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*A alguém cujo valor é digno desta  
dedicatória.*

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Gostaria de agradecer a X

## ABSTRACT

## ABSTRACT INGLES

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# Chapter 1

## Daily activity patterns in the Anillaco Tuco-tuco (*Ctenomys sp.*)

### 1.1 Introduction

- Contexto:
- Síntese do conhecimento: O que se sabe sobre o tema central?
- Como a questão investigada se encaixa nesse contexto teórico?
- Rever anotações

### 1.2 Methods

- Adicionar descrição da estatística
- Adicionar Kernel Density Estimation para os padrões

#### 1.2.1 Study Species

The studied *Ctenomys* population lacks a formal phylogenetic and taxonomic classification but there are some lines of evidence suggesting that the study area is occupied by a single unidentified species (Amaya et al. 2016). In other studies this *Ctenomys*' species has been referred informally as the Anillaco tuco-tuco

(Amaya et al. 2016) and as *Ctenomys aff. knightii* (Tomotani et al. 2012) or *Ctenomys cf. knightii* (Valentinuzzi et al. 2009).

### 1.2.2 Study Site

Field work was conducted at one site located approximately 5km away from the village of Anillaco, in the province of La Rioja, northwest of Argentina. The study site (-66.95°, -028.80, 1325m; Fig. 1.1) is a relatively undisturbed natural area, with little human disturbance and no artificial light source. The area is surrounded by the Sierra de Velasco mountain range, located within the Monte Desert biome. The Monte Desert is characterized as an open shrubland dominated by Zygophyllaceae (*Larrea cuneifolia* Cav., *Tricomaria usillo*), Fabaceae (*Prosopis torquata*, *Senna aphylla*) and Cactaceae (*Trichocereus* spp, *Tephrocactus* spp) (Abraham et al. 2009; Fracchia et al. 2011; Aranda-Rickert and Fracchia 2011). At the study site a non-extensive survey of the plant community divided in three transects showed a dominance of the families Zygophyllaceae (*Larrea cuneifolia*, *Tricomaria usillo*), Poaceae (*Microchloa indica*, *Aristida mendocina*) and Fabaceae (*Zuccagnia punctata*) (see Appendix). The climate is arid with marked daily cycle and seasonality in temperature and rainfall (see Appendix). The mean annual temperature is 16.6°C (Fracchia et al. 2011), with clear differences in the daily range and between summer and winter months (Abraham et al. 2009). The mean annual rainfall ranges from 145 to 380mm concentrated almost exclusively in the summer months (Fracchia et al. 2011).

### 1.2.3 Animal Capture and Handling

A total of 47 tucos were capture between 2019 and 2020. Out of these, REF were part of the present study and we were able to recaptured, and thus collect data, for 21 animals. Trapping was conducted in four different campaigns to the study site between 2019 and 2020. Three campaigns were done in 2019 during March-April, July and October. A fourth campaign was done in February 2020. A fifth

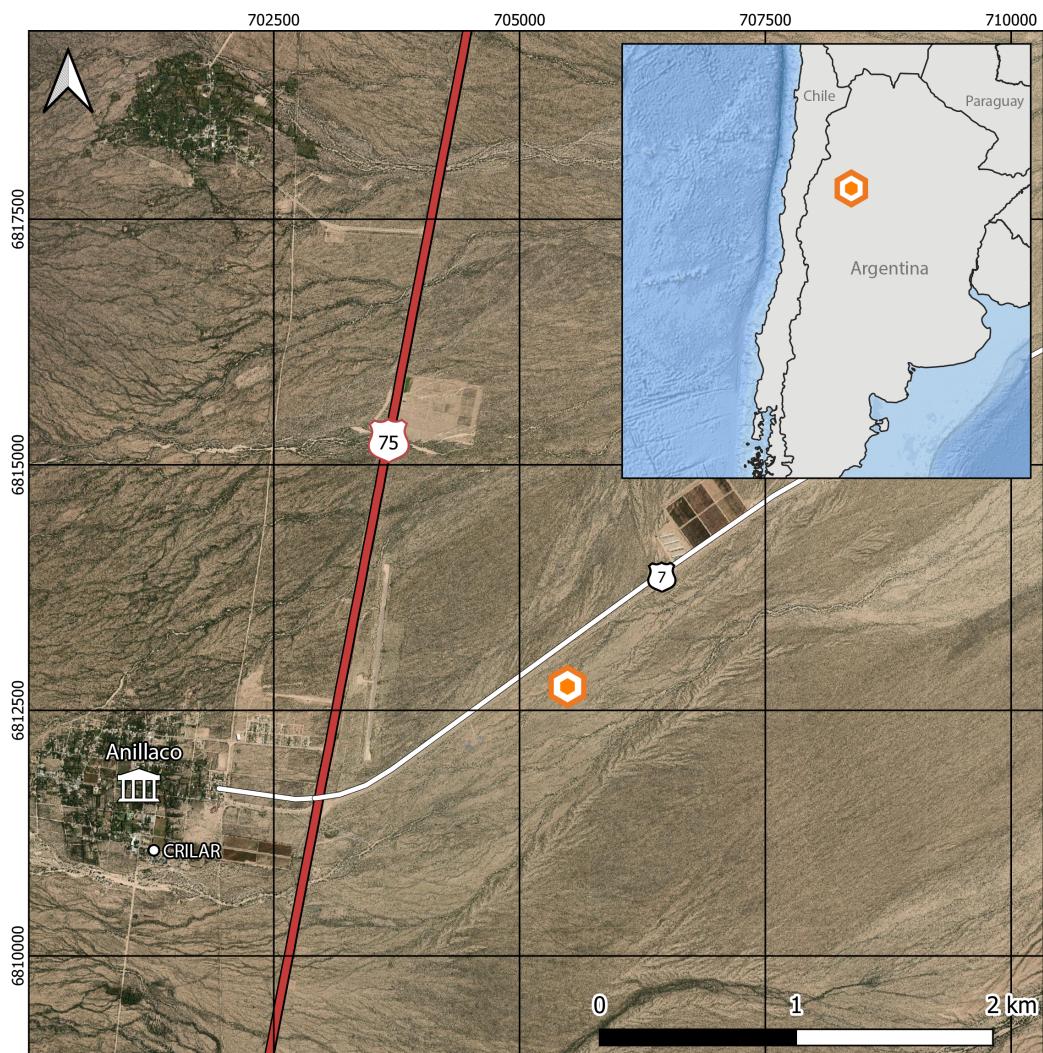


Figure 1.1: Study site location (orange icon) at the Monte Desert, approximately 5km away from the village of Anillaco, northwest of Argentina

campaign was planned to occur in April 2020 but had to be canceled due to the COVID outbreak. Tucos were captured using a custom made PVC tubing trap (35cm length, 10cm diameter) with a spring-loaded aluminum door at one end and a cul-de-sac at the other. Before setting the trap the study site were scouted for active tuco's burrows. Active burrows could be identified by the presence of freshly excavated soil mounds. Once found burrows were excavated to open the access to the underground tunnels. Traps were placed at all active burrows found at the study site, limited to the number of traps available. Traps were placed horizontally at the burrow's entrance following the tunnel's orientation. Traps were set in the field during the morning and checked every 2 hours. At dusk traps were checked one last time and taken out, the exact time of the trap placement changed accordingly to the seasons. At every check traps were reset if they had been plugged with soil or if they had been activated without any tuco capture.

After capture, adult tucos (>120g) were first anesthetized in order to be carefully examined and receive a collar. We used a clear plastic anesthesia chamber (318.5cm<sup>3</sup>) with a clip-on lid and a cotton ball inside. The cotton ball inside the chamber received approximately 0.5 mL of isoflurane (REF) before transferring the animal from the trap to the chamber. While in the chamber tucos were observed for breathing, blinking and loss of righting reflex. Once the tucos could not right themselves they were removed from the chamber. Anesthetized animal were weighted (CSseries, OHAUS, ± 1 g precision), sexed, marked with a subcutaneous identification PITTag (Passive Integrative Transponder. Allflex, Brasil) and fitted with biologging collar

Animals were released in the same burrow they were originally captured. They were left in the field for 5-18 days before being recaptured for collar recovery. The telemetry transmitter were used to maximize the animals relocation, thus avoiding the loss of the other devices. All animal captures, procedures and animal handling were authorized by the local authorities at *Dirección General de*

*Ambiente y Desarrollo Sustentable – Secretaría de Ambiente del Ministerio de Producción y Desarrollo Local – La Rioja, Argentina (#00501-17). All procedures were also approved by the Ethics Committee at the Instituto de Biociências (#308-2018) and Faculdade de Medicina Veterinária (#2045300519) of the Universidade de São Paulo.*

- Ao adicionar numero de animais tbm comentar da dificuldade em recapturar e em alguns casos capturar machos! Legal para futuras referencias. (Talvez nos resultados?)
- não esquecer de colocar os tucos com colar que não foram recapturados

#### **1.2.4 Activity Sensors**

Accelerometer (Axy-4, TechnoSmart, Italy) and lightloggers (W65, Migrate Technology, UK) were used to record general motor activity and light exposure respectively. These biologgers were fixed to a collar made of a cable tie inserted through silicon tubing (Jannetti et al. 2019; Williams et al. 2014). Out of the 22 captured animals, 13 received a collar containing an accelerometer, a lightlogger and a telemetry transmitter (SOM-2011. Wildlife Materials, USA). The remaining 9 animals received a collar containing only a telemetry transmitter and an accelerometer. The complete collar setup weighted approximately a total of 6g. Collars without the lightlogger weighted 5.3g. All accelerometers recorded tri-axial acceleration at a 10Hz sampling frequency with a 4G sensitivity. Lightloggers were set to sample light every minute but only recorded the maximum sampled value each 5 minutes.

- foto tuco com colar

#### **1.2.5 Data Processing**

A total of 22 complete datasets were obtained from biologgers deployed in the field. Data were recorded onboard of the sensors and later downloaded and converted to raw text files. Accelerometer and lightlogger data were read and

merged accordingly to date and time of recordings using purposely written R scripts. Time of recordings of accelerometers and lightloggers were not synchronized to the minute consequently we had to round the lightlogger recording times to the nearest 5 minutes in order to merge both data streams. We also removed the first and last days of each dataset, corresponding to the days of capturing and recapturing efforts, in order to minimize any effects that the capture, handling or recapture efforts could have in the animal's behavior.

Acceleration data was used to measure the gross motor activity. The tri-axial acceleration data was first converted to one dimensional value using the Vectorial Dynamic Body Acceleration (VeDBA, Qasem et al. 2012). VeDBA is commonly used as a proxy for the animal's activity level and energy expenditure (REFS). VeDBA was calculated by: (i) Estimating the effect of the gravitational force over the accelerometer, also known as static acceleration. The static acceleration can be estimated by applying a moving average over the raw acceleration data. There is not a consensus over the the number of points to calculate the moving average with, which can be dependent on the study species and device's recording frequency. In the case of this study we opted to use a 4-second moving average after following the methodology proposed by (Shepard et al. 2008, see Appendix). (ii) Calculating the acceleration correspondent to the animal's movement, also know as Dynamic Body Acceleration (DBA). The DBA was calculated by subtracting the static acceleration from the raw data. (iii) Lastly, we calculate the VeDBA by the vectorial sum of the DBA over the device's axis. Following VeDBA calculations the 1Hz acceleration data was downsampled by taking the median over a 1 minute non-overlapping sliding window.

$$VeDBA = \sqrt{Xd^2 + Yd^2 + Zd^2}$$

All VeDBA datapoints were classified as occurring during the daytime or night-time based on the daylength od recording dates. Daytime activity was in turn classified as being above or underground. Daylength was calculated using the

*maptools* package in R (Bivand and Lewin-Koh 2020), which uses the National Oceanic and Atmospheric Administration (NOAA) equations for estimating Twilight times. We used Civil Twilight times, defined as the times in which the center of the sun is  $6^{\circ}$  below the horizon, as thresholds to calculate daylength and classify datapoints as occurring during the day or nighttime. Daylength change along the year can be seen in the Appendix.

Light exposure data was used to further classify data points as above or below ground during the daytime. The threshold for considering a data point as being aboveground was 2 lux, consistent with what has been done in (Jannetti et al. 2019). All data processing and statistical analysis were conducted in R v4.0.2 (R Core Team 2020) unless noted otherwise.

### 1.2.6 Hidden Markov Models

Behavioral States were inferred using Hidden Markov Models (HMMs). HMMs are type of dependent mixture models where the components of the mixture are selected by a underlying Markov Process. HMMs are composed of two time series: the observable *state-dependent process* ( $X_t$ ) and a underlying, or hidden, *state process* ( $S_t$ ). The underlying *state process* follow the Markov Property and take temporal dependency into account. The Markov property denotes that a state  $S_t$  depends only on the previous state  $S_{t-1}$ . In the case of accelerometer and animal movement studies the states are representations of the animals' behavior and can take on finite number ( $N$ ) of possible values. The number of states can be chosen *a priori* or based on model selection (Pohle et al. 2017). The changes probabilities between states are also part of the of HMM formulation, summarized by a Transition Probability Matrix that gives the probability of transitioning from the current state to a possible future state. The *state process* is also what drives the observations and what we are interested in estimating.

In the basic HMM formulation the observable *state-dependent process* comes from a mixture of  $N$  distributions, one for each state. These distribution come

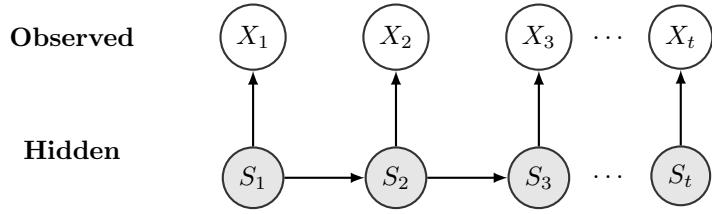


Figure 1.2: Basic dependence structure for a Hidden Markov Model

from a common family (e.g. Normal, Weibull or Gamma) and each one have their own set of parameter values. The active distribution is determined by the state the system is in at a given time  $t$ . The observations therefore are a realization from one of these distributions. The distribution parameters, state transition probabilities and other model parameters can be estimated by numerical maximization of the Likelihood (Zucchini, Iain MacDonald, and Roland Langrock 2016). With the model parameters in hand, the most probable state sequence can be found by the Viterbi algorithm (Brett T. McClintock et al. 2020; Zucchini, Iain MacDonald, and Roland Langrock 2016).

- vantagem do HMM para modelar series temporais

### 1.2.7 Model Formulation and State Classification

In our models we have chosen VeDBA as our activity metric from which we want to infer the possible state sequences. We determined *a priori* that the hidden *state-process* could assume three different states ( $N = 3$ ). This decision was made based on our research question, in the VeDBA distributions (see Appendix; Exploratory Data Analysis) and in the biological interpretability of the states. It is important to note that states do not correspond directly to specific behaviors (e.g. feeding, foraging or digging) but can be assumed to roughly correspond to behavioral modes (e.g. activity levels) that can encompass a range of different behaviors (Leos-Barajas et al. 2017; Papastamatiou et al. 2018). We labelled the states as roughly corresponding to “Rest,” “Medium Intensity Activity” and “High Intensity Activity.”

HMMs can be fitted individually (e.g. van de Kerk et al. 2015) or to a pool of animals (Langrock et al. 2012). The models can also include covariate effects that modify either the *state-dependent* distribution parameters or the transition probabilities (Patterson et al. 2009; Langrock et al. 2012). We fitted a 3-state HMM to the 1-minute downsampled VeDBA data using a ‘complete pooling’ approach. Using this approach the *state-dependent* distribution parameters are common to all animals. This means that we assume that individuals are independent and behaviors do not change between animal and across the year. However, given that the season/month of the year seems to be a important feature influencing the VeDBA distribution (see Appendix; Exploratory Data Analysis) we included season as a covariate in the *state process*. Therefore, we let the probability of changing from one state to another vary in relation to the season/month of the year assuming that animals have the same **repertoire** of behaviors. We also fitted an empty model, with no covariate effects, and used Akaike’s Information Criteria (AIC) to select the model with best fit to the data (Burnham, Anderson, and Burnham 2002).

Models were fitted using the momentuHMM package in R (Brett T. McClintock and Michelot 2021). We used the gamma distribution, parametrized with mean and standard deviation, to model VeDBA. The gamma distribution is a flexible distribution, usually used in movement studies (REFS), that accommodates positive right-skewed data. Appropriate starting values for likelihood maximization of the model’s parameters were found by following procedures suggested by Michelot and Langrock (2019). Season was included as a categorical variable, its influence over the transition probabilities was summarized using stationary probabilities plots (Leos-Barajas et al. 2017). The most probable state sequence was decoded using the Viterbi algorithm (Zucchini, Iain MacDonald, and Roland Langrock 2016). The decoded sequence was then used to conducted other *post-hoc* analysis of rhythmicity and diurnality. We checked model assumptions and goodness of fit by visual inspection of the pseudo-residuals (Zucchini,

Iain MacDonald, and Roland Langrock 2016).

- michelot 2017 - Estimation and simulation of foraging trips in land-based marine predators. *Ecology* 98, 1932–1944. doi.org/10.1002/ecy.1880

### 1.2.8 Rhythmicity and Diurnality Index

## 1.3 Results

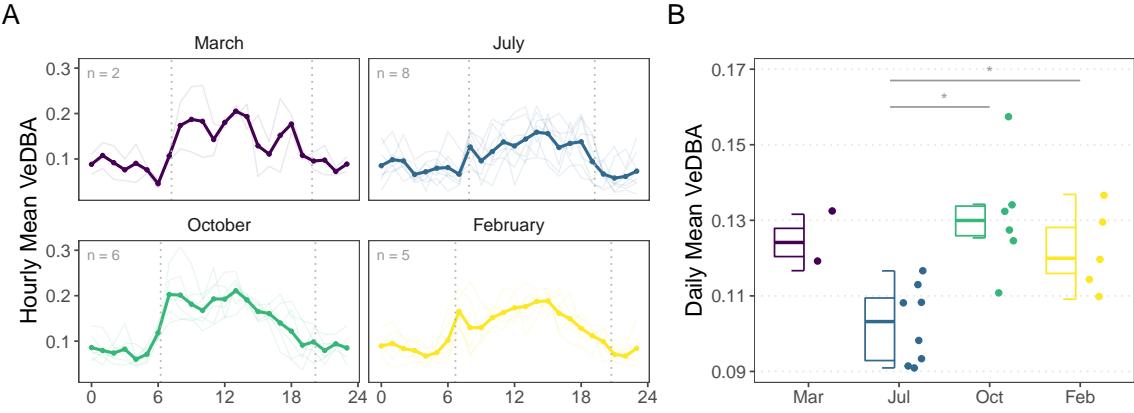
During 2019-2020, we captured 30 tucos, 20 females and 10 males. Each tuco received a biologging collar, mostly containing an accelerometer and a lightlogger. We were able to recapture 24 tucos and recover 21 collars (Table 1.1). One collar was lost because one tuco got predated and the collar was found malfunctioning. The other two lost collar fell or were taken out of the tuco's neck between the time of capture and recapture. All 21 animals that were recapture received a collar containing an accelerometer. However, only 13 also received a lightlogger (Table 1.1). In total we have 13 complete datasets, with acceleration and light exposure data, and 8 datasets with only acceleration data.

*Table 1.1:* Number of captured animals and sensors deployed in the field. There was a higher number of females captured independent of the season. Recapture rates in February 2021 are lower because field work had to be interrupted due to the covid outbreak. Not all recaptured tucos still had their collars. Some collar were taken out by the animals between the time of captured and recaptured. One tuco was predated and the collar was found 1km away from the initial capture burrow malfunctioning.

	Captured		Recaptured		Recovered Collars	Accelerometers	Lightloggers
	Males	Females	Males	Females			
February	3	7	2	5	5	5	5
July	4	5	4	5	8	8	6
March	0	2	0	2	2	2	0
October	3	6	1	5	6	6	2

### 1.3.1 Daily Activity Levels

Tuco's activity levels are significantly lower during July in comparison to other months. Accelerometer data was used to calculated the Vectorial Dynamic Body



*Figure 1.3: Tuco-tuco’s Daily VeDBA levels. (A) VeDBA was binned by hour (0-23). Background lines show data for individual animals. Thick lines show mean hourly VeDBA. (B) Points show daily (24h) VeDBA mean for each animal. In July Tuco-tuco’s exhibited lower Daily VeDBA than October and February. Dashed lines in Panel A shows time of civil dawn and dusk.*

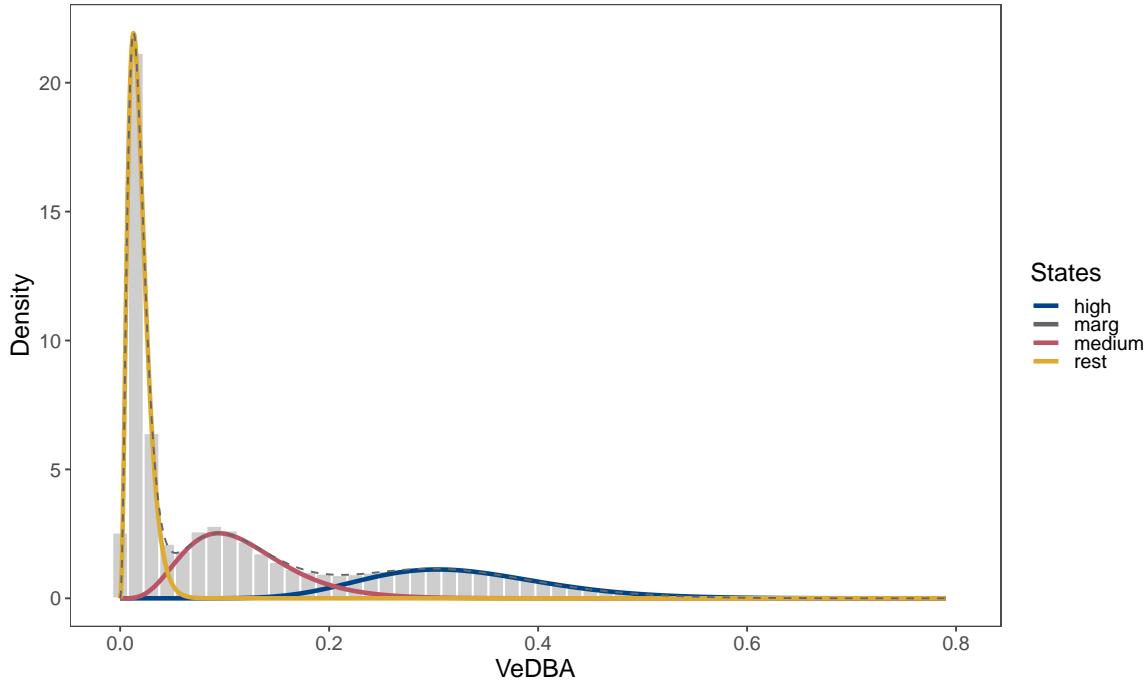
Acceleration (VeDBA) that we use as a proxy for animal activity. Tuco’s daily activity levels (24h average), measured by VeDBA, are significantly different across the year (ANOVA;  $F = 7.182$ ,  $p < 0.01$ ; Fig. 1.3). Post hoc comparisons using Tukey-Kramer’s Test shows significant group differences between July-October and July-February ( $p < 0.05$ ). In both pairwise comparisons July Daily VeDBA levels are lower, showing a difference in means of 0.029g and 0.019g in comparison to October and February, respectively. In sum, daily VeDBA activity levels are lower in July in comparison to October and February (Fig 1.3).

- Tirar?:

The daytime VeDBA (Light Phase Average) is also significantly different between Months (ANOVA;  $F = 7.282$ ,  $p < 0.001$ ). Post hoc comparisons using Tukey-Kramer’s Test shows a difference in mean of 0.035 between October-July ( $p < 0.05$ ). However, daytime activity levels are only significantly different between July and October.

### 1.3.2 State Classification

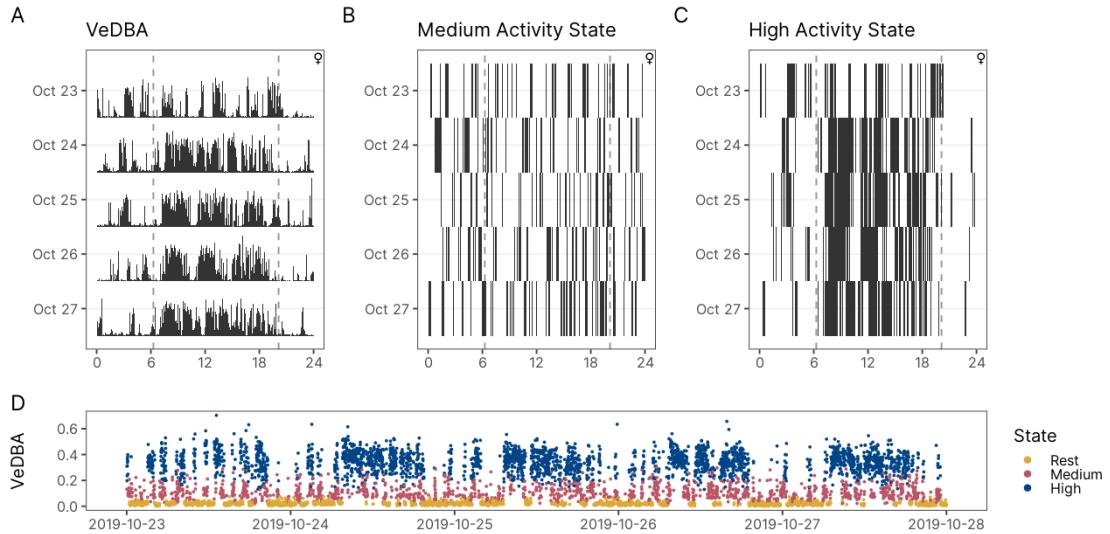
We modeled and classified VeDBA into three distinct behavioral states using Hidden Markov Models (HMM). We fitted two different models, one empty model, with no covariates, and a second one with ‘*season*’ as a covariate in the transi-



*Figure 1.4:* State-dependent distributions of the selected Hidden Markov model fitted to the VeDBA acceleration metric. Histogram, in grey, shows the Vectorial Dynamic Body Acceleration (VeDBA) from the data of 21 Anillaco's tuco-tuco. State-dependent gamma distributions are shown above the histograms. These distributions are weighted accordingly to the proportion of observations assigned to each state.

tion probability matrix. The second model was selected based on informational criterion ( $\Delta\text{AIC} > 2$ ; REF Tabela AIC nos supps).

The estimated state-dependent distributions are shown in Figure 1.4. We interpreted and labelled these states as ‘rest,’ ‘medium intensity activity,’ and ‘high intensity activity’ corresponding to low, intermediate and high VeDBA values respectively. The marginal distribution (Fig. 1.4; dashed line) has a good correspondence to the empirical VeDBA distribution. A visual analysis of the Pseudo-residuals (See Appendix; REF) show that the residuals deviates from the expected normal distribution, especially in the lower end values, and that there is still significant residual autocorrelation. Nevertheless, the overall fitting seems to be reasonable. The estimated state-dependent parameters are shown in the Appendix (Table G.1). We labelled VeDBA data using the Viterbi algorithm. With the state-labeled data we were able to disassociated and visualize the daily patterns of each different state. Time series plots and actograms, a classic form of visualization in chronobiology, shows how the different states are related to the calculated



*Figure 1.5:* Actograms and Time Series Plot of VeDBA and state-labelled data of a representative animal (ID:OCT09). The actograms shows daily patterns of VeDBA (A) and of Medium and High State occurrences (B and C). Medium Activity State shows no clear pattern of a daily rhythm. High Activity is disperse throughout the day with a higher concentration during daylight hours. The time series (D) shows state-labelled VeDBA data. Dashed lines shows time of dawn and dusk.

VeDBA. We can also begin to qualitatively evaluate diel rhythms in VeDBA and in the state-labelled data. Figure 1.5 shows one representative animal's actograms and time series plot. Visually, the daily rhythm is more defined in High Activity in comparison to Medium Activity. However, despite being more concentrated during the daylight hours, High Activity episodes also occurs sporadically during the night. Medium Activity, in turn, seems to be more disperse throughout the day with no clear daily rhythm. Individual Actograms for VeDBA and state-labelled data are presented in the Appendix (Figure ??).

### 1.3.3 Daily Time-Activity Budgets

Using the state-labelled data we calculated that on average tucos spent between 45-50% of the 24 hours resting, depending on the month. The remaining time is spent in an active state, either Medium or High Activity State (Table 1.2). ANOVA test shows no statistical difference between the percentage of time spent resting between groups (ANOVA;  $F = 1.93$ ,  $p = 0.163$ ).

Tuco-tucos spent a variable percentage of their daily active time in one of the two active state, High or Medium Activity, across seasons. Daily time spent in High Activity was lower in July (15.8%) and higher in October (29.4%; 1.2). In contrast, daily time spent in a Medium Activity State was higher in July (34.1%) and lower in October (24.8%). There is a significant difference in the percentage of time spent in Medium (Fig. 1.6; ANOVA:  $F = 4.457$ ,  $p = 0.0175$ ) and High Activity State (Fig. 1.6; ANOVA:  $F = 13.62$ ,  $p = < 0.001$ ). Tukey's post hoc test shows that the mean percentage of time spent in the Medium Activity State is 9% lower in October than in July ( $p = 0.01$ ). For the High Activity State, pairwise Tukey's test shows a significant difference between October-July ( $p < 0.001$ ) and February-July ( $p < 0.01$ ). In comparison to July the mean daily percentage of time spent in a High Activity State is 13% higher in October and 8% higher in February (Fig. 1.6).

*Table 1.2:* Average percentage of time spent in each state.

season	n	Rest	Medium	High	Active
March	2	45.01	32.06	22.94	55.00
July	8	50.09	34.13	15.78	49.91
October	6	45.78	24.78	29.44	54.22
February	5	45.14	30.18	24.68	54.86

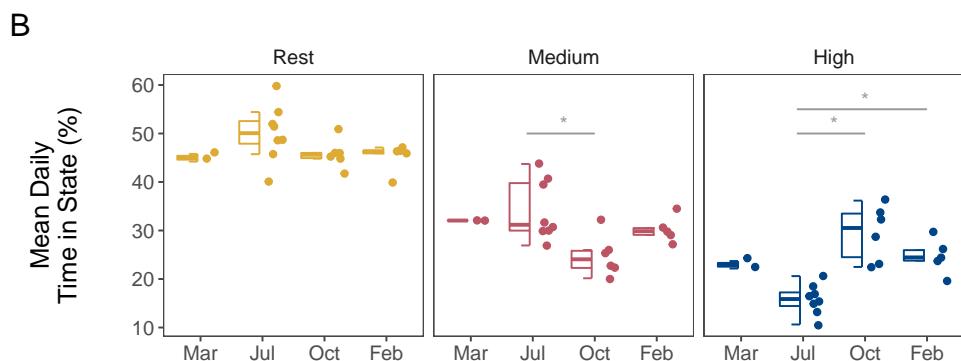
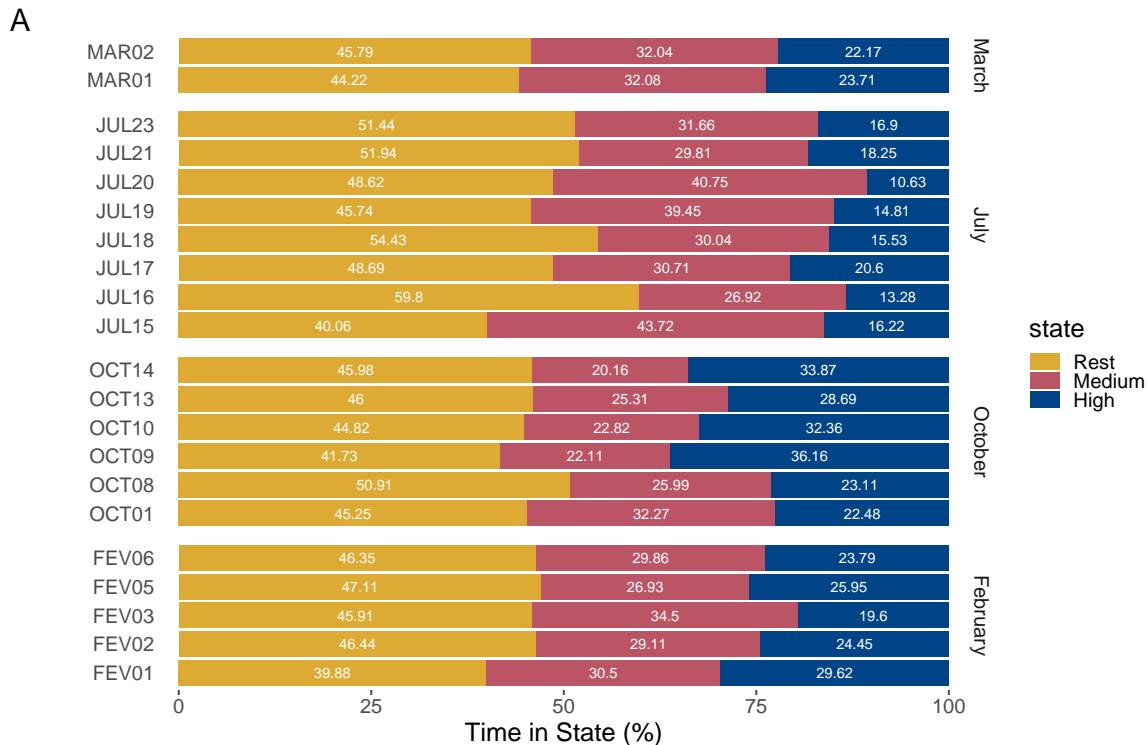
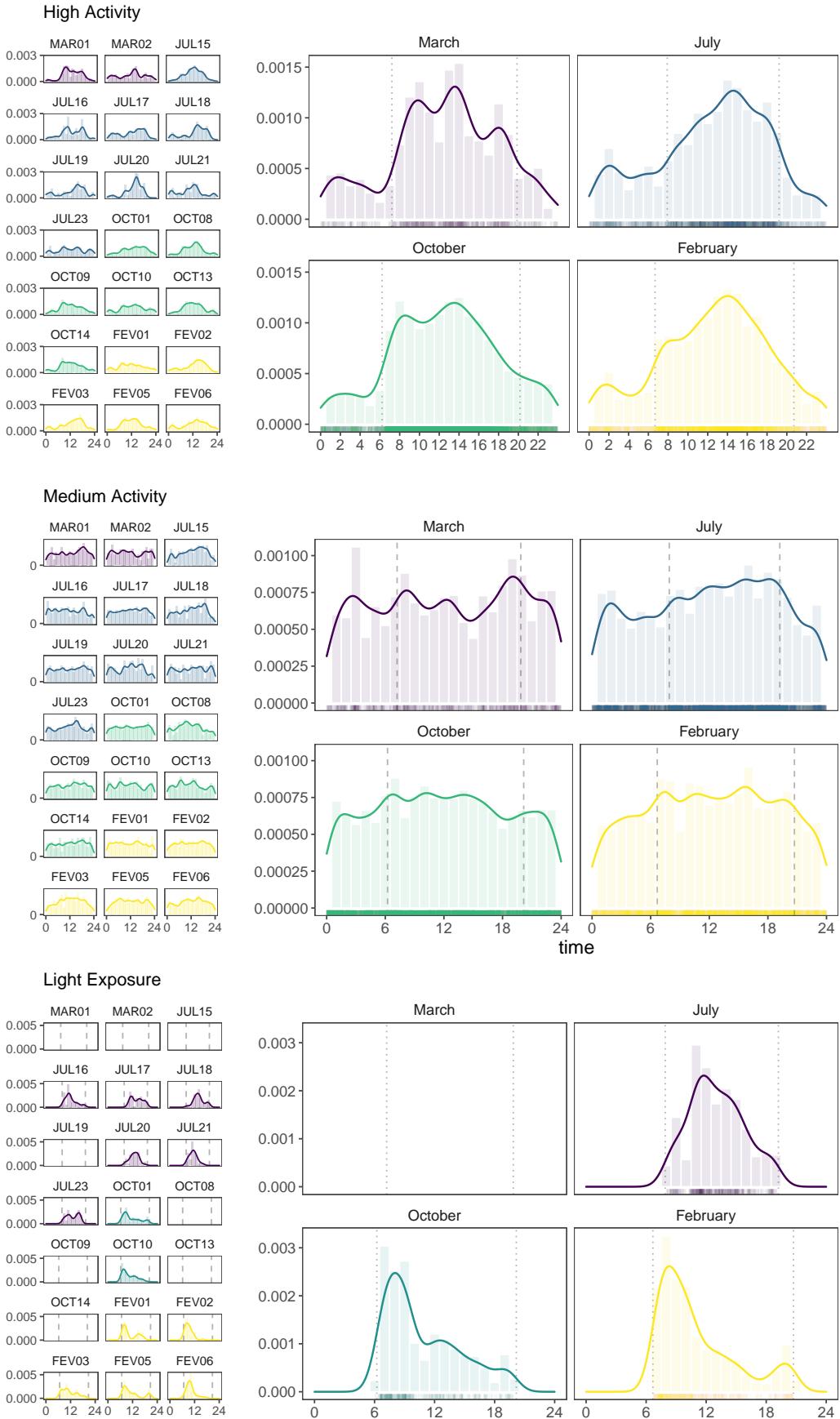


Figure 1.6: Daily time-activity budgets for the behavioral states. (A) Percentage of time spent in each behavioral state per animal. (B) Distribution of the mean percentage of time spent in each behavioral state calculated by animal. The mean percentage of time spent in the High Activity State is lower in July in comparison to October and February. The mean percentage of time spent in the Medium Activity State, however, is higher in July in comparison with October.

### 1.3.4 Daily Activity Patterns

Daily activity rhythms for each behavioral state is shown in Figures REF. These plots show that, qualitatively, when considered separately the timing of occurrence of High Activity and Light Exposure episodes follow a diurnal pattern. Medium Activity, however, is spread out along the 24h and do not follow a daily (24h) rhythm. It is important to note that the timing of peak occurrence of High Activity behavior does not appear to change dramatically along the year. In all four Months the peak of High Activity seems to be around 14:00. In turn, Light Exposure patterns changes along the year. In July, the peak of episodes of light exposure is more concentrated in the middle of the day. In other seasons the peak of Light Exposure episodes appears to be multimodal, with a higher peak in the first hours of daylight and a much smaller peak at the end of daylight.

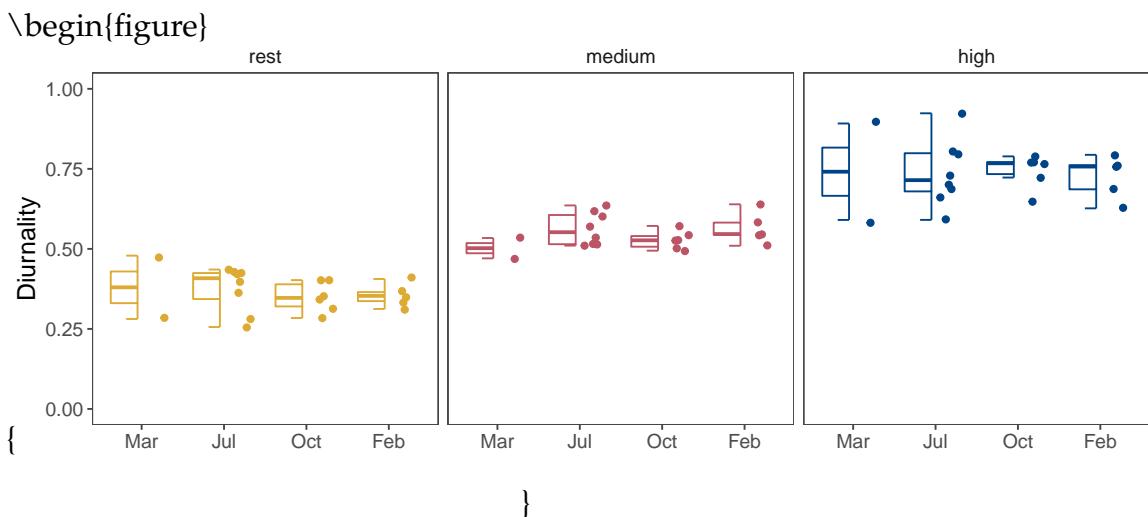
- calculate peak
- adicionar linha do meio dia solar



*Figure 1.7:* Density estimate of daily activity patterns of tuco-tucos' behavioral states. Solid lines indicate the Gaussian kernel density estimates. Light-colored bars show observed distribution of each behavioral state occurrence. Rug lines above the x-axis shows individual occurrences. Dotted vertical lines show time of civil twilights. High Activity State shows a diurnal pattern independent of the time of the year. Medium Activity State shows no daily pattern. Light Exposure shows a diurnal rhythm that changes according to the season.

### 1.3.5 Diurnality

Only the High Activity State behavior is predominately diurnal. The average diurnality for the High Activity State is higher than 70% for all seasons (Table @ref:(tab:table-mean-time-in-state)). Medium Activity is evenly spread out along the 24h with a diurnality that ranges from 50% in March to 56% in July and February (Table @ref:(tab:table-mean-time-in-state)). The Rest State is predominantly nocturnal with Diurnality lower than 38% for all season. An ANOVA test show no difference in the mean diurnality between Months for each state (Figure 1.3.5).



\caption{Distribution of each state's diurnality. Only the High Activity State is predominantly diurnal. High Activity State had a average diurnality greater than 70% for all season.} \end{figure}

### 1.3.6 Rhythmicity

(...)

## 1.4 Discussion

- Optamos pelo tipo de modelos mais simples com outras a analises a posteriori. Existem outros métodos interessantes Patterson 2009. Extensions to out model could include (...)

*Table 1.3: Mean diurnality of each state.*

Season	State	Mean Diurnality
March	rest	0.38
March	medium	0.50
March	high	0.74
July	rest	0.38
July	medium	0.56
July	high	0.74
October	rest	0.35
October	medium	0.53
October	high	0.74
February	rest	0.35
February	medium	0.56
February	high	0.73

- limitações dos dados de lightlogger: não sabemos se os picos podem se extender durante a noite tbm.

# Apêndice {-}

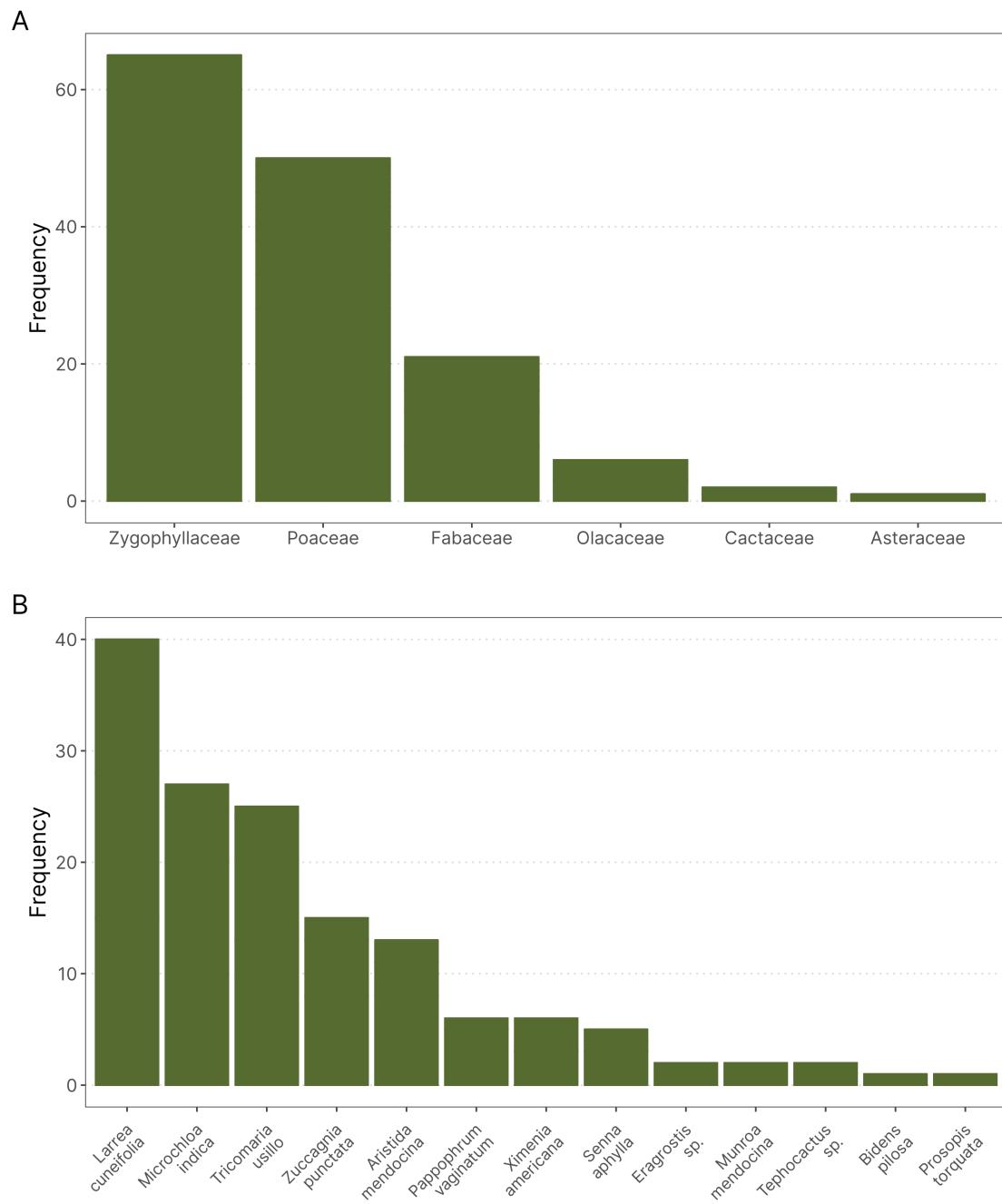
# Appendix A

## Anillaco's Plant Community

Following methods similar to (Aranda-Rickert, Diez, and Marazzi 2014) a non-extensive survey of the plant community was done in May 2019. Three perpendicular 50m transects were defined near the study site (COORDINATES).

A point-intercept method was used to record plant species present in the transects, species right below the sampling points were registered in the data. Sampling points were defined every 1m along the 50m transects. Plant species were identified in the field by a Botanist, except for a few members of the Poaceae family.

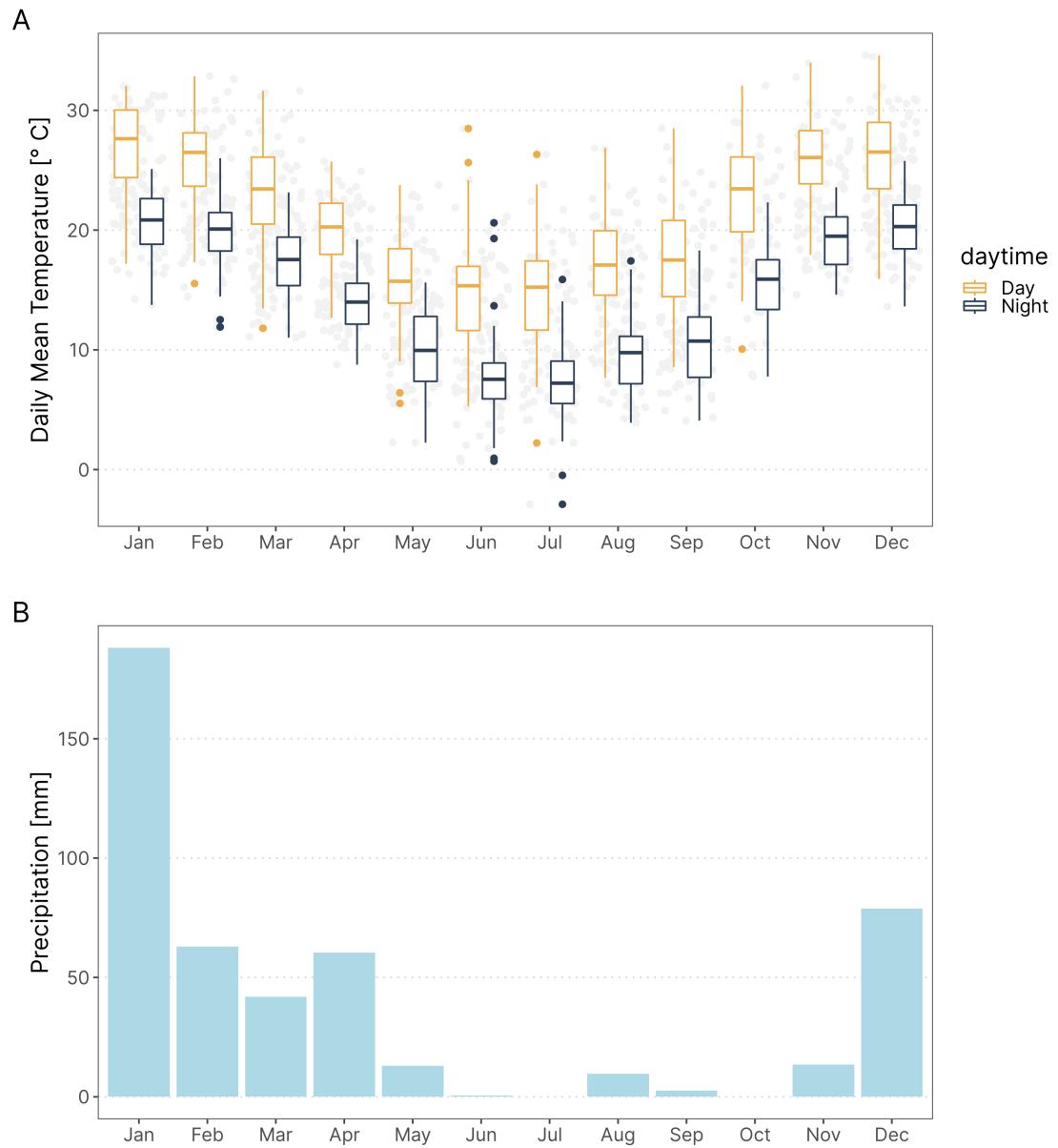
The results for the plant survey is in line with what has been described in the literature for the region (Abraham et al. 2009; Aranda-Rickert, Diez, and Marazzi 2014; Fracchia et al. 2011). The results show a dominance of Zygophyllaceae, Poaceae and Fabaceae families. The relative frequency of plant families and species recorded in the area are shown in the graphs below (Fig. A.1).



*Figure A.1:* Relative frequency of plants family (A) and species (B) in three transects near the Study Site. The plant community is dominated by members of the Zygolhyllaceae, Poaceae and Fabaceae families and is in accordance with what has been described in the literature. (n = 145)

## **Appendix B**

### **Anillaco's Weather**

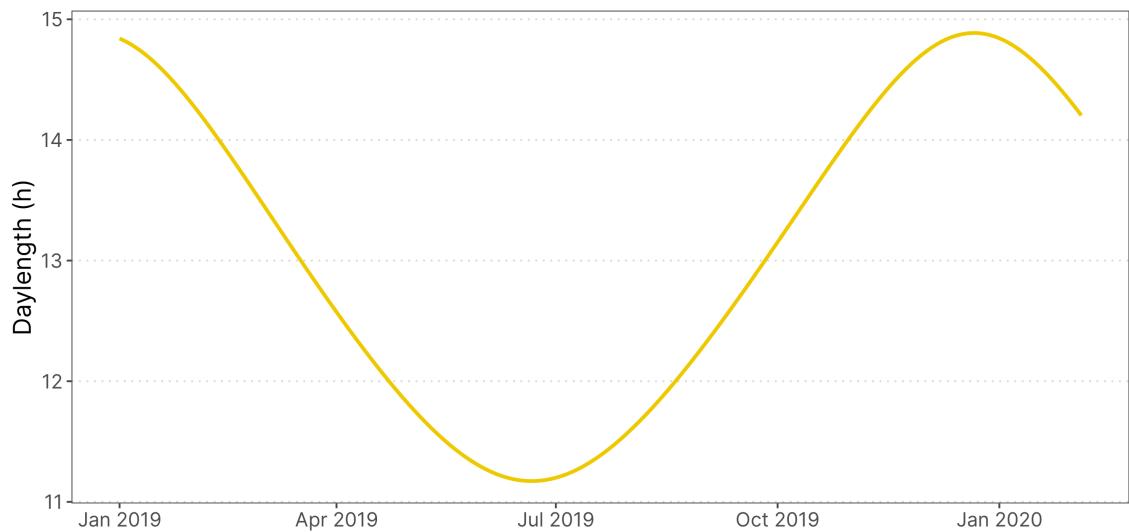


*Figure B.1:* Temperature and Rainfall yearly trends in Anillaco, Argentina. Data was collected in the years 2017 and 2019 from a weather Station (Vantage Pro 2, Davis Instruments. USA.) maintained in CRILAR, approximately 5km away from the study site.

## Appendix C

### Anillaco's Yearly Daylength Changes

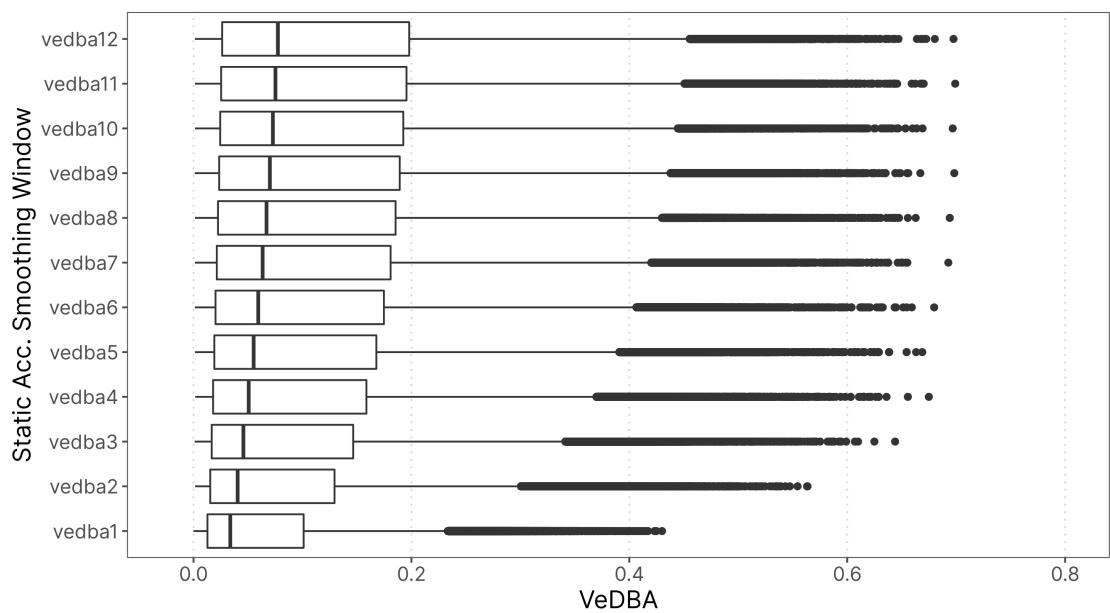
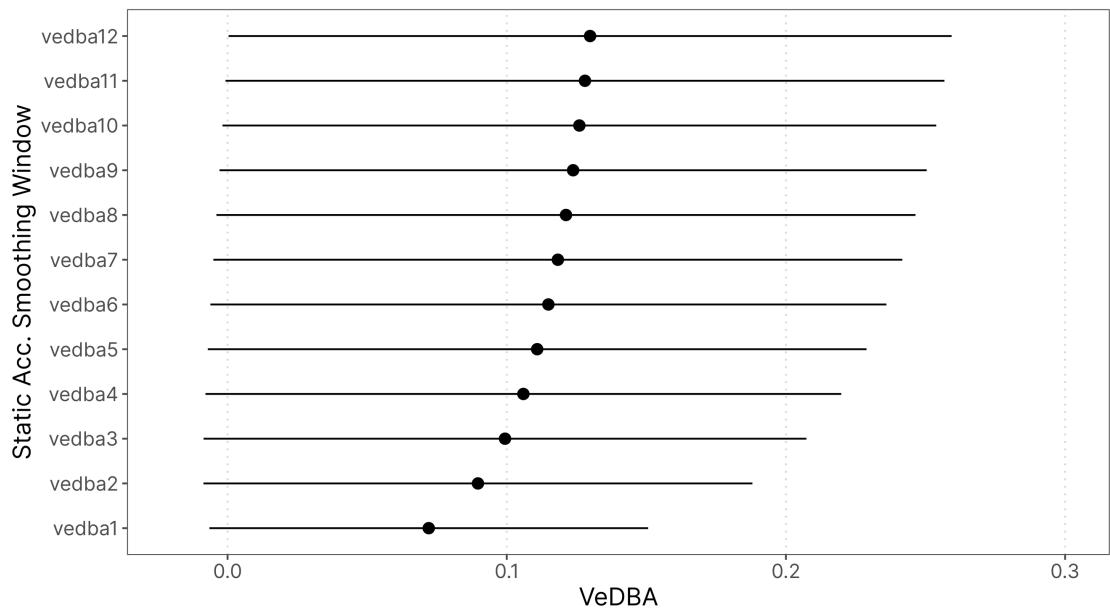
- Adicionar tabela com duração do dia nas datas de coleta



*Figure C.1:* Changes in daytime changes across the year in Anillaco, La Rioja. Maximum duration of daytime, during summer, is 14 hours and 53 minutes. Minimum duration of daytime, during winter, is 11 hours and 10 minutes.

## **Appendix D**

# **Static Acceleration Smooth Window Assessment**



# Appendix E

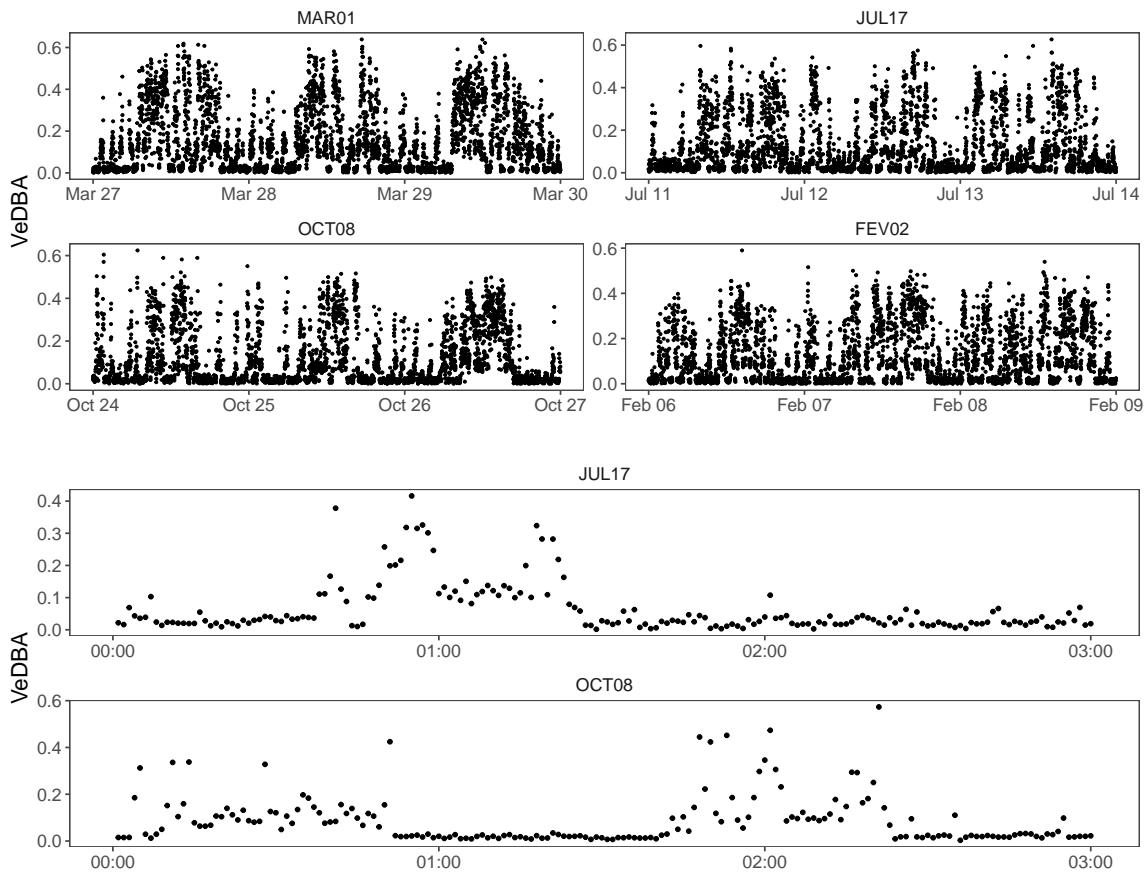
## Exploratory VeDBA data Analysis

- adicionar descrição dos animais
  - peso, por sexo e estação

### E.1 Time Series Plot

Primeiro uma verificação geral nos dados em formato de série temporal. Os gráficos mostram apenas os 4 primeiros dias de registro de cada animal.

Não é possível ver muita diferença entre os animais então nas séries temporais então estão plotados apenas 4 animais. É interessante que em alguns animais já é possível ver que os pontos parecem estar mais ou menos organizados em três regiões distintas na vertical.



## E.2 Histogramas e Gráficos de Densidade

Antes de seguir para outras análises vamos observar as distribuições dos dados de acelerômetros para ver se há muita heterogeneidade entre os animais. Os dados de atividade para esses gráficos foram limitados à 4 dias por animal, assim o número de amostras por animal é o mesmo.

As distribuições de VeDBA parecem ter um range muito próximo de valores. Ou seja, parece não haver animais que possuam uma atividade muito mais intensa do que outros, o que também pode ser visto na tabela abaixo. Porém, o formato da distribuição muda entre alguns animais, principalmente entre estações. Por exemplo, os animais capturados em outubro parecem ter maior número de amostras com valores mais à direita da distribuição, entre 0.2 e 0.5. Alguns animais capturados em Fevereiro parecem continuar com essa tendência. Em julho, porém, os animais parecem ter uma distribuição com maior concentração em valores mais centrais, entre 0.05 e 0.2. Essas mesmas tendências também podem ser observadas de uma forma mais compacta no gráficos de densidade por animal.

Então, os animais, apesar de terem distribuição de VeDBA que não distoam muito uns dos outros no seu range, parecem passar tempos diferentes em tipos de diferentes de comportamentos.

ID	season	Mean	Median	Max	Min	Range	VeDBA_Sum
MAR01	March	0.145	0.097	0.639	0.001	0.638	624.996
MAR02	March	0.115	0.055	0.728	0.001	0.727	494.680
JUL15	July	0.123	0.079	0.755	0.000	0.755	532.374
JUL16	July	0.091	0.030	0.740	0.002	0.738	393.167
JUL17	July	0.109	0.042	0.627	0.000	0.627	471.670
JUL18	July	0.096	0.034	0.623	0.000	0.623	413.211
JUL19	July	0.101	0.075	0.641	0.001	0.641	435.153
JUL20	July	0.091	0.063	0.624	0.000	0.624	395.131
JUL21	July	0.112	0.056	0.609	0.001	0.608	485.622
JUL23	July	0.114	0.047	0.711	0.001	0.710	491.648
OCT01	October	0.111	0.056	0.672	0.007	0.665	477.646
OCT08	October	0.102	0.036	0.624	0.000	0.624	439.019
OCT09	October	0.167	0.099	0.657	0.001	0.656	722.404
OCT10	October	0.147	0.089	0.593	0.000	0.593	635.926
OCT13	October	0.126	0.064	0.540	0.001	0.539	542.222
OCT14	October	0.130	0.066	0.555	0.007	0.548	563.757
FEV01	February	0.138	0.089	0.629	0.000	0.629	594.794
FEV02	February	0.113	0.072	0.590	0.000	0.590	488.959
FEV03	February	0.103	0.072	0.654	0.000	0.654	445.102
FEV05	February	0.119	0.049	0.601	0.007	0.594	514.446
FEV06	February	0.129	0.069	0.577	0.002	0.576	557.528



*Figure E.1:* Histograma dos valore de VeDBA por animal (cada quadro). As cores representam os meses em que esses animais foram capturados.

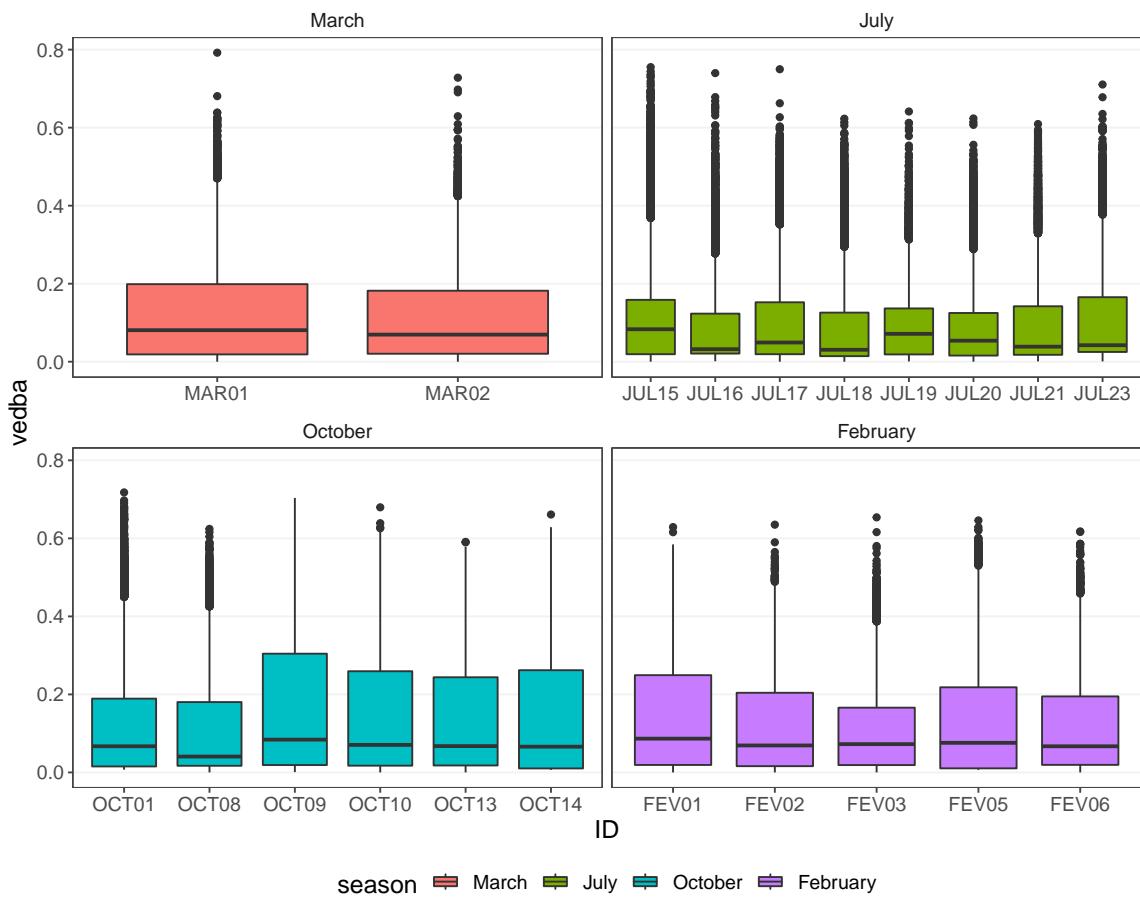
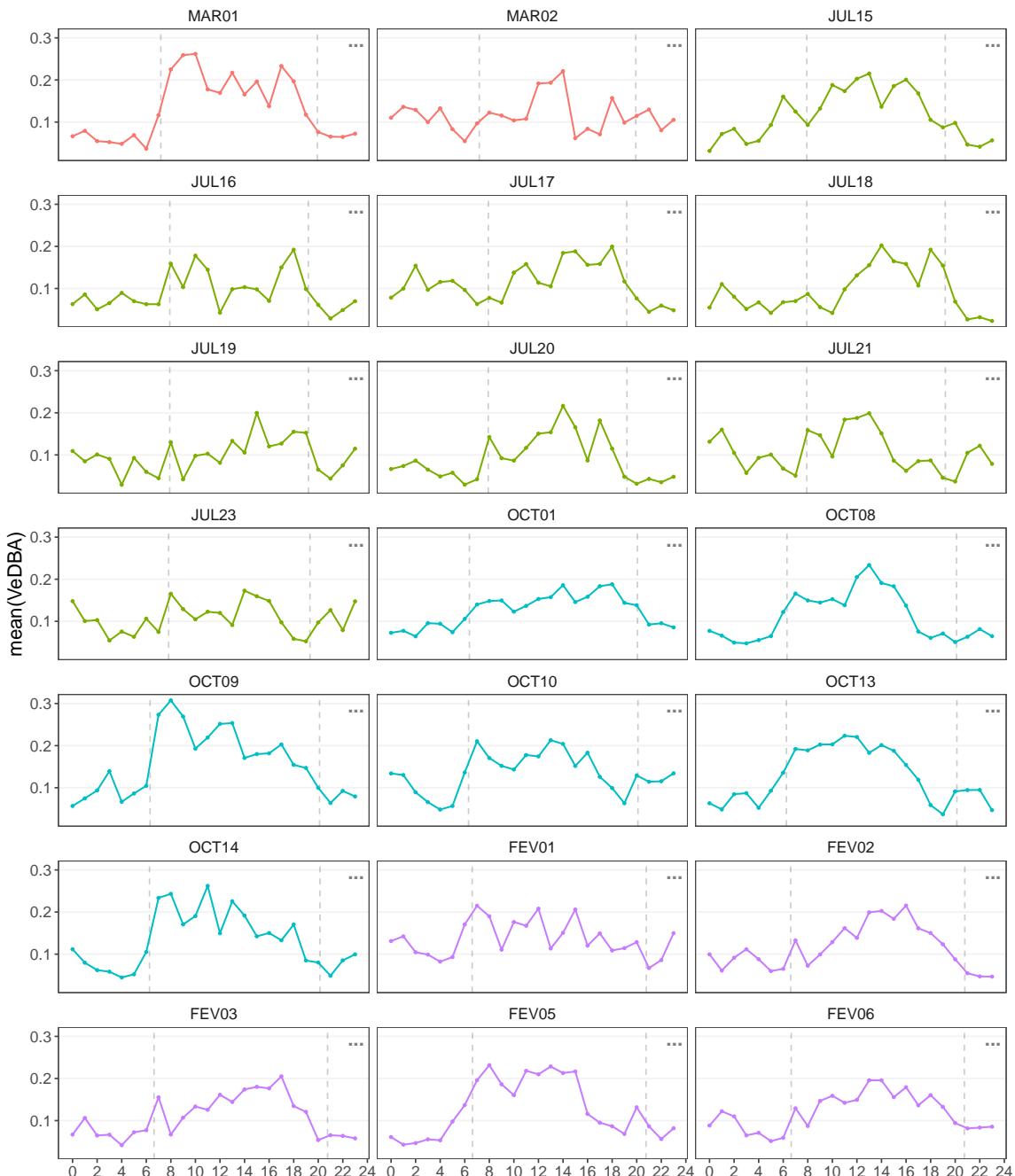


Figure E.2: Ridge plot mostrando a densidade da distribuição dos valores de VeDBA divididos por animal. As cores representam os meses em que os animais foram capturados.

### E.3 Padrões Médios de Atividade por Animal

Para terminar, é interessante ver como é o “ritmo médio” ao longo de todo tempo de registro dos animais. Acho que esse gráfico é especialmente interessante para pessoas fora da cronobiologia, já que é bem mais intuitivo do que os actogramas.

Nesses primeiros gráficos foi plotado a média por hora dos valores de VeDBA de cada animal.



## E.4 Gráficos Agrupados por Estação e Sexo

### E.4.1 Histogramas/Gráfico de Densidade

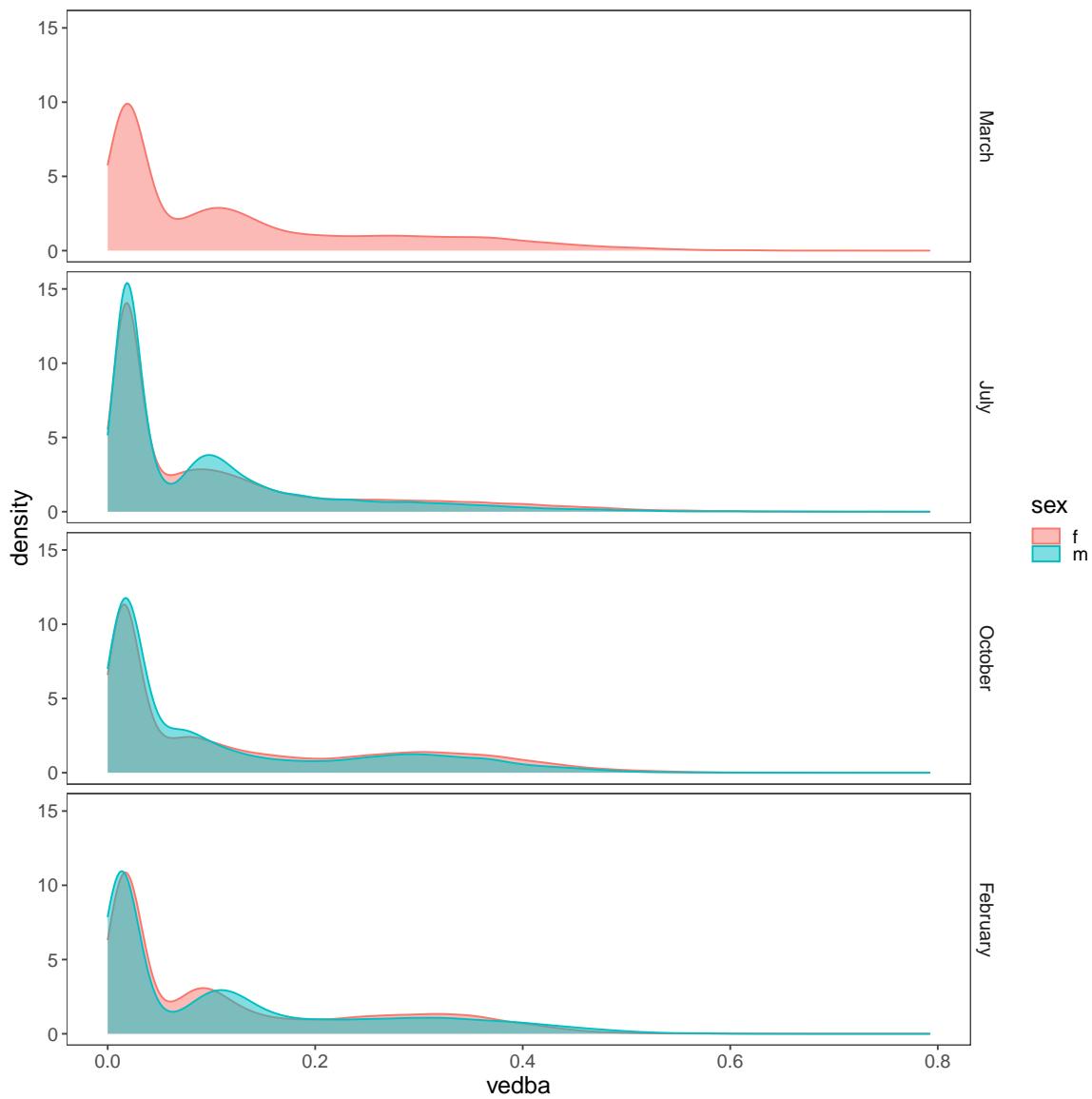
Visualmente parece haver alguma diferença sazonal nas atividade dos tucos.

Vamos inspecionar melhor isso agrupando os dados por estação e sexo.

Como o número de amostras varia entre estações e sexo o histograma não seria muito informativo nesse caso. Então pra isso podemos fazer um gráfico de densidade. Esses gráficos basicamente refletem a forma do histograma mas, nesse caso, tem a vantagem de que são padronizados para que a área abaixo da curva seja sempre igual a 1.

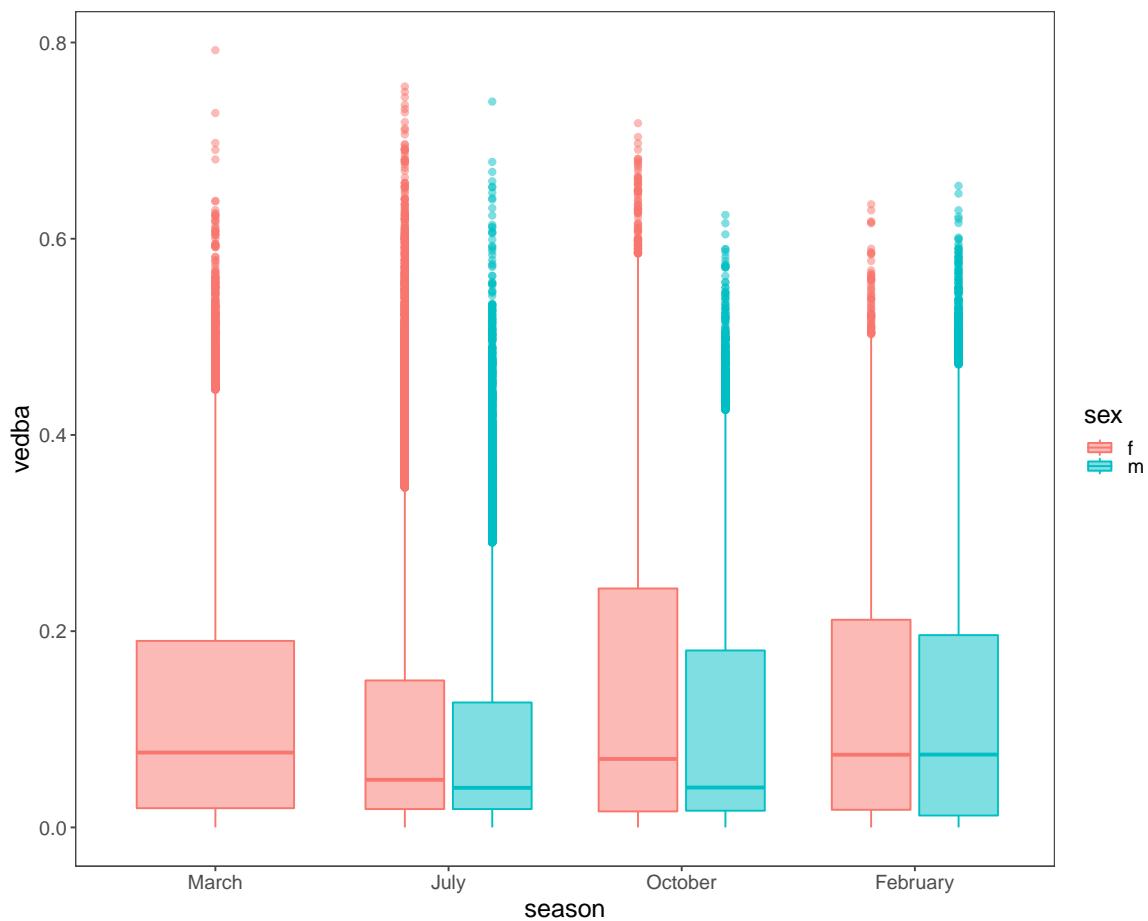
Assim, podemos ver como o perfil das distribuições muda ao longo das estações e entre sexos mesmo tendo um número de amostras diferente para cada condição. Os valores em y não significam muita coisa individualmente.

Visualmente temos o que também vimos nos histogramas anteriores. A distribuição parece mudar ao longo do ano. No entanto, quando sobreponemos as distribuições de cada sexo parece não haver muita diferença entre machos e fêmeas.

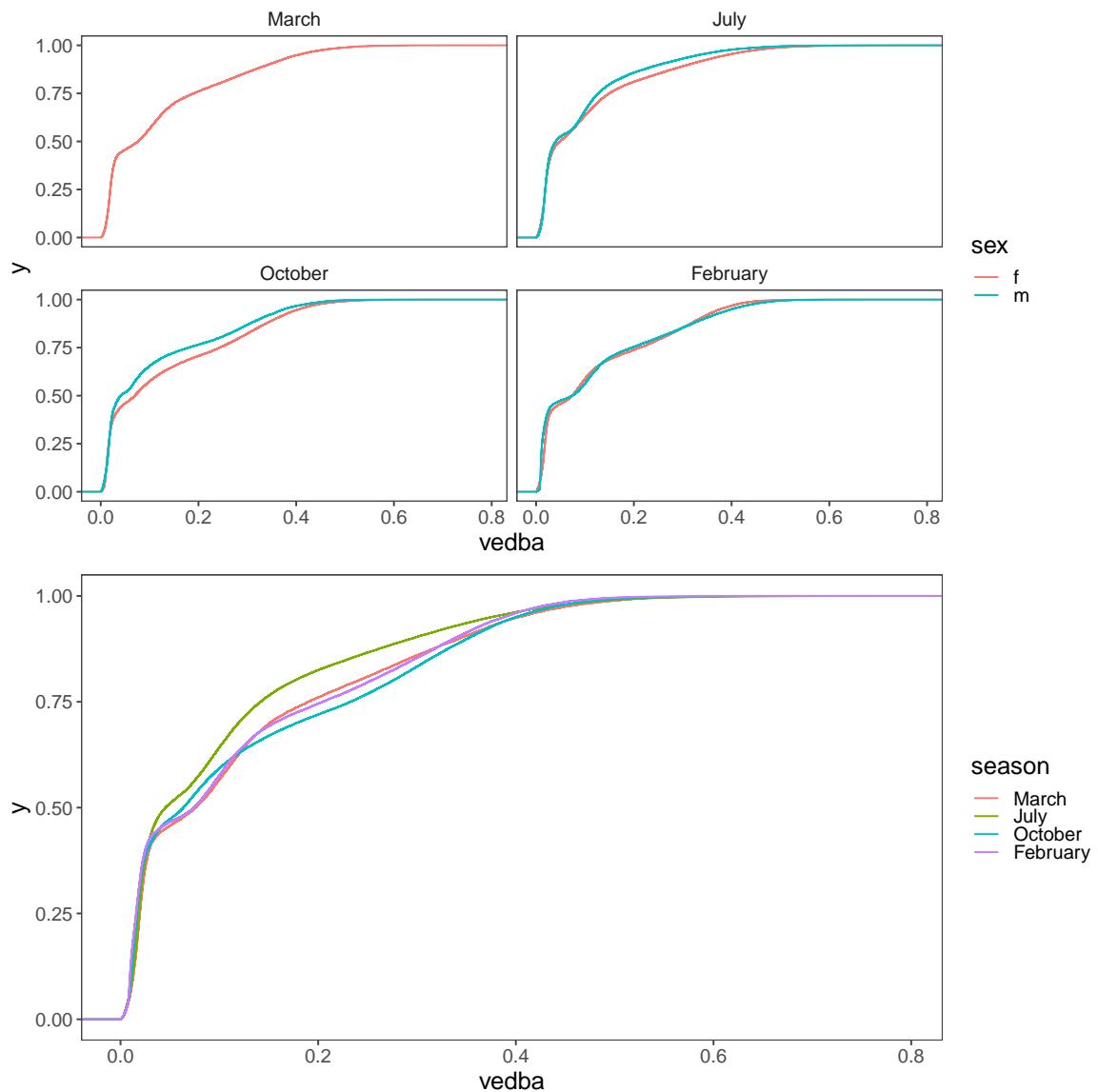


## E.4.2 Medianas e Boxplots

season	sex	median	mean	n.animals	n.points
March	f	0.076	0.124	2	17278
July	f	0.049	0.108	5	41755
July	m	0.040	0.093	3	18717
October	f	0.070	0.133	5	74875
October	m	0.041	0.110	1	21599
February	f	0.074	0.122	3	33117
February	m	0.074	0.121	2	28798



## E.5 ECDF

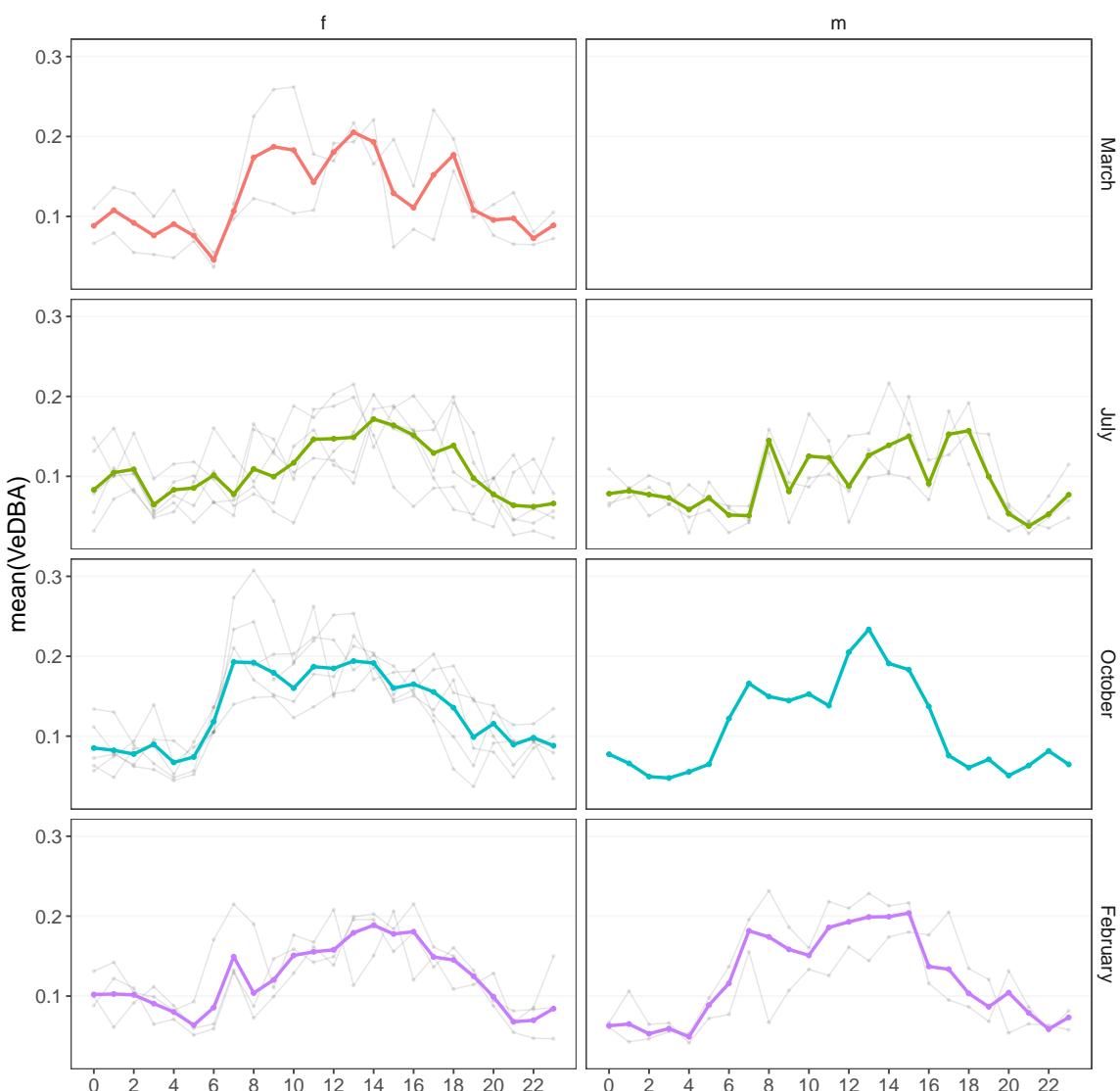


## E.6 Padrão Médio de Atividade por Estação e Sexo

Nesse último gráfico eu queria verificar se temporalmente existe alguma diferença entre macho e fêmeas. Cada painel é um grupo entre as opções de combinação de sexo e estação.

As mesmas curvas de VeDBA médio por hora são mostradas em cinza ao fundo, onde cada curva representa um animal diferente. Em cores, colorido por estação, está a média de VeDBA por hora do grupo representado no painel.

Aparentemente também não existe uma diferença tão grande entre machos e fêmeas quanto aos horário de atividade. Porém, temos um n bem baixo de machos capturados o que torna difícil fazermos uma observação muito concreta.



# Appendix F

## Models' AIC

- Adicionar o LL

Model	Formula	AIC
m2	~season	-935612.2
m1	~1	-934800.8

# Appendix G

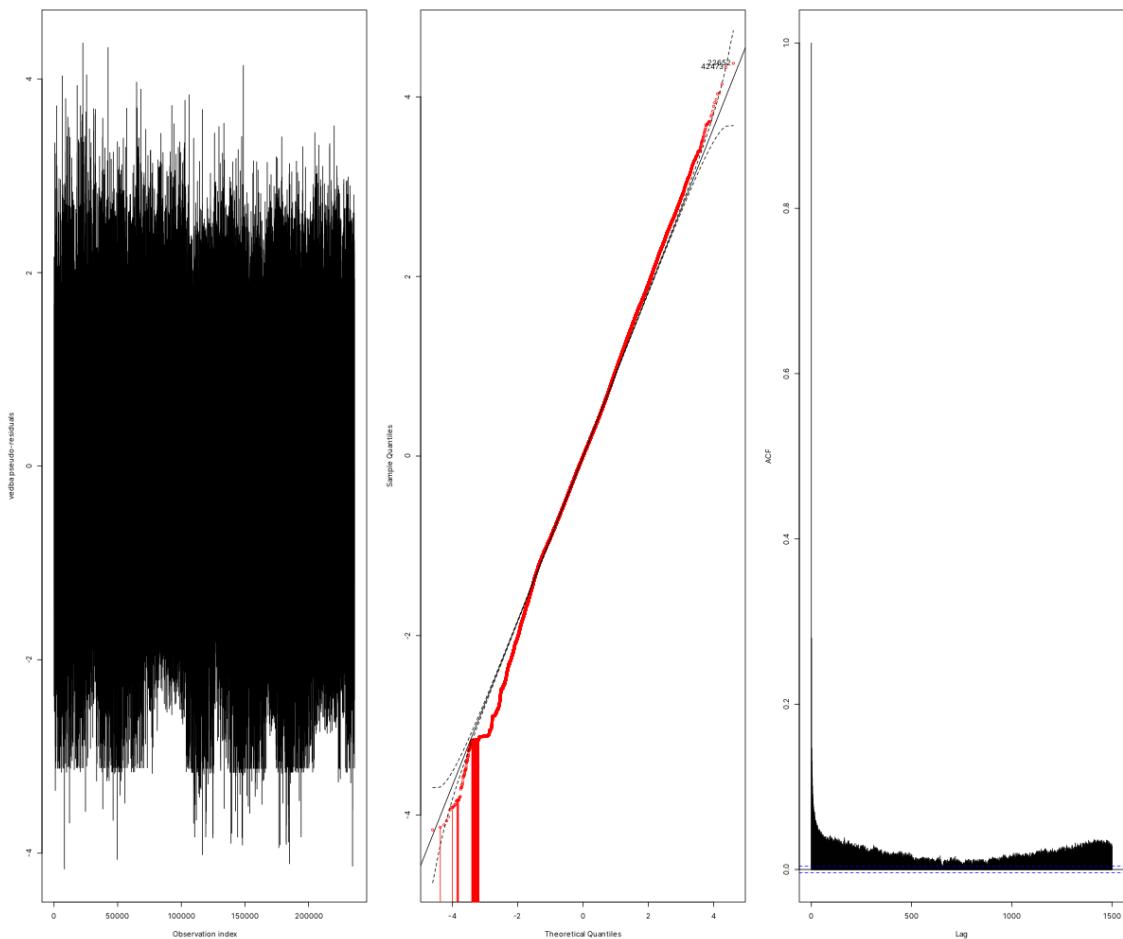
## Model's Estimated Parameters

Table G.1: Gamma State-dependent distribution parameters, mean and standard deviation, estimated by a three-state Hidden Markov Model.

Parameter	State	Estimate	CI
mean	Rest	0.018	[0.018, 0.018]
mean	Medium	0.116	[0.116, 0.117]
mean	High	0.327	[0.326, 0.328]
sd	Rest	0.010	[0.01, 0.01]
sd	Medium	0.051	[0.05, 0.051]
sd	High	0.087	[0.086, 0.087]

# Appendix H

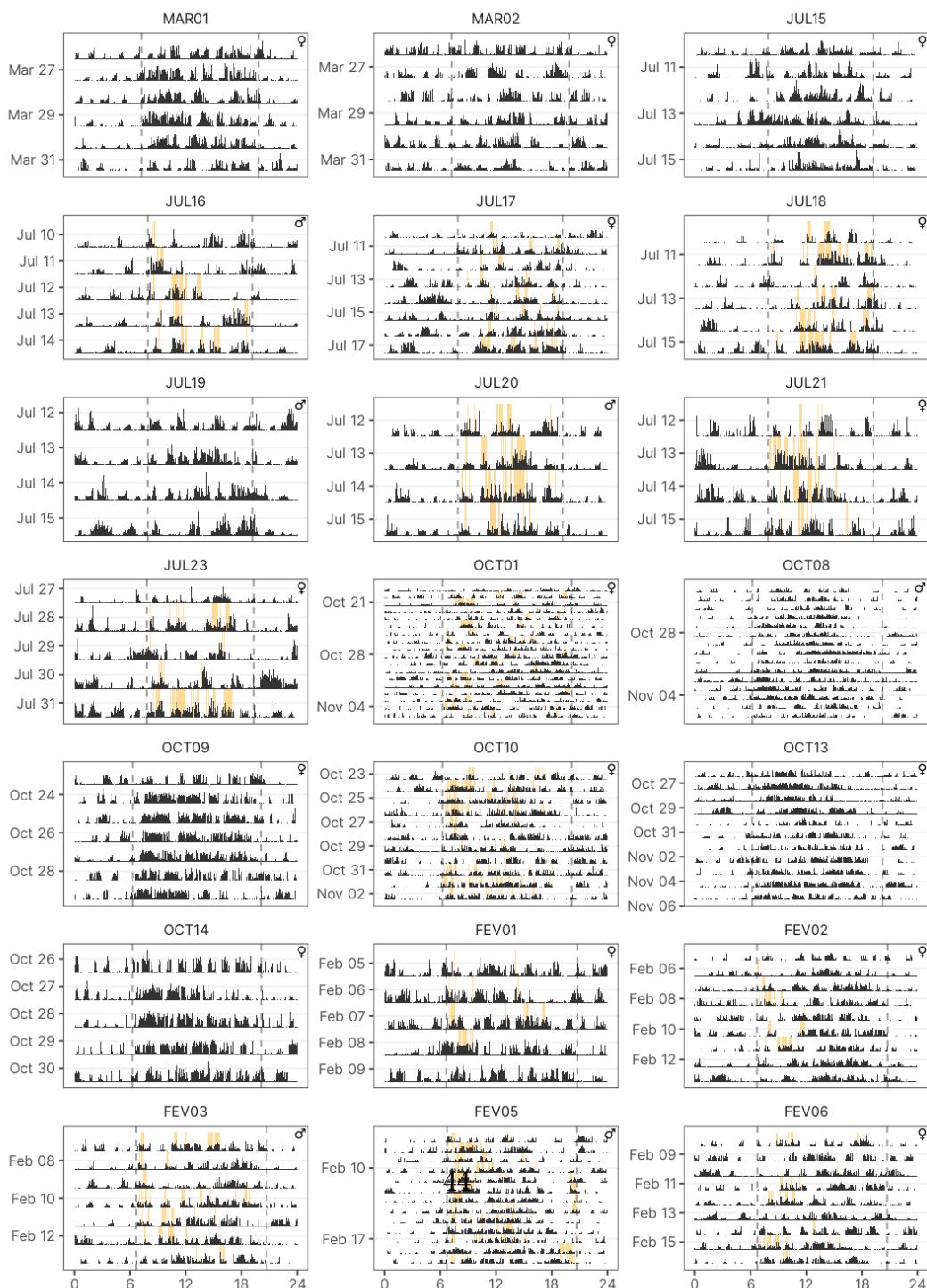
## Pseudo-residuals





# Appendix I

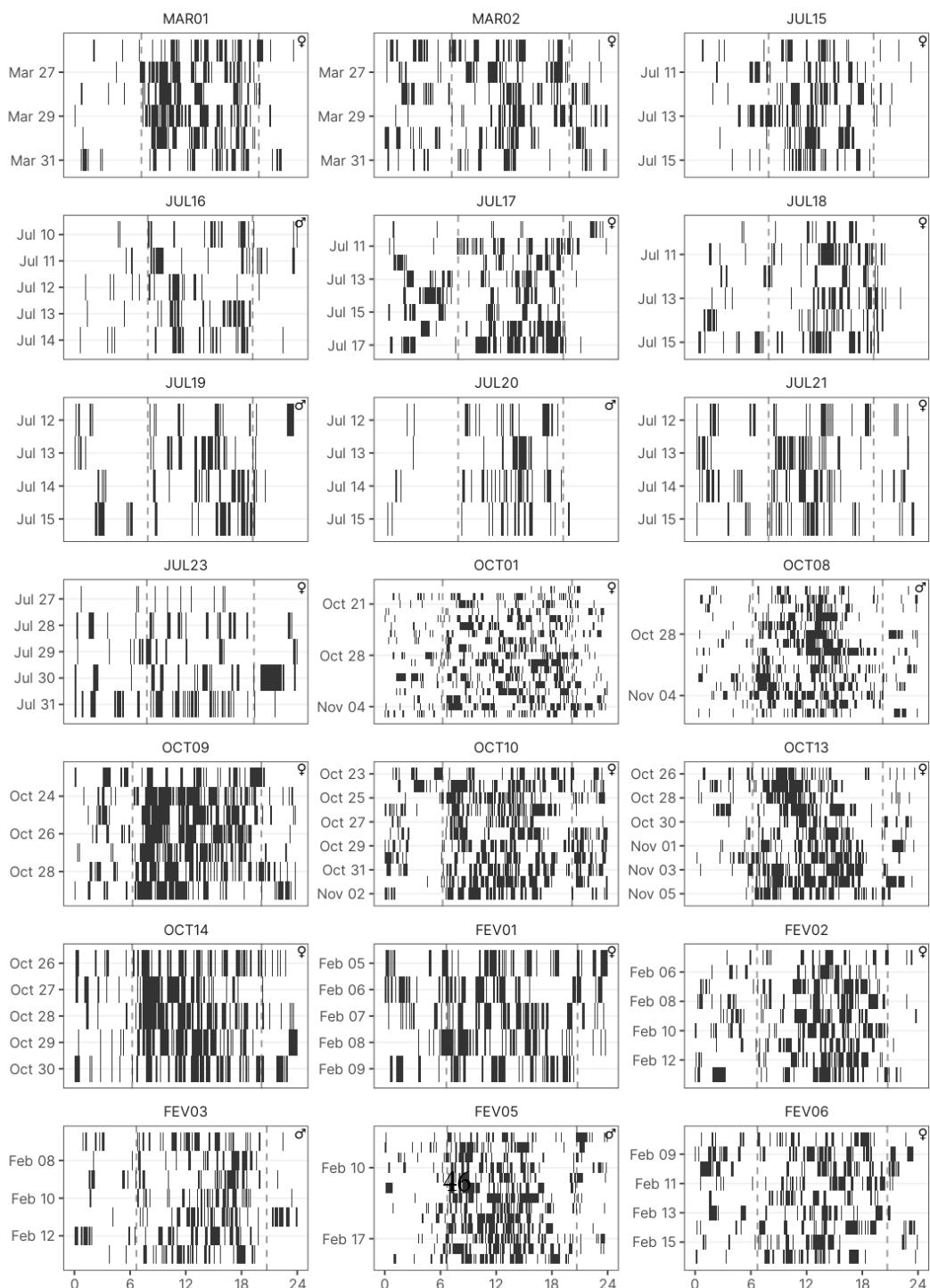
## VeDBA Actograms





# Appendix J

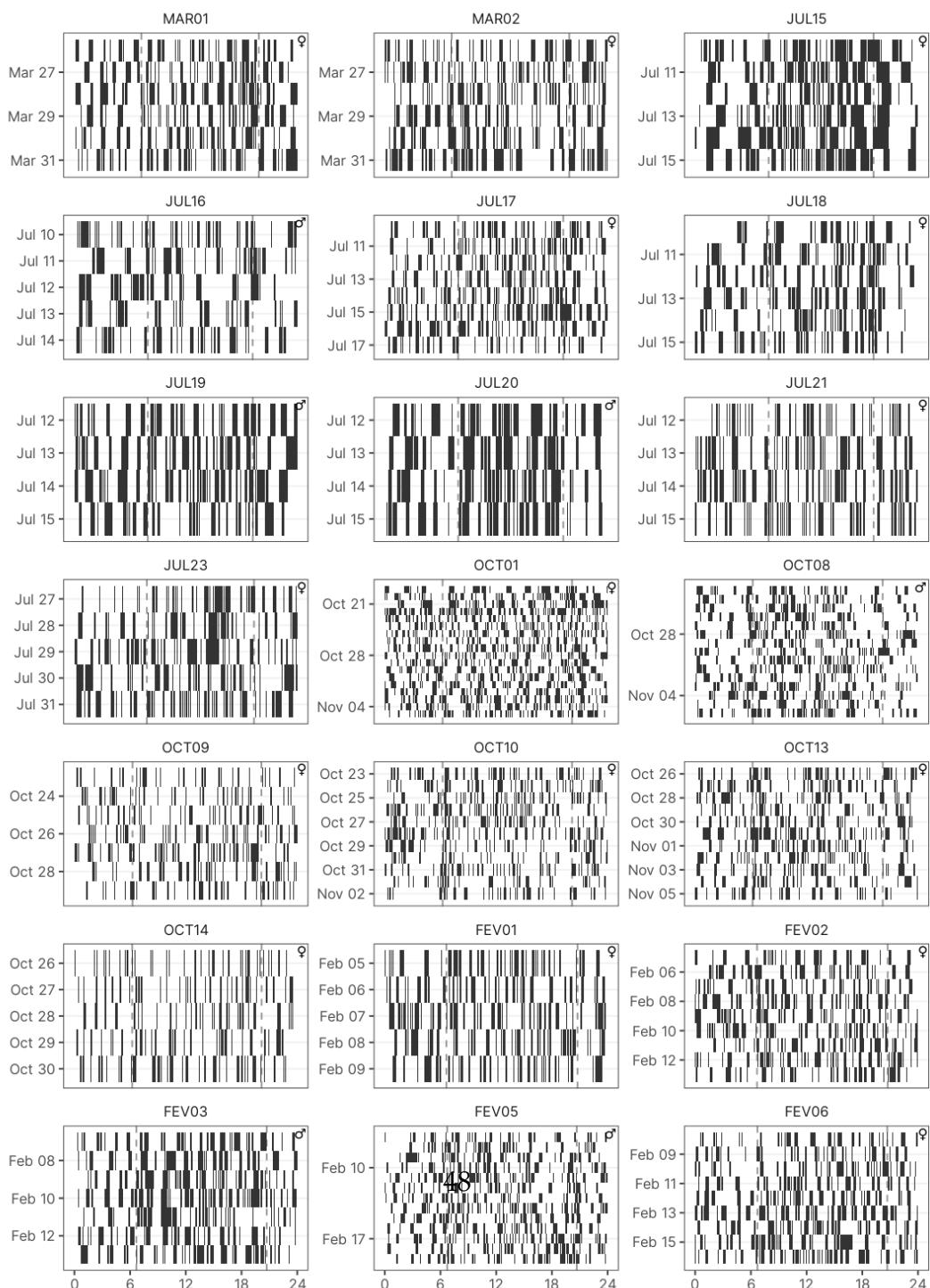
## High Activity Actograms





# Appendix K

## Medium Activity Actograms



## **Appendix L**

### **Medium Activity Daily Patterns**

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