Conservation and geographic distribution of crocodylians in Bolivia (*Caiman yacare, Caiman latirostris, Melanosuchus niger, Paleosuchus palpebrosus, Paleosuchus trigonatus*)

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Introduction

In Bolivia five crocodylian species occur: *Caiman yacare*, *Melanosuchus niger*, *Caiman latirostris*, *Paleosuchus palpebrosus*, and *Paleosuchus trigonatus* (Ergueta & Pacheco, 1990; King & Videz-Roca, 1989). Currently, *C. latirostris* and *M. niger* are listed on Appendix I by the Convention on Trade in Endangered Species of Wild Fauna and Flora (CITES), and included on the Red List of Bolivian Vertebrates, categorized as "Endangered" and "Vulnerable", respectively (MMAA, 2009). *P. palpebrosus*, *P. trigonatus*, and *C. yacare* are listed on Appendix II and not categorized as threatened within Bolivia, mainly because they are considered commercially worthless in the case of both *Paleosuchus* species or have shown to be resilient to harvesting programs in the case of *C. yacare* (Ergueta & Pacheco, 1990; Ross, 1998).

Unfortunately, these categorizations cannot currently be supported due to limited biological knowledge, and all five species need a thorough status re-assessment by the Bolivian government to clearly understand the current conservation status and promote conservation programs that are ecologically sustainable and economically efficient (Pacheco & King, 1995).

Thus, the main goal of this research was to summarize and assess the current state of biological knowledge of crocodylians in Bolivia and, based on a comprehensive ecological framework, address two main objectives: 1) propose regional conservation priorities that integrates spatial distribution and ecological information of the five species in Bolivia; and 2) propose a strategy to improve the estimation of suitable habitats currently occupied by *C. yacare* (Area of Occupancy – AOO) based on species distribution modeling techniques such as Maxent, maintaining consistency with the IUCN Red List assessments (IUCN Standards and Petitions Committee, 2019).

Methodology

I first conducted a literature search and review for studies with spatial information of the five species. With the high-quality spatial data compilation, I estimated the distribution range of crocodylians in Bolivia by delineating the Extent of Occurrence (EOO), identified Crocodylian Geographic Regions (CGRs), and delineated Crocodylian Study Units (CSUs). Ecoregions inside CSUs were defined as Crocodylian Conservation Units (CCUs), for which I developed a geographic priority setting. I categorized them as Regional Habitat Priority (RHP) areas with sufficient biological information to implement management and sustainable use programs aimed at species and habitat conservation, or as Regional Research Priority (RRP) areas with the absence or insufficiencies of biological information to prioritize research and monitoring programs.

To estimate the AOO for *Caiman yacare*, I used Maxent v3.4.0 (Phillips et al., 2017) including published recommendations to address drawbacks related to 1) selection of study area extent (Barve et al., 2011; Merow et al., 2013), 2) partitioning of occurrences (Hijmans,

2012; Radosavljevic & Anderson, 2014), 3) configuration of feature class (FC) and regularization multiplier (RM) (Shcheglovitova & Anderson, 2013; Syfert et al., 2013), and 4) model evaluation (Lobo et al., 2008; Peterson et al., 2008).

Results

I reviewed 105 documents written from 1977 to 2017 and compiled occurrences from 44 of the documents, which were used to develop spatial distributions maps of Crocodylians in Bolivia. I integrated current distribution and biological information to generate ecological information, such as the estimation of 654,930 km^2 as the potential occupied range by the species (Extent of Occurrence - EOO), identification of 17 representative ecoregions within the EOO (Crocodylian Geographic Regions – CGRs), and definition of 93 areas where viable crocodylian populations are known to occur (Crocodylian Study Units – CSUs). My analysis was also able to define 167 Crocodylian Conservation Units (CCUs), out of which 29 were categorized as RHP and 138 as RRP, each one of these representing a core of viable crocodylian populations for which conservation strategies might be based (Figure 1) (details in Rodriguez-Cordero et al. [2019]).

Currently, the traditional method to estimate the AOO by the IUCN Red List assessments led to an area of 8,652 km2, covering 0.79% of the Bolivian territory, and clearly underestimating the potential distribution of the species. This method relies exclusively on the amount and quality of spatial distribution data, which tend to be geographically biased, with some areas being sampled more than others or nor sampled at all. Conversely, based on the optimal parameter tuning settings in Maxent for this research that combined a reduced study SAE, the "masked geographically structured biased extrapolated" approach, the LQ feature class, and RM 0.25, I estimated an area 364,656.68 km2 as the potential AOO, representing 33.65% of the country's extent (Figure 3). This extent is justified by accurately representing the habitat requirements of the species and have been validated through an independent model evaluation (details in Rodriguez-Cordero [2019]).

Conclusions

This study is the first country-wide range assessment of the current state of knowledge for the five crocodylian species found in Bolivia and constitutes the first attempt to estimate the suitable habitat for potential geographic distributions of crocodylian species based on an integrative analysis of high-quality spatial data and recent comprehensive "presence-only" modeling techniques, using Maxent. I then integrated current distribution and biological information to generate relevant ecological information.

The estimate of the Extent of Occurrence (EOO) of crocodylians in Bolivia was 654,930 km^2 (60.4% of the geopolitical area) including 17 (74%) out of the 23 CGR representatives in Bolivia, ranging from the northern Pando Amazon Forest to the southern Great Chaco in Tarija, showing a wide distribution and a broad variety of environments where the species inhabit. I delineated 93 Crocodylian Study Units (CSUs), representing those areas where viable crocodylian populations are known to occur in Bolivia, which covered an extent of 102,603 km^2. This discrepancy demonstrates the poor extent of knowledge of crocodylian distributions in the country (only 15.7 % of the EOO). I defined 167 Crocodylian Conservation Units (CCUs), covering an area of 90,176.04 km^2 and covering the 13.8% of the currently EOO. Moreover, this study indicates that 109,100 km^2 (16.7% of the EOO) and 10,608 km^2 (11.8% of the CCUs extent) are protected in Bolivia, I also identified 28,926.18

km^2 of disturbed areas within the EOO and 4,420.66 km^2 within the CCUs, indicating that the 4.4% and 4.9% of the EOO and CCUs, respectively, have suffered habitat loss and/or fragmentation before year 2015. To define regional priorities, I evaluated each CCU based on variables that have been considered important for crocodylians and characterized them as Regional Habitat Priority (RHP) or Regional Research Priority (RRP), covering 51.3% and 48.7% of the CCUs' extent, respectively.

The Maxent tool was used to estimate the AOO based on formal statistical evaluations and maintaining consistency of the IUCN Red List assessments. Based on optimal parameter settings, I estimated an AOO of 364,656.68 km^2, representing the 33.65% of the country's extent. Although the findings are relevant for the target species and acquired dataset, the same principles should be relevant (not absolute) as a guide for other crocodylian species (and perhaps even other species). This argument is strictly based on the assumption that the amount, quality, and representativity of the location datasets and selection on the environmental variables were optimal. However, I also support the idea that my results are not definitive and that crucial methodological issues need to be explored and resolved. I emphasize the need for species-specific tuning of Maxent parameters to reduce overfitting models and increase discriminatory performance evaluation (Anderson & Gonzales, 2011). Furthermore, Maxent clearly constitutes a promising tool for modeling suitable habitat of potential crocodylian species distribution, applicable in many areas of ecological research (e.g., relative abundance, population structure, population dynamics, population trends) that undoubtedly will generate relevant information to achieve more successful management planning strategies and guarantee the effective conservation of crocodylians in Bolivia and potentially throughout the world.

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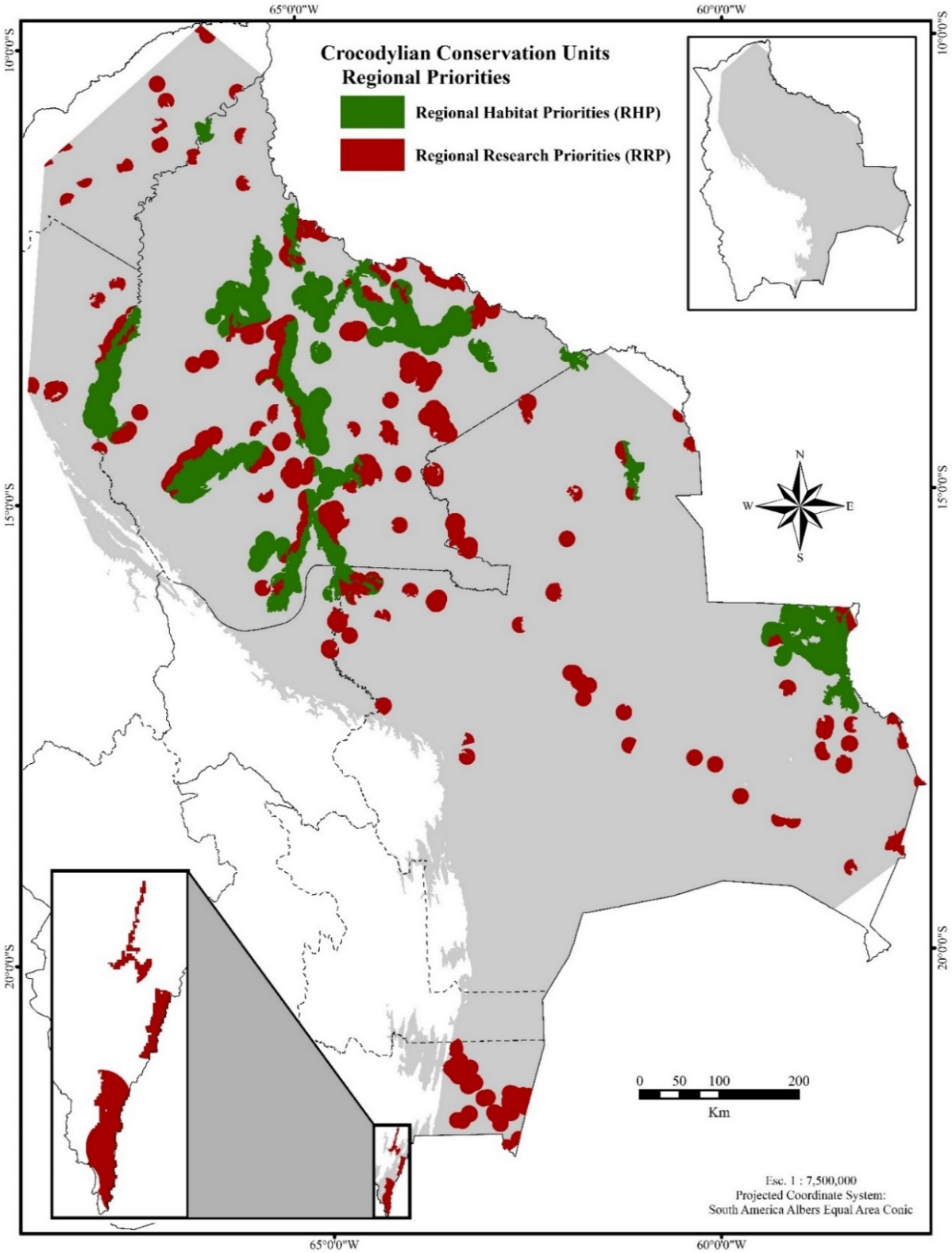


Figure 1. Classification of Crocodylian Conservation Units (CCUs) into Regional Habitat Priority (RHP) and Regional Research Priority (RRP). RHP represent areas where sufficient scientific and technical information has been generated and constitute potential units for the development of management strategies. RRP area areas that require research and biological monitoring to update the conservation status of potential crocodylian populations.

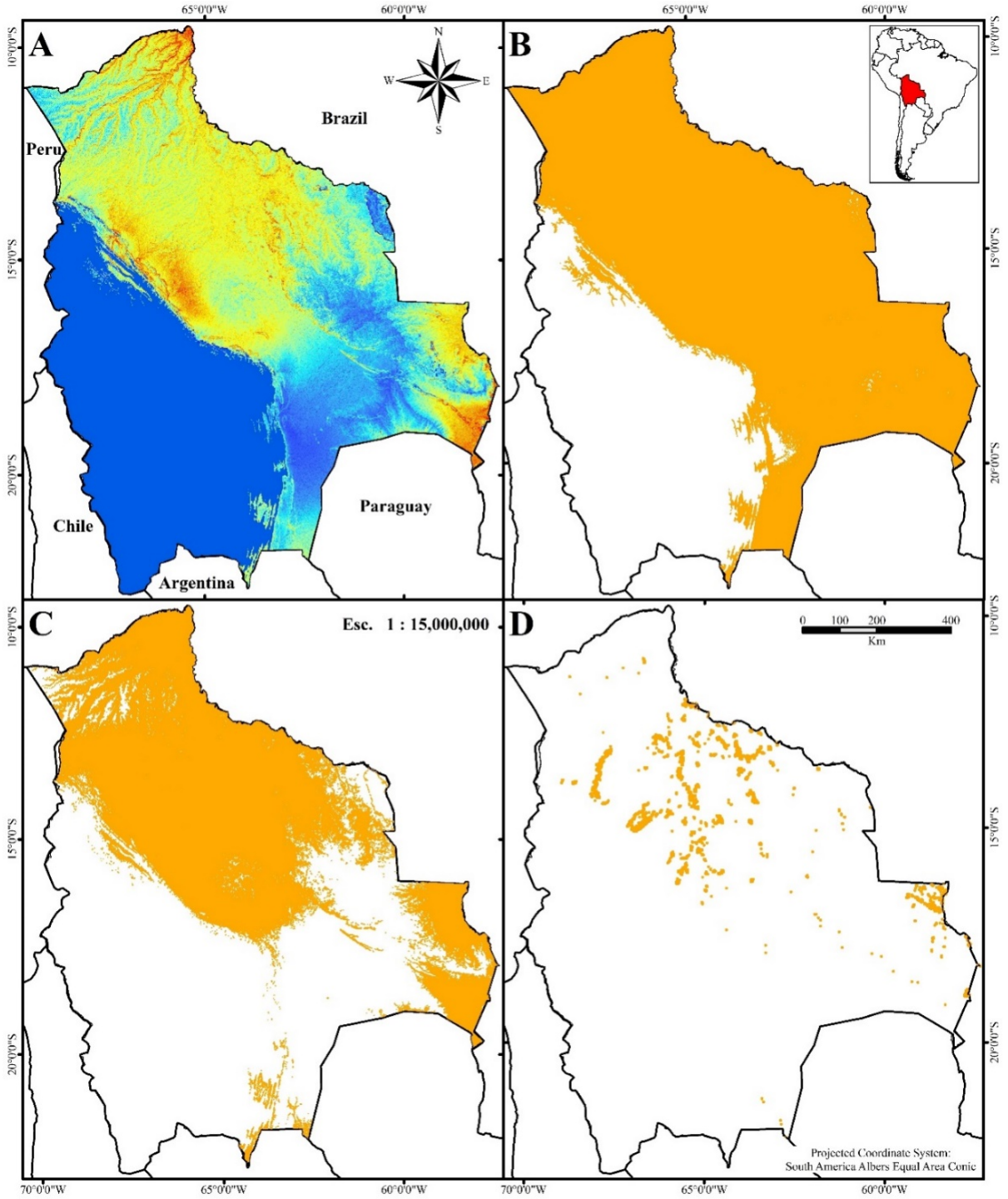


Figure 2. Estimation of the Area of Occupancy (AOO) (depicted in orange in panels B, C and D) based on species distribution modeling by Maxent. (A) Continuous independent-threshold model (shows suitable gradients from low (blue) to high (red)) used to estimate suitable habitats for potential species distribution of *Caiman yacare* in Bolivia. (B) Binary dependent-threshold model estimated with the Minimum calibration training presence as a threshold to estimate the AOO. (C) Binary dependent-threshold model estimated with the 10 percent calibration training presence as a threshold to estimate the AOO (in orange). (D) Estimation of the AOO based on the method suggested by the IUCN, where the total number of occupied 2 x 2 km cells and the respective area represent the AOO.