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Model for determining alligator harvest quotas (*Caiman yacare*) and contributions to the knowledge of black caiman (*Melanosuchus niger*) in Bolivia

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SUMMARY

Within the framework of the project "Study on the population status of the yacare (*Caiman yacare*) and the black caiman (*Melanosuchus niger)* in their natural distribution areas in Bolivia", it is proposed to update and improve the model for estimating alligator harvest quotas in Bolivia and the contribution of scientific technical inputs for the conservation and management of the black caiman with a view to a future sustainable use.

Key words: Ecological niche, potential distribution, caiman program, conservation

BACKGROUND

From the 1950s, the yacare (*Caiman yacare*) and the black caiman (*Melanosuchus niger*) were exploited owing to their leather high costs (OJASTI 1996), consequently, decreasing their populations and driving *M. niger* to the verge of extinction (THORBJARNARSON 1998). Therefore, from 1961 in Bolivia, legal actions initiated to partially stop their hunting and, by 1967, hunting was totally banned. This decision was ratified in subsequent years (AGUILERA et al. 2007), favoring the alligator recovery as demonstrated throughout its original distribution, by 1999 (APARICIO et al. 1999, 1999, AGUILERA *et al*. 2007); As a consequence, Bolivian legislation was modified allowing its sustainable use (LLOBET et al. 2004).

The National Program for the Conservation and Sustainable Use of the Yacaré began with the supreme decree DS 25458 of 1999 permitting hunting following development of species-specific sustainable use plans. Subsequently, the program, and its respective regulations, was consolidated (Resolution 147/02 of 2002). On the other hand, in Bolivia there are no successful management experiences for the black caiman (CISNEROS 2006) and insufficient knowledge about its population parameters hinders developing management programs (PACHECO 1999, MMAyA 2009); Moreover, in Bolivia the black caiman is included in Appendix I of CITES and, therefore, its trade is banned (CITES 2021). As for the conservation status, *C. yacare* is not included in the threatened category in Bolivia, but *M. niger* falls into the Vulnerable category (MMAyA 2009).

With regard to the determination of alligator harvest quotas at the national level, stands out a first model developed, at the request of the Government of Bolivia (APARICIO and RIOS 2004), by the Canadian cooperation "CESO-SACO", along with two subsequent stages led by the Noel Kempff Mercado Natural History Museum (MHNNKM) in its role as CITES Scientific Authority, initially creating in 2004 a model to justify and distribute harvest quotas. The model was updated in 2010. In these little more than 11 years, new information has emerged on the population status and distribution of species, adding technological improvements to statistical and ecological tools and geographic information systems; In this sense, within the project "Study on the population status of the yacaré *(Caiman yacare*) and the black caiman (*Melanosuchus niger*) in their natural distribution areas in Bolivia", this article proposes the updating and improvement of the model to estimate alligator harvest quotas in Bolivia, and presents technical scientific inputs to support the conservation and future management of the black caiman.

METHODOLOGY

Study area

The geographic scope of this study was suggested by Rodriguez-Cordero *et al*. (2019). They consider accessible areas for the dispersal of crocodilians in Bolivia are below 850 m.a.s.l. Geopolitically, the study area encompasses the departments of Pando, La Paz, Beni, Cochabamba, Santa Cruz, Chuquisaca, and Tarija and, biogeographically, it comprises mainly seven ecoregions (IBISCH & MÉRIDA 2003, Figure 1).

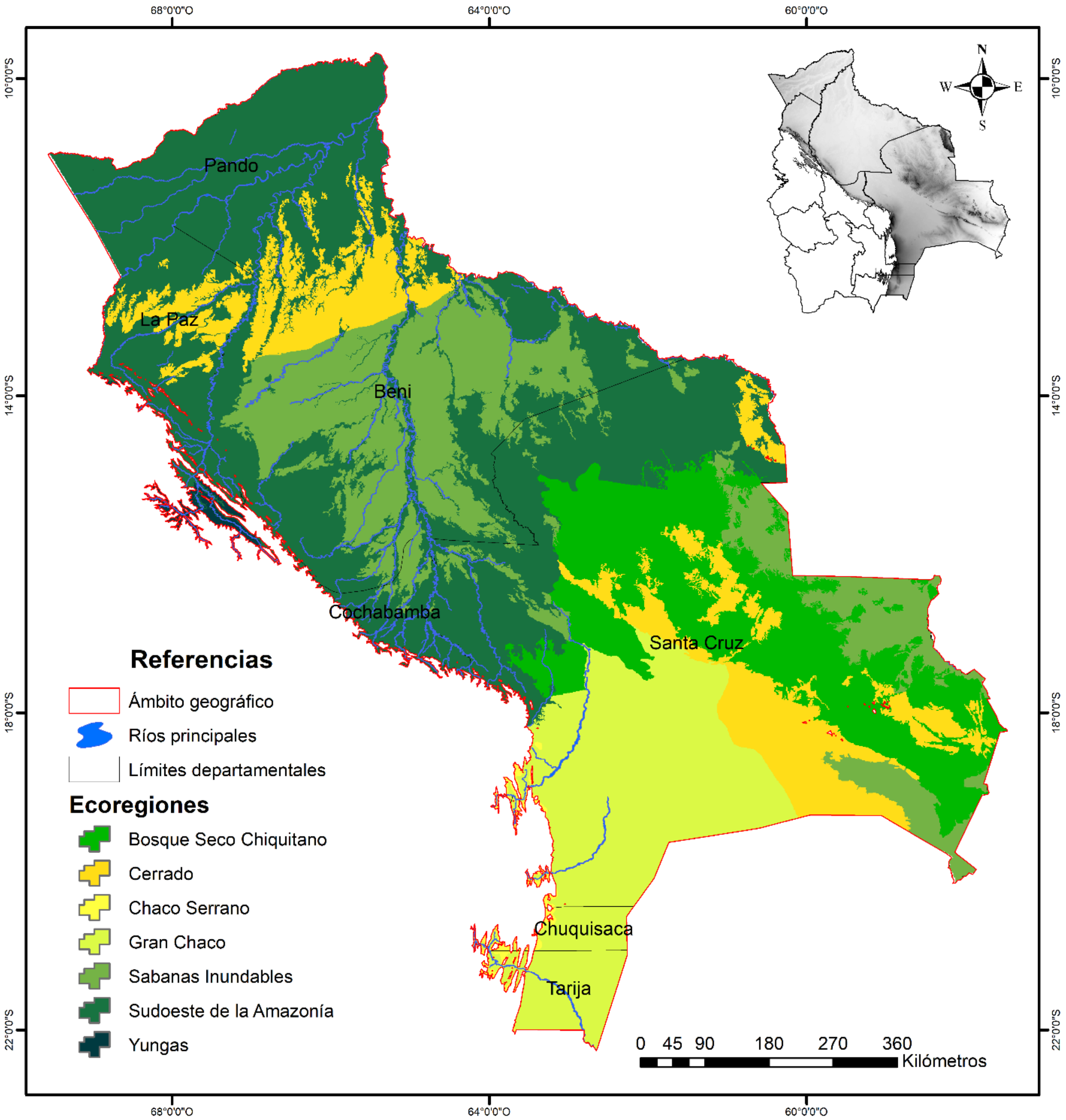

Figure 1. *Territorial extension, geopolitical and biogeographic division of the study area. Its position with respect to Bolivia and elevation details (<850 masl) are indicated in the enclave.*

Analysis

Initially, ecological niche models were developed; data on the occurrence of alligator and black caiman in Bolivia were collected and refined; and 30 predictor variables that are part of bioclimatic variables, elevation, land cover, and biogeography were considered. Redundant variables were removed using Spearman correlation and the niche models were run using MaxEnt v.3.4.4. (PHILLIPS *et al.* 2021), Models assessment used the area under the ROC/AUC curve (SWETS 1988) and, finally, the potential distribution was determined by mapping the models, generating maps that depict low (0) and high (1) habitat suitability values for each species (PALMA-ORDAZ & DELGADILLO-RODRÍGUEZ 2014).

Subsequently, the model for determining the alligator harvest quotas was established, both with updated population data and in the absence of these. The population data are the result of field evaluations conducted within the project, and management plans and evaluations of previous years conducted by different institutions. The number of exploitable individuals per km of shoreline was determined based alligator conservation and sustainable use regulations. Only data from population counts carried out this year (2021) were filtered to be considered up-to-date data. The geographical position of the localities where the counts were made was crossed with the land tenure coverage, and then, for each evaluated locality, its habitat suitability value was determined based on what was established in the ecological niche model.

Finally, for each locality, Bing satellite images were measured, and the water body considered for population counting was identified, and its total linear (if it is a lotic water body) or perimeter (if it is lentic) extension in km was calculated within the territorial limits of the property. ArcMap v.10.4. (ESRI 2011) was used for all cartographic management. The mathematical formula for estimating exploitation potential of the resource was determined once the data corresponding to the density of usable individuals per km of shore, the value of habitat suitability, and on-farm linear or perimeter extension of the evaluated water body (or evaluated water bodies) were managed and organized. For this purpose, the model proposed by the MHNNKM in 2010 was used.

Likewise, to generate useful information to establish alligator harvest quotas in the absence of current population data, potential densities of usable individuals per km of shore were established based on historical data. For this, based on the niche models, a clustering analysis was performed using the k-means algorithm to identify the existence of geographic areas with similar niche conditions. In the case of *C. yacare*, according to each geographical area identified based on its ecological niche values, the historical values of usable individuals per km of shore were classified among those corresponding to lotic (main rivers, secondary rivers, streams) and lentic (any body of water not considered as lotics) water bodies, to determine the existence of statistically significant densities differences of usable individuals reported among these water bodies.

Harvest quotas were not established for the black caiman and the study was limited to generating only descriptive information on priority areas throughout its natural distribution, where useful management guidelines for non-commercial purposes are used to strengthen existing populations (eg, hatching eggs for incubation and subsequent release of newborns). These areas were designated by discriminating places with habitat suitability values greater than 0.9. Likewise, geographic groups were identified based on the ecological niche values that allow understanding the differentiation of existing habitat suitability throughout the distribution of the species in Bolivia.

OUTPUTS

Occurrences records of both species in Bolivia

For *C. yacare*, a total of 1692 records were obtained which, after purging, were reduced to 984 (Figure 2). On the other hand, 165 records were obtained for *M. niger*, which were reduced to 141 after purge (Figure 2). In general terms, it was observed that alligator records are more distributed across the geopolitical and biogeographic scope of the study compared to *M. niger*, with records mostly in the north of the country concentrated mainly in the departments of Beni, La Paz and Pando.

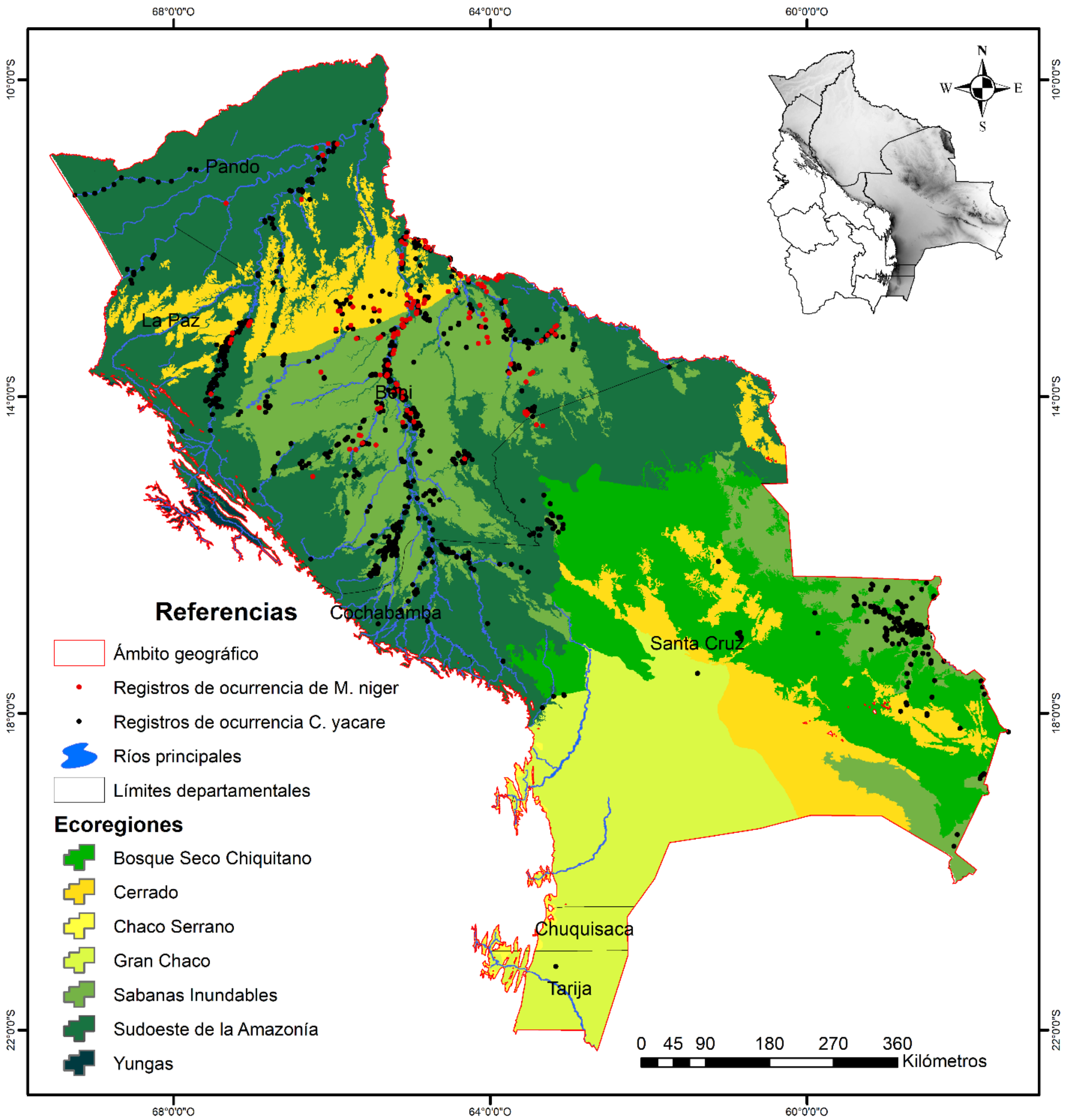

Figure 2. *Location of records for both species in the study.*

Niche models and potential distribution

Regarding the alligator, 18 uncorrelated predictor variables (Table 1) were selected providing independent information, and summarizing the information considered in the 30 initial variables in an optimal manner.

Table 1. *Variables selected to develop ecological niche models and potential distribution for the alligator*

Nbr	Code	Variable	Category
1	bio1	Average annual temperature	Annual trends
2	bio2	Mean Diurnal Range (Mean of monthly (max temperature - min temperature))	Monthly trends
3	bio3	Isothermality	Annual trends
4	bio4	Temperature seasonality	Seasonal trends
5	bio10	Max Temperature of Warmest Quarter	Limiting factors
6	bio11	Mean Temperature of Warmest Quarter	Limiting factors
7	bio12	Annual Precipitation	Annual trends
8	bio14	Precipitation of Driest Month	Limiting factors
9	C2_evergreenForest	Evergreen woody vegetation	Vegetation cover
10	C3_DecidiousForest	Deciduous woody vegetation	Vegetation cover
11	C4_SemiDecidiousForest	Semi deciduous woody vegetation	Vegetation cover
12	C5_Bushes	Bush vegetation	Vegetation cover
13	C6_Herbaceous	Herbaceous vegetation	Vegetation cover
14	C7_CultivatedVegetation	Agricultural crops and forest plantations	Vegetation cover
15	C8_VegRegFlooded	Vegetation regularly flooded	Vegetation cover
16	C12_OpenWaters	Permanent water bodies	Vegetation cover
17	Ecoregion	Ecoregions	Biogeography
18	SolarRadiation	Solar radiation	Monthly trends

The most influential variables for the niche model were permanent water bodies, regularly flooded vegetation, and annual precipitation. The model demonstrated a good accuracy level (AUC = 0.891, ± 0.003). Geopolitically, the greatest availability of suitable habitats for the presence of the species occurs mainly in the department of Beni followed by Santa Cruz (Figure 3).

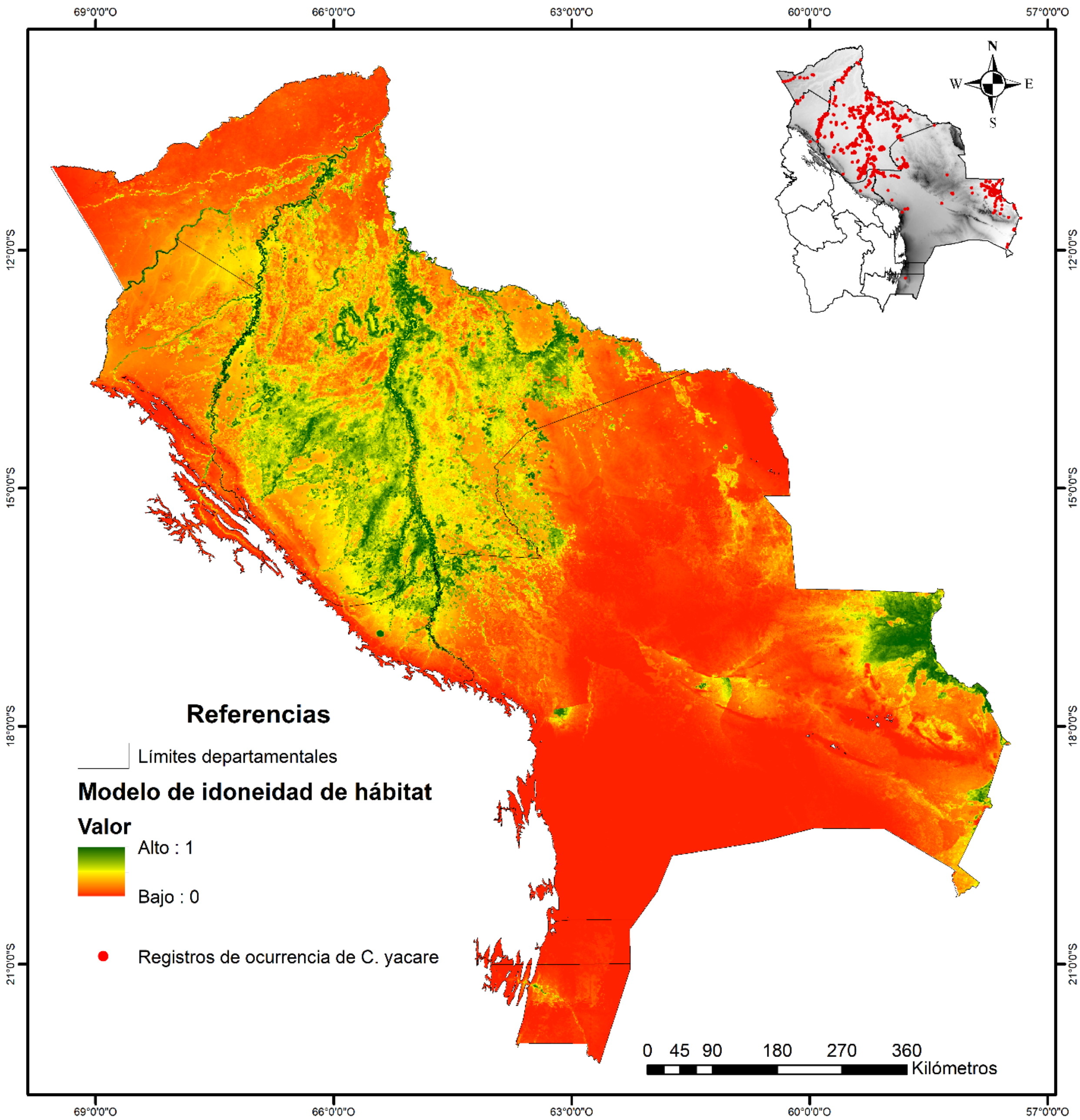

Figure 3. *Habitat suitability model for alligator.*

For *M. niger*, 22 uncorrelated predictor variables were used (Table 2), which adequately summarize the environmental information without the need to consider the 30 initially proposed variables.

Table 2. *Variables selected to develop ecological niche models and potential distribution for black caiman.*

Nbr	Code	Variable	Category
1	bio1	Average annual temperature	Annual trends
2	bio2	Mean Diurnal Range (Mean of monthly (max temperature - min temperature))	Monthly trends
3	bio3	Isothermality	Annual trends
4	bio5	Max Temperature of Warmest Month	Limiting factors
5	bio6	Max Temperature of Coldest Month	Limiting factors
6	bio7	Temperature Annual Range	Annual trends
7	bio8	Mean Temperature of Wettest Quarter	Limiting factors
8	bio12	Annual Precipitation	Annual trends
9	bio14	Precipitation of Driest Month	Limiting factors
10	bio18	Precipitation of Warmest Quarter	Limiting factors
11	bio19	Precipitation of Coldest Quarter	Limiting factors
12	C2_EvergreenForest	Evergreen woody vegetation	Vegetation cover
13	C3_DecidiousForest	Deciduous woody vegetation	Vegetation cover
14	C4_SemiDecidiousForest	Semi deciduous woody vegetation	Vegetation cover
15	C5_Bushes	Bush vegetation	Vegetation cover
16	C6_Herbaceous	Herbaceous vegetation	Vegetation cover
17	C7_CultivatedVegetation	Agricultural crops and forest plantations	Vegetation cover
18	C8_VegRegFlooded	Vegetation regularly flooded	Vegetation cover
19	C12_OpenWaters	Permanent water bodies	Vegetation cover
20	Ecoregion	Ecoregions	Biogeography
21	SolarRadiation	Solar radiation	Monthly trends
22	Elevation	Elevation (masl)	Geographic trends

The model presented an excellent performance (AUC = 0.971, ± 0.004). Permanent water bodies and elevation were more influential in determining the model. Regarding elevation, the most favorable values for the presence of *M. niger* were between 100 and 200 meters above sea level, with its maximum peak at 150 m. The largest area of habitat suitability for the potential distribution of the *black caiman* occurs in Beni, mainly concentrated in the lower parts of the Mamoré river, and its associated habitats, where there is a landscape dominated by lagoons. In the case of the Machupo, Iténez, Itonama, Baures, Blanco and San Martin rivers they presented highly suitable habitats for the occurrence of the species (Figure 4).

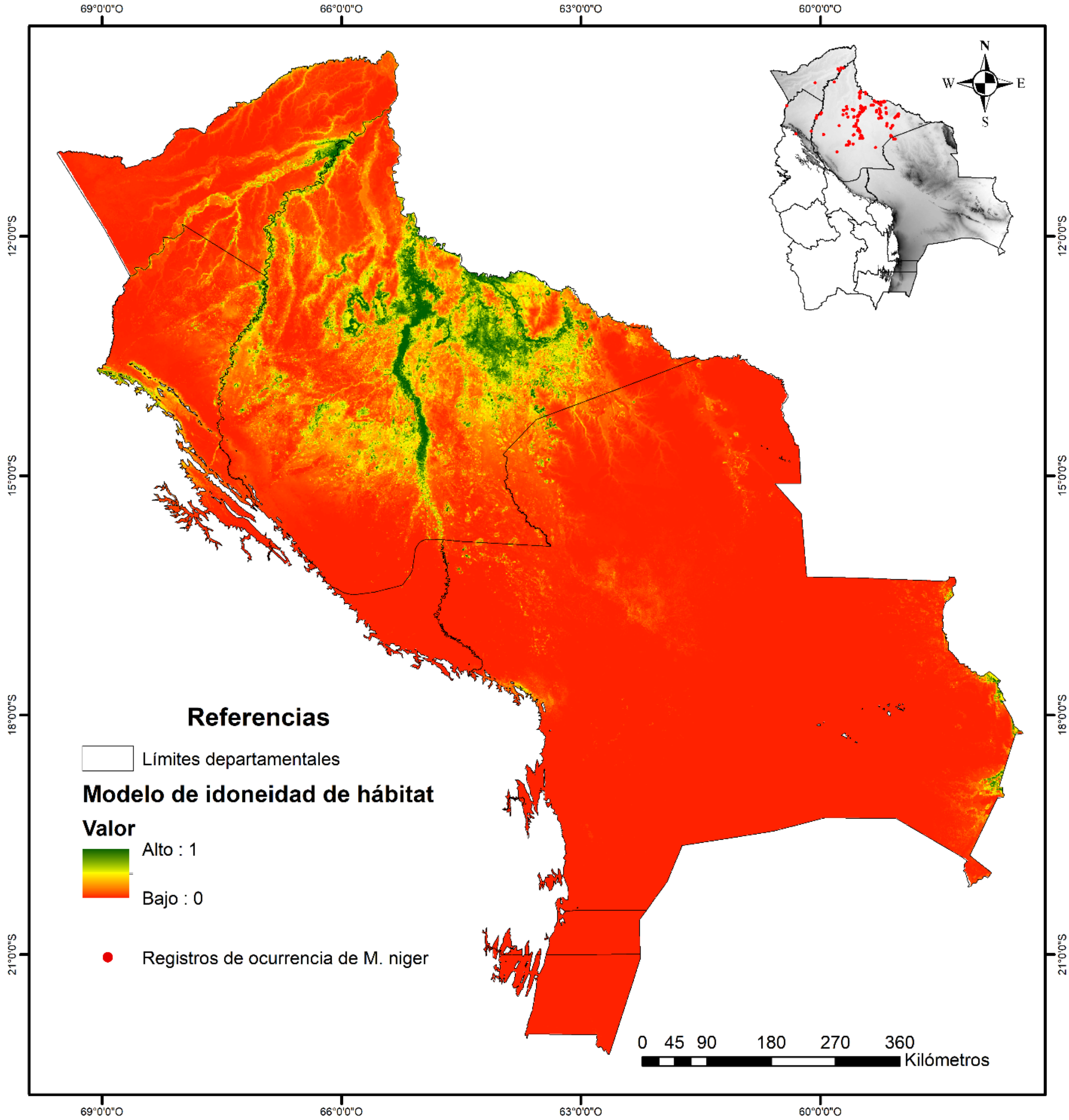

Figure 4. *Habitat suitability model for black caiman.*

Harvest quota determination model for alligator

In the event of updated population data, the mathematical model presented below should be used to determine harvest quotas based on the density of exploitable individuals per km of shoreline according to Bolivian legislation. However, in the absence of current data, potential densities of exploitable alligators per km were determined as explained in the methodology chapter. In this regard, 4 geographic zones were revealed (Figure 5); **Group 1**. It includes Pando, north of La Paz and north-central Beni. **Group 2.** Central portion of La Paz and the central-southern part of Beni. **Group 3.** Mainly the bordering landscape between Beni and

Cochabamba. **Group 4.** Especially in the department of Santa Cruz, but it also includes Tarija.

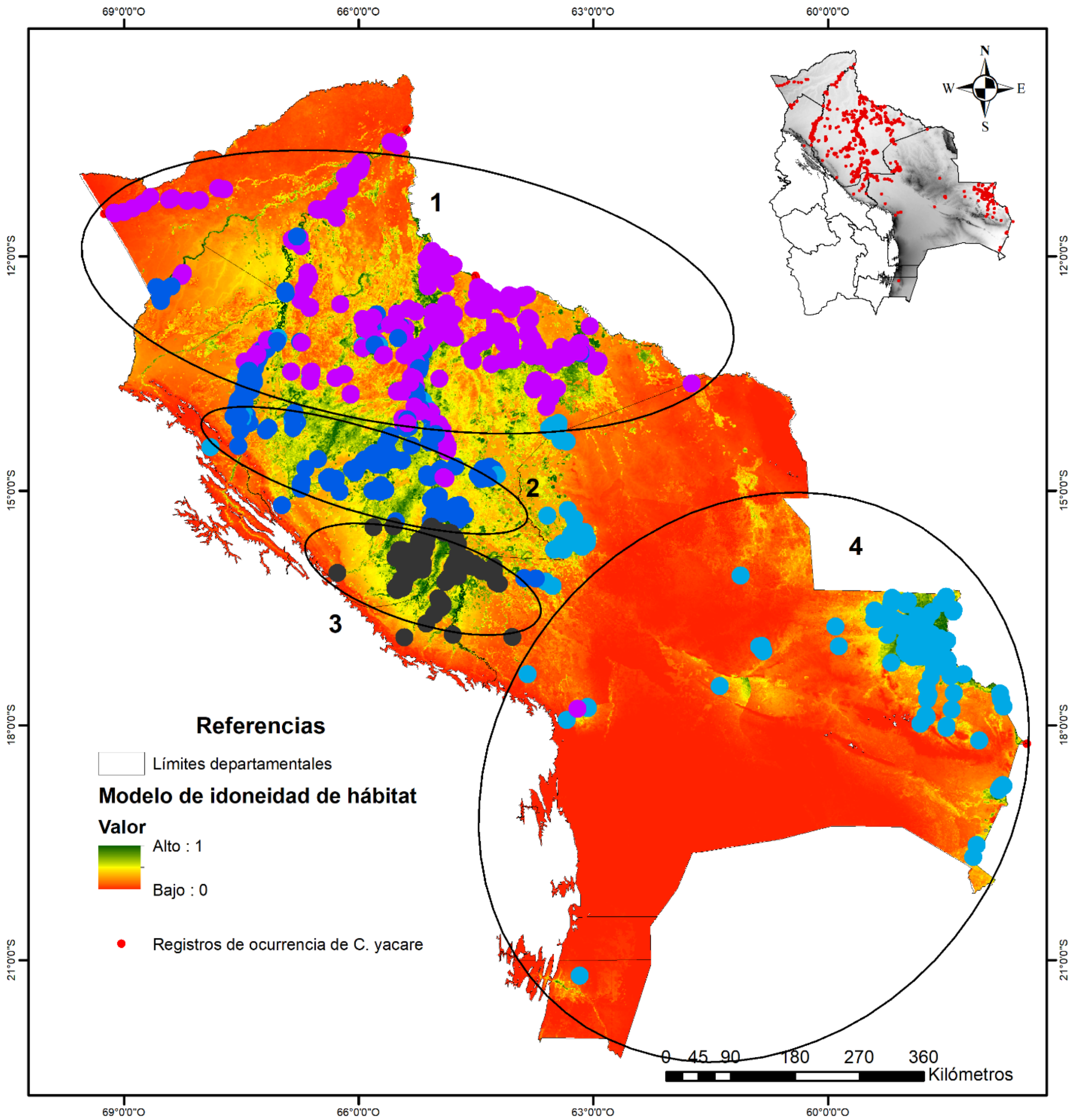

Figure 5. *Geographical groups determined based on ecological niche values for alligator.*

In this sense, depending on the types of water bodies classified, of the 4 geographic groups, only groups 1 and 4 showed statistically significant differences between the density values of exploitable alligators per km of shore, between types of water bodies, finding higher density values in lentic water bodies (Figure 6).

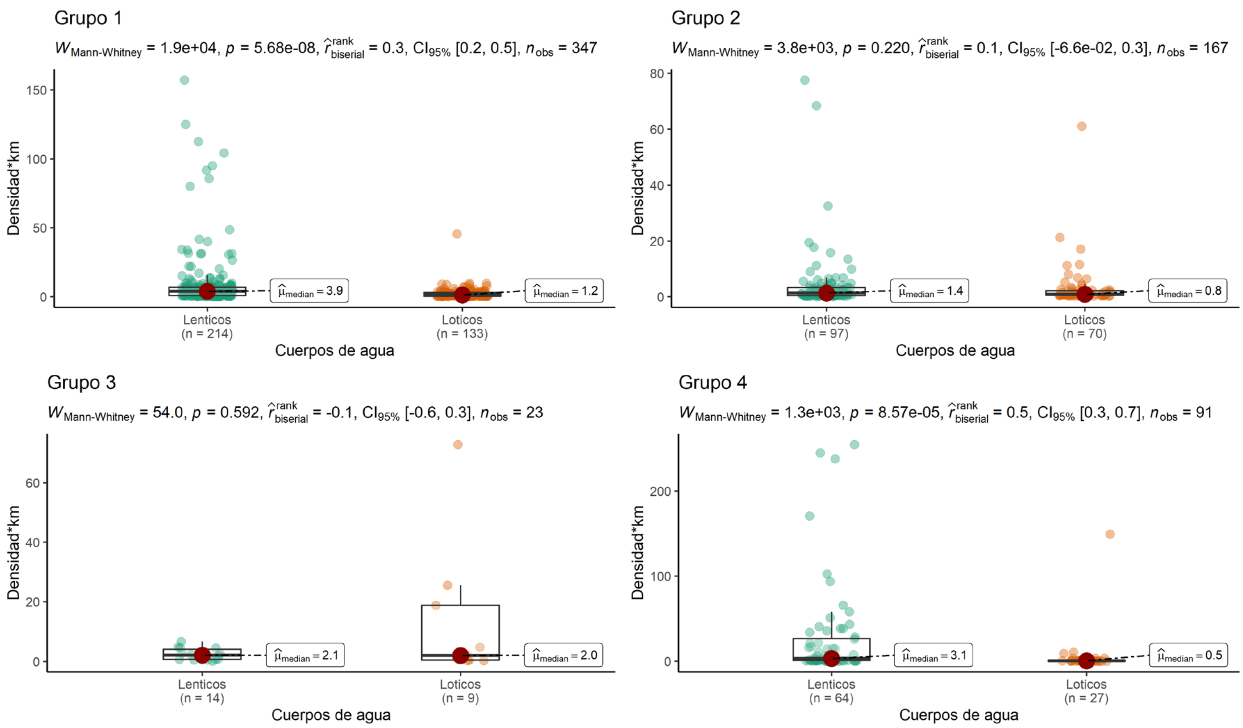

Figure 6. *Contrast of the density of usable alligators per km of shore between types of water bodies for each geographic group.*

Based on these results, typical density values of exploitable individuals per km of shore were established. These values are considered for alligator harvest quotas, in the absence of updated population data, using the mathematical model proposed in this study (Table 3).

Table 3. *Potential number of exploitable alligators per km of shoreline to be considered in harvest quotas in the absence of updated population data and based on the type of water body and geographic group identified.*

ID	Species	Group	Water Body	Usable individuals * km of shore
1	Alligator	1	Lentic	4
2			Lotic	1
3		2	Lentic	1
4			Lotic	1
5		3	Lentic	2
6			Lotic	2
7		4	Lentic	3
8			Lotic	1

Finally, the following figure (Figure 7) presents the proposed mathematical formulas and synthesizes the model developed to determine the alligator harvest quotas in Bolivia. Likewise, it will serve as a procedural decision tree to facilitate the application of the model to the authorities responsible for determining annual alligator harvest quotas at on-farm, departmental and national levels.

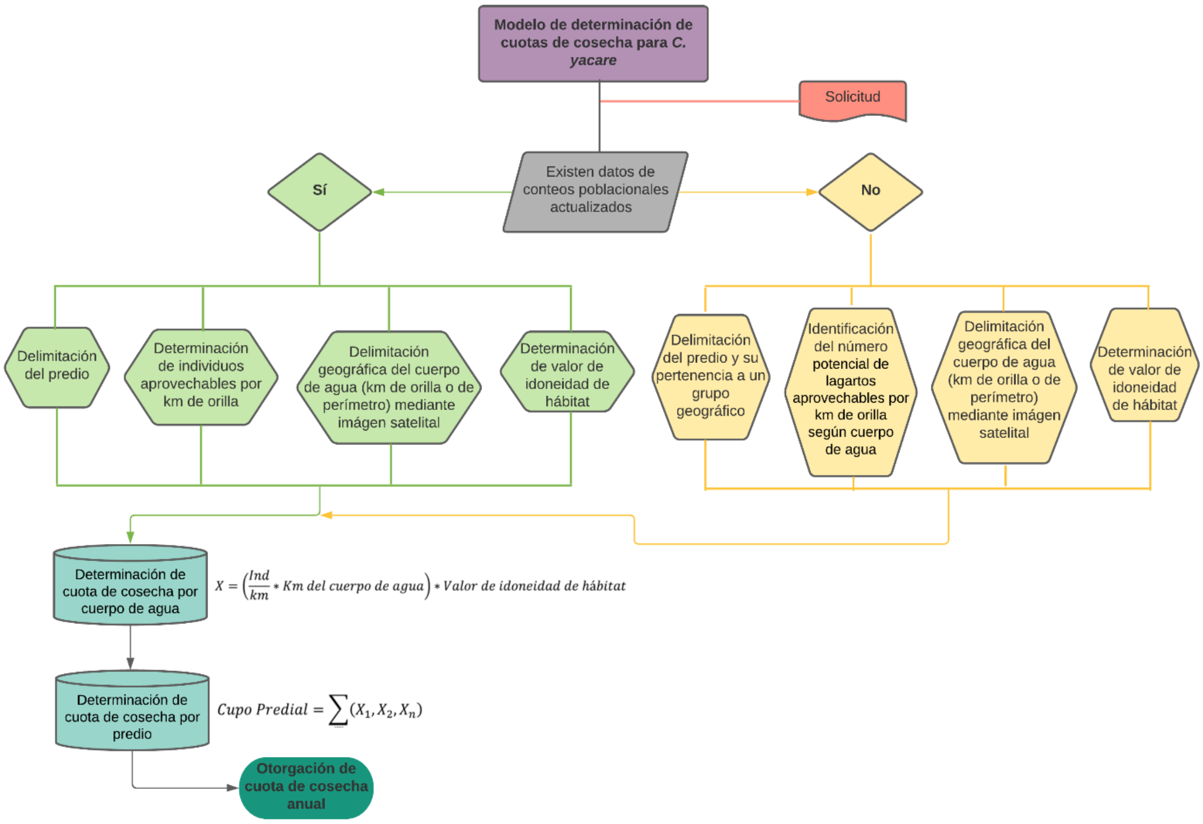

Figure 7. *Flowchart synthesizing the model for determining alligator harvest quotas.*

In this regard, the existence of 2 geographic zones was revealed for black caiman (Figure 8); **Group 1**. Pando and north-central Beni. **Group 2.** Central portion of La Paz and the central-southern part of Beni.

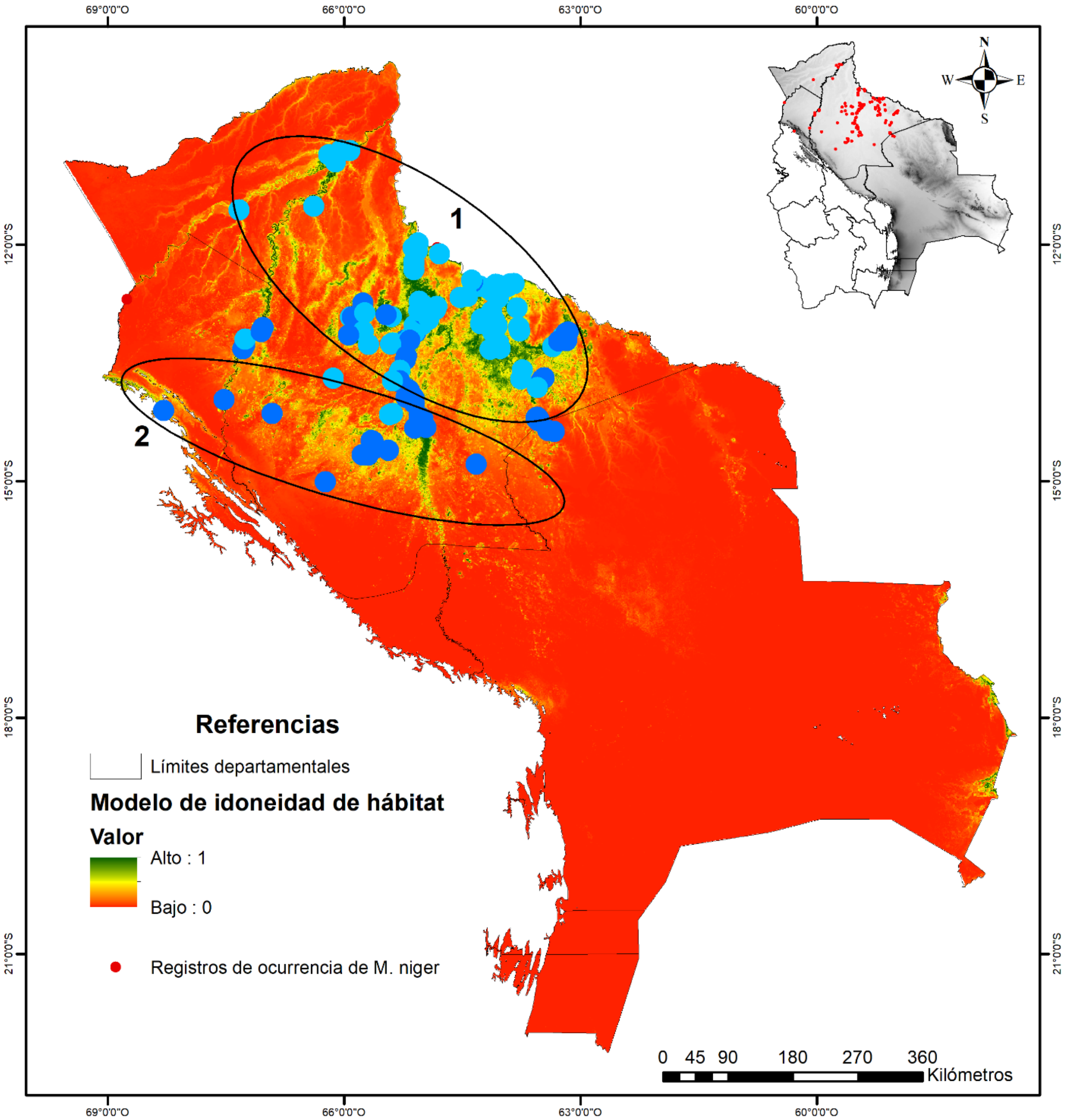

Figure 8. *Geographic groups determined based on ecological niche values for black caiman.*

Finally, priority areas were decided in Beni where management and conservation actions for black caiman populations could be developed (Figure 9). mainly associated with large lagoons (Rogaguado, Largo and Yahehaja) and main rivers (Mamoré, Iténez and San Martín). In these habitat conservation efforts should be given priority as they offer high values of habitat suitability for population strengthening of *M. niger*.

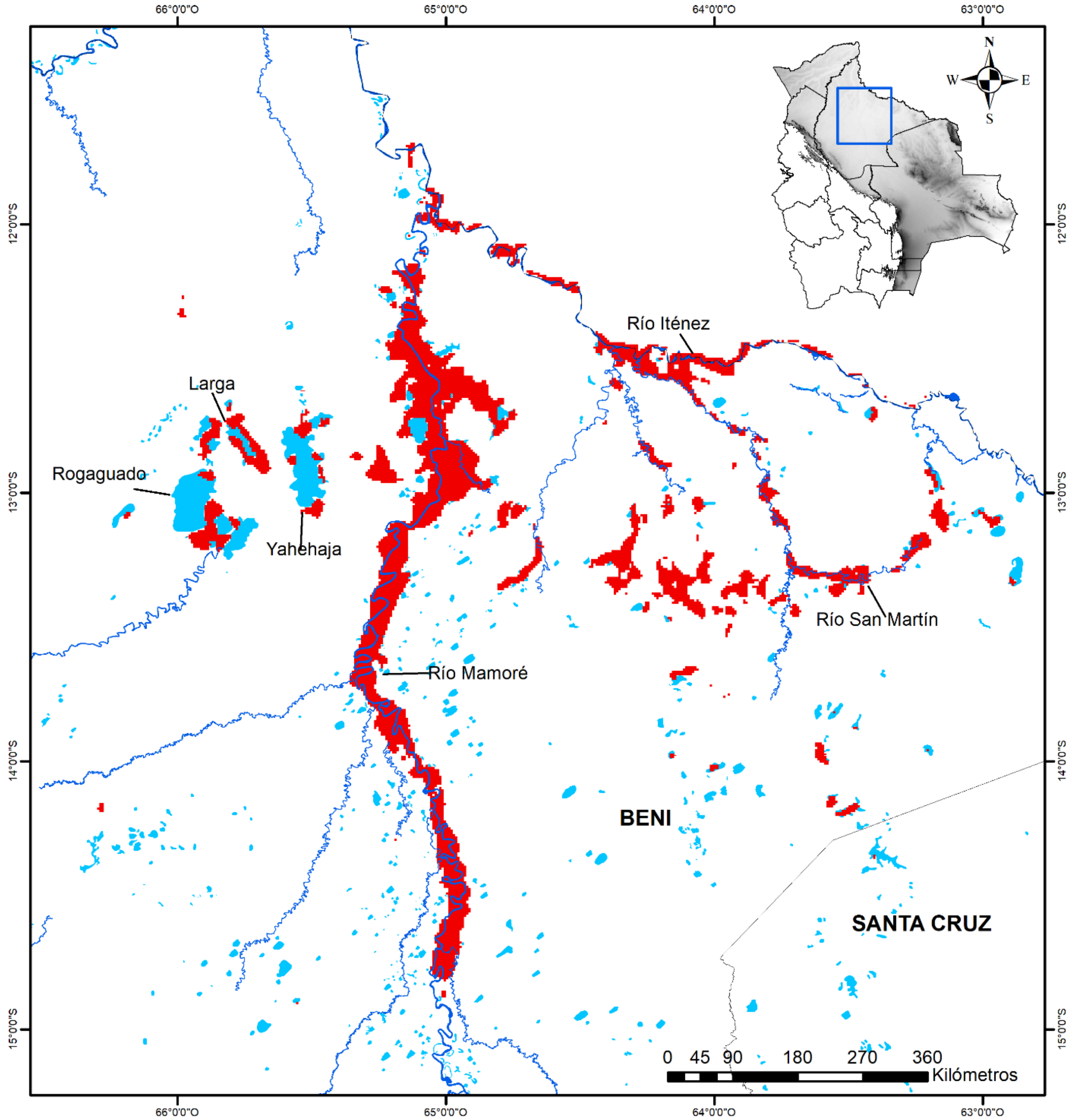

Figure 9. *Priority conservation areas for M. niger based on high habitat suitability values for the species.*

CONCLUSIONS

- The model proposed by the MHNNKM for alligator harvest quotas at the national level was updated and adjusted.
- In this adjusted model, two aspects which were not considered previously are involved, that may improve its accuracy; ***i.*** Habitat suitability values that are related to the natural history of the species. ***ii.*** The whole geographic extension of the evaluated water bodies was determined individually, through

manual digitization, using high-resolution satellite images.

- The model to determine alligator harvest quotas should ideally be executed with updated data about the species population status, since there will always be uncertainty in the probable annual harvest; However, historical data can also be used considering the typical densities of exploitable individuals according to the type of water body determined and the geographic group identified.
- The model is a biological, statistical, and geospatial tool that will allow to efficiently determine alligator harvest quotas in Bolivia. It must be exhaustively tested, both with current and historical data, in order to continue adjusting it, if necessary, in favor of the management and conservation of crocodilians in Bolivia.
- In relation to the black caiman, two different geographic groups were chosen based on their ecological niche values, as well as priority conservation areas that are relevant to initiate population strengthening actions for the species.
- Finally, the results obtained should not be considered as definitive or static over time, since they are directly a function of the amount of data available on the population situation of the alligator or black caiman in Bolivia, therefore, both the niche models and the mathematical model developed for determining alligator harvest quotas, can and should continue to be updated as they are tested and new data be generated through on-field population evaluations.

REFERENCES

Aparicio, J., A. Llobet & L. Pacheco. 1999. Criterios utilizados para recomendar una cuota de cosecha de *Caiman yacare* en Bolivia para 1999. Viceministerio de Desarrollo Sostenible y Medio ambiente, La Paz, Bolivia.

Aparicio J. & J.N. Rios. 2004. Experiencias de manejo en el proceso de aprovechamiento sostenible del Lagarto (*Caiman yacare*) en Bolivia (1995 –2004). Rev. Electrónica Manejo de Fauna Silvestre en Latinoamérica. 103 -110.

Aguilera, X., J.S. Coronel, T. Oberdorff & P.A. Van Damme. 2007. Distribution patterns, population status and conservation of *Melanosuchus niger* and *Caiman yacare* (Crocodylia, Alligatoridae) in oxbow lakes of the Ichilo river floodplain, Bolivia. Revista de Biología Tropical 56(2): 909-929.

Cisneros, F. 2006. Bases para el manejo y repoblamiento del Caiman negro (Melanosuchus niger) en el Territorio Indígena Parque Nacional Isiboro Secure (T.I.P.N.I.S.). 101 p.

CITES. Checklist of CITES. Checklist of CITES. Sitio Web: https://www.cites.org/

ESRI. 2011. ArcGIS Desktop: Release 10. Redlands, CA: Environmental Systems Research Institute.

Ibisch, P.L. & G. Mérida. 2003. Biodiversidad: La riqueza de Bolivia. Estado de conocimiento y conservación. Ministerio de Desarrollo Sostenible. Editorial FAN, Santa Cruz de la Sierra - Bolivia.

Liceaga, I., S. Ten & M. González. 2001. Abundancia y estructura poblacional de crocodilios en la Reserva Inmovilizada Iténez (Beni, Bolivia). Revista Boliviana de Ecología y Conservación Ambiental 10: 117-123.

Llobet, A., L.F. Pacheco & J. Aparicio. 2004. Analysis of the Program of

Conservation and Use of the spectacled alligator (*Caiman yacare*) in Bolivia, and recommendations to improve it. In Proceedings of the 17th Working Meeting of the Crocodile Specialist Group, IUCN. The World Conservation Union, Gland, Switzerland.

MMAyA. 2009. Libro rojo de la fauna silvestre de vertebrados de Bolivia [Red Book of the Vertebrate Wildlife of Bolivia]. Ministerio de Medio Ambiente y Agua. La Paz, Bolivia.

Ojasti, J. 1996. Wildlife utilization in Latin America: Current status and prospects for sustainable management. FAO, Rome, Italia.

Pacheco, L.F. 1999. Plan de Acción para los Caimanes de Bolivia. Ecología de Bolivia. 27(10): 46-49.

Palma-Ordaz, S. & J. Delgadillo-Rodríguez. 2014. Distribución potencial de ocho especies exóticas de carácter invasor en el estado de Baja California, México. Botanical Sciences 92(4): 587-597.

Phillips, S., M. Dudík & R.E. Schapire. 2021. Maxent software for modeling species niches and distributions (Version 3.4.1). Available through: http://biodiversityinformatics.amnh.org/open_source/maxent/.

Rodriguez-Cordero, A.L., S.A. Balaguera-Reinab, L.D. Densmore. 2019. Regional. conservation priorities for crocodylians in Bolivia. Journal for Nature Conservation 52(2019): 1-13.

Swets, J.A. 1988. Measuring the accuracy of diagnostic systems. Science 240: 1285-1293.

Thorbjarnarson, J. 1998. Status, ecology, and conservation of crocodile (Crocodylus intermedius) in Venezuela. FUDENA. Caracas, Venezuela.

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