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Forest Plantations in Manabí (Ecuador): Assessment of Fragmentation and Connectivity to Support Dry Tropical Forests Conservation

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Abstract: In many tropical regions, national forests plantation programs have been promoted. Those plantations frequently contribute to habitat changes. However, the associated effects of forest plantations on habitat fragmentation and landscape connectivity are unclear. From 2008 to 2018, we examined land use changes, plantations, and deforestation of the Manabí province (Ecuador) provided by the Ecuadorian Ministry of the Environment. Four scenarios were created: (i) land uses in 2008, (ii) land uses in 2018, (iii) land uses in 2018 without deforestation, and iv) land uses in 2018 including reforestation. Fragmentation and connectivity metrics were analyzed using ArcGisPro and Graphad 2.6 software, respectively. *Puma yagouaroundi* was selected as the reference species. At regional scale, forest plantations had a significant effect on land uses changes and fragmentation during the study period. Forests decreased from 33.7% to 32.4% between 2008 and 2018, although other natural land uses, mostly those involving shrubs, increased by almost double (from 2.4% to 4.6%). Most of the deforestation affected native forests during this period, and most reforested areas in 2018 covered former agricultural land. Fragmentation decreased in the number of patches and increased in the average patch size. When considering reforestation, deforestation was higher than the reforested area (58 km^2 of difference), increasing the number of patches but with smaller size. Reforestation increased connectivity with a higher number of links and distance, particularly in central and extreme northeast areas of Manabí province. The scenario without deforestation also increased connectivity for *Puma yagouaroundi* in the west part of the Manabí province. Our findings suggest that forest plantations contribute to forest conservation by increasing the connectivity between fragmented patches.

Keywords: afforestation; edge effects; landscape management; dry tropical forests; connectivity

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1. Introduction

Afforestation is a major forest activity in many parts of the world, especially in areas where forests replace degraded lands to promote soil protection, habitat conservation and connectivity [1]. However, afforestation in tropical areas frequently occurs in natural ecosystems such as grassland and secondary forests that are considered poorly productive but might not be the most suitable areas to maximize conservation and biodiversity goals [2]. Additionally, large-scale afforestation for carbon sequestration has received a lot of attention [3,4] bringing into question the possibility of influencing conservation [5]. Thus, it is of paramount importance to understand the link between afforestation programs and landscape functionality to evaluate the environmental costs and benefits of afforestation policies. One of the most significant effects of afforestation is changes in landscape characteristics. New commercial forest plantations could produce the fragmentation of large, continuous native habitats into smaller, isolated patches surrounded by a land use matrix that may be hostile to resident fauna [6]. On the other hand, forest plantations may result in a positive effect when the target is the expansion of native forests [7]. However, according to several authors, planted forests appear to be insufficient for promoting conservation of wildlife communities [8], even though those are influenced by forest management and composition [9]. Plantations may also have other negative effects because they remove species with high conservation value from the habitats they replace, particularly birds strictly associated with open habitat and grasslands [8].

Although theoretical and empirical evidences suggest that the effects of forest plantations may extend beyond forest boundaries [10], little is known about the impact of afforestation on fragmentation. These effects are brought about by habitat fragmentation, in which complex land uses matrixes (agriculture, secondary forests, grasslands, etc.) are broken up into smaller patches. The capacity of animal and vegetal species to use the matrix surrounding forest plantations partly determines the degree to which plantations contribute to connect isolated forest areas [11]. The idea that fragmented systems are composed of "island-like" remnants of suitable habitat surrounded by land uses with no ecological value can oversimplify the complexity of fragmented landscapes and underestimate the ecological values of anthropic landscapes [12]. Those landscapes can still provide sufficient connectivity through ecological corridors to sustain or at least allow the movement of wild animal and plant propagules, even if those landscapes lack the characteristics required for permanent habitat suitability [13]. Forest plantations can significantly increase the amount of suitable habitat at landscape scale through changes in species richness, composition, and abundances [14]. For instance, some species may experience an increase in habitat availability due to an increase in forest edges. These species tend to benefit from more fragmented landscapes [15], suggesting that forest plantations on agricultural dominated lands may contain more species than simple agricultural habitats. Additionally, penetration of edge effects into adjacent habitats created by forest plantations may greatly influence changes in landscape features [13,16]. Therefore, understanding changes in landscape configuration and composition due to forest plantations is extremely relevant when characterizing their potential effects on fragmentation and connectivity.

Tropical forests in Ecuador have been extensively deforested, primarily for agricultural purposes, and about 24% (2020–2022) of these forests have vanished [16]. To reverse this process, Ecuador has promoted an ambitious National Forest Plantation Program [17] A long-term trend of social rural changes and abandonment of poorly productive soils have led to an increase in afforestation rates on marginal agricultural land in Ecuadorian tropical dry forests over the past decade. Implementation of public regulations provided financial support for afforestation and was partly justified by the goal of restoring ancient forest habitats and their associated biodiversity [18,19]. Our main goal was to characterize how new forest plantations from 2008 to 2018 have changed habitat fragmentation and connectivity in dry areas of the Manabí providence (Ecuador). Specifically, we aimed to (i) assess land use changes and their effect on fragmentation and connectivity across planted landscapes in comparison to native forests remains, (ii) identify consequences of these changes for certain vertebrate species that are quality indicators of Ecuadorian tropical dry forests, and (iii) determine whether particular areas of the landscape are important in future plantations in this fragmented system. Based on this, we analyzed the implications of afforestation for conservation in dry tropical areas of Ecuador.

2. Materials and Methods

2.1. Study Sites

Manabí is located in the center of the coastal region of Ecuador and in the most western part of the South American continent, on the margins of the Pacific Ocean. It has an extension of 19,516.6 km^2, 7.36% of national surface, positioning it as the fourth province with the largest continental area and the first in agricultural production. The study area covers six cantons (Jipijapa, Pajan, Santa Ana, 24 de Mayo, Olmedo and Puerto López) [20], all located in the southern zone of the province of Manabí (0°45′00′′ S–80°05′00′′ W, Figure 1), and in the biogeographical region of Ecuador Coast. Five types of ecosystems are found in this area: low deciduous forest, deciduous shrub, grassland, deciduous forest, semi-deciduous forest, and seasonal evergreen forest [21–23]. Deciduous forests present a higher degree of threat, greater fragility and less connectivity, in addition to less protection and research than seasonal evergreen forests [24].

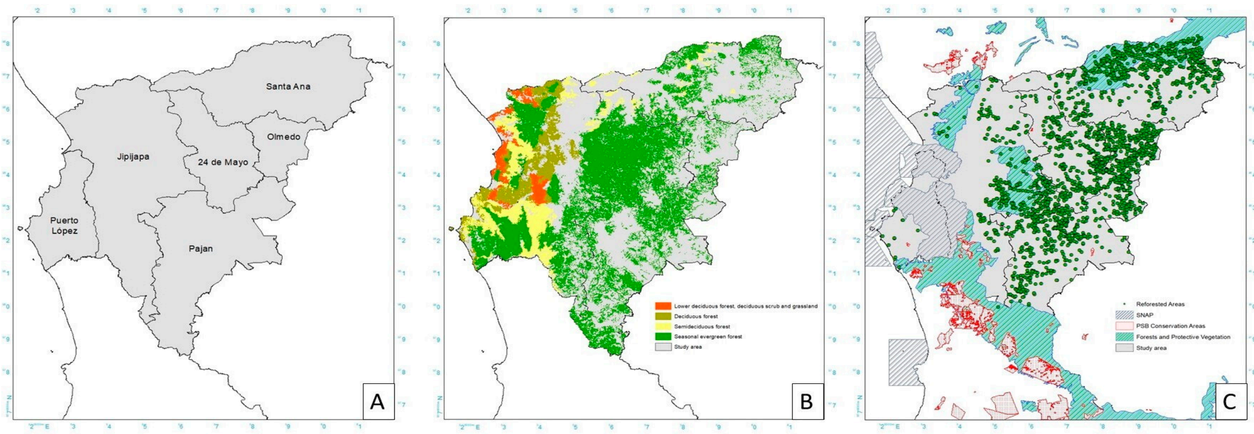

Figure 1. (**A**) Study area politically delimited in cantons. (**B**) Ecosystems in the study area. (**C**) protection figures present in the area.

The Manabí Region is characterized by high levels of biodiversity [25], although large forest areas have been modified from extensive and unsustainable agricultural practices, leading to fragmented landscapes with forest patches in the range from 5 to 100 ha [26]. Manabi presents three types of nature protection areas: National Systems of Protected Areas (SNAP), Forests and Protective Vegetation and *Programa Socio Bosque* (PSB) Conservation Areas. SNAP are in the highest category of protection under national environmental legislation, covering 51 nature reserves covering 20% of Ecuador. They are areas of land and/or sea especially dedicated to the protection and maintenance of biological diversity, natural resources and associated cultural myths. PSB Conservation Areas provide economic incentives to peasants and indigenous communities that voluntarily commit to the conservation and protection of their native forests, moorlands, or other native vegetation. Protective forests are natural or planted forests, shrub, or herbaceous formations in public or private domain located in areas of rugged topography, in critical watersheds, which are not suitable for agriculture or livestock farming. In Ecuador, it has been shown that SNAP prevent deforestation, but not all protection figures are effective [27]. In addition, in Ecuador, there have been new approaches since the year 2000. With the incorporation of basic criteria for Sustainable Forest Management and the publication of secondary forest regulations in forest legislation (Ministerial Agreement 125 of the Ministry of Environment and Water of Ecuador), sustainable forest management was integrated in Ecuadorian forestry policy. However, even after 20 years, it has not yet been possible for forest owners to manage natural forests with a long-term vision, ensuring that they maintain their sustainability [28].

2.2. GIS Sources

We downloaded GIS vector layers to delimit the provinces, land uses, and deforested-forested areas between 2008 and 2018. Administrative division was obtained from the Military Geographic Institute of Ecuador (available at https://www.geoportaligm.gob.ec/portal/index.php/cartografia-de-libre-acceso-escala-50k/, accessed on 23 February 2023). Land use maps for the years 2008 and 2018 and deforestation layers (2008–2014, 2014–2016, and 2016–2018) were obtained by the Ecuadorian Ministry of the Environment (available at http://ide.ambiente.gob.ec/mapainteractivo, accessed on 23 February 2023) based on Landsat and ASTER satellite images at a pixel size of 30 m [22,29,30]. Based on validation fieldwork, the Kappa index of these maps was approximately 0.7 [22]. Land use maps contains twelve distinct land uses, of which ten were present in the study area (Table 1). A single deforestation layer was calculated as a merge of the three periods indicated above. To obtain the geographical location of the reforested areas, we obtained the coordinates and area of all reforested plots from the Department of Environmental Management of the Provincial Government of Manabí, for the period 2008–2018. For each set of coordinates, we created individual forest plantations polygons. As the shape of the plantation was not available, we created squared polygons centered at each set of coordinates maintaining the size of the reforested area reported. The geographic coordinate of the centroid of each forest plantation was used for fragmentation and connectivity analyses.

2.3. Land Cover Change and Fragmentation

To estimate land use changes between 2008 and 2018, we created an intersection matrix taking 2008 (LUSES2008) as the initial year. First, we intersected deforested and reforested layers to identify three different cases of land use change between 2008 and 2018 (only reforested, only deforested and deforested+reforested). Then, this layer was intersected with the LUSES2008 layer and LUSES2018 to identify land use changes. In this analysis, we considered four different groups of land use classes derived from the initial classification: native forests, agriculture land, anthropic zones, water, and other natural terrain (Table 1).

To estimate fragmentation metrics, we elaborated four scenarios of land use using the full list of classes (see Table 1): (i) LUSES2008, (ii) LUSES2018, (iii) LUSES2018 + deforestation (the areas deforested between 2008–2018 are added as native forest in LUSES2018) and (iv) LUSES2018 + forested (the areas reforested between 2008–2018 are added as native forest in LUSES2018). Then, three fragmentation metrics were calculated for the native forest class in each scenario: number of patches, average patch size and edge density [31].

Table 1. Classification of Land uses classes of Ecuador from Ecuadorian Ministry of the Environment (available at http://ide.ambiente.gob.ec/mapainteractivo, accessed on 23 February 2023) based on Landsat and ASTER for the study areas [32] and cost values (resistance values to move through them).

Name	Group	Definition	Cost
Native forest	Native forest	Arboreal ecosystem, primary or secondary, regenerated by natural succession; it is characterized by the presence of trees of different native no dry forest species, varied ages and sizes, with one or more strata.	1
Forest Plantation	Other natural terrain	Anthropically established tree mass with one or more forest species.	1
Shrub vegetation	Other natural terrain	Areas with a substantial component of non-tree native woody species. Includes degraded areas in transition to dense canopy coverage and paramo.	2
Herbaceous Vegetation	Other natural terrain	Areas made up of native herbaceous species with spontaneous growth, which do not receive special care, and are used for sporadic grazing, wildlife, or protection purposes.	2
Natural water	Water	Surface and associated volume of static or moving water.	5
Artificial water	Water	Surface and associated volume of static or moving water associated with anthropic activities and the management of water resources.	5
Populated Area	Anthropic zones	Areas mainly occupied by homes and buildings intended for communities or public services.	10
Infrastructure	Anthropic zones	Areas for transport, communication, agro-industrial and social.	10
Area without vegetation cover	Other natural terrain	Areas generally devoid of vegetation, which due to their edaphic, climatic, topographic or anthropic limitations, are not used for agricultural or forestry use; however, they may have other uses.	2
Agricultural Land	Agricultural Land	Area under agricultural cultivation and planted pastures, or within a rotation between them, includes areas of annual crops, semi-permanent crops, permanent crops, grasslands and agricultural mosaic.	5

2.4. Connectivity Analysis

We used graph theory to study structural connectivity. Graph theory is a good way to find conservation targets because unlike most other conservation priority methods, it does not need demographic data [26]. According to Calabrese and Fagan [33], this approach provides a comprehensive, robust analysis of connectivity with minimal data requirements. Graphad 2.6 software [34] was used to evaluate the functional connectivity.

Functional connectivity was calculated using *Puma yagouaroundi* (jaguarondi) as the reference species (medium-sized mammal), for the four scenarios indicated in Section 2.3 [35]. First, these scenarios were converted to raster layers (30 × 30 m) and each land cover was assigned a cost (Table 1). This cost is an estimated resistance value for the reference species to move through each land-cover type. Native forest areas were considered "habitat" (cost value of 1). Subsequently, links between patches were created that accumulated the cost values between patches. Links between patches only occur if the accumulated cost is less than 166 (approximately 5 km of distance with a cost value of 1). This approach allowed us to assess the significance of individual planted patches (i.e., nodes in the network) within each regional network (via node-level metrics that can identify which patches facilitate landscape connectivity [36]. In this method, a component is a group of connected nodes. Species can move (link) between patches (nodes) across the same component, but not across different components [37]. We calculated global connectivity metrics (Flux, Equivalent Connectivity, Probability of Connectivity and Number of Components) and metric per patch (Current Flow) (Table 2). Global connectivity metrics show different features, with probability of connectivity (PC) being the most useful (value between 0 and 1) to compare connectivity among ecosystems. Current flow (CF) is based on circuit theory and analysis of the links between patches at landscape scale. These metrics have already shown their usefulness in analyzing connectivity in fragmented landscapes [38,39]. The number, distance in cost and distance of the links for the four scenarios were also calculated. Finally, corridors were calculated as the accumulated number of links between patches given the maximum cost distance of 166 [34]. Corridors show the area that can be traversed between two patches of habitat (i.e., the area representing the set of possible paths connecting two patches) [34] and were used to establish potential areas representing a set of possible "new forested paths" for connecting natural forest areas. The corridor was divided into six categories: no corridor (0), very low (1–13), low (14–55), medium (56–138), high (139–291) and very high (>292).

Table 2. Description of connectivity metrics analyzed according to [40].

Metric	Level	Formula	Meaning	References
Flux (*F*)	Global level and Components level	$SF = \sum_{i=1}^{n} \sum_{\substack{j=1 \\ J \neq i}}^{n} a_j^{\beta} e^{-ad_{ij}}$	Sum of potential dispersion from all patches	[41–43]
Equivalent Probability (*EC*)	Global level	$EC = \sqrt{\sum_{i=1}^{n} \sum_{j=1}^{n} a_i a_j e^{-ad_{ij}}}$	Square root of the sum of products of capacity of all pairs of patches weighted by their interaction probability	[44]
Probability of connectivity (*PC*)	Global level	$PC = \frac{1}{A^2} \sum_{i=1}^{n} \sum_{j=1}^{n} a_i a_j e^{-ad_{ij}}$	Sum of products of capacity of all pairs of patches weighted by their interaction probability, divided by the square of the area of the study zone. This ratio is the equivalent to the probability that two points randomly placed in the study area are connected.	[45]
Number of Components (*NC*)	Global level	*NC* = nc	Number of components of the graph.	[46,47]
Current Flow (*CF*)	Local Level	$CF_i = \sum_{j}^{n} c_i^j$	Sum of currents passing through the patch i. c_i^j represents the current through the patch i when currents are sent from all patches (except j) to patch j. Patch j is connected to the ground [48].	

Where: N: number of patches, nc: number of components, n_k: number of patches in component k, Ni: all patches close to patch I, a_i: capacity of patch i (generally the surface area), ac_k: capacity of component k (sum of the capacity of the patches composing k), A: area of the study zone, d_{ij}: distance between patches i and j (generally the least-cost distance between them), $e^{-\alpha dij}$: probability of movement between the patches i and j, α = brake on movement distance, β = exponent to weight with more or less capacity.

3. Results

3.1. Land Cover Change and Fragmentation

In 2018, the dominant land use in the study area (4791.43 km^2) was agriculture (61.91%; Figure 2). Forest areas decreased from 33.7% to 32.45% between 2008 and 2018 (Figure 2), although other natural land uses, mostly shrubs, almost doubled (from 2.4% to 4.68%). Most of the deforestation affected native forests during this period, and most reforested and afforested areas in 2018 covered former agricultural land (Figure 2).

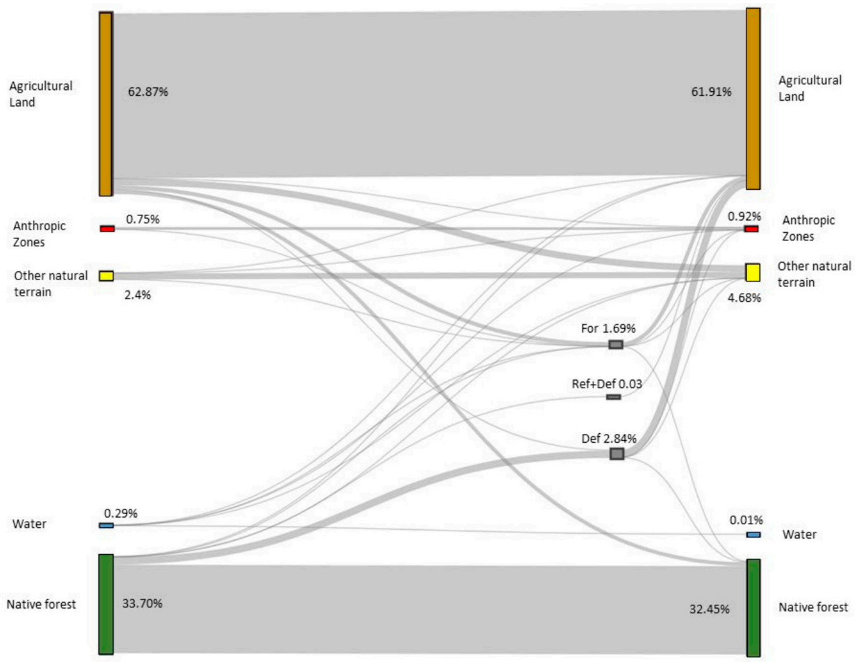

Figure 2. Transition in land uses between 2008 and 2018 in study area (in %).

Fragmentation data showed that 61.48 km^2 of native forests were lost between 2008 and 2018, decreasing the number of patches and increasing the average size (Table 3). The 2018+forested scenario showed a large increase in the number of patches, but a decrease in their average size, and also increased the number of patches compared to 2018, but not compared to 2008, with an average area close to the scenario of 2018 (Table 3).The comparison between the scenarios 2018+forested and 2018+deforestation showed that the area lost due to deforestation is greater than the afforested area (58 km^2 of difference; Table 3).

Table 3. Fragmentation metrics for native forest (number of patches, patch area and total edge) in the Manabí province (Ecuador) for Land uses scenarios: 2008 (LUSES2008), 2018 (LUSES2018), 2018 avoiding deforestation (LUSES2018 + def), and 2018 considering reforestation (LUSES2018 + for).

Scenario	Overall Area (km^2)	Number of Patches	Patch Area (km^2)			ED = Patch Perimeter/Patch Area		
			Average	Median	S.D	Average	Median	S.D
LUSES2008	1614.54	1600	1.01	0.01	23.80	1809.59	77.78	56,280.65
LUSES2018	1553.06	1434	1.08	0.05	24.21	215.85	28.21	1895.71
LUSES2018 + for	1623.46	3340	0.49	0.02	16.23	109.91	31.17	1245.31
LUSES2018 + def	1681.79	1581	1.06	0.02	24.85	1651.67	44.44	56,493.51

3.2. Connectivity Analysis

The scenarios with better connectivity were those in which forest areas increased (LUSES2018 + deforestation and LUSES2018 + forested). In this case, reforestation increased connectivity, even though LUSES2018 + forested had less area than LUSES2018 + deforested, LUSES2018 + forested presented better flux and CF (Table 4 and Figure 3).

Table 4. Connectivity metrics across native forest patches (Flux, F; Probability of Connectivity, PC; Number of Components, NC; and Current Flow CF) in the Manabí province (Ecuador) for Land uses scenarios: 2008 (LUSES2008), 2018 (LUSES2018), 2018 avoiding deforestation (LUSES2018 + def), and 2018 with reforestation (LUSES2018 + for).

	Scenario			
Metric	**2008**	**2018**	**2018 + def**	**2018 + for**
F	4.14×10^{11}	5.01×10^{11}	6.08×10^{11}	1.23×10^{12}
EC	1.14×10^{9}	1.14×10^{9}	1.25×10^{9}	1.19×10^{9}
PC	0.01383299	0.01384695	0.01669168	0.015178734
NC	57	63	55	55
CF (Average)	3042.34	6346.05	5791.91	64,658.92
CF (patch with higher CF)	206,443.39	281,173	345,865.63	3,353,361.40

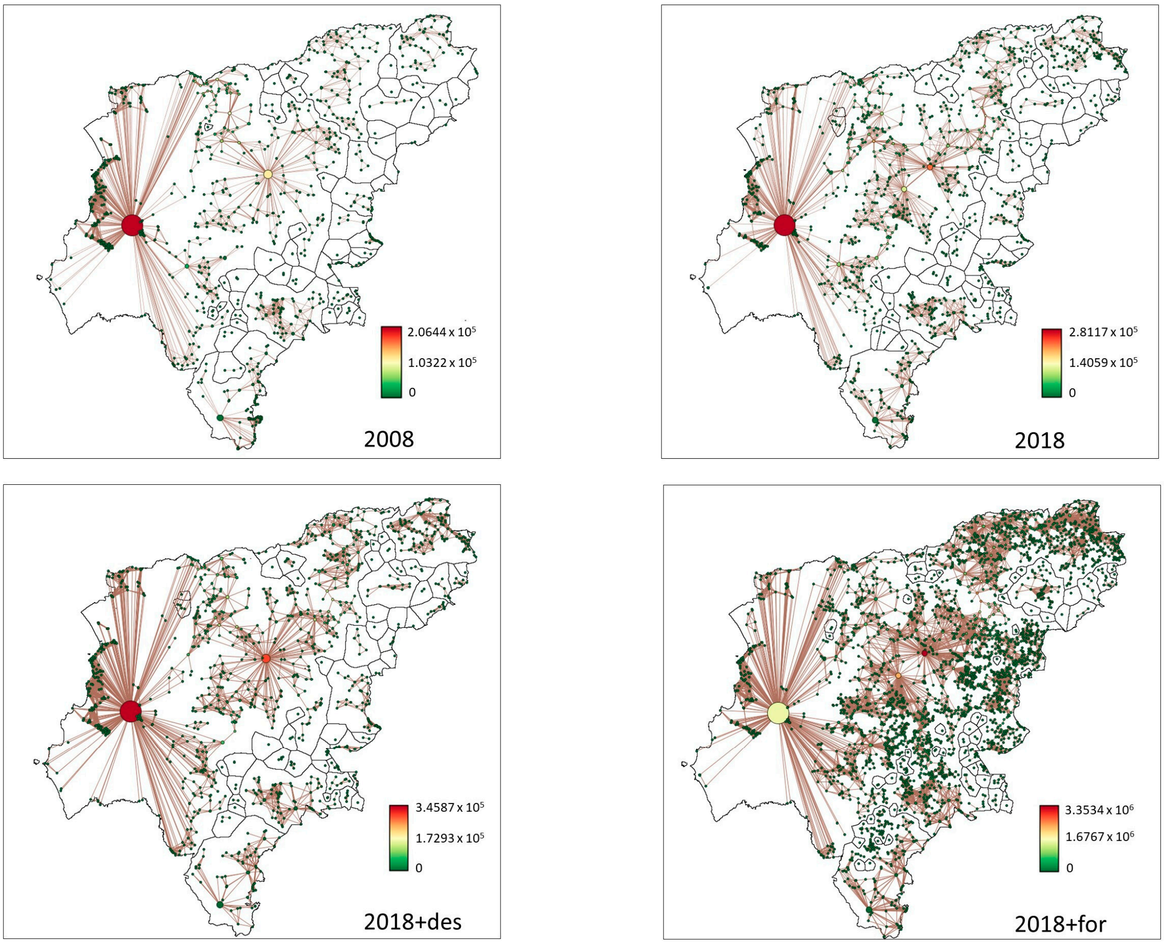

Figure 3. Current flow metric in the Manabí province (Ecuador) for land use scenarios: 2008 (LUSES2008), 2018 (LUSES2018), 2018 avoiding deforestation (LUSES2018 + def), and 2018 considering deforestation and reforestation (LUSES2018 + for). Components (areas outlined in black), connections between the patches (the size of the line indicates the connectivity; greater thickness indicates more connectivity) and connectivity of the patch (color of the circle) are shown. The size of the circle indicates the relative size of each patch.

Links analysis showed that scenarios with increasing forest areas (LUSES2018 + deforested and LUSES2018 + forested) had a higher number of links. LUSES2018 + deforested scenario had a number of links four times greater than that of LUSES2008, (Table 5 and Figure 4).

Table 5. Number of links, distance in cost and meters of the links generated in the 4 scenarios.

Number of Links		Distance in Cost			Distance in Meters		
		Average	**Median**	**S.D**	**Average**	**Median**	**S.D**
2008	4928	84.10	86.37	49.27	1482.60	1235.95	1152.19
2018	5301	86.27	90.08	50.02	1381.92	1146.40	1096.18
2018 + for	18430	96.89	103.34	46.74	1247.94	1026.40	918.51
2018 + des	6001	84.83	87.91	49.70	1520.34	1301.54	1170.28

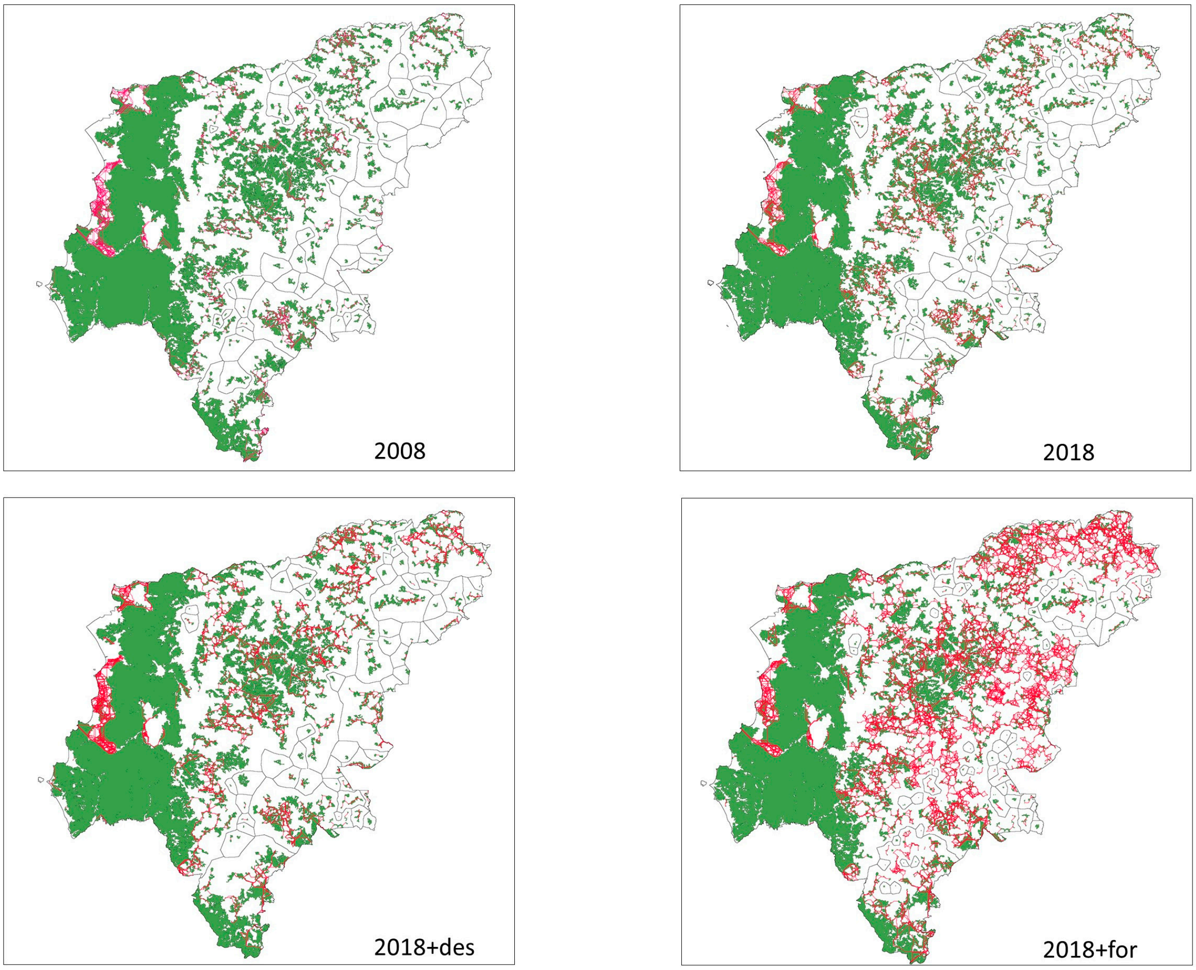

Figure 4. Forest patches (green), links between the patches (red) and components (areas delimited by black lines) in the Manabí province (Ecuador) for Land uses scenarios: 2008 (LUSES2008), 2018 (LUSES2018), 2018 avoiding deforestation (LUSES2018 + def), and 2018 avoiding deforestation and reforestation (LUSES2018 + for).

When considering only the LUSES2018 + deforestation scenario, connectivity increased for the referenced vertebrate species in the west part of the Manabí province (Figure 5). On the other hand, for the reforestation scenario (LUSES2018 + forested), the number of links also increased in central and extreme northeast areas (areas where most of the reforestation was carried out) (Figure 5).

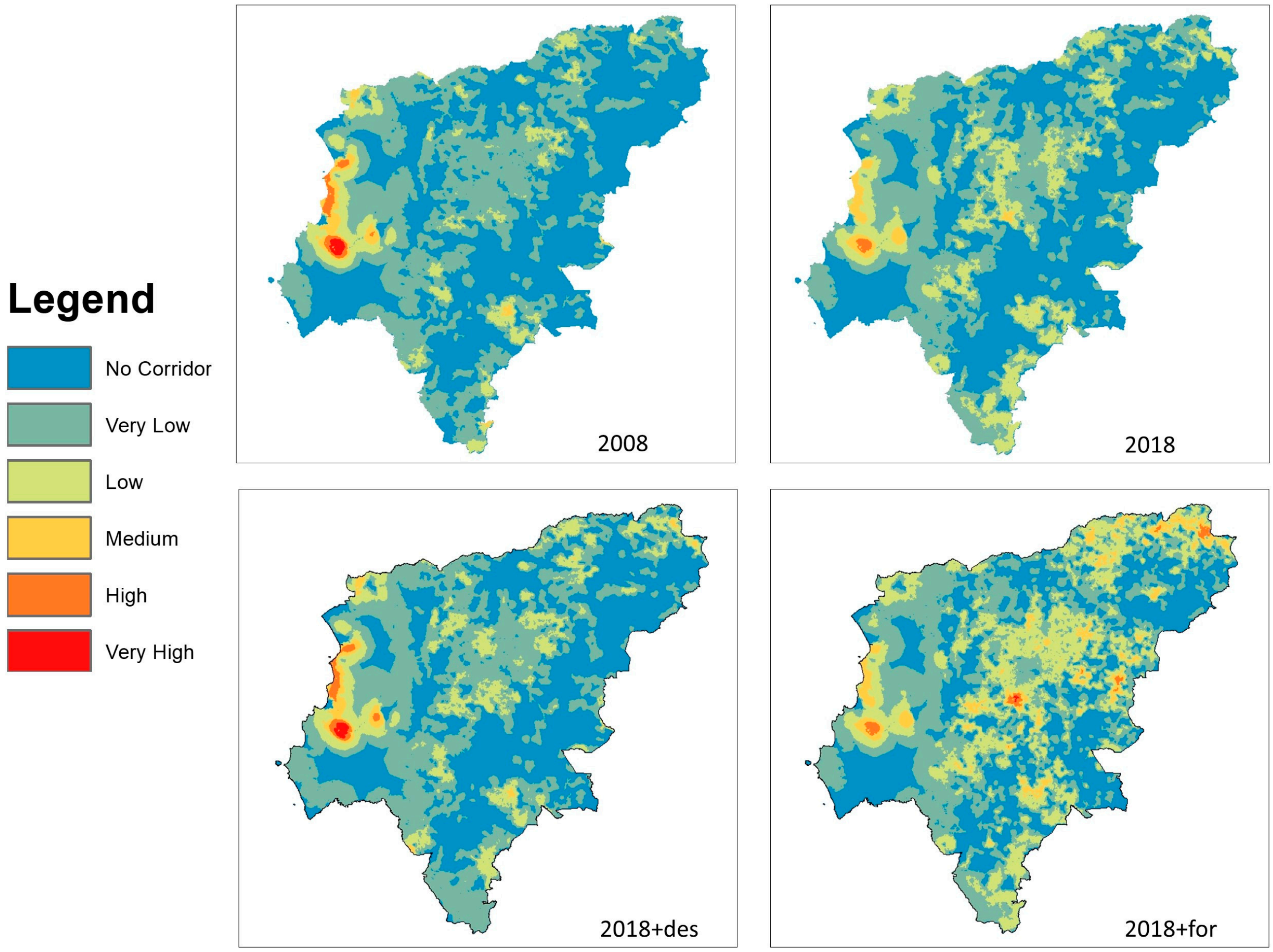

Figure 5. Corridor in the Manabí province (Ecuador) for land use scenarios: 2008 (LUSES2008), 2018 (LUSES2018), 2018 avoiding deforestation (LUSES2018 + def), and 2018 considering reforestation (LUSES2018 + for). Corridors show the area representing the set of possible paths connecting two patches. Corridors were divided into six categories: no corridor (0), very low (1–13), low (14–55), medium (56–138), high (139–291) and very high (>292).

4. Discussion

National reforestation programs are a frequent policy in rural areas of the tropical countries, and are often implemented to reduce poverty and to increase biodiversity [27]. In recent decades, the balance between economic growth and ecological preservation has become a pressing issue in Ecuador [49]. Thus, forest plantations have been promoted as an essential part of the rural development policy, and it is likely that there will be ongoing pressure to establish additional plantations. Our findings suggest that forest plantations increase fragmentation but may contribute to landscape connectivity between habitat patches in dry tropical forests. Forest plantations provide new links between native fragments in both agricultural and forestry landscapes at the cost of increasing fragmentation in terms of edge availability and number of patches. The increase in edge forest habitats might be relevant for generalist species but might limit the suitability of forest patches for species strictly associated with Ecuadorian dry forests.

4.1. Land Uses Changes and Fragmentation

It is generally accepted that land use changes affect biodiversity levels, modifying the dynamics of animal and vegetal populations and their long-term viability [49]. Fragmentation relies on the structural complexity of the land use matrix, modifying the dispersion capability for species in the landscapes. According to our results, reforestation activities resulted in a more compact network with more fragmentation (i.e., an increasing number of patches and average patch size decreases). Those effects were more concentrated along areas with native forests remnants. Areas with dominant agricultural uses maintained high values of fragmentation metrics [50]. Our results are consistent with previous findings, showing that forest plantation expansion may increase native forest habitat but also increased fragmentation [51]. This contrasting pattern may lead us to perceive that the current shift from marginal tropical agricultural lands to plantations will have a negative effect on flora, fauna and some ecosystem services [52]. However, the presence of remnants of patches of forests, as part of an interdependent forest net, can act as safeguarded areas contributing to landscape arrangement [53]. Forest plantations may increase the dispersion availability in fragmented landscapes, with plantations serving as steppingstones. On this case, generalist species can easily move across a landscape because they do not need specific habitat conditions, prefer open spaces or more edges, or have a larger home range or higher dispersion capability than specialist species [54].

Our results also show that forest area in Ecuador is decreasing, and reforestation efforts are not enough to reduce the high rates of deforestation suffered in the country. Ecuador is one of the South American countries with the highest deforestation rate. The coast of Ecuador presents highly fragmented ecosystems with very little protection [24,55]. It is essential to stop deforestation, since if this trend continues, a highly fragmented ecosystem will be formed, with very small patches, harming species that have a high area requirement or forest specialists.

4.2. Connectivity

To provide insights into the interaction of forest plantations within heterogeneous landscapes, numerous studies have examined changes in landscape pattern and connectivity [56]. The landscape connectivity of dominant land uses changed significantly over time in the Manabí province (i.e., class types and surface of land uses) as result of forest plantations, despite relatively constant dominance of agricultural cover. When we compared connectivity in scenarios considering only deforestation and reforestation, we found that forest plantations contribute to linking native forest fragments, which have a middle to high conservation value. Thus, as we initially stated in our hypothesis, forest plantations have contributed to improving connectivity, as well as the preservation of native forest remains (Figure 6).

Threatened species receive priority in conservation planning because, among other factors, their populations are declining due to habitat fragmentation [53]. Therefore, maintaining or restoring connectivity between fragmented habitats has been suggested as the key action to reduce the negative trends for several endangered species populations. Connected habitats more effectively preserve species and ecological functions. According to our results, we found an increase in connectivity due to the new reforested areas. Despite being small, reforestation can act as a steppingstone to connect patches with larger surfaces [57,58]. This information is important because many key species have connectivity requirements. For instance, jaguarundi (*Puma yagouaroundi*) occupy less human-influenced landscapes and are very sensitive to habitat loss and disturbed areas [53]. As a result, they face a greater risk of extinction [54]. Our research revealed that changes in connectivity due to reforestation activities may generate critical landscape connections for jaguarundi. In this instance, this species would benefit from the use of reforestation strategies that preserve or improve landscape connectivity in the study area. Many species have long-distance movement in the landscape, but others are less mobile and need “forest islands” to move around and spread out across the land uses matrix [54]. Thus, habitat connections between strictly Protected Areas and the mosaics of forest plantations could contribute to species conservation.

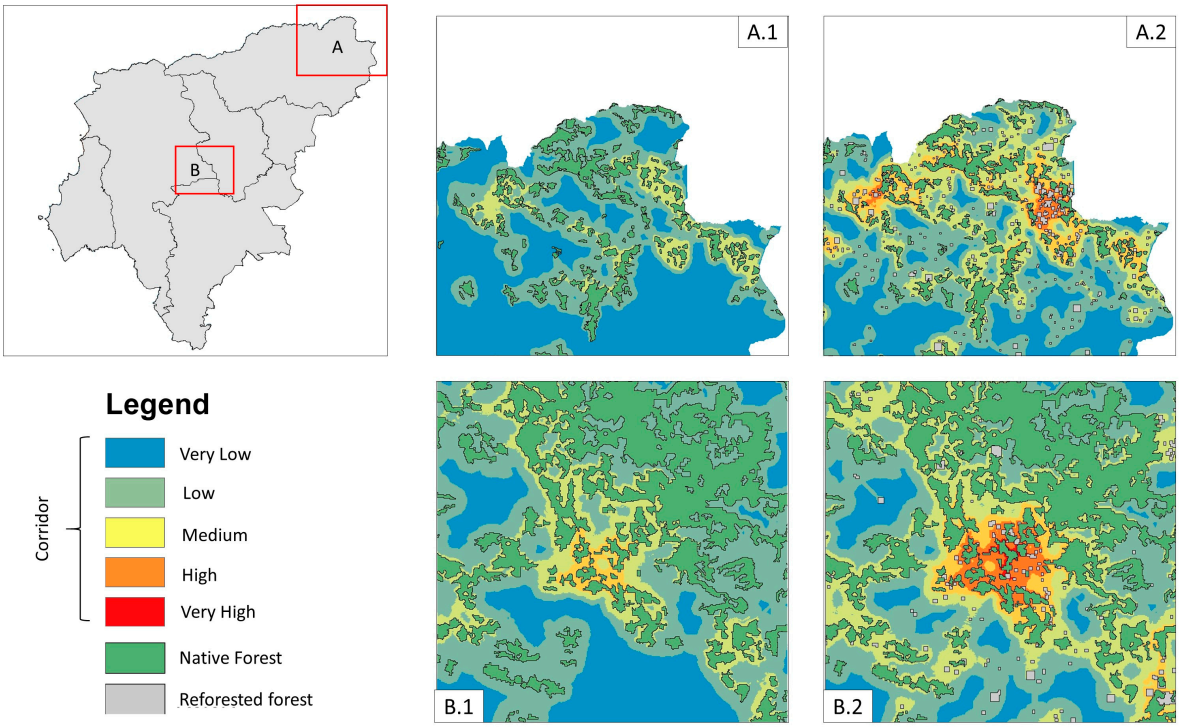

Figure 6. Corridor in the Manabí province (Ecuador) related to native and reforested forests in two locations (North—A and Central—B) and two scenarios (**A1**,**B1**) Land use scenarios 2018 (LUSES2018), (**A2**,**B2**) Land use scenarios 2018++forested (LUSES2018 + forested). The reforested patches in scenario LUSES2018 + forested are in grey color. The corridor was divided into six categories: no corridor (0), very low (1–13), low (14–55), medium (56–138), high (139–291) and very high (>292).

4.3. Prioritization of Forest Plantations to Improve Connectivity

Forest plantations may contribute to prioritize connectivity and safeguard local threatened species [56]. We presented a network of corridors under the current afforestation program in Ecuador and identified potential corridors that combine various current land uses (Figure 5). Because they have the potential to improve the impact of forest plantations in terms of biodiversity, these findings are relevant to the National Forest Plantation Program. First, native forest fragments have high conservation value, and plantations can improve their connectivity by incorporating spatial structural complexity for specialist species with dispersal ability across the landscape [54]. Second, even though the technical viability of this multi-species plantation framework needs to be further evaluated, it provides preliminary evidence of contributing to improving corridor networks, ensuring the persistence of species with distinct habitat preferences, sensitivity to native forest replacement, and movement capacity. To avoid clearing of native forests within the potential corridors that could be used in the connectivity network, forest plantation and forest management must include biological corridors as a critical task in their planning [59]. As a result, preservation of landscape elements that make a more significant contribution to landscape connectivity should be a top priority for the sustainable planning of forestry landscapes in Ecuador. By specifying the effects of plantations on the landscape-scale movement of multiple species, the temporal dynamic of natural and planted forestry landscapes must be considered, and focal species should be identified. Additionally, the socio-ecological framework of forestry of rural communities is not well understood. Therefore, by restoring habitat, forestry could contribute to the improvement of threatened species' population viability, connecting the landscape to avoid detrimental effects on animal and plant populations. Promoting sustainable forest plantations may contribute to establishing a link between forest sustainability and conservation biology, as well as the care and protection of endangered and endemic species.

5. Conclusions

Deforestation has been the primary cause of fragmentation in Ecuador during the last few decades. The remnant forest areas are particularly susceptible to additional habitat loss. Our results indicate that reforestation activities that have occurred in the Manabí province since 2008 have increased fragmentation. However, they have also increased connectivity by linking remanent forest patches. Although there is no in-depth knowledge of species requirements in terms of habitat fragmentation and connectivity, these changes probably contribute positively to species conservation. To address this issue, significant, long-term projects tracking changes in biodiversity and forest cover over time and space are required. We suggest that the new forest plantations patches can be used for native fauna as steppingstones to colonize other native forest areas at the cost of adding higher fragmentation in terms of edge availability and number of patches. It is fundamental to increase the amount of forest cover in Ecuador, and to focus on the reduction of drivers promoting deforestation.

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