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# Estimating the Abundance of Andean Ibis (*Theristicus branickii*) in the High Andes of Northern Ecuador

**Adrián Naveda-Rodríguez[1], Tatiana Santander[2], Víctor Utreras B.[3], and Galo Zapata-Ríos[1]**

**Abstract**

The Andean Ibis (*Theristicus branickii*) is discontinuously distributed in western South America from Ecuador to northern Chile. In Ecuador, it inhabits high elevations (>3,700 m) where it is classified as critically endangered because of its low population number caused by hunting and habitat loss. However, the population size of Andean Ibis in Ecuador is unknown, hindering the implementation of conservation actions. We performed a survey to estimate the abundance of Andean Ibis in the Ecuadorian Andes. In February 2016, and January 2017 and 2018, we conducted 11 point counts. Point counts were located in two provinces, each point count had nine 30-min visits. We recorded Andean Ibis in eight point counts, all in the Province of Napo. Detectability was explained by the amount of nontree vegetation cover and terrain slope, whereas abundance corresponded to gross primary productivity, annual mean temperature, and annual precipitation. We estimated there were 85 (95% credible interval [CI]: 63–117), 94 (95% CI: 32–125), and 134 (95% CI = 77–210) individuals of Andean Ibis in 2016, 2017, and 2018, respectively. The fact that abundance increased in the past 3 years could be explained by an increase in gross primary productivity. We suggest continuing population monitoring and adopting the sampling protocol and data analysis methods presented here as a baseline to better understand the spatiotemporal variation in abundance.

**Keywords**

gross primary productivity, N-mixture model, Northern Andes, population size, Threskiornithidae

## Introduction

The Andean Ibis (*Theristicus branickii*) inhabits open areas such as natural grasslands and wetlands shores over 3,700 m above sea level in páramos and puna ecosystems (BirdLife International, 2014; del Hoyo, Collar, & Garcia, 2016). It is discontinuously distributed in western South America from Ecuador to north Chile (del Hoyo et al., 2016; eBird, 2012), with isolated populations in the Ecuadorian Andes, the Andean region of Peru and Bolivia (BirdLife International, 2014; Collar & Bird, 2011; eBird, 2012; Ridgely & Greenfield, 2006; Schulenberg, Stotz, Lane, O'Neill, & Parker, 2007). Andean Ibis ecology is poorly known; basic aspects such as geographic distribution and population size have not been studied in depth. Knowledge of these parameters is critical to better understand the current conservation status of the species and for the design and implementation of management actions for its habitats.

This species is catalogued as a near-threatened species in its distribution area (BirdLife International, 2014). However, in Ecuador, it is considered a critically endangered species because of its low population numbers caused by hunting and habitat loss (Granizo et al., 2002). Previous estimations using different

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methodological approaches suggested an area of occupancy of less than 100 $km^2$ to the west of Antisana Volcano and an abundance of less than 60 individuals (Olmedo-Gordón, 2001; West, 2014); nonetheless, these estimations lack of standardized survey design and did not account for imperfect detection and for environmental variables that could affect Andean Ibis abundance, such as food availability (Gantz, Sade, Yañez, & Rau, 2015).

In this work, we used a standardized protocol designed to monitor the abundance of this species in the high Andes of Northern Ecuador using field surveys conducted during February 2016, and January 2017 and 2018. Specific objectives were to test the effects of topography and vegetation cover on detection probabilities and to test the hypothesis that Andean Ibis abundance is correlated with food availability (Gantz et al., 2015) as suggested for other waterbird species (Crick, 2004; Velasquez et al., 1991)

## Methods

We designed a standardized monitoring protocol to collect data in a consistent manner to survey Andean Ibis. We sampled 7 to 9 point counts simultaneously in the provinces of Napo and Pichincha (Figure 1); we conducted the survey of Andean Ibis, during 15–17 February 2016, 25–27 January 2017, and 12–14 January 2018, in the Northern Andes of Ecuador (0°31'S, –78°12'W, WGS84). Point counts were systematically located within the same areas previously surveyed by Olmedo-Gordón (2001) and West (2014) or where the species was previously detected by park rangers in Antisana Ecological Reserve, Antisanilla Reserve, and Cotopaxi National Park; furthermore, point counts were separated at least 1 km from each other between 3,380 and 4,420 m above sea level. Ecosystems in point counts corresponded to *páramo* grasslands and subnival wet *páramo* grasslands (Ministerio del Ambiente del Ecuador, 2013a). Annual mean temperature and annual precipitation across point counts were $5.0 \pm 1.7$ °C and $1379 \pm 115$ mm, respectively (Ministerio del Ambiente del Ecuador, 2013b).

Point counts consisted in a circle of 300 m of radius that was subdivided into three 100-m detection strips (100-m radius); detection strips were field marked using colored stakes. We conducted simultaneous surveys in each point count between 08:30 and 11:30

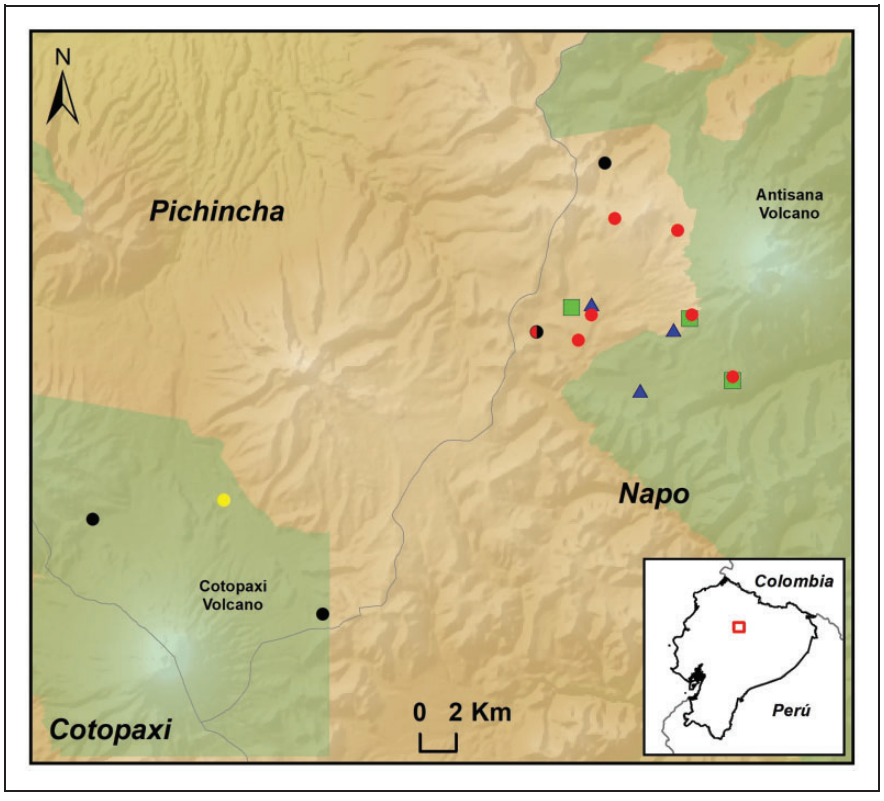



**Figure 1.** Point counts surveyed during 15–17 February, 2016, 25–27 January, 2017, and 12–14 January 2018. Red dots = point counts surveyed in 2016–2018. Black dots = point counts surveyed in 2016. Yellow dot = point count surveyed in 2017. Bicolor dot = point count surveyed 2017–2018. Blue triangle = point surveyed by Olmedo-Gordón (2001). Green square = point surveyed by West (2014). Green areas represent the National System of Protected Areas of Ecuador.

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during 3 consecutive days to meet the assumption of closed population (no births, deaths, immigration, or emigration). Two observers in each point count performed field observations using 10× binoculars and 20–60× spotting scopes. We divided these 9 total hours in eighteen 30-min time slots in each point, and for the analysis, we used detections (number of individuals observed) from three time periods each day (08:30–09:00, 09:30–10:00, and 10:30–11:00). We decided to conduct observations 3 h in a row per day based on the fact that Andean Ibis spends up to 80% of daylight in foraging activities, and 80% of such activities occur between 08:00 and 10:00 (Olmedo-Gordón, 2001). Foraging behavior of Andean Ibis (birds walk slowly one after the other in straight, separated by ∼1 to 2 m) allows for easy detection and avoid double counting of individuals. In each detection event, observers recorded time; age-class (adult: head, neck, and breast pale buff; juvenile: faint dusky streaks on neck); and the initial detection distance using the detection strips. Because Andean Ibises are sexually monomorphic, it was not possible to distinguish males and females.

We carried out a hierarchical N-mixture model (Royle, 2004) to estimate population size of Andean Ibis. N-mixture model uses data from repeated counts of unmarked individuals in multiple sites to estimate detection probability and abundance of animal populations in each site. N-mixture model is appropriate when individual identification is not possible or when animal detection is not perfect, such as the case of the Andean Ibis in our study area. We used the pcount function in the R package unmarked (Fiske & Chandler, 2011) to estimate Andean Ibis probability of detection and abundance in each point count and year surveyed; total abundance estimates correspond to the sum of estimated abundance in each point count. Based on our expert knowledge, we identify environmental variables that we think are related to the detectability and abundance of Andean Ibis, and we measured these variables from freely available remote sensed data. We used the percentage of nontree vegetation cover (woody vegetation <5 m height and grass, derived from MODIS MOD44B, DiMiceli et al., 2015), elevation, and terrain slope derived from a 250-m digital elevation model (Jarvis, Reuter, Nelson, & Guevara, 2008) as detection covariates. Gross primary productivity (derived from MODIS MOD17A2, Running, Mu, & Zhao, 2015) as a proxy of food availability, annual precipitation (derived from CHIRPS, Funk et al., 2015), and mean annual temperature (derived from MODIS MOD11A1, Wan, Hook, & Hulley, 2015) were included as abundance covariate; precipitation and abundance were considered to affect demography and population trends (Crick, 2004). To reduce collinearity, we performed a Pearson's pairwise correlation test; variables highly correlated ($r > .75$) were removed from the analysis. All variables were standardized to facilitate model convergence; no explanatory variables used exhibited high correlation (max $r = -.53$, elevation and mean annual temperature).

For each year, we fitted a null model (intercept only) and all possible combinations of detection and abundance covariates; the best detection model was used in abundance models. We did not test for differences among point counts or years. We ranked the models using second-order Akaike's information criterion (AICc) and AICc weights using the aictab function in the R package AICcmodavg (Mazerolle, 2016). The model with ΔAICc <2 and AICc weight >0.75 was selected as best model; otherwise, we averaged competing models (ΔAICc <2 and AICc weight <0.75). We tested for model overdispersion using Pearson residuals using the function chat in the R package nmixgof (Knape et al., 2018).

## Results

We performed a sampling effort of 216 observation hours and recorded 426 Andean Ibis detections (2016: nine point counts, 81 h and 123 detections, 2017: eight point counts, 72 h and 143 detections, 2018: seven point counts, 63 h and 160 detections). Andean Ibis detections occurred in eight of the 11 point counts, all in the Province of Napo.

We fitted 16 detection and abundance models (Table 1); probability of detection decreased from 0.11 (95% Bayesian credibility interval [BCI]: 0–0.21) in 2016 to 0.09 (95% BCI: 0–0.14) in 2017, and 0.07 (95% BCI: 0–0.11) in 2018 (Figure 2(a)); the percent of nontree vegetation cover and terrain slope showed a positive and negative relationship, respectively, with probability of detection in 2016 (Figure 2(c) and (d)); nonetheless, null detection models were top-ranked in 2017 and 2018 (Table 1). Abundance estimates varied from 85 individuals (95% BCI: 63–117) in 2016, 94 individuals (95% CI: 32–125) in 2017 to 134 individuals (95% BCI: 77–210) in 2018 (Figure 2(b)); abundance was explained by gross primary productivity in 2016 (Figure 2(e)), and temperature and precipitation in 2017 (Figure 2(f) and (g)), whereas none of the covariates used could explain abundance in 2018 (Table 1).

## Discussion

This is not the first effort to estimate the population size of Andean Ibis in Northern Ecuador. Previous efforts, in the buffer area of Antisana Ecological Reserve, estimated between 33 and 52 individuals (Olmedo-Gordón, 2001; West, 2014). The first study (Olmedo-Gordón, 2001) performed a sampling effort of 524 h of observation distributed in 12 months, while the second one

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**Table 1.** Probability of Detection (p) and Abundance ($\lambda$) Models Candidate Sets for the Andean Ibis (*Theristicus branickii*) in Ecuador.

| Year | Model | K | AICc | ΔAICc | AICc weight |
|---|---|---|---|---|---|
| 2016 | p(Nontree+Slope) $\lambda$(.) | 4 | 309.6 | 0.0 | 0.9 |
| | p(Elevation+Nontree+Slope) $\lambda$(.) | 5 | 315.7 | 6.1 | 0.0 |
| | p(Nontree) $\lambda$(.) | 3 | 316.3 | 6.7 | 0.0 |
| | p(Slope) $\lambda$(.) | 3 | 318.2 | 8.6 | 0.0 |
| | p(.) $\lambda$(.) | 2 | 319.9 | 10.3 | 0.0 |
| | p(Elevation) $\lambda$(.) | 3 | 323.5 | 13.9 | 0.0 |
| | p(Elevation+Slope) $\lambda$(.) | 4 | 325.3 | 15.6 | 0.0 |
| | p(Elveation+Nontree) $\lambda$(.) | 4 | 332.8 | 23.2 | 0.0 |
| | p(Nontree+Slope) $\lambda$(.) | 4 | 309.6 | 0.0 | 0.6 |
| | p(Nontree+Slope) $\lambda$(GPP) | 5 | 310.2 | 0.5 | 0.4 |
| | p(Nontree+Slope) $\lambda$(Precipitation) | 5 | 316.1 | 6.5 | 0.0 |
| | p(Nontree+Slope) $\lambda$(Temperature) | 5 | 319.4 | 9.8 | 0.0 |
| | p(Nontree+Slope) $\lambda$(GPP+Precipitation) | 6 | 328.1 | 18.5 | 0.0 |
| | p(Nontree+Slope) $\lambda$(GPP+Temperature) | 6 | 334.0 | 24.4 | 0.0 |
| | p(Nontree+Slope) $\lambda$(Temperature+Precipitation) | 6 | 339.6 | 30.0 | 0.0 |
| | p(Nontree+Slope) $\lambda$(GPP+Temperature+Precipitation) | 7 | 398.6 | 89.0 | 0.0 |
| 2017 | p(.) $\lambda$(.) | 2 | 267.3 | 0.0 | 0.7 |
| | p(Nontree) $\lambda$(.) | 3 | 269.8 | 2.5 | 0.2 |
| | p(Slope) $\lambda$(.) | 3 | 271.3 | 4.1 | 0.1 |
| | p(Elevation) $\lambda$(.) | 3 | 272.0 | 4.7 | 0.1 |
| | p(Nontree+Slope) $\lambda$(.) | 4 | 278.8 | 11.5 | 0.0 |
| | p(Elevation+Nontree) $\lambda$(.) | 4 | 278.8 | 11.5 | 0.0 |
| | p(Elevation+Slope) $\lambda$(.) | 4 | 279.1 | 11.8 | 0.0 |
| | p(Elevation+Nontree+Slope) $\lambda$(.) | 5 | 296.9 | 29.6 | 0.0 |
| | p(.) $\lambda$(Temperature) | 3 | 264.6 | 0.0 | 0.4 |
| | p(.) $\lambda$(Temperature+Precipitation) | 4 | 265.3 | 0.7 | 0.3 |
| | p(.) $\lambda$(GPP) | 3 | 266.8 | 2.2 | 0.1 |
| | p(.) $\lambda$(.) | 2 | 267.3 | 2.6 | 0.1 |
| | p(.) $\lambda$(GPP+Temperature) | 4 | 270.4 | 5.8 | 0.0 |
| | p(.) $\lambda$(Precipitation) | 3 | 272.1 | 7.4 | 0.0 |
| | p(.) $\lambda$(GPP+Precipitation) | 4 | 276.1 | 11.5 | 0.0 |
| | p(.) $\lambda$(GPP+Temperature+Precipitation) | 5 | 284.0 | 19.3 | 0.0 |
| 2018 | p(.) $\lambda$(.) | 2 | 235.8 | 0.0 | 0.8 |
| | p(Elevation) $\lambda$(.) | 3 | 239.6 | 3.9 | 0.1 |
| | p(Nontree) $\lambda$(.) | 3 | 242.1 | 6.3 | 0.0 |
| | p(Slope) $\lambda$(.) | 3 | 242.1 | 6.4 | 0.0 |
| | p(Elevation+Slope) $\lambda$(.) | 4 | 252.2 | 16.5 | 0.0 |
| | p(Elevation+Nontree) $\lambda$(.) | 4 | 253.5 | 17.8 | 0.0 |
| | p(Nontree+Slope) $\lambda$(.) | 4 | 255.7 | 20.0 | 0.0 |
| | p(Elevation+Nontree+Slope) $\lambda$(.) | 5 | 294.2 | 58.5 | 0.0 |
| | p(.) $\lambda$(.) | 2 | 235.8 | 0.0 | 0.8 |
| | p(.) $\lambda$(Temperature) | 3 | 238.6 | 2.8 | 0.2 |
| | p(.) $\lambda$(Precipitation) | 3 | 242.2 | 6.5 | 0.0 |
| | p(.) $\lambda$(GPP) | 3 | 242.7 | 7.0 | 0.0 |
| | p(.) $\lambda$(Temperature+Precipitation) | 4 | 251.9 | 16.1 | 0.0 |
| | p(.) $\lambda$(GPP+Temperature) | 4 | 252.3 | 16.5 | 0.0 |
| | p(.) $\lambda$(GPP+Precipitation) | 4 | 256.1 | 20.3 | 0.0 |
| | p(.) $\lambda$(GPP+Temperature+Precipitation) | 5 | 293.7 | 58.0 | 0.0 |

*Note*. AICc = second-order Akaike's information criterion; Nontree = percentage of nontree vegetation cover (%); Slope = percentage of terrain slope (%); Elevation = meters above sea level (m); GPP = gross primary productivity (kg C $km^2$); Precipitation = annual precipitation (mm); Temperature = mean annual temperature (°C).

(West, 2014) completed 59 h of observation in November 2014. Both studies did not conduct their surveys in their point counts at the same date and time, did not account for imperfect detection, and were limited to three localities without detailing the total point counts used in each one. These limitations certainly introduce bias to the results by excluding other areas where the species might be present and increase the possibility of double

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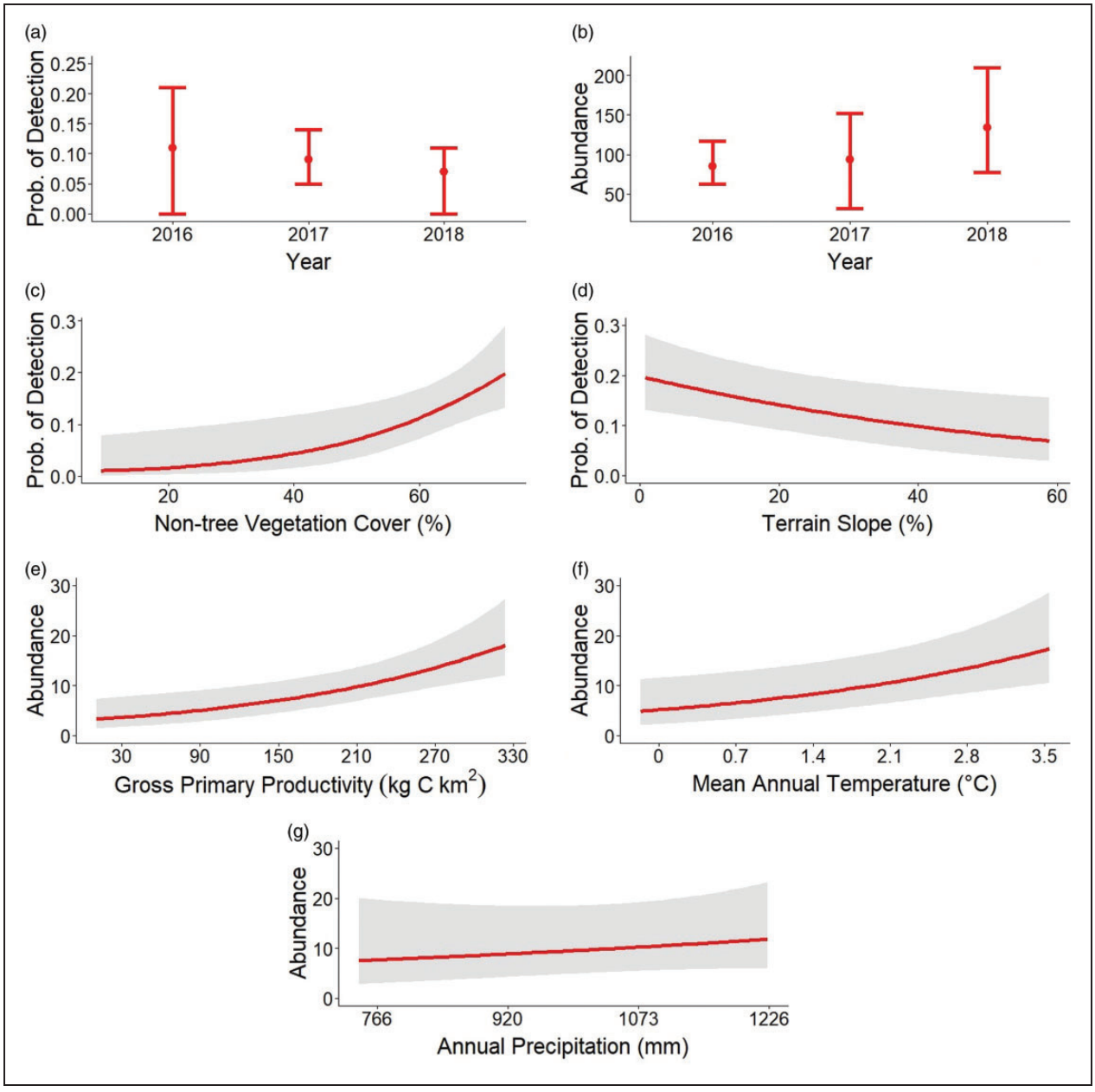



**Figure 2.** Estimated relationship between probability of detection and abundance of Andean Ibis (*Theristicus branickii*) in Ecuador. Plots (a) and (b): red dots and bars correspond to mean and 95% confidence intervals, respectively. Plots (c) to (g): red lines and gray shading correspond to mean response and 95% confidence interval, respectively. Plot (c) and (d): probability of detection in 2016. Plot (e): abundance in 2016. Plot (f) and (g): abundance in 2017.

counting individuals. The discrepancy in the estimations reported in each study might be due to differences in sampling season, sampling effort, and sampling protocol used in each case and should not be associated to biological factors (e.g., recruitment/mortality) or anthropic pressures (e.g., hunting), as these aspects were not evaluated in these studies.

Andean Ibises were not detected in all point counts within the study area, and all the detections were done in the west of Antisana Volcano in Napo Province. Our results could not explain these nondetections; however, based in previous records and the testimony of park rangers, we speculate this could be associated to undescribed local seasonal movements or habitat suitability. Andean Ibis populations in Ecuador, Peru, and Bolivia are considered sedentary with possible altitudinal migration (del Hoyo et al., 2016; Elphick, 2007).

The probability of detecting an Andean Ibis is maximized in flat terrain; steep slopes can reduce ground visibility by interrupting the line-of-sight of a given point

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(Güthlin et al., 2014; Liu et al., 2010) and therefore ibises detectability. The relationship of nontree vegetation cover and the probability of detection allows us to hypothesize about the importance of this vegetation community for the Andean Ibis who could avoid areas with low vegetation cover, such as *páramo* cushion plants, which do not provide protection against weather or predators. A greater amount grassland and shrubs will offer feeding resources to be exploited and hence a greater amount of time to spent moving slowly during foraging activities in this vegetation cover, which facilitate the detectability from a fixed position as a point count. We attribute the decrease in detection probability over the years to a reduction in survey effort because the percent of nontree vegetation was similar across surveys.

The effect of primary productivity, annual mean temperature, and annual precipitation on the abundance of Andean Ibis was expected. Areas with high productivity harbor greater arthropods and earthworm biomass (Perner et al., 2005; Sánchez-de León et al., 2018), which constitute the main items in the diet of the Andean Ibis and whose abundance is positively correlated with the ibis abundance (Gantz et al., 2015). The diversity and abundance of *páramo* arthropods is also positively correlated with temperature and precipitation (Díaz et al., 1997). Moreover, rainfall and temperature have impacts on demographic factors of avian species, specifically extreme weathers regimes can directly influence food availability that certainly has an impact of adult body condition, nest survival, and therefore in population size (Crick, 2004).

Our preliminary results constitute the first quantitative estimates of population abundance for the Andean Ibis in Ecuador, which was estimated in 52 individuals 18 years ago (Olmedo-Gordón, 2001), and since then it has been used as baseline information for conservation and management. A simple comparison of this baseline with our estimates could be interpreted as an increase in population size; however, this should be taken with caution due to differences in sampling and experimental design. In addition, BirdLife International (2014) points out to a decreasing population trend; however, this affirmation it is not supported by quantitative data either.

Our estimates do not support previous inferences on population decline for this species; on the contrary, they suggest an increase of 157% in the abundance between 2016 and 2018, and this cannot be linked with survey effort since in 2018 we performed 22% less effort and 130% more detections than in 2016; when comparing abundance estimates of the same number of point counts surveyed in 3 years (same survey effort, six point counts in each year), we found that Andean Ibis abundance appears to have increased from 60 individuals in 2016 to 115 individuals in 2018. The fact that Andean Ibis abundance increased in the past 3 years could be explained by (a) the permanent surveillance activities performed every week by the Ministry of Environment of Ecuador in Antisana Ecological Reserve that have significantly contributed to reduce poaching and increase habitat protection where Andean Ibis inhabit, (b) an increase in gross primary productivity, (c) the impact of weather anomalies, or an interaction of all of them; however, none of these hypothesis were tested in the course of this work. There is no previous information on systematic surveys of Andean Ibis abundance before the implementation of surveillance activities, so we cannot make any inference on this. To address the second and third explanation, we speculate that the abundance is greater in years with high productivity or in years with stable weather regimes. We compare gross primary productivity during survey days using the information available in remote sensing data (Running et al., 2015), and we found that productivity was similar in 2016 and 2018 and significant lower in 2017 (Kruskal–Wallis test: $h = 15.494$, $p < .001$), but population abundance increased from year to year. On the other hand, 2016 was a very strong, El Niño/Southern Oscillation (ENSO) year, 2017 no ENSO year, first quarter of 2018 was a moderate La Niña year (National Oceanic and Atmospheric Administration/National Weather Service, 2017), and our results show an increase in abundance during non-ENSO years. We cannot draw any conclusion in any of these scenarios as the number of years of observations is too low.

Next step is to continue monitoring Andean Ibis yearly increasing the number of point counts; we encourage stakeholders to do so and to adopt the sampling protocol, data analysis methods, and results presented here as a baseline to test the hypothesis raised here. According to information provided by park rangers of Cotopaxi National Park and Antisana Ecological Reserve, optimal conditions (e.g., no rain, no fog) for Andean Ibis detection are present during December and February of each year; therefore, we suggest future surveys to be conducted during these months as we did in this study.

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## Appendix 1. Organizations and Volunteers That Provided Logistic and Field Assistance During the National Census of Andean Ibis (*Theristicus branickii*) in Ecuador 2016–2018

Ministerio del Ambiente del Ecuador, Wildlife Conservation Society Ecuador Program, Aves y Conservación, Fundación de Conservación Jocotoco, Fondo para la Protección del Agua, and Empresa Pública Metropolitana de Agua Potable y Saneamiento de Quito. Alejandro Aguayo, Ana Carrión, Andrea Terán, Andrés Jungbluth, Andrés Marcayata, Ángel Ushca, Augusto Granda, Carlos Cuichán, Daniel Armijos, Daniel Catagña, Diego Cuichán, Diego Moreno, Edison Mejía, Edwin Taimal, Elisa Levy, Esteban Guevara, Fernando Males, Francisco Sornoza, Galo Carrasco, Gia Brichetto, Gino Chiang, Gregorio Nuñez, Héctor Cadena, Ibeth Alarcón, Isidro Bautista, Ítalo Aimara, Javier Oña, Javier Robayo, Jimmy Villareal, Josué Artega, Juan Diego Molina, Luis Calvopiña, Luis Ordoñez, Luisa Machado, Manuel García, Marcelo Cuichán, María Fernanda Solórzano, Mariela Chauca, Mario Iglesias, Mario Pilataxi, Pablo Medrano, Patricio Cachumba, Patricio Muñoz, Patricio Taco, Pedro Ordoñez, Poncho Cuichán, Quenny López, Ricardo Mogollón, Rodolfo Carvajal, Rolando Hipo, Rubén Cueva, Santiago Herrera, Susana Escandón, Víctor Obando, Vladimir Ushiña, Xavier Cueva, and Ximena Fuentes.

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