Chapter 7
Significance of SEPLs in Ecological Connectivity and Conservation of the Tropical Dry Forest: An Experience in the Dry Enclave of the Dagua River in Colombia

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Abstract Globally, forest covers and many strategic ecosystems face significant threats from human activities. The middle basin of the Dagua River in Colombia, ranging from 500 to 1850 m above sea level, includes diverse ecosystems such as grasslands, cloud forests, and tropical dry forests, all of which are highly vulnerable and understudied. These forests in Colombia are critically fragmented and degraded due to historical land-use changes. In this basin, maintaining connectivity between dry and cloud forests is essential for biodiversity, species migration, climate change resilience, ecosystem preservation, and local community reliance on crucial ecosystem services. By 2018, rapid transformation in the middle basin had led to 48% of the area being converted to productive systems, reflecting a significant loss of natural cover. Fortunately, this impact was mitigated by the establishment of two Socio-Ecological Productive Landscapes (SEPLs) in the region. Since 2007, Atuncela has been promoting forest conservation and sustainable production through effective

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area management and the establishment of the Integrated Management Regional District (IMRD). In 2015, El Chilcal joined these efforts with its own IMRD declaration, thus safeguarding these two SEPLs. These initiatives have successfully countered the broader conversion trend. Before SEPL implementation, deforestation rates were similar inside and outside the SEPL areas. However, post-implementation, deforestation rates significantly decreased within the SEPLs, demonstrating their effectiveness in reducing deforestation. Moreover, a higher proportion of productive systems within SEPLs supports forest species connectivity compared to areas outside. The SEPLs have maintained elevational and longitudinal connectivity across the basin, aided by low deforestation rates (0% since 2018) and effective management of productive systems. These outcomes highlight how community empowerment supports sustainable production while ensuring ecosystem connectivity and biodiversity conservation.

Keywords Connectivity · Biodiversity conservation · Community empowerment · Tropical dry forest · Colombia

7.1 Introduction

Globally, wildland covers and particularly many strategic ecosystems are widely threatened by anthropogenic activities. In general, these anthropogenic pressures generate changes in land use, land covers and lead in many cases to degradation or fragmentation (De Lima et al. 2021). Particularly, fragmentation is a process that tends to disturb the ecological integrity and functionality of ecosystems and that ends up affecting the connectivity of wildland covers, for example, by the reduction of the habitat surface, the decreased size of patches, and their isolation in the landscape (Luther et al. 2020).

Particularly, in Colombia, the tropical dry forest is in a critical state of fragmentation and deterioration, attributed to landscape transformations and land-use changes that have occurred since the last century (Etter et al. 2008). Currently, the tropical dry forest ecosystem is represented by small forest fragments immersed in anthropogenic matrices, where agricultural and livestock use territories predominate, exerting strong pressure on these remnants (Pizano and Garcia 2014). On the other hand, the Andean montane forests (1000 to 3500 m.a.s.l.) have one of the highest conservation priorities due to their richness and high species endemism (Olson and Dinerstein 1997), but like the dry forest, they also show high rates of fragmentation and habitat loss due to different human activities (Etter and Wyngaarden 2000).

One way to reduce the harmful effects of fragmentation and habitat loss on biodiversity and associated ecological processes is through improving connectivity. However, for there to be dynamics between fragments, landscapes must be accessible and traversable between them (Howell et al. 2018). This connectivity is defined as the degree to which the landscape facilitates or hinders the dispersal of biodiversity, vital elements such as water, ecological interactions, and ecosystem processes between habitat remnants (Taylor et al. 1993; Crooks and Sanjayan 2006). In this field, socio-ecological production landscapes and seascapes (SEPLS), which allow interactions between ecosystems and humans that favor the creation of various ecosystem services for human well-being (Takeuchi 2010), might at the same time contribute to conservation and landscape connectivity. In this context, this chapter aims to highlight the importance of SEPLS and their articulation in territorial planning in the conservation and connectivity of the landscape, taking as a case the middle basin of the Dagua River in Colombia, which encompasses an altitudinal gradient ranging from 500 to 1850 m.a.s.l., including different types of ecosystems such as grasslands, cloud forests, and tropical dry forests.

7.2 Methodology

7.2.1 Study Area

The Integrated Management Regional District Subxerophytic Enclave of Atuncela (henceforth IMRDSEA) and the Integrated Management Regional District El Chilcal (henceforth IMRDEC) are two socio-ecological production landscapes (henceforth SEPLs) located in the middle basin of the Dagua River on the eastern slope of the Western Cordillera. In this area, there are rural communities involved in traditional agricultural practices, such as subsistence farming and manual cultivation techniques. Additionally, small-scale producers employ semi-technical methods, which may include the use of basic machinery, improved crop varieties, and more efficient irrigation systems. These farming practices vary in their level of technology and intensity, influencing both the local economy and the surrounding environment. Additionally, to the north, there is a subxerophytic zone characterized by low precipitation levels (Fig. 7.1).

7.2.1.1 Integrated Management Regional District Subxerophytic Enclave of Atuncela (IMRDSEA)

The Integrated Management Regional District Subxerophytic Enclave of Atuncela (IMRDSEA) is in the Corregimiento de Atuncela, Municipality of Dagua, Valle del Cauca, Colombia. It covers 2334.37 ha of protected land, declared by the Regional Autonomous Corporation of Valle del Cauca—CVC (the regional environmental authority) (Fig. 7.1 and Table 7.1). This area, previously identified as a SEPL by Quintero-Angel et al. (2025), overlaps with the Key Biodiversity Area (KBA) known as the dry enclave of Dagua (COL 36) (Critical Ecosystem Partnership Fund 2021). Situated at altitudes ranging from 500 to 1000 m.a.s.l., the IMRDSEA has an average temperature of 23.2 °C, with annual precipitation levels ranging from 700 to 800 mm. It follows a bimodal precipitation pattern, with rainy seasons typically

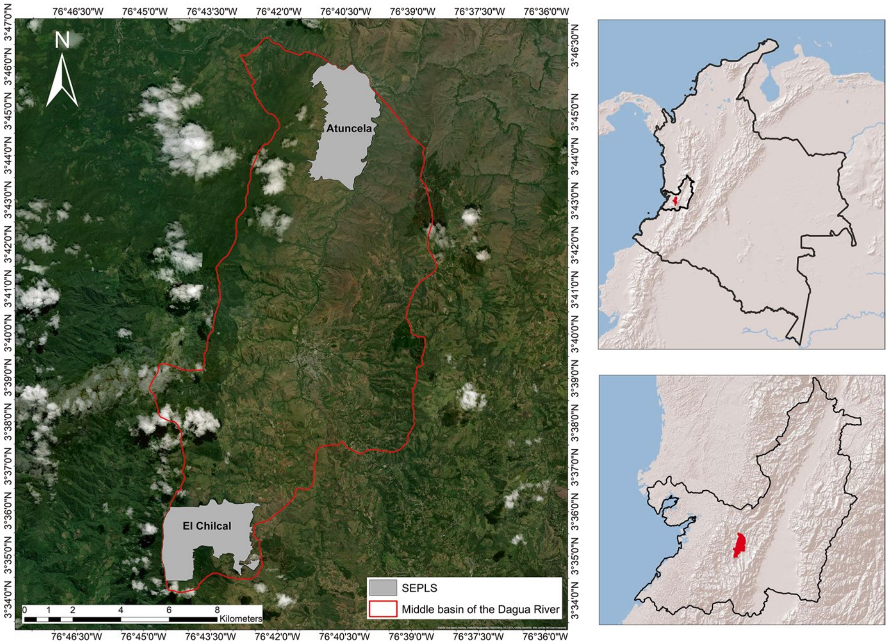

Fig. 7.1 Study area: at the extremes of the middle basin of the Dagua River are the SEPL IMRDSEA and IMRDEC. (Source: Created by the authors using ESRI basemap)

Table 7.1 Basic information of the study area (Authors' elaboration 2024)

	IMRDSEA	IMRDEC
Country/region	Colombia	
Province	Valle del Cauca	
Municipality	Dagua	
Size of the geographical area (hectare)	1011.5	912.47
Dominant ethnicity(ies), if appropriate	Atunceleños	Chilcaleños
Size of the case study/project area (ha)	15,359	
Dominant ethnicity in the project area	Mixed-race peasants	
Number of direct beneficiaries (people)	357	280
Number of indirect beneficiaries (people)	357	280
Geographic coordinates (latitude, longitude)	3° 46′ 21.2484″N, 76° 39′ 42.1272″E	3° 35′ 24.36″N, 76° 42′ 54.54″E

Fig. 7.2 Panoramic view of IMRDSEA (Source: CORFOPAL 2023)

occurring in May, October, and November and dry periods from February to March and June to August (CORFOPAL & CVC 2022a).

The IMRDSEA encompasses three ecosystems: two dry and very dry forest ecosystems in the middle and lower parts and a transition to tropical humid forest in the upper part (CVC & FUNAGUA 2010). The area contains 20 types of vegetation cover, with natural cover constituting 56.68% of the total area, including forests, streams, and successional shrubs. The remaining 43.32% consists of transformed or production-intended covers, such as pastures for livestock, crops, and residential areas (CORFOPAL & CVC 2022a) (Fig. 7.2). In the IMRDSEA, approximately 357 residents are primarily engaged in various primary economic activities, including agriculture, livestock farming, poultry farming, fish farming, panela (brown sugarcane) production, and tourism (Municipality of Dagua 2002).

The IMRDSEA showcases a diverse array of life, harboring 155 species of plants, 14 species of fish, 15 species of amphibians, 138 species of birds, 23 species of mammals, and 14 species of reptiles. Among these documented species are endangered endemics like the Ruiz's robber frog (*Strabomantis ruizi*) and Tlatepusco vanilla (*Vanilla odorata*). Additionally, species such as the Cauca poison frog (*Andinobates bombetes*), the northern tiger cat (*Leopardus tigrinus*), and the Colombian night monkey (*Aotus lemurinus*) are categorized as vulnerable. Moreover, regionally threatened species, though not globally threatened, include the Cauca lily (*Eucharis caucana*), the Loboguerrero cactus (*Melocactus curvispinus* sub. *loboguerreroi*), and the Colombian red howler monkey (*Alouatta seniculus*) (CORFOPAL & CVC 2022a).

Fig. 7.3 Panoramic view of IMRDEC. (Source: CORFOPAL 2023)

7.2.1.2 Integrated Management Regional District El Chilcal (IMRDEC)

The Integrated Management Regional District El Chilcal (IMRDEC), previously identified as a SEPL by Orjuela-Salazar et al. (2018), is in the El Chilcal village at an elevation of 1330 m.a.s.l. in the El Limonar township in the Municipality of Dagua (Fig. 7.1 and Table 7.1). IMRDEC experiences temperatures between 18 and 24 °C, with annual precipitation levels ranging from 800 to 1000 mm. This 912.47 ha area was declared a protected area in 2015 by the CVC. It features two sub-Andean dry forest ecosystems in the lower parts and a transition to tropical humid forest in the middle and upper parts (CORFOPAL & CVC 2022b). The area is characterized by very shallow soils with steep and very steep slopes, frequent landslides, high susceptibility to erosion, shallow effective depth, and low fertility (Fig. 7.3). Its agroecological conditions demand the presence of permanent forest cover (Municipality of Dagua 2002).

In the IMRDEC, approximately 280 people reside, primarily engaged in various primary economic activities such as agriculture, livestock farming, poultry farming, fish farming, mining, and tourism (Municipality of Dagua 2002). This area boasts abundant biodiversity, including 102 species of resident birds, constituting roughly 13% of those recorded in Valle del Cauca. Additionally, there are 27 mammal species, 8 reptile species, 14 amphibian species, and 261 flora species, with the majority being pioneer and early successional species (GAIA & CVC 2014; Orjuela-Salazar et al. 2019).

Among the documented species are endangered endemics, such as the Cauca poison frog (*Andinobates bombetes*) and the Ruiz's robber frog (*Strabomantis ruizi*). Other notable species include the Colombian night monkey (*Aotus lemurinus*), the glass frog (*Centrolene savagei*), the Pichinde robber frog (*Pristimantis gracilis*), and the red cedar (*Cedrela odorata*). Additionally, species like the Santa Rita rocket frog (*Colostethus fraterdanieli*) are classified as near-threatened and are endemic to the region. Furthermore, there are six species facing national or regional threats within the IMRDEC, including the bronze-winged parrot (*Pionus chalcopterus*), jaguarundi (*Herpailurus yagouaroundi*), long-tailed weasel (*Mustela frenata*), Parker's antbird (*Cercomacra parkeri*), the apical flycatcher (*Myiarchus apicalis*), and the Colombian chachalaca (*Ortalis columbiana*) (CORFOPAL & CVC 2022b).

7.2.2 Information Gathering and Analysis

7.2.2.1 Governance, Management, Decision-Making, and Stakeholder Engagement in the SEPLs

To address the governance, management, decision-making, and engagement of stakeholders in IMRDSEA and IMRDEC, a systematic information search was conducted following the methodology developed by Aldunce et al. (2008). This involved the detection, acquisition, and consultation of relevant literature for the research, based on predefined search criteria, information sources, and keywords. Subsequently, interviews were conducted with key informants (Geilfus 2002), and participatory observation outings (Kawulich 2005) and knowledge exchange sessions (PRATEC 2012) were implemented to gather specific information about these SEPLs.

7.2.2.2 Loss of Forest Cover

One of the main drivers of connectivity in a landscape is the loss or gain of natural areas. Therefore, the first step we took was to determine the importance of the SEPL as decelerators of forest cover loss. To do this, we compared the amount of tree cover within each SEPL before and after its declaration. These results were compared with the amount of tree cover outside the SEPL in the middle basin of the Dagua River (Fig. 7.1). The percentage loss values of tree cover were obtained from the Global Forest Watch platform (https://www.globalforestwatch.org), which monitors forest cover loss at a pixel resolution of 30 x 30 m. Statistical comparisons were made using paired Student's t tests.

7.2.2.3 Land Use and Resistance Map

Based on a CORINE Land Cover classification[1] at a scale of 1:100,000 (resolution of 30 x 30 m), we identified the different land uses present both inside and outside the SEPLs in the middle basin of the Dagua River. For land cover associated with productive systems, we calculated the percentage that still preserves natural spaces that can be used by biodiversity, increasing the permeability of the matrix. We used

[1] The CORINE (Coordination of Information on the Environment) Land Cover classification was initially developed by the European Environment Agency to map and categorize land cover across Europe. It classifies land into various types, such as forests, agricultural areas, and urban areas, based on satellite imagery and other data sources. Although originally created for Europe, this classification system has been adapted for use around the world, supporting environmental monitoring, land management, and spatial planning globally.

this layer to generate a resistance matrix to determine forest connectivity. We did not consider a particular species but rather focused on the general landscape characteristics that can offer costs and difficulty of movement for forest-associated species and reduce the flow of ecological processes, increasing the risk of mortality and avoidance behavior. In this sense, construction, roads, and human settlements offer the highest resistance, followed by pastures, crops, and mosaics with natural spaces.

7.2.2.4 Connectivity

To determine the longitudinal connectivity of the middle basin of the Dagua River, we conducted a least-cost path analysis between the two SEPLs as they are located at the ends of the basin (Fig. 7.1) using the Linkage Mapper Toolkit version 2.0 (McRae and Kavanagh 2011). Linkage Mapper utilizes the least-cost distance map, generated from the resistance matrix, to determine the corridors between the SEPLs. The least-cost corridor is presented as a vector layer, and other possible paths as a raster map, where the value of each cell in this raster indicates the suitability of that cell to provide connectivity.

To determine connectivity, we divided the watershed into three altitudinal bands, from 500 to 1000, 1000 to 1500, and 1500 to 1850 m above sea level. The SEPL IMRDEC fell within the band between 1000 and 1500 m.a.s.l., and the SEPL IMRDSEA between 500 and 1000 m.a.s.l. Using Sentinel-2 10 m Land Use/Land Cover Time Series images (Karra et al. 2021), we determined the forest fragments present for the years 2017 and 2021 in each of the bands, both within and outside the SEPLs, which constitute our units of analysis (Fig. 7.4). We estimated the connectance index, which is defined as the number of functional connections between the patches of the corresponding patch type, where each pair of patches is either connected or not, based on a user-defined distance criterion. Connectance is expressed as a percentage of the maximum possible connectance given the number of patches. In this analysis, we use a dispersal threshold of 30 m. We used Fragstats to calculate the connectance index (McGarigal et al. 2023).

7.3 Results

7.3.1 Governance, Management, Decision-Making, and Stakeholder Engagement in the SEPLs

According to IUCN guidelines for the type of governance, both IMRDSEA and IMRDEC have a Type A governance scheme, which is exercised by the government, as established by "*one or more government agencies*" (Borrini-Feyerabend et al. 2014). In this case, the Regional Autonomous Corporation of Valle del Cauca (CVC)

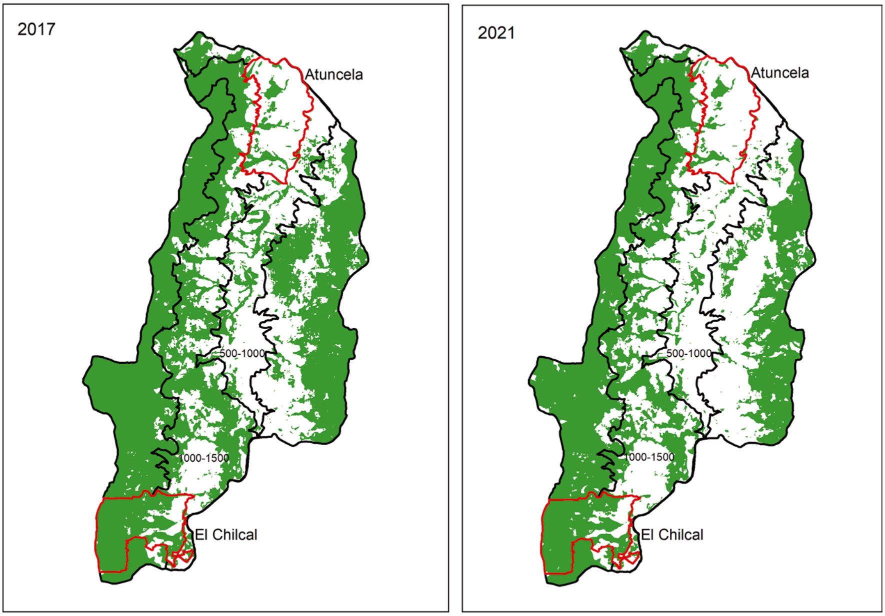

Fig. 7.4 Forest fragments for the years 2017 and 2021 in the middle basin of the Dagua River, with green color corresponding to forest fragments. (Source: Created by the authors using information from Sentinel-2 10 m Land Use/Land Cover Time Series images)

holds the authority and responsibility and is accountable for the management of the protected area, determining its conservation objectives and developing and implementing its management plan. However, the CVC has established, through ordinance and its guidelines, a participatory and binding governance scheme involving other stakeholders in the management of the protected area, known as the Co-Management Committee.

According to the provisions of Ordinance 471 of 2017, which adopts the Departmental System of Protected Areas of Valle, SIDAP Valle: "*The Committees are the social and political basis of the Governance scheme that must guarantee the participation of different actors considering elements taken from the analysis of actors of SIDAP Valle, such as competencies, local participation, benefits, and social and citizen commitment in conservation, cross-cut by ethnic-cultural and political aspects in terms of decision-making*" (CVC 2021).

In both IMRDSEA and IMRDEC, we determined that the established co-management committees have undertaken numerous governance activities, organized into five governance axes. The implementation of these axes has played a significant role in mitigating threats to the area while also fostering effective management, decision-making, and stakeholder engagement. These governance axes, along with the corresponding activities, are detailed in Table 7.2.

Another factor identified in decision-making and stakeholder engagement is the development of planning instruments for each of the SEPLs (Fig. 7.5). These instruments are elaborated through participatory processes involving workshops, social

Table 7.2 Governance axes for IMRDSEA and IMRDEC. (Authors' elaboration 2024)

Governance Axes	Description	Governance Actions	
		IMRDSEA	IMRDEC
Capacity strengthening	This axis aims to enhance the skills of the stakeholders involved in the committee to manage the area. Therefore, training has been provided on a variety of relevant topics.	Qualified participation Administration. Leadership and organization. Conflict resolution. Project formulation.	Qualified participation Leadership and organization. Conflict resolution.
Co-management and coordination	This axis aims to ensure that decisions affecting the territory are agreed upon in a timely manner within the committee and that the implementation of agreed actions is jointly coordinated.	Contextualized planning. Assignment of roles and responsibilities. Management with partners. Monitoring and evaluation. Articulation with institutional bodies.	Contextualized planning. Management with partners. Monitoring and evaluation.
Information dissemination	This axis seeks to ensure that information related to the area and decisions made are shared among committee members and the wider community.	Information dissemination. Information custody. Communication channels. Articulation with other stakeholders.	Information dissemination. Information custody. Communication channels.
Knowledge	Similar to the previous axis, the goal of this axis is to leverage local knowledge to support decision-making. In this sense, the committee collects studies and works carried out in the SEPL by other entities or its own members and keeps them for consultation if necessary.	Research and innovation. Knowledge exchange. Sectorized training.	Research and innovation. Knowledge exchange. Sectorized training. Knowledge custody.
Sustainability	This final axis seeks to ensure that decisions related to the management and use of resources within the SEPL take sustainability into account, in order to promote biodiversity conservation.	Resource management. Resource optimization. Positive reputation.	Resource management. Resource optimization. Teamwork.

mapping, and decision-making meetings. They consist of several phases: a territorial diagnosis phase where biophysical and socioeconomic information of the area is gathered, an organizational phase where conservation and management objectives are established, and a zoning exercise that identifies three main zones—preservation areas, restoration areas, and areas for sustainable use. Additionally, the type of activities allowed and prohibited in each zone is determined. Lastly, there is

Fig. 7.5 Stakeholder engagement in the development of planning instruments for each of the SEPLs: IMRDSEA (above) and IMRDEC (below). (Source: CORFOPAL 2023)

a programmatic phase where actions and projects necessary to maintain the area's integrity are identified (CORFOPAL & CVC 2022a, b). It is through the development and subsequent implementation of these planning instruments that the co-management committees manage the areas and promote biodiversity conservation and ecological connectivity.

7.3.2 Loss of Forest Cover

Although forest cover is not dominant in the middle basin of the Dagua River, it is one of the most important land covers in terms of biodiversity and ecosystem services. As seen in Fig. 7.6, loss of forest cover has been variable over time but has completely ceased within the SEPLs since 2018. Considering that the SEPL IMRDSEA was declared in 2007 and IMRDEC in 2015, we compared the loss of forest cover inside and outside the SEPLs before and after the declaration of the first

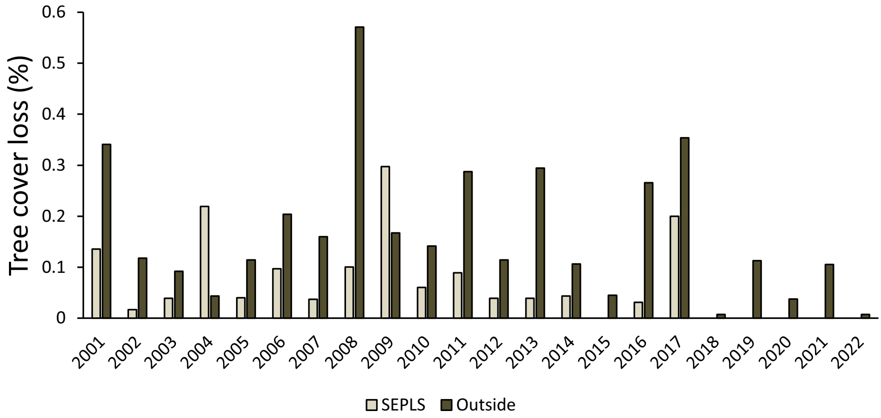

Fig. 7.6 Percentage of tree cover loss per year inside the SEPLs and outside them. (Source: Created by the authors using data from Global Forest Watch; https://www.globalforestwatch.org/map/)

SEPL (2007). In the period before the declaration, the percentage of loss on average per year within the SEPLs was 0.08% (SD = 0.07) and that outside was 0.15% (SD = 0.09), without statistically significant differences being evident ($t = -1.55$, $P = 0.19$). From 2007, a decrease in loss of cover within the SEPLs is evident with an average value of 0.06% (SD = 0.17), while outside, the percentage of forest loss remains (0.085%, SD = 0.15). This leads to significant differences in cover loss ($t = -3.2$, $P = 0.003$).

7.3.3 Land Use

According to the land cover map based on the CORINE Land Cover classification for Colombia, in the middle basin of the Dagua River in 2018, 47.9% of the area was under some type of productive system. Within the SEPLs, 58% of the area was under productive systems, while the figure for outside was 46%. However, within the SEPLs, 39.4% of the productive systems maintain areas of natural spaces compared to 33.7% outside of them.

7.3.4 Connectivity

The analysis of least-cost paths between the SEPLs shows that the path of least resistance corresponds to the upper part of the basin where sub-Andean cloud forest dominates. In general terms, the western part of the basin presents lower resistance than the eastern part. Both inside and outside the SEPLs in the western zone, the streams are the paths of least resistance (Fig. 7.7).

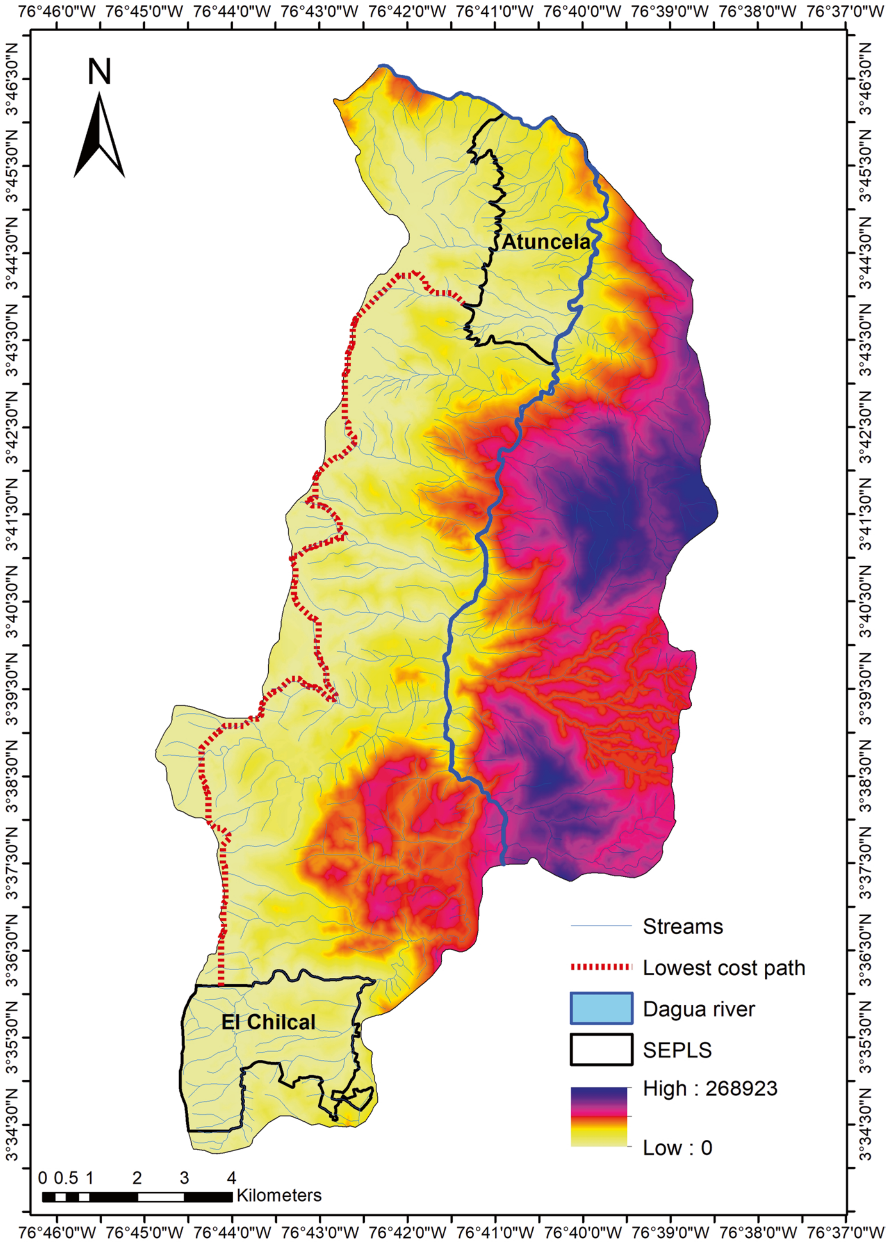

Fig. 7.7 Resistance map and least-cost routes, with light color corresponding to the lowest mobility resistance for forest species and associated flows of ecological processes. (Source: Created by the authors using spatial information provided by the CVC geovisor; https://geo.cvc.gov.co/visor_avanzado/)

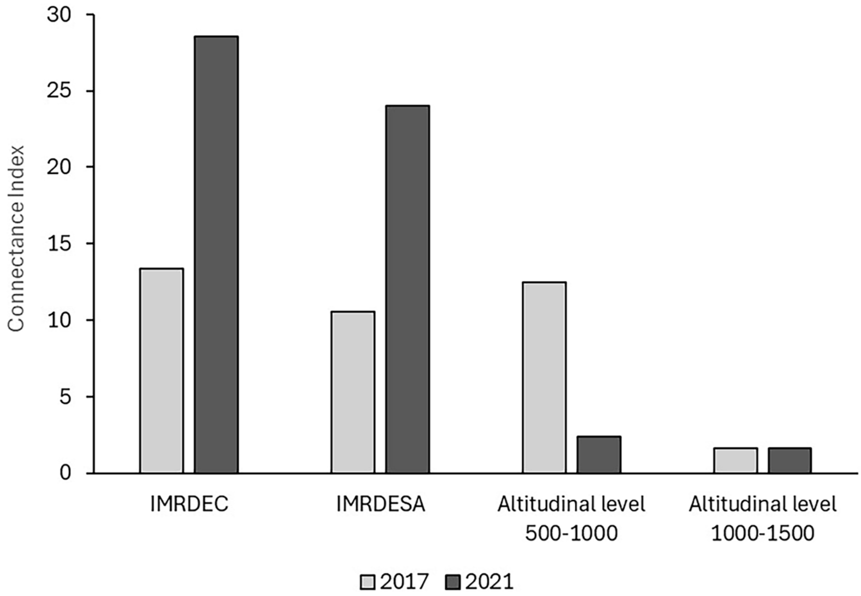

Fig. 7.8 Changes in connectance index between 2017 and 2021 for the SEPLs and the altitudinal ranges outside of them. IMRDEC is in the altitudinal range of 1000 to 1500 m above sea level, and IMRDSEA is situated between 500 and 1000 m above sea level. (Source: Created by the authors)

The connectance index varies among altitude ranges, inside and outside the SEPLs, and between years. For the SEPL IMRDEC, located between 1000 and 1500 m.a.s.l., the connectivity was 13.3 for the year 2017, while for the year 2021, it increased to 28.5. Meanwhile, outside the SEPL in the same altitude range, the connectance index was 1.6 for both 2017 and 2021. On the other hand, in the altitude range between 500 and 1000 m.a.s.l., where the SEPL IMRDSEA is located, a connectivity of 10.5 was observed within the SEPL for the year 2017, rising to 24 in 2021. Whereas, outside, the connectivity decreased significantly, dropping from 12.5 in 2017 to 2.4 in 2021 (Fig. 7.8).

This trend is primarily due to the positive effects of SEPL implementation. Inside SEPLs, better land management, conservation practices, and restoration activities have significantly increased connectivity. These areas benefit from targeted efforts to enhance ecological corridors and maintain natural habitats. In contrast, outside SEPLs, the lack of effective management or less stringent enforcement may lead to poor land management practices, resulting in minimal or even negative changes in connectivity. Human activities such as deforestation, urbanization, and agriculture further disrupt connectivity outside protected areas.

7.4 Discussion

Our analysis reveals substantial changes in forest cover, indicating significant pressure on habitat remnants in the middle basin of the Dagua River. Although forest cover is not predominant in this area, it is crucial to highlight the vital role played by these forest fragments in preserving biodiversity and providing ecosystem services in adjacent environments, considering that such impact is moderated by the isolation of the fragments in the landscape (Mitchell et al. 2014). Nevertheless, a complete halt in the loss of forest cover within the SEPLs has been observed since 2018, underscoring the effectiveness of the conservation strategies in the territory.

The comparison between the loss of cover before and after the declaration of the SEPLs reveals a statistically significant decrease in these areas, indicating a positive impact on forest preservation. These results support the effectiveness of conservation policies and local protected area management in safeguarding natural ecosystems in the Dagua River basin, aligning with previous studies that have demonstrated the importance of such policies in mitigating deforestation, as indicated by Cuenca et al. (2016).

The cessation of deforestation in the SEPLs is attributed to a combination of community and institutional conservation actions. On the one hand, the active involvement of local communities has promoted sustainable land-use practices[2] and fostered the conservation of natural resources (Orjuela-Salazar et al. 2018, 2019; Quintero-Angel et al. 2025). On the other hand, institutional measures, such as the declaration of protected areas and the implementation of a participatory governance framework, have contributed to preserving forest cover by establishing regulations and guidelines for the proper use of land. It is worth mentioning that since the rules and regulations are developed through governance frameworks within co-management committees, they are embraced and adhered to by the communities. This is because the communities feel involved in the decision-making process for the care of their territory, rather than having to comply with imposed rules established from the city without considering the local context. These combined actions have resulted in a significant reduction in deforestation (zero within the SEPLs), highlighting the effectiveness of an integrated strategy involving both local communities and government institutions in biodiversity conservation, which has also favored ecological connectivity.

The analysis of land uses in the middle basin of the Dagua River reveals that nearly half of the area is devoted to productive systems, posing challenges for

[2] Within the SEPLs, various sustainable land-use practices have been promoted, resulting in significant increases in connectivity. These practices include agroforestry, ecosystem restoration, organic farming, and integrated pest management. Additionally, sustainable forestry, crop rotation, watershed protection, rotational grazing, conservation agriculture, and participatory community development have been implemented. Specifically, shade-grown coffee cultivation, silvopastoral systems, and sustainable community-based panela (brown sugar cane) production have been introduced. These practices enhance biodiversity, soil health, and climate resilience, benefiting both ecosystems and local communities.

biodiversity conservation. Within the SEPLs, 58% of the area is under productive systems, compared to 46% outside of them. Despite this higher proportion within the SEPLs, it is encouraging to observe that 39.4% of the productive systems within these areas conserve natural spaces, compared to 33.7% outside of them. These findings suggest a complex interaction between productive activity and conservation, demonstrating the effectiveness of SEPLs in reconciling these objectives. Examples of productive systems within SEPLs, such as shade-grown coffee cultivation and silvopastoral systems, illustrate their positive impact on biodiversity. Shade-grown coffee integrates coffee plants under the canopy of native trees, promoting habitats for various bird species, insects, and other wildlife while maintaining forest cover, reducing soil erosion, and enhancing soil fertility. In contrast, conventional coffee plantations outside SEPLs might clear native vegetation, reducing habitat complexity and biodiversity. Silvopastoral systems combine forestry with livestock grazing, integrating trees and shrubs into pasture lands, increasing habitat diversity, supporting pollinators, and improving carbon sequestration. This practice also provides shade for animals, enhancing their welfare and productivity, whereas traditional livestock grazing without trees often leads to soil compaction, erosion, and a decline in plant species diversity. These examples highlight the effectiveness of SEPLs in balancing productive activity with biodiversity conservation by promoting sustainable practices that conserve natural spaces that favor connectivity. The importance of evaluating agricultural and productive practices within the SEPLs to ensure alignment with conservation objectives is highlighted, and future studies could explore more effective management strategies in this context.

The analysis of least-cost routes between the SEPLs in the middle basin of the Dagua River highlights the importance of conserving fragmented landscapes (Arroyo-Rodríguez and Mandujano 2006; Lion et al. 2016). It is observed that the upper part of the basin, characterized by sub-Andean cloud forest, represents the path of least resistance, underscoring the need to protect this key habitat. The western zone, with lower resistance compared to the eastern part, demonstrates the relevance of planning effective conservation strategies in specific areas of the landscape aimed at reducing pressures from productive systems on forest fragments, particularly tropical dry forest, which is one of the most threatened ecosystems and less represented in the country (Pizano and Garcia 2014).

The identification of streams as routes of least resistance, both within and outside the SEPLs, highlights the importance of preserving and restoring these natural corridors to promote altitudinal connectivity between habitat fragments, allowing for altitudinal connectivity, which is essential for preserving biological diversity, facilitating species migration, increasing resilience to climate change, conserving specific ecosystems such as subxerophytic forest, and ensuring the continuity of essential ecosystem services for local communities. Additionally, analysis of the connectance index reveals that the presence of SEPLs significantly contributes to improving landscape permeability, underscoring the need to strengthen and expand such protected areas to mitigate the impacts of fragmentation on biodiversity and ecosystem services. These results emphasize the urgency of implementing specific conservation measures in fragmented landscapes to ensure the ecological integrity and long-term sustainability of the Dagua River basin.

The establishment of governance within these two SEPLs, with the active involvement of stakeholders, was achieved through the application of a participatory action research methodology. In this approach, social actors, who are residents of the protected areas, are regarded as sentient individuals who construct knowledge based on their social and cultural contexts, as well as their personal experiences. This empirical knowledge is then engaged in a dialogue with scientific and technical expertise, encompassing both the biophysical and socioeconomic aspects of the SEPLs, to catalyze real-world transformations. These transformations lead to adjustments in social and productive practices that are in line with the conservation objectives of these landscapes. Consequently, local stakeholders play a direct role in social and environmental assessments, zoning initiatives, and decision-making processes related to environmental governance within the areas. Their involvement is on equal terms with institutional actors involved in area management. Through this collaborative process, an inclusive collective knowledge is forged, integrating local practices with the theoretical and technical underpinnings of area governance. As described by Calderon and López (2014), participatory action research represents an ongoing dialectical process whereby facts are analyzed, problems are conceptualized, and actions are planned and executed to effect transformations within the contexts and among the involved stakeholders.

7.5 Conclusions

The analysis of forest cover and land use in the middle Dagua River basin reveals significant pressure on the remaining natural habitat, emphasizing the importance of conservation strategies like SEPLs. These SEPLs have effectively halted forest cover loss and even fostered its increase, striking a balance between productive activity and conservation goals. Moreover, identifying pathways with minimal resistance, such as riparian forests, underscores the critical need to maintain landscape connectivity for preserving biodiversity and associated ecosystem services.

These findings underscore the pressing need to implement targeted conservation measures in fragmented landscapes to ensure the long-term ecological integrity and sustainability of the Dagua River basin. The establishment of SEPLs and the empowerment of the communities where they are located represent proven conservation strategies that can be effectively utilized to address these challenges.

Studying SEPLS from a spatial perspective, supported by land systems science, is highly relevant as it enables the analysis of land use and cover dynamics. It particularly contributes to advancing SEPLS monitoring and aiding decision-making and policies for their conservation. However, traditional remote sensing-based monitoring has been challenging and costly for conservation efforts. This is due to the reliance on specialized software, trained personnel, and the expense of acquiring images. These factors have restricted the use of remote sensing in conservation decision-making, particularly in developing nations. Nevertheless, in recent years, remote sensing data has become more abundant and accessible, thanks to initiatives like the Global Forest Watch platform. This increased accessibility holds promise for supporting decision-making processes.

The governance of both IMRDSEA and IMRDEC, led by the CVC as the departmental environmental authority, is crucial for achieving conservation goals and sustainability. However, the active involvement of community-based actors and organizations is essential for its effectiveness. Dialogue between environmental experts and local leaders ensures that management plans align with community needs and realities, leading to greater community ownership, establishment of effective use regulations, and, ultimately, conservation of biodiversity and ecological connectivity.

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