# Effects of the environmental conditions and seasonality on a population census of the Andean Condor *Vultur gryphus* in the tropical Andes

**Sandra Márquez-Alvis** [1, 2], **Luis Martín Vallejos Bardales** [Corresp., 3, 4], **Santiago Paredes-Guerrero** [5], **Luis Pollack-Velasquez** [1, 4], **Gabriel Silva Santos** [6, 7]

1 Departamento de Biologia, Facultad de Ciencias Biologicas, Universidad Nacional de Trujillo, Trujillo, La Libertad, Peru
2 CONSERVACCION, Lima, Lima, Peru
3 Programa de Pós-Graduação em Ecologia, Instituto de Biologia, Universidade Federal do Rio de Janeiro, Rio de Janeiro, Rio de Janeiro, Brazil
4 Departamento de Ornitologia, CINBIOTYC, Piura, Piura, Peru
5 Reserva Nacional Pampa Galeras Bárbara D'Achille, SERNANP, Ayacucho, Ayacucho, Peru
6 Programa de Pós-Graduação em Ecologia e Evolução., Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Rio de Janeiro, Brazil
7 Instituto Nacional da Mata Atlântica, Santa Teresa, Espirito Santo, Brazil

Corresponding Author: Luis Martín Vallejos Bardales
Email address: martin.vallej@gmail.com

**Background**: Among the New World vultures, the Andean condor is considered one of the most cultural and ecological important species. Yet, their populations are declining over their entire distributional range. In response, conservation strategies have been implemented in many countries to reverse the increasing extinction risk of this bird. The initiatives rely on extensive population censuses to gather basic information necessary to implement policies and to efficiently intervene. Less attention has been paid to standardize the censuses according to seasonality and to suitable environmental conditions over its distributional range. Aiming to fill such important gaps, we provide the first assessment of the role played by temperature, rainfall, and seasonality in censuses of Andean condors in a communal roost of the central Peruvian Andes. **Methods:** we associated environmental variables with census counts of adult and young condors at three different times of the day and three times a week between June 2014 and March 2015 using an autoregressive generalized linear model. **Results**: We found that both, adults and young Andean condors, showed a threefold reduction in the use of the communal roost after the beginning of the rainy season. Colder and drier days are preferable for censusing, as the total number of condors using communal roosts is expected to reduce under rainy (pluviosity = -0.53 ± 0.15) and warm (Temperature= -0.04 ± 0.025) days. Finally, the significant variation in use of roosts across seasons, daily and hourly should be carefully accounted for in national censuses, at the risk of undermining the full potential of the communal roost censuses. At the local level, our results also present important finds, such as the higher recorded juvenile (about to 76%) in the juvenile:adult ratio and a remarkable absence of Andean condors during the dry season that might suggest that unknown communal roosts might be hierarchically used. Such results provide important information for selecting priority areas for conservation, and the results may open an important avenue for further research for the conservation of the Andean condor.

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Sandra Milagros Márquez-Alvis[1,2], Luis Martin Vallejos[3,4], Santiago Paredes Guerrero[5] Luis Pollack Velásquez[1,4], Gabriel Silva Santos[6,7]

[1]Facultad de Ciencias Biológicas. Universidad Nacional de Trujillo, Trujillo, Perú.
[2]ONG CONSERVACCION, Lima, Perú.
[3]Programa de Pós-Graduação em Ecologia, Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brazil
[4]Centro de Investigación en Biología Tropical y Conservación- CINBIOTYC, Piura, Perú.
[5]SERNANP - Reserva Nacional Pampa Galeras Bárbara D'Achille, Ayacucho, Perú.
[6] Universidade do Estado do Rio de Janeiro, Programa de Pós-Graduação em Ecologia e Evolução. Rio de Janeiro, RJ, Brasil.
[7]National Institute of the Atlantic Forest (INMA), Santa Teresa, Espírito Santo, Brazil.

Corresponding Author:
Luis Martin Vallejos [3,4]
Programa de Pós-Graduação em Ecologia, Universidade Federal do Rio de Janeiro, Av. Carlos Chagas Filho, 373, Cidade Universitária - Ilha do Fundão Rio de Janeiro, 21941-902, Brazil
Centro de Investigación en Biología Tropical y Conservación- CINBIOTYC, Asent. H. Almirante Miguel Grau, II etapa. Mz "E" lote 16 – Piura, 20004, Perú.
Email address: martin.vallej@gmail.com

## Abstract

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**Methods:** we associated environmental variables with census counts of adult and young condors at three different times of the day and three times a week between June 2014 and March 2015 using an autoregressive generalized linear model.
**Results**: We found that both, adults and young Andean condors, showed a threefold reduction in the use of the communal roost after the beginning of the rainy season. Colder and drier days are preferable for censusing, as the total number of condors using communal roosts is expected to reduce under rainy (pluviosity = -0.53 ± 0.15) and warm (Temperature= - 0.04 ± 0.025) days. Finally, the significant variation in use of roosts across seasons, daily and hourly should be carefully accounted for in national censuses, at the risk of undermining the full potential of the communal roost censuses. At the local level, our results also present important finds, such as the higher recorded juvenile (about to 76%) in the juvenile:adult ratio and a remarkable absence of Andean condors during the dry season that might suggest that unknown communal roosts might be hierarchically used. Such results provide important information for selecting priority areas for conservation, and the results may open an important avenue for further research for the conservation of the Andean condor.

## Introduction

The Andean condor (*Vultur gryphus*) is an emblematic species in Andean countries of South America (Ibarra et al., 2012) The species has a wide latitudinal and altitudinal distribution that has an important historical and cultural relevance beside other species of the Cathartidade family (*e.g.*, tourism, scavenging, art; Michel, Whelan & Verutes, 2020). Yet, Andean condor populations are decreasing (BirdLife International, 2022). Recently, the globaly threatened status of the Andean condor increased to Vulnerable (VU) in the IUCN Red Book (BirdLife International, 2022), and more critical situations are reported in Peru and Ecuador as Endangered (EN) (Freile et al., 2012; SERFOR, 2018), and in Venezuela and Colombia as Critically Endangered (CR) (Rodríguez, Barrera & Ciri, 2005; Renjifo et al., 2016). Large specialized vultures such as the Andean condor, are the most threatened avian functional guild in the world (Buechley & Şekercioğlu, 2016). The main causes of this are illegal hunting, habitat destruction, and poisoning (Buechley & Şekercioğlu, 2016). To reverse the current conservation status of the Andean condor, several Andean countries (*e.g.*, Colombia, Ecuador, Peru, Bolivia and Argentina) are preparing national conservation plans and selecting priority areas for conservation (*e.g.*, Rodríguez, Barrera & Ciri, 2005; SERFOR, 2015; Ministerio del Ambiente & The Peregrine Fund., 2018; Ministerio de Agua y Ambiente, 2020). The first step for these national conservation plans of the Andean condors includes extensive censuses at well-known and potential communal roosts. Thus, optimizing Andean condor censuses is timely to overcome financial, staff, and logistical limitations.

A standardized census protocol is an essential element for fostering robust and comparable estimates of population sizes. National Andean condor censuses have been performed, particularly in Chile and Argentina (Escobar, 2014; Vargas et al., 2018). These censuses, mainly performed at communal roosts, providing a low-cost and non-invasive method that provides efficient information for science-based conservation plans (Bibby, 2000). However, there are no specific protocols (Miguel et al., 2019; Wallace, Reinaga & Piland, 2022). Non-standardized censuses could lead to erroneous conclusions about which communal roosts should be prioritized for conservation (Wallace et al., 2020). For example, it is important for bird censuses to know the weather and timing conditions to estimate desirable numbers in the studies (e.g., Hoodless, Inglis & Baines, 2006; Ellis & Taylor, 2017; Oliveira et al., 2018).

The Andean condor is a gliding bird, so the use of thermals to keep and save energy in the different behavior activities is paramount. External factors, such as environmental variables, play an important role for this bird (García-Jiménez, Pérez-García & Margalida, 2018). Some studies have shown that scavenger competition and aggregation have a higher incidence in colder season (in subtropical areas) and feeding areas (Selva & Fortuna, 2007; Sebastián-González et al., 2016). Other studies pointed out that temperature is related to the time spent foraging (Shepard et al., 2011) and flying (Perrig et al., 2020). Several studies in temperate regions have reported some seasonal differences in the use of communal roosts (Sarno, Franklin & Prexl, 2000; Kusch, 2004; Lambertucci, Jácome & Trejo, 2008; Lambertucci, 2010; Pavez, 2020). Thus, variables are expected to affect the Andean condor census but there is no information assessing this so far. Moreover, there is a scarcity of this kind of study in the tropical Andes. Thus, the conservation importance of communal roosts is likely to be underestimated if censuses are conducted under unfavorable climatic conditions (see Villén-Pérez, Carrascal & Soane, 2013; Wood et al., 2017) ; or in less desirable seasons of the year (Rogers et al., 2006).

Financial sources, logistic requirements, and trained staff limit long-term censuses (Ellis & Taylor, 2017; Vieira, 2020). Thus, censuses frequently are carried out in a short and defined period of time (Santos et al., 2009; Ellis & Taylor, 2017). Consequently, it is necessary to identify suitable censusing windows that require some knowledge about the effects of climatic conditions that affect the species (*e.g.*, Santos et al., 2009; Ellis & Taylor, 2017). The objective of this research was to correlate these climatic variables with the use of a communal roost in the tropical Andes of Peru. We are particularly interested in assessing the effect of temperature and pluviosity on the census of Andean condors, and we hope to describe better climatic conditions for censusing. We expect that this information will allow us to determine the most appropriate stations and variables for carrying out census campaigns that make it possible to obtain accurate results for effective management of this species.

## Materials & Methods

Andean Condor population data were made available through the monthly monitoring plan of the Andean condor in the Pampa Galeras-Bárbara D'Achille National Reserve – SERNANP Ayacucho. The survey was carried out in a communal roost (74W 20' 09", 14S 38' 27"), located in the buffer zone of the Pampa Galeras-Bárbara D’Achille National Reserve (RNPG-BA), in the province of Lucanas, Ayacucho, Peru. It is located in a high Andean plain of the central Andes of Peru at 4100 m. elevation (Figure 1). This area has hills from 50 to 150 m and slopes from 40% to 65%. The climate is cold-dry with minimum temperatures of -8 °C and a maximum of 16 °C; and annual rainfall is 450 mm, while the winds can reach speeds between 2 km/h - 40 km/h. (SERNANP, 2015).

Between November 2015 and March 2016, one of us (*i.e.*, SM), visited the communal roost three times a week to perform three censuses per day (06:00 a.m., 12:00 p.m., and 06:00 p.m.) (Modified from Lambertucci, 2008). Observations in the roost were made for 10 minutes with 10 x 50 mm binoculars. Perched individuals were counted (Modified from Gargiulo, 2012) differentiating adults from immatures (juveniles and subadults; Gargiulo, 2012). Distinguishing between males and females was difficult under certain distances as well as during the sunset. Thus, we decided not to distinguish males and females in this study. Censuses were used to estimate:

- The minimum population size using the communal roost, calculated as the maximum number of adults plus maximum number of immatures recorded during the censuses;
- Immature and adult ratio, calculated as immature/adult.

Parallel to the censuses, temperature and pluviosity were recorded from the *Servicio Nacional de Meteorologia e Hidrologia* (SENAMHI) weather station. The weather station is located in the facilities of the RNPG-BA checkpoint, 7 km to the southwest from the communal roost and provides climatic information at 7:00 am, 1:00 pm and 7:00 pm that was used for our statistical analyses.

<u>Statistical analyses</u>

We used a two-way ANOVA to compare the Andean condors censused among the surveys and seasons. We tested the contribution of temperature, total precipitation (hereafter pluviosity), and seasonality to determine the number of condors recorded in the communal roosts. Competing autoregressive generalized linear models (Autoregressive GLMs thereafter) representing all possible combinations were performed and compared using AICc (small sample correction Akaike information criteria). We assumed models were significatively different when $\Delta$AICc > 2 between models. We classified the census date for dry and wet seasons. The GLM models and the seasonality categorization is better explained below.

To assess the role played by environmental variables to condor censuses we fitted an autoregressive GLM with a negative binomial distribution using the *tscount* package version 1.4.3 (Liboschik, Fokianos & Fried, 2017). As the condor census resulted in a timeseries, an autoregressive GLM was necessary. An autoregressive GLM accounts for the temporal autocorrelation among observations. It means, that the number of individuals censused in an observation *y*, in time *t* ($y_t$), is related to the number of individuals observed in previous ($y_{t-1}$), where *i* is the number of previous observations. In other words, if two observations are performed, the number of individuals recorded in the second observation is related to the number of individuals recorded in the first observation. To model an autoregressive GLM, the number of previous observations assumed to affect the observation (*i.e.,* partial autocorrelation - PACF) should be informed prior to the GLM model. Therefore, we assessed the partial autocorrelation using the *forecast* package (Hyndman & Khandakar, 2008 ; Hyndman et al.,2022), that suggests that observation $y_{t-1}$ is strongly related to one or two observations back in time *i, i* = 1 or 2.

Dry and wet seasons were classified statistically and provided support for the visual inspection of the environmental conditions. Visual inspection in the number of censused condors unveils a gradual decrease over the year from about October, coinciding with an increase in the frequency and pluviosity. The temperature over October no longer achieves negative values. Thus, to settle up a breakpoint between the dry and wet seasons, we have used *cpt.meanvar* at default from the *changepoint* package (Killick & Eckley 2014). The *cpt.meanvar* detects changes between the mean and the variance in the time series and was used to detect a change point in the timeseries of the number of condors, temperature, and pluviosity. This approach allows us to establish an arbitrary breakpoint between the dry and wet season with statistical support. The breakpoints detected by the changepoint package were respectively 22-October for censused condors, 27-August for temperature, and 29-August for pluviosity. We have decided to use the mean value among these three values that is represented by mid-September (15-September) as the breakpoint between dry and wet seasons. Then, the dry season in our study ranged from July to mid-September and mid-September to March for the wet season. The limits settled were similar to other studies in the tropical Andes (*e.g.,* wet season: Oct-Mar. [Jomelli et al., 2012]; and Sep-Apr, [Silva, Takahashi & Chávez, 2008]).

## Results

Censusing at 6 AM (7.13 ± 7.49; mean and standard deviation) and 6 PM (7.59 ± 7.59) significatively recorded higher numbers of condors compared to censuses performed at 12 AM (2.12 ± 4.34) (Figure 2). The slight difference between total censused condors at 6AM and 6PM did not differ significatively (Supplementary material S1, Figure S1.1). Despite the differences among censuses performed during the daytime, we did not detect significant differences in the proportion of adults among them (ANOVA, $F_{Season} = 2.51$, df=2, p=0.08). Therefore, we performed our analyses using the censused condors at 6 AM but comparative results are provided for 6 AM and 6 PM in the supplementary materials S1.

The minimum population size using the communal roost was estimated at 38 individuals (10 adults and 28 immatures recorded) in the dry season and 35 (8 adults and 27 immatures recorded) in the wet season. The minimum population using the communal roost estimate suggested an adult: immature ratio of 1:2.28 in the dry season and 1:3.2 in the dry season (Table

1). Despite a similar minimum population size estimate between dry and wet seasons, the average number of individuals recorded in the censuses was three times higher in the dry season 14.00 ± 6.69 the wet season 4.01 ± 5.52 (ANOVA, $F_{Season} = 168.00$, df=1, $p < 0.01$). The proportion of adults censused in the dry season was 0.174 ± 0.11 and more than double of 0.31 ± 0.27 in the wet season (ANOVA, $F_{Season} = 9.92$, df=1, $p < 0.01$). Regardless of the fluctuation during the year, the results suggest a clear bias of immatures over adults.

The best autoregressive GLM model supports that temperature and pluviosity play an important role for the total censused condors in the study site (see Table 2). The best autoregressive GLM supports a marginal negative contribution of temperature to censused condors (effect size, $\beta_{Temperature} = -0.04 \pm 0.025$, t= 3.96, p-value = 0.10; calculated by normal approximation as suggested by Altman and Bland (2011), as well as a strong negative effect of pluviosity ($\beta_{Pluviosity} = -0.5313 \pm 0.1548$, t=3.432, p<0.01). We did not find significant differences among the models when considering only temperature and pluviosity but only for seasonality, including the three variables together (ΔAIC < 2, table 2). Yet, all these aforementioned models adjusted better than the null model, supporting the importance of these variables to Andean condor censusing (Figure 3).

## Discussion

We found a negative relationship between the number of Andean condors in the communal roost and climatic variables such as temperature and pluviosity. In addition to that, there is a strong tendency for the use of the communal roost in the dry season rather than the wet season. Our results are similar in some other open-habitat birds or for other raptors (*e.g.,* Figueira et al., 2006; Hoodless, Inglis & Baines, 2006; Calladine & Richard, 2012). Yet, our results provide important pieces and guidance for designing better surveys and protected areas for Andean condor conservation (Wallace et al., 2022). Below we outline the contribution of our results for the biology of the Andean condor with a special focus on tropical Andes, followed by more general guidelines for improving the efficiency of national surveys to select priority areas for conservation.

*Updates about the biology of the Andean condor*

Communal roosts are assumed to be located where they can provide shelter from adverse climatic conditions and refuge from potential predators. Lambertucci and Ruggiero (2013) provide important information about the effects of climatic variables on the selection of communal roosts at regional scales. In fact, some authors also have reported seasonal variation without a pattern of regional use, roost use, and home range with some kind of variations (e.g. Sarno, Franklin & Prexl, 2000; Kusch, 2004; Lambertucci, 2010; De Martino et al., 2011; Pavez, 2020). However, the previously cited research was carried out in subtropical ecosystems and without a study correlating the census effect on roosts with temperature and rain variables. In Peru there are few studies that have evaluated the behavior of the Andean condor in communal roosts. In this regard, we only have the work of (Vásquez, 2015) in which he reports on the arid coast, a continuous use throughout the year with maximum peaks corresponding to the wet and dry seasons. So, our result might suggest that this species could be making a differential use of the habitat depending on the ecosystem in which it lives, or a possibility of altitudinal migration (see Barcante, Vale & Alves, 2017). Another possibility is that during the wet season there may be more dispersal. This could be due to the fact that the bird spends more time returning to the communal roost due to a lower probability of foraging and flying in higher temperatures (Perrig et al., 2020).

The adult: immature ratio found at our study site is also remarkable and sheds light on important insights about the biology and conservation of the Andean condor. The minimum population size estimated suggests an adult: immature ratio of 1:3.2, that is highly disparate compared to previous studies that have reported a ratio close to 1:1 [range, 1:046-1:1.5] (*i.e.*, Sarno, Franklin & Prexl, 2000; Ríos-Uzeda & Wallace, 2007; Lambertucci, 2010; Escobar et al., 2015; Pavez, 2020). For long-lived and slow-reproductive species, the adult: immature ratio usually tends to be biased towards adults, which have small annual clutch sizes ( e.g Saether & Bakke, 2013; Tella et al., 2013; Margalida et al., 2020). We identified two potential non-competing processes behind this adult/immature bias with different implications for conservation. First, biases towards a high number of immatures may suggest good recruitment in recent years. If this is the case, our results might suggest that the population of Andean condors in Pampa Galeras is increasing. Alternatively, the social hierarchy might also be a potential explanation. It is well-known that adults higher in the social hierarchy have access to the best resources leaving, lower quality resources for the lowest individuals in the social hierarchy, usually the youngest individuals (Kirk & Houston, 1995; Donazar et al., 1999). Thus, if the social hierarchy is that important for the adult/immature ratio, the communal roost conservation priority must consider a population spatially segregated with different communal roosts providing shelter mainly for specific stages of the Andean condor life cycle.

*Guidance for conservation*

Our results support the necessity for multiple potential communal roosts censused concomitantly during each season (*e.g.*, Vásquez, 2015). These censuses should be particularly carried out early in the morning or late in the evening to avoid underestimation. Daily climatic conditions also play an important role for avoiding underestimates (Lambertucci & Ruggiero, 2013; Perrig et al., 2020). Particularly for the study site, but potentially for other sites in the tropical Andes, surveys on colder and dryer days are more prone to capture the full potential of the communal roosts for the Andean condors. Finally, as expected, given the great capacity of soaring to great distances of the Andean condors (see Piana, 2014; Perrig et al., 2020), protected areas should not be expected to work alone in the conservation of Andean condors (Wallace et al.,2020). Instead, a network of protected areas including communal roosts with different characteristics is important to provide effective protection for Andean condors (Wallace et al., 2020). Further research should focus on unveiling the genetic differences for the use of communal roosts by individuals of Andean condors as well as to synthetize in a national guideline the best practices for surveying Andean condors, considering different climatic conditions and seasonality throughout the tropical and subtropical Andes.

## Conclusions

We first studied the effect of environmental conditions and seasonality in the Andean condor in a communal roost in the tropical Andes. We found that temperature, pluviosity and seasonality exert great importance and might undermine the importance of the communal roosts if not taken into account during the censuses. The highly disparate proportion of juveniles compared to adults, and the dramatic reduction of the total condors censused during the wet season, support that this population must be using different communal roosts during the year. The effect of environmental conditions, seasonality, and potential spatial segregation, represents important characteristics to define efficient conservation areas and census protocol. These important pieces might potentially differ along the latitudinal gradient in the Andes, suggesting a careful extrapolation from results for conservation purposes.

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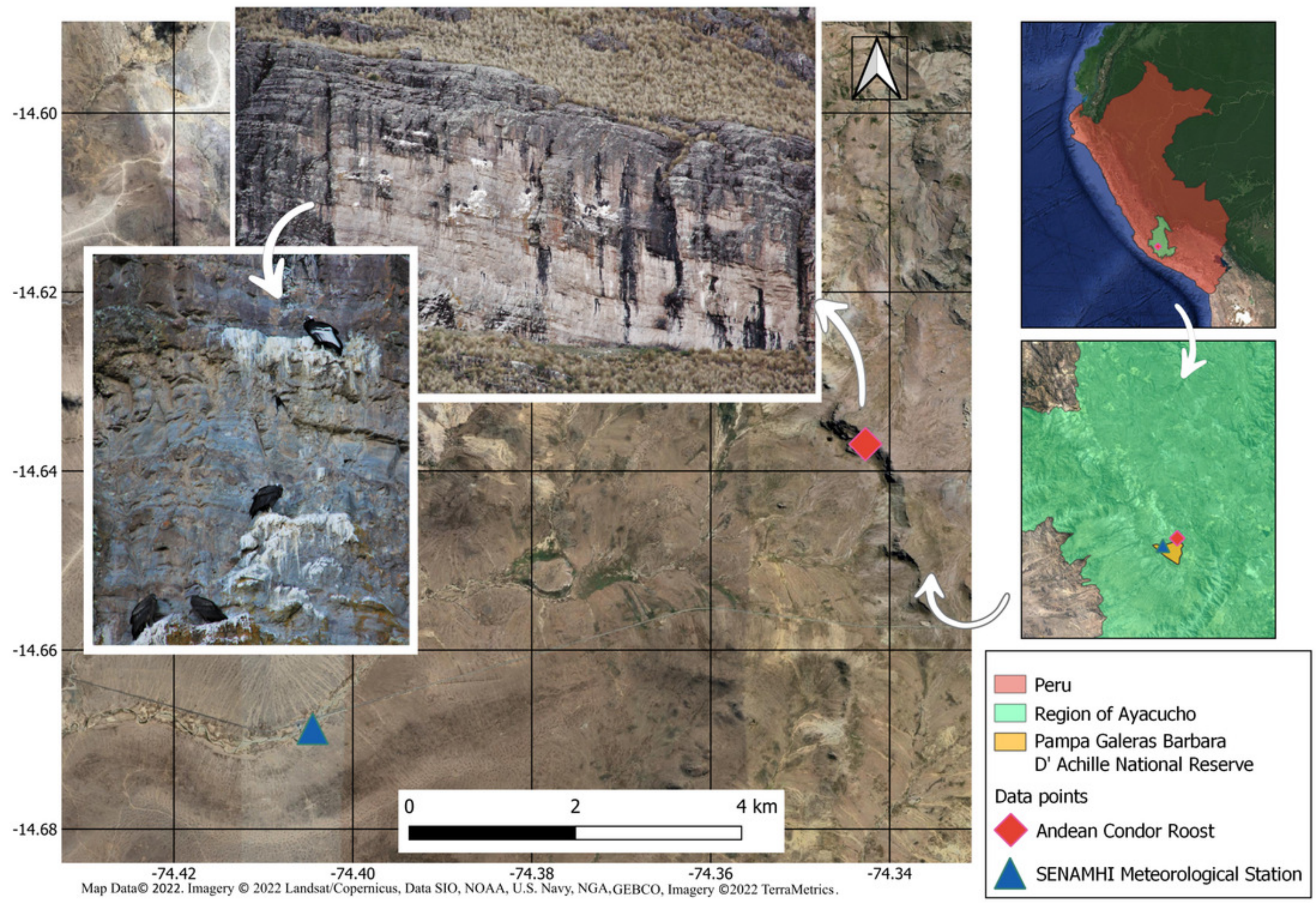
# Figure 1

Study area

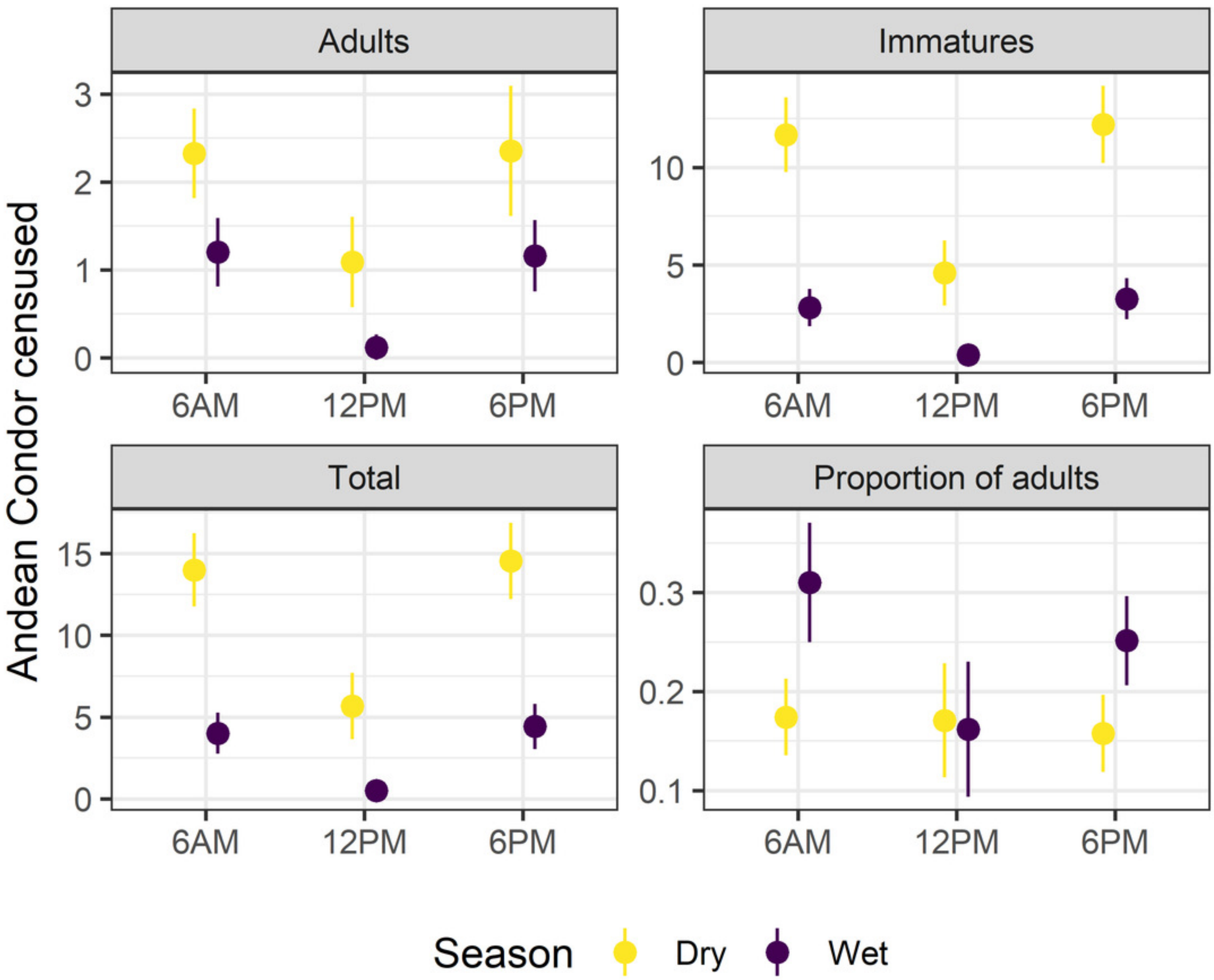
The Andean Condor roost survey and SENAMHI Meteorological Station. Pampa Galeras Barbara D'Achille National Reserve - SERNANP, Lucanas, Ayacucho, Peru. The image shows different Andean Condor individuals roosting early in the morning.



# Figure 2

Survey time and season affects the Andean Condor Census.

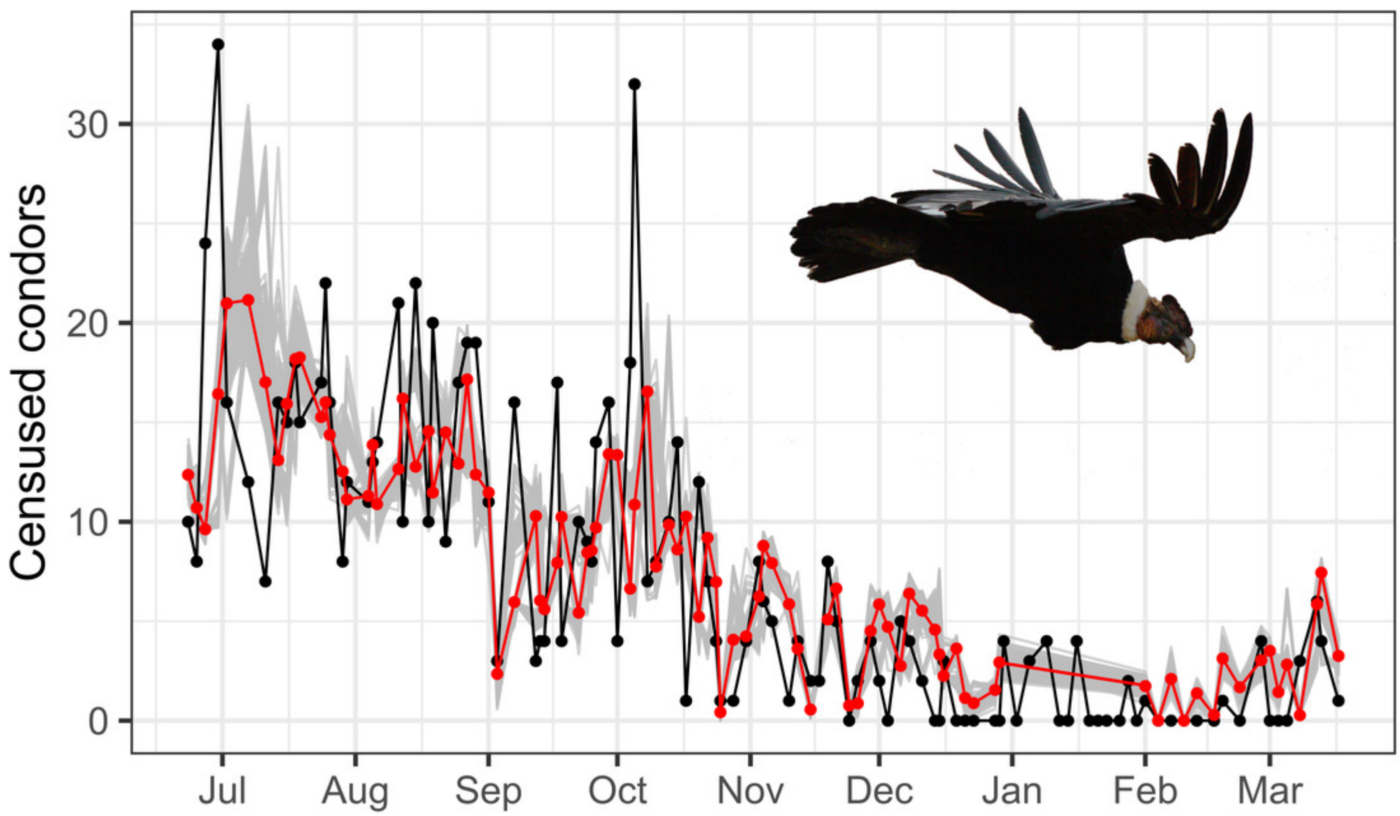
The figure shows the mean and confidence interval 95% of censused condors during dry and wet seasons. Detailed statistical analyses are presented in the supplementary material S1 (Figure S1.1)



# Figure 3

Time serie plot of censused and estimated condor

Total Andean condors censused (in black) are displayed against the best autoregressive GLM fitted (in red). A bootstrap with 1000 randomizations is presented in gray.



## Table 1 (on next page)

Minimum population estimated profile.

Total maximun number, maximun number of adults, maximun number of , percentage of adults inmatures, percentage of inmatures, and A:inm proportion of Andean condors obtained during dry and wet season.

| | Dry | Wet |
|---|---|---|
| Total maximum number | 38 | 35 |
| Maximum number of adults | 10 | 8 |
| Maximum number of immatures | 28 | 27 |
| Percentage of adults | 26.3 | 23.8 |
| Percentage of immatures | 73.7 | 76.2 |
| Adult: immature | 1:2.28 | 1:3.2 |

## Table 2 (on next page)

Competing autoregressive Generalized Linear Models Poisson distributed ranked by level of support (AICc).

Two of three models find that the best models are three variables (Temperature, Pluviosity and Seasonality). There is not significant difference (AICc > 2) between the three best models.

| MODEL | K | AICc | AICc | Weights | cum.Weights | Log-Like |
|---|---|---|---|---|---|---|
| Temperature + Pluviosity | 4 | 532.08 | 0.000 | 0.5161 | 0.5161 | -260.70 |
| Seasonality | 4 | 533.92 | 1.84 | 0.2059 | 0.7220 | -261.62 |
| Temperature + Pluviosity + Seasonality | 5 | 534.08 | 2.01 | 0.1892 | 0.9113 | -260.57 |
| Temperature | 3 | 535.64 | 3.56 | 0.0868 | 0.9981 | -263.6 |
| Temperature + Seasonality | 3 | 544.86 | 12.78 | 0.0008 | 0.9990 | -268.21 |
| Pluviosity | 4 | 546.36 | 14.28 | 0.0004 | 0.9994 | -267.84 |
| Pluviosity + Seasonality | 3 | 546.41 | 14.33 | 0.0003 | 0.999 | -268.98 |
| NULL | 2 | 548.10 | 16.02 | 0.0001 | 1 | -270.92 |