Bird Conservation International

www.cambridge.org/bci

Review Article

Cite this article: Derlindati EJ, Arengo F, Michelutti M, Romano MC, Fabre HS, Ortiz E, Rocha O, Jahn AE, Chanampa MM, Barberis IM (2024). A review of the ecology and conservation of the Andean Flamingo *Phoenicoparrus andinus* and Puna Flamingo *P. jamesi* in South America. *Bird Conservation International*, **34**, e37, 1–10
https://doi.org/10.1017/S0959270924000273

Received: 27 May 2023
Revised: 16 August 2024
Accepted: 09 September 2024

Keywords:
Action plan; Andes; Conservation priorities; Phoenicopteridae; Wetlands

Corresponding author:
Ignacio M. Barberis;
Email: ignaciobarberis@yahoo.co

A review of the ecology and conservation of the Andean Flamingo *Phoenicoparrus andinus* and Puna Flamingo *P. jamesi* in South America

Enrique J. Derlindati[1,2], Felicity Arengo[2,3], Matías Michelutti[2,4], Marcelo C. Romano[2,5], Heber Sosa Fabre[2,6], Enver Ortiz[2,7], Omar Rocha[2,8], Alex E. Jahn[9], Mariana M. Chanampa[10] and Ignacio M. Barberis[2,11]

[1]Biología de la Conservación, Facultad de Ciencias Naturales, Universidad Nacional de Salta (UNSa), 4400 Salta, Argentina; [2]Grupo de Conservación Flamencos Altoandinos (GCFA); [3]Center for Biodiversity and Conservation, American Museum of Natural History, New York, USA; [4]Tucumán 276, X5143 Miramar, Córdoba, Argentina; [5]Centro de Investigaciones en Biodiversidad y Ambiente (ECOSUR), 2000 Rosario, Argentina; [6]Fundación para el Estudio en Intervención Socioambiental (FEISA), Godoy Cruz 5501, Mendoza, Argentina; [7]Centro de Ornitología y Biodiversidad (CORBIDI), Huertos de San Antonio, Surco, Lima 33, Peru; [8]BioparqueMunicipal Vesty Pakos, La Paz, Bolivia; [9]Department of Biology, Indiana University, Bloomington, USA; [10]Cátedra de Epistemología y Metodología de la Ciencia, Facultad de Ciencias Naturales, Universidad Nacional de Salta (UNSa), 4400 Salta, Argentina and [11]Instituto de Investigaciones en Ciencias Agrarias de Rosario, Universidad Nacional de Rosario, Consejo Nacional de Investigaciones Científicas y Técnicas, Zavalla, Argentina

Summary

There are six species of flamingos in the world, all under pressure from human activities in their wetland habitats. Obtaining global population estimates for flamingos is challenging because of their broad geographical range, nomadic movements, capacity for long-distance flight, and the complexity of international monitoring. Two species, the Andean Flamingo *Phoenicoparrus andinus* and Puna Flamingo *P. jamesi*, during key parts of their life cycle, use wetlands in the Andes of South America, where they coexist at various sites. We compiled historical information on population estimates and ecology for these two species and integrated data collected on regional simultaneous censuses to describe population trends, current and emerging threats, and provide recommendations for conservation action. Long-term population trends have been difficult to establish given the unreliability of population estimates prior to the late 1990s. Systematic, regional censuses carried out regularly since 1997 have produced robust population estimates for the Andean and Puna flamingos (most recently, 78,000 and 154,000, respectively) and show populations of both species to be stable and increasing. Increasingly rapid changes in wetlands caused by human activities such as industrial-scale mining in breeding and foraging sites in the high Andes wetlands, and agro-industrial activities in their lowland wintering sites, focused on areas of the highest concentrations of flamingos pose threats to their survival and ability to reproduce. In addition, climate change is projected to reduce wetland habitats and some localised effects have already been detected. Continued research on the ecological drivers of flamingo abundance, movements, and population genetics to understand population structure and dynamics are necessary, as well as the identification of response variables to changing environmental conditions. Interdisciplinary and systems-level approaches in the context of international collaboration in monitoring and conservation planning among a diversity of stakeholders will be required to safeguard flamingo populations and wetland habitats.

Introduction

Flamingos are charismatic, gregarious, and extremely specialised birds that have inspired humans for centuries. Indeed, their scientific name, the Phoenicopteridae, or "Phoenix-winged", reflects their status as the *Phoenix*, or "firebird", described by the ancient Greek writer Herodotus (McMillan 1972). Like that mythic bird, their populations seem to be reborn from almost zero to thousands of individuals in just a few days (Balkiz et al. 2007; Krienitz 2018). In addition, their flight capacity allows them to reach isolated sites where they rapidly gather, and they frequently breed in wetlands near volcanic activity (Caziani et al. 2007; Krienitz 2018; Torres et al. 2019). They are indeed extraordinary birds, being one of the few groups of birds that are filter-feeders (Anderson 2017).

There are three flamingo species, with overlapping distributions in the Southern Cone. The Chilean Flamingo *Phoenicopterus chilensis* has a broad distribution, occupying diverse high-altitude, lowland, and coastal wetlands, while the Andean Flamingo *Phoenicoparrus andinus* and the Puna (or James's) Flamingo *Phoenicoparrus jamesi* are primarily restricted to wetlands in the high Andes of Argentina, Bolivia, Chile, and Peru (Caziani et al. 2007). Owing to their strong association with these wetlands, Puna and Andean flamingos are frequently referred to as "high Andes" flamingos (Caziani and Derlindati 2000), although a portion of their population has been recorded in lowland wetlands in central Argentina (Caziani et al. 2007; Cruz et al. 2013; Derlindati et al. 2014; Jahn et al. 2023).

There are large differences in population sizes among the six extant flamingo species in the world. In Africa and Eurasia, there are over 3,000,000 individuals of Lesser Flamingo *Phoeniconaias minor*, and the overall population of Greater Flamingo *Phoenicopterus roseus* is estimated at between 550,000 and 680,000 individuals. In the Americas, there are between 260,000 and 330,000 American Flamingo *Phoenicopterus ruber*, and over 500,000 Chilean Flamingos (BirdLife International 2012; Marconi et al. 2020; Unterkofler and Blanco 2016), while the Andean and Puna flamingos have the smallest population sizes, with current population numbers being less than 80,000 and 160,000 individuals, respectively (Marconi et al. 2020). Based on these estimates, the Andean Flamingo is categorised as "Vulnerable", while the Puna Flamingo is categorised as "Near Threatened" (IUCN 2023).

The wetland habitats that these two flamingo species use are changing rapidly, which poses potentially serious threats to their survival. Industrial-scale mining in high Andean environments and widespread agro-industrial activities in the lowland Pampas have undergone recent rapid and unprecedented growth (Gajardo and Redón 2019; Nanni et al. 2020; Tapia et al. 2022; Ugarte-Núñez and Mosaurieta-Echegaray 2000). However, the effects of these activities on flamingo populations are still largely unknown (Delfino and Carlos 2024; Rocha et al. 2021). In addition, climate change models predict that temperatures in the Andean plateau will increase while precipitation will decrease (Zubieta et al. 2021), suitable wetland habitat areas will decrease (Delfino 2023), and several studies are beginning to document detectable changes in wetlands in this direction (De los Ríos-Escalante et al. 2024; Gutiérrez et al. 2022). Thus, our objective was to synthesise the information available on the ecology of the Andean and Puna flamingos and highlight the critical conservation issues that need to be tackled immediately at global, regional, and local levels. We describe population trends and distribution of both high Andes flamingo species, and the threats to their associated habitats, including changes in land-use pressures. We describe current conservation strategies (and their limitations) and provide recommendations for further action.

Methods

We obtained Andean and Puna flamingo population numbers and information on wetland sites from a review of the published literature, unpublished reports, field guides, and personal experience. The search considered combinations of the following two terms in different languages: (1) the Andean region (i.e. "high Andean", "Andes", "Altiplano") + (2) the high Andes flamingos by their common names (i.e. "Andean Flamingo", "Puna Flamingo", "Flamenco Andino", "Flamenco Puna", "James's Flamingo", "Parina", "Parihuana") or their scientific names ("*Phoenicoparrus andinus*", "*Phoenicoparrus jamesi*"). Since 1997, data on Andean and Puna flamingo distribution and abundance have been collected via a regional collaborative effort by the "Grupo de Conservación Flamencos Altoandinos" (GCFA) that coordinates range-wide censuses of the species in Argentina, Bolivia, Chile, and Peru (Caziani et al. 2007; Marconi et al. 2020). These comprehensive censuses have been carried out every five years since 2005. In these censuses, direct counts are conducted over a 10-day period following a standardised survey protocol during the breeding season (late January–early February) at over 250 wetlands by about 20 teams of 4–5 people (EJD, FA, MM, MCR, HSF, EO, OR, and IMB participated in most censuses). To date, a total of six simultaneous censuses have been carried out covering the global distribution of the Andean and Puna flamingos (Marconi 2010; Marconi et al. 2020). These censuses provided reliable global population estimates of both high Andes flamingo species, identified flamingo occurrence and abundance at specific wetland sites, and allowed us to evaluate conservation issues and identify priority sites for conservation action (Marconi et al. 2020).

Results and Discussion

Population size and geographical range of high Andes flamingos

The Andean Flamingo was first described by Philippi in 1854 from a type specimen from the Salar de Atacama, Chile. The Puna Flamingo was described in 1895 from a type specimen collected in Laguna Parinacota, Chile in 1850 (Allen 1956). Until the late 1950s, the scientific community surmised that the Puna Flamingo could be extinct because it had not been observed in many years, however, an expedition to Laguna Colorada, Bolivia, in 1957 reported a few hundred Puna Flamingos (Behn et al. 1957; Johnson et al. 1958).

Since the early 1960s and until the late 1980s, there were only vague population estimates for the two high Andes flamingo species (Kahl 1975; Peña 1962), and their distribution was uncertain (Bucher 1992; Fjeldså and Krabbe 1990; Hurlbert 1978, 1981; Parada 1990). Estimating the size of flamingo populations is a difficult task because of their flight capacity, their remote wetland habitats, and the extent of their geographical range (Béchet 2017). Population estimates were based on extrapolations from counts conducted at a few wetland sites (Cordier 1965; Hurlbert 1978, 1981; Johnson 1967; Kahl 1975; Parada 1990). Most studies were focused on where these flamingo species were feeding or breeding in high Andes wetlands (Figure 1; see Supplementary material Table S1 for more details). During this period, estimates of total abundances, winter distributions, and movement patterns were mostly hypothetical (Valqui et al. 2000).

In the 1970s, several flamingo censuses were carried out in summer and winter in different wetlands of Peru, Chile, Bolivia, and Argentina (Hurlbert 1978, 1981) (Figures 1 and 2), showing that the Puna Flamingo was not as rare as believed and that there was marked spatial variation in flamingo abundance. In the 1980s, censuses were carried out in different seasons and years in a set of wetlands in Chile (Parada 1990) (Figures 1 and 2). In the 1990s, regional studies were carried out in Bolivia (Rocha 1997) and Argentina (Caziani and Derlindati 2000).

The systematic censuses of the GCFA initiated in 1997 showed that high Andes flamingos are present in a diversity of over 200 wetlands across Argentina, Bolivia, Chile, and Peru, including lagoons, salt lakes, salt flats, flooded meadows, marshes, and rivers, from 0 to 4,740 m a.s.l. in the highlands of central Andes (Caziani et al. 2007; Marconi et al. 2011, 2020) (Figure 3). During the breeding season, about 70% of the global population of both flamingo species is concentrated in highland wetlands situated around the tri-national border of Argentina, Bolivia, and Chile (Caziani et al. 2007; Marconi et al. 2011, 2020). Moreover, 50% of the population of both flamingo species is concentrated in just a few wetlands, some of them important nesting sites; thus, any impact on these few wetlands could seriously affect their populations (Caziani and

	50-'60s	70-'80s	'90-'00s	'00s-
Main Objectives	• Identification • Natural history • Distribution • Abundance	• Distribution • Abundance	• Regional abundance	• Global distribution • Global abundance
Problems		• Low accuracy in species identification	• Only regional or national censuses	
Advances		• Incorporation of winter censuses • Larger survey areas	• Incorporation of winter censuses • Improved accuracy in species identification	
Difficulties	• Accesibility	• Accesibility		
Threats				• Mining • Agriculture
References	• Behn et al. 1957 • Johnson et al. 1958 • Peña 1962 • Morrison 1972 • Kahl 1975	• Hurlbert & Keith 1979 • Hurlbert 1978 • Hurlbert 1981 • Fjeldsa & Krabbe 1990	• Parada 1990 • Bucher 1992 • Rocha 1997 • Caziani & Derlindati 2000	• Valqui et al. 2000 • Caziani et al. 2007 • Marconi et al. 2020

Figure 1. Time arrow of the high Andes flamingo research from the 1950s to the present. Changes in main objectives, problems, advances, difficulties, and threats are shown.

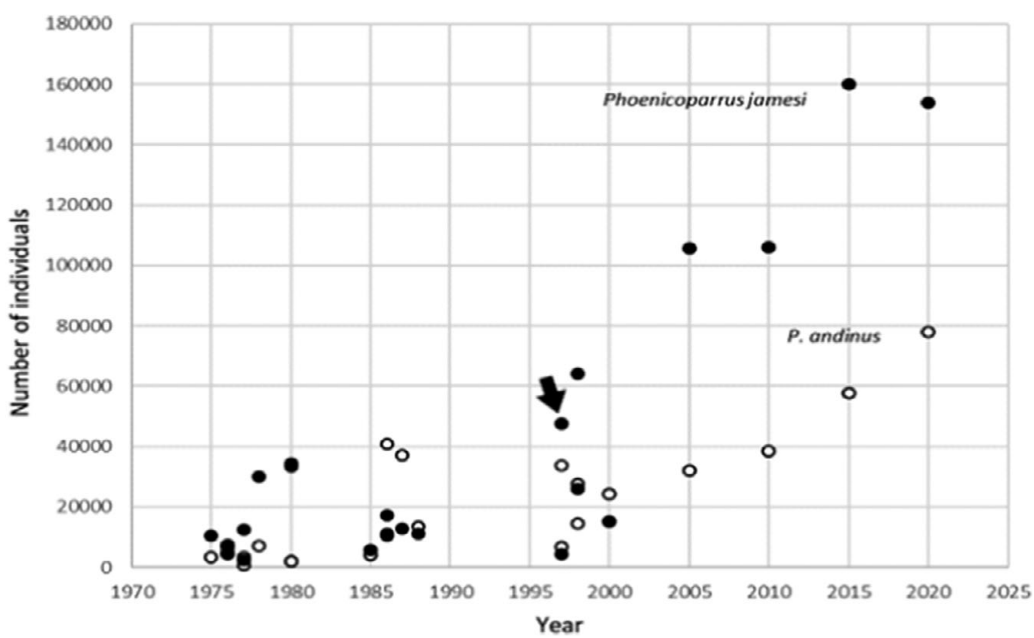

Figure 2. Total numbers of individuals by species derived from censuses conducted in the 1970s through to the second decade of the 2000s (data collated from Caziani et al. 2007; Hurlbert 1978, 1981; Marconi et al. 2020; Parada 1990; Valqui et al. 2000). Arrow shows the first International Simultaneous Census (Caziani et al. 2007).

Derlindati 2000). Summer censuses carried out every five years from 2005 until 2020 with similar coverage showed flamingo populations stable and increasing (Marconi et al. 2011, 2020).

The two simultaneous censuses carried out in winter (1998, 2000) showed that almost 40% of the global population of the Andean Flamingo is mainly found in several lowland wetlands in Argentina and a few highland lakes (Poopó and Uru Uru) in Bolivia (Caziani et al. 2007). Among the most important lowland wetlands are the Laguna Melincué and the Pampa de las Lagunas systems in southern Santa Fe province, and the Mar Chiquita/Río Dulce wetlands in Córdoba and Santiago del Estero provinces (Bucher 1992; Cabaña et al. 2018; Romano et al. 2009, 2017). These wintering sites show a large inter-annual variation in the abundance of this flamingo species (Romano et al. 2017). In contrast, the wintering sites of the Puna Flamingo remain largely unknown (Bucher 1992; Cruz et al. 2013; Marconi et al. 2020; Quiroga and Llugdar 2022).

Andean and Puna flamingos breed at high elevations in the Andes in summer (October–February). A portion of the Andean Flamingo

https://doi.org/10.1017/S0959270924000273 Published online by Cambridge University Press

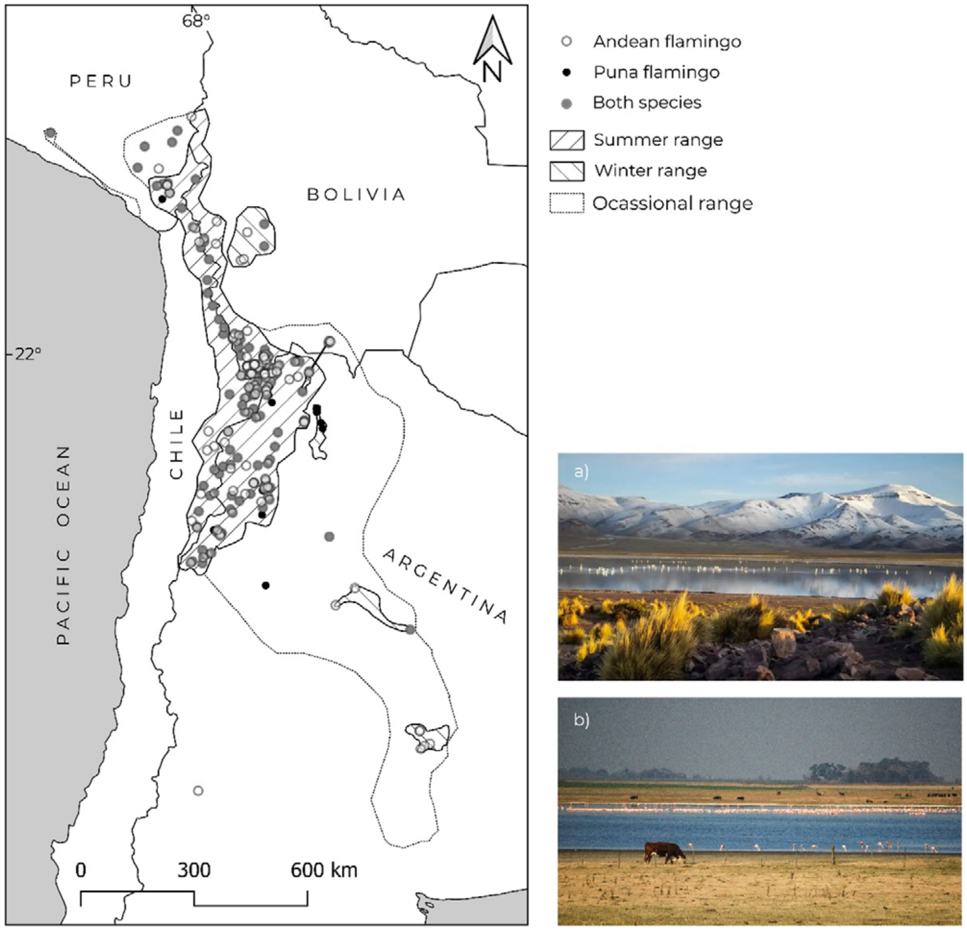

Figure 3. Current known distribution of Andean Flamingo *Phoenicoparrus andinus* and Puna Flamingo *P. jamesi* across Argentina, Bolivia, Chile, and Peru: (a) example of a high Andes wetland, Lagunas de Vilama (4,600 m a.s.l.) in north-western Argentina; (b) a lowland wetland, Laguna La Dulce (80 m a.s.l.) in central Argentina. (Photographs: E. J. Derlindati and M. Romano)

population moves to lowland wetlands in the grasslands of Argentina (the Pampas), particularly when the high Andean wetlands freeze completely (Caziani et al. 2007). This movement occurs across an altitudinal gradient of over 4,000 m; therefore, these individuals are considered partial altitudinal migrants (Jahn et al. 2020), a behaviour that sets them apart from other flamingo species (Caziani et al. 2007). A portion of the population of the high Andes flamingos spends the entire year at several Andean lakes located at lower elevations or where geothermal activities prevent the water from freezing (Caziani et al. 2007; Johnson et al. 1958). Most of the lowland wetlands used by Andean Flamingos during the winter season are immersed in a matrix of highly intensive agroecosystems of the Humid Pampas (Nanni et al. 2020; Romano et al. 2005, 2008, 2011, 2017). Puna Flamingos are occasionally observed in lowland wetlands and a few sites on the Peruvian coast in winter (Caziani et al. 2007; Cruz et al. 2013; Derlindati et al. 2014; Dias and Cardozo 2014; Hughes 1980). Records of high Andes flamingo species wandering outside their normal range are shown in Appendix S1.

Habitat characteristics, flamingo distribution, and spatial patterning

The main habitats used by Andean and Puna flamingos are unique and specific wetlands that have distinctive characteristics and relatively few variables and conditions are known to affect their abundance and distribution (Boyle et al. 2004; Caziani and Derlindati 2000; Derlindati et al. 2014; Dib et al. 2009; Hurlbert and Keith 1979; Ortiz et al. 2020; Polla et al. 2018; Valqui et al. 2000; Vides-Almonacid 1990). These species use habitats with a very narrow range of salinity, productivity, and water levels (Mascitti 2001; Mascitti and Bonaventura 2002; Polla et al. 2018). The inter-annual variation in climatic conditions (e.g. dry and wet years associated with El Niño – La Niña events) modifies the lake water area and water chemistry (Bucher and Curto 2012; de la Fuente et al. 2021; Guerra et al. 2019), leading to inter-annual variations in the abundance and distribution of both high Andes flamingos in highland and lowland areas (Bucher 1992; Moschione and Sureda 2008; Romano et al. 2009, 2017).

In the late 1990s, lakes in north-western Argentina and northern Chile showed marked variations in depth, transparency, and pH, and these variations in salinity and depth were strongly related to the presence of waterbird communities, especially flamingos (Boyle et al. 2004). In the high Andes, all three flamingo species forage in saline wetlands (Hurlbert and Keith 1979), and there are wetlands where all three species occur. However, Andean and Puna flamingos tend to forage in hypohaline lakes characterised by 3–20 g/L of salt, dissolved organic matter of low molecular weight, high silicon concentration, and high dissolved oxygen (e.g. lakes Purulla, San Francisco, and Grande in Catamarca province, Argentina), whereas Chilean Flamingos tend to forage in mesohaline lakes characterised

https://doi.org/10.1017/S0959270924000273 Published online by Cambridge University Press

by 20–50 g/L of salt, high total organic carbon concentration (e.g. lakes Archibarca and Las Peñas in Catamarca province, Argentina) (Frau et al. 2015). With a range of occurrences according to pluriannual cycles or seasons, there are differences in the distributional overlap among the lakes, with the highest overlap observed between Chilean and Andean flamingos, and the lowest between Chilean and Puna flamingos (Hurlbert and Keith 1979). Within a lake, flamingos typically form single-species flocks, although mixed flocks also form, with the highest overlap occurring between Andean and Puna flamingos (Hurlbert and Keith 1979). In lowlands, all three flamingo species are found foraging in some wetlands, forming single species flocks, but both Andean and Puna flamingos are most often associated with Chilean Flamingos in mixed flocks (Castro and Torres 2014).

Foraging behaviour and diet

High Andes flamingos mainly forage in shallow waters using different foraging modes, but mainly forage with their beak, head or neck submerged, walking along the coast filtering water and mud (Hurlbert 1982; Hurlbert and Keith 1979). Puna Flamingos walk slowly (10–15 steps/minute), spending more time feeding at each spot, while Andean Flamingos walk faster (20–30 steps/minute) (Hurlbert 1982).

Andean and Puna flamingos have a deep-keeled bill and mainly feed on diatoms (Frau et al. 2021; Hurlbert 1982; Hurlbert and Chang 1983; Mascitti 1998; Mascitti and Kravetz 2002; Ortiz et al. 2020; Tobar et al. 2012), but they likely ingest considerable amounts of mud with microbes when feeding (Mascitti 1998; Polla et al. 2018). In the high Andes, Andean Flamingos primarily filter the larger (>80 μm long) diatoms while Puna Flamingos primarily filter smaller ones (<60 μm long; Hurlbert 1982). In lowland wetlands, Andean Flamingos showed a high positive selection for diatoms, and a strong negative selection for microinvertebrates (Polla et al. 2018).

Nesting sites and breeding biology

Although the breeding ranges of the Andean and Puna flamingos extend over large areas in the Andes of Chile, Bolivia, and Argentina, the currently known nesting sites are limited to very few isolated, shallow hypersaline lakes (Caziani et al. 2007; Childress 2005; Derlindati et al. 2010; Marconi and Clark 2011; Marconi et al. 2020; Rocha et al. 2021; Torres et al. 2019; Valqui et al. 2000). Until 2006, the most important breeding sites for the Andean Flamingo were five wetlands in northern Chile (Caziani et al. 2007; Childress 2005; Parada 1990), while for the Puna Flamingo, it was Laguna Colorada, a lake in south-western Bolivia (Caziani et al. 2007; Rocha et al. 2009; Valqui et al. 2000). Such a limited number of nesting colonies, plus the frequent colony failures due to natural (e.g. predation by foxes; Lagos et al. 2023) or human-induced (e.g. egg harvesting by local people; Rocha and Quiroga 1997; Torres et al. 2019) causes, are likely to play a central role in the present population dynamics of high Andes flamingos, resulting in unique conservation challenges.

Intermittent breeding and shifting of nesting colony locations are common events for flamingos worldwide (Baldassarre and Arengo 2000; Balkiz et al. 2007; Boucheker et al. 2011). Similar patterns have been reported for Andean and Puna flamingos at a regional scale (Parada 1990; Torres et al. 2019). For example, since 2005, the Andean Flamingo has been reported breeding in south-western Bolivia in several wetlands, with Laguna Colorada being one of the most important breeding sites (Rocha et al. 2009, 2021). In contrast, both the number of nesting pairs and the number of fledglings of Andean Flamingos have declined in Chile (Marconi et al. 2020). In Argentina, Andean Flamingo nesting activity was first recorded in 1986 in Mar Chiquita, where 100 active nests were mixed within a Chilean Flamingo nesting colony (Cobos et al. 1999). This finding caught the attention of flamingo specialists since this lake is located at 64–71 m a.s.l. in the Chaco ecoregion (Cobos et al. 1999), whereas Andean Flamingos were previously known to only nest from 2,300 to 4,300 m a.s.l. (Parada 1990; Rocha et al. 2021; Torres et al. 2019). Subsequently, the Andean Flamingo was recorded nesting in Laguna La Brava (La Rioja Province, 4,200 m a.s.l.) in 1998 (Bucher et al. 2000), and in Los Aparejos and Purulla lakes (Catamarca Province, 4,200 m and 3,500 m a.s.l.) in 2001 and 2010, respectively (Caziani et al. 2007; Marconi and Clark 2011), and Laguna Llancanelo (Mendoza Province, 1,300 m a.s.l.) in 2010 (Sosa and Martín 2010). Subsequently, six new breeding sites for this species were reported in Argentina (Torres et al. 2019). These nesting colonies never exceeded 200 individuals, unlike the main colonies in Chile with thousands of individuals, which have declined in number and size in concert with increasing mining activities over the last four decades (Torres et al. 2019).

The Puna Flamingo breeds in a few salt flats above 4,000 m a.s.l. (Caziani et al. 2007; Derlindati et al. 2010). Up to 1998, the main known breeding sites were in Bolivia (Caziani et al. 2007), but in 2000 a breeding colony was found in the Laguna Brava Provincial Reserve, La Rioja Province (Argentina), which has been more recently abandoned due to red fox (*Pseudalopex culpeus*) predation (H. Sosa, personal communication). Subsequently, new colonies were found in Surire and San Pedro de Atacama (northern Chile) in addition to those already known in southern Bolivia (Caziani et al. 2007). Between 2007 and 2009, new breeding sites were reported from Laguna Vilama (Jujuy Province) and Laguna Santa María (Salta Province), Argentina (Derlindati et al. 2010). Despite this, Laguna Colorada in Bolivia remains a key and central site for the Puna Flamingo, with thousands of pairs breeding there annually (Rocha et al. 2021). We have observed Puna Flamingos breeding in Laguna Grande (Catamarca Province), Argentina, regularly since 2010, although there is anecdotal evidence that they had bred there in the early 2000s.

The reasons for the apparent tendency towards more frequent and widespread breeding events in recent years are unclear. Records of nesting colonies at several new sites suggest high behavioural plasticity, although breeding success at lower altitudes remains unknown. Some individuals may prevent others from settling in high-quality habitats so that the group of individuals arriving last at an established breeding colony is forced to use lower-quality habitats in which their fitness is lower. This frequently occurs in Greater Flamingo colonies during years of extreme environmental conditions and resource constraints when older birds displace younger age classes toward suboptimal habitats (Boucheker et al. 2011; Rendón et al. 2001). The recorded variability in food availability and nesting suitability for flamingo species has major monitoring and management implications, because the maintenance of a stable flamingo population depends on the availability and connectivity of multiple foraging and nesting sites, although any given site may not be continually active (Cortés-Avizanda et al. 2011; Latta et al. 2003). For instance, Greater Flamingos are opportunistic breeders able to change their breeding sites spatially and temporally in response to variations in conditions and resources (Rendón et al. 2001), a relationship that remains unknown for high Andes flamingos.

https://doi.org/10.1017/S0959270924000273 Published online by Cambridge University Press

Inter-annual variation in the number of flamingos nesting at a given site is likely in part a response to the quantity and quality of habitat that flamingos find in these wetlands (Gálvez Aguilera and Chávez-Ramírez 2010; Li et al. 2013; Stirnemann et al. 2012). The effects of human activities on these activity patterns are poorly understood but could negatively affect flamingos by decreasing the time they spend foraging or courting, potentially negatively affecting their fitness.

Global and regional pressures, threats, and drivers

Global climatic conditions have changed significantly over the past 50 years and models suggest future increases in temperature and changes in precipitation regimes throughout the world, which will directly affect the number, extent, seasonality, and salinity of wetlands (Guevara et al. 2021). In this scenario, many species will have to adapt or change their distributions in response to climate change (La Sorte and Jetz 2012). Even though high Andes flamingos can move between wetlands with adequate resources and conditions, the trade-offs involved when undertaking such movements, or how climate change will transform wetland characteristics and their availability remain unknown. Recent research from Chile suggests that high Andes flamingos are negatively impacted by climate change (Gutiérrez et al. 2022), although the mechanisms involved are not identified. A recent study based on habitat suitability models predicts that climate change will lead to a decrease in the distribution of both Andean and Puna flamingos. In the short term (2021–2040), both high Andes flamingo species will lose area (area change: -2.02% to -10.78% and -8.16% to -21.6%, respectively), and these values will be higher in the medium to long term (Delfino 2023).

During the non-breeding season, changes in meteorological conditions may result in mortality and dispersal into highly unsuitable habitats. In spring 2017 (September–November), Andean Flamingos were recorded stopping in unsuitable areas at intermediate sites along their migratory routes (E. J. Derlindati, personal observation). Unfortunately, these individuals were very weak or incapable of flying to complete their seasonal movements. These results are likely to be the effects of climate conditions on their wintering habitat, exacerbated by human-caused encroachment into their wetlands. In November 2023, during a regional avian influenza outbreak, 237 dead individuals of Puna Flamingo were recorded in north-west Argentina (220 individuals in Catamarca Province and 17 individuals in La Rioja Province). Based on limited sampling, the mortality of at least 23 of the Catamarca flamingos was attributed to HPAI H5 virus infection (EFSA et al. 2023). This report of avian influenza on Puna Flamingo raises concern about the populations of both high Andes flamingos.

The natural heterogeneity and seasonality of their habitats cause variations in habitat availability and water quality (e.g. salinity), and thus in the density, diversity, and availability of potential food items for them (Caziani and Derlindati 2000). These variations directly affect flamingo activity patterns, especially the balance between time spent foraging and breeding (Derlindati et al. 2014), which may ultimately impact their abundance, fitness, and reproductive success. Although we have robust population estimations for both high Andes flamingo species, and information on their presence and abundance at sites throughout their range since 2000, details on mechanisms and/or drivers of their population dynamics remain unknown.

Flamingo habitats in the high Andes are increasingly threatened by human activities, notably mining for lithium which has experienced exponential growth since 2016 throughout the so-called "Lithium Triangle" that encompasses high Andes wetlands in Argentina, Bolivia, and Chile (Gutiérrez et al. 2022; Marconi et al. 2022). Mining lithium impacts wetlands directly in terms of habitat loss, conversion, and degradation (Garcés and Álvarez 2020; Liu et al. 2019; Sticco 2021), and sustained extraction of groundwater and surface water will likely affect hydrological balance, chemical composition, and ultimately the rich biodiversity dependent on these wetlands (Gajardo and Redón 2019; Marconi et al. 2020, 2022; Torres et al. 2019), especially in arid ecosystems where the water balance is negative, and uncertainties in the fundamental hydrology remain (Moran et al. 2024). Lithium mining is occurring in the areas with the highest concentration of high Andes flamingos, including protected areas and breeding sites (Gajardo and Redón 2019; Liu et al. 2019; Marconi et al. 2020, 2022), Mining permits have been granted without a robust understanding of hydrological cycles and the effects of extraction and changes in chemical composition on biological communities, and without consideration of cumulative and synergistic effects of multiple mining projects on water sources (Gutiérrez et al. 2022; Marconi et al. 2022; Petavratzi et al. 2022).

It is important to note that when the first studies on these birds were conducted (during the 1980s and 1990s), there was little human disturbance (Caziani et al. 2007). The current situation is very different, especially in the last two decades during which mining pressure has increased and tourism has grown with limited regulation (Marconi et al. 2022) (Figure 1). On the other hand, several of the lowland wetlands used by high Andes flamingos have been affected by channelling and drainage for agriculture, resulting in a drastic reduction in landscape heterogeneity, and therefore, in biodiversity (Brandolin et al. 2013; Romano et al. 2014, 2017) (Figure 1). A hydrological management plan that includes wetland restoration and conservation should be developed and implemented (Canevari et al. 1999) and must consider the long-term cycles that dictate the local hydrological dynamics (Romano et al. 2014). Strong El Niño Southern Oscillation conditions regularly affect the central plains of Argentina, and therefore large areas of lowland wetlands experience cycles of flooding and drought. Variation in rainfall directly affects flamingos, as changes in water levels modify salinity levels and the availability of nesting and fledgling habitats (Romano et al. 2017). Human actions can modify the hydrology of wetlands and therefore affect flamingo abundance. For example, in the 1990s and 2000s, the abundance of Andean Flamingos in Laguna Melincué (in the central plains of Argentina) increased during the dry cycles of the El Niño Southern Oscillation due to a reduction in lake water area and an increase in water salinity. Water pumping in the 2010s also reduced the lake water area, but as salt water was pumped out and the lake was then replenished by rainfall, water salinity dropped markedly leading to a strong reduction in the abundance of Andean Flamingos (Romano et al. 2017).

Global and regional conservation strategies

The main successes in the conservation of the high Andes flamingos in South America are synthesised in two strategies proposed by regional experts in high Andes flamingos (Caziani et al. 2007; Marconi et al. 2020; Rodríguez 2006). The first strategy is based on the evaluation and estimation of the size of populations and their geographical distributions. Despite this robust information, more detailed research is needed to identify specific actions that are necessary to effectively conserve these species, update conservation

https://doi.org/10.1017/S0959270924000273 Published online by Cambridge University Press

criteria, and update the conservation status of specific populations. As part of this, the status of population connectivity still needs to be described (Cohen et al. 2018; Knight et al. 2021).

The other strategy is through the Network of Wetlands for Flamingo Conservation, a network of priority sites of importance because of flamingo numbers, presence of breeding sites, biodiversity value, conservation status, and functional connectivity with other sites (Marconi and Sureda 2008; Marconi et al. 2007). Since their identification, these sites have been focal areas for the implementation of management and action plans, including the establishment of new Ramsar Sites and subnational reserves (Marconi et al. 2022), but additional steps that result in a commitment by different stakeholders, particularly governments, to undertake conservation actions throughout the network are necessary.

Knowledge gaps and recommendations for further actions

There is an urgent need for further research and action that can serve to create effective and adaptive conservation planning for these unique bird species. At the population level, these include continuous monitoring of flamingo occurrence and abundance throughout their range, combined with a collection of detailed movement data to estimate season- and age-specific survival probabilities (Rushing et al. 2017). Most of the census effort has been focused on the breeding season distribution of flamingos. However, results from winter regional censuses (1998 and 2000) and localised counts (Romano et al. 2005, 2006, 2008, 2009) show that winter monitoring yields essential information on distribution and habitat use for both flamingo species, but especially Andean Flamingos (Marconi et al. 2011). Given the rapid changes in the environment since the last comprehensive range-wide winter census in 2000, periodic winter censuses at key sites would contribute valuable information on the response of flamingo populations. Understanding the spatial and temporal drivers of mortality is a basic requirement for effective conservation planning because mortality may be driven by mechanisms operating within a given season (e.g. nest predation) or between seasons (e.g. winter habitat quality affecting reproductive success in summer; Hostetler et al. 2015; Rushing et al. 2017). Quantifying these demographic links among seasons requires a full-annual cycle approach that relies on tracking data with high spatial and temporal resolution (Marra et al. 2015), allowing the quantification of seasonal population connectivity (Knight et al. 2021). Remote sensing tools and specialised software programs could be used to understand these major habitat requirements, including responses to climate and human land use (De los Ríos-Escalante et al. 2024).

Population genetics research would also help to determine the extent to which different populations are genetically distinct, whether gene flow is sufficient to avoid inbreeding, and whether the genetic variation is sufficient to overcome current and future rapid environmental change (Bay et al. 2018). Results from a recent study show that individual Andean Flamingos move between lakes located hundreds of kilometres apart, sometimes visiting all three countries in the central Andes (Argentina, Bolivia, and Chile) in a matter of a few months (Jahn et al. 2023). Thus, international research collaborations in these topics will be vital to developing meaningful results.

At the individual level, it is necessary to measure behavioural and physiological responses to change, as well as activity patterns at different sites throughout the year to anticipate future challenges to their survival and proactively implement conservation plans. This could also include research on various aspects of their ecology (e.g. diet) and physiology (e.g. immune function), exposure to toxins (Rocha et al. 2021), as well as detailed studies of the relationship between their body condition, climate, wetland hydrology, and food availability.

Combining such individual- and population-level data will ultimately allow an assessment of the drivers of flamingo population dynamics. Linking demographic, climate, and movement data within an integrated population model can be used to inform a regional index of population size and recruitment rates in driving overall population dynamics (Saracco et al. 2022).

After almost two decades of research, important gaps remain. More research is needed to understand their ecology and the effects of rapidly changing environmental conditions and resource availabilities on their fitness and population dynamics. It will be important to quantify the environmental characteristics that determine the choice of nesting colony location, the drivers of breeding success, the behavioural responses to regional climatic patterns, the functional role these birds play within their habitats, and the ages of the individuals in the new breeding colonies. Thus, further research is needed on the foraging ecology and reproductive physiology of high Andes flamingos, as well as detailed studies on wetland hydrology and food availability.

Both high Andes flamingo species generally have limited distributions and specific habitat requirements, making them extremely vulnerable to climate change and other regional-scale environmental stressors (Caziani et al. 2007; Gutiérrez et al. 2022). One of the main threats is water overexploitation from these systems (e.g. Gutiérrez et al. 2022); therefore, a commitment from mining companies and better oversight of mining activities by public agencies are necessary to conserve these wetlands. Specifically, it is key to adjust wetland use and management plans to address flamingo conservation, accompanied by up-to-date and adequate legislation that protects environmental services and biodiversity. Only through a combination of interdisciplinary research, monitoring, and effective conservation planning that extends across political boundaries, with input from various stakeholders, including local communities, will the future of high Andes flamingo populations be safeguarded.

Supplementary material. The supplementary material for this article can be found at http://doi.org/10.1017/S0959270924000273.

Acknowledgements. We thank the following people, who were indispensable in the fieldwork: Hugo Asencio, Andrés Elias, Sebastián Martín, Marcelo Cuevas Amorelli, Marcelo Gallego, Lucila Castro, Laura Álvarez Borla, Patricia Marconi, Ricardo Clark, Mario Mosqueira, Ana Laura Sureda, Rodrigo Valdez, Lucas Aros, Francisco Estive, Jerónimo Sosa, Pedro Barrera, and Cirilo Urriche. We thank the staff from Secretaría de Ambiente Gobierno de La Rioja, Salta, and Jujuy and park rangers from Laguna Brava (la Rioja), Los Andes (Salta), and Las Chinchillas (Jujuy) Reserves. Funding was provided by Consejo de Investigación de la Universidad Nacional de Salta (Grants # 2.229/0 and 1151) and Universidad Nacional de Rosario (Grant # 80020190300097UR). Author contributions: EJD and IMB conceived the idea and design. EJD, FA, HSF, and IMB wrote the paper, and AEJ, EJD, FA, HSF, IMB, MM, MMC, MCR, EO, and OR edited the paper.

References

Allen R. (1956). *The Flamingos: Their Life History and Survival*. New York: National Audubon Society.

Anderson M.J. (2017). *Flamingos: Behavior, Biology, and Relationship with Humans*. New York: Nova Science Publishers.

Baldassarre G.A. and Arengo F. (2000). A review of the ecology and conservation of Caribbean Flamingos in Yucatán, Mexico. *Waterbirds* **23**(Special Publication 1), 70–79. https://doi.org/10.2307/1522149

Balkiz Ö., Özesmi U., Pradel R., Germain C., Siki M., Amat J.A. et al. (2007). Range of the Greater Flamingo, *Phoenicopterus roseus*, metapopulation in the Mediterranean: new insights from Turkey. *Journal of Ornithology* **148**, 347–355. https://doi.org/10.1007/s10336-007-0136-2

Bay R.A., Harrigan R.J., Underwood V.L., Gibbs H.L., Smith T.B. and Ruegg K. (2018). Genomic signals of selection predict climate-driven population declines in a migratory bird. *Science* **359**, 83–86. https://doi.org/10.1126/science.aan4380

Béchet A. (2017). Flight, navigation, dispersal, and migratory behavior. In Anderson M. (ed.), *Flamingos: Behavior, Biology, and Relationship with Humans*. New York: Nova Publishers, pp. 97–106.

Behn F., Johnson A. and Millie G. (1957). Expedición ornitológica a las cordilleras del norte de Chile. *Boletín de la Sociedad de Biología de Concepción* **32**, 95–131.

BirdLife International (2012). IUCN Red List. Available at http://www.birdlife.org.

Boucheker A., Samraoui B., Prodon R., Amat J.A., Rendón-Martos M., Baccetti N. et al. (2011). Connectivity between the Algerian population of Greater Flamingo *Phoenicopterus roseus* and those of the Mediterranean basin. *Ostrich* **82**, 167–174. https://doi.org/10.2989/00306525.2011.607856

Boyle T.P., Caziani S.M. and Waltermire R.G. (2004). Landsat TM inventory and assessment of waterbird habitat in the southern *altiplano* of South America. *Wetlands Ecology and Management* **12**, 563–573. https://doi.org/10.1007/s11273-005-1761-2

Brandolin P.G., Ávalos M.A. and de Angelo C. (2013). The impact of flood control on the loss of wetlands in Argentina. *Aquatic Conservation: Marine and Freshwater Ecosystems* **23**, 291–300. https://doi.org/10.1002/aqc.2305

Bucher E.H. (1992). Population and conservation status of flamingos in Mar Chiquita, Córdoba, Argentina. *Colonial Waterbirds* **15**, 179–184. https://www.jstor.org/stable/1521451

Bucher E.H., Chani J.M. and Echevarría A.L. (2000). Andean flamingos breeding at Laguna Brava, La Rioja, Argentina. *Waterbirds* **23**(Special Publication 1), 119–120.

Bucher E.H. and Curto E. (2012). Influence of long-term climatic changes on breeding of the Chilean flamingo in Mar Chiquita, Córdoba, Argentina. *Hydrobiologia* **697**, 127–137. https://doi.org/10.1007/s10750-012-1176-z

Cabaña I., Steffolani M.L., Lassaga V., Michelutti M., Michelutti P. and Castro L. B. (2018). Censo aéreo de flamencos en la laguna Mar Chiquita y bañados del Río Dulce, Córdoba, Argentina, en verano e invierno del año 2018. *Flamingo* **e1**, 48–53.

Canevari P., Blanco D.E., Bucher E.H., Castro G. and Davidson I. (1999). *Los Humedales de la Argentina. Clasificación, Situación Actual, Conservación y Legislación*. Buenos Aires: Wetlands International.

Castro L. and Torres R. (2014). Foraging behavior, direct interference and habitat use in three species of flamingos (*Phoenicopterus chilensis*, *Phoenicoparrus andinus* and *Phoenicoparrus jamesi*) in Mar Chiquita Lagoon, Córdoba, Argentina. *Acta Geologica Sinica* **88**, 63–64. https://doi.org/10.1111/1755-6724.12266_9

Caziani S.M. and Derlindati E. (2000). Abundance and habitat of High Andes flamingos in Northwestern Argentina. *Waterbirds* **23**, 121–133. https://www.jstor.org/stable/1522157

Caziani S., Rocha Olivio O., Rodríguez Ramírez E., Romano M., Derlindati E.J., Tálamo A. et al. (2007). Seasonal distribution, abundance, and nesting of Puna, Andean, and Chilean Flamingos. *The Condor* **109**, 276–287. https://doi.org/10.1093/condor/109.2.276

Childress B. (2005). Flamingo population estimates for Africa and Southern Asia. *Flamingo* **13**, 18–21.

Cobos V., Miatello R. and Baldo J. (1999). Algunas especies de aves nuevas y otras con pocos registros para la provincia de Córdoba, Argentina. *II.* Nuestras Aves **39**, 7–11.

Cohen E.B., Hostetler J.A., Hallworth M.T., Rushing C.S., Sillett T.S. and Marra P.P. (2018). Quantifying the strength of migratory connectivity. *Methods in Ecology and Evolution* **9**, 513–524. https://doi.org/10.1111/2041-210X.12916

Cordier C. (1965). Op zoek naar flamingo's in de Andes. *Zoo Antwerp* **30**, 83–88.

Cortés-Avizanda A., Almaraz P., Carrete M., Sánchez-Zapata J.A., Delgado A., Hiraldo F. et al. (2011). Spatial heterogeneity in resource distribution promotes facultative sociality in two trans-Saharan migratory birds. *PLOS ONE* **6**. https://doi.org/10.1371/journal.pone.0021016

Cruz N.N., Barisón C., Romano M., Arengo F., Derlindati E.J. and Barberis I. (2013). A new record of James's Flamingo (*Phoenicoparrus jamesi*) from Laguna Melincué, a lowland wetland in East-Central Argentina. *The Wilson Journal of Ornithology* **125**, 217–221. https://doi.org/10.1676/12-111.1

de la Fuente A., Meruane C. and Suárez F. (2021). Long-term spatiotemporal variability in high Andean wetlands in northern Chile. *Science of the Total Environment* **756**, 143830. https://doi.org/10.1016/j.scitotenv.2020.143830

Delfino H.C. (2023). A fragile future for pink birds: habitat suitability models predict a high impact of climate change on the future distribution of flamingos. *Emu – Austral Ornithology* **123**, 310–324. https://doi.org/10.1080/01584197.2023.2257757

Delfino H.C. and Carlos C.J. (2024). Still standing on one leg: a systematic review of threats, priorities, and conservation perspectives for flamingos (Phoenicopteridae). *Biodiversity and Conservation* **33**, 1227–1268. https://doi.org/10.1007/s10531-024-02816-x

De los Rios-Escalante P.R., Esse C., Correa-Araneda F., Rodríguez L., Fernández C.E. and Prado P.E. (2024). Potential effects of climate change in saline shallow lakes in the North of Chile (Salar de Atacama, 23° S, Chile) and South Lipez of Bolivia (Khalina Lake, 22.61° S). In Singh A.L., Jamal S. and Ahmad W.S. (eds), *Climate Change, Vulnerabilities and Adaptation: Understanding and Addressing Threats with Insights for Policy and Practice*. Cham: Springer, pp. 171–182.

Derlindati E.J., Moschione F.N. and Cruz N.N. (2010). Nuevas colonias de nidificación de la parina chica (*Phoenicoparrus jamesi*) en el noroeste de la Argentina. *Nótulas Faunisticas* **56**, 1–5.

Derlindati E.J., Romano M.C., Cruz N.N., Barisón C., Arengo F. and Barberis I. M. (2014). Seasonal activity patterns and abundance of Andean Flamingo (*Phoenicoparrus andinus*) at two contrasting wetlands in Argentina. *Ornitologia Neotropical* **25**, 317–331.

Dias R.A. and Cardozo J.B. (2014). First record of the Puna Flamingo *Phoenicoparrus jamesi* (Sclater, 1886) (Aves: Phoenicopteridae) for the Atlantic coast of South America. *Check List* **10**, 1150–1151. https://doi.org/10.15560/10.5.1150

Dib J.R., Weiss A., Neumann A., Ordoñez O., Estévez M.C. and Farías M.E. (2009). Isolation of bacteria from remote High Altitude Andean Lakes able to grow in the presence of antibiotics. *Recent Patents on Anti-Infective Drug Discovery* **4**, 66–76. https://doi.org/10.2174/157489109787236300

European Food Safety Authority (EFSA), European Centre for Disease Prevention and Control (ECDC), European Union Reference Laboratory for Avian Influenza (EURL), Adlhoch C., Fusaro A., Gonzales J.L. et al. (2023). Scientific report: Avian influenza overview September–December 2023. *EFSA Journal* **21**, e8539. https://doi.org/10.2903/j.efsa.2023.8539

Fjeldså J. and Krabbe N. (1990). *Birds of the High Andes: A Manual to the Birds of the Temperate Zone of the Andes and Patagonia, South America.* Copenhagen: Zoological Museum.

Frau D., Battauz Y., Mayora G. and Marconi P. (2015). Controlling factors in planktonic communities over a salinity gradient in high-altitude lakes. *Annales de Limnologie–International Journal of Limnology* **51**, 261–272. https://doi.org/10.1051/limn/2015020

Frau D., Moran B.J., Arengo F., Marconi P., Battauz Y., Mora C. et al. (2021). Hydroclimatological patterns and limnological characteristics of unique wetland systems on the Argentine High Andean plateau. *Hydrology* **8**, 164. https://doi.org/10.3390/hydrology8040164

Gajardo G. and Redón S. (2019). Andean hypersaline lakes in the Atacama Desert, northern Chile: Between lithium exploitation and unique biodiversity conservation. *Conservation Science and Practice* **1**, 1–8. https://doi.org/10.1111/csp2.94

Gálvez Aguilera X. and Chávez-Ramírez F. (2010). Distribution, abundance, and status of Cuban Sandhill Cranes (*Grus canadensis nesiotes*). *The Wilson Journal of Ornithology* **122**, 556–562. https://doi.org/10.1676/09-174.1

Garcés I. and Álvarez G. (2020). Water mining and extractivism of the Salar de Atacama, Chile. In Casares J. (ed.), *Environmental Impact V*. Southampton: WIT Press, pp. 189–199.

Guerra L., Martini M.A., Córdoba F.E., Ariztegui D. and Piovano E.L. (2019). Multi-annual response of a Pampean shallow lake from central Argentina to regional and large-scale climate forcings. *Climate Dynamics* **52**, 6847–6861. https://doi.org/10.1007/s00382-018-4548-x

Guevara E.A., Santander T., Espinosa R. and Graham C.H. (2021). Aquatic bird communities in Andean lakes of Ecuador are increasingly dissimilar over time. *Ecological Indicators* **121**, 107044. https://doi.org/10.1016/j.ecolind.2020.107044

Gutiérrez J.S., Moore J.N., Donnelly J.P., Dorador C., Navedo J.G. and Senner N. R. (2022). Climate change and lithium mining influence flamingo abundance in the Lithium Triangle. *Proceedings of the Royal Society B. Biological Sciences* **289**, 20212388. https://doi.org/10.1098/rspb.2021.2388

Hostetler J.A., Sillett T.S. and Marra P.P. (2015). Full-annual-cycle population models for migratory birds. *The Auk* **132**, 433–449. https://doi.org/10.1642/AUK-14-211.1

Hughes R.A. (1980). Midwinter breeding by some birds in the High Andean of Southern Perú. *The Condor* **82**, 229–231.

Hurlbert S.H. (1978). *Results of Five Flamingo Censuses Conducted Between November 1975 and December 1977*. Andean Lake and Flamingo Investigations, Technical Report No. 1. San Diego: San Diego State University.

Hurlbert S.H. (1981). *Results of Three Flamingo Censuses Conducted Between December 1978 and July 1980*. Andean Lake and Flamingo Investigations, Technical Report No. 2. San Diego: San Diego State University.

Hurlbert S.H. (1982). Limnological studies of flamingo investigations and distributions. *National Geographic Research Reports* **14**, 351–356.

Hurlbert S.H. and Chang C.C.Y. (1983). Ornitholimnology: Effects of grazing by the Andean Flamingo (*Phoenicoparrus andinus*). Proceedings of the National Academy of Sciences – PNAS **80**, 4766–4769. https://doi.org/10.1073/pnas.80.15.4766

Hurlbert S.H. and Keith J.O. (1979). Distribution and spatial patterning of flamingos in the Andean Altiplano. *The Auk* **96**, 328–342. https://digitalcommons.usf.edu/auk/vol96/iss2/10

International Union for Conservation of Nature (IUCN). (2023). The IUCN Red List of Threatened Species. Version 2022-2. Available at https://www.iucnredlist.org.

Jahn A.E., Cereghetti J., Hallworth M.T., Ketterson E.D., Ryder B., Marra P.P. et al. (2023). Highly variable movements by Andean Flamingos (*Phoenicoparrus andinus*): implications for conservation and management. *Avian Conservation & Ecology* **18**, 13. https://doi.org/10.5751/ACE-02521-180213

Jahn A.E., Cueto V.R., Fontana C.S., Guaraldo A.C., Levey D.J., Marra P.P. et al. (2020). Bird migration within the Neotropics. *The Auk* **137**, 1–23. https://doi.org/10.1093/auk/ukaa033

Johnson A.W. (1967). Family Phoenicopteridae. In Johnson A.W. *The Birds of Chile and Adjacent Regions of Argentina, Bolivia and Peru*: vol. **II**. Buenos Aires: Platt Establecimientos Gráficos, pp. 404–406.

Johnson A.W., Behn F. and Millie W.R. (1958). The South American flamingos. *The Condor* **60**, 289–299. https://doi.org/10.2307/1365154

Kahl M.P. (1975). Distribution and number – a summary. In Kear J. and Duplaix-Hall K. (eds), *Flamingos*. London: Bloomsbury Publishing, pp. 93–102.

Knight E.C., Harrison A.L., Scarpignato A.L., Van Wilgenburg S.L., Bayne E.M., Ng J.W. et al. (2021). Comprehensive estimation of spatial and temporal migratory connectivity across the annual cycle to direct conservation efforts. *Ecography* **44**, 665–679. https://doi.org/10.1111/ecog.05111

Krienitz L. (2018). *Lesser Flamingos: Descendants of Phoenix*. Berlin: Springer.

La Sorte F.A. and Jetz W. (2012). Tracking of climatic niche boundaries under recent climate change. *Journal of Animal Ecology* **81**, 914–925. https://doi.org/10.1111/j.1365-2656.2012.01958.x

Lagos N., Villalobos R., Vianna J.A., Espinosa-Miranda C., Rau J.R. and Iriarte A. (2023). The spatial and trophic ecology of culpeo foxes (*Lycalopex culpaeus*) in the high Andes of northern Chile. *Studies on Neotropical Fauna and Environment* **58**, 564–573. https://doi.org/10.1080/01650521.2021.2005393

Latta S.C., Rimmer C.C. and McFarland K.P. (2003). Winter bird communities in four habitats along an elevational gradient on Hispaniola. *The Condor* **105**, 179–197. https://doi.org/10.1093/condor/105.2.179

Li Z., Wang Z. and Ge C. (2013). Time budgets of wintering red-crowned cranes: effects of habitat, age and family size. *Wetlands* **33**, 227–232. https://doi.org/10.1007/s13157-012-0371-z

Liu W., Agusdinata D.B. and Myint S.W. (2019). Spatiotemporal patterns of lithium mining and environmental degradation in the Atacama Salt Flat, Chile. *International Journal of Applied Earth Observation and Geoinformation* **80**, 145–156. https://doi.org/10.1016/j.jag.2019.04.016

Marconi P. (2010). *Proyecto Red de Humedales Altoandinos y Ecosistemas Asociados, Basada en la Distribución de las Dos Especies de Flamencos Altoandinos*. Salta: Fundación Yuchán.

Marconi P., Arengo F., Castro A., Rocha O., Valqui M., Aguilar S. et al. (2020). Sixth International Simultaneous Census of three flamingo species in the Southern Cone of South America: Preliminary analysis. *Flamingo* **e3**, 67–75.

Marconi P., Arengo F. and Clark A. (2022). The arid Andean plateau waterscapes and the lithium triangle: flamingos as flagships for conservation of high-altitude wetlands under pressure from mining development. *Wetlands Ecology and Management* **30**, 827–852. https://doi.org/10.1007/s11273-022-09872-6

Marconi P.M. and Clark R. (2011). First confirmed nesting record of Andean Flamingo *Phoenicoparrus andinus* in Catamarca, Argentina, and remarks on its breeding ecology. *Cotinga* **33**, 150–151.

Marconi P.M. and Sureda A.L. (2008). High Andean Flamingo Wetland Network: Evaluation of degree of implementation of priority sites-preliminary results. *Flamingo* **16**, 36–40.

Marconi P.M., Sureda A.L., Arengo F., Aguilar M.S., Amado N., Alza L. et al. (2011). Fourth simultaneous flamingo census in South America: preliminary results. *Flamingo* **18**, 48–53.

Marconi P.M., Sureda A.L., Rocha Olivio O., Rodríguez Ramírez E., Derlindati E., Romano M.C. et al. (2007). Network of important wetlands for flamingo conservation: Preliminary results from 2007 monitoring at priority sites. *Flamingo* **15**, 17–20.

Marra P.P., Cohen E.B., Loss S.R., Rutter J.E. and Tonra C.M. (2015). A call for full annual cycle research in animal ecology. *Biology Letters* **11**, 20150552. https://doi.org/10.1098/rsbl.2015.0552

Mascitti V. (1998). James Flamingo foraging behavior in Argentina. *Colonial Waterbirds* **21**, 277–280. https://doi.org/10.2307/1521921

Mascitti V. (2001). Habitat changes in Laguna de Pozuelos, Jujuy, Argentina: Implications for South American Flamingo populations. *Waterbirds* **24**, 16–21. https://doi.org/10.2307/1522238

Mascitti V. and Bonaventura S.M. (2002). Patterns of abundance, distribution and habitat use of flamingos in the High Andes, South America. *Waterbirds* **25**, 358–365. https://www.jstor.org/stable/1521978

Mascitti V. and Kravetz F.O. (2002). Bill morphology of South American flamingos. *The Condor* **104**, 73–83. https://doi.org/10.1093/condor/104.1.73

McMillan D.J. (1972). The Phoenix in the Western world from Herodotus to Shakespeare. *The D.H. Lawrence Review* **5**, 238–267. https://www.jstor.org/stable/44233403.

Moran B.J., Boutt D.F., Munk L.A. and Fisher J.D. (2024). Contemporary and relic waters strongly decoupled in arid alpine environments. *PLOS Water* **3**, e0000191. https://doi.org/10.1371/journal.pwat.0000274

Moschione F. and Sureda A. (2008). Monitoring high-Andes flamingos at Laguna de los Pozuelos National Monument, Argentina: preliminary results. *Flamingo* **16**, 48–50.

Nanni A.S., Piquer Rodríguez M., Rodríguez D., Núñez Regueiro, M., Periago M. E., Aguiar S. et al. (2020). Presiones sobre la conservación asociadas al uso de la tierra en las ecorregiones terrestres de la Argentina. *Ecología Austral* **30**, 304–320. https://doi.org/10.25260/EA.20.30.2.0.1056

Ortiz E., Gamboa M., Salas M. and Vera J. (2020). Ítems alimenticios potenciales para la parina grande (*Phoenicoparrus andinus*, (Philippi, 1854)) en dos tipos de hábitats acuáticos de la laguna de Parinacochas, Ayacucho, Perú. *Biotempo* **17**, 311–320. https://doi.org/10.31381/biotempo.v17i2.3400

Parada M. (1990). Flamencos en el Norte de Chile, distribución, abundancia y fluctuaciones estacionales del número. In Parada M., Rottmann J. and Guerra C. (eds), *I Taller Internacional de Especialistas en Flamencos Sudamericanos*. San Pedro de Atacama: Corporación Nacional Forestal y Sociedad Zoológica de Nueva York, pp. 54–66.

Peña L.E. (1962). Notes on South American flamingos. *Postilla* **69**, 1–8.

Petavratzi E., Sánchez-López D., Hughes A., Stacey J., Ford J. and Butcher A. (2022). The impacts of environmental, social and governance (ESG) issues in achieving sustainable lithium supply in the Lithium Triangle. *Mineral Economics* **35**, 673–699. https://doi.org/10.1007/s13563-022-00332-4

Polla W.M., Di Pasquale V., Rasuk M.C., Barberis I., Romano M., Manzo R. et al. (2018). Diet and feeding selectivity of the Andean Flamingo *Phoenicoparrus* *andinus* and Chilean Flamingo *Phoenicopterus chilensis* in lowland wintering areas. *Wildfowl Journal* **68**, 3–29.

Quiroga O.B. and Llugdar J.E. (2022). Primer registro documentado de la Parina Chica (*Phoenicoparrus jamesi*, Phoenicopteriformes: Phoenicopteridae) en Santiago del Estero, Argentina. *Acta Zoologica Lilloana* **66**, 71–78. https://doi.org/10.30550/j.azl/2022.66.1/2022-05-24

Rendón M.A., Garrido A., Ramírez J.M., Rendón-Martos M. and Amat J.A. (2001). Despotic establishment of breeding colonies of greater flamingos, *Phoenicopterus ruber*, in southern Spain. *Behavioral Ecology and Sociobiology* **50**, 55–60. https://doi.org/10.1007/s002650100326

Rocha O. (1997). Fluctuaciones poblacionales de tres especies de flamencos en Laguna Colorada. *Revista Boliviana de Ecología* **2**, 67–76.

Rocha O., Aguilar S., Vargas M. and Quiroga C. (2009). Abundancia, reproducción y anillado de Flamencos Andinos (*Phoenicoparrus jamesi* y *P. andinus*) en Laguna Colorada, Potosí – Bolivia. *Flamingo* **17**, 16–21.

Rocha O., Pacheco L.F., Ayala G.R., Varela F. and Arengo F. (2021). Trace metals and metalloids in Andean flamingos (*Phoenicoparrus andinus*) and Puna flamingos (*P. jamesi*) at two wetlands with different risk of exposure in the Bolivian Altiplano. *Environmental Monitoring and Assessment* **193**, 535. https://doi.org/10.1007/s10661-021-09340-3

Rocha O. and Quiroga C. (1997). Primer Censo Simultáneo Internacional de los flamencos *Phoenicoparrus jamesi* y *Phoenicoparrus andinus* en Argentina, Bolivia, Chile y Perú, con especial referencia y análisis al caso boliviano. *Ecología en Bolivia* **30**, 33–42.

Rodríguez E. (2006). Flamencos Altoandinos Phoenicopterus andinus (*Philippi, 1854*), Phoenicopterus jamesi (Sclater, 1886) y Phoenicopterus chilensis (Molina, 1782), en el Norte de Chile: Estado Actual y Plan de Conservación. Antofagasta: Corporación Nacional Forestal (CONAF).

Romano M., Barberis I., Arengo F., Caselli A., Minotti P., Morandeira N. et al. (2011). Seasonal variation of Andean and Chilean Flamingos in lowland wetlands of central Argentina. *Flamingo* **18**, 12–13.

Romano M., Barberis I.M., Derlindati E., Pagano F., Marconi P.M. and Arengo F. (2009). Variation in abundance of Andean and Chilean Flamingos wintering in lowland wetlands of central Argentina in two contrasting years. *Flamingo* **17**, 11–16.

Romano M.C., Barberis I.M., Guerra L., Piovano E.L. and Minotti P. (2014). *Sitio Ramsar Humedal Laguna Melincué: Estado de situación*. Santa Fe: Secretaría de Medio Ambiente de la provincia de Santa Fe.

Romano M.C., Barberis I.M., Pagano F. and Maidagan J. (2005). Seasonal and interannual variation in waterbird abundance and species composition in the Melincué saline lake, Argentina. *European Journal of Wildlife Research* **51**, 1–13. https://doi.org/10.1007/s10344-005-0078-z

Romano M.C., Barberis I.M., Pagano F. and Romig J. (2006). Flamingo winter abundance in Laguna Melincué, Argentina. *Flamingo* **14**, 17.

Romano M.C., Barberis I.M., Pagano F., Marconi P.M. and Arengo F. (2008). Winter monitoring of Andean and Chilean Flamingos in lowland wetlands of central Argentina. *Flamingo* **16**, 45–47.

Romano M.C., Barberis I.M., Pagano F., Minotti P. and Arengo F. (2017). Variaciones anuales en la abundancia y en la distribución espacial del flamenco austral (*Phoenicopterus chilensis*) y la parina grande (*Phoenicoparrus andinus*) en el Sitio Ramsar Laguna Melincué, Argentina. *El Hornero* **32**, 215–225. https://doi.org/10.56178/eh.v32i2.508

Rushing C.S., Hostetler J.A., Sillett T.S., Marra P.P., Rotenberg J.A. and Ryder T. B. (2017). Spatial and temporal drivers of avian population dynamics across the annual cycle. *Ecology* **98**, 2837–2850. https://doi.org/10.1002/ecy.1967

Saracco J.F., Cormier R.L., Humple D.L., Stock S., Taylor R. and Siegel R.B. (2022). Demographic responses to climate-driven variation in habitat quality across the annual cycle of a migratory bird species. *Ecology and Evolution* **12**, e8934. https://doi.org/10.1002/ece3.8934

Sosa H. and Martín S. (2010). Primer registro de parina grande (*Phoenicoparrus andinus*) nidificando en Laguna Llancanelo, Mendoza, Argentina. *Nótulas Faunísticas* **42**, 1–3.

Sticco M., Guerra G., Kwaterka V. and Valdés S. (2021). *Impactos Ambientales de la Explotación de Litio en los Humedales y Recursos Hídricos del Altiplano.* Fundación para la Conservación y el Uso Sustentable de los Humedales/ Wetlands International.

Stirnemann R.L., O'Halloran J., Ridgway M. and Donnelly A. (2012). Temperature-related increases in grass growth and greater competition for food drive earlier migrational departure of wintering Whooper Swans. *Ibis* **154**, 542–553. https://doi.org/10.1111/j.1474-919X.2012.01230.x

Tapia J., Murray J., Ormachea-Muñoz M. and Bhattacharya P. (2022). The unique Altiplano-Puna Plateau: environmental perspectives. *Journal of South American Earth Sciences* **115**, 103725. https://doi.org/10.1016/j.jsames.2022.103725

Tobar C., Rau J.R., Iriarte A., Villalobos R., Lagos N., Cursach J. et al. (2012). Composition, diversity and size of diatoms consumed by the Andean Flamingo (*Phoenicoparrus andinus*) in salar de Punta Negra, Antofagasta Region, northern Chile. *Ornitología Neotropical* **23**, 243–250.

Torres R., Marconi P., Castro L.B., Moschione F., Bruno G., Michelutti L. et al. (2019). New nesting sites of the threatened Andean flamingo in Argentina. *Flamingo* **e2**, 3–10.

Ugarte-Núñez J.A. and Mosaurieta-Echegaray L. (2000). Assessment of threats to flamingos at the Salinas and Aguada Blanca national nature reserve (Arequipa, Peru). *Waterbirds* **23**, 134–140. https://doi.org/10.2307/1522158

Unterkofler D.A. and Blanco D.E. (2016). *El Censo Neotropical de Aves Acuáticas 2015. Una Herramienta para la Conservación*. Buenos Aires: Wetlands International.

Valqui M., Caziani S.M., Rocha O. and Rodríguez R.E. (2000). Abundance and distribution of the South American altiplano flamingos. *Waterbirds* **23** (Special Publication 1), 110–113. https://doi.org/10.2307/1522154

Vides-Almonacid R. (1990). Observaciones sobre la utilización del hábitat y la diversidad de especies de aves en una laguna de la Puna Argentina. *El Hornero* **13**, 117–128. https://doi.org/10.56178/eh.v13i2.1094

Zubieta R., Molina-Carpio J., Laqui W., Sulca J. and Ilbay M. (2021). Comparative analysis of climate change impacts on meteorological, hydrological, and agricultural droughts in the Lake Titicaca Basin. *Water* **13**, 175. https://doi.org/10.3390/w13020175

https://doi.org/10.1017/S0959270924000273 Published online by Cambridge University Press