ECOLOGICAL CORRIDORS PROPOSAL FUNCTIONAL FOR *Saguinus Oedipus* (TITÍ CABECIBLANCO)

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SUMMARY

The BOSQUE COLOMBIANO ORG led a mapping initiative of 4 ecological corridors and 4 sub-populations of the 'Saguinus oedipus' primate, in the Sierra Nevada de Santa Marta, in Colombia. The *Saguinus oedipus,* endemic to Colombia and declared Critically Endangered (CR) by the International Union for the Conservation of Nature (IUCN), has been the subject of various studies where ecological aspects are described and the population density is studied. TO based on the consultation of said studies, the selection of various factors was based to generate a proposal of a functional biological corridor with the use of GIS tools. They were obtained three products, the first one raster that represents the suitability of each pixel as habitat optimal being a very small area in proportion to the selected study area, a shapefile file was also generated with the representation of suitable areas as patches of habitats that allow reproduction and finally several runner series were generated based on the two previous products and the most appropriate one was selected according to home- *Saguinus oedipus* range , what is necessary to ensure that the species can maintain its space required as habitat and at the same time be susceptible to being sustainable.

Keywords: Ecological aspects; Functional biological corridor; GIS tools; Home- range.

INTRODUCTION

In order to design a proposal for a functional biological corridor between the Paramillo National Natural Park located in the departments of Córdoba and Antioquia and Los Rosales Regional Natural Park in the department of Atlantic for the *Saguinus oedipus* known as the white-headed marmoset, it developed a modeling methodology that is described by integrating
concepts.
The area of distribution of the species is located only in the Northwest of Colombia, being an endemic species and in turn threatened due to pressures for Illegal hunting and loss of their habitat. Although they have Parks National Naturals and Regional Natural Parks that maintain species conservation strategies do not yet have a corridor biological that connect these areas. The historical distribution area is taken As a study area. Taking the available literature of studies as a source of information scientists describing ecological aspects based on observations field, as well as population density and organizational studies social, several factors related to the requirements were contemplated Ecological species for the analysis of the area and the generation of the proposal. Making use of GIS processing tools exactly the Corridor Designer tools an ArcGIS extension, it was possible the biological corridor modeling by allowing to treat each of the elements or inputs as limiting factors or facilitators of the survival of the species generating a first product that categorizes each of the pixels
according to its suitability to be an optimal habitat.

Based on the first product generated and some space data required for reproduction, another product focused on identifying was generated the pixels that meet the space conditions and suitability to be habitat patches and finally generate a modeling of a corridor that based on considering a resistance value for the passage of the species in each pixel when taking as inverse the suitability inverse, in this way a distance cost calculation and the route with the lowest cost was selected.

The calculations of areas of each of the generated products are presented and each of the results obtained in terms of aptitude or suitability are analyzed of habitat, habitat patches and the selected corridor, further discussed some situations presented in the methodological process and in the treatment of the information.

1. THEORETICAL FRAMEWORK

The *Saguinus oedipus,* is a primate of the family Callitrichidae, known as Tití cabeciblanco, endemic to the northwestern part of Colombia. Its Historical distribution extends to the departments of Antioquia (area of Urabá), Atlántico, Bolívar, Córdoba, Sucre and part of Chocó, being limited between the Magdalena river and the Atrato river.

This species is currently declared Critically Endangered (CR) by the International Union for the Conservation of Nature (IUCN)[1]; they have identified several factors that have led the species to this state, among they extracting their habitat from approximately 30,000[2] individuals destined to biomedical research between the 60's and 70's. Illegal hunting and disturbances in their habitat have also contributed to the decrease of the species by replacing the forest with the incursion of activities economic such as livestock which has caused the fragmentation of its ecosystem. A population of 7,394 animals is estimated[3].

Fragmentation is understood as the "decrease in plant cover, leaving the original vegetation of a certain area reduced to small fragments isolated from each other immersed in a matrix more or less altered"[4], a situation that affects the population of Saguinus oedipus and although in the historical distribution area have been declared Natural Regional Parks

dedicated to the preservation of the species and other Natural National Parks that declare it as an object of conservation, so far it has not been designed or raised a biological corridor[5] that maintains connectivity structural or functional between these fragments and allow their displacement.

Biological corridors are not defined by fixed criteria that allow its identification, but it can be traced according to a functional connectivity which "refers to the different behavioral responses by the individuals to the physical structure of the landscape. The scale at which a species perceives and is able to move within the matrix, its habitat requirements and their degree of specialization, their level of tolerance for changes in the environment, the types of displacement and its response to predators and competitors"[6].

There are multiple studies of *Saguinus oedipus* that describe various ecological and social organization aspects registered in their natural habitat.

This information allows to deduce some factors associated with the identifiable ecological or habitat requirements in some areas potentials for functional connectivity between forest fragments found in the protected areas present in the area of distribution of the species. Two potential areas for connectivity are the El Natural National Park Paramillo located between the

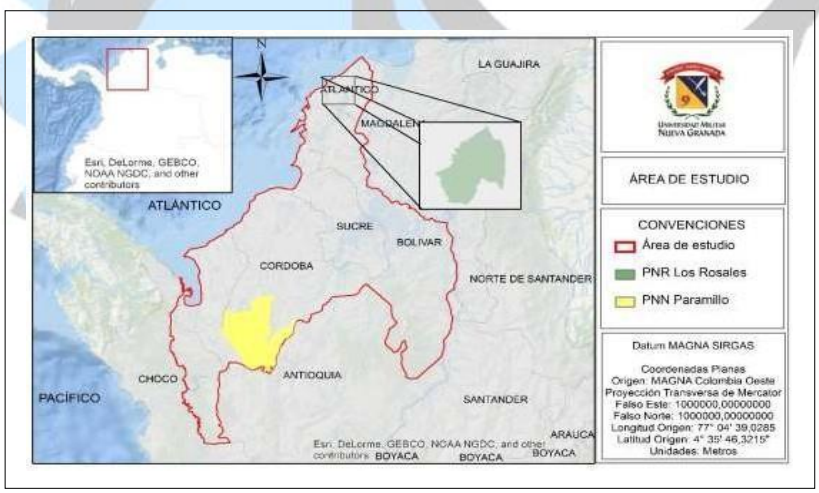
[1] IUCN, 2016
[2] (Savage, Thomas, Leighty, Soto, & Medina, 2010)
[3] (Savage, Thomas, Leighty, Soto, & Medina, 2010)
[4] (War Magic, and others, 2002)
[5] "A Biological Corridor can be conceived as a modified habitat link, in which activities
[6] (National System of Conservation Areas, 2008)

departments of Antioquía and Córdoba, where see Saguinus oedipus as one of the mammals objects of conservation , and Los Rosales Regional Natural Park in Luruaco, Atlántico for its high ecological potential and to be a refuge for the species. Geographic information systems have been widely used for the identification of these areas through tools designed to evaluate criteria in the selection of areas with biological potential that may be connected and trace the route. Through tools such as extension corridor designer[7] it is possible to model these corridors, based on factors related to habitat requirements.

- **Study area**

The selected study area includes the departments of Bolívar, Sucre, Atlántico, the Urabá Antioqueño area and part of the municipalities of Acandí, Unguía, Riosucio, Bojayá, Quibdó, El Carmen de Atrato, Belén de Bajirá, and El Carmen del Darién of the department of Chocó, occupying an extension of 82,094.42 km 2 . Within the area are sections of the Atrato rivers, Cupcake and Cauca. (Watch Map N. 1) The Paramillo National Natural Park has a total area of 460,000 ha[8], "It retains an altitudinal gradient that collects different ecosystems, such as: Páramo, Andean High Forest, Andean Forest (foggy forests: 700-1,200 masl), Tropical Wet Forests of Piedmont (200-700 masl) and Wet Forests in Flooded Plains (Manso and Tigre)"[9]. Los Rosales Regional Natural Park has an area of 1,304.5 ha, "It has minimum temperatures of 25ºC and maximum of 38ºC, and rainfall 1500 mm annual "[10].

Map N. 1 Study area



Source: Own

- **Ecological requirements elaboration, 2016**

[7] Majka D., J. Jenness and P. Beier. 2007. CorridorDesigner: ArcGIS tools for designing and evaluating corridors Available at http://corridosdesign.org

[8] National Parks of Colombia., 2005

[9] National Parks of Colombia., 2005

[10] (Alexander von Humboldt Biological Resources Research Institute, 2012)

This species "is found in rainforest, flood forests, forest deciduous, secondary growth wooded areas and sub-xerophytic forest (although not in xerophytic forest)"[11]. According to what is published in the biodiversity catalog

of Colombia, they find up to 800[12] meters of altitude; Defler describes in his book that "it has registered up to about 400 meters above sea level as maximum height; however it is it may be found at higher altitudes of the upper Sinú river valley"[13], which It would be around 1500 meters above sea level. Within the descriptions of the ecological aspects of Saguinus oedipus in Neyman's reports (1975) mention having observed between foods "Tiny to large fruits of trees, vines, epiphytes, insects, flowers, tender leaves, buds, leaf petioles and on one occasion a frog ", in addition having seen a group lick leaf water but not go looking for others places; Another important review was that "a fodder group can be extended over an area of up to 35 m or more in diameter "

In the study conducted by De La Ossa V. & De La Ossa-Lacayo in 2014, where an analysis is made in the relationship between these factors, a table of the plant species available in the study area, which are food of Saguinos oedipus, identifying species of the families of Fabaceae, Moraceae, Lecythidaceae, among others. In one of the statements from the study "it is determined that the supply of food has an effect on the size population and influences sex ratios"[14]. "Marmosets got their food at all levels of the forest and sometimes in the soil (eg, fallen fruits Psidium guajava). However, most of the Trees used were those of the middle stratum. Medium stratum (5-15 m)"[15]. Neyman (1977) states that in his observations "the size of households for The three groups were 7.8, 7.8 and 10.0 hectares with the group size corresponding (maximum number and minimum number) from 13 to 5; 5 to 3; and 6 to 3 individuals The overlapping of adjacent housing groups was from 20 to 30 percent"[16]. It also points out that the lengths traveled daily They fluctuate between 1.5 and 1.9 km.

Neyman's investigation showed that his resting sites are not randomly selected, otherwise they are different trees where they would have rested before; the trees where more specimens were sighted was in those of "fork or broad branch near the trunk" with heights of 10 to 22 m. However, Defler points out that the roosts "are in the part canopy high (13.5 to 20 m)" based on other research. They are named Epiphytes and Vines as other resting sites. As for the Defler activity pattern, he describes that calculated by Savage, the time this species devotes to foraging is 31- 44%, however, 29-37% and displacement 19-40%.

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[11] (Defler, 2010)
[12] Saguinus oedipus (L., 1758). Biodiversity Catalog of Colombia. Available in http://catalogo.biodiversidad.co/fichas/111#distribucion. Retrieved on [2016-11-15] [13] (Defler, 2010)
[14] (De La Ossa V. & De La Ossa-Lacayo, 2014)
[15] (Neyman & IDERENA, 1975
[16] (Neyman & IDERENA, 1975

2. DATA

The BioModels of Humboldt[17] Institute species were taken in order to obtain a trophic map from the BioModels of 44 species that make part of the trophic chain of Saguinus oedipus . A DEM[18] of the area was obtained of study with 30 m resolution used as an altitude map. He took the 2012 land cover map of IDEAM[19] and a national road map as input to determine the appropriate distances for plotting the runner. Shape files of the spatial boundaries of the areas Protected to connect were taken from SIAC[20].

3. METHODOLOGY

The methodology[21] for the identification of the biological corridor is based on Conceptual steps for designing wildlife corridors de Beier, P., Majka, D., & Jenness, J. (2007) with an adaptation to the conditions of Saguinus oedipus by applying the corridor designer tools. Through this tool set it is possible to perform a habitat modeling (aptitude habitat) based on factors related to the important components in the habitat of the species where the permeability or suitability of each species is identified pixel, model the runner based on the modeling mentioned above (assuming that the cost or resistance of the pixel for the passage of the species is the inverse of the permeability) and in the calculation of patches where possible the reproduction and population of the species according to the minimum size required for it.

• **Habitat modeling.**

As stated above, this modeling is based on GIS factors. that influence or are related to the habitat requirements of the species to determine habitat fitness given by pixel suitability. For that matter of Saguinus oedipus (Tití Cabeciblanco) it was decided to contemplate 4 factors important, each divided into classes (which groups sets of pixels). The factors were reclassified, assigning them higher suitability values or lower to each class, depending on their importance in the requirements of habitat. Factor 1 altitudinal map: Its importance is that it allows establishing areas that are at a height suitable for the species, as a determinant of different environmental conditions. For this map there was a model Digital elevation of 30 m spatial resolution. According to the literature, Saguinus oedipus is evidenced in areas with altitude between 100 and 400

[17] " BioModelos is a digital tool that allows communication between biodiversity experts to the development of distribution models of the existing species in Colombia collaboratively and open ". Laboratory of Applied Biogeography and Bioacoustics. 2014. Biomodels. Alexander von Institute Humboldt Available at http://biomodelos.humboldt.org.co . Retrieved on [2016-10-10]

[18] Digital Elevation Model- Digital Elevation Model

[19] Institute of Hydrology, Meteorology and Environmental Studies Sub-Directorate of Ecosystems and Information

[20] System of information Environmental of Colombia. Available in http://www.ideam.gov.co/web/siac/catalogo-de-mapas. Retrieved on [2016-10-13] twenty-one

[21] It can be consulted at http://corridordesign.org

masl, so it is the range within the classification from this map the one that receives a higher value, while at higher altitudes at 1500 m they will have an assessment within the minor analysis.

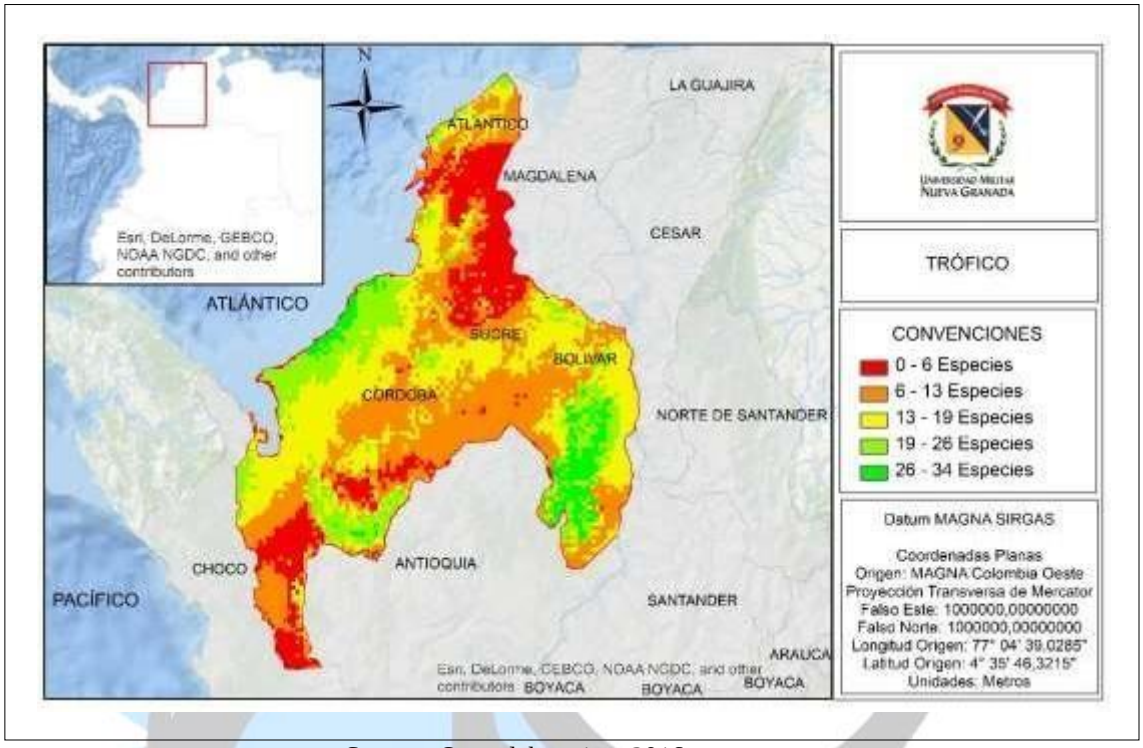
Factor 2 Map of land cover: The map for Colombia was taken from year 2012 of the IDEAM to establish the coverage that presents less or greater permeability for the passage of thespecies through these in the study area. Based on the requirements of the species to maintain its habitat, it consulted various sources in which forest cover is indicated and secondary forest coverings are suitable for these species, assigning them a high suitability value within the map classification, while hedges of artificial territories receive the lowest value due to its inability to provide shelter or food to the species and prevent The passage of the species.

Factor 3 Road distance map: This factor requires great attention in the time to draw ecological corridors because they are barriers to connectivity and facilitates the intervention of man within the corridor, in addition to present a high risk of mortality due to traffic accidents. With the tool of influence in multiple rings[22] map was generated with a output cell size of 30m. The distances were classified from 60 meters as the minimum distance to the edge of the tracks, assigning them the smallest suitability score.

Factor 4 Trophic map: In this a spatialization of the possible distribution of forest species food source for Saguinus Oedipus This map was obtained with information taken from the BioModels of the Humboldt Institute, in which an estimate of the distribution of several is made species with a resolution of 1 km 2 , being possible to collect this Information on 44 important species within the Trophic chain of Titi. By using the raster Calculator[23] tool , the map was generated trophic when adding all the overlapping pixels of the 44 covers and having as result a last coverage with a value for each pixel according to a more or less presence of forest species, it was also necessary to make resampling with the Resample[24] tool to resize the pixel and reduce it to 30 m as the other factors worked. In the reclassification made for this map it was decided to give it greater value of suitability to pixels where they are presumed there is a greater presence of species within the trophic chain, defined in a range (class) of 26 to 34 being this Last the highest value obtained from the procedure described above (**See Map N. 2**).

[22] Create several zones of influence at specified distances around the input entities" (ESRI, 2016)
[23] "Build and execute a simple Map Algebra expression using Python syntax in a interface similar to a calculator "(ESRI, 2016).
[24] "Change the spatial resolution of your raster dataset and set rules to add or interpolate values in the new pixel sizes "(ESRI, 2016).

Map N. 2 Trophic



Source: Own elaboration, 2016

In order to define the overall fitness of each pixel as habitat, a combination of the factors assigning a weight for each of them of according to its relevance for an optimal habitat and the activity pattern of the Saguinus oedipus . The algorithm used for this estimate was the average Weighted geometric.

Tabla N. 1 Factores de peso

FACTOR	PESO
Altitudinal	20
Coberturas de la tierra	35
Distancia a vías	10
Trófico	35
Total	100

Fuente: Elaboración propia, 2016

Once the suitability values were assigned for each class and adjudicated the weights to each of the factors were determined categories that classifies the fitness of each pixel according to a range determined from the calculation of the values that the pixels could throw in the output raster in several scenarios critical for the survival of the species.

Habitat patches

The tool calculates a map of habitat patches in order to integrate them into the corridor generation, based on minimum size data of the patch for the reproduction of Saguinus oedipus (according to consulted in the bibliography its home-range 25 is approximately 10 ha), in addition to the minimum area required to maintain a population in the patch for at least 10 years (50 ha) and a viability threshold, that is the point in the which habitat does not meet as a breeding habitat determined at 65. It get a potential population patch, potential reproductive patch and a patch smaller than the potential reproduction.

Corridor modeling

The runner's determination is based on the calculation of distance-cost 26 , taking in each pixel a cumulative resistance value. The resistance value is assumed as the inverse of the overall suitability value of each pixel obtained from habitat modeling or habitat fitness. Inside this tool You also have natural parks to connect and habitat patches. Corridor selection: With the principles described, the tool presents a series of corridors with different widths according to an increase in the threshold in the maximum resistance values, of which the most must be selected suitable; the selection in this case is based on the area required as home- range of 10 has the equivalent of 0.1 km 2 , so it is decided to take as a width of approximately 0.00063246 km when assuming an area of a square and increase the size twice.

The study area has a total of 6,334.20 Km 2 classified as habitat optimal (most suitable area) for saguinus oedipus , that is, only 7.72% of the area meets the conditions of land cover, presence of species trophies, distance to roads and altitude range more suitable to facilitate greater survival and greater reproductive success; another 13,600.85 km 2 were identified (16.57%) of surface that although it does not classify within an optimal range, if find the conditions under which species can have a reproduction and use of these areas as sub-optimal habitat.

With the analysis, 41,207.84 km 2 of surface were found, although they are not suitable for reproduction if they allow the development of other activities, calculates approximately 50% of the total area, however they were established 19,875.51 Km 2 (11.61%) in which they hinder the stability of the species or in definitively do not meet any of the conditions established in this study as suitable for the habitat of Saguinus oedipus . 1,076.02 km 2 were found within which it was not possible to determine the aptitude of habitat due to lack of information on any of the factors in those areas A total of 62,222.54 km 2 of surface area not suitable for reproduction or for habitat support for a population of at least 10 years, being approximately 76% of the total area evaluated, only approximately 23% meet the criteria of habitat suitability and patch size to support populations.

According to what was mentioned in the methodology, the corridor according to a suitable width; it was decided to select the broker with a threshold of 10%, because in all its route it does not have a width less than 0.00063246 km (0.63246 m), contrary to the 10% threshold model where there are widths that do not meet the condition; the other runners they were not selected because the destination of resources for their management it may be unfeasible for the area that needs to be maintained.

The corridor extends over 26 municipalities, Turbo being in the Department of Antioquia which contains the largest area of the corridor with 18.48% (152.99 km 2) of the total area and the municipalities of Clemencia and San Estanislao with approximately 0.0002% (1,930 m 2) and 0.0004% (3,720 m 2) of the total area respectively the corridor contain the smallest proportion. The corridor presents in large proportion areas under the category of Used occasionally, followed by areas with optimal habitat fitness. The categories of habitat in smaller proportion found within the corridor correspond to no habitat and avoid adding in total 29.9 km 2 3.62% of the area, however in the northern part of the study area at the height of the municipalities of Villanueva, Turbaco and Arjona there are areas categorized as avoided bordering to the corridor; a similar situation is seen at the height of the municipalities of San Bernardo del Viento and Moñitos where areas are presented under the category of no habitat as habitat aptitude which can generate edge effects that affect the maintenance of the corridor and the stability of the species. In the rest of the corridor there is more influence of areas categorized as habitat Used occasionally that may be less pressure on populations of Saguinus Oedipus.

4. DISCUSSION

The analysis identifies optimal areas that facilitate the the survival of the species when evaluating the factors related to Habitat Requirements It is not possible to affirm that the species actually decides to establish its Habitat in the polygons identified as optimal and not in others with less Suitability, spatialized in tools. Some other conditioning factors. The results in habitat aptitude that show a reduced space for the establishment of the optimal habitat of Saguinus oedipus and otherboth categorized and sub - optimal can to a certain degree not correspond to reality due to the analysis performed previously, without however, according to the results the stability of the species may be strongly threatened. Over the total area. historical distribution Four conditioning or limited factors were estimated and were weighted according to their relevance for optimal habitat and patterns of activity of the species; as described above these factors do not corresponds directly to ecological requirements such as the temporality in climatic conditions but the factors evaluated as the that determine the existence of forest species in this case those identified within the food chain. Among the factors used in the analysis, the trophic map was assumed as a factor of great importance because access to food determines the survival of any species; This map was obtained from some BioModels where a spatialization of different enunciated species is presented as a food source for Saguinus oedipus, which had a resolution

of 1 Km 2, this being evidently larger than the resolution of the other factors, for which it was decided to resample and reduce the pixel size to 30 m which, although it does not generate a greater detail within the information contained in the trophic map if it influences the output information in the raster generated from the combination of the different factors. For the purposes of management and sustainability of the corridor, the one that has a width at least 2 times larger than the home-range of the Saguinus oedipus was chosen, what is necessary to ensure that the species can maintain its required space as a habitat and at the same time allow the passage of other individuals of the same or different species without territorial disputes.

Because the resources allocated for these areas are limited, care must be taken to select a corridor that guarantees the above but at the same time is feasible for sustainability over time.

There are some areas of the corridor in which it has around zonas que they were classified as avoiding, that is, they are areas for which the cost is very high for the passage of the species or for the establishment of the habitat, which can be managed from GIS tools through the establishment of a wider area to calculate the average habitat adequacy in a focal pixel 27 to avoid edge effects, although in this case it was useda habitat patch threshold of 65 which was determined when considered several critical scenarios that hinder the survival of the species, from of which the values that the pixels could throw in the raster of exit in habitat suitability. Also within the processing of factors for the generation of habitat fitness map was used as estimation algorithm the weighted geometric mean with which it was intended guarantee that no pixel would have a global suitability in case any of the factors had a class with a value of 0. Although tools are used as a corridor designer that considers multiple factors that are intended to make a functional modeling and consider factors strictly linked to the ecological requirements of the species and are properly evaluated, within the planning process, modeling and establishment of area management strategies is also important to link actors or communities in the area of influence, because no effort in resources that is destined to corridor will take effect if the communities do not support the strategies launched for the maintenance and improvement of the corridor, and to ensure the permanence of the species. In this particular case, it is necessary to raise awareness of the danger in which S aguinus oedipus is found, which has been subject to illegal hunting, in addition to seeing its habitat reduced due to changes in land use.

5. CONCLUSIONS

The study of the ecological aspects of the species are fundamental in the advancement of the recognition and grouping of GIS elements that help to model the optimal conditions under which their survival is possible and the establishment of their habitats in order to generate true functional corridors that fulfill the objective under which they have been designed. Although GIS tools are very useful for generating biological corridors, certainly the result will also be affected by external conditions such as operator decision-making, such as the case of resample on which

more accurate information depend on generated in the processing or at the time of the evaluation of habitat suitability. The designed corridor aims to meet the objective of being functional for the Saguinus oedipus, attending optimal, sub-optimal and optimal habitat conditions used occasionally in greater proportion that allows a greater probability of survival of the species and the passage of individuals through patches of habitats translated into a genetic exchange between populations when determining a route with less resistance that in turn connects the National Natural Park Paramillo with the Los Rosales Regional Natural Park.

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