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Can traditional selective logging secure tree regeneration in cloud forest?

Perla Ortiz-Colín (1), Tarin Toledo-Aceves (1), Fabiola López-Barrera (1), Patricia Gerez-Fernández (2)

Unplanned selective logging for charcoal and firewood is a common practice in tropical montane cloud forest (TMCF), a high priority ecosystem for biodiversity conservation at the global scale. However, limited information is available regarding the impact of such logging on forest regeneration. We evaluated the abundance and composition of tree regeneration in four TMCF sites subject to traditional selective logging in southern Mexico. At each site, we calculated a tree extraction index based on the number of stumps, logs and charcoal kilns and established six 200 m^2 plots where the abundance of adult, sapling and seedling trees were recorded and canopy cover estimated. Based on the extraction index and estimated basal area values, two sites each were classified as being of low (L) and high (H) logging intensity; the extraction index was three times lower in L (7.5 and 9.2) than in H (35 and 35) sites, while basal area was significantly higher in L than in H sites (80.2 ± 10.2 *vs*. 41.9 ± 4.96 m^2 ha^{-1}, respectively). No significant differences were found among sites in terms of canopy cover, diameter and density of adult trees or in the density of saplings and seedlings (0.72 individuals m^{-2}). In all sites, species of intermediate shade-tolerance dominated the regeneration (76%), followed by the shade-tolerant (23%) and pioneer (1%) species. Regeneration of *Quercus* spp. (four species) dominated at all sites (50.5%); this is a group of particular interest to the local communities because of its utility for firewood and charcoal. The similarity in composition between adult and regenerating tree species was relatively high in all of the sites (Morisita-Horn Index L1=0.86, L2=0.64, H1=0.69 and H2=0.71). These results indicate that, under the evaluated selective logging intensities, TMCF can sustain sufficient regeneration of *Quercus* spp. and thus presents an opportunity for sustainable management. The legacy effects of traditional selective logging on TMCF tree regeneration are discussed.

Keywords: Firewood, Forest Management, Mexico, *Quercus*, Seedlings, Timber Harvesting, Tropical Montane Cloud Forest, Disturbance

Introduction

Secondary and degraded forests currently form the dominant components in tropical landscapes, covering an area larger than that of primary forests (Chazdon 2003, FAO 2015). The degree of contribution of degraded forests to biodiversity conservation depends on the type, intensity and frequency of disturbance to which these have been subjected (Gibson et al. 2011, Putz et al. 2012). A common cause of degradation in tropical forests worldwide is selective logging to obtain timber, firewood and charcoal (Chidumayo & Gumbo 2013). This unplanned practice consists of the isolated extraction of trees above a certain trunk diameter, and involves no measures to reduce the consequent negative impacts on diversity. Compared to other types of disturbance, such as the conversion of forest to agricultural and livestock production uses, selective logging has considerably less impact on the diversity of species in tropical forests (Gibson et al. 2011, Carreño-Rocabado et al. 2012); however, the impacts of traditional selective logging on the regeneration of different tropical forests are poorly understood because of the particular nature of the characteristics and traditional uses in each ecosystem.

Chronic selective logging is an activity historically practiced in the tropical montane cloud forest (TMCF), one of the most threatened tropical ecosystems worldwide (Scatena et al. 2010). This ecosystem has high conservation priority status because of its high alpha and beta diversity, as well as the range of environmental services it provides (Kappelle et al. 1996, Scatena et al. 2010). The TMCF are frequently located in inaccessible gullies and on steep slopes, with trees of variable commercial quality and low productivity (Scatena et al. 2010) that present low potential for timber forestry (Toledo-Aceves et al. 2011). Nevertheless, these forests are exploited daily by local communities through unregulated traditional extraction, whose production is essentially of subsistence (Rüger et al. 2008). Despite the wide distribution of forest management practices in Mexico, there

(1) Instituto de Ecología A. C., Carretera antigua a Coatepec 351, El Haya, Xalapa 91070, Veracruz (México); (2) Instituto de Biotecnología y Ecología Aplicada, Universidad Veracruzana, Zona Universitaria, Xalapa 91090, Veracruz (México)

@ Tarin Toledo-Aceves (tarintoledo@gmail.com)

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are no records of TMCF under authorized forest management (CONABIO 2010). In addition to other factors of change, selective logging threatens the persistence of populations of tree species that are exclusive to this ecosystem. It is estimated that more than 60% of TMCF tree species in Mexico are threatened and many of these species are affected by a decline in their natural regeneration (González-Espinosa et al. 2011).

Regeneration is a key process, since the establishment and survival of seedlings is crucial to the reproductive success and population dynamics of species. Among the main effects of selective logging is increased canopy openness, which affects germination and growth of established seedlings (Guariguata & Pinard 1998, Kozlowski 2002, Nabe-Nielsen et al. 2007). Studies of the effect of selective logging on the diversity of tree regeneration in tropical forests under planned forestry management have produced contrasting results. While selective logging can negatively affect the diversity and regeneration of tropical and temperate forests (Farwig et al. 2008, Clark & Covey 2012), opening of the canopy as a consequence of planned extraction can also have positive effects on the regeneration of certain timber species (Guariguata & Sáenz 2002, Götmark 2007, Duah-Gyamfi et al. 2014). In a recent meta-analysis of tropical forests, Martin et al. (2015) found that tree richness increased with low logging intensities and *vice versa*. Most studies agree that selective logging has a significant influence on species composition (Decocq et al. 2014, Farwig et al. 2008), while other studies report effects on functional guilds or ecological groups (Carreño-Rocabado et al. 2012, Imai et al. 2012).

Understanding the regeneration dynamics in response to tree extraction is therefore essential for effective TMCF management. However, there are very few studies that address selective logging in TMCF and its effects on the structure and composition of arboreal regeneration (Rüger et al. 2008). The objectives of this study were therefore: (i) to evaluate the extent of extraction in TMCF fragments subjected to chronic selective logging; (ii) to determine the nature of its relationship with tree structure and composition, as well as its influence on tree regeneration.

Methods

Study area

The study was conducted in the sub-basin of the River Pixquiac, within the La Antigua basin, in Veracruz, Mexico. This is a region of high priority for the conservation of TMCF (Toledo-Aceves et al. 2011). The landscape is dominated by patches of secondary and degraded TMCF, livestock pastures and agricultural land (Muñoz-Villers & Lopez-Blanco 2008). Total annual precipitation is 1650 mm and the annual average temperature is 14 °C (Williams-Linera 2002). Selective extraction of trees in this region varies in intensity and frequency, but it is a widely distributed practice that follows no planned method. Trees ≥40 cm in diameter and species of high dendroenergetic value are selected for extraction. These mainly belong to the genus *Quercus* and are mainly used to produce firewood and charcoal (Haeckel 2006). In order to produce charcoal, logs are cut within the forest and processed in rudimentary kilns constructed in the forest soil.

Site selection and degree of extraction

In order to evaluate the status of regeneration with selective logging, four TMCF sites were chosen with a history of frequent selective logging over recent decades, but with no other form of disturbance (*e.g.*, grazing in the forest, fires, introduction of exotic species - Tab. 1). Since no undisturbed forests were present within the study area (due to selective logging or other perturbations, such as grazing and unpaved forest roads), it was not possible to select a control treatment as reference. In the studied forests, clandestine tree extraction continues to occur with no authorization from the landowners. Analysis of panchromatic aerial photographs (1975, 1995 and 2004 – 1:20.000 scale, INEGI) confirmed that the four study sites had maintained continuous forest cover over the preceding 40 years. Slope varied from 58 to 69% among the sites.

An extraction index (modified from Ramírez-Marcial et al. 2001) was developed in order to characterize each site. An area of ~1.2 ha within and around the vegetation measurement plots (described below) was examined, and the numbers of tree stumps, logs and charcoal kilns recorded. Tree stump diameter was measured at the base (10 cm above ground level).

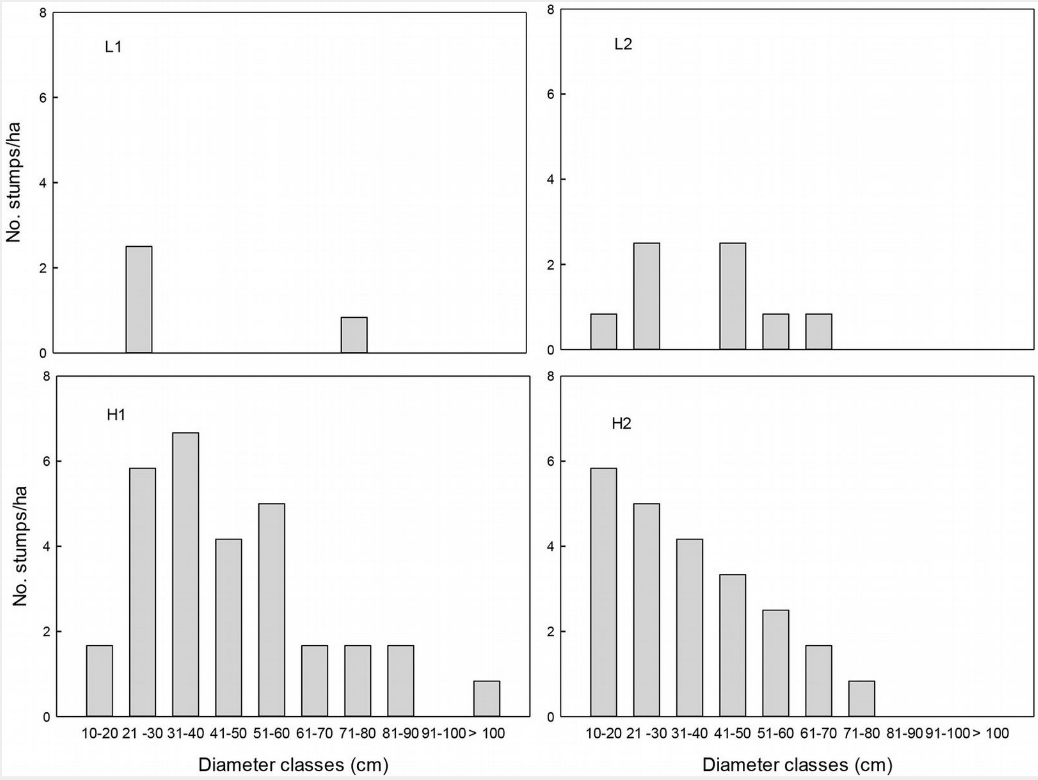
Woody vegetation and canopy coverage

In each site, six plots of 10×20 m (200 m^2) were established at least 15 m far from the edge of the forest fragment and were distributed equidistantly. In each plot, the diameter at breast height (DBH, 1.3 m above the ground) of all trees with DBH ≥ 10 cm was recorded, while the height of the five trees with the largest trunks was determined with a clinometer. A subplot of 5×5 m (25 m^2) was randomly established in one of the corners of each 200 m^2 plot in order to record all saplings >1 m in height and <10 cm DBH. The height and DBH values of all the individual saplings were recorded. In addition, four subplots of 1×1 m were established along the central axis of each 200 m^2 plot (two at each side in an alternating pattern) in order to record tree seedlings > 0.2 m and ≤ 1 m in height. The 1 m^2 subplots were located at a distance of 3 m from the extremes of the plot and were equidistantly distributed. Maximum seedling height and stem basal diameter were recorded. In order to evaluate the relationship between canopy coverage and regeneration, the canopy coverage in the center of each 1 m^2 plot was measured with a convex densiometer.

Tab. 1 - Cloud forest structural variables (mean ± standard error) and tree diversity in sites with low (L1 and L2) and high (H1 and H2) selective logging intensities in Veracruz, Mexico. Data pertaining to seedlings (0.20-1 m height), saplings (>1 m height and <5 cm DBH) and adult trees (> 10 cm DBH) are presented. (DBH): diameter at breast height; (H′): Shannon-Wiener index, calculated for adult trees. Different letters denote significant differences between logging levels after Tukey's *post hoc* analysis (*P* < 0.05).

Parameter	Logging Level			
	L1	L2	H1	H2
Coordinates	19° 31′ 36″ N 96° 59′ 30″ W	19° 31′ 59″ N 97° 00′ 08″ W	19° 30′ 58″ N 97° 00′ 27″ W	19° 31′ 04″ N 97° 00′ 16″ W
Altitude (m)	1522	1630	1661	1651
Seedlings (no m^{-2})	0.79 ± 0.26	1.17 ± 0.24	1.13 ± 0.36	0.79 ± 0.16
Seedling height (m)	0.59 ± 0.06	0.46 ± 0.05	0.50 ± 0.05	0.39 ± 0.05
Saplings (no m^{-2})	0.50 ± 3.76	0.39 ± 1.61	0.53 ± 1.19	0.43 ± 1.01
Sapling height (m)	2.06 ± 0.13	2.23 ± 0.15	2.45 ± 0.14	2.22 ± 0.15
Adult trees (no ha^{-1})	1158.33 ± 26.48	991.67 ± 16.30	1191.67 ± 15.28	1025.00 ± 12.31
Basal area (m^2 ha^{-1})	87.80 ± 16.1^a	72.50 ± 13.1^a	44.86 ± 8.59 ^{b}	38.98 ± 5.57 ^{b}
DBH (cm)	37.49 ± 4.08	34.99 ± 3.89	28.92 ± 2.66	30.00 ± 2.68
Canopy height (m)	25.02 ± 2.55	24.95 ± 2.00	21.30 ± 1.15	23.28 ± 0.51
Canopy cover (%)	85.09 ± 1.49	88.43 ± 1.26	89.56 ± 0.74	85.92 ± 0.76
H′	2.69	2.86	3.11	2.85

Fig. 1 - Density of tree stumps by diameter class in tropical montane cloud forest fragments with low (L1 and L2) and high (L1 and L2) selective logging intensities in Veracruz, Mexico.



Specimens were identified with the help of specialists and voucher specimens were deposited in the IE-XAL herbarium in Xalapa, Mexico. Most of the seedlings were only identified to genus due to the lack of morphological characteristics enabling further identification. Where previous information on the shade-tolerance of the species was available, these were classified into three groups: shade-intolerant or pioneer, intermediate and shade-tolerant (Tab. S1 in Supplementary material).

Data analysis

A timber extraction index was constructed based on the sum of three variables: the numbers of cut tree stumps, logs and kilns. Moreover, the tree stumps were also categorized into diametric size-classes. Since extraction data was recorded in only one sampling event per site, no measurements of variation were calculated. Based on the obtained values of the extraction index, the sites were grouped into two categories: low (L) and high (H) selective logging.

A mixed general linear model (GLM) was applied to evaluate the differences among the levels of extraction in terms of tree densities (≥10 cm DBH), DBH, basal area and canopy coverage. The extraction intensity was considered a fixed factor within the model with two levels (L and H), while the site was included as random factor (Quinn & Keough 2002). Adult tree density values were Box-Cox (λ=0) transformed in order to comply with the assumptions of normality (Crawley 2002). To assess differences in the density of seedlings and saplings between the two extraction intensities, a generalized linear model was used with a log-link function and a Poisson type distribution (Quinn & Keough 2002) using the software package SPSS® ver. 20.0 (IBM Corp., Armonk, NY, USA). Linear regression was performed to determine whether a relationship existed between canopy coverage and total density of seedlings. For this analysis, the density of seedlings was Box-Cox (λ=0) transformed and the percentage of canopy coverage was arcsine square root transformed (Crawley 2002). This analysis was performed with the software MiniTab® ver. 16 (Minitab Inc., State College, PA, USA).

To evaluate the composition of the vegetation and determine species dominance, the importance value index (IVI) was calculated for trees with DBH >10 cm. This index measures the ecological value of the species through the sum of three variables: relative number of individuals, relative frequency and relative dominance (basal area) per species (Mueller-Dombois 1974 – see also Tab. S2 in Supplementary material). Relative values were calculated dividing the observed value of each species by the total of species.

To calculate the diversity of adult trees in each site, the Shannon-Wiener index was applied (Magurran 2004) using the software EstimateS 9.1.0 (Colwell 2013). In the case of regeneration, an index of diversity was not determined because many individuals could not be reliably identified to the species level. Similarity between tree species in the mature canopy and in the understory layer was evaluated in each site with the Morisita-Horn index. This index is based on abundances and is not affected by bias due to sample size (Magurran 2004). Relative abundance curves were generated per genus or per species in order to compare the community of adults with the regeneration.

Results

Structure and diversity of cloud forest after traditional selective logging

Based on the extraction index, the surveyed sites were classified into two selective logging intensities: low (L) and high (H). Index values were approximately three times lower in L than in H (L1=7.5, L2= 9.2, H1=35 and H2=35, respectively). In the L sites, all of the tree stump diametric categories were underrepresented, as compared with the H sites (Fig. 1). The basal area of standing trees was significantly higher in L than in H sites (F=11.35, df=1, P=0.003). No significant differences were found between the extraction levels in terms of DBH, density of adult individuals (DBH>10 cm) and canopy coverage (P >0.05 – Tab. 1). The distribution of diametric classes among all tree species of DBH ≥10 cm in the four sites followed an inverted J pattern, but many diametric classes were not present in the H sites (Fig. 2).

A total of 37 tree species were found over all sites, belonging to 32 genera and 25 families, of which 16 species are threatened and/or included in conservation priority lists (González-Espinosa et al. 2011). Of the species recorded in this study, eight are used for timber; three of these are endemic to Mexico (*Quercus delgadoana, Q. sartorii* and *Turpinia insignis*) and classified

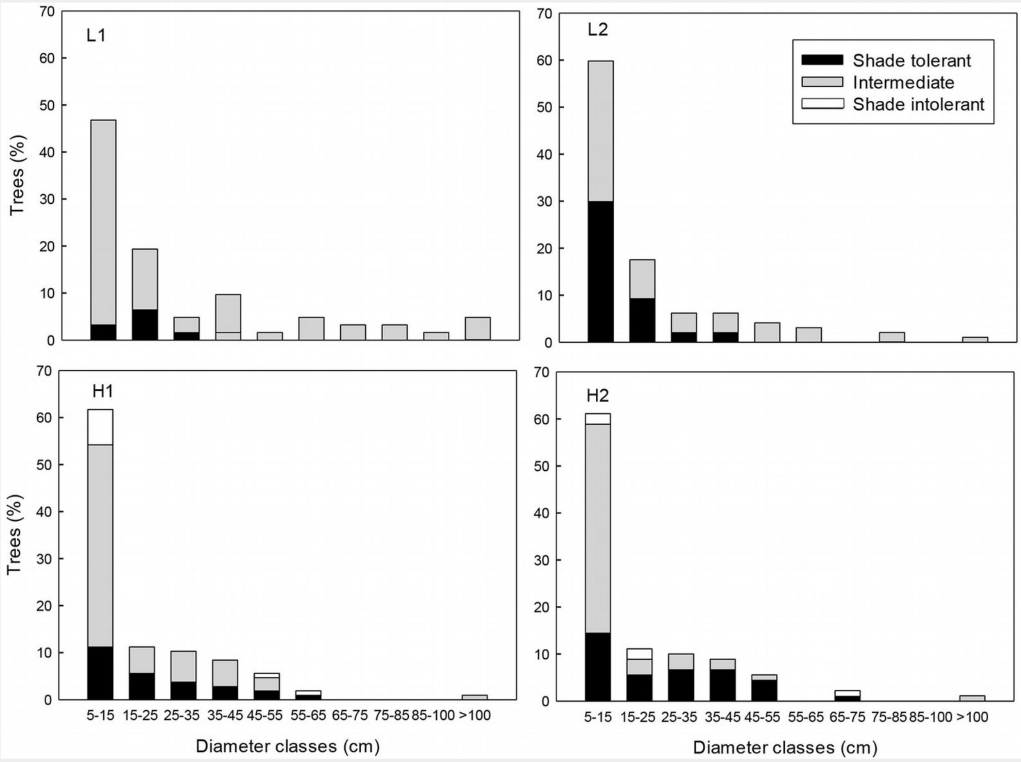


Fig. 2 - Percentage of trees (DBH ≥ 5cm) classified according to shade tolerance (shade tolerant, intermediate and shade intolerant) in tropical montane cloud forest with low (L1 and L2) and high (H1 and H2) selective logging intensities in Veracruz, Mexico.

as threatened (González-Espinosa et al. 2011).

The genus *Quercus* was dominant in the canopy at all sites, with a higher dominance in the L (56.4% and 67.4%) than in the H (39.9% and 60.2%) sites (Tab. S2 in supplementary material). Other dominant species at the L sites were *Carpinus caroliniana* (IVI = 13.6), *Liquidambar styraciflua* (IVI = 11.3) and *T. insignis* (IVI = 6.11), while at the H sites these were *Clethra macrophylla* (IVI = 11.5), *L. styraciflua* (IVI = 11.1) and *Zanthoxylum melanostictum* (IVI = 7.9 – Tab. S2 in the Supplementary material).

Of the 37 species recorded, 29 are reported in the literature within one of the three functional groups of shade-tolerance. Species of intermediate tolerance were the most abundant in all sites (L1 = 87.1%, L2 = 55.7%, H1 = 64.5% and H2 = 55.6%), followed by the shade-tolerant species (L1 = 12.9%, L2 = 44.3%, H1 = 27.1% and H2 = 40.0% – Fig. 2). Pioneer species were absent in the L sites and showed low relative abundance at the H sites (H1 =8.4 % and H2=4.4 % – Fig. 2).

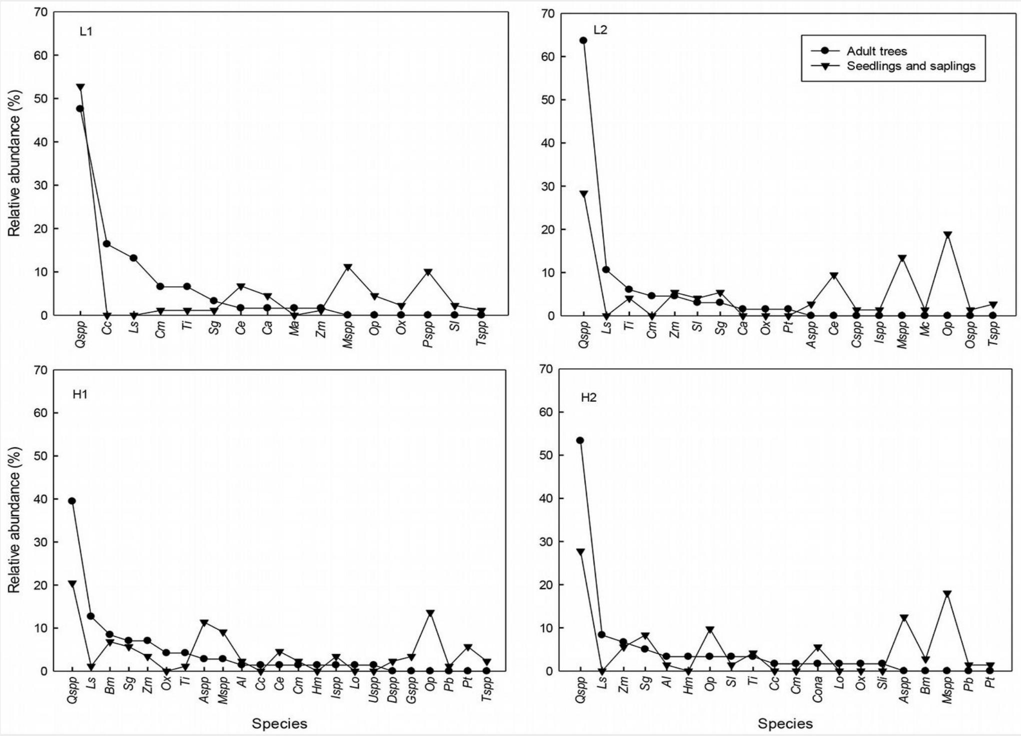


Fig. 3 - Relative abundance (%) of adult trees (DBH ≥ 5cm) and regeneration (seedlings and saplings) in tropical montane cloud forest with low (L1 and L2) and high (H1 and H2) selective logging in Veracruz, Mexico. (*Al*): *Alchornea latifolia*; (*Aspp*): *Ardisia* spp.; (*Bm*): *Bernardia macrocarpa*; (*Cc*): *Carpinus caroliniana*; (*Ce*): *Cinnamomum effusum*; (*Cspp*): *Citharexylum* spp.; (*Cm*): *Clethra macrophylla*; (*Ca*): *Cojoba arborea*; (*Cona*): *Conostegia arborea*; (*Dspp*): *Deppea* spp.; (*Gspp*): *Guarea* spp.; (*Hm*): *Hedyosmum mexicanum*; (*Ispp*): *Inga* spp.; (*Ls*): *Liquidambar styraciflua*; (*Lo*): *Lonchocarpus orizabensis*; (*Ma*): *Meliosma alba*; (*Mspp*): *Miconia* spp.; (*Mc*): *Myrsine coriacea*; (*Op*): *Ocotea psychotrioides*; (*Ox*): *Oreopanax xalapensis*; (*Ospp*): *Osmanthus* spp.; (*Pb*): *Prunus brachybotrya*; (*Pt*): *Prunus tetradenia*; (*Pspp*): *Psychotria* spp.; (*Qspp*): *Quercus* spp.; (*Sl*): *Saurauia leucocarpa*; (*Sg*): *Styrax glabrescens*; (*Sli*): *Symplocos limoncillo*; (*Tspp*): *Trophis* spp.; (*Ti*): *Turpinia insignis*; (*Uspp*): *Ulmus* spp.; (*Zm*): *Zanthoxylum melanostictum*.

Tree regeneration in traditionally logged cloud forests

Seedling and sapling densities did not differ between levels of extraction (seedlings: Wald X^2= 1.7, df=1, P=0.19; saplings: Wald X^2=0.14, df=1, P=0.70). The mean seedling density per treatment (0.97 ± 2.46 m^{-2} – mean ± 1 SE) was approximately double that of the saplings (0.46 ± 4.80 m^{-2}) in all of the sites (Tab. 1). The relationship between canopy coverage and seedling density was not significant in any site (R^2: L1=0.05, L2= 0.46, H1= 0.07, H2=0.11; P > 0.05). The most abundant species among seedlings were *Quercus* spp. in all sites (four species representing together 50.5%), followed by *Ocotea psychotrioides* (13%) and *Cinnamomum effusum* (7.3% – Fig. 3). Of the total number of seedlings and saplings, 76% belonged to the group of intermediate tolerance, 23% to that of shade-tolerance and 1% to the pioneers. According to the Morisita-Horn index, similitude among the genera and species of the canopy and those of the regeneration was relatively high in the four sites (L1= 0.86, L2 = 0.64, H1=0.69 and H2=0.71).

Discussion

Effects of selective logging on cloud forest structure and diversity

Traditional selective logging is a common though illegal practice in the TMCF, with no records that could allow to quantify its intensity, frequency and extent of extraction. This study shows that the degraded TMCF in the studied plots differ in terms of the accumulated impact of selective timber extraction. In comparison with other TMCF in Mexico, even the sites with highest extraction (H) showed a relatively low exploitation (Williams-Linera 2002, Ramírez-Marcial et al. 2003). In tropical montane rain forests subject to planned extraction, its intensity varies from 1 to 7 trees ha^{-1} $year^{-1}$; in Costa Rica, this is 1.8 trees ha^{-1} $year^{-1}$ at low intensity, 3 trees ha^{-1} $year^{-1}$ at medium intensity and 5 trees ha^{-1} $year^{-1}$ at high intensity (Aguilar-Amuchastegui & Henebry 2007), while 2 to 7 trees ha^{-1} $year^{-1}$ are extracted in the Central African Republic (Decocq et al. 2014). The number of tree stumps per ha in this study was between 3.3 and 29.1. However, given that the values reported are cumulative, it is likely that the actual annual rate may be less than the figures reported for other countries. Even in the sites with higher selective logging (H), a high basal area value has been maintained that is still within the interval reported for mature or conserved TMCF. For the primary TMCF of Costa Rica, basal area values of 60.7 m^2 ha^{-1} have been reported (Kappelle et al. 1996), with values of 29.6 to 40.7 m^2 ha^{-1} reported in the conserved TMCF of Peru (Ledo et al. 2012).

While the TMCF are characterized by high beta diversity and elevated structural and compositional heterogeneity (Williams-Linera 2002), the overall richness of trees found in this study (13 to 18 species per site) was lower than that reported for other TMCF in Mexico (41 to 56 species – González-Espinosa et al. 1991, Muñiz-Castro et al. 2012, Fortanelli-Martínez et al. 2014). The lower richness found could be the result of species local extinction, due to the legacy effects of historical over-extraction which led to the long-term reduction of diversity (Farwig et al. 2008). In this study, the greatest diversity of adult trees was recorded in the forest with the highest intensity of extraction (H1); however, this stems from the lower dominance of shade-tolerant species and the greater contribution of pioneer species. The opening of clearings by extraction can reduce the competitive exclusion of shade-tolerant species, thus favoring pioneer species (Sheil & Burslem 2003).

Chronic selective logging: threat to cloud forest regeneration?

The density of seedlings and saplings found below the stands was unaffected by the intensity of logging and was lower than that reported in other TMCF with illegal selective logging in Mexico (1-5 stems m^{-2} – Alvarez-Aquino 2001) but similar to that reported in tropical montane forests with high selective logging in East Africa (0.5-1.93 stems m^{-2} – Kirika et al. 2010). Regeneration in the studied sites was mainly represented by seedlings <1 m in height, while saplings were less represented. This indicates that around 50% of the seedlings do not reach the sapling stage. However, the survival of tree seedlings could be affected by biotic and abiotic factors at the site level and requires further evaluation.

The species composition of seedlings and saplings was dominated by *Quercus* spp., the group of greatest interest for the production of firewood and charcoal. Growth and survival of seedlings of the genus *Quercus* is favored by moderate disturbance of the TMCF or partial opening of the canopy (Galindo-Jaimes et al. 2002, Guariguata & Sáenz 2002) and simulated conditions of intermediate shade (Ramírez-Marcial et al. 2003). Oaks also have a high capacity of resprouting from the root, allowing for their persistance in degraded sites (Johnson et al. 2009). In contrast, the lower regeneration abundance of species with higher requirements of solar radiation (*e.g.*, *L. styraciflua* and *C. caroliniana*) could be limited by the elevated canopy coverage observed at the study sites (85.09-89.56%). This could be due to a relatively fast canopy closure that masks the effect of selective logging on canopy (Toledo-Aceves et al. 2009).

The high similarity found between the diversity of adults and that of regeneration could be the result of the fact that the dominant species make a greater contribution to the Morisita-Horn similarity index, thus leading to underestimation of the effect of less abundant species (Magurran 2004). For example, species such as *Meliosma alba, Lonchocarpus orizabensis, Hedyosmum mexicanum, Symplocos limoncillo* and *Ulmus mexicana* were not abundant in the canopy and were not recorded in the regeneration. The little or null regeneration of rare species in the canopy can be related to various causes that include, among others: a low density of adult individuals that hampers their sexual reproduction, high rates of seed predation, low rates of germination, damage by pathogens or herbivores following germination and excessive competition with herbaceous plants or lianas (Mostacedo & Fredericksen 1999, Harms & Paine 2003). Moreover, some tree populations have locally disappeared in the study region because of uncontrolled exploitation. These are mainly shade-tolerant hardwood species such as *Taxus globosa* and *Ocotea disjunta* (Paré & Gerez 2012). However, more investigations are needed to understand whether the low abundance of the rare species is due to their patterns of natural distribution in tropical forests (Harms & Paine 2003) or is a consequence of over extraction.

Planned forestry management in tropical montane cloud forest

The development of effective forest management strategies in TMCF is complex due to its high heterogeneity and diversity and the insufficient availability of ecological information on the attributes and requirements of each species. We focused on the group *Quercus* spp. because: (a) these are the trees of choice for the production of firewood and charcoal; (b) their dominance in the canopy with several species; (c) their dominance in the regeneration; (d) their high capacity for resprouting; and (e) information is available about their management in other regions (Guariguata & Sáenz 2002, Götmark 2009). Planning of selective extraction of *Quercus* spp. for the production of firewood and charcoal could be a viable strategy, as partial cutting could also favor the growth of the remnant trees (Götmark 2009). In other forestry systems, it has been reported that extraction stimulates residual tree growth, germination and recruitment (Guariguata & Sáenz 2002, Duah-Gyamfi et al. 2014).

At the landscape scale, low impact exploitation could be a viable option if complemented by the maintenance of no-felling zones within the forest (retention forestry) in order to increase and diversify tree regeneration. A scenario of low disturbance typical of fuel wood extraction in the TMCF was simulated by Golicher & Newton (2007), who found only slight fluctuations over time in the total number of individuals and basal area. Furthermore, charcoal production has been associated with forest degradation, though not necessarily cause deforestation (Chidumayo & Gumbo 2013). Traditional selective logging in TMCF contributes to the provision of firewood and charcoal, which play an important role in energy provision to local human populations. Considering the high value of TMCF for biodiversity conservation and the increasing demand for fuel wood from tropical forests, it is essential that the planned management of TMCF includes practices such as enrichment plantations using rare and vulnerable species in order to secure the maintenance of their populations.

Conclusions

In this study, traditional selective logging in the TMCF varied across sites in terms of extraction intensity, but this variation did not impact the density and composition of tree regeneration. Oaks (*Quercus* spp.) were the dominant species in both the canopy and the regeneration. Tree species which were rare in the canopy and threatened at regional level were not represented in the regeneration. Therefore, we recommend the establishment of conservation areas within the TMCF with the aim of maintaining its high tree diversity and counterbalancing the detrimental effects of selective logging at the landscape level. The results of this study suggest that planned selective logging (in particular on species belonging to the genus *Quercus*) could be a viable management strategy compatible with the maintenance of these priority forests.

Acnowledgements

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Supplementary Material

Tab. S1 - List of tree species (DBH>10 cm) in four sites of tropical montane cloud forest with traditional selective logging in Veracruz, Mexico.

Tab. S2 - Importance Value Index (IVI) of trees (DBH >10 cm) in tropical montane cloud forest sites with low (L1 and L2) and high (H1 and H2) selective logging in Veracruz, Mexico.

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