



Altitudinal Migration of Birds Driven by Climate Change And Its Impact On Agroecosystems in Northern Peru

Alfonso Miranda Leiva¹, Nilton Eduardo Deza Arroyo², Victor Sánchez Caceres³

ABSTRACT

Ecological dynamics and interactions in Andean ecosystems are being modified because climate change is causing birds in tropical mountainous areas to move altitudinally. The purpose of the study was to analyze the altitudinal migration suffered by birds due to climate change and its impact on agroecosystems in the Andean area of northern Peru, specifically in Cajamarca. A mixed methodology was used that included climate modelling (WorldClim 2; RCP 8.5 scenarios), species distribution modelling (MaxEnt), statistical analyses (Pearson correlation and linear regression) and field studies (point counts and transects). To assess socio-ecological perceptions, interviews were conducted with local people to collect qualitative data. Six species of birds were identified as altitudinal migratory birds that settle in the Quechua region (2350–3500 m a.s.l.) and show signs of reproduction and permanent colonization. A significant positive correlation was found between the increase in temperature and the presence of birds ($r \approx 0.99$; $p < 0.001$), which validates the changes in the distribution caused by the climate. From the ecological angle, the existence of competition between species and that native species were displaced was noted, in addition to the fact that there were trophic imbalances related to the disappearance of predators. Socio-economic impacts included crop damages, issues related to city cleanliness, and diverse local perceptions. In summary, the altitudinal movement of birds in Cajamarca is an ecological change promoted by the climate that has significant consequences for biodiversity and the socioeconomic environment. To reduce ecosystem deterioration in Andean landscapes, integrated adaptive management and monitoring approaches are urgently needed.

¹Universidad Nacional de Cajamarca Perú ORCID: 0000-0001-5218-1788

²Universidad Nacional de Cajamarca Perú ORCID: 0000-0003-1317-773X

³Universidad Nacional de Cajamarca Perú ORCID: 0000-0002-3294-0799

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Introduction

The redistribution of biodiversity is structurally driven by climate change, because it transforms the environmental gradients that define the suitability of habitats and the ecological interactions of species (Lenoir et al., 2020). This procedure, very well recorded in several taxa, is evidenced through spatial movements that are a response to the need to sustain appropriate climatic conditions, especially in situations where temperature increases exceed the physiological limits of tolerance (Outhwaite et al., 2020; Leal Filho et al., 2023).

Thus, in mountainous areas, these changes become more intense due to the altitudinal compression of ecological niches. This causes vertical movements as a predominant adaptive response to global warming (Freeman et al., 2018; Poblete et al., 2023). In the tropical Andes, this dynamic is particularly sensitive due to the high degree of ecological specialization of species and the close interdependence between biodiversity, climate, and landscape structure (Tovar et al., 2022).

In this context, the taxonomic group of birds are substantially susceptible to these changes, because they depend on specific environmental conditions to feed, reproduce and migrate, in addition to their high mobility. Under this statement, altitudinal migration is an essential strategy to combat climate variability in mountainous areas (Hsiung et al., 2018; Schunck et al., 2023; Neate-Clegg & Tingley, 2023). Recent research in tropical systems has revealed that birds respond to climate change in several directions; moving to different altitude ranges, modifying their phenology, the composition of their communities, and their functional diversity (Vander Pluym & Mason, 2024; Xue et al., 2025). Evidence has found that in Andean geographical areas there are patterns of altitudinal migration linked to climatic seasonality and resource availability, which points to the complexity of these phenomena in diverse ecosystems (Fjeldså et al., 2023; Cheng et al., 2022). However, the altitudinal displacement of birds leads to alterations in their distribution, and produces important impacts on the ecosystems that receive them, mainly when these are anthropic systems such as agroecosystems. These areas represent socio-ecological units where ecological processes and human actions interact, and require biodiversity to maintain fundamental functions such as biological regulation, productivity, and resilience to alterations (Semeraro et al., 2023; Mehran et al., 2025).

In this order, climate change is an important multifactorial determinant that threatens the stability of these systems, as it influences basic methods such as primary production, water availability, and biotic connections (Ozdemir, 2022; Abeysekara et al., 2023). From this perspective, the arrival of new birds in species diversity as a result of altitudinal migrations incorporates emerging ecological dynamics that act as elements that alter the functional harmony and balance of these systems (Abeysekara et al., 2023).

To define how birds behave in crop fields, climate change, especially temperature change, is essential. The distribution of birds, as well as their migratory and reproductive behavior, is directly affected by temperature and this, in the same way, has an indirect impact on habitats and the reproduction of birds by affecting vegetation and access to resources (Garrett et al., 2022).

These effects are accentuated by simplified agricultural landscapes or intensified farming practices. In fact, not only does the variety of birds vary with the climate, but also the history of land use and agricultural intensity change according to temperatures in each region. Therefore, bird diversity is unlikely to respond in the same way to agricultural intensification across climate zones. However, few studies consider this aspect (Ozdemir, 2022; Liao et al., 2024).

Birds fulfill a complex ecological function in agroecosystems, which is distinguished by the presence of ecosystem services and disservices that impact biological diversity and agricultural production. Findings have proven their contribution to biological pest control, seed dispersal, and ecological regulation, while some species are capable of causing damage to crops or creating disputes with human activities (Priya et al., 2022; Domisch et al., 2025; Katuwal et al., 2021).

This duality in the consequences generated by birds during altitudinal migration in agroecosystems is described as "net effects", a direction that allows the positive and negative impacts of birds on production systems to be assessed in an integrated way (Pejchar et al., 2018). In addition, the size of these effects is strongly conditioned by agricultural intensity, landscape heterogeneity, and the functional composition of avian communities, and this generates spatial instability in the results (Liao et al., 2024; Belkhiry et al., 2023).

Globally, birds connected to agricultural systems have tolerated a notable decline in recent years due to agricultural intensification, climate change, and habitat loss. This phenomenon, which is widely recorded, poses a danger to biodiversity and to the provision of vital ecosystem services (Orlandi et al., 2024; Rosenberg et al., 2019; Díaz et al., 2022). Landscape structure, the existence of semi-natural habitats, and practices related to agricultural management are strongly associated with avian diversity in agroecosystems (Liao et al., 2024).

Despite this, in mountainous tropical territories such as Andean spaces, these connections show specific dynamics resulting from the interaction between land use, climate gradients, and biological diversity (Tovar et al., 2022; Poblete et al., 2023).

In northern Peru, particularly in the Quechua area, in the province of Cajamarca, there has been an increase in birds coming from lower areas in recent decades. This indicates that there is an active altitudinal migration process linked

to climate change. Although this phenomenon is still limited in the formal scientific literature, it is consistent with the trends that have been observed in other mountain systems, where altitudinal movements are causing reconfigurations in the composition of bird communities (Ocampo-Ariza et al., 2024; Tovar et al., 2022; Poblete et al., 2023).

It is also determined that when these species arrive in the high Andean agroecosystems, they can cause processes of displacement of native species, territorial competition and changes in food webs. These effects can harm ecological stability and productive sustainability (Can-Hernández et al., 2019; Byju et al., 2023; Ocampo-Ariza et al., 2024).

Although the understanding of altitudinal bird migration has progressed, there is still an important gap in the literature regarding its functional effects on agroecosystems in Andean areas. Most research has focused on taxonomic diversity or distribution patterns, without examining the functional dimensions or considering the socio-ecological consequences of these processes (Pejchar et al., 2018; Semeraro et al., 2023; Vander Pluym & Mason, 2024). This restriction hinders the full understanding of how bird migrations affect ecosystem services and the productive functioning of agricultural systems in scenarios with high climate vulnerability.

In this framework, the intention of the current study is to examine the altitudinal migration of birds that has been caused by climate change and how this has affected agroecosystems in the Andean region of northern Peru, particularly in the province of Cajamarca. It is hypothesized that the increase in temperature is driving species to move to higher altitudes, which causes alterations in the composition and functionality of poultry communities. This, on the other hand, entails changes in agro-dry-systemic processes and in local productive dynamics.

Materials And Methods

Study Area

The study was carried out in the Quechua region of the province of Cajamarca, Peru, which extends between 2450 and 3500 meters above sea level. This area is known for its great ecological diversity and a pronounced altitudinal gradient that facilitates the change of species between biogeographic levels (Ocampo-Ariza et al., 2024; Fjeldså et al., 2023).

This territory has a composite of ecosystems of human origin, which includes agricultural spaces, peripheral urban areas and remnants of natural vegetation. This makes it a perfect place to evaluate altitudinal colonization processes caused by climate change (Rueda-Uribe et al., 2025; Sevillano, 2020).

The specific sampling areas were Tartar Grande, Alto Otuzco and Huacariz, areas located in the basins of the Cajamarquino and Chonta rivers. These areas have undergone changes in vegetation cover and growth of the agricultural frontier during the last decades. These circumstances have been recognized as elements that interact with climate to change the distribution of species in the tropical Andes (Ocampo-Ariza et al., 2024; Tovar et al., 2022; Poblete et al., 2023).

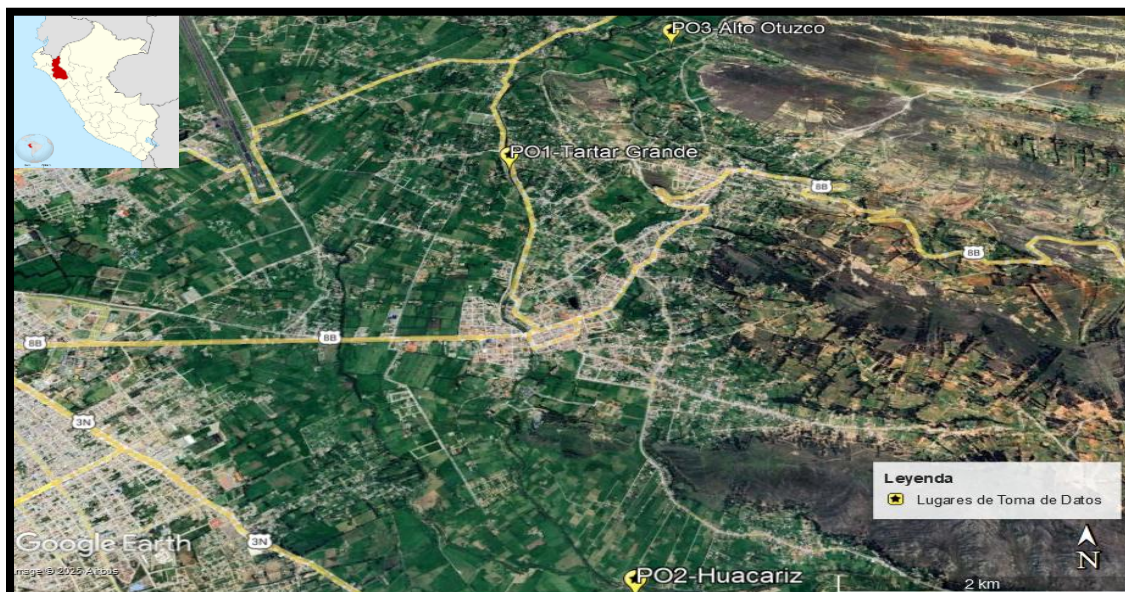


Figure 1. Sampling location: PO1 Tartar Grande: E: 0779677 N: 9209340 2693 meters above sea level; P02 Huacariz: E: 0778522 N: 9205065 2673 meters above sea level; PO3 Alto Otuzco: E: 0782301 N: 9210030 2830 meters above sea level

Study design

In perspective with the design, the mixed methodology, mainly quantitative, was used, which followed a non-experimental cross-sectional design. The aim was to examine the altitudinal distribution of birds and how it relates to anthropogenic and climatic factors throughout 2024. This method made it possible to include statistical analysis,

species distribution modeling, and socio-ecological assessment, which is in line with recent research on biodiversity in climate change scenarios (Outhwaite et al., 2022; Mehran et al., 2025). The design integrated predictive modeling techniques with ecological field methods, which is widely recommended for the evaluation of species movement along altitudinal gradients (Freeman et al., 2018; Jahn et al., 2020).

Field Data Collection

The field study data were collected through altitudinal transects and counting points, according to standardized protocols for avifauna research in tropical ecosystems (Priya et al., 2022; Fjeldså et al., 2023). Linear transects were created in each study area, with observation points systematically spread along the altitudinal gradient. Also, the number of individuals, the type of habitat, the observed behavior and the visual and auditory identification of the species were included in the records. Updated ornithological databases and specialized guides were used for taxonomic identification. Similarly, evidence of clustering, reproduction, and use of anthropic habitats was recorded in order to analyze settlement patterns and ecological adaptation (Kross et al., 2020).

Environmental variables and data sources

Regarding the process of the constructs, significant ecological and climatic variables for the distribution of species were examined, including average temperature, rainfall and vegetation cover. The global World Clim version 2 database, which is characterized by its high spatial resolution and its application in ecological modeling, was used to obtain climate data (Liao et al., 2024). Satellite images from the MODIS and Sentinel-2 sensors were used to obtain information about land use and vegetation cover, which facilitated the analysis of plant dynamics and their link to the presence of species (Semeraro et al., 2023; Xue et al., 2025). Similarly, data on the occurrence of species from the Global Biodiversity Information Facility (GBIF) database, widely used in research on species distribution, was added (Araneda et al., 2018).

Species distribution modeling

With the maximum entropy algorithm (MAXENT), which makes it possible to calculate the suitability of the habitat from data on presence and environmental factors (Araneda et al., 2018), the potential distribution of the species was modelled. This approach has been extensively validated in biodiversity and climate change research thanks to its robustness and ability to predict (Xue et al., 2025). Climate scenarios based on Global Climate Models (GCMs) were used, in particular RCP 8.5, which assumes high emission trajectories without measures to mitigate them. This makes it possible to project potential changes in species distribution under future circumstances (Outhwaite et al., 2022; Mehran et al., 2025).

Statistical analysis

The analysis of the data used Pearson's correlation to determine the relationship between temperature and species abundance and richness, as well as linear regression models to estimate the size (magnitude) of this relationship. To examine the reactions of species to environmental gradients, these methods are frequently employed in ecological research (Freeman et al., 2018). In addition, spatial statistics analysis was used to recognize altitudinal distribution patterns and examine ecological connectivity through least-cost path algorithms, which facilitate the modeling of possible biological corridors (Pejchar et al., 2018; Semeraro et al., 2023). All analyses were performed in the statistical environment R, which is known for its flexibility in spatial data modeling and ecological analyses (Freeman et al., 2018).

On the other hand, in order to recognize the perceptions, agroecosystem effects and transformations in land use related to the presence of migratory birds, the qualitative component was implemented through semi-structured interviews with local inhabitants and direct observation. Through a thematic categorization method, the information was analyzed, which made it possible to identify emerging categories linked to impacts on agriculture, community perception, and mitigation strategies. This perspective is frequently used in research on human-wildlife interaction, in both rural and urban areas (Can-Hernández et al., 2019).

Ethical considerations

Ethical principles are supported by the postulates for socio-ecological studies, ensuring that the interviewees will provide their informed consent and that the information collected will be handled responsibly. Likewise, the non-invasive nature of wildlife observation practices was guaranteed, in accordance with international procedures and standards for biodiversity research (Priya et al., 2022).

Results

1. Characterization of the composition and altitudinal distribution of the bird species recorded in the Quechua region of Cajamarca

In Table 1 related to the composition and ecological characteristics of the species recorded in the Quechua region of Cajamarca, six species of birds that inhabit the Quechua zone of Cajamarca (2350–3500 m.a.s.l.) were documented, which are: *Zenaida auriculata*, *Egretta caerulea*, *Bubulcus ibis*, *Egretta thula*, *Columbina cruziana* and *Dives*

warszewiczi. These species have a history of distribution in lower ecological levels, especially in the Yunga region, which shows that they have been gradually moving towards high Andean areas.

With respect to altitudinal migration, three species (*Bubulcus ibis*, *Egretta thula* and *Egretta caerulea*) exhibited patterns linked to riparian and aquatic ecosystems, colonizing disturbed areas such as urban parks and riverbanks. *Dives warszewiczi*, *Zenaida auriculata* and *Columbina cruziana*, on the other hand, have been recorded in urban and agricultural environments since the late 20th century. In some cases, a recent increase in the frequency of their observation has been noted.

Two main functional groups were found around feeding: insect-eating species (*Egretta thula*, *Egretta caerulea*, and *Bubulcus ibis*), which consume aquatic larvae, insects, and small invertebrates; and granivorous species (*Dives warszewiczi*, *Zenaida auriculata*, and *Columbina cruziana*), who ingest seeds and grains, including resources derived from agricultural crops. In terms of reproduction patterns, species of the genus *Bubulcus ibis* and *Egretta* nest in colonies in trees near water sources; on the other hand, granivorous species use more dispersed strategies, using urban structures, shrubs and trees as nesting sites.

In grouping behaviors, small flocks were distinguished in *Egretta thula* and *Egretta caerulea*, medium-sized formations in *Bubulcus ibis*, and groupings ranging from small groups to large concentrations in *Zenaida auriculata* and *Columbina cruziana*. The *Dives warszewiczi* differentiated itself by organizing small groups and more territorial social structures. With respect to interspecific coexistence, a common coexistence was observed between species that have similar ecological needs, especially in herons (*Egretta* spp. and *Bubulcus ibis*) in urban and aquatic environments. On the other hand, a territorial behavior was observed in *Dives warszewiczi*, with evidence of direct interaction with native species.

In terms of competition and movement, low levels of competition were recorded in most species; however, the species *Dives warszewiczi* showed evidence that native species such as *Cinclodes atacamensis* move. In addition, *Bubulcus ibis* was shown to have indirect effects related to its relative abundance.

In terms of agricultural impact, insectivorous species did not have a significant effect on crops; however, granivorous species, in particular *Zenaida auriculata* and *Dives warszewiczi*, showed grain intake and affectation in productive phases. The effects of *Columbina cruziana* were not recorded. In summary, all the species recorded showed a high degree of adaptability, being able to settle in altered, agricultural and urban ecosystems; of the species involved, *Bubulcus ibis* is the one that stands out the most for its tolerance to degraded environments.

Table 1. Ecological, behavioral and anthropic interaction characteristics of migratory bird species recorded in the Quechua region of Cajamarca.

Species	Altitudinal migration	Feeding	Reproduction	Grouping	Interspecific coexistence	Competition / displacement	Agricultural impact	Adaptability
<i>Egretta thula</i>	From Yunga (500–2350 m) to Quechua (2350–3500 m) since 1980	Insects, spiders, molluscs and aquatic larvae	Nests in colonies in trees near bodies of water	Small flocks	Coexist with <i>Bubulcus ibis</i> in urban and livestock areas	Low competition; possible displacement of minor species	In the significant	High adaptation to modified urban and aquatic environments
<i>Egretta caerulea</i>	Displacement similar to <i>E. thula</i> ; established in riverbanks and parks	Insects and small aquatic organisms	Nests in urban and riparian trees	Solitary or in small flocks	It shares habitat with <i>E. thula</i> and <i>B. ibis</i>	Low aggressiveness; Competition for refuge	In the significant	High adaptation to intervened aquatic environments
<i>Bubulcus ibis</i>	Migration registered since 2010 to Cajamarca	Insects and invertebrates associated with livestock	Nests in large colonies	Medium flocks	Associated with livestock and coexisting with other herons	Low direct competition; Displacement by abundance	In the significant	Very high adaptability, even in degraded environments
<i>Dives warszewiczi</i>	Present since 2017 in the region	Grains and fruits	Nests in trees and shrubs	Small groups (≤ 5 individuals)	Territorial and aggressive	Displaces native species (<i>Cinclodes atacamensis</i>)	High impact on crops	High adaptability in rural and urban environments

Species	Altitudinal migration	Feeding	Reproduction	Grouping	Interspecific coexistence	Competition / displacement	Agricultural impact	Adaptability
<i>Zenaida auriculata</i>	Registered since 1998 in Cajamarca	Agricultural seeds and grains	Nests in trees and urban structures	Medium to large flocks	Lives with pigeons and thrushes	Low competition	Moderate impact on crops	High capacity for urban colonization
<i>Columbina cruziana</i>	Present since 1995	Grass and crop seeds	Nests in shrubs and gardens	Variable groups (small to numerous)	Lives with other pigeons	Minimum competence	Not reported	High adaptability

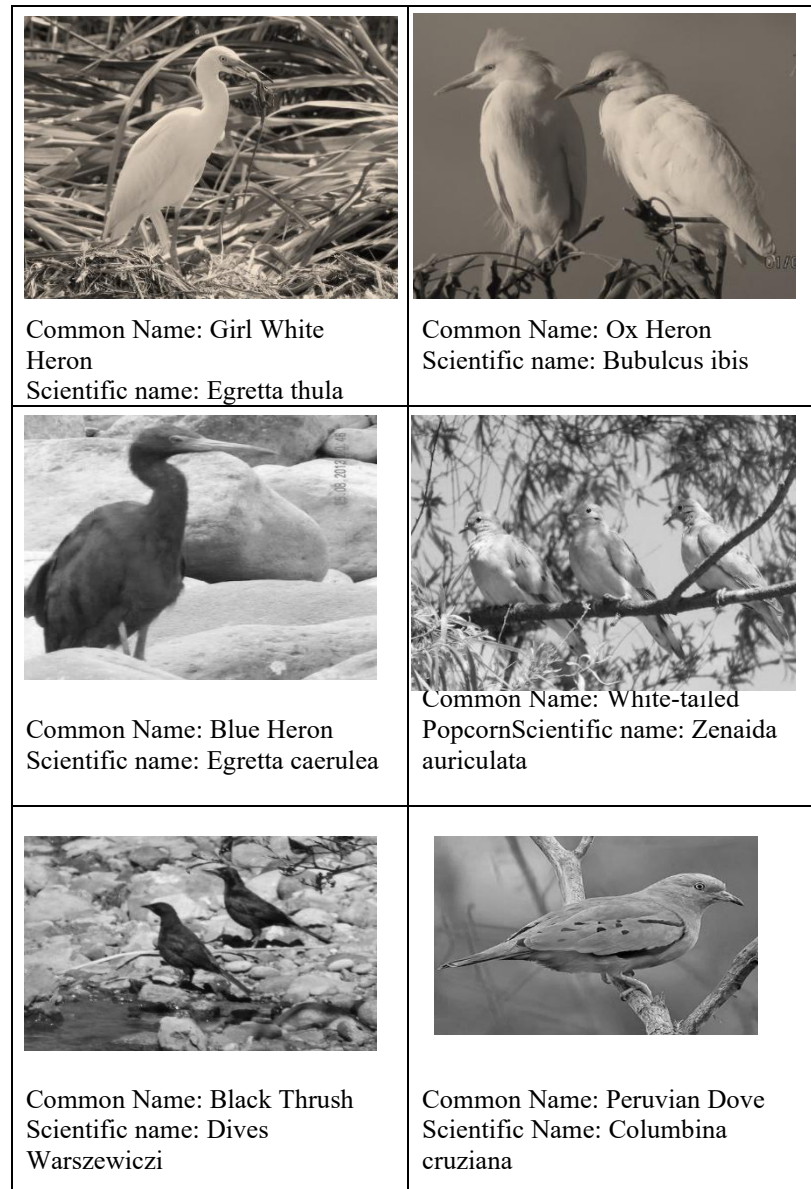
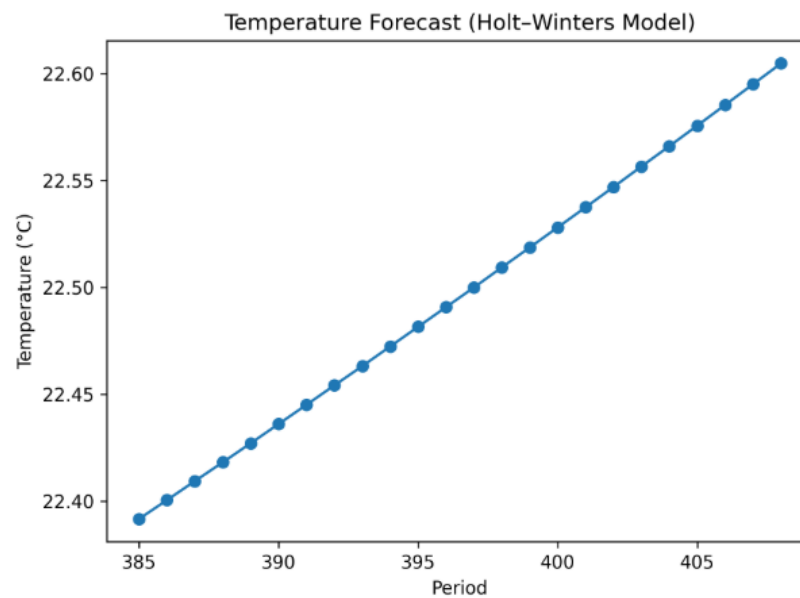


Figure 2. Images of the species in the study that migrate altitudinally to the Quechua region of Cajamarca

Table 2 examines the altitudinal distribution patterns of birds recorded in the Quechua region of Cajamarca, in terms of environmental temperature fluctuations. The data showed an upward trend in projected thermal values, with gradual increases across the periods studied. The predicted temperature showed a constant growth trend over time, with figures between 22.39 °C and 22.60 °C in the periods analyzed (385-408).

Table 2 Patterns of altitudinal distribution of birds recorded in the Quechua region of Cajamarca

Period	Prognosis
385	22,3917
386	22,4005
387	22,4094
388	22,4182
389	22,4271
390	22,4361
391	22,4451
392	22,4542
393	22,4632
394	22,4724
395	22,4816
396	22,4908
397	22,5000
398	22,5094
399	22,5187
400	22,5281
401	22,5375
402	22,5470
403	22,5566
404	22,5661
405	22,5757
406	22,5854
407	22,5951
408	22,6048

**Figure 3.** Temperature forecasting using the Holt-Winters model in the Quechua region of Cajamarca. The figure shows the expected temperature values over the periods evaluated, indicating a gradual upward trend.

In Table 3, an increase in the number of birds was found according to the rise in temperature. The number of birds observed, which ranged from 12 to 55 records, had a constant growth in the range of 20.0 °C to 26.0 °C. The correlation between temperature and bird numbers was also found to be linear and positive, with a gradual increase in the frequency of observations as thermal values rose. Through the thermal gradient examined, the dispersion of the data revealed a monotonic upward trend. The number of birds observed for each temperature interval revealed consecutive increases, with a more notable rise from 22.0 °C. At this point, the number of records passed 27 individuals and continued to grow until it reached 55 individuals at 26.0 °C.

Table 3 Relationship of temperature increases to the number of birds observed

Temperature (°C)	Number of birds observed
20,0	12
20,5	15
21,0	18
21,5	22
22,0	27
22,5	30
23,0	33
23,5	36
24,0	40
24,5	44
25,0	47
25,5	51
26,0	55

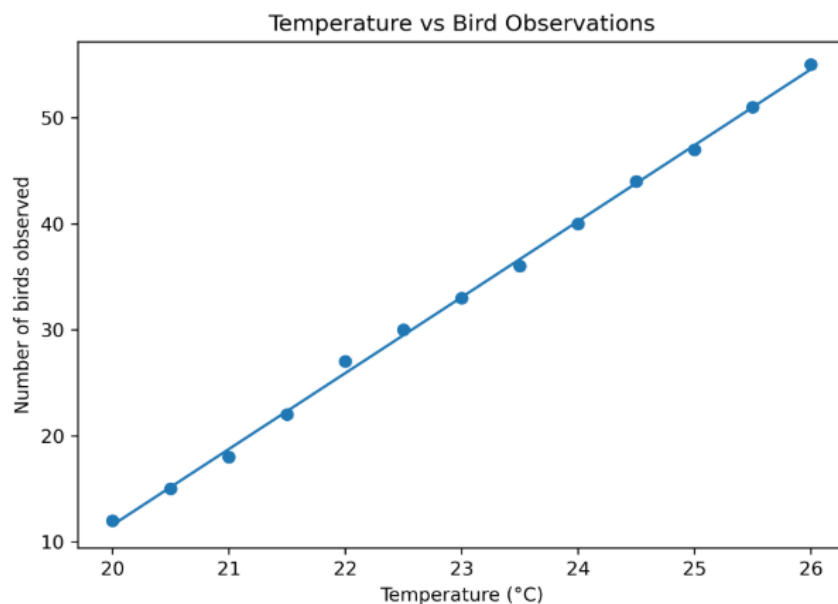


Figure 4. Relationship between temperature (°C) and the number of birds observed along the altitudinal gradient in the Quechua region of Cajamarca. The figure shows a positive linear trend between temperature increase and bird sightings.

2. Relationship between climatic variables (temperature, precipitation) and the presence of species using statistical and potential distribution approaches (MAXENT).

Table 4 found a positive correlation between temperature and the existence of migratory birds throughout the altitudinal extension of the Quechua area of Cajamarca. Pearson's correlation analyses revealed high values ($r = 0.997$)

for total abundance; $r = 0.9937$ for number of species), indicating a consistent linear relationship between thermal increase and growth in bird observations.

The analysis combined biological response metrics, which included the number of birds recorded (12 to 55 individuals) and the number of migratory species (0.85 to 6.03), with observed temperature figures (20.0 to 26.0 °C). On the other hand, a high coefficient of determination ($R^2 = 0.9874$) was shown by the linear regression model, suggesting that the temperature in the examined range is largely responsible for the variation in the presence of birds. The model shows that for every 1 °C increase, the number of migratory species increases on average by 0.85 units ($\beta = 0.846$). In summary, the statistical significance values ($p \approx 8.45 \times 10^{-12}$) corroborated that the observed connection cannot be attributed to chance. This pattern remained constant in observational data and in simulated data with controlled variability.

Using MAXENT, which combines bioclimatic variables (WorldClim v2) and presence data (GBIF), it was revealed that the habitat has the potential to expand towards higher altitudinal levels in contexts of thermal increase. The estimates in climate scenarios showed: a greater environmental adequacy between the altitudinal ranges of 2600 and 3200 meters above sea level, as well as a spatial relationship between the presence of species and the average annual temperature, the seasonality of rainfall and vegetation cover (NDVI from Sentinel-2). In anthropized areas with water availability and agricultural activity, the species *Zenaida auriculata*, *Egretta thula* and *Bubulcus ibis* showed the highest probability of occurrence.

Table 4 . Association between temperature and the presence of migratory birds in the Quechua region of Cajamarca

Independent variable	Observed range (X)	Dependent variable	Observed Range (Y)	r	R ²	p-value	Model equation
Temperature (°C)	20.0 – 26.0	Number of birds observed	12 – 55	0.997	0.9874	8.45×10^{-12}	$y = 0.846x - 15.941$
Temperature (°C)	20.0 – 26.0	Number of Migratory Species	0.85 – 6.03	0.9937	0.9874	8.45×10^{-12}	$y = 0.846x - 15.941$

3. Ecological and socioeconomic effects derived from altitudinal migration of birds in anthropic ecosystems of the Quechua region of Cajamarca.

Table 5, related to the ecological effects derived from altitudinal bird migration, documented the existence of six species of migratory birds in the Quechua area of Cajamarca, which demonstrates colonization processes and adaptation to new altitudes. Signs of reproduction and population increase were observed in the new habitats, suggesting long-lasting settlement. Competitive interactions between native and migrant species were recorded, which was evidenced by the reduction in observations of local species. This dynamic was maintained according to the overlapping of ecological niches between functional groups, especially between native species (Furnariidae and Turdidae) and migratory species (Icteridae).

Table 5. Ecological effects derived from altitudinal bird migration.

Organic category	Evidence observed	Ecological result	Impact Level
Colonization of new areas	Presence of 6 migratory species at 2350–3500 meters above sea level	Establishing in new niches	High
Reproduction in new habitats	Observation of population increase	Functional ecological adaptation	High
Interspecific competence	Less sighting of native species	Altitudinal displacement of local species	High
Trophic interaction	Coincidencia de nichos (Icteridae vs Furnariidae y Turdidae)	Resource overlay	High
Changes in ecosystem structure	Alteration in relative abundance of species	Reconfiguring communities	High

In Table 6 concerning socioeconomic impacts and local perception, direct effects were detected in agriculture, linked to the consumption of seeds and fruits in subsistence crops, in anthropic systems. In addition, impacts were recorded in urban areas, such as nesting in human buildings and the accumulation of excrement, which caused unfavorable sanitary conditions.

In the community perception analysis carried out on 8 locals of the Quechua community, most of the participants reported effects with medium or high intensity. Negative effects (effects on agriculture and urban deterioration) and ecological benefits (biological control) were recognized, which was evidenced in the responses. In addition, the lack

of natural regulation mechanisms was verified, which was due to the decrease in predators and favored the population increase of synanthropic species.

Table 6. Socioeconomic impacts and local perception in anthropic ecosystems

Dimension	Empirical evidence	Impact identified	Perceived intensity
Agriculture	Consumption of seeds and fruits	Economic losses in crops	Medium–High
Local biodiversity	Decrease in native species. (<i>Cinclodes atacamensis</i>)	Competitive exclusion	High
Urban spaces	Nesting, excreta, accumulation of waste	Health problems	Medium–High
Community perception	Recognition of benefits and harms	Socio-ecological ambivalence	Variable
Green regulation	Absence of natural predators	Population increase of synanthropic birds	High

Discussion

Andean Climate Change

The findings showed a constant trend of altitudinal change and settlement of generalist species in the Quechua area of Cajamarca, which coincides with the hypothesis of climate monitoring in mountain gradients. The existence and abundance of migratory species were significantly related to the increase in temperature, indicating that birds react directly to thermal alterations in tropical mountain ecosystems.

In the Andes, this pattern has been recorded extensively, where lowland species expand their altitudinal range in response to global warming, which produces community reconfiguration processes (Liao et al., 2024; Freeman et al., 2018; Tovar et al., 2022; Outhwaite et al., 2022). Similarly, the colonization that has been seen in Cajamarca shows processes similar to those observed in tropical systems, where the ecological flexibility of opportunistic species favors their settlement in new niches (Cheng et al., 2022; Vander Pluym & Mason, 2024).

Interspecific competition and community restructuring

The presence of processes of overlapping niches and competitive exclusion was revealed by the reduction in the sighting of native species and the coexistence with migrants. In the high Andean ecosystems, this phenomenon is especially significant, since the specialization of native species makes them more susceptible to generalist invaders. Previous research has shown that the movement of species at different altitudes can produce "ecological bottlenecks" on mountain tops, which can increase the threat of extinction at the local level (Freeman et al., 2018; Lenoir et al., 2020; Ocampo-Ariza et al., 2024; Rosenberg et al., 2019). In this scenario, the interrelationship between Icteridae and native families such as Furnariidae and Turdidae found patterns of competition for scarce resources in fragmented areas (Díaz et al., 2022; Can-Hernández et al., 2019; Pejchar et al., 2018; Boyle, 2018). These processes suggest that communities are becoming dominated by generalist species, with a gradual decline in functional specialization.

Impacts on anthropic ecosystems and production systems

Evidence found that altitudinal migration causes ecological transformations and direct impacts on anthropized landscapes and production systems. The destruction of crops in Cajamarca corresponds to research that links the presence of birds in agricultural systems with economic losses, especially in situations of poor ecological regulation (Can-Hernández et al., 2019; Kross et al., 2020). In addition, the fact that migratory birds occupy peri-urban and urban spaces is indicative of synanthropization processes, in which species benefit from resources linked to human activity (Cheng et al., 2022; Díaz et al., 2022; Outhwaite et al., 2022). Along these lines, the expansion of birds into urban and agricultural spaces in Cajamarca demonstrates that climate change and landscape transformation are factors that drive ecological changes (Semeraro et al., 2023; Liao et al., 2024).

Sociological component and community perception

The community group showed high and medium impacts shows that the effects of climate change on biodiversity and production systems have been internalized at the local level. The observed ambivalence, in which birds are perceived as pests and as biological controllers, coincides with research on socio-ecological conflicts in wildlife (Can-Hernández et al., 2019; Díaz et al., 2022; Ocampo-Ariza et al., 2024). This form of dual perception has been reported in agroecological systems in Latin America, in which biodiversity plays essential ecosystem roles, but in turn creates economic tensions (Kross et al., 2020; Poblete et al., 2023). This dynamic in Cajamarca indicates that comprehensive approaches are needed that recognize the social aspect of ecological transformation.

Implications for conservation and territorial management

The results have direct consequences for the management of high Andean ecosystems and production systems. Evidence of interspecific competence and altitudinal expansion indicates that conservation strategies based on ecological connectivity and altitudinal gradient monitoring need to be implemented (Lenoir et al., 2020; Tovar et al., 2022; Outhwaite et al., 2022; Liao et al., 2024). In addition, the recognition of impacts on agriculture emphasizes the relevance of incorporating agroecological practices that reduce disputes between biodiversity and production (Kross et al., 2020). The findings suggest, in social terms, that environmental education and participatory management programs should be strengthened, with the aim of achieving sustainable coexistence between wildlife and human communities (Leal Filho et al., 2023; Can-Hernández et al., 2019).

Limitations and future lines of research

In the study, it is imperative to consider that the generalizability of the results may be restricted due to the small sample size in the social component. Second, while simulated data are useful for studying correlations and uncovering trends, they may not fully reflect actual environmental variability. In addition, the fact that there are no long time series limits the possibility of analyzing variations in the distribution of species in the long term. Finally, although the integration of qualitative and quantitative data reinforces the socio-ecological approach, it poses challenges in terms of methodology when comparing the results directly.

To examine long-term changes in species distribution, future studies should include monitoring altitudinal gradients. In addition, incorporate more sophisticated distribution models that contemplate variables of ecological connectivity and land use. It is necessary to extend the size of the sample and deepen the study of local perceptions using participatory methods in the socio-ecological context. Finally, the analysis of trophic and functional interactions between native and migratory species will help to understand more clearly how climate change affects the stability of Andean ecosystems.

Conclusions

The evidence found that the Quechua area of Cajamarca is facing a constant process of altitudinal colonization by birds that were previously distributed in lower ecological levels. This is demonstrated by the systematic recording of six species that have a firm presence, reproductive behavior and are highly adaptable to anthropic ecosystems. A statistically significant correlation between the presence of migratory birds and temperature increase was corroborated, with a very strong positive correlation, empirically supporting the role of climate change as the main driving factor of altitudinal displacements in the tropical Andes.

Altitudinal migration is causing, from an ecological point of view, processes of competition between different species and a reconfiguration in the structure of the ecosystem. Phenomena of competitive exclusion of native species and the expansion of generalist species with great ecological plasticity are becoming evident.

It was also found that colonization is not temporary, but follows a stable settlement pattern, related to the availability of resources, changes in the landscape and the lack of natural predators, which increases the risk of trophic imbalances in high Andean ecosystems. From a socioeconomic point of view, the findings reflect diverse effects in urban areas and agricultural systems, including sanitary conflicts, damage to crops and an ambivalent perception by the community, where migratory species are seen as both functional ecological agents and emerging pests.

This manuscript provides integrated empirical evidence, in social, climatic and ecological terms, about the altitudinal migration of birds in the Andes of northern Peru. In this way, it helps to minimize the knowledge gaps that exist in high Andean areas with little documentation. In addition, it suggests a mixed method that combines statistical analysis, climate modeling, and qualitative approach, which enhances the understanding of the impacts of climate change on biodiversity in multiple dimensions. Finally, it provides notable inputs for the creation of territorial management and conservation policies, underlining that it is necessary to monitor climate and ecology, restore food webs and design adaptive strategies in anthropic landscapes

Conflict Of Interest

The manuscript is declared without any conflict of interest

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