Introduction

Amongst conservation scientists, global consensus highlights that alien species represent one of the main causes of the worldwide current biodiversity crisis (Blackburn et al. 2019; Liu et al. 2020; Pyšek et al. 2020). Following a parsimony principle, all alien species may exert impacts on native ecosystems (Kumschick and Nentwig 2010; Blackburn et al. 2014; Evans et al. 2018), and these effects should be limited through addressed management actions (Hulme 2006; Mazzamuto et al. 2020; Saavedra and Medina 2020), often involving high economic costs (Bacher et al. 2018; Diagne et al. 2020). Early detection and surveillance programs of new invasions (or newly invaded areas) by alien

Rescue data as an alternative for assessing trends and phenological changes in two invasive parakeet species

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Abstract

Monitoring population trends of alien species is pivotal to design effective management plans to preserve native biodiversity, particularly urban areas, where most populations of alien birds are established. Urban wildlife rescue centers, with personnel trained to record species, age and sex of each individual brought by the public, may represent a reliable citizen-science based method to estimate both local changes in alien species phenology and population trends. In this work, we analysed records of monk and ring-necked parakeets by comparing rescue records in the urban area of Rome from the last 15 years. We also tested whether breeding phenology of alien parakeets showed any changes since the start of the invasion processes.

We recorded a strong correlation between the number of rescued parakeets and their population trends, thus confirming the importance of wildlife rescue centers in monitoring populations of alien species in urban areas. We also observed a shift in the breeding phenology of these parakeet species. The hatching peak for ring-necked parakeet occurred in early spring, in line with previous studies on the reproduction of this species, but with a slight increase in the number of months with evidence of breeding in the last years. As to the monk parakeet, our findings support the expansion of its reproductive season between 2006 and 2020 in Rome, with chicks currently being observed for seven months a year. Therefore, data collected through wildlife rescue centers may help improving models of population growth of alien species established in urban areas.

Keywords Alien species · Myiopsitta monachus · Population increase · Psittacula krameri · Reproductive season · Urban parks
species are therefore recommended by policy makers and field conservationists (Vall-Llosera et al. 2017; Kalandarishvili and Heltai 2019; Larson et al. 2020; Fierro-Calderón and Fierro-Calderón 2020; Rocha et al. 2020). Conversely, monitoring dynamics of established populations of invasive species is far more challenging and expensive in the long term, as it usually involves intensive field efforts (Daume 2016; Luna et al. 2016; Shivambu et al. 2020), or technologies requiring expertise and research practice (Le Louarn et al. 2017). Yet, established populations, particularly when not managed, need to be carefully monitored, as their increase in size and range might eventually result in further or worse impacts (Engeman et al. 2006; Martinoli et al. 2010; Berthier et al. 2017; Boscherini et al. 2020; Mazzamuto et al. 2020). Monitoring large populations is challenging and may require a high number of field operators, particularly in the case of invasive species with high mobility such as birds, with increasing difficulties when surveillance is required in urban areas, where most populations of introduced birds thrive (Rodriguez-Pastor et al. 2012; Sol et al. 2017). Monitoring urban animal populations is also hindered by the difficulties in applying several methods for census counts (including direct captures for marking), e.g. due to restricted access to private properties, or conflict with the general public opinion and animal-rights groups (cf. La Morgia et al. 2017; Archibald et al. 2020).

The ring-necked parakeet *Psittacula krameri* and the monk parakeet *Myiopsitta monachus* are the most widespread alien parakeets (Aves: Psittaciformes) in Europe (e.g. Strubbe and Matthysen 2009a; Pârâu et al. 2016; Postigo et al. 2019). Their impacts on ecosystems have been assessed in several countries where they’ve been introduced (e.g. Menchetti and Mori 2014; White et al. 2019; Mori and Menchetti 2021, for reviews), although they are not yet included amongst alien species of European concern (European Union 2020). Impacts by introduced parakeets might be locally important: for instance, a growing population of ring-necked parakeets is considered responsible for the dramatic decline of the threatened giant noctule *Nyctalus lasiopterus* in Sevilla, Spain (Hernández-Brito et al. 2018). In other countries, this alien species is responsible for the decline of hole-nesting birds (e.g. Strubbe and Matthysen 2009b; Yosef et al. 2016; Covas et al. 2017; Mori et al. 2017; Grandi et al. 2018; Ivanova and Symes 2019). Ecological impacts by monk parakeets are still poorly known (Mori and Menchetti 2021), although this species is responsible for crop damages (Senar et al. 2016; Battisti 2019) and possibly parasite spread to native species (Mori et al. 2019), and its nest may help the spread of other invasive species (e.g. the sacred ibis *Threskiornis aethiopicus*: Castiglioni et al. 2015; Hernández-Brito et al. 2021). Populations of both parakeet species are currently growing, particularly in Mediterranean countries (e.g. Domènech et al. 2003; Postigo et al. 2017; Grandi et al. 2018; Per 2018; Viviano and Mori 2021) and thus their impacts may become manifest or increase in the near future (White et al. 2019; Mori et al. 2020). In Southern Europe, breeding phenology of the ring-necked parakeet may have helped its invasion success, as it occupies tree cavities earlier than native birds for breeding purposes (Luna et al. 2017). Similarly, introduced populations of monk parakeets show a higher reproductive capacity, i.e. with double flegding success and triple the number of couples attempting second broods, compared to populations in the species’ native range (Senar et al. 2019).

Given the times of economic crisis that research and conservation biology are facing (Cagnacci et al. 2012), methods and platforms of citizen science have been developed to monitor population expansion of alien species, including parrots, by fostering the general public attention and participation (Symes 2014; Ancillotto et al. 2016; Per 2017; Diamond and Ross 2019). However, citizen scientists may incorrectly identify species and local experts have to review data, with some possibilities of misidentifications, particularly where several species of non-native parrots occur (Uehling et al. 2019). Moreover, counts by different citizen-scientists might be unreliable due to different observer errors, thus making results incompatible with previous studies. The staff of Wildlife Rescue Centers (hereafter, WRCs) in urban areas is usually trained to record species, age and sex of each individual brought by the public, i.e. representing an invaluable source of wildlife data, particularly in urban environments (Ancillotto et al. 2013; Shine and Koenig 2001). Animals rescued by the public may thus provide researchers reliable data on their ecology, distribution and epidemiology, otherwise difficult to obtain (Reeve and Huijser 1999; Molony et al. 2006; Aaziz et al. 2015; Ancillotto et al. 2018). Therefore, WRCs act as a reliable citizen-science based method to estimate both local changes in species phenology and population trends.

Here we aimed at testing whether wildlife rescue centers may act as monitoring centers for alien parakeet population trends. Thus, we analysed records of two introduced parakeet species from a wildlife rescue center in Rome, where the two largest parakeet populations of Italy occur. We compared rescue records with census data across 15 years, and assessed whether rescue records may be used as a proxy of local population trends. Moreover, we tested whether the breeding phenology of the two species showed any change since the start of the invasion process.
We assigned each non-adult bird to its month of presumed hatch, by assigning nestlings, fledglings and juveniles to 1, 2 and 3 months before admission date, to test for changes in the reproductive phenology.

**Rescues as a proxy of population size**

Trends in the numbers of rescued birds and population growth were assessed by running log-linear Poisson regressions on the numbers of rescued birds per year across the study period, using year as explaining variable; the relationship between numbers of rescued birds and estimated population size was then assessed by running a Pearson’s correlation test with Bonferroni correction for the estimation of p-values. Population size was available for 5 (P. krameri: 1996, 2007, 2011, 2018 and 2020) and 4 (M. monachus: 1996, 2008, 2016 and 2018) time intervals. At each population size assessment, parakeets were counted using standard count methods, i.e. winter roosts surveys for RNP, and nest counts for MP (for a detailed description of methods see: Pârâu et al. 2016; Postigo et al. 2019; Chessa 2020).

**Changes in reproductive phenology**

We performed a Hermans-Rasson (HR) test for circular data for assessing whether the numbers of hatchlings followed a uniform distribution over the year and eventually identify peak months of births (Landler et al. 2019). The Hermans–Rasson test was computed through the R package circMLE (Fitak 2020). We also tested whether the numbers of months with evidence of hatching activity increased over the years between 2006 and 2019 by running a linear regression. All tests were performed with R 3.3.3 (R Core Team 2013), considering significant results when p < 0.05.

**Results**

**Rescues as a proxy of population size**

In total, 548 RNPs and 860 MPs were admitted at Rome WRC between 2006 and 2020; among rescued parakeets, 45.4% and 24.1% of RNPs and MPs, respectively, were admitted as adults; of the remaining immature birds, 74.4, 10.3 and 15.2% were classified juveniles, fledglings and nestlings respectively, in the case of RNP; in the case of MP, the same classes respectively represented 75.9, 15.1 and 9.0% of the immature birds. Both parakeet species showed strongly significant exponential trends in numbers of rescued birds as well as in estimated population sizes (Fig. 1). For the RNP, the first rescued bird occurred in 2005, and the rescue trend followed an exponential slope of 0.24 ± 0.03
(p<0.001); the first population count dates back to 1996 (10 birds), and followed a slope of 0.19±0.00 (p<0.001), reaching an estimated number of at least 6,800 birds in 2019. For the MP, first census (in 1996) reports 15 birds as total population, which exponentially increased up to 5,500 in 2019 (slope: 0.35±0.01, p<0.001); similarly, rescued MP were first recorded in 2007, also following an exponential growth (slope: 0.29±0.02, p<0.001).

The numbers of rescued birds and population counts showed a strongly positive significant linear relationship for both species: RRP: Estimate±SE=148.72±24.84, t=5.99, p<0.01, adjusted R²=0.90; MP: Estimate±SE=132.50±36.08, t=3.67, p<0.05, adjusted R²=0.82.

**Changes in reproductive phenology**

For MP, the HR test evidenced an uneven distribution of breeding events in all years (n=10, out of 14 years with available data) except for 2006–2008, when too few rescues were recorded (between 0 and 1); in all other years, events were significantly biased, and a progressive advance of the breeding peak was evidenced. In the first years (2009–2013) breeding events peaked in June, while they were more frequent in May during the 2014–2018 interval, and in April in 2019. Moreover, the numbers of months with evidence of breeding also significantly increased with time (linear regression slope: 0.38±0.03, t=11.04, p<0.001; R²=0.84), rising from 1 to 4 months (2006–2011) up to 7 (2017–2019), indicating a concurrent expansion of the reproductive season (Fig. 2).

The HR test for RRP revealed significant results for most years (n=7, out of 10 years with available data), evidencing a biased distribution of breeding events throughout the year, with a peak in March-April; no evidence of phenological shift was found for this species. A slight but non-significant increase in the number of months with evidence of breeding was also found along the study period (linear regression slope: 0.10±0.04, t=2.87, p: n.s., R²: 0.56).

**Discussion**

Our findings confirmed the importance of WRCs in monitoring the population increase of alien species in urban and suburban ecosystems. Accordingly, a strong correlation occurred between the number of rescued parakeets belonging to two species and their population increase in an European metropolitan area. RNP are present in Rome since the end of the 1980s, whereas first records of MP date back to early 1990s, but their populations have been limited both in distribution and individual numbers until early 2000s (e.g. Zocchi 1982; Cignini et al. 1996; Zocchi et al. 2009; Frati-celli and Molajoli 2002; Fraticelli 2014; Pârâu et al. 2016; Mori et al. 2020). However, before 2005, no parakeet was rescued in Rome. Currently, about 7,000 RNPs and nearly 6,000 MPs are suggested to occur in Rome. The sharp population increase of both parakeet species was shown to be clearly mirrored by the number of rescued individuals at WRCs.

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The analysis of data from WRCs also showed an expansion in the breeding phenology of these parakeets, and predictive models suggest further increases in the number of parakeets (Pitzalis et al. 2005; Strubbe and Matthysen 2009c; Di Febbraro and Mori 2015; Le Gros et al. 2016). Lag phases in biological invasions can postpone important management interventions (Crooks 2005); as long-lived species, parrots usually reach sexual maturity several years after their birth (i.e. 3 years for both the RNP and the MP: Pithon and Dytham 1999; Postigo et al. 2017), so they are a good example of lag phase effects on population dynamics. Therefore, these species offer excellent conditions to rapidly manage their populations at the beginning of their invasion process; as such, the small breeding colony of Alexandrine parakeets *Psittacula eupatria* in Rome (Ancillotto et al. 2016) should be rapidly removed before any
Further population increase. Since it is important to monitor both new invasions and to keep those already present under monitoring and control even in a period of economic crisis (Nentwig et al. 2018), WRCs may provide researchers not only with health data (Ancillotto et al. 2018), but also genuine and low-cost proxies of population trends. Besides, assessing population dynamics, including data on productivity and recruitment, is pivotal for the control of introduced species (Pruett-Jones et al. 2007; Conroy and Senar 2009). Determining population recruitment and reproductive timing requires addressed and long-lasting monitoring projects (Viana et al. 2016; Luna et al. 2017; Senar et al. 2019).

The breeding period of the RNP in the native range is reported to be limited to spring, with increasing hatching success at lower latitudes (Shwartz et al. 2009; Luna et al. 2017). Pithon and Dytham (1999) suggested a low reproductive output in small populations of RNPs in UK, which may be linked to the low RNP densities recorded for these populations. Accordingly, in early 2000s, i.e. at the start of the invasion process in Europe, the reproductive season was similar between the native and the invasive ranges (Sim-wat and Sidhu 1973; Butler et al. 2013), with the mean day of first laid egg occurring in late March. However, differently from the native range (Hossain et al. 1993), Butler et al. (2013) were not able to detect any second brood by this species in England. Fledging inflight success was also similar to that recorded in the native range (i.e. about 1.5 young fledged/nest: Shivanarayan et al. 1981). Reproductive phenology of the RNP has been reported as a factor limiting the establishment at northern latitudes (Luna et al. 2017). RNPs are able to adapt to suitable areas by reproducing earlier (starting from late February) than native birds in relatively warm areas (Luna et al. 2017). In our work, we observed that RNP births peak in early spring, which is in line with previous studies on the reproduction of this species (Shivanarayan et al. 1981; Hossain et al. 1993; Butler et al. 2013; Luna et al. 2017), but a slight increase in the number of months with evidence of breeding was detected in the last years (i.e. up to June-July).

As to MPs, Senar et al. (2019) reported that fledgling success was higher in Europe than in the native range (Peris and Aramburú 1995). Although potentially recorded also in Argentina, presumably as a replacement brood (Navarro et al. 1992), the presence of a second brood has been recorded to be more common in the invasive range than in the native one (Peris and Aramburú 1995; Senar et al. 2019). This may also be due to the high environmental temperature and low predation pressure in European cities, which allow MPs to produce a higher number of offspring and for a longer period (7 months) with respect to the native range (5 months: Navarro et al. 1992; Peris and Aramburú 1995; Senar et al. 2019). Furthermore, Senar et al. (2019) reported that, in the invasive range, MPs reach the sexual maturity earlier their conspecifics in the native range, and also yearling birds are able to reproduce, increasing their invasion success. Our findings supported the expansion of the reproductive season of the MP in the last 15 years also in Italy, with chicks currently rescued at the WRC for seven months a year.

The impacts of introduced parakeets have been reviewed in a number of studies (e.g. Mori and Menchetti 2014, 2021; White et al. 2019). The ongoing exponential expansion of Mediterranean populations (see Pârâu et al. 2016; Postigo et al. 2019) is unlikely to be due to continuous releases, but it is possibly linked to increased reproductive outputs (Butler et al. 2013). Particularly, fast expanding populations require continuous monitoring or management actions, to limit impacts on native biodiversity and human wellness (e.g. Luna et al. 2016; Per 2018; Postigo et al. 2017,2019; Saa-vedra and Medina 2020). Monitoring large and widespread populations of alien species requires a good surveillance system, possibly involving a high amount of personnel (Vall-llosera et al. 2017). We have now shown that WRCs may provide reliable data on population trends, therefore helping to improve models of population growth of invasive species and to design effective management plans.

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Author contribution EC and LA conceived the research; EC, VS and CC collected most data on the field; LA ran the analyses; LA and EM wrote the first draft of the manuscript. All authors contributed to and approved the final draft.

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Data Availability All data are available via the corresponding author.

Declarations

Ethics approval and consent to participate This study did not involve human subjects. All applicable international, national, and/or institutional guidelines for the care and use of animals were followed.

Consent for publication All authors agree and consent with the publication of the study.

Conflict of interest Authors declare that they have no competing interest.

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