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DEPARTAMENTO DE BIOLOGIA

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Orientação:

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Utilização de dados de ciência cidadã para monitorizar espécies de aves exóticas

Resumo

As consequências ecológicas da introdução de espécies exóticas, é uma das questões de conservação mais preocupantes mundialmente. A utilização de dados de ciência cidadã, tem sido proposta como uma solução alternativa para analisar este problema. Assim, o nosso principal objectivo foi avaliar a adequabilidade de dados de ciência cidadã para monitorizar as tendências populacionais e de distribuição de espécies exóticas (Psittaciformes and Sturnidae) na região urbana de Lisboa, utilizando três principais grupos de fontes de dados. Estes dados foram validados, uma vez que foram recolhidos por colaboradores experientes, a quantidade de registos foi considerável, e os padrões espácio-temporais relativamente homogéneos. Entre as oito espécies mais registadas, o periquito-rabijunco e o mainá-de-crista, tiveram o maior aumento populacional e de distribuição. Para o periquitão-de-cabeça-azul, foi igualmente registado um aumento, mas menos marcado, enquanto as restantes espécies registadas ocasionalmente. Desta forma, a ciência cidadã demonstrou ser uma ferramenta útil alternativa à ciência convencional.

Palavras-Chave: Aves exóticas, monitorização, ciência cidadã, ecossistemas urbanos, Psittaciformes, Sturnidae

Abstract

The ecological consequences from the introduction of non-native species are among the major conservation concerns worldwide. Using citizen-science data has been proposed as an alternative solution to asses this problem. Thus, our main goal was to evaluate the suitability of citizen-science data to monitor the population and distribution trend of non-native species (Psittaciformes and Sturnidae) in the urban region of Lisbon. The evaluation included three major groups of data sources. We validated the suitability of citizen-science data since the contributors' expertise is in general high, the amount of records is considerable, and the spatio-temporal patterns are relatively homogeneous. Among the eight most recorded species, the Ring-necked Parakeet and the Crested Myna showed a noticeable increase in population and distribution range. The Blue-crowned Parakeet also increased but less markedly, while for the remaining species there were only occasional records. Therefore, the citizen-science showed to be a valuable alternative to conventional science.

Keywords: Non-native species, bird invasions monitoring, citizen-science, urban environments, Psittaciformes, Sturnidae.

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Contents

General introduction

The public participation in a scientific project is not a new practice. In fact, it has been practiced for centuries all around the world (Kobori *et al*. 2016). For example, the 1200-year old records of the timing of cherry blossom in Japan (Kobori *et al*. 2016), or the records of bird strikes by lighthouse keepers in 1880 in the United States (Bonney *et al*. 2009a, 2009b). What is relatively new is the definition of this practice as "citizen-science". Since the mid-90's when the term emerged in the literature, it has been used to describe different ways of public participation in scientific projects (Peters *et al*. 2015). At first, it was used to describe "expertise by lay people" (Follet & Strezov 2015). Now, it can be defined as "general public engagement in scientific research activities where citizens actively contribute to science either with their intellectual effort or surrounding knowledge or their tools and resources" (European Commission Green Paper 2013).

Differently from the historical volunteering-based projects which engaged the public with an exclusive environmental education purpose (McCaffrey 2005, Kobori *et al*. 2016), the citizen-science approach refers to a completely different and more complex practice. It also intends to increase the public scientific literacy, through their participation and understanding about scientific methods and processes (Dickinson *et al*. 2010). As the concept evolved, public participation became more diversified and integrated in the scientific processes. Nowadays citizen-science even engages participants to cooperate in different phases of the project development. Therefore, their participation can be classified as (1) contributory (when the participants only contribute to data collection), (2) collaborative (when the participants contribute in the definition of the project design, data collection, data analysis and in the communication of the project results) and (3) co-creative (when participants cooperate in all steps of the project development, even during project design, e.g., definition of study aims and methods) (Bonney *et al*. 2009b, Jordan *et al*. 2015, Peters *et al*. 2015). Participants can also be engaged based on the project type and its study aims. This includes the public engagement in research projects (i.e. projects with a scientific research aim), conservation projects (i.e. projects with natural resource management aims), virtual projects (i.e. projects with a scientific research aim, where the public cooperate exclusively online), action projects (i.e. volunteers-based projects with the aim to raise attention to a local that needs intervention from the competent entities), and education projects (i.e. projects developed by schools with the aim to increase participants knowledge) (Follet & Strezov 2015).

The use of citizen-science as an alternative to the traditional scientific approach has been advantageous in many ways. One of the most important citizen-science advantages is having the public support and opinion as an influence in the decision making-process (Aceves-Bueno *et al*. 2015; Wright *et al*. 2015), which in many cases are performed by politicians. Despite that, the use of citizen-science offers a cost-effective solution, in which the volunteers perform the work instead of professionals (Aceves-Bueno *et al*. 2015). They also can share information they helped to collect and promote the project and its findings (Aceves-Bueno *et al*. 2015). Here, the contribution of the internet tools has been playing an important role. Besides promoting the project visibility, it also promotes its functionality and accessibility (Bonney *et al*. 2014). It's easier for the project developers to reach the target audience, engage them in their projects of interest, lead them to understand the projects and their objectives, explain how they can cooperate and which process they need to follow, and integrate them as part of the project. With the contribution of mobile phone technologies advancements, this process is even easier. It also allows a faster contribution from participants through the collection and submission of data (Catlin-Groves 2012).

Despite the advantages, the citizen-science projects are often criticized and their acceptance as a valuable method is questioned (Dickinson *et al*. 2010; Bonney *et al*. 2014). This includes concerns about data accuracy and precision (Luckyanenko *et al*. 2016), a consequence from relying on the contribution of a variety of participants with different skills, backgrounds, and lack of scientific training (McCaffrey 2005; Dickinson *et al*. 2010). Another concern refers to the effects in the temporal and spatial distribution of the data collected in the representation of an adequate effort, as a result of insufficient sample size and the geographically inequity of data distribution (Dickinson *et al*. 2010; Luckyanenko *et al*. 2016). However, the effects of the data quality concerns in the citizen-science outcomes have been poorly addressed. As shown by Follett & Strezov (2015), of the 900 publications reviewed only 3% have mentioned the concerns of citizen-science data quality, including articles comparing the quality of the data collected between participants and professionals. Such comparisons are inadequate since they rely on indicators created to assess data quality in traditional scientific projects (Lukyanenko *et al*. 2016).

In fact, integrating the citizen-science approach in research projects have allowed the creation of larger temporal databases (Catlin-Groves 2012), which would be logistically impossible through the traditional scientific methods (Lye *et al*. 2011). The field of Ornithology is one of the most relevant areas that has been explored this practice (Trumbull *et al*. 2000, Catlin-Groves 2012) and it is, probably, the main contributor in the increasing number of publications using citizen-science data in the current decade (Kullenberg & Kasperowski 2016). Birds have several characteristics that make them a very suitable group to be studied by citizen-science projects. In addition to being present in almost all environments, their abundance, behavioural and morphological conspicuousness, such as the fact that most species have diurnal activity, make most bird species easy to observe (Sullivan *et al*. 2009). Such characteristics not only make them a high popular group among the public, but also in the scientific community because birds can be considered as environmental indicators, and thus a very important group to study (Sullivan *et al*. 2009).

In North America this practice has a long history. Projects like the Christmas Bird Count (1900 – Present), North American Breeding Bird Survey (1966 – Present), Project FeederWatch (1987 – Present), and eBird (2002 – Present), are examples of citizen-science projects with international extent, as well as dozens to hundreds of scientific publications based on their datasets (Dickinson *et al*. 2010). One of the most successful citizen-science projects of the 21st century is eBird. This project was developed by the Cornell Laboratory of Ornithology and the National Audubon Society, and consists in a free access platform and global citizen-science project with several regional partnerships around the world, which engages thousands of volunteers to collect bird observations worldwide (Wood *et al*. 2011). The volume of data collected has been increasing since the beginning of the project. Of the 21 million observations gathered until 2008 (Sullivan *et al*. 2009), these have increased to over 140 million in 2013 (Sullivan *et* al. 2014), and to over 300 million in 2015 (Sullivan *et al*. 2017). Nowadays, eBird's database is one of the largest worldwide, providing about 20% of all data in the Global Biodiversity Information Facility (Sullivan *et al*. 2017). The data from eBird has multiple applications which can be explored by a wide audience (Sullivan *et al*. 2014), providing information about bird species distribution, frequency and relative abundance that can be used for education, research and conservation (Sullivan *et al*. 2017). To minimize the effects created by data bias and to maintain data quality, eBird has its own data verification process. First, the data is validated by an automatic filter process which flags unusual bird records based on species distribution and phenology. Secondly, the data is reviewed by a network of regional experts. The main purpose of the data reviewers is the assurance of data quality by refining the platform filters in a given geographical area. Despite that, they also have an educational feedback to the users, providing information about bird species proper identification and improving their data collection skills (Sullivan *et al*. 2009).

Overall, the data collected in citizen-science projects has contributed greatly in several aspects to the ecological studies and conservation of birds. This includes subjects like the effects of global climate-change on species ranges, phenology, species richness and community composition, macroecology studies, habitat loss and fragmentation, population and community ecology (e.g. species life-history evolution, ecology of infectious diseases, and interspecific competition), the effects of biocontaminants in species, studies of spatial variation in biochemical and ecological processes, as well as in ecosystem studies (Dickinson *et al*. 2010). Two other themes that appear to fit in the citizen-science approach are the study and detectability of non-native bird species (Dickinson *et al*. 2010), and the study of birds in urban environments (McCaffrey 2005).

Non-native species are, by definition, "taxa that are transported and introduced outside of their natural range either intentionally or unintentionally by humans" (Hulme 2009). The introduction of non-native species is among the major conservation concerns worldwide (Wright *et al*. 2010), being a threat to native biodiversity, ecosystems processes and to economic services

(Rodríguez-Pastor *et al*. 2012). When these impacts occur, the species is considered as invasive. However, only a small number of species that are transported beyond their native range are introduced in the wild, and only a subset of these become established in the new environments, and finally, a lower number spread and become invasive (Abellán *et al*. 2016).

Since the invasive species can cause severe ecological problems, the knowledge of their distribution is crucial to monitor their populations and to create an action plan if needed (Muñoz & Real 2006). This is possible using citizen-science data, especially in urban environments. First, the urban environments are often suitable to the spread of non-native bird species (Lowe *et al*. 2011). This is mostly because these environments may offer less resistance to the invaders' proliferation. For instance, through the loss of native species and potential competitors (e.g. due to habitat destruction and conversion in build areas), absence of their natural predators and parasites, and the high probability of these species to find a favourable niche to occupy (as a result of structural heterogeneity of the urban environments) (Sol *et al*. 2017). Other factors can be related to the new opportunities conferred by humans which may be less explored by native species (e.g. nesting sites in man-made structures and food supplies, such as artificial feeders and human wastes) (Sol *et al*. 2017). Secondly, because a large number of potential participants are already in the intervention site and, in many cases, they are interested in cooperating (Cooper *et al*. 2007). This is a major advantage. Not only because it's possible to collect large amounts of data and cover larger areas, but also because the surveys can be regularly repeated (McCaffrey 2005).

In this work, we evaluated the suitability and usefulness of data from several citizen-science sources to monitor non-native bird species in urban environments, and thus, determine their distribution and population trend. We selected as our case-study, the urban area including Lisbon and its surroundings, located in southern Portugal. To accomplish our goal, we: (1) characterized the profile of the contributors of citizen data to assess potential bias in expertise; (2) verified the spatio-temporal patterns of citizen-science data to assess potential bias in coverage; (3) determined which non-native bird species have been systematically registered in the study area and (4) used the citizen-science data to estimate the distribution and population trend of non-native species in the study area.

1. Introduction

The practice of citizen-science can be defined as the "general public engagement in scientific research activities where citizens actively contribute to science either with their intellectual effort or surrounding knowledge or their tools and resources" (European Commission Green Paper 2013). There is a long history of public participation in scientific projects. For example, the 1200-year old records of the timing of cherry blossom in Japan (Kobori *et al*. 2016), or the records of bird strikes by lighthouse keepers in 1880 in the United States (Bonney *et al*. 2009a, 2009b). Naturally, as the concept evolved, the public participation became more diversified and integrated in the scientific processes, cooperating even through different phases of the project development (Bonney *et al*. 2009b, Jordan *et al*. 2015, Peters *et al*. 2015). This engagement promotes the understanding about scientific methods and processes, increasing the public scientific literacy (Dickinson et al. 2010).

Citizen-science offers a cost-effective solution to the traditional scientific approach, allowing to develop projects at larger spatial and temporal scales (Aceves-Bueno *et al*. 2015). With this approach it is possible to collect a high volume of data, cover a wider area and in a shorter period of time, which for many projects would be impossible without the citizens' engagement (McCaffrey 2005, Lye *et al*. 2011). The internet and the new technologies contributed also for the growing of the citizen-science (Catlin-Groves 2012, Bonney *et al*. 2014). Nowadays project coordinators can easily reach a broader audience, promote their projects, disseminate the results and acknowledge the participants. Similarly, participants can share their involvement, and the information they helped to collect (Aceves-Bueno *et al*. 2015).

Despite the advantages, the citizen-science projects are often criticized and their acceptance as a valuable method is questioned (Dickinson et al. 2010; Bonney et al. 2014). This includes concerns about data accuracy and precision (Luckyanenko et al. 2016), a consequence from relying on the contribution of a variety of participants with different skills, backgrounds, and lack of scientific training (McCaffrey 2005; Dickinson et al. 2010). Another concern refers to the effects in the temporal and spatial distribution of the data collected in the representation of an adequate effort, as a result of insufficient sample size and the geographically inequity of data distribution (Dickinson et al. 2010; Luckyanenko et al. 2016). However, the effects of the data quality concerns in the citizen-science outcomes have been poorly addressed. As shown by Follett & Strezov (2015), of the 900 publications reviewed, only 3% have mentioned the concerns of citizen-science data quality, including articles comparing the quality of the data collected between participants and professionals. Such comparisons are inadequate since they rely on indicators created to assess data quality in traditional scientific projects (Lukyanenko *et al*. 2016).

The field of Ornithology is, probably, the main responsible for the increasing number of publications using citizen-science data, especially from 2010 onwards (Kullenberg &

Kasperowski 2016). Birds are a highly popular group among the public, with millions of birdwatchers around the world recording species, sounds, and photos each day. Most of these records are freely available to any researcher, through several online platforms for bird data collection. One of the most successful platforms is eBird. Of the 21 million observations gathered until 2008 (Sullivan et al. 2009), the number of observations increased to over 140 million in 2013 (Sullivan et al. 2014) and to over 300 million in 2015 (Sullivan et al. 2017). Nowadays, eBird's database is one of the largest worldwide, providing about 20% of all data in the Global Biodiversity Information Facility (Sullivan et al. 2017).

Data collected in citizen-science projects has contributed to a variety of studies on bird conservation, including the effects of climate-change, distribution and community composition, non-native species, urban environments, habitat loss and fragmentation (Dickinson *et al*. 2010).

The introduction of non-native species is among the major conservation concerns worldwide (Wright *et al*. 2010), being a threat to native biodiversity, ecosystems processes and to economic services (Rodríguez-Pastor *et al*. 2012). Thus, it is crucial to know their distribution and abundance (Muñoz & Real 2006). The use of citizen-science data can be a valuable solution to study non-native species populations. The data collection of data on large scales allows the study of species distribution and abundance, and thus, allowing to monitor changes in populations over time (McCaffrey 2005). The urban environments are often suitable for the spreading of non-native species, since they offer less resistance to non-native species proliferation and confer new opportunities for them to explore (Sol *et al*. 2017). Assessing non-native species in urban environments can also be advantageous since these areas are usually high populated, and a good source of potential participants are already in place (McCaffrey 2005).

In this work, we evaluated the suitability and usefulness of data from several citizen-science sources to monitor non-native bird species in urban environments, and thus, determine their distribution and population trend. We selected as our case-study, the urban area including Lisbon and its surroundings, located in southern Portugal. To accomplish our goal, we: (1) characterized the profile of the contributors of citizen data to assess potential bias in expertise; (2) verified the spatio-temporal patterns of citizen-science data to assess potential bias in coverage; (3) determined which non-native bird species have been systematically registered in the study area and (4) used the citizen-science data to estimate the distribution and population trend of non-native species in the study area.

2. Methodology

2.1. Study area

The study area is located in southern Portugal (Figure 1). The region is geographically divided by the Tagus (Tejo) estuary and is delimited westwards and southwards by the Atlantic Ocean. The climate is Mediterranean with an air temperature ranging between 15-17.5 C and an annual rainfall ranging between 500-800 mm; the slope is soft and mostly below the 200 m a.s.l. (APAmbiente 2017).

This area includes the country's capital and its satellite cities, holding about three million people. Between 1960s and 1970s, the urban development was generalized across the whole region following an industrialization process; while in the last three decades, the main urban development occurred outside the suburbs of Lisbon and Setúbal (Gonçalves *et al*. 2015). In the northern part of the study area and embedded in the built area, there are several gardens from XVIII century which are rich in tropical trees (Carita & Homem-Cardoso 1998). In the southern part, there is a mixed landscape with dispersed building and small remnant patches of woods (mainly pine woods) and agricultural fields. Other widespread habitats include woods, great agricultural fields in the uppermost part of the Tagus estuary and coastal habitats such as sandy beaches and cliffs. Despite its population density, the region has a great popularity among birdwatchers and bird photographers particularly as of the last two decades (Moore *et al*. 2014).

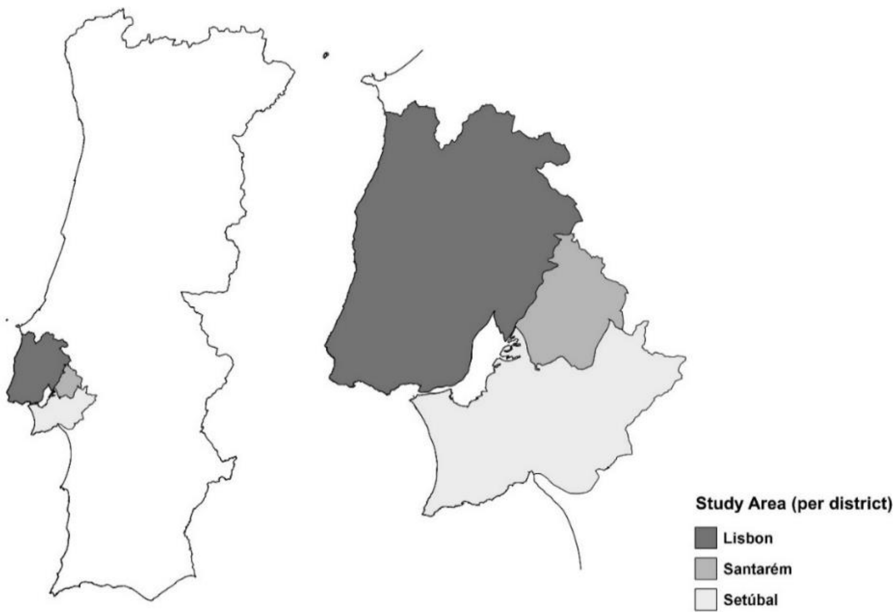

Figure 1 Location of the study area in the Portuguese territory and its representation per district

2.2. Citizen-science data

All the data used in this study was compiled in two datasets. The first dataset included the records of all non-native bird species registered in the study area (hereafter "non-native dataset"). This dataset allowed us to analyse and characterize the species temporal and spatial distribution of records, and thus evaluate the species spatial distribution and population trend over time. To assemble the dataset, we searched for published records in non-scientific literature such as the Portuguese Ornithological Yearbooks and Ornithological News (compiled by the Portuguese Society for the Study of Birds – SPEA), four online databases and eight websites that compile bird observations and/or photographs (Appendix 1). From this review, we compiled a total of 4401 records from 18 non-native bird species from two groups (14 species from order Psittaciformes and 4 from family Sturnidae; Appendix 2), in a timespan between 1990 and 2016. Based on an exploratory analysis of the number of records (number of times that a species was registered), and of its inherent year range of occurrence (number of years with records), we excluded all the species we considered not to fit in our study aim (i.e. occasional species; Appendix 2). This resulted in a reduction of the number of records contained in our data set to 4380 records from eight species (Table 1). Each record was geo-referenced and included date, number of individuals observed (assumed as one when not specified) and observer's name.

The second dataset was used to assess potential bias in coverage that could compromise the suitability of citizen-science data (hereafter "control dataset"). This dataset was composed by bird records from PortugalAves (www.ebird.org/portugal). This is a regional portal of the eBird site (www.ebird.org), managed by SPEA, and a national database for birds in Portugal. The database is organized in a structure of "checklists", and each checklist consists in a sampling unit that assembles the information of each observation event, and where some of the fields are obligatory to fill in (i.e. date, observation site, survey protocol, and species presence or individual count), and others optional (i.e. starting time, duration and distance travelled). In the end, the effort information contained in each checklist will depend on which of the available survey protocols was used. This includes a set of effort-based sampling protocols that require all the survey effort information (obligatory and "optional"), such as (1) travelling count protocol (when the observer has travelled a specific route, e.g. a trail), (2) area count protocol (when the observer has covered a specific ground repeatedly), and (3) stationary count protocol (when the observer remains in a fixed location; only requires the time of sampling). The remaining protocols are less rigorous, and only require the obligatory data, for example the casual observation protocol (which can be applied when bird observation was not the primary purpose, e.g. observe a bird while driving). Considering the effort required by each observation protocol, the portal distinguishes the checklists submitted as "complete checklists” (i.e. checklists with an effort-based protocol) or as “incomplete checklists” (i.e. checklists without a rigorous effort protocol). Our second dataset included all the eBird checklists (complete and incomplete) registered in the study area from 1998 to 2016. Since this data was used to define and characterize the temporal and spatial coverage of citizen-science data, all the records with potential to cause an oversampling and analytical bias were removed. This included: (1) duplicated checklists (several observers birding together and sharing the same list); (2) birds that were not identified to the species level; (3) hybrid individuals; (4) domestic and semi-freedom birds (e.g. ducks, geese and swans in city parks), (5) sea birds; (6) vagrant bird species that need the homologation of the Portuguese Rarities Committee (available at www.spea.pt); (7) all the bird records not validated by the eBird regional reviewers; and (8) all non-native bird species. We decided to exclude the non-native species to ensure the independence of the dataset from the study species data, and to produce a reliable characterization to be used for comparison to other sites. If included it could lead to an erroneous characterization, since the study area structure (which included the largest Portuguese metropole and estuary) can increase the recording of non-native bird species.

Table 1 Number of records and date of first record per data source used.

Source	Year 1st record	N records
SPEA Ornithological Yearbooks & News	1999	201
Biodiversity4all	2003	427
eBird	1997	3568
Aves exóticas em Portugal	2005	70
Aves de Portugal Continental	2012	68
Websites	2008	46
	Total	**4380**

2.3. Study species

Our study was focused in the eight most recorded non-native bird species. Six of these are Psittaciformes. The Budgerigar *Melopsittacus undulatus*, a native species from inland Australia that occurs in a wide range of arid and semi-arid habitats, such as open plains, lightly wooded grassland, scrubland, open woodland, savanna, and mulga *Acacia aneura* desert (Juniper & Parr 1998; Collar & Boesman 2018a). The Monk Parakeet *Myiopsitta monachus*, a native species from subtropical and temperate zones of South America. This species occurs in a wide range of lowland habitats (< 1000m a.s.l.), including open forests, along watercourses, savannas, dry scrublands (Sol *et al*. 1997), as well as human-altered habitats such as farmlands, orchards, forestry plantations and urban settlements (Sol *et al*. 1997, MacGregor-Fors *et al*. 2011). The Cockatiel *Nymphicus hollandicus*, an Australian native species with a widespread distribution throughout inland arid and semi-arid areas. This species can be found in a variety of habitats such as riparian forests, open woodland, acacia scrub, grasslands, orchards and farmlands (Juniper & Parr 1998). The Senegal Parrot *Poicephalus senegalus*, a native species from western region of the sub-Saharan belt (Dami & Kirnan 2009). The species occurrence seems to depend on the availability of trees, being mainly registered in the peripheral savanna areas (Dami & Kirnan 2009), but also in open woodland, open farmland with scattered trees, closed-canopy woodlands, riparian woodlands (Juniper & Parr 1998), and in human settlements (Dami & Kirnan 2009). The Ring-necked Parakeet *Psittacula krameri* is a native species from tropical regions in the sub-Saharan Africa and Southwest Asia (Sa *et al*. 2014 Luna *et al*. 2016; Menchetti *et al*. 2016). Throughout this range, this species has a wide distribution and it can occur in a wide range of habitats, including several woodland types, urban and forested agricultural areas, from 0 to 1600-2000 m a.s.l. (Juniper & Parr 1998). Lastly, the Blue-crowned Parakeet *Thectocercus acuticaudatus*, is a native species from South America. This species occurs in three scattered populations which reflects their avoidance of rainforest (Butler *et al*. 2002), preferring less dense and dry forest in lowland areas, mostly up to 400-600 m a.s.l. (Juniper & Parr 1998). This includes open deciduous woodlands, scrub (Butler *et al*. 2002), and in pasturelands and agricultural areas in dry forest zones (Juniper & Parr 1998). As secondary cavity-nesters, all species nest solitary using mainly tree holes, except the Monk Parakeet which builds a communal nest of twigs (Sol *et al*. 1997, Muñoz & Real 2006). The diet of the Budgerigar and the Cockatiel is mainly composed by a wide variety of seeds from herbaceous plants, including several grain crops (Collar & Boesman 2018a; Rowley & Kirwan 2018). The other four species are more generalist. In addition to the seeds (e.g. from herbs, trees and grain crops), their diet includes a wide variety of fleshy fruits (Collar & Boesman 2018b; Collar *et al*. 2018a, 2018b; Collar & Kirwan 2018). The Monk Parakeet can also feed on blossoms, leaf buds and insects (Collar & Boesman 2018b).

The remaining two species belong to the Sturnidae family: The Crested Myna *Acridotheres cristatellus*, a native species from southeast Asia that occurs in a wide range of lowland habitats, including open country, orchards, cultivated and urban areas (Yap & Sodhi 2004; Robson 2008), to which the the species seems to be closely associated (Gonzalez 2006); and the Common Myna *Acridotheres tristis*, a native species from subtropical regions of central and southern Asia (Peacock *et al*. 2007; Lowe *et al*. 2011) which occurs in open dry woodlands, grasslands, flood plains, desert oases, mountain foothills, dry and disturbed woodland, farmland and urban habitats (Rasmussen & Anderton 2012). Both species are secondary cavity-nesters, using natural cavities (e.g. in trees and cliffs) and cavities in a wide range of man-made structures (Holzapfel *et al.* 2006; Craig & Feare 2018). Omnivorous species, feeding on fruits, seeds, invertebrates, small vertebrates, and on human wastes (Craig *et al*. 2018; Craig & Feare 2018).

As a consequence of the above-mentioned species being popular in the pet market, several events of intentional releases and/or escapes of captivity birds have occurred over the years, leading to the observation of free-living individuals outside their natural range (Butler 2005, Chiron *et al*. 2010, Martin-Albarracin *et al*. 2015, Cardador *et al*. 2017). The morphological and behavioural conspicuousness of these exotic species facilitates their detection. This might be an advantage, allowing an average observer to easily identify them, and thus minimising misidentification.

2.4. Evaluation of data suitability

We performed two types of assessments to evaluate the suitability of citizen-science data to our case-study: (1) characterization of the expertise of data contributors; (2) analysis of the spatio-temporal coverage of citizen-science data.

2.4.1. *Expertise of data contributors*

The characterization of data contributors was used to assess the expertise of the observers that contributed to the study species data collection, as a measure of the reliability of using a volunteer-based project to monitor non-native bird species. A dual approach analysis was used for the characterization. First including the definition of the observer's profile. All the observers with at least 20 records of the study species were included in the profile, creating a criterion of exclusion to the occasional observers. To set the profile, the observers were characterized by (1) age; (2) professional linkage with the study of birds; (3) years of experience in bird observation; (4) collaboration in collecting bird data, by using the total number of effort-based checklists (complete checklists), and the mean number of effort-based checklists submitted on eBird per year. Instead of restricting this evaluation to the study area, we evaluated the observers based on their contribution to data collection in Portugal. All the personal data about the observers was collected through their public eBird profile, or in any other online database when eBird profile was not available. Secondly, we verified the overlap between the profiled observers and the observers from the control dataset. This allowed us to quantify the contribution of the profiled observers to the study area sampling effort. We used the same proportion of contributors/data collected (defined by the criterion used to selection of the profiled observers) to verify the contributors overlap.

2.4.2. *Spatio-temporal coverage of citizen-science data*

This characterization was based on temporal and spatial data distribution of citizen-science data, which quantified the annual variation of records of the study species (using the "non-native dataset") and all bird records from the "control dataset".

The temporal variation in the non-native dataset was based on the year of each record, where we determined: (1) the total number of records from all study species per year; (2) the number of records of each study species per year; and (3) the temporal range of occurrence for each study species (i.e. total number of years of occurrence). The results were summarized using the mean and the standard deviation. The data from the control dataset was used to determine (1) the total number of checklists submitted to eBird, and (2) the total number of bird records per year.

To determine the spatial distribution in the non-native dataset, we assigned all the observations to a UTM grid of 2x2 km (QGIS ver. 2.8.3) and thus determined the (1) the number of squares with records of the study species per year (global and for each species), and (2) the total number of squares where each species was registered. The mean and the standard deviation were used to summarize the results. The same procedure was applied to the control dataset, which calculated the number of squares visited per year.

To further validate the use of citizen-science data for our case-study, we determined the spatial distribution of survey effort (using the "control dataset") and performed two analyses of the contribution of data coverage in the study area. The spatial distribution of survey effort determined the locations of systematic data collection. The locations were defined based on the creation of effort indicators, which were determined using the number of squares sampled with the data from the control dataset. The indicators used were the number of checklists (total number of observation events), number of species (total number of bird species registered), and sampling time (total observation time span, in hours). Only the squares with at least five checklists, 30 species registered, and four hours of sampling time were included to determine the systematic data locations. These conditions selected the squares we considered adequately sampled, in which the probability to observe a species may be higher than in others that were poorly sampled. This procedure was applied to two time series, i.e. (A) 1998-2006 and (B) 2007-2016, allowing a comparison of the survey effort distribution.

The contribution of citizen-science data to increase our knowledge on bird occurrence and distribution in the study area was estimated by an indicator of the relative contribution of records (RCR). The RCR was used to verify if the contribution of data collected continually enhance the study area knowledge. This analysis was applied to the two datasets (non-native and control). The RCR was calculated as the coefficient of the number of squares sampled per year and the number of records registered per year. We also analysed the relationship between the variable "year" and the variables determined by the previous data analysis to the non-native and control datasets, i.e. (1) number of records, (2) number of squares, and (3) RCR. The relation between the number of records in each dataset was also considered. All relationships were calculated using Pearson's correlations, and performed with the RStudio software (version 0.99.489, 2015). Statistical significance was set as $p < 0.05$.

2.5. Spatial distribution and population trend of non-native species

Considering the number of squares sampled with records of the study species per year (determined in 2.4.2), we created maps of occurrence for each species. The maps were analysed through the comparison of the number of squares between two sampling periods, suggesting the species distribution range. We considered the same sampling periods defined in the Survey effort distribution procedure (2.4.3), and thus maintained the sampling coherence.

To determine the population trend for each species, we used the maximum number of individuals registered per square, per year. All species without a period of occurrence of ten consecutive years and squares without at least five years with records were excluded from the analysis. The data was modelled with the software R 3.2.3 (R Foundation of Statistical Computing, 2015), using a log-linear Poisson regression technique from Generalized Additive Models (GAM).

3. Results

3.1. Expertise of citizen-science data contributors

The expertise of the contributors was based on the profile of 41 contributors. Their contribution represents 86% of the total number of records of the study species that have been collected. The profile analysis showed that: (1) about 63% of the contributors were born between the 1960s and 1970s (Fig. 2); (2) 63.4% were not professionals in the field of ornithology *sensu lato* (Fig. 3); (3) 56.1% had more than 10 years of experience in bird observation, 34.2% had between 10 and 5 years of experience, and only 4.9% had less than 5 years of experience (Fig. 4); (4) 53.7% of the observers had submitted more than 500 checklists in total at the date, and 41.5% had submitted more than 50 checklists on average per year (Figs. 5 and 6, respectively), suggesting high involvement of most of the contributors in collecting bird data in Portugal. We could also verify a high diversity of data contribution in the assessment performed to characterize the observers, ranging from 139 to 6361 checklists submitted in total and from 9,9 to 227,2 checklists submitted on average per year. About a third of all observers had a great contribution: 29.3% (12 observers), contributing with more than 1000 checklists submitted in total; and 26.8% (11 observers) with more than 100 checklists submitted on average per year.

Of the 72 contributors (from a total of 607) that contributed to the 86% of the data compiled in the control database, 35 of them corresponded to profiled contributors of non-native bird records. This means an overlap of 48.6% between the profiled observers and the observers who contributed to the study area sampling effort, of which 20.8% (15 collaborators) were those that greatly contributed to the study species data collection.

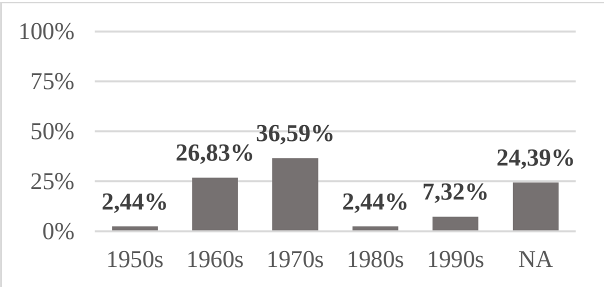

Figure 2 Percentage of observers per decade of birth (n=41).

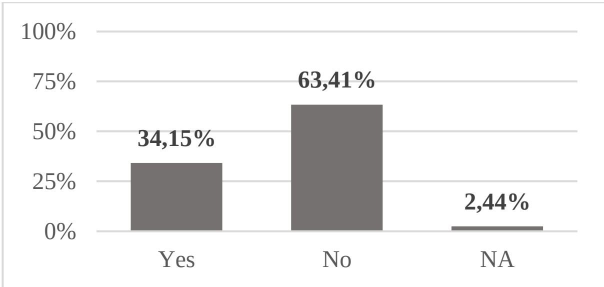

Figure 3 Percentage of observers by their professional linkage with the study of birds (n=41).

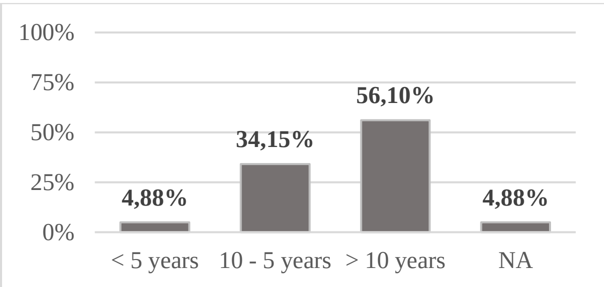

Figure 4 Percentage of observers by their experience in bird observation (n=41).

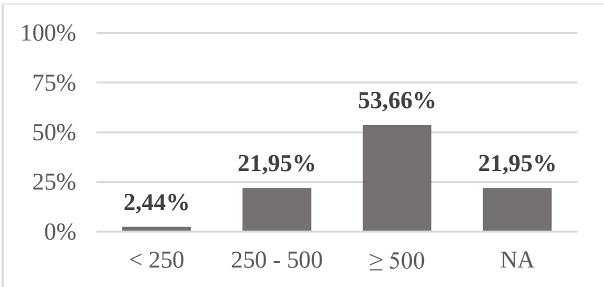

Figure 5 Percentage of observers by the number of checklists submitted in Portugal (n=41).

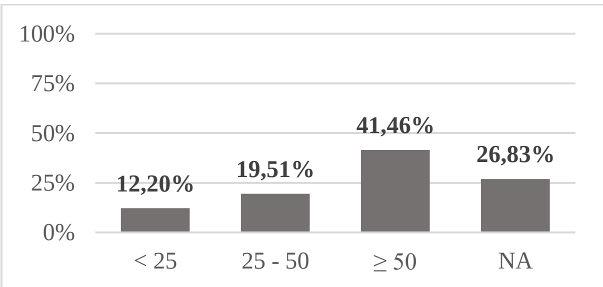

Figure 6 Percentage of observers by the average number of checklists submitted per year, in Portugal (n=41).

3.2. Spatio-temporal coverage of citizen-science data

Temporal coverage

There was an overall increase in the number of records of non-native species over time (Fig. 7). However, when the analysis was applied to each species, we noticed that only four of the eight species were increasingly recorded over time (Fig. 8; in detail in the appendix 3). The Ring-necked Parakeet and the Crested Myna were the most recorded species with a total of 2098 and 1705 records, respectively (Appendix 3). From the second half of the 2000s onwards, the annual number of records of both species increased almost constantly. Especially as of 2013 for the Ring-necked Parakeet, and 2015 for the Crested Myna, there was an exponential growth in the number of records (Fig. 8). Additionally, the Ring-necked Parakeet and the Crested Myna occurred in the greatest range of years (27 and 20 years, respectively; Table 2), and had the highest number of records on average per year (Table 3). The Blue-crowned Parakeet and the Senegal Parrot were the other most recorded species with a total of 297 and 128 records respectively (Appendix 3), within a range of 19 years of occurrence (Table 2). Despite the considerably long period of occurrence, the temporal analysis to the Blue-crowned Parakeet data showed a continuous increase mostly in the last four years (Fig. 8; Appendix 3). The Senegal Parrot was the only species without an evident pattern of increase in the annual number of records. This species was irregularly registered, showing only a slight increase in the last three years of the time span (Appendix 3). For the remaining species, the number of records per year did not show an evident pattern of increase. However, despite the existence of years without any records, all species were regularly registered in the study area (Appendix 3). Among them, the Common Myna was the species with most records (54 records; Appendix 3). The Monk Parakeet, the Cockatiel, and the Budgerigar were the least registered species in the study area (38, 32, and 28 records, respectively). In agreement, these species had the lowest mean number of records per year (Table 3).

The temporal analysis of the control data showed an annual variation similar to the study species temporal analysis. It indicates an overall increase both in the number of all checklists (Fig. 9), and in the number of bird records (Fig. 10). In the beginning the amount of data remained low, increasing almost constantly from 2002 onwards. The period of increase in the effort data was not coincident with the increase observed in the number of records of the study species, which only started as of 2007.

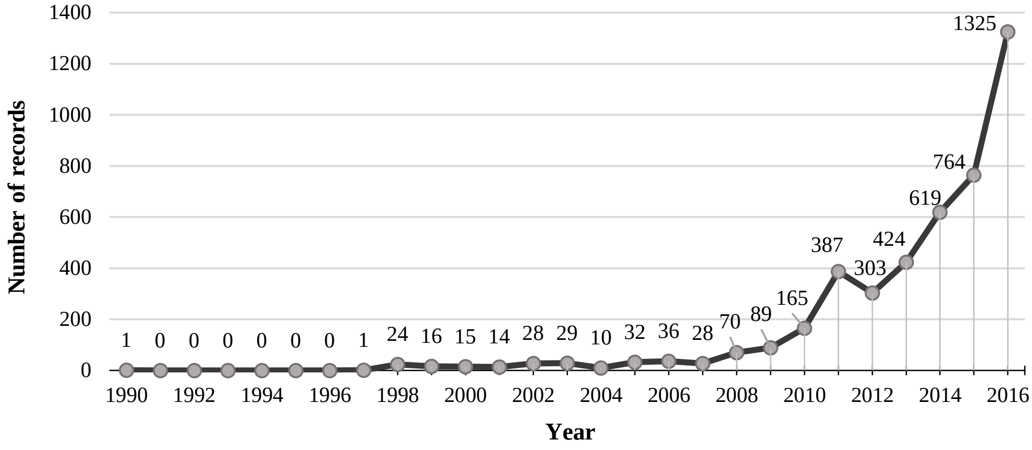

Figure 7 Annual variation in the number of records from the Budgerigar *Melopsittacus undulatus*, Monk Parakeet *Myiopsitta monachus*, Cockatiel *Nymphicus hollandicus*, Senegal Parrot *Poicephalus senegalus*, Ring-necked Parakeet *Psittacula krameri*, Blue-crowned Parakeet *Thectocercus acuticaudatus*, Crested Myna *Acridotheres cristatellus*, and Common Myna *Acridotheres tristis*. All records were registered in the study area between 1990 and 2016.

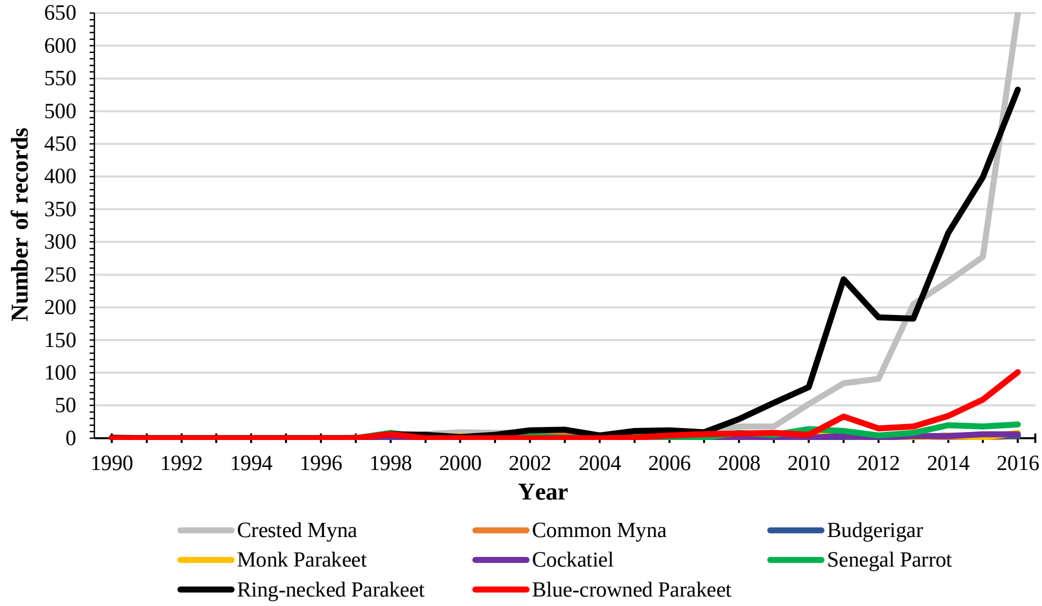

Figure 8 Annual variation in the number of records by each species (Budgerigar *Melopsittacus undulatus*, Monk Parakeet *Myiopsitta monachus*, Cockatiel *Nymphicus hollandicus*, Senegal Parrot *Poicephalus senegalus*, Ring-necked Parakeet *Psittacula krameri*, Blue-crowned Parakeet *Thectocercus acuticaudatus*, Crested Myna *Acridotheres cristatellus*, and Common Myna *Acridotheres tristis*) registered in the study area between 1990 and 2016.

Table 2 Temporal analysis of the study species in the study area. This shows the year of the first record and the year of the last record of each non-native bird species, the number of years that each exotic bird species occurs in the study area since their first record (range) and the effective number of years with records.

Species	Year of 1st record	Year of last record	Range
Budgerigar *Melopsittacus undulatus*	1998	2016	19
Monk Parakeet *Myiopsitta monachus*	1998	2016	19
Cockatiel *Nymphicus hollandicus*	2003	2016	14
Senegal Parrot *Poicephalus senegallus*	1998	2016	19
Ring-necked Parakeet *Psittacula krameri*	1990	2016	27
Blue-crowned Parakeet *Thectocercus acuticaudatus*	1998	2016	19
Crested Myna *Acridotheres cristatellus*	1997	2016	20
Common Myna *Acridotheres tristis*	2000	2016	17

Table 3 Temporal analysis of the study species in the study area. M_1 represents the mean value of records per year (includes all years since the first year with records – range) and SD_1 is the standard deviation; M_2 represents the mean value of records per year (includes all years since the first year with records from 1998 to 2016) and SD_2 is the standard deviation.

Species	M_1	SD_1	M_2	SD_2
Budgerigar *Melopsittacus undulatus*	1.5	1.3	1.5	1.3
Monk Parakeet *Myiopsitta monachus*	2.0	2.6	2.0	2.6
Cockatiel *Nymphicus hollandicus*	2.3	2.0	2.3	2.0
Senegal Parrot *Poicephalus senegallus*	6.7	7.0	6.7	7.0
Ring-necked Parakeet *Psittacula krameri*	77.7	140.9	110.4	157.7
Blue-crowned Parakeet *Thectocercus acuticaudatus*	15.6	25.9	15.6	25.9
Crested Myna *Acridotheres cristatellus*	85.3	157.7	94.7	163.9
Common Myna *Acridotheres tristis*	3.2	2.3	3.2	2.3

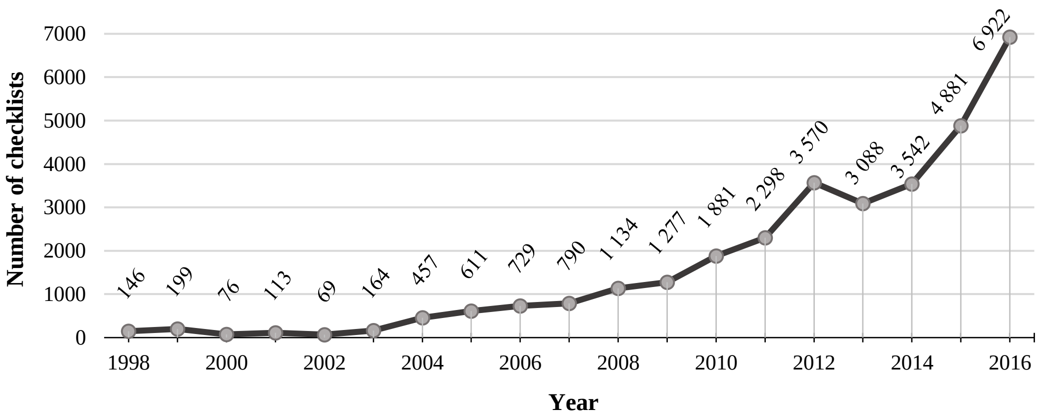

Figure 9 Annual variation in the number of checklists (complete and incomplete) submitted to eBird and registered in the study area between 1998 and 2016.

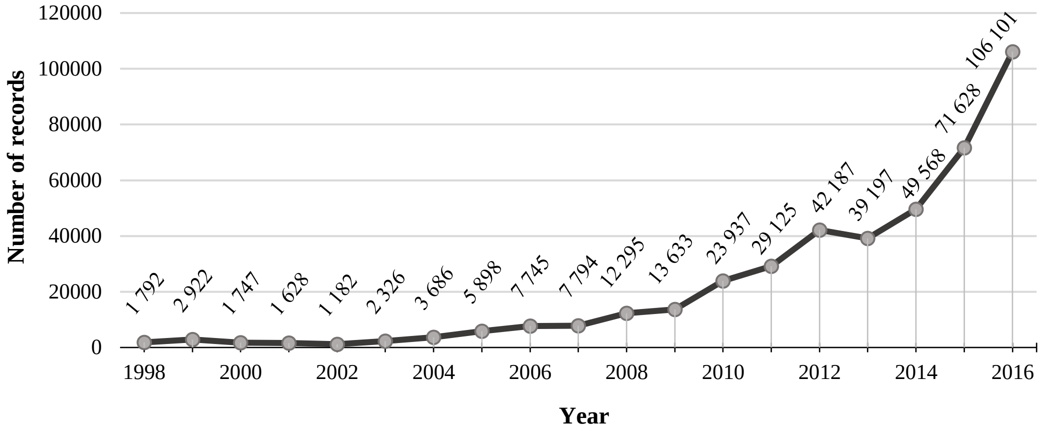

Figure 10 Annual variation in the number of bird records collected in the study area between 1998 and 2016.

Spatial coverage

The spatial analysis suggests an overall increase in the number of squares sampled with the study species data, per year (Fig. 11). The Ring-necked Parakeet, Crested Myna and the Blue-crowned Parakeet were the only species being recorded in more squares over the years (Fig. 12). For the Crested Myna and Ring-necked Parakeet this increase was clearly more evident, especially from 2004 onwards. Both species were also the species recorded in the largest number of squares (102 and 101, respectively; Table 4) and, consequently, registered in the highest mean number of squares per year (16.8, and 12.6, respectively; Table 4). Despite the moderate increase from 2008 onwards, the Blue-crowned Parakeet was only recorded in 24 squares (with an average number of squares of 4.2 per year; Table 4). In the remaining species, the number of squares per year remained low, fluctuating between zero and seven in the Senegal Parrot, zero and five in the Monk Parakeet, Cockatiel and the Common Myna, and zero and four in the Budgerigar (Appendix 4). The number of squares with records of each of these species was lower than 20 and the mean number of squares per year lower than 3.0 (Table 4).

There was an overall increase in the number of squares sampled per year in the case of the control dataset (Fig. 13), suggesting an increase in sampling coverage along the study period. Since 2003, the number of squares with coverage started to increase annually and it remained higher than in the beginning of the study period, even after the coverage decreased between 2012 and 2014. The period of increase in the number of squares with data from the control dataset was coincident with the increasing of number of squares containing the study species data.

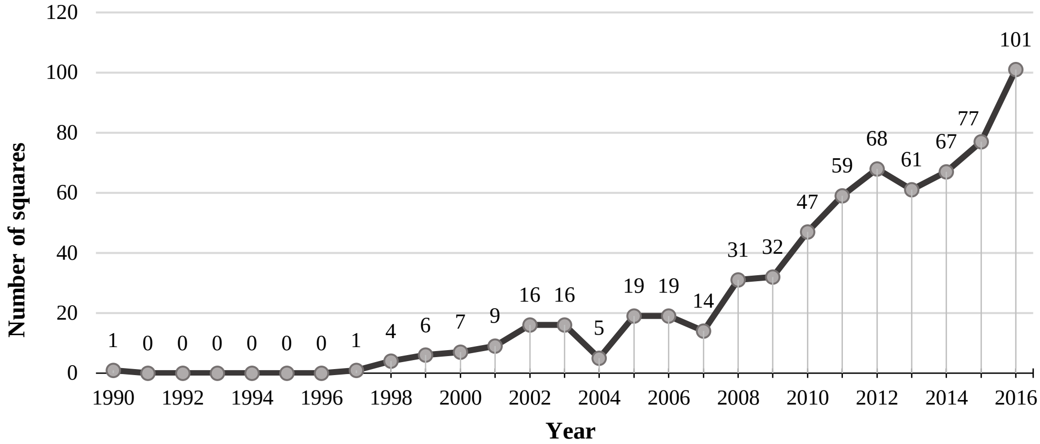

Figure 11 Spatial variation (per year) in the number of records of Budgerigar *Melopsittacus undulatus*, Monk Parakeet *Myiopsitta monachus*, Cockatiel *Nymphicus hollandicus*, Senegal Parrot *Poicephalus senegalus*, Ring-necked Parakeet *Psittacula krameri*, Blue-crowned Parakeet *Thectocercus acuticaudatus*, Crested Myna *Acridotheres cristatellus*, and Common Myna *Acridotheres tristis*. All records were registered in the study area between 1990 and 2016.

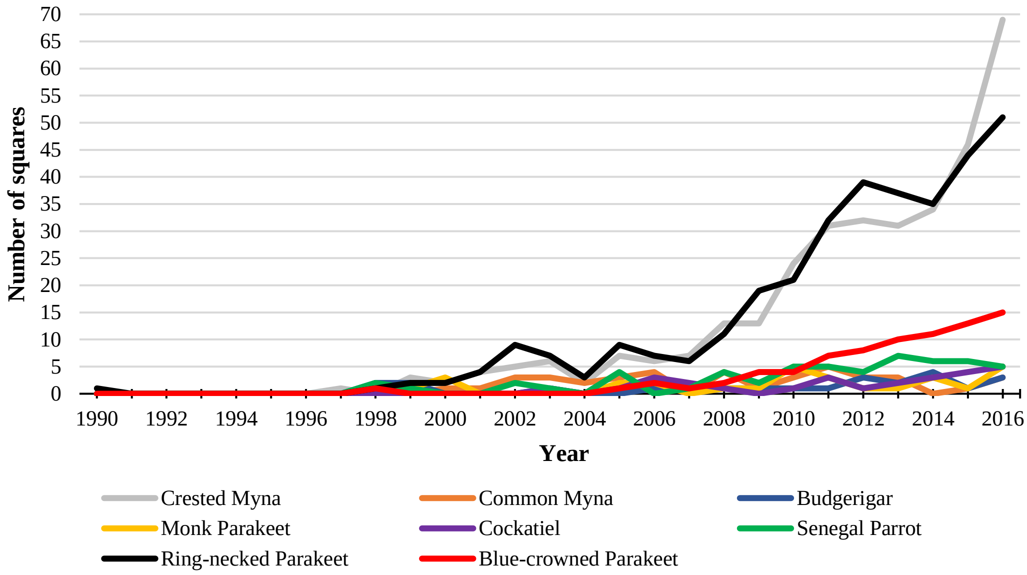

Figure 12 Spatial variation (per year) in the number of records by each species (Budgerigar *Melopsittacus undulatus*, Monk Parakeet *Myiopsitta monachus*, Cockatiel *Nymphicus hollandicus*, Senegal Parrot *Poicephalus senegalus*, Ring-necked Parakeet *Psittacula krameri*, Blue-crowned Parakeet *Thectocercus acuticaudatus*, Crested Myna *Acridotheres cristatellus*, and Common Myna *Acridotheres tristis*) registered in the study area between 1990 and 2016.

Table 4 Total number of squares sampled with records of Budgerigar *Melopsittacus undulatus*, Monk Parakeet *Myiopsitta monachus*, Cockatiel *Nymphicus hollandicus*, Senegal Parrot *Poicephalus senegalus*, Ring-necked Parakeet *Psittacula krameri*, Blue-crowned Parakeet *Thectocercus acuticaudatus*, Crested Myna *Acridotheres cristatellus* and Common Myna *Acridotheres tristis*, mean (M) number of squares sampled per year (includes all years since the first year with records – range) and the standard deviation (SD).

Species	Number of squares	M	SD
Budgerigar *Melopsittacus undulatus*	15	1.3	1.1
Monk Parakeet *Myiopsitta monachus*	16	1.6	1.6
Cockatiel *Nymphicus hollandicus*	18	1.9	1.5
Senegal Parrot *Poicephalus senegallus*	13	2.9	2.4
Ring-necked Parakeet *Psittacula krameri*	101	12.6	16.0
Blue-crowned Parakeet *Thectocercus acuticaudatus*	24	4.2	5.0
Crested Myna *Acridotheres cristatellus*	102	16.8	18.5
Common Myna *Acridotheres tristis*	19	2.4	1.5

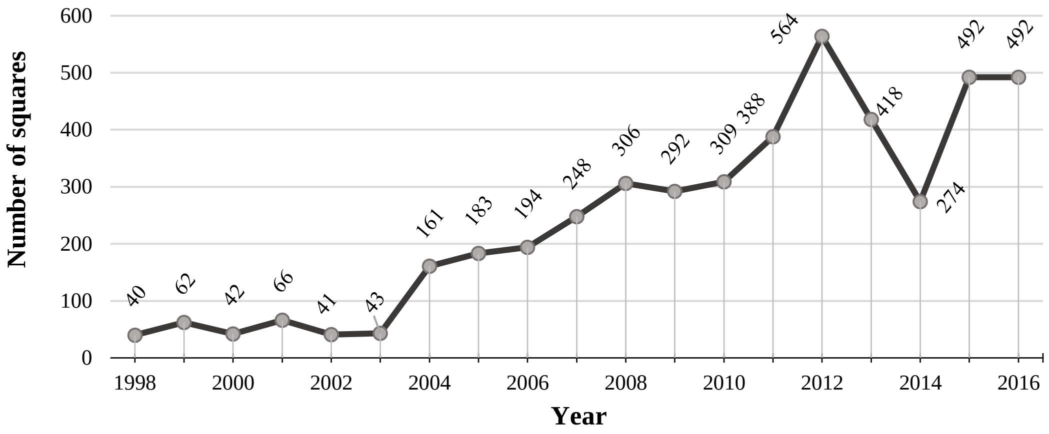

Figure 13 Annual variation in the number of 2x2 km squares sampled with data from the control dataset between 1998 and 2016.

Effort indicators

All the indicators of the effort carried out by citizen-science contributors strongly increased from the first to the second sampling periods, (Table 5). with a near ten times increase in the amount of effort-based information (data with more precise sampling effort information; from 2266 to 22028 complete checklists). There was also an increase in the duration of each observation event, which resulted in a growth of 91.3% in the number of minutes of field survey from the first to the second sampling period.

There was an increase of 63.4% in the amount of area covered by the data from the control database between the two periods: from the 968 squares visited in the whole period, 335 were visited between 1998 and 2006, and 949 were visited between 2007 and 2016. This trend was followed even when we determined the systematic data locations. From the first to the second sampling period, the number of squares adequately sampled increased from 204 to 640 (Appendix 5-8), which equals to an increase of 66.36% in the amount of area sampled between the two periods (Fig. 14).

Table 5 Survey effort in two sampling periods (1998-2006 and 2007-2016) and in total. The effort was determined using the visits with control data and characterized by the number of checklists (total number of observation events), number of species (total number of species registered in the total of the observation events), and sampling time (sum of the total number of minutes of each observation event). The "C" checklists indicate the total number of complete checklists (checklists with effort-based information, i.e., distance and time traveled during the observation event). The "I" checklists indicate the total number of incomplete checklists (checklists that do not require any effort-based information, e.g. casual observations). The number of squares indicates the amount of 2x2 km UTM squares sampled with control data per period of sampling and in total.

		1998 - 2006		2007 - 2016		Total	
Number of checklists	**C**	2 564	2 266	29 383	22 028	31 947	24 294
	I		298		7 355		7 653
Number of species		224		247		247	
Sampling time		78 720		1 724 795		1 803 515	
Number of squares		335		949		968	

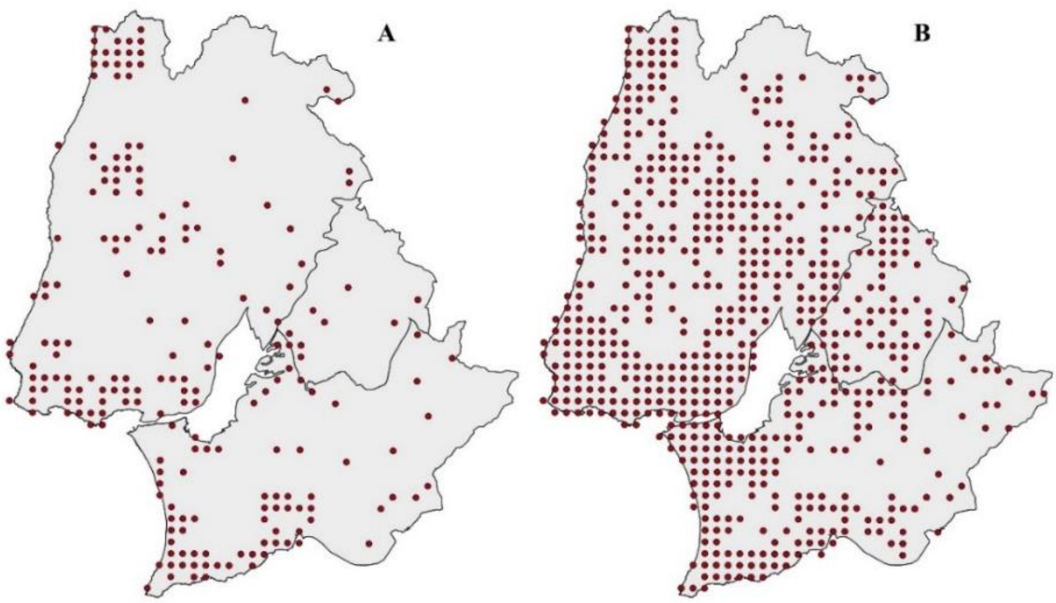

Figure 14 Number of squares adequately sampled in (A) 1998-2006 and (B) 2007-2016. These images show the number of 2x2 UTM squares that fulfill at least one of the effort indicators (i.e. 30 species registered, 5 checklists, 4 hours of sampling time), and each red dot is a square's centroid.

Evaluation of the contribution of citizen-science data

The relative contribution of records (RCR) was similar for both the records of non-native species and all species (Figs. 15, 16), with an overall increase in the contribution of data until the first half of the 2000s but a continuous decrease over the following years. Since the Ring-necked Parakeet and the Crested Myna were the only species registered before 1998 (with only one record for each species; Appendix 3), we only included the RCR from 1998 onward.

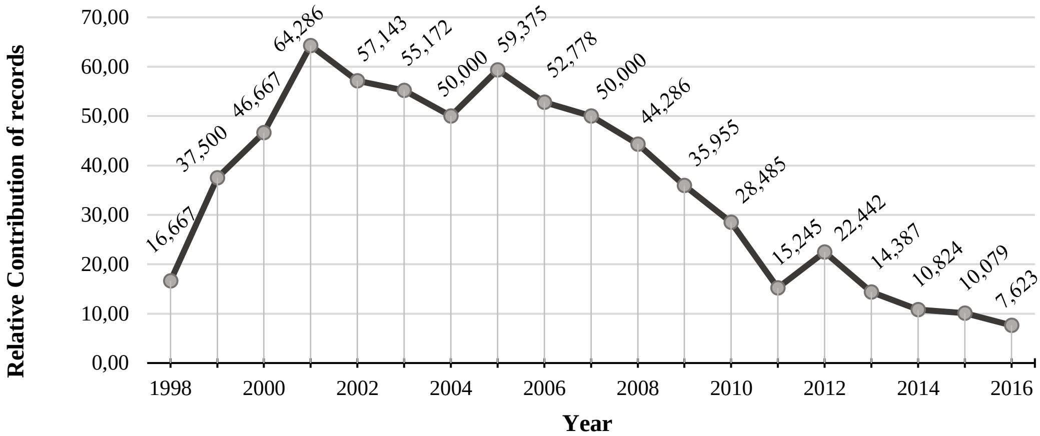

Figure 15 Relative contribution of records from the Budgerigar *Melopsittacus undulatus*, Monk Parakeet *Myiopsitta monachus*, Cockatiel *Nymphicus hollandicus*, Senegal Parrot *Poicephalus senegalus*, Ring-necked Parakeet *Psittacula krameri*, Blue-crowned Parakeet *Thectocercus acuticaudatus*, Crested Myna *Acridotheres cristatellus*, and Common Myna *Acridotheres tristis* in the study area between 1998 and 2016.

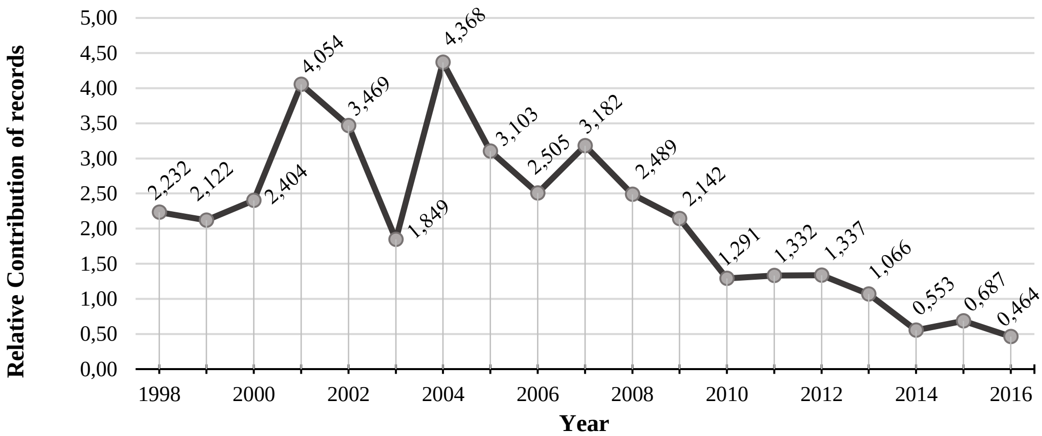

Figure 16 Relative contribution of records of the control dataset from 1998 and 2016.

In the relationships analysed we found: (1) a strong positive correlation between the variables "year" and "number of records of non-native species" ($r = 0.79$, $p < 0.001$; Fig. 17), and between the variables "year" and the "number of records of all bird species" ($r = 0.85$, $p < 0.001$; Fig. 18); (2) a strong positive correlation between the variables "year" and "number of squares with non-native species" ($r = 0.93$, $p < 0.001$; Fig. 19), and between the variables "year" and "number of squares with control data" ($r = 0.92$, $p = < 0.001$; Fig. 20); (3) a strong negative correlation between the variables "year" and "RCR for non-native species" ($r = -0.67$, $p = 0.0017$; Fig. 21), and between the variables "year" and "RCR for all bird species" ($r = -0.71$, $p < 0.001$; Fig. 22); and (4) a strong positive correlation between the "number of records of non-native species" and the "number of records of all bird species" ($r = 0.98$, $p < 0.001$; Fig. 23).

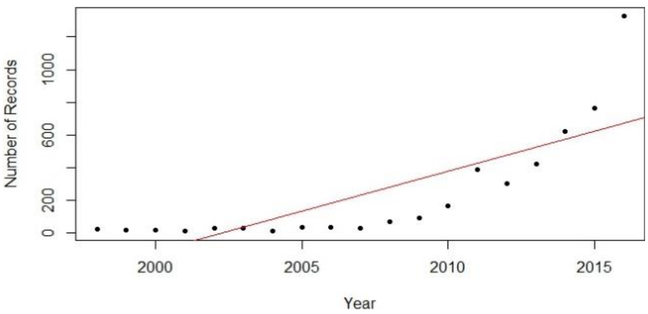

Figure 17 Pearson's correlation between the variables "Year" and "Number of records" of Budgerigar *Melopsittacus undulatus*, Monk Parakeet *Myiopsitta monachus*, Cockatiel *Nymphicus hollandicus*, Senegal Parrot *Poicephalus senegalus*, Ring-necked Parakeet *Psittacula krameri*, Blue-crowned Parakeet *Thectocercus acuticaudatus*, Crested Myna *Acridotheres cristatellus,* and Common Myna *Acridotheres tristis*.

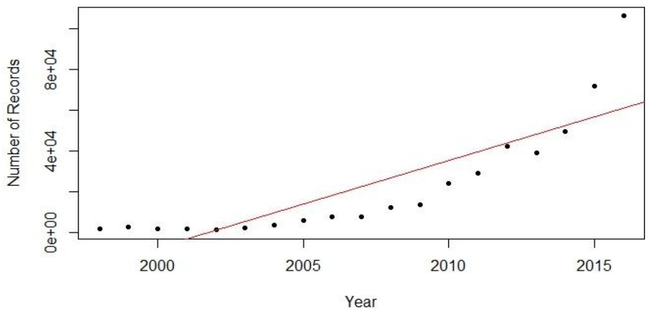

Figure 18 Pearson's correlation between the variables "Year" and "Number of records" of control dataset.

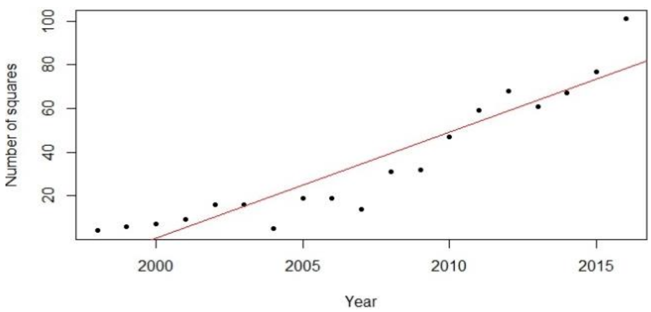

Figure 19 Pearson's correlation between the variables "Year" and "Number of squares" sampled with the records from Budgerigar *Melopsittacus undulatus*, Monk Parakeet *Myiopsitta monachus*, Cockatiel *Nymphicus hollandicus*, Senegal Parrot *Poicephalus senegalus*, Ring-necked Parakeet *Psittacula krameri*, Blue-crowned Parakeet *Thectocercus acuticaudatus*, Crested Myna *Acridotheres cristatellus*, and Common Myna *Acridotheres tristis*.

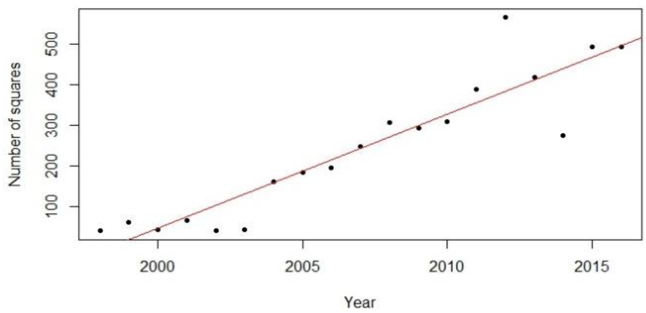

Figure 20 Correlation between the variables Year and Number of squares sampled with data of control dataset.

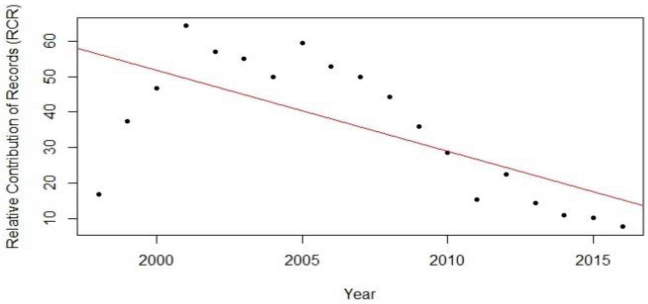

Figure 21 Pearson's correlation between the variables "Year" and the "Relative Contribution of Records" (RCR) from the study species data (i.e. the records from the Budgerigar *Melopsittacus undulatus*, Monk Parakeet *Myiopsitta monachus*, Cockatiel *Nymphicus hollandicus*, Senegal Parrot *Poicephalus senegalus*, Ring-necked Parakeet *Psittacula krameri*, Blue-crowned Parakeet *Thectocercus acuticaudatus*, Crested Myna *Acridotheres cristatellus,* and Common Myna *Acridotheres tristis*).

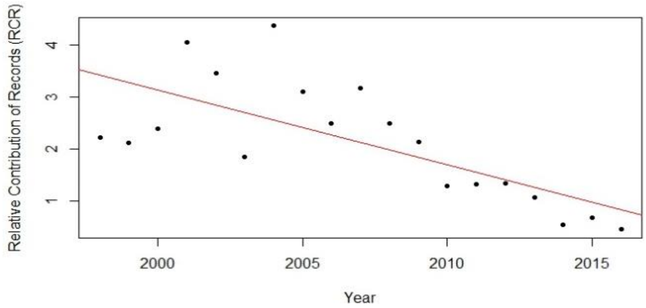

Figure 22 Pearson's correlation between the variables Year and the Relative Contribution of Records (RCR) of control dataset.

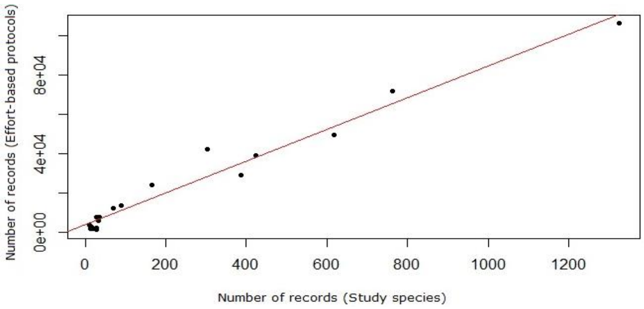

Figure 23 Pearson's correlation between the variables "Number of records" from the study species (i.e. Budgerigar *Melopsittacus undulatus*, Monk Parakeet *Myiopsitta monachus*, Cockatiel *Nymphicus hollandicus*, Senegal Parrot *Poicephalus senegalus*, Ring-necked Parakeet *Psittacula krameri*, Blue-crowned Parakeet *Thectocercus acuticaudatus*, Crested Myna *Acridotheres cristatellus,* and Common Myna *Acridotheres tristis*) and "Number of records" of control dataset.

3.3. Spatial distribution and trend of the study species populations

Spatial distribution

Between the first and the second periods (1998-2006 and 2007-2016), the number of squares with records from all non-native species increased from 51 to 158, respectively (Fig. 24). This was observed in all eight non-native bird species (Table 6), but especially in the Ring-necked Parakeet and the Crested Myna, which increased from 30 to 90 and from 19 to 100 squares, respectively.

The figures 25 to 32 show the spatial distribution (squares with records) for each species. With Ring-necked Parakeet (Fig. 30), Crested Myna (Fig. 31) and Blue-crowned Parakeet (Fig. 29), the spatial distribution suggests continuity, and, consequently, a possible range expansion of these species. For the remaining species, such appreciations are not possible due the scattered pattern of the distribution of records and the low number of squares where these records were registered.

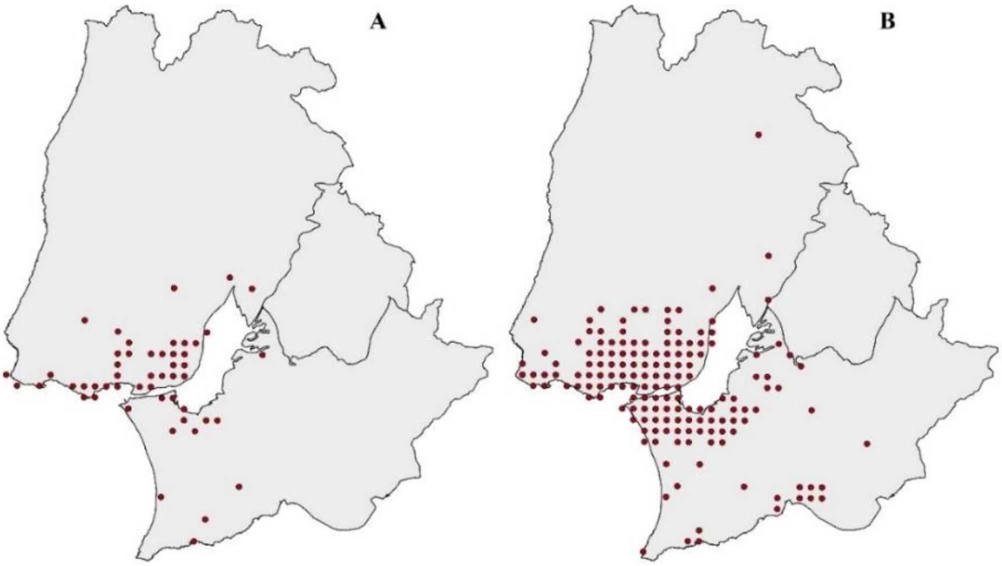

Figure 24 Spatial distribution of the records of Budgerigar *Melopsittacus undulatus*, Monk Parakeet *Myiopsitta monachus*, Cockatiel *Nymphicus hollandicus*, Senegal Parrot *Poicephalus senegalus*, Ring-necked Parakeet *Psittacula krameri*, Blue-crowned Parakeet *Thectocercus acuticaudatus*, Crested Myna *Acridotheres cristatellus*, and Common Myna *Acridotheres tristis*, in the study area between (A) 1998 to 2006 and (B) 2007 to 2016. These images show the total number of squares (2x2 km UTM system) with records of those species, and each red dot represents a square centroid.

Table 5 Number of squares with records of each non-native bird species in the study area per each period.

Species	1998- 2006	2007-2016
Budgerigar *Melopsittacus undulatus*	2	14
Monk Parakeet *Myiopsitta monachus*	6	13
Cockatiel *Nymphicus hollandicus*	4	17
Senegal Parrot *Poicephalus senegalus*	7	12
Ring-necked Parakeet *Psittacula krameri*	30	90
Blue-crowned Parakeet *Thectocercus acuticaudatus*	2	24
Crested Myna *Acridotheres cristatellus*	19	100
Common Myna *Acridotheres tristis*	10	12

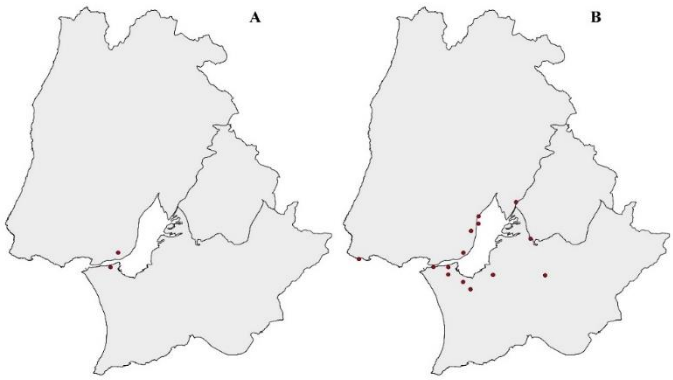

Figure 25 Number of squares (UTM 2 x 2 km) with records of Budgerigar *Melopsitacus undulatus* (A) from 1998 to 2006 and (B) from 2007 to 2016.

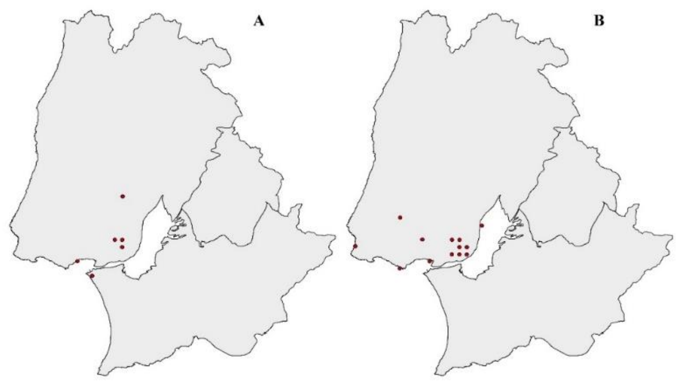

Figure 26 Number of squares (UTM 2 x 2 km) with records of Monk Parakeet *Myiopsitta monachus* (A) from 1998 to 2006 and (B) from 2007 to 2016.

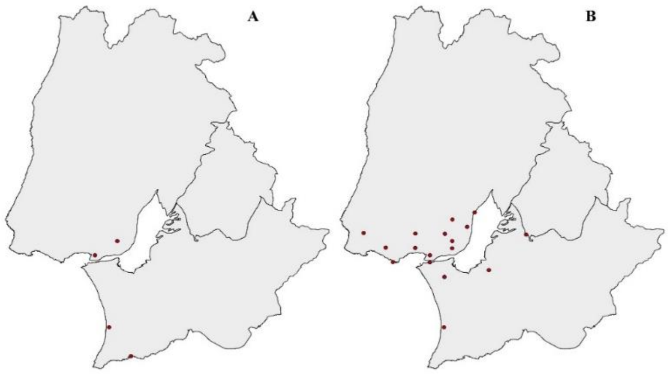

Figure 27 Number of squares (UTM 2 x 2 km) with records of Cockatiel *Nymphicus hollandicus* (A) from 1998 to 2006 and (B) from 2007 to 2016.

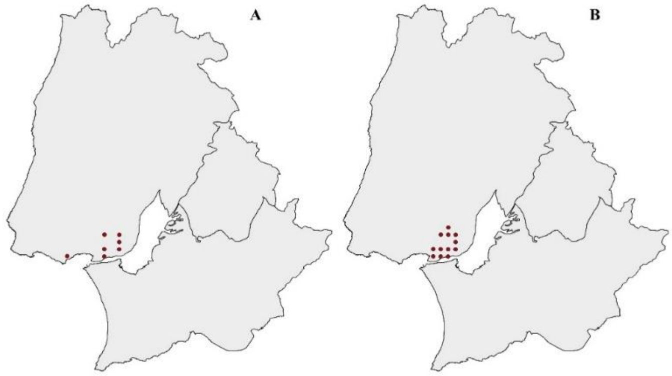

Figure 28 Number of squares (UTM 2 x 2 km) with records of Senegal Parrot *Poicephalus senegalus* (A) from 1998 to 2006 and (B) from 2007 to 2016.

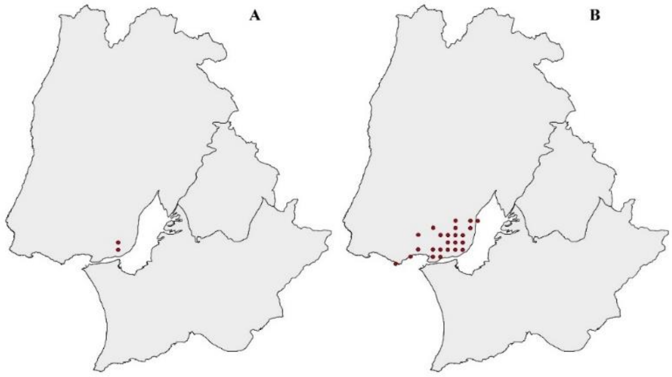

Figure 29 Number of squares (UTM 2 x 2 km) with records of Blue-crowned Parakeet *Thectocercus acuticaudatus* (A) from 1998 to 2006 and (B) from 2007 to 2016.

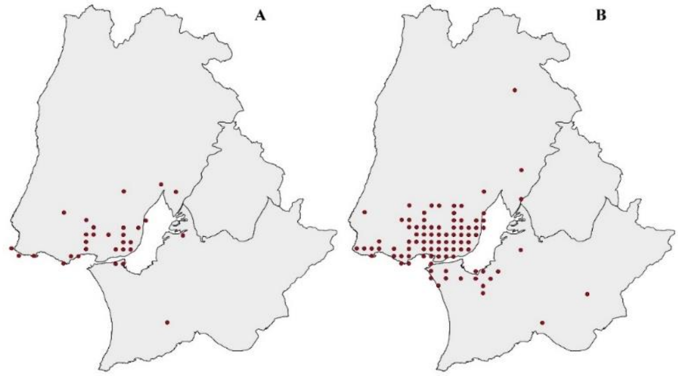

Figure 30 Number of squares (UTM 2 x 2 km) with records of Ring-necked Parakeet *Psittacula krameri* (A) from 1998 to 2006 and (B) from 2007 to 2016.

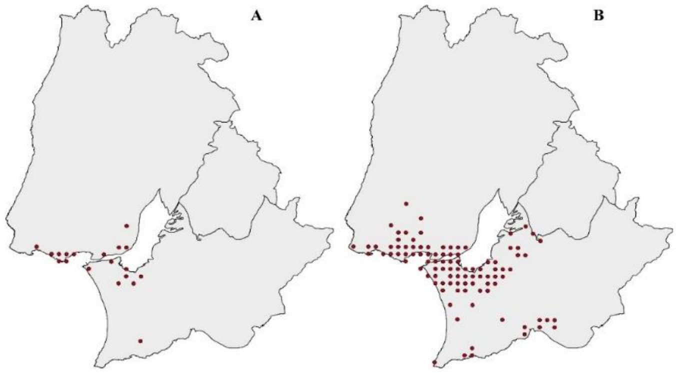

Figure 31 Number of squares (UTM 2 x 2 km) with records of Crested Myna *Acridotheres cristatellus* (A) from 1998 to 2006 and (B) from 2007 to 2016.

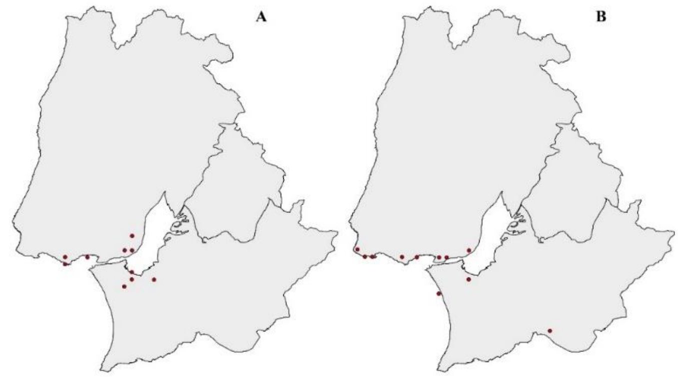

Figure 32 Number of squares (UTM 2 x 2 km) with records of Common Myna *Acridotheres tristis* (A) from 1998 to 2006 and (B) from 2007 to 2016.

Population trend

Only four of the eight non-native species met the requirements proposed in terms of number of records and temporal span to estimate the population trend – Senegal Parrot, Ring-necked Parakeet, Blue Crowned Parakeet, and Crested Myna. The generalized additive models (GAMs) determined for each species showed a good adjustment to the linear data (Table 7).

The data from the Senegal Parrot only allowed an estimate of the population trend from 2007 to 2016 (Fig. 33). During this period, the maximum number of individuals registered per square (N) remained low (mostly less than 6 individuals) and the population model showed an inconsistent pattern oscillating between these low values, with no conclusive trend.

The Ring-necked Parakeet data allowed a population trend estimation from 1998 to 2016 (Fig. 34). The model suggests that the Ring-necked Parakeet population remained stable and low until 2008. After this, the model showed an increase between 2008 and 2011 followed by a stabilization of the population of the Ring-necked Parakeet.

The population trend of the Blue-crowned Parakeet was determined for the period 2005 – 2016 (Fig. 35). Despite some oscillations, overall the population of the Blue-crowned Parakeet showed a moderate increase over time. Both the number of squares with presence and the maximum number of individuals per square (N) oscillated over time, suggesting an agreeing positive trend.

The population trend of the Crested Myna was determined for the period between 1999 and 2016 (Fig. 36). The model showed modest but consistent increase of the population over time, especially from 2009 onwards. The number of squares with presence and the maximum number of individuals per square (N) both progressively increased over time.

Table 7 Parameters of the generalized additive models (GAM) used to estimate the population trends of the Senegal Parrot *Poicephalus senegalus*, Ring-necked Parakeet *Psitacula krameri*, Blue-crowned Parakeet *Thectocercus acuticaudatus*, and Crested Myna *Acridotheres cristatellus*.

Parameter	***Poicephalus senegalus***	***Psittacula krameri***	***Thectocercus acuticaudatus***	***Acridotheres cristatellus***
edf	5.907	7.855	8.442	8.816
Ref. df	7.081	8.502	8.909	8.989
χ^2	27.64	1131	120.4	654.4
p-value	< 0.001	< 0.001	< 0.001	< 0.001
Adjusted r^2	0.0933	0.225	0.146	0.0369
Deviance explained (%)	24.0	40.4	28.0	13.9
UBRE score	1.4749	5.4642	5.0649	12.973
n	50	532	72	360

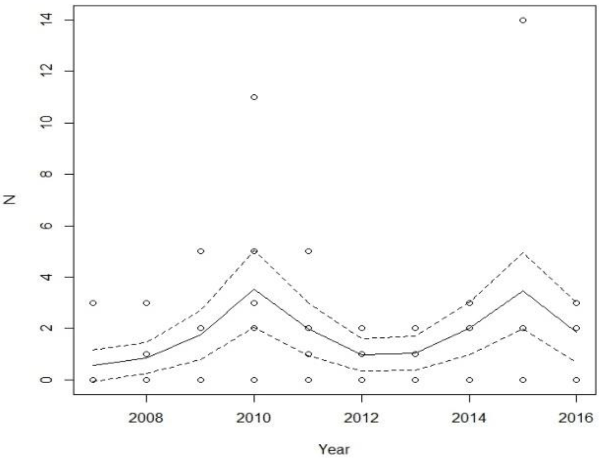

Figure 33 Population trend estimate (2007-2016) using the maximum number of individuals of the Senegal Parrot *Poicephalus senegalus* per square. GAM curve estimate (solid line) with the standard error of the model (dashed lines). The dots represent the maximum number of individuals registered in a given 2x2 km UTM square (N).

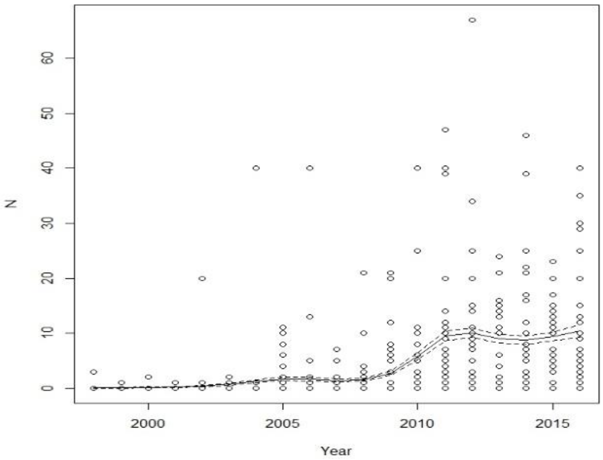

Figure 34 Population trend estimate (1998-2016) using the maximum number of individuals of the Ring-necked Parakeet *Psittacula krameri* per square. GAM curve estimate (solid line) with the standard error of the model (dashed lines). The dots represent the maximum number of individuals registered in a given 2x2 km UTM square (N).

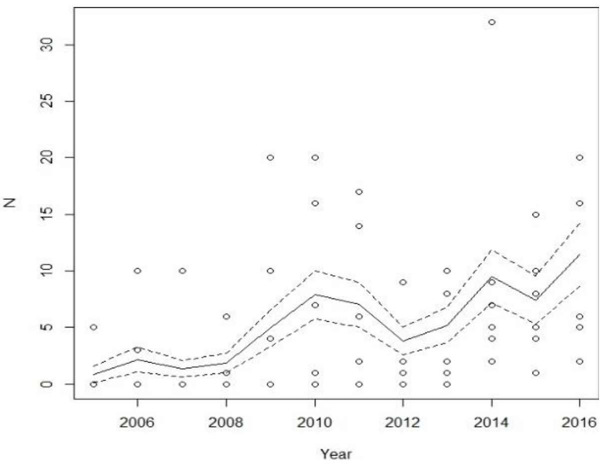

Figure 35 Population trend estimate (2005-2016) using the maximum number of individuals of the Blue-cowned Parakeet *Thectocercus acuticaudatus* per square. GAM curve estimate (solid line) with the standard error of the model (dashed lines). The dots represent the maximum number of individuals registered in a given 2x2 km UTM square (N).

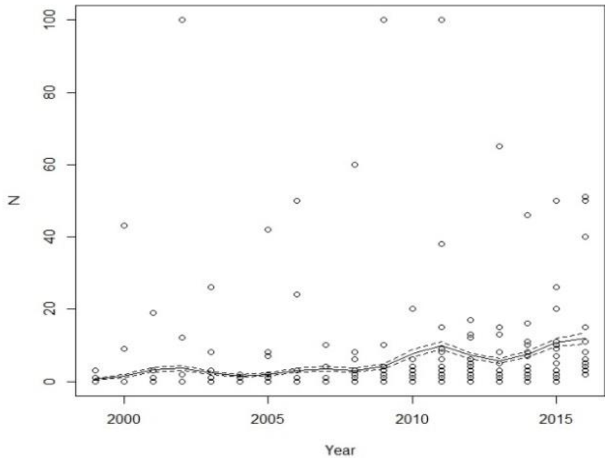

Figure 36 Population trend estimate (1999-2016) using the maximum number of individuals of the Crested Myna *Acridotheres cristatellus* per square. GAM curve estimate (solid line) with the standard error of the model (dashed lines). The dots represent the maximum number of individuals registered in a given 2x2 km UTM square (N).

4. Discussion

In our particular case-study – monitoring the trend in population and distribution range of non-native bird species in the urban region of Lisbon – the data resulting from citizen-science seem to be a reliable source of information. This happened due to of the combination of good expertise of contributors, and a considerable amount of records, that ensured a reasonable homogeneity.

The first strong point, the vast majority of the data has been provided by contributors with good expertise in bird identification. Although most contributors do not work professionally with birds, they have many years of regular birdwatching (often more than 10 years), which should contribute to a strong reliability in the detection and correct identification of the non-native bird species. In addition, most of the non-native bird species considered in our study have distinctive morphological characteristics, being colourful and having diagnostic plumages traits, which facilitates their easily identification, even by less-experienced observers. Behaviourally, many of these species have high-pitched and distinct calls and are gregarious (e.g. outside their breeding season, when they can form large feeding and roosting flocks), also drawing attention of observers.

The second strong point in the use of citizen-science for our case study is the large number of records available. Particularly the motivation of birdwatchers by the eBird platform has made available a very large number of bird records, including non-native species. This happens because the characteristics of birds that facilitate their observation, thus creating many bird enthusiasts throughout the world, and consequently making of birds one of the best groups for studies relying on citizen-science (Sullivan *et al*. 2009). Since the appearing of online platforms, the number of contributors and records have been consistently raising, which is promising for the continued use of citizen-science data to assess distribution and population trends of non-native birds (Sullivan *et al*. 2017).

A third point to highlight is the temporal coverage of the data. Records are available for many years, allowing a 20-year series. Even though the eBird platform has a relatively recent implementation in Portugal (launched in 2002, it became more popular in Portugal after 2005, and boosting particularly after 2015), most contributors have been motivated to make available most of their historical records. This means that, for our case-study, there was a strong possibility to detect the approximate moment of introduction of the non-native bird species in the study area. We found an increasing temporal trend in the number of records for all bird species, i.e. a growth in the amount of citizen-science data available along the years. At first sight this is a potential source of bias to assess the population trends of non-native bird species. However, when we compared the curves of increase in the number of records for all bird species and only the non-native species, we found that the first started in 2002, while the second only started in 2007. This suggests that when the most noticeably population increase of non-native species started, the observation effort carried out was already considerable. Although we consider this an indicator of reliability, we cannot absolutely discard an effect of the growth of bird records on the trends we found for the non-native species. Still, we consider that the bias is not strong enough to produce a fake trend. This is also suggested by the fact that the relative contribution of records (RCR) started decreasing very soon (2004 for all bird species and 2001 for non-native species).

Regarding the fourth aspect, which is the spatial coverage of the citizen-science data, we also found no strong bias. There was a strong increase in the number of squares with adequate coverage along the last two decades, which started at 15% and reached 46% of the total number of squares of the study area. However, this coverage has always been relatively well distributed spatially along the years, which should allow the detection of relevant changes in the distribution range of non-native bird species. Consequently, we assumed that for our case-study, the citizen-science data can reliably inform about trends in distribution range. Our study area is the most populated area in Portugal, which promotes a large number of birdwatchers and consequently a large number of records. Therefore, we acknowledge that an eventual replication of this study on a less populated area, may no yield sufficient data from citizen-science.

In summary, and considering the above-mentioned points, we conclude that the use of citizen-science to estimate the population and distribution trends of non-native species can be a reliable alternative to traditional scientific methods, and it may also work as a complementary way of filling information gaps (Dickinson *et al*. 2010, Klemann-Junior *et al*. 2017). Although we found a few data sources fitting the concept of citizen-science, by far the most promising for our case-study was the platform eBird. It is highly relevant to add that, for an equivalent period and extension, there is very little published scientific data that could be a more accurate alternative to estimate population and distribution trends (but see Costa *et al*. 1997, Matias 2002, Equipa Atlas 2008, Matias 2008, Catry *et al*. 2010, Saavedra *et al*. 2015, Luna *et al*. 2016).

The data from citizen-science sources proved to be efficient in detecting the two groups of non-native species (Psittaciformes and Sturnidae), taking into account that we compiled records from a total of 18 species of non-native species, which is far more than what has been reported in the Portuguese breeding bird atlas for this period (Equipa Atlas 2008), and to the number reported by Matias (2002), who compiled records of non-native bird species in Portugal. We also found the species we compiled and the species introduced in Portugal and Spain for longer periods to be coincident (Abellán *et al*. 2016). These two particular groups of birds are generally conspicuous, leaving close to humans (e.g. parakeets in gardens) or foraging in the open (e.g. mynas feeding on the ground in parks and other areas with grass). The use of citizen-science data may be more limited in the case of more discrete non-native species, when these occur in low density, or in remote and forested areas (e.g. Pereira *et al*. 2017).

Among the species systematically detected, the Ring-necked Parakeet was the most recorded. Our results suggest both a population increase and a range expansion, especially from 2007 onwards. Luna *et al*. (2016) also suggest a population increase in the city of Lisbon, based on roost counts. The Ring-necked Parakeet is a very successful invader in many European countries (Strubbe & Matthysen 2009a, Czajka *et al*. 2011, Butler *et al*. 2013, Pârâu *et al*. 2015), which indicates it is capable to adapt to several mild to warm climates, and it does not seem to be strongly limited by nest availability or food resources constraints. The Ring-necked Parakeet is known to interact with native species, having a potential for competitive interactions for food and nest sites, namely by interference (Strubbe & Matthysen 2009b, Czajka *et al*. 2011, Newson *et al*. 2011, Hernández-Brito *et al*. 2014, Peck *et al*. 2014, Le Louarn et al. 2016, Mori *et al*. 2017)

The Crested Myna showed a marked increasing trend in population and distribution range in the urban region of Lisbon. Saavedra *et al*. (2015) also suggest that the Crested Myna was registering an exponential increase (up to the date of 2011). This species has also been introduced in a few locations in Spain, but the region of Lisbon seems to currently be the only established population in Europe (Saavedra *et al*. 2015, Craig & Feare 2018). This species seems to be well-adapted to the environmental conditions in the study area. We found no references to potential impacts of the Crested Myna on other species or human activities. However, the congener Common Myna is known to compete with native species (Lowe *et al*. 2011) and to be hard to eradicate when the population reaches a larger size (Saavedra 2010).

Despite less markedly than the case of the Ring-necked Parakeet and Crested Myna, the Blue-crowned Parakeet also seems to be increasing, both in population size and distribution range. It has been regularly seen since 1998, occupying similar sites as the Ring-necked Parakeet (mostly gardens and parks). Despite its slightly larger size, the Blue-crowned Parakeet has not gained advantage over the Ring-necked Parakeet to the point of displacing it from these sites. As a result of being one of the most traded south American bird species, the Blue-crowned Parakeet has been found breeding successfully and regularly outside its native range in the United States of America (i.e. in Florida, California and Hawaii), in the United Kingdom, and in Spain (Fernández-Juricic 1998).

We could not determine a population trend for the Senegal Parrot. It has remained in low numbers in the study area, occupying more or less the same locations (i.e. restricted to city centre of Lisbon). Despite the first records date from 1998, and being regularly observed after that, the Senegal Parrot has not been able to establish a stable population. This can be due to a small founder population, and/or environmental limitations. Nevertheless, this species has been occasionally registered in urban environments from several countries such as the United States (Witmer *et al*. 2007), including Hawaii (Runde *et al*. 2007) and Puerto Rico (Falcón & Tremblay 2018), Lebanon (Ramadan-Jaradi & Ramadan-Jaradi 2012), Spain, France and Germany (Mori *et al*. 2013).

The records of the Monk Parakeet have been regular in the study area since 1998, however, only in low numbers and in low number of individuals simultaneously observed (two on average). This can be a disadvantage in colder climates, since the species nests and roots communally and their survival seems to be dependent of the thermoregulatory benefits from this reproductive strategy (Burger & Gochfeld 2009, Strubbe & Matthysen 2009a). However, it should not be the case of the study area, where the winter is mild. The reasons for the establishment failure are not clear. A possible explanation can be related to the species being released or escape from captivity only in low numbers. Despite that, the species has self-sustaining populations across North America and Western and Southern Europe (Sol *et al*. 1997, Di Santo *et al*. 2016). In fact, it is established in several cities in Spain (Murgui 2001, Domènech et al. 2003, Muñoz & Real 2006) and a possible range expansion to Portugal is not to be discarded, since the species has a high invader potential (MacGregor-Fors *et al*. 2011, Di Santo *et al*. 2016, 2017).

The Budgerigar has been regularly recorded in the study area since 1998, but with very few records every year. Apparently, this species has not been capable of establishing an introduced population, which suggests that the individuals that escape from captivity have low probability of survival. The climate should not be a limitation to this species, leaving in turn the explanation to the food limitation, namely through competition with other species, as observed in the population established in Florida (Wenner & Hirth 1984, Butler *et al*. 2005). Despite its introduction in many countries worldwide as a consequence of being a popular cage bird, most of the introductions were unsuccessful, existing no records of an established population in Europe (Wenner & Hirth 1984, Juniper & Parr 1998, Pranty 2001).

In a pattern similar to the Budgerigar, the Cockatiel has been regularly recorded in the study area since 2003, but the number of records per year is very reduced. The Cockatiel is a popular cage bird, which promotes regular birds escapes from captivity, but this should almost always occur in a small number (predominantly 1 individual at a time). This smaller founder population size, together with some limitations to survival (e.g. lack of food, competition for food and refugia) may explain why the Cockatiel has no established populations in the study area, despite often escaping from captivity. Worldwide, the Cockatiel has no established populations outside its native range, suggesting a low potential as invasive species.

The Common Myna has been introduced in several countries outside its native range (Peacock *et al*. 2007), being one of the non-native bird species with the highest global impact (Martin-Albarracin *et al*. 2015), earning a mention among the “100 of world’s worst invasive alien species” by the World Conservation Union – IUCN (Lowe *et al*. 2000). It has been recorded since 1997, but the number of records has remained low all along the last two decades. Thus, despite its strong potential as invasive species, the Common Myna has been constrained by some factors that have prevented its establishment and consequent population increase. Although we have no evidence, we may speculate that the competition with the Crested Myna may be a limiting factor to the Common Myna, since they are expected to explore similar foraging habitats and food sources. A smaller founder population may also be a reason why the Common Myna has not invaded the study area. However, considering the invasive potential, it is highly important to regularly monitor this species spatio-temporal coverage of the data.

5. Conclusion

Monitoring non-native species is essential to know their distribution and population trend, and thus to anticipate and mitigate their threats to biodiversity and the ecosystems. With the development of new technologies, it is more easier and faster to collect information and anyone interested can contribute, increasing our understanding about this ecological problem. Large-scale datasets, such as eBird's, are a great example of how a large number of contributors can influence the knowledge in many ways. However, it is important to recognize the potential weaknesses of these databases to proper analyse the data they provide.

In our case-study we could verify the use of citizen-science data was a valuable solution to assess non-native species populations. The results we found can be considered relevant, since this problematic is poorly explored in the area we evaluate. From the eight species more frequently recorded in the study area, two show a distinct pattern of population and distribution increase: The Ring-necked Parakeet and the Crested Myna. Therefore, these two species would deserve a future investment in assessing their status as invasive non-native species, including a risk assessment.

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Appendix

Appendix 1 Data sources reviewed to assemble the non-native species data set.

Source
SPEA Ornithological Yearbook
Matias, R. (2003). Aves exóticas em Portugal: anos de 2000 e 2001. Anuário Ornitológico 1: 47-57
Matias, R. (2004). Aves exóticas em Portugal: ano de 2002. Anuário Ornitológico 2: 55-63
Matias, R. (2006). Aves exóticas em Portugal: anos de 2003 e 2004. Anuário Ornitológico 4: 55-63
Matias, R. (2010). Aves exóticas em Portugal: anos de 2005-2008. Anuário Ornitológico 7: 95-108
Matias, R. (2011). Aves exóticas em Portugal: anos de 2009 e 2010. Anuário Ornitológico 8: 94-104
Matias, R. (2012). Aves exóticas em Portugal: ano de 2011. Anuário Ornitológico 9: 57-65
SPEA Ornithological News
Noticiário Ornitológico 218
Noticiário Ornitológico 386
Online databases
BioDiversity4All - http://www.biodiversity4all.org/
eBird - https://ebird.org/portugal/home
Aves exóticas em Portugal - https://www.flickr.com/groups/aves_exoticas_portugal/
Aves de Portugal Continental - https://www.facebook.com/groups/121307984660183/
Websites
Arca de Noé - http://www.arcadenoe.pt/
Birding Cascais - http://birdingcascais.blogspot.pt/
Birding Lisbon - http://lisbon.avesdeportugal.info/
Cadernos de Ornitologia - https://sites.google.com/site/cadernosdeornitologia/
Fórum Aves – Aves de Portugal - http://aves.team-forum.net/
O Jumento - http://jumento.blogspot.pt/2012/10/umas-no-cravo-e-outras-na-ferradura_9.html
Passarinhadas - https://passarinhadas.wordpress.com/
Travels with birds - http://travellingbirder.blogspot.pt/

Appendix 2 Total number of records and the total number of years with records of all non-native bird species registered in the study area.

Group	*Species*	*Number of records*	*Years with records*
Psittaciformes	Fischer's Lovebird *Agapornis fischeri*	3	1
Psittaciformes	Rosy-faced Lovebird *Agapornis roseicollis*	4	4
Psittaciformes	Orange-winged Amazon *Amazona amazonica*	2	2
Psittaciformes	Yellow-crowned Amazon *Amazona ochrocephala*	1	1
Psittaciformes	White Cockatoo *Cacatua alba*	1	1
Psittaciformes	Burrowing Parrot *Cyanoliseus patagonus*	2	2
Psittaciformes	Budgerigar *Melopsittacus undulatus*	28	14
Psittaciformes	Monk Parakeet *Myiopsitta monachus*	38	14
Psittaciformes	Nanday Parakeet *Nandayus nenday*	3	1
Psittaciformes	Cockatiel *Nymphicus hollandicus*	32	12
Psittaciformes	Senegal Parrot *Poicephalus senegalus*	128	15
Psittaciformes	Ring-necked Parakeet *Psittacula krameri*	2098	20
Psittaciformes	Grey Parrot *Psittacus erithacus*	2	1
Psittaciformes	Blue-crowned Parakeet *Thectocercus acuticaudatus*	297	13
Sturnidae	Crested Myna *Acridotheres cristatellus*	1705	19
Sturnidae	Common Myna *Acridotheres tristis*	54	15
Sturnidae	Common Hill Myna *Gracula religiosa*	1	1
Sturnidae	Purple Starling *Lamprotornis purpureus*	2	2
	Total	**4401**	

Appendix 3 Total number of records and the number of records (per year) of Budgerigar *Melopsittacus undulatus*, Monk Parakeet *Myiopsitta monachus*, Cockatiel *Nymphicus hollandicus*, Senegal Parrot *Poicephalus senegalus*, Ring-necked Parakeet *Psittacula krameri*, Blue-crowned Parakeet *Thectocercus acuticaudatus*, Crested Myna *Acridotheres cristatellus,* and Common Myna *Acridotheres tristis.*

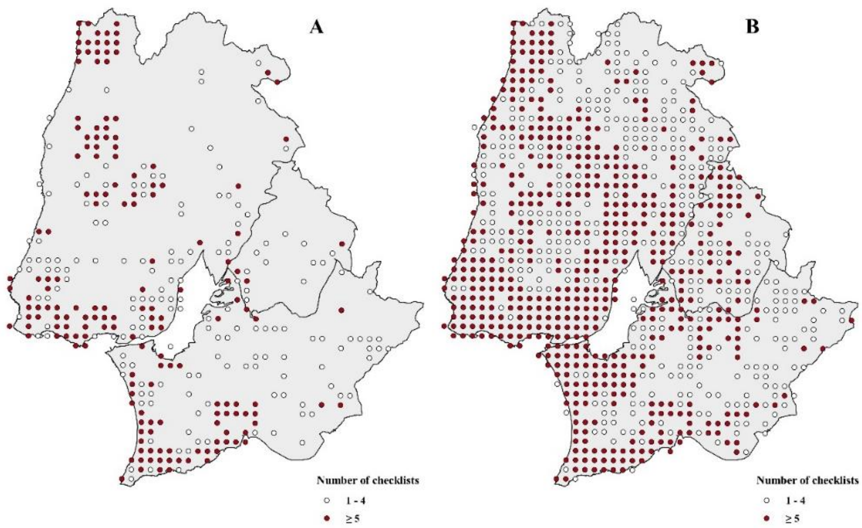
Years	Melopsittacus undulatus	Myiopsitta monachus	Nymphicus hollandicus	Poicephalus senegalus	Psittacula krameri	Thectocercus acuticaudatus	Acridotheres cristatellus	Acridotheres tristis	Total
1990	0	0	0	0	1	0	0	0	**1**
1991	0	0	0	0	0	0	0	0	**0**
1992	0	0	0	0	0	0	0	0	**0**
1993	0	0	0	0	0	0	0	0	**0**
1994	0	0	0	0	0	0	0	0	**0**
1995	0	0	0	0	0	0	0	0	**0**
1996	0	0	0	0	0	0	0	0	**0**
1997	0	0	0	0	0	0	1	0	**1**
1998	3	1	0	8	6	6	0	0	**24**
1999	3	1	0	1	5	0	6	0	**16**
2000	0	3	0	0	2	0	9	1	**15**
2001	0	0	0	0	5	0	8	1	**14**
2002	0	0	0	4	12	0	9	3	**28**
2003	1	0	1	1	13	0	9	4	**29**
2004	0	0	0	0	4	0	2	4	**10**
2005	0	2	1	4	11	1	9	4	**32**
2006	1	2	4	0	12	4	8	5	**36**
2007	1	0	2	1	9	6	9	0	**28**
2008	1	1	1	8	29	7	18	5	**70**
2009	1	1	0	5	54	8	18	2	**89**
2010	1	9	1	14	78	5	52	5	**165**
2011	1	3	3	11	243	33	84	9	**387**
2012	3	1	1	4	185	15	91	3	**303**
2013	2	1	3	8	183	18	205	4	**424**
2014	4	4	3	20	314	34	240	0	**619**
2015	3	1	6	18	399	59	277	1	**764**
2016	3	8	6	21	533	101	650	3	**1325**
Total	**28**	**38**	**32**	**128**	**2098**	**297**	**1705**	**54**	**4380**

Appendix 4 Number of 2 x 2 km UTM squares (per year) sampled with records of Budgerigar *Melopsittacus undulatus*, Monk Parakeet *Myiopsitta monachus*, Cockatiel *Nymphicus hollandicus*, Senegal Parrot *Poicephalus senegalus*, Ring-necked Parakeet *Psittacula krameri*, Blue-crowned Parakeet *Thectocercus acuticaudatus*, Crested Myna *Acridotheres cristatellus,* and Common Myna *Acridotheres tristis.*

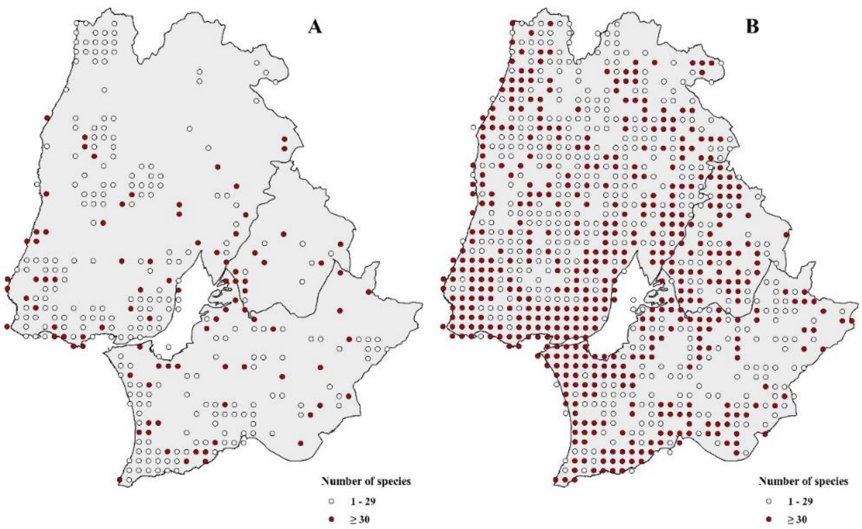
Years	Melopsittacus undulatus	Myiopsitta monachus	Nymphicus hollandicus	Poicephalus senegalus	Psittacula krameri	Thectocercus acuticaudatus	Acridotheres cristatellus	Acridotheres tristis
1990	0	0	0	0	1	0	0	0
1991	0	0	0	0	0	0	0	0
1992	0	0	0	0	0	0	0	0
1993	0	0	0	0	0	0	0	0
1994	0	0	0	0	0	0	0	0
1995	0	0	0	0	0	0	0	0
1996	0	0	0	0	0	0	0	0
1997	0	0	0	0	0	0	1	0
1998	2	1	0	2	1	1	0	0
1999	2	1	0	1	2	0	3	0
2000	0	3	0	0	2	0	2	1
2001	0	0	0	0	4	0	4	1
2002	0	0	0	2	9	0	5	3
2003	1	0	1	1	7	0	6	3
2004	0	0	0	0	3	0	2	2
2005	0	2	1	4	9	1	7	3
2006	1	2	3	0	7	2	6	4
2007	1	0	2	1	6	1	7	0
2008	1	1	1	4	11	2	13	4
2009	1	1	0	2	19	4	13	1
2010	1	5	1	5	21	4	24	3
2011	1	3	3	5	32	7	31	5
2012	3	1	1	4	39	8	32	3
2013	2	1	2	7	37	10	31	3
2014	4	3	3	6	35	11	34	0
2015	1	1	4	6	44	13	46	1
2016	3	5	5	5	51	15	69	3
Total	**15**	**16**	**18**	**13**	**101**	**24**	**102**	**19**

Appendix 5 Number of squares adequately sampled (i.e. with 5 checklists, 30 species and 4 hours of sampling time) per sampling period (1998-2006 and 2007-2016). The total shows the total number of squares that fulfill at least one of the effort indicators, per sampling period.

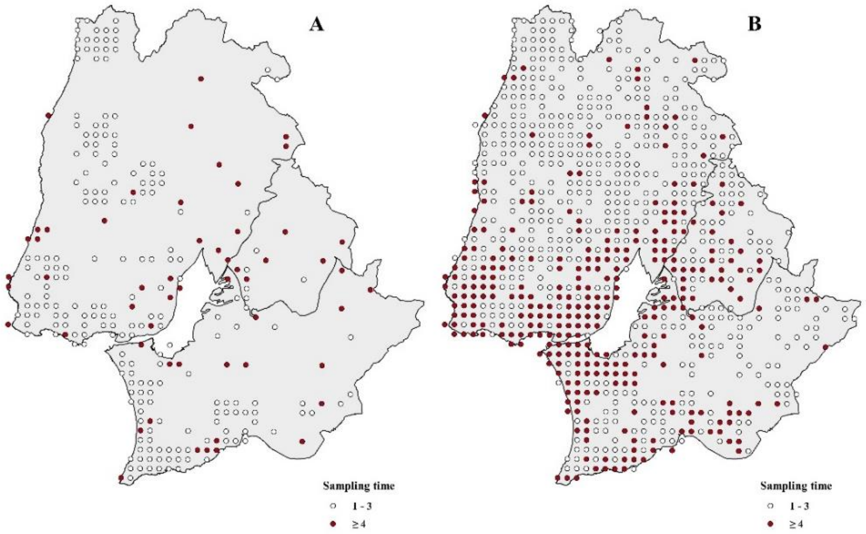
Effort indicators	≥ 5 checklists	≥ 30 species	≥ 4 hours	Total
1998 - 2006	168	92	55	**204**
2007 - 2016	554	503	303	**640**



Appendix 6 Spatial distribution of squares (2x2 km UTM) sampled with less than 5 checklists (white dots) and with 5 or more checklists (red dots) per sampling period (A: 1998-2006; B: 2007-2016). Each dot represents a square's centroid.



Appendix 7 Spatial distribution of squares (2x2 km UTM) sampled with less than 30 species (white dots) and with 30 or more species (red dots) per sampling period (A: 1998-2006; B: 2007-2016). Each dot represents a square's centroid.



Appendix 8 Spatial distribution of squares (2x2 km UTM) sampled with less than 4 hours (white dots) and with 4 or more hours of sampling time (red dots) per sampling period (A: 1998-2006; B: 2007-2016). Each dot represents a square's centroid.