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Impact of forest plantations on fragmentation and connectivity: implications for dry tropical forests conservation in Manabí (Ecuador)

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Abstract: In many tropical regions, national forests plantations programs have been promoted. Those plantations contribute frequently to habitat changes. However, it is unclear associated effects on habitat fragmentation and landscape connectivity. From 2008 to 2018, we examined plantation and deforestation data base of Manabí province (Ecuador) for assessing fragmentation and connectivity. 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 32.45% between 2008 and 2018 in the study area, although other natural land uses, mostly shrubs, increased almost double (from 2.4% to 4.68%). Most of the deforestation affected native forests during this period, and most of reforested and afforested areas in 2018 covered former agricultural land. In this period, fragmentation data shows a decrease in the number of patches and an increase in patch average size. When considering reforestation, deforestation was higher than the afforested area (58 km² of difference) increasing the number of patches but with smaller size. The scenarios that presented better connectivity were those where forest areas increased: avoiding deforestation and considering reforestation. Those scenarios had in general a higher number of links and distance. Regionally, the avoiding deforestation scenario increased connectivity for *Puma yagouaroundi* in the west part of the Manabí province. On the other hand, for the reforested scenario, the number of links also increased on central and extreme northeast areas. Our findings suggest that plantations may contribute to conservation thanks to an increase in forest plantations connectivity between fragmented patches.

Keywords: Afforestation, Edge effects, Landscape management, dry tropical forests, connectivity

1. Introduction

Afforestation is a major forest activity in many parts of the world, especially in areas where forests replace degraded lands in order to promote soil protection, habitat conservation and connectivity [1]. Nevertheless, afforestation activities in tropical areas frequently occur on natural ecosystems such as grassland and secondary forests that are considered poorly productive but might not be the most suitable to maximize conservation goals and increase biodiversity levels [2]. Also, large-scale afforestation for C sequestration has received a lot of attention [3,4] bringing into question the possibility of influencing conservation goals [5]. Thus, it is of paramount importance to understand the link between afforestation activities and biodiversity levels in order to evaluate the environmental costs and benefits of afforestation policies and to design afforestation programs that contribute rather than reduce biodiversity levels.

On this direction, one of the most significant effects of afforestation is changes in landscape characteristics. Fragmentation of large, continuous habitats into smaller, isolated patches surrounded by a matrix that may be hostile to resident fauna is one major consequence of forest plantations [6]. On the other hand, forest plantations may result in a positive effect when the targets are the expansion of forests [7]. However, according to several authors planted forests appear to be insufficient for promoting conservation forest

wild animal communities [8], even though this is influenced by forest management and composition [9]. Plantations may also have 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 evidence suggests that effects of forest plantations may extend beyond forest boundaries [10], little is known about the effects 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 those contribute to connect to one another and other isolated forest areas [11]. The idea that fragmented systems are comprised of "island-like" remnants of suitable habitat surrounded by matrices with no ecological value can oversimplify the complexity of fragmented landscapes and underestimate ecological values of anthropic landscapes [12]. Those "human matrix" can still provide sufficient connectivity to sustain populations even if it lacks the characteristics required for more complex habitat functionality [13]. This matrix can significantly increase the amount of suitable habitat in a forest planted landscape mediating changes in species richness, composition, and abundances [14]. For instance, some species may experience an increase in habitat availability due to an increase of forest edges. These species tend to rise in more fragmented landscapes [15], suggesting that forest plantations on agricultural dominated lands may contain more species than either of the adjacent simple agricultural habitats. Also, the penetration of edge effects into adjacent habitats, which may be greatly influenced by changes in edge and landscape features, determines the magnitude of these impacts [16]. Due to the synergistic interactions between edge and patch area effects [13], their strength may shift with forest plantations. Therefore, understanding the changes in landscape configuration and composition due to forest plantations is extremely relevant to characterize 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 has led to an increase in marginal agricultural land afforestation 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 Ecuador. Specifically, we aimed to i) assess land cover 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 that, we analyzed the implications of afforestation for conservation in dry tropical areas of Ecuador.

2. Materials and Methods

2.1. Study sites

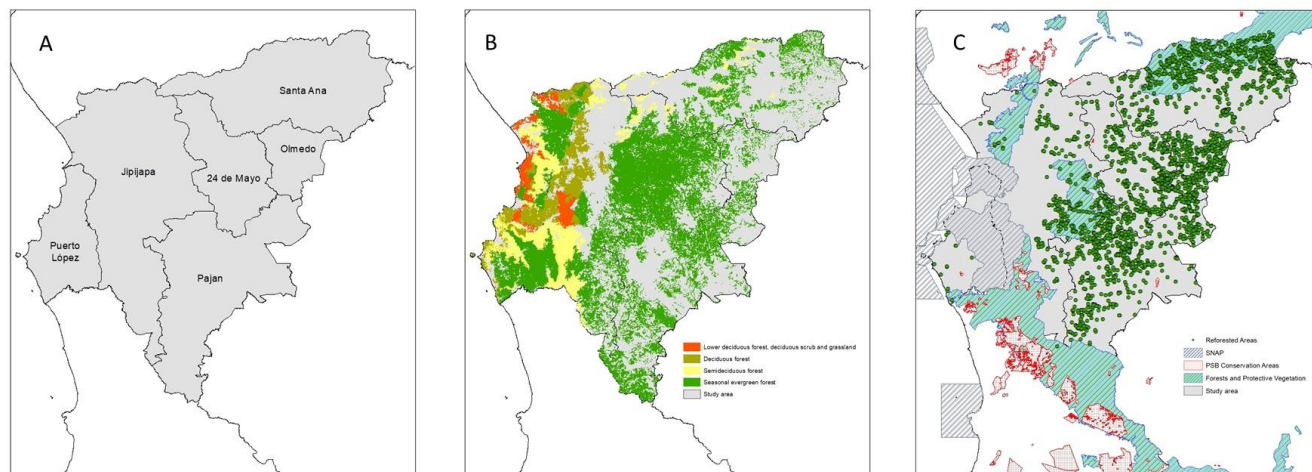
Manabí is located in the center of the coastal region of Ecuador and in the most western part of the South American continent, on the margins of the Pacific Ocean. It maintains an extension of 19,516.6 km², 7.36% of the national surface, positioning it as the fourth province with the largest continental area and the first in agricultural production. Manabí is distributed in three zones [20] (north, center and south), in this last zone our study area covered six cantons (Jipijapa, Pajan, Santa Ana, 24 de Mayo, Olmedo and Puerto López), all of them located in the southern zone of the province of Manabí (0°45'00"S-80°05'00"W,

Fig. 1), in the biogeographical region of Ecuador Coast. Five types of ecosystems are found in this area: low deciduous forest, deciduous scrub and grassland, deciduous forest, semi-deciduous forest, and seasonal evergreen forest [21–23]. The types of forests can be divided into two: deciduous (low deciduous forest, deciduous forest and semi-deciduous forest). Deciduous forests presenting a higher degree of threat, greater fragility and less connectivity, in addition to less protection and research than green forests [24].

Manabí Region is characterized by high levels of biodiversity [25], although large forest areas are modified from extensive and unsustainable agricultural practices leading to fragmented landscapes with forest patches in the range of 5 and 100 ha. Due to their proximity to primary lowland dry forests, these fragmentary remnants represent primary forests. However, large areas of forests suffer from uncontrolled deforestation and land use change [26].

Manabí presents three types of nature protection areas: National Systems of Protected Areas (SNAP), Forests and Protective Vegetation and PSB Conservation Areas. SNAP covers 51 nature reserves that extend in approximately 20% of the surface of Ecuador oriented to guaranty connectivity of the most important ecosystems. PSB Conservation Areas are zones that maintain native forest, paramo, and other native vegetable formations, of natural or legal persons that meet the objectives indicated in the agreement established by the socio bosque program and Protective forests and vegetation are those plant formations, natural or cultivated, arboreal, shrubby or herbaceous in the public or private domain, which are located in areas of rugged topography, in the headwaters of hydrographic basins or in areas that due to their climatic, edaphic and hydric conditions. In Ecuador it has been shown that SNAP prevent deforestation, but not all protection figures are effective [27].

Figure 1: A) Study area politically delimited in cantons. B) Ecosystems in the study area. C) protec-



tion figures present in the area.

2.2. GIS sources

We downloaded GIS layers to delimit the provinces, land uses, and deforested-for-ested areas between 2008 and 2018. Administrative division was obtained from of the Military Geographic Institute of Ecuador (available at <https://www.geoportaligm.gob.ec/portal/index.php/cartografia-de-libre-acceso-escala-50k/>). Land uses and deforestation were obtained by the Ecuadorian Ministry of the Environment (available at <http://ide.ambiente.gob.ec/mapainteractivo>) based on Landsat and ASTER satellite images at a pixel size of 30 m to quantify land uses changes for the years 2008 and 2018 [22,28,29]; Table 1). Kappa index of this maps was approximately 0.7 [22]. To obtain the geographical location of the reforested areas, we obtained the coordinates and area of all reforested activities

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 with square shape and the size of the area reforested. The geographic coordinates of the centroid of each forest plantation were calculated for fragmentation and connectivity analyses.

2.3. Land cover change and fragmentation.

A land-use changes matrix was made taking 2008 (LUSES2008) as the initial year. This land-uses layer was intercepted with land uses of 2018 (LUSES2018), and with deforested and reforested areas. This allows to measure land use changes between 2008-2018, between LUSES2008 and forested and deforested areas, and between forested and deforested areas and LUSES2018. With these layers (see section 2.2), four study scenarios were created: i) LUSES2008, ii) LUSES2018, iii) LUSES2018 + avoiding deforestation (the areas deforested between 2008-2018 are added as native forest in LUSES2018) and iv) LUSES2018+ reforested (the areas reforested between 2008-2018 are added as plantations in LUSES2018). Once the four scenarios were formed, several fragmentation metrics were calculated: number of patches, average patch size and edge density [30].

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

Name	Definition	Cost
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.	0
Native dry forest	Arboreal ecosystem, primary or secondary, regenerated by natural succession; it is characterized by the presence of trees of different native dry forest species, varied ages and sizes, with one or more strata	0
Forest Plantation	Anthropically established tree mass with one or more forest species	1
Shrub vegetation	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	Areas made up of native herbaceous species with spontaneous growth, which do not receive special care, used for sporadic grazing, wildlife or protection purposes.	2
Natural water	Surface and associated volume of static or moving water.	5
Artificial water	Surface and associated volume of static or moving water associated with anthropic activities and the management of water resources.	5
Populated Area	Areas mainly occupied by homes and buildings intended for communities or public services	10
Infrastructure Area	Civil works of transport, communication, agro-industrial and social.	10
Area without vegetation cover	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	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
No information	It corresponds to areas that have not been able to be mapped.	5

2.4. Connectivity analysis.

We used graph theory to look at structural connectivity. Graph theory is a good way to find conservation targets because it does not need demographic data like most other conservation priority methods do [26]. According to Calabrese and Fagan (2004), this approach provides a comprehensive, robust analysis of connectivity with minimal data requirements. Graphad 2.6 software [31] was used to evaluate structural connectivity.

Functional connectivity was calculated for a set of generic species, for the four scenarios, and these scenarios were converted to raster layers (30 x 30 m) and each land cover was assigned a displacement cost (Table 1). Native forest areas were considered "habitat". Subsequently, the links between the patches were created with a maximum cost of 166 (this equates to approximately 5 km of distance if the terrain has a cost of 1). This value represents a gradient of vagility for some of the characteristic fauna of Ecuadorian forests, such as the jaguarondi (*Puma yagouarondi*) [32]. It allowed to assess the significance of individual planted patches within each regional network (via node-level metrics that can identify which patches facilitate landscape connectivity [33]). Subsequently, global connectivity metrics (Flux, Equivalent Connectivity, Probability of Connectivity and Number of Components) and metric per patch (Current Flow) were calculated (Table 2). Number, distance in cost and distance of the links for the four scenarios were also calculated. Finally, with these links, the corridors were calculated for a distance equal to that of the links (166). Corridors were used to establish the potential areas representing a set of possible "new forested paths" for connecting natural forest areas.

Table 2.- Description of connectivity metrics analyzed according to.[34]

Metric	Level	Formula	Meaning	References
Flux (F)	Global level and Components level	$S\#F = \sum_{i=1}^n \sum_{\substack{j=1 \\ j \neq i}}^n a_j^\beta e^{-ad_{ij}}$	Sum of potential dispersion from all patches	[35–37]
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	[38]
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.	[39]
Number of Components (NC)	Global level	NC = nc	Number of components of the graph.	[[41]
Current Flow (CF)	Local Level	$CF_i = \sum_j^n c_i^j$	Sum of currents passing through the patch i. C_i represents the current through the patch i when	

currents are sent from all patches

(except j) to the patch j . The patch j

is connected to the ground [42].

Where: N : number of patches, n_c : Number of components, n_k : Number of patches in de component k , N_i : All parches close to the patch i , a_i : Capacity of the patch i (generally the surface area), a_k : Capacity of the component k (sum of the capacity of the patches composing k), A : Area of the study zone, d_{ij} : Distance between the patches i and j (generally the least-cost distance between them), $e^{-\alpha d_{ij}}$: Probability of movement between the patches i and j , α = Brake on movement distance, β = Exponent to weight more or less capacity

3. Results

3.1. Land cover change and fragmentation.

In 2008, the dominant land use in the study area (4791.43 km²) was agriculture (61.91%). Forest areas decreased from 33.7% to 32.45% between 2008 and 2018 (Figure 2), although other natural land uses, mostly shrubs, increased almost double (from 2.4% to 4.68%). Most of the deforestation affected to native forests during this period, and most of reforested and afforested areas in 2018 covered former agricultural land.

Fragmentation data showed that 61.48 km² of native forests were lost between 2008 and 2018, decreasing the number of patches and increasing the average size (Table 3). The 2018+forestation scenario showed a large increase in the number of patches, but decreasing 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.

The comparison between the scenarios 2018+forestation and 2018+ avoiding deforestation shows us that the area lost due to deforestation is greater than the afforested area (58 km² of difference), this makes the dynamic a loss of forest, each time with less area, with a greater number of patches and smaller patches.

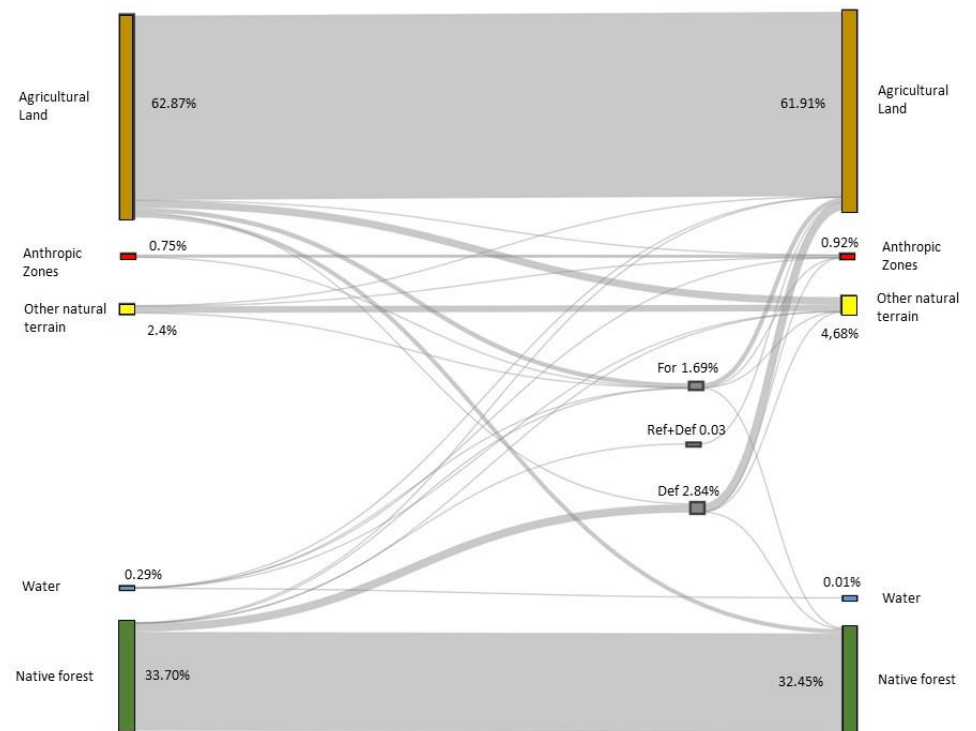


Figure 2. Transition in land uses between 2008 and 2018 in study area (in %).

3.2. Connectivity analysis.

The scenarios that presented better connectivity were those where forest areas increased (LUSES2018 + deforested and LUSES2018 + reforested). In this case, reforestation increased connectivity, even though LUSES2018 + reforested had less area than LUSES2018 + deforested, LUSES2018 + reforested presented better flux and CF (Table 5, Fig. 3).

Links analysis showed that scenarios with increasing forest areas (LUSES2018 + deforested and LUSES2018 reforested) had higher number of links and distance. LUSES2018 + deforested scenario had 10 times a greater number of links than LUSES2008, reaching almost twice the distance in cost and four times more in distance in meters (Table 5 and Fig. 4).

Table 3.- Fragmentation metrics (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 deforestation and reforestation (LUSES2018+ref)

Scenario	Overall area (km ²)	Number of patches	Patch area			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	56280.65
LUSES2018	1553.06	1434	1.08	0.05	24.21	215.85	28.21	1895.71
LUSES2018+ref	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	56493.51

Table 4. Connectivity metrics (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 avoiding deforestation and reforestation (LUSES2018+ref).

Metric	Scenario			
	2008	2018	2018+def	2018+ref
F	4.14E+11	5.01E+11	6.08E+11	1.23E+12
EC	1.14E+09	1.14E+09	1.25E+09	1.19E+09
PC	0.01383299	0.01384695	0.01669168	0.015178734
NC	57	63	55	55
CF (Average)	3488.34	7467.24	5791.91	64658.92
CF (patch with higher CF)	214596.13	288738.98	345865.63	3353361.40

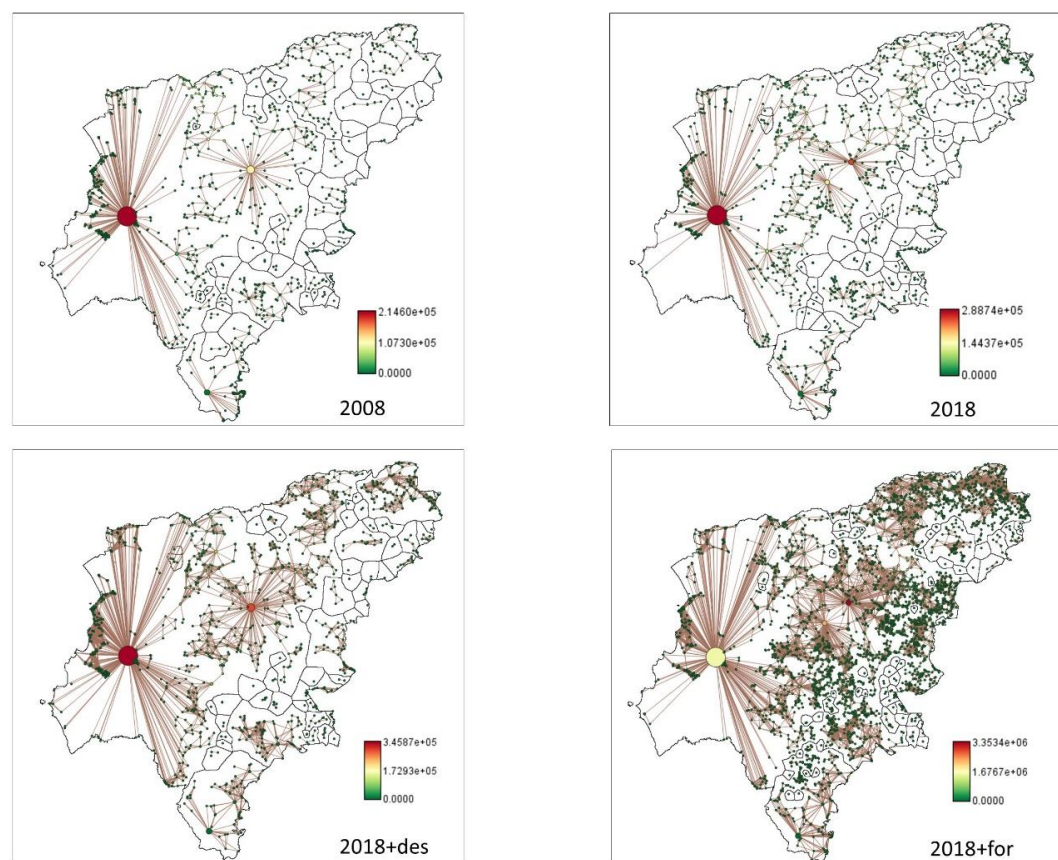


Figure 3: Current flow metric in the Manabí province (Ecuador) for Land uses scenarios: 2008 (LUSES2008), 2018 (LUSES2018), 2018 avoiding deforestation (LUSES2018+def), and 2018 considering deforestation and reforestation (LUSES2018+for). Components (areas outlined in black), connections between the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

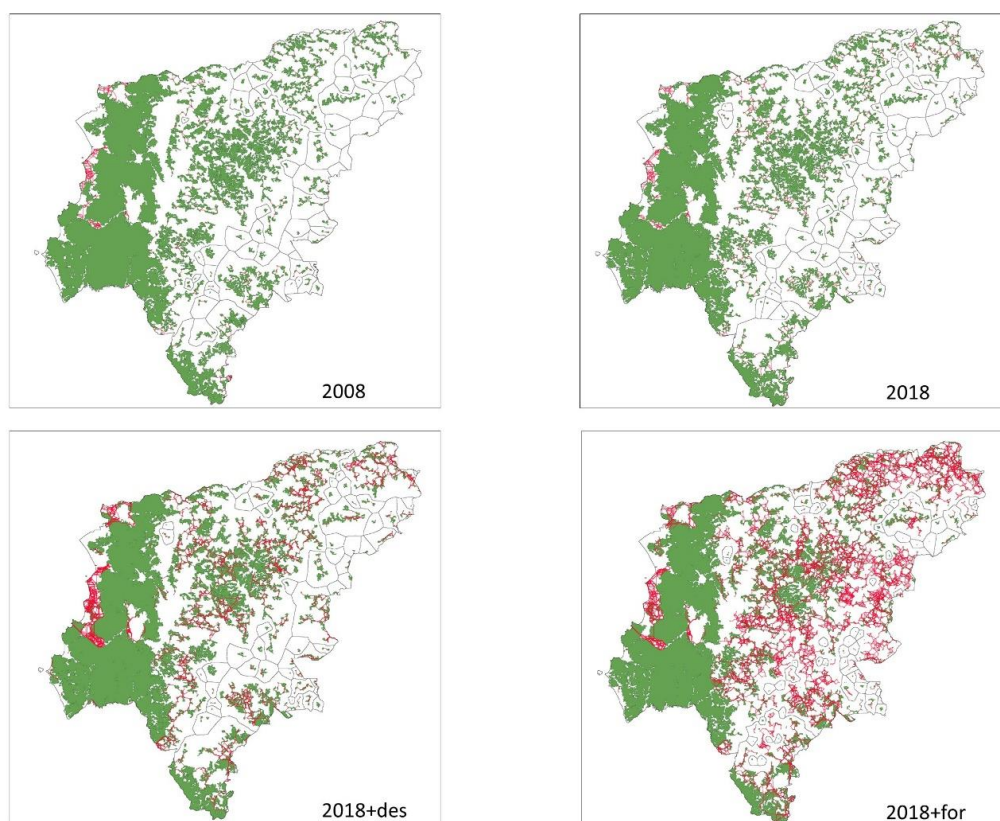


Figure 4: Forest patches (green), links between the patches (red) and components (areas delimited by black lines) in the Manabí province (Ecuador) for Land uses scenarios: 2008 (LUSES2008), 2018 (LUSES2018), 2018 avoiding deforestation (LUSES2018+def), and 2018 avoiding deforestation and reforestation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

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	1487	42.32	25.56	40.89	385.40	254.56	363.08
2018	1922	47.59	31.00	43.11	408.56	254.56	386.36
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

When considering only the 2018+avoiding deforestation scenario, connectivity increased for the reference vertebrate species in the west part of the Manabí province (Fig. 5). On the other hand, for the reforestation scenario (LUSES2018 + reforested) the number of links also increased on central and extreme northeast areas (areas where most of the reforestation was done) (Fig. 5).

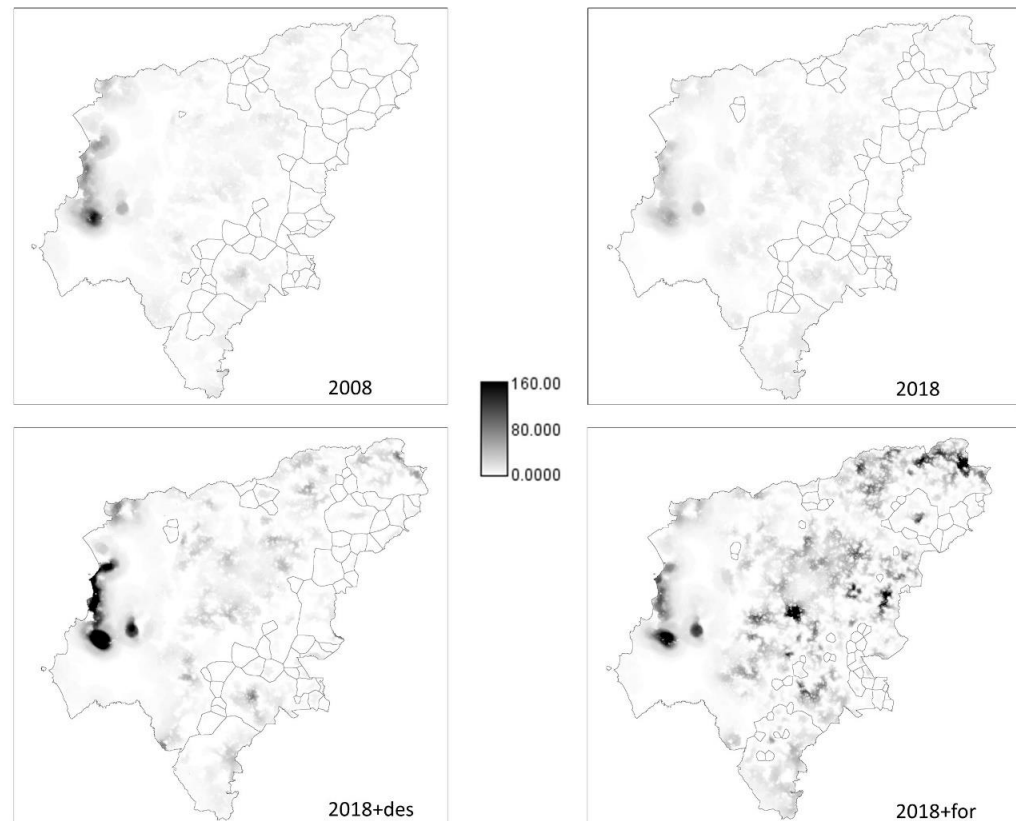


Figure 5: Corridor in the Manabí province (Ecuador) for Land uses scenarios: 2008 (LUSES2008), 2018 (LUSES2018), 2018 avoiding deforestation (LUSES2018+def), and 2018 considering reforestation (LUSES2018+for). Corridors show the area representing the set of possible paths connecting 2 patches and having a distance less than the distance. Dark colors show more connectivity.

4. Discussion

National reforestation programs are a frequent policy in rural areas of the Tropic to reduce poverty and increase biodiversity [43]. In recent decades, balance between economic growth and ecological preservation has become a pressing issue in Ecuador [44]. Thus, forest plantations have been promoted as an essential part of rural development 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 to native fragments in both agricultural and forestry landscapes at the cost of adding higher fragmentation in terms of edge availability and number of patches. The increase in edge forest habitat 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 uses changes affect biodiversity levels modifying the dynamics of animal and vegetal populations and their long-term viability [44]. Fragmentation relies on the structural complexity of the land uses 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. increasing number of patches). Those effects were more concentrated along areas with native forests remnants. Areas with dominant agricultural uses maintained high values of fragmentation metrics [45]. Our results are consistent with previous findings, showing that forest plantation expansion may increase forest habitat but also increased fragmentation [46]. This contrasting pattern may lead to perceive that the current shift from marginal tropical agricultural lands to plantations will have a negative effect on the flora, fauna and some Ecosystem Services [47]. However, the presence of remnants patches of forests, as part of an interdependent forest net, can act as safeguarded areas contributing to the landscape arrangement [48]. Forest plantations may increase this dispersion availability in fragmented landscapes, with plantations serving as steppingstones. On this case, generalist species can easily move across a landscape because they don't need specific habitat conditions, prefer open spaces or more edges, or have a larger home range or higher dispersion capability than specialist species [49].

Our results also show that the forest area is decreasing, and reforestation efforts are not enough to reduce the high rates of deforestation suffered in the study area. Ecuador is one of the South American countries with the highest deforestation rate. The coast of Ecuador presents highly fragmented and very little protected ecosystems [24,50]. 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 [51]. Landscape connectivity of dominant land uses changed significantly over time in 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 link native forest fragments, which have a middle to high conservation value and occupy less territory. Thus, as we initially stated in our hypothesis, forest plantations have contributed to improve connectivity, as well as the preservation of native forest remains.

Maintaining or restoring connectivity between fragmented habitats or plots has been suggested as the key to countering many of the negative consequences of fragmentation. Connected habitats more effectively preserve species and ecological functions. According to our result, in areas with complex land uses, connectivity due to forest plantations experienced the greatest relative increase associated proximity to natural vegetation areas and natural reserve boundaries. Despite being small, reforestation can act as stepping stones to connect patches with larger surfaces [52,53].

This information is important because many key species have connectivity requirements. Jaguarundi (*Puma yagouaroundi*) habits less human-influenced landscapes and is very sensitive to habitat loss and disturbed areas [54]. As a result, they face a greater risk of extinction [55]. Our research revealed that changes in connectivity due to forest plantations may generate critical landscape connections for jaguarundi. In this instance, the species would benefit from the use of reforestation strategies that preserve or improve landscape connectivity in the study area. Habitat connections between strictly Protected Areas and the mosaics of forest plantations could contribute to species conservation. Threatened species receive priority in conservation planning because, among other factors, their populations are declining due to habitat fragmentation [48]. 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 [49].

4.3. Prioritization of forest plantations to improve connectivity

Forest plantations may contribute to restore connectivity among natural areas. Forest plantations may contribute to prioritize connectivity and safeguard local threatened species [51]. A multi-taxa plantation framework, as the example presented here, may allowed to establish various networks of connected habitat based on the landscape-optimized movement corridor for key-species and threatened species in forest management in Ecuador. We presented a network of corridors under the current afforestation program in Ecuador and identified potential corridors that combine various current land uses. 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 [49]. Second, even though technical viability of this multi-species plantation framework needs to be further evaluated, it provides preliminary evidence of contributing to improve 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 methodological task in their planning [56]. As a result, the 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. Also, the socio-ecological framework of forestry of rural communities is not well understood. Therefore, by (1) restoring habitat, forestry could contribute to the improvement of threatened species' population viability; 2) connectivity in the landscape to avoid detrimental effects on these 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

Our results indicate that reforestation activities in the Manabí province during the last decades has increased fragmentation but may contribute to landscape connectivity between native forest patches in dry tropical forests. 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.

Supplementary Materials: The layers of geographic information used can be downloaded from <http://ide.ambiente.gob.ec/mapainteractivo>

Author Contributions: Conceptualization, A.Q.G., R.M.N-C. and C.A.R.; methodology, R.M.N-C., C.A.R., A.Q.G.; formal analysis, C.A.R., A.Q.G., R.M.N-C., P.G.M.; investigation, C.A.R., A.Q.G., R.M.N-C.; resources, UNESUM.; data curation, A.Q.G.; writing—original draft preparation, R.M.N-C., A.Q.G., C.A.R., P.G.M.; writing—review and editing, all authors; supervision, R.M.N-C.; project administration, A.Q.G.; funding acquisition, A.Q.G. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: And the data generated by the authors from these original layers are available by request to the corresponding author.

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Conflicts of Interest: The authors declare no conflict of interest

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