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Delimitation of connectivity corridors between geographically protected urban-rural areas of the Guayaquil canton Delimitación de corredores de conectividad entre áreas urbano-rurales geográficamente protegidas del cantón Guayaquil

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ABSTRACT Ecological corridors, as components of green space at the urban and rural level, significantly reduce the effects of high urban compactness. The built space exerts pressure on the territory and the green space is a means of decompression. The purpose of this research is to delimit the connectivity of ecological corridors between protected areas of Guayaquil, through the connection of ecosystems, linking the rural periphery with the urban core, for the sustainability of the urban green structure. To standardize the components the landscape matrix criterion was used, where the corridors link elements of protected areas with flexible land use connections. Thus, to determine the similarity of ecosystems, the similarity index was used as a statistical sampling technique. The results allowed us to identify ecological corridors that can be part of territorial strategic planning.

RESUMEN Los corredores ecológicos, como componentes del espacio verde a nivel urbano y rural, disminuyen de manera importante los efectos de una compacidad urbana elevada. El espacio edificado ejerce presión sobre el territorio y el espacio verde es un medio de descompresión. La presente investigación tiene por objeto delimitar la conectividad de corredores ecológicos entre áreas protegidas del área cantonal de Guayaquil, mediante la conexión de ecosistemas, enlazando la periferia rural con el núcleo urbano, para la sostenibilidad de la estructura verde urbana. Para la unificación de similitud de componentes se utilizó el criterio de matriz de paisaje, en donde los corredores vinculan elementos que conforman áreas protegidas con conexiones flexibles de uso de suelo. A su vez, con el fin de determinar la similitud de ecosistemas se usó el índice de similitud como técnica de muestreo estadístico. Los resultados permitieron identificar corredores ecológicos que se pueden constituir en parte de una planeación estratégica territorial.

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PALABRAS CLAVE corredores ecológicos, áreas protegidas, diversidad sostenible, planificación territorial, paisaje urbano

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1. Introduction

Due to population growth and the territorial expansion of cities, among other factors, the sustainability and quality of urban developments are becoming increasingly important in the urban context. The world is becoming more urbanized, and it is estimated that by the year 2050, 75% of the global population will live in cities (CEPAL, 2017). In order to promote more sustainable development of the natural and built environment, cities must be planned with an integrated approach.

Urban development in Latin America has been marked by land occupation processes, leaving behind a fragmented urban landscape with a lack of quality spaces. Guayaquil is no exception to this trend and offers a particular view of the dynamics of these processes, resulting in an urban expansion area that surpasses the natural boundaries of the city (Delgado, 2013). The quality of urban space is an essential element, as the urban environment we live in is one of the factors that most influences our well-being and personal satisfaction.

Urban green coverage and natural spaces are indispensable parts of the fabric with which cities are built, organized, and function. The presence of natural areas results from the application of practical resource management decisions or, simply, from various territorial planning criteria (Fadigas, 2017).

In urban areas, the potential benefits of green spaces can include the reduction of the heat island effect, the mitigation of potential flooding, the absorption of CO2, the facilitation of sustainable transportation options (such as pedestrian and cyclist pathways), and the promotion of mental health and well-being (ESPON, 2020).

The purpose of this study is to define ecological corridors between geographically protected areas within the urban area of Guayaquil and its immediate cantonal context. This will be done by connecting ecosystems and providing inputs for the definition of regulations and possible land uses in both the urban area and part of the rural area. The study will rely on information related to the design of conservation corridors and the delineation of urban green coverage and natural spaces.

The research aims to study the connectivity between protected areas, focusing on the aforementioned area of study, and considering environmental variables such as green corridors. An integrated approach will be adopted, considering the characteristics of the natural environment in the immediate vicinity of the urban context.

The study will apply a multimodal methodology with quantitative and qualitative data analysis, allowing for the articulation of different analytical levels, scales, and territorial locations. A similar method was used in the Bogotá district with the aim of increasing and maintaining biodiversity capacity in rural areas and urban expansion zones, as in the case of the present study (Alcaldía Mayor de Bogotá, 2023).

One of the main ecological problems in Ecuador, and particularly in the city of Guayaquil, is the destruction of ecosystems, which goes against the sustainable development of any geographic area. This deterioration is linked to various aspects and impact processes, largely caused by human activity, varying in intensity, consequences, and level of difficulty. In this sense, a habitat with low connectivity corresponds to a landscape where individuals are highly restricted in their movement. Thus, when there is an imbalance between built space and open space, it results in the deterioration of quality of life. In compact cities, the lack of green spaces causes migration from the city to its periphery, resulting in the creation of new residences and high land consumption. Therefore, a high level of compactness tends to indicate conflicts (Feoli, 2013), although this is not necessarily a disadvantage compared to a dispersed city, since it is a complex process, as in the case of Guayaquil. The conservation of landscape connectivity is increasingly gaining attention to mitigate the negative effects of habitat fragmentation and climate change on biodiversity (Gurrutxaga, 2014).

In line with the above, a sustainable management approach is proposed for urban-rural natural landscapes, aligned with the territorial planning and zoning framework. This approach considers the need to define connectivity through ecological corridors between the urban area and protected areas, by linking ecosystems and connecting the rural periphery with the urban core, ensuring the sustainability of the urban green structure.

The intervention area for the feasibility-level definition of connectivity corridors will be the city of Guayaquil, within its cantonal administrative boundaries, which includes the rural parish of El Morro, covering an area of 4.196,37 km² (Municipality of Guayaquil, 2021), and the Guayas River estuary.

The canton of Guayaquil has a total population of 2.746.403 inhabitants, with the majority living in the urban area, representing 96,5% of the population, while 3,5% live in the rural area. It borders the Nato estuary and the cantons of Vicente Piedrahíta and Isidro Ayora to the north, the Gulf of Guayaquil to the south, the Daule and Guayas rivers to the east, and the province of Santa Elena to the west (Municipality of Guayaquil, 2021). Its cantonal capital, the city of Guayaquil, is located on the left bank of the Guayas River, near its mouth at the Gulf of Guayaquil and, in turn, the Pacific Ocean, on the northwestern coast of South America. The cantonal area is administratively divided into 15 urban parishes that make up the city of Guayaquil and 5 rural parishes. The canton has a warm, humid climate, with an average annual temperature of 26°C, a maximum of 35,8°C, and a minimum of 19,2°C; it receives an annual total rainfall of 1.273,2 mm, and experiences two seasons: a dry, cool season from May to December, and a rainy, hot season from January to April (Figure 1).

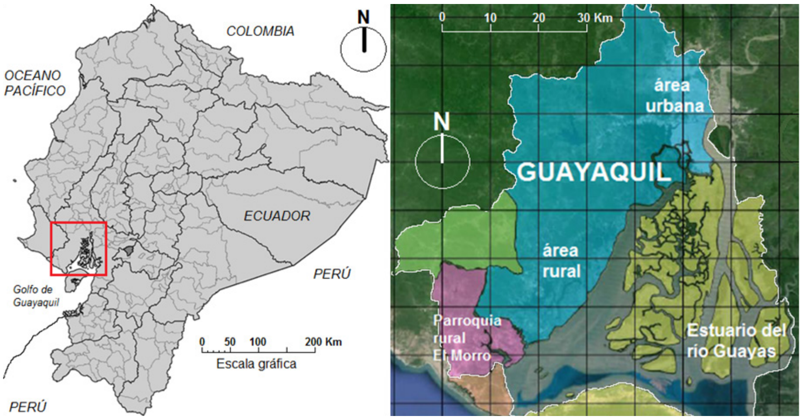

Figure 1: Area of intervention for the study of connectivity corridors between geographically protected areas. Authors, Wikipedia (2015), Municipality of Guayaquil (2016)

Ecoregions: An ecoregion is a geographically defined area that is distinguishable from its surroundings and characterized by its apparent homogeneity in terms of climate, hydrology, soils, and consequently its vegetation cover and associated fauna. As a result, there is an organization of life zones for both fauna and plant formations. For this description, the classifications available in Ecuador for faunal classes have been used (Albuja, 2011).

According to Albuja's (2011) zoogeographic classification, the study area corresponds to the Southwestern Tropical floor, which extends from Bahía de Caráquez to Tumbes, forming a strip of variable width interrupted by the extension of the coastal mountain range. This strip is characterized by its dry climate and has a flat and undulating topography, where the elevations do not exceed 300 meters in height.

Life zones: Vegetation classification systems have been designed to identify the ecological characteristics of a formation at the regional level. A life zone is a set of plant groupings within a natural climate classification, taking into account the conditions for adaptation to the soil and having a similar appearance anywhere in the world (Bravo, 2014).

By applying the vegetation classification system, the vegetation participating within an ecosystem will be determined, which will help identify the type of vegetation that grows according to physical characteristics such as rainfall and temperature.

The study area, based on its meteorological characteristics, presents three bioclimatic regions known as Very Dry Tropical, Subtropical Dry, and Tropical Sub-Desertic (Cañadas, 1983). The following table records the vegetation according to the presence of its species in each life zone of the Guayaquil canton (Table 1).

Conservation areas: Ecuador has a significant concentration of species that coexist with human communities of great cultural diversity and extensive traditional knowledge. However, urban communities and natural ecosystems are facing significant threats due to global changes and inadequate resource management, depleting the few options for sustainable development, in line with studies such as D'Amico (2015).

Protected areas: These are regions of land or water dedicated to the conservation and protection of biodiversity, natural and cultural resources, as well as the preservation of ecosystems and endangered species. These areas can include national parks, natural and marine reserves, wildlife sanctuaries, among others (International Union for Conservation of Nature [IUCN], 2021).

Protected areas in Ecuador represent about 20% of the national territory that is conserved. According to the Constitution of the Republic, they are part of one of the subsystems of the National System of Protected Areas (SNAP), known as the State Natural Heritage Areas (PANE), which includes significant resources that benefit both urban and rural areas. The Ministry of the Environment administers, controls, and regulates these protected areas and works on generating tools to declare properties as protected areas.

Bioclimatic regions and life zones			
Region	**Very dry tropical**	**Dry subtropical**	**Tropical sub-desert**
Location of the region	Located inland from the dry coastal area. Precipitation increases as one moves toward the continent.	It is located on the coast, as is the case with the Chongón-Colonche hills and Cerro Blanco.	It extends along the coast; the coastal strip of this region lies adjacent to air and water masses from the Pacific.
Height	From 5 to 300 meters above sea level.	From 300 to 1900 meters above sea level.	From 0 to 300 meters above sea level.
Average annual temperature	From 23°C to 26ºC	From 23°C to 26ºC	Between 23 and 26°C
Average precipitation	Between 500 and 1000 mm. From 5 to 8 dry months.	Between 500 and 1000 mm. From 5 to 9 dry months.	Between 200 and 500 mm. From 8 to 10 dry months.
Holdridge life zone	**Very dry tropical forest**	**Dry pre-mountain forest**	**Tropical thorny scrub**
Location of living area	Parallel to the tropical thorny bush	Superimposed on the b.m.s.T. in Cerro Blanco and Chongón.	It extends throughout the tropical desert scrub.
Landscape	Mangroves, savannas, wetlands, and beaches. Original vegetation replaced by agriculture and livestock, leaving only a secondary forest with isolated species that testify to such intervention.	Soils located in predominantly mountainous areas, covered with grasses along with shrubs and scattered trees. Cattle are grazed.	A mix of wetlands or dry channels, salt flats, and mangroves along its coasts, further inland crossed by hills and chains of higher mountains, such as those in Chongón.

Table 1: Bioclimatic Regions and Life Zones of the Study Area. Cañadas, L. (1983)

Protected area management subsystems			
Parish	**Protected area**	**Type**	**Subsystem**
	Woods		
	Cerro Blanco		Subsistema privado
	Cerro Paraíso		
	Prosperina	Protective forest	
	Papagayo		
Urban and urban expansion of Guayaquil	Sendero Palo Santo		
	Estero Salado		
	Subcuenca Rio Chongón		State subsystem
	Los Samanes	National Recreation Area	
	Manglares El Salado	Wildlife Production Reserve	
	Parque Lago	National Recreation Area	
Estuario del río Guayas	Manglares El Churute	Ecological Reserve	
Parroquia Rural El Morro	Manglares El Morro	Wildlife Reserve	Community Subsystem

Table 2: Management Subsystem of Protected Areas. Ministry of Environment of Ecuador [MAE], (2015)

The Strategic Plan of the National System of Protected Areas (SNAP) emphasizes the need to work on connectivity corridors, which are a biodiversity conservation strategy, but above all, an important form of territorial planning that transcends the boundaries of protected areas.

As part of the analysis of ecological corridors, the protected areas and the subsystem managing the mentioned protected area are identified (Table 2).

The protected areas described represent the cores of the corridors, as these areas conserve samples of various ecosystems.

Ecological corridors: An ecological corridor, also known as a green, environmental, or biological corridor, is an area that connects valuable natural spaces for flora and fauna, facilitating key ecological processes such as species migration and genetic exchange (Sánchez, 2023). Therefore, achieving ecological connectivity allows for the flow of natural processes and the free movement of species that sustain life on Earth (International Union for Conservation of Nature [IUCN], 2021). Various studies have addressed the exploration, interpretation, and identification of green and ecological corridors (Xiu, N. et al., 2020; Zhou, Q. et al., 2021).

Green spaces are defined as delineated territories where vegetation exists, which can be a forest, jungle, park, or garden. Moreover, when referring to urban green spaces, we focus on those located within an urban development or city (Cardona, 2018).

Urban corridors, in turn, help compensate for compact cities by improving the distribution of green areas and reducing gas emissions and vehicular noise. They are essential for properly planning boundaries, transitions, and urban growth. Their importance lies in the connection between urban green areas and natural spaces. Thus, urban compactness, along with cohesion, complexity, and efficiency, provides the best response to sustainability challenges (Feoli, 2013).

In Ecuador, the Ministry of Environment, Water, and Ecological Transition recognizes and promotes management for connectivity that complements and strengthens the planning, zoning, and territorial management processes of municipal governments. Through Ministerial Agreement No. 19, dated June 10, 2020, published in Official Registry No. 221, guidelines and technical criteria for the design, establishment, and management of connectivity corridors are issued. This includes the purposes of the corridors, technical design and establishment criteria, corridor management, and a glossary of terms, among others (Ministry of Environment of Ecuador [MAE], 2020).

Delimitation of urban-rural ecological corridors: The delimitation of urban-rural ecological corridors is a practice that has been implemented in various cities around the world to promote ecosystem connectivity and biodiversity conservation in urban environments and their surrounding areas (Bracke et al., 2022).

The corridors within and outside cities allow for the connection of urban areas with protected natural spaces, urban parks, restored rivers, and green walking and cycling routes. These connections are achieved through urban planning strategies that incorporate green corridors and natural spaces within the urban structure. This facilitates the flow of environmental services and provides benefits such as the creation of recreational spaces, the promotion of biodiversity, the protection of wildlife habitats and threatened species, the facilitation of species migration, and the improvement of air and water quality, as well as the mitigation of surrounding climate change effects (Bracke et al., 2022). Additionally, these natural corridors and the green infrastructure that supports them become fundamental tools for creating healthy environments that enhance the physical and mental well-being of their inhabitants (FAO, 2018).

Protected areas in the study area: Below are the characteristics of the main urban and rural ecosystems in the city of Guayaquil (Figure 2).

Cerro blanco protective forest: It is one of the few protected areas managed by a private foundation. Like other protected areas, it is surrounded by various interventions such as urban developments, informal settlements, quarries, agricultural activities, pipelines, and water transfer. Despite being highly intervened, the forest has areas that will allow for the creation of connection corridors with other protected areas (Figure 3a).

Chongón river sub-basin protective forest: This area is located between the boundary that divides the urban and rural zones of the Guayaquil canton, which is why it is not surrounded by human activities. The activities conducted around it include quarrying and agricultural practices. Fortunately, this area borders Cerro Blanco and Parque El Lago, which facilitates connection and ensures the reduction of fragmentation of the linked ecosystems in a sustainable manner (Figure 3b).

Bosqueira protective forest: It is located to the north of the city of Guayaquil, near the road to Daule. This area experiences high pressure due to the socioeconomic activities present, such as rice fields and access roads to nearby towns and urbanizations. Adjacent to the described area is the Chorrillo security polygon, an area designated for the development of hydrocarbon facilities that serve the entire province (Figure 4a).

Papagayo protective forest: It is located to the northwest of the city of Guayaquil. Its designation is due to the allocation of additional areas for the conservation of the city's symbolic bird, the parrot. This area is bordered by agricultural activities and inhabited zones. The western side of the forest does not show significant human activity and is close to other forests, such as Cerro Blanco and the Chongón Colonche Mountain Range. Therefore, this area is considered for the formation of the ecological conservation corridor (Figure 4b).

Prosperina protective forest: Due to its characteristics and proximity to Guayaquil's Perimetral Road, this area has been developed to house the campus of the Escuela Superior Politécnica del Litoral. Additionally, it is crossed by the Libertad Pascuales Pipeline, which has a 15-meter safety zone on each side of its axis where no activities are permitted. The forest is surrounded by residential areas but directly borders the Cerro Blanco Protective Forest, which facilitates the creation of areas for ecological conservation (Figure 5a).

Cerro paraíso protective forest: This area is located within the urban zone of Guayaquil, surrounded by Bombero Avenue, Carlos Julio Arosemena Avenue, Barcelona Sporting Club, and Rodríguez Bonín Avenue. It is bordered by residential areas and crossed by the San Eduardo Tunnel, which connects the western suburban sectors with the road to Daule. Its proximity to the Estero Salado is interrupted by Barcelona Sporting Club Avenue, making it difficult to establish a corridor between these areas (Figure 5b).

Sendero palo santo protective forest: This forest is located within the urban area of Guayaquil, surrounded by residential zones and several access roads, which limit its boundaries in such a way that it is not possible to create a conservation corridor (Figure 6a).

Los samanes national recreation area: As its name suggests, this area is not intended for conservation. However, due to its activities and the areas it comprises, it clearly has the potential to be part of an ecological conservation corridor.

The area is surrounded by residential zones and crossed by avenues such as Francisco de Orellana and Narcisa de Jesús. By bordering the Daule River, this body of water can be identified as part of an ecological conservation corridor. The Cerro Colorado Protective Forest is a protected area that has been part of the Samanes Park since 2010 (Figure 6b).

Manglares El Salado wildlife production reserve: This area was expanded to include the entire Estero Salado that enters the city of Guayaquil, thereby delineating new zones. In this regard, the reserve areas are bordered by several populated centres, highly trafficked roads in the city of Guayaquil, human activities such as port operations, and aquaculture activities like shrimp farms, which hinder the inclusion of new ecological conservation corridors that would allow interconnection with other protected areas nearby.

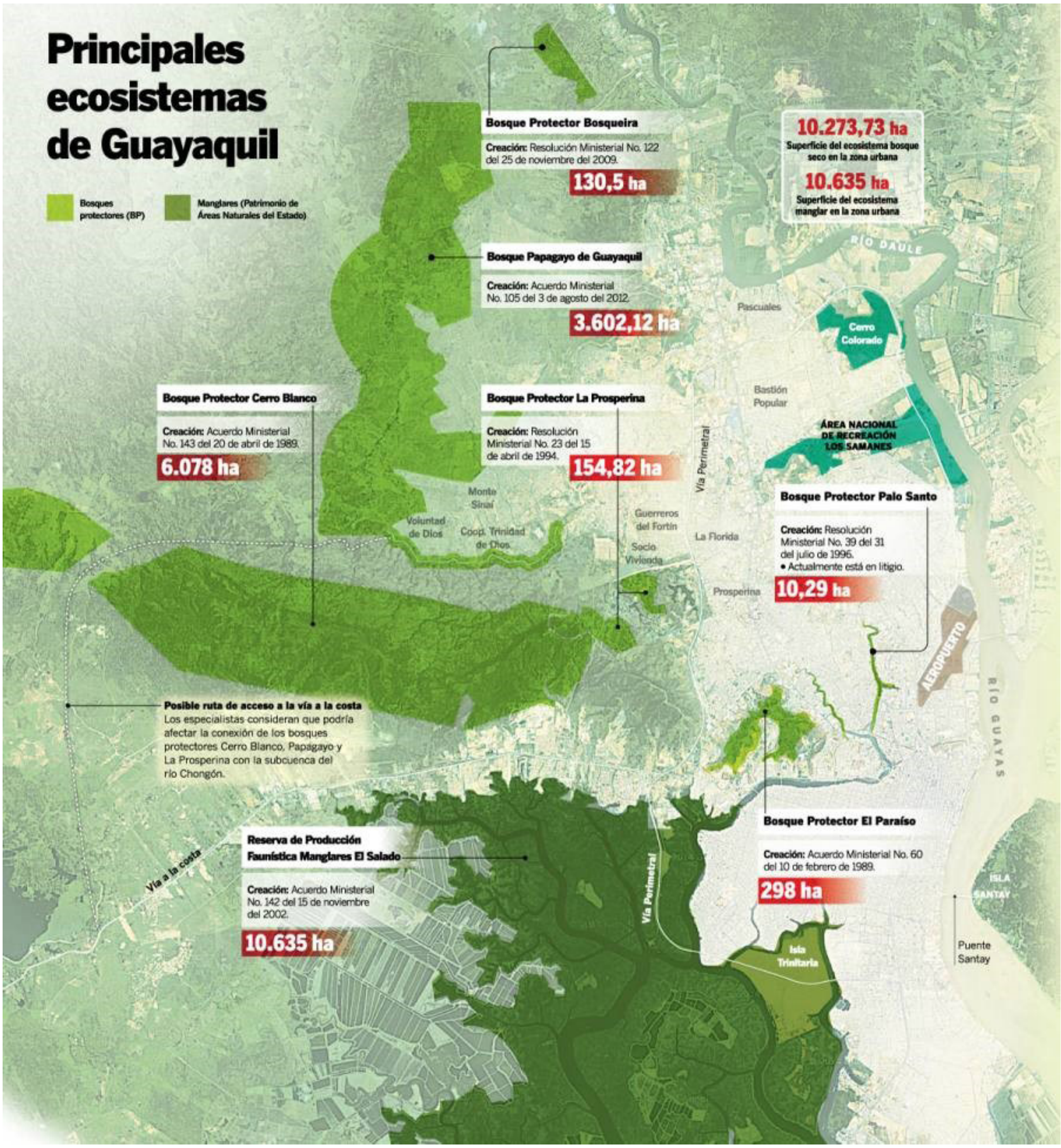

Figure 2: Location of the Main Ecosystems and Protected Areas of Guayaquil. Diario El Universo (2014, July 24)

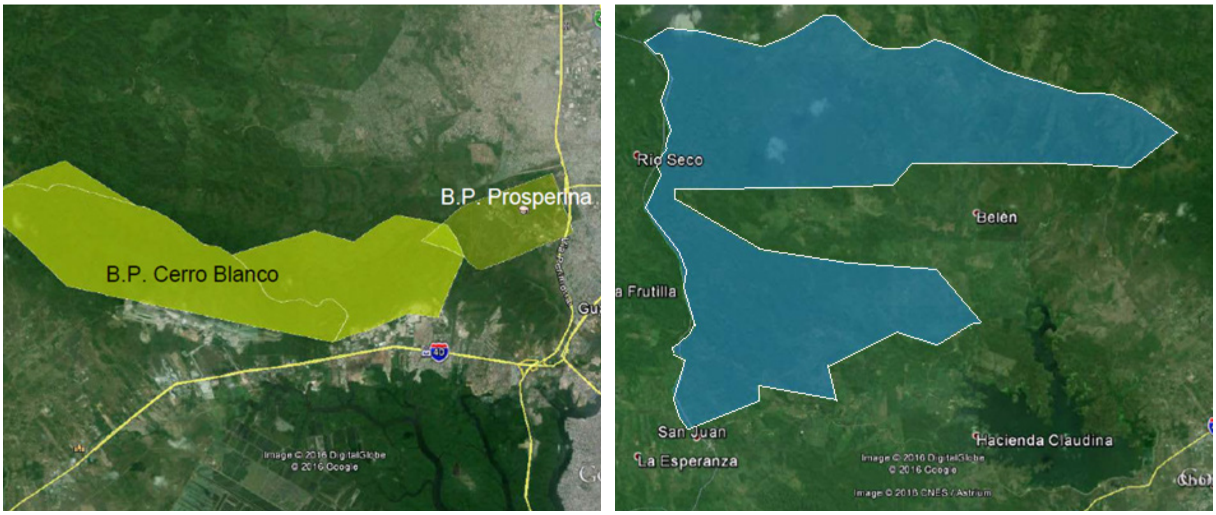

Figure 3: (a) Cerro Blanco Protective Forests and (b) Chongón River Sub-basin. Ministry of Environment of Ecuador [MAE] (2015)

Figure 4: (a) Bosqueira Protective Forest and (b) Papagayo Protective Forest. Ministry of Environment of Ecuador [MAE] (2015)

Figure 5: (a) Prosperina Protective Forest and (b) Cerro Paraíso Protective Forest. Ministry of Environment of Ecuador [MAE] (2015)

Figure 6: (a) Sendero Palo Santo Protective Forest and (b) Los Samanes National Recreation Area. Ministry of Environment of Ecuador [MAE] (2015)

However, the southeastern tip of the reserve has plots that have not been occupied by human activities, allowing for the creation of a corridor towards the Manglares El Morro Wildlife Reserve (Figure 7a).

Estero Salado protective forest: This refers to the protective forest located in Section A of Estero Salado, specifically the branch that intersects with Juan Tanca Marengo Avenue. This protected area is surrounded by urban developments, and the only connection to a nearby protected area is through the existing body of water. Therefore, it is recommended to establish a corridor through Estero Salado (Figure 7b).

Manglares El Morro wildlife reserve: It is in the rural parish of El Morro and has high tourist appeal due to the opportunity to observe dolphins in their natural habitat. The reserve is mostly surrounded by aquaculture activities; however, its direct access to the Gulf of Guayaquil allows for the conservation of native flora and fauna species.

Since there are areas that have not yet been impacted by nearby human activities, the creation of an ecological conservation corridor is considered to facilitate the connection with the Manglares El Salado Wildlife Production Reserve (Figure 8a).

Parque Lago national recreation area: The purpose of creating this area is for water storage for agricultural use and drinking water treatment in coastal areas.

The geographical location of Parque Lago allows it to receive water from the existing watersheds around it. Given that the water it receives is intended for human consumption, there is a cantonal land-use regulation that prohibits the development of urban projects around it or any other human activities that could introduce pollutants into the water.

Parque Lago is mostly surrounded by areas where no productive activities are carried out, and its proximity to other protected areas allows for the identification of zones that can be designated for conservation corridors (Figure 8b).

Conservation gaps analysis. Using available information regarding land use, existing vegetation, and protected areas, the Prefecture of Guayas identified spaces that can be considered strategic for conservation to be worked on together with municipalities and parish councils (Camacho et al., 2013). The results show a provincial map indicating the location of gaps. It is important to note that the process of identifying conservation areas for the province of Guayas did not consider the territorial planning of the Municipal Decentralized Autonomous Governments. However, it proposes conservation areas like the sites previously identified in this study.

Water resources study of the Guayaquil canton. The consultancy for the Study of Water Resources in the Rural Area of Guayaquil Canton and the Chongón Urban Planning Area

Figure 7: (a) Manglares El Salado Wildlife Production Reserve and (b) Estero Salado Protective Forest. Ministry of Environment of Ecuador [MAE] (2015)

provides necessary environmental recommendations for land use, such as: In protective forests, the minimum area into which land can be divided may vary between 30 and 100 hectares, depending on slopes, soil types, native or planted vegetation, etc. However, whatever the area, it must adhere to the management plans and restrictions imposed by a protective forest (Escobar, 2000).

2. Methods

The methodology detailed below is based on studies that characterize the physical, biological, and social components within the protected areas present in the study area. The social components are derived from opportunities for urban and rural recreation and leisure, as well as the presence of areas for research and environmental education.

Landscape matrix: The landscape matrix is the framework that connects the land to its background, within which all landscape elements fit, including patches, edges, and corridors (De la Fuente, 2014). Natural ecosystems require the similarity of their component elements for unification, and in this case, the landscape matrix criterion is used. Within this context, ecological corridors are natural links that connect protected areas in diverse landscapes.

The process scheme for establishing an ecological corridor includes, within the landscape matrix, the analysis of natural, semi-natural, and artificial coverage, in addition to connectivity criteria and the presence of natural or semi-natural areas.

To identify protected areas and conservation areas to be connected, digital images of the study sector were used, which show the physical characteristics between these areas. The handling of the following images and their components contributed to defining the type of corridor that exists (Municipality of Guayaquil, 2016).

- Base map of the Guayaquil canton, scale 1:250,000.
- Base map of rural parishes in the Guayaquil canton, scale 1:50,000.
- Map of water systems in the Guayaquil canton, scale 1:250,000.
- Flood susceptibility map, scales 1:50,000 and 1:250,000.
- Maps of non-developable areas in the Guayaquil canton, scale 1:50,000.
- Map of productive capacity and flood-affected areas, scale 1:250,000 Source: M.I. Municipality of Guayaquil.

Regarding the identification of fauna and flora susceptible to fragmentation in the area, available inventories from each protected area or from nearby zones with similar characteristics were used.

Similarity analysis: The similarity index is a qualitative method that expresses resemblance between two samples by considering the composition of flora and fauna species. It reflects the relationship between the number of shared species and the total number of unique species between the samples. It measures the degree to which two samples are similar based on the species present within them (Benites, 2021).

The Jaccard index is used to assess the similarity of ecosystem components between protected areas and to determine the potential for connectivity between them. The results will reveal the presence or absence of ecosystem connections through shared species. The rating values are (0) when no species are shared between two places and (1) when both sites have the same species composition. Similarity is calculated using the following formula, where (a) is the number of species common to both samples, and (b) is the number of unique species.

$$Ij = [\ a / (a + b)\ ] \times 100$$

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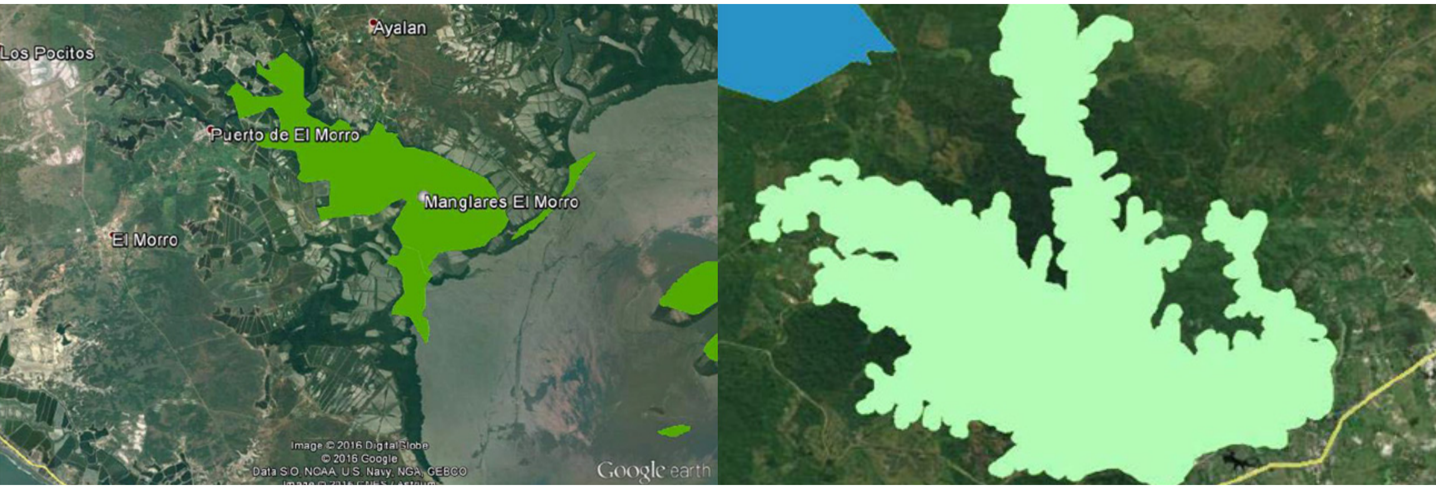

Figure 8: (a) Manglares El Morro Wildlife Reserve and (b) Parque Lago National Recreation Area. Ministry of Environment of Ecuador [MAE] (2015)

Satellite images and digital thematic cartography: Satellite images and digital thematic cartography of the study area are used for the identification of protected areas and conservation areas to be connected. The management of images and their components (roads, populated centres, water systems) and thematic maps contributed to defining the type of corridor that exists.

Analysis criteria: The analysis criteria focused on the following aspects: "a." The matrix on which the corridor is designed, "b." Variables: fauna, flora, morphology, hydrology, roads, populations, and land use, and "c". Areas containing species that can move using the corridor. This information is reflected in the similarity analysis of plant and animal species in the study area. Roads, populations, and land uses, among others, are identified through the thematic cartography mentioned below and satellite images of the study area.

Aspects to consider in the delimitation of urban and rural connectivity corridors:

a. Connection of ecosystems promoting the migration and dispersal of species; b. Designing corridors to ensure the reduction of ecosystem fragmentation; c. Considering the prioritized areas (at the level of protected areas) by the Ministry of Environment in the verification of interconnection corridors.

Moreover, the natural areas that are part of the National System of Protected Areas (SNAP) constitute the core of the corridors, and the remaining forests and natural vegetation designated for conservation are conceived as integration circuits. It is important to identify areas with a higher incidence of human activity, ecological fragility, and zones where the Ministry has greater conservation management. These places should include corridors that promote population development through coherent land-use planning between development and the maintenance of natural resources. These aspects do not constitute any criteria or results; they are merely inputs to consider in the delimitation of connectivity corridors.

According to what is described in the studies, several geo-referenced information layers were obtained, which are considered in the determination of a conservation corridor, where, using a geographic information system, the following was determined:

- Delimitation of the study area
- Determination of protected areas by the Ministry of Environment
- Flood-prone areas and bodies of water
- Areas with human intervention (shrimp farms, crops, etc.).

Subsequently, the overlapping of layers is performed to visualize the areas that meet the following conditions:

- Areas not occupied by human activities
- Areas prone to flooding
- Existing bodies of water.

3. Results

In the implementation of connectivity and conservation corridors, economic, ecological, and social benefits are identified:

- Economic: They provide resources for vegetation reproduction, improving the economy of the populations located within the corridor.
- Ecological: Protection of biodiversity, soils, ecosystems, and watersheds. Maintenance of ecological balance and climate regulation through the vegetation present in the area.
- Social: Opportunities for recreation and leisure in urban and rural settings. Areas for research and environmental education.

These initial results are obtained from the interpretation of the purposes of the connectivity corridors (Ministry of Environment of Ecuador [MAE], 2020).

The evaluation of the landscape matrix is carried out using indicators provided by secondary information collected in each protected area, with data on natural forest vegetation, wetlands, and wooded passages. Table 3.

From the comparative analysis of the calculated similarity, it shows that among the evaluated life zones, there is greater species similarity between the very dry tropical forest and the tropical thorny scrub, reaching an index of 25%* (9 common species and 27 non-common species); in the relationship between the very dry tropical forest and the premontane dry forest, there is a similarity of 15,4% (6 common species and 33 non-common species); and between the premontane dry forest and the tropical thorny scrub, the species show no presence of similarity (0 common and 42 non-common species).

Mathematical example of the calculation**:** *Ij = [a / (a + b)] x 100*

Where:
a= number of common species
b= number of non-common species

Species present in the very dry tropical forest (bmsT) and in the tropical thorny scrub (meT):
a=9 common species
b=15 species only from bmsT + 12 species only from meT = 27 non-common species

Ij= [9 / (9+27)] x 100 = 25%

The study area corresponds to 5 areas that are part of the National System of Protected Areas (PANE). As initially pointed out, birds were chosen due to their ability to move in search of environments with better characteristics for their existence. Official information

Common name	Very dry tropical forest	Pre-montane dry forest	Tropical thorny forest	Common name	Very dry tropical forest	Pre-montane dry forest	Tropical thorny forest	Common name	Very dry tropical forest	Pre-montane dry forest	Tropical thorny forest
Ovo de Monte		YES		Zapote de Perro			YES	Cedro Colorado		YES	
Mango	YES		YES	Guarumo		YES		Algarrobo			YES
Ciruela	YES	YES		Beldaco	YES	YES		Barbasco			YES
Mangle Negro			YES	Mangle Blanco			YES	Muyuyo de Montaña		YES	
Higuerilla	YES		YES	Niguito			YES	Nim	YES		
Bototillo	YES		YES	Coquito		YES		Figueroa		YES	
Ceibo	YES		YES	Grosella	YES			Ajo	YES	YES	
Mangle Jelí			YES	Balsa. O.Lagopus	YES			Fernán Sánchez	YES	YES	
Pasayo		YES		Guayacán	YES		YES	Ébano			YES
Pigío		YES		Guachapelí	YES	YES		Mangle Rojo			YES
Barba Salvaje	YES			Vainillo. Casia S.P.	YES			Mangle Zapatero			YES
Laurel	YES			Palo prieto	YES			Jagua		YES	
Muyuyo	YES		YES	Samán	YES		YES	Piñuelo			YES
Cardo			YES	Amarillo		YES		Guasmo	YES		YES
Vainillo. Senna S.	YES	YES		Charán Blanco		YES		Sapote Colorado		YES	
Tamarindo	YES			Cocobolo		YES		Pechiche	YES		
Acacia Roja	YES		YES	Pepito Colorado		YES		Balsa. Popayanensis		YES	

Table 3: Presence of vegetation in the life zones of Guayaquil. Ministry of Environment of Ecuador [MAE] (2015)

on available bird inventories from each protected area was consulted. In Ecuador, 1.722 bird species have been identified (Ecuadorian Committee for Ornithological Records [Cero], 2022), of which 279 correspond to these protected areas.

The Churute Mangrove Ecological Reserve, the El Salado Mangrove Wildlife Production Reserve, and the El Morro Mangrove Wildlife Refuge are situated in a tropical thorny scrub life zone, with a similarity index of 32% across 272 species, of which 88 are common and 184 are non-common. In contrast, the National Recreation Area Lago Park and the National Recreation Area Los Samanes, located within the very dry tropical forest, have a similarity of 73% with 212 species, of which 154 are common and 58 are non-common. Additionally, the following table lists the similarity indices between El Salado and El Morro mangroves, Churute and El Salado, Churute and El Morro, and El Salado and Lago Park (Table 4).

Investigations using satellite images revealed that some protected areas are being intervened, making the creation of connectivity corridors difficult. In Guayaquil, the forests within the urban area are surrounded by roads, informal settlements, housing developments, and industries. Many of these areas were intervened before being declared protected. Additionally, they face threats such as the construction of new roads and developments, especially along the highway to Salinas.

Identification of conservation corridors. The identification of conservation corridors was carried out between the nearby protected areas and within the city of Guayaquil, leading to the definition of the following areas:

Part of the development of conservation corridors involves promoting the connection of ecosystems to avoid fragmentation. Therefore, the existing bodies of water within and near the city of Guayaquil are primarily considered part of the conservation corridor.

Among the bodies of water that allow for the connection of various protected areas are the Daule River, Guayas River, Salado Estuary, and Gulf of Guayaquil, which form part of the conservation corridor.

The area formed between the Protective Forests of Cerro Blanco, Papagayo, and the Chongón River Sub-basin constitutes a node that facilitates movement from the sources through the matrix, according to the methodology used. Therefore, it meets all the characteristics outlined to determine a conservation corridor. Within this area, no significant human activities are developed; the watershed located in the sector allows for the channelling of water towards Lake Park (Figure 9a).

The presence of flora and fauna in the area where the development of the conservation corridor is proposed is in accordance with the identified life zone, based on the similarity index analyses mentioned earlier.

The areas of minimally human-intervened voids present between the protective forests and vegetation become connection areas between them. The mangroves of the coastal fringe connect through the continuity of this vegetation, as well as through the presence of salt marshes, wetlands, and estuaries found in the area. Rivers and estuaries facilitate connections inland and throughout the Guayas River estuary.

Between the El Salado Wildlife Production Reserve and the El Morro Wildlife Reserve, productive projects such as cacao and mango cultivation are being developed. Additionally, the new airport for the city of Guayaquil is being developed in Daular. Consequently, areas where human activities do not occur were identified; this criterion also included the existence of flood-prone areas, which are fundamental for the development of the existing fauna in the sector (Figure 9b).

As previously indicated, bodies of water are part of the conservation corridor. Therefore, to connect protected areas located on an island, areas that link the protective forests with the Gulf of Guayaquil were defined.

As a complement to the connectivity corridors mentioned earlier, preservation, reservation, and conservation corridors 300 meters wide are included along the water transfer channel from the Daule River to the Santa Elena Peninsula, extending 96.13 km. This corridor passes through Lake Park and the Cerro Blanco

Protected areas	Sector	Similarity index	Common species	Uncommon species	Total species
Manglares Churute Ecological Reserve Manglares El Salado Wildlife Production Reserve Manglares el Morro Wildlife Refuge	m.e.T	32,4%	88	184	272
National Recreation Area Parque Lago Los Samanes National Recreation Area	b.m.s.T	72,6%	154	58	212
Manglares El Salado Wildlife Production Reserve Manglares el Morro Wildlife Refuge	Mangrove	46%	92	108	200
Manglares Churute Ecological Reserve Manglares El Salado Wildlife Production Reserve	Mangrove	61,9%	164	101	265
Manglares Churute Ecological Reserve Manglares el Morro Wildlife Refuge	Mangrove	36,7%	92	159	251
Manglares El Salado Wildlife Production Reserve National Recreation Area Parque Lago	Distances less than 10 km	78%	156	44	200

Table 4: Similarity indices between protected areas according to the life zone. Ministry of Environment of Ecuador [MAE] (2015)

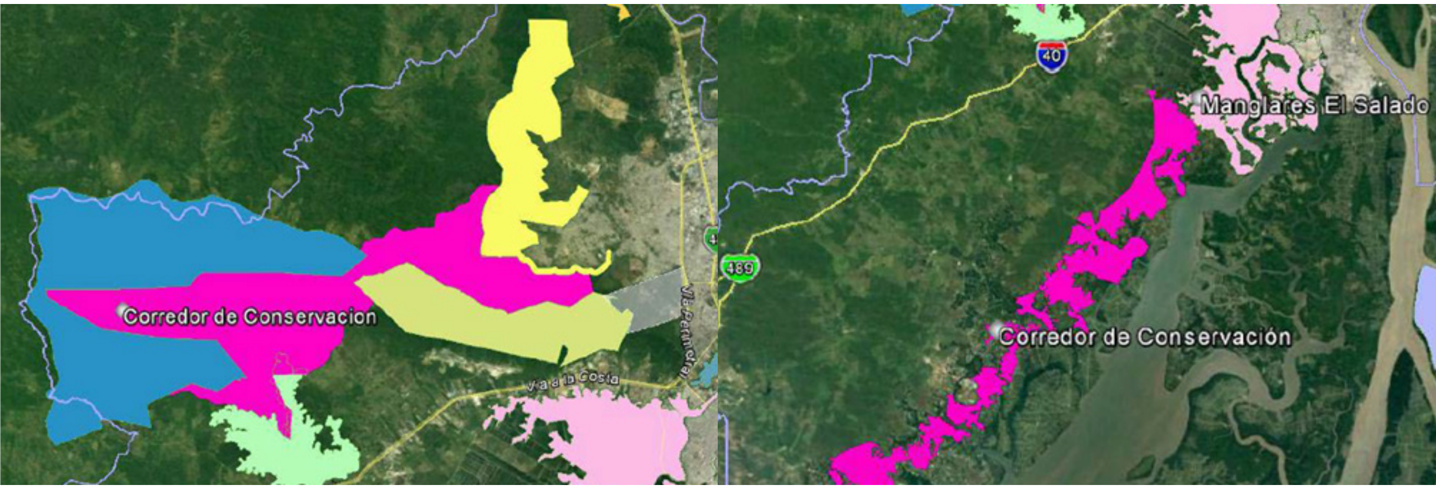

Figure 9. (a) Conservation corridor between the protective forests located north of Guayaquil and (b) conservation corridor between the protected areas of El Morro and El Salado. Asingesa (2016)

protective forest, bordering the Papagayo and Bosqueira forests until it connects with the Daule River. Additionally, this study includes the hydrological systems of the sub-basins and micro-basins in the Guayaquil canton area, which intersect the channel and the protected areas of the study area.

Among the future research proposed in this study is the updating of the Development and Land Use Plan for the Guayaquil canton, concerning the zoning maps, land classification, and road structure in the cantonal area, as well as the territorial impacts in the areas near the future international airport of Guayaquil in the Daular sector and the developable and non-developable lands in the urban expansion area of the city of Guayaquil (Figure 10).

4. Discussion and conclusions

From the review of the Conservation Gap Analysis studies mentioned in this study (Camacho et al., 2013), it is evident that areas have been identified that allow them to be managed as a conservation corridor. According to the aforementioned studies, there are protected areas that converge with the gaps identified by the Guayas Prefecture. However, the scope of action of the Prefecture does not allow for a gap analysis (focused on natural areas) within urban areas, as it falls under municipal jurisdiction, and it is limited to conducting a macro study at the rural and provincial levels.

The presence of conservation corridors and natural landscapes within a city allows for rehabilitation, urbanization, and improvement of consolidated urban spaces to occur with a low degree of stress and greater respect for the environmental levels that contribute to urban sustainability (Fadigas, 2017).

Regarding the review conducted on the environmental recommendations of the Study of Water Resources in the Rural Area of the Guayaquil Canton (Escobar, 2000), it is indicated that at least 30 hectares are recommended for the establishment of protective forests, a concept that can be extrapolated to an ecological conservation corridor. However, the Palo Santo Protective Forest in Guayaquil has only 10,29 hectares, yet it constitutes an important natural park for the city, where the creation of ecologically healthy environments has implications for urban sustainability.

The previous study also proposes measures to adequately protect natural drainage systems and surface water structures. This includes establishing a protection zone of 15 meters from their outer edge and recommending activities such as reforestation, construction of structures to maintain the waterways, and the creation of paths and bridges for the communication of the inhabitants. However, the study does not take into account the hydrological sub-basins

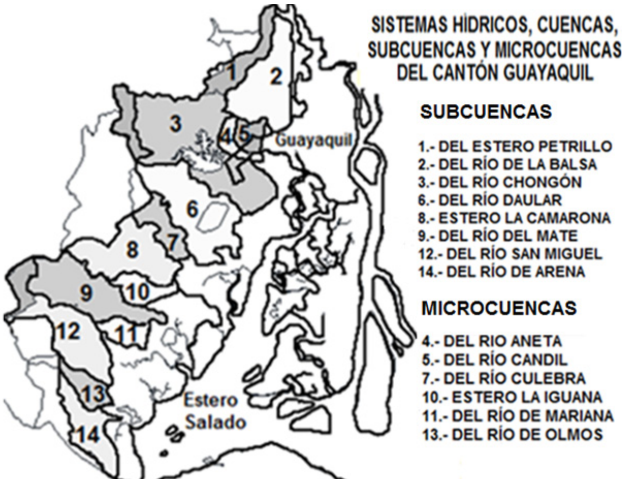

Figure 10: (a) Water transfer channel from the Daule River to the Santa Elena Peninsula. (b) Hydrological systems, basins, sub-basins, and micro-basins of the Guayaquil canton. (2024)

that interconnect the protected areas of the canton, among which are the Petrillo estuary, Balsa River, and Daular River, as well as the micro-basins of the Aneta, Candil, Culebra, and Iguana rivers, among others.

It also does not reference the Water Transfer Canal from the Daule River to the Santa Elena Peninsula, the main artificial body of water that runs through a large part of the urban and rural area of the Guayaquil canton, which has an urban length of 22,85 km and a rural stretch of 73,28 km. The protection of the canal is referred to as the Preservation, Reservation, and Conservation Corridor, which has a width of 300,00 m, extending 150,00 m from the centreline on both sides of the canal. Due to being non-developable land, no use is permitted except for the cultivation of plant species that contribute to the stabilization of the canal edges.

Corridors promote harmonious coexistence between the city and nature, contributing to urban sustainability (Hu et al., 2023). They offer benefits by acting as multifunctional green spaces that improve air quality, regulate the climate, reduce flooding, and promote conservation and mobility for wildlife species. Additionally, they reestablish connectivity between modified habitats, increasing the resilience of urban ecosystems to climate change and biodiversity loss (Feoli, 2013).

From the inputs obtained, the importance of implementing connectivity corridors to promote sustainability and ensure the quality of life for residents can be established (Fuchs et al., 2021). This sustainability addresses the relationship between natural and human systems within the urban environment, promoting balance and harmony between both (Shebek, 2020). Protected areas help to curb the development of urban zones in Guayaquil.

In Guayaquil, a city in constant growth, urban sustainability is vital. It is necessary to expand and improve the quality of urban green areas, making them more accessible. Currently, these areas are unevenly distributed across the city, concentrated in the northeast and southeast zones and scattered in the northwest and southwest zones. Additionally, informal settlements lack green areas within them (Municipality of Guayaquil, 2021). Thus, it can be inferred that there is a lack of and inequitable distribution of green areas in the city.

Guayaquil has endemic species that reproduce in protected areas but are constantly threatened by informal urbanization. Other areas lack a functional landscape relationship with the developments located in their context (Municipality of Guayaquil, 2021). As a result, portions of forests have been left fragmented amid the development of urban areas and the city. Additionally, deforestation and fires caused by land invaders have devastated hundreds of hectares of protected areas, destroying a significant percentage of species.

Thus, despite the benefits of connectivity corridors in urban contexts, their implementation faces significant challenges. Their planning and design must consider the needs and concerns of the local community, as well as the imperatives of urban development (Ahn and Juraev, 2023).

Territorial and urban planning must address challenges such as biodiversity conservation and the improvement of environmental and social quality, leading to an enhancement of the quality of life for the population (Pineo, 2022; Casasanto, 2020), identifying corridors to maintain natural capital and establishing management plans for their consolidation.

Additionally, at the urban level, it is essential to define clear indicators to assess the success of connectivity corridors over time. This could include variables, components, and sustainability indicators such as urban form, diversity, mobility, and environmental quality (Torres and Delgado, 2023).

It is essential to incorporate the results of the research into policies and urban plans at the local, regional, and national levels. This involves sharing and discussing the findings with municipal authorities and other relevant stakeholders, as well as involving residents, non-governmental organizations, and authorities in the design, implementation, and management of connectivity corridors. Given the diverse dimensions of these corridors, ranging from ecology to urban planning and governance, it is crucial to promote interdisciplinary collaboration among experts to ensure comprehensive approaches and integrated solutions. Thus, urban sustainability must integrate planning, urban design, environmental management, community participation, and intersectoral collaboration to create equitable, resilient, and liveable cities.

Conflict of Interests. The author declare no conflict of interests.

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