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Population trends and viability of the critically endangered Cozumel Curassow: a 25-year perspective

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ABSTRACT
The Cozumel Curassow (*Crax rubra griscomi*) is a critically endangered endemic bird from Cozumel Island, Mexico. After it was believed to be extinct, it was rediscovered in 1994. Its population status was assessed in 1994–1995, and later in 2005, predicting a population decline over the next four decades. A new evaluation of its population size was carried out in 2017 and 2019. Some of the main factors that affect the population size of this cracid were identified with a generalized linear model. With a line transect sampling effort over 360 km, a population size of 499 ± 172 individuals was estimated in the tropical semi-deciduous forest occurring in the island, which was slightly higher compared to previous population evaluations. The distance to water bodies was significantly associated with the population size of the Cozumel Curassow, as well as the abundance of some species of fauna and flora. By modeling various scenarios, population viability was assessed over a period of 100 years, predicting a relatively stable population size with great variability depending on scenarios. However, as estimated in previous studies, given its small population size and continued threats, the Cozumel Curassow continues to be endangered.

RÉSUMÉ
Le grand hocco de Cozumel (*Crax rubra griscomi*) est une sous-espèce d'oiseau en danger critique endémique à l'île de Cozumel (Mexique). Alors qu'elle était considérée éteinte, elle a été redécouverte en 1994 et la taille de sa population a été estimé en 1994-1995 et en 2005, prédisant un déclin pendant les quatre décennies suivantes. Dans la foulée d'une nouvelle évaluation réalisée en 2017 et en 2019, un modèle linéaire généralisé a été utilisé pour déterminer les facteurs principaux affectant la taille de population de ce cracidé. Avec un effort d'échantillonnage linéaire sur plus de 360 km, la population a été estimée à 499 ± 172 individus dans la forêt tropicale semi-décidue de l'île, ce qui est légèrement supérieur aux estimations précédentes. La distance à un plan d'eau était significativement associée à la taille de population du grand hocco de Cozumel, ainsi qu'à l'abondance d'autres espèces fauniques et floristiques. En modélisant différents scénarios, la viabilité de la population a été évaluée sur une période de 100 ans, prédisant une relative stabilité, mais montrant une forte variabilité entre les scénarios. Toutefois, tel que suggéré par des études précédentes, le grand hocco de Cozumel demeurera en péril en raison de la petite taille de sa population et des menaces qui continuent de peser sur lui.

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Introduction

Cracidae is a family of vulnerable neotropical birds (Delacour and Amadon 1973). Among them, the Cozumel Curassow (*Crax rubra griscomi*) is an insular endemic bird exclusively linked to the tropical semi-deciduous forest of Cozumel Island, in the Mexican Caribbean (Martínez-Morales 1996, 1999). This cracid is listed as endangered according to the Mexican government (NOM-059; SEMARNAT 2010), due to its small population size (<500 individuals; Martínez-Morales 1996, 1999; Martínez-Morales et al. 2009). *C. rubra griscomi* was believed to be extinct until it was rediscovered in 1994 by Martínez-Morales (1996, 1999), who provided information on its population status as well as its habitat preference and conservation prospects. In 2005, Martínez-Morales et al. (2009) carried out a new evaluation of its population trend and viability, in which a severe decline was predicted for the next decades due to vulnerability to various factors.

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Among the factors that affect the Cozumel Curassow population is the impact of hurricanes, which modify the environmental conditions and ecological processes in the Cozumel Island ecosystem (Martínez-Morales 1999; Martínez-Morales et al. 2009; Perdomo-Velázquez et al. 2017). It has been documented that hurricane frequency, duration, and extent in the Caribbean basin have increased since the 1990s and that this trend could continue (Webster et al. 2005). The Cozumel Curassow is also threatened by the introduction of non-native predators, as it may have evolved in the absence of predators (Martínez-Morales and Cuarón 1999; Romero-Najera 2004; Valenzuela-Galván et al. 2022). Exotic species have increased in concordance with the growth of the local human population (Morales-Contreras et al. 2020; García-Arroyo et al. 2021), which in the last 20 years has increased by at least 70% (INEGI 2015). This is in addition to the 4 to 5 million tourists that Cozumel receives annually (Palafox-Muñoz and Collantes-Chávez 2009). Therefore, the pressures on the habitat of the Cozumel Curassow have increased, including land-use use change from forest to housing complexes and hotels, and illegal hunting. Habitat loss and fragmentation make the island less resilient to extreme meteorological phenomena. In addition, the densification of the road network fragments the vegetation and leads to frequent collisions (Fuentes-Montemayor et al. 2009; Morales-Contreras 2020). Another threat is the exploitation and contamination of freshwater, which is essential for the prevalence of this cracid (Martínez-Morales 1999; Martínez-Morales et al. 2009).

The Cozumel Curassow could be key in forest functioning as it disperses seeds, which help tropical forest regeneration (Rivas 1995; Bovo et al. 2018). Due to its large size, *Crax rubra* is an important part of the diet of some predators (mammals, birds, reptiles; Chinchilla 1997). Even for the human population that overlaps with its distribution, it has been a source of protein since pre-Columbian times (Herrera-Flores and Marku-Götz 2014).

The objectives of this study were (1) to evaluate if the density and population size of the Cozumel Curassow have changed compared to previous estimates from 1995 and 2005 (Martínez-Morales 1999; Martínez-Morales et al. 2009); (2) to analyze the effects that some environmental and anthropogenic variables have on population size; and (3) to analyze population viability by modeling population trends under different scenarios and ecological conditions. This information is valuable for the development of management and conservation strategies for the Cozumel Curassow.

Material and methods

Study area

Cozumel Island is located 17 km off the east coast of the Yucatan Peninsula (20° 26′N, 86° 55′W). It is the largest island of coralline origin in the Mexican Caribbean (c. 480 km^2). It is the Mexican island with the highest number of endemic taxa; more than 40 have been registered (Cuarón 2009). Cozumel Island has important coastal lagoons to the north and south, but due to its karst nature, it does not have rivers or lakes. However, there are water bodies on the island, such as *aguadas* (temporary retention) and *cenotes* (sinkholes, geomorphological structures; Martínez-Morales 1999). The rainy and hurricane season is from May to November. Hurricanes are probably the main abiotic factors that affect the structure and composition of the island's vegetation and ecosystems (Martínez-Morales et al. 2009; Perdomo-Velázquez et al. 2017).

The main vegetation types on Cozumel Island are tropical semi-deciduous forest, low tropical deciduous forest, mangrove, *tasistal*, and halophilic vegetation (Cuarón 2009). The tropical semi-deciduous forest is the most extensive vegetation type, covering an area of approximately 310 km^2 (Romero-Nájera 2004). It is made up of two types of arboreal strata that range from 8 to 20 m in height; a portion of the understory has species in the juvenile stage of the arboreal stratum. The low tropical deciduous forest exhibits two strata, arboreal and shrub (Tellez-Valdéz and Cabrera 1987; Tellez-Valdéz et al. 1989). Mangrove vegetation ranges from 5 to 10 m in height (Tellez-Valdéz et al. 1989). Low tropical deciduous forests and mangroves are distributed around the tropical semi-deciduous forest. Cozumel Island presents areas of secondary vegetation due to the destruction of primary vegetation by natural disturbances (hurricanes) and human activities (Romero-Nájera 2004).

Sampling sites

To generate data comparable with the evaluations carried out in 1995 and 2005 (Martínez-Morales 1999; Martínez-Morales et al. 2009), the estimation of the abundance and population density of the Cozumel Curassow was carried out using the distance sampling method (Buckland et al. 1994). In 2017, 14 transects of 1–3 km length were established, separated by at least 0.5 km, for a total of 23.9 km. In 2019, two more transects were added for a total of 16, with a total length of 29.8 km. The length of each transect was determined by the characteristics of the terrain and the presence of pre-existing transects in each area of the island.

Transects were in Cozumel's three main vegetation types: 22.1 km in tropical semi-deciduous forest, 7.2 km in low tropical deciduous forest, and 0.5 km in mangrove. To include environmental heterogeneity in each type of vegetation, transects were established at different distances from roads, human settlements, and water bodies.

Each cluster of transects was sampled monthly by the same observer and a field assistant, in 2017 (14 transects per month), from June to November, and in 2019 (16 transects per month), from January to September. Surveys were conducted between 06:00 and 13:00 hrs. For every bird detected, plumage characteristics, size of swollen knob on bill, sex, age (when possible), geographic coordinates, date, and time were recorded to avoid duplication of records on the transects. Additionally, the precise perpendicular distance to the detection of the individual or group of individuals was measured; a tape measure was used for perpendicular distances less than 7 m and a rangefinder for lengths greater than 7 m. Binoculars were used to aid observations. Total sampling effort was 360.4 km. In the same journey, data on fauna were collected simultaneously. In order not to violate the distance sampling assumptions, on the walk back, data on tree species were collected using the same method.

Spatial reference for each abiotic variable and Euclidean distances between Cozumel Curassow records and human settlements and water bodies (*cenotes* and *aguadas*) were obtained with the ArcMap 10.5 software. These variables were considered under the hypothesis that distance to human settlements and exotic fauna negatively affect the population of the Cozumel Curassow, while water sources and availability of tree species that are part of the bird's diet will have a positive effect on the population (Table 1; for details see Martínez-Morales 1996; Martínez-Morales and Cuarón 1999; Martínez-Morales et al. 2009; Ortega-Gamboa 2019).

Data analysis

The estimation of the density and population size of the Cozumel Curassow was carried out with the Distance 7.3 software (Thomas et al. 2010). Due to the number of detections, the two collection seasons (2017–2019) were combined in the analysis. Since it was possible to distinguish the phenotypic characteristics between individuals, the detections remained as independent events, as well as the distance data of the repeated transect visits. Two records were removed for the analysis because they did not comply with these assumptions. The detection function selected by the program Distance based on the Akaike Information Criterion was a model with a uniform key function with simple polynomial adjustment. The effective strip half-width obtained to estimate the Cozumel Curassow density was 19 m. To determine if there was a difference between the density estimates and the encounter rate of the three evaluations (1994–1995, 2005, and 2017–19), an ANOVA was performed with a significance level of 95%, as well as the Tukey test to identify differences between groups.

A generalized linear model (GLM) was performed to test whether the abundance of tree species individuals (*Bursera simaruba, Brosimum alicastrum, Cecropia obtusifolia, Cordia dodecandra, Manilkara zapota, Metopium brownei, Pouteria campechiana, Sideroxylon foetidissimum, Vitex gaumeri*) influence the abundance of the Cozumel Curassow. A generalized linear mixed model (GLMM; Poisson distribution and log link function) was used to test whether the abundance of endemic and exotic fauna individuals (*Nasua nelsoni, Pecari tajacu nanus, Canis familiaris, Dasyprocta punctata, Odocoileus*

Table 1. Description of the biotic, abiotic and anthropogenic variables used, and hypothesized effect on Cozumel Curassow population size.

Variable	Type	Description	Hypothesized effect on Cozumel Curassow population size
Animal species abundance	Biotic	Abundance of two native mammal species (*Nasua nelsoni; Pecari tajacu nanus*), three exotic mammal species (*Canis familiaris; Dasyprocta punctata; Odocoileus virginianus*), and one exotic reptile species (*Mastigodryas melanolomus*) within transect.	Negative effect: Exotic species and continental congeners of native species have been introduced on the island, some could act as predators or competitors.
Tree species abundance	Biotic	Abundance of nine tree species (*Bursera simaruba; Brosimum alicastrum; Cecropia obtusifolia; Cordia dodecandra; Manilkara zapota; Metopium brownei; Pouteria campechiana; Sideroxylon foetidissimum; Vitex gaumeri*) within transect.	Positive effect: The Cozumel Curassow has been recorded using several of these tree species
Distance to water bodies	Abiotic	Minimum Euclidean distance of Cozumel Curassow records to water bodies.	Positive effect: There is evidence that the Cozumel Curassow stays close to water bodies
Distance to human settlements	Anthropogenic	Minimum Euclidean distance of Cozumel Curassow records to human settlements.	Negative effect: The Cozumel Curassow is an elusive species

virginianus, Mastigodryas melanolomus) was associated with the abundance of the Cozumel Curassow. In this model, the year of data collection and transect identity were included as random factors. Finally, a GLM (Poisson distribution and log link function) was carried out to test whether the distance to water bodies and human settlements was associated with the abundance of the Cozumel Curassow. For this model, the distance between each record of the Cozumel Curassow and the explanatory variables (water bodies and human settlements) was considered every 250 meters. All statistical analyzes were performed in R v.3.5.3 (R Core Team 2019). GLMMs were built using the lme4 package (Bates et al. 2015). The selection of models was carried out following the procedure proposed by Zuur et al. (2009), in which all explanatory variables are included in the first model and if some explanatory variable are unimportant ($P > 0.05$) they are dropped from the final model.

The Vortex software (version 10.3.8; Lacy and Pollak 2020) was used to perform the population viability analysis (PVA). The parameters were selected following the characteristics of the PVA carried out by Martínez-Morales et al. (2009; Appendix 1). The only variable that was modified from this protocol was the initial population size, as the density estimate obtained in this evaluation was used. The previous population sizes of 1995 and 2005 were also considered, parameters such as age were maintained, which was considered a stable distribution. In addition, with prior knowledge of the monogamy of the Cozumel Curassow, it was assumed that 95% of the fertile males reproduced effectively in one year. In this context, it was assumed conservatively that reproductive age spans from 2 to 12 years. It was considered that 95% of females lay two eggs and 5% only one, and the sex ratio at birth was 1:1. The maximum potential population size of 1550 individuals for the semi-deciduous forest (310 km^2) was considered as the carrying capacity. These unmodified features were used for the base scenario. Simulated scenarios to determine the probability of extinction of the Cozumel Curassow were: (1) increase or (2) decrease in the probability of hurricanes; (3) increase or (4) decrease in carrying capacity; (5) increase in mortality rate; and (6) population supplementation from a captive breeding program. The features that were modified for each scenario are explained in Appendix 1.

Results

Population density and size

During the sampling period in 2017 and 2019, 14 records (18 individuals) were obtained for the Cozumel Curassow, 10 of which were during transect samplings and the other four were incidental records (i.e., outside of systematic transect sampling). All records were obtained in the tropical semi-deciduous forest and only in five of the transects (Figure 1). A population density of 2.01 ± 0.70 individuals/km^2 and population size of 499 ± 172 were estimated for the entire tropical semi-deciduous forest area on Cozumel. The estimated Cozumel Curassow density in 2017 and 2019 indicates that the population trend remained relatively stable and was slightly higher in comparison with the 1995 and 2005 data (Martínez-Morales 1999; Martínez-Morales et al. 2009; Table 2). The ANOVA revealed that there was a statistically significant difference in mean Cozumel Curassow density between the three sampling periods ($F(2, 15) = [11.81]$, $P = 0.00083$). Tukey's HSD test for multiple comparisons indicated that mean density was significantly different between 2017–2019 and 1995 ($P = 0.001$, 95% C.I. = [0.512, 0.812]), and between 2017–2019 and 2005 ($P = 0.003$, 95% C.I. = [0.327, 1.652]).

In terms of the proportions of sexes and age classes, 10 males were observed, of which three were juveniles (based on the size of the swollen knob on the bill). Eight females were also registered, of which two were juveniles (based on the coloration and wear of their feathers). Small groups of 2 to 3 individuals made up of males and females were observed in 21.5% of the records (n = 3) and the rest were solitary individuals (78.5%, n = 11). The maximum number of sightings was made from 06:00 to 12:00 hrs, at perpendicular distances of 0 to 10 m. Most records were made between March and September (n = 10). Transects with the most records were in the central area of the island, in El Cedral, and in the southeast area of the island, in Punta Chiqueros.

Biotic, abiotic, and anthropogenic variables

Only one tree species (*Brosimum alicastrum*) had a significant relationship with the Cozumel Curassow (Table 3; Figure 2). In addition, Cozumel Curassow records showed a positive relationship with *Nasua nelsoni* and *Dasyprocta punctata*, and a negative relationship with *Odocoileus virginianus* and *Pecari tajacu nanus* (Table 4; Figure 2). Euclidean distances between Cozumel Curassow records and water bodies (*cenotes* and *aguadas*), were less than 750 m, whereas the distance to human settlements was up to 4 km. However, only the distance to water bodies was significant, as most of the records were within 250 m (Table 5; Figure 2).

Population viability analysis

The population viability analysis predicted a slight increase in population size compared to the baseline

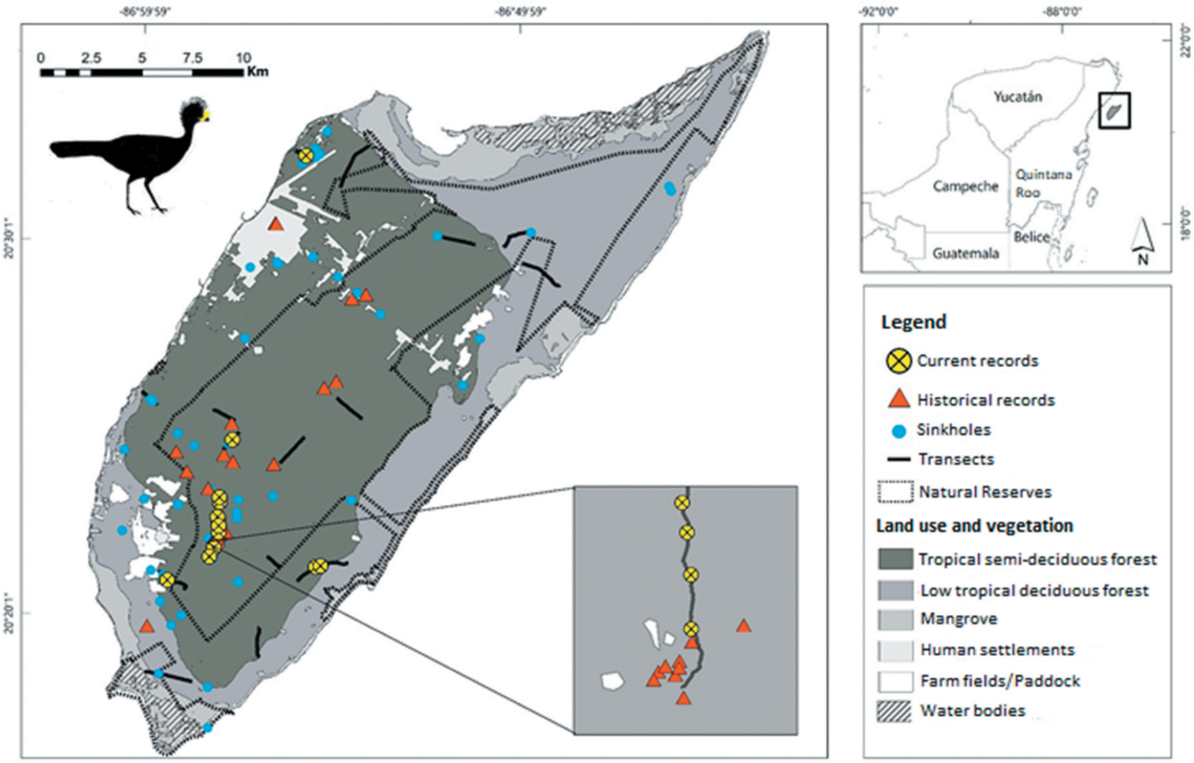

Figure 1. Location of the sampling transects. Also shown are the current and historical records of the Cozumel Curassow, the main vegetation types, the location of state reserves, water bodies and human settlements.

Table 2. Cozumel Curassow evaluated parameters. The evaluation periods correspond to 1995 (October 1994 to June 1995; Martínez-Morales 1996, 1999); 2005 (July to November; Martínez-Morales et al. 2009), 2017 and 2019 (June to November 2017, and January to September 2019; this study).

	Sampling period		
	Oct 1994-June 1995	July-Nov 2005	June-Nov 2017 Jan-Sept 2019
Records	17	14	14
Females	9	9	6
Males	8	5	8
Sampling effort (km)	386	217	360
Encounter rate	0.04 ± 0.01	0.03 ± 0.01	0.03 ± 0.01
Density (individual/km^2)	0.87 ± 0.28	1.02 ± 0.42	2.01 ± 0.70
Population size	304 ± 98	417 ± 171	499 ± 172

scenario, in which the calculated maximum population size was 767 individuals in 100 years (Figure 3). Four of the simulated scenarios suggest that the Cozumel Curassow population is at a point where the probability of recovery is greater than that of extinction. These include, in order of importance, a reduction in the probability of hurricanes, an increase of the carrying capacity, population supplementation from a captive breeding program, and the baseline scenario. A stable population is expected in the case of a reduction of the carrying capacity. In contrast, the population would decline towards extinction if there is an increase in the probability of hurricanes or an increase in mortality rate resulting from factors such as illegal hunting.

Discussion

Population abundance and density

Despite the importance of long-term systematic population monitoring of endangered bird species, few assessments are long-term, representative, and comparable (Villaseñor-Gómez and Santana 2003). Therefore, the relevance of monitoring the Cozumel Curassow through three evaluations over 25 years makes this study unique and could be fundamental in the development of conservation proposals for other cracids or Neotropical species.

The population trend of the Cozumel Curassow remains relatively stable; it is expected to increase slightly but there is uncertainty around the estimate, which could be a statistical artifact as a consequence of the standard error in the estimation of density. Despite a greater sampling effort, the number of registered

Table 3. Results of the GLM of the relationship between tree species within transects and presence of Cozumel Curassow individuals.

Species	Estimate	Standard Error	Z	*P*
Manilkara zapota	−0.017	0.012	−1.42	0.155
Metopium brownei	−0.006	0.007	−0.979	0.327
Pouteria campechiana	0.033	0.017	1.949	0.052
Sideroxylon foetidissimum	0.025	0.073	0.352	0.724
Vitex gaumeri	0.047	0.035	1.346	0.178
Brosimum alicastrum	0.068	0.011	6.233	<0.001
Bursera simaruba	−0.01	0.012	−0.994	0.32
Cecropia obtusifolia	−0.028	0.082	−0.339	0.734
Cordia dodecandra	0.034	0.178	0.192	0.848

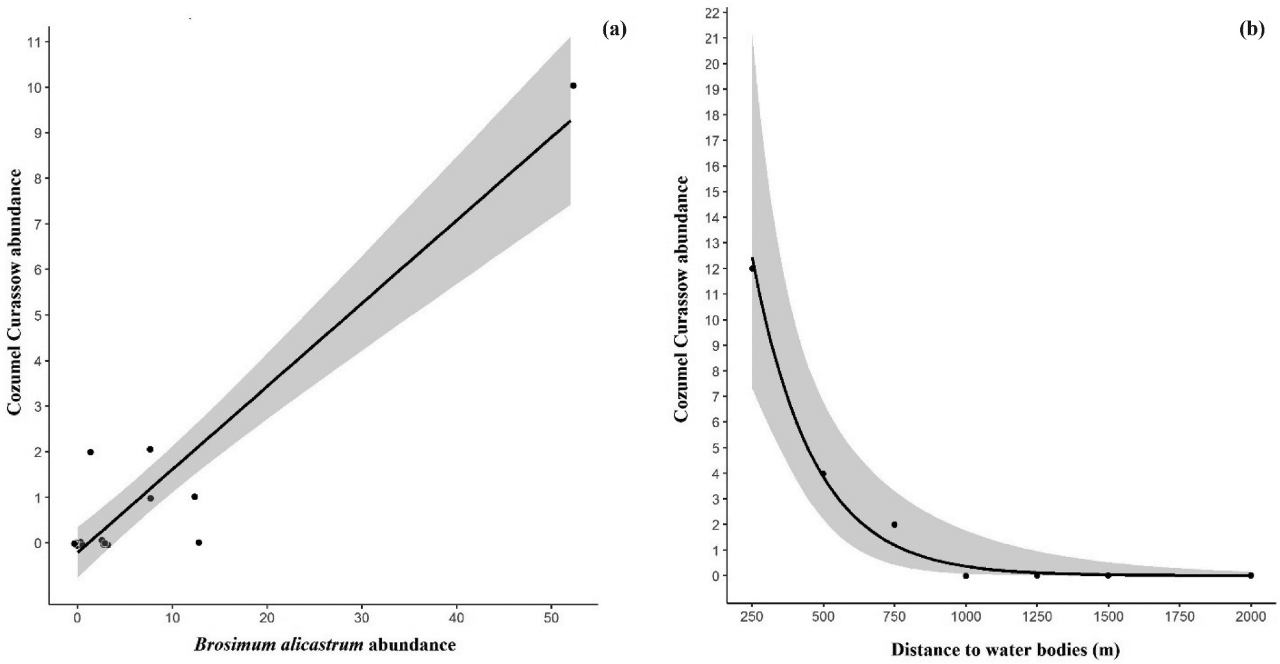

Figure 2. Relationship between the abundance of Cozumel Curassow and *Brosimum alicastrum* abundance (A) and the Euclidian distance to water bodies (B).

Table 4. Results of the GLMM of the relationship between Cozumel Curassow presence and faunal species on Cozumel Island.

Species	Estimate	Standard error	Z	*P*
Canis familiaris	−0.372	1.237	−0.301	0.764
Nasua nelsoni	0.044	0.003	13.06	<0.0001
Dasyprocta punctata	0.112	0.003	32.61	<0.0001
Odocoileus virginianus	−0.114	0.00	−33.24	<0.0001
Pecari tajacu nanus	−0.068	0.003	−19.69	<0.0001
Mastigodryas melanolomus	0.149	0.437	0.341	0.733
Random effects	**Variance**	**Standard. deviation**		
Transect ID	2.558	1.559		
Monitoring year	0.00008	0.009		

individuals was similar to those obtained in previous evaluations. This could be due to the evasive behavior of the Cozumel Curassow.

The density of the Cozumel Curassow is low compared to some population evaluations on the mainland. For example, in Punta Manabique, a protected area in Guatemala, a density of 4 individuals/km^2 was estimated (Eisermann 2004). Baur (1998) reported a density of 4.75 individuals/km^2 in a forest area in Guatemala. In both places there were indications of hunting. Polisar et al. (1998) recorded a density of 6.35 individuals/km^2 for a population in Tikal, Guatemala, where hunting is prohibited, likely benefitting the Curassow population. In contrast, a density of 0.4 to 1.2 individuals/km^2 was

Table 5. Results of the GLM of the relationship between the presence of Cozumel Curassow individuals and the Euclidian distance to human settlements and water bodies.

Variable	Estimate	SE	Z	*P*
Distance to human settlements	−0.00001	0.000017	−0.108	0.914
Distance to water bodies	−0.004	0.0011	−3.94	< 0.0001

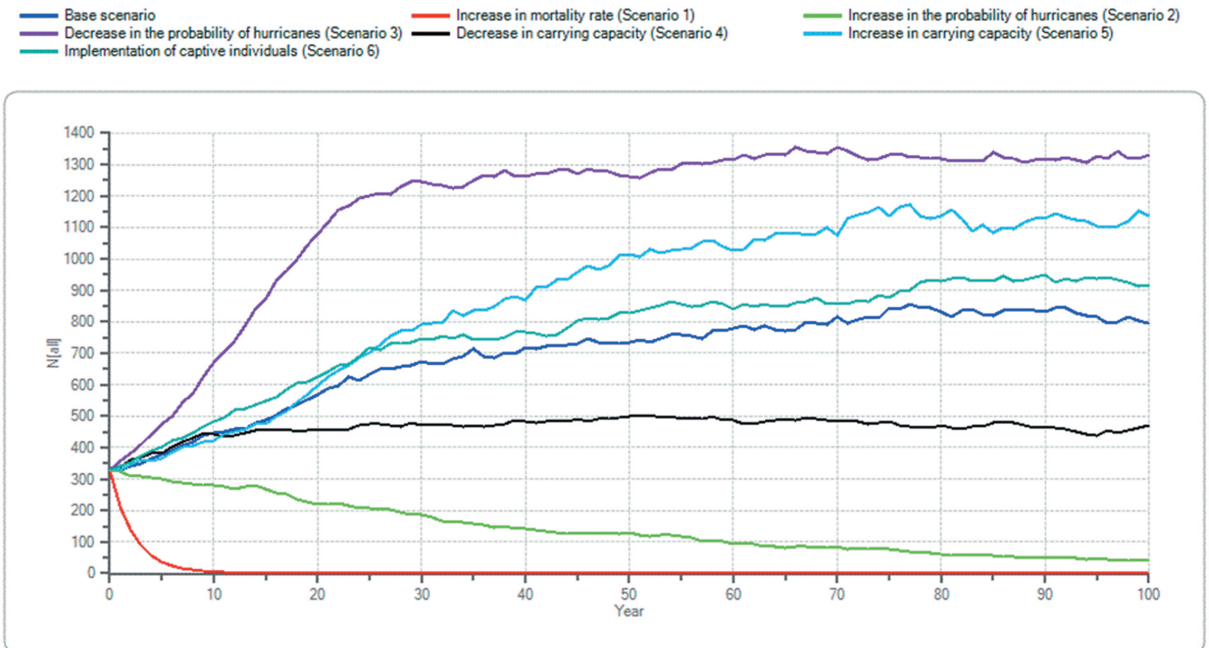

Figure 3. Population viability analysis over a period of 100 years for different scenarios.

reported for Costa Rica by McCoy (1997), which is lower than that of the Cozumel Curassow. In general, our population density estimates are among the lowest for any species in the Cracidae family, which are around 20 individuals/km^2 (Chalukian 1997; Ríos et al. 2005; Bertschand and Barreto 2008; Kattan et al. 2016), even in places where hunting exists (Terborgh et al. 1990; Bezerra et al. 2019). The density of the Cozumel Curassow continues to be among the lowest for the family. Low population size could lead to other pressures, such as inbreeding depression and loss of biological fitness (Hedrick 2011).

All the Cozumel Curassow records were linked to the tropical semi-deciduous forest, even those outside of the sampling period, and in past evaluations (Martínez-Morales 1999; Martínez-Morales et al. 2009). In the present study, all the sightings were in five of the 16 transects located in the center and southeast sections of the island, except for an observation of a male to the north (the first record in that area). As reported for mainland cracids (Kattan et al. 2016), it is possible that the Cozumel Curassow does not present habitat selection plasticity, explaining why its presence is limited to tropical semi-deciduous forest. Such affinity or dependence could be the result of different ecological and evolutionary processes, such as competition, predation, or association and interaction with other species such as the tree species considered in this evaluation (Solomon 1949; Bezerra et al. 2019; Ortega-Gamboa 2019). Restriction to a vegetation type could also represent a habitat specialization that influence vulnerability (Brooks 1998), in addition to the fact that the Cozumel Curassow is endemic to the island. Hence, documenting habitat specialization is essential to conserve the Cozumel Curassow population (Martínez-Morales 1999). Understanding habitat use contributes to reduce knowledge gaps in the biology of the species. In turn, the evaluation of biotic, abiotic, and anthropogenic factors that affect the population of this cracid will help better understand its population and its trends.

The nine tree species used as explanatory variables present a diversity of fruits with different colors and shapes, from drupes to small berries. These species also have the highest Importance Value Index (IVI) according to Ortega-Gamboa (2019), that is, species that give broad plant structure to the Cozumel Island ecosystem.

However, these nine species are only an approximation to the vast range of woody species that could be used by the Cozumel Curassow (Martínez-Morales 1996).

A single species was identified to have a significant effect on Cozumel Curassow abundance: *Brosimum alicastrum*. This result coincides with Rivas (1995), who found that *B. alicastrum* accounted for a quarter of the fruits in the crops of 43 individuals from the Peten Maya Reserve in Guatemala. The high availability of the species (it has several long fruiting periods per year), its anatomical characteristics (the testa that surrounds the seeds protects them for a long time), the nutritional conditions of the fruits and the large DBH of this tree are factors that probably explain high consumption by the Cozumel Curassow (Pennington and Sarukhán 2005). Additionally, local hunters corroborated that *B. alicastrum* is highly consumed by this cracid species (Rivas 1995). Similarly, Sermeño (1997) studied the feeding and reproduction of *C. rubra* in El Salvador through direct observation of individuals for three years (1977–1979) and identified the use of *B. alicastrum* for nesting and feeding.

It is worth noting that Martínez-Morales (1999), in the first Cozumel Curassow study, evaluated vegetation characteristics using plots (200 x 40 m) along the majority (eight of 10) of his established transects and did not report a relationship with *Brosimum alicastrum*, possibly because this species was not bearing fruit during the study season. Martínez-Morales (1999), mentions that *B. alicastrum* is closely associated with *cenotes* and that if there was a statistical relationship between these two species, it may have been biased as plots close to cenotes were removed from his analysis to avoid bias. It should be noted that in the present evaluation all the records of trees along each transect were used, so our data can be considered for statistical analysis. It should also be considered that when Martínez-Morales (1999) carried out his study, *cenotes* and water bodies were not georeferenced as they were in this study. Therefore, the *Brosimum alicastrum*-Cozumel Curassow relationship could be important for conservation strategies. However, the results presented here should be considered with caution due to the possible leverage effect of a single outlier (Figure 2).

Martínez-Morales (1999) mentions that the Cozumel Curassow's relationship with *M. zapota* and *S. foetidissimum* trees is greater where the largest trees (DBH ≥ 29 cm) are found. Although *Bursera simaruba* and *Metopium brownei* are the most abundant tree species on Cozumel Island (Morales-Contreras 2020), their presence was not related to Cozumel Curassow abundance, although they are used by many bird species in the Yucatan Peninsula (e.g., Scott and Martin 1984). Similarly, *Cecropia obtusifolia* did not show any relationship with the Cozumel Curassow, despite being a common tree whose fruits are consumed by both specialized and opportunistic frugivorous species. The fruits of *C. obtusifolia* contain a moderate amount of proteins and lipids, compared to other species of the *Moraceae* and *Lauraceae* families, which are recognized as important feeding sources for Curassows (Estrada et al. 1984; Sermeño 1997).

Ortega-Gamboa (2019) reported that there is greater competition among Cozumel Island frugivorous species for fruits in the understory than for those in the canopy. Therefore, with the increasing number of non-native fauna species on the island, the Cozumel Curassow could be affected by competition for the same resources with other animal species. This effect could be direct since this bird seeks its food mainly on the ground.

For the case of associated fauna, *Odocoileus virginianus* had an effect on the Cozumel Curassow population, possibly by direct competition (Ortega-Gamboa 2019). During field-work, *O. virginianus* were observed feeding on the shoots of *Brosimum alicastrum*. The introduction of this ungulate on the island represents a significant threat to biodiversity. Likewise, a negative relationship was identified between the endemic *Pecari tajacu nanus* and the Cozumel Curassow, possibly reflecting competition for *M. zapota* and *S. foetidissimum*, and for space because both species are foraging in the understory (Rivas 1995; Ortega-Gamboa 2019). *Nasua nelsoni* (a Cozumel endemic species) and *Dasyprocta punctata* (a non-native species) present a type of relationship with the Cozumel Curassow. Ortega-Gamboa (2019) reported through canonical correlation analysis that these species are associated with the use of *M. zapota, P. campechiana* and *S. foetidissimum*. *Nasua nelsoni* has greatly increased its population since 1995 (Martínez-Morales 1996; Caballero-Cruz 2007; Morales-Contreras 2020), which may generate greater competition for resources with the Cozumel Curassow, as their diets include similar species. Furthermore, this procyonid is a mesopredator known to feed on young birds or eggs (Valenzuela-Galván 1998).

One potential important co-occurring species is *Leopardus wiedii* (margay), a potential predator (Valenzuela-Galván et al. 2022). However, we could not include it in our analysis as it was only observed once during sampling, on the transect with the greatest number of Cozumel Curassow records. This could be due to the nocturnal activity pattern of the margay and to its evasive behavior (Cinta-Magallón et al. 2012), but also to its fairly recent presence on the island (Valenzuela-Galván et al. 2022). Pérez-Irineo and Santos Moreno (2017) evaluated the population status of *C. rubra* in a mountainous region in southern Mexico and found that the probability of *C. rubra* detection was higher in sites with more records of a potential predator, *L. wiedii*. The authors suggested two possible hypotheses to explain this association: similarity in habitat use and predation. Although there are no reports of *C. rubra* being a part of the diet of *L. wiedii*, there are records of other cracids in their feces (Cinta-Magallón et al. 2012). It is also important to consider that the presence of feral dogs could harm the Cozumel Curassow population, as they are a potential prey for dogs (Martínez-Morales 1999; Bautista 2006; Caballero-Cruz 2007). This has been reported for other Cozumel native species (e.g., *Pecari tajacu nanus, Procyon pygmaeus, Nasua nelsoni*; Cuarón et al. 2004; Cuarón 2009; Palacios-Aldana 2017).

In terms of abiotic and anthropogenic factors, our analyses showed that water bodies are a significant factor explaining the abundance of the Cozumel Curassow. This result coincides with those obtained by Martínez-Morales (1996, 1999) and Caballero-Cruz (2007), whose Curassow records were also not more than 700 m away from water bodies. Cozumel Island is karstic, which means that cavities are formed where a large amount of water is stored in the rainy season, making available water reservoirs in the dry season. This could modify the distribution and abundance of the Cozumel Curassow between seasons. On the other hand, most human settlements were more than 4 km from our sightings, so there was likely little influence of that factor on Curassow population. However, this reflects the importance of conserving the habitat of Cozumel Curassow.

Between 2005 and 2019, no major hurricanes (category > 3) passed over or near Cozumel Island, which could explain a stable population. Compared with the evaluation carried out in 1994–1995, when the population density did not exceed 1 individual/km^2, only six years had elapsed since the impact of hurricane Gilbert (category 5; 1988), one of the most severe and devastating recorded hurricanes. After completing fieldwork for the 1995 Cozumel Curassow population assessment, the island was affected by Hurricane Roxana (category 3), which greatly threatened the viability of the already vulnerable and reduced Cozumel Curassow population.

After 10 years, Cozumel Island was impacted by hurricanes Emily and Wilma (both category 5, 2005) during the Cozumel Curassow population assessment. Wilma was one of the most devastating hurricanes to have occurred in the Caribbean and caused a great impact on the Cozumel Curassow population (Caballero-Cruz 2007). Hurricanes are one of the main factors that generate disturbances in Caribbean Island ecosystems, and they are an important regulator of flora and fauna populations (e.g. Perdomo-Velázquez et al. 2017), including the Cozumel Curassow. The effect of climate change on hurricanes on Cozumel Island (increased frequency, duration, and magnitude) could have an important influence on the population trend of the Cozumel Curassow. It should thus be included as a key factor in conservation strategies (Martínez-Morales 1996; Webster et al. 2005). Some of the conservation strategies that have emerged to preserve the habitat and make the Cozumel ecosystem more resilient are the creation of natural protected areas. Based on the official Regional Land-use Plan for the Municipality of Cozumel (*Programa de Ordenamiento Ecológico Local*; SEDUMA 2008), the *Reserva Estatal Selvas y Humedales de Cozumel* (Tropical Forests and Wetlands of Cozumel State Reserve) was created in 2011 (19, 846 ha; POQROO 2011; Cuarón et al. in press), while the *Área de Protección de Flora y Fauna Isla de Cozumel* (Cozumel Flora and Fauna Protection Area) was created in 2012 (37, 829 ha; DOF, 2012; Cuarón et al. in press).

Despite the limitations of the population viability analysis method (Reed et al. 1998), its use continues to be key in decision-making for conservation and categorization in the IUCN. Our population viability analysis estimated an average population size limit of 727 individuals, which showed an increase compared to the previous PVA (< 400 individuals). Therefore, the population could be in a recovery process reflecting the long period since the previous hurricanes, and/or the effectiveness of habitat protection on the island. This population size, however, is still low compared to the effective proposed population size of 4,500 individuals from a genetic perspective (Frankham 1995), or the average of 5,816 individuals for vertebrates (Reed et al. 2003), or 3,742 individuals for birds (Traill and Bradshaw 2007). The population density of 2.01 individuals/km^2 estimated in the present study is low compared to Martínez-Morales' (1999) assertion that to assume the population of the Cozumel Curassow as healthy, it should have at least 5–8 individuals/km^2 and a population between 1,700 and 3,400 individuals. Therefore, the low population density estimated in this study supports the categorization of the Cozumel Curassow as 'endangered' in Mexican regulations (SEMARNAT, 2010). Its small population size, restricted distribution, and continued vulnerability to numerous threats, justify that the Cozumel Curassow is considered Critically Endangered (CR) according to the IUCN system. Yet, its slight population recovery provides grounds for optimism.

Recommendations

It is necessary to create a captive breeding program for the Cozumel Curassow, to at least have a backup population to conserve its genetic pool. It is also important to continue conserving significant continuous areas of tropical semi-deciduous forest on the island, and to maintain the structure of the forests to preserve the sites with the longest-living trees. This will favor ecosystem resilience in the face of extreme meteorological phenomena and could even be an action for adaptation to climate change. In addition, it is important to carry out population control and, ideally, eradications of exotic species, especially those considered as predators (*C. familiaris* and *L. wiedii*) and competitors (*O. virginianus* and *D. punctata*) of the Cozumel Curassow. It is also important to carry out actions that prohibit illegal hunting to avoid the population decline of the Cozumel Curassow and other endemic taxa of Cozumel Island. The accelerated increase in the human population on Cozumel Island has brought with it serious problems regarding the island's water resources, both the abrupt exploitation of the water stored in the aquifers, and their contamination (Coronado-Alvarez et al. 2011). For this reason, a stricter control of the management of this natural asset becomes necessary, as the island's biota, as well as the human population, depend on the availability of water with good quality and quantity.

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References

Bates D, Mächler M, Bolker B, Walker S. 2015. Fitting linear mixed-effects models using lme4. J Stat Softw. 67(1):1–48. doi:10.18637/jss.v067.i01.

Baur E 1998. Final report: study of subsistence hunting in the forestry concession of Carmelita, San Andrés, Petén. Unpublished report. Flores (Guatemala): Propetén-Conservation International.

Bautista SM. 2006. Distribución, abundancia y dieta de perros y gatos ferales en la Isla Cozumel [Master's thesis]. Veracruz (México): Instituto de Ecología, A. C.

Bertschand C, Barreto GR. 2008. Abundancia y área de acción del paují de copete (*Crax daubentoni*) en los llanos centrales de Venezuela. Ornit Neotr. 19:287–293.

Bezerra DMM, Simoes CR, Barros de Araujo C, Machado CCC, Alves RRN, Pereira de Araujo HF. 2019. Habitat use, density and conservation status of the white-browed guan (*Penelope jacucaca* Spix, 1825). J Nat Conserv. 51:125733. doi:10.1016/j.jnc.2019.125733.

Bovo AAA, Ferraz KMP, Magioli M, Alexandrino ER, Hasui E, Ribeiro MC, Tobias JA. 2018. Habitat fragmentation narrows the distribution of avian functional traits associated with seed dispersal in tropical forest. Perspect Ecol Conserv. 16:90–96.

Brooks DM. 1998. Habitat variability as a predictor of rarity in large Chacoan mammals. Vida Silvestre Neotropical. 7:115–120.

Buckland ST, Anderson DR, Burngham KP, Laake JL. 1994. Distance sampling: estimating abundance of biological populations. London (UK): Chapman and Hall.

Caballero-Cruz P. 2007. Estado de conservación de *Crax rubra griscomi* en la Isla de Cozumel, México: evidencia empírica y modelos predictivos [Bachelor's thesis]. Hidalgo (México): Universidad Autónoma del Estado de Hidalgo.

Chalukian S. 1997. Estudio preliminar de la pava de monte (*Penelope obscura*) en el parque nacional El Rey, Argentina. In: Strahl SD, Beaujon S, Brooks SM, Begazo AJ, Sedaghatkish G, Olmos F, editors. The Cracidae: their biology and conservation. New York: Hancock House Publishers; p. 64–69.

Chinchilla FA. 1997. La dieta del jaguar (*Panthera onca*), el puma (*Felis concolor*) y el manigordo (Felis pardalis) (Carnivora: Felidae) en el Parque Nacional Corcovado, Costa Rica. Rev Biol Trop. 45:1223–1229.

Cinta-Magallón CC, Bonilla Ruz CR, Alárcon CI, Arroyo-Cabrales J. 2012. Dos nuevos registros de margay (*Leopardus wiedii*) en Oaxaca, México, con datos sobre hábitos alimentarios. UNED Res J. 4(1):33–40. doi:10.22458/urj.v4i1.131.

Coronado-Alvarez L, Gutierrez-Aguirre MA, Cervantes-Martinez A. 2011. Water quality in wells from Cozumel Island, Mexico. Trop Subtrop Agroecosyst. 13:233–241.

Cuarón AD. 2009. Cozumel. In: Gillespie RG, Clague DA, editors. Encyclopedia of islands. Berkeley: University of California Press; p. 203–206.

Cuarón AD, Bojórquez-Tapia LA, González-Baca C, Martínez-Morales MA, Valenzuela-Galván D, Vázquez-Domínguez E, Vázquez L-B. inpress. Isla Cozumel, biodiversidad, conservación y desarrollo sustentable. In: Rivera Arriega R, Azuz Aseath I, editors. La Ciencia que necesitamos para el océano que México quiere: la década del océano 2021-2030. Sección 7: gestión Sustentable de Islas. Campeche: Universidad de Campeche.

Cuarón AD, Martínez-Morales MA, McFadden KW, Valenzuela D, Gompper ME. 2004. The status of dwarf carnivores on Cozumel Island, Mexico. Biodiv Conserv. 13 (2):317–331. doi:10.1023/B:BIOC.0000006501.80472.cc.

Delacour J, Amadon D. 1973. Curassows and related birds. New York: American Museum of Natural History.

DOF (Diario Oficial de la Federación). 2012. Decreto por el que se declara área natural protegida con el carácter de Área de protección de flora y fauna, la porción norte y la franja costera oriental, terrestres y marinas de la Isla de Cozumel, Municipio de Cozumel, Estado de Quintana Roo. Mexico: Diario Oficial de la Federación.

Eisermann K. 2004. Status of Great Curassow (*Crax rubra*) in Punta de Manabique, Guatemala: habitat, population size and human impact. Bulletin of the IUCN/BIRDLIFE/WPA Cracid Specialist Group. 18:4–14.

Estrada A, Coates-Estrada R, Vazquez-Yanes C. 1984. Observations on fruiting and dispersers of *Cecropia obtusifolia* at Los Tuxtlas, Mexico. Biotropica. 16(4):315–318. doi:10.2307/2387942.

Frankham R. 1995. Effective population-size adult-population size ratios in wildlife – a review. Gen Res. 66(2):95–107. doi:10.1017/S0016672300034455.

Fuentes-Montemayor E, Cuarón AD, Vázquez-Domínguez E, Benítez-Malvido J, Valenzuela Galván D, Andresen E. 2009. Living on the edge: roads and edge effects on small mammal populations. J Anim Ecol. 78(4):857–865. doi:10.1111/j.1365-2656.2009.01551.x.

García-Arroyo M, Gomez-Martinez MA, MacGregor-Fors I. 2021. The queen of the island: on the density and distribution of the Eurasian Collared-Dove (*Streptopelia decaocto*) in Cozumel. Urban Ecosyst. 25(1):285–290. doi:10.1007/s11252-021-01147-x.

Hedrick PW. 2011. Genetics of populations. Phoenix: Arizona State University.

Herrera-Flores DA, Marku-Götz C. 2014. La alimentación de los antiguos mayas de la península de Yucatán: consideraciones sobre la identidad y la cuisine en la época prehispánica. Estud Cult Maya. 43:71–98.

[INEGI] Instituto Nacional de Estadística, Geografía e Informática. 2015. Conteo de población y vivienda 2005. Accessed 21 June 2021. http://cuentame.inegi.org.mx/monografias/informacion/qroo/poblacion.

Kattan GH, Muñoz MC, Kikuchi DW. 2016. Population densities of Curassows, guans, and chachalacas (*Cracidae*): effects of body size, habitat, season, and hunting. Condor. 118 (1):24–32. doi:10.1650/CONDOR-15-51.1.

Lacy RC, Pollak JP 2020. Vortex: a stochastic simulation of the extinction process. Version 10.3.8. Brookfield (Illinois): Chicago Zoological Society.

Martínez-Morales MA 1996. The Cozumel Curassow: abundance, habitat preference and conservation. [Master's thesis]. Cambridge (UK): University of Cambridge.

Martínez-Morales MA. 1999. Conservation status and habitat preferences of the Cozumel Curassow. Condor. 101:14–20.

Martínez-Morales MA, Cruz PC, Cuarón AD. 2009. Predicted population trends for Cozumel Curassows (*Crax rubra griscomi*): empirical evidence and predictive models in the face of climate change. J F Ornithol. 80(4):317–327. doi:10.1111/j.1557-9263.2009.00237.x.

Martínez-Morales MA, Cuarón AD. 1999. Boa constrictor, an introduced predator threatening the endemic fauna on Cozumel Island, Mexico. Biodivers Conserv. 8(7):957–963. doi:10.1023/A:1008815004072.

McCoy M. 1997. Country report on cracids of Costa Rica. In: Strahl SD, Beaujon S, Brooks SM, Begazo AJ, Sedaghatkish G, Olmos F, editors. The Cracidae: their biology and conservation. New York: Hancock House Publishers; p. 298–313.

Morales-Contreras J. 2020. Estimación de la abundancia poblacional del hocofaisán de Cozumel (*Crax rubra griscomi*) en función de variables bióticas, abióticas y antrópicas [Master's thesis]. Chiapas (México): El Colegio de la Frontera Sur.

Morales-Contreras J, Martínez-Morales MA, Marquéz-Luna U. 2020. Recursos florales usados por el colibrí esmeralda de Cozumel (*Chlorostilbon forficatus*). Huitzil. 21:e–589.

Ortega-Gamboa TG. 2019. Mecanismos que inciden en los ensambles de vertebrados frugívoros de la selva mediana subcaducifolia de isla Cozumel [Master's thesis]. Chiapas (México): El Colegio de la Frontera Sur.

Palacios-Aldana LF. 2017. Selección de habitat, abundancia y propuestas para la conservación del pecarí enano (*Pecari tajacu nanus*) endémico de la Isla Cozumel [Master's thesis]. Chiapas (México): El Colegio de la Frontera Sur.

Palafox-Muñoz A, Collantes-Chávez CA. 2009. El turismo en ambientes sensibles. Caso Isla Cozumel, México. Análisis del turismo. 4:49–63.

Pennington TD, Sarukhán J. 2005. Árboles tropicales de México. Manual para la identificación de las especies. Mexico: Fondo de Cultura Económica.

Perdomo-Velázquez H, Andresen E, Vega E, Schondube JE, Cuarón AD. 2017. Effects of hurricanes on the understory forest birds of Cozumel Island. Trop Conserv Sci. 10:1–14. doi:10.1177/1940082917737759.

Pérez-Irineo G, Santos Moreno A. 2017. Occupancy, relative abundance, and activity patterns of Great Curassow (*Crax rubra*) in Southeastern Mexico. Ornithol Neotrop. 28:313–320.

Polisar J, McNab RB, Quigley H, Gonzalez MJ, Cabrera M. 1998. A preliminary assessment of the effects of subsistence hunting in the Mayan biosphere reserve. Part 1: progress report – game populations in Tikal National Park and Uaxactun. Chetumal: POQROO.

POQROO (Periódico Oficial del Estado de Quintana Roo). 2011. Decreto mediante el cual se declara como área natural protegida con la categoría de Reserva Estatal la Región Denominada Selvas y Humedales de Cozumel, Quintana Roo. Chetumal: POQROO.

R Core Team. 2019. A language and environment for statistical computing. Vienna: R Foundation for Statistical Computing. http://www.R-project.org/

Reed JM, Murphy DD, Brussard PF. 1998. Efficacy of population viability analysis. Wildl Soc Bull. 26:244–251.

Reed DH, O'Grady JJ, Brook BW, Ballou JD, Frankham R. 2003. Estimates of minimum viable population sizes for vertebrates and factors influencing those estimates. Biol Cons. 113(1):23–24. doi:10.1016/S0006-3207(02)00346-4.

Ríos MM, Londoño GA, Muñoz MC. 2005. Densidad poblacional e historia natural de la pava negra (*Aburria aburri*) en los andes centrales de Colombia. Ornitol Neotrop. 16:205–217.

Rivas RJA. 1995. Preferencias alimenticias del Faisán o Pajuil (*Crax rubra* L.) en condiciones naturales [Bachelor's thesis]. San Carlos (Guatemala): Universidad de San Carlos.

Romero-Nájera I. 2004. Distribución, abundancia y uso del habitat de *Boa constrictor* introducida a la Isla Cozumel. [Masters's thesis]. Morelia (México): UNAM.

Scott PE, Martin F. 1984. Avian consumers of *Bursera, Ficus*, and *Ehretia* Fruit in Yucatan. Biotropica. 16(4):319–323. doi:10.2307/2387943.

SEDUMA (Secretaria de Desarrollo Urbano y Medio Ambiente). 2008. Programa de Odenamiento Ecológico Local del Municipio de Cozumel. Accessed 28 june 2021. http://seduma.qroo.gob.mx/bitacora/index.php?option=com_docman&task=catview&grid=108&Itemid=33 .

SEMARNAT (Secretaría de Medio Ambiente y Recursos Naturales). 2010. Norma Oficial Mexicana NOM-059-SEMARNAT-2010, Protección ambiental-Especies nativas de México de flora y fauna silvestres-categorías de riesgo y especificaciones para su inclusión, exclusión o cambio-lista de especies en riesgo. Mexico: Secretaría de Medio Ambiente y Recursos Naturales.

Sermeño A. 1997. Alimentación y reproducción del Paujil (*Crax rubra*) en el Salvador. In: Strahl SD, Beaujon S, Brooks SM, Begazo AJ, Sedaghatkish G, Olmos F, editors. The Cracidae: their biology and Conservation. New York: Hancock House Publishers; p. 71–78.

Solomon M. 1949. The natural control of animal populations. J Anim Ecol. 18(1):1–35. doi:10.2307/1578.

Tellez-Valdéz O, Cabrera EF. 1987. Florúla de la Isla Cozumel, Quintana Roo. Listados florísticos de México. Mexico: Universidad Nacional Autónoma de México.

Tellez-Valdéz O, Cabrera EF, Linares E, Bye R. 1989. Las plantas de Cozumel. Guía botánico-turística de las isla de Cozumel. Mexico: Universidad Nacional Autónoma de México.

Terborgh J, Robinson TA, Parker IIITA, Munn CA, Pierpont N. 1990. Structure and organization of an Amazonian forest bird community. Ecol Mon. 60(2):213–238. doi:10.2307/1943045.

Thomas L, Buckland ST, Rexstad EA, Laake JL, Strindberg S, Hedley SL, Bishop JRB, Marques TA, Burnham KP. 2010. Distance software: design and analysis of distance sampling surveys for estimating population size. J Appl Ecol. 47 (1):5–14. doi:10.1111/j.1365-2664.2009.01737.x.

Traill LW, Bradshaw CJA. 2007. Minimum viable population size: a meta-analysis of 30 years of published estimates. Biol Conserv. 139(1–2):159–166. doi:10.1016/j.biocon.2007.06.011.

Valenzuela-Galván D. 1998. Natural history of the white-nosed coati, Nasua narica, in a tropical dry forest of western Mexico. Revista Mexicana de Mastozoología. 3(1):26–44. doi:10.22201/ie.20074484e.1998.3.1.59.

Valenzuela-Galván D, Cuarón AD, Martínez-Morales MA, Vázquez LB, E V-D. 2022. First records of margay on Cozumel Island: a conservation paradox. Anim Conserv. 25 (1):1–3. doi:10.1111/acv.12748.

Villaseñor-Gómez JF, Santana E. 2003. El monitoreo de poblaciones: herramienta necesaria para la conservación de aves en México. In: Gómez de Silva H, Oliveras de Ita A, editors. Conservación de aves. Mexico: CIPAMEX, Sección Mexicana; p. 224–262.

Webster PJ, Holland GJ, Curry JA, Chang HR. 2005. Changes in tropical cyclone number, duration, and intensity in a warming environment. Science. 309(5742):1844–1846. doi:10.1126/science.1116448.

Zuur AF, Ieno EN, Walker NJ, Saveliev AA, Smith GM. 2009. Mixed effects models and extensions in ecology with R. New York: Springer.

Appendix 1. Parameters applied for the population viability analysis of the Cozumel Curassow with the Vortex software. The protocol written by Caballero-Cruz (2007) and Martínez-Morales et al. (2009), with modifications in the current population status, was used as a basis

Base scenario

- Simulations: 100
- Years: 100
- Report interval: 10 years
- Definition of extinction: 0.0 individuals of any sex
- Populations: 1
- Inbreeding depression: No
- Concordance between reproduction and survival? Yes
- Type of catastrophe: 1
- Monogamous, polygamous, hermaphrodite: Monogamous
- Age of first reproduction in females: 2 years
- Age of first reproduction in males: 2 years
- Maximum age for reproduction: 10 years
- Sex ratio (percentage of males): 50.0
- Annual progeny (0 = normal distribution): 2
- Density dependent reproduction: No
- Breeding females: 80.0
- Environmental Variation (EV) of breeding females: 8.0
- Mortality in females and males age 0: 50.0 EV:10.0
- Mortality in females and males age 1: 10.0 EV:5.0
- Mortality in females and males age 2: 10.0 EV:5.0
- Mortality in females and males adulthood: 10.0 EV:5.0
- Catastrophe probability: 40%
- Reproduction severity: 0.5
- Survival severity: 0.9
- Do all males reproduce? Yes
- Start at a stable distribution age? Yes
- Initial population size: 499
- Carrying capacity (K): 1430 EV (K): 0

Variables modified by scenario

Scenario 1:
Mortality rate (> 1 year): 50%

Scenario 2:
Catastrophe probability: 60%

Scenario 3:
Catastrophe probability: 20%

Scenario 4:
Decrease in carrying capacity by 5% every 10 years

Scenario 5:
Increase in carrying capacity by 5% every 10 years

Scenario 6:
Introduction of individuals to population every two years. From the second year to the year 100; a male and a female of one year, a male and a female of two years.