four aguajes in this plot, the average measurements is more prone to be noticeably lower or higher compared to the others. There is one tree in the wet conditions that is only 7 meters tall. When it is one out of four is that much shorter, the average becomes noticeable less compared to the other two places. If we ignore the tree that's only 7 meters tall, and calculate the average of the three remaining trees, the average AGB in plot number 1 is 307,7 kg. With this in mind, there's no significant difference in the average biomass of the trees in the three plots, but the number of trees in each plot is notable. They vary from four trees in plot 1 to 12 trees in plot 2, *Non-constant water table above ground*.

Transects

The average height for the trees within the transects is 9,3 meters. This is almost one meter shorter than the average tree height in the three plots, and results in the average biomass also being 30 kg lighter compared to the average of the three plots. This is probably because the number of trees in each environment is more evenly distributed within the nine transects. In the three plots, 12 of the 22 trees are within the same 200 m^2 (plot 2) and therefore living in the same environment with same living conditions. Because there are smaller transects scattered around the aguajal, this gives a more even distribution and the average height of the trees will be different.

CO_2 emissions

The carbondioxide emission of a tree is calculated with the formula:

$$CO_2\ emission = \frac{Biomass}{2} \cdot 44/12$$

Biomass is divided by 2 because this is the average amount of carbon in biomass for plants. The amount of carbon is multiplied by 44/12. 44 is the weight of a CO_2 atom in units, and 12 is the weight of carbon. The carbon in the biomass that is released into the atmosphere will react with oxygen to become CO_2.

$$CO_2\ emission = \frac{279{,}5\ kg}{2} \cdot \frac{44}{12} = 512{,}5\ kg$$

The amount of CO_2 emitted from the average aguaje: CO_2 emission for the average aguaje in this plot, if it was cut down would be 512,5 kg. The CO_2 emission from cutting down the aguajes on one hectare is calculated. First the total biomass of aguaje will be calculated. The data area is 960 m^2, and the total biomass is 13.978,6 kg. The biomass per m^2 is multiplied by 10.000 m^2 to know the biomass per hectare, and then the formula for measuring the CO_2 emission is used. The result is divided by 1.000, to know the emission in tons.

$$CO_2\ emission\ (1\ ha) = \left(\frac{\frac{13.976{,}3\ kg}{960\ m^2} \cdot 10.000\ m^2}{2} \cdot \frac{44}{12}\right) = \frac{266.918{,}6\ kg}{1000} = 266{,}1\ t/ha$$

Cutting down 1 hectare of aguaje palms would lead to 266,1 tons of CO_2 being emitted into the atmosphere. It is important to note, that aguaje is mixed with other plant species, and if these die as well, when the aguaje palms are cut, this will have to be added to the total CO_2 emission of one hectare. Also, it is important to consider the CO_2 that the tree will not absorb once it has died. The amount of CO_2 a tree absorbs per year varies between species and during different stages of its lifetime, but usually it is assumed to be around 25 kg CO_2 a year.

It plays a significant role how the wood is treated after being cut. Is it for example burned, the carbon, that will react with oxygen, is released instantly, but if it is left as it is, it will decompose naturally, and it will take years before it is fully decomposed. The carbon the tree has absorbed during its lifetime is then slowly released into the atmosphere and can create living habitat for various animals and fungi in the meantime.

Biodiversity

Another issue with cutting down the aguaje is, that they are cut so people can harvest their fruits. That means only the female palms are cut down, because these are the ones that produce fruits. If alle the trees left are males, it will not be possible for them to reproduce or to produce fruits and the population will eventually die out in an area where this happens.

Combining all twelve plots, 960 m^2 were covered, and the data from 50 trees was collected. To calculate how many m^2 one tree covers, the 50 trees are divided between 960 m^2:

$$\frac{50\ trees}{960\ m^2} = 19{,}2\ trees\ pr.m^2$$

If the trees were evenly distributed there would be one tree per 19,2 m^2. Looking at this number, cutting down one tree could have a big impact on the biodiversity in an area because the environment within that square would change significantly. Considering the aguajes are often grouped together, if only one is cut down, the neighboring trees would likely be able to cover for
the tree that has been cut down, but if multiple trees next to each other are cut, it would lead to a bigger area with a changed environment, and that would affect the biodiversity.

Reforestation with aguaje

Based on the data collected for this project, it will be possible to give an idea of the ideal place for aguaje to grow, and if we were to plant it, where this would give the best results. The three plots are placed in different environments, and from these it is easy to see, where there are the most aguaje trees, and where they are doing the best. The transects are evenly dispersed throughout the aquajal, but with the written notes about the environment each transect is placed in, they are also giving an indication of the best environment for aguaje.

Based on the research for this project, the ideal places to plant aguaje are in areas, where the soil is moist, but not too wet. The reason they thrive better here than other places could be because of a number of resons. The most important factors in how well a specific plant species is growing in a certain area, is competition with other plant species and the availability of water and nutrients. Plants are adapted to

Picture 6. Aguaje roots.

different environments and aguaje likes a very moist soil, where it can grow due to its roots that are rised above the water, and therefore still are able to absorb oxygen from the atmosphere. Not many plants are adapted to these conditions where the soil is not wet nor dry, and therefore there is not a lot of competition from other plant species here, and it could be one of the reasons why there are a significantly more dense aguaje population in these areas, like plot 2, *Non-constant water level above ground.*

When looking at the health of the trees, it is also clear, that the trees near the edge of the forest look unhealthier and many of them are missing their bark. Even though these were the trees with the highest average biomass, trees cannot transport water to their leaves if they have no bark, and they will eventually die.

Conclusion

Cutting down aguaje trees has a huge impact on the environment, both when it comes to the global climate and the biodiversity in the aguajal where they are cut. Cutting down one hectare of aguaje palms leads 266,1 ton of CO_2 being emitted into the atmosphere, and when the trees are being cut down, the wet soil underneath gets exposed to the sun which will lead to an increased evaporation in wetland areas. Wetlands are carbon sinks, and when they dry out, the biological materials that are stored under the water starts to decompose, and the carbon from this is emitted into the atmosphere as well. Cutting down aguaje will lead to a change in the local ecosystem of the specific area and the biodiversity will be affected negatively.

Works Cited

Virapongse, A., Endress, B. A., Gilmore, M. P., Horn, C., & Romulo, C. (2017). Ecology, livelihoods, and management of the *Mauritia flexuosa* palm in South America. *Global Ecology and Conservation*, 10, 70–92. https://doi.org/10.1016/j.gecco.2016.12.005

Rosa, R. K., & Koptur, S. (2013). New findings on the pollination biology of *Mauritia flexuosa (Arecaceae)* in Roraima, Brazil: Linking dioecy, wind, and habitat. *American Journal of Botany*, 100(3), 613–621. http://www.jstor.org/stable/23433583

Hergoualc'h, K., van Lent, J., Dezzeo, N. et al. Major carbon losses from degradation of *Mauritia flexuosa* peat swamp forests in western Amazonia. *Biogeochemistry* 167, 327–345 (2024). https://doi.org/10.1007/s10533-023-01057-4

Goodman, R. C., Phillips, O. L., del Castillo Torres, D., Freitas, L., Cortese, S. T., Monteagudo, A., & Baker, T. R. (2013). Amazon palm biomass and allometry. *Forest Ecology and Management*, 310, 994–1004. https://doi.org/10.1016/j.foreco.2013.09.045

Koolen, H. H. F., da Silva, F. M. A., da Silva, V. S. V., Paz, W. H. P., & Bataglion, G. A. (2018). *Burit*i fruit— *Mauritia flexuosa.* In Exotic Fruits (pp. 61–67). Elsevier. https://doi.org/10.1016/B978-0-12-803138-4.00004-6

Saro, I., Robledo-Arnuncio, J. J., González-Pérez, M. A., & Sosa, P. A. (2014). Patterns of pollen dispersal in a small population of the Canarian endemic palm (*Phoenix canariensis*). *Heredity*, 113(3), 215–223. https://doi.org/10.1038/hdy.2014.16

Barfod, A. S., Hagen, M., & Borchsenius, F. (2011). Twenty-five years of progress in understanding pollination mechanisms in palms (*Arecaceae*). *Annals of Botany,* 108(8), 1503–1516. https://doi.org/10.1093/aob/mcr192

Dise, N. B. (2009). Peatland Response to Global Change. *Science*, 326(5954), 810–811. https://doi.org/10.1126/science.1174268

National Geographic, Bloudoff-Indelicato, Mollie (23rd of March 2015). Deforestation threatens Peru's food system, *Environment*. https://www.nationalgeographic.com/culture/article/deforestation-threatens-perus-food-system-environment