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Monk parakeet invasion success : a role for nest thermoregulation and bactericidal potential of plant nest material?

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1 **Monk parakeet invasion success: a role for nest thermoregulation and bactericidal**  
2 **potential of plant nest material?**

3

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22

23 **Abstract**

24 Invasive species are a global threat to biodiversity, economy and human wellbeing. To  
25 mitigate these threats, identifying and halting the introduction of potentially invasive  
26 species is crucial. Although progress has been made in elucidating mechanisms  
27 underlying invasion success, the role of species behavioral strategies has only received  
28 scant attention. Here, we use the invasion of monk parakeets in Santa Catarina state,  
29 southern Brazil to study whether behavioral strategies such as nest thermoregulation and  
30 the ability to self-medicate against pathogens contribute to the establishment success of  
31 invading species. We relate data on monk parakeet reproductive success to ambient  
32 temperatures in- and outside nesting chambers and test the bactericidal potential of  
33 plants transported to the nest by breeding monk parakeets. Compared to breeding data  
34 from other invaded ranges and parts of the species' native range, our results suggest  
35 both thermoregulation and the use of bactericidal plants could potentially influence  
36 monk parakeet reproductive success. Thermoregulation maintains stable temperatures of  
37 incubator chambers compared to large fluctuations (especially hotter extremes) outside  
38 the nest. At least one of the plants brought to the nest effectively inhibited growth of  
39 pathogenic bacteria. The union of these two factors could increase reproductive rates  
40 and may consequently aid the expansion of the species in new non-native environments.

41

42 **Keywords:** Ambient temperature; anti-parasite behaviour; establishment success; monk  
43 parakeets; *Myiopsitta monachus*; nesting behavior.

44

## 45 **Introduction**

46

47       Ecosystem invasion by alien species is often idiosyncratic, yet characteristics of  
48 the environment invaded, species life-history traits and features of the introduction  
49 process have been shown to influence invasion success (Cassey 2002; Lockwood et al.  
50 2007). Avian invaders have been particularly well-studied, and life-history traits such as  
51 brain size, dispersal ability, the ability to tolerate or adapt to a variety of (often human-  
52 modified) habitats and reproductive strategies balancing immediate population growth  
53 rates with future reproductive success have been shown to facilitate avian invasion  
54 success (Blackburn and Duncan 2009; Sol et al. 2012). Among birds, an unlikely but  
55 highly successful avian invader is the monk parakeet (*Myiopsitta monachus* Boddaert).  
56 This species' native distribution corresponds to Bolivia, Paraguay, Uruguay, Argentina  
57 and Brazil to the south and the southwest regions of Rio Grande do Sul and Mato  
58 Grosso do Sul states (Sick 1997). Over the last  $\pm$  150 year, the species has considerably  
59 expanded its native range, taking advantage of human-induced land-use changes.  
60 Especially across grassland pampas, monk parakeets have strongly benefitted from the  
61 introduction of eucalyptus trees (nowadays a preferred nesting tree), and from the  
62 conversion of natural grasslands to crops and urban areas (Bucher and Aramburù 2014).  
63 Due to its popularity as a pet cage bird, the species has been transported and introduced  
64 worldwide, giving rise to numerous non-native populations across the globe (Lever  
65 1987; Strubbe et al. 2010). In South America, non-native populations have been  
66 reported from Chile, but also from parts of Brazil outside of its natural distribution  
67 range. Amorim and Piacentini (2006) report that escaped pet birds have led to the  
68 establishment of non-native monk parakeet populations in the states of Santa Catarina,  
69 Paraná, São Paulo, Rio de Janeiro, Mato Grosso, Goiás and Ceará. In both native and

70 invasive areas, monk parakeets can cause considerable agriculture damage (Domènech  
71 et al. 2003; Bucher and Aramburú 2014). The species also often constructs its  
72 communal stick nests on anthropogenic structures, and as these wooden nests are prone  
73 to catch fire, monk parakeets can cause (electric) power outages, thereby causing  
74 significant damage to transformers and other utility equipment (Avery et al. 2008).

75         In the native range, monk parakeet only breed once per season (with often only  
76 one clutch), exhibit low fledging rates (1–2 per nest), a high variance in breeding  
77 performance across individuals, and delayed first reproduction (Navarro et al. 1995;  
78 Eberhard 1998). In addition, natal dispersal seems to be restricted to relatively short  
79 distances of 2 km or less (Martín and Bucher 1993). These characteristics are indicative  
80 of slow population growth and reduced capacity to disperse to suitable habitats, both of  
81 which are inconsistent with the reproductive and dispersal capacities considered  
82 essential for successful invasion in birds (Blackburn and Duncan 2009; Da Silva et al.  
83 2010). Yet, the species has successfully invaded a range of different climates and  
84 habitats.

85         To better understand the factors underlying the success of this unlikely invader,  
86 here, we test whether traits related to monk parakeet nesting behavior can contribute to  
87 their success as an invasive species. Monk Parakeets are unique among Psittacids in  
88 using sticks and twigs to construct bulky, communal nests where cooperative breeding  
89 can occur (Forshaw 1989; Eberhard 1998). Bird nests perform a variety of functions,  
90 and nest composition and structure impacts upon functions such as the degree of  
91 protection against predators, microclimate control and the presence of invertebrate  
92 communities and nest microorganisms, including parasites (Hilton et al. 2004, Lucas  
93 and Heeb 2005). Bacteria and arthropods living in bird nests are a major cause of  
94 mortality in nestlings, due to the loss of blood or the transmission of pathogens (Duffy

95 1983; Merino 2010). Parasites can become particularly troublesome for birds that reuse  
96 the same nesting sites during several breeding seasons (Humphrey-Smith and  
97 Moorehouse 1981). Parasite load affects how nestlings allocate resources between  
98 immune defense and growth rates (Merino and Potti 1995, 1996; Blondel et al. 2006),  
99 although this trade-off is modulated by food availability (Hoi-Leitner et al. 2001;  
100 Tschirren and Richner 2006; Brzek and Konarzewski 2007). Widespread and well-  
101 known behavioral adaptations against nest parasites include nest sanitation by the  
102 ejection of feces, removal of the fecal sacs and frequent renovation of nest lining  
103 material (Clark and Mason 1985; Petit et al. 2002). However, recent studies have  
104 uncovered more sophisticated mechanisms of biological control, including the use of  
105 volatile substances present in some plants (Gwinner and Berger 2005; Pires et al. 2012;  
106 Tomás et al. 2012) to limit contact with parasites and/or reduce parasite numbers  
107 (Wimberger 1984; Shutler and Campbell 2007; Mennerat et al. 2009a,b).

108         Microclimates within the nest may also play a key role in determining  
109 reproductive success (Wiebe 2001; Butler et al. 2009), as temperatures inside the nest  
110 can be a determining factor for the survival and growth of nestlings (Lloyd and Martin  
111 2004). When temperatures deviate too strongly from optimal conditions, energy loss  
112 due to thermoregulation may reduce growth rates of nestlings, or results in increased  
113 mortality (Krijgsveld et al. 2003). For example, in Europe, cavity-nesting birds that nest  
114 later in the breeding season tend to have smaller clutches in order to reduce the risk of  
115 nestling death through hyperthermia (Balen and Cavé 1969). Nest cavities can however  
116 also reduce the risk of hypothermia, e.g. in Poland, Maziarz and Wesółowski (2013)  
117 found that cavities used by breeding great tits (*Parus major*) were warmer and drier  
118 than unoccupied natural cavities. Therefore, certain nest types, including the closed  
119 stick nests of monk parakeets, may dampen daily temperature fluctuations and/or

120 provide a more moderate, stable thermal environment throughout the day compared to  
121 outside conditions (Paclík and Weidinger 2007; Coombs et al. 2010).

122 Here, we evaluate whether nest thermoregulation and bactericidal activity of  
123 plants brought to the nest could potentially contribute to monk parakeet invasion  
124 success. Specific objectives were: (1) to evaluate if temperature oscillations are lower  
125 inside than outside the nest; (2) to experimentally evaluate whether green plants brought  
126 to monk parakeet nests exhibit bactericidal activity; and (3) to collect breeding  
127 performance parameters and to compare these with literature estimates from other areas.  
128 Our main hypothesis is that the union of these two factors (thermoregulation and  
129 bactericidal potential of plants) may allow for higher reproductive rates, and  
130 consequently aides the expansion of the species into new, non-native habitats.

131

## 132 **Methods**

133

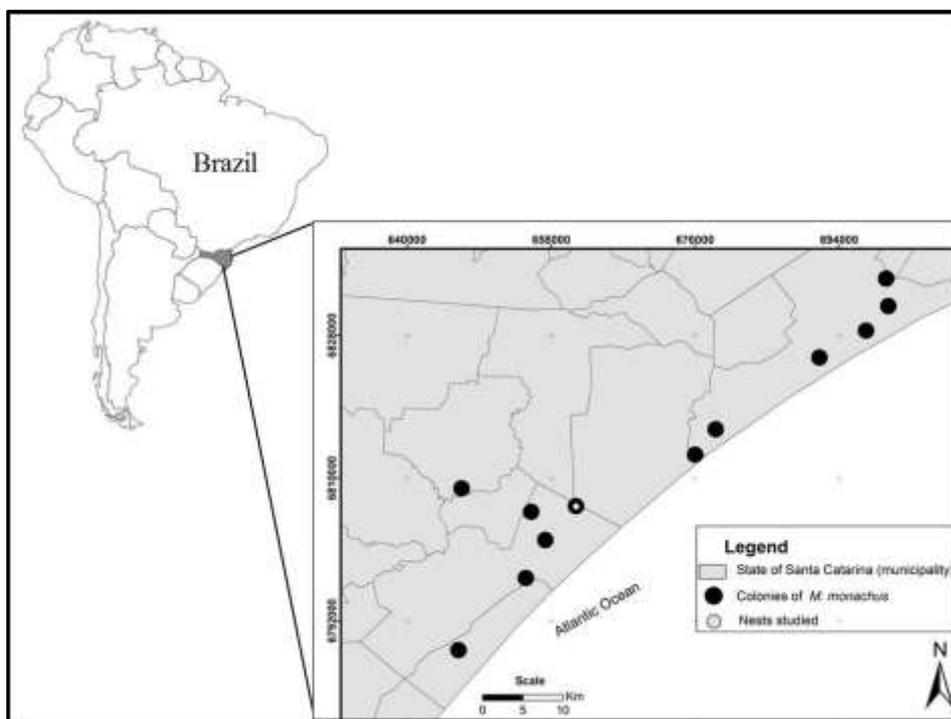
### 134 **Study Site**

135

136 This study was carried out at the coastal area of the southern portion of Santa  
137 Catarina state, southern Brazil (28° 52' S, 49° 20' W, Fig. 1). This region lies about 300  
138 km from the edge of the species' natural distribution range (based on native-range  
139 distribution maps obtained from BirdLife & NatureServe (2011)). No monk parakeet  
140 occurrence records are available from this area before 2002, when the species was first  
141 observed in the State capital Florianopolis (Amorim and Piacentini 2006). The study  
142 area is characterized by ombrophilous forests (Leite and Klein, 1990), whereby dense  
143 forest patches are intermingled with a matrix composed mainly of open areas (such as  
144 horticultural crops, fallow fields, pastures and pioneer vegetation), rural installations

145 and houses and *Eucalyptus* spp. and *Pinus* spp. commercial plantations. The climate  
146 according to the Köppen (1948) classification is humid subtropical (Cfa; revised by  
147 Alvares et al. 2014), i.e. constantly moist subtropical climate, with no dry season, hot  
148 summers, and average temperature of the warmest month exceeding 22 °C. Mean annual  
149 precipitation is about 1220-1660 mm, with a total of 102-150 rainy days per year,  
150 evenly distributed throughout the year (Epagri 2001).

151



152

153 **Figure 1.** Location of monk parakeet colonies studied.

154

155 Population surveys and measurements of breeding performance

156

157 From 2010 to 2013, we surveyed all nesting sites (colonies) of the species along  
158 the southern coastal area of Santa Catarina, Brazil. We interviewed local residents  
159 regarding the presence of the species outside their homes, and also performed  
160 audio/visual sampling at places considered suitable for nest establishment. For each

161 colony detected, we counted the number of nests present. A count of the numbers of  
162 individuals to quantify the size of each colony was made through direct observation,  
163 always before dusk (September and October 2014, corresponding to the beginning of  
164 the breeding season (Sick 2001)), when all individuals return to their nests for the night,  
165 according to procedures contained in Fatsy (2008). Field binoculars of 8 x 42 were used  
166 at a distance of 100 meters from the colony. However, for colonies in which the number  
167 of nests was higher than 15, the count was done in three subsequent days to be  
168 confronted, and so minimize counting errors.

169       Because of the difficulty to reach the nests (height and diameter of the branches),  
170 data on clutch sizes, hatching and fledging success and nestling mass were only  
171 collected from two nests (during four breeding seasons, 2010 - 2013). We also  
172 measured the length and width of each egg with a pachymeter ( $\pm 0.05$  mm) while egg  
173 mass was obtained using a dynamometer ( $\pm 0.01$  g). Lastly, we also monitored the  
174 length of the incubation period and the duration of the fledgling period by marking each  
175 egg (with pencils) and nestling (with washers) individually. After first egg laying, the  
176 nests were checked at intervals of one day until that all nestlings fledged from their  
177 nests. The nestlings were caught directly in the nests for all measures of biometric data.  
178 Reproductive success was evaluated in three categories: clutch size, hatching success  
179 and fledging success. Chambers in the stick nests were considered as 'nests' when at  
180 least one egg was laid in the chamber under consideration (Robinson et al. 2000).  
181 Hatching and fledging success were calculated as the ratio of number of eggs hatched  
182 and birds fledged to the number of eggs laid.

183

184 Microclimate measurements

185

186           Because of logistical constraints, only three nests (different from the nests where  
187 breeding success was studied) were monitored for recording internal nest temperatures.  
188 All three nests contained two incubation chambers. To quantify the variation in  
189 temperature inside and outside nests, we used four electronic temperature collectors  
190 (data loggers). Collectors were installed in the center of each nests to collect inside  
191 temperatures, and another collector was placed just next to the nests to collect the  
192 outside temperatures. Collectors recorded temperatures at one hour interval for 274  
193 days, from August 29, 2013 to June 29, 2014.

194

195 Experimental tests of bactericidal activity of selected plants

196

197           During the monitoring of nests for measuring reproductive parameters, we found  
198 two species of plants (*Eucalyptus saligna* Smith and *Solanum sisymbriifolium* Lam),  
199 which had been brought to the nest by breeding monk parakeets. *E. saligna* leaves were  
200 brought every day in the early morning and mid-afternoon, whereas the fruits of *S.*  
201 *sisymbriifolium* were brought at intervals of one day in the morning. While it is known  
202 that these plants can repel ectoparasites (Rossini et al. 2008; Sasaki-Crawley et al.  
203 2010), few studies have addressed potential bactericidal effects of these plants.  
204 Therefore, we collected *E. saligna* leaves and fruits of *S. sisymbriifolium* in the  
205 surroundings of the nests, and rinsed them with distilled water in three subsequent baths  
206 series. This was done to eliminate bacterial and fungal contamination and thus prevent  
207 interactions with bacterial cultures for experiments. The leaves, fruits and seeds were  
208 dehydrated in a stove at 50° C and crushed into small pieces using a Wiley mill (Melo et  
209 al. 2004).

210 The aqueous extract filtrate from each of the substrates (*E. saligna* leaves, seeds  
211 and fruits of *S. sisymbriifolium*) was obtained through an infusion, from the use of 1 g  
212 substrate per 10 ml of boiling water, placed on the substrate and allowed to act for 1  
213 hour (Anvisa 2011). The following substrate combinations were prepared for each  
214 bacterial test: leaves; fruits; seeds; and leaves+fruits+seeds (in that the substrate ratio  
215 was 0.33 g of each component per 10 ml of water). We tested three replicates for each  
216 bacterial species and control. We use four standard bacteria strains: *Staphylococcus*  
217 *aureus*, *Staphylococcus epidermidis*, *Pseudomonas aeruginosa* and *Escherichia coli*, as  
218 these bacteria are known to negatively impact upon psittacine health (Bangert et al.  
219 1988; Hermans et al. 2000).

220 For the evaluation of antimicrobial activity, bacteria were seeded on plate count  
221 agar (PCA) in petri dishes, and in punches of 6.35 mm diameter, we applied 6 µl of  
222 extract. These plates were incubated for 24 h at 37° C and the efficiency of the  
223 compounds was quantified using the size of the growth inhibition zone around the  
224 punch (Sandri et al. 2007; Silveira et al. 2011). The results were expressed by means of  
225 measures (in millimeters) of inhibition zones produced.

226

## 227 **Results**

228

### 229 Population surveys

230

231 We recorded 12 colonies containing 140 nests, with an estimated total  
232 abundance of 893 individuals. The number of individuals per nest varied from 2 to 15,  
233 with an average of 6.4 (Table 1). All nests were constructed on eucalyptus trees

234 (*Eucalyptus* spp.), with building material composed of twigs of eucalyptus (*Eucalyptus*  
 235 spp.) and thorn (*Mimosa bimucronata* O. Kuntze)).

236

237 **Table 1**

238 Number of nests and individuals for colonies and the relationship of individuals/nest.

239

Colony	Nest	Individual	Individual/Nest
Na	2	4	2
Nb	7	21	3
Nc	60	268	4.5
Nd	15	96	6.4
Ne	1	2	2
Nf	16	112	7
Ng	3	8	2.7
Nh	15	150	10
Ni	12	180	15
Nj	1	2	2
Nk	5	44	8.8
Nl	3	6	2
<b>Total</b>	<b>140</b>	<b>893</b>	<b>6.4</b>

240

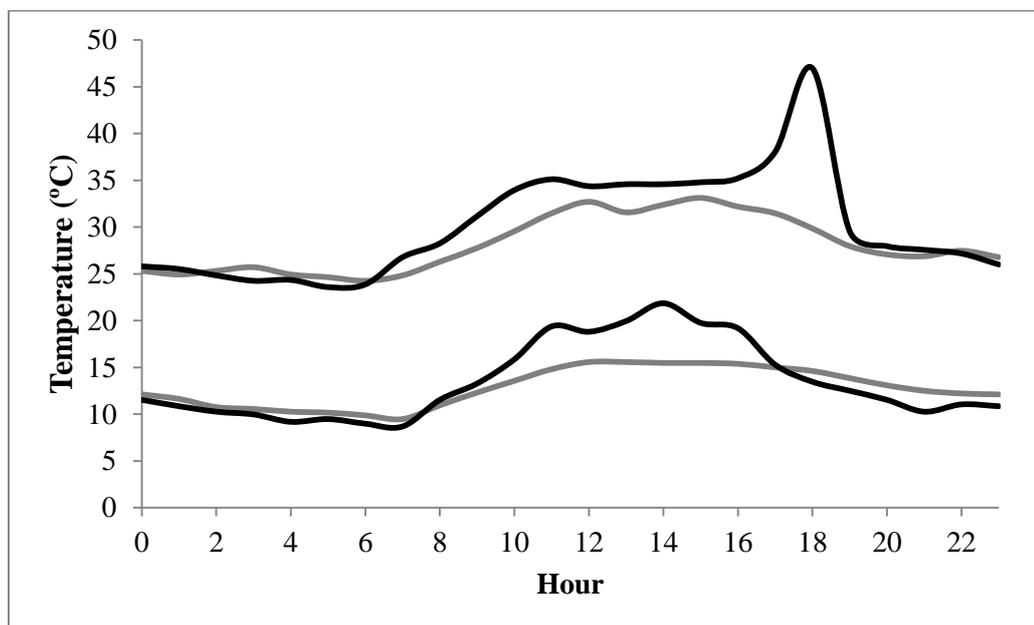
241 Microclimatic measurements

242

243 During 274 days of temperature sampling, we recorded 6,576 temperature  
 244 measurements in each of the four data loggers. Data show that monk parakeet

245 communal stick nests buffer against temperature fluctuations, leading to a more stable  
 246 microclimate in nest chambers. During the breeding season (Oct. – Dec.), outside  
 247 ambient temperatures oscillated between 11.0 and 40.5 °C while nest microclimates  
 248 only ranged from 12.9 to 33.5 °C. Similarly, during the non-breeding season, outside  
 249 temperatures fluctuated between 8.3 to 47.0 °C while nest microclimate temperature  
 250 variation was limited from 8.9 to 34.3 °C. Nests were especially successful in buffering  
 251 against temperature maxima, as nest chambers were up to 7.0 (breeding season) and  
 252 12.7 °C (non-breeding) less hot than ambient temperatures. The nests' buffering effect  
 253 is illustrated in Fig. 2, where temperatures inside and outside nests are plotted for the  
 254 warmest (Jan 29) and coldest day (May 24) recorded. On the hottest day, diurnal  
 255 thermic amplitude inside nests was only 8.86 °C compared to 23.40 °C outside.

256



257

258 **Figure 2.** Daily changes minima (24 May) and maxima (29 January) of temperature in  
 259 three nests of colony and outside. The black line represents the outside temperature, and  
 260 the mean inside temperatures are represented by gray color.

261

262 Experimental tests of bactericidal activity

263

264 Bactericidal activity was observed for *E. saligna* leaves, and for the combination  
 265 of *E. saligna* leaves, *S. sisymbriifolium* fruits and seeds, as their application resulted in  
 266 growth inhibition zone around plate holes seeded with *S. aureus* bacteria. This growth  
 267 inhibition of *S. aureus* has proven to be effective both in a ratio of 1 g: 10 ml (Table 2).  
 268 The other combinations of substrates did not inhibit bacterial growth.

269

270 **Table 2**

271 Evaluation of bactericidal activity of *Eucalyptus saligna* extracts (leaves) and *Solanum*  
 272 *sisymbriifolium* (fruits and seeds). Where S - Sensitive and R - Resistant.

273

<b>Bacteria</b>				
Substrates	<i>S. Aureus</i>	<i>S. epidermidis</i>	<i>P. aeruginosa</i>	<i>E. coli</i>
Leave (Le)	S (25 mm)	R	R	R
Fruit (Fr)	R	R	R	R
Seed (Se)	R	R	R	R
Le+Fr+Se	S (15 mm)	R	R	R

274

275 Parakeet breeding performance

276

277 *This study:*

278 The two nests monitored during the four breeding seasons (2010, 2011, 2012  
 279 and 2013) were located at  $11.4 \pm 0.8$  m above the ground, with mean nest length of 1.7

280  $\pm 0.2$  m and a mean width of  $1.3 \pm 0.2$  m. The average diameter of the chambers  
281 entrances these two nests was  $17 \times 12.5$  cm, and depth of the incubation chambers of  $59$   
282  $\pm 4.2$  cm. Both nests contained an existing single-chambered nest made with straw and  
283 grasses stems, as well as (crushed) eucalyptus leaves. Feces and wastes of nestlings  
284 were deposited around the chamber forming a circle around the eggs and nestlings.

285 Over the course of the 4 years of research, the two nests studied contained 44  
286 eggs in total (mean  $5.5 \pm 1.6$  eggs/nests/breeding season). Egg mass was  $7.0 \pm 0.2$  g and  
287 egg length and width measured  $26.8 \pm 0.4 \times 21.6 \pm 0.2$  cm respectively. From 44 eggs  
288 laid, 40 hatched (corresponding to a hatching success of 90.9%) and 37 nestlings left the  
289 nest (fledging success: 84.1%). The nestlings weighed on average  $6.0 \pm 0.2$  g after  
290 hatching, and achieved an average weight of  $120.0 \pm 4.7$  g before fledging. Incubation  
291 period averaged  $32.0 \pm 4.2$  days and nestlings abandoned the nests  $47 \pm 7.1$  days after  
292 hatching.

293

294 *Literature review:*

295 Data on monk parakeet reproductive success were only available from native-  
296 range Argentina. From the invaded range, no data on breeding success were found in the  
297 literature, although review publications mention invasive monk parakeet populations  
298 typically exhibit exponential growth (Van Bael and Pruett-Jones 1996; Pruett-Jones et  
299 al. 2007). From Spain and the USA, only information on population sizes was available,  
300 summarizing the number of communal nests detected and estimates of the total number  
301 of monk parakeets present. The number of birds recorded per nest was similar to our  
302 study (4.5 on average, range: 2 to 6.9 compared to 6.4 in this study, see above). Egg and  
303 nestling masses were largely comparable (5.8 and 127g versus 6 and 120, respectively).  
304 Compared to our study, an average hatching success was low (on average 52.0%, range:

305 47.5% to 56% compared to 90.9% here), as was fledging success (30.8%, range: 8.9%  
306 to 52.3% compared to 84.1% here). Incubation periods reported from other areas were  
307 shorter than observed here (22.5 versus 32 days), as was the fledging period (40 versus  
308 47 days).

309

310 **Table 3**

311 Summary of studies evaluating parakeet breeding performance in any of the stages.

312

Study	Native area	Amount			Success (%)		Period (day)		Weight (g)		
		Nest	Egg	Nestling	Individual/nest	Hatching	Fledging	Incubation	Leave the nest	Egg	Nestling
Arumburú (1991)	Yes	90				52.2	17	23±3	40±2.1		127.7±2.3
Navarro et al. (1992)	Yes					56	45				
Peris and Aramburú (1995)	Yes	47			6.9±2.1	52.2	8.9	22±2.1		5.8±1.3	
Domenech et al. (2003)	No	313		1441	4.6						
Domenech et al. (2003)	No	492		2199	4.5						
Fatsy (2008)	No	59		170	2±3.4						

## 313 **Discussion**

314

315         Our results suggest that the combined effects of two factors, thermoregulation  
316 and bactericidal potential of plants, may benefit monk parakeet reproduction in several  
317 ways. The bactericidal potential of plants that are transported to the nest on a daily basis  
318 may potentially inhibit growth of pathogenic bacteria near the nestlings, while the  
319 relatively stable and milder nest microclimate may benefit both fledglings and parents.  
320 Fledglings may need to spend fewer resources on thermoregulation as the nest  
321 microclimate at least partially shelters them from both hypo- and hyperthermia. This  
322 can also reduce the amount of time parents need to help their young maintain optimal  
323 body temperatures, and can thus free up time for foraging. We argue that the  
324 combination of these factors potentially underpins the high reproductive success found  
325 in this study compared to other studies.

326         Species' nest-site preferences should be adaptive such that preferred nest sites  
327 confer the most amenable conditions for adults, nestlings, and eggs (Lloyd and Martin  
328 2004; Loli 2008). Under high ambient temperatures, resources spent in reducing  
329 hyperthermia cannot be allocated to development, resulting in lowered growth rates  
330 (Krijgsveld et al. 2003). When physiological thermoregulatory capacities are exceeded,  
331 death by dehydration may occur (Mckechine and Wolf 2010; Catry et al. 2011). Our  
332 temperature measurements during the breeding season show that the maximum  
333 temperature attained inside the nest was 32.50 °C ( $\pm$  1.19 °C) while outside it reached  
334 40.53 °C. In its native range, monk parakeets predominantly occur in temperate climates  
335 (Lloyd and Martin 2004; Bucher and Aramburú 2014). The large differences found in  
336 temperature in- and outside nests suggest that nest microclimate regulation is a crucial  
337 factor that allows monk parakeets to persist and invade hot, subtropical climates as

338 found in our study area. Invasive monk parakeet populations are also present in New  
339 Jersey (USA), and Caccamise and Weathers (1977) observed that the mean temperature  
340 inside monk parakeet nests in winter was 1.8 °C above the outside temperature, while  
341 the maximum temperature difference recorded amounted to no less than 4.6 °C. The  
342 resulting energy savings may help monk parakeets survive (very) cold winters in the  
343 northern parts of the USA and Europe, where they have established numerous invasive  
344 populations (Strubbe and Matthysen 2009). In these cold invaded areas, the monk  
345 parakeet's communal nest building behavior may also contribute to its reproductive  
346 performance. Schwartz et al. (2009) found that in colder parts of Europe, another  
347 invasive parakeet (the ring-necked parakeet *Psittacula krameri*) suffers from a low  
348 breeding success because of cold-induced egg infertility. The higher temperatures inside  
349 monk parakeet nests may allow this species to avoid such detrimental climate impacts.  
350 As in our study region winters are warm while summers can be very hot, the role of the  
351 nest in providing favorable microclimates is most probably especially important in  
352 summer rather than during winter.

353         Bactericidal activity in plants may directly stimulate nestling immune system,  
354 development, or condition (Gwinner et al. 2000). In a study on European starlings,  
355 Gwinner et al. (2000) found basophil granulocytes were present in greater numbers in  
356 the blood of nestlings from nests which contained herbs compared with control nests  
357 containing grass only. In general, basophils synthesize and secrete mediator molecules  
358 which control the development of immune responses (Roitt et al. 1996). Basophils thus  
359 act as 'immunostimulants', activating effector mechanisms of the defense system  
360 (Steinegger and Hansel 1988). In most cases, females start bringing aromatic plants to  
361 the nest from the first days after hatching (Cowie and Hinsley 1988; Banbura et al.  
362 1995) and, in some species, aromatic plants are continually brought to the nest, up to the

363 moment where nestlings are ready to fledge (Lambrechts and Dos Santos 2000). Why  
364 birds transport fresh plant material to their nests has been much debated, but one of the  
365 major hypotheses is that this plant material functions as insecticides or insect repellents  
366 by releasing secondary compounds (Bucher 1988). Many plants produce compounds  
367 acting as a chemical defense against herbivores and pathogens, and naturally occurring  
368 insecticides and bactericides in plants are widespread (Clark and Mason 1985; Veiga et  
369 al. 2006; Mennerat et al. 2009). Thus, another hypothesis, which has received little  
370 attention, is that aromatic plant material may not only act against nest arthropods, but  
371 also protects nestlings from infection by pathogenic microorganisms. Infection by  
372 pathogens represents a significant risk, especially when energy is limited as nestlings  
373 have to balance growth against immune function (Sheldon and Verhulst 1996; Soler et  
374 al. 2003; Tschirren and Richner 2006). For example, Mennerat et al. (2008) highlight  
375 that plants brought to the nests by female blue tits (*Cyanistes caeruleus*), although not  
376 directly effective against nest ectoparasites, reduced both bacterial richness and  
377 bacterial density on nestlings, especially under high ectoparasite infestation. Also,  
378 Mennerat et al. (2009b) showed that experimental supplementation of aromatic plants  
379 reduces abundance and diversity of the bacterial community living on skin and feathers  
380 of nestlings on blue tits.

381         We experimentally verified that *Eucalyptus* spp. plant material brought to monk  
382 parakeet nests inhibits the growth of certain bacteria. Such results corroborate Malheiros  
383 (2008), Porfirio et al. (2009) and Ribeiro et al. (2009), who found bactericidal activity  
384 in the extract of *Eleutherine plicata*, showing greater activity against Gram-positive  
385 bacteria such *S. aureus*, while little effects were observed on strains of *E. coli* and *P.*  
386 *aeruginosa*. The presence of tannins in *E. plicata* extract may underlie the antimicrobial  
387 activity of the plant (Djipa et al. 2000), while *Eucalyptus* spp. show large amounts of

388 tannins, phenols and flavonoids (Naranjo et al. 2009). We however acknowledge that an  
389 experimental manipulation of plant material availability sensu Gwinner and Berger  
390 (2005) is necessary to identify the exact underlying mechanisms or to rule out  
391 alternative explanations. We argue that the monk parakeets' behavioral strategy of  
392 bringing plants material exhibiting bactericidal effects to their nests may help them to  
393 achieve higher reproductive rates than reported before.

394 Monk parakeet invasion success may thus be facilitated by microclimatic  
395 advantages conferred by their communal stick nests and by their use of fresh plant  
396 material with bactericidal potential. Future research on invasive monk parakeets could  
397 benefit from quantifying the energetic gains these parakeets obtain through their  
398 communal nesting behavior. To better understand the function of aromatic plants in bird  
399 nests, studies should focus on identifying the bacteria present in bird nests, the  
400 mechanisms through which they impact upon nestling development and the effectivity  
401 of plants harboring secondary compounds in reducing bacterial loads.

402

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