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**The reproductive capacity of monk parakeets *Myiopsitta monachus* is higher in their invasive range**

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Keywords:	<i>Myiopsitta monachus</i> , breeding parameters, clutch size, productivity, reproductive potential, invasion range, juvenile breeding



1 **The reproductive capacity of Monk Parakeets *Myiopsitta***  
2 ***monachus* is higher in their invasive range**

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27 **Running head: Reproductive capacity of invasive Monk Parakeets**  
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33

34 **Abstract**

35 We provide detailed breeding parameters for the population of monk  
36 parakeets, *Myiopsitta monachus*, in Barcelona, Spain, based on data collected for 651  
37 nests over five breeding seasons. This invasive population has a high reproductive  
38 capacity compared to the native range: fledging success was double, the percentage of  
39 pairs attempting second broods three times higher, and 55% of one-year old birds bred  
40 compared to almost zero in South America.

41 **Keywords:** *Myiopsitta monachus*, breeding parameters, clutch size, productivity,  
42 reproductive potential, invasion range, juvenile breeding

43

For Peer Review

44 An understanding of population dynamics is critical for the control of pest species.  
45 Measurement of productivity, recruitment and survival rates allows population growth  
46 forecasts and permits changes in population size under different control scenarios to  
47 be modelled (Williams *et al.* 2002; Conroy & Carroll 2009; Rockwood & Witt 2015).  
48 Monk parakeets (*Myiopsitta monachus*) are among the most invasive **bird** pest species  
49 (Carrete & Tella 2008; Menchetti & Mori 2014; Carrete & Tella 2016). Some effort has  
50 been made to model their population growth and spread within their invasive range  
51 (Pruett-Jones *et al.* 2007), but these simulations were based entirely on information  
52 obtained from their native populations in South America. Data on survival rates from  
53 invasive populations is now available (Conroy & Senar 2009), but equivalent data on  
54 breeding parameters is almost non-existent, apart from some incomplete information  
55 from Florida, USA, on brood size and fledgling success derived from a small sample of  
56 pairs (Avery *et al.* 2012). There is also some limited data based on only two nests in  
57 Brazil, where the species has recently spread (Viana *et al.* 2016). Information from  
58 Europe, where **Monk Parakeets** are a widespread invasive species with significant  
59 negative economic impacts on ornamental vegetation, human facilities and agriculture  
60 (Menchetti & Mori 2014; Senar *et al.* 2016), is totally non-existent.

61 The aim of this study is to quantify breeding parameters for the **Monk Parakeet** within  
62 its invasive **European** range. Our results are based on data from almost 500 pairs over  
63 five breeding seasons between 2002 and 2018.

64

## 65 MATERIAL AND METHODS

66 The study was carried out in Barcelona city, Spain (**N 41.39, E 2.17**). The first **Monk**  
67 **Parakeet** nests were detected in Barcelona in the early 1970s (Batllori & Nos 1985).  
68 Since then, the population has increased exponentially (Domènech *et al.* 2003;  
69 Rodríguez-Pastor *et al.* 2012), becoming one of the largest populations in Europe that  
70 comprises in excess of 5,000 birds (Molina *et al.* 2016; Senar *et al.* 2017).

71 Nests were sampled in the breeding seasons of 2002-2003 and 2016-2018.  
72 Observations were conducted from 1<sup>st</sup> March to the end of September in 2002 and  
73 2016, and to the end of June in the other years. **Monk Parakeets** are unique amongst  
74 the *Psittacidae* in building their own nests from twigs rather than nesting in cavities.  
75 They build communal nests containing from 1 to 60 separate nest chambers (1-12  
76 recorded in our study area) (Burger & Gochfeld 2005), each occupied by a different  
77 pair. Communal nests are usually clustered in loose colonies in the same or adjacent  
78 trees. Nest inspections were conducted using a cherry-picker, and our sample unit was  
79 the chamber. In 2002, we focused on colonies in six locations within the city limits  
80 (Ciudadella, Lluís Companys, Diagonal, Jardí Infantes, Tetuán, Institut Montserrat). In  
81 2003, we focused on the same colonies except for those at the Institut Montserrat. In  
82 2016, sampling was carried out on 28 colonies all over Barcelona (**see figure 1 in Mori**  
83 **et al. (2019)**). In 2017, sampling was focused on Ciudadella, Lluís Companys, Marina  
84 and Tetuán. In 2018, we monitored colonies only in Ciudadella. For the majority of  
85 locations, each nest was visited a minimum of three times, with the final visit timed so  
86 that the chicks were 35 days or older and could be ringed. Some adults and juveniles

87 from colonies in Ciutadella Park were captured using a walk-in trap baited with food in  
88 the summer of each year of the study. Both juveniles and adults, when captured, and  
89 chicks in the nests, were marked with numbered aluminum rings and with unique  
90 medals attached to neck collars that allowed identification of the birds at distance  
91 (Senar *et al.* 2012).

92 Clutch size was determined from the total number of eggs and/or chicks found in the  
93 two first chamber inspections. The date of clutch initiation was estimated for each nest  
94 chamber by back-dating, based on a 2-day interval between successive eggs and a 24-  
95 day incubation period (Bucher *et al.* 1991; Navarro *et al.* 1992). The age of nestlings  
96 was also used for back-dating when necessary, age being calculated from appearance  
97 and body size measurements, according to Carrillo-Ortiz (2009). In about 50 clutches,  
98 no laying date could be estimated, for instance if it was found as a completed clutch  
99 and the eggs failed to hatch, giving no reference date. This resulted in differences in  
100 sample sizes between different breeding parameters. We provide detailed data on  
101 phenology for 2016 only, because the greatest number of nests was inspected over an  
102 extended time span during that breeding season. **We also think that 2016 was a**  
103 **representative year for the phenology estimates.** Overall productivity of the  
104 population was calculated as the number of fledglings per pair monitored, including  
105 pairs whose nests failed. The number of fledglings was determined in the final visit,  
106 when the chicks were ringed.

107 We refer to first clutches as the number of eggs laid by the female in her first breeding  
108 attempt in the season. Some first clutches failed for a variety of reasons and  
109 replacement clutches were laid; in our analyses we did not distinguish between  
110 replacement clutches (started following failure of the first clutch), and second clutches  
111 (laid after a successful first brood), referring to both as second broods. Thus, first  
112 brood productivity included both successful and failed first clutches, and any second  
113 clutches, either replacement or true second brood, were used to determine second  
114 brood productivity. For all the parameters we provide the mean value  $\pm$  standard  
115 deviation.

116

## 117 RESULTS

118 We found a total of 651 nests with eggs. Mean clutch initiation date for 2016 was 25<sup>th</sup>  
119 April (N = 316; range 5 March – 8 August), notably, there was clear bimodality in the  
120 frequency distribution of laying dates (Figure 1). Based on Figure 1, we defined 1<sup>st</sup> May  
121 as the last date for first clutches and the start of second clutches. Mean clutch  
122 initiation date for 2016 first clutches was 27<sup>th</sup> March (N = 189), and for second clutches  
123 was 6<sup>th</sup> June (N = 127). The distribution of lay dates in 2016 (Figure 1) reflected those  
124 recorded in other years. The earliest initial egg laying date was recorded on 2<sup>nd</sup> March  
125 2012 and the latest on 18<sup>th</sup> August 2016.

126 Mean clutch size for the first brood in Barcelona across years was estimated as  $5.0 \pm$   
127  $1.90$  eggs (N = 468; Table 1). The maximum clutch size was 16; large clutches are not  
128 unusual in our **Monk Parakeet** population (see Table 1). Average clutch size for the

129 second brood was significantly smaller than first clutch size ( $3.6 \pm 1.63$  eggs,  $N = 183$ ;  
130 two-sample t-test:  $t = 8.44$ ,  $df = 649$ ,  $P < 0.001$ ; Table 1). **Clutch size did not differ**  
131 **between Europe and their native range, both for first and second clutches (1st:  $5.0 \pm$**   
132  **$0.94$  vs.  $5.8 \pm 0.90$ ; t-test:  $t = 1.30$ ,  $df = 7$ ,  $P = 0.24$ ; 2nd:  $3.5 \pm 0.28$  vs.  $4.0 \pm 1.88$ ,  $P =$**   
133  **$0.62$ ; Table 1).**

134 Fledging success (i.e. productivity) for the first brood was estimated to be  $3.3 \pm 2.10$   
135 chicks per pair across all years of the study ( $N = 323$ ; Table 1), with considerable  
136 variation across years (range: 1.6 – 4.3 fledglings per pair; Table 1). The maximum  
137 number of fledglings produced by a pair from a single breeding attempt was 11.  
138 Fledging success from second broods was significantly lower ( $1.5 \pm 1.61$  chicks,  $N = 59$ )  
139 compared to that of first broods (t-test:  $t = 6.40$ ,  $df = 380$ ,  $P < 0.001$ ; Table 1). **f**  
140 **Fledging success during the first brood in Europe was substantially larger than in their**  
141 **native range ( $3.3 \pm 1.08$  vs.  $1.6 \pm 0.53$ ; t-test:  $t = 2.97$ ,  $df = 6$ ,  $P = 0.02$ ; Table 1; we were**  
142 **unable to investigate this in second broods because data from South America were not**  
143 **available).** The percentage of pairs engaged in second broods, estimated from  
144 sampling in 2002, 2016 and 2018 was  $56\% \pm 9.93$  (Table 1).

145 Detailed monitoring in 2018 of the breeding activity of juveniles previously ringed as  
146 nestlings in 2017, showed that 18 out of 33 yearlings (55%) observed at colonies in our  
147 study site in Ciutadella Park occupied chambers in which breeding attempts were  
148 made (with eggs and/or chicks) during their first year of life. The remaining 15  
149 juveniles used roosting chambers where no breeding was attempted ( $n = 9$ ) or formed  
150 part of a trio ( $n = 6$ ) and were not computed as breeders. There were other juveniles  
151 present in our study site but that their nests were not checked and therefore we can  
152 draw no conclusions on their breeding status.

153

## 154 DISCUSSION

155 Our results provide the first breeding parameters for the **Monk Parakeet** in Europe,  
156 and aside from data on clutch size and breeding success in Florida and Brazil for a small  
157 number of birds (Avery *et al.* 2012; Viana *et al.* 2016), we provide the first  
158 comprehensive data on breeding parameters in the invasive range of the species.

159 Clutch size did not differ between Europe and their native range. **However, fledging**  
160 **success in Europe was the double than in South America.** The lower fledgling success in  
161 the native compared to the invasive range could be due to the greater incidence of  
162 nest predation in their native range (Navarro *et al.* 1992). In North America, despite  
163 predation being possible, no direct observations of nest predation have been recorded  
164 (Avery & Shiels 2018). In Europe, black rats, *Rattus rattus*, have been observed  
165 depredating **Monk Parakeet** nests (Scortecci 1953), and black rats have been observed  
166 entering **Monk Parakeets** nests on several occasions (Hatchwell & Senar pers. obs.).  
167 Grey herons, *Ardea cinerea*, have also been occasionally observed to predate on **Monk**  
168 **Parakeets** chicks (Garcia & Tomas 2006). In addition, **red** squirrels, ***Sciurus vulgaris*,**  
169 could potentially be nest predators, since they have been observed depredating ring-  
170 necked parakeet, *Psittacula krameri*, nests (Mori *et al.* 2013). However, it is clear that

171 these predators, at least in the city of Barcelona, are not as active as snakes and  
172 opossums in the native range in South America (Navarro *et al.* 1992).

173 Clutch size and fledging success of second (and replacement) broods was  
174 approximately 50% lower than those of first brood attempts. This pattern was also  
175 observed in the native range in South America (Navarro *et al.* 1992), and **it also**  
176 **appears in other** ~~is generally true across~~ bird species (Deeming & Reynolds 2015).  
177 However, the percentage of pairs engaged in second broods, either true second  
178 broods or replacement broods, was far larger in the invasive range than in the native  
179 range ( $56 \pm 9.93\%$  vs. 15%) (Navarro *et al.* 1992). Despite the productivity of second  
180 broods being lower than that of first broods, the higher frequency of second broods  
181 could have a marked effect on yearly productivity of the species within their invasive  
182 range. Our data also demonstrates how long the breeding season can be in European  
183 populations, spanning from the start of March to the end of September; close to seven  
184 months of breeding activity *per annum*. In South America breeding spans six months  
185 from October to March (Navarro *et al.* 1992).

186 In relation to the age of first reproduction and although data is limited, we found that  
187 compared to the native range where breeding by yearling birds is seemingly extremely  
188 rare (Bucher *et al.* 1991; Martín & Bucher 1993), in the invasive range about 50% of  
189 juveniles fledged the previous year were engaged in breeding activities during their  
190 first breeding season. This early onset of reproduction is also likely to increase the  
191 breeding output of the species within their invasive range.

192 Overall, our observations in Barcelona, where the **Monk Parakeet** is present at one of  
193 the highest population densities in Europe, reveal the high potential reproductive rate  
194 of the species in their invasive range. Given the economic damage that this species can  
195 cause in its invasive range (Conroy & Senar 2009; Kumschick & Nentwig 2010;  
196 Menchetti & Mori 2014; Senar *et al.* 2016; Avery & Shiels 2018), action to control  
197 their population growth is becoming increasingly necessary, **especially in**  
198 **Mediterranean areas** (Postigo *et al.* 2019). The results presented here can help to  
199 improve models of population growth for this species in invasive areas and contribute  
200 to designing effective management strategies.

201

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305 **Table 1.** Breeding parameters recorded in Barcelona **Monk Parakeet** population. Second brood  
 306 refers to true second broods (when the first was successful) and replacement broods. We  
 307 provide, for comparison, data from South and North America. The literature sources from our  
 308 review appear in the author column.

Parameter / Year	Mean	SD	N	Min	Max	Location	Author
<b>Clutch size (1st brood)</b>							
2002	4.1	1.45	18	2	6	Europe	This work
2003	5.1	1.39	48	1	8	Europe	This work
2016	4.8	1.67	189	1	11	Europe	This work
2017	4.6	1.69	149	1	10	Europe	This work
2018	6.6	2.54	64	1	16	Europe	This work
1993-94	4.8		15	3	7	South America	Eberhard (1998)
1998-99	6.9	2.10	13	5	12	South America	Peris & Aramburú (1995)
1982	6.0	1.75	52	1	11	South America	Navarro et al. (1992)
1983-88	5.4	2.30	313	1	9	South America	Navarro et al. (1992)
2006-07	4.2	4.81	50			North America	Avery et al. (2008)
<b>Clutch size (2nd brood)</b>							
2002	3.3	1.39	24	1	6	Europe	This work
2016	3.8	1.54	127	1	7	Europe	This work
2018	3.4	2.06	32	1	8	Europe	This work
1982-88	4.0	1.88	33			South America	Navarro et al. (1992)
<b>Fledgling success (1st brood)</b>							
2002	3.1	1.92	18	0	6	Europe	This work
2003	4.2	2.36	48	0	7	Europe	This work
2016	4.3	1.74	84	0	11	Europe	This work
2017	3.2	1.78	110	0	9	Europe	This work
2018	1.6	1.80	63	0	6	Europe	This work
1982	2.2		52			South America	Navarro et al. (1992)
1983-88	1.4		313			South America	Navarro et al. (1992)
1998-99	1.2		13			South America	Peris & Aramburú (1995)
2006-07	3.1	1.41	14	1	6	North America	Avery et al. (2012)
<b>Fledgling success (2nd brood)</b>							
2002	1.8	1.40	12	0	4	Europe	This work
2016	1.4	1.66	47	0	5	Europe	This work
<b>% pairs engaged in 2nd broods</b>							
2002	50					Europe	This work
2016	67					Europe	This work
2018	50					Europe	This work
1982-88	15					South America	Navarro et al. (1992)

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312 **Figure 1.** Frequency distribution for Monk Parakeet clutch initiations in Barcelona city during  
313 2016 (N= 316).

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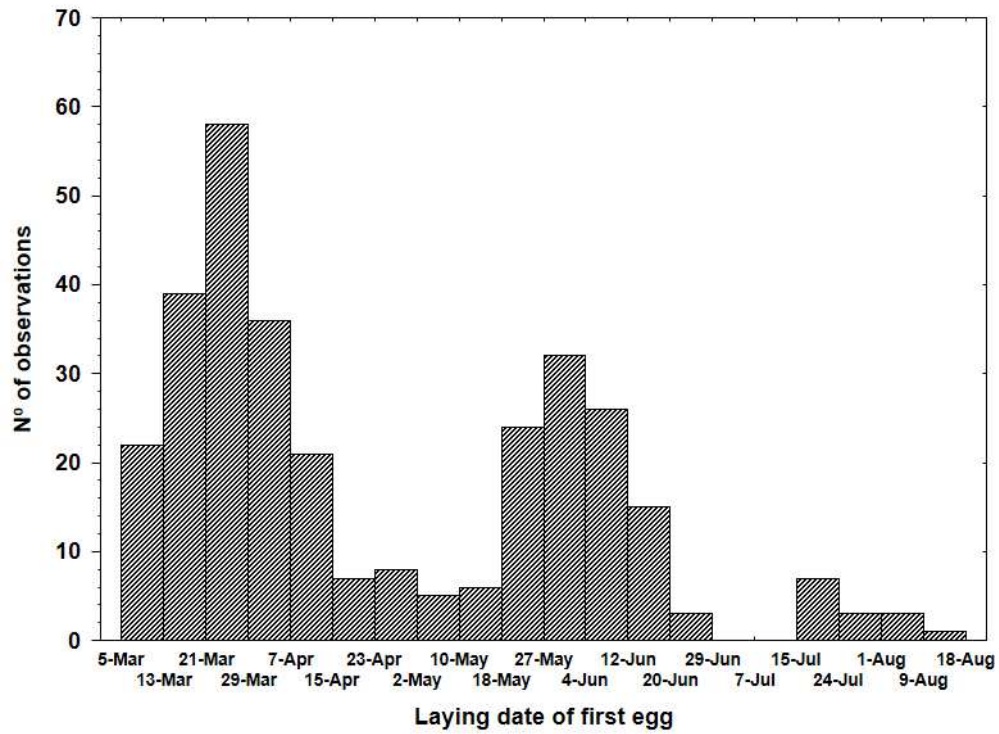


Figure 1. Frequency distribution for Monk Parakeet clutch initiations in Barcelona city during 2016 (N= 316).

206x154mm (96 x 96 DPI)