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Records of breeding activity in birds of the Lima Metropolitan Area, central coast of Peru, based on citizen science data

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Abstract: We compiled 302 breeding records from an in-depth review of bird observational records from the Lima Metropolitan Area (Lima-Peru), from eBird and iNaturalist, during 2000-2020. We (1) determined the geographic distribution of breeding records and breeding activity of species, (2) examined periods of breeding activity, and (3) described nesting patterns including nesting habitat use, host plant preference, and clutch size. Records occurred in 27 districts and encompassed 45 species. *Haematopus palliatus* (n=52) and *Podiceps major* (n=36) had the highest numbers of breeding records, and *Zenaida meloda* had the highest diversity of breeding activity (6 types of records). We established breeding periods for 21 species, including those breeding throughout the year (n=10), during the dry-warm season (December-April, n=5), during the humid-cold season (June-October, n=3), and some others showing some variation between the two seasons (n=3). Out of a total of 82 nesting records, 52.4% were associated with natural or artificial aquatic environments. We identified 15 host plant species, that provided support to eight nesting species. Nests of *Charadrius vociferus* (3 eggs), *H. palliatus* (1-4 eggs), and *Z. meloda* (2 eggs) showed invariable clutch sizes compared to what has been reported for these species in other areas of the Peruvian central coast. We showed that citizen science data is a useful tool for studying breeding biology, especially of Peruvian birds, where more traditional data sources are scarce.

Key words: citizen science, urban birds, breeding biology, Lima-Peru, eBird, iNaturalist

Resumen: Registros de actividad reproductiva en aves del Área Metropolitana de Lima, costa central del Perú, con base en datos de ciencia ciudadana. Recopilamos 302 registros reproductivos a partir de una revisión en profundidad de registros de observación de aves del Área Metropolitana de Lima, (Lima-Perú), de eBird e iNaturalist, durante 2000-2020. Nosotros (1) determinamos la distribución geográfica de los registros reproductivos y la actividad reproductiva de las especies, (2) examinamos los períodos de actividad reproductiva y (3) describimos los patrones de anidación, incluido el uso del hábitat de anidación. Los registros ocurrieron en 27 distritos y abarcaron 45 especies. *Haematopus palliatus* (n=52) y *Podiceps major* (n=36) tuvieron el mayor número de registros de reproducción, y *Zenaida meloda* tuvo la mayor diversidad de actividad de reproducción (6 tipos de registros). Establecimos periodos de reproducción para 21 especies, incluyendo las que se reproducen durante todo el año (n=10), durante la estación seca-cálida (diciembre-abril, n=5), durante la estación húmeda-fría (junio-octubre, n=3), y algunos otros que muestran alguna variación entre las dos estaciones (n=3). De un total de 82 registros de anidación, el 52,4% estuvo asociado a ambientes acuáticos naturales o artificiales. Identificamos 15 especies de plantas hospederas, que brindaron apoyo a ocho especies anidadoras. Los nidos de *Charadrius vociferus* (3 huevos), *H. palliatus* (1-4 huevos) y *Z. meloda* (2 huevos) mostraron tamaños de puesta invariables en comparación con lo reportado para estas especies en otras áreas de la costa central peruana. Mostramos que los datos de la ciencia ciudadana son una herramienta útil para el estudio de la biología reproductiva, especialmente en las aves peruanas, donde las fuentes de datos más tradicionales son escasas.

Palabras clave: ciencia ciudadana, aves urbanas, biología reproductiva, Lima-Peru, eBird, iNaturalist

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INTRODUCTION

Breeding is an energetically demanding event in the life history of birds that can directly influence parental fitness and population persistence (Berl *et al.*, 2014; Frei *et al.*, 2015). Detailed descriptions on breeding biology provide natural history data that describe patterns of variation and can be used to address questions of evolutionary, ecological, or conservation significance. Knowledge of basic aspects of breeding biology, such as the breeding season, nest characteristics, clutch size, and nest success is well documented for most Nearctic and Holarctic birds (Xiao *et al.*, 2017) and has helped to understand the influence of phylogenetic history of species on such reproductive traits, the influence of selective pressures on reproductive strategies, or to implement sound management and conservation actions for these birds and their habitats (Martin, 1995; Martin & Clobert, 1996; Keller, 2014; Böhning-Gaese *et al.*, 2000; Hudson *et al.*, 2017). Unfortunately, the information available about basic aspects of breeding biology is still insufficient for Neotropical birds, being known for only 19% of these species (Xiao *et al.*, 2017). Several neotropical countries, including Venezuela, Argentina, Brazil, Paraguay, Ecuador, and Colombia, have made great progress in providing the first available information about the breeding biology of hundreds of bird species, but this information is mostly anecdotal and has been collected on a short-term basis (Fierro-Calderón *et al.*, 2021). Notable exceptions of systematic long-term studies are found in Venezuela and Argentina, which have allowed large-scale comparisons of some reproductive traits (i.e., territory size, incubation period, egg size variation, clutch size, brood size, and nestling growth rates) between north-temperate or tropical birds and south temperate birds (Martin, 2008; Martin *et al.*, 2011; Llambías *et al.*, 2015; Martin *et al.*, 2018); or Panama and Brazil, from which studies of nest success have increased our understanding of predation and forest fragmentation pressures in tropical forests (Robinson *et al.*, 2000; Libsch *et al.*, 2008; Borges & Marini, 2010). Information about the breeding biology of Peruvian birds is also at the frontier of exploration. Most published data comes from first nest descriptions, anecdotal observations in general avifaunal inventories, and monitoring of nesting and incubation behavior in remote places (such as guano islands, desert scrubs, high-Andean region, humid eastern montane forest, and lowland rainforest) (Franke, 2017), while only a few studies have focused on the breeding biology of birds inhabiting urban areas (Gonzalez, 1998; Gonzalez *et al.*, 1999; Gonzalez, 2004; Ortiz, 2012; Ortiz, 2013; Tavera, 2011; Rivas *et al.*, 2013; Amaro & Goyoneche, 2017; Angulo & Moran, 2019; Arenas *et al.*, 2020; Díaz *et al.*, 2022).

Methods that explore the breeding biology of birds include systematic search (i.e., nest searching, nest monitoring, or spot mapping), and the capture and marking of birds; however, these methods often take a long time for researchers to compile a significant amount of data (Alegria, 2018). Furthermore, these approaches can be very labor intensive and costly, so most studies are limited to a small geographic area, a small proportion of the population, or a small group of target species (Ralph *et al.*, 1993). Large databases are needed to gain a comprehensive understanding of when, where, and how Neotropical birds breed. The use of citizen science databases as a potential new method to examine the breeding biology of birds might overcome the limitations mentioned above (Fierro-Calderón *et al.*, 2021). The main purpose of citizen science portals is to report the occurrence/abundance of biodiversity, but also, optionally, additional details from the sightseeing can be provided, including the organism's age, sex, behavior, observation effort, etc. Additionally, the advances in computing and communication technology now make it possible for observers and researchers to upload media files (i.e., photography, videos, and sounds) on these portals, resulting from their observations in the field from anywhere and at any time (Pocock *et al.*, 2018). Through these widespread networks of observers, millions of observational bird reports accumulate across multiple sites all over the world throughout the year, providing an unprecedented trove of information. This information might include a considerable number of breeding records throughout a species' annual cycle, however, no efforts related to an in-depth examination of bird records retrieved from citizen science portals have yet been published according to a review of the "Bibliography of birds of Peru" (Plenge, 2020).

Currently, eBird (https://ebird.org) and iNaturalist (https://inaturalist.org) are two important worldwide citizen portals used by Peruvian birdwatchers. These portals host tens to hundreds of thousands of records across the country (eBird, 2022; iNaturalist, 2022), but possess different data models and different data quality control strategies. eBird is considered a "semistructured" database (i.e., when the design of the database allows extracting of information on sampling effort or completeness) managed by the Cornell Lab of Ornithology (Sullivan *et al.*, 2009). Data quality in this platform is controlled based on accepted species distributions and their estimated counts and suspected unusual records are then reviewed by regional expert reviewers (Wood *et al.*, 2011). On the other hand, iNaturalist is an "unstructured" database (i.e., when the database lacks relevant information on sampling effort) managed by the California Academy of Sciences that allows users to submit single observations of multiple taxa even without previous knowledge about specific taxonomic groups (Nugent, 2018). Data quality in this platform is controlled based on a community identification process but also facilitated by a machine learning algorithm that makes suggestions on species identification to the participant (Van Horn *et al.*, 2018).

Neotropical cities are growing rapidly, expanding over native habitats, and generally conserving only small green areas (de Camargo Barbosa, 2021). A paradigmatic case is the Lima Metropolitan Area (LMA) (Fig. 1), which is considered the most populous and the largest metropolitan area in Peru because it hosts over 30% of the total national population (10.7 million inhabitants) settled in only 0.2% of the national territory (2811.65 km2) (Instituto Nacional de Estadística e Informática, 2015; Instituto Nacional de Estadística e Informática, 2020). The LMA has a vegetation coverage, made up of hills, wetlands, valleys, and green areas, which only represent 14.4% of its total area (405.29 km2,) (Lima Cómo Vamos, 2014). Despite such a small area, these spaces can still harbor important bird diversity including native, exotic, migrant, and rare species (Nolazco, 2012). Given the limited information on the breeding biology of Peruvian urban birds, even opportunistic data compiled from citizen science projects merits publication. The aim of this study was threefold: (1) to determine the geographical distribution of breeding records and patterns of breeding activity, (2) to examine the timing of breeding activity, and (3) to describe patterns of nesting behavior (i.e., nesting habitat use, host plant preference, and clutch size) based on bird observational records retrieved from two citizen science portals, eBird and iNaturalist, from the LMA during the 2000-2020 period (Figs. 2, 3). We also discuss the benefits and challenges of using citizen science data to study Peruvian birds' breeding biology.

METHODS

Study area. The Lima Metropolitan Area (LMA) is in the central and western zone of the South American continent (longitude 77°W and latitude 12°S), in Peru, in the department of Lima. It is an area formed by the conurbation of the Peruvian provinces of Lima and Callao that extends on a large alluvial plain formed by the valleys of the Chillón, Rímac, and Lurin rivers (Rojas *et al.*, 2021). The LMA is considered to have a subtropical desert climate with almost no rainfall throughout the year (average annual precipitation is 10 mm), a temperature range of 14°C to 27°C (average annual temperature is 19°C), and relative humidity of 70% to 100% (average annual humidity is 80%) (SENAMHI, 2016). The dry-warm season occurs from December to April, and the humid-cold season from June to October, with May and November as transition months (Reátegui-Romero *et al.*, 2018). Dominant habitat substrates within the study area can be classified into three major groups following Tello-León (2021): green space, referred to as areas covered with vegetation, including parks, gardens, street trees, and coastal hills; blue space, referred to as waterbodies or watercourses in the city, including artificial reservoirs, river valleys, wetlands, and beaches; and gray spaces, referred to man-made structures formed by paved areas with a civic function, including streets, parking areas, buildings, and utility poles (Online Appendix 1).

Datasets used in this study and description of breeding records. We included photos and videos that evidenced breeding activity collected from 1st January 2000 to 31st December 2020, across 50 municipal districts of the Lima Metropolitan Area (including 43 from Lima Province and 7 from Callao Province), from eBird and iNaturalist. We classified breeding records into nine categories: courtship or copulation (C), adult carrying nesting material (CN), occupied nest (ON), nest with egg (NE), active nest at unknown stage (AN), nestling (N), feeding young (FY), carrying food for young (CF), and recently fledged young (FL). We considered evidence of breeding for non-passerine and passerine birds, including waterfowl, shorebirds, waterbirds, and landbirds. We did not consider evidence of adult birds of certain species spotted on burrows, cavities, or holes, including parrots, wrens, owls, and swallows, because they use it not only for nesting but also for roosting. We also excluded cases of potential hybrids. Descriptions

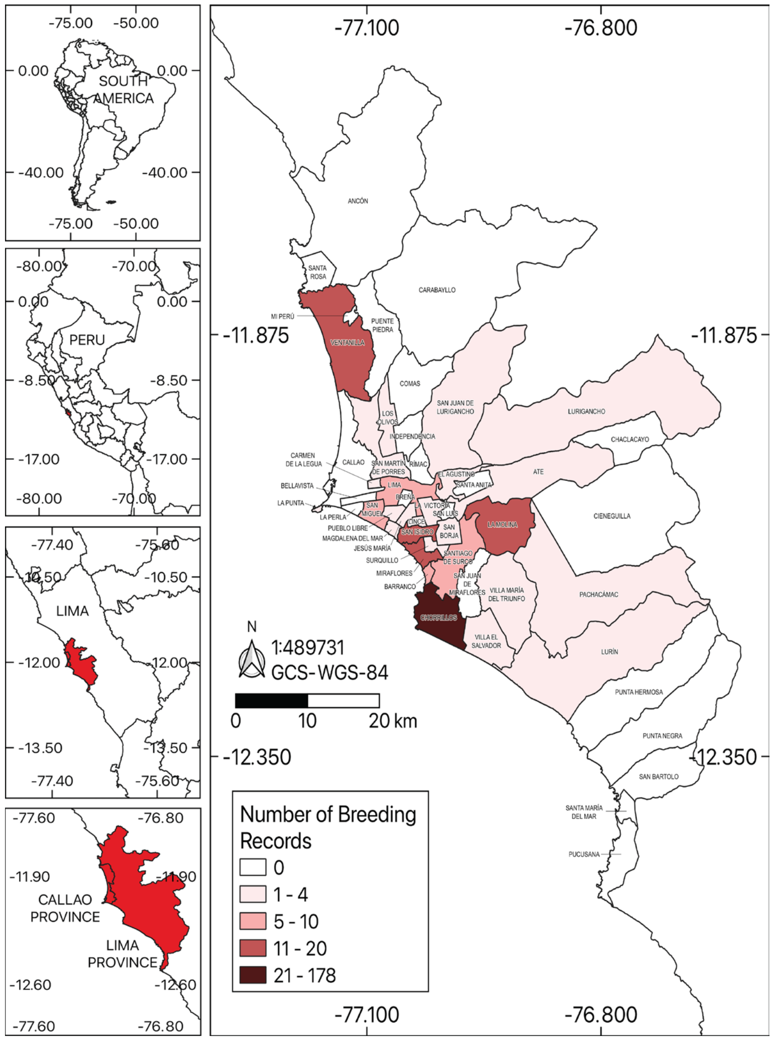

Fig. 1. Map of the Lima Metropolitan Area and the density of breeding records by district retrieved from eBird's and iNaturalist's citizen science data from January 2000 to December 2020.

of breeding events included, when possible, information on mating behavior, clutch size, nest location, the identity of the plant supporting the nest, and parental and young behavior (Online Appendix 2). Age terminology for young birds provided in descriptions followed the consensus definitions proposed by Wood (1946), including "nestling", a bird within and not ready to leave the nest; "fledgling", a bird that has grown enough to acquire its initial flight feathers and is preparing to leave the nest and survive but still being cared for by its parents; "juvenile", a bird in its first plumage of non-downy feathers (juvenal plumage) that has left the nest and is entirely independent; and "immature", a bird in any non-adult plumage, including (but not limited to) the juvenal plumage. The juvenal plumage is very short-lived in most passerines compared to non-passerine birds (Pittaway, 2000) and certain neotropical passerines can disperse long distances even wearing such plumage (Pyle *et al.*, 2015; Gorleri & Areta, 2021), hence, cases of "juveniles" and "immature" birds were excluded from our collection of breeding records given that the goal of our study was to include the closest reliable records in time and place to the mating event.

Preparation of citizen science datasets. We used eBird basic datasets (data upon request on 10 July 2021; version ebd_Jun-2021) and included data from any type of observational pro-

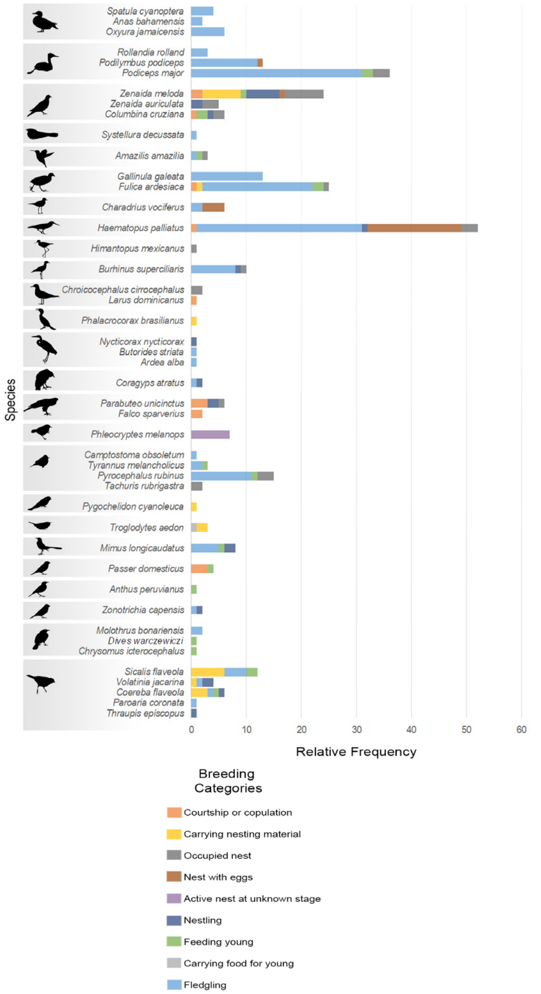

Fig. 2. Number of breeding records per species, classified by their activity, retrieved from eBird and iNaturalist's citizen science data from January 2000 to December 2020.

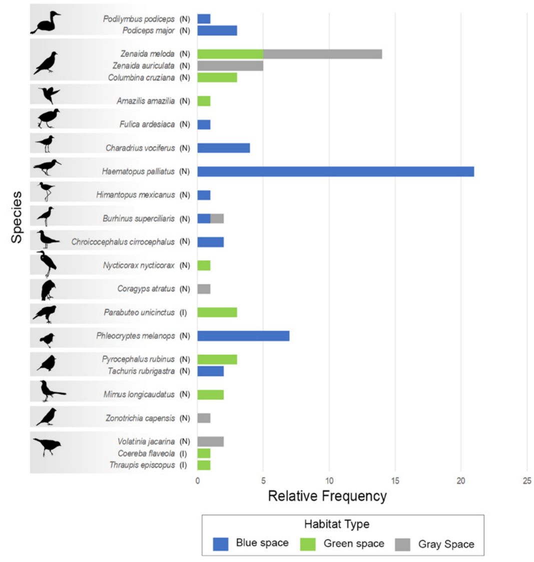

Fig. 3. Number of nesting records by habitat type retrieved from eBird and iNaturalist's citizen science data from January 2000 to December 2020. Occurrence status in LMA: N = native species, I = introduced species.

tocol (stationary, travelling, incidental, historical, or other specialized sampling protocols) (For more details on the eBird methodology, see here: https://support.ebird.org/en/support/home). iNaturalist datasets only included observation reaching the "research grade" status, i.e., when two-thirds of the identifiers of the iNaturalist community confirm the species-level identification for a given observation (For more details on the iNaturalist methodology, see here: https://inaturalist.org/pages/getting+started). Filtered data status from both citizen science portals does not necessarily ensure that the identification of species are correct, as even knowledgeable users and reviewers can sometimes make mistakes (Austen *et al.*, 2018; Callaghan *et al.*, 2021; Rocha-López *et al.*, 2021; Gorleri & Areta, 2021). Moreover, information about breeding behavior of birds might not necessarily be explicit or correctly expressed solely by notes or standardized codes in records from both portals. To account for these biases, we thoroughly scrutinized records with photographs or videos that allowed us to reliably evidence some aspect of the breeding biology of birds. Furthermore, in some cases, eBird checklists and iNaturalist observations might contain multiple images of different individuals that allow us to evidence more than one type of breeding event. For these cases, we treated images showing different types of breeding events as independent records. We also ordered images by date and observer's name to allow a better tracking of individuals from breeding records, thus minimizing the duplication of data from both portals. Given that the information about the breeding biology of Peruvian birds is poorly know, limited data available from eBird and iNaturalist projects related to this aspect could also be expected. Hence, breeding data from both portals were combined for descriptive analyses in this study.

A systematic search was also performed on two specialized Facebook groups, named "Aves de Lima", and "Aves Del Peru", on 10th December 2021, using the following keywords "reproducción” (breeding), “apareamiento” (mating), “copula” (copulation), “nido” (nest), “huevo” (egg), “polluelo” (nestling), “pichon” (nestling), “volantón” (fledgling), to locate records published by users. We only considered records that were not previously published on the eBird and iNaturalist citizen portals. When the information found on one Facebook group was repeated on another, only the first was considered. Then we asked users to submit their breeding records to any of the previously mentioned citizen science portals. An eBird’s group account named “Biologia Reproductiva de Aves Peruanas” was created to incorporate records of users who did not intended to create their own account but provided us permission to submit their records with the assurance that the images would not be used for other purposes. In addition, we created an iNaturalist’s traditional project and announced it in Facebook groups to encourage users to submit additional unreleased breeding records to such citizen science portal.

Geographic distribution of breeding records and breeding activity of species. Since datasets from these citizen science portals did not provide location data at the district level, we intersected observations (based on their latitude/longitude reported location) with a shapefile of Peruvian districts retrieved from Geo GPS Perú (2014) using QGis 2.14 (Quantum GIS Development, 2016). The geographic distribution of breeding bird records was examined by plotting a choropleth map showing the frequency of the different types of breeding activity record per district of the LMA. Breeding species and the types of breeding activity found were represented in a stacked bar graph showing the frequency of each type of breeding record per species.

Breeding seasonality. The timing of breeding activity for each species was examined by summing up all types of breeding records per month to establish periods of breeding activity. Breeding months were then compared to preliminary data for the central coast of Peru (latitudes ~9.5°S to ~14.5°S) to determine coincidences that would corroborate or improve the knowledge of preliminary information. Comparisons followed the criteria proposed by Verea *et al.* (2009), in which the timing of breeding is considered as “coincident” when the breeding months matches identically or falls within the breeding period preliminary proposed for a particular species; “improved”, when there was no preliminary information or if, after coinciding with it, additional months of breeding activity were observed; and “noncoincident”, when the breeding months did not coincide in any way with preliminary data. We analyzed breeding periods for birds that showed at least four continuous monthly records of breeding activity. Also, we considered a species able to breed throughout the year for those whose number of breeding months was equal to or greater than nine

Patterns of nesting behavior. Description of nesting patterns was based on records of nesting birds, including categories of “occupied nest”, “nest with egg”, “active nest at unknown stage”, and “nestling”. Nesting-habitat use was described by plotting a stacked bar graph showing the type of habitat used (green, blue, and gray spaces) per each species of nesting birds. Host plant preference was described by showing a list of identified plant species that provided support to each species of nesting bird by habitat type. We excluded cases of photos or videos that made it harder to correctly identify plant species, especially the ones with poor focus or inadequate zooming on the host plants. Finally, clutch frequency of each species per habitat was described based solely on the records belonging to the category “nest with egg”.

RESULTS

A total of 21424 bird species records containing photographs from eBird (14668 records from 3277 checklists) and iNaturalist observations (6756 records) were examined for this study. The total breeding records corresponded only to 1.4% (n=302) of the total records examined, from which photographs or videos had sufficient evidence to assess their breeding status (Figs. 4–10; Online Appendix 2). From the total breeding records, 220 records were unique to eBird, 69 records were unique to iNaturalist, and 14 records were shared between both portals. We were able to retrieve breeding records spanning 45 bird species, including waterfowl, shorebirds, waterbirds, and landbirds (Fig. 2), which constituted 37.8% of the 119 native and established introduced species that might potentially breed in the LMA (Municipalidad Metropolitana de Lima, 2020).

Geographic distribution of breeding records and breeding activity of species. We recovered records from 27 districts of the LMA,

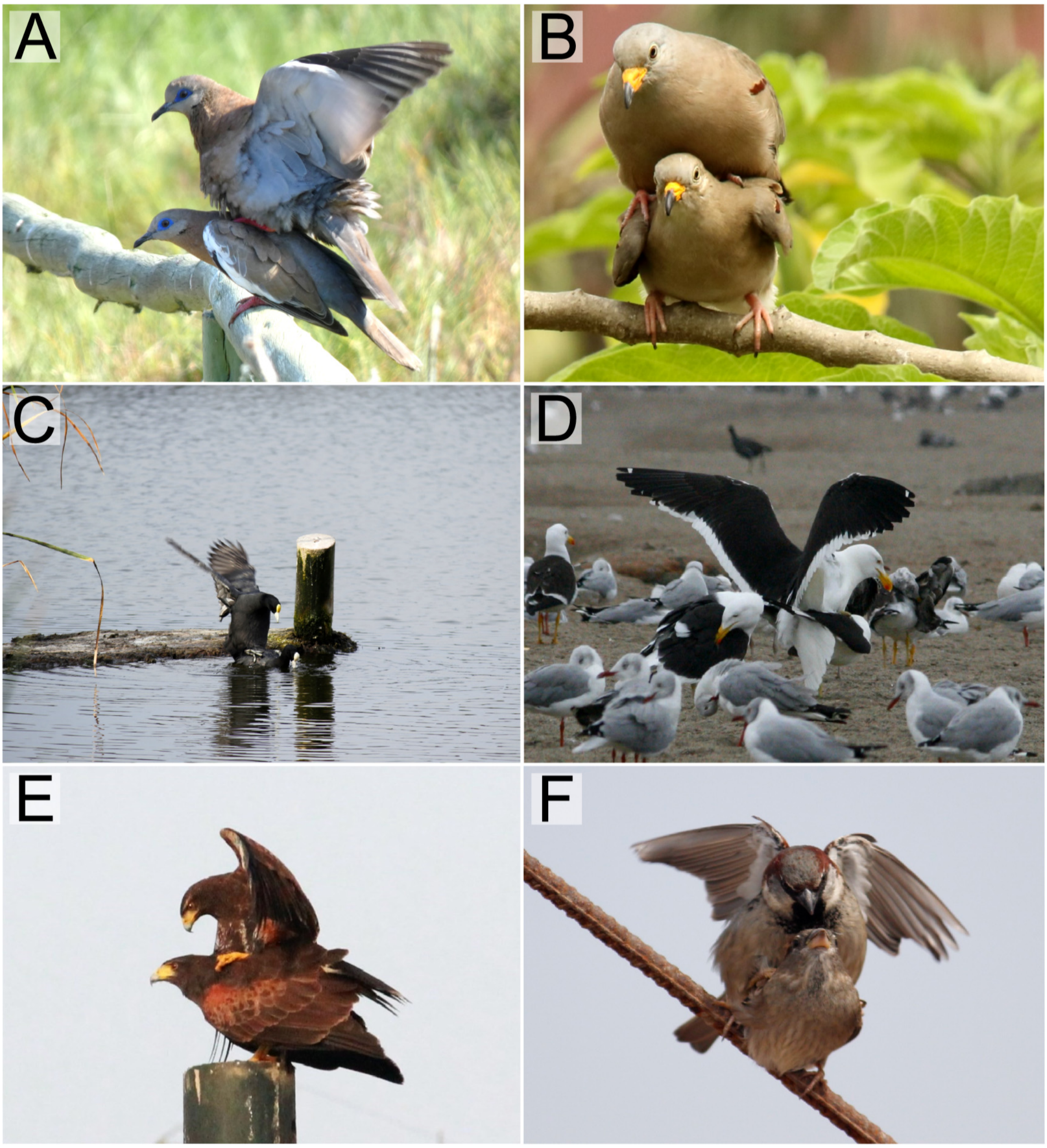

Fig. 4. Examples of records of copulation. For location details, see Online Appendix 2. (A) *Zenaida meloda* (8 March 2020, ML253545841, James Court); (B) *Columbina cruziana* (25 September 2017, ML107087521, Gord Smith); (C) *Fulica ardesiaca* (31 December 2020, iNat[Photos]108843442, Ruth Gutiérrez); (D) *Larus dominicanus* (1 November 2015, ML286328901, Oscar Johnson); (E) *Parabuteo unicinctus* (4 April 2020, ML220540281, Rutger Koperdraad); (F) *Passer domesticus* (13 September 2020, ML262861781, Ruth Gutiérrez).

including 24 districts from Lima Province and 3 districts from Callao Province (Fig. 1; Online Appendix 2). The amount of breeding data coming from both citizen science portals together was markedly greater in the Chorrillos district (60.3%, n=182) than in other districts of the LMA. The American Oystercatcher (*Haematopus palliatus*) and the Great Grebe (*Podiceps major*) were among the top two species with most records contributed during our study period, representing 17.2% (n=52), and 11.9% (n=36) of the total breeding records found, respectively (Fig. 2). The West Peruvian Dove (*Zenaida meloda*) was the species with the highest diversity of breeding re-

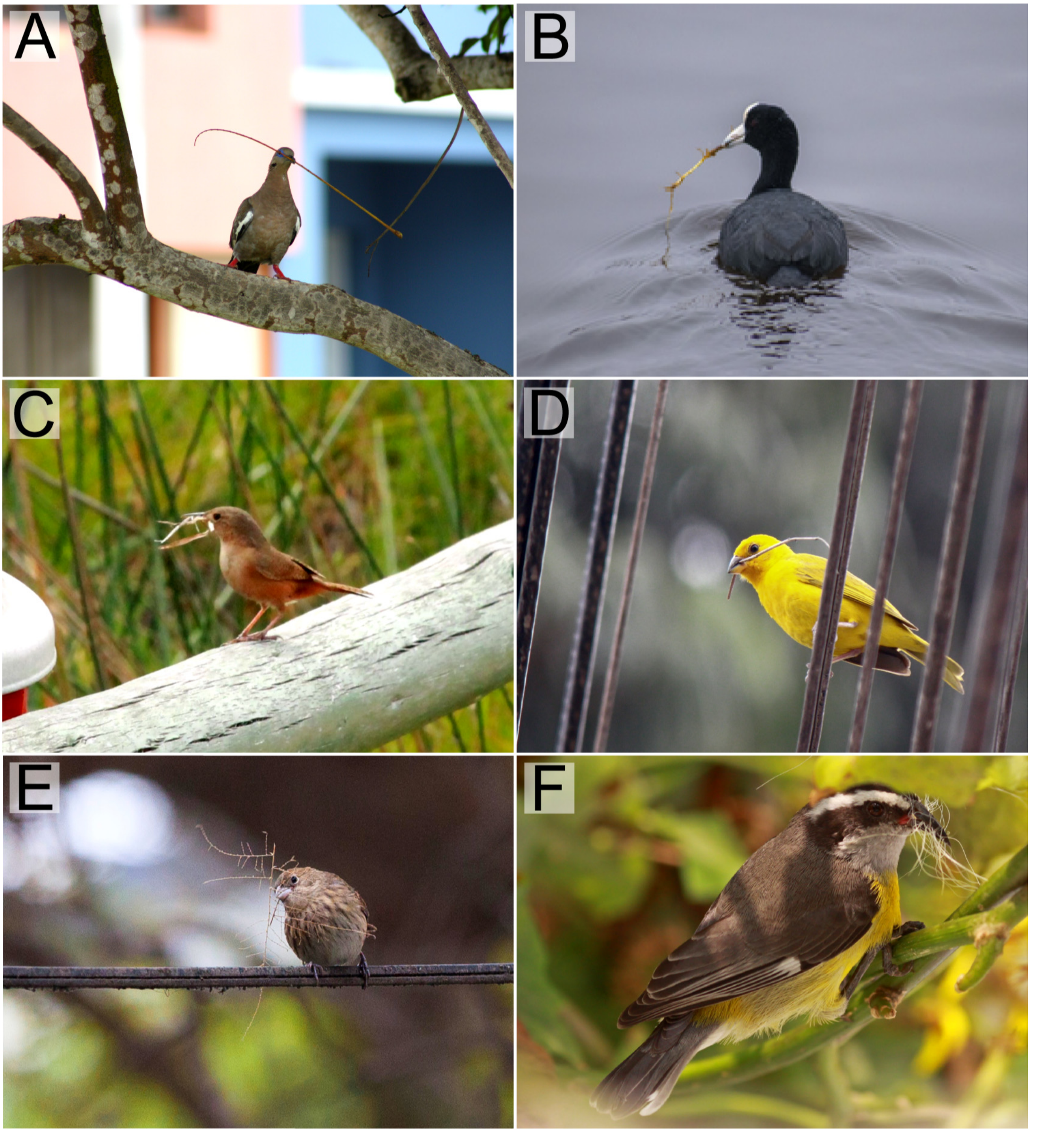

Fig. 5. Examples of records carrying nesting material. For location details, see Online Appendix 2. (A) *Zenaida meloda* (6 October 2019, iNat[Photos]54916985, Camden Bruner); (B) *Fulica ardesiaca* (27 July 2019, iNat[Photos]71812367, Mónica Paredes); (C) *Troglodytes aedon* (7 January 2018, ML81127221, Rutger Koperdraad); (D) *Sicalis flaveola* (3 April 2015, ML23543891, Laura Mae); (E) *Volatinia jacarina* (5 September 2015, iNat[Photos]2406656, Manuel Miranda); (F) *Coereba flaveola* (15 April 2011, ML79594031, Larry Silvio).

cords compiled per species by showing six types of breeding activity records (Fig. 2).

Timing of breeding activity. We were able to establish breeding periods for 24.4% (n= 11) of the total breeding bird species retrieved from citizen science portals. The monthly frequency of breeding records for each species and preliminary information about periods of breeding activity are shown in Table 1. Evidence of breeding activity was found for the following species: the Ruddy Duck (*Oxyura jamaicensis*) and the Pied-billed Grebe (*Podilymbus podiceps*) during the humid-cold season; the Common Gallinule

Fig. 6. Examples of occupied nests. For location details, see Online Appendix 2. (A) *Podiceps major* (11 September 2016, ML70764301, Merryl Edelstein); (B) *Zenaida auriculata* (14 December 2019, ML193256191, Rutger Koperdraad); (C) *Amazilis amazilia* (4 February 2016, ML24650971, Laurie Koepke); (D) *Fulica ardesiaca* (21 November 2012, ML179817281, Simon Walkley); (E) *Himantopus mexicanus* (9 September 2019, ML235292521, Reid Rumelt); (F) *Tachuris rubrigastra* (11 September 2018, ML117175631, Craig Caldwell).

(*Gallinula galeata*) at the end of the humid-cold season and during the dry-warm season; the Peruvian Thick-Knee (*Burhinus superciliaris*), the Vermilion Flycatcher (*Pyrocephalus rubinus*), the Long-tailed Mockingbird (*Mimus longicaudatus*), and the Saffron Finch (*Sicalis flaveola*) during the dry-warm season; and the American Oystercatcher (*H. palliatus*), the Great Grebe (*P. major*), the West Peruvian Dove (*Z. meloda*), and the Slate-colored Coot (*Fulica ardesiaca*) throughout the year.

After comparing our data with preliminary information, we determined that 31.1% (n=14) of the total number of breeding species in our data was "coincident", and in the 13.3% (n=6) of these species our data was "noncoincident".

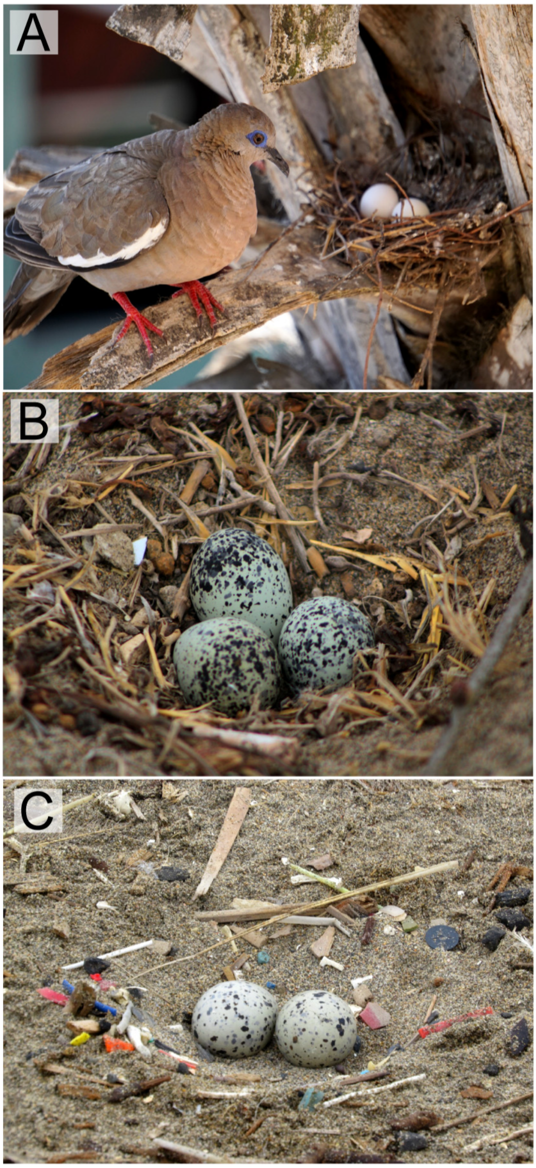

Fig. 7. Examples of nests with eggs. For location details, see Online Appendix 2. (A) *Zenaida meloda* (24 April 2020, iNat[Photos]68437119, Katherine Zapata); (B) *Charadrius vociferus* (19 December 2020, ML289965911, Jorge Ubillas); (C) *Haematopus palliatus* (17 October 2020, ML272466331, Autoridad Municipal de Los Pantanos de Villa PROHVILLA).

In 55.6% (n=25) of these species, an "improved" knowledge of their timing of breeding was obtained; including the fact that in 18 species, such as the White-cheeked Pintail (*Anas bahamensis*), Ruddy Duck (*Oxyura jamaicensis*), the White-tufted Grebe (*Rollandia rolland*), the Pied-billed Grebe (*Podilymbus podiceps*), the West Peruvian Dove (*Zenaida auriculata*), the Common Gallinule (*Gallinula galeata*), Slate-colored Coot (*Fulica ardesiaca*), Kelp Gull (*Larus dominicanus*), Striated Heron (*Butorides striata*), Great Egret (*Ardea alba*), Black Vulture (*Coragyps atratus*), Harris's Hawk (*Parabuteo unicinctus*), American Kestrel (*Falco sparverius*), Tropical Kingbird (*Tyrannus melancholicus*), Peruvian pipit (*Anthus peruvianus*), Scrub Blackbird (*Dives warczewiczi*), Yellow-headed Blackbird (*Chrysomus icterocephalus*), Saffron Finch (*Sicalis flaveola*), there was no preliminary data available about the timing of their breeding activity from central coast of Peru (Table 1).

Patterns of nesting behavior. Records of nesting birds represented 27.1% (n=82) of the total breeding records, from which we described following behavioral patterns:

Nesting-habitat use: We identified 23 species of nesting birds occurring in all three types of habitats (Fig. 3). Blue space had the greatest number of breeding species (n=10) and number of occurrence records (52.4%, n=43), from which nests were found in wetlands and sandy beaches. The American Oystercatcher (*H. palliatus*) was the species with the highest number of records (n= 21) in this type of habitat. Green and gray spaces comprised nine and six breeding species and represented 24.4% (n=20) and 23.2% (n=19) of total number of occurrence records of nesting birds, respectively (Fig. 3). Nests found on green spaces were found on parks, and street trees, whereas nests on gray spaces were found on roof eaves, roof drainages, window box planters, indoor plant pots, shed bases, pillars, utility poles, electricity wires, and roadsides. The West Peruvian Dove (*Z. meloda*) was the species with highest number of records found in green (n = 5) and gray spaces (n=9).

Host plant preference: Records of host plants that we were able to identify represented 30% (n=18) of total records of nesting birds. We identified 15 species of plants that provided support to eight different species of nesting birds in two habitat types (Table 2). Nests were built on horizontal branches or forks of field-grown trees, and pot-grown plants located on green and gray spaces (Online Appendix 2).

Clutch size: Records of nest with eggs represented 26.8% (n=22) of the total nesting bird records and comprised three species occurring in two habitat types (Table 3). Clutch size ranged from one to four eggs for the American Oystercatcher (*H. palliatus*) and three eggs for

Fig. 8. Example of nestlings. For location details, see Online Appendix 2. (A) *Haematopus palliatus* (18 July 2019, ML169273161, Daniel Lane); (B) *Burhinus superciliaris* (14 February 2016, ML359146251, Santiago Pease); (C) *Nycticorax nycticorax* (29 June 2019, iNat[Photos]65401463, Tatiana Danilina); (D) *Coragyps atratus* (9 September 2020, iNat[Photos]141596082, Jose Huaman); (E) *Parabuteo unicinctus* (2 February 2019, ML349896001, Shirley Freyre); (F) *Volatinia jacarina* (31 December 2012, ML364482411, Cynthia Cerna).

the Killdeer (*Charadrius vociferus*) in the blue space, and two eggs for the West Peruvian Dove (*Z. meloda*) in one record located in the green space.

DISCUSSION

We demonstrated that eBird and iNaturalist can be used together to study the breeding biology of Peruvian birds. Our study is the first to determine breeding sites and patterns of breeding activity of bird species in the LMA based on an in-depth review of citizen-science data, as well as, to confirm and improve the knowledge of timing of breeding activity and nesting patterns

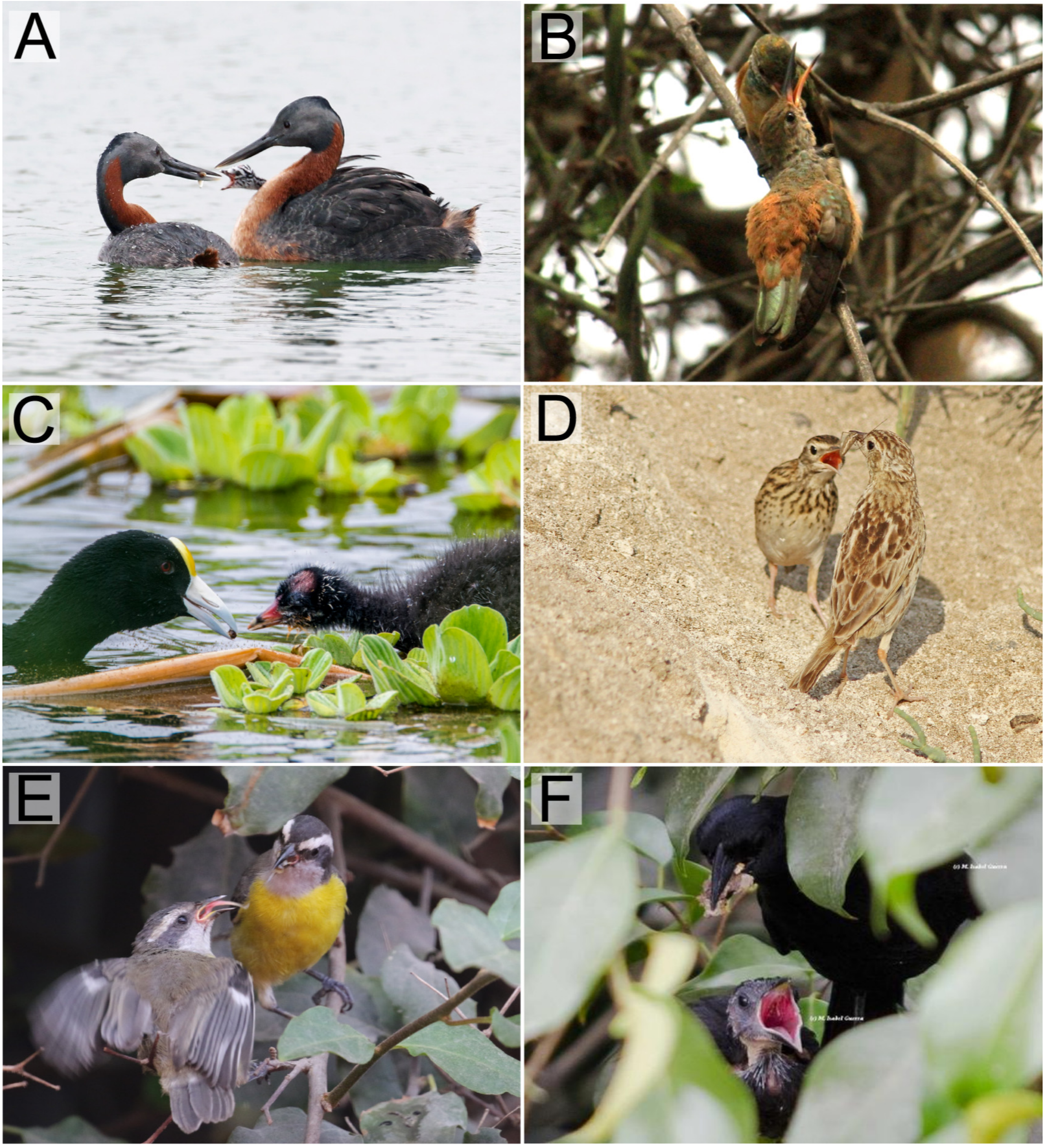

Fig. 9. Example of records feeding young. For location details, see Online Appendix 2. A) *Podiceps major* (19 September 2016, ML35580861, Andrew Spencer); (B) *Amazilis amazilia* (8 January 2017, ML351932971, Mariano Cordova); (C) *Fulica ardesiaca* (19 October 2019, ML182997981, David Belmonte); (D) *Anthus peruvianus* (4 October 2015, ML21069791, David Beadle); (E) *Coereba flaveola* (6 June 2016, ML36073761, Gil Ewing); (F) *Dives warczewiczi* (30 March 2013, iNat[Photos]141455481, Isabel Guerra).

of birds from the Peruvian central coast. The study of the breeding biology of birds involving citizen participation originated in northwestern Europe (Atlas of breeding birds in Great Britain and Ireland; Sharrock, 1976) and this idea was subsequently spread to the rest of the world at a wide range of spatial scales (Gibbons *et al.*, 2007). In South America, the first effort was led by Chile, with its first national atlas ("Atlas de Aves Nidificantes de Chile"), which included the participation of nearly 1500 observers, who simultaneously collected and uploaded more than 600000 breeding records to eBird during 2011-2016 (Red de Observadores de Aves y Vida

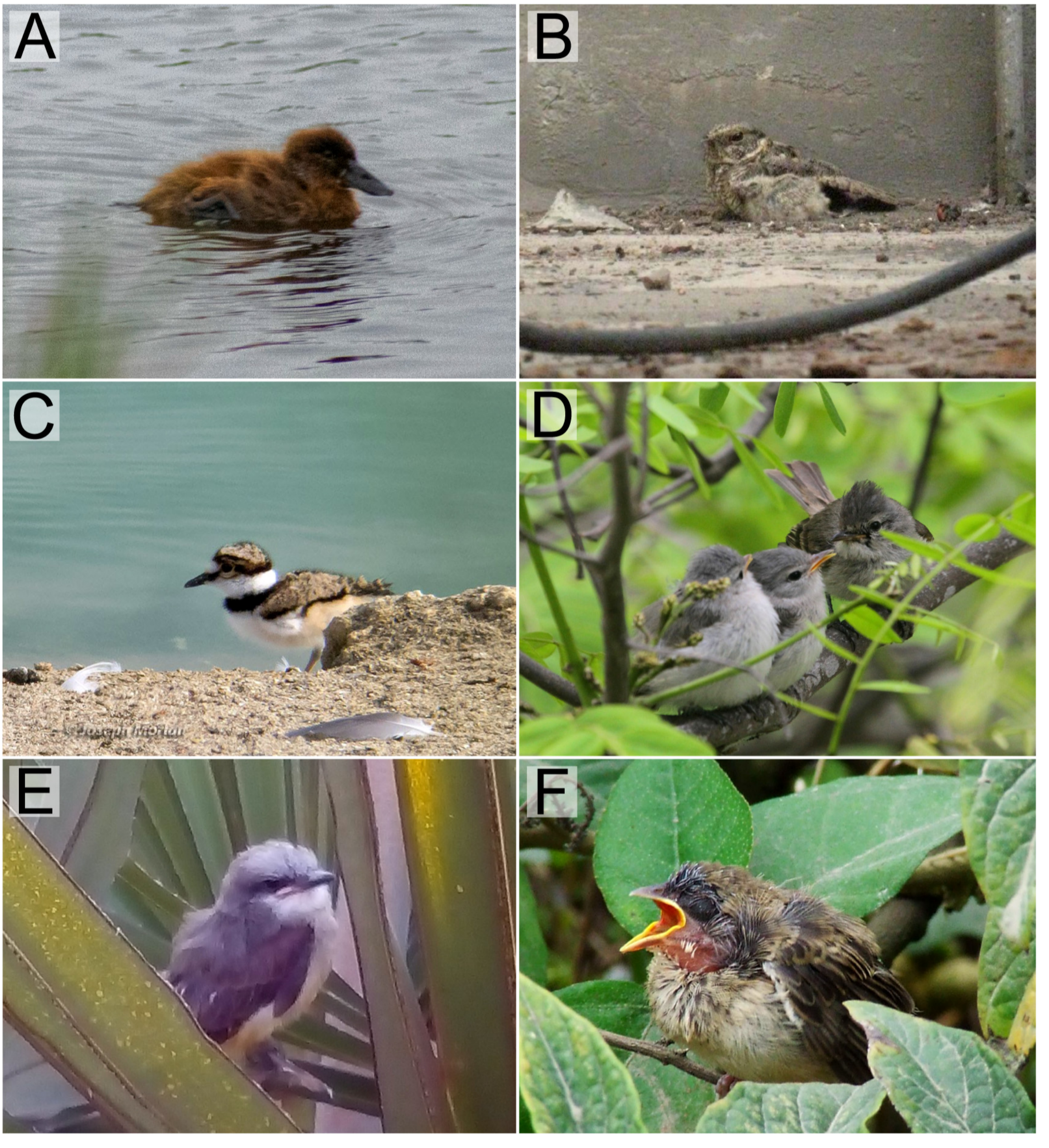

Fig. 10. Example of fledglings. For location details, see Online Appendix 2. (A) *Oxyura jamaicensis* (18 August 2019, ML174198501, Mónica Paredes); (B) *Systellura decussata* (13 July 2015, ML367546241, Biología Reproductiva de Aves Peruanas [Rodrigo Pulgar]); (C) *Charadrius vociferus* (13 December 2017, ML85015661, Joseph Morlan); (D) *Camptostoma obsoletum* (24 November 2010, ML96678041, Stephen Gast); (E) *Tyrannus melancholicus* (3 February 2019, ML140234891, Rutger Koperdraad); (F) *Volatinia jacarina* (1 November 2014, ML204817641, Oscar Delareina).

Silvestre de Chile, 2018). However, obtaining nationwide or even city-wide data for monitoring breeding activity of birds can be very time-consuming and costly. Hence, the thorough examination of already existing citizen science data constitutes a less time-consuming and expensive method to obtain valuable information on breeding birds. Also, our data was collected without concerns of causing an additional disturbance to the nest sites or damaging the health of captured birds. Further strengths of this study are that the information gathered from photographs can be preserved for studies on repeatability or future research uses. However, conclusions should be taken cautiously owing to spatial, taxonomic, and temporal limitations in citizen science data that will be further discussed below.

Breeding records were concentrated towards the southwest of the LMA, specifically in the Chorrillos district, in the Pantanos de Villa wetlands (Fig. 1, Online Appendix 1), the latter being an area that provides refuge for 211 bird species, and breeding ground for 61 resident bird species (Pulido, 2018). However, the considerably greater number of breeding records might not only be attributed to the occurrence of birds in this important ecological reserve but also to their high and increasingly growing demand for birdwatching tourism in recent years (Carhuas & Jacinto, 2020; Aponte *et al.*, 2020). On the other hand, it is often assumed that the occurrence of a species at a given location during the breeding season is an indication of breeding activity and suitable breeding habitat. However, it might not always be the case. Survey sites might include non-breeding individuals, juveniles away from natal sites, might not entirely cover the nesting area, or the detection of unpaired males by sight might be more related to the presence of relegated males looking for sites in low-quality habitats for breeding (Fogarty *et al.*, 2022; Gorleri & Areta, 2021). The location of records shown here does not necessarily reflect breeding habitat suitability. For example, although most of the breeding records for the American Oystercatcher (*H. palliatus)* were gathered from the Pantanos de Villa wetlands, previous research has evidenced low reproductive success for this species during the summer-fall season caused by anthropogenic disturbances in such areas (Arenas *et al.*, 2020). In conjunction with future contributions, however, these data should help establish suitable habitats for breeding birds in LMA. Nowadays, this type of study can benefit from associations with citizen science crowdsourcing campaigns to cover spatial limitations in photograph/video distributions.

Despite such diversity of breeding birds, our records can be taxonomically biased because of an uneven detection of breeding bird taxa. Often breeding birds are secretive when they are on the nest to avoid attracting attention from predators, and some species are far more secretive than others; hence, breeding individuals of some species might not be easily approached or detected by an observer and, consequently, are frequently overlooked. Such is the case of the Peruvian Pipit (*Anthus peruvianus*) and the Tschudi's Nightjar (*Systellura decussata*), two secretive birds recently reclassified to species level and uncommonly to commonly distributed along the Pacific coast of Peru (Begazo, 2020); being the latter zone an area increasingly recognized as an avian region of endemism and from which very little is known about the biology of its species (Arcco *et al.*, 2020). *A. peruvianus* occurs in open areas often hiding in grassy riparian zones, while *S. decussata* is a nocturnal species that occurs in arid scrubs or urban sites (del Hoyo *et al.*, 2020a, b). Our compilation of citizen science data has revealed the first and second photographic evidence of breeding activity of *S. decussata* and *A. peruvianus* for Peru (Figs. 9F, 10B, Online Appendix 2), respectively; although we do not discard the existence of other photographic evidence for these species that remain unpublished. It is also important to note that the record of *S. decussata* consisting of the presence of a downy fledgling accompanied by an adult inside an uninhabited area of a house building (Fig. 10B) evidences how observations provided by building owners can be of great benefit because they may encounter species that might be very difficult to detect elsewhere.

Our results also provided information about timing of breeding activity for 45 bird species, from which we were able to establish breeding periods for 24.4% (n=11) of these species. However, because of the relatively small sample size per species and the arbitrary nature of dates when observations were made, records presented here do not strictly reflect the presence or absence of breeding seasonality. Moreover, despite the coincident and improved knowledge of breeding activity timing gathered for 86.7% (n=39) of total species described here, it was not possible to establish periods of breeding activity for 53.3% (n=24) of them due to the lack of continuous months of breeding activity. However, preliminary information did allow us to establish a clearer period of breeding activity for the Vermilion Flycatcher (*Pyrocephalus rubinus*) and other 10 additional species (Table 1): the Cinnamon Duck (*Spatula cyanoptera)* during the humid-cold season; the Wren-like Rushbird (*Phleocryptes melanops*) and the Many-colored Rush Tyrant (*Tachuris rubrigastra*) during the humid-cold season and at the beginning of the dry-warm season; the Rufous-collared Sparrow (*Zonotrichia capensis*) during the dry-warm season with an additional short period during the humid-cold season; the Killdeer (*Charadrius vociferus*) during the dry-warm season; and the Croaking Ground-Dove (*Columbina cruziana*), the Vermilion Flycatcher

(*Pyrocephalus rubinus*), the House wren (*Troglodytes aedon*), the House Sparrow (*Passer domesticus)*, the Blue-black Grassquit (*Volatinia jacarina)*, and the Bananaquit (*Coereba flaveola*) throughout the year. The latter fact brings the number of species able to breed year-round to 10, representing 47.6% of species with known breeding periods in our study. This, coupled with the existence of more discrete periods of reproductive activity in most of these species in further north or south latitudes of their distributions, including the American Oystercatcher (*H. palliatus)*, Great grebe (*P. major),* Vermilion flycatcher (*P. rubinus)*, House Wren (*T. aedon*), House Sparrow (*P. domesticus)*, Bananaquit (*C. flaveola)*, and the Blue-black Grassquit (*V. jacarina*) (Greenquist, 1982; Wunderle, 1982; Bugoni *et al*., 2002; Zuria & Rendón-Hernández, 2010; Ippi *et al*., 2012; Marini *et al*., 2012; Llambías *et al*., 2015; Dubois, 2016; Figueroa & Stucchi, 2016; Medrano *et al*., 2019; Hilty & Christie, 2020; Johnson, 2020; Llimona *et al*., 2020; Lowther & Cink, 2020; Rising, 2020), provides additional evidence that tropical birds can breed throughout the year (Hau *et al*., 2008; Echeverry-Galvis & Córdoba-Córdoba, 2008). Further continuous records over multiple years are needed to better understand the temporal patterns of breeding activity for these species.

Concerning nesting habitat selection, we found species nesting in all three types of habitats, with the lowest number of species and occurrences found in gray spaces. However, because of the small sample size of nesting birds in each type of habitat, it is difficult to envision how habitat selection influences the choice of nesting territory in the LMA. It is known that introduced bird species tend to exploit anthropogenic habitats that are inefficiently used by native species such as the gray spaces (Savard & Falls, 1981; Sol *et al*., 2012); however, there are other important factors that can influence nesting habitat selection of birds in urbanized areas, including vegetation coverage, nest protection, and the level of human disturbance (Pennington & Blair, 2011; Soulsbury & White, 2015; Zhou *et al*., 2020). The presence of several native species nesting on gray spaces, including, among others, the Peruvian Thick-knee (*B. superciliaris*) and the West Peruvian Dove (*Z. meloda*), might suggest a limited availability of suitable nesting sites given the growing reduction of green and blue spaces in Lima city (Quispe, 2017; Velásquez *et al*., 2018). Gray spaces can also offer protection against bad weather, brood parasitism, and nest predation as has been shown for urban birds in other parts of the world (Liang *et al*., 2013; Vincze *et al*., 2017; Mainwaring, 2015). However, the main disadvantage of gray spaces as nesting habitats is that they sometimes can act as ecological traps because species can be negatively affected by the temporary availability of man-made structures which may cause an inadvertent loss of nesting sites (Reynolds *et al*., 2019). Concerning host-plant preference of nesting birds, most of the plant species identified were considered as introduced while only one were native to the LMA (Table 2). Introduced species included nine field-grown tree species and six pot-grown plants, which provided nesting support to five native and two introduced bird species in the LMA. The only native host plant species identified was a field-grown tree that provided nesting support to one native bird species in the LMA. Previous studies have evidenced that some native birds prefer to nest under the protective cover of introduced plant species, however, in some cases, introduced plants can also act as ecological traps by altering vegetation structure, decreasing food availability, and increasing nest predation (Schmidt & Whelan, 1999; Borgmann & Rodewald, 2004; Nelson *et al*., 2017). More evidence on plant-nesting bird interaction is needed to understand the impact of such introduced plant species on the bird breeding community at our study site. Furthermore, host plant species only coincided for two species with previous reports from the Peruvian central coast, which is likely influenced by the lack of information on this aspect of avian breeding biology in such region and/or the cultivated nature of many plant species occurring in the LMA. Vegetation structure in urban cities depends on residents' aesthetic values, protection, and economics, as well as jurisdictional policies, and the LMA is no stranger to such conditions (Zhang *et al*., 2013; Sabogal, 2021; Handayani & Mardikaningsih, 2022). Concerning clutch size, the three native bird species from which we were able to appreciate nest content, namely the Killdeer (*C. vociferus*), the American Oystercatcher (*H. palliatus*), and the West Peruvian Dove (*Z. meloda*), showed invariable clutch sizes to those reported for these species in other areas of the Peruvian central coast. Unfortunately, we did not have enough data to infer the potential influence of urbanization on clutch size or other aspects of nesting behavior. For example, it has been evidenced that increased urbanization correlates significantly with smaller clutch size, lower offspring productivity, and increased nestling periods (Ibañez-Álamo & Soler, 2010).

On the other hand, citizen science portals might not constitute a good approach to study some other aspects of the breeding biology of birds that still need to be addressed through *in situ* field observations or other methods. Detailed descriptions of nest building, nestling growth, nest survival rates, regimes of parental care, or nest-site fidelity cannot be inferred from a remote examination of photographs made by a third-party investigator. Moreover, assessing age, sex, and reproductive status of individuals from the photographs described here might not be comparable in accuracy to examining plumage, sexing on the bases of external characteristics (i.e., brood patch or cloacal protuberance), gonad descriptions, or other extended phenotypes (e.g., eggs, nest, etc.) retrieved from living birds or museum specimens. The combination of all these methods, however, will allow us to fill multiple gaps related to the breeding biology of birds with more accuracy and from a broader perspective. Furthermore, citizen-science data can also provide complementary information to answer questions related to other aspects of the natural history of birds, including distributional patterns, foraging ecology, molt patterns, and habitat use (McCaffrey, 2005; DeGroote *et al.*, 2020; Panter & Amar, 2021; Pyle, 2022; Lopes & Schunck, 2022). Hence, we encourage researchers to gather and publish similar or larger-scale studies to those presented here for other urban and non-urban areas of Peru and other neotropical developing countries. Finally, we encourage the participation of citizens in contributing with more photographs of birds to citizen-science portals to increase scientific knowledge and community awareness of the value of bird biodiversity and their habitats.

Table 1. Monthly records of breeding activity per each species found in the LMA, retrieved from eBird and iNaturalist's citizen science data from January 2000 to December 2020, compared to preliminary data for the Peruvian central coast. Dry-warm season occur from December to April, and Humid-cold season occur from June to October. Concerning preliminary data: [1]Coincident; [2]Improved; [3]Noncoincindent.

Species	n	J	F	M	A	M	J	J	A	S	O	N	D	Preliminary Data
ANATIDAE														
Spatula cyanoptera[2]	4										X	X		August & September (Pulido, 2018)
Anas bahamensis[2]	2					X		X						No data
Oxyura jamaicensis[2]	6								X	X	X	X		No data
PODICIPEDIDAE														
Rollandia rolland[2]	3			X						X	X			No data
Podilymbus podiceps[2]	13				X	X		X	X	X	X		X	No data
Podiceps major[1]	36	X	X			X	X	X	X	X	X	X	X	Year-round with small peak season in May-July (Quiñonez & Hernández, 2017); December & January (Amaro & Goyoneche, 2017)
COLUMBIDAE														
Zenaida meloda[1]	24	X	X	X	X	X	X	X		X	X	X	X	January, February & June-March (Lüthi, 2011); Year-round (Pulido *et al.*, 2013)
Zenaida auriculata[2]	5	X								X	X		X	No data
Columbina cruziana[1]	6		X	X					X	X			X	Main season in February-July (mainly in March-June) & secondary season in September-December (mainly in Oct-Dec) (Lüthi, 2011); January (Pulido *et al.*, 2013)
CAPRIMULGIDAE														
Systellura decussata[3]	1							X						October (Lüthi, 2011)
TROCHILIDAE														
Amazilis amazilia[2]	3	X	X					X						January (Pulido *et al.*, 2013)
RALLIDAE														
Gallinula galeata[2]	13	X	X				X			X	X	X	X	No data
Fulica ardesiaca[2]	25	X	X		X	X	X	X	X	X	X	X	X	No data

Species	n	J	F	M	A	M	J	J	A	S	O	N	D	Preliminary Data
CHARADRIIDAE														
Charadrius vociferus[2]	6						X					X	X	October (Torres *et al.*, 2006); January (Chávez-Villavicencio *et al.*, 2015); January (Pulido *et al.*, 2013); December & March (Amaro & Goyoneche, 2017)
HAEMATOPODIDAE														
Haematopus palliatus[1]	52	X	X	X	X	X	X	X	X	X	X	X	X	January, February, & April-July with a peak season in May-June (Figueroa & Stucchi, 2016); February & March (Amaro & Goyoneche, 2017); September & October (Arenas *et al.*, 2020)
RECURVIROSTRIDAE														
Himantopus mexicanus[1]	1											X		October (Torres *et al.*, 2006); November (Amaro & Goyoneche, 2017)
BURHINIDAE														
Burhinus superciliaris[3]	10	X	X	X	X					X				November (Amaro & Goyoneche, 2017); August (Pulido *et al.*, 2013)
LARIDAE														
Chroicocephalus cirrocephalus[1]	2		X			X								May, July & September (Tovar & Ashmole, 1970); January-March (Amaro & Goyoneche, 2017)
Larus dominicanus[2]	1											X		No data
PHALACROCORACIDAE														
Phalacrocorax brasilianus[3]	1							X						April-June (Quiñonez & Hernández, 2017); December-February (Amaro & Goyoneche, 2017)
ARDEIDAE														
Nycticorax nycticorax[3]	1						X							December (Amaro & Goyoneche, 2017); April & May (Ulfe-Gámez, 2019)
Butorides striata[2]	1	X												No data
Ardea alba[2]	1										X			No data
CATHARTIDAE														
Coragyps atratus[2]	2			X						X				No data
ACCIPITRIDAE														
Parabuteo unicinctus[2]	6		X		X			X	X		X		X	No data
FALCONIDAE														
Falco sparverius[2]	2					X								No data
FURNARIIDAE														
Phleocryptes melanops[2]	7	X					X		X			X	X	October, November & January (Lüthi, 2011); September-December (Quiñonez & Hernández, 2017); December & January (Amaro & Goyoneche, 2017)
TYRANNIDAE														
Camptostoma obsoletum[1]	1											X		November (González, 2004); April (Lüthi, 2011); April (Díaz *et al.*, 2022)
Tyrannus melancholicus[2]	3		X										X	No data
Pyrocephalus rubinus[1]	15	X	X	X		X			X		X	X	X	September & October (González, 2004); November (Tavera-Fernández, 2011); January-June (mainly in March-June) & August-November (mainly in September-November), both periods may overlap (Lüthi, 2011); November & February (Díaz *et al.*, 2022); Year-round (Pulido *et al.*, 2013)
Tachuris rubrigastra[2]	2									X	X			November (Lüthi, 2011); October-December (Quiñonez & Hernández, 2017); December (Amaro & Goyoneche, 2017)

Species	n	J	F	M	A	M	J	J	A	S	O	N	D	Preliminary Data
HIRUNDINIDAE														
Pygochelidon cyanoleuca[3]	1									X				February (Lüthi, 2011); January (Pulido *et al.*, 2013)
TROGLODYTIDAE														
Troglodytes aedon[1]	3	X			X								X	Year-round, but with two main seasons: late November to mid-April & late May to mid-October (Lüthi, 2011); February, April, August, September & November (González, 2004)
MIMIDAE														
Mimus longicaudatus[2]	8	X	X	X	X		X					X		November (González, 2004); February, March, September, November & December (Lüthi, 2011); January & April (Pulido *et al.*, 2013); January (Amaro and Goyoneche, 2017)
PASSERIDAE														
Passer domesticus[1]	4	X								X		X		January, May & October-December (González, 2004); Year-round (Pulido *et al.*, 2013)
MOTACILLIDAE														
Anthus peruvianus[2]	1										X			No data
PASSERELIDAE														
Zonotrichia capensis[1]	2						X	X						June-March (mainly in August-March) (Lüthi, 2011); October-March, with a small second peak in June-July (Davis, 1971); January, April, August, November & December (González, 2004)
ICTERIDAE														
Molothrus bonariensis[2]	2				X								X	January-April (Lüthi, 2011)
Dives warczewiczi[2]	1			X										No data
Chrysomus icterocephalus[2]	1												X	No data
THRAUPIDAE														
Sicalis flaveola[2]	12	X	X	X	X	X				X			X	No data
Volatinia jacarina[1]	4			X						X		X	X	Year-round (mainly in September-June, including two or more reproduction cycles) (Lüthi, 2011), January, April, August, November & December (González, 2004); Year-round (Pulido *et al.*, 2013)
Coereba flaveola[1]	6		X		X		X				X	X		April, June & October (González, 1998); February, March, May, August, November & December (González, 2004); April, October & November (Díaz *et al.*, 2022)
Paroaria coronata[3]	1											X		January (Angulo & Morán, 2019)
Thraupis episcopus[1]	1			X										December (González, 2004); February, March & October (Díaz *et al.*, 2022)

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DECLARATION OF INTEREST STATEMENT

No potential conflict of interest was reported by the authors.

Table 2. Nesting of different bird species observed on various plants by grown habit and habitat type found in the LMA, retrieved from eBird and iNaturalist's citizen science data from January 2000 to December 2020, compared to preliminary data for the Peruvian central coast. Occurrence status of birds and plants: [1]Native species; [2]Introduced species. Growth habit of plants: [a]Field-grown tree found in green area; [b]Pot-grown plant found in gray area

Bird species	# of host plant species	Host plant species	Preliminary Data
Amazilia Hummingbird (*Amazilis amazilia*)[1]	1	*Tecoma sp.*[1,a]	
West Peruvian Dove (*Zenaida meloda*)[1]	4	*Codiaeum variegatum*[2,b], *Olea europea*[2,a], *Schinus terebinthifolius*[2,a], *Tipuana tipu*[2,b]	*Bougainvillea sp.*, *Spathodea campanulata*[2] (Lüthi, 2011)
Eared Dove (*Zenaida auriculata*)[1]	3	*Euphorbia lactea*[2,b], *Justicia brandegeeana*[2,b], *Plectranthus australis*[2,b]	
Croaking Ground Dove (*Columbina cruziana*)[1]	1	*Ficus benjamina*[2,a]	*Araucaria sp.*[2], *Eucalyptus sp.*[2], *Phoenix dactylifera*[2], *Tipuana tipu*[2] (Lüthi, 2011)
Harris's Hawk (*Parabuteo unicinctus*)[2]	2	*Casuarina sp.*[2,a], *Eucalyptus sp.*[2,a]	*Araucaria sp.*[2], *Eucalyptus sp.*[2] (Piana *et al*., 2013)
Vermilion Flycatcher (*Pyrocephalus rubinus*)[1]	3	*Delonix regia*[2,a], *Ficus sp.*[2,a], *Schinus terebinthifolius*[2,a]	*Casuarina sp.*[2] (Lüthi, 2011); *Schinus terebinthifolius*[2] (Tavera, 2011)
Blue-black Grassquit (*Volatinia jacarina*)[1]	1	*Chusquea sp.*[2,b]	*Acacia dealbata*[2], Bambusoideae, *Cassia fistula*[2], *Fuchsia sp., Geranium sp., Gossypium sp., Nerium oleander*[2], *Punica granatum*[2], *Rosa sp.*[2], *Vicia sp.*[2] (Lüthi, 2011)
Blue-gray Tanager (*Thraupis episcopus*)[2]	1	*Eriobotrya japonica*[2,a]	

Table 3. Clutch size of different bird species by habitat type found in the LMA, retrieved from eBird and iNaturalist's citizen science data from Jan 2000 to Dec 2020, compared to preliminary data for the Peruvian central coast.

Species	Number of eggs				Preliminary Data
	1	2	3	4	
Coastal wetlands					
Charadrius vociferus			4		4 eggs (Chávez-Villavicencio *et al*., 2015)
Haematopus palliatus	3	7	6	1	1-4 eggs (Figueroa & Stucchi, 2016) 1-3 eggs (Arenas *et al*., 2020)
Green areas					
Zenaida meloda		1			

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