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Planning restoration in human-modified landscapes: New insights linking different scales

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ABSTRACT

The transformation of tropical ecosystems by humans have resulted in forest loss, which, in turn, have caused negative impacts on biodiversity and the provisioning of ecosystem services. There is an urgent need to plan the restoration of these human-modified landscapes, using methodological approaches that consider key processes occurring at different spatial scales while engage local community participation, offering them the best possibilities of tangible benefits. In this study, was evaluated the landscape spatial pattern and local conservation status of existing forest remnants, showing an analysis of possible restoration scenarios for a human-modified landscape in La Montaña, an indigenous region in southwestern Mexico. Therefore, landscape and local scale approaches were linked to identify specific landscape elements where efforts to improve connectivity must be concentrated. Also, this approach allowed finding a set of species from reference sites that showed the best socioecological characteristics to be used in different restoration strategies. As expected, La Montaña region showed a spatial pattern typical of highly human-modified landscapes, i.e., several small (<21 ha) and irregular forest remnants with strong forest edge effects. Furthermore, these small and irregular forest fragments displayed forest structure, diversity and composition characteristics similar to those communities disturbed by selective harvesting or in an early successional phase. However, about 100 of woody species were found inside the fragments, some with important potential to provide ecosystem services. The landscape connectivity was very low, and an analysis of possible restoration scenarios showed that is equally important to restore the productive areas as well as open forest, to recover up to 47% of landscape connectivity. In this sense, it was proposed a productive restoration strategy to enrich open forests and create biodiversity-friendly habitat in agricultural areas, using species with high socioecological potential. We believe that the same approach could be applied to other highly human-modified tropical landscapes with similar socioecological problems.

1. Introduction

Forest loss is a global concern, particularly in countries with a high abundance of natural forest resources (FAO, 2010, pp. 9–23). Between 2000 and 2012, it was estimated that 2.3 million km^2 of forests worldwide were lost by human disturbances (Hansen et al., 2013), causing negative impacts to biodiversity and provisioning of ecosystem services (Cardinale et al., 2012). Human activities, such as agriculture, deforestation and mining, are considered to be the main drivers of forest loss (Foley et al., 2011; Houghton, 2012). Furthermore, poverty and ecosystem fragility frequently contribute to forest loss and land degradation, creating a negative cycle or "poverty traps" (Sachs & McArthur, 2005).

Forest loss can also cause forest landscape fragmentation and a negative impact on biodiversity when isolation and edge effects entail habitat loss (Haddad et al., 2015; Heather & Fahrig, 2013). Forest fragmentation reduces genetic diversity and species

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population growth rates within fragments, altering the interactions among species and promoting local extinctions (Haddad et al., 2015; Ponce-Reyes, Nicholson, Baxter, Fuller, & Possingham, 2013; Sork & Waits, 2010). The social consequences of forest fragmentation involve the loss of ecosystem services provision and thereby quality of life, especially for those people most dependent of forest resources (Chao, 2012; FAO, 2010, pp. 9–23).

The management and restoration of human-modified landscape to ameliorate countless negative effects from fragmentation is a crucial global issue (Chazdon et al., 2015; Damschen, Haddad, Orrock, Tewksbury, & Levey, 2006; Holl, 2017; Mitchell, Bennett, & Gonzalez, 2013; Ng, Xie, & Yu, 2013). However, identifying an effective methodological approach to guide landscape restoration planning poses several challenges because all ecological systems are unique and their composition and ecological processes are in function of their location, spatial context, history and current status as well as type of land use (Lindenmayer et al., 2008). Instead of providing specific recommendations for on-the-ground management and because specific applications will be always context-dependent, some authors have proposed a set of general considerations to guide a better landscape conservation and restoration planning. These considerations embrace and identify not only the landscape dynamics but also consider both the amount and configuration of habitats and particular land cover types, identify important species, ecological processes as well as landscape restoration strategies (Bennett & Mac Nally, 2004; Lindenmayer et al., 2008; Maginnis, Rietbergen-McCracken, & Sarre, 2012; Rudnick et al., 2012; Turner, Donato, & Romme, 2013).

Landscape restoration strategies could focus on several issues such as forest remnant conservation and increase in forest area and connectivity among forest remnants, through wildlife corridors or improvement of the matrix permeability (Haddad et al., 2015; Metzger & Brancalion, 2013; Perfecto & Vandermeer, 2010). These strategies should also take into account the predominant type of disturbance in the landscape (acute vs. chronic; Arroyo-Rodríguez et al., 2015; Ribeiro, Arroyo-Rodríguez, Santos, Tabarelli, & Leal, 2015), processes that occur on different scales of space and more importantly, the participation of local communities (Ceccon, 2013, pp. 139–149; Flores-Ramírez & Ceccon, 2014; Metzger & Brancalion, 2013; Perfecto & Vandermeer, 2010). In a landscape that has suffered strong chronic human disturbances, succession can be slow or arrested with direct effects on ecosystem functions (Arroyo-Rodríguez et al., 2015). Under these circumstances, it is imperative to assess the role of secondary forest remnants to serve as biodiversity repositories and provide ecosystem services. Therefore, an appropriate remnant management would potentiate their functions according to specific conservation and social goals at a landscape scale (Arroyo-Rodríguez et al., 2015).

Mexico is a megadiverse country; however, it presents high rates of net deforestation at national and regional scale (García-Barrios et al., 2009; Hansen et al., 2013; Mas & Cuevas, 2015). La Montaña region, in the south of Guerrero state, has one of the highest levels of land degradation and social vulnerability in Mexico (Bollo Manent, Hernández Santana, & Méndez Linares, 2014; Landa, Meave, & Carabias, 1997). In an evaluation about the state of environmental integrity in the country using 15 indicators associated with anthropic modification and socioeconomic status, Bollo Manent et al. (2014) found that La Montaña region had an unstable state, i.e., high vegetation degradation and social vulnerability in terms of health, education and quality of life.

Most landscapes in this region are subject of chronic disturbance (Arroyo-Rodríguez et al., 2015), predominantly by harvesting of timber and fuelwood (Locally, 100% of population use firewood to cook; Salgado, 2015), extraction of non-timber forest products, subsistence agriculture, hunting and livestock. This region is also one of the poorest in the country (CDI, 2005, pp. 10–47; PNUD, 2012), some of the municipalities in the area show a Human Development Index similar to some sub-Saharan African countries (Taniguchi, 2011), with strong isolation and social marginalization (Landa & Carabias, 2009). The dependency on natural resources has been evident in some of the recent studies carried out in the region. For example, Miramontes, DeSouza, Hernández, and Ceccon (2012), found a deterministic searching pattern of firewood in this region, which is typical of degraded landscapes with scarcity of resources. Likewise, Salgado (2015) found that species with the highest firewood potential are rarely used due to a low abundance in their natural habitats.

At present, in the La Montaña region, there are numerous governmental and non-governmental initiatives; such as Xuajin Me Phaa, A.C., a non-governmental organization dedicated to reversing the negative effects of forest fragmentation and land degradation in two municipalities of the region. However, these objectives can only be reached by developing programs that include restoration and protection of forest remnants, and activities incentivized by the organization that also offer tangible benefits for 990 families who belong to the indigenous group Me'Phaa.

A long partnership between the research group and Xuajin Me'Phaa A.C., in the region has resulted in some important studies that give us valuable lessons about the communities' dependency on natural resources, traditional knowledge, lifestyles, and their urgent socioeconomic needs (Borda-Niño, Carranza, Hernández-Muciño, & Muciño-Muciño, 2016; Ceccon, 2016; Galicia-Gallardo & Ceccon, 2016; Hernández-Muciño, Sosa-Montes, & Ceccon, 2015; Hernández-Muciño, Borda-Niño, & Ceccon, 2016; Miramontes et al., 2012; Salgado, 2015).

In a human-modified landscape such as La Montaña region and considering the socioecological complexity of ecological restoration in the country (Ceccon, Barrera-Cataño, Aronson, & Martínez-Garza, 2015), a suitable methodological approach to landscape restoration planning must link local and landscape scales and should include, at least, the following five components: i) assessment of the landscape spatial pattern and connectivity, ii) knowledge of the conservation status of existing forest remnants, iii) recognition of specific landscape elements where efforts to improve connectivity should be concentrated, iv) identify species in reference sites with the best socioecological characteristics (species with high potential as ecosystem services providers), to establish different restoration strategies, and v) establish possible restoration scenarios to improve landscape connectivity, according to a set of general considerations for restoration planning (Bennett & Mac Nally, 2004; Lindenmayer et al., 2008; Maginnis et al., 2012; Turner et al., 2013). This study aimed to assess these components in order to generate information which can provide the scientific foundations for designing future landscape restoration strategies in the La Montaña region, and in any other human-modified tropical landscapes with similar socioecological conditions. This research approach included collaboration with communities and the non-governmental organization; Xuanjin Me'Phaa A.C., and represent an innovative action-participation model that is applicable and achievable to have a positive impact on people's welfare.

2. Material and methods

2.1. Study site

This study was carried out in a human-modified landscape of the La Montaña region, located in the municipality of Acatepec, in eastern Guerrero state, Mexico (UTM coordinates; 498209-493082X a 1908985-1890946Y). The study site was located in a transition zone of mixed pine-oak forests and tropical deciduous forests (Landa et al., 1997), which ranges in elevation from 520 m to 2600 m in altitude and typically receives an average annual rainfall of 1500 mm to 1800 mm, with rainy summers (SMN, 2013). Mean annual temperatures average from 18 °C to 22 °C (SMN, 2013). Soils are mostly Arenosols (susceptible to erosion and low holding water capacity; SEMARNAT, 2008; WRB, 2008, pp. 103–117), and a small portion of Leptosols (stony, shallow, with coarse textures, and excessive drainage; SEMARNAT, 2008; WRB, 2008, pp. 103–117). In the study site, the main disturbance factors included continuous hunting, extraction of firewood, timber and non-timber forest products, subsistence agriculture and livestock (Borda-Niño et al., 2016; Galicia-Gallardo & Ceccon, 2016; Landa et al., 1997; Miramontes et al., 2012; see Fig. 1).

2.2. *Landscape scale: spatial pattern analysis*

2.2.1. *Image pre-processing*

The data used were from two high-resolution satellite images: a Spot-5 panchromatic image (pixel size: 2 × 2 m) and multispectral image (size pixel 10 × 10 m) supplied by the Research Center of Environmental Geography of the National Autonomous University of Mexico. Both images were obtained on December 29, 2010 with a preprocessing level 2A, and were orthorectified with ground control points (GCPs) using "ERDAS IMAGINE 2010" software, employing nearest neighbor resampling scheme with a root mean square error of less than five meters. In the same software the GCPs were obtained from a mosaic of orthorectified aerial photographs from 1995 (scale 1:75000) provided by National Institute of Geography and Statistics, México.

2.2.2. *Image classification and land cover map*

Hybrid classification techniques (a combination of supervised classification and visual interpretation) were used in mapping of land cover (scale 1: 15000 and minimum mapping unit 4 × 4 mm or 3600 ha) according to the classification proposed by INEGI (2012, pp. 20–42), for the induced vegetation, and Rzedowski (2006, pp. 160–168), for natural vegetation classification. Over 150 training sample data were used to determine the land cover classes and then train a supervised classification of the multispectral image applying a maximum likelihood classifier using "IDRISI Taiga 16.0" software. The training samples were polygons manually defined representing sampling areas of the following land cover classes: *Pinus* forest, *Quercus* forest, Induced grassland, Agriculture, and Human settlements. The training samples were arranged by visual interpretation of the Spot-5 images RGB composite (bands 1, 2, 3) supported by "Google Earth" overviews. The output raster dataset was converted into vector format.

For the visual interpretation, the multispectral and panchromatic orthorectified images were fused employing the Principal Components transformation method and nearest neighbor resampling scheme using Pan-Sharpened of "ERDAS IMAGINE 2010" software. The pixel size of the fused image was 2.5 m. The vector file format obtained of the supervised classification was superimposed on the fused image, and then hand-editing was used to clean up misclassified areas. Main activities to correct polygon boundaries were to assign the polygons into four new categories (Tropical deciduous forest, Gallery vegetation, River, Bare soil and Unpaved road) and to reassign the polygon to the correct category. These activities were supported by high-resolution images in "Google Earth" software and a field visit that involved the observation of 7–12% of the polygons for each land cover class. In addition, during the visual interpretation, the Agriculture class was classified as "Rainfed agriculture" and "Irrigated agriculture". Moreover, the Grassland class was classified in "Induced grasslands" (dominance of herbaceous vegetation) or "Induced grassland with trees" (dominance of herbaceous vegetation and 5–10% of tree cover), and the *Pinus* and *Quercus* forest classes were classified as "Open" (10–40% of tree cover) and "Closed" (more than 40% of tree cover). In the Tropical deciduous forest class, this distinction was not conducted due to the physiognomic particularities of this vegetation class (De la Barreda-Bautista, López-Caloca, Silván-Cárdenas, & Couturier, 2011).

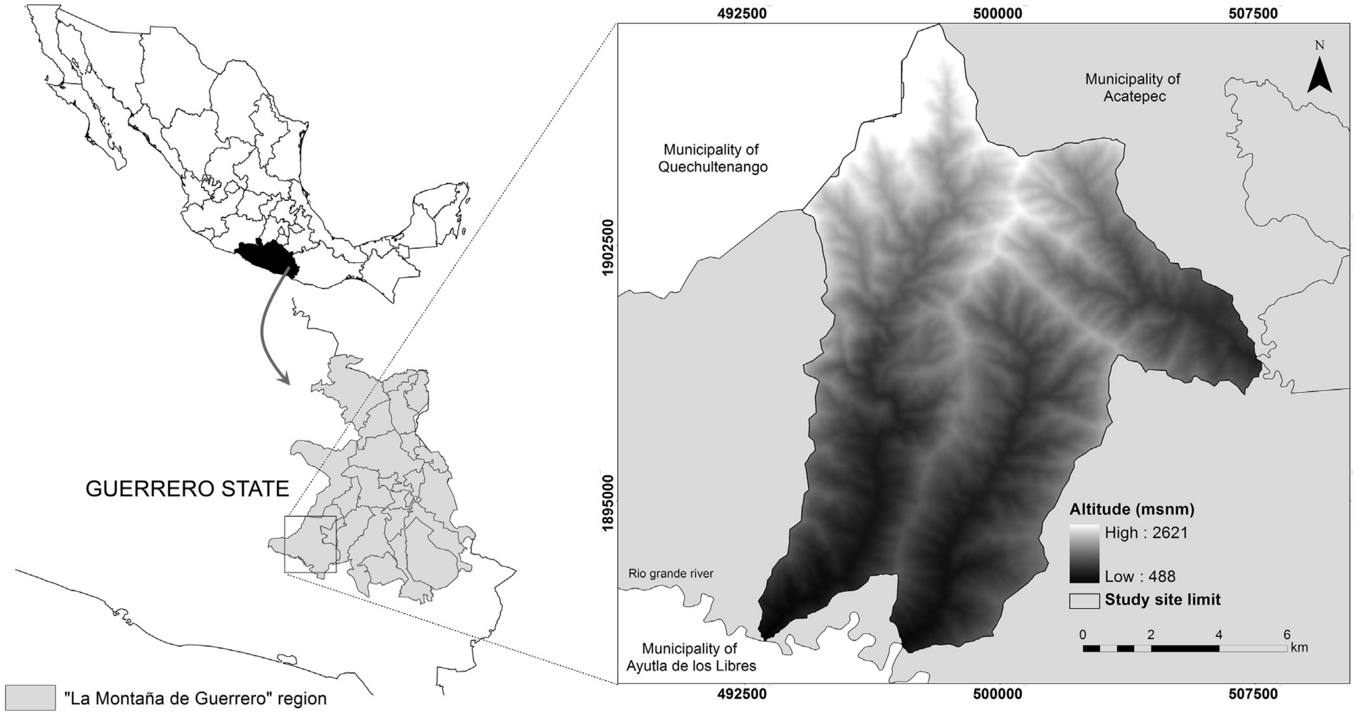

Fig. 1. Study site in the east of Guerrero State, México.

2.2.3. Accuracy assessment

The land cover map generated by the hybrid classifier was compared with reference information (100 verification sites were randomly displayed in "Google Earth" images). The error matrix method (Munsi, Areendran, Ghosh, & Joshi, 2010) was used to assess the errors of omission and commission, producer accuracy, accuracy and overall accuracy of the land cover map generated.

2.2.4. Landscape metrics

The analysis of the landscape spatial patterns was conducted based on the land cover map and landscape metrics. Landscape metrics were calculated at class level (by Rutledge, 2003, pp. 11–20; Rempel, Kaukinen, & Carr, 2012 parameters), using the extension Patch Analyst of "ArcMap 9.3" software: Number of Patches (NumP), Patch Density (PD) and Class Area (CA) were calculated for forest and non-forest class. Median Patch Size (MedPS), Mean Shape Index (MSI) and Median Size Core Area (MedCA) were calculated for *Pinus* closed forest, *Quercus* closed forest and Tropical deciduous forest. The median was calculated because the size and core area of the patches showed an asymmetric distribution. The metrics at class level do not provided information about the location of the patches within the mosaic but were important to describe the spatial heterogeneity of the landscape and their potential effect in the species dynamics.

2.3. Local scale: composition, structure and diversity of tree and shrub species in the reference sites

The landscape was divided into three altitudinal ranges (2606 to 1607 m; 1606 to 1072 m and 1071 to 520 m) according to the main vegetation types distribution in Mexico, especially tropical deciduous forest and *Pinus* and *Quercus* forest (Rzedowski, 2006, pp. 160–168). In each of them, the three least disturbed forest remnants were selected for the sampling. Thirty (50 × 2 m) transects (total area by transect = 0.01 ha, area by altitudinal range = 0.3 ha, total study area = 0.9 ha), were established perpendicular to the slope, separated by 20 m to maximize the topographic heterogeneity within them. Within each transect, diameter at breast height (DBH; $\geq$ 2.5 cm) was measured of all trees and shrubs. The individuals collected were identified and their scientific names correspond to report by The Plant List (2010). In restoration planning, the description of existing reference sites in a landscape provides relevant information to define the reference ecosystem. However, in practice, defining it requires a comprehensive study from diverse sources of information on local native species and abiotic conditions (McDonald, Gann, Jonson, & Dixon, 2016, pp. 11–24). In this study, the existing reference sites were described to survey the native species with the best socioecological characteristics (species with high potential as ecosystem services providers) that could potentiate the restoration efforts according with specific goals.

A species accumulation curve was constructed and adjusted to asymptotic Clench model with STATISTICA 10.0 software, to determinate if the number of registered species by altitude range reflected the species richness expected (Soberon & Llorente, 1993). Data of species identity, the stem diameter distribution and Relative Importance Value Index (RIVI; Curtis & McIntosh, 1950) were calculated to describe community composition and structure. Diversity was performed by estimating the Shannon's species diversity (H; Colwell, 2009) using "PAST 1.75b" Software for each forest remnant and reported as average value by altitudinal range. Finally, a Pearson correlation analysis was used to test the relationship between diversity and altitude range.

2.4. Linking scales: landscape and plant species management

2.4.1. Connectivity analyses

The connectivity among patches of the closed forest (habitat patches) in the landscape was calculated using "Conefor Sensinode 2.2" software (Saura & Torné, 2009). It was calculated the Integral Index of Connectivity (IIC) for 50 different dispersal distances (between 100 and 5000 m) and the Integral Index of Connectivity Importance Value (CIV). The dispersal distance was chosen based on a multi-species point of view (i.e., setting different dispersal distances; Devi, Murthy, Debnath, & Jha, 2013; Rothley & Rae, 2005), and according to the total area of the study site and the shortest path between every pair of patches. The IIC is a binary index (connected *vs.* not connected patch) that combines the attributes of the patches (area in this case) with the number of links in the shortest path between every pair of patches, and ranges from 0 to 1 increasing with improved connectivity. On the other hand, the CIV measures the individual habitat patches contribution or its importance in the overall landscape connectivity with reference to the IIC. The dispersal distance selected to calculate the CIV was the dispersal distance under which there were no changes in the IIC value. Organisms with this dispersal capacity are especially sensible to landscape connectivity changes (e.g., patches removal), whereas for organisms with smaller dispersal capacities, some changes in landscape connectivity will not result in significant differences in their mobility. The information required by Conefor Sensinode (the node file and the connection file) was calculated using the extension Conefor Inputs of "ArcMap 9.3" software.

In order to know the landscape elements where restoration activities to improve connectivity should be concentrated, the IIC and the CIV were calculated for two different scenarios. In the first (A) new habitat patches were included after conducting restoration activities in the patches of open forest (10–40% of tree cover). In the second (B), new habitat patches were included after conducting restoration activities in the patches of Rainfed agriculture, Induced grassland and Induced grassland with trees. In both scenarios, the patches of closed forest were maintained. The dispersal distance selected to calculate the IIC and CIV was 1000 m. The scenario recommended was that in which two characteristics were present: inclusion of patches resulted in a greater value of the IIC, and in an increase in areas occupied by patches with very high importance in the overall landscape connectivity according to CIV. These two scenarios were chosen considering that open forests possess low agricultural potential and are more suitable for passive restoration practices, while agricultural areas require more active restoration practices with a strong productive emphasis (Ceccon, 2013, pp. 139–149).

2.4.2. Plants species for restoration

The potential in restoration activities of the 10 tree and shrubs species with the highest Relative Importance Value Index (RIVI), registered in the forest remnants in each altitudinal range, was evaluated regarding their life history traits (LHT). The main characteristics evaluated were regrowth capacity, seed dispersal syndrome (preference by zoochorous species), nitrogen-fixing capability and successional group (preference for fast-growing species). Additionally, other multipurpose characteristics of the species, such as timber provision, fuelwood quality, melliferous properties, food and fodder provision as well as medicinal use, were also considered. These features from species were obtained from bibliographic information or by direct observation and local knowledge. The information was ordered in a table, which included the scientific name of the species, the common name in Me'Phaa language, the altitudinal range where the species presented a high

Table 1

Land cover classes and landscape metrics in a human-modified landscape in La Montaña region, east of Guerrero State, México. CA= Class Area, NumP = Number of Patches, PD= Patch Density (Patches/100ha), MedPS = Median Patch Size, MSI = Mean Shape Index and MedCA = Median Size Core Area. RA = Rainfed agriculture, PCF= *Pinus* closed forest, QOF = *Quercus* open forest, POF= *Pinus* open forest, QCF = *Quercus* closed forest, IGT= Induced grassland with tree, IG= Induced grassland, HS= Human settlements, TDF = Tropical deciduous forest, UR= Unpaved road, GV = Gallery vegetation, BS= Bare soil, BSG= Bare soil by glide and R = River.

Land cover classes	CA (ha)	CA (%)	NumP	PD	MedPS (ha)	MSI (–)[a]	MedCA (ha)
RA	3995.75	29.6	158	1.17	–	–	–
PCF	2242.32	16.6	34	0.25	20.45	2.33	8.7
QOF	2102.15	15.6	97	0.72	–	–	–
POF	2016.85	15	91	0.68	–	–	–
QCF	1577.72	11.7	38	0.28	20.65	2.37	3.5
IGT	585.67	4.3	71	0.53	–	–	–
IG	376.78	2.8	51	0.38	–	–	–
HS	224.45	1.7	33	0.25	–	–	–
TDF	116.09	0.9	19	0.14	2.83	2.79	0
UR	93.77	0.7	21	0.16	–	–	–
GV	70.61	0.5	13	0.1	–	–	–
BS	52.12	0.4	10	0.07	–	–	–
BSG	10.23	0.1	3	0.02	–	–	–
R	4.36	0.1	1	0.01	–	–	–

[a] (–) mean without units.

value of RIVI, the evaluated characteristics, and the reference sources.

3. Results

3.1. Landscape scale: spatial patterns analysis

3.1.1. Land cover map and accuracy assessment

Using the hybrid classification a map was produced with 14 land cover classes (Table 1). The classes with highest omission errors (>42%) were Bare soil, Induced grassland and Human settlements, and with commission errors (>60%) was Bare soil, which possess high spectral similarity with glides and Induced grasslands. The class with the lowest producer and user accuracy was Induced grassland (between 40 and 50%). However, the overall accuracy was 81%, suggesting a good graphic representation considering the mountainous nature of the landscape.

3.1.2. Landscape metrics

The study area comprised a 13468.8 ha distributed in 640 patches. The landscape metrics analysis (Table 1) showed that human managed areas comprised by Rainfed agriculture class (CA = 29.6%), Induced grassland with trees (CA = 4.3%), Induced grassland (CA = 2.8%), Human settlements (CA = 1.7%), Unpaved road (CA = 0.7%), Bare soil (CA = 0.4%), Bare soil by glide and River (CA = both 0.1%), representing 40% of the total area. On the other hand, native vegetation area comprised by *Pinus* closed forest (CA = 16.6%), *Pinus* open forest (CA = 15%), *Quercus* open forest (CA = 15.6%), *Quercus* closed forest (CA = 11.7%), Tropical deciduous forest (CA = 0.9%) and Gallery vegetation (CA = 0.5%), representing 60% of the total area.

The Rainfed agriculture class possesses the highest number of patches (NumP) in the landscape (158; 1.17 patches/100 ha); followed by *Quercus* open forest (97; 0.72/100 ha) and *Pinus* open forest (91; 0.68/100 ha). Conversely, the classes with less NumP were *Quercus* closed forest (38; 0.28/100 ha), *Pinus* closed forest (34; 0.25/100 ha), Tropical deciduous forest (19; 0.14/100 ha) and Gallery vegetation (13; 0.10/100 ha). Also, 188 (64%) from 292 patches of native vegetation were considered as “open” (10–40% of tree cover).

The median size of patches of *Pinus* closed forest, *Quercus* closed forest and Tropical deciduous forest classes was <21 ha, and all of them showed irregular shape (MSI = 2.33, 2.37 and 2.79, respectively). According with the core area analyses, 61% of the *Pinus* closed forest and *Quercus* closed forest patches had core area, assuming 100 m of buffer area from the edge, and 50% of them were <10 ha (MedCA = 8.7 and 3.5 ha, respectively). A similar trend was observed in the Tropical deciduous forest patches; only 21% had core area, and all of them were <11 ha (MedCa = 0 ha).

3.2. Local scale: composition, structure and diversity of tree and shrub species in the reference sites

3.2.1. Floristic composition

According to the asymptotic Clench model, sampling effort was enough, achieving around 75% of trees and shrub species (DBH; ≥ 2.5 cm) in the forest remnants from each altitudinal range. Although, according with the model, sampling was more thorough in the highest range (2606 to 1607 m; Table 2).

In total, 1995 woody individuals were found in 90 sampling units from the study area, representing 37 families, 69 genera, and 99 species. Only eight species were not identified (Table 3). Family composition varied with the altitudinal range. In the highest altitudinal range forest remnants (2606 to 1607 m), Fagaceae and Ericaceae were the most species rich families (six

Table 2

Number of species observed, asymptotic richness and the percentage of the asymptotic richness registered at different altitudinal ranges in a human-modified landscape in La Montaña region, east of Guerrero State, México.

	Altitudinal range (m)		
	2606-1607	1606-1072	1071-520
Number of transect (0.01 ha)	30	30	30
Sampled area (ha)	0.3	0.3	0.3
Number of species observed	25	28	61
Asymptotic richness	29	33	81
Percent of the asymptotic richness registered	86.2	84.8	75.3

Table 3
Floristic composition of trees and shrubs with a DBH ≥ 2.5 cm at different altitudinal ranges in a human-modified landscape in La Montaña region, east of Guerrero State, México.

	Altitudinal range (m)		
	2606-1607	1606-1072	1071-520
Number of individuals	839	621	535
Families	15	13	25
Genera	20	19	46
Species	26	28	61

and five species respectively). In the middle range (1606 to 1072 m) were Fagaceae and Leguminosae (eight and five species respectively), while in the lowest range (1071 to 520 m) were Leguminosae and Malvaceae (10 and six species respectively). *Quercus scytophylla* (Fagaceae) was the most abundant species in the highest altitudinal range, *Q. elliptica* (Fagaceae) in the middle and *Pseudobombax ellipticum* (Malvaceae) in the lowest range.

3.2.2. The relative importance value index (RIVI)

The most important species inside the highest altitudinal range forest remnants were *Q. scytophylla* (RIVI = 23%) and *Q. obtusata* (IVIR = 13%), in the middle range were *Q. elliptica* (RIVI = 19%) and *Q. magnoliifolia* (IVIR = 15%) and in the lowest range were *P. ellipticum* (RIVI = 19%) and *Cochlospermum vitifolium* (RIVI = 10%; Fig. 2).

3.2.3. Diametric distribution

The analysis of diametric distribution showed a highest proportion of individuals with small DBH (<11 cm) encompassing between 40 and 60% of the individuals in all altitudinal ranges (Fig. 3).

3.2.4. Diversity of tree and shrub species

The Pearson correlations analysis showed that Shannon's species diversity index was negative correlated with the altitude range ($r = -0.82$, $P < 0.01$; Table 4).

3.3. Linking scales: landscape and plant species management

3.3.1. Connectivity analyses

The Integral Index of Connectivity (IIC) showed that the current connectivity in the landscape was very low for all dispersal distances evaluated (<0.1 in the all cases, Fig. 4), considering that ranges from 0 to 1, and increases as connectivity is improved. Additionally, revealed that there wasn't any change in the IIC value for the species with a dispersal capability less to 1000 m, indicating that these species are the most affected by the current arrangement of habitat patches.

According with the results, the Integral Index of Connectivity Importance Value (CIV) was calculated for a dispersal distance of 1000 m. The importance wasn't equal for all habitat patches and was highest in the larger patches (Fig. 5).

After comparing the two scenarios: A (new habitats from restoration in open forests patches) or B (new habitats from restoration in productive patches), it was observed that the IIC value for the species with a dispersal capability of 1000 m was similar in both scenarios (scenario A = 0.23 and scenario B = 0.24). In both cases, the IIC value increased in relation to its original value from current landscape for this dispersal capability (current IIC = 0.006; Fig. 4). On the other hand, the area occupied by patches of high importance in the overall landscape connectivity according

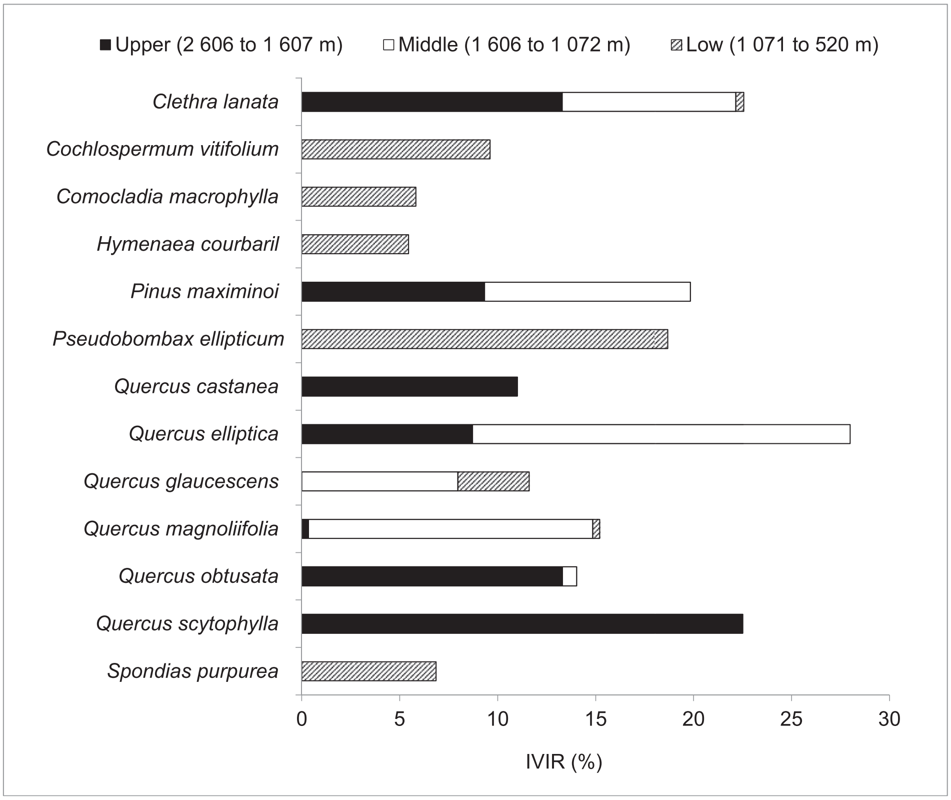

Fig. 2. Relative Importance Value Index (RIVI) of the five most important species at different altitudinal ranges in a human-modified landscape in La Montaña region, east of Guerrero State, México.

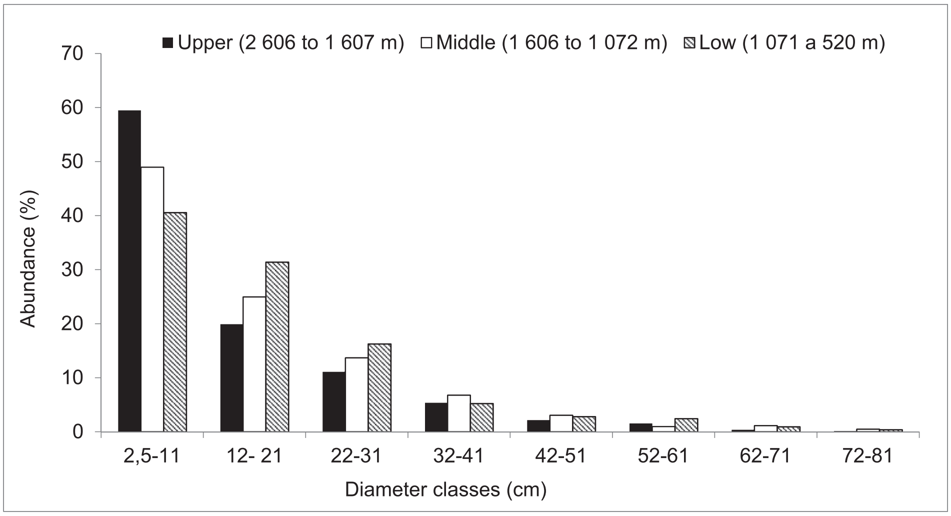

Fig. 3. Stems distribution of trees and shrubs with a DBH ≥ 2.5 cm at different altitudinal ranges in a human-modified landscape in La Montaña region, east of Guerrero State, México.

Table 4
Diversity: Shannon diversity index (H) and the correlations analysis (Pearson) at different altitudinal ranges in a human-modified landscape in La Montaña region, east of Guerrero State, México. Indexes were reported by altitudinal range as the average (mean ± SE) of the values obtained for each of the sampling sites.

	Altitudinal range (m)			Pearson (r)
	2606-1607	1606-1072	1071-520	
Shannon diversity (H)	1.5 ± 0.20	1.8 ± 0.09	2.8 ± 0.24	$r = -0.82$, $P < 0.01$

to the CIV, was 6465 ha in the first scenario and 6569 ha in the second (Fig. 6).

3.3.2. Plants species for restoration

From 24 assessed species, 12 (50%) showed regrowth capacity and five (20.8%) of them were frequently used as living fences. Also 12 of species (50%) were zoochorous, mostly were dispersed by birds and small mammals. Nine (37.5%) of the species assessed were fast-growing trees and only two (8.3%) of them were nitrogen-fixing species. Related to main uses, 17 of them (70.8%) were frequently used as fuelwood, 18 species (75%) were used in manufacture of tools, and 14 (58.3%) were human or animal food source. Finally, 14 species (58.3%) were used in traditional medicine and five (20.8%) were melliferous (Table 5).

4. Discussion

In the La Montaña region, the landscape showed a spatial pattern characteristic of a highly human-modified landscape (Brancalion, Melo, Tabarelli, & Rodrigues, 2013). Although it was covered mainly by forest (60% of total area), most fragments (64%) were considered "open", indicating that their forest structure and composition had been highly modified. These results were opposed to those found by Tambosi, Martensen, Ribeiro, and Metzger (2014), who considered landscape forest cover between 40 and 60% as a high resilient landscape, able to recover by autogenic processes, though they did not consider local conditions or the modification levels of forest remnants.

The mapped open forests possibly were a product of intensive fuelwood extraction (Miramontes et al., 2012; Salgado, 2015). In this region, 100% of the people use fuelwood for cooking (Salgado, 2015) and their pattern of fuelwood searching was typical of degraded landscapes (Miramontes et al., 2012). In fact, the diversity of *Quercus* closed forest remnants and *Pinus* closed forest remnants, in the highest and middle range (H' = between 1.5 ± 0.20 and 1.8 ± 0.09), was within the range of other mixed Pine Oak communities, disturbed by selective harvesting in Mexico (H' = 0.8 to 2.19; Castellanos-Bolaños, Treviño-Garza, Aguirre-Calderón, Jiménez-Pérez, & Velázquez-Martínez, 2010). On the other hand, a forest structure analysis showed that the most species used as fuelwood by Me'Phaa peasants (Salgado, 2015) presented a high percentage (between 50 and 70%) of small trees (DBH < 21 cm). This large abundance of small individuals was probably due to selective harvesting of larger (older) trees generating light niches for tree regeneration from seed or regrowth from harvested trees (Ajbilou, Marañón, & Arroyo, 2003; Martínez-Ramos & Álvarez-Buylla, 1995). Selective harvesting in a degraded landscape may decrease the population size and basal area, reducing tree species richness and phylogenetic diversity (Silva, Kanashiro, Ciampi,

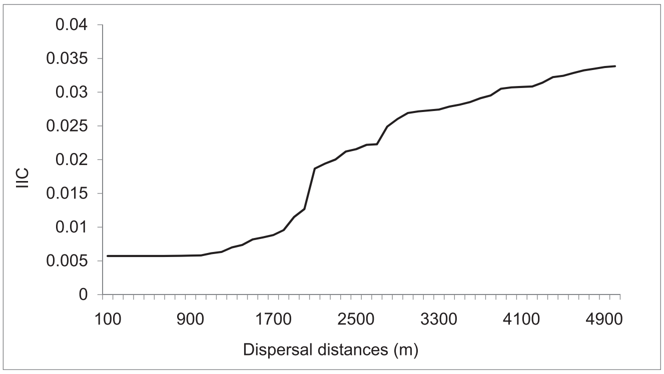

Fig. 4. The Integral Index of Connectivity (IIC) value to different dispersal distances in a human-modified landscape in La Montaña region, east of Guerrero State, México.

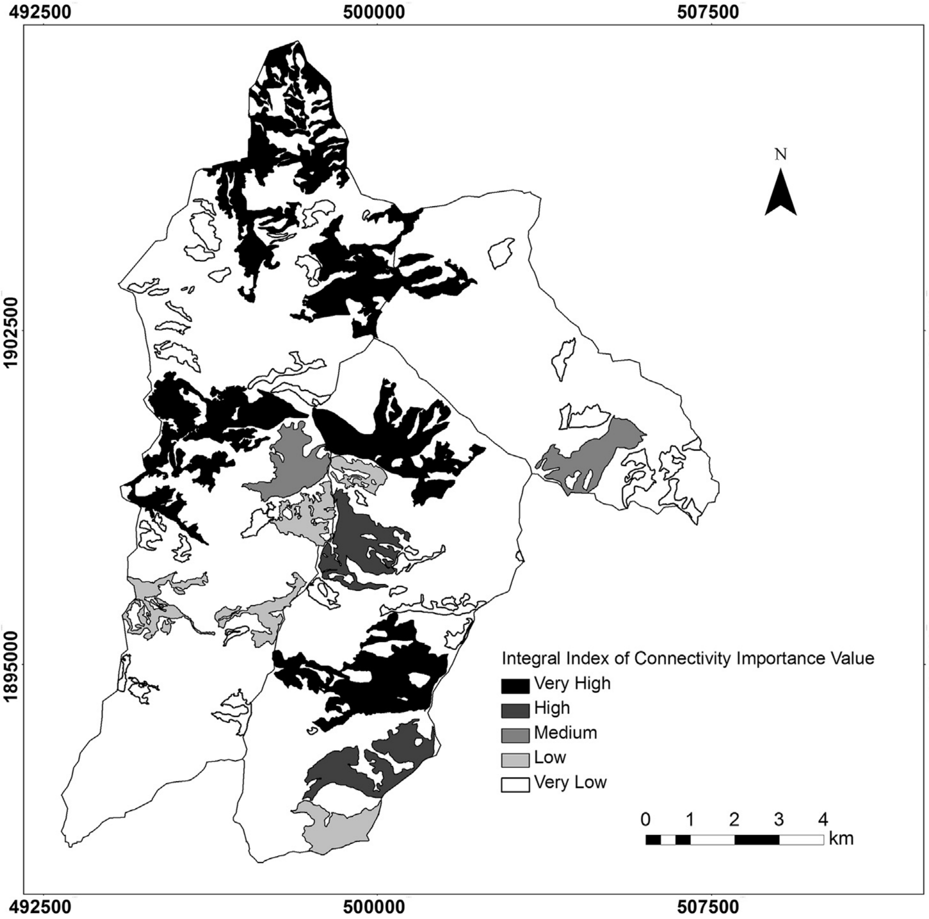

Fig. 5. The Integral Index of Connectivity Importance Value (CIV) of habitat patches in a human-modified landscape in La Montaña region, east of Guerrero State, México.

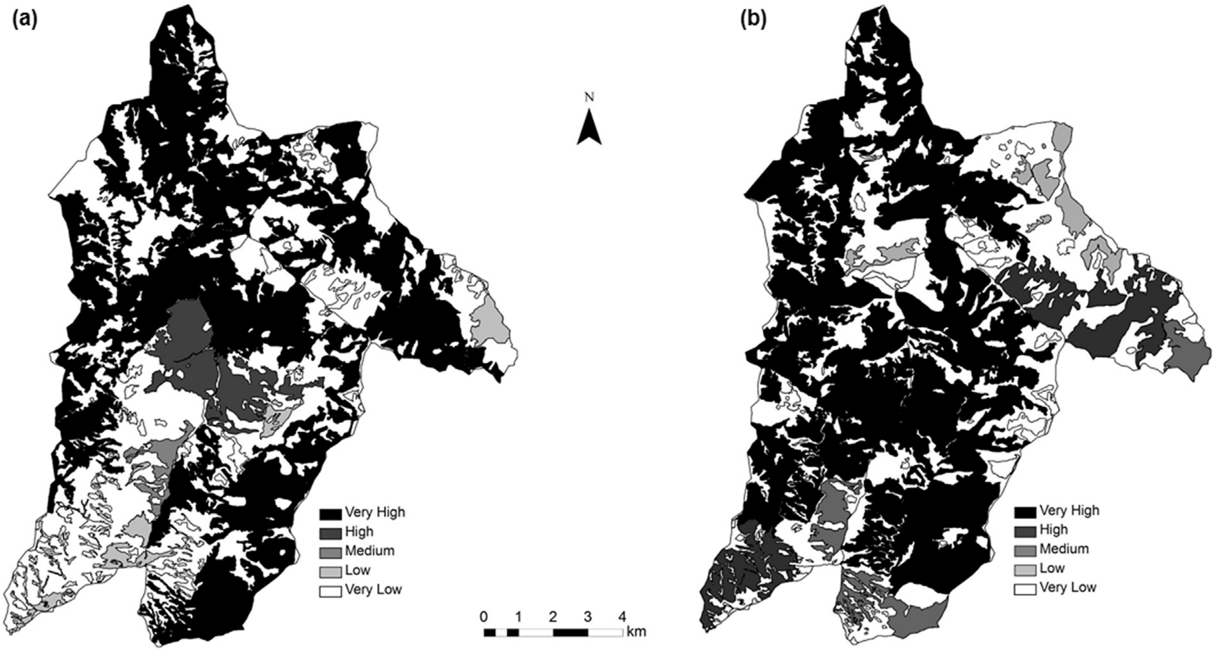

Fig. 6. The Integral Index of Connectivity Importance Value (CIV) of habitat patches in two different scenarios, in a human-modified landscape in La Montaña region, east of Guerrero State, México: (a) Scenario A: new habitat patches are included after conducting restoration activities in the patches of open forest. (b) Scenario B: new habitat patches are included after conducting restoration activities in patches of Rainfed agriculture, Induced grassland and Induced grassland with trees.

Table 5
Plants species for restoration in a human-modified landscape in La Montaña region, east of Guerrero State, México. ^{a}AR (altitudinal range where species was registered): u = upper range (2606 to 1607 m), m = middle (1606 to 1072 m), l = low (1071 to 520 m). ^{b}LHT (Life History Traits): R = Regrowth, R* = Regrowth and report as live fence, Z = Zoochorous, FG= Fast-growing trees, N= Fix nitrogen. ^{c}Others: Fw = Fuelwood, T = Timber, F= Food, fruit and/or edible seeds, Md = Medicinal, Me = Melliforous.

Specie	Common name in Me'Phaa	^{a}AR	^{b}LHT	^{c}Others	Reference source
Arbutus xalapensis	Ixi Xixii	u	R,Z	Fw,T,F	22,23,25,26,17,10
Byrsonima aff. *crassifolia*	Ixi Luxo	m,l	R*,Z, FG	Fw,T,F,Md, Me	10,8,6,15,13,24,4
Ceiba aesculifolia	Ixi Mogorixi	l		F,Md	1,4
Clethra lanata	Ixi Maja	u, m,l		Fw,T	27,20
Cochlospermum vitifolium	Ixi Xtabiyu	l	R*,FG	Fw,T,F,Md, Me	27,5,15,13,24,4
Comocladia macrophylla	Ixi Xtin	l	With irritating substance		27,22
Hymenaea courbaril	Ixi Reejne	l	R,Z,N	Fw,T,F,Md, Me	27,22,6,24,18,4
Leucothoe mexicana	Ixi Nixo	u,m		Mi	27
Myrsine coriacea	Ixi Razií	u	Z,FG	Fw,T,md	12
Pinus maximinoi	Xtikaa	u,m	R,FG	Fw,T,Md	27,13,3,21,4,20
P. oocarpa	Xtikaa	m	R,FG	Fw,T	10,6,21
Plumeria rubra	Ixi Ri'sut	l	R*,FG	Md	13,24
Pseudobombax ellipticum	Ixi Ruma Xtuwa	l	R*,FG	Fw,F,Md	10,13,4,14
Pterocarpus acapulcensis	Ixi E'jdi	l	N	M	22,15
Quercus aff. *martinezii*	Ixi Xtuxa	m	Z	Fw,T	22,7,9,2
Q. castanea	Ixi Nunií	u	R,Z	Fw,T,F	22,9,11,2,20
Q. conspersa	Ixi Xtein	m,l	Z	Fw,T,F,Md	22,9,11,2
Q. elliptica	Ixi Xtamaña	u,m	R,Z	Fw,T,Md	27,22,9,6,11,2,4,20
Q. glaucescens	Ixi chabón	m,l	Z	Fw,T,Md	22,9,11,2
Q. magnoliifolia	Ixi Ixtapaá	u, m,l	R,Z	Fw,T,F,Md	27,22,11,16,2,4,20
Q. obtusata	Ixi Xó	u,m	Z	Fw,T,F, Md	22,7,11,2,20
Q. scytophylla	Ixi xáno	u	Z	Fw,T,F	27,22,7,9,11,2,20
Spondias purpurea	Ixi Sidín	l	R*,Z, FG	T,F,Md,Me	27,10,8,6,19,13,24,4
Xylosma intermedia	Ixi Súwan	l	Z		22

References source: **1.** Aguilar and García (2004), **2.** Arizaga, Martínez, Salcedo, and Bello (2009), **3.** Arteaga and Pérez (2001), **4.** Biblioteca digital de la medicina tradicional mexicana, UNAM (2009), **5.** Cedano and Villaseñor (2004), **6.** Cordero and Boshier (2003), **7.** De la Paz Pérez (1974), **8.** Esquivel et al. (2003), **9.** González (1986), **10.** Hernández, González, and González (1991), **11.** Luna, Montalvo, and Rendón (2003), **12.** Mahecha, Ovalle, Camelo, and Rozo (2004), **13.** Martínez, Evangelista, and Basurto (2007), **14.** Navarrete and Orellana (2010), **15.** Pennington and Sarukhán (2005), **16.** Peña and Bonfil (2003), **17.** Powell (1988), **18.** Rodríguez, Sinaca, and Jamangapé (2009), **19.** Ruíz-Alemán, Gómez, and Harvey (2005), **20.** Salgado (2015), **21.** SIRE (2005), **22.** Standley (1920–1926), **23.** Van Dersal (1938), **24.** Vázquez-Yanes, Batis, Alcocer, Gual, and Sánchez (1999), **25.** Vines (1960), **26.** Wiedenfeld (1975), **27.** Information obtained in field.

Thompson, & Sebbenn, 2008; Toyama et al., 2015).

Several authors in diverse temperate and tropical ecosystems have found negative effects of the irregular shape and size reduction of fragments on the species population dynamics, mostly related to edge effects (Benítez-Malvido & Arroyo-Rodríguez, 2008; Haddad et al., 2015; Laurance et al., 2002; Pardini, De Souza, Braga-Neto, & Metzger, 2005; Torrella, Ginzburg, Adámoli, & Galetto, 2013). Forest edge effects can reach up to 100 m from the forest edge, consequently, irregular fragments with less than 10 ha are completely affected by this phenomenon (Gonzalez et al., 2010; Laurance et al., 2002). In this study, half of the tropical deciduous forest remnants, and *Quercus* and *Pinus* closed forest remnants were small (<3 ha and <21 ha respectively), and all of them were irregularly shaped, indicating a strong edge effects (Gonzalez et al., 2010; Laurance et al., 2002). Probably, these edge effects also helped to generate the current forest structure of the study area.

Moreover, the use and modification of remaining natural habitats by people that depend on local natural resources may create a "novel ecosystem" (*sensu* Hobbs, Higgs, & Harris, 2009) that differs from original counterparts in terms of provision of ecosystem services and landscape biodiversity conservation (Collier, 2015; Ferraz et al., 2014; Pütz et al., 2014). Thus, remaining forests in these landscapes must to be conserved and restored because of their importance as landscape biodiversity refuges and propagules sources for surrounding areas. Furthermore, biodiversity levels and resilience in these refuges are much greater than in areas were forest has been completely cleared (Viani, Mello, Chi, & Brancalion, 2015).

In La Montaña region, as well as in the rest of Mexico, the situation of tropical deciduous forest is critical (Trejo & Dirzo, 2000), since this biome is restricted to areas with steep slopes and occupies now only 5% of its original distribution, if we consider all the study area below 1000 m as its historical distribution (Rzedowski, 2006, pp. 160–168). Moreover, in this study, although the tropical deciduous forest remnants showed a diversity (H' = 2.8 ± 0.24) similar to that reported in some Mexican old tropical deciduous forests (H' = 3.34 Lebrija-Trejos, Bongers, Pérez-García, & Meave, 2008; H' = 3.0 Lebrija-Trejos, Meave, Poorter, Pérez-García, & Bongers, 2010), they still exhibited a structure and species composition characteristic of disturbed communities in a early successional phase (Cordero & Boshier, 2003, pp. 1–223; Pennington & Sarukhán, 2005, pp. 149–165). These results emphasize that tropical deciduous forest restoration is an urgent priority in La Montaña region.

The current landscape connectivity was very low for all dispersal distances evaluated (between 100 and 5000 m) and those species with a capacity for dispersal up to 1000 m were the most severely affected by the current distribution of habitat patches. The largest fragments also showed a greater importance in overall landscape connectivity. This result highlights the need to protect the largest and more conserved remnants and improve the connectivity in the landscape by increasing the area of smaller fragments or improving the quality of the agricultural matrix, which will increase the connectivity among forest remnants. According to several authors, reducing the isolation among habitat patches can be more effective than only conserving the diversity within the patches or manipulating their shapes (Flores-Ramírez & Ceccon, 2014; Perfecto & Vandermeer, 2010; Tambosi et al., 2014). Loss of forest remnants is likely to reduce biodiversity within agricultural matrix and exacerbate overall biodiversity loss in the landscape (Anand, Krishnaswamy, Kumar, & Bali, 2010).

Regarding the improvement of connectivity among fragments, it was found that the enrichment in open forests remnants and the restoration of new habitats patches in productive areas were similar in terms of connectivity increasing (Fig. 6). According to current socioecological conditions found in La Montaña region, as well the strong pressure on the ecosystem resources for fuelwood extraction (Salgado, 2015), the most suitable option for restoration should includes the involvement of communities and should offer the best possibilities of tangible benefits for them (Brancalion et al., 2013; Ceccon, 2013, pp. 139–149; Harvey et al., 2008; Perfecto & Vandermeer, 2010). In this sense, we propose activities in both scenarios: protection and enrichment of open forest remnants with native species mostly used for fuelwood by local people (Salgado, 2015), promoting natural regeneration and making restoration more attractive and useful for these rural communities (Brancalion, Viani, Strassburg, & Rodrigues, 2012; Ceccon, 2013, pp. 139–149). Moreover, the restoration of new habitats in productive areas should be carried out by using a productive restoration strategy (*sensu* Ceccon, 2013, pp. 139–149), which uses agroecological and agroforestry tools to benefit local populations by creating more resilient and biodiversity-friendly landscapes (Chappell, Vandermeer, Badgley, & Perfecto, 2009; Melo, Arroyo-Rodríguez, Fahrig, Martínez-Ramos, & Tabarelli, 2013; Perfecto & Vandermeer, 2010).

According with the landscape and local analysis provided in this study, an appropriate starting point for any of the two landscape restoration scenarios is conducting restoration activities in “highly important” patches in the overall landscape connectivity (Fig. 6), and with the most important plant species for each altitude range (Table 5). However, to define specific restoration sites and strategies is necessary to involve all the communities, decision makers, and institutions in a coordinated effort. Thus, Xuajin Me’Phaa A.C. could play a key role to achieve this goal.

5. Conclusion

The landscape of La Montaña region showed a spatial pattern characteristic of a highly human-modified landscape. Although most of the landscape was covered by forest, most of fragments were considered “open”, half of them were small (>21 ha) and all had an irregular shape, indicating the possibility of strong forest edge effects.

Temperate forest remnants showed a structure and diversity characteristic of communities disturbed by selective harvesting. The situation for the tropical deciduous forest was critical because, in the study site, it occupied only 5% of its historical distribution and showed a structure and species composition characteristics of disturbed communities.

The current landscape connectivity was very low for all the evaluated dispersal distances, and the largest fragments showed greater importance in the overall landscape connectivity. Conservation of these forest remnants through protection and restoration of local habitats and increased landscape connectivity needs to be prioritized.

The protection and enrichment of open forests remnants and the restoration of new habitats in productive areas were found as equally important strategies for the restoration of the connectivity. Ideally, the enrichment of open forest remnants could be implemented with native and useful species (e.g., mainly species used for fuelwood by local people) and the restoration of new habitats could be enhanced using productive restoration strategies such as the use of agroecological and agroforestry tools.

Linking landscape and local approaches within a socioecological context is fundamental for implementing strategies to improve the connectivity and reducing the negative effects of fragmentation. Although this study focused on a human-modified landscape of La Montaña region, the same approach could be applied to other highly human-modified tropical landscapes with similar socioecological problems.

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We emphasize that we sympathize with the pain and anger of family of young Ayotzinapan; we demand that the facts clarified shortly, irrefutably, and that the guilty are punished to the fullest extent of the law, regardless of their political and economic hierarchy. We also insist on the real and peaceful resolution of social conflicts in our multinational and democratic society, with a vision of sustainable regional development with social inclusion.

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