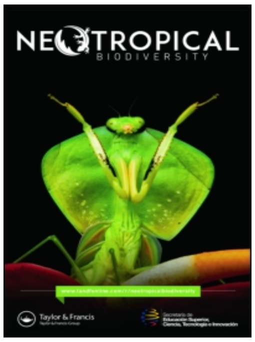

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Camera traps provide valuable data to assess the occurrence of the Great Curassow Crax rubra in northeastern Costa Rica

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Camera traps provide valuable data to assess the occurrence of the Great Curassow *Crax rubra* in northeastern Costa Rica

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The Great Curassow (*Crax rubra*) is an endangered species in Costa Rica due to habitat loss and hunting pressure. Little is known about the spatial ecology of cracids and there is a need to assess their distribution to establish efficient conservation strategies. In this study, we integrated camera trapping data with occupancy models to examine landscape factors that affect the distribution of the Great Curassow in the San Juan-La Selva Biological Corridor in Northeastern Costa Rica. We established remote camera traps at 38 sites within the corridor between July 2009 and July 2011. The Great Curassow was detected on 56 occasions at 19 of the 38 sites. Eight of the 19 occupancy models contained plausible support to predict Great Curassow occurrence, but distance to villages and forest cover were the most important factors positively related to their occurrence. These results suggest the distribution of the Great Curassow is largely susceptible to forest loss and human disturbance in the corridor. Both camera traps and occupancy analyses are useful tools to study medium to large terrestrial birds in the Neotropics.

Keywords: biological corridor; camera traps; *Crax*; Great Curassow; occupancy

El pavón real (*Crax rubra)* es una especie amenazada in Costa Rica debido a la tala de bosques primarios y la presión de caza. Sin embargo, se conoce muy poco sobre la ecología de los crácidos en general, por lo que es necesario evaluar su distribución para apoyar estrategias eficientes de conservación. En este estudio empleamos técnicas de fototrampeo, usualmente aplicadas a mamíferos, para examinar los factores de paisaje que influyen en la ocurrencia y distribución del pavón en un corredor biológico en el norte de Costa Rica. El pavón fue detectado en 56 ocasiones en 19 de los 38 sitios evaluados. Ocho de 19 modelos mostraron apoyo suficiente para predecir la ocurrencia del pavón. Sin embargo, distancia a poblados y porcentaje de cobertura boscosa fueron las variables mas importantes con una relación positiva con la ocurrencia. Estos resultados sugieren que la distribución del pavón es suceptible a la perdida de bosque y la infraestructura humana. Por otra parte, este estudio constituye un ejemplo de como el fototrampeo y los análisis de ocurrencia pueden ser de utilidad para estudiar aves de terrestres de tamaño mediano o grande en el Neotrópico.

Palabras clave: Corredor biológico; trampas de cámara; *Crax*; pavón real; ocupación

Introduction

Mesoamerica is one of the planet's biodiversity hotspots [1]. However, high rates of population growth, rapid expansion of agriculture, and an increasing demand for goods and services from tropical forests are major causes of deforestation in this region [2]. Several Mesoamerican countries have adopted initiatives to improve connectivity for wildlife in the isthmus. For over three decades, Costa Rica has developed biological corridors within its territory including the consolidation of the Mesoamerican Biological Corridor at the turn of the century [3].

The Biological Corridor of San Juan-La Selva (hereafter: CBSS) was established in 2001. This corridor is a key linkage within the Mesoamerican corridor because it connects the biological reserve of Indio-Maíz in Nicaragua and the central volcanic range conservation area in Costa Rica [3]. Despite the CBSS benefiting from great organization of social investment, there remains suitable habitat that is threatened with deforestation. Furthermore, it is critical to assess biodiversity inhabiting this territory to evaluate corridor effectiveness [4].

Costa Rica is within the geographic distribution of 5 of the 10 cracid species in Mesoamerica [5]. Several of these species are locally endangered, mainly due to hunting and habitat loss [6]. The Wildlife Conservation law Nº 32633 lists the Great Curassow (*Crax rubra*) as threatened due to the loss of approximately 69% of its original habitat [7]. General information about the ecology and distribution of the Great Curassow in Costa Rica is poorly documented [6,8] and it is suggested to be restricted to national parks and refuges [6,9,10]. Great Curassows prefer undisturbed forest and may serve as indicator species of forest health [11], yet their occurrence in secondary forests has also been reported [8]. Cracids are valuable seed dispersers and play an important role in maintaining tropical forests [12].

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Finally, curassows are important prey for several threatened species, such as jaguars (*Panthera onca*) and ocelots (*Leopardus pardalis*) [13].

Cracids are censused with multiple techniques with variable results. Standardized line transects paired with distance sampling is a popular technique to provide relatively robust population estimates by accounting for detection bias, however, these methods require substantial survey effort [11,14]. In Cozumel, Martinez-Morales [11] covered 386 km of survey transects to detect 17 individual curassows via visual and aural surveys. Although visual surveys are commonly recommended, Jimenez et al. [14] recommended that aural surveys are more effective to detect curassows because the birds are easier to detect at further distances and hence you can survey more area, but they also acknowledged that aural surveys could be biased toward male detections. Standardized point-counts are also commonly used to survey bird communities, but these methods seem relatively inefficient for curassows, e.g. only 2 *Crax rubra* detections out of 2061 bird detections in La Sierra, Tabasco, Mexico [15]. Camera traps are a popular non-invasive technique for studying and monitoring wildlife, especially mammals [e.g. 16,17,18]. Camera traps are also useful tools for observing large terrestrial birds, even though they might not be the target organisms of surveys [19]. In fact, Beirne et al. [20] recently used camera traps to detect the critically endangered Sira curassow (*Pauxi koepckeae*) in the Peruvian Andes and the authors suggested camera traps would prove to be essential monitoring tools for Cracids in the future. We conducted a large-scale project to assess mammal occurrence within and around the CBSS [21,22]. Cameras were effective at detecting several non-target species; specifically, the Great Curassow was one of the most frequently detected [23]. Our objectives were to evaluate the potential use of camera trap techniques to estimate curassow occupancy and the influence of landscape variables on its distribution in a Neotropical biological corridor.

Methods

Study area

The CBSS lies in the northern portions of Heredia and Alajuela Provinces, Costa Rica, between the Sarapiquí and San Carlos districts (Figure 1). The total area covers 2466.08 km^2, 56% of which is pristine forest, secondary forest, and managed forest plantations [24]. The area established for the corridor (public and private areas) is subdivided into three categories depending on the level of priority: Maquenque National Wildlife Refuge (540 km^2), which is the focus of conservation, followed by three areas of medium priority, which constitute the 'core' corridor (Tiricias-Crucitas, Astilleros-Sardinal, and Arrepentidos). The remaining area constitutes the matrix that extends for 30 km from the volcanic mountain range [25,26]. The corridor altitudinal range varies from 30 to 3000 m, generating gradients of temperature and precipitation, causing a rich range of habitats. The primary habitats include: tropical moist forest, wetlands, secondary forest, and various crops (especially pineapples) and pastures. There are also up to 16 small towns, 30 villages and some small communities on the banks of major rivers, registering, approximately 75,000 inhabitants at the turn of the century [4].

Camera trapping

We surveyed a total of 38 sites (Figure 1) within and around the corridor. We selected sites to be representative of all the different land cover types in the region and ensured a minimum separation of 2 km to avoid lack of independence [21]. To test the effect of the number of cameras on the detection of biodiversity, we placed them in different configurations (e.g. 4–10 stations). We positioned four cameras in a triangular array with a central camera and minimum spacing of 250 m between cameras. Larger arrays (e.g. 6–10 stations) were arranged in rectangular configuration with the same 250 m spacing. Each station consisted of a single passive infrared digital camera (ScoutGuard SG550, HuntingCam Online, Norcross, Georgia, USA) or a traditional passive flash digital camera (StealthCam STC-1850 StealthCam, LLC Grand Prairie, Texas, USA). The cameras were fastened on trees at a height of approximately 20 cm and left activated in the field from 15 to 35 days depending on logistics or access to the site. Further details in camera sampling can be found in other published accounts [21,22].

Analysis

Occupancy (ψ) is either defined as the proportion of an area occupied by a species or the probability of occurrence at a spatial survey unit [27]. In this study, we consider occupancy as a state variable, which allowed us to draw inferences about the distribution of *Crax rubra* in the CBSS and the possible variables that influence their presence within the corridor. We estimated occupancy using the single-season models developed by MacKenzie et al. [27], which use maximum likelihood estimation based on detection/non-detection data. The single-season model implies three assumptions: (1) the method used to detect the species must generate non-equivocal presence data, (2) different sampled sites must be 'closed' to change in occupancy for the duration of the survey period, and (3) detection of the species at a site should be independent from the detections at any other site. The model framework is robust and allows the incorporation of covariate effects on detection probability (e.g. time-varying, site-specific) and on occupancy by integrating site characteristics that might influence species occurrence [27].

We selected five covariates that we hypothesized influence the distribution of the Great Curassow in this zone (Table 1). We measured landscape variables using Geographic Information System (GIS- Quantum GIS

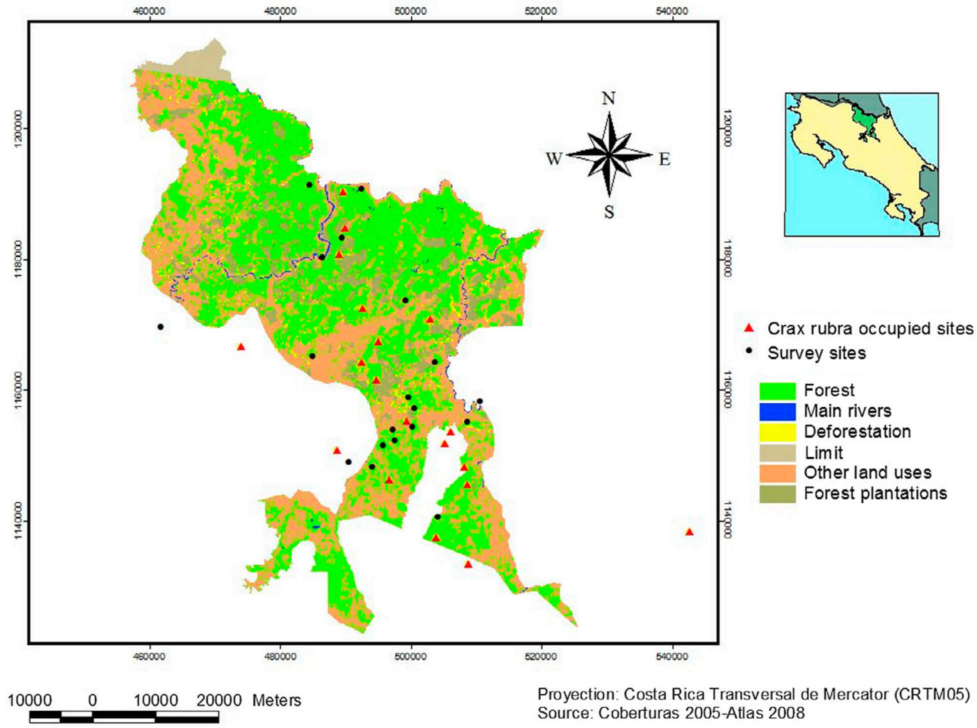

Figure 1. Camera trap survey locations, including habitat cover and *Crax rubra* occupied sites in and adjacent to the San Juan-La Selva Biological Corridor (CBSS), Costa Rica, 2009–2011.

Table 1. Habitat and sampling covariates for *Crax rubra* occupancy models derived from camera trap data in the San Juan-La Selva Biological Corridor, Costa Rica, 2009–2011.

Covariate name	Description	A priori Hypothesis
Distance to protected area	Distance to the nearest protected area of more than 30 000 ha (0 km, <2 km, <5 km, <10 km, or >10 km)	$\beta_1 < 0$, occupancy decreases as proximity to protected area increases
Distance to nearest town	Distance from the central point of the cameras to the nearest town	$\beta_1 > 0$, occupancy increases as proximity to human settlements increases
Percent forest coverage	Percent forest coverage in a 1 km radius buffer	$\beta_1 > 0$, occupancy increases as forest cover increases
Forest state	Protected (0) or managed forest (1)	$\beta_1 > 0$, occupancy increases with forest management because resource availability increases
Latitude	Latitude of the central point of the cameras	$\beta_1 > 0$, occupancy increases with latitude
Sampling effort	Number of cameras used in the site (4–10). This variable was used only for detection probability.	$\beta_1 > 0$, detection increases as you add cameras to each survey site

version 1.6.0). The digital land cover layer was the 2005 Atlas of Costa Rica 2008 (FONAFIFO 2005 [28]) in Costa Rica Map Projection Transverse Mercator 2005 (CRTM05).

We tested the effect of patch isolation in the context of habitat fragmentation. To measure this criterion, we focused on site distance to the nearest protected area, which was either Braulio Carillo National Park or Maquenque Wildlife Refuge. We used the center of the polygon formed by camera traps to measure this distance for different sites. We created buffers at 2, 5, and 10 km from the boundaries of the two protected areas to examine the effect at different scales. This was a categorical variable because several sites fell within the boundaries of the protected areas, which made the use of a continuous covariate inappropriate. We measured percent forest within a 1 km radius buffer from the central point of the cameras at each site. We also measured the distance to the nearest village as a proxy to quantify human pressure [21]. We considered management status of the forest as either protected (0) or managed (1) for timber and resources. We included latitude as a covariate because forest cover at the north of the corridor is better protected and more continuous than the south [4].

Finally, we included a sampling effort covariate because of variable survey designs to model curassow detection probability.

We categorized photos into binary detection histories (1 = detected, 0 = not detected) by aggregating five survey days as a single survey occasion, such that each site could have up to seven survey occasions. We compared 19 *a priori* models to predict Great Curassow occupancy in the CBSS (Table 2). First, we tested each covariate alone and then we made additive models including two or three variables. We analyzed the occupancy models with the program Presence 3.1 (https://www.mbr-pwrc.usgs.gov/software/presence.html). Models were ranked and weighted in order of parsimony, using Akaike's Information Criterion [AIC; 29,30]. We designated models presenting a ΔAIC < 2 as the top candidate set with substantial evidence as competing models [30]. From those models, we considered covariates to be important if they had relatively high-summed Akaike weights and they outcompeted the null model [ψ(.), p(.)] with constant occupancy and detection to provide the most useful information regarding covariates that relate to Great Curassow occupancy.

Results

Our survey totaled 6356 trapnights of camera trap sampling in the CBSS between June 2009 and July 2011. We obtained 62 photos of Great Curassows on 56 occasions (occasion = 5-day aggregate) at 19 of the 38 sites, (i.e. naïve $\psi = 0.50$). Male individuals were documented in 24 of the photos and females documented in 34 of the photos for a sex ratio of 0.71:1. The remaining four individuals were juveniles. More specific information regarding group sizes, color morphs, and daily activity patterns are presented by Lafleur et al. [23].

No single model garnered most of the model support to explain Great Curassow occupancy. Eight of 19 *a priori* models had considerable support with ΔAIC < 2 (Table 2). Only two covariates were important because they met the criteria of gaining more model support than the constant model. Distance to village obtained a summed Akaike weight of 46% with a positive relationship with occupancy ($\beta_1 = 0.78 \pm 0.53$SE). Percent forest cover contributed 44% of the Akaike weight to the occupancy of the Great Curassow with a positive relationship between curassow occupancy and increasing forest cover ($\beta_1 = 0.02 \pm 0.01$SE). Forest management was also included in three of the top-ranked models with a negative association ($\beta_1 = -0.95 \pm 0.86$SE) with curassow occupancy, but it was not included in any models that outperformed the null model. Two covariates (distance to protected area and latitude) were not present in any top-ranked models for occupancy.

Among top-ranking models, detection probability ranged between 0.36 [C.I. = 0.30–0.42] and 0.37 [C.I. = 0.31−0.43]. Sampling effort was only included in one of the top models with a negative relationship to detection probability.

Discussion

There were eight possible models that received some support to predict the occupancy of the Great Curassow in the CBSS. We suggest the first two models best predict the curassow-landscape associations because they received more support than the constant model. Distance to nearest town had the greatest positive relationship to Great Curassow occupancy, suggesting that occupancy increases as the distance from human disturbance increases. This could be a result of hunting pressure exerted by humans, confirming its vulnerability to altered

Table 2. Model selection for *Crax rubra* occupancy in the San Juan-La Selve Biological Corridor, Costa Rica. Information presented for each model includes: the AIC values, AIC difference relative to the top model (ΔAIC), AIC weight (AIC *wi*, weight of evidence in favor of a given model), number of parameters (k), and model likelihood (−2Log-likelihood).

Model	AIC	ΔAIC	AIC *wi*	k	−2Log-likelihood
ψ(distance to village), p(.)	169.81	0.00	0.14	3	163.81
ψ(forest cover), p(.)	169.97	0.16	0.13	3	163.97
ψ(.), p(.)	170.39	0.58	0.10	2	166.39
ψ(forest management + distance to village), p(.)	170.49	0.68	0.10	4	162.49
ψ(forest management), p(.)	170.83	1.02	0.09	3	164.83
ψ(distance to village + forest cover), p(.)	171.14	1.33	0.07	4	163.14
ψ(forest management + forest cover), p(.)	171.31	1.50	0.07	4	163.31
ψ(distance to village), p(sampling effort)	171.80	1.99	0.05	4	163.80
ψ(distance to protected area + forest cover), p(.)	171.83	2.02	0.05	6	159.83
ψ(forest cover), p(sampling effort)	171.96	2.15	0.05	4	163.96
ψ(distance to village + forest cover + forest management), p(.)	172.25	2.44	0.04	5	162.25
ψ(.), p(sampling effort)	172.35	2.54	0.04	3	166.35
ψ(distance to protected area + distance to village), p(.)	172.56	2.75	0.04	6	160.56
ψ(forest management), p(sampling effort)	172.83	3.02	0.03	4	164.83
ψ(distance to village + forest cover), p(sampling effort)	173.13	3.32	0.03	5	163.13
ψ(forest management + forest cover), p(sampling effort)	173.31	3.50	0.03	5	163.31
ψ(distance to protected area), p(.)	173.72	3.91	0.02	5	163.72
ψ(distance to protected area + forest management), p(.)	175.39	5.58	0.01	6	163.39
ψ(latitude), p(.)	177.28	7.47	0.00	3	171.28

and accessible landscapes [11]. There is no reliable hunting data from across the corridor, but it is well known that the Great Curassow is an important hunting target in Costa Rica [6,8,10], Guatemala [31] and Mexico [11]. The observed sex ratio was biased toward females, which is similar to the observed sex ratio in Cozumel [32]. This sex ratio suggests that the population in the corridor may be hunted because breeding males have higher mortality rates than females due to their easy detection while displaying during the breeding season. Distant and largely inaccessible forest patches are also less affected by harvesting and extraction of biological material, and have less exposure to potential human-associated curassow predators such as domestic dogs (*Canis familiaris*) and cats (*Felis catus*).

Percent forest coverage was the second most important covariate, revealing a positive relationship with Great Curassow occupancy. This result suggests habitat fragmentation has a negative effect at a local scale and confirms that the cracid could be an appropriate indicator of habitat quality as previously suggested [e.g. 12]. These results correspond with those observed by Martinez-Morales [11] where settlements had negative effects and mature forest had positive effects on the abundance of the Great Curassow on the island of Cozumel, Mexico.

It has been suggested that selectively logged forest and timber plantations have species-specific impacts on bird communities [33]. In some cases, it could enhance the presence of some herbivores or generalist species because the regeneration process can increase availability of plant resources [34], but the effect can be contrary for insectivores [33]. Models including forest management were also part of the top-ranked curassow models. The negative association between forest management and curassow occupancy was opposite of our *a priori* hypothesis that selective logging could enhance food resource availability. However, we suspect that forestry practices might expose forests to more access for curassow hunting and other detrimental extractions because these sites were not necessarily protected.

The constant detection model was most supported with moderate detection probabilities. Future surveys would benefit from comparing detection probabilities derived from camera traps to point counts or line-transect surveys for Great Curassow. Camera traps are advantageous because they allow continuous monitoring in remote areas. We detected many more curassows (62 individuals) than most other published surveys using alternative techniques [11,14,15]. Point counts and line-transects have advantages in that researchers can survey larger areas (e.g. unlimited radius point counts) as opposed to the relatively small detection zone in front of the camera trap sensors. Additionally, researchers could conduct auditory surveys for curassows to assess their occurrence. Automated audio recorders could also provide useful information if researchers can distinguish curassows from other noise in recordings. However, comparisons of these methods will be necessary to aid researchers in future survey method selection. In particular, it would be beneficial to compare sex ratios among methods because aural surveys can be male-biased [14]. We recommend surveys might also benefit from using attractants, such as fruits or seeds, to further increase detection probability in front of camera traps.

Even though this project was originally planned for surveying mammals, the information gathered for the Great Curassow shows an important extension of this technique. Our results suggest that both camera traps and occupancy analysis are useful tools for the study of ground-dwelling birds and can provide useful data for the conservation status of those species. We obtained sufficient detections to conduct analyses, which allowed us to have consistent results showing logical positive or negative habitat relationships. These initial results give the first insight of the status of this bird in the corridor.

Conservation implications

The reported occurrence of this endangered bird in the corridor shows the value of maintaining this important linkage. Our results suggest that Great Curassow presence is related to high forest coverage and the absence of villages or people in the vicinity. Given that the species had an occupancy estimate over 50% we suggest that this bird is less rare than anticipated in the CBSS. We believe conservation of this species across the corridor is feasible, but further land cover changes and hunting need to be reduced or mitigated. Additionally, curassows might be invaluable seed dispersers in the reforestation process and we suspect that further surveys might reveal additional ecosystem benefits if the species colonizes secondary forests. Private reserves and ecolodges play an important role in maintaining suitable habitat for curassows and other biodiversity.

There was previously only one research project of Great Curassow populations in Costa Rica [35], so our study provides valuable baseline data to develop monitoring strategies for these populations. Designing and expanding these surveys will allow managers to calculate other parameters like extinction and colonization rates. Globally, there are many camera trap surveys for various taxa and we encourage researchers to report data associated with by-catch species because they can provide useful information for conservation managers and land owners.

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