Article

Species distribution modeling and conservation assessment of the black-headed night monkey (*Aotus nigriceps*) – A species of least concern that faces widespread anthropogenic threats

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Abstract Deforestation rates in the Brazilian Amazon have been steadily increasing in recent years. Due to recent government policy, the projected growth of agriculture and expansion of the cattle industry is expected to further strain biodiversity across the region, with many wide-ranging primate species within these areas facing declines as a result. In this study, we examined the anthropogenic impact on the widely distributed black-headed night monkey, *Aotus nigriceps*, which is listed as least concern but whose distribution and population status has yet to be assessed. In this study, we 1) modeled species distribution in *A. nigriceps*; 2) estimated impact of habitat loss and degradation on population trends; and 3) highlight landscape-based conservation actions which maximize potential for their long-term sustainability in the region. We found the black-headed night monkey to be restricted by biotic and environmental factors such as higher elevation, low temperature range, low isothermality and high forest cover. Over the last two decades, over 132,908 km^2 of tree cover (18.3 %) within their documented range has been lost.

We found only 40.4 % of their range contained suitable habitat, a loss of 17.1 % from their estimated distribution in 2000, and just over 22.3 % of suitable habitat was in protected areas. Projected deforestation rates across present-day modeled distribution of *A. nigriceps* equates to an additional loss of 37,295 km^2 of habitat over the next decade. This study demonstrates how this species of least concern actually has a far smaller distribution and is likely more at risk than previously described. The future impact of continued expansion of mono-cultured crops, cattle ranching, and wildfires is still unknown. However, expanded use of participatory and jurisdictional REDD+, sustainable agroforestry in buffer zones, secured land tenor for indigenous communities, maintenance of wildlife corridors, and the expansion and strengthening of protected areas can help ensure viability and reduce risk of widespread loss for this and other species throughout the Amazon Basin.

Keywords Amazon, *Aotus nigriceps*, Peru, Brazil, deforestation, MaxEnt, primate, REDD+

Introduction

Deforestation rates in the Amazon rainforest have recently accelerated due to expansion of mono-cultured agriculture (e.g., palm oil and soy), cattle ranching, wildfires, and urban expansion (Davidson et al., 2012; PRODES 2020); with models predicting up to 40% of all Amazonian forests will be lost by 2050 (Gomes et al., 2019). These at-risk areas overlap with many neotropical primate species whose populations may suffer large declines. This includes the black-headed night monkey, *Aotus nigriceps*, one of eleven currently recognized species of night monkey found in Central and South America (Defler and Bueno 2007; Ruiz-Garcia et al., 2011). Although common, the impact of anthropogenic disturbances on the long-term viablity of *A. nigriceps* remains unknown.

Aotus nigriceps is a wide-ranging nocturnal monkey species which lives in degraded habitats, utilizes agroforested landscapes, and is known to tolerate human populations (Helenbrook et al., 2020). Nevertheless, while night monkeys are adaptable and persist in degraded landscapes, they still require connective forest cover, access to seasonally available fruiting trees, sleeping sites, and are restricted by environmental conditions (Wright 1981; Aquino & Encarnación 1994; Fernandez-Duque et al., 2001; Helenbrook et al., 2020). This species is found in Southern Peru, northern Bolivia, and central-western Brazil with density estimates ranging from 19-50 individuals/km^2 (Helenbrook et al., 2020). The International Union for Conservation of Nature (IUCN) currently lists this species as Least Concern because of their extensive range, suspected large and sustained population size, and presumed low risk of extinction. However, no known population size estimates or trends have been described due to a lack of information on presence data throughout their range. This is concerning since large portions of its range overlap with areas experiencing some of the highest deforestation rates in

the world (Estrada et al., 2018). Besides habitat loss, their long-term viability is also projected to be further impacted by altered phenology and increased average maximum temperatures which will force species to adapt their distribution or face increased risk from extinction (e.g., Raghunathan et al., 2014; Cohn et al., 2019; Carvalho et al., 2019a).

Assessing the population status of *Aotus nigriceps*, and any species in general, requires accurately describing their distribution, baseline population size, and predicting future population growth or loss. This information can be used to build predictive models that can indicate priority regions for conservation action. Species distribution modeling is a well-known approach, which evaluates the relationship between environmental variables and their predicted distribution based on estimated habitat suitability for a species and has been previously shown in other primates (e.g., Bett et al., 2012; Kamilar & Tecot 2015; Rabelo et al., 2018). The MaxEnt program is especially suited for this task and is considered the most accurate maximum entropy machine learning model, achieving high predictive accuracy without true absence data, incomplete data, and small sample sizes (Phillips & Dudik 2008). With the use of MaxEnt and other distribution models, species requirements can be projected across space to predict habitat suitability. However, it is typically not used for species of least concern and only after a species has significantly declined.

For this study, we used species distribution modeling with MaxEnt to estimate *A. nigriceps* distribution and then projected density measurements across their predicted distribution. The objectives of this study are to: 1) develop distribution models on the occupancy of *A. nigriceps* utilizing ecological, biogeographical, and environmental data; 2) establish impact of habitat loss and degradation on population size; and 3) identify priority conservation actions needed to sustain black-headed night monkey populations.

Methods

Species occurrence and environmental data

We constructed an occurrence data set (N=75) for *Aotus nigriceps* from several sources, including published manuscripts, iNaturalist, and field records provided by the Wildlife Conservation Society. We only included data sets which had confirmed species identity and accurate geographic location. All records were then plotted in QGIS (3.12.1) and created a polygon layer that included all records and followed major river barriers (Figure 1A). The polygon represented species' extent of occurrence which corresponds to the current IUCN description (Shanee et al. 2018).

We used bioclimatic variables as environmental predictors based on their presumed ecological or physiological relationship to black-headed night monkey suitability as previously used in other neotropical primate studies (e.g., Holzmann et al., 2014; Rabelo et al., 2018). Climatic variables were downloaded from WorldClim dataset and included annual mean temperature, annual temperature range, annual precipitation, and isothermality (defined as mean diurnal range [mean of monthly (max temperature – min temp)] divided by temperature annual range) (Fick & Hijmans 2017). We used the Shuttle Radar Topographic Mission elevation dataset (SRTM 2020). We also obtained percent forest cover data from 2000, forest gain from 2000-2012 and forest loss between 2000-2018 from Earth Engine Partners (Hansen et al. 2013). To calculate the most current cover percentage for the year 2018, the cumulative gain and loss between 2000 and 2018 were added and subtracted from the 2000 cover layer, respectively. We calculated protected area within *A. nigriceps* range and predicted distribution using polygons obtained from Protected Planet (UNEP-WCMC & IUCN 2020). All layers utilized in the study were in 30 seconds (1 km) spatial resolution.

Distribution models

We used MaxEnt (Version: 3.4.1) to develop a correlative species distribution model for *Aotus nigriceps*, relating known geographic occurrences to the set of environmental variables to estimate suitable habitat (Phillips & Dudík, 2008; Franklin 2009). To create a best-fit model for *Aotus nigriceps* habitat, we paired species occurrences and environmental layers to predict distribution of the species. To model their predicted distribution, we used 2000 forest cover layer and 2018 cover layer to predict their most current distribution. We used 70 % of known species' localities as training data and 30 % of the localities were set aside as test data. A bootstrap method was used with a maximum of 5,000 iterations, 10,000 randomly selected background points, a prevalence of 0.75, and 15 replicates with a random seed. Since there was a spatial sampling bias with many of the observations, a regularization multiplier of 6 was added to constrain the model and avoid overfitting, reduce complexity, and generate less localized predictions (Morales 2007; Anderson & Gonzalez, 2011; Merow et al., 2013; Shcheglovitova & Anderson, 2013). Sites with 50 % or greater likelihood of being occupied were considered suitable habitat.

To assess model discriminatory power and compare performance of species distribution models, we measured the area under the receiver operating characteristic curve (AUC) (Fielding & Bell, 1997; Babar et al., 2012; Phillips & Dudík, 2008; Stohlgren et al., 2011). We used a 10 % training omission rate (Peterson & Soberon, 2012). To measure variable importance and determine which variables contributed most to the model, we performed a Jackknife analysis with and without each variable in isolation. We imported the MaxEnt model predicting the presence of *A. nigriceps* into QGIS and calculated total area with greater than 50% probability of occurrence.

Population Size Estimates and Threat Assessment

To estimate habitat loss over time we 1) calculated tree cover loss within their documented range from Global Forest Watch data layers (Hansen et. al. 2013) and 2) calculated the amount of suitable habitat between 2000 and 2018 using the MaxEnt modeled species distribution. We then used upper and lower population density estimates obtained from Helenbrook et al. (2020) to extrapolate across projected habitat using both methods. We highlight management practices needed to minimize habitat loss, maintain connectivity, and restore populations regionally.

Results

Species Distribution Modeling

MaxEnt models showed strong support for predicting observed distribution (AUC = 0.837). The test omission rate was 0.09 (ranging from 0 - 0.235) with $P < 0.0001$ in all replicates, and close to the 10% training omission rate as expected. Annual precipitation was removed from the final models due to strong sampling bias with many observations near areas with the highest precipitation levels in South America. Occupancy increased with greater forest cover (range 0 - 100 %) and elevation (range 1 - 3,062 m); mean temperature (range 16.29 - 27.8 C), isothermality (range 6.4-8.7 %), and temperature (range 10.12-19.71 C) (Supplementary Fig. 1). All three climatic variables (mean temperature, temperature range, and isothermality) had the highest permutation importance (Table 1). Elevation and mean temperature were the most effective variables for predicting the distribution of the occurrence data set aside for training (Supplementary Fig. 2A), testing (Supplementary Fig. 2B), and when predictive performance was measured using AUC (Supplementary Fig. 2C). The largest contributing environmental

variable when omitted in all jackknife tests was temperature range and isothermality, suggesting that both contribute the most information not found in the other variables.

TABLE 1: Relative contribution estimates of environmental variables to the MaxEnt model predicting *Aotus nigriceps* occupancy. For percent contribution, the increase in regularized gain for each iteration of the training algorithm is added to the contribution of the corresponding variable or subtracted if the change to the absolute value of lambda is negative. For permutation importance, the values of the environmental variable on training presence and background data are randomly permuted. The model is reevaluated on the permuted data, and the resulting drop in training AUC is normalized to percentages. Values shown are averages over replicate runs.

Variable	Percent contribution	Permutation importance
Elevation	42.5	13
Forest cover	28.6	3.5
Mean temperature	14.9	32.5
Isothermality	7	23.1
Temperature range	7	28

Estimated extent of occurrence for *Aotus nigriceps* was 1,591,711 km^2 based on distributional layers obtained from IUCN (Shanee et al. 2018: Fig. 1). Using satellite imagery from Global Forest Watch we calculated a loss of 18.3 % of forest cover between 2000-2018 (Fig. 1a,b). Protected areas represented 13.99 % of their range and exhibited some forest cover loss over the past decade (4.7 %). Species distribution calculations using > 50 % likelihood cutoff showed 40.4 % (642,733 km^2) of their known range contained suitable habitat (Figure 1c),

a loss of 17.14% from the predicted 48.73 % in 2000. Of their predicted distribution only 22.3 % was in protected areas (Fig. 1d).

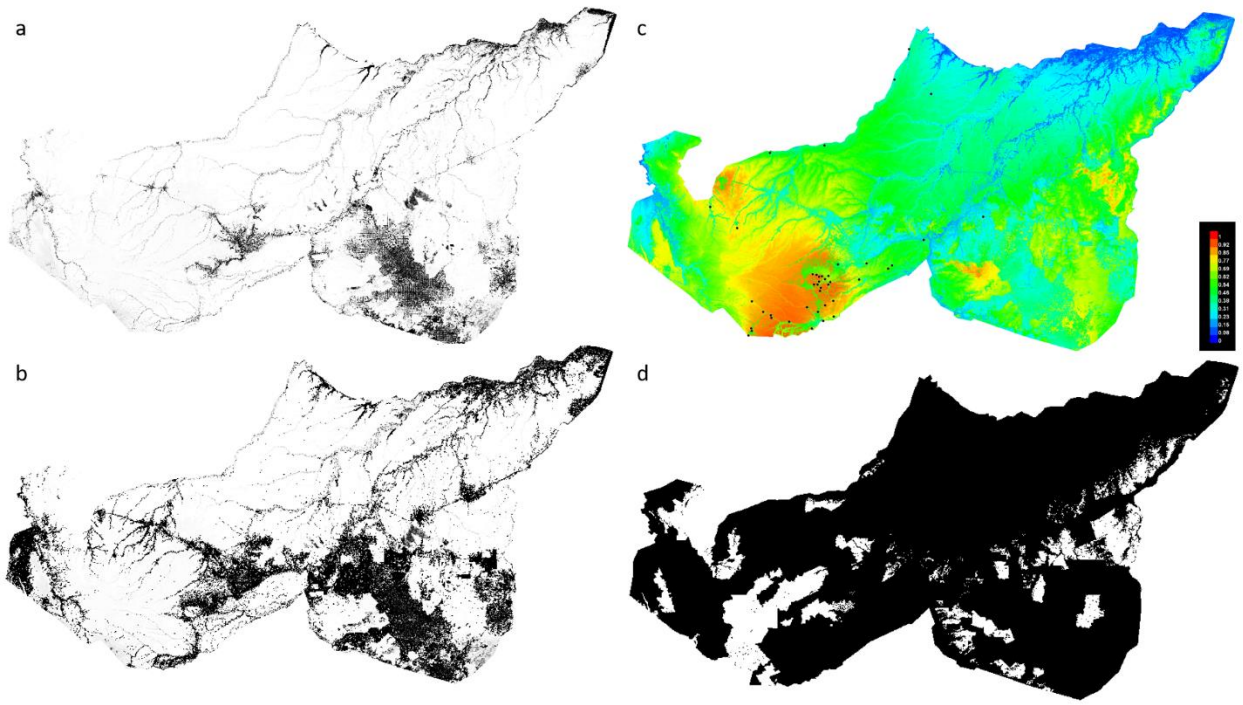

FIG. 1: (a) forest cover in 2000 (white), (b) forest cover in 2018 (white), (c) estimated extent of occurrence and estimated species distribution of *Aotus nigriceps* using 2018 forest cover data and MaxEnt (> 50 % likelihood cutoff represented as green to red), and (d) predicted occupancy in protected areas based on 50% likelihood threshold.

Current population estimates using modeled viable habitat coupled with density estimates from previous studies (i.e., 19-50 individuals per km^2) range from 12,211,927 to 32,136,650 individuals (Helenbrook et al., 2020). Based on species distribution contraction between 2009-2018, we estimate a loss of 160,816 – 423,200 individuals. If we instead used rates of tree cover loss within the area of occurrence, the population size was reduced by 1,006,240 – 2,648,000

individuals over the past decade. Deforestation rates in the Brazilian Amazon (0.3%) have accelerated in 2019 (29.5% increase over 2018 per Butler, 2020). Current extrapolated deforestation rates across present-day modeled distribution of *A. nigriceps* equates to an additional loss of 30,181 km^2 of habitat over the next decade.

Discussion

This is the first study to assess the species distribution, population status, and landscape-scale conservation management plans for the black-headed night monkey. Although considered least concern due to their adaptability to a variety of habitat types including the moist forests of the Southwest Amazon, Jurua-Purus, Purus-Maderia, and Maderia-Tapajos, *A. nigriceps* distribution appears restricted by biotic and environmental factors. In particular, suitable habitat was represented by high altitudes, low isothermality, low temperature range, and high forest cover. We found that although not considered a species of concern due to its broad distribution across several Amazon Basin ecoregions, they currently occupy a much smaller distribution than the previously described extent of their range would suggest. Even two decades ago, their distribution was predicted to be only half of their presumed extent of occurrence. Furthermore, we estimate that between 2000 and 2018, this species has been reduced by 1 to 2 million individuals. Although this species is currently considered common, they will likely continue to decline significantly due to widespread anthropogenic pressures, especially since less than a quarter of their suitable habitat is within protected areas.

This study provides evidence that *A. nigriceps* has experienced sharp declines in forest cover in portions of their range over the last couple of decades and will continue to experience habitat loss and degradation resulting in population decline over the coming decade. Deforestation rates have surged recently in Brazil driven by heavy pressure from cattle ranching

and mono-cultured agriculture (Gomes et al., 2019; IMAZON 2020). Some of the highest deforestation rates in the Amazon occur in the Brazilian States of Pará, Rondonia, and Mato Grosso where this nocturnal species occurs. Systematic conservation planning based solely on the black-headed night monkey appears premature at this time due to the broad distribution of the species and without an understanding of underlying taxonomy and molecular variability throughout its range. However, the expansion of several existing conservation strategies would benefit *A. nigriceps* and contribute to overall biodiversity conservation. First, extensive protected areas and indigenous territories exist in Peru, Bolivia, and Brazil, though level of protection varies widely (Amazonia Socioambiental 2019; Paiva et al. 2020). Forest loss and degradation still occurs within protected and indigenous lands, though the degree to which these areas is impacted depends on the type of protected area and management (e.g., indigenous, federal, or state: Herrera et al., 2019). Secondly, continued support for participatory and jurisdictional REDD+ programs also appears effective though this approach requires realistic expectations among local communities regarding benefits and participation, secured land tenor, and a mix of intervention strategies including incentives, disincentives, and introduction of alternative livelihoods (Simonet et al., 2019; Dupuits & Cronkleton 2020). Thirdly, specific to Brazil, where the majority of black-headed night monkey habitat exists, deforestation is a result of extractive industries which have found federal favor and have been able to overturn a decade of progressive legislation. To counter this, several actions have been proposed, including bolstering environmental agencies, integrating agricultural and environmental policies while consolidating enforcement across federal, state and local authorities, improving supply chain transparency, and increased efficacy of monitoring programmes (Carvalho et al., 2019b). Lastly, agroforestry research related to night monkey species is limited, though a study in the northern Andes

suggests that coffee plantations can benefit night monkeys while also providing farmers with income (Guzmán et al., 2016). Whether this is applicable to lowland rainforest environments and to what extent this would be feasible with other types of cash crops and with farmers who principally raise livestock remains unknown. We have previously shown that the black-headed night monkey is quite common in secondary forest and that they make use of orchards (Helenbrook et al., 2020). The main issue would appear to be whether connected canopy is maintained in order for night monkeys to traverse a complex matrix with forest fragmentation and diverse land uses. In cases where forest connectivity is an issue, then restoration ecology may be a consideration. The simplest form would be to simply remove perturbations to allow the forest to recover in strategic locations which enhances habitat corridors. Even secondary forest contributes to dispersal of not only night monkeys but many other types of sympatric wildlife (Beier & Noss 1998; Lees & Peres 2008; Boyle & Smith 2010).

Although our distribution model was robust, caution should be used in interpreting results. Most long-term *A. nigriceps* studies are based in southeastern Peru, and occurrence data is heavily focused in Peru and southwestern Brazil. This geographic emphasis on the southern range may bias against those conditions in the north, which include lower elevations, floodplains, and lower temperatures. Furthermore, many observations were in sites with the highest rainfall in South America, so rainfall could therefore not be used in the models. Increased focus on field sampling in the northern Brazilian Amazon in future studies can help reduce these biases and determine the importance of rainfall for this species. Using MaxEnt can help add new information and create better models as one of the main benefits is being able to hone predictions based on new data and changing conditions over time. Nevertheless, this study provides critical

information of areas highly likely to have black-headed monkeys which can be used for future conservation monitoring and planning.

This study provides the first analysis of black-headed night monkey species distribution along with recommendations for increasing landscape connectivity. Although considered a species of least concern, their distribution appears far smaller than extent of occurrence would suggest. This species has experienced extensive habitat loss over the past couple of decades and there will likely be continued habitat loss and degradation, threatening this relatively common species. Necessary next steps include expanded sampling into interior portions of the Brazilian Amazon which are currently underrepresented and determine phylogenetically distinct conservation priorities that may exist within the species driven by river barriers which transect much of their distribution. A regional landscape-level conservation plan that maintains forest connectivity and minimizes habitat loss would benefit not only the black-headed night monkey but the many other sympatric species who are under increasing threat in the region.

Author contributions

Study design, data collection, analysis, and writing: WDH; Modeling and assistance with writing: JWV

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Conflicts of Interest

None.

Ethical Standards

This research complied with the *Oryx* Code of Conduct.

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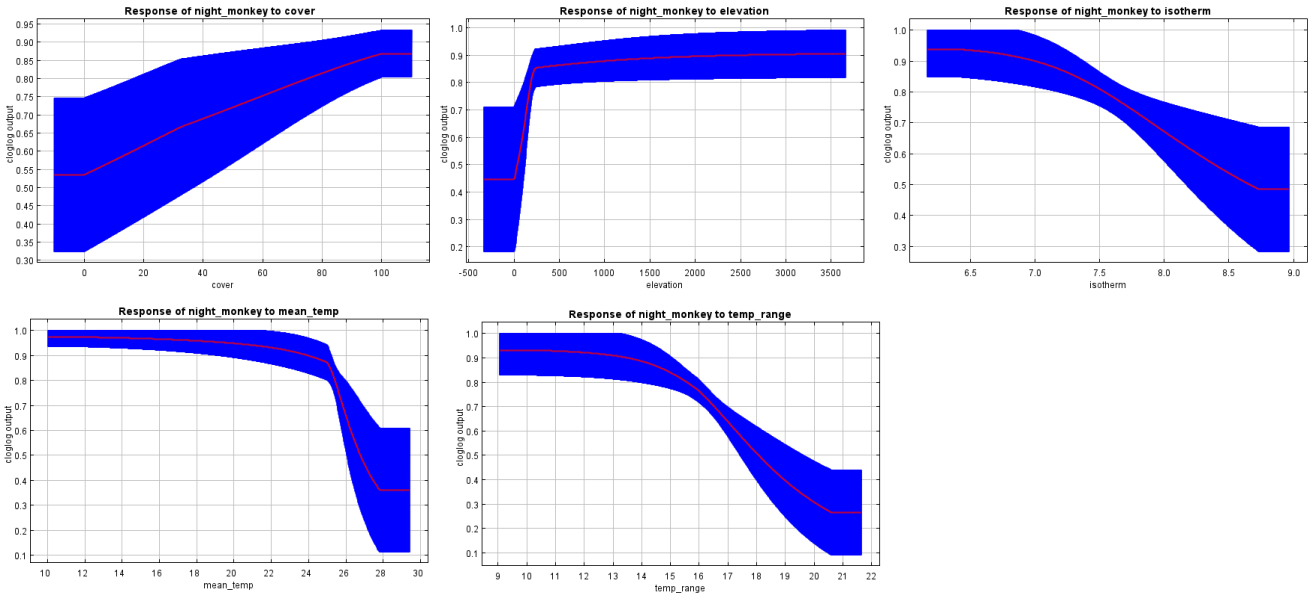

Supplementary FIG. 1. The predicted probability of *Aotus nigriceps* occupancy of each environmental variable, keeping all other variables at their average sample. The curves represent the mean response of 15 replicate MaxEnt runs (red) and +/- one standard deviation (blue).

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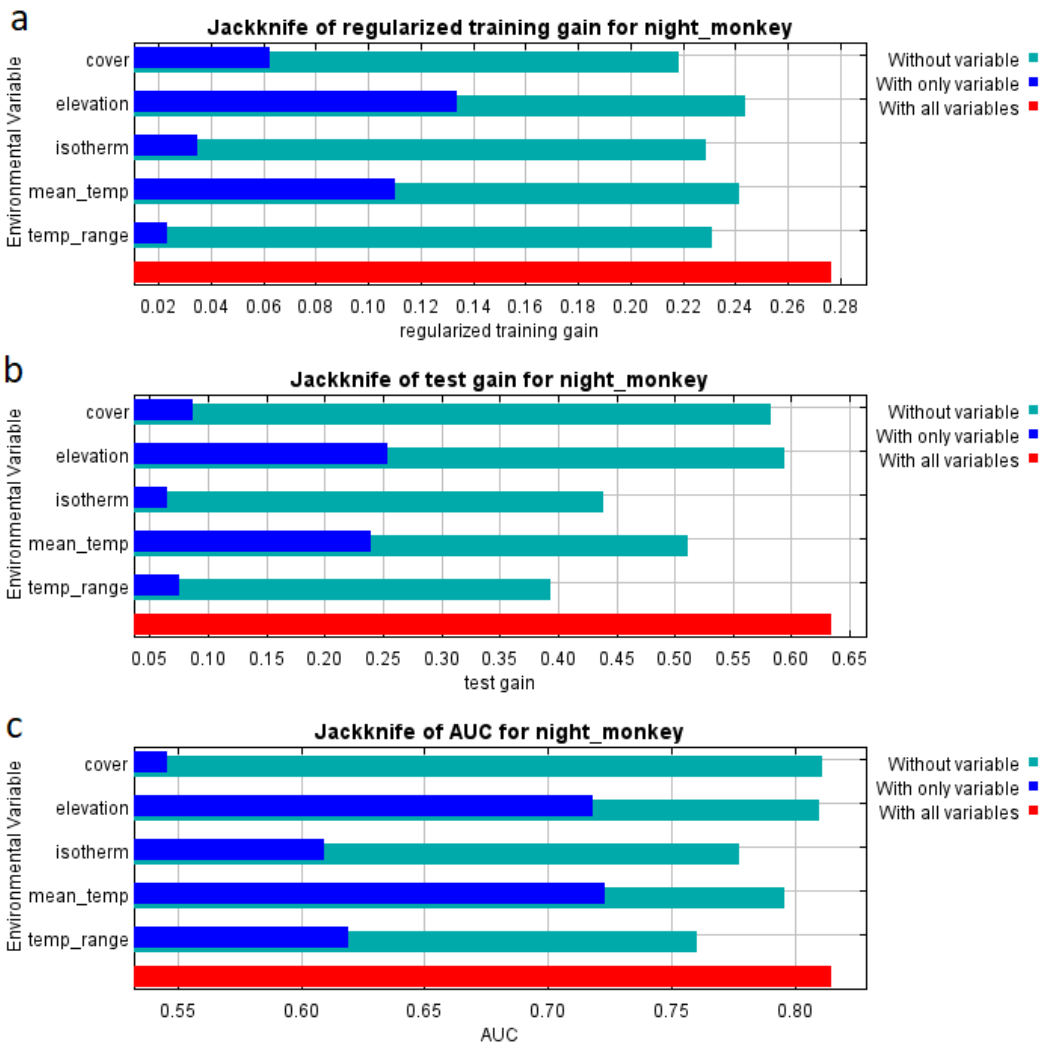

Supplementary FIG. 2. Jackknife tests for variable importance for (A) regularized training gain, (B) test gain, and (C) AUC averaged over 15 replicate bootstrap runs for predicting *Aotus nigriceps* occupancy.