land

MDPI

Article

The Effects of Implementing Three Climate-Smart Practices with an Integrated Landscape Approach on Functional Connectivity and Carbon Storage

Juan José Von Thaden [1], Debora Lithgow [2,*], Daniel A. Revollo-Fernández [3], María del Pilar Salazar-Vargas [4] and Aram Rodríguez de los Santos [5]

[1] Laboratorio de Planeación Ambiental, Departamento El Hombre y su Ambiente, Universidad Autónoma Metropolitana-Xochimilco, Calzada del Hueso 1100, Coyoacan, 04960 Mexico City, Mexico; jvonthaden@correo.xoc.uam.mx
[2] Red de Ambiente y Sustentabilidad, Instituto de Ecología, A.C., Carretera Antigua a Coatepec 351, El Haya, Xalapa, 91073 Veracruz, Mexico
[3] Área Crecimiento y Medio Ambiente, Departamento de Economía, Universidad Autónoma Metropolitana-Azcapotzalco/Consejo Nacional de Humanidades, Ciencia y Tecnología, San Pablo Xalpa 180, Azcapotzalco, 02128 Mexico City, Mexico; darevollof@conahcyt.mx
[4] Posgrado en Ciencias de la Sostenibilidad, Unidad de Posgrado, Universidad Nacional Autónoma de México, Ciudad Universitaria, Coyoacan, 04510 Mexico City, Mexico; pilar.salazar@comunidad.unam.mx
[5] Dirección de Economía Ambiental y de Recursos Naturales, Instituto Nacional de Ecología y Cambio Climático, Picacho-Ajusco 4219, Tlalpan, 14210 Mexico City, Mexico; aram.rodriguez@inecc.gob.mx
* Correspondence: debora.lithgow@inecol.mx; Tel.: +52-228-842-1800 (ext. 6501)

Abstract: Climate-smart practices are actions that can be implemented without affecting agricultural activities and that can promote these activities, generating direct and indirect benefits in ecosystem services provision and increasing agricultural productivity and private income. The present study evaluated the effect of three climate-smart actions (establishment of isolated trees, recovery of riparian vegetation, and implementation of live fences) on increased functional landscape connectivity and carbon storage. Three scenarios with rates of participation ranging from 5 to 100% were tested in two watersheds with different degrees of conservation and a high priority for national food production in Mexico. The main results suggest climate-smart practices positively impact landscape connectivity and carbon sequestration. However, the improvement in landscape connectivity mainly benefits species of short displacement (50–100 m), and the increase in carbon storage is directly linear to the area implemented in these practices. Also, the effectiveness of the modeled actions depends on the landscape structure, which was implemented with the highest benefits in watersheds with intense agricultural activity. The findings can support decision-makers in selecting the best strategies to increase landscape connectivity and carbon sequestration in productive landscapes.

Keywords: ecosystem services; landscape connectivity; climate-smart practices

check for updates

Citation: Von Thaden, J.J.; Lithgow, D.; Revollo-Fernández, D.A.; Salazar-Vargas, M.d.P.; Rodríguez de los Santos, A. The Effects of Implementing Three Climate-Smart Practices with an Integrated Landscape Approach on Functional Connectivity and Carbon Storage. *Land* **2024**, *13*, 389. https://doi.org/10.3390/land13030389

Academic Editor: Jianjun Zhang

Received: 10 February 2024
Revised: 13 March 2024
Accepted: 17 March 2024
Published: 19 March 2024

1. Introduction

Agricultural activities occupied 38% of the world's land surface by 2020 [1]. This conversion of land from natural ecosystems to agricultural land has brought with it strong consequences for natural ecosystems, such as loss of biodiversity, soil degradation, water pollution, and degradation of ecosystem service provision, as well as being a major cause of greenhouse gas emissions or GHGs [2,3]. Simultaneously, the human population depends on agricultural activities and enhancing food production techniques, such as "climate-smart practices." These practices have been proposed to increase productivity, improve resilience and adaptation to climate change effects, increase the provision of key ecosystem services, and reduce GHG emissions from agricultural activity [4].

Various climate-smart practices, such as crop rotation, soil erosion prevention and water management, irrigation efficiency, and agroforestry, are recognized for providing multiple environmental and socioeconomic benefits [5]. However, despite these win–win scenarios, several challenges constrain their wider implementation, such as a costly initiation process, lack of public policies and institutional support, complexity in management, lack of awareness of their existence and possible benefits, and limited knowledge of the implementation process to visualize the potential benefits and associated costs [6]. Consequently, providing technical evidence at the local and landscape levels is key to boosting acceptance by landowners and institutions and finding funding to support implementation and monitoring [5–7].

Agroforestry is recognized as a set of climate-smart practices, defined as the intentional integration of trees and shrubs into cropping and animal husbandry systems to create environmental, economic, and social benefits [8]. These practices generate multiple benefits at the local and landscape levels, including higher biodiversity and landscape connectivity, improved soil health, increased carbon sequestration rates, water purification, and provisioning services (water, food, wood, etc.), among others [6].

Landscape connectivity and carbon sequestration are two potential benefits of climate-smart practices, but their contributions are highly dependent on the context [9]. In the first case, the creation of landscape connectivity networks is frequently proposed as a mitigation strategy to facilitate the movement of species whose spatial distribution is affected by changes in climatic conditions [10]. In the second case, the carbon sequestration capacity of agroforestry crops, such as coffee, is part of the efforts to absorb greenhouse gases (GHGs) from the atmosphere [7].

In this sense, innovative approaches to enhancing ecosystem services and agricultural productivity must be based on comprehensively evaluating how local interventions such as recovering riparian vegetation, establishing isolated trees, and installing living fences can work in synergy. A detailed analysis of the interaction between landscape structure and the effectiveness of climate-smart practices would highlight whether these strategies could contribute to sustainable development efforts and climate resilience. The present study is a detailed analysis that intends to provide a valuable reference for implementing the evaluated strategies in other regions and finding practical and effective solutions to contemporary environmental challenges.

Generating evidence with quantitative data on the benefits of practices is key for decision-making to select the best options to be implemented in highly transformed agricultural landscapes. First, this paper quantitatively describes, with a high degree of precision, the landscape structure, functional connectivity, and carbon storage and sequestration of the current landscape by mapping each arboreal element in the agricultural matrix of two coastal priority watersheds with different levels of degradation. Then, the relative contributions of three climate-smart practices (isolated tree establishment, riparian vegetation recovery, and the implementation of live fences) in terms of landscape connectivity and carbon sequestration capacity are evaluated through simulations. Finally, the effect of different levels of landowner participation is modeled to identify the minimum number of participants needed to have an effect at the landscape scale from these practices.

2. Materials and Methods

2.1. Study Site

Two Mexican watersheds were analyzed: Ameca–Mascota (Jalisco–Nayarit) and Jamapa (Veracruz-Puebla; Figure 1). Both cases are considered priority watersheds for biodiversity conservation [11]. The Ameca–Mascota watershed is on the Tropical Pacific coast, within the physiographic province of the Sierra Madre del Sur, and extends over 2745 km^2, where 334 localities are located. The Jamapa watershed is located on the Gulf of Mexico plain, within the physiographic provinces of Chiconquiaco, the Anahuac lakes and volcanoes, and the Veracruz coastal plain. Jamapa extends over 3921 km^2 with a total of 1527 localities.

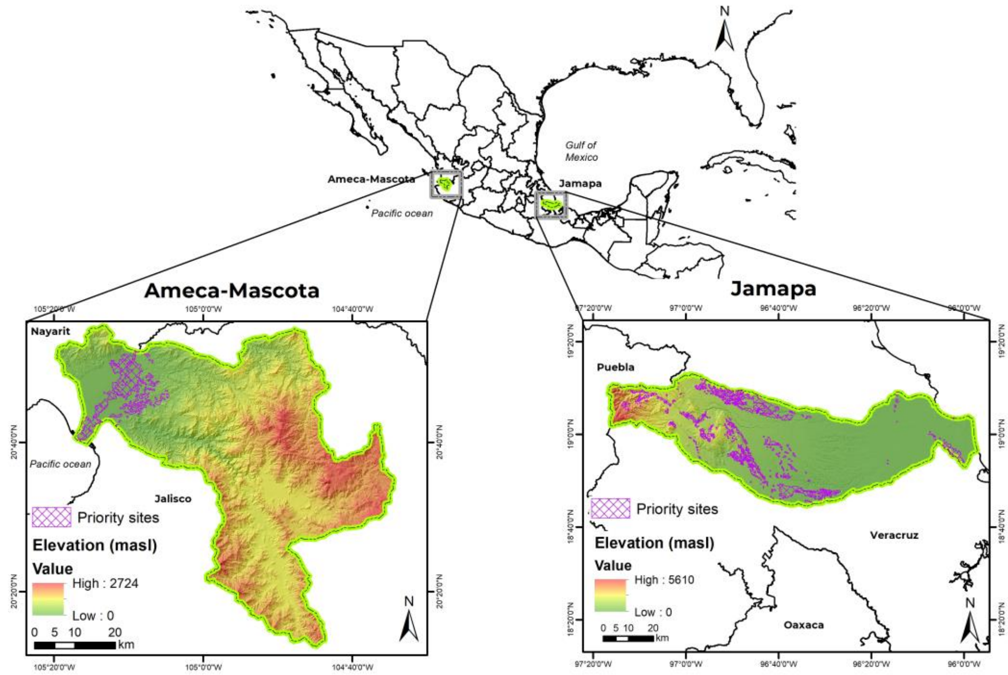

Figure 1. Location of the Ameca–Mascota and Jamapa watersheds and priority sites for improving cattle ranching and agriculture practices.

Each watershed has an Integrated Watershed Management Action Plan (IWAP). This territorial planning instrument identifies the activities needed to conserve the provision of critical ecosystem services in the face of climate change. These IWAPs include the priority sites for improving cattle ranching and agriculture (Figure 1). The low-to-medium provision capacity of ecosystem services due to environmental degradation and a high vulnerability to climate change effects on livestock production are characteristics of these priority sites [12].

To evaluate the effects of climate-smart practices, it is necessary first to make a map with a high level of detail of the forest vegetation and thus evaluate the current situation of the structure and connectivity of the landscape with the information obtained from the scenarios. The steps of the multiple analytical and mapping procedures are synthesized in Figure 2.

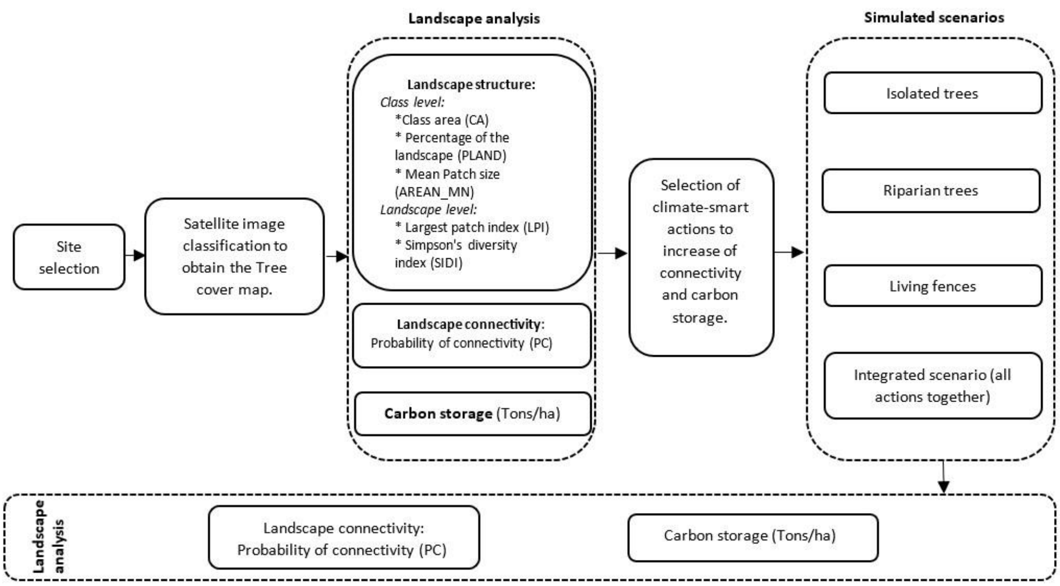

Figure 2. Schematic diagram of the workflow carried out in this study.

2.2. Tree Cover Map: Current Scenario and Future Trends

The land use and tree cover map was made from SENTINEL 2A satellite imagery (scenes from 17 February and 6 March 2022 for Jamapa and Ameca, respectively) downloaded from Scihub-Copernicus https://dataspace.copernicus.eu/ (accessed on 15 May 2022). Using the Maximum Likelihood algorithm in Qgis software v.3.22.1, each image was classified using blue, green, red, and NIR bands. One of the disadvantages of these pixel-based algorithms is the well-known "salt and pepper" effect, which consists of pixels being classified erroneously during the classification process, mainly due to difficulties in interpreting spectral signatures [13]. Two processes were carried out to reduce this bias. The first involved using a filter (eliminate) to clean all polygons classified with an area of 100 m^2 (i.e., one pixel), and a screen photo interpretation was performed at a fixed scale of 1:2500 to correct most of the salt and pepper effect errors. Two categories were established to perform the classification: tree cover (cloud forests, pine–oak forests, deciduous forests, forest plantations, and coffee plantations) and non-tree cover (pasture, crops, and human settlement). Training for the 2022 image classification was performed with 200 points (100 points per class) taken from field visits and recent Google Earth images. The final map was validated with 100 points (50 per class), with which a confusion matrix and Kappa index were generated to determine the classification accuracy of the results [14].

2.3. Landscape Structure and Functional Connectivity

Landscape structure analyses were performed at the class and landscape levels to describe the diversity and spatial arrangement of the physical elements in each watershed [14]. For tree cover and non-tree cover classes, the following metrics were calculated in Fragstats v4.2.1 [15]: class area (CA), percentage of the landscape occupied by each class (PLAND), and mean patch size (AREA_MN), which are basic measures of landscape composition and indicate specifically the proportion of the landscape per class type. At the landscape level, the largest patch index (LPI) and Simpson's diversity index (SIDI) were calculated [16].

The functional component of connectivity evaluates how species respond to the physical structure of the landscape [17], and the degree to which the landscape facilitates species' movement between elements defines the degree of connectivity. Therefore, this measure is directly associated with the effect of location, shape, and extent of forest patches on the abundance and distribution of species in a landscape. The present study applied the probability of connectivity (PC) index to integrate the area of habitat patches and their connectivity using graph theory to measure landscape connectivity. The PC index was calculated with Graphab Software 2.8.5 [18], which allows potential landscape connectivity to be quantified from functional and structural perspectives.

The functional perspective is evaluated from dispersal distances (mean, median, or maximum dispersion), while the structural perspective considers data on the distribution of tree cover fragments in the landscape [17]. In this case, six potential movement distances across open areas were established for organisms to reach separate forest fragments or tree elements (distances: 50, 100, 200, 200, 300, 400, and 500 m). These distances were selected from several studies of animal movement through the agricultural matrix conducted in different areas of the two States where the watersheds are located (Veracruz and Jalisco), including birds [19], bats [20], reptiles [21], and rodents [22]. These studies show that some forest species only move up to 100 m across cleared open areas, while others move up to 200 m. Therefore, the distances were chosen to represent the known displacement distance of groups of species with different capacities to move through pastures and agricultural fields.

2.4. Carbon Storage and Sequestration

Total carbon storage was estimated with the InVEST (Integrated Valuation of Ecosystem Service and Tradeoffs) software v.3.14.0. https://naturalcapitalproject.stanford.edu/software/invest (accessed on 30 June 2022). Previous studies have shown that the InVEST model is a feasible and reliable way to quantify carbon storage [23,24]. The InVEST "carbon storage model" simplifies the carbon cycle calculated by multiplying the average carbon content of four carbon pools (aboveground, belowground, soil, and dead litter) of each land use or land cover type by the corresponding areas. In detail, aboveground biomass includes leaves, bark, branches, trunks, and other living plant material above ground level. Belowground biomass includes the living root systems of aboveground biomass. Dead organic matter includes standing and lying dead wood and litter. Data for the four carbon pools were obtained through tables of coefficients for each LULC type; in this case, average values of carbon storage for the four pools were parameterized based only on secondary forest values of local and regional information to reflect the expected carbon storage capacity of the species (native or exotic) used in the climate-smart practices [25].

2.5. Simulated Climate-Smart Actions to Improve Functional Connectivity and Carbon Storage

Scenarios are models that allow evaluation of the advantages and disadvantages of implementing a strategy, such as climate-smart practice, in the landscape. In this way, generating hypothetical scenarios could support decision-making regarding providing key ecosystem services at the landscape level. To understand the effect of the evaluated climate-smart practices on mitigating the impact of climate change and improving ecosystem service provision, a comparison of the effect of their implementation with the current scenario, the tree cover map of the year 2022, was needed.

Three climate-smart practice scenarios for pastures and agriculture crops were simulated: (1) planting isolated trees in pasture parcels and crop fields, (2) extending tree-lined riparian corridors along permanent rivers, and (3) establishing live fences at properties' limits where livestock or crop activities are carried out. The connectivity index for the three alternatives was compared to the connectivity values of the 2022 classification before the simulation to determine the relative contribution of each option.

Then, the participation rate was determined by considering the number of parcels within the priority sites of Ameca–Mascota and Jamapa (760 and 1200, respectively) and different proportions of parcels (proxy of landowners) that could participate (5, 10, 25, 50, 50, 75, and 100%) in the climate-smart practices. The plots where the actions were modeled were randomly selected to avoid biases.

The first simulated proposal (isolated trees) was based on the idea of forest islands created by Benayas et al. (2008), which proposed an alternative to forest restoration in agricultural landscapes. The approach uses small-scale active restoration to drive passive restoration at larger scales through regeneration by nucleation [26,27]. The isolated trees scenario consisted of a random point (planted tree) set in each randomly selected plot, where a 5 m radius buffer (10 m diameter) was generated to simulate the tree canopy area. The scenario assumes successful tree plantations that promote the natural regeneration of woody plants in the understory. The second hypothetical practice was the expansion of forested riparian corridors along all streams. Water currents were determined using vector maps of streams in the study area ([28]; scale 1:50,000), and riparian corridors with a continuous 10 m wide tree canopy (5 m along each bank) were simulated. The riparian corridor width was established based on the Mexican Federal Water Law [29]. The third practice was the creation of live fences on the plots' boundaries with a buffer of 5 m in radius (10 m in diameter), which was established by simulating the canopy of the live fences.

Finally, the maximum possible impact of the actions was evaluated with an "integrated scenario" that included the combination of the three climate-smart practices.

3. Results

3.1. Landscape Structure and Functional Connectivity

The land use and vegetation map's overall accuracy and kappa indices were 91.74% (K = 0.83) and 90.10% (K = 0.80) for Ameca–Mascota and Jamapa, respectively. In Ameca–Mascota, the class area (CA) and Landscape Percentage (PLAND) indexes indicate the dominance of non-tree cover (6326.13 ha; 81% of the surface area) over tree cover (1522.42 ha; 19% of the surface area) and an average tree cover patch size of 0.24 ha (AREA_MN).

Non-tree cover also dominates the Jamapa landscape (10,895.94 ha; 56% of non-tree cover vs. 8428.5175 ha; 44% of tree cover), but with less intensity than in Ameca–Mascota, and the average size of the tree cover patches is 0.5 ha (AREA_MN).

The landscape in Ameca–Mascota is highly fragmented (LPI value: 70.84) and homogeneous (SIDI value 0.31), dominating only a few cover classes with a large proportion of the area covered by agriculture. The Jamapa landscape is less fragmented (LPI value: 41.71) but more homogenous (SIDI value 0.49).

In 2022, the connectivity probability value (PC; Figure 3) was higher in the Ameca–Mascota priority site than in Jamapa (Figure 1). In Jamapa, the PC value between the threshold distance of 50 and 500 m increased by 74%, with the most significant increase (44%) between 50 and 200 m, highlighting that after the 200 m threshold, the PC value increase is inversely proportional (at greater distances, the increase in connectivity is less) to the threshold distance, resulting in a PC value increase of 38% between 300 and 500 m. In contrast, the PC value in Ameca–Mascota increased by 32% between the 50 and 500 m threshold distances, and like Jamapa, the most significant PC increase was obtained between 50 and 200 m (19%), with a marginal increase (11%) between 300 and 500 m. The PC values at short distance thresholds (50 m or less) were up to seven times higher in Jamapa than in Ameca–Mascota. However, the difference decreased to 2.5 times at the widest evaluated distance threshold (500 m).

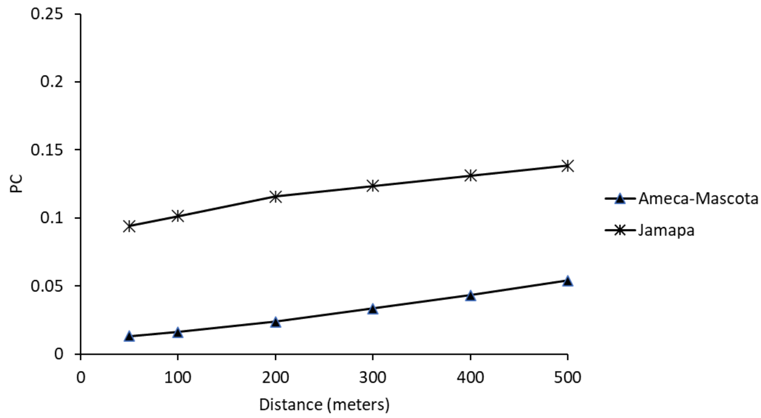

Figure 3. PC values for the actual scenario (2022) in Ameca–Mascota and Jamapa.

3.2. Carbon Storage and Sequestration

The Ameca–Mascota priority site is mainly bordered by deciduous forest, while three forest types (pine–oak forest, mountain forest, and deciduous forest) surround the Jamapa priority site (Series VII, INEGI, 2018). Consequently, it was assumed that the species planted in the climate-smart practices should be characteristic of these vegetation types. Therefore, average carbon storage values of 156.61 tons/ha and 242.47 tons/ha were considered in Ameca–Mascota and Jamapa, respectively (GPM-INECC, 2022). A second assumption of the model was that these carbon storage capacity values are homogeneous in all the practices implemented throughout the watersheds. However, values could differ depending on the planted species; no information was available, and similar trends were found in the literature. The carbon sequestration estimation in the 2022 scenario showed that the total carbon storage was 238,504.50 tons/yr and 2043,478.97 tons/yr in Ameca-Mascota and Jamapa, respectively.

3.3. Simulated Climate-Smart Practices to Increase Functional Connectivity and Carbon Storage

The analyses showed that climate-smart practices have the most significant positive impact on the functional connectivity of the Ameca-Mascota landscape, and the effect varies depending on the proportion of participating landowners in all cases. The effects are more visible in the "Integrated scenario", where in comparison with landscape connectivity in 2022, the participation of 5% of the landowners increases the landscape connectivity by 14%, by 36% with 10% of landowners participating, by 131.5% with a quarter of the landowners participating, by 451.5% when half of the landowners participate, by 726% with two-thirds of owners participating, and by 897.5% when all available parcels are included. The direct effect of the implementing climate-smart practices in the connections between fragments is shown in Figure 4 for a small area of the Ameca–Mascota study case.

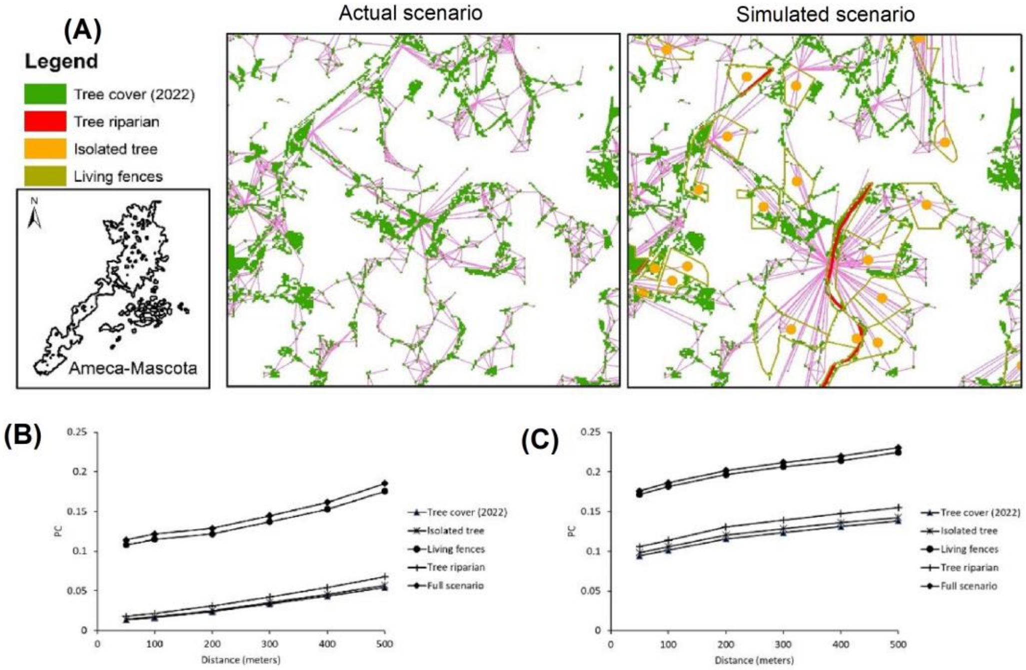

Figure 4. (**A**) Examples of connections between fragments at a threshold of 100 m in Ameca–Mascota for the current scenario (2022) and the integrated scenario (includes the three practices). (**B**) Probability of connectivity (PC) for a 50% participation scenario in Ameca–Mascota. (**C**) Probability of connectivity (PC) for a 50% participation scenario in Jamapa.

The analysis of the "Integrated scenario" effect regarding connectivity in the Jamapa landscape showed that a minimum participation rate of 5% increases the functional connectivity by 13%, with a slight improvement (14%) when 10% of landowners are involved and more significant effects when climate-smart practices are implemented in a quarter (+30.8%), half (75.1%), three-quarters (118.4%), and all parcels (209.5%). Figure 4 shows the effects of threshold distances in connectivity values considering a 50% participation scenario for Ameca–Mascota and Jamapa.

The benefits of landscape connectivity differ between climate-smart practices and watersheds and, in all cases, increase with landowner participation. Living fences had the highest contribution in both watersheds, ranging from 12% to 813% in Ameca–Mascota and 10% to 138.4% in Jamapa. The second practice with better performance was the restoration of riparian vegetation (riparian tree scenario), with a connectivity improvement of 9% to 61% in Ameca–Mascota and from 5% to 14% in Jamapa. Lastly, the isolated tree scenario (tree cover scenario) could increase connectivity by 5% to 7% in Ameca–Mascota and 3% to 4% in Jamapa.

Climate-smart practices benefit connectivity in both watersheds more at short threshold distances (50 and 100 m) than at long thresholds (400 and 500 m). For example, in the 5% landowner participation scenario, the average benefit was 15% increased connectivity at 50 and 100 m threshold distances, while the connectivity only increased by 10% at 400 and 500 m lengths. Also, in the 100% participation scenario, the benefit of practices at short distances is 1096%, while the connectivity increase is less than half (467%) at 400–500 m.

Table 1 shows that the most significant benefits in carbon storage would be obtained in Jamapa due to two factors: a higher number of properties than in Ameca–Mascota and the higher carbon storage capacity of the vegetation types around the priority site. In both watersheds, the ecosystem service of carbon storage is proportional to the intervened area (i.e., the more extensive the recovered area, the higher the amount of carbon storage in the landscape).

Table 1. Area (ha) occupied per climate-smart practice and amount of stored carbon (tons/ha) in Ameca–Mascota and Jamapa.

Ameca–Mascota						
	5% (59 parcels) Sup; ha–tons/yr	10% (118 parcels) Sup; ha–tons/yr	25 (294 parcels) Sup; ha–tons/yr	50% (589 parcels) Sup; ha–tons/yr	75% (883 parcels) Sup; ha–tons/yr	100% (1177 parcels) Sup; ha–tons/yr
Isolated tree	0.46–72.20	0.92–144.41	2.25–353.67	4.60–720.80	6.89–1080.59	9.19–1440.38
Tree riparian	6.92–1085.12	15.62–2447.06	29.44–4611.753	65.75–10,297.64	95.29–14,924.16	115.88–18,148.10
Living fences	49.42–7740.17	100.02–15,664.23	233.50–36,568.87	429.33–67,238.55	590.13–92,421.05	709.38–111,096.88
"Integrated" scenario	56.81–8897.50	116.56–18,255.70	265.20–41,534.30	499.69–78,256.99	692.33–108,425.81	834.46–130,685.37
Jamapa						
	5% (59 parcels) Sup; ha–tons/yr	10% (118 parcels) Sup; ha–tons/yr	25 (294 parcels) Sup; ha–tons/yr	50% (589 parcels) Sup; ha–tons/yr	75% (883 parcels) Sup; ha–tons/yr	100% (1177 parcels) Sup; ha–tons/yr
Isolated tree	1.08–263.36	2.53–615.81	4.84–1173.57	10.85–2631.12	16.27–3946.89	21.70–5262.67
Tree riparian	8.44–2048.25	13.67–3314.67	31.04–7526.67	81.53–19,770.89	149.09–36,150.49	149.09–36,150.49
Living fences	88.11–21,366.06	183.95–44,603.23	411.31–99,732.23	845.05–204,899.28	1161.71–281,681.30	1431.75–347,156.99
"Integrated" scenario	97.65–23,677.68	200.16–48,533.72	447.19–108,432.48	937.44–227,301.30	1327.08–321,778.69	1602.54–388,570.16

4. Discussion

Tree elements included in climate-smart practices and planted in and around agricultural matrices are increasingly recognized as critical structures that improve landscape connectivity, forest restoration, biodiversity conservation, and the essential provision of ecosystem services, such as carbon sequestration, in highly transformed landscapes [30,31]. However, the effectiveness of climate-smart practices regarding specific ecosystem services and the role of the level of landowner participation have been scarcely studied. The results of this research obtained through modeling scenarios contribute to boosting climate-smart practice implementation focused on tree elements, demonstrating their benefits on functional connectivity and carbon storage. This study highlighted that benefits differ depending on the modeled practice, the level of landowner participation, and the landscape matrix where they are implemented.

4.1. Main Contributors to Landscape Connectivity and Storage of Carbon

Our results suggest that landscape structure defines the effectiveness of climate-smart practices, implying that the benefits obtained from a practice depend on the implementation context, a statement that has been the subject of several theoretical models and debates where the importance of landscape structure for biodiversity maintenance has been highlighted [32]. These models suggest that maintaining more habitat in the landscape benefits biodiversity [33]. Increasing the amount of habitat in a landscape is considered a conservation measure because it facilitates the movement of individuals and accessibility to resources (e.g., food and refuge) located in different areas of the landscape [33]. Therefore, climate-smart practices that include arboreal elements favor landscape structure recovery and, despite being small elements from a landscape scale, allow biodiversity conservation in highly fragmented areas functioning as corridors and stepping stones for species that can utilize the matrix and move between fragments [34]. Similarly, the presented results support these ideas and highlight that the practices have more significant effects in landscapes with high levels of fragmentation and homogeneity.

Climate-smart practices affect forest organisms differently depending on their displacement capacity. The three evaluated practices benefit species with short distance thresholds (50–100 m), because these species have a high dependency on tree structures located at close distances to move through the landscape easily. In contrast, species with higher displacement capacity (e.g., bats and birds) can move between areas devoid of vegetation.

For example, species with short distance thresholds are more affected by landscape transformation, and climate-smart practices with arboreal elements could help recover their population. The scorpion lizard, a species distributed close to the coast of Jalisco, has a maximum displacement distance from its refuge of 236 m and depends on trees for feeding; consequently, extensive agricultural activities that eliminated tree elements have caused a severe population decrease [21,35]. These species are the ones that would benefit the most from the implementation of the analyzed climate-smart practices.

Live fences had the greatest functional connectivity and carbon sequestration benefits because they create micro-corridors and occupy a larger area than the other two practices; however, each practice fulfills specific functions. Isolated trees are stepping stones between habitat patches and are less invasive for landowners, requiring less space and maintenance, making it easier for landowners to access these practices. In ecological terms, these small patches could be the habitat of a diverse pollinator community [36].

Riparian tree recovery was the second practice with the highest effect on connectivity and carbon sequestration, and multiple additional direct and indirect benefits [37,38] have also been documented, including water regulation, which is a critical resource for agricultural activities. Both live fences and the recovery of riparian areas form corridors but differ in the provision of ecosystem services. For example, riparian vegetation has the potential to provide a much wider range of ecosystem services, ranging from the aesthetic value of the landscape to the mitigation of diffuse pollution [38]. Despite the importance of riparian vegetation, trees are often harvested as the last forest resource in highly degraded areas [39].

The results suggested that the carbon sequestration amount is proportional to the implemented area of the actions. Although the present study tried to find an approximation of the potential benefits of carbon sequestration, modeling limitations and the effects on the amount of carbon estimations are explicitly recognized; for example, the amount of stored carbon could differ depending on the applied method, even in the same study area [40–43], because the models do not consider several field factors. Consequently, results derived from field data could differ from those obtained through simulations. Other factors that could influence the carbon sequestration capacity in the context of climate-smart practices are the selected species, maintenance activities such as trimming, a favorable or harmful climate for the selected species' growth, and the occurrence of fires and pests [44].

4.2. Methodological Caveats

The present study comprehensively analyzed the benefits of three climate-smart practices aimed at increasing functional connectivity and carbon storage. However, such analyses rely on assumptions such as the survival of all planted individuals and homogeneous canopies due to the implementation of uniform buffers. These conditions, in reality, are dependent on the species used. Although the use of native vegetation is strongly recommended, the choice of species is critical to the effectiveness of these practices because each species has particular structural growth characteristics, shape, and canopy height, which will determine carbon storage and sequestration, as well as their contribution to functional connectivity [45,46]. Another significant challenge is to ensure landowners' engagement in maintaining these actions over the years, as the results may only be evident years after the strategies are implemented. In this context, environmental education becomes a fundamental pillar for the success of these initiatives. Facilitating the long-term knowledge transfer of climate-smart practices enhances and promotes a culture of sustainability and ecological responsibility within society.

5. Conclusions

The findings of this study suggest that climate-smart practices generate benefits at the watershed scale but that the effectiveness depends on multiple factors, such as the landscape structure and level of landowner participation. This evidence raises awareness of the importance of engaging in these practices, including these efforts in public policy, and securing funding to cover initial maintenance and monitoring costs. In this sense, a significant challenge to be addressed in future studies is the design and implementation of monitoring plans to track the practices' goals and analyze the perception of the associated costs and benefits. In the first case, the perception and willingness to participate should be evaluated through surveys carried out at the plot, household, or community level, and in the second case, cost–benefit analyses can be carried out to assess and highlight the feasibility and benefits from the private and social standpoints.

Despite the multiple benefits of climate-smart practices, their implementation must be carefully planned to avoid compromising the livelihoods of landowners, duplication of efforts, and the promotion of conflicting public policies while increasing their feasibility through financial mechanisms such as tax reduction and seeking synergies to achieve greater benefits for producers and biodiversity in a context where adaptation to climate change is increasingly relevant.

Author Contributions: Conceptualization, J.J.V.T. and D.L.; methodology, J.J.V.T. and D.L.; software, J.J.V.T.; validation, J.J.V.T.; formal analysis, J.J.V.T., D.L. and D.A.R.-F.; investigation, J.J.V.T., D.L. and D.A.R.-F.; writing—original draft preparation D.L.; writing—review and editing, J.J.V.T., D.L., D.A.R.-F., M.d.P.S.-V. and A.R.d.l.S.; visualization, J.J.V.T. and D.L.; supervision, M.d.P.S.-V. and A.R.d.l.S.; project administration, M.d.P.S.-V. and A.R.d.l.S. All authors have read and agreed to the published version of the manuscript.

Funding: The presented results were derived from the targeted technical assistance "Economic Valuation of Ecosystem Services to Strengthen Integrated Landscape Management in Selected Watersheds in Mexico", financed by the World Bank's Global Program for Sustainability Trust Fund (TF0C0157) and under the "Connecting Watershed Health with Sustainable Livestock and Agroforestry Production" CONECTA project.

Data Availability Statement: Data are contained within the article.

Acknowledgments: The authors are grateful to the National Institute of Ecology and Climate Change (INECC) and the World Bank's Global Program for Sustainability Trust Fund for their support, and to Citlalli A. González Hernández for proofreading the manuscript.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. FAO. Land Use in Agriculture According to the Numbers. 2020. Available online: https://www.fao.org/sustainability/news/detail/es/c/1279267/#:~:text=La%20superficie%20de%20tierra%20destinada,y%20pastizales%20para%20el%20pastoreo (accessed on 11 June 2023).
2. IPBES. Global Assessment Report on Biodiversity and Ecosystem Services. 2019. Available online: https://www.ipbes.net/global-assessment (accessed on 21 July 2023).
3. Mititelu-Ionuș, O.; Simulescu, D.; Popescu, S.M. Environmental assessment of agricultural activities and groundwater nitrate pollution susceptibility: A regional case study (Southwestern Romania). *Environ. Monit. Assess.* **2019**, *191*, 1–15. [CrossRef] [PubMed]
4. Zhao, J.; Liu, D.; Huang, R.A. Review of Climate-Smart Agriculture: Recent Advancements, Challenges, and Future Directions. *Sustainability* **2023**, *15*, 3404. [CrossRef]
5. Lipper, L.; Thornton, P.; Campbell, B.M.; Baedeker, T.; Braimoh, A.; Bwalya, M.; Caron, P.; Cattaneo, A.; Garrity, D.; Henry, K.; et al. Climate-smart agriculture for food security. *Nat. Clim. Change* **2014**, *4*, 1068–1072. [CrossRef]
6. Dissanayaka, D.M.N.S.; Dissanayake, D.K.R.P.L.; Udumann, S.S.; Nuwarapaksha, T.D.; Atapattu, A.J. Agroforestry—A key tool in the climate-smart agriculture context: A review on coconut cultivation in Sri Lanka. *Front. Agron.* **2023**, *5*, 1162750. [CrossRef]
7. Scherr, S.J.; Shames, S.; Friedman, R. From climate-smart agriculture to climate-smart landscapes. *Agric. Food Secur.* **2012**, *1*, 1–15. [CrossRef]
8. Muschler, R.G. Agroforestry: Essential for Sustainable and Climate-Smart Land Use? In *Tropical Forestry Handbook*, 1st ed.; Pancel, L., Köhl, M., Eds.; Springer: Berlin/Heidelberg, Germany, 2016; Volume 2, pp. 2013–2116. [CrossRef]
9. Harvey, C.A.; Chacon, M.; Donatti, C.I.; Garen, E.; Hannah, L.; Andrade, A.; Bede, L.; Brown, D.; Calle, A.; Chará, J.; et al. Climate-smart landscapes: Opportunities and challenges for integrating adaptation and mitigation in tropical agriculture. *Conserv. Lett.* **2014**, *7*, 77–90. [CrossRef]
10. Travers, E.; Härdtle, W.; Matthies, D. Corridors as a tool for linking habitats–Shortcomings and perspectives for plant conservation. *J. Nat. Conserv.* **2021**, *60*, 125974. [CrossRef]

11. INECC-FONNOR. Plan de Acción para el Manejo Integral de Cuencas Hídricas Región Vallarta. Proyecto: Conservación de Cuencas Costeras en el Contexto del Cambio Climático. 2018. Available online: https://www.gob.mx/inecc/acciones-y-programas/conservacion-de-cuencas-costeras-en-el-contexto-de-cambio-climatico-c6 (accessed on 1 April 2023).
12. INECC-FGM. Plan de Acción para el Manejo Integral de Cuencas Hídricas: Cuenca del río Jamapa. 2018. Available online: https://datos.abiertos.inecc.gob.mx/Datos_abiertos_INECC/CGACC/PAMICs/PAMIC_rio_Jamapa.pdf (accessed on 18 January 2024).
13. Hirayama, H.; Sharma, R.C.; Tomita, M.; Hara, K. Evaluating multiple classifier system for the reduction of salt-and-pepper noise in the classification of very-high-resolution satellite images. *Int. J. Remote Sens.* **2019**, *40*, 2542–2557. [CrossRef]
14. Congalton, R.G.; Green, K. *Assessing the Accuracy of Remotely Sensed Data: Principles and Practices*, 2nd ed.; CRC/Taylor & Francis: Boca Raton, FL, USA, 2009; p. 178.
15. McGarigal, K.; Cushman, S.A.; Ene, E. FRAGSTATS v4: Spatial Pattern Analysis Program for Categorical and Continuous Maps. Computer Software Program Produced by the Authors at the University of Massachusetts, Amherst. Available online: https://www.fragstats.org/ (accessed on 18 January 2024).
16. Lu, D.; Qiu, L.; Jiao, M.; Feng, Z.; Wang, Z.A. Quantitative analysis of the spatial diversity of Moraceae in China. *Front. Ecol. Evol.* **2023**, *11*, 1110018. [CrossRef]
17. Alonso, A.M.; Finegan, B.; Brenes, C.; Günter, S.; Palomeque, X. Evaluation of structural and functional connectivity in the Podocarpus-Yacuambi conservation corridor, Ecuador. *Caldasia* **2017**, *39*, 140–156. [CrossRef]
18. Foltête, J.C.; Vuidel, G.; Savary, P.; Clauzel, C.; Sahraoui, Y.; Girardet, X.; Bourgeois, M.A. Graphab: An application for modeling and managing ecological habitat networks. *Softw. Impacts* **2021**, *8*, 100065. [CrossRef]
19. Almazán-Núñez, R.C.; Mariano-Rendón, A.; Rodríguez-Godínez, R.; Méndez-Bahena, A.; Pineda-López, R. Las aves frugívoras y su papel en la restauración pasiva del bosque tropical caducifolio del sur de México: Un caso de estudio con la cactácea *Pachycereus weberi*. In *Manejo y Conservación de Fauna Nativa en Ambientes Antropizados*, 1st ed.; Mercado, S.N., Val de Gortari, E., Eds.; REFAMA/UAQ: Querétaro, México, 2021; pp. 61–83.
20. Galindo-González, J.; Sosa, V.J. Frugivorous bats in isolated trees and riparian vegetation associated with human-made pastures in a fragmented tropical landscape. *Southwest Nat.* **2003**, *48*, 579–589. [CrossRef]
21. Beck, D.D.; Lowe, C.H. Ecology of the beaded lizard, Heloderma horridum, in a tropical dry forest in Jalisco, Mexico. *J. Herpetol.* **1991**, *25*, 395–406. [CrossRef]
22. Castellanos, Y.D.; López, F.P.; González, G.C. Uso de hábitat de los roedores arborícolas en Chamela, Jalisco. *Rev. Mex. Mastozoo.* **2007**, *11*, 21–33. [CrossRef]
23. Polasky, S.; Nelson, E.; Pennington, D.; Johnson, K.A. The impact of land-use change on ecosystem services, biodiversity and returns to landowners: A case study in the state of Minnesota. *Environ. Resour. Econ.* **2011**, *48*, 219–242. [CrossRef]
24. Zhao, M.; He, Z.; Du, J.; Chen, L.; Lin, P.; Fang, S. Assessing the effects of ecological engineering on carbon storage by linking the CA-Markov and InVEST models. *Ecol. Indic.* **2019**, *98*, 29–38. [CrossRef]
25. GPM-INECC. Valoración de Servicios Ecosistémicos Clave en Cuencas de México: Reporte Final. Banco Mundial, Instituto Nacional de Ecología y Cambio Climático (INECC), México. 2022. Available online: https://www.gob.mx/cms/uploads/attachment/file/805434/02_Informe_Final_GPS_Mexico_2022_.pdf (accessed on 3 May 2023).
26. Zahawi, R.A.; Holl, K.D.; Cole, R.J.; Reid, J.L. Testing applied nucleation as a strategy to facilitate tropical forest recovery. *J. Appl. Ecol.* **2013**, *50*, 88–96. [CrossRef]
27. Guzmán-Luna, A.; Martínez-Garza, C. Performance of 15 tropical tree species recruited or transplanted on restoration settings. *Bot. Sci.* **2016**, *94*, 757–773. [CrossRef]
28. INEGI. Simulador de Flujos de Agua de Cuencas Hidrográficas. 2023. Available online: https://antares.inegi.org.mx/analisis/red_hidro/siatl/ (accessed on 1 May 2023).
29. CONAGUA. Ley de Aguas Nacionales. 1992. Available online: https://www.diputados.gob.mx/LeyesBiblio/pdf/LAN.pdf (accessed on 1 April 2023).
30. Gutiérrez-Granados, G.; León-Villegas, R.I.; Rodríguez-Moreno, A.; Coates, R. Loss of connectivity in a highly fragmented tropical landscape: Use of ecological processes as functional indicators of biodiversity decline. *Biodivers. Int. J.* **2018**, *2*, 48–56. [CrossRef]
31. Arroyo-Rodríguez, V.; Fahrig, L.; Tabarelli, M.; Watling, J.I.; Tischendorf, L.; Benchimol, M.; Tscharntke, T. Designing optimal human-modified landscapes for forest biodiversity conservation. *Ecol. Lett.* **2020**, *23*, 1404–1420. [CrossRef]
32. Galán-Acedo, C.; Arroyo-Rodríguez, V.; Estrada, A.; Ramos-Fernández, G. Forest cover and matrix functionality drive the abundance and reproductive success of an endangered primate in two fragmented rainforests. *Landsc. Ecol.* **2019**, *34*, 147–158. [CrossRef]
33. Fahrig, L. Rethinking patch size and isolation effects: The habitat amount hypothesis. *J. Biogeogr.* **2013**, *40*, 1649–1663. [CrossRef]
34. Fahrig, L. Ecological responses to habitat fragmentation per se. *Annu. Rev. Ecol. Evol. Syst.* **2017**, *48*, 1–23. [CrossRef]
35. Domínguez-Vega, H.; Balderas-Valdivia, C.J.; Manjarrez, J.; Monroy-Vilchis, O. Conociendo al lagarto escorpión: Leyendas, realidad y potencial de una rareza biológica. *CIENCIA Ergo-Sum* **2018**, *25*, 1–9. [CrossRef]
36. Proesmans, W.; Bonte, D.; Smagghe, G.; Meeus, I.; Decocq, G.; Spicher, F.; Kolb, A.; Lemke, I.; Diekmann, M.; Henrik, B.H.; et al. Small forest patches as pollinator habitat: Oases in an agricultural desert? *Landsc. Ecol.* **2019**, *34*, 487–501. [CrossRef]
37. Sonesson, J.; Ring, E.; Högbom, L.; Lämås, T.; Widenfalk, O.; Mohtashami, S.; Holmström, H. Costs and benefits of seven alternatives for riparian forest buffer management. *Scand. J. For. Res.* **2021**, *36*, 135–143. [CrossRef]

38. Cole, L.J.; Stockan, J.; Helliwell, R. Managing riparian buffer strips to optimise ecosystem services: A review. *Agric. Ecosyst. Environ.* **2020**, *296*, 106891. [CrossRef]
39. Von Thaden, J.J.; Laborde, J.; Guevara, S.; Mokondoko-Delgadillo, P. Dinámica de los cambios en el uso del suelo y cobertura vegetal en la Reserva de la Biosfera Los Tuxtlas (2006–2016). *Rev. Mex. Biodivers.* **2016**, *91*, e913190. [CrossRef]
40. Rodríguez, L.R.; Jiménez, P.J.; Aguirre, C.A.; Treviño, G.E.J. Estimación del carbono almacenado en un bosque de niebla en Tamaulipas, México. *Ciencia UANL* **2006**, *9*, 179–188. Available online: http://eprints.uanl.mx/id/eprint/1750 (accessed on 2 February 2024).
41. Cargua, F.E.; Rodríguez, M.V.; Recalde, C.G.; Vinueza, L.M. Cuantificación del contenido de carbono en una plantación de pino insigne (*Pinus radiata*) y en estrato de páramo de ozogoche bajo, Parque Nacional Sangay, Ecuador. *Inform. Tecnol.* **2014**, *25*, 83–92. [CrossRef]
42. Paz-Pellat, F.; Salas-Aguilar, V.M.; Sánchez-Sánchez, C.D.; Libert-Amico, A.; Bolaños-González, M.A. Caracterización de los almacenes de carbono, estructura y diversidad de los cafetales bajo sombra y vegetación natural en la Sierra Madre de Chiapas, México. *Elem. Polít. Públicas* **2022**, *6*, 101–122. Available online: https://www.elementospolipub.org/ojs/index.php/epp/article/view/46/45 (accessed on 2 February 2024).
43. Benítez, G.; Ruelas-Monjardín, L.C.; Von Thaden, J.; Acosta-Rosado, I.; Alvarado-Castillo, G.; Equihua, M. Carbon Storage in a Peri-urban Neotropical Forest: Assessing its potential and patterns of change over half a century. *Urban For. Urban Green.* **2023**, *86*, 128009. [CrossRef]
44. Cao, S.; Ma, H.; Yuan, W.; Wang, X. Interaction of ecological and social factors affects vegetation recovery in China. *Biol. Conserv.* **2014**, *180*, 270–277. [CrossRef]
45. Ameray, A.; Bergeron, Y.; Valeria, O.; Montoro Girona, M.; Cavard, X. Forest carbon management: A review of silvicultural practices and management strategies across boreal, temperate and tropical forests. *Curr. For. Rep.* **2021**, *7*, 245–266. [CrossRef]
46. Uezu, A.; Metzger, J.P.; Vielliard, J.M. Effects of structural and functional connectivity and patch size on the abundance of seven Atlantic Forest bird species. *Biol. Conserv.* **2005**, *123*, 507–519. [CrossRef]