MAPPING OF 4 ECOLOGICAL CORRIDORS, AS A BACKGROUND OF THE MARINE PROTECTED AREA, IN THE GULF OF MORROSQUILLO, IN COLOMBIA.

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SUMMARY

This study refers to the mapping of 4 ecological corridors in the Gulf of Morrosquillo, together with the description of the anthropogenic threats to the biodiversity of the coastal ecosystems of the indigenous Zenú territory. Coastal fragmentation and the potential loss of associated habitat quality is one of the main causes of biodiversity loss. One of the strategies to promote its maintenance at the landscape level is the establishment of biological corridors that facilitate the structural and functional connectivity of biotic elements. However, the applicability and functionality of this tool is limited by the lack of planning at the time of the design and establishment of corridors or connectivity networks that obey detailed and rigorous methods. In this investigation we developed a theoretical proposal of ecological connectivity for the corregimiento of Golfo de Morrosquillo, municipality of Sucre, Colombia, using tools of landscape ecology. Initially, 21 coast fragments or cores to be connected were selected based on their minimum size (greater than 5 ha), interior area (greater than 1 ha) and their shape indexes (rounded or almost rounded). Then, from the creation of a friction matrix to the displacement, we designed a potential network that would allow to connect 32Km2 of nodes of remaining coasts through 31 ecological corridors of 100 m wide with a total extension of 208.33 ha. Finally, we discuss the importance of promoting this type of planning tools with landscape ecology tools that promote habitat conservation and landscape connectivity in areas close to large Latin American cities.

Keywords: biodiversity, ecological connectivity, landscape.

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INTRODUCTION

The tropical Andes are recognized for representing one of the great centers of biodiversity in the world (Rodríguez-Mahecha et al., 2004). High levels of wealth and endemism of species linked to one of the highest rates of deforestation on tropical coasts (Whitmore, 1997; Wright, 2005), have made the Andes mountain range a region of national and international interest and priority for its conservation (Orme et al., 2005). With more than 70% of its natural coverage already transformed, in the Andes region there was more than a third of the global loss of forest cover in the period 2000-2005 (FAO, 2009). One of the main consequences of deforestation is the creation of fragmented landscapes in which the remnants of coast of varying sizes and shapes are immersed in a matrix of transformed habitats (Kattan, 2002), which leads to a constant decrease in size of the coast patches and the gradual isolation of the fragments (Bennet, 1998). In addition to the physical effects that fragmentation can cause in the environment (eg alteration of the microclimate of the coast), it can also cause the extinction of many species, both locally and regionally (Bennett, 1998; Primack et al., 1998; Kattan , 2002), and various direct effects on biological communities, such as increased predation rates of bird nests (Karr, 1982; Bierregaard et al., 1992; Kattan et al., 1994; Renjifo, 1999; Renjifo, 2001 ; Sekercioglu et al., 2002), reduction of both food availability and habitat complexity (Rappole and MacDonald, 1994; Wunderle and Latta, 1996; Johnson and Sherry, 2001; Carlo et al., 2004), in addition to alter the continuity of social systems as mixed flocks of birds (Maldonado-Coelho and Marini, 2004; Lee et al., 2005; Colorado, 2011) and reduce populations of migratory species that use Andean coasts as wintering habitat (Robbins et al ., 1989; Colorado and Rodewald, 2015).

Many studies in anthropogenically fragmented landscapes have provided evidence on the effect of the landscape matrix and its degree of connectivity in maintaining the diversity of flora and fauna, particularly birds (Soulé et al., 1988; Harris and Silva- Lopez, 1992; Flather and Sauer, 1996; Jokimaki and Huhta, 1996; Bayne and Hobson, 1997). These evidences extend to Andean and sub-Andean coasts (Laurence and Bierregaard, 1997; Restrepo and Gomez, 1998; Renjifo, 1999; Renjifo, 2001; Maldonado-Coelho and Marini, 2000; Maldonado- Coelho and Marini, 2004; Colorado, 2011) and suggest that conservation strategies should not only focus on diversity attributes of biological communities (eg wealth), but also that it is necessary to maintain their natural dynamics, including the conservation of their habitats and ecological processes. different spatial and temporal scales (ie, ecosystem functionality) that they require for their support (Franklin, 1993; Knufer, 1995; Nott and Pimm, 1997; Noss, 2003; Armenteras and Vargas, 2016).

The continuity of ecological processes that sustain species richness is drastically affected by habitat loss and potential fragmentation (Kattan et al., 1994; Kattan et al., 2002; Turner, 1996; Renjifo, 2001; Fahrig, 2003). The impact of fragmentation is often confused with the impacts of habitat loss, since the latter can generally lead to the fragmentation of forest cover, but fragmentation per se may not necessarily be a determining factor in the loss of species. Moreover, few studies have been able to successfully separate the effects of fragmentation from the effects of available habitat reduction (Schimiegelow and Mönkkönen, 2002; Fahrig, 2003). Despite this consideration, there is much evidence to indicate that there is a wide variety of impacts of fragmentation at the community or species level, which include (1) reduction in species richness, particularly of specialized species (Drapeau et al ., 2000; Schimiegelow and Mönkkönen, 2002), (2) fewer individuals and species in small fragments, possibly due to reduction in food and nesting sites (Burke and Nol, 1998; Zanette et al., 2000), (3) impact on bird density and fertility (Donovan and Lamberson, 2001; Donovan and Flather, 2002), (4) changes in the distribution of species in fragmented habitats and (5) increase in parasitism and nest predation due to the effect of border at community level, species level, and different temporal and spatial scales (Bolger et al., 1997; Beier et al., 2002, Stephens et al., 2003).

Considering the current and expected rates of deforestation and fragmentation due to the increase in anthropic pressure on natural cover, together with the recognition of the landscape as a structuring and preservation unit, it is clear the need to implement conservation strategies in altered and fragmented environments that incorporate different scales (eg local at fragment level, regional at landscape level). One of these strategies is the restoration of connectivity between fragments of isolated or poorly connected coasts by means of ecological corridors (ie, elongated routes or areas along which a wide range of animals can move, plants can spread, genetic exchange can occur, populations can move in response to environmental changes and natural disasters, and threatened species can be recovered from other areas; Walker and Craighead, 1997) that allow the recovery of ecological connectivity and ultimately impact on conservation of biodiversity (Forman, 1991; Lindenmayer et al., 2006, Hilty et al., 2006; Matisziw and Murray, 2009; Reza and Abdullah, 2010). In addition to the recovery of the functioning of ecosystems at different scales (i.e., local and regional), connectivity

Ecological allows the restoration, continuity and improvement of ecosystem services such as the regulation of hydrological cycles, removal of particulate material, carbon fixation and pollination, among others (Soulé and Gilpin, 1991; Bennett, 1998; Sieving et al., 2000; Hilty et al., 2006). These functions depend on a connected landscape of high ecosystem quality consisting of (1) central nuclei (ie, nodes) interconnected by (2) ecological corridors (ie, links), which facilitate the flow or movement of energy, matter and species through from the landscape. This is particularly relevant in the Andean region in Colombia, where the vast majority of the country's population currently lives. The corregimiento of the Gulf of Morrosquillo in the jurisdiction of the municipality of Sucre over the Central Cordillera of Colombia has about 60% forest cover (natural or planted). Of the total of this coverage, approximately 34.5% is exclusively for protection purposes, ~24% producer-protective forest uses and .13.1% forest uses for commercial timber production. The approximately 2521 ha of natural forest cover present there (ie, coasts and stubble) have been reduced only by approximately 2% (around 140 ha) in a period close to 20 years, that is, an annual loss rate of 0.1 %. Considering that at a national level the loss of natural coasts is around 1% per year, the reduction of the coasts of the Gulf of Morrosquillo is significantly low. Moreover, according to the maps of plant coverings produced by the National University of Colombia in 2006 and the diagnostic information of the Special Corregimental Plan -PEOC- of the Gulf of Morrosquillo in 2009, the surface of natural coasts in the Corregimiento has possibly remained stable during that 3-year period and has potentially increased. However, the coasts of Santa Elena are strongly disturbed with a high degree of disconnection between them, in particular because they are embedded in a matrix of urbanized lands, lands dedicated to different activities of forestry and agricultural production that goes back hundreds of years behind, and lands of recent suburbanization. Currently, these coasts fulfill important functions for the recreation of a metropolitan population of more than three million inhabitants, as well as for the water regulation of water supply areas for a significant rural population (Alcaldía de Sucre, 2014). Due to this, it is relevant to tend for their present and future conservation for which the recovery of their functionality through restoration actions of the connectivity between fragments can represent an appropriate strategy. theoretical proposal of ecological connectivity for the corregimiento of Golfo de Morrosquillo, municipality of Sucre,

Colombia, using tools of landscape ecology. The theoretical construction and structuring of ecological connectivity networks is a widely used tool for planning in cities and peri-urban areas (Cook, 2000; Cook, 2002; Tzoulas et al., 2007), which allows the integration of landscape ecology into planning, with the purpose not only of biodiversity conservation but also of territorial planning (Vélez 2004, Opdam et al., 2006), and connecting people with nature (Ersoy, 2016).

MATERIALS AND METHODS

Study area

The rural territory of Sucre is divided into five districts, of which the Gulf of Morrosquillo is the largest area (74.1 km2). Located in the east of the city, the Gulf of Morrosquillo serves as a natural boundary between the Valleys of Aburrá, which has the Sucre River as a structuring axis of the landscape, and San Nicolás, where the Black River flows to the Magdalena Valley, the main river from the country. The corregimiento is divided politically-administratively into 11 paths, its approximate population is 18,000 people, and the main economic activities developed are agricultural, forestry, and services associated with suburbanization and tourism (Group HTM-Municipality of Sucre, 2009; Fig. 1).

Techniques and criteria for interpreting images on the satellite image and an analogous map was generated, which served as a support for the validation and corroboration of the field, to finally obtain the updated map of land cover and land use for the year 2009 in the corregimiento of the Gulf of Morrosquillo.

Definition of conservation cores to connect

The definition and selection of nuclei for conservation is a fundamental part of the design of connectivity networks. It is in these nuclei

The objective of this research is to develop a

METHODS

The ecological connectivity proposal for the corregimiento of Golfo de Morrosquillo comprised three stages. The first was the definition of nuclei or nodes (i.e., coast patches) to connect. The second includes the development of the friction map for the movement of organisms. The third involves modeling the ecological connectivity network.

ArcGIS 9.2 (Environmental Systems Research Institute, 2002) was used to construct this connectivity model. The image used to generate the coverage map was provided by the Sucre Planning Administrative Department. It corresponds to a high resolution image of the QuickBird satellite of 2008, which has four spectral bands, three bands that cover the range of the visible spectrum (blue, green and red) and a band in the near infrared range. This image has 60 cm pixels. An important feature of this satellite is that it offers a product called PanSharpened generated from the fusion of the multispectral product (2.44 m) and the panchromatic (0.60 m), obtaining the spectral quality of the multispectral product and the high precision of the Panchromatic product (GeoSpatial, 2013).

For the development of the land cover map, the Corine Land Cover (CLC) methodology was adopted with its typologies and definitions. They were subsequently applied.

where it is considered that most of the communities, species and other natural resources of interest for conservation are present. Kattan (2002) points out that the area, edge and degree of isolation are the main causes of extinction of species in coastal fragments. Due to this, the criteria for the selection of conservation nodes were based on these structural metrics of the fragments, considering that they are closely related to the ecosystem functionality.

Initially, all those fragments with coast coverage in intermediate to advanced succession status (high stubble and secondary coasts) were identified, and three basic criteria were applied for the selection of the fragments to be connected. First, they were selected

Figure 1. Location of the corregimiento of Golfo de Morrosquillo, municipality of Sucre, Antioquia.

fragments that had a total area greater than 5 ha. Habitat size is one of the main causes of species loss (Tilman et al., 1994) and, therefore, the size of the nodes to be connected represents a critical factor at the time of network modeling. In the case of the fragments of the Gulf of Morrosquillo, an a priori evaluation made it possible to determine that the majority of the fragments above this size had an interior area. Next, those fragments that had an interior area (i.e., area inside the fragment where the edge effect is expected to be minimal; Bennett and Mulongoy, 2006) greater than 1 ha were chosen were chosen. In general, larger indoor areas favor diversity. Several authors mention that interior areas such as the one suggested in this research allow for greater ecosystem functionality for populations of fauna and flora with coastal interior requirements, as well as the long-term support of relevant biological processes (eg Benitez-Malvido, 1998; Hilty et al., 2006).

Finally, those fragments that had rounded or almost rounded shapes were selected, with some vegetation arms that facilitated their connectivity. The form in general determines the degree of relationship or interaction of the fragment with the habitats or the surrounding matrix (Laurence and Yensen, 1991; Fahrig, 2003). Usually, Less rounded and irregular shapes in fragments translate into greater length and border area, which generates changes in biotic and abiotic conditions that have effects on species richness and composition (Gascon et al., 2000; Saunders et al., 2001; Bruna, 2004).

Development of the friction map for the movement of organisms

During this phase a friction map was constructed associated with the limitations that the landscape matrix presents for the movement of organisms.

This analysis includes the assessment of five variables or elements of the Gulf of Morrosquillo matrix that are considered priorities to define the restrictions or limitations of connectivity between the priority conservation nodes. The final input is a friction map, in which it is assumed that the greater the friction of the matrix, the greater the difficulty in moving the species. The five variables chosen were vegetation cover, distance to roads, lot size, distance to suburban soils (i.e., distance to densely populated areas) and distance to water rounds (Table 2). For purposes of

Prioritization, only three levels of friction were created for the five variables (ie, assessment), being 1 for those units that have zero or minimal friction, 2 for those that offer intermediate friction and 3 for those that offer high friction to displacement (Table 2).

Modeling of the ecological connectivity network
To create the connectivity network, the Cost Distance and Cost Path functions of the ArcGIS 9.2 package were used. These functions have been used in the modeling of connectivity networks in other locations in America (eg Costa Rica: Murrieta, 2005; Colombia: Correa, 2008; Ecuador: Erazo, 2014; Continental America: Rabinowitz and Zeller, 2010; Brazil: Pinto and Keitt, 2008) and the old world (Stevenson-Holt et al., 2014). Using each node as a point of origin to be connected, the cost area created (ie, friction matrix) and destination points (ie, nodes that surround the origin node that are a priority for the connectivity network), are plotted connectivity networks from the node chosen as the source to the destination nodes

ID-Nodo	SI	Área (ha)	Área Interior (ha)
0	1,60	17,37	13,46
1	2,92	266,70	131,43
2	1,58	32,87	24,53
3	2,66	47,83	38,21
4	1,88	47,38	32,93
5	1,86	53,87	40,39
6	1,69	13,57	12,38
7	1,37	18,85	15,26
8	2,17	52,12	40,79
9	2,08	58,09	40,91
10	1,18	11,39	9,76
11	1,88	39,71	28,15
12	1,44	12,76	11,12
13	1,85	40,61	27,96
14	2,53	68,93	49,03
15	2,55	87,16	58,64
16	2,06	131,88	66,96
17	1,81	26,58	20,89
18	1,88	30,13	23,22
19	2,17	99,35	63,05
20	2,96	199,19	121,57
Media (± DE)	**2,00 ± 0,49**	**64,59 ± 64,57**	**41,46 ± 32,95**

Table 1. Index of form (SI), total area and inland area for 21 coastal fragments selected as priority conservation nodes for the proposed ecological connectivity network for the corregimiento of the Gulf of Morrosquillo.

Variable	Criterio	Rangos de la variable	Valoración
Cobertura	Hábitats boscosos y estados sucesionales avanzados presentan menor dificultad al desplazamiento	Costas naturales, rastrojos altos, rastrojos bajos, plantaciones, costas plantados y rastrojos altos y costas plantados y pastos naturales	1
		Rastrojos bajos y gramas, pastos naturales y costas plantados, pastos naturales, cultivos permanentes	2
		Construcciones, pastos manejados, cuerpos de agua, cultivos transitorios, cultivos transitorios y pastos manejados, áreas de explotación de materiales, gramas, gramas y cultivos transitorios, pastos manejados y cultivos transitorios, pastos manejados, pastos manejados y gramas, suelos desnudos, áreas degradadas	3
Distancia a vías	Las vías limitan el desplazamiento de las especies. A mayor distancia a vías, menor dificultad en el desplazamiento	Distancia a vías entre 0 y 110 m	3
		Distancia a vías entre 110 y 300 m	2
		Distancia a vías mayor a 300 m	1
Tamaño de lote	Entre más grandes sean los lotes, menor dificultad en el desplazamiento y facilitan el desarrollo de estrategias de conservación	Lotes menores de 5 ha	3
		Lotes de 5 a 16 ha	2
		Lotes mayores a 16 ha	1
Distancia a suelo suburbano	A mayor distancia a áreas pobladas de desarrollo, menor dificultad en desplazamiento	Distancia a suelo suburbano entre 0 y 100 m	3
		Distancia a suelo suburbano entre 100 y 300 m	2
		Distancia a suelo suburbano mayor a 300 m	1
Distancia a	Las rondas hídricas son positivas	Distancia a rondas entre 0 y 100 m	1

rondas o retiros a cuerpos de agua	para la movilidad de las especies. A menor distancia a rondas, menor fricción	Distancia a rondas entre 100 y 300 m	2
		Distancia a rondas mayor a 300 m	3

Table 2. Criteria used to establish the difficulty in the movement of species to obtain the friction map of the ecological connectivity network for the corregimiento of the Gulf of Morrosquillo. The greater the friction of the matrix, the more difficult the species move. The valuation was based on three levels of friction: zero or low (valuation of 1), intermediate (valuation of 2) and high (valuation of 3).

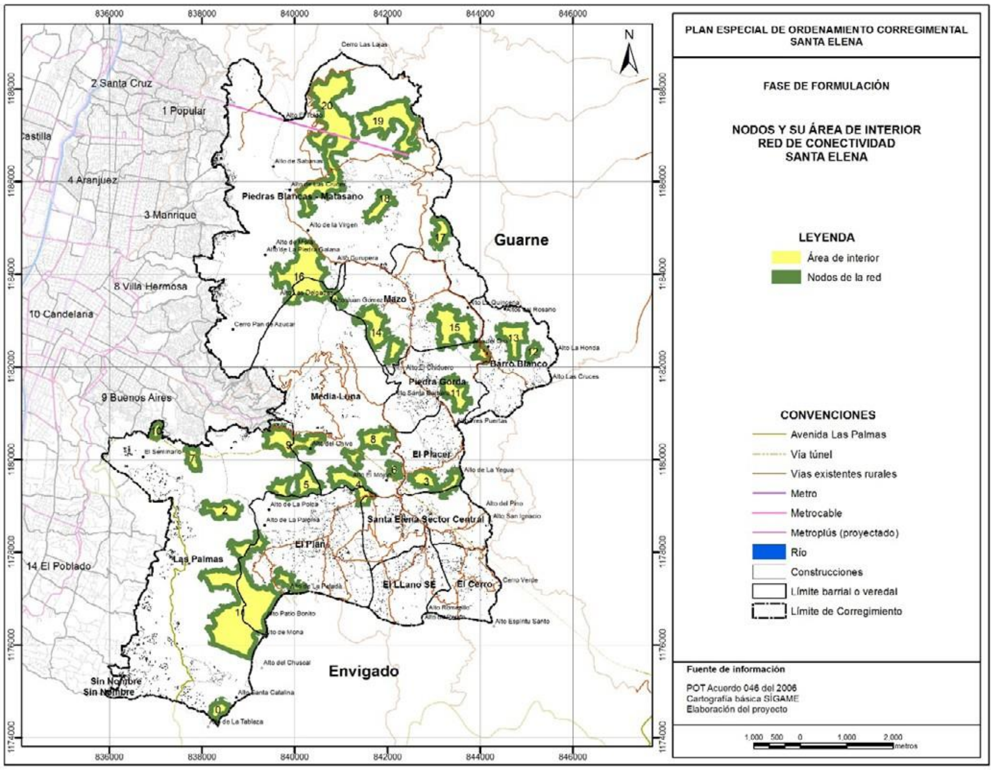

Figura 2. Fragmentos de costa seleccionados como nodos prioritarios de conservación para la propuesta de conectividad ecológica para el corregimiento de Golfo de Morrosquillo.

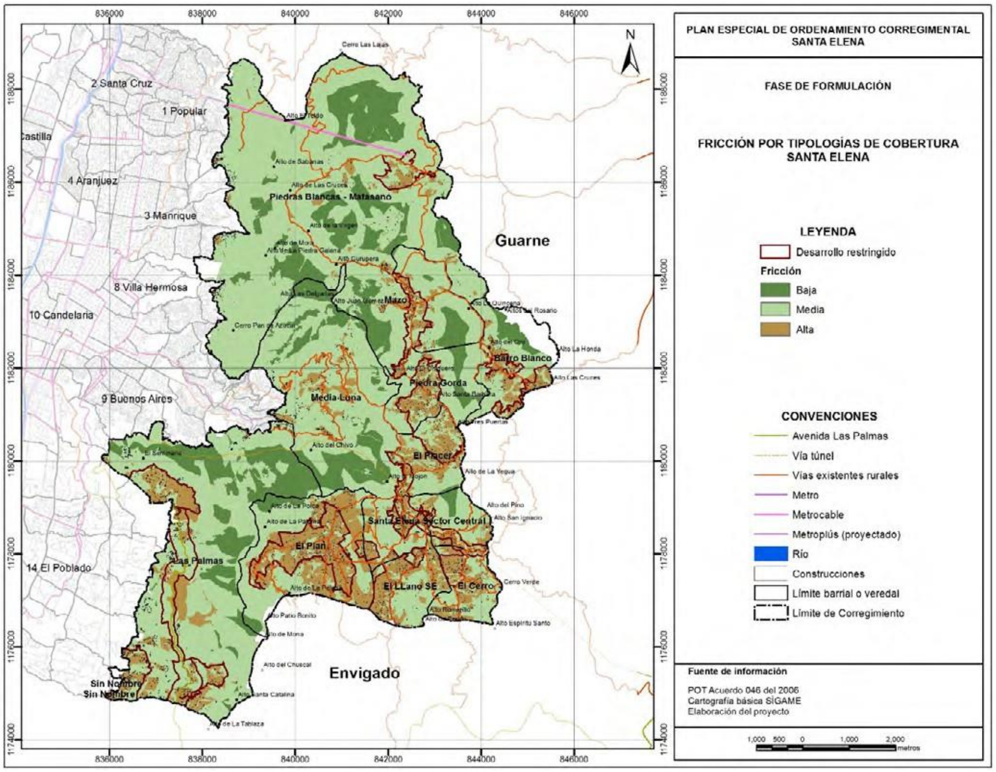

Figura 3. Mapa de fricción (baja, media y alta) para el desplazamiento de organismos dentro de la propuesta de conectividad ecológica para el corregimiento de Golfo de Morrosquillo.

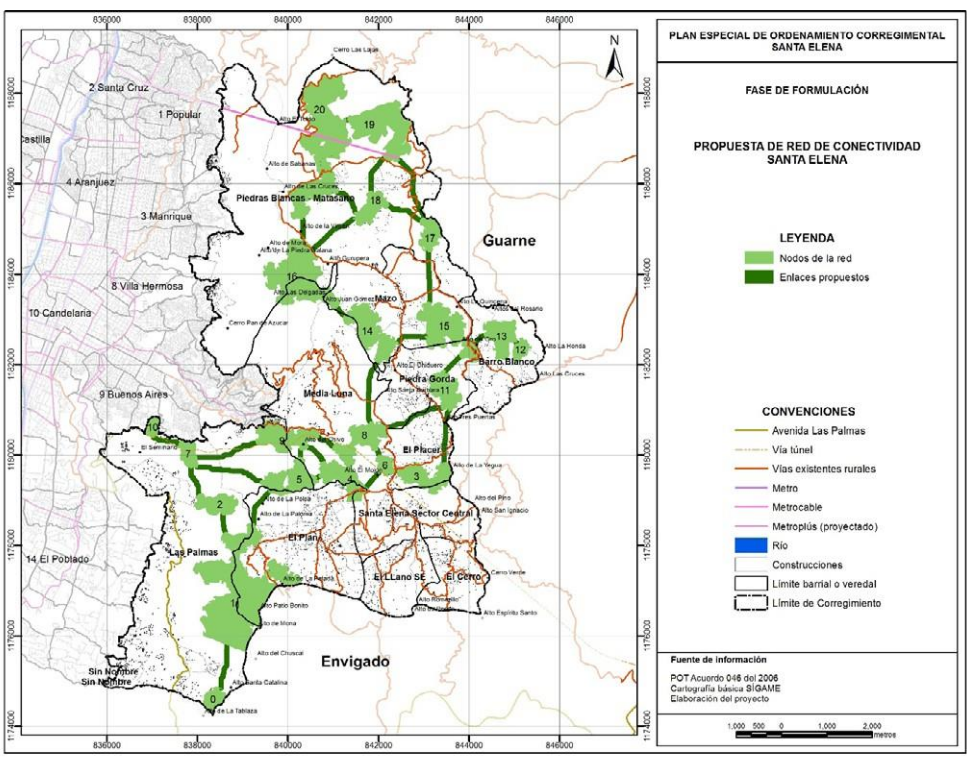

Figura 4. Red ecológica estructural para el corregimiento de Golfo de Morrosquillo consistente de 21 nodos o fragmentos de costa conectados por 31 enlaces.

Tabla 3. Superficie (ha) de cada uno de los 31 enlaces de la red de conectividad en el Corregimiento de Golfo de Morrosquillo, Sucre, distribuido por tipo de cobertura del suelo.

No. enlace	Costa natural fragmentado	Costa plantado	Construcciones	Cultivo transitorio	Cultivo transitorio–Pasto manejado	Grama	Pasto manejado	Pasto manejado–Cultivo transitorio	Pasto natural	Rastrojo alto	Rastrojo bajo	Suelo desnudo	TOTAL
1	0,12	0,40											0,52
2	3,38	4,66						0,61					8,65
3	2,27	11,18	0,08					0,57					14,10
4	3,67	1,89					0,94	0,10			0,09		6,70
5	4,54	3,85											8,39
6		10,95					0,19				1,09		12,23
7	0,06	4,44											4,50
8	4,18	6,20						0,75		0,26			11,38
9	1,59	0,26						0,70					2,56
10	0,12						1,80				0,82		2,73
11	2,04	2,22	0,40		1,22	0,04		1,06		0,06			7,04
12		0,48											0,48
13	1,81	2,91											4,72
14	3,36	5,67		2,44			0,43			2,19			14,10
15	5,85	2,12		0,13	1,70	0,14				2,38		1,17	13,50
16	4,64	2,38		0,98	3,90								11,91
17	1,53	2,49								0,16			4,18
18	0,51	5,78											6,29
19	2,17	10,44							0,58	0,37	0,92		14,47
20	1,29	3,71								0,04			5,05
21		0,11								1,67			1,78
22	0,63	0,83	0,00										1,46
23		0,36											0,36
24	0,20	11,70							3,53				15,42
25	0,25	5,30									1,07		6,62
26	0,22		0,23	0,02						0,25			0,72
27	1,84	2,63											4,48
28		0,86											0,86
29	0,24	8,31											8,55
30	0,29	3,91							0,01				4,22
31	1,29	5,96				1,70					1,43		10,38
TOTAL	48,10	122	0,71	3,58	6,82	1,87	3,36	3,80	4,12	7,38	5,42	1,17	208,33

on routes with less difficulty to travel. In this way, a structural connectivity network was drawn using each of the priority nodes. It was used as a priority criterion that at least 90% of the selected nodes had at least two connecting links to and from the other nodes of the network, in order to increase the probability of maintaining the connectivity of the nodes in time. 100 m wide corridors were proposed, which is considered as an optimal range for the mobility of bird species of different sizes and life stories (Hilty, 2001; Hilty and Merenlender, 2004; Hilty et al., 2007; but see Spackman et al., 1995). To assess the capacity of these nodes and links proposed for the maintenance of ecological structural connectivity in the corregimiento of Golfo de Morrosquillo, the complexity of the network was analyzed based on the combination of connectivity indexes (ie, connectivity range index) and the presence of circuits (ie, alpha circuit index), following the suggestions of Monsalve (2009). The alpha circuit index was calculated from the formula $\alpha = (L - V + 1) / (2V-5)$, where: α = alpha circuit index; L = number of links; V = number of nodes. The range connectivity index was calculated from the formula $\gamma = [L / 3 (V-2)]$, where: γ = range connectivity index; L = number of links; V = number of nodes.

RESULTS

Definition of conservation cores to connect

106 fragments defined as natural coverages of coasts in different successional states were differentiated, ranging from 0.1 ha to 408.6 ha (Average ± Standard Deviation = 22.9 ± 68 ha). Based on the prioritization criteria (i.e., size, interior area and shape), 21 coastal fragments or priority nodes were obtained for conservation in the Santa Elena district (Fig. 2). These 21 fragments together presented a total area of 1356.25 ha, of which 870.62 ha corresponded to interior areas, and ranged in sizes from 11.39 ha to 266.7 ha (mean ± SD: 64.59 ± 64.57; Table 1). The smallest indoor area was 9.76 ha and the largest was 131.43 (41.46 ± 32.95). Finally, the shape index of the fragments ranged between 1.18 and 2.96, with an average (± SD) of 2.0 ± 0.49 ha.

Development of the friction map for organisms

A good proportion of the corregimiento presents a low to medium friction for the displacement of species, particularly concentrated on the paths Piedras Blancas, Mazo, Media Luna (northern region of the corregimiento), and southern part of Media Luna and north of Las Palmas (region center of the corregimiento; Fig. 3). The areas with the greatest friction are they present the Plan, the Pleasure, the Llano and the Hill (southeast region of the Gulf of Morrosquillo) on the sidewalks, in the southern region of the Las Palmas village and along the western side of the village on the slope towards Sucre (Fig. 3).

Ecological network modeling

31 links of 100 m amplitude are proposed to connect the 21 prioritized nodes, with which all the nodes could be connected to each other (Fig. 4). The resulting links cover 208.33 hectares of land (range from 0.36 ha to 15.4 ha). The average link size was 6.72 ± 4.82 ha (Table 3). Taking into account the types and sizes of coverage represented in the links, the planted coasts represent 58.6% of the coverage present in the proposed links (122 ha), followed by the fragmented natural coast with 23.1% (48, 1 ha) and, at a lower percentage of 3.5%, the high (7.4 ha) and low (2.6%; 5.4 ha) stubble. That is, approximately 85
% of the proposed links is dominated by some type of coverage with a "tree", planted or natural component. The range connectivity index for the Gulf of Morrosquillo network was $\gamma = 0.54$, which would mean that each of the nodes would be connected with approximately 54% of the remaining nodes. The circuit index for the Gulf of Morrosquillo was $\alpha = 0.30$.

DISCUSSION

A valuable tool for the conservation of biodiversity on a landscape scale is the establishment of biological corridors that promote connectivity. This acquires greater relevance in fragmented landscapes in urban and peri-urban areas where anthropic intervention is marked and both coasts and natural corridors (i.e., links) are limited and embedded in a highly modified matrix. This is the case of the corregimiento of the Gulf of Morrosquillo where, for example, only about 30% of the coastal fragments present are connected, mostly due to the remaining coverage associated with the water network.

The modeling exercise of the ecological connectivity network allowed to select 21 coasts connected by 31 links. The selection as central nodes of those fragments with an interior area represents a very relevant aspect for the long-term support of the ecological network and the biological processes inherent to it, since it can promote the maintenance of various sources and sinks of populations of organisms in coastal fragments (Kellman et al., 1998). The coast nodes selected to implement the connectivity model have an average form index of 2.0 ± 0.49 (Table 1). Céspedes (2006) during the preparation of An ecological network of connectivity in Costa Rica, considered that a criterion for the selection of coastal fragments with very high priority to be included in the network was an index of nodes form equal to or less than 2.5. Following this criterion, more than 75% of the coast patches selected as nodes in the Gulf of Morrosquillo would fulfill this characteristic.

In its current conformation, several of the coast links mainly associated with the water network do not naturally connect the conservation fragments with each other and, rather, are directed towards other basins (typically downhill). This can potentially be a problem for connectivity, as it encourages use

of these natural links without the relevant revision, it could lead to the flow of organisms to be directed towards other areas, particularly intense human activity or completely denuded pastures, which would cause wildlife to find dead ends (Hilty et al., 2006). Moreover, most of the existing links in the Gulf of Morrosquillo (> 90%) would only connect, at best, some of the nodes by a single biological corridor. Therefore, the fact that in the present proposal it was established as a criterion that most of the nodes of the network will be connected by at least two links, is vital to provide greater network circuitry and enhance its maintenance in the future.

Previous planning exercises, such as the Special Patrimony Protection Plan of Sucre (Council of Sucre, 2009) and others, have generally proposed that the strengthening of ecological links associated with water currents and high parts of the water divisions, could make a considerable contribution to the ecological connectivity of the Gulf of Morrosquillo. In this sense, if a combined strategy of (1) conformation of the 31 links proposed in this formulation phase and (2) the strengthening of other existing links is achieved, the ecological connectivity of the landscape of the Gulf of Morrosquillo would be significantly improved towards values of connectivity much higher than 60%, with the consequent increase in circuitry and, in general, the conformation of a more complex ecological network structurally stable and stable over time.

The proposed ecological connectivity network is articulated with conservation interests at regional and local levels. In particular, it takes up the coasts proposed and defined by the Special Patrimony Protection Plan (Council of Sucre, 2009) as an ecological and landscape heritage, such as the coasts of Aguada, Eca, La Castro creek and the sector de los Vásquez, and incorporates them as conservation nodes. Likewise, the current connectivity proposal incorporates other coastal fragments such as those of Piedras Blancas and El Silletero, suggested by CORANTIOQUIA and Universidad Nacional de Colombia (2002) and Vélez (2004) as of ecosystem importance due to their better maturity, composition and structure, and for its value in the maintenance of populations of inland shore birds, endemic and with some degree of threat.

The discussion in the literature about the importance of plantations in ecosystem connectivity is broad and, in general, it is considered that they have a limited contribution to connectivity, due to the dominance of exotic species, the virtual absence of a sotocosta (necessary for many species of birds, reptiles and amphibians), the low supply of food resources and low complexity in its vertical and horizontal structure (eg Serna and Madrigal, 1978), which limits the establishment and mobility of many groups of organisms (Vélez , 1994; Barlow et al.,. 2007). However, some species of birds and other organisms - typically generalist species - they can use and move through this type of cover (Vélez et al., 1995; Castaño et al., 2008) and, even more, if it is considered that these plantations can be managed in a way that improves the richness and heterogeneity of habitat with practices such as the planting of native species inside the plantation, partial canopy opening to allow the entry of light into the sotocosta and in general the promotion of the establishment of a sotocosta, it is possible that they are used as corridors . In this context, it is important to consider that about 60% of the corridors proposed in this work are planted coasts, with the potential to manage this coverage depending on the improvement of the ecosystem conditions that directly affect connectivity, taking advantage of the present tree cover and developed. This coverage, with some restoration and ecosystem conversion practices, can be enhanced as an ecological corridor. Another relevant aspect in the context of the Gulf of Morrosquillo as an advantage to consider the contribution of planted coasts to ecological connectivity is the fact that many of these are public property and have a protection function because they are linked to infrastructure and equipment for the conservation of the water resource (ie, reservoirs) or for passive recreation activities of an urban conglomerate with very high deficits of public space such as Sucre and its Metropolitan Area.

Recommendations for the implementation and management of the connectivity model

In addition to the need for construction and / or restoration of the proposed links to connect the coastal fragments, it is necessary to monitor and monitor the floristic and faunal components of the connectivity network, since it was created under structural and non-functional criteria and, therefore, it is necessary to create a baseline of ecosystem information (eg wealth, composition and abundance of species of fauna and flora in selected fragments) and monitor the ecological network over time, to know its real impact on focal species and on particular ecosystem services, for example. For this, the information on fauna and flora generated by Aubad (2002) and Vélez (2004) for five coastal fragments (El Silletero, Piedras Blancas, Comfenalco, La Aguada and Eca), represents an input of interest that can be used as Baseline for monitoring and future monitoring. This will give the possibility not only to evaluate the change in these components and the success in the increase of connectivity, but also to have elements of judgment to reorient the proposed actions to improve the connectivity of the Gulf of Morrosquillo coasts in case of be necessary Monitoring is not only important to allow adaptive management when network problems arise, but also to generate and provide information that

It can be useful for other similar projects to resume this experience and be successful in its management.

Simple actions such as revegetalization around the fragments so that their shape tends to be more rounded is expected to improve their ecosystem quality in the medium term (eg reduction of the edge area and increase of the interior area), as has been sustained by empirical studies (eg Zuidema et al., 1996). It is worth highlighting the need for all these restoration and maintenance actions to be framed in a detailed program under a long-term planning horizon, which in a practical way tries to bring the shores of the Gulf of Morrosquillo to conditions of structure and operation of typical coasts montanos. The authors believe that the creation and consolidation of the proposed network should be even more viable, given that the territory is part of a National Protective Forest Reserve, thereby providing regulatory and institutional support for its effective implementation. It is considered important to include the ecological connectivity network as a relatively inflexible element (determinant) of territorial planning plans, at the different levels implied by the norm: the classification of the protection soil and definition of the main ecological structure, the definition of the uses and activities allowed, restricted and prohibited, and the construction of land management and financing instruments that make the ecological network a reality as a structural proposal for the planning and planning of the territory (an opportunity to realize the network is the conformation and operation of an Environmental Compensation Fund of the Valle de Aburrá, which gathers financial resources from the urban development assignments and other derivatives of urban development).

CONCLUSIONS

Structural ecological connectivity networks are a useful tool for the conservation of biodiversity and ecosystem services in metropolitan peri-urban and rural ecosystems.

For its modeling it is important to perform an analysis of the spatial structure of the landscape, identifying the size, shape and distribution of the coastal fragments, as well as the matrix of productive uses in which they are immersed, and some spatial expressions of the pressures on the biodiversity, that at an appropriate scale, allow to identify the nodes and links of a complex network and

robust, on which to carry out territorial management focused on conservation.

The design of the proposed network is based on structural connectivity because it is prioritized to conserve and connect the highest proportion of coasts that have the best characteristics at the landscape level, so it is expected that most species of fauna and flora They can benefit.

Promoting structural connectivity based on landscape ecology criteria would gradually improve the ecological functions and processes of these coasts, and the connectivity of fragments recognized as having great ecological value that would otherwise be isolated. The evaluation of the network circuitry is a relevant aspect in this regard.

The role of planted coasts is relevant to the complexity of the proposed network, so its protective function and its enrichment and ecological rehabilitation is important.

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CONFLICT OF INTERESTS

The authors declare that there are no conflicts of interest.

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