Research Article

Invasion status of the African collared dove *Streptopelia roseogrisea* (Sundevall, 1857) in Mexico

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Abstract

Due to the environmental and economic costs caused by invasive bird species, it is crucial to document their initial stages of invasion and manage them before control efforts become unfeasible. In this study, we conducted extensive sampling in search of the African collared dove (*Streptopelia roseogrisea*) in three regions of Mexico: The Northwest, "*El Bajío*" (central Mexico), and the Southeast. We documented five records of this species in two northwestern states (Sonora and Baja California) and analyzed additional sightings from citizen science and scientific literature to evaluate its presence and geographic distribution in Mexico. *Streptopelia roseogrisea* has been reported in nine Mexican states (32 records), with its first record occurring in 2000 in Tijuana, Baja California. The species is invading Mexico on two fronts: from populations established in the southern United States expanding southwards into northern Mexico, and individuals escaped/released from captivity invading central Mexico. Additionally, we used temperature and precipitation data to determine its climatic niche in Mexico. We compared it with the climatic niches of the United States populations and with the climatic space of its original distribution range in Africa and the Arabian Peninsula. We found that the climatic niche of the Mexico and the Southern United States populations is similar, and did not overlap with the climatic space present in its original geographic distribution. This suggests that niche models based on the climate of its original distribution could fail to predict the invasibility of this species in North America. Although *S. roseogrisea* does not seem to constitute a high-risk invader, it is important to document its early invasion process and take action before it spreads throughout the country, as it recently happened with the Eurasian collared-dove (*S. decaocto*).

Key words: early invasion process, collared-doves, citizen science, bird trade, climatic niche

Introduction

Environmental and economic risks associated with invasive bird species

Although not all exotic species manage to thrive in the sites where they have been introduced, those that become successfully established can represent a risk factor for both native biodiversity and human productive activities (Mack et al. 2000; Simberloff 2001; Andersen et al. 2004; Pyšek et al. 2020). Today, there are more than 400 bird species that have established populations in regions other than their original distribution (Dyer et al. 2017). Some of these species have caused damage to biodiversity, agriculture, and human well-being in several regions of the world (Duncan et al. 2003; Shirley and Kark 2009; Kumschick et al. 2013; Evans et al. 2023a). Some of their ecological effects include competition with native bird species for food and nesting sites (MacGregor-Fors et al. 2010; Camacho-Cervantes and Schondube 2018), reducing local fauna populations through predation (Blanvillain et al. 2003), reducing genetic diversity through hybridization (Rhymer et al. 1994), and disease transmission (Stimmelmayr et al. 2012). As a result, successful bird invasions can modify the structure of local bird communities (MacGregor-Fors et al. 2010). Regarding economic repercussions, it is known that some invasive birds cause damage to infrastructure and agricultural production (Coombs et al. 1981; Bomford and Sinclair 2002; Newman et al. 2008). The estimated annual costs of the impacts of alien birds around the world amount to approximately US$3.6 billion, and particularly for pigeons and doves, the costs amount to $1.9 billion per year (Evans et al. 2023a).

The Eurasian collared-dove (*Streptopelia decaocto*) is one of the most successful invasive dove species, having successfully colonized much of Europe, Asia, North Africa, North America, and the Caribbean Islands in a relatively short time (Romagosa 2012; Eraud 2020). Since *S. decaocto* shows aggressive behavior both with columbids and with other bird species (Romagosa and Labisky 2000; Eraud 2020), it has been shown to competitively displace the native species with which it cohabits at the invaded sites (Rocha-Camarero and de Trucios 2002; Beckett et al. 2007; Romagosa 2012; Camacho-Cervantes and Schondube 2018). Camacho-Cervantes and Schondube (2018) showed that the presence of this species can reduce local dove diversity in environments modified by human activities. Additionally, this species can usurp the nests of native species, particularly the American robin (*Turdus migratorius*; Kasner and Pyeatt 2016), and act as a disease vector to native species through the transport of protozoa, viruses, and bacteria (Eraud 2020 and references therein). Regarding economic impacts, *S. decaocto* is known to consume large quantities of stored grains and food delivered to livestock and poultry (Coombs et al. 1981; Robertson 1990; Eraud 2020), including wheat, sorghum, mustard seeds, and even crops grown in gardens like lettuce (Hudson 1965; Kour 2016). However, there is no global estimate of agriculture losses caused by this species.

Particularly for the African collared dove (*Streptopelia roseogrisea*), a species phylogenetically closely related to *S. decaocto* (Johnson et al. 2001), their potential environmental and economic repercussions at their introduced sites are still unknown. However, it has been suggested that they could generate environmental and economic costs (Department of Agriculture and Food Australia 2010; Blancas-Calva et al. 2014; CONABIO 2017), and given that the species has established/breeding alien populations, it was assessed by the "Environmental Impact Classification for Alien Taxa" (EICAT; Evans et al. 2016) and then included in the "Global Avian Invasions Atlas" (GAVIA; Dyer et al. 2017). Due to the adverse environmental and economic impacts associated with invasive bird species like the Eurasian collared-dove, it is of paramount importance to document the initial stages of their invasion processes (Duncan et al. 2003; Cassey et al. 2004; Holzapfel et al. 2006).

However, while birds are conspicuous animals that tend to be easy to sample over large geographic areas (Bibby et al. 2000), exotic bird species in a new geographical region and their potential costs can be ignored until the species is well established and efforts to control them become hard to achieve (Bomford and Sinclair 2002; Shirley and Kark 2009; Kumschick and Nentwig 2010; Evans et al. 2023a). This situation becomes especially problematic in countries like Mexico, where policies to manage invasive species are unclear, and the contribution from citizen science is scarce, as the culture of birdwatching is nascent (Cantú et al. 2011). However, birdwatching has significantly increased in recent years (Cantú et al. 2020), posing the possibility of using citizen science to detect avian invaders (see Ceja-Madrigal et al. 2023 as an example). An example of an exotic species that has gone almost unnoticed by the scientific community in Mexico is the African collared dove.

The African collared dove

The African collared dove (*Streptopelia roseogrisea* Sundevall, 1857) is a medium-sized columbid native to a transversal strip in northern Africa and the southeastern end of the Arabian Peninsula (Baptista et al. 2020; see Figure 1). It is sedentary in most of its range and inhabits dry zones, open deserts, sandy riverbeds, and farmlands. They forage on the ground, feeding primarily on grass seeds and eating other vegetable matter, insects, and snails (Baptista et al. 2020). Like most doves, they build an open cup nest in bushes or trees, where they lay one or two eggs. The nesting period includes 14–15 incubation days and 15 fledging days (Baptista et al. 2020). This species is abundant in different regions of its native range, sometimes forming flocks of hundreds of individuals (Baptista et al. 2020). Although they prefer sites with low human population densities in their native range (Baptista et al. 2020), in the regions where they have been introduced, they seem to thrive in urban environments, similarly as occurs with *S. decaocto* (Smith 1987; CONABIO 2017; Ceja-Madrigal et al. 2023).

Humans have introduced it to New Zealand and Australia, Japan, much of Europe, the United States, some Caribbean islands, and the northern part of South America (Donegan and Huertas 2002; Álvarez Romero et al.

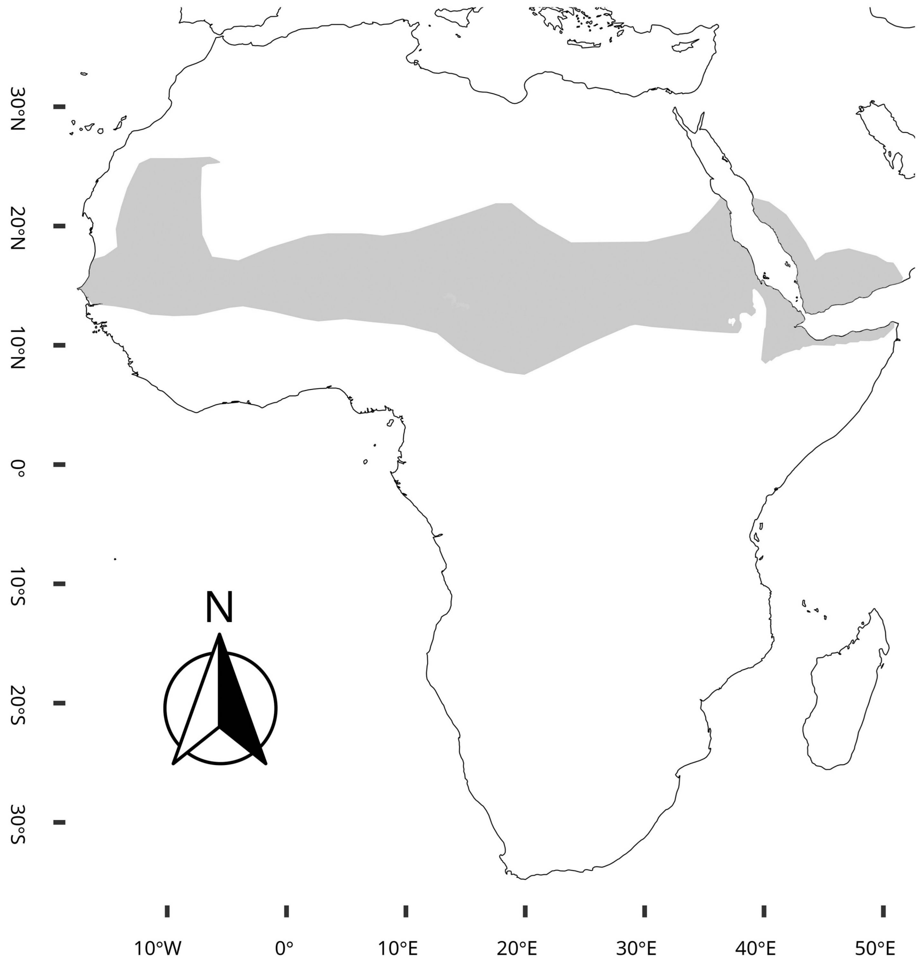

Figure 1. Original geographic distribution of the African collared dove (*Streptopelia roseogrisea*). Data provided by Birdlife International and Handbook of the Birds of the World (2021).

2008; Baptista et al. 2020; Birdlife International and Handbook of the Birds of the World 2021). However, little is known about its invasion processes and the potential risks and costs of their presence in different regions. Although this species poses a high risk of invasion (Álvarez Romero et al. 2008; Henderson and Bomford 2011; CONABIO 2017), its survival depends highly on human presence (Baptista et al. 2020). Given the intensive urbanization occurring in several regions of Mexico, *S. roseogrisea* could represent an invasion threat similar to that posed by *S. decaocto*, which successfully invaded North America at an extremely fast rate in the past decades (Fujisaki et al. 2010; Scheidt and Hurlbert 2014; Ceja-Madrigal et al. 2023).

According to the Environmental Impact Classification for Alien Taxa (EICAT), *S. roseogrisea* is listed as Data Deficient (DD; Evans et al. 2016). While this might suggest that the species represents a minimal risk, and due to its lack of visibility, there is little to no research on the subject (Evans et al. 2018, 2023b). It is also possible that the species could have environmental or economic impacts, but these may not be evident. This is particularly important if the species is still in the lag-phase of its invasion, as data from the Breeding Bird Survey suggests (GBIF.org 2023). The existing information on the economic costs of *S. decaocto*, given its close phylogenetic relationship and ecological similarities with *S. roseogrisea*, suggests that we need to pay attention to the arrival of *S. roseogrisea* to Mexico (Blancas-Calva et al. 2014; CONABIO 2017).

Study objectives

In this study, we aimed to: 1) Determine the presence of the African collared dove (*Streptopelia roseogrisea*) in different regions of Mexico by conducting fieldwork and searching for georeferenced records in citizen science platforms and published literature; 2) describe its invasion history based on the found records; and 3) determine if the species is invading regions with similar climatic conditions to those present in its native range, discussing the probabilities of this species expanding across Mexico.

It is important to clarify that since our study only included visual and auditive records and not genetic data, there could be some uncertainty regarding the exact identity of the taxon we studied. Some of the records included here could be from the domesticated form named "Ringed turtle dove" or "Barbary dove" (*S. risoria*; Romagosa and McEneaney 1999). However, given that the African collared dove is considered the primary ancestor of these domesticated forms (van Grouw et al. 2023), we decided to consider using *Streptopelia roseogrisea* as the name of our study taxa.

Materials and methods

Searching for the African collared dove in Mexico

To learn about the current situation of the African collared dove invasion in Mexico, we carried out a mixed strategy that included field surveys and a search for records in public databases and scientific literature. Our fieldwork consisted of extensive sampling in three regions of the country: The Northwest (Sonora and Baja California), "El Bajío" (Michoacán, Guanajuato, and Querétaro), and the Yucatán Peninsula (Southern Veracruz, Tabasco, Campeche, Yucatán, and Quintana Roo). We surveyed 7176 km of road transects in these three regions (Figure 2). These regions were selected because they have been previously related to the arrival of invasive bird species to Mexico (Northwest and Yucatán Peninsula) and due to their importance as an agricultural region ("El Bajío"). Due to security issues related to drug cartel activity, we could not sample the country's Northeast region (Tamaulipas, Nuevo León).

We conducted an extensive sampling along routes located mainly on secondary roads in the three regions. We used two teams to cover 6649.6 km of transects (Figure 2). These teams sampled 50 routes (Northwest: 20 routes, Nov.–Dec. 2021; "El Bajío": 5 routes, February 2023; and Yucatán peninsula: 25 routes, Nov.–Dec. 2022). Each route consisted of 18 sampling points separated by 8 km, for a total distance of 144 km. The routes were

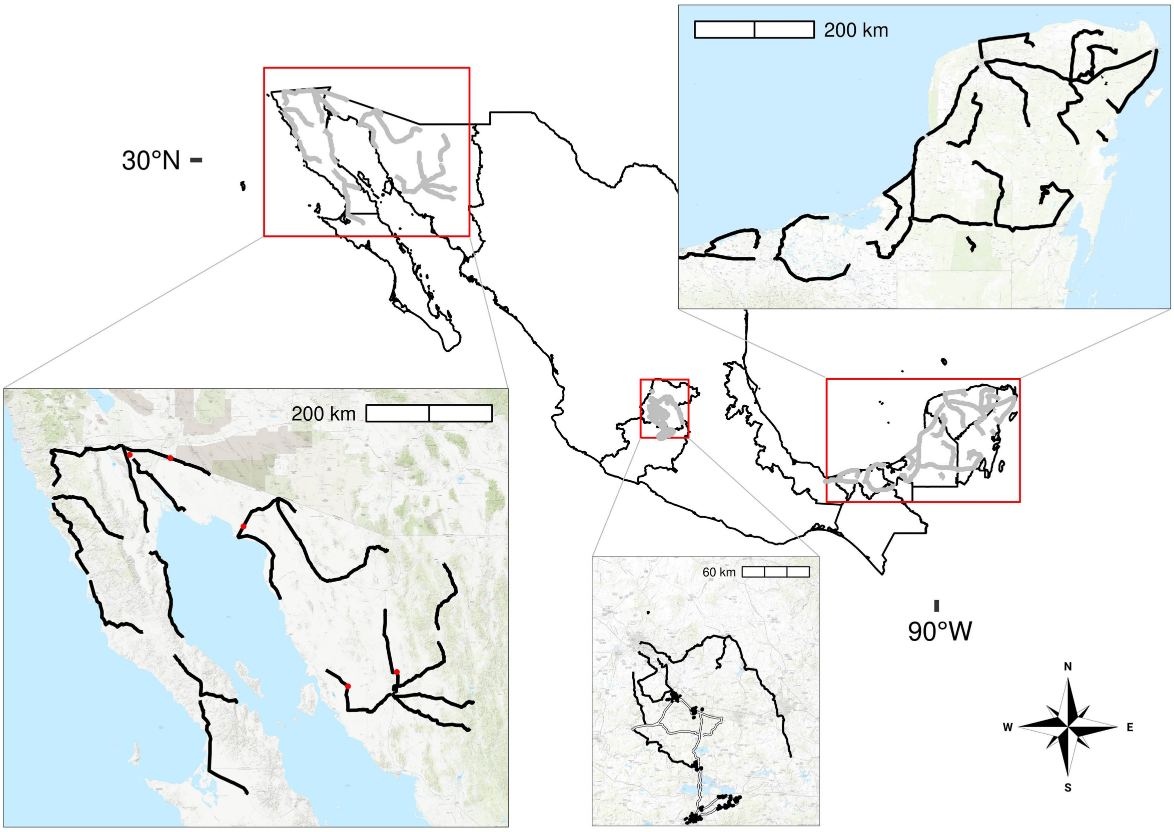

Figure 2. Extensive sampling for invasive bird species was conducted in three regions of Mexico: The Northwest region (left enlarged box), "El Bajío" (center enlarged box), and the Yucatán peninsula (right enlarged box). In addition to the extensive sampling routes used in the three regions, we conducted an additional sampling route (grey line) and point counts in 13 towns and cities (cloud of black points) of "El Bajío".

selected to have sampling points in urban areas, productive areas (agriculture), and remnants of native vegetation with different levels of human disturbance. We carried out a 5-minute point count with distance estimation at each sampling point. Additionally, we recorded any invasive bird individuals detected between the sampling points of our routes, recording the geographic coordinates of the locality. Each route was surveyed from dawn to 11 a.m., and bird data were collected by two expert observers of comparable quality (AC-M and JCP-M).

We conducted additional sampling in "El Bajío" by performing point counts with distance estimation (winter 2018–2019 and summer 2019) and road surveys where we traveled on secondary roads at low speed, stopping every time we detected a pigeon of any species (summer 2022), covering 526.3 km of such road surveys. The counting points were randomly distributed in 13 localities in this region, covering three habitat conditions: urban areas (166 points), productive areas (agricultural and livestock; 131 points), and remnants of native vegetation (105 points; Figure 2). The points were separated by at least 250 m. We recorded all birds seen or heard in 10 minutes (splitting the data into two 5-minute periods) and determined their distance from the observer using a rangefinder (Nikon Forestry Pro II; Bibby et al. 2000). The samplings occurred between dawn and 11:00 a.m. and were conducted by a single expert observer (AC-M).

Due to the ease of confusing our study species with *S. decaocto* individuals, we used fundamental plumage differences between both species to ensure correct identification. *Streptopelia roseogrisea* is characterized by a black neck collar contrasting with a uniform whitish body. It is noticeably lighter than *S. decaocto*, has white undertail coverts, and presents a gray tone instead of brown in the primary wing feathers (Smith 1987; Romagosa and McEneaney 1999; Baptista et al. 2020). As a result, it shows a less marked contrast between the wingtips and the rest of the body than *S. decaocto*. Another way to differentiate these two species is through their vocal patterns; *S. decaocto* emits a three-note "cuc-cuc-cuhú", while *S. roseogrisea* emits a two-note "cu-crrrruuu" (Kaufman 2005; Blancas-Calva et al. 2014). Our expert observers were trained to identify both species and in case of doubt, they obtained photographic evidence of the records. This process allowed us to conduct a detailed analysis of all images to confirm the identification, reducing the risk of making identification errors. We could not detect hybrids of *S. roseogrisea* and *S. decaocto* during our fieldwork. However, there is the possibility that we could have misidentified some hybrid individuals as one of the two species.

To acquire information on the presence of *S. roseogrisea* in other regions of Mexico and have a historical context of its invasion, we obtained records from citizen science databases, biodiversity databases, and scientific literature. Citizen science data included here came from "EncicloVida" (https://www.enciclovida.mx/). This platform, created by the National Commission for the Knowledge and Use of Biodiversity (Comisión Nacional para el Conocimiento y Uso de la Biodiversidad, CONABIO), integrates information from the National Biodiversity Information System (Sistema Nacional de Información sobre Biodiversidad, SNIB), Naturalista (https://www.naturalista.mx/), and AverAves (https://www.ebird.org/home). We analyzed each georeferenced record, using only those with photographic evidence that allowed us to corroborate the sightings. Also, we directly contacted the individual observers for greater certainty about each record. Records from the southern regions of the United States were obtained from the eBird database through the Global Biodiversity Information Facility website (https://www.gbif.org; GBIF.org 2022).

To carry out our search in the scientific literature, we used the online platforms "Google Scholar", "SciELO", and "Connected Papers", filtering by keywords related to the invasion of the African Collared Dove (*Streptopelia roseogrisea/risoria*) in Mexico. The search was conducted in both Spanish and English.

Description of the invasion process of the African collared dove in Mexico

All records obtained in this study from fieldwork and our database search were used to describe the pattern of invasion of the species in Mexico. We used QGIS software (version 3.16.10; http:QGIS.org 2022) to generate a map of the species records on the continental surface of Mexico, using a color gradient to represent the date of each record. Additionally, this map indicated sightings associated with three established populations in the southern United States (states of the Southwest, Texas, and Florida). Finally, to understand the growth trends of the populations near the northern border of Mexico, we graph the number of new eBird records per year (1959–2022) for the United States.

Comparison of the African collared dove's climatic niche in Mexico and the United States versus that of their original range in Africa and the Arabian Peninsula

To investigate the invasive capacity of the African collared dove, we visually compared the degree of climatic niche overlap among its original geographical distribution and the sites it has invaded in Mexico and the United States. Due to our low number of records, instead of conducting statistical analyses, we compared the climatic niches in a two-dimensional plot, showing the annual mean temperature and precipitation conditions of both its original distribution and the invaded sites. Data on annual mean temperature and mean precipitation were downloaded from the WORLDCLIM platform for each reported locality of the species (Fick and Hijmans 2017). We then obtained the total frequency of occurrence of both climatic conditions in its native distribution (Birdlife International and Handbook of the Birds of the World 2021). With the compiled climatic information, we generated a two-dimensional plot with the Mexican and US records' mean precipitation and annual mean temperature and the frequency of these conditions in its native distribution. To describe the climatic niche of its original distribution, we generated a kernel density distribution polygon with the corresponding climatic values of Africa and the Arabian Peninsula. To represent the climatic niche of its established populations in the United States, we generated three polygons encompassing the climatic distribution of three regions where the species has established populations (Florida, Texas, and the Southwest states).

Results

*Records of the African collared dove (*Streptopelia roseogrisea*) in Mexico*

Most areas of the country were free of this species, with no records at "El Bajío" and the Yucatán Peninsula routes and sampling sites. Some dove individuals sighted at "El Bajío" had lighter coloring in the coverts below the tail, but the other distinctive signs did not match the species. Only during our sampling of the Northwest in 2021 did we confirm the presence of the African collared dove in four localities of Sonora and one in Baja California, three of them with photographic records (Figure 3) as described below:

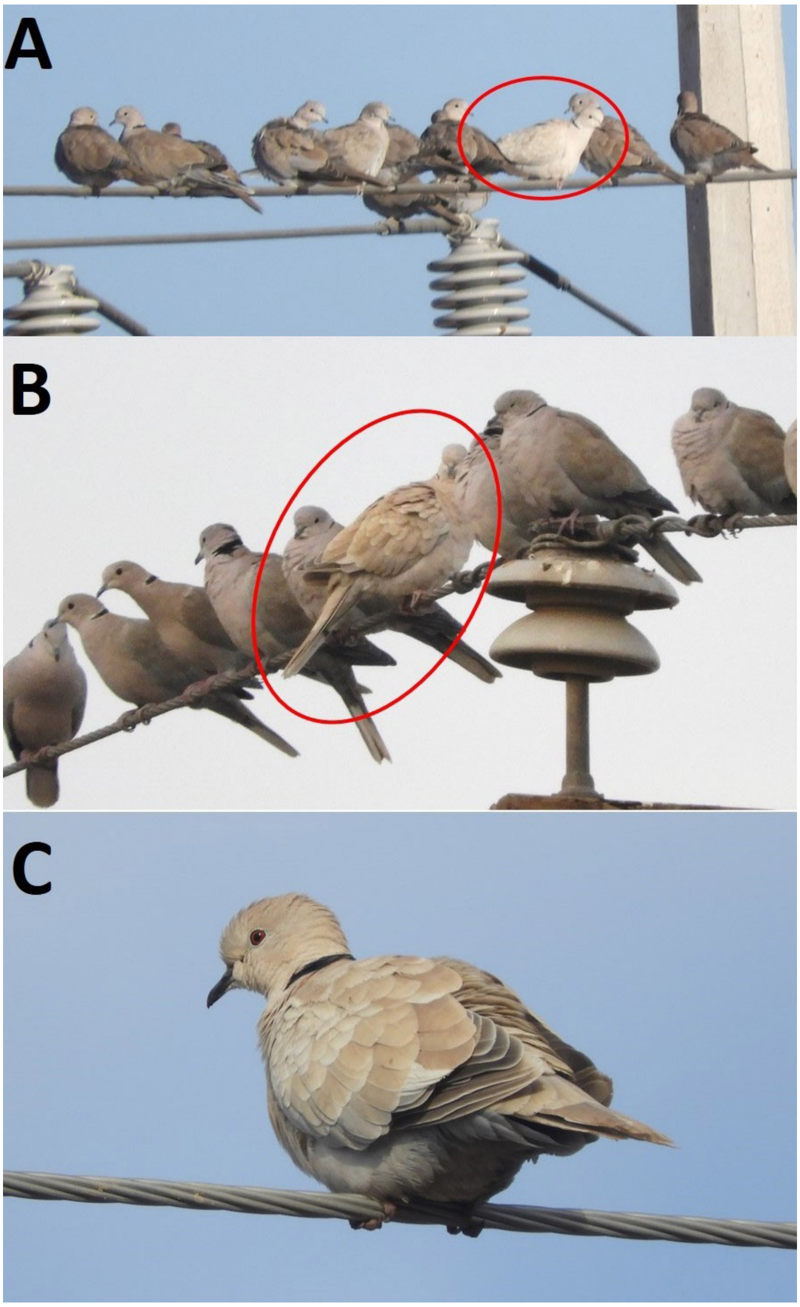

Figure 3. Photographic record of three of our five sightings of the African collared doves (*Streptopelia roseogrisea*) in Sonora and Baja California, Mexico, during November and December 2021. Photographs by Yanet Villaseñor-Cortez (A) and Adrián Ceja-Madrigal (B–C).

– The first sighting of *S. roseogrisea* was made on November 19th, 2021, on the outskirts of Pesqueira, Sonora, on the Pesqueira-San Miguel de Horcasitas highway (coordinates 29°22′48.90″N; 110°54′14.40″W). At least four individuals were perched on power cables alongside 90 other individuals of *S. decaocto*; Figure 3A).

– On November 22nd, 2021, we recorded another individual of *S. roseogrisea* in the northern region of Sonora, coordinates 31°28′1.04″N; 113°26′39.47″W. The bird was perched on communication cables at 6 m height outside a small house in the middle of Federal Highway #8 (Puerto Peñasco – Sonoyta). It was with 17 individuals of *S. decaocto*.

– On November 23rd, 2021, we recorded two individuals of *S. roseogrisea* in Baja California (coordinates 32°29′33.44″N; 115°19′45.38″W). The birds were perched on a cyclone fence on the outskirts of the "Ganadera J Cinco" ranch in Mexicali, Baja California, which has large metal silos to store grain. Around 480 individuals of *S. decaocto* were estimated in the area, alongside six rock pigeons (*Columba livia*).

– On the same date, we recorded another individual of *S. roseogrisea* on the outskirts of San Luis Río Colorado, Sonora, on Federal Highway #2, on the border with the United States (coordinates 32°26′43.40″N; 114°39′22.50″W), approximately 67 kilometers from the previous sighting. The dove was perched on power cables, 7 m high, among 25 *S. decaocto* doves (Figure 3B).

– Finally, on December 3rd, 2021, we recorded a juvenile plumaged individual of *S. roseogrisea* (Figure 3C) on the outskirts of some settlements on Federal Highway #3, west of Hermosillo, Sonora (coordinates 29°10′33.2″N; 111°42′46.5″W). It was perched on communication cables at a 6 m height alongside 17 *S. decaocto* individuals and 32 Brewer's blackbirds (*Euphagus cyanocephalus*).

According to citizen science platforms (eBird and Naturalista), there are 32 confirmed records of *S. roseogrisea* in Mexico, distributed across the states of Veracruz, Baja California, Guerrero, Nuevo León, Querétaro, Nayarit, Coahuila, and Chihuahua (Table 1; Figure 4A). Based on this information, the first individual in the country was recorded in the border city of Tijuana, Baja California, in 2000, and the most recent one in the town of Coyuca de Benítez, Guerrero, in 2021. One sighting in Nayarit lacks a registration date. In addition to the citizen science reports, there are only two records of *S. roseogrisea* for Mexico from a scientific publication. In that work, Blancas-Calva et al. (2014) reported it as an ornamental species widely traded in the localities of Chilpancingo and Chilapa, Guerrero (Table 1; Figure 4A).

Invasion history

The species arrived in the United States earlier than Mexico (1929; Smith 1987), and its records can be grouped into three clusters – the first one in the Southwest (California, Arizona, Nevada, Utah, and Colorado); the second one in Texas; and the final one in Florida (Figure 4A). The established populations of African collared doves in the United States seem to be acting as sources of propagules that are expanding toward Mexico, as it occurred with the Eurasian collared-dove (Ceja-Madrigal et al. 2023).

Analyzing our records and those from citizen science (Figure 4A), we observed two patterns of invasion of Mexico. First, individuals from the US and Texas Southwest cluster populations are moving south into northern Mexico (Baja California Peninsula, Sonora, Chihuahua, Coahuila, Nuevo León, and Tamaulipas). Second, locally established individuals in the Gulf

Table 1. Records of the African collared dove (*Streptopelia roseogrisea*) in Mexico. The new sightings in Sonora and Baja California reported in this paper are highlighted in black. Two of the records from Guerrero are from captive individuals (Blancas-Calva et al. 2014).

State	Locality	Date	Ind.	Latitude	Longitude	Source
Sonora	**Hermosillo**	**03/12/2021**	**1**	**29.175889**	**−111.712917**	**This study**
Baja California	**Mexicali**	**23/11/2021**	**2**	**32.492622**	**−115.329272**	**This study**
Sonora	**San Luis Río Colorado**	**23/11/2021**	**1**	**32.445389**	**−114.65625**	**This study**
Sonora	**Puerto Peñasco**	**22/11/2021**	**1**	**31.466956**	**−113.444297**	**This study**
Sonora	**Pesqueira**	**19/11/2021**	**4**	**29.38025**	**−110.904**	**This study**
Guerrero	Coyuca de Benítez	06/10/2021	1	16.948788	−100.115839	iNaturalist
Querétaro	San Juan del Río	06/09/2021	1	20.385536	−99.966418	iNaturalist
Chihuahua	Delicias	19/11/2020	1	28.1943939	−105.494586	eBird
Querétaro	San Juan del Río	07/09/2020	1	20.388887	−99.964702	eBird
Veracruz	Veracruz	18/07/2020	3	19.1834874	−96.1810287	eBird
Querétaro	San Juan del Río	07/07/2020	1	20.3961716	−99.9676313	eBird
Veracruz	Orizaba	06/01/2020	1	18.836985	−97.09669	eBird
Querétaro	Querétaro	13/03/2019	1	20.5920136	−100.410007	eBird
Guerrero	Buenavista de Cuéllar	03/02/2019	1	18.4558411	−99.4077358	eBird
Querétaro	Querétaro	13/07/2018	1	20.617613	−100.3984	eBird
Querétaro	Querétaro	05/06/2018	1	20.622225	−100.393546	eBird
Coahuila	Piedras Negras	01/03/2018	1	28.656944	−100.555556	iNaturalist
Querétaro	El Marques	06/01/2018	1	20.5614383	−100.221448	eBird
Baja California	Ensenada	28/09/2017	1	31.7155808	−116.666339	eBird
Querétaro	Tequisquiapan	17/09/2017	1	20.5173133	−99.8958411	eBird
Veracruz	Ursulo Galván	30/08/2017	1	19.4733769	−96.3719358	eBird
Querétaro	Querétaro	27/06/2017	1	20.5930336	−100.397408	eBird
Querétaro	Querétaro	12/06/2017	2	20.5958127	−100.383024	eBird
Querétaro	Querétaro	18/02/2017	1	20.5930738	−100.39198	eBird
Veracruz	Puente Nacional	10/10/2016	1	19.3437024	−96.4641611	eBird
Veracruz	La Antigua	31/08/2016	5	19.3703749	−96.3776155	eBird
Querétaro	Jalpan de Serra	04/02/2016	3	21.218428	−99.4706638	eBird
Nayarit	San Blas	01/06/2015	1	21.5428266	−105.285106	eBird
Querétaro	Querétaro	05/03/2015	2	20.562468	−100.417082	eBird
Veracruz	Perote	08/01/2015	2	19.60591	−97.3700799	eBird
Veracruz	Xico	03/01/2015	4	19.4018558	−96.9936988	eBird
Guerrero	Chilpancingo	24/08/2013	20	17.563978	−99.511597	Blancas-Calva et al. 2014
Nuevo León	Linares	31/05/2011	1	24.854245	−99.573984	iNaturalist
Guerrero	Chilapa	02/02/2011	16	17.592258	−99.179881	Blancas-Calva et al. 2014
Veracruz	Tuxpan	15/04/2008	2	20.9422622	−97.4203202	eBird
Baja California	Tijuana	05/07/2000	3	32.4995552	−116.938906	eBird
Nayarit	Tepic	ND	1	21.51461	−104.884452	iNaturalist

of Mexico coast (presumably from bird trade) are moving westwards from Veracruz to the country's central region, where other intentional or unintentional releases occur (Blancas-Calva et al. 2014). Although we did not find evidence of the presence of this species in the Yucatán Peninsula, both the Veracruz and Florida cluster populations may represent potential sources of propagules for its arrival in this region.

Comparison of the climatic niche between its region of origin, the United States and Mexico

The climatic niche of the Mexican records coincides with the climatic values from the United States records (Figure 5), indicating that the populations of *S. roseogrisea* in both countries are becoming established in sites with similar climatic conditions. However, the range of precipitation

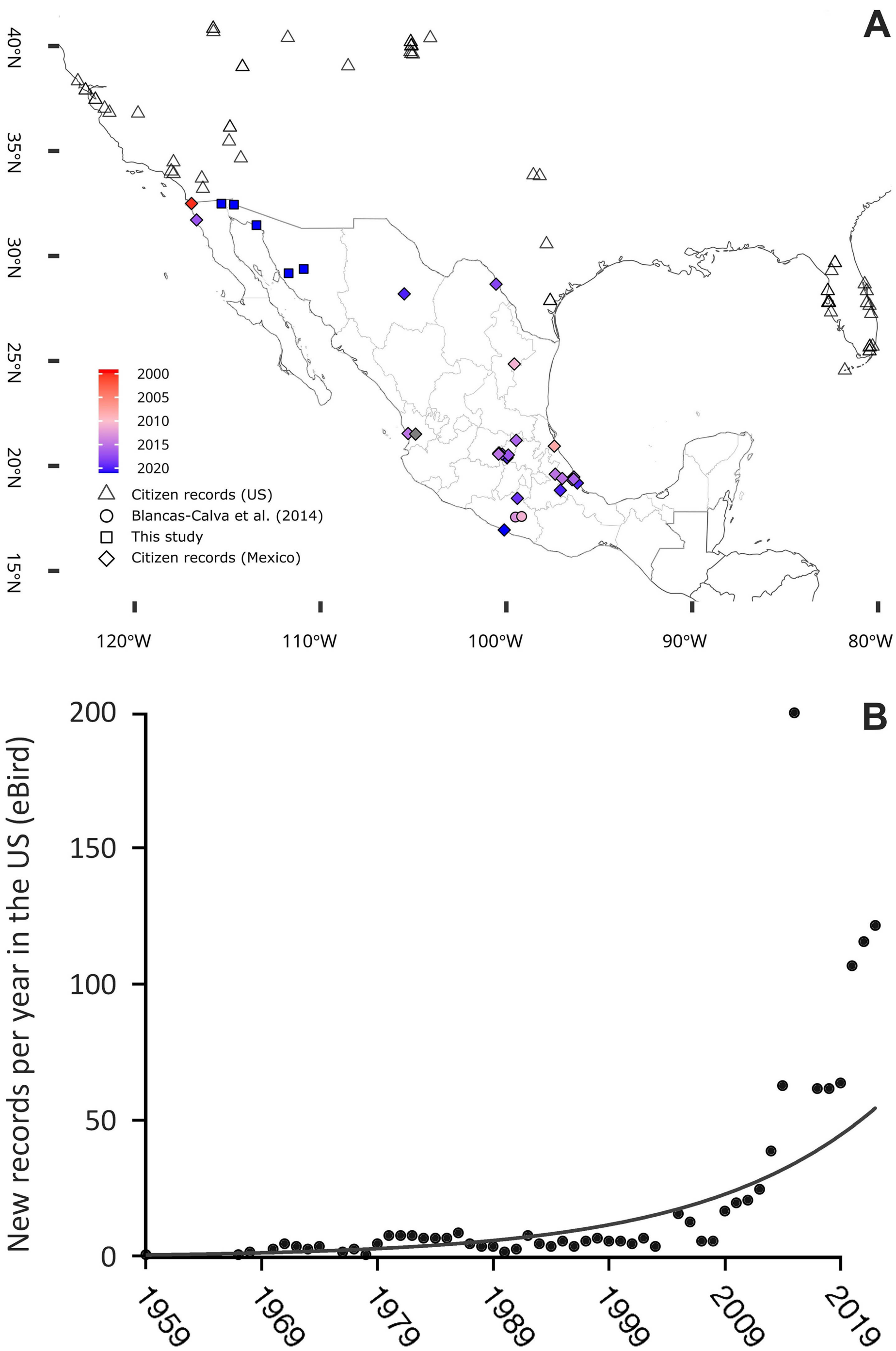

Figure 4. A. Geographical location of the African collared dove records in citizen science platforms for Mexico (diamonds; 2000–2021) and the United States (triangles). The captive records reported by Blancas-Calva et al. (2014) for Guerrero (circles; 2011–2013) and the records we report in this study in the states of Sonora and Baja California (squares; 2021) are also shown. The fill color of the icons in Mexico represents the registration date in a chronological gradient from red (oldest) to blue (most recent). B. Number of new eBird records per year of the African collared dove (*Streptopelia roseogrisea*) in the United States.

and temperature values that correspond to the geographic location in the United States and Mexico did not overlap with its climatic niche in Africa and the Middle East (Figure 5). In its original distribution, the African collared dove distribution includes sites with lower precipitation and higher temperatures than in Mexico and North America.

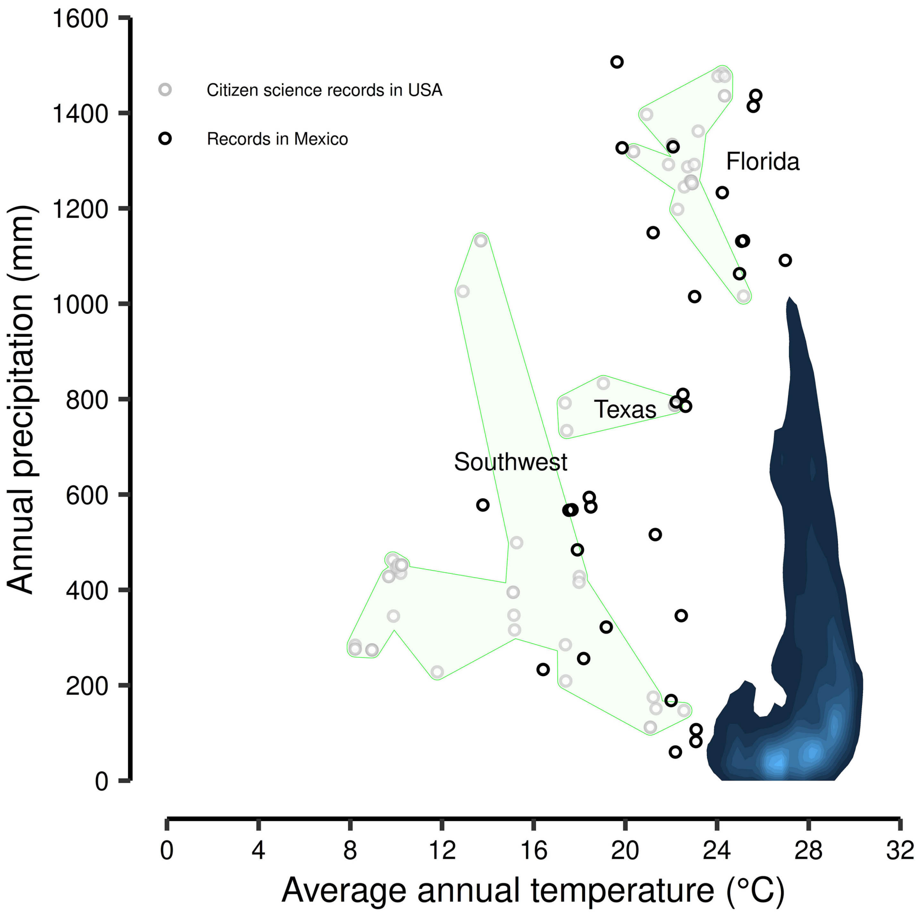

Figure 5. Two-dimensional representation of the climatic niche (precipitation and mean temperature) occupied by the African collared dove (*Streptopelia roseogrisea*) both in its region of origin in Africa and the Arabian Peninsula (blue polygon with contour lines; the climatic space with higher frequency occurs in the lighter areas) as well as in Mexico (black circles) and the United States (gray circles). The light green polygons enclosing the United States records represent its climatic niche in three regions (Florida, Southwestern United States, and Texas).

Discussion

The African collared dove was first confirmed in Mexico in 2000, but it may have arrived earlier and remained unnoticed due to low numbers. Because we are uncertain about its arrival date, it's difficult to understand how invasive the species is. There have been relatively few sightings of the species in Mexico, and it has taken a long time for the species to spread geographically, which suggests that it may not pose a significant threat. Similar to what is happening in Mexico, citizen science data from the United States shows that the species was first seen there in 1959 and had a slow increase in sightings until 2004, with an average of 3.7 per year. However, after 2005, the number of new sightings grew to an average of 65.2 per year. This suggests that the species may be finishing the lag phase of its invasion in the United States (see Figure 4B), but more research is needed to confirm this and determine the potential threat this species represents in North America (Donegan and Huertas 2002; Bonter et al. 2010; Department of Agriculture and Food Australia 2010).

Although we are not certain if *S. roseogrisea* arrived recently in Mexico, or if it arrived earlier and was not detected because of low numbers, due to its close phylogenetic relationships and ecological similarities with *S. decaocto* we considered it important to document the extent of its presence in different regions of the country. Like *S. decaocto*, populations of *S. roseogrisea* may present invasive behavior (Department of Agriculture and Food Australia 2010; Blancas-Calva et al. 2014; CONABIO 2017). A recent analysis conducted by our research group showed that *S. decaocto* invaded 38% of Mexico in a relatively short time (< 30 years), and it was expanding its geographic distribution at a rate of 45,900 km^2 per year in 2016 (Ceja-Madrigal et al. 2023). The high invasion rate of this species is worrisome because it can act as a *Trichomonas* carrier, passing the disease to native species (Powell and Hollander 1982; Stimmelmayr et al. 2012; CONABIO 2017). However, the invasion potential of *S. roseogrisea* and the costs of its interactions with native avifauna in Mexico and other regions where it has been introduced are unknown. Although significant efforts have been made to systematize and expose the economic damages of invasive species worldwide (i.e., InvaCost; Diagne et al. 2020), the monetary costs associated with collared-doves, specifically for Mexico, remain unexplored (Rico-Sánchez et al. 2021).

The spatial and geographic distribution of the limited number of *S. roseogrisea* records in Mexico suggests that this species is starting its invasion of the country. The chronology of records in the geographic space suggests two expansion patterns throughout the country. Earlier records in the western region of the US-Mexico border indicate colonization of northern Mexico from the already established populations in the Southwest region of the United States (Álvarez Romero et al. 2008). This is similar to the expansion process of *S. decaocto* in Mexico. This species first established populations in the United States before colonizing northern Mexico (Romagosa and McEneaney 1999; Fujisaki et al. 2010; Eraud 2020; Ceja-Madrigal et al. 2023).

A second expansion pattern is related to the appearance of *S. roseogrisea* individuals in several unconnected locations at different times, suggesting that the species is invading the country facilitated by the bird trade (Romagosa and McEneaney 1999; EP-N *personal observations*). The simultaneous presence of the species in central Veracruz and the agricultural region of "El Bajío" in 2015 could hardly be achieved by this species without the help of humans moving individuals for long distances (Romagosa and McEneaney 1999; Romagosa and Labisky 2000). So, the compiled records analyzed in this study indicate that the expansion of *S. roseogrisea* in Mexico is both a colonization, with propagules from nearby populations in the United States moving south, and an invasion process, with captive individuals being moved by the bird trade (Donegan and Huertas 2002; Blancas-Calva et al. 2014; Roldán-Clarà et al. 2017).

Several records from citizen science platforms included close pictures of *S. roseogrisea* individuals that presented intense tail feather wear. These pictures suggest that these birds were used to interacting with humans, allowing them to get close to photograph them, and likely escaped from captivity (*observers' comments*). While no government agencies (i.e., SEMARNAT, PROFEPA, and CONABIO) have provided permits to import and commercialize species from the genus *Streptopelia* in Mexico, there is evidence that both species (*S. decaocto* and *S. roseogrisea*) are traded in local markets as pets (*personal observations* and see Blancas-Calva et al. 2014).

To determine how meaningful bird trade has been for the invasion process of *S. roseogrisea*, we interviewed researchers studying social aspects of animal trade. Our examination indicated that before 2005, doves of the genus *Streptopelia* were not commonly sold in markets in Mexico. However, from 2013 onwards, there was a substantial increase in *Streptopelia* marketing. This trade continued until 2016, albeit in smaller quantities (Graciela Gómez-Álvarez and Blanca Roldán-Clarà *personal communication*). Traded species included both *S. decaocto* and *S. roseogrisea*.

Additionally to this national trade, we found that *S. roseogrisea* was being sold to be liberated as part of social events (weddings, baptisms, and "quinciañera" celebrations) in the city of Morelia, and traded as a pet bird in the local markets of Oaxaca (*personal observations*). Therefore, we recommend closely monitoring and controlling the species in the country's internal bird trade. Due to the profound cultural tradition of having wild birds as pets in Mexico, it is critical to work with bird trade organizations ("pajareros") and pet shops to stop the spreading of invasive bird species (López-Medellín and Íñigo-Elias 2009; Roldán-Clarà et al. 2017).

Streptopelia roseogrisea individuals detected in Sonora and Baja California were relatively far from people and did not present the characteristic wear at the tips of the rectrices produced by captivity. This suggests that they were not recent escapees but members of local populations capable of reproducing in the wild (Donegan and Huertas 2002). Probably, they are descended from the populations established in the United States Southwest region. This idea is supported by the fact that the earlier records for the species in Mexico occurred in this region in 2000, giving the species enough time to get established locally (Fujisaki et al. 2010). Similarly, records from the urban region of Querétaro, with a difference of one or two years (2017–2019), suggest that the species may be capable of surviving and reproducing in the wild without human assistance. As a result, monitoring *S. roseogrisea* populations to determine their survival and productivity is crucial for understanding their invasion's local status and potential to colonize other regions of Mexico (Álvarez Romero et al. 2008; CONABIO 2017).

The five new records for *S. roseogrisea* result of this study were obtained in areas with human buildings and agricultural production. They always occurred in the presence of *S. decaocto*. Two non-excluding hypotheses could explain this association between the two species: 1) *S. roseogrisea* could be gaining benefits from interacting with its phylogenetically close relative, and 2) they were found together because both species were searching for similar habitat conditions (Johnson et al. 2001; Baptista et al. 2020). The physical proximity of *S. roseogrisea* with *S. decaocto* suggests that both species take advantage of food and nesting resources similarly (Hanane and Yassin 2017; Squalli et al. 2021). *Streptopelia roseogrisea* could be protected from *S. decaocto* numbers and benefit from interspecific social interactions (Prum 2014), which could make this species very common all over Mexico. This association between *S. roseogrisea* and *S. decaocto* individuals should be investigated since they can hybridize producing fertile offspring (Smith 1987; Romagosa and McEneaney 1999), although inviability and sterility increase in second-generation hybrids (Lijtmaer et al. 2003). Curiously, S. *roseogrisea* populations in Spain seem to be replaced by the larger individuals of *S. decaocto* (Santos 2022), suggesting that differences in local conditions can dramatically affect the interactions among both species.

Our visual comparison of the climatic conditions of the African collared dove region of origin and the sites in which this species has been recorded both in the United States and Mexico did not overlap. This is surprising because previous research indicated that climatic conditions tend to be the factor that better explains the invasion success of birds (Peterson 2003; Lovell et al. 2021). Birds that invade areas with climatic conditions similar to those in their original distribution area are more successful than those that invade regions with very different climatic conditions (Blackburn and Duncan 2001; Strubbe et al. 2013). Our finding suggests that this species can survive in sites with a wide range of climatic conditions. This would imply that in its original range, the species' expansion should probably be restricted by local ecological conditions (Lovell et al. 2021) and biotic restrictions imposed by other species (Duncan et al. 2003).

Our result also showed that the climatic niche generated from the Mexican records overlapped with the climatic conditions present in the three invaded regions of the United States. This suggests that this species is colonizing/invading areas in Mexico with similar environmental conditions to those in the regions where the United States populations were first established (Romagosa and McEneaney 1999). If most of the birds invading Mexico come from the three populations established in the United States, we can expect them to be able to perform well in a wide range of climatic conditions, expanding their distribution fast by founding new breeding populations (Romagosa and Labisky 2000).

While our approach to compare the climatic niches of the regions of interest in Mexico, the US, and Africa, is rough and limited, overestimating the actual climatic niche of the species, it clearly shows that this species can inhabit areas with colder and wetter environments than those present in its original distribution. This fact limits our ability to predict the sites the species can invade in the future, coinciding with the recent findings of Strubbe et al. (2023), who stated that climatic modeling based on native areas of the species distributions tends to underpredict their potential area of invasion. However, these authors demonstrated that it is possible to accurately predict the potential areas at risk of any bird invasion based on their ecophysiological traits (Strubbe et al. 2023). Our study indicates that to predict the geographic areas that some species can invade, it is crucial to include the environmental conditions of sites where the species has been established and those present in its original distribution (Lovell et al. 2021).

The presence of only a few records of *S. roseogrisea* throughout the country poses a crossroads of scenarios that deserve analysis. From an ecological point of view, we have the opportunity to document in detail an invasion process, including the environmental, economic, and social repercussions that it entails (Duncan et al. 2003). For example, although this species can compete for food and nesting sites with native pigeons (*Zenaida* spp.; Álvarez Romero et al. 2008) and act as a vector for the transmission of pathogens and diseases such as avian trichomonosis (Stimmelmayr et al. 2012; CONABIO 2017), there is no evidence of this species generating negative impacts on the native biodiversity (Baptista et al. 2020; Evans et al. 2016; CONABIO 2017). However, this species is categorized as being "Data Deficient" (DD) under the EICAT, which means that is likely to have low monetary costs (Evans et al. 2023b).

From a conservation point of view, we are in time to propose management strategies to limit the expansion of this species to other regions of the country (Henderson and Bomford 2011). In Mexico, we ignore whether it can expand its distribution without human help, and we do not know if it is hybridizing with *S. decaocto* (Álvarez Romero et al. 2008). As a result, resources need to be invested in obtaining critical information for managing the species adequately while at the same time actively limiting its use as a pet in the bird trade (Lockwood et al. 2019).

Authors' contribution

All authors conceived the initial idea and designed the study strategy. ACM, RP-M, JES and EP-N conducted the field work in the Bajío region. ACM, JCP-M, JES, YV-C, PR and EP-N participated in the field work in the Northwest and Southeast regions. JCP-M, AC-M and RP-M collected and analyzed citizen science and published data. RP-M constructed the distribution maps and modeled the climatic niches. EP-N carried out fieldwork in search of the species in local markets. AC-M took the lead in writing the paper with inputs and suggestions from all contributing authors. JES revised the first draft. All authors read and approved the final manuscript.

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