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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

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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 1st 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 25th
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 1st 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 27th March (N = 189), and for second clutches
123 was 6th 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 2nd March
125 2012 and the latest on 18th 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 ± 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 ± 0.90 ; t-test: $t = 1.30$, $df = 7$, $P = 0.24$; 2nd: 3.5 ± 0.28 vs. 4.0 ± 1.88 , $P =$**
 133 **0.62 ; Table 1).**

134 Fledging success (i.e. productivity) for the first brood was estimated to be 3.3 ± 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 ± 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 ± 1.08 vs. 1.6 ± 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
Clutch size (1st brood)							
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)
Clutch size (2nd brood)							
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)
Fledgling success (1st brood)							
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)
Fledgling success (2nd brood)							
2002	1.8	1.40	12	0	4	Europe	This work
2016	1.4	1.66	47	0	5	Europe	This work
% pairs engaged in 2nd broods							
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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311

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

314

For Peer Review

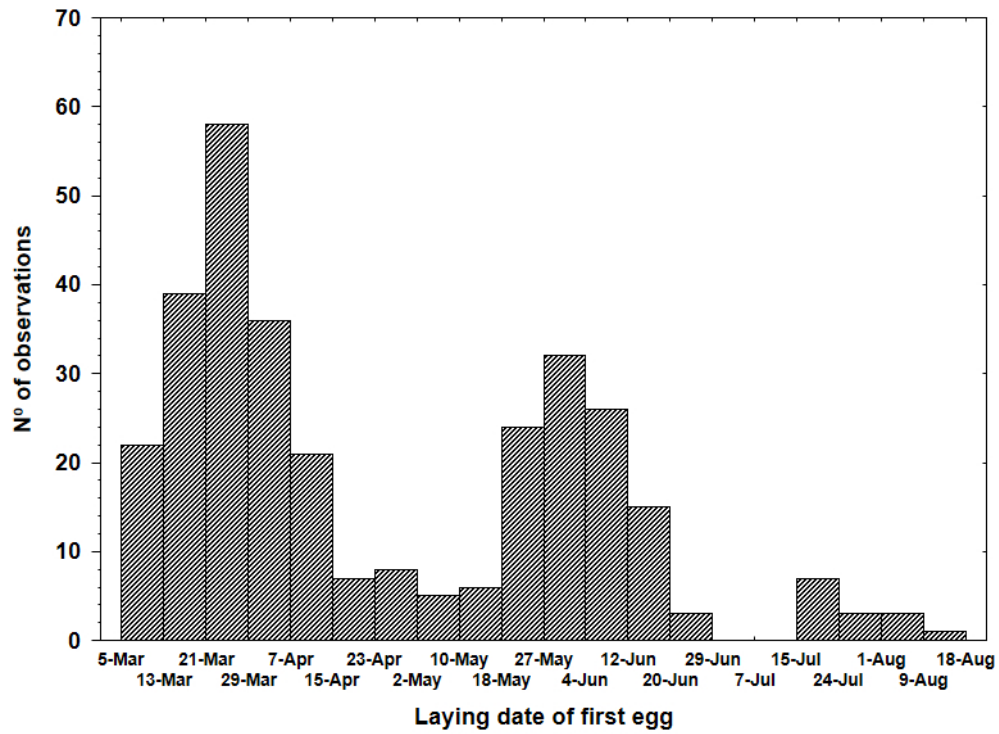


Figure 1. Frequency distribution for Monk Parakeet clutch initiations in Barcelona city during 2016 (N= 316).

206x154mm (96 x 96 DPI)