



UNIVERSIDADE DE BRASÍLIA
INSTITUTO DE CIÊNCIAS BIOLÓGICAS
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Is the response of insectivorous bats to vegetation
cover scale – dependent?

A resposta de morcegos insetívoros à cobertura
vegetal é dependente da escala espacial?

CAMILA MONIZ FREIRE RODRIGUES

BRASÍLIA

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CAMILA MONIZ FREIRE RODRIGUES

Orientadora: Prof. Dr. Ludmilla M. S. Aguiar

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Pós-Graduação em Ecologia do Instituto
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obtenção do título de Mestre em Ecologia.

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Data da defesa:

Nota: _____

BANCA EXAMINADORA

Dr^a Ludmilla Moura de Souza Aguiar
(Presidente)

Dr. Patrício Adriano da Rocha
(1^o Titular)

Dr. Pedro Henrique Brum Togni
(2^a Titular)

Dr^a Marina Regina Frizzas
(Suplente)

*“Every phase of your life teaches you
how to grow, how to heal and how to deal.”*

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66 and 300m 50

67 **ABSTRACT**

68

69 Cerrado is the second biggest biome in Brazil, characterized by a mosaic of
70 phytophysionomies. However, it has been severely threatened due to intensive human
71 actions, which promote native vegetation suppression to multiple land uses. Considering
72 those constant anthropical pressures, information on the wildlife responses to vegetation
73 structure is essential, especially in Cerrado. In this context, the present study aimed to
74 evaluate to what extent vegetation structure strongly influences the activity and species
75 composition of insectivorous bats in a protected area surrounded by agriculture.
76 Insectivorous bat passes were analyzed using the software Avisoft SASLab Pro. After,
77 echolotaion passes and feeding buzzes were counted to estimate bat activity and buzz
78 ratio, respectively, in each site. We then identified the passes at species level based on
79 specific literature. To estimate percentage of vegetation cover, we processed satellite
80 images in the QGIS 3.6.3 software to each of the eight circular landscapes scales (25m –
81 300m in radius). We then modelled the relationship between bat activity and percentage
82 of vegetation cover. Overall, 4.993 insectivorous bat passes were counted, 15.5%
83 (773) IAU and 70.3% (3.511) IAB passes. The results showed bat activity difference
84 between the guilds (p – value = 0.03423), but no discrepancy in terms of taxonomic
85 family, as expected. NDVI values revealed low active biomass in all the sites,
86 characterizing grassland areas predominantly, with sparse shrub and herbaceous
87 vegetation in minor percentage. In opposition to the expected, there was no strong
88 correlation between bat activity and percentage of vegetation cover to scales smaller up
89 to 300m in radius. These results suggest that the use of spatial scales relatively larger
90 than those used may be more appropriate and informative to investigate the response of
91 insectivorous bats to vegetation cover in predominant grassland savannah formations. In

92 addition, insectivorous bats may respond stronger to vegetation structure than only
93 percent vegetation cover and distance to water sources. Thus, it is recommended to
94 evaluate aerial insectivorous responses to vegetation at multiple scales.

95

96 **Key words:** Guilds, acoustic activity, echolocation, Chiroptera, Cerrado.

97 **RESUMO**

98

99 O Cerrado é o segundo maior bioma do país, marcado por um mosaico de
100 fitofisionomias. No entanto, este tem sido severamente ameaçado devido à supressão da
101 vegetação nativa para usos múltiplos. Diante dessas constantes pressões, informações
102 acerca da resposta da fauna silvestre às mudanças na estrutura da vegetação são
103 essenciais, especialmente no Cerrado. O presente estudo visou avaliar a extensão pela
104 qual a estrutura da vegetação nativa exerce influência sobre a atividade e composição de
105 morcegos insetívoros em uma área de proteção circundada por atividade agrícola.
106 Passes emitidos por morcegos insetívoros foram analisados e contabilizados utilizando
107 – se o software Avisoft SASLab Pro, a fim de se estimar a atividade desses morcegos
108 nos pontos amostrados. Para identificação no nível de espécie, tais dados foram
109 comparados à literatura científica específica. A percentagem de cobertura da vegetação
110 para cada uma das escalas (25m – 300m de raio) foi estimada a partir de imagens de
111 satélite e analisadas no software QGIS 3.6.3. Modelos lineares generalizados foram
112 gerados a fim de se analisar a relação entre atividade de morcegos e a porcentagem de
113 cobertura vegetal. Ao todo, foram contabilizados 4.993 passes de morcegos insetívoros,
114 sendo 15,5% (773) de morcegos de áreas abertas e 70,3% (3,511) de morcegos de áreas
115 de borda. Os resultados demonstraram que a atividade de morcegos entre os grupos
116 diferiu ($p - \text{value} = 0,03423$), fato não foi observado entre as famílias taxonômicas. Os
117 valores de NDVI indicaram presença de vegetação predominantemente caracterizada
118 por formações campestres, com presença de manchas esparsas de formação savânica
119 herbáceo – arbustivas em todos os pontos amostrados. Não houve, dessa forma, forte
120 correlação entre atividade de morcegos e porcentagem de cobertura vegetal em todas as
121 escalas menores que 300m de raio. Tais resultados sugerem que a utilização de escalas

122 espaciais relativamente maiores às utilizadas podem ser mais informativas para
123 investigar a resposta de morcegos insetívoros à cobertura vegetal em fitofisionomias
124 savânicas com predominância de formações campestres. Ainda, é possível que a
125 atividade de morcegos insetívoros aéreos seja mais fortemente associada a outras
126 variáveis ambientais não analisadas no presente estudo, como a estrutura da vegetação.
127 Dessa forma, recomenda-se avaliar a resposta de morcegos insetívoros aéreos à
128 vegetação sob múltiplas escalas espaciais
129
130 **Palavras - chave:** Guildas, atividade acústica, ecolocalização, Chiroptera, Cerrado.

131 **INTRODUCTION**

132 **Bats: diversity and ecosystem services**

133 Cerrado is the second largest biome in Brazil, comprising about 22% of the
134 Brazilian territory (Sano et al, 2010). It is a complex mosaic of grassland, savannah and
135 forest environments (Ribeiro & Walter, 2008). Due to its high environment
136 heterogeneity, this biome provides multiple resources to wildlife, such as food, roost
137 and protection against predators and anthropic disturbs. All these factors acting together
138 contribute to high endemism of plant and animal species, which make Cerrado one of
139 the species - richest tropical savannah in the world (Myers et al, 2000). Despite this, the
140 biome is considered one of the 25-biodiversity hotspots in the world. Multiple factors
141 have been contributing to Cerrado vegetation suppression and landscape fragmentation:
142 intensive human activities - mostly agricultural practices, charcoal, unbridled
143 urbanization and seasonal burnings (Klink & Machado, 2005).

144 Bats (Mammalia: Chiroptera) are widely spread throughout the globe. They
145 represent over 22% of the global extant mammals diversity (BCI, 2018). Brazil has the
146 second highest richness of bat species worldwide, distributed in nine families, 69 genera
147 and 182 species formally described. From these species, over 55% are classified as
148 insectivorous bats (SBEQ, 2018). In the Cerrado, this taxon represents the second
149 highest mammal diversity, after rodents, with 103 species listed at the date (Aguiar &
150 Zortéa, 2008). Phyllostomidae is the predominant family, counting 55 species in total,
151 followed by Molossidae, represented by 20 species, and Vespertilionidae, with 12
152 species. Nevertheless, according to Bernard et al (2011), information on the occurrence
153 and distribution of bats remain fragmented or minimally surveyed in Brazil.

154 Besides its high species diversity, bats provide important ecological and
155 socioeconomic roles through their varied diet (Kunz et al, 2011; Ghanem & Voigt,
156 2012). Fruit – eating bats and nectar – drinking bats pollinate flowers of many plant
157 species of socioeconomic value, as the pequi tree (Gribel & Hay, 1993) and the passion
158 flower (Sazima & Sazima, 1978). They also act as seed disperser of pionner plants,
159 promoting early ecological succession of degraded environments (Muscarella &
160 Fleming, 2007; Sato et al, 2008; Quesada et al, 2009). Insect – eating bats are key
161 biological controlers of pest insects, (Cleveland et al, 2006; Aguiar & Antonini, 2008;
162 Boyles et al, 2011), leading to crop yield improvement in tropical agroforestry systems
163 (Maas et al, 2013) and to food security (Wanger et al, 2014), for example. Bats has also
164 assumed a significant importance in the human rabies epidemiology in Americas, as
165 they are rabies virus vector (Dantas – Torres, 2008).

166

167 **Bat bioacustics and study techniques**

168 While navigating in space, most bats use a sophisticated sensory system, called
169 echolocation (Griffin, 1944; Grinnell & Griffin, 1958). This complex mechanism works
170 by processing discrepancies in pulse – to – pulse interval of durantion and in frequency
171 between the emited calls and its echoes. Through navigation calls – calls emited during
172 bat navigation phase, echolocating bats recognize the environment multidimensionally
173 with accuracy and precision (Fenton et al, 2012; Denzinger et al, 2016). As acoustic
174 signatures, bat signals can recognize the presence of obstacles and surfaces, position,
175 distance and even the texture of preys. Moreover, some echolocating bats are able to
176 recognize conspecific and heterospecific individuals, demonstrating a dual function of
177 echolocation calls (Voight – Heucke et al, 2011).

178 Adapted to different habitat types, bats can forage under different clutter
179 conditions (Kalko et al, 1996). Using information on their hunting strategies, habitat
180 preferences and call designs, it is possible to classify them in groups with ecological
181 similarities (Schnitzler & Kalko, 2001; Schnitzler et al, 2003; Denzinger & Schnitzler,
182 2013). Aerial uncluttered space bats, for example, usually search for flying insects high
183 above vegetation and far from obstacles, while aerial background – cluttered space bats
184 are normally associated to edge spaces, hunting mainly insects that fly near foliage or
185 water surfaces (Appendix.1). Bats that forage in these places generally roost inside
186 forests and explore the edges or fly over the water to prey acquisition. On the other hand,
187 aerial highly cluttered bats generally explore narrow spaces, with dense and highly
188 connected canopy, usually close to surfaces and within vegetation (Aldridge &
189 Rautenbach, 1987; Neuweiler, 1989). Bats can also show another foraging strategies
190 and habitat preferences, yet I focused on insectivorous bats, which are poorly captured
191 in conventional trapping techniques.

192 An efficient and non - invasive alternative to conventional trapping techniques is
193 the use of bioacoustic methods. Studies on bat bioacoustics are widespread in developed
194 countries, where most of them has well - stablished bat acoustic inventories (EBC,
195 2013; BCT, 2019). On the other hand, most of the Neotropical countries have
196 significant bat biodiversity, yet lack information on their bat acoustic repertoire. This
197 fact is mostly due to the high cost of acoustic equipment, which makes them even more
198 unfeasible to developing countries. Another reason is that, in general, insectivorous bats
199 either fly high above vegetation or tend to detect traps and, consequently, avoid them
200 (Berry et al, 2004; Hourigan et al, 2008; Linttot et al, 2013). Also, they are generally
201 difficult to assess in certain habitats, because of their nocturnal habit, small bodies and
202 fly maneuverability (Barclay & Brigham, 1991).

203 Only since the last years, this scenario has progressively changed. Bat acoustic
204 equipment and sound softwares became more affordable and widespread, especially in
205 developing countries. Such innovation led to multiple advantages, such as the
206 identification of new bat species, improving bat inventories (Ochoa *et al*, 2000; Rydell
207 *et al*, 2002; MacSwiney *et al*, 2008; Barquez *et al*, 2009; Briones – Salas *et al*, 2013);
208 the elaboration of local acoustic libraries and guides (Zamora-Gutierrez *et al*, 2016;
209 Arias – Aguilar *et al*, 2018); the monitoring of bat distribution (Espinal & Mora, 2012);
210 the study of geographic variations of bat acoustic patterns (Gillam & McCracken, 2007;
211 Heer *et al*, 2015; Jiang *et al*, 2015; Oliveira *et al*, 2018); and the evaluation of
212 anthropical impacts on bat activity and diversity (Ahlén, 2003; Estrada – Villegas *et al*,
213 2010; Long 2011; Bernard *et al*, 2014; Bader *et al*, 2015; Bunkley *et al*, 2015).

214 Researchers have been making efforts on how insectivorous bats deal with
215 landscapes with different levels of structural complexity. From those studies, it was
216 found that aerial insectivorous bats often produce constant frequency calls (CF) with
217 long pulse duration, which allow them to detect prey quickly and at long distances
218 during the flight (Kalko *et al*, 1996; Schnitzler & Kalko, 2001; Appendix.1). On the
219 other hand, quasi – constant frequency calls (qCF) are frequently related to spaces with
220 some degree of clutter, often edge of vegetation or water surfaces (Appendix.1). In the
221 Neotropical region, Mormoopidae bats are the main representatives of qCF calls, with
222 long duration and high duty cycle (Mora & Macías, 2011; Mora *et al*, 2013). Some
223 authors also argument that, despite being aerial insectivorous, Molossidae bats
224 developed high acoustic plasticity, and can either emit frequency modulated (FM) or
225 qCF calls, depending on clutter degree (Schnitzler & Kalko, 2001; Fenton, 2013).

226 Besides the aforementioned contributions, the effect of habitat structure on
227 insectivorous Brazilian bats remains unclear and poorly studied. It is known that bat

228 assemblages are direct and indirect associated to vegetation structure, composition and
229 complexity. Although, it is urgent to develop researches focused on assessing how the
230 surrounding vegetation structure influences insectivorous bat activity, especially in
231 Cerrado, which has been progressively threatned over the years. Thus, I developed the
232 present study in order to better understand to what extent insectivorous bats strongly
233 respond to different spacial small – scales. Information about this matter contributes to
234 subsidize management plans in Cerrado, especially those involving the suppression or
235 addition of vegetation.

236

237 **OBJECTIVES**

238 The objectives of my study was established to examine two hyphoteses:

239 **H₁** : Bat activity and buzz ratio of insectivorous aerial bats of background - cluttered
240 spaces (IAB) are positively influenced by percentage of vegetation cover and negatively
241 influenced by distance to water sources, and

242 **H₂** : Bat activity and buzz ratio of insectivorous aerial bats of uncluttered spaces (IAU)
243 are negatively influenced by percentage of vegetation cover and positively influenced
244 by distance to water sources.

245 The specific objectives are:

- 246 **1.** Survey acoustically the species richness of the Parque Estadual de Terra Ronca in
247 terms of insectivorous non – Phyllostomidae bats;
- 248 **2.** Correlate bat activity and buzz ratio to percent vegetation cover in each of the 10
249 sampled sites

250 3. Evaluate the scale of effect that stronger influences insectivorous bat response to
251 vegetation cover.

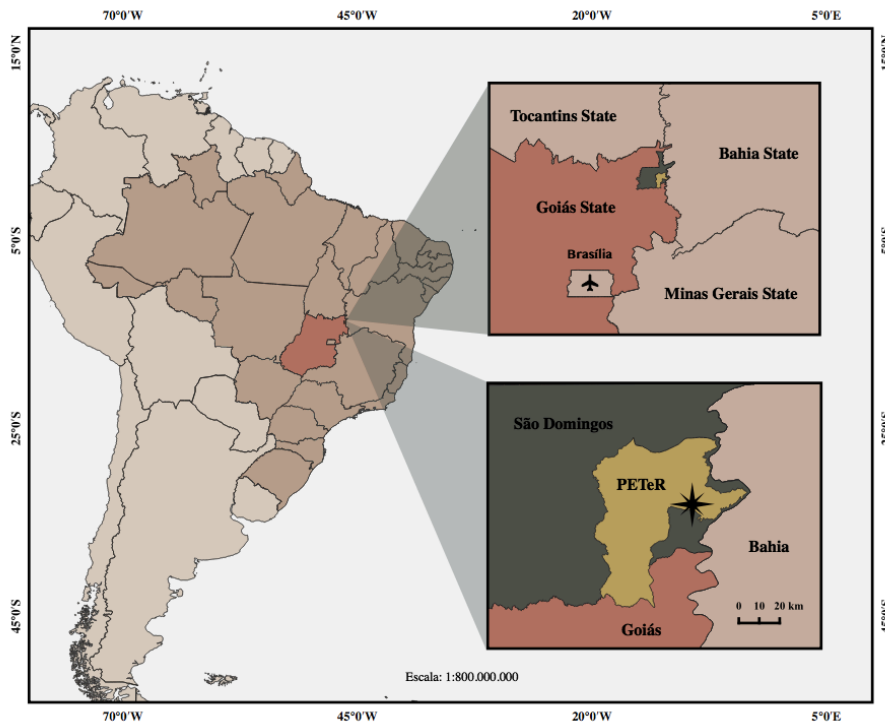
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253 MATERIAL & METHODS

254

255 **Study area.** The study was carried out in the eastern portion of the Parque Estadual de
256 Terra Ronca (PETeR), a fully – protected area located in São Domingos, 350km from
257 Brasília, central Brazil (Fig.1). The region is predominantly characterized by cerrado
258 *sensu stricto* (savannah formation) and grasslands, with sparse veredas (palm swamps)
259 and gallery forests near water courses (riparian vegetation) (IBGE, 1995). The park has
260 numerous karstic landscapes, with complexes of caverns and small caves that provide
261 ecotourism activities (Lino & Allievi, 1980). It is also located in a region that includes
262 the watershed of the São Francisco and Tocantins hydrographic basins (IBGE, 1995).
263 According to the Köppen–Geiger system, the climate is classified as Aw, tropical
264 humid, with average annual precipitation of 1677mm and average temperature of 24.9°
265 C. There are two distinct climatic seasons, a wet summer (October - April) and a dry
266 winter (May - September).

267 **Field study.** Two sampling nights were conducted during the wet summer of 2015 using
268 the “rapid survey” method (Walter & Guarino, 2006). We used 10 ultrasound recorders
269 (SM2BAT+ 384kHz, Wildlife Acoustics) connected to one unidirectional microphone
270 (SMX – US, Wildlife Acoustics) each, settled to work from 18:00 to 06:00 each night.
271 The ultrasound recorders were placed along two parallel line-transects of 5km, distant
272 1km to each other. We positioned them at 45° to the parallel axis to the ground, at 3m of
273 heigh, removing all obstacles near the microphones. Recorders were triggered at
274 minimum thresholds of 7kHz of frequency and 12dB of intensity, which correspond to
275 the aimed acoustic spectrum.



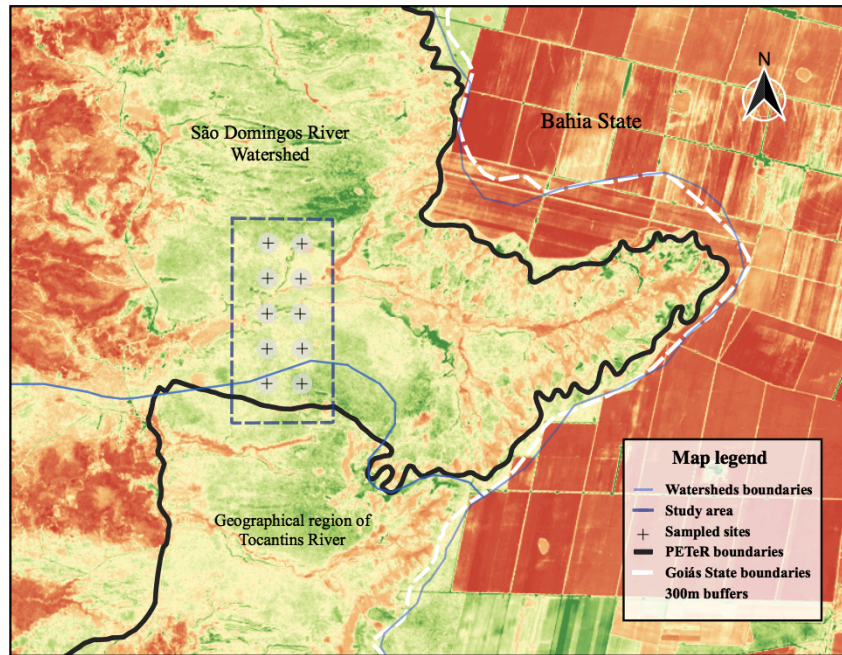
276
277 **Figure 1** : The Parque Estadual de Terra Ronca (PETeR), located in the municipality of São Domingos,
278 Goiás State, central Brazil. Study area location is represented by the black star icon, in the eastern region
279 of PETeR territory.

280
281 **Data collection.** Each sound file was manually analyzed and measured using the sound
282 analysis software Avisoft SASlab Pro (Avisoft Bioacoustics). After, we counted them to

283 estimate bat activity at each site. Average values of at least three consecutive
284 echolocation pulses from navigation phase (Fenton, 1970) were measured and tabled.
285 Therefore, We considered the following acoustic parameters: start frequency, final
286 frequency, peak frequency, pulse duration, interpulse duration, dominant acoustic
287 harmonic, repetition rate and duty cycle. Then, these data were compared to specific
288 literature to identify the signals at species level, when possible (Barclay, 1983; Jung et
289 al, 2014; Arias – Aguilar et al, 2018). We also calculated the buzz ratio at a site as:
290 $BR_{site} = FB_{guild} / FB_{site}$, where FB_{guild} represents the number of feeding buzzes of a guild
291 in a site and FB_{site} the total feeding buzzes in the related site. Calls from insectivorous
292 Phyllostomidae bats were not considered to the study, due to poor information on its
293 acoustics. Moreover, these bats are usually low – flight, trawling hunters, which makes
294 them easily captured by mist – nets.

295

296 ***Percent vegetation cover.*** Digital images from Landsat 8 (USGS data set) were
297 extracted, with maximum cloud cover up to 10%, dated in February 11, 2015. Red and
298 near infrared spectral bands (TM4, 630 – 690nm and TM5, 760 – 900nm, respectively)
299 were analyzed in the QGIS 3.6.3 software. I then generated UTM projected images
300 (EPSG: 32623, WGS 84), based on GPS coordinates along the sites. I calculated the
301 Normalized Difference Vegetation Index (NDVI) to each of the eight circular landscape
302 scales: 25m, 50m, 75m, 100m, 150m, 200m, 250m and 300m in radius (Fig. 2). The
303 NDVI index was calculated based on spectral reflectance data using the formulae:
304 $NDVI\ index = (NIR - RED) / (NIR + RED)$, where NIR and RED represent red and
305 near infrared reflectance values. Many studies have found satisfactory results using
306 NDVI values to estimate percentage of vegetation cover, as there is a positive
307 correlation between vegetation cover and leaf area, green phytomass and gross primary



308

309 **Figure 2.** Study area in the PETeR, produced from merged digital images of the spectral bands of red
 310 (B3) and near infrared (B5). Landsat 8 OLI sensor data extracted from the USGS data set, in 11 February
 311 2015, with 6% of cloud cover and UTM projected.

312

313 production (Tucker, 1985; Purevdorj et al, 1998). We then estimated the scale of effect
 314 as the radius with both a strong relationship between bat activity and percent tree cover
 315 and a good fit of the data to the model. For this analysis, I considered only sites with at
 316 least 30 records from each guild, and species with at least 10 records.

317 **Statistical analysis.** Acoustic data were tabulated and its distribution was checked using
 318 the Shapiro – Wilk normality test (R language version 3.6.0, *nortest* package). To
 319 compare bat activity and buzz ratio between the guilds, I ran a two – sample Mann –
 320 Whitney U test and a non – parametric t – test, respectively. Kruskal – Wallis tests
 321 (*vegan* package in R) were run to evaluate bat activity and buzz ratio differences
 322 between the four predominant families and also to compare species richness between
 323 the sites, followed by the *post hoc* Dunn test (Bonferroni method). For all

324 aforementioned tests, I considered a standardized probability value of $p < 0.05$. I also
325 generated generalized linear models (GLMs) to evaluate if bat activity (at guild and
326 species level) and buzz ratio (at species level only) are influenced by the explanatory
327 variable of percentage of vegetation cover. Models were checked, validated and ranked
328 according to the Akaike Information Criterion (AIC).

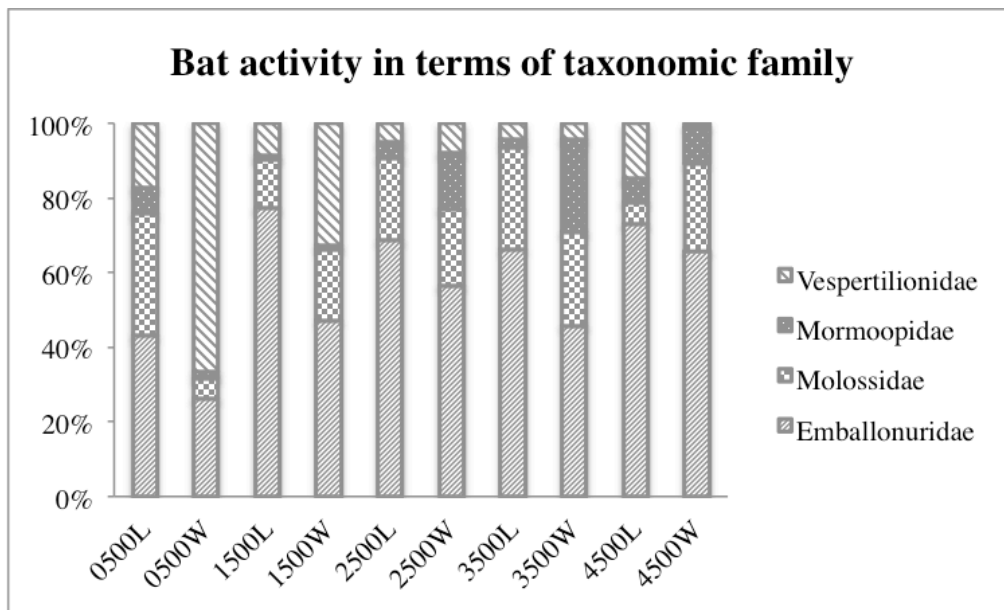
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330 **RESULTS**

331 During the study, 91% over a total of 3,772 sound files registered presence of
332 insectivorous bats, belonging to six families (Appendix 1). The Molossidae was the
333 most diverse family, with a total of 20 species (about 40% of the total registered),
334 followed by Emballonuridae and Vespertilionidae, both composed by 10 species.
335 Despite its lower species - richness (*Pteronotus gymnonotus*, *Pteronotus cf parnellii* and
336 *Pteronotus personatus*), Mormoopidae concentrated about 5% (183 files).
337 Noctilionidae (*Noctilio leporinus*) and Thyropteridae (*Tryroptera* sp.), with one species
338 both, were registered twice during all the study. *Eumops auripendulus*, *Eumops*
339 *dabbenei*, *Histiotus laephotis*, *Histiotus velatus* and *Molossops mattogrossensis* had a
340 single record each.

341 Forty – five different call designs were identified at species level, grouped in
342 two foraging guilds: insectivorous bats of uncluttered spaces (IAU) – 23 species – and
343 insectivorous bats of background cluttered spaces (IAB) – 21 species (Appendix 1).
344 *Pteronotus cf parnellii* was not included in any guild, as it was the only aerial highly
345 cluttered space bat registered. Calls identified only at genera or family were also not
346 included in any guild, as they might result in some uncertainty on foraging strategy

347 information. The Vespertilionidae family, for example, has both IAB and IAU species.
 348 The same occurs within some genera, such as Lasiurus and Pteronotus.

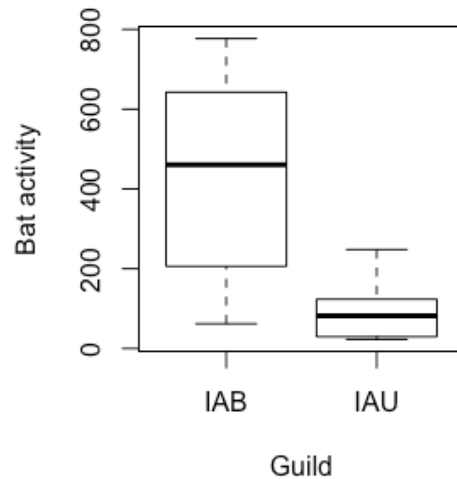


349

350 **Figure 3.** Relative bat activity of each predominant taxonomic family, present in all sampled sites, during
 351 the nights of 12 February 2015 and 07 March 2015.

352 Bat activity was distinct between some of the sampled groups. Over 4,993 bat
 353 passes counted, about 62% (2,820 passes) were emitted by Emballonuridae bats, 16.3%
 354 (739) Molossidae and 16.4% (738 passes) Vespertilionidae bats (Fig.3). Although, the
 355 Kruskal – Wallis test found no difference between these families ($X^2 = 5.6571$, $df = 3$,
 356 p - value = 0.1295) considering bat activity. In terms of foraging guild, IAB bats
 357 corresponded to over 80% (3,511 passes) of total bat activity, and it was significantly
 358 different and higher in all the 10 sampled sites ($W = 21.5$, p – value = 0.03423, Fig. 4).
 359 Despite being the only highly cluttered spaces bat species, *Pteronotus cf parnellii*
 360 activity summed 86 passes, approximately 2% of total passes. The buzz ratio was distinct
 361 only between Emballonuridae and Mormoopidae families ($Z = 3.9740$, p – value

362 <0.001). On the other hand, the non – parametric t – test revealed no difference in buzz
363 ratio between the guilds ($t = - 0.7964$, $p - \text{value} = 0.4362$).



364

365 **Figure 4.** Number of identified taxa in each site, during the two nights of sampling,, at taxonomic family,
366 genera and species level.

367 Total sampling effort for the study was 240 hours of recording, 12 hours each
368 night per ultrasound recorder. The highest richness was found at 1500L and 2500L, with
369 29 species listed each, followed by 2500W, with 26, 3500L and 4500L, with 23 each.
370 The 3500W was characterized by the lowest richness, with 10 species recorded only
371 (Fig. 4).

372 Comparing all the ten sites, the pairwise Dunn test showed significant species
373 richness differences between 0500L and 2500W ($Z = - 4.7145$, $p - \text{value} = 0.0199$),
374 2500W and 4500W ($Z = - 4.8966$, $p - \text{value} = 0.0296$), 2500L and 3500W ($Z = 4.9055$,
375 $p - \text{value} = 0.0286$) and 2500W and 3500W ($Z = 5.2110$, $p - \text{value} = 0.0210$). No
376 differences were found between the other sites in terms of species richness.

377 Vegetation cover values ranged from $- 0.0617$ to 0.0351 (Appendix 3). The
378 0500L site presented the highest average vegetation amount, with 0.0137 , followed by

379 the 2500L, with -0.0181 and the 3500W, with -0.0214 . The distribution of pixel
 380 values (Appendix 2) revealed low cumulative active biomass in all the sites, which
 381 characterizes areas with sparse vegetation, grasslands with some exposed ground
 382 patches, water surfaces, or burned areas. Despite the low average pixel values for all
 383 sites, the areas contain, even in lesser percentage, patches of greener areas, such as
 384 grassland savannah and, in minor quantity, small patches of sparse shrub herbaceous
 385 vegetation (Rouse et al, 1974). Considering the distance to water sources, although they
 386 look visually distincts (Tab.1), the Kruskal – Wallis test showed no difference between
 387 all the sites ($X^2 = 9$, $df = 9$, $p - \text{value} = 0.437$).

Site	Distance to water (km)
0500L	0.537
1500L	0.211
2500L	0.405
3500L	0.704
4500L	1.370
0500W	1.665
1500W	2.362
2500W	2.617
3500W	3.378
4500W	3.566

388 **Table 1.** The distance to water sources in each of the 10 sites, in kilometers. The sites were aligned along
 389 two line transects, with five sites in each one: 0500L – 4500L and 0500W – 4500W. A watercourse
 390 crosses between the first two sites of each transect (view Figure 2 for more details).

391 For the guild models, I excluded the 0500L and 3500W sites, as they had less
 392 than 30 bat records in both or one of the groups, with 21 IAU and 24 IAB in the 0500L
 393 site and 12 IAU and 31 IAB in the 3500W. For the species modelling, I removed all
 394 species that had less than five records in the site. Additionally, the buzz ratio was not
 395 modelled, as it did not show any difference between the guilds ($t = -0.7964$, $p - \text{value} =$
 396 0.4362). For the species models, I excluded all species with less than five records in a
 397 site. Buzz ratio was different between some species, and for this reason, it was included

398 in the species modelling only. Also, the vegetation cover values were log – transformed.
399 Six generalized linear Poisson models were then generated and adjusted, after checking
400 for residuals distribution. Among them, two models had a good – fit, both included the
401 explanatory variable vegetation cover ($Activity_{guild} \sim Veg\ Cover$ and $Activity_{species} \sim$
402 $Veg\ Cover$).

403

404 **DISCUSSION**

405

406 The results on species richness were partially consistent with the expected, based
407 on Nogueira et al (2014) Brazilian bat checklist. Molossidae was the richest family,
408 followed by Vespertilionidae and Emballonuridae. According to Bichuette et al (2018)
409 review, which upgraded a checklist of bats from Distrito Federal and Goiás state,
410 overall 66 species are formally recorded in those areas. These study, though, didn't
411 compile data from bioacoustic methods, which may provide additional information on
412 the subject. The present study recorded 24 bat species not formally listed before in the
413 Goiás State, according to Bichuette and collaborators review: *Diclidurus albus*,
414 *Peropteryx kappleri*, *P. leucoptera/palidoptera*, *P. trinitatis*, *Cynomops greenhalli*,
415 *Eumops auripendulus*, *E. dabbenei*, *E. glaucinus*, *E. nanus*, *E. perotis*, *Molossops*
416 *neglectus*, *Molossus currentium*, *M. rufus*, *M. sinaloae*, *Nyctinomops laticaudatus*, *N.*
417 *macrotis*, *Promops centralis*, *P. nasutus*, *Tadarida brasiliensis*, *Pteronotus personatus*,
418 *Myotis albescens*, *M. lavalii*, *M. riparius* and *M. ruber*.

419 The present data suggest that bat diversity in the Goiás state might be higher in
420 comparison to current data available to the region. It is known that local distribution of
421 many Neotropical insectivorous bats remain largely unknown, with sparse and

422 fragmented information on the occurrence and distribution of some species in all biomes
423 (Bernard et al, 2011). Some studies reviewed species distribution and indicated no
424 occurrence of some of them in the Cerrado biome, such as *P. leucoptera* and *C.*
425 *greenhalli*, both with formally occurrence in the Amazon and Atlantic Forest biomes
426 (Mikalauskas et al, 2014; Solari, 2015). *E. dabbenei* is listed to occur in the Pantanal
427 biome, yet no report is known for the Cerrado at the date (Fischer et al, 2015). Some
428 authors listed species in other states in central Brazil, as *D. Albus*, with few records of in
429 the State of Bahia (Ferreira et al, 2013) and *P. trinitatis*, in the Mato Grosso (Santos et
430 al, 2016). Coelho & Leal (2009) reported the closest evidence of *E. auripendulus*, in the
431 municipality of Uberaba, Minas Gerais State. The southern records of *E. perotis* in
432 Brazil come from the States of Mato Grosso, Minas Gerais, Rio de Janeiro, São Paulo
433 and Rio Grande do Sul (Suckow et al, 2010). Also, Tavares et al (2010) reported the
434 occurrence of *M. currentium* in the state of Minas Gerais.

435 Bat activity results indicated differential echolocation call emissions within the
436 taxonomic families. Despite its highest number of species, Molossidae showed no
437 difference in comparison to Emballonuridae and Vespertilionidae. Mormoopidae,
438 Noctilionidae and Thyropteridae bats had the lowest absolute and relative bat activities,
439 which can be explained by their low species richness, with three Mormoopidae species
440 (*Pteronotus gymnonotus*, *P. parnellii* and *P. personatus*), one Noctilionidae (*Noctilio*
441 *leporinus*) and one Thyropteridae (*Thyroptera sp.*). Another point to consider is that *N.*
442 *leporinus* is not a strictly insect – eating species, and also feed on small fish, amphibians
443 and small invertebrates (Bordignon, 2006). Additionally, *N. leporinus* is often found
444 near water courses and riverside vegetation, where they catch their preys near the water
445 surface. On the other hand, Thyropteridae bats are hard to detect, as they emit low –
446 intensity echolocation calls, and propagate at very short distances in the air. Due to this,

447 these bats can only be accurately recorded very close to the microphones, usually at 20
448 to 30 cm from them (Fenton et al, 1999).

449 Insectivorous bats from background – cluttered space concentrated expressive
450 number of echolocating passes overall, revealing significant difference in comparison
451 to insectivorous bats from uncluttered spaces. These data possibly indicate that, despite
452 the low active biomass in all sites (low average NDVI values), relative cluttered
453 vegetation structure distributed in small patches may be determining the presence of
454 certain species in detriment to the others. This can be corroborated by the number of
455 IAB species in the sites, which represent the species richness majority in most of the
456 sites. Additionally, the buzz ratio analyses indicated higher hunting activity of
457 insectivorous aerial bats from background – cluttered spaces in almost all sites.

458 In opposition to the expected, the Poisson models for both guild and species
459 level indicated a positive, but weak influence of the vegetation cover on bat activity at
460 300m scale ($\rho = 0.302$). The average vegetation cover of the sites was not significantly
461 different in almost all scales, even with the presence of few patches of sparse
462 vegetation, as in the 0500L site. Bats are flying mammals and some of them are able to
463 travel long distances in a single night. For this reason, the measured distances to water
464 sources may not be substantially perceived by insectivorous aerial bats, even if it may
465 represent significant changes in the surrounding vegetation in some cases. The present
466 results also suggest that the use of spatial scales relatively larger than those used may be
467 more appropriate and informative to investigate the response of insectivorous bats to
468 vegetation cover in predominant grassland savannah formations. In addition,
469 insectivorous bats may respond stronger to vegetation structure than only percent

470 vegetation cover and distance to water sources. Thus, it is recommended to evaluate
471 aerial insectivorous responses to vegetation at multiple dimensions.

472

473 **CONCLUSION REMARKS**

474

475 The present study was the first acoustic survey on insectivorous bats of the
476 Parque Estadual de Terra Ronca. These data provided additional information on bat
477 species richness of the Goiás State, which reaffirms the importance of multiple
478 approaches studies. As explained by Bernard et al (2011), there is an urgent need to
479 promote studies focus on bat occurrence and distribution in Brazil. It is important to
480 emphasize that, although the acoustic methods allow a non - invasive sampling of
481 insectivorous bats, such information must be validated through the capture of these
482 individuals to validate their occurrence.

483 An alternative to it is the combination of traditional capture techniques and
484 acoustic methods, which has gained some attention over the last years. Acoustic
485 equipment have been more affordable and widespread, although, it is important to
486 choose multiple approaches over a single one, as they may provide a larger and accurate
487 sampling range for Brazilian bat diversity. Another alternative, but less affordable, is the
488 use of acoustic lures to attract high – flying bats to the mist nets or harp traps. which
489 had effective results in some developed countries, as the United States of America
490 (Quackenbush et al, 2016; Braun de Torrez et al, 2017), British (Hill & Greenaway,
491 2005), Basque Country (Goiti et al, 2007), Scotland (Linttot et al, 2013), Norway
492 (Michaelsen et al, 2011), Japan (Hill et al, 2014) and Australia (Hill et al, 2015).

493 Vegetation features influence direct and indirect insectivorous bats, as shown in
494 the literature. Nevertheless, the responses of this group to vegetation cover is still
495 uncertain at small geographical scales, especially in the Cerrado biome,. Additionally,
496 the PETeR is a fully – protected park with karstic formations that provide roosts for
497 some of the surveyed species, as *P. macrotis* and *P. parnellii*, which naturally occupies
498 the interior and entrances of caves (Bordignon, 2006; Trajano, 2012). Information about
499 the dimensions on which associated fauna better responds to vegetation features in
500 protected areas can provide subsidies for management actions, especially in areas with
501 either suppression or replacement of native vegetation.

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Table 2. Insectivorous bat species recorded in the Parque Estadual de Terra Ronca (PETeR) classified in terms of foraging guilds. Insectivorous bats from uncluttered spaces, with 23 species, and insectivorous bats from background – cluttered spaces, with 21 species recorded.

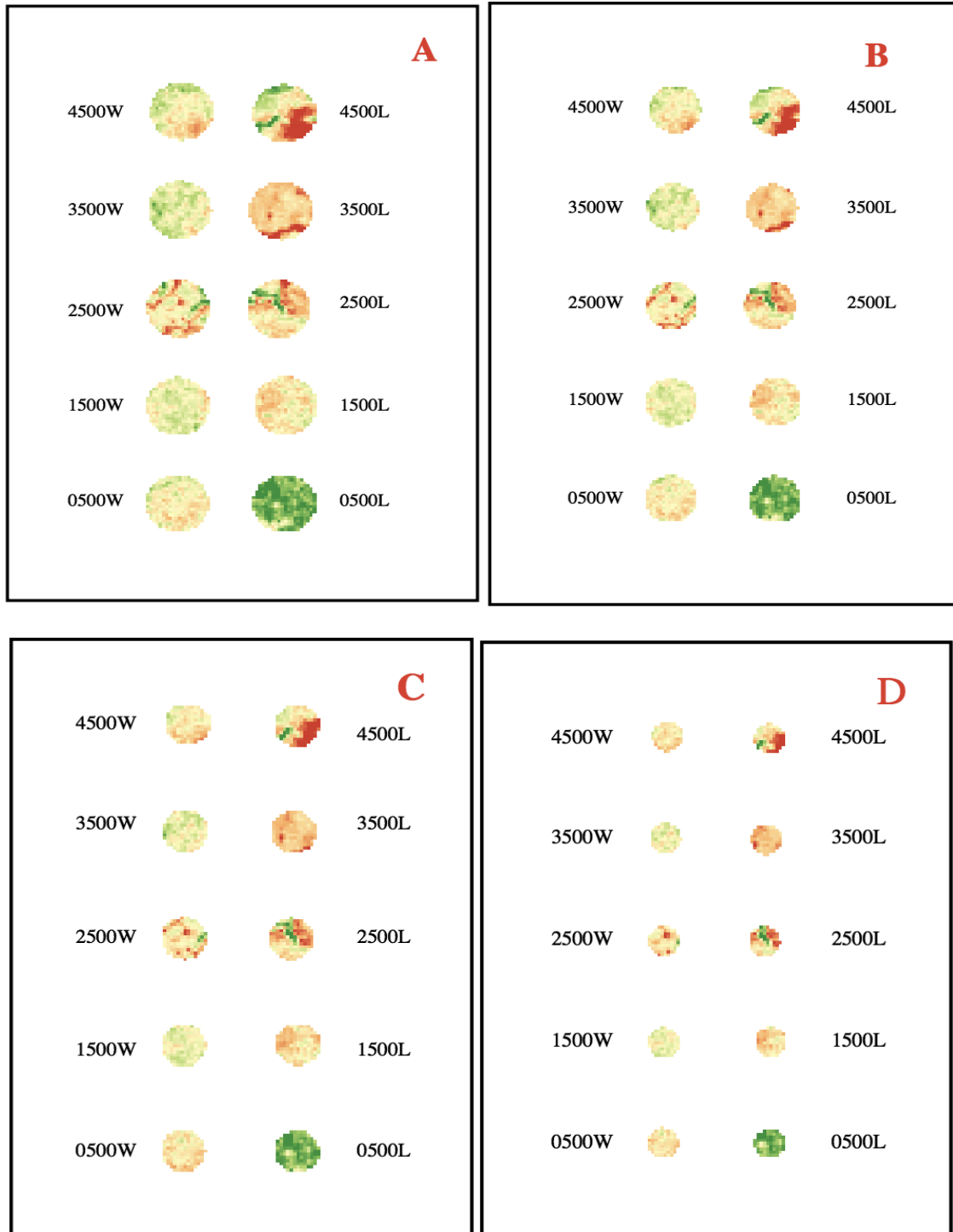
Guild	Species	Family	Sources
Uncluttered space/ aerial insectivorous	<i>Diclidurus albus</i>	EMB	Schnitzler et al (2003), Jung et al (2007), Moscoso & Tirira (2009)
	<i>Peropteryx macrotis</i>	EMB	Schnitzler et al (2003), Marques et al (2016), López - Baucells et al (2016), Zamora - Gutierrez et al (2016)
	<i>Cynomops abrasus</i>	MOL	Peracchi et al (2011)
	<i>Cynomops greenhalli</i> (?)	MOL	Marques et al (2016)
	<i>Cynomops planirostris</i>	MOL	Marques et al (2016)
	<i>Eumops auripendulus</i>	MOL	Schnitzler & Kalko (2001), Schnitzler et al (2003), Jung et al (2014)
	<i>Eumops dabbenei</i>	MOL	Schnitzler & Kalko (2001), Schnitzler et al (2003)
	<i>Eumops glaucinus</i>	MOL	Schnitzler & Kalko (2001), Schnitzler et al (2003), Jung et al (2014)
	<i>Eumops nanus</i>	MOL	Schnitzler & Kalko (2001), Schnitzler et al (2003)
	<i>Eumops perotis</i>	MOL	Schnitzler & Kalko (2001), Schnitzler et al (2003), Jung et al (2014), Marques et al (2016)
	<i>Molossops mattogrossensis</i>	MOL	-
	<i>Molossops neglectus</i>	MOL	Schnitzler & Kalko (2001), Schnitzler et al (2003), Zamora - Gutierrez et al (2016)
	<i>Molossops temminckii</i>	MOL	Schnitzler & Kalko (2001), Schnitzler et al (2003), Jung et al (2014), Dias - Silva et al (2018)
	<i>Molossus currentium</i>	MOL	Schnitzler & Kalko (2001), Schnitzler et al (2003), Jung et al (2014), Dias - Silva et al (2018)
	<i>Molossus molossus</i>	MOL	Schnitzler & Kalko (2001), Schnitzler et al (2003), Jung et al (2014), Zamora - Gutierrez et al (2016), Dias - Silva et al (2018)
	<i>Molossus rufus</i>	MOL	Schnitzler & Kalko (2001), Schnitzler et al (2003), Jung et al (2014), Zamora - Gutierrez et al (2016), Dias - Silva et al (2018)
	<i>Molossus sinaloae</i> (?)	MOL	Zamora - Gutierrez et al (2016)
	<i>Nyctinomops laticaudatus</i>	MOL	Jung et al (2014), Zamora - Gutierrez et al (2016)
	<i>Nyctinomops macrotis</i>	MOL	Jung et al (2014)
	<i>Promops centralis</i>	MOL	Schnitzler & Kalko (2001), Schnitzler et al (2003), Zamora - Gutierrez et al (2016)
	<i>Promops nasutus</i>	MOL	Schnitzler & Kalko (2001), Schnitzler et al (2003)
	<i>Tadarida brasiliensis</i>	MOL	Jung et al (2014), Zamora - Gutierrez et al (2016)
	<i>Lasiurus cinereus</i>	VES	Zamora - Gutierrez et al (2016)
Background space/ aerial insectivorous	<i>Centronycteris maximiliani</i>	EMB	Kalko et al (1996), Hice & Solari (2002)
	<i>Histiotus laeophotis</i>	EMB	Miranda et al (2007)
	<i>Histiotus velatus</i>	EMB	-

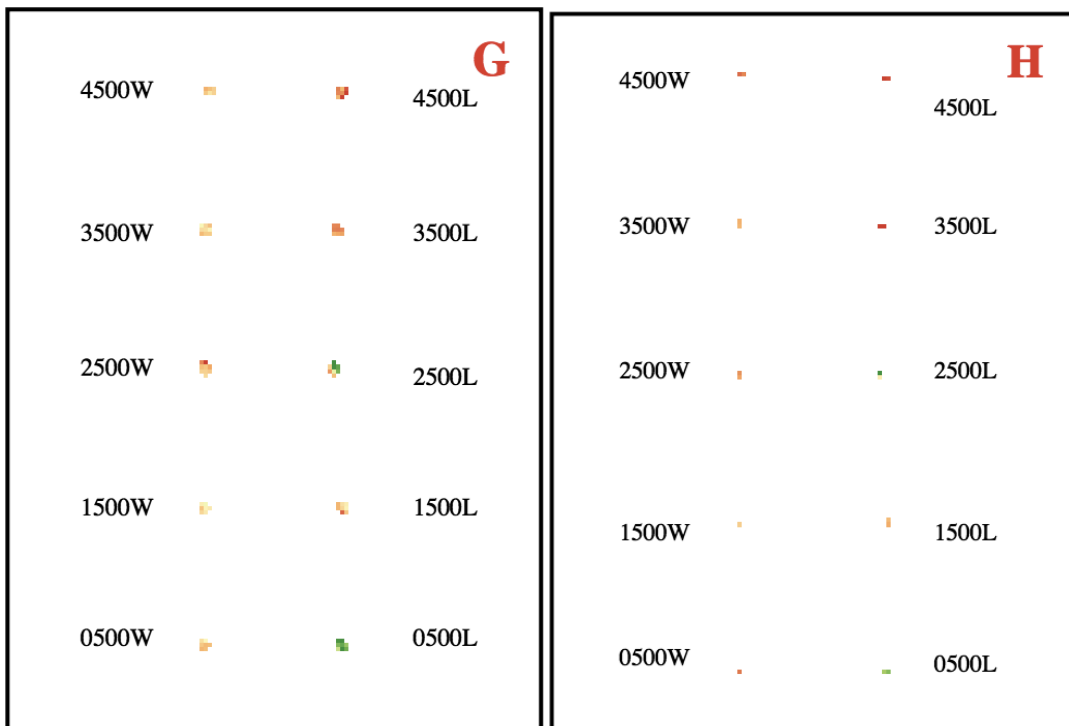
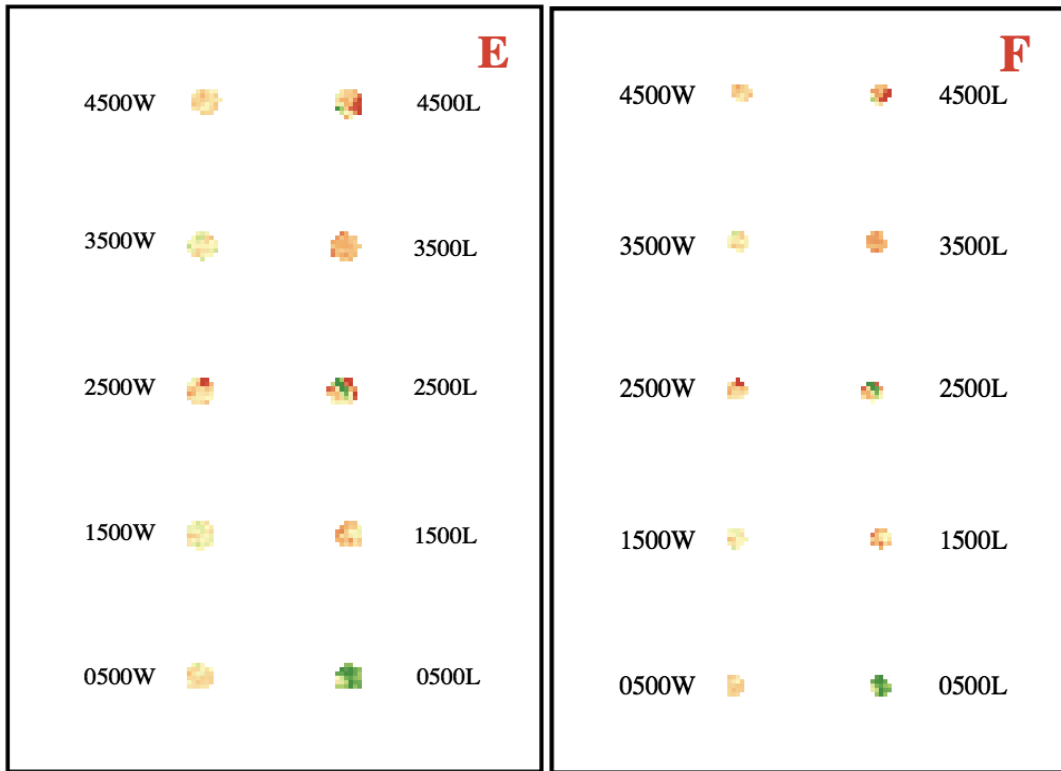
<i>Saccopteryx leptura</i>	EMB	Schnitzler & Kalko (2001), Schnitzler et al (2003), Zamora - Gutierrez et al (2016)
<i>Pteronotus gymnonotus</i>	MOR	Zamora - Gutierrez et al (2016)
<i>Pteronotus personatus</i>	MOR	Schnitzler & Kalko (2001), Schnitzler et al (2003)
<i>Eptesicus brasiliensis</i>	VES	Ochoa et al (1999), Rydell et al (2002), López - Baucells et al (2016), Zamora - Gutierrez et al (2016), Dias - Silva et al (2018)
<i>Eptesicus furalis</i>	VES	Rydell et al (2002), Peracchi et al (2011), López - Baucells et al (2016), Zamora - Gutierrez et al (2016), Dias - Silva et al (2018)
<i>Myotis albescens</i>	VES	Schnitzler & Kalko (2001), Schnitzler et al (2003)
<i>Myotis lavalii</i>	VES	Schnitzler & Kalko (2001), Schnitzler et al (2003)
<i>Myotis nigricans</i>	VES	Ochoa et al (1999), Rydell et al (2002), López - Baucells et al (2016), Zamora - Gutierrez et al (2016), Dias - Silva et al (2018)
<i>Myotis riparius</i>	VES	Ochoa et al (1999), Rydell et al (2002), López - Baucells et al (2016), Zamora - Gutierrez et al (2016), Dias - Silva et al (2018)
<i>Myotis ruber</i>	VES	Ochoa et al (1999), Rydell et al (2002), López - Baucells et al (2016), Zamora - Gutierrez et al (2016), Dias - Silva et al (2018)
<i>Lasiurus blossevillii</i>	VES	Rydell et al (2002), Peracchi et al (2011), López - Baucells et al (2016), Zamora - Gutierrez et al (2016), Dias - Silva et al (2018)
<i>Lasiurus ega</i>	VES	Ochoa et al (1999), Rydell et al (2002), López - Baucells et al (2016), Zamora - Gutierrez et al (2016), Dias - Silva et al (2018)
<i>Thyroptera</i> sp.	THY	Zamora - Gutierrez et al (2016)
<i>Noctilio leporinus</i>	NOC	Kalko et al (1996), Schnitzler & Kalko (2001), Schnitzler et al (2003), Peracchi et al (2011)

**Highly cluttered
space/ aerial
insectivorous**

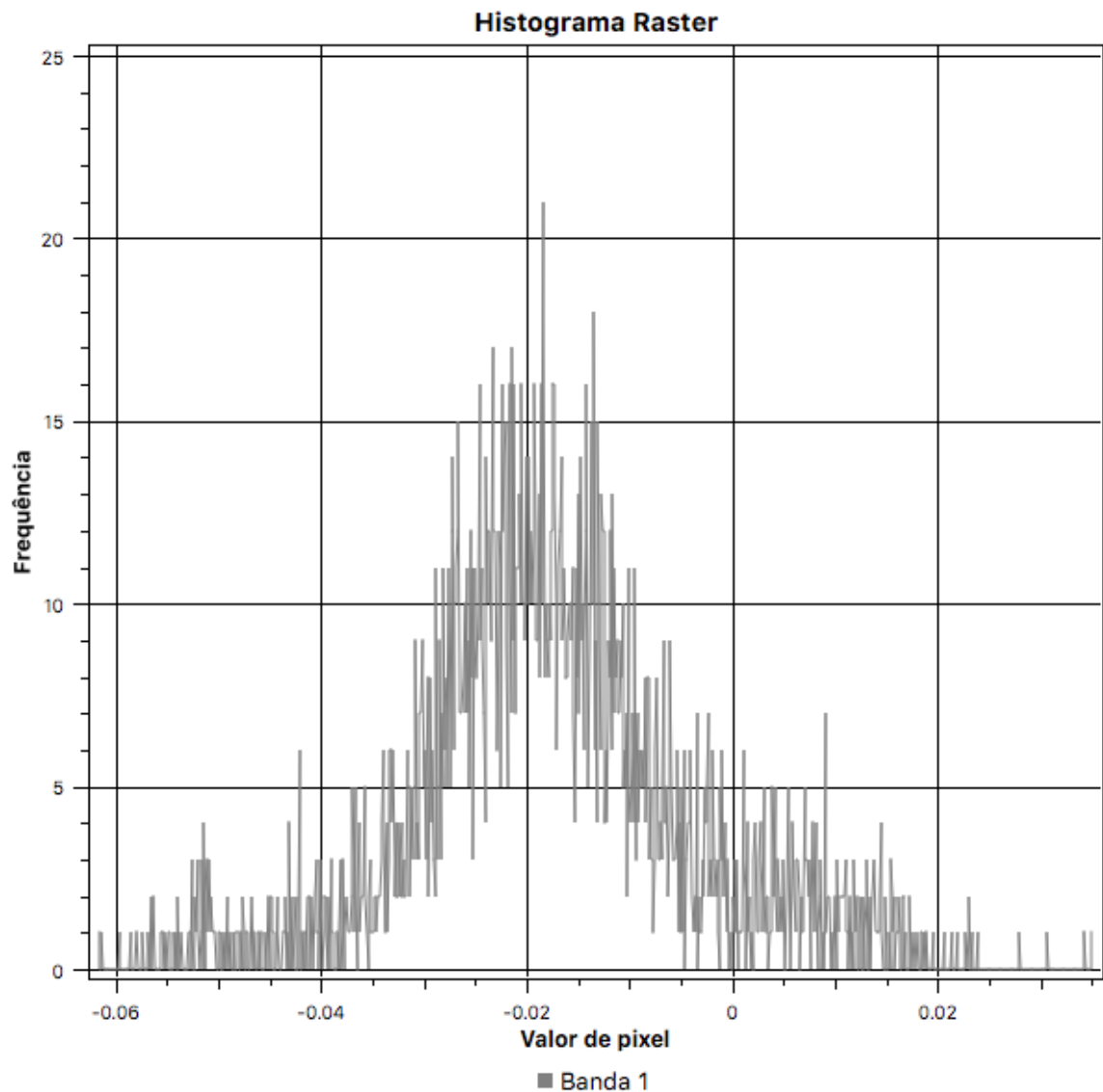
<i>Pteronotus parnelli</i>	MOR	Schnitzler & Kalko (2001), Schnitzler et al (2003)
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Appendix 1 : Cumulative rendered NDVI images for each sampled site, with 15 x 15m of resolution. Landsat 8 OLI sensor data extracted from the USGS data set, in 11 February 2015, with 6% of cloud cover and UTM projected. Eight landscape scales are shown: A = 300m, B = 250m, C = 200m, D = 150m, E = 100m, F = 75m, G = 50m and H = 25m.

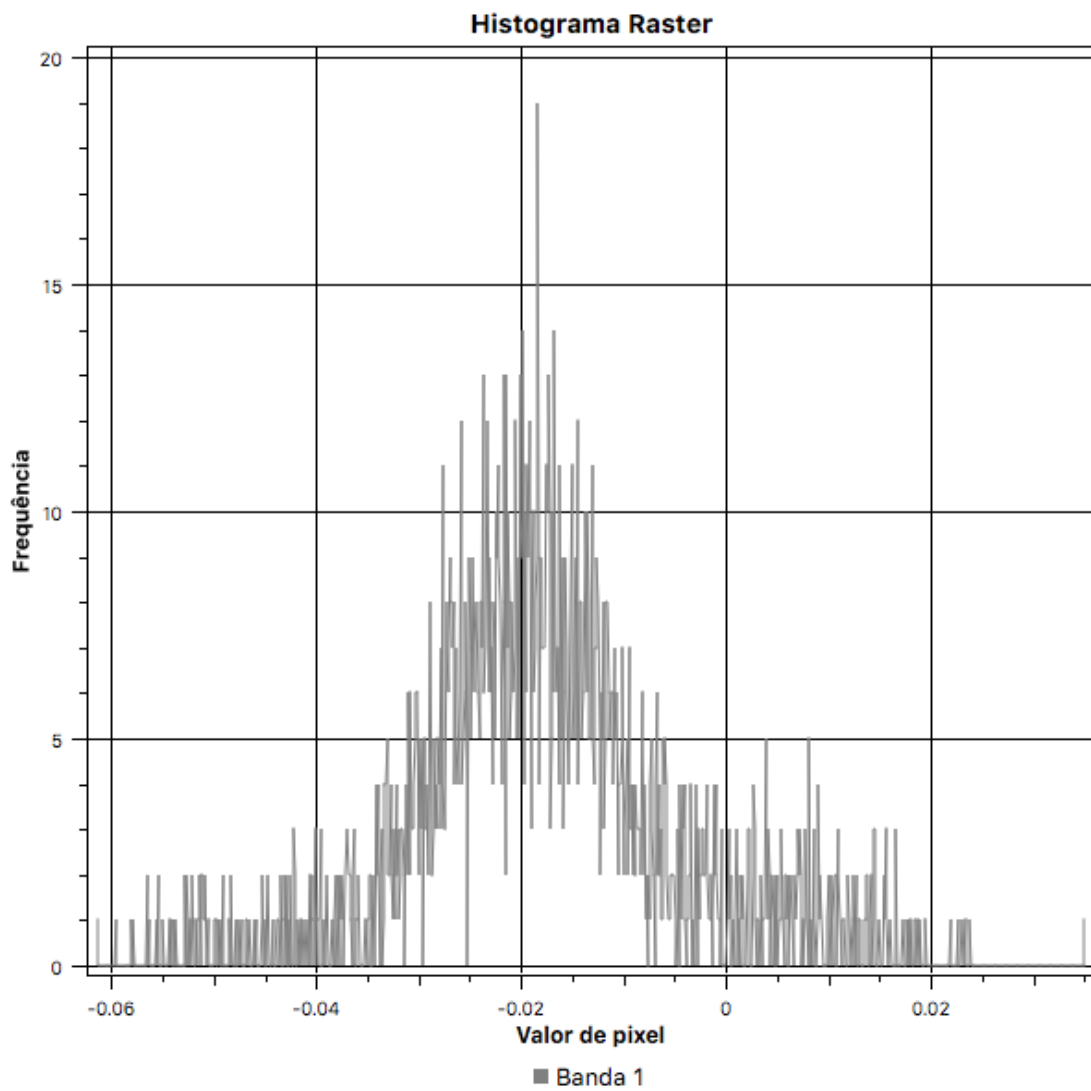




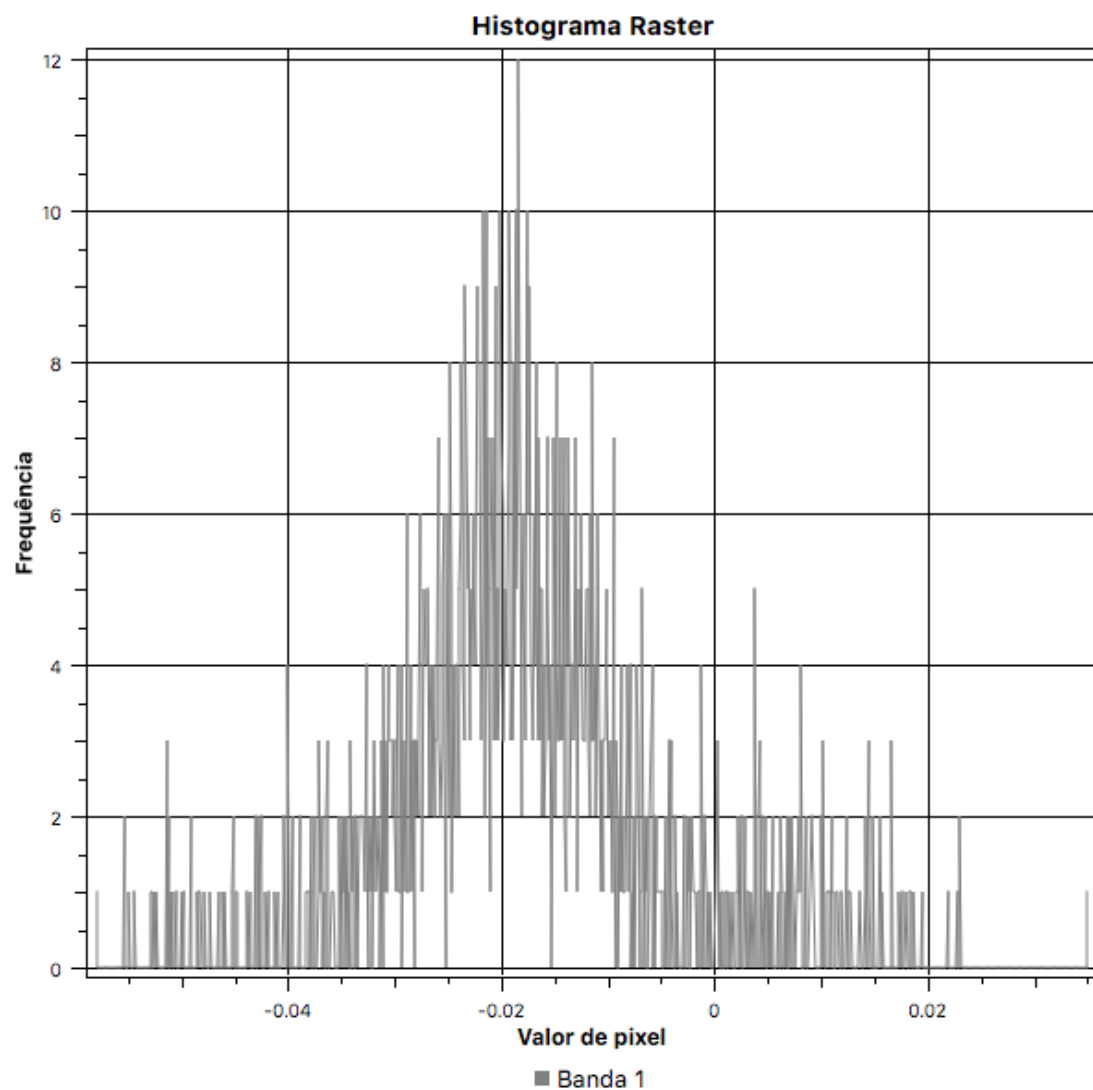
Appendix 2. Distribution of pixel values from the NDVI raster image for each of the eight landscape scale adopted. NDVI index can achieve a range of values, from -1 to +1. The near to +1 is the pixel value, the greener is the observed area. The histograms are shown in the following order of scale: 300m, 250m, 200m, 150m, 100m, 75m, 50m and 25m.



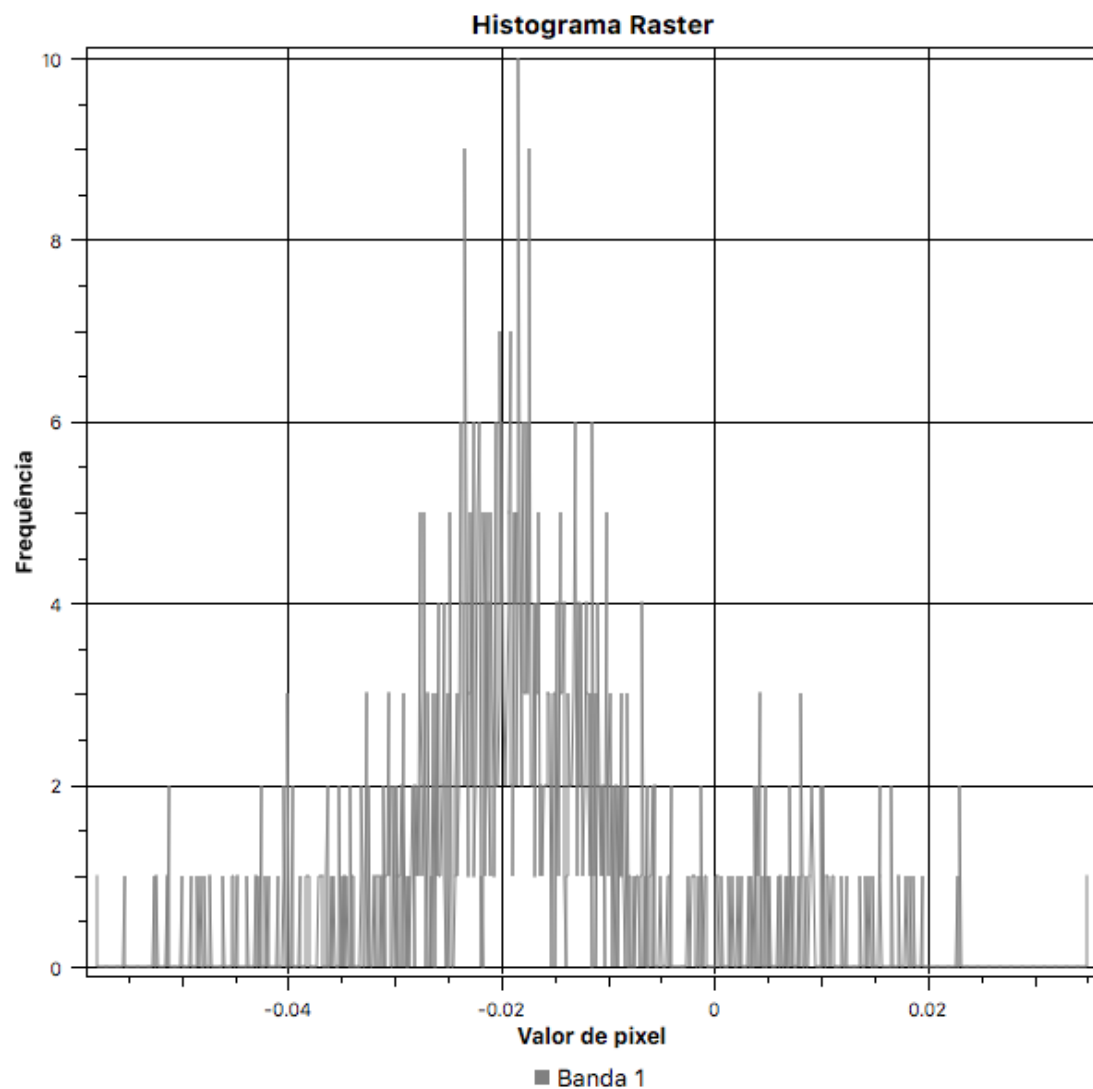
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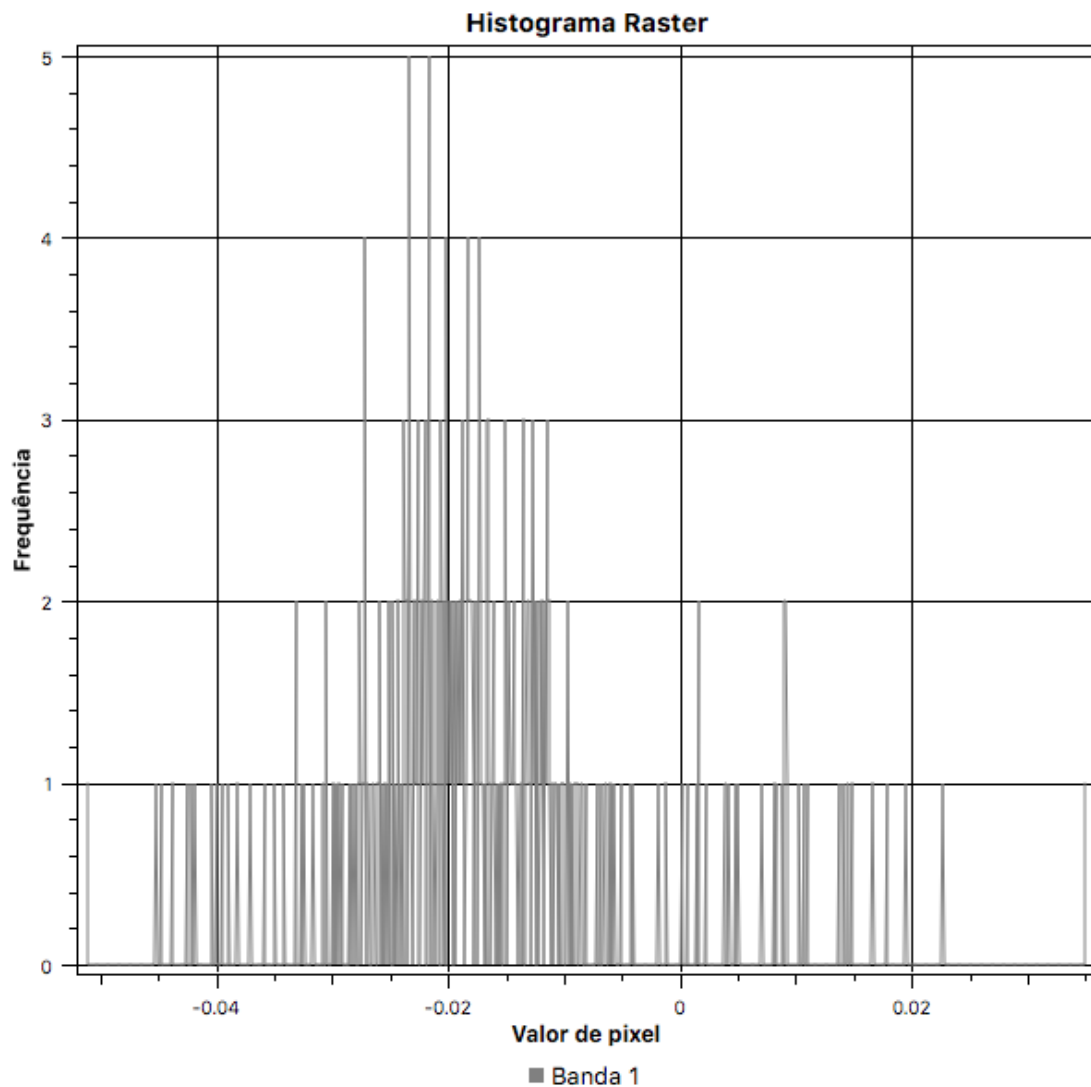
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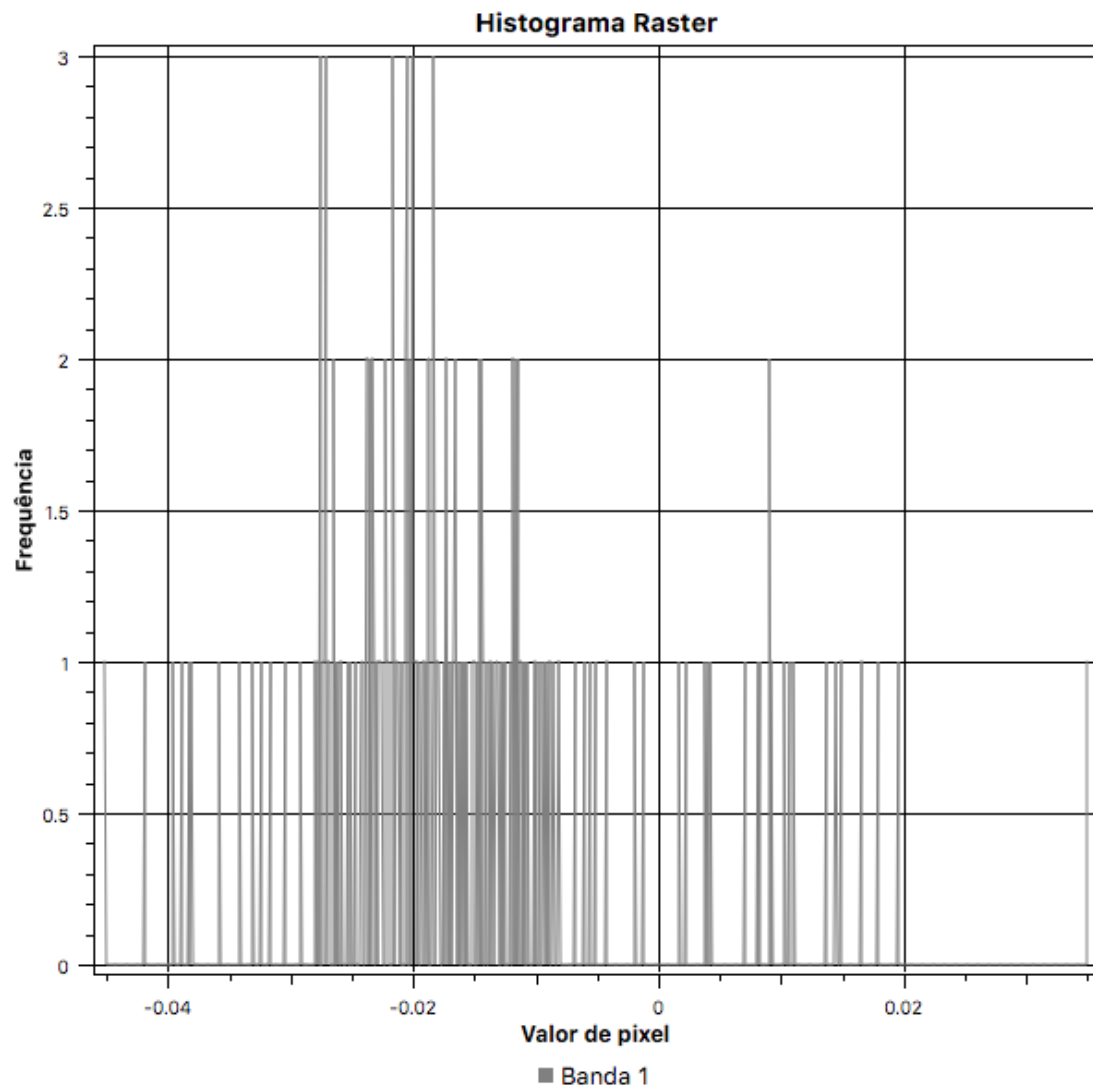
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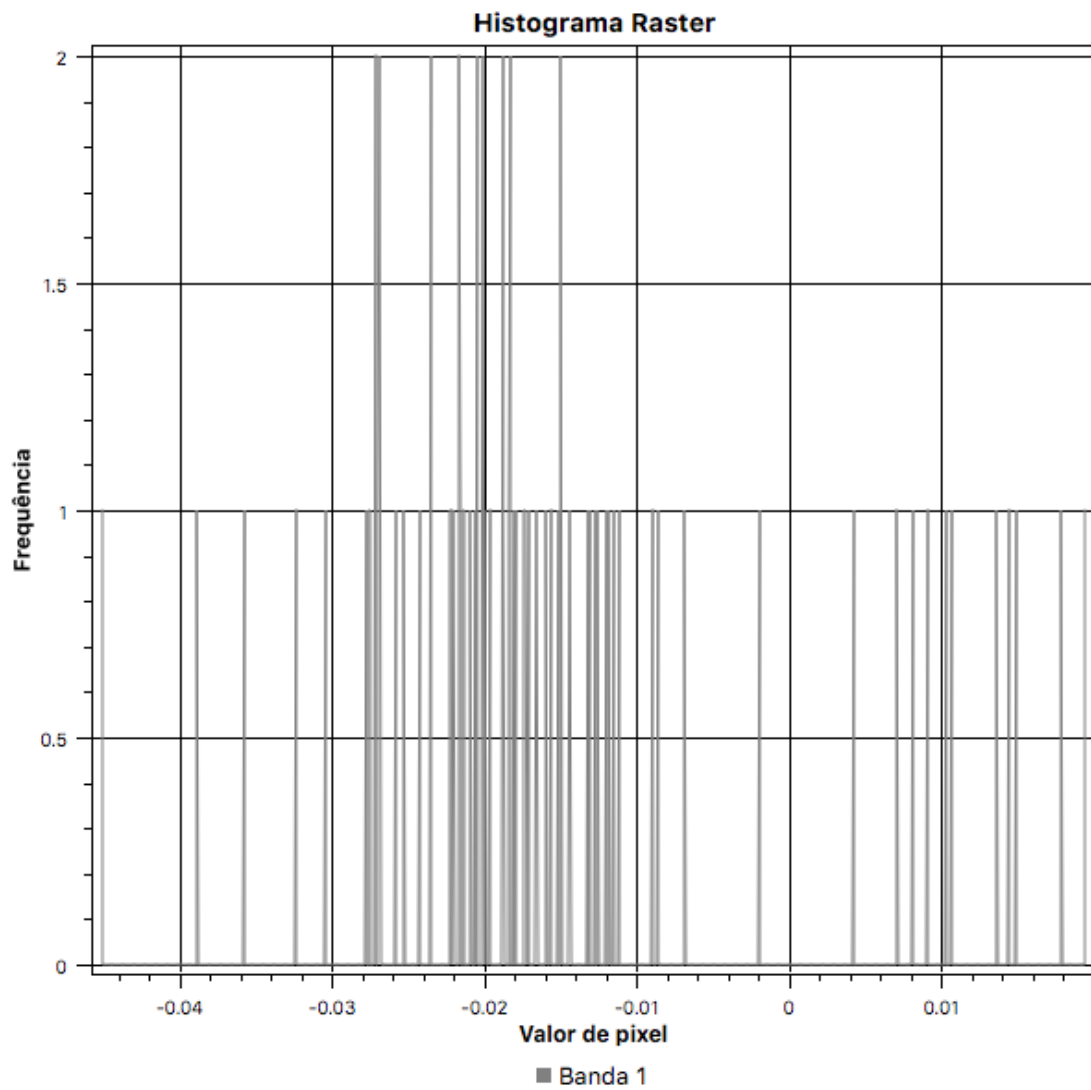
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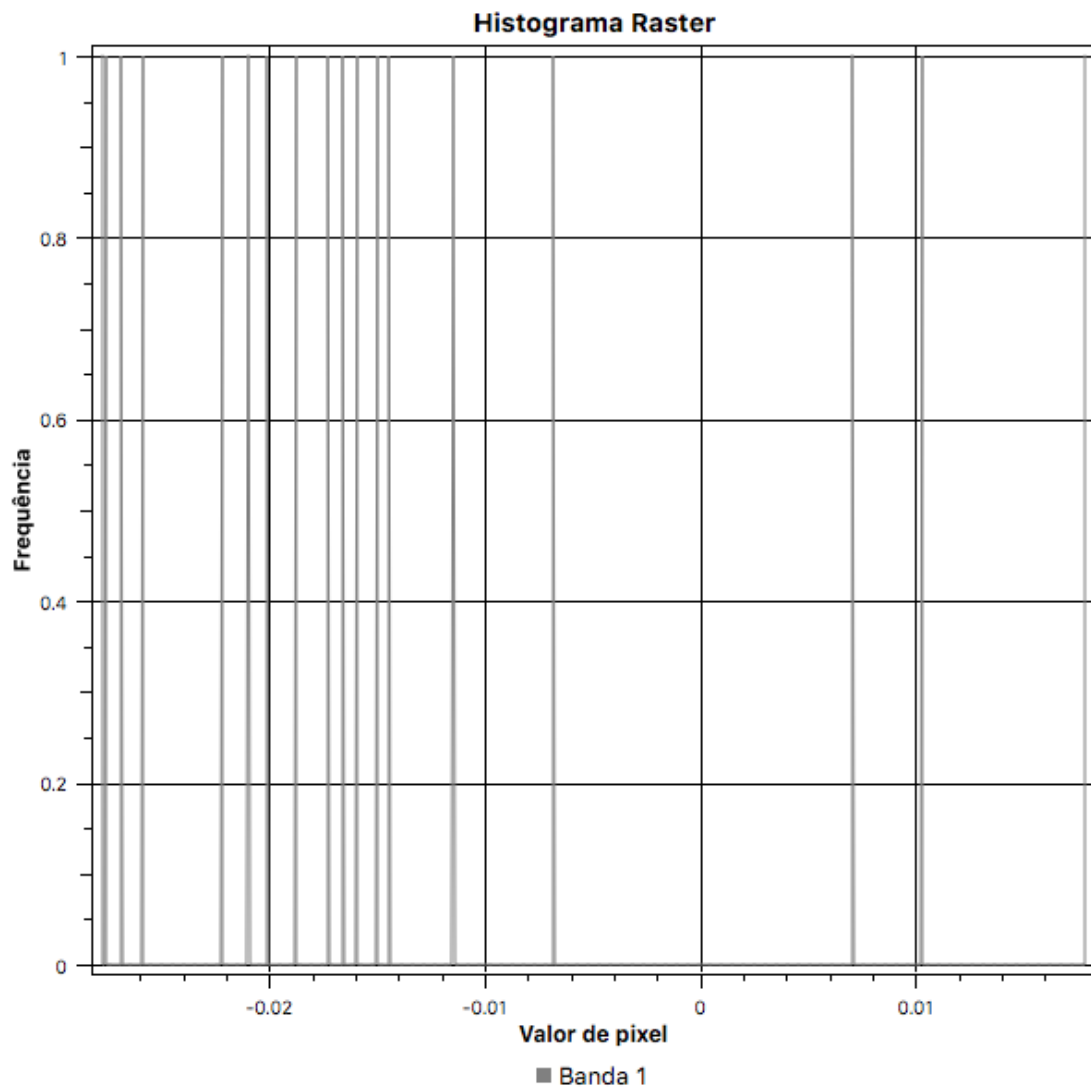
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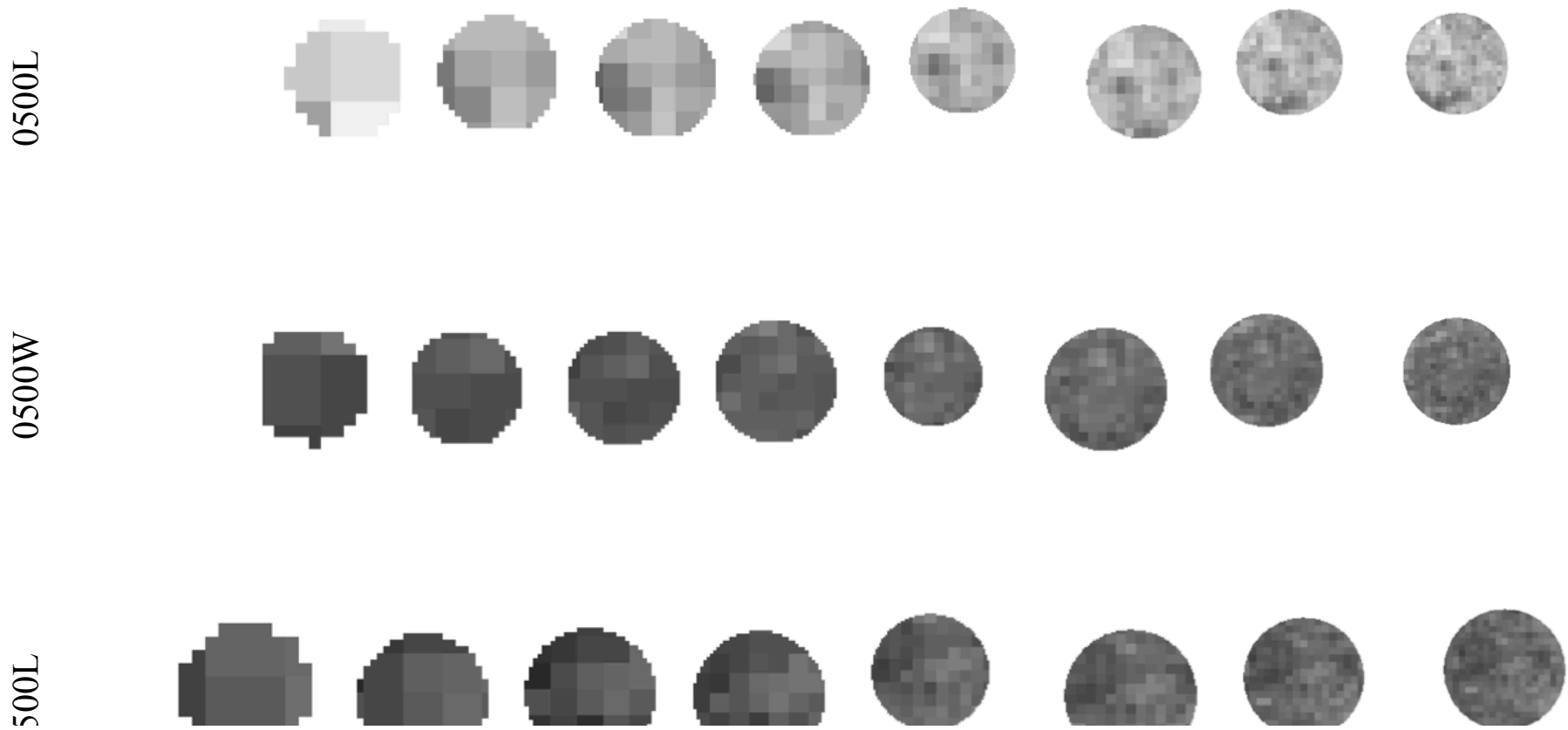
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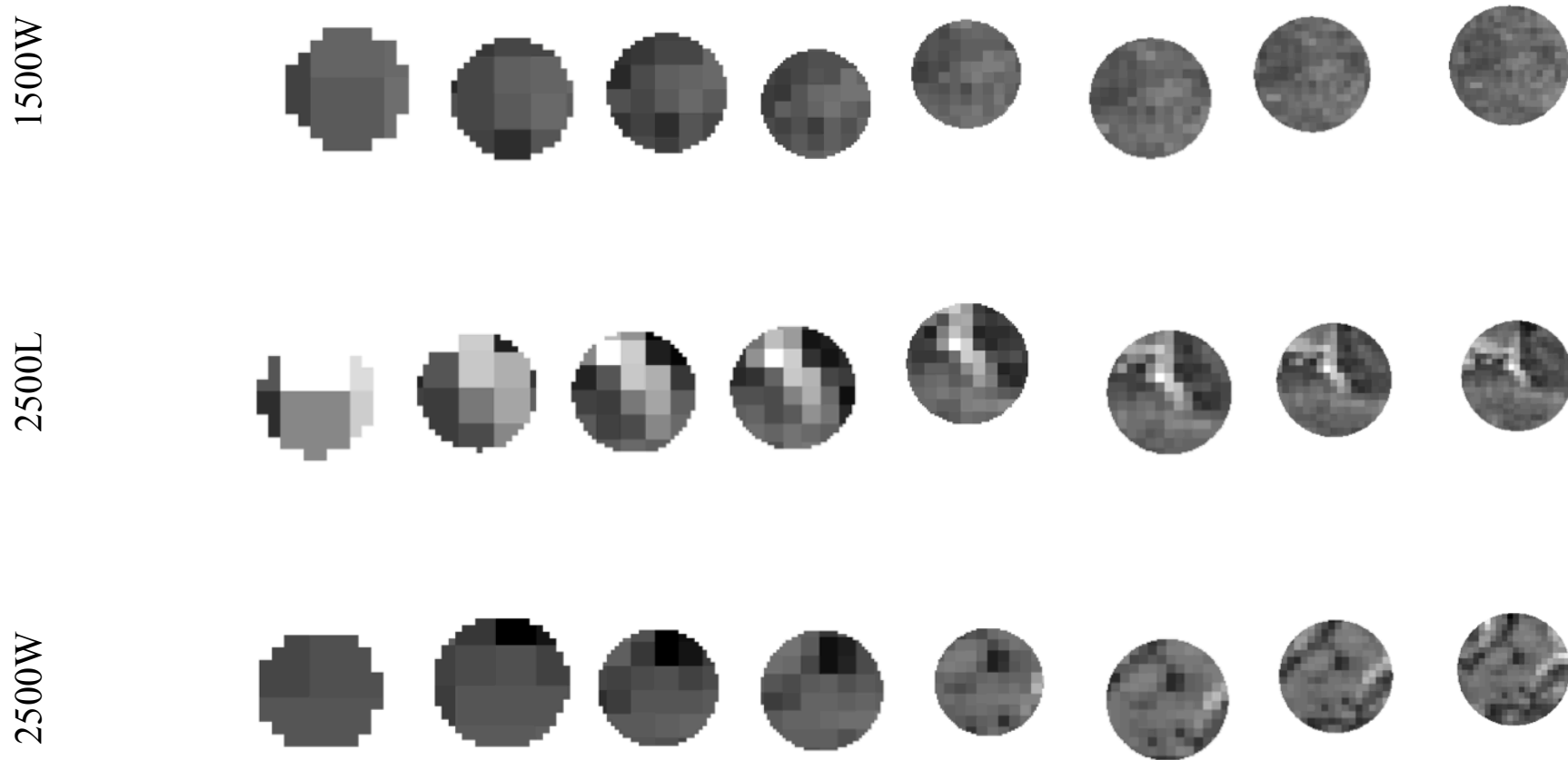
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Appendix 3. NDVI single band images of the eight landscape scales taken from Landsat 8 OLI sensor, in 11 February 2015, with 6% of cloud cover and pixel length of 5x5m. Scales increase from the left to right: 25m, 50m, 75m, 100m, 150m, 200m, 250m and 300m. Lighter pixels indicate NDVI values close to +1, representing large amount of photosynthetically active vegetation. Overall NDVI values ranged from -0.0617 to 0.0351 .



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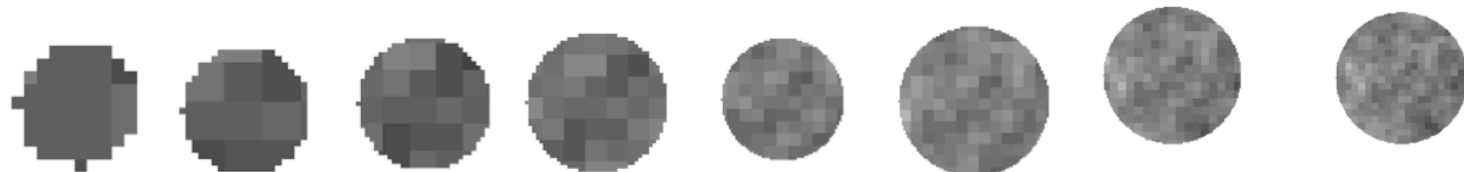


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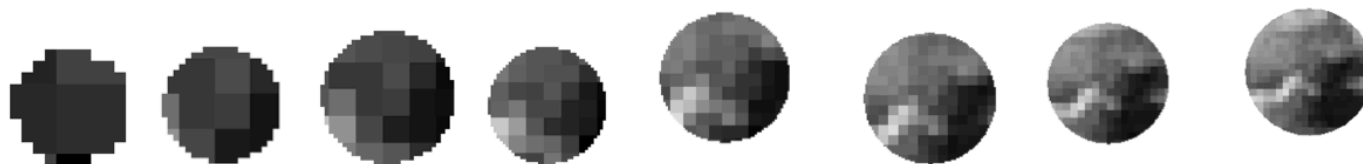
3500L



3500W



4500L



Appendix 3. NDVI single band images of the eight landscape scales taken from Landsat 8 OLI sensor, in 11 February 2015, with 6% of cloud cover and pixel length of 5x5m. Scales increase from the left to right: 25m, 50m, 75m, 100m, 150m, 200m, 250m and 300m. Lighter pixels indicate NDVI values close to +1, representing large amount of photosynthetically active vegetation. Overall NDVI values ranged from - 0.0617 to 0.0351.

4500W

