Analysis of Activity Patterns of Two Primate Species (*Plecturocebus discolor* and *Pithecia aequatorialis*) in Amazonian Ecuador

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Abstract
The purpose of this project was to employ the R statistical programming language to explore the patterns of activity across the circadian cycle for two species of nonhuman primates (titi monkeys: *Plecturocebus discolor* and sakis: *Pithecia aequatorialis*) in the rainforest of Amazonian Ecuador. The activities of one male individual of each species were recorded by attaching a collar with an accelerometer that generated a pulse train whose frequency was proportional to the accelerations of the monkey. These sensors allowed for monitoring the activity of the monkeys even when monkeys were out of sight or when observers were out of the field at night. Activity data for the titi monkey subject (Loki) were collected for one month in 2017 (July 17th to August 21st), while activity data for the saki subject (Morpho) were collected for about eight months from 2017 to 2018 (July 21st to March 28th). Activity data were sorted and analyzed by applying multiple packages in R; graphs were constructed using the *ggplot2* package. Based on these two primate species' activity graphs and recent literature on titis and sakis, I examined these two species' activities in coexistence in the west Amazonian Ecuador area by analyzing their temporal activity distribution, identifying individual circadian cycles, and proposing directions for future research. I found these two diurnal monkey species start exhibiting intensive activity within a range of fifteen minutes before or after sunrise, but stay inactive after sunset and throughout the night. The titi monkey tends to end a day at times ranging from 1 to 2 hours later than the saki, who stays active for about 10 hours after sunrise and has higher activities than the titi for much of the day.

Introduction
Ecologists have found that different platyrrhine primates (monkeys from Central and South America) have established sympatric coexistence through niche partitioning, such as having different temporal activity patterns (Krofeld-Schor et al., 2003; Snodderly et al., 2019; Veilleux et al., 2021).

Due to low visibility to observers and challenging forest habitats, accelerometer technology has been applied to the study of primate temporal activity patterns. For instance, studies have used accelerometers to study species that live in swamp and forest habitats (Sha et al., 2017). Not only that, one field study with Rhinopithecus primates also benefited from using accelerometers to track in steep karst limestone hills (Quyet, 2004). Another study with Japanese macaques (*Macaca fuscata*) used accelerometers to study the circadian rhythm and night time activity of *Macaca fuscata* (Sha et al., 2017). In our study, two species of nonhuman primates' accelerometers were put on platyrrhine primates to measure both monkeys' activities and detect their niche partitioning patterns over months.

I focused on *Plecturocebus discolor* (titi) and *Pithecia aequatorialis* (saki) with one monkey for each diurnal species and examined their activity patterns. To evaluate the hypothesis that both monkeys are less active at night and are more active during the day, I also speculated that these two species start their days at about the same time with respect to sunrise, and they have different temporal niche partitioning patterns during the day. Moreover, with a temporal niche partitioning difference, different distributions of the two monkeys' overall activities throughout the day could be expected. With the hypotheses, I used R to construct monkeys' daily and overall activity distributions, interpreted their daily activity patterns corresponding to behavioral notes, and compared monkeys' actions—leaving the sleeping tree for the first time in a day and entering the sleeping tree for the last time in a day as ending the day—with times relative to sunrise and sunset.

I found that both monkeys stay inactive after sunset and throughout the night with activity pulse rates that are below 500 pulses/min, This rate is the maximum recorded during rest periods documented by behavioral observations. both diurnal monkey species begin to have pulse rates above 500 within a range of fifteen minutes before or after sunrise. There are differences between the monkeys in the daytime, in which saki maintains high pulse rates of over 500 for 10 hours after sunrise, while titi stays active and returns to the tree at times ranging from 1 to 2 hours later than saki. Within those 10 hours, saki has continuous higher-pulse rates than titi for 6.17 hours. Additionally, titi's overall distribution is different from saki's during the day. Titi reaches the highest pulse of the day when he starts foraging before 8 AM, then the pulses start decreasing, and he has the lowest signal pulse between 11 AM and noon. Due to a temporal niche partitioning difference, Saki's pulses gradually increase, but he does not reach the highest pulse or begin to forage consistently until the time between noon and 1 PM.

Materials and Methods

Original data and behavioral notes

To detect monkeys' activity pulse rates, accelerometer collars were used. An accelerometer is a device that detects and converts accelerations into trains of pulses with frequencies that are proportional to the magnitude of the acceleration. The pulses were accumulated in one-minute intervals (Actical Activity Data Acquisition Description).

These two monkeys were captured via remote anesthetization by using a DanInject Co2-powered rifle and PneuDart commercial Darts (type P, volume sizes 0.5, 1.0, 1.5, and 2.0 cc) filled with an appropriate dosage of either ZolatilTM (tiletmine/zolazepam: 12-18 mg/kg body weight) or ketamine HCl (~25-50 mg/kg body weight). All remote anesthetization processes, capture protocols, strategies for dealing with capture risks, and health monitoring procedures are based on published recommendations and consultation with both wildlife and lab-based veterinarians (Snodderly et al., 2019). While anesthetized, they were fitted with an accelerometer on a collar.

The behavioral notes and activity pulse rates for these two species of monkeys were collected at the Tiputini Biodiversity Station in the western Ecuador area from July 2017 to August 2018 (D.M. Snodderly & A. Di Fiore, unpublished behavioral notes 2017-2018). The titi monkey received an accelerometer collar on July 16th, and the saki monkey received an accelerometer on July 21st. About one month of activity data for the titi monkey subject (Loki) was collected from July 17th to August 21st in 2017, while activity data for the saki subject (Morpho) were collected from July 22nd of 2017 to March 28th of 2018 for about eight months.

The use of the accelerometers eliminated potential biases due to missing the earliest movements or due to the effects of human observers on the behavior of the monkeys. To minimize bias before analyzing the data, the behavioral notes only include if 1) the sleeping tree was known from the previous evening's records, and 2) the observer saw the monkeys in the same sleeping tree on the next day of observation(Snodderly et al., 2019).

Activity data were analyzed in R, version 4.2.0. Analyses were conducted by using functions from libraries of *"tidyverse"* version 1.3.1, *"ggplot2"* version 3.3.6, *"dslab"* version 0.7.4, *"stringr"* version 1.4.0, *"dplyr"* version 1.0.9, and *"ggnewscale"* version 0.4.8.

Overall activities and responses to sunrise and sunset

I created graphs for each monkey's overall activities and activity patterns, containing the time of sunrise and sunset. Each graph was drawn by using *geom_bar()* and *geom_point()* functions, and the time of sunrise and sunset was indicated based on the Tiputini Biodiversity Station's sunrise and sunset dataset. Loki's overall activity includes the recorded dates from July 17th to August 21st, and an overall activity histogram that includes dates from July 22nd to March 28th was constructed to indicate Morpho's. Additionally, to improve the visualization of patterns in the cumulative histograms of activity, the activity pulse rates were accumulated in 5-min bins and a smoothing function *ksmooth()* was applied. Graphs of activity on single days retained the 1-min time resolution. The Mann-Whitney U-Test was used to test whether the total daily activity of these two monkeys was significantly different.

Pipeline and filtering process

For the pipeline and filtering process of the *loki_activity_grouped_month* dataframe, the total activity levels were added every five minutes from the Activity_Data*()* column and combined with a time column. With activity levels of every five minutes, two monkeys' overall activity trends within 24 hours were indicated. The *Time_Fraction* column from the new dataset was vectorized and added by using *cut(), as.character(),* and *mutate()* functions as a character column named *Time_Fraction_Groups* with an interval range of *5/24 hours*. Then, the time ranges column was grouped by using the *group_by()* function and sorted with the total activity levels for every five minutes named *Activity_Data* in the *loki_acitivty_grouped_month* variable by using the *summarize()* function with the sum of activity levels. And the final pipe operator was used to make the *loki_acitivty_grouped_month* variable as a dataframe.

Instead of having time ranges, the *str_extract_all()* function was used with parameters of *"-?[0-9]+" and function(x) max(as.numeric(x))* to select the highest value of each time range and represent it as a time of every five minutes. To sort and combine two columns by assigning a new name to the *Time_Fraction_Label_month* column, the new dataset *loki_activity_group_month* was created. The *arrange()* function was used for dataset *loki_activity_group_month* to reorder the time point in ascending order. Each smoothed graph has a large number of points, so the moving average for both monkeys' activities over one month could be determined the best with smaller spans. A span indicates a variance of the kernel smoothing. Having different span values, such as 0.75, the smoothing line did not cover or go through most of the pulse. For instance, the kernel smoothing with a span of 0.75 showed the movements of both monkeys starting earlier than their actual data points. In contrast, a span of 0.5 showed the best coverage of activity pulse rates with optimal smoothed lines. The *geom_point()* function was used to graph out total activity pulse rates every five minutes. The overall moving averages for Loki and Morpho were respectively shown as a continuous trend line by using the *ksmooth()* function with *kernel="normal"*.

Daily collected activities

To interpret each monkey's daily activity data corresponding to behavioral notes, daily activity graphs were constructed based on the days that were recorded in the behavioral notes. With all the columns from the original dataset, seven new datasets were built separately based on different dates for Loki by using the geom_bar*()* function. Additionally, the *geom_bar()* function was applied to graphs for another five days' datasets correspondingly by selecting that certain date from the original dataset for Morpho.

Identification of daily activities relative to sunrise

To compare monkeys' daily activities with times relative to sunrise and sunset, the daily activity graphs with times of sunrise and sunset were constructed based on the days that were recorded in the behavioral notes and the Tiputini Biodiversity Station's sunrise and sunset dataset. Two days of 2017, August 5th and August 7th, from the behavioral notes were used to construct graphs of Loki's activities relative to sunrise. Similarly, fourteen days, between July 22nd and December 2nd, were also selected to construct Morpho's activities relative to sunrise. Two sets of dataset of each monkey were combined by using the *left_join()* function, and graphs were created by using *geom_bar()* and *geom_point()* functions.

Mean, standard deviation, relative standard deviation, and standard error calculation

The differences between two monkeys' activity levels were calculated and compared by running the "*tidyverse"* package to calculate the mean, standard deviation, relative standard deviation, and standard error of each monkey's pulse rates.

Results

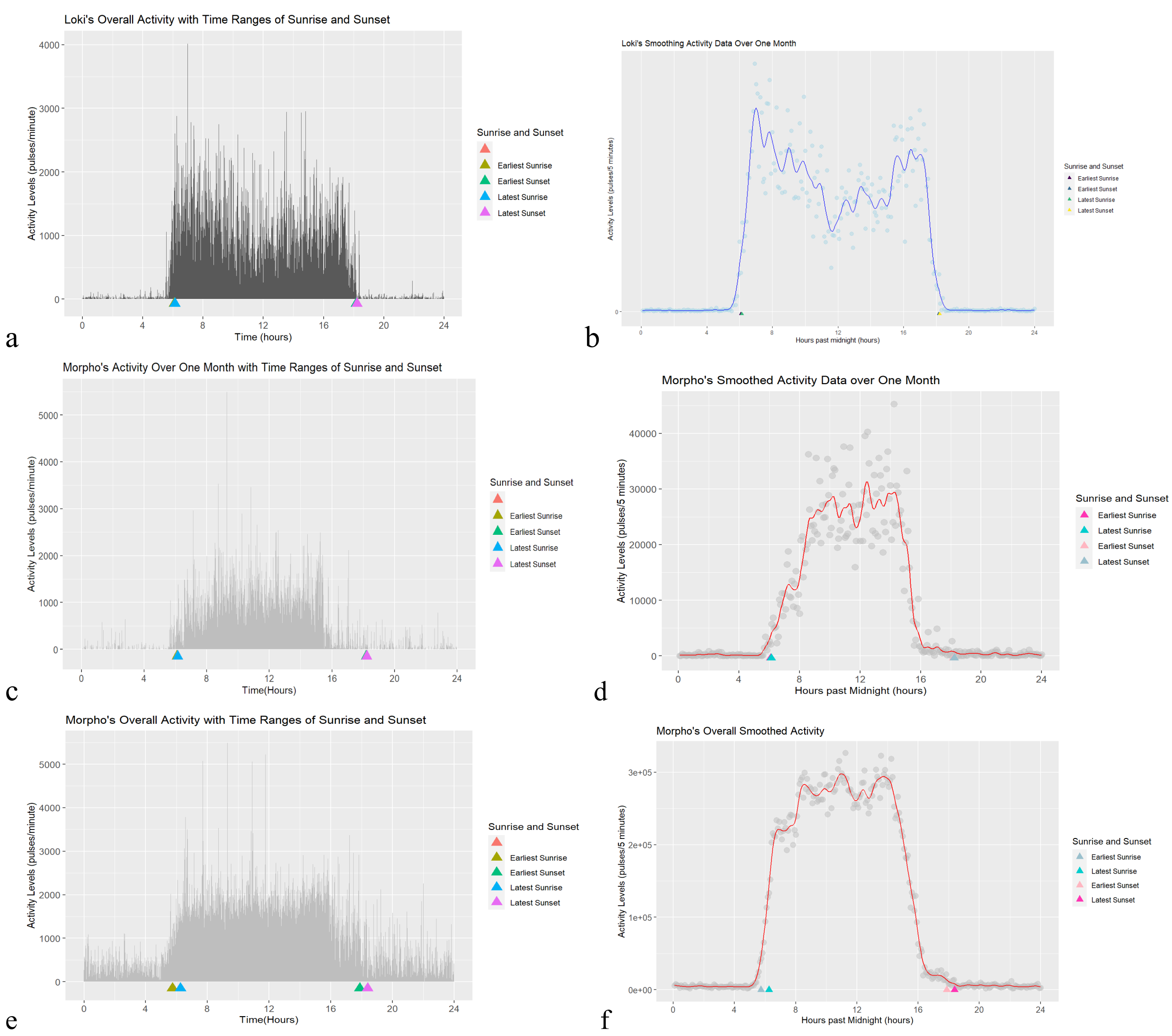
Overall activities and responses to sunrise and sunset

During the time from 0 AM to 11:59 PM and the time ranges of both sunrise (5:44 AM - 6:15 AM) and sunset (5:52 PM - 6:23 PM) in the legend, Loki began showing some signal pulses that were above 500 at times about fifteen minutes earlier than sunrise. Then, he stayed active with pulses above 500 until around sunset (*Fig. 1a)*. Loki's smoothed activity distribution shows that he reached the highest pulse rate of the day before 8 AM; the lowest pulse rate during the day was between 11 AM and noon (*Fig. 1b; 1g)*.

Similarly, Morpho also began showing some pulse rates that were above 500 at times about fifteen minutes earlier than sunrise, but he only showed consecutive activity pulse rates that were above 500 until about 2 hours before sunset (*Fig. 1c)*. Morpho's smoothed activity distribution over one month shows that the highest pulse rate of the day was between noon and 1 PM *(Fig. 1d)*. Although the activity pulse rate was not the lowest between 11 AM and noon at daytime, Morpho also lowered his activity to a pulse that is between 20000 and 25000 (*Fig. 1d; 1g)*.

According to the activity distribution over one month, both monkeys exhibited higher activity levels with increasing levels of sunlight, so they were diurnal and more active during the day. While the activities of both of them were impacted by the times of sunrise and sunset, Loki started showing relatively more intense signs of action with pulses over 20000 pulses per five minutes after sunrise at 6:08 AM, whereas Morpho did not have activity pulse rates that were over 20000 pulses per five minutes until after 8 AM (*Fig. 1b; 1d)*. Overall, Loki's intense activities started at about 6 AM and ended at about 6 PM. Morpho tended to maintain a higher activity level from 6 AM to 4 PM (*Fig. 1g)*. The behavioral notes also show that Loki began foraging after leaving the sleeping tree for the first time in a day, but Morpho did not forage until around 10 AM. Furthermore, with continuous high pulses that were over 500, Loki lasted about 1 hour longer in high pulses than Morpho before sunset at daytime (*Fig. 1a; 1c; 1g)***.**

The skewness of both monkeys' activity data over one month fails the normality assumption, so both data do not appear to be normally distributed. With other assumptions of being random samples and having independent observations, Mann-Whitney U-Test tested whether the level amounts of activity pulse rates of both monkeys are the same in days. Having the conventional acceptance of statistical significance at a *p-value* of 0.05, the results showed a *p-value* of 0.5469 with W = 42,676. Hence, it fails to reject the null hypothesis, and there is no significant difference in the level amounts of activity pulse rates among these two monkeys (W = 42,676, $p>0.05$).



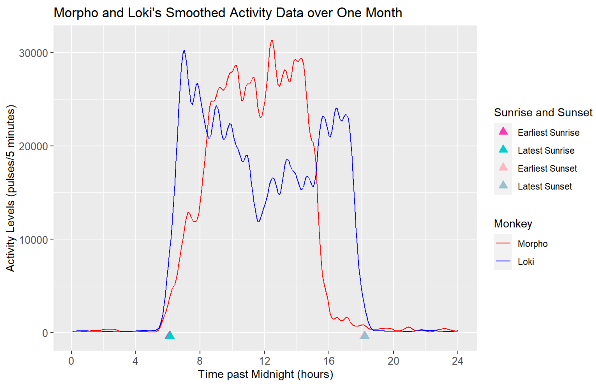


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Fig. 1a. Loki's Overall Activity over One Month with Time Ranges of Sunrise and Sunset. From July 17th to August 21st**,** according to Tiputini Biodiversity Station's sunrise and sunset dataset, the average time range of sunrise is from 6:05 AM to 6:08 AM, and two labels indicating the time ranges of sunrise are *Earliest Sunrise* and *Earliest Sunset*. The average time range of sunset is from 6:10 PM to 6:13 PM, and two labels indicate the time ranges of sunset as *Latest Sunrise and Latest Sunset*.

Fig. 1b. Loki's Smoothed Activity Data over One Month. By combining the activity levels for every 5 minutes, the moving average was calculated based on a span of 0.5. The average time range of sunrise is from 6:05 AM to 6:08 AM, and two labels indicating the time ranges of sunrise are *Earliest Sunrise* and *Earliest Sunset*. The average time range of sunset is from 6:10 PM to 6:13 PM, and two labels indicate the time ranges of sunset as *Latest Sunrise and Latest Sunset*.

Fig. 1c. Morpho's Activity over One Month with Time Ranges of Sunrise and Sunset. From July 22nd to March 28th, according to Tiputini Biodiversity Station's sunrise and sunset dataset, the time range of sunrise is from 6:05 AM to 6:08 AM, and two labels indicating the time ranges of sunrise are *Earliest Sunrise* and *Earliest Sunset*. The time range of sunset is from 6:10 PM to 6:13 PM, and two labels indicate the time ranges of sunset as *Latest Sunrise and Latest Sunset*.

Fig. 1d. Morpho's Smoothed Activity Data over One Month. By combining the activity levels for every 5 minutes, the moving average was calculated based on a span of 0.5. The average time range of sunrise is from 6:05 AM to 6:08 AM, and two labels indicating the time ranges of sunrise are *Earliest Sunrise* and *Earliest Sunset*. The average time range of sunset is from 6:10 PM to 6:13 PM, and two labels indicate the time ranges of sunset as *Latest Sunrise and Latest Sunset.*

Fig. 1e. Morpho's Activity Overall Activity with Time Ranges of Sunrise and Sunset. From July 22nd to March 28th, according to Tiputini Biodiversity Station's sunrise and sunset dataset, the average time range of sunrise is from 5:44 AM to 6:15 AM, and two labels indicating the time ranges of sunrise are *Earliest Sunrise* and *Earliest Sunset*. The average time range of sunset is from 5:52 PM to 6:23 PM, and two labels indicate the time ranges of sunset as *Latest Sunrise and Latest Sunset*.

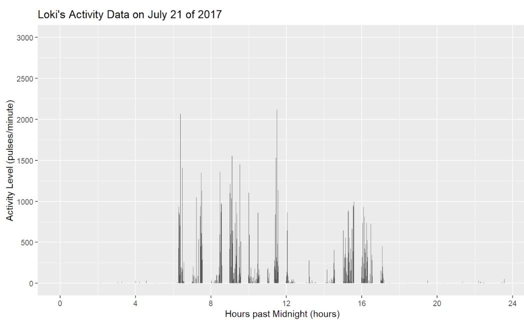
Fig. 1f. Morpho's Overall Smoothed Activity Data. By combining the activity levels for every 5 minutes, the moving average was calculated based on a span of 0.5. The average time range of sunrise is from 5:44 AM to 6:15 AM, and two labels indicating the time ranges of sunrise are *Earliest Sunrise* and *Earliest Sunset*. The average time range of sunset is from 5:52 PM to 6:23 PM, and two labels indicate the time ranges of sunset as *Latest Sunrise and Latest Sunset*.

Fig. 1g. Morpho and Loki's Smoothed Activity Data over One Month. From July 17th to August 21st**,** according to Tiputini Biodiversity Station's sunrise and sunset dataset, the average time range of sunrise is from 6:05 AM to 6:08 AM, and two labels indicating the time ranges of sunrise are *Earliest Sunrise* and *Earliest Sunset*. The average time range of sunset is from 6:10 PM to 6:13 PM, and two labels indicate the time ranges of sunset as *Latest Sunrise and Latest Sunset*.

Daily collected activities

After seeing the monkeys' overall activities above, some daily activities of each monkey were extracted and interpreted based on the behavioral notes *(Fig. 2a-c; 3a-e)*.

Except for having activity levels over 1000 pulses before 6 AM on August 5th, over 85% of the days that contain activity pulses over 500 shows that Loki started having an activity level over 500 pulses after 6 AM (*Fig. 2a-c)*. The behavioral notes also recorded that Loki started foraging after leaving the tree till noon. While observers could not see Loki after he crossed the creek around noon, over 85% of the days show that Loki had lower activity pulses below 500 at times between 12:00 PM and 4:00 PM *(Fig. 2a-c)*. Moreover, all of the graphs below show that Loki's activity level decreased to below 500 pulses at times between 5:30 PM and 6 PM.



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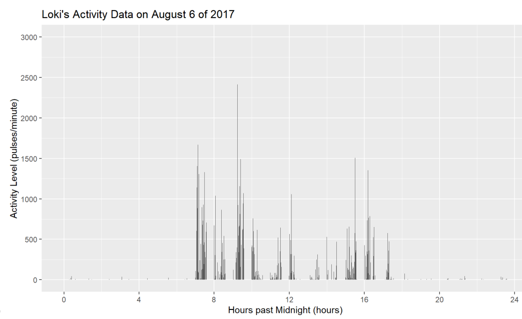

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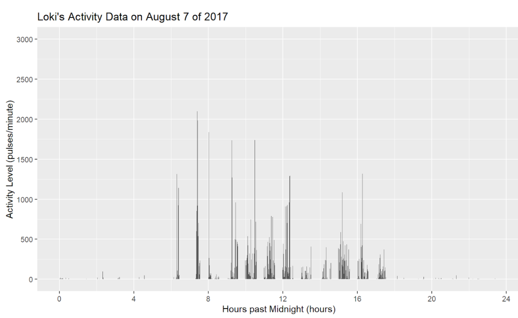

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Fig. 2a-c. Loki's daily activity level. The activity graphs have x-axis indicating the hours past midnight, with an interval of every minute, from 0 AM to 11:59 PM, and activity level pulses on the y-axis.

Besides having activity pulses after 8 AM on July 30th and August 4th, 60% of the days that have activity pulses below 500 show that Morpho started days with lower pulses than Loki after 6 AM *(Fig. 3a-e)*. Unlike Loki, Morpho did not show signs of foraging after leaving the sleeping tree. Instead, he rested around the site for hours after leaving the tree. Then, Morpho walked to a different site and started foraging until at times between 3 PM and 3:30 PM. Additionally, all graphs show that Morpho ended days at times between 2:30 PM and 4:00 PM as the activity level dropped below 500 pulses before 4 PM, which was earlier than Loki at times ranging from 2 to 3 hours.

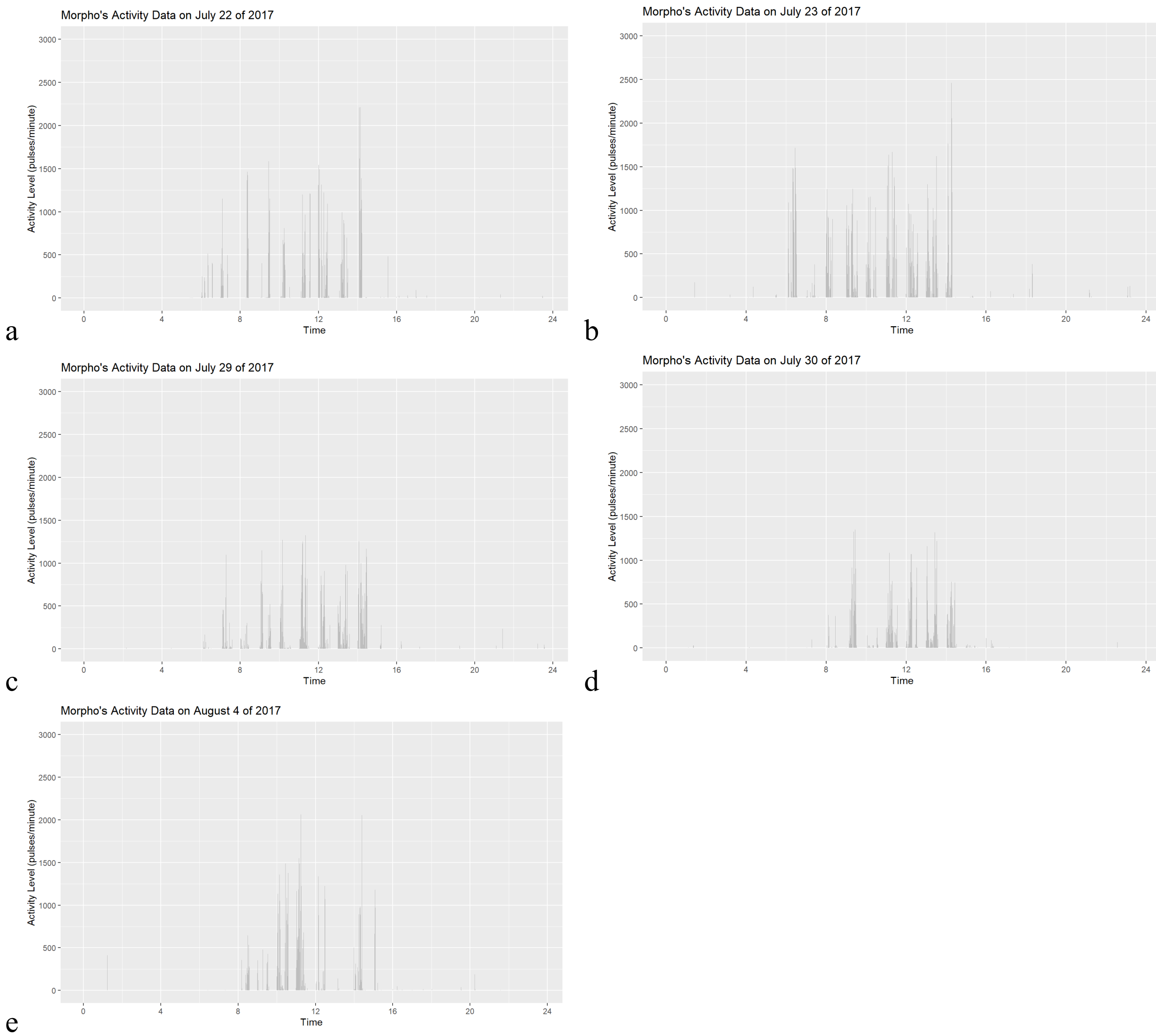


Fig. 3a-e. Morpho's daily activity level. The activity graphs have x-axis indicating the hours past midnight, with an interval of every minute, from 0 AM to 11:59 PM, and activity pulse rates on the y-axis.

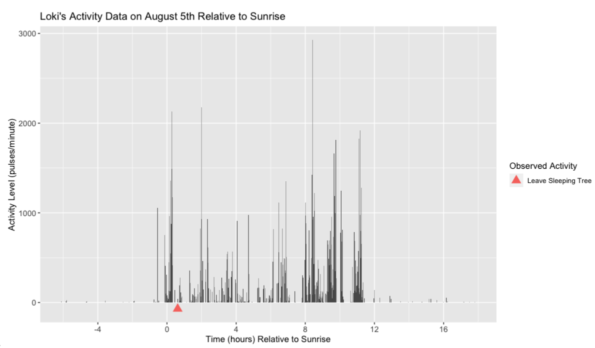
Identification of daily activities relative to sunrise

According to the overall activity graphs, Loki and Morpho's activities reveal dependence on the time of sunrise and sunset. To have a better look at the effects of sunrise and sunset on their activities, I created graphs showing their activities and the time when the monkeys started and ended their day. With the inputs of units of hours relative to the time of sunrise, where the *0* on the x-axis indicates the time of sunrise, the *geom_bar()* and *geom_pint()* functions were applied to indicate the outputs of monkeys' daily *Activity Level* (y-axis) on graphs.

To make the time ranges of both monkeys' activities during the days more accurate, the times of sunrise for each day and the times of both monkeys leaving and going back to the tree were added to the graphs.

Loki started his day determined when the first time he left the sleeping tree in a day (*Fig. 4a-b)*. Both days include the times when Loki left the sleeping tree on the x-axis *time relative to the sunrise*. According to behavioral notes, on August 5th, Loki started moving along branches and feeding at sunrise, 6:08 AM, but he stayed in the tree until 7:26 AM. Then, he left the tree and foraged low in the canopy along a trail. After having some rest in the canopy, he crossed the creek at noon. Additionally, on August 6th, Loki left the tree at a time of 24 minutes after sunrise. However, Loki jumped to a different tree at 6:39 AM and stayed in the sleeping tree until 8:03 AM because of the rain. Then, he started foraging until noon and crossed the creek again at 12:39 PM.

Both graphs below show that Loki had a series of high activity pulse rates that were over 500 throughout the day for about 12 hours after sunrise. The times of returning to the trees were not recorded in the notes, so both graphs did not include the times of Loki returning to the trees.



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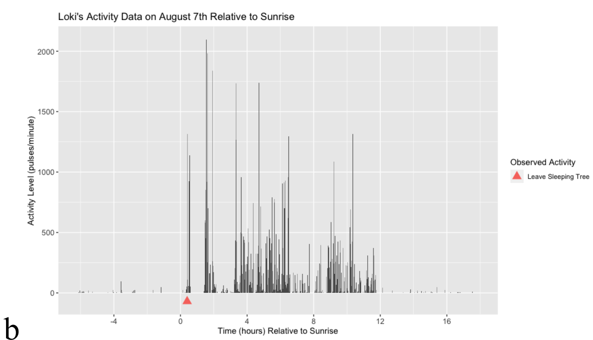

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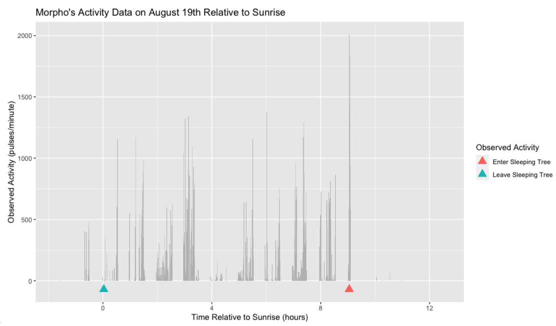
Fig. 4a-b. Loki's daily activity level relative to sunrise. The activity graphs have x-axis indicating the time relative to sunrise, with an interval of every minute, from 4:30 AM to 6:59 PM, and activity pulse rates on the y-axis. According to Tiputini Biodiversity Station's sunrise and sunset dataset, the average sunrise for August 5 and 7 is 6:08 AM.

The observers identify Morpho's leaving the sleeping tree for the first time in a day as starting his day and his entering the sleeping tree for the last time in a day as ending the day (*Fig. 5a-n)*. According to the behavioral notes, due to the rain, Morpho stayed in the tree after sunrise for 38 minutes on September 22nd, and for more than 2 hours on October 7th. There were five days indicating that Morpho left the tree at times ranging from 1 to 14 minutes after sunrise. On one day, Morpho left the tree at a time of 5 minutes before sunrise, On another day, Morpho left the tree at a time of 14 minutes before sunrise. Also, the notes recorded times when Morpho returned to the trees at times between 2:19 PM and 3:47 PM.

In 80% (*8 of 10*) of the graphs below, it is shown on the x-axis *time relative to the sunrise* that Morpho left the sleeping tree closely at sunrise (hour 0). While the hour of sunrise on average varied monthly, 90% *(9 of 10)* of the graphs that contain Morpho's leaving the sleeping tree show that he did not start the day until sunrise or later. Also, Morpho had relatively higher activity levels that were over 500 throughout the day for about 10 hours after sunrise. Over 91%

(13 of 14) of the graphs that contain Morpho's returning to the sleeping tree show that there were no further intense activities above the activity level of 500 pulses.



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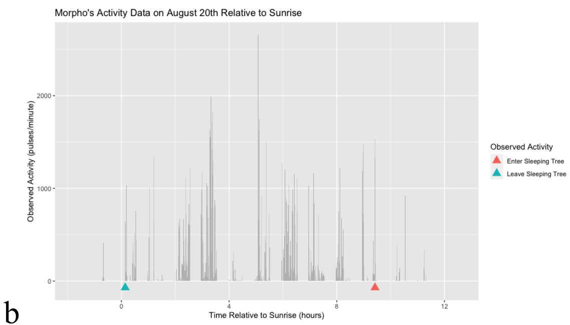

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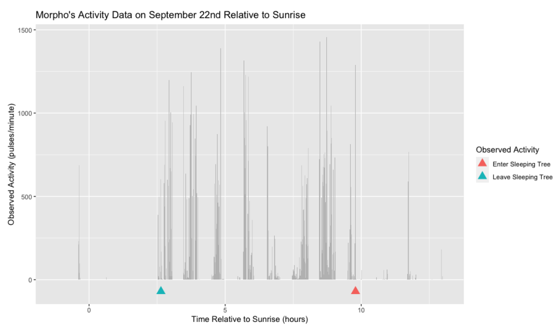

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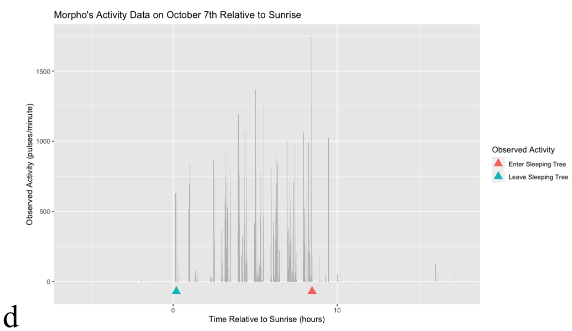

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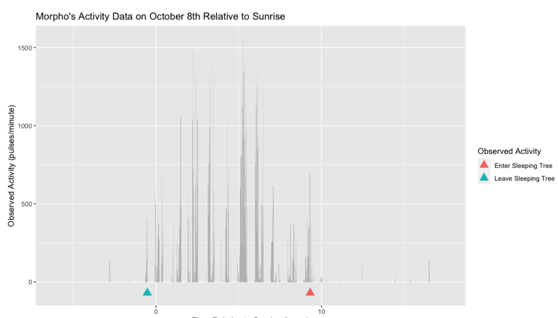

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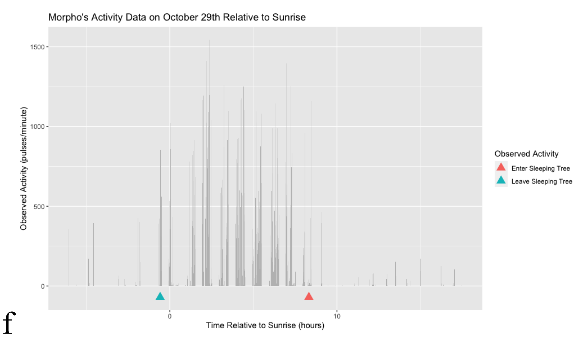

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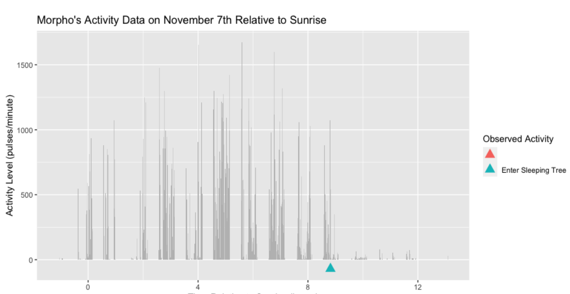

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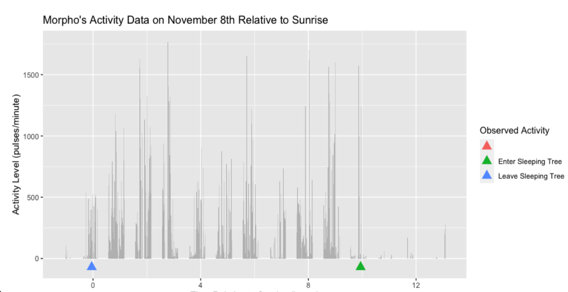

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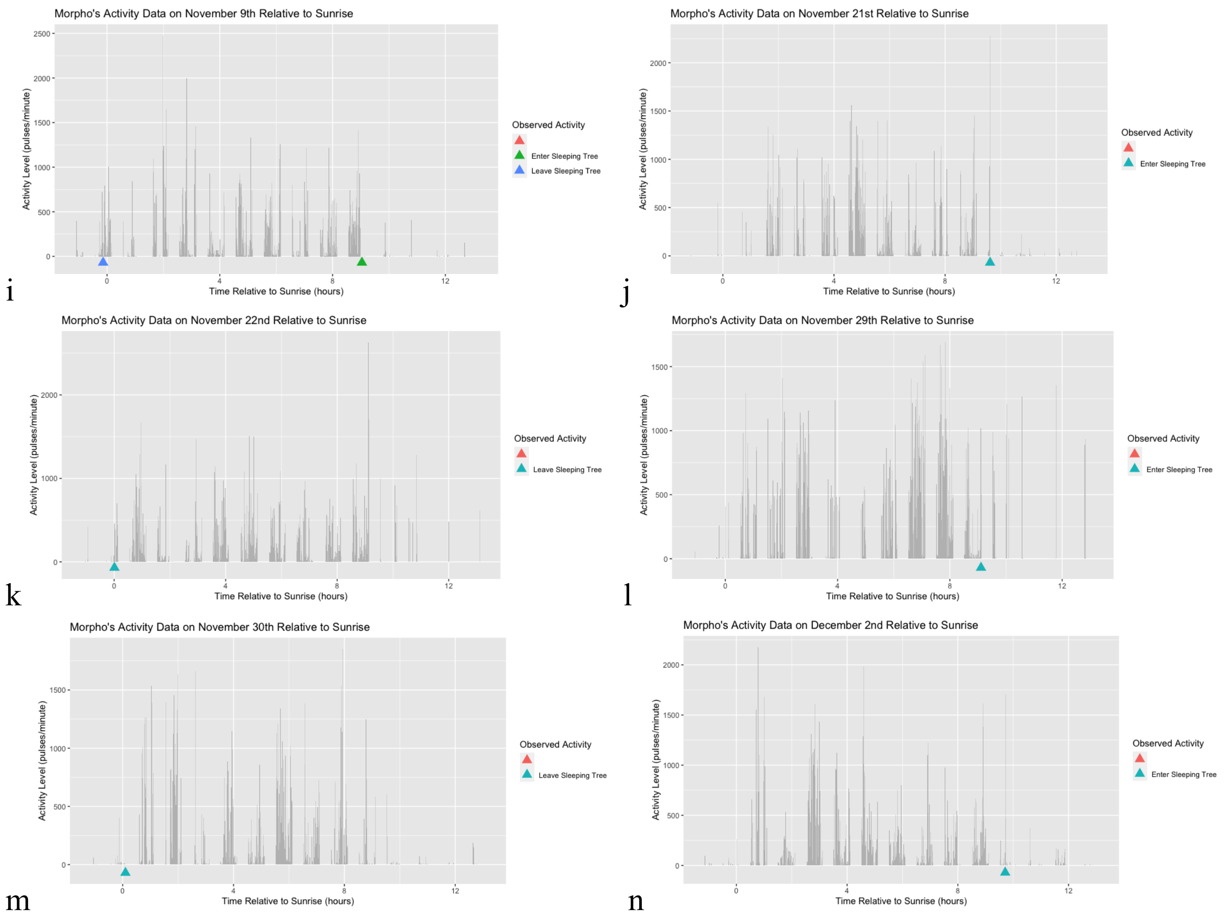

Fig. 5a-n. Morpho's daily activity level relative to sunrise. The activity graphs have x-axis indicating the time relative to sunrise, with an interval of every minute, from 4:30 AM to 6:59 PM, and activity pulse rates on the y-axis. According to Tiputini Biodiversity Station's sunrise and sunset dataset, the hour of sunrise on average varied monthly. The range of average sunrise is between 5:44 AM and 6:05 AM. The respective average sunrise of each day is 6:05 AM, 6:05 AM, 5:54 AM, 5:49 AM, 5:49 AM, 5:44 AM, 5:44 AM, 5:44 AM, 5:44 AM, 5:46 AM, 5:46 AM, 5:48 AM, 5:48 AM, and 5:49 AM.

Comparing Morpho's activity pulses with Loki's at a time of 2 hours after sunrise, over 85% *(12 of 14)* of the graphs show that Morpho's activity levels were below 2000 pulses, and Loki's were around or above 2000 pulses. Thus, Morpho was less active than Loki for 2 hours after sunrise. Furthermore, while the behavioral notes did not record times of Loki going back to the sleeping tree, he did not show any intense activity pulses that were over 500 at times of 12 hours after sunrise on graphs, so an estimated time for Loki returning to the tree is between 5:30 PM and 6:05 PM. The behavioral notes indicate that Morpho ended his days at times between 2:19 PM and 3:47 PM, so he had relatively higher activity levels that were over 500 throughout the day for about 10 hours after sunrise. Hence, Morpho had the consistency of returning to the tree at times ranging from 1 to 2 hours earlier than Loki.

Discussion

This study compares and interprets each monkey's activity pulse rates corresponding to the notes to examine the influence of sunrise and sunset on the circadian cycles of two primate species.

The daily temporal patterns of these two monkeys indicates four basic features: 1) both monkeys start showing activity pulse rates that are over 500 about fifteen minutes prior to sunrise or about fifteen minutes after sunrise *(Fig. 1g; 4-5)*, 2) Loki tends to start a day with higher activity pulse rates than Morpho, but his activity pulse rates tend to become and stay lower than Morpho's from a time between 8:20 AM and 8:25 AM to a time between 3:10 PM and 3:15 PM *(Fig. 1g)*, 3) When Loki shows the lowest signal pulse, Morpho tends to be the most active and starts to forage at a time between noon and 1 PM *(Fig. 1g),* and 4) Loki tends to have a series of high activity pulse rates that are over 500 for about 12 hours after sunrise, and Morpho tends to end a day at times ranging from 1 to 2 hours earlier than Loki *(Fig. 1g)*.

Similarities of activities at sunrise and sunset

This study shows both diurnal monkeys perform activities based on the times of sunrise and sunset, and the time difference between sunrise and sunset is about twelve hours. Both species have continuous high activity pulse rates that are above 500 during the daytime, and the activity pulse rates at midnight are relatively lower which are below 500. Notably, the sample sizes with *Plecturocebus discolor (n = 1)* and *Pithecia aequatorialis (n = 1)* are small. Studies with more monkeys and a larger time-range difference in different locations should be considered and expanded to determine whether these two species have different duration of activities if the time difference between sunrise and sunset varies. Additionally, the Mann-Whitney U-Test's result shows that there is no significant difference in the daily activity level of the Loki and Morpho monkey species (W = 42,676, $p>0.05$).

Differences of activities within species

The result of this study also indicates the differences in activities throughout the day. Based on the smoothed activity graphs, both monkeys start their day around 6 AM. While both monkeys continuously show high activity pulse rates between sunrise and sunset, Loki stayed active from 6 AM to 6 PM, and Morpho stayed active from 6 AM to 4 PM. The range of staying active for Loki lasts about 2 hours longer than Morpho, and Morpho's activity pulse rates stay higher than Loki's during the day for 6.17 hours within Morho's active hours *(Fig. 1b; 1d; 1f)*.

Moreover, Loki's highest activity pulse rate of the day is shown before 8 AM. The lowest signal pulse of Loki is between 11 AM and noon, and he stays less active than Morpho for a few hours in the afternoon. In contrast, Morpho does not reach the highest pulse until the time between noon and 1 PM, and he maintains higher activity pulse rates than Loki until a time between 3:10 PM and 3:15 PM *(Fig. 1g)*. According to Enya Liu's group research contribution to the temperature of sites for both monkey species, their results show that the averaged temperatures of both foraging and sleeping sites reach peaks at a time around 1 PM, then the temperature will be lowered at a time around 3 PM. Hence, the temperature of sites potentially has an influence on Loki's activity during the day: when the temperature starts increasing during the day, Loki's activity pulse rates start decreasing to below 3000. But the temperature does not have an obvious effect on Morpho's activity during the time between 11 AM to 3 PM. Besides observer bias, to have a better comparison and conclusion about these two monkey species' circadian cycle, more data collection and behavioral notes should be collected for both saki and titi monkeys. With more data, it will help further determine whether the abundance of fruit and the temperature will have a significant effect on species' temporal niche partitioning activities throughout the year.

While the Mann-Whitney test concluded that the total daily activity of these two monkeys was not significantly different, in respect of quality control, studies with more numbers of observations on the same species should be expanded. Collecting more daytime behavioral activities with a larger month range will improve predictions of other activities when they are out of sight, and determine whether the abundance of food resources has different impacts on monkeys throughout the year.

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Literature Cited

Bicca-Marques, J. C., & Heymann, E. W. (2013). Ecology and behavior of titi monkeys (genus Callicebus). In A. A. Barnett, L. M. Veiga, M. A. Norconk, & S. F. Ferrari (Eds.), Evolutionary biology and conservation of titis, sakis and uacaris (pp. 196–207). https://doi.org/10.1017/CBO97 81139034210.023

Boyle, S. A., Thompson, C. L., Deluycker, A., Alvarez, S. J., Alvim, T. H. G., Aquino, R., et al. (2016). Geographic comparison of plant genera used in frugivory among the pitheciids Cacajao, Callicebus, Chiropotes, and Pithecia. Am J Primatol. Vol. 78(5):493–506. https://doi.org/10.1002/ajp.22422 PMID: 26031411

Kronfeld-Schor, N., Dayan, T. (2003). Partitioning of time as an ecological resource. Annu Rev Ecol Evol Syst. Vol. 34:153–81. https://doi.org/10.1146/annurev.ecolsys.34.011802.132435

Quyet L. K., (2004). Distribution and conservation of the tonkin snub-nosed monkey (Rhinopithecus avunculus) in du gia nature reserve, ha giang province, northeast vietnam. In U. Nadler, T. Streicher, & H. T. Long (Eds.), *Conservation of primates in vietnam*. Frankfurt Zoological Society. 58-62. https://doi.org/10.1007/s10531-018-1507-0

Sha, Fam, S. D., & Ang, A. H. F. (2019). Southeast Asian Primates in Flooded Forests. In *Primates in Flooded Habitats* (pp. 347–358). Cambridge University Press.

Sha, Kaneko, A., Suda, Hashimoto., N., He, T., Take, M., Peng, Z., & Hanya, G. (2017). Estimating activity of Japanese macaques (Macaca fuscata) using accelerometers. *American Journal of Primatology*, *79*(10), e22694–n/a. https://doi.org/10.1002/ajp.22694

Snodderly, D. M., Ellis, K. M., Lieberman, S. R., Link, A., FernandezDuque, E., & Fiore, A. D. (2019). Initiation of feeding by four sympatric Neotropical primates (Ateles belzebuth, Lagothrix lagotricha poeppigii, Plecturocebus (Callicebus) discolor, and Pithecia aequatorialis) in Amazonian Ecuador: Relationships to photic and ecological factors. PLoS One, 14(1), e0210494. https://doi.org/10.1371/journ al.pone.0210494

Souza-Alves, J.P., Fontes, I. P., Chagas, R. R. D., Ferrari, S. F. (2011). Seasonal versatility in the feeding ecology of a group of titis (Callicebus coimbrai) in the northern Brazilian Atlantic Forest. Am J Primatol. Vol. 73(12):1199–209. https://doi.org/10.1002/ajp.20990

Veilleux, C. C., Kawamura, S., Montague, M. J., Hiwatashi, T., Matsushita, Y., Fernandez-Duque, E., Link, A., Fiore, A. D., & Snodderly, D. M. (2021). Color vision and niche partitioning in a diverse neotropical primate community in lowland Amazonian Ecuador. DOI: 10.1002/ece3.7479. https://doi.org/10.1002/ece3.7479

Appendix/Computer Code

(on a different attached file)

Reflection

(on a different attached file)