Distribution And Abundance of Flamingos (Phoenicopteriformes: Phoenicopteridae) In the Salt-Affected Wetlands of The Peruvian Andes

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Abstracts: This study investigates the distribution and abundance of flamingos (Phoenicopteriformes: Phoenicopteridae) in salted high-Andean wetlands of Peru. These wetlands are located at an altitude between 3 200 and 4 600 meters above sea level and represent key habitats for these birds. However, there is little information about the presence of flamingos in these environments and their relationship with salinity. To analyze the distribution and abundance of flamingo species in the salted wetlands of the Peruvian Andes. Sampling was carried out in 11 wetlands over a period of time from August to October 2021. Both adult and juvenile individuals were recorded, and data on physicochemical water parameters and environmental variables were collected. They reveal interesting patterns regarding the distribution and abundance of flamingos in these salted wetlands. It was observed that the Loriscota wetland harbors the largest population of flamingos, with a total of 14 750 individuals belonging to the species Phoenicopterus chilensis, Phoenicoparrus andinus, and Phoenicoparrus jamesi. Among these species, Phoenicopterus chilensis was the most abundant. Furthermore, a positive correlation was found between the presence of flamingos and certain environmental and physicochemical parameters. Water pH, maximum ambient temperature, and relative humidity showed a significant association with the presence of flamingos in the wetlands. This study provides important information about the distribution and abundance of flamingos in the salted high-Andean wetlands of Peru, which will contribute to the understanding of interactions between flamingos and their habitat. Additionally, they will serve as a basis for future conservation and management strategies for these species and the wetlands.

Keywords: Conservation; Species; Flamingos; Salted Wetlands; Water Parameters.

1. INTRODUCTION

Flamingos (Phoenicoptaridae) are gregarious birds that inhabit shallow, brackish water environments (Barison et al. 2014), ranging from sea level to approximately 4 500 meters above sea level (Romano et al. 2017). Currently, there are four species of flamingos in South America: *Phoenicopterus ruber* (American flamingo), *P. chilensis* (Chilean flamingo), *Phoenicoparrus jamesi* (James's flamingo), and *Phoenicoparrus andinus* (Andean flamingo) (SACC), and three of them (*P. jamesi, P. andinus,* and *P. chilensis*) have been recorded in Peru (Rodríguez 2005; Caziani et al. 2007).

Chilean flamingo has a wide geographical distribution, inhabiting high-altitude lagoons and lowland wetlands in South America (Tobar *et al*. 2017). On the other hand, James's flamingo and the Andean flamingo are endemic to the central Andes and Puna environments (Quiroga and Llugdar 2022), using high Andean lagoons and salt flats to nest and feed during the summer (Caziani *et al*. 2007).

Adult and juvenile flamingos move through the Peruvian highlands, between lakes and lagoons located at altitudes ranging from 3 200 to 4 400 meters above sea level, during the dry season (March-August), as well as at the beginning of the rainy season (November-December) (Ricalde 2003). The largest breeding population of James's flamingos and Chilean flamingos has been recorded at Salinas Lagoon, located in the Salinas and Aguada Blanca National Reserve in the Arequipa region. Additionally, there are reports of a high number of individuals at Loriscota Lagoon in Puno and Parinacochas in Ayacucho (Hurlbert and Keith 1979; Ugarte-Nuñez and Musaurieta-Echegaray 2000; MINAGRI 2013; Luque-Fernández *et al*. 2021).

The Chilean flamingo and James's flamingo are globally considered Near Threatened (NT), while the Andean flamingo is globally Vulnerable (VU) (IUCN 2020).According to Peruvian legislation (D.S. N° 034-2004-AG), the Chilean flamingo is considered Near Threatened (NT), while the Andean flamingo and James's flamingo are classified as Vulnerable (VU). However, the status given to the two endemic Peruvian Andean species is based on insufficient information (MINAGRI 2013).

The systematic conservation planning through satellite tracking of flamingos is essential to guide the design of protected areas and identify significant Ramsar sites (Javed *et al*. 2019). This methodology also contributes to understanding the status of species like the Andean flamingo in the province of Jujuy, Argentina (Chiale *et al*. 2021). High-altitude arid wetlands, fragile ecosystems due to water scarcity, are assessed through flamingo populations (Machuca-Sepúlveda *et al*. 2021), as their decline is linked to various factors such as mining activity, surface water extraction, habitat alteration, and consequent decrease in the reproductive rates of the three species of high Andean flamingos. This decrease is attributed to the scarcity of essential microalgae in their diet, especially diatoms of the Surirella genus (Machuca-Sepúlveda *et al*. 2021).

In the context of Caribbean flamingos in Cuba, the Boca Grande wetland stands out as a crucial site for their reproduction. Despite the colony's disappearance in the 1990s due to human intervention, a new breeding colony was rediscovered in 2017. The number of nests was determined directly: in 2017, 238 empty nests were found; the following year, 635 nests were recorded, the majority of which were occupied. This reappearance reinforces the vital importance of the wetland for species conservation (Ramírez *et al*. 2020). For instance, the Austral flamingo in Patagonia has recently documented a new breeding locality (Sosa et al. 2022). In wetlands like Ventanilla in Peru, the Andean flamingo mainly rests and feeds before migrating to more southern areas, such as the Andes (Wendy and Yasmin 2022). These shallow wetlands, with saline or alkaline water and sparse vegetation, are primarily used for nesting, especially on islands that protect them from terrestrial predators (Rendon *et al*. 2023).

In the surveys of the Greater Flamingo conducted in Spain in 2007, a monthly average of 41 550 birds was observed, reaching a peak of 62 826 in January and a minimum of 28 080 in June (Rendón-Martos et al. 2009). During the winter, the flamingos prefer to inhabit primarily coastal wetlands such as marshes, salt pans, and fish farms. However, under favorable water availability conditions, they also occupy temporary wetlands (Rendón-Martos and Garrido 2012). Regarding the breeding of the Greater Flamingo in Spain, record figures were reached in the years 2017, 2019, and 2020, with 2 600 pairs, 2 365 hatched chicks, and 1 973 chicks that successfully fledged (Picazo 2020).

The Greater Flamingo is highly vulnerable to human impact, especially during its breeding period. A comprehensive nest census was carried out using aerial images, recording a total of 1 896 nests. The vast majority (1 754) of these nests contained eggs, while a smaller number (142) harbored newly hatched chicks (Petracci *et al*. 2020). In the Salinas lagoon in Peru, conditions are ideal for maintaining a reproductive population of the Greater Flamingo during the austral winter (More *et al*. 2020). These key habitats for the flamingos are linked to the interaction between the wetland and the accumulation of sediment from dredging, as well as the moisture upwelling caused by the seepage of irrigation water (Ywanaga *et al*. 2021).

The objective of the study was: To analyze the distribution and abundance of flamingo species in the salted wetlands of the Peruvian Andes.

2. MATERIALS AND METHODS

2.1. Study Area

The study sites are located in southern Peru at altitudes ranging from 3 800 to 5 500 meters above sea level. This region has a cold and arid climate with intense solar radiation, strong winds in August, and daily temperature fluctuations ranging from -25 to 15 °C. Additionally, frost occurs during the months of May to July. In the high Andean region, various terrestrial and aquatic ecosystems can be found, as well as numerous watercourses. These wetlands are particularly relevant to the distribution and population abundance of flamingos since most high Andean wetlands have high levels of salinity due to geological factors such as endorheic basins and the relationship between low precipitation and high evaporation (Seeligmann and Maidana 2019). For this research, 11 specific wetlands were selected (Table 1 and Fig. 1).

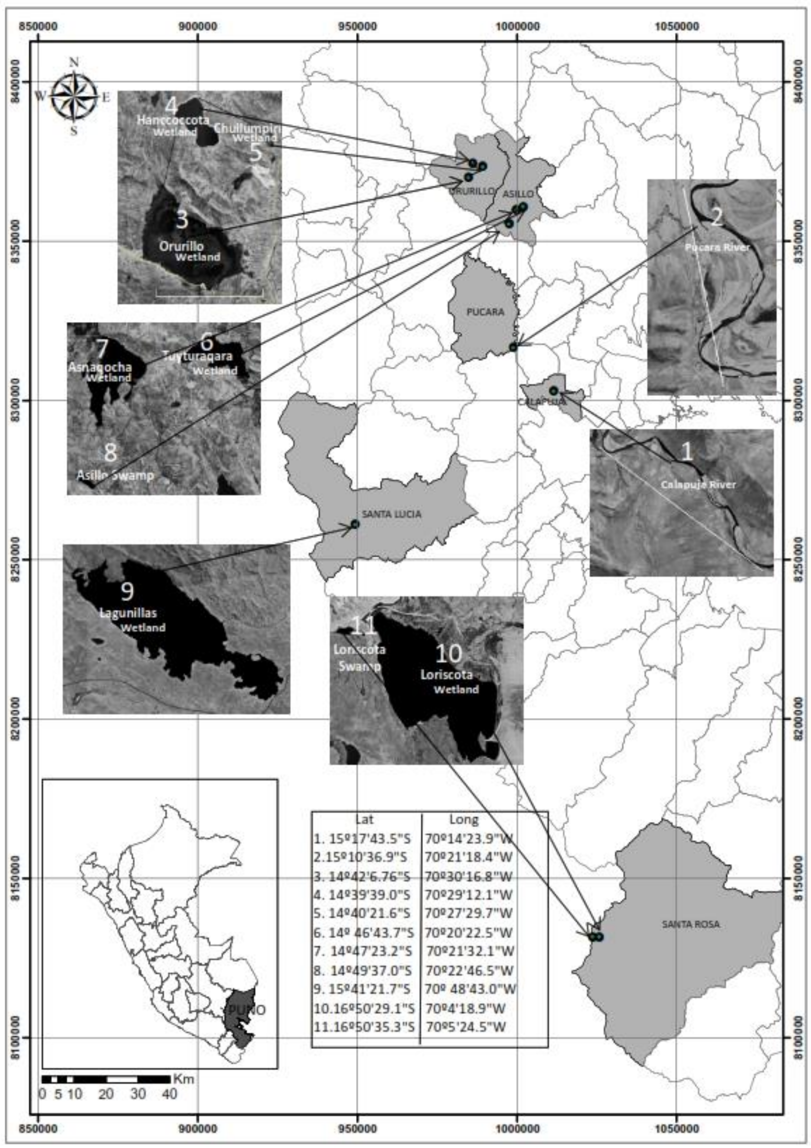

Fig. 1 Location of the wetlands studied in the high Andean region of Puno, Peru

2.2. Sampling Stations

To carry out the flamingo count, a 4x4 vehicle was used, which allowed us to move to each wetland, with the participation of four people. Sampling was conducted in February, August, and October 2021, as during these months flamingos migrate to the high Andean wetlands where they find suitable conditions for feeding, nesting, and breeding (MINAGRI 2013; Luque *et al*. 2021).

Species identification and counting were performed using 10x50 mm Bushnell binoculars from an approximate distance of 300 m to avoid any kind of disturbance to the birds. Estimation of population size in each lagoon was carried out with the participation of four observers. At each sampling point, each observer made an independent estimation of the population size. Subsequently, the average of the four estimations was used for further analysis (Table 1).

The wetlands of Orurillo, Hanccoccota, and Chullumpiri, located north of the Puno region, were sampled on the same day to avoid local movements of the flamingos, considering that these sites are approximately 20 km apart. On the other hand, the wetlands of Tuyturaqara, Asnaqocha, and Asillo (swamp), which are approximately 18 km from the Chullumpiri wetland, were studied the following day. The wetlands of Lagunillas and Loriscota are located at distances greater than 100 km from the aforementioned wetlands.

An important factor influencing the presence of flamingos is the salinity of the water, which is estimated through its electrical conductivity (µS/cm) and allows for the classification of lagoons into alkaline, saline, and hypersaline categories (Mirande and Tracanna 2009). Hypersaline wetlands, due to their richness in diatoms, constitute an almost exclusive habitat for flamingos (Caziani and Derlindati 1999). In each wetland, on-site measurements were carried out with 5 repetitions of the physicochemical characteristics of the water, such as electrical conductivity (EC; µS/cm), salinity (PSU), dissolved oxygen (mg/L), and pH, using a multiparameter meter Hanna HI9829. The geographic coordinates and altitude were also recorded. Additionally, environmental variables such as average relative humidity (%) and ambient temperature (maximum and minimum) in °C were considered, which were obtained from the National Meteorology and Hydrology Service - Puno (SENAMHI) website, corresponding to the weather stations closest to the wetlands studied during the flamingo sampling days and/or dates. This data allowed for obtaining information about the water properties of the lagoons and establishing relationships between these characteristics and the distribution of flamingos.

For the statistical analysis and experimental design, a principal component analysis (PCA) was conducted to identify the main contributions of environmental variables and wetlands to flamingo abundance. The 2020 version of the InfoStat program was used for the statistical analysis, and version 10.5 of ArcGIS was used for map development.

3. RESULTS

The obtained results have determined that the three species of Peruvian flamingos were recorded in southern Peru. The Chilean flamingo (*P. chilensis*) was recorded in all 11 wetlands studied, while the Andean flamingo (*P. andinus*) was recorded in four, and the James's flamingo (*P. jamesi*) only in two wetlands. The three species were observed simultaneously only in two wetlands: Loriscota and Chullumpiri. The highest number of Chilean flamingos and Andean flamingos were recorded in Loriscota, followed by Orurillo, which had a similar number of Chilean flamingos (Table 1).

Table 1 Number of flamingos recorded in high Andean wetlands in southern Peru.

Sampling date (2021)	Wetland	Area (ha)	Altitude (msnm)	Species		
				P. chilensis	*P. andinus*	*P. jamesi*
13 Agosto	Calapuja River	1	3847	233	7	
13 August	Pucara River	2	3862	183		
13 August	Orurillo	1285	3894	1355		
13 August	Hanccoccota	239	3926	450		
14 August	Chullumpiri	69	3917	566	6	11
12 February y 14 August	Tuyturaqara	191	3885	690		
12 February y 14 August	Asnaqocha	338	3887	225		
14 August	Asillo (Swamp)	19	3923	74		
19 August	Lagunillas	6640	4186	750		
02 October	Loriscota	2904	4568	14633	115	2
02 October	Loriscota (Swamp)	27	4561	185	13	
Total				19344	141	13

Principal Component 1 (PC1) explained 44.1 % of the total variance in the population size data matrix, while PC2 explained 26.3 %. James' flamingo was not taken into account in the analysis because it was only recorded in two wetlands. Regarding PC1, a positive association was observed between the abundance of the Chilean flamingo and the Andean flamingo with water pH, maximum ambient temperature, and average relative humidity (RH %) (Fig. 2).

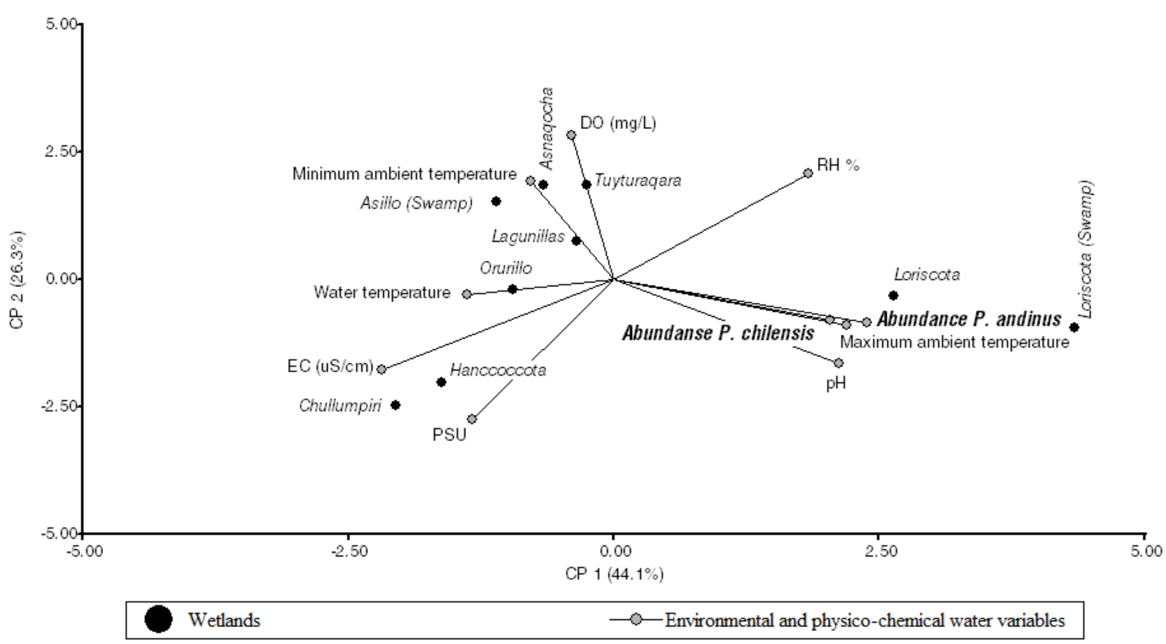

Fig. 2 Principal Component Analysis (PCA) on the abundance of *P. chilensis* and *P. andinus.*

The highest populations of *P. chilensis* are found mainly in the Loriscota and Orurillo wetlands, while populations of P. *andinus* are located in the Loriscota bofedal wetland. Lastly, populations of *P. jamesi* are only found in the Chullumpiri and Loriscota wetlands (Fig. 3).

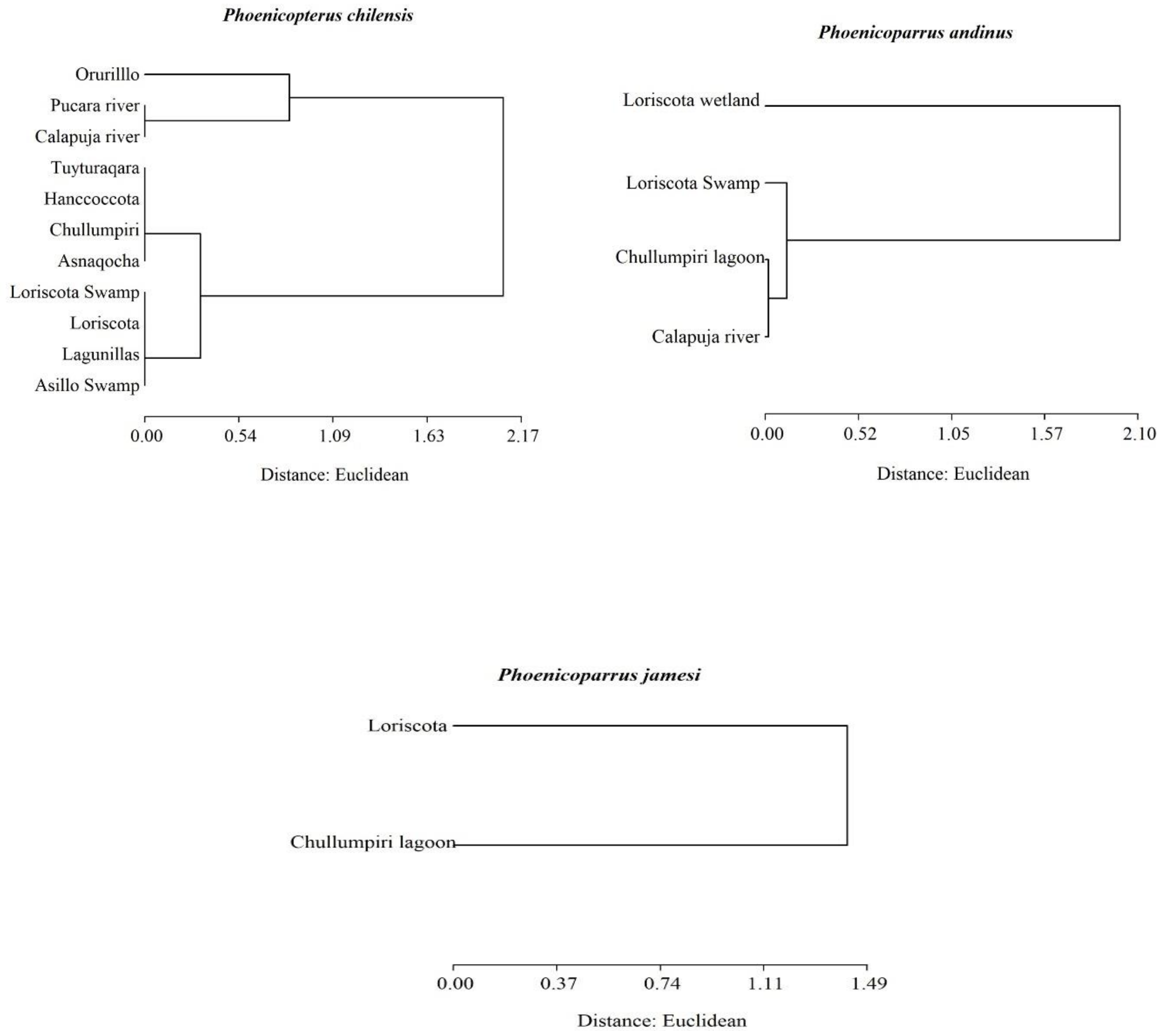

Fig. 3 Cluster analysis for populations of flamingos *P. chilensis, P. andinus*, and *P. jamesi*.

The largest population of *P. chilensis, P. andinus* recorded in the Loriscota wetland is associated with alkaline pH and low electrical conductivity compared to other wetlands. Meanwhile, populations of *P. jamesi* are linked to higher water salinity and greater electrical conductivity, making this species more selective in its habitat.

Various physicochemical parameters of the water and environmental conditions were analyzed to assess their influence on the properties of the studied wetlands. The analysis of the average in 11 wetlands allowed determining the physicochemical aspects of the wetlands (Table 2).

Table 2 Physicochemical parameters of the wetlands studied in the Puno region, Peru.

Variables	ECAS	Orurillo	Hanccoccota	Chullumpiri	Tuyturaqara	Asnaqocha	Asillo (Swamp)	Lagunillas	Loriscota	Loriscota (Swamp)
EC (µS/cm)	1000	2 054.8	3 597.2	4 703	1 008.2	1 148.6	2 576.6	2 181	2 903	887
Salinity (PSU)		1	22.7	32.6	0.5	0.6	1.3	0.4	1	0.4
DO (mg/L)	>5	0.5	0.4	0.4	3.8	3	2.9	5.3	0.5	0.6
pH	6.5 a 9	7.9	9	8.5	8.5	7.6	7.6	8.6	10.2	10.3

For Chullumpiri and Hanccoccota, which refer to the water aspect, maximum values were obtained in salinity, while the pH ranged from 7.6 to 10.3, and the dissolved oxygen (DO) (mg/L) varied from 0.4 to 3.8. Some of these values correspond to levels typically found in high-Andean lentic aquatic ecosystems, such as lagoons and lakes, according to the Environmental Quality Standards (EQS) established by the Ministry of Environment (MINAM) in 2017. However, due to the lack of studies, no information was found on the physicochemical properties of these wetlands, as many of them are privately owned.

4. DISCUSSION

In a report from the Ministry of Agriculture (MINAGRI) in 2013, it was reported that there was a greater abundance of the Chilean flamingo compared to the other two species in the Loriscota wetland. In our study, the total number of Andean flamingos and James's flamingos recorded (154 individuals) represents only a small fraction of the total number of individuals recorded throughout Peru in the year 2 000 (4 796 individuals) (Ricalde 2003).

Further analysis of the properties and quality of wetlands is necessary, especially regarding electrical conductivity, which is positively associated with salinity. The higher the water evaporation, the higher the salinity (Drago and Quiros 1995). Wetlands that primarily dry up due to lack of rainfall and human activities may require wetland management policies that include techniques such as the application of organic amendments.

A positive relationship was found between the abundance of flamingos and water pH and ambient temperature. Therefore, the abundance of James's flamingo is higher in alkaline lagoons (Frau *et al*. 2015), shallow and hypersaline lakes, with a higher presence of diatoms and cyanobacteria but scarcity of zooplankton (Caziani and Derlindati 2000). On the other hand, the Chilean flamingo is a selective predator that feeds on larger macrophytes and zooplankton, and is generally found in deep lakes, while the Andean flamingo is non-selective and is found in shallow lakes (Battauz *et al*. 2013; Caziani and Derlindati 2000). Additionally, it has been observed that the abundance of flamingos increases when the water level decreases (Romano *et al*. 2017).

The Andean Flamingo primarily faces threats stemming from habitat alteration and human activities related to water use. Moreover, the conservation efforts made so far are inadequate, necessitating more intense and specific attention to protect both the species and its fundamental habitats in Peru (Ortiz et al. 2023). In this context, in Argentina, the Phoenicopteridae family includes diverse species. For instance, the Chilean Flamingo (*P. chilensis*), with a wide geographic distribution; meanwhile, the Andean Flamingo (*P. andinus*) and the James's Flamingo (*P. jamesi*) reside in the Puna and high Andean areas during reproduction, migrating to wetlands in the central part of the country afterward. Highlighted by Quiroga and Llugdar (2022), the presence of the latter species has been recorded in ten Argentine provinces. These flamingos inhabit salt lakes and brackish lagoons located between 3500 and 4 000 meters above sea level, where they ultimately reproduce.

The Phoenicopteridae flamingos possess a highly specialized ecology, unique among birds, making them a model for understanding avian adaptation and diversification. Using mitochondrial markers (mtDNA), the genetic variation of these birds has been explored through DNA sequencing. The mtDNA sequences confirmed a distinct metapopulation represented by two minimal variable mtDNA barcodes in Chilean flamingos. Both likelihood and Bayesian methods revealed identical phylogenies, dividing the flamingos into subclades of shallow-keeled (Greater, American, and Chilean Flamingos) and deep-keeled (Lesser, Andean, and James's Flamingos) species. This finding in the widely distributed Chilean Flamingo supports similar observations in other widely distributed flamingo species. The robust species phylogeny aligns with previous classifications based on feeding morphology. It is likely that Phoenicopteridae flamingos originated in the New World, with at least one dispersal across the Atlantic (Torres et al. 2014).

The Early Eocene Juncitarsus was recognized as one of the first flamingo fossils, playing a crucial role in the hypothesis suggesting a shorebird-like origin for Phoenicopteriformes. Although the Phoenicopteriform affinities of Juncitarsus conflict with the recently proposed relationship between flamingos and grebes (Podicipediformes), which exhibit notably different morphologies, a comprehensive assessment of Juncitarsus' evolutionary significance has not yet been conducted. The affinities of Juncitarsus and its position as the sister group to the clade

(Phoenicopteriformes + Podicipediformes) are reviewed. The osteology of Juncitarsus suggests that swimming adaptations evolved within the lineage of this latter clade after the divergence of Juncitarsus. Charadriiformes continue to be among the potential closest living relatives of flamingos and grebes (Mayr 2014).

Conclusion

a) They reveal interesting patterns regarding the distribution and abundance of flamingos in these saline wetlands, which will contribute to the understanding of the interactions between flamingos and their habitat.

b) Water pH, maximum ambient temperature, and relative humidity showed a significant association with the presence of flamingos in the wetlands.

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Author Contributions

All authors contributed to the conceptualization of the study and its design. ACG in the methodology, statistics and final drafting of the manuscript, KPM in data collection and initial drafting of the manuscript, GCM in the design and elaboration of graphs, MSCHA in data collection and statistical processing, NIMG data collection and improvement of the initial drafting of the manuscript, GBQ formal data analysis and revision of the manuscript and FCM data processing and revision of the manuscript.

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Declarations

Conflict of Interest The authors declare that they have no conflict of interest

Ethical Approval Not applicable

Consent for Publication All authors give consent for manuscript to be published in its current form.

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