PROPOSAL FOR ECOLOGICAL CORRIDORS AND BUFFER ZONES AS MEASURES TO RESTORE CONNECTIVITY TO THE HABITAT OF THE CARRANCHINA TURTLE, IN COLOMBIA

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SUMMARY

In the present study, the design of ecological corridors and buffer zones is proposed as a measure for the expansion and restoration of the connectivity of the habitat of the endemic species Carranchina turtle (Mesoclemmys dahli) in the north-central provinces of Sucre and Córdona, located to the northwestern Colombia. The methodology used, the result of modifications to the Bentrup (2008) proposal, was based on the analysis of geographic parameters that define areas with the best territorial aptitude for the habitat of the species. Likewise, the study is based on a cost analysis that, through a Geographic Information System, allows defining the potential location of the functional connectors. In this way, the model provides reliable information that makes it possible to accurately propose the layout of corridors and buffer zones. As will be noted in due course, the methodology used can be adjusted for other species.

Keywords: ecological corridors; buffer zones; Mesoclemmys dahli; Colombia

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INTRODUCTION

The fragmentation of ecosystems and the loss of ecological connectivity, two of the main factors that have a profound impact on biodiversity, are largely caused by the increase and homogenization of agricultural and urban activities (Rodríguez-Soto et al., 2013; De León Mata et al., 2014; Johnstone et al., 2014; Gao Q, 2014; García-Marmolejo et al., 2015; Loro et al., 2015; Van Langevelde, 2015; Villemey et al., 2015 ; Burkart et al., 2016; Peled, 2016). Ecological connectivity is defined according to the degree to which the territory facilitates or hinders significant ecological processes such as the movement of species through existing habitat resources in the landscape (San Vicente, 2014). Therefore, the preservation of ecological connectivity helps to minimize the negative effects of habitat fragmentation (Johnstone et al., 2014).

One way to contribute to reducing the loss of ecological connectivity consists in the design of ecological corridors that function as zones that cushion the negative effects of fragmentation. In this sense, it is vital to consider the theoretical insights of Bentrup (2008), who defines ecological corridors as "vegetation strips incorporated into the landscape [that serve] to influence ecological processes and provide a variety of goods and services. They are known by various names, such as wildlife corridors, greenways, windbreaks, and filter strips" (p.1). However, other authors such as Tres and Reis (2007) argue that many of these models have a strong tendency to fill areas with tree species that limit the space available for natural regeneration. However, it should be added that the success of ecological corridors depends on the degree to which their design contributes to eliminating the biotic and abiotic barriers that degrade the ecosystem.

Although Colombia is characterized by having a high biodiversity, according to the red list of endangered animals it is one of the countries with the highest number of threatened species in the world (International Union for Conservation of Nature, 2014). Among the factors that accentuate this situation, it is worth highlighting the intense deforestation of forests and the overexploitation of natural resources due to hunting and illegal animal trafficking (Sierra, 2013; Rodríguez and Ortega, 2012; De Osma Vargas-Machuca et al., 2014). These circumstances contribute in various ways to the reduction and fragmentation of the habitat of endemic species such as the Dahl's Toad-headed Turtle (Mesoclemmys dahli), known locally as Icotea 'Carranchina turtle'. The Carranchina turtle has a wide geographical distribution in the neotropical region of the northern territory of Colombia, in the middle of the Zenú indigenous territory: it inhabits the humid, dry, tropical and subtropical forests of the Colombian Atlantic Coast, as well as some Andean foothills below. of 700 masl (Albuja et al., 1993; Tirira, 2007).

According to the IUCN - SSC | Tortoise & Freshwater Turtle Specialist Group (2019), the species is in CRITICALLY ENDANGERED; Its survival in northwestern Colombia is threatened by multiple factors, among which its own reproductive characteristics stand out; the loss and fragmentation of the native forest and wells—their natural habitat—due to the effects of deforestation, and the increase in poaching, since it is used as food by the indigenous and rural populations of the region (Tirira, 2007, 2011; Rodríguez and Ortega, 2012; Bonilla-Morales et al., 2013; Pozo, 2013; De Osma Vargas-Machuca et al., 2014).

As stated in the study by De Osma Vargas-Machuca et al. (2014), despite their decline and fragmentation, the forests continue to be the habitat of the Carranchina tortoise (Mesoclemmys dahli), and to a lesser extent of other species such as the Magdalena River Turtle (Podocnemis lewyana). These species are located in the remnants of native forests located in the northwest of the Zenú indigenous territory. Accordingly, the objective of this research is to propose the design of ecological corridors and buffer zones in the sectors with the best territorial aptitude for the Carranchina turtle; surfaces defined according to socio-economic, biophysical and social factors. Thus, the purpose of the project is to provide adequate measures to restore ecological connectivity between the remnants of native forest and wells; and thus favor an increase in the habitat of the species. In particular, it seeks to facilitate the mobility of the Carranchina turtle in a sector that covers 144 km2 in the center-north of the province of Sucre and Córdoba: space for agricultural, silvopastoral, fishing and agroforestry activities.

Although it is not under a specific political-administrative delimitation, the study area includes part of the corregimientos of SACANA, MOMIL, SAN ANTONIO DE PALMITOS and COVEÑAS. The surface is located between the following coordinates: 9°13'00.3"N and 75°47'08.9"W; as the northwestern point; 9°13'12.2"N 75°39'43.6"W; as northeastern point; 9°06'51.2"N 75°39'41.0"W; as the southwestern point, and 9°07'46.5"N 75°44'57.1"W; as the southeastern point (figure 1).

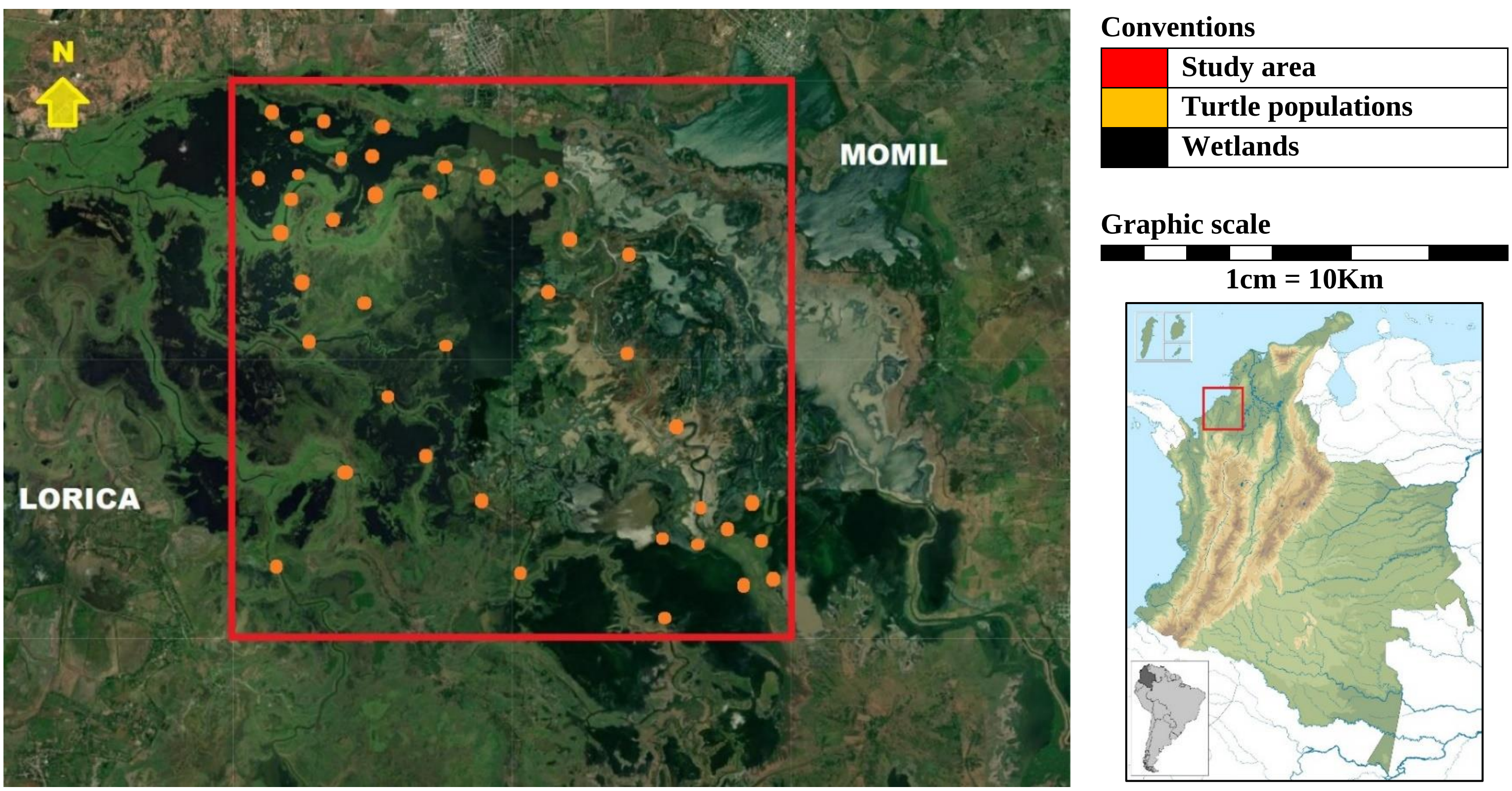

Figure 1. Location of the study area

Cartographic source: base map of Google Maps (2022) and thematic maps of the Ministry of the Environment of Colombia (2021)

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METHODOLOGY

For the formulation of a proposal for ecological connectors in the study area, it was necessary to a) identify the native forest cover; b) identify the territorial aptitude for the presence of the Carranchina turtle; c) propose the creation of connectors —ecological corridors and buffer zones—, and d) process the geoinformation (figure 2).

Identification of native forest cover

Through the visual analysis provided by the ArcGIS Geographic Information Systems package (version 10.1), the forest cover was interpreted and delimited. The procedure was developed on a set of orthophotomaps at a scale of 1:5000 generated by the Ministry of Agriculture by the Program of the National System of Information and Management of Rural Lands and Technological Infrastructure (Sigtierras), under the supervision of the Military Geographic Institute (IGM). . The orthophotomaps correspond to a UTM coordinate system, datum WGS-84, Zone 17. Likewise, these coordinates were acquired in the year 2021.

Identification of variables and preparation of maps of optimal areas by criteria

To develop the research, firstly factors, variables and criteria were defined in a matrix that represented the cartographic model. Subsequently, we proceeded with the collection of cartographic information and other suitable remote sensor products for the formulation of a map of territorial aptitude in which the presence of the Carranchina turtle could be observed. Next, With this information, the ecological corridors and buffer zones suitable for the particular case.

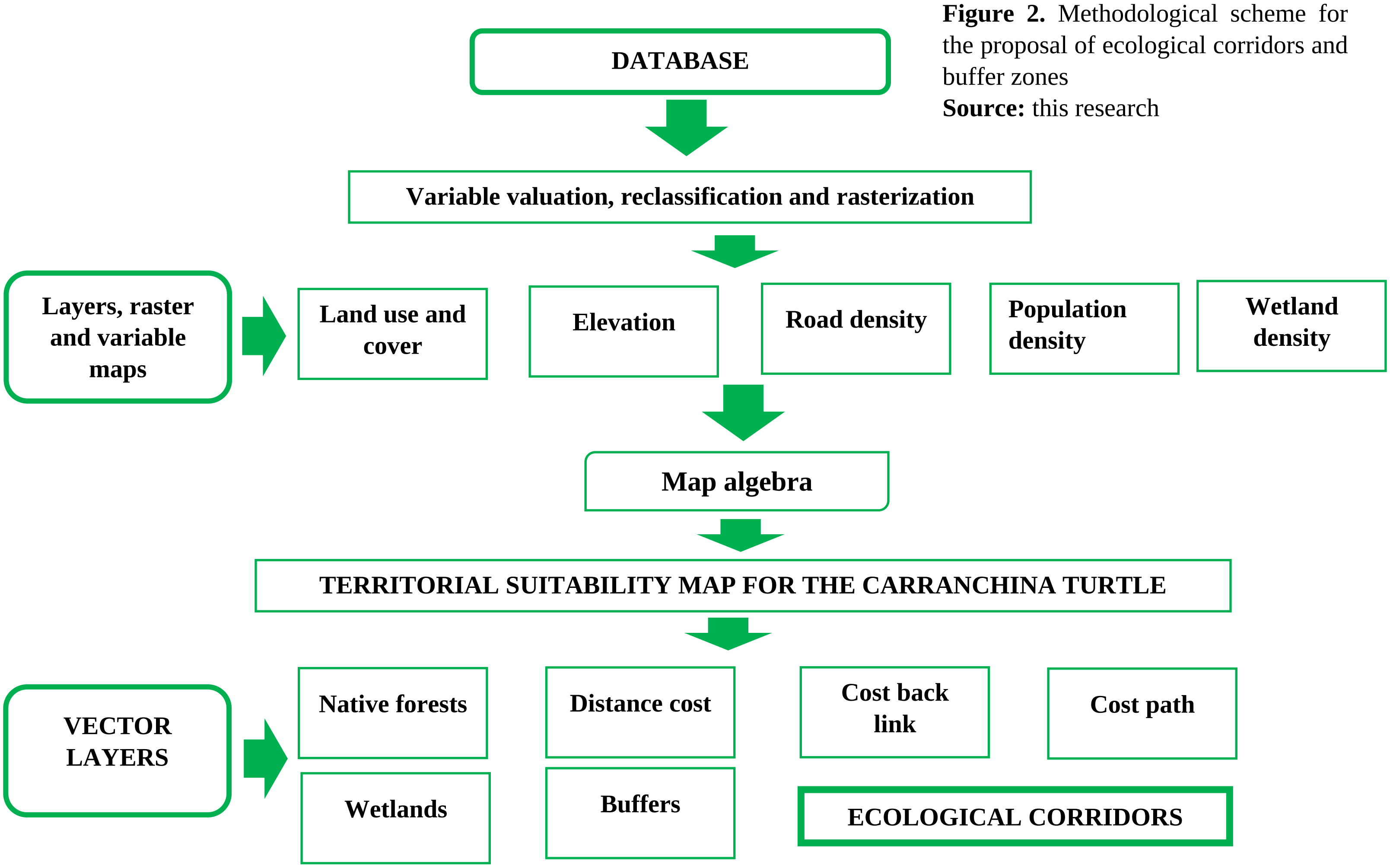

Figure 2. Methodological scheme for the proposal of ecological corridors and buffer zones
Source: this research

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Each of the variables was valued according to its importance for the presence of the species in the study area. The evaluation was carried out by experts who integrated a multidisciplinary team related to the ecological and biological contingencies of the species. In short, the research group proposed higher values or scores for the circumstances in which certain variables implied more favorable conditions for the presence of gloves. Despite the particular assessments of the aforementioned factors, it was decided not to formulate differentiated percentage weightings for any of them. In other words, in the final stage of the map algebra, no particular weight was given to any of the variables, since the level of adaptability of the species to the conditions offered by the environment was unknown. Consequently, differences of a greater or lesser incidence of social, biophysical and economic factors were ruled out (Table 1).

For the evaluation and cartographic representation of the study, the ArcGIS 10.1 program was implemented. As a result, a map was obtained for each one of the variables considered, with which a total of six layers in raster format was constituted. Next, each one of them was zoned based on its level of importance —high, medium, low—, which was determined according to the environmental conditions for the existence of the species.

In some cases, we worked at the vectorial level and through the selection of attributes. The variables of the shapefiles layers were chosen and values were subsequently given to them as shown in Table 1. Thus, in the case of the land use and cover layer, values of 3 were given to forests; from 2 to agroforestry areas, and from 1 to pastures. On the other hand, in the aspect of vegetation phenology, a value of 3 was given to areas characterized by the presence of evergreen forests; from 2 to seasonal evergreen forests and, finally, from 1 to c forests.

Table 1. Factors, criteria, variables and weighted assessment to obtain the map of territorial aptitude. **Source:** this research

Factor	Criterion	Variable	Value	Source of information
Socioeconomic	**Land cover**	forests	3	MAE-Magap 2021, 1:100,000
		Agroforestry	2	
		Grass	1	
Bio-physical	**water density**	high	3	IGM 2020, 1:50.000
		half	2	
		Low	1	
	vegetation phenology	Evergreen forests	3	MAE 2013, 1:100.000
		seasonal forests	2	
		semideciduous	1	
	Elevation	487 – 680 m	3	Curvas de nivel IGM 2020, 1:50.000
		294 – 486 m	2	
		100 – 293 m	1	
Social	**population density**	Low	3	IGM 2013,1:50.000
		Half	2	
		High	1	
	road density	Low	3	IGM 2013,1:50.000
		Half	2	
		High	1	

For the study of the topography of the place, it was necessary to create an irregular triangle network (TIN) in advance: a digital data structure used in a geographic information system (GIS) to represent a surface. In this particular case, a layer of official level curves made every 40 meters was taken as the starting point. Subsequently, the measurements were adapted to the raster format and the appreciations were reclassified into three equal ranges according to the elevation. Thus, values of 3 were given to heights that ranged between 680 and 487 meters; from 2 to those that oscillated between 486 and 294 meters, and 1 to those that oscillated between 293 and 100 meters.

In the cases of water, population and road densities, the density tool was used. Its use was fundamental both for the study of shapefile factors in line format —water bodies and roads— and for the study of elements that correspond to points —populated centers—. Starting from a vector layer, this tool calculated the density of features in a radius corresponding to each output cell. Subsequently, a new layer was generated that estimated the densities required so that they were, in turn, reclassified into three categories.

Regarding the population and road densities, values of 3 were given to the areas with the lowest concentration; from 2 to those that had a medium density, and from 1 to those that showed a significant presence of said variables. It is worth noting that water density corresponded to values based on the concentration of water bodies in contexts in which a higher water density —or a greater presence of water bodies per land unit— made the areas more suitable for the species survival. Consequently, a value of 3 was given to areas with a high density of water bodies; one of 2 to those of medium density, and one of 1 to those of low density.

Preparation of the territorial aptitude map

After obtaining the layers of each criterion, a map crossing known as map algebra was performed in the raster calculator of the program. As a result, around 11 classes were generated. Next, the calibration of the model was carried out through reclassification processes. A total of three classes were obtained, which coincided with the following cataloging standard: the zone with value 3 corresponded to the one with the greatest territorial aptitude; that of value 2 with a medium territorial aptitude, and that of value 1 with a low territorial aptitude. It is worth noting that the transformation from raster to vector format was necessary for the metric statistics of the surface of each of these values to be obtained.

Connectors proposal: ecological corridors and buffer zones

Based on strategic modifications of the Bentrup (2008) guidelines, a proposal was developed that allows the identification of vital landscape elements for the optimal design of ecological corridors and buffer zones. The identification in the landscape of the matrix was taken as a starting point, as well as core areas or nodes. The core areas are biological units of great importance for the rescue of biodiversity and are represented by the remnants of native forest. For its part, the matrix corresponds to the areas that have been occupied by agroforestry, pastoral and urban activities.

The ecological corridors and buffer zones were designed according to the location and size of the nodes. It is worth noting that an ecological corridor is defined as an elongated connector that fulfills the functions of restoring the territorial connections that link the nodes and increasing access to resources. Ecological corridors can be of various types: linear, landscape corridors or stepping stones. For their part, buffer zones, transitional areas represented by strips of vegetation that are incorporated into the landscape around core areas or forest nodes, fulfill various functions such as increasing habitat; influence ecological processes; provide the population with a variety of goods and services, and protect the edges of the remaining forests from possible threats (Bentrup, 2008). In this sense, we proceed to work on the layers of native forest cover and identification of territorial aptitude. Since the latter meets the necessary conditions for the presence of the glove to prosper in the study area, the proposal for the creation of ecological connectors was developed in accordance with the guidelines described below.

A selection of data by attributes was made from which the most significant remnants of native forest cover in terms of area were chosen. The choice of these extensions as nodal segments had as selection criteria the dimensions of the remnants and the size of the species that inhabited them. In this case, a small reptile like the Carranchina turtle requires a minimum area of 2.5 acres, an extension that is equivalent to 10,117.14 m2 (Bentrup, 2008). Consequently, the measurement obtained as a reference value for the remnants of vegetation corresponds to ≥1 ha.

Next, the core forest areas were divided into blocks, according to their concentration levels per unit of land. This allowed the elaboration of a proposal directed towards the need for connectivity of the remnants. Likewise, a buffer area of 30 meters was applied to all bodies of water with permanent flow, with which they came to be considered reforestation zones. However, many of them had riparian vegetation in their surroundings, so it was concluded that reforestation along the entire length of the canal was unnecessary. These bodies of water thus became natural connectors for patches of selected native forests.

In order to generate matrix images for the proposed corridors, the Spatial Analyst Tools extension of the ArcGIS 10.1[1] program was implemented. The use of said systematized tool It allowed the planning of corridors for areas lacking natural connectors. In this context, it is essential to consider the importance of a matrix image, which consists of the representation of one or several combined factors that have an impact on the route or journey through a certain area (De Oliveira Lozada, 2010).

For the starting node of the corridors layout, the process called Cost Distance was carried out. In this phase, it was essential to bias the parameter, which led to defining the best route or the one with the lowest cost. Such an analysis has considerable scope since its effects vary depending on the factor being analysed: in other words, the effects change depending on whether they are based on, for example, slope or water bodies. Given that in this particular case the study was based on territorial aptitude, the traced route implied the calculation of the zones —or cells— that met the best territorial conditions for the survival of the species.

The Cost Back Link tool was applied for the remainder of the beginning of the route of the corridors. The study allowed the optimal cells to be defined to organize a route towards the nearest sources or remnants. Next, the process called Cost Path was carried out, in order to obtain the path from the origin node to the destination node. A buffer of 100 meters on each side was generated for these routes, which corresponded to the areas of the corridors that had to be restored. On the other hand, the nearby forest remnants that were larger than one hectare and that shared similarities in the appearance of the vegetation, were grouped with a 100-m buffer that allowed them to remain connected. As a final result, a graphic representation of the ecological corridors of the areas that presented the best territorial characteristics was obtained.

RESULTS AND DISCUSSION

Figure 3 shows and classifies, according to defined criteria, the optimal areas for the development of the habitat of the species Mesoclemmys dahli. It is observed that for coverage and use the largest area is covered by pastures with a surface of 926.31 km2 (61%). Meanwhile, an area of 334.69 km2 (22%) corresponds to agroforestry land and only 253.38 km2 (17%) correspond to forests, which are distributed in a dispersed manner, mainly to the southeast and center of the study area. The most homogeneous phenology and the greatest territorial distribution occurs in the seasonal evergreen forest, given its 1102.98 km2 (73%). In contrast, the evergreen forest covers 39.54 km2 (2%) restricted to a strip to the east, which constitutes it as

[1] Use was made of the Cost Distance, Cost Back Link, and Cost Path tools located within the Distance toolbox.

the area with the most appropriate phenology. Said territorial extension extends to the west with the semi-deciduous forest, which has 373.56 km2 (25%). It is observed that the optimum altitude range is between 487 and 680 masl (36.92 km2 and 3%). This area is characterized by its difficult access, which keeps it away from anthropic disturbances. The other elevation strips are located between 292 and 486 masl and occupy 1447.92 km2 (97%).

It is important to take into account that the water density is an essential criterion for the study, since the Carranchina turtle usually inhabits areas close to fluvial tributaries and/or with high concentrations of humidity. As can be seen in the maps, the sectors that have optimal water conditions for the survival of the species are scarce: they only correspond to 196.21 km2 (13%) of the 1500 km2 of the study area. On the other hand, the area with the lowest road density, which represents the optimal space for the survival of the species, consists of 204.52 km2 (13%). The surface is located in the southeast of the territory, which coincides with the area with the lowest population density; surface that in turn occupies a little more territory: 242.85 km2. The study of the exposed cartographic representation can lead to conclusive results for the purpose of writing. In the territorial aptitude map it can be seen that 51% (761 km2) of the area has a medium territorial aptitude for the development of the species, while 27% (408 km2) of the territory presents low conditions, and 21% (331 km2) of the study area has the best characteristics for the conservation of the Carranchina turtle. The area whose characteristics are most desirable is distributed in a dispersed manner in the south and east of the study sector, and coincides with 66.51 km2 of native forest remnants (figures 4 and 5).

IDEAL AREAS FOR THE PRESENCE OF THE CARRANCHINA TURTLE

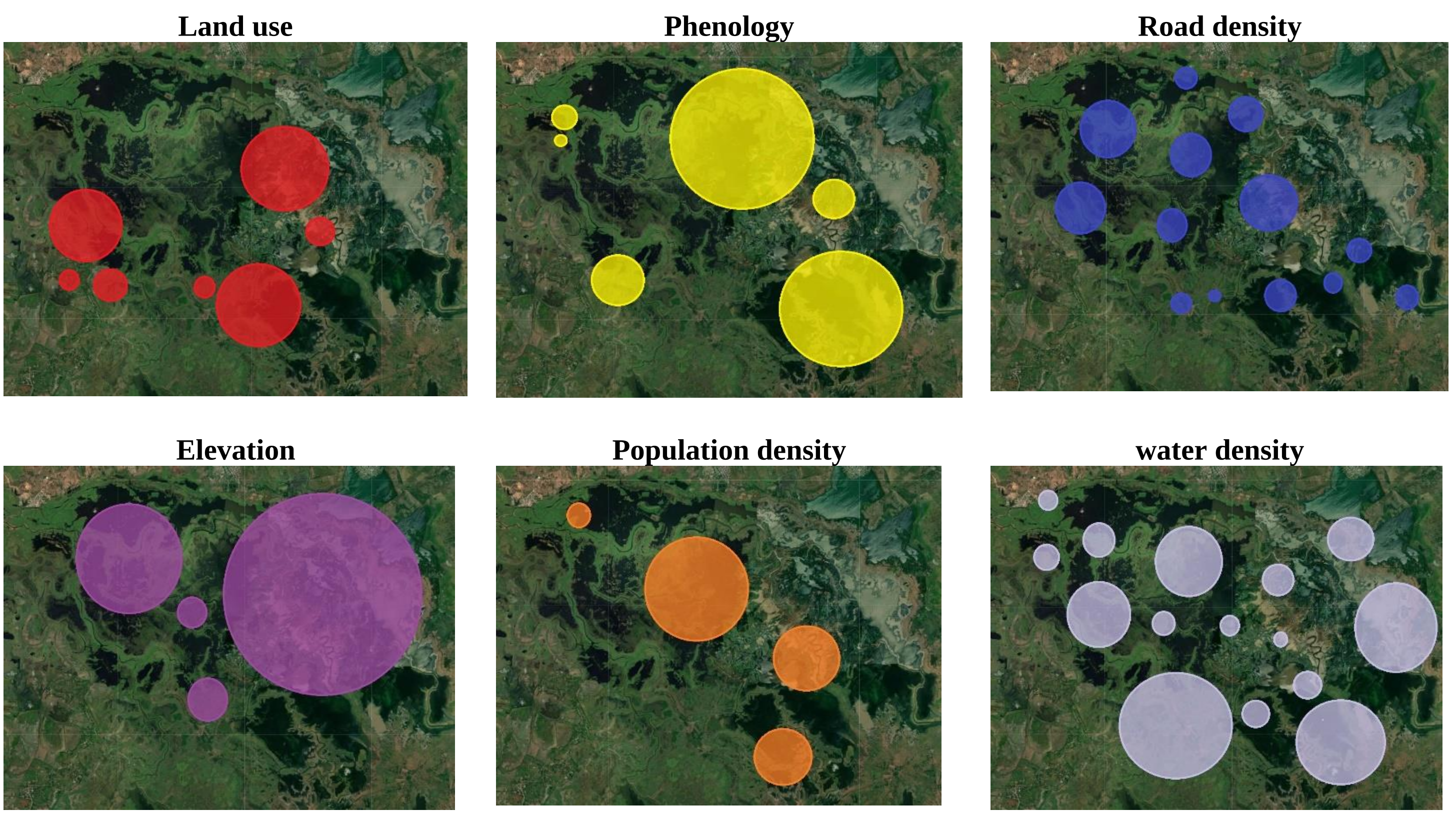


Figure 3. Maps of optimal territories divided by criteria. **Source:** this research.

The territorial aptitude map provided guidelines that led to determining which areas could be reforested through the buffer method and/or through the design of ecological corridors (figure 6). Consequently, the area was subdivided into seven subsets or blocks based on the territorial location and the proximity between the remnants of native forest (figure 7 and table 2). In block 1, the creation of 11 short ecological corridors is proposed that would link the main nucleus with smaller patches around it: 2.27 km2 would be reforested and 3.90 km2 of forest would be preserved, since this is one of the sectors in which the agricultural matrix is more homogeneous. Something similar would happen with block 2, which is located to the south of the largest populated center in the Flavio Alfaro area. In this case, a corridor that requires the reforestation of 0.43 km2 is recommended.

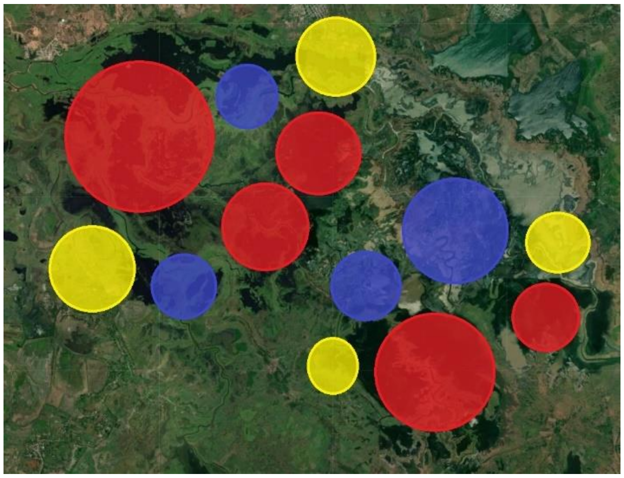
Block 3 is located in a sector with low anthropic intervention. However, the road separates it from the subsets of forest remnants to the south and east that correspond, respectively, to blocks 4 and 5. Consequently, the creation of a buffer zone that allows grouping more than 10 remnants is proposed. of forest and two corridors, which would allow connecting two patches that, despite being the most isolated, make up the current habitat of the Carranchina Tortoise. In the process, 9.64 km2 of forest would be reforested.

In the case of block 4, a buffer zone is proposed that allows connecting more than 25 remaining forests with surfaces greater than one ha, in addition to two ecological corridors. For the process, which would involve the preservation of the current 19.39 km2 of forest, the reforestation of 43.74 km2 is required.

Although it is characterized by the isolation caused by the presence of the road in the previous block, block 5 is one of the most important in the area, since it is located in an area associated with the Sinú river basin and which suffers few disturbances. In this sector, a complex of ecological corridors and buffer zones, which would imply a greater investment in terms of reforestation, since attention would be required to 84.86 km2. The additional benefits of the articulation of the proposed initiatives would be proportional to the effort since 61.70 km2 of natural forest would be conserved. Block 6 is located to the north, which groups 7.65 km2 of natural forest. The largest remnant was designed with seven connectors that integrate six small patches around it and an elongated patch that corresponds, in turn, to a riparian forest. In the process described, less than 1 km2 would be reforested. Finally, block 7, located to the east of the study area, has 2.87 km2 of natural forest. In his case, it is proposed that six connectors join seven pieces to the nucleus, with which 1.48 km2 would be reforested.

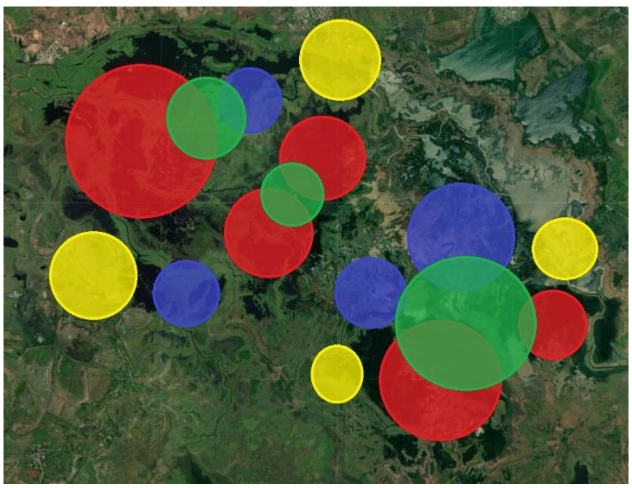
This proposal seeks to increase the size of the habitat of the Carranchina turtle and other associated wildlife, in addition to contributing to the preservation of current native forests and the restoration of connectivity between patches of natural forest. Therefore, the design of vegetal zones that help to protect the remnants of forest is suggested: an increasingly necessary conservation and regeneration measure in tropical landscapes. It is essential to recognize that connectors play an essential role in the potential conservation and recovery of biodiversity because they reverse the loss of forests that has caused profound changes in the composition of the community, as well as the loss and isolation of wild species (Durães et al., 2013; Rodríguez-Soto et al., 2013; Peles et al., 2016).

It is worth remembering that ecological corridors are landscape elements that avoid the negative effects of fragmentation and improve the prospects for biodiversity in green and urban spaces (Vergnes et al., 2012; Guneroglu et al., 2013; Loro et al. al., 2015). For this reason, it is important to take them into account within comprehensive territorial planning, since their administration is essential to optimize the effectiveness of nature conservation policies (San Vicente and Valencia, 2012).



	3
	2
	1

Figure 4. Map of territorial aptitude



	3
	2
	1
	Forest

Figure 5. Map of territorial aptitude and remnant of natural forests. **Source:** this research

	Study area
	Forest
	Ecological corridors and buffers zone

Figure 6. Proposal for ecological corridors and buffer zones. **Source:** this research

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Table 2. Areas to be reforested in km2 and ha, and quantity of natural forest by blocks. **Source:** this research.

Block	Area to reforest (Km2)	Area to reforest (Ha)	Current Natural Forest per block (km2)
1	2.77	277	3.90
2	0.43	43	1.47
3	9.64	964	5.09
4	43.75	4375	19.39
5	84.75	8475	61.70
6	0.82	82	7.65
7	1.48	148	2.87
Total	**143.76**	**14376**	**102.10**

At this point it is worth evaluating the strategies that allowed the development of the project. The key to restoring a landscape made up of mosaics of forest remnants consisted in providing reforestation configurations based on multicriteria spatial analysis. Namely, the integration of social and physical-natural factors provided a basis for spatial analysis, while the biological and ecological components allowed refining the selection of sectors with the best territorial aptitude for Mesoclemmys dahli. This procedure was necessary to achieve ecologically consistent results and to avoid excluding valuable reforestation options a priori.

Likewise, the use of multiple criteria based on distance allowed to capture the variations of the pixels: fundamental aspects for the construction of the territorial aptitude map. For its part, distance represents a significant element for the evaluation of proximity to biodiversity hotspots of certain types and to sources of disturbance such as towns and roads. In this sense, the availability of geographic data played an important role in the grouping of the criteria.

The valuation adopted enhances the suitability of nearby forests and minimizes the effects of nearby sources of disturbance. In the latter case, viability was very low in all easily accessible areas, which left them open to exploitation. In this sense, for future research it is considered ideal to improve the effectiveness of the methodology, selecting another set of data that is related to the level of adaptability of the species to the conditions offered by the environment.

CONCLUSIONS

The study area consists of an area of 1500 km2 divided into fragmented native forests (253.38 km2) and a homogeneous agricultural-urban matrix of considerable territorial breadth (1246.62 km2). Through the proposal of ecological connectors, the recovery of a total of 143.76 km2 is proposed, with which it is proposed to contribute to the restoration of connectivity; the improvement of the terrestrial habitat of the Carranchina turtle; the reduction of the negative effects of fragmentation, and the conservation of biodiversity.

The methodology used to define ecological corridors and buffer zones is one of the few that is based on geographical and biological criteria aimed at identifying the ideal spaces for the development of the project. This methodology is very useful at the level of planning and territorial ordering. Although this proposal corresponds to the species Carranchina turtle, the methodology used can be adapted to other types of habitats and specimens.

Thus, for species or functional groups of species associated with forest ecosystems, it is only necessary to adjust the width of the ecological corridors and the buffer zones to the areas that the species require to develop their habitats.

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