

Supplementary material

Annual censuses and citizen science data show rapid population increases and range expansion of invasive Rose-ringed and Monk parakeets in Seville, Spain

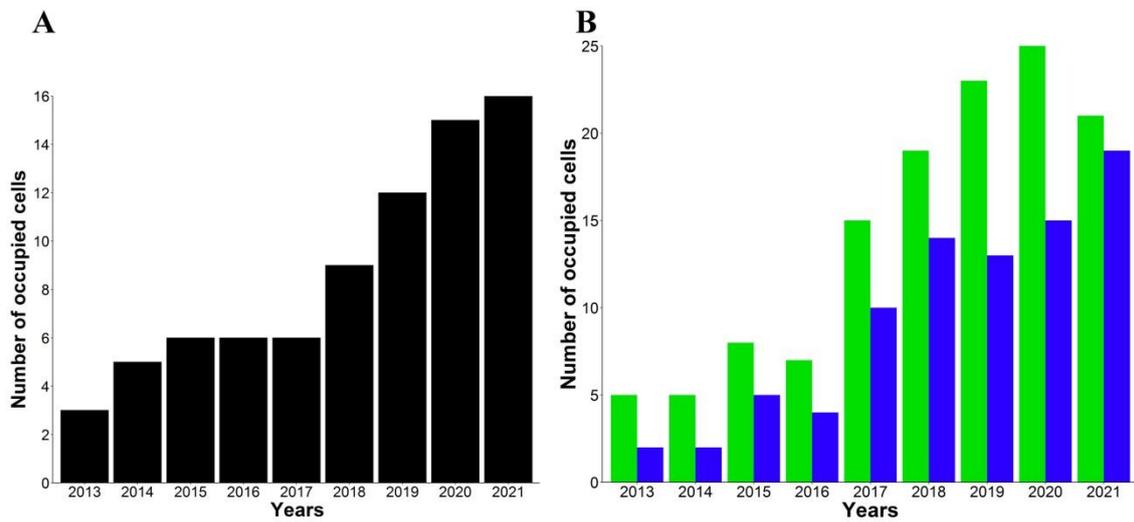


Figure S1. Temporal evolution of the spatial distribution of rose-ringed and monk parakeets in the metropolitan area of Seville (southern Spain). Graphs show the cumulative number of 5x5 km occupied cells over time (2013-2021) regarding A) monk parakeet nests and B) observations of both parakeet species (green bars: rose-ringed parakeets, blue bars: monk parakeets) recorded by citizen science (eBird and Observation).

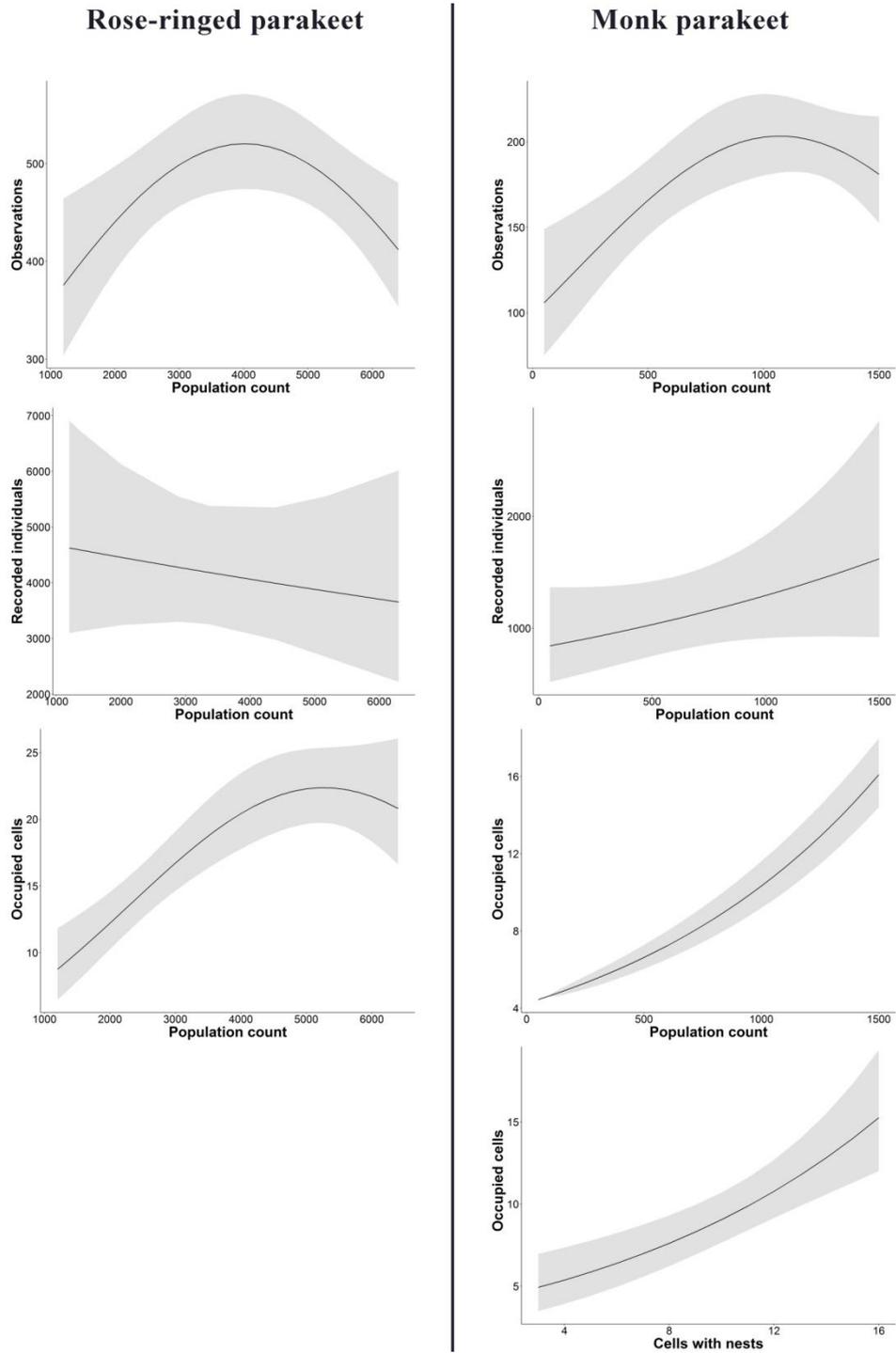


Figure S2. Relationship between the number of observations, the number of recorded individuals, and the number of occupied cells included in the citizen science platforms and our population counts of rose-ringed and monk parakeets and the number of cells with monk parakeet nests. All models included the number of bird observations or the number of cells with bird observations as an offset variable to control for differences in sampling effort over years.

Table S1. Annual population sizes of rose-ringed and monk parakeets established in the metropolitan area of Seville from 2013 to 2021. For the monk parakeet, we estimated the associated 95% CI.

Year	Rose-ringed parakeet	Monk parakeet
2013	1200	70 ± 13
2014		100 ± 19
2015	1367	199 ± 37
2016	2000	372 ± 69
2017	2891	587 ± 108
2018	3360	904 ± 167
2019	4338	1043 ± 192
2020	5185	1307 ± 241
2021	6300	1487 ± 273

Table S2. Generalized linear models (GLM; negative binomial error distribution, log link function) obtained to test the population trend (Survey) of rose-ringed and monk parakeets in the metropolitan area of Seville from 2013 to 2021. Final models were the model with the lowest AIC. dev. expl.: deviance explained (%).

Rose-ringed parakeet							
Model	Variable	Estimate	SE	z	p	AIC	dev. expl.
Survey ~Year	Intercept	-445.22	26.06	-17.08	<0.0001	117.89	97.23%
	Year	0.22	0.01	3.87	<0.0001		
Survey ~Year ²	Intercept	7.96	0.03	250.49	<0.0001	119.73	
	Year	1.59	0.09	17.53	<0.0001		
	Year ²	0.04	0.09	0.4	0.689		
Monk parakeet							
Model	Variable	Estimate	SE	z	p	AIC	dev. expl.
Survey ~ Year ²	Intercept	6.07	0.02	262.44	<0.0001	94.02	99.56%
	Year	3.16	0.08	39.76	<0.0001		
	Year ²	-0.77	0.06	-12.11	<0.0001		
Survey ~ Year	Intercept	-800.56	63.9	-12.53	<0.0001	115.6	
	Year	0.4	0.03	12.63	<0.0001		

Table S3. Number of nesting substrates per tree species used by monk parakeets in the metropolitan area of Seville from 2013 to 2021.

Tree species	Family	Total	Percentage (%)
<i>Phoenix dactylifera</i>	Arecaceae	527	73.81
<i>Phoenix canariensis</i>	Arecaceae	106	14.85
<i>Washingtonia robusta</i>	Arecaceae	25	3.50
<i>Washingtonia filifera</i>	Arecaceae	24	3.36
<i>Platanus × acerifolia</i>	Platanaceae	12	1.68
<i>Trachycarpus fortunei</i>	Arecaceae	10	1.40
<i>Yucca gigantea</i>	Asparagaceae	6	0.84
<i>Eucalyptus camaldulensis</i>	Myrtaceae	2	0.28
<i>Ulmus minor</i>	Ulmaceae	2	0.28

Table S4. Linear model (LM), quadratic regression model (QM), and generalized additive model (GAM) obtained to test the temporal trend of the mean annual number of active chambers per nest in a monk parakeet population established in the metropolitan area of Seville from 2013 to 2021. In GAM, the independent variable (Year) is denoted by smooth terms. edf: effective degrees of freedom, Ref.df: reference degrees of freedom used in computing test statistic and the p-values. GAM was significantly better than LM and QM (ANOVA; $p < 0.013$).

Linear model (LM)						
Dependent variable	Independent variable	Estimate	±SE	<i>t</i>	<i>p</i>	R ²
Number mean of chambers	Intercept	-201.75	52.67	-3.83	0.006	0.64
	Year	0.1	0.02	3.87	0.006	
Quadratic regression model (QM)						
Dependent variable	Independent variable	Estimate	±SE	<i>t</i>	<i>p</i>	R ²
Number mean of chambers	Intercept	1.95	0.04	45.74	<0.0001	0.85
	Year	0.78	0.13	6.11	0.0009	
	Year ²	-0.43	0.13	-3.38	0.015	
Generalized additive model (GAM)						
Dependent variable	Independent variable	Estimate	±SE	<i>t</i>	<i>p</i>	R ²
Number mean of chambers	Intercept	1.95	0.04	45.93	<0.0001	0.85
	Year	edf	Ref.df	<i>F</i>	<i>p</i>	
		1.91	1.99	25.36	0.0014	

Table S5. Models obtained to relate the number of rose-ringed and monk parakeet observations and individuals recorded in the citizen science platforms to our annual population counts (Survey) conducted in the metropolitan area of Seville from 2013 to 2021. The number of bird observations recorded in these platforms was fitted as an offset variable to control for changes in sampling effort over years. We also include models obtained to relate the number of cells with rose-ringed and monk parakeet observations recorded in these platforms to the annual population counts and the number cells with monk parakeet nests (Nests). The number of cells with bird observations recorded in these platforms was fitted as an offset variable to control for changes in sampling effort over years.

Rose-ringed parakeets					
Dependent variable	Independent variable	Estimate	SE	z	p
	Intercept	-3.46	0.13	-26.49	<0.0001
Number of observations	Survey	<0.0001	<0.0001	0.52	0.6
	Intercept	-3.43	0.04	-82.4	<0.0001
Number of observations	Survey	0.16	0.12	1.29	0.19
	Survey ²	-0.3	0.11	-2.8	0.005
Number of individuals	Intercept	<-0.0001	<0.0001	-0.62	0.54
	Survey	-1	0.06	-16.97	<0.0001
Number of individuals	Intercept	-1.34	0.13	-10.73	<0.0001
	Survey	-0.24	0.35	-0.67	0.502
	Survey ²	-0.23	0.35	-0.64	0.522
Number of cells	Intercept	-1.45	0.11	-9.41	<0.0001
	Survey	0.0001	0.31	2.92	0.00353
Number of cells	Intercept	-1	0.06	-16.97	<0.0001
	Survey	0.98	0.17	5.28	<0.0001
	Survey ²	-0.41	0.15	-2.69	0.008
Monk parakeets					
Dependent variable	Independent variable	Estimate	SE	z value	p
	Intercept	-4.35	0.13	-32.45	<0.0001
Number of observations	Survey	0.0003	0.0001	2.62	0.0237
	Intercept	-4.2	0.06	-6.6	<0.0001
Number of observations	Survey	0.63	0.2	3.2	<0.002

	Survey2	-0.35	0.15	-2.41	0.02
	Intercept	-2.38	0.03	-75.71	<0.0001
Number of individuals	Survey	<0.0001	<0.0001	0.791	0.429
	Intercept	-2.56	0.13	-18.98	<0.0001
Number of individuals	Survey	0.72	0.41	1.77	0.08
	Survey2	-0.62	0.4	-1.53	0.12
	Intercept	-2.12	0.14	-14.54	<0.0001
Number of cells	Survey	0.0009	0.0001	6.63	<0.0001
	Intercept	-1.56	0.07	-22.16	<0.0001
Number of cells	Survey	1.51	0.21	7.06	<0.0001
	Survey2	-0.28	0.17	-1.69	0.09
	Intercept	-2.24	0.23	-9.77	<0.0001
Number of cells	Nests	0.09	0.02	4.57	<0.0001
	Intercept	-1.52	0.09	-16.4	<0.0001
Number of cells	Nests	1.32	0.27	4.97	<0.0001
	Nests2	-0.39	0.26	-1.51	0.13
