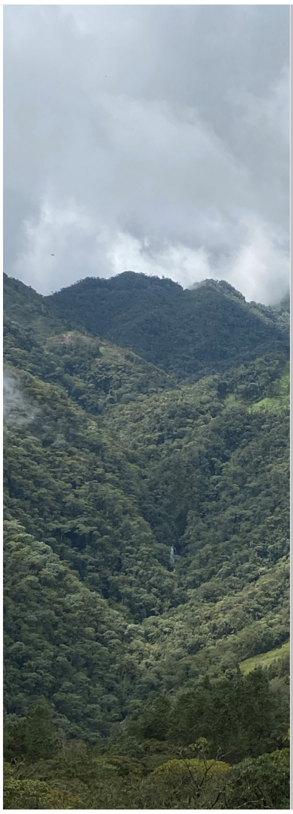

ANTI-PERSONNEL MINES AFFECT TREE DIVERSITY IN THE SELVA DE FLORENCIA NATIONAL NATURAL PARK, COLOMBIA

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ABSTRACT
Armed conflicts alter the dynamics of human communities settled near protected areas. This situation modifies the use intensity of natural resources in these areas. Particularly, zones with anti-personnel mines seem to be reservoirs of biodiversity because the conflict causes these areas to be abandoned and excluded from extractive activities. Colombia has endured five decades of armed conflict, which prompted farmers to abandon rural areas and, in some cases, reduced the exploitation of natural resources in those regions, favouring the conservation of native forests. In this study, we aimed to determine the indirect effects of the armed conflict on the tree diversity of Selva de Florencia National Natural Park, Central Andes, Colombia. We established vegetation transects in areas that, during the armed conflict, had anti-personnel mines (mined zone) and areas free of anti-personnel mines (non-mined zone) within the park. We determined that species richness, composition and structure differed between mined and non-mined zones. We found larger tree sizes and more timber trees in the mined zone compared to the non-mined zone. Our results suggest that anti-personnel mines create inaccessible zones within the park, where activities such as selective logging ceased for almost two decades. Accordingly, the armed conflict favoured forest conservation. The information gathered here is relevant to post-conflict protection and management.

Key words: forced displacement, landscapes of fear, native forests, post-conflict, selective logging, timber forest use

INTRODUCTION
Ninety percent of armed conflicts between 1950 and 2000 occurred in countries important for biodiversity conservation (Hanson et al., 2009; Lawrence et al., 2015). Historically, several studies have documented that armed conflicts cause adverse direct and indirect effects on biodiversity through, for example, habitat loss, reduced wild populations, and/or alterations to ecosystem functioning (Lawrence et al., 2015; Loucks, et al., 2009). Moreover, protected areas are highly vulnerable to the indirect effects that armed conflicts can have on biodiversity (Gaynor et al., 2016; Ordway, 2015). Armed conflicts alter the social dynamics of the communities living near protected areas (e.g. conflicts can either prompt the establishment or abandonment of human settlements). Consequently, protected areas can become a refuge for conflict groups or displaced persons, who can drastically alter the forests by overharvesting for firewood, the timber trade, or the construction of military camps, or housing for refugees (Bauman & Kuemmerle, 2016; Dudley et al., 2002; Hanson, 2018). However, areas subjected to armed conflict can also become biodiversity reservoirs as these sites are abandoned or excluded from economic activities (Bauman & Kuemmerle, 2016; Lawrence et al., 2015; Sánchez-Cuervo & Aide, 2013). For example, the Korean Demilitarized Zone is a mined area that became a de facto protected area for many endemic and

threatened species (Healy, 2007). In ecological terms, the indirect effects of armed conflict on biodiversity appear to resemble a landscape of fear (a spatial variation in perceived predation risk of prey leading to changes in their behaviour and, consequently, on the structure of habitats, see Palmer et al., 2022; Gaynor et al., 2019). In our context, humans (prey) change their behaviour regarding the exploitation of resources within the protected area due to armed conflict. Therefore, the indirect effects that armed conflicts may pose on biodiversity are a controversial topic that must be addressed in future post-conflict mitigation strategies (Hanson, 2018).

In Colombia, the armed conflict has lasted over 50 years and is mainly centred in critical areas for biodiversity conservation (Hanson et al., 2009). In this regard, Sánchez-Cuervo and Aide (2013) have suggested that armed conflict in Colombia might promote biodiversity conservation (i.e. allowing vegetation to regrow) by reducing human disturbance in abandoned areas. One of the areas most affected by the armed conflict is the Tropical Andes biodiversity hotspot, which hosts over 10 per cent of the world's vascular plant species (Young et al., 2015). Notably, the Selva de Florencia National Natural Park (SFNNP), located within this hotspot, is an area that was disputed by left-wing guerilla groups, the national army and paramilitary groups from the 1990s. The non-state armed groups that occupied the park until a peace agreement was signed in 2016 used anti-personnel mines to limit access to the park (García et al., 2015; Unidad de Víctimas, 2016). Therefore, armed groups heavily restricted farmer access to the park core zone for nearly two decades. According to García et al. (2015), this military strategy promoted the environmental conservation of this region. Farmer communities migrated to urban centres and abandoned activities related to timber exploitation, which were often illegal. Overall, SFNNP offers an ideal scenario to explore the indirect effects of armed conflict on biodiversity.

We assessed tree species richness and vegetation structure in two zones of the park: a non-mined and a mined zone, to establish the possible indirect effects of the armed conflict on SFNNP's forests. Considering that the forest area was mined, and this limited the extraction of timber resources, we expected forests located in the mined zone to have a higher diversity of trees than those in the non-mined zone. The forests located on the edge overlap with several human settlements that rely on selective logging for construction and firewood. Additionally, we identified and compared the trees used for timber in the two study zones.

METHODS

Study area

The Selva de Florencia National Natural Park was declared a protected area in 2005. It is located on the eastern slope of the Central Andes in the Caldas region, Colombia (5°29'07.85" N 75°04'09.66" W, Figure 1). The park covers 10,000 hectares and has an elevational range between 850 and 2,400 m a.s.l. The average annual precipitation and temperature are 8,000 mm and 19ºC. The SFNNP is considered a strategic area for biodiversity conservation as it is located in the Chocó-Magdalena biogeographical province and constitutes a habitat for various endemic and threatened species (Organización Colparques, 2018). The park has historically been inhabited by 20 farmer families who developed subsistence farming and selective logging for firewood and commercial purposes. Therefore, the park has trails from its edge to the interior (Herrera et al., 2016). The armed conflict drastically affected the park and its surroundings from 1996 to 2010. In particular, the presence of mined areas and other unexploded ordnances during that period reduced by 90 per cent the areas of the park that could be easily accessed (Herrera et al., 2016). Thus, the park became inaccessible to farmers, loggers and even park employees. In 2016, the Oficina del Alto Comisionado para la Paz of the Colombian government initiated the humanitarian demining programme in the park interior.

Vegetation sampling

We selected the San Antonio river basin to conduct the tree sampling since this area was mostly demined by 2016. We defined two zones in the basin (with an elevational range between 1,361 and 1,690 m) based on the presence of anti-personnel mines during the armed conflict (information provided by locals using an

Selva de Florencia National Natural Park, Colombia. © G.Castaño-Villa

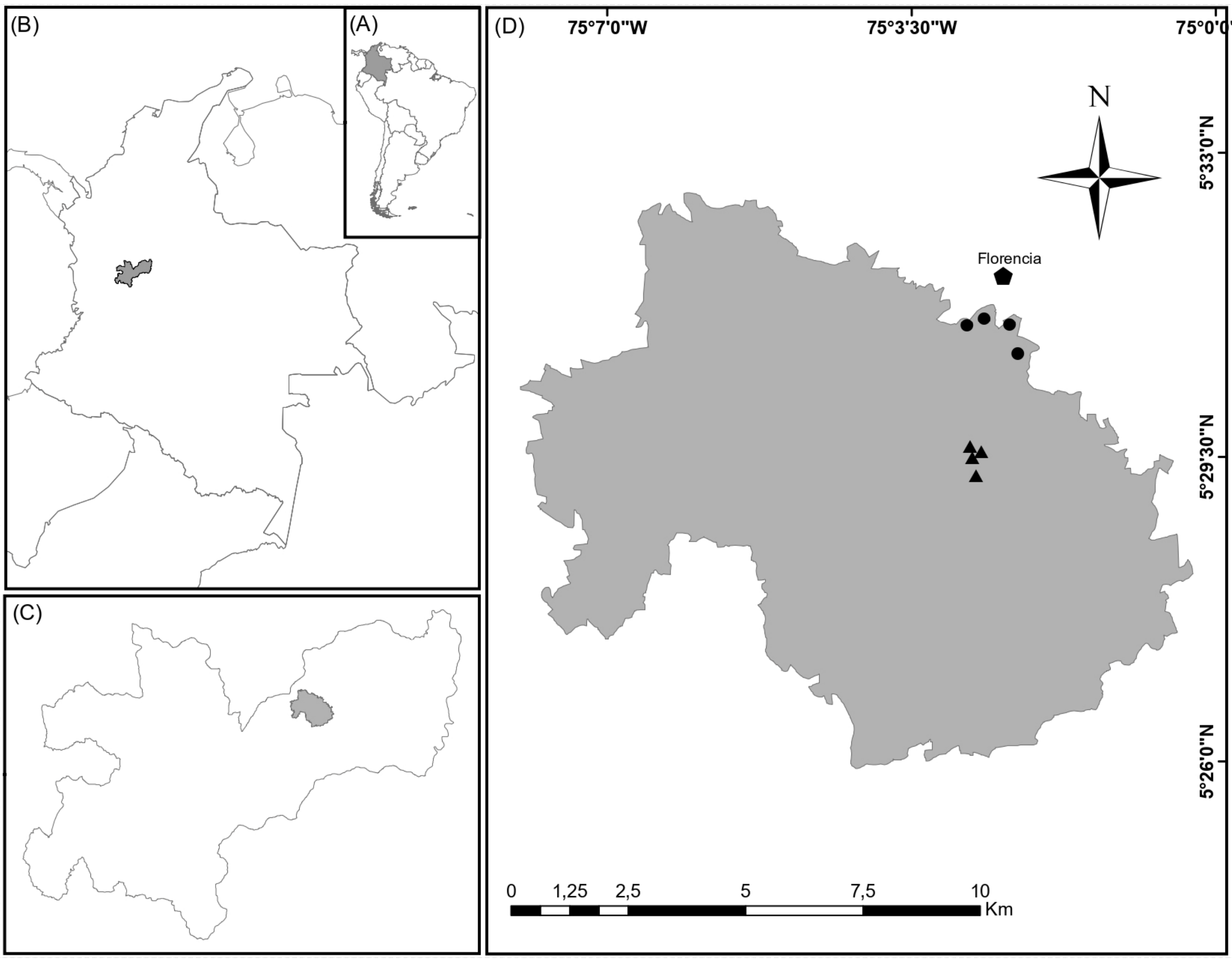

Figure 1. Study area. (A) Location of Colombia in South America; (B) Location of the Caldas region in Colombia; (C) Location of Selva de Florencia National Natural Park within the Caldas region, and (D) location of the sampling sites within the national park. Non-mined zone (●), and mined zone (▲).

unstructured interview), accessibility (measured as the duration of the walk to the site) and distance from the closest human settlement (township of Florencia). Both areas present the same forest type, with similar abiotic characteristics (i.e. topography, geology and rainfall). Accordingly, the study zones corresponded to the non-mined zone (1 km and 1-hour walk) and mined zone (4.6 km and 5-hour walk; Figure 1). We identified secondary forests (forests not older than 30 years) in each zone with the help of park employees and residents. To determine the species richness and composition, and vegetation structure, between October 2017 and April 2018, we established four Gentry forest transects (50 x 2 m) in each zone, with modifications from Villareal et al. (2004). Transects were separated by at least 100 m. Thus, transects have a 30 gradient and at least 100 m from trails or streams to reduce the possible effects of landscape heterogeneity on forest structure. Additionally, the sampled forests did not show evidence of recent natural disturbances, such as fallen trees or landslides.

In each transect, we counted all the individuals trees with a DBH > 1 cm (DBH: diameter at breast height, measured at 130 cm above the ground). Also, we registered the height of canopy trees at each transect through visual estimation (tree height estimates were made by only one person who has previous experience in measuring trees using a Haga altimeter). In order to identify the species, we collected botanical specimens and deposited them at the herbarium of Universidad de Caldas (FAUC). Plant species identification followed the taxonomic keys of Galeano and Bernal (2010) and Bernal et al. (2018). Furthermore, the samples were compared to the herbarium collections of Universidad de Caldas (FAUC) and Universidad de Antioquia (HUA). We also referred to the virtual collections of the Field Museum (2018), Global Plants (2018), Herbario

Nacional de Colombia (2018) and the Missouri Botanical Garden (2018). Species distribution and taxonomic classification were corroborated following Bernal et al. (2018) and the Angiosperm Phylogeny website version 14 (Stevens, 2001). The collected individuals were categorised according to DBH as large trees (DBH≥10 cm, hereafter trees) or small trees (1>DBH<10 cm). The trees were further categorised as timber species (used for construction, tool and crafts manufacturing, and firewood) or non-timber species (without any known local use). The uses were determined with the help of park employees and literature on the study area (Camacho & López, 2002; David et al., 2014).

Data analysis

We compared the species richness of trees between the two study zones to establish the possible indirect effects of the armed conflict. First, we determined differences in tree species richness by visually assessing the overlap of the lower and upper 84 per cent confidence intervals of the expected richness (Sest: expected number of species in t pooled samples, given the reference sample, see Colwell, 2019). We used this indicator for its usefulness in contrasting diversity values (MacGregor-Fors & Payton, 2013). We considered expected species richness to be significantly different (at an a level of 0.05) if confidence intervals do not overlap (MacGregor -Fors & Payton, 2013; Oksuz et al., 2020). The sampling efficiency (expressed as a percentage) was calculated as the ratio between the observed and expected richness, calculated using the bootstrap estimator (Castaño-Villa et al., 2014; Fontúrbel et al.,2020). Expected richness (Sest) and bootstrap estimator were calculated using 999 permutations on EstimateS version 9.1 (Colwell, 2013). Second, to compare the species composition between mined and non-mined zones, we performed a one-way analysis of similarities (ANOSIM), a non-parametric permutation test based on species abundance (Clarke, 1993). This analysis was conducted using the Jaccard similarity index using 999 permutations, a measure used in previous studies to compare plant communities (Hernández-Vargas et al., 2019).

With the information collected in the vegetation sampling, we defined four vegetation structure variables (basal area, canopy height, diameter at breast height, and density). The structural vegetation variables of the two zones were compared with Student's t-test and Wilcoxon test (when data did not fit a normal distribution). Goodness-of-fit to a normal distribution was assessed through a Shapiro–Wilk test. Homogeneity of variances was assessed using a Levene test. The total tree density (total individuals per DBH category at each zone) was compared through an X^2 test. The ANOSIM, t-Student, Wilcoxon test and X^2 were conducted in R version 3.4.3 (R Development Core Team, 2016), using the MASS and Lattice packages (Sarkar, 2008; Venables & Ripley, 2002).

RESULTS

Species richness and composition

We recorded 33 tree families and 58 genera within the study area. Furthermore, we found 135 tree morphospecies and identified 58 of these at the species level (Table S1). We recorded 94 morphospecies in forests located in the non-mined zone and 54 morphospecies in forests located in the mined zone. We obtained an average sampling efficiency of 79.4 per cent in the two zones (Table 1). Species richness of small trees was higher in the non-mined than in the mined zone (Figure 2A, non-mined: S_{est} = 59, and mined: S_{est} = 20). On the other hand, we did not find significant differences in tree species richness between the two zones (Figure 2B, non-mined: S_{est} = 35, and mined: S_{est} = 35). In the non-mined zone were commonly found plants of the families Arecaceae (e.g. *Wettinia kalbreyeri, Geonoma concinna* and *Bactris setulosa*) and Euphorbiaceae (e.g. *Alchornea* spp. and *Tetrorchidium macrophyllum*). Sixty percent of the morphospecies recorded in the non-mined zone were exclusive to this zone. Also, 30.7 per cent of the morphospecies were exclusive to the mined zone. The non-mined and mined zones shared only 9.6 per cent of the plant morphospecies. Moreover, the floristic composition (small and large trees) differed between the non-mined and mined zones (ANOSIM R = 0.60, p = 0.004)

Forest structure

The forest vegetation structure differed between the two zones with DBH of the trees and small trees being larger in the mined than non-mined zone (Trees: W = 2846.0;

Table 1. Observed and expected species richness for zones located in the non-mined and mined zones of Selva de Florencia National Natural Park. The expected species richness was calculated using a bootstrap estimator.

	Non-mined zone	Mined zone	Total
Species richness			
Observed	93	55	135
Expected	119	67	-
Sampling effectiveness (%)	77.8	81.0	-

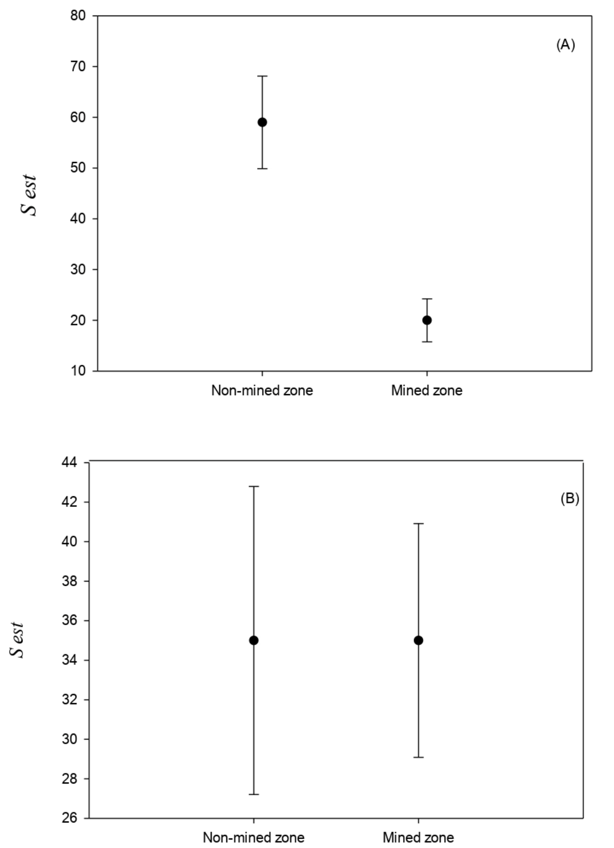

Figure 2. Expected species richness (Sest) for (A) Small trees (1>DBH<10 cm) and (B) Trees with DBH ≥10 cm in the non-mined (n = 4) and mined zones (n = 4) of Selva de Florencia National Natural Park. Error bars represent an 84% confidence interval of the expected richness estimations. Expected species richness to be significantly different (at an a level of 0.05) if confidence intervals do not overlap.

$p = 0.019$ and Small trees: $W = 1815.5$; $p = 0.005$; Figure S1). The average basal area was greater in the mined zone (mean = 2.30 ± 0.36 cm) than non-mined zone (mean = 0.71 ± 0.25 cm) ($t6 = 7.20$; < 0.001). Tree density in the mined zone was 123 and in the non-mined zone 59 individuals. In contrast, the density of small trees was greater in the non-mined zone (92 individuals) than in the mined zone (33 individuals). The density of trees and small trees differed between the two zones ($X^2 = 48.65$; $p < 0.001$, Table S2). Canopy height did not differ between mined and non-mined zones ($W = 140.0$; $p = 0.104$; Figure S2).

Plant uses

We identified 58 species of trees (i.e. 43 per cent of total morphospecies registered) historically used in the region for construction (houses, fences and poles), tool manufacturing and firewood (Table S1). Several species, such as *Acalypha macrostachya*, *Cecropia garciae*, *Miconia affinis*, *Miconia caudata*, *Isertia laevis* and *Elaeagia utilis*, are used locally for construction and are only found in the mined zone. In addition, in the mined and non-mined zone we identified ten and eight trees used for firewood, respectively (e.g. *Clusia dixonii* and *Cordia bicolor*). According to tree use, the number of trees and small trees with any use (i.e. construction, tool manufacturing or firewood) significantly differs between mined and non-mined zones ($X^2 = 20.2$, $p < 0.001$; Table S2). The remaining 32 per cent of trees in the non-mined zone are suitable for firewood, while 58 per cent of trees can be used for construction.

DISCUSSION

Our results suggest that forest degradation during 20 years of armed conflict was lower in the mined zones compared to the non-mined zone of the park. The period of relative protection due to the armed conflict may have resulted in substantial recruitment and growth of several trees. This phenomenon is likely indirectly associated with the armed conflict that affected the region for nearly two decades and which resulted in 40 local victims of anti-personnel mines reported in this region between 2002 and 2009 (Oficina del Alto Comisionado para la Paz, 2019). For 20 years, farmers were displaced to urban centres. They abandoned their extractive and agricultural activities inside the park. The farmers who extracted timber resources in the park limited their access to the mine-free park zones (the farmers were alerted to the presence of anti-personnel mines by the belligerent groups). Farmers abandoned extractive activities in the mined zone during the armed conflict and reduced the selective logging of fine timber trees (locally used for construction and carpentry) (García et al., 2015). Therefore, selective logging within the park was abandoned due to fear of the mined fields. This situation is similar to what occurred in the Korean Demilitarized Zone, where the presence of anti-personnel mines promoted this area as an animal and plant refuge since its inaccessibility allowed protection of the forests (Dudley et al., 2002; Kim, 1997).

The changes in forest species richness, composition, structure and use in the park may reflect variations in the intensity of anthropogenic disturbances in the park during the armed conflict. During this time, the park mined zone became inaccessible to people unrelated to the conflict. Consequently, this zone does not show evidence of recent selective logging since commercial timber trees are still standing (DBH > 30 cm), and are not found in the other park zones. This finding suggests that reducing selective logging intensity favoured forest conservation during the conflict. Likewise, more intense anthropogenic disturbances in the park's non-mined zone may explain the higher small tree diversity. During the armed conflict, this zone remained subject to sporadic selective logging for household uses. This low disturbance level may have positively affected plant diversity, similar to the effect of fallen trees and the formation of forest canopy gaps (Dechnik-Vásquez et al., 2016; Imai et al., 2016). These canopy gaps, caused by selective logging, display high plant diversity and dominance by pioneer species such as *Chusquea latifolia*, *Cecropia hispidissima*, *Cecropia montana* and *Handrosanthus chrysantha* sub. *pluvicola* (Berry et al., 2008; Gaui et al., 2019). The armed conflicts alter the use of natural resources near settlements and promote significant biodiversity changes (Ordway, 2015).

CONCLUSIONS

Our results show the effects of armed conflicts on tree richness, composition and forest structure. During the armed conflict, the park's mined zone became inaccessible, precluding selective logging and resulting in the mined parts of the forest today having larger trees. Consequently, this phenomenon favoured forest conservation during the armed conflict. Unfortunately, during the post-conflict period, the national government has not consolidated an institutional presence in national parks, which is why illegal farms and illicit crops have expanded within them. Therefore, in post-conflict, the government entities should promptly initiate strategies to reduce selective logging within the park (e.g. surveillance and control measures). Also, it would be essential to create community forest plantations in the park buffer zone that sustainably supply the needs for wood for construction and firewood.

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SUPPLEMENTARY ONLINE MATERIAL

Table S1. Total morphospecies registered in Selva Florencia National Natural Park for non-mined and mined zones.

Table S2. Tree density in study area

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RESUMEN

Los conflictos armados en todo el mundo alteran la dinámica de las comunidades humanas asentadas en áreas protegidas. Esta situación modifica la intensidad de uso de los recursos naturales en estas áreas. En particular, las zonas con minas antipersonal parecen ser reservorios de biodiversidad porque el conflicto hace que estas áreas sean abandonadas y excluidas de las actividades extractivas. Colombia ha soportado cinco décadas de conflicto armado, que llevó a los agricultores a abandonar las zonas rurales y, en algunos casos, redujo la explotación de los recursos naturales en esas regiones, favoreciendo la conservación de los bosques nativos. En este estudio, nuestro objetivo fue determinar los efectos indirectos del conflicto armado en la diversidad de árboles del Parque Nacional Natural Selva de Florencia, Andes Centrales de Colombia. Para ello, establecimos transectos de vegetación en zonas que durante el conflicto tuvieron minas antipersonales (en la actualidad desminadas) y en zonas libres de minas antipersonal (no minadas) dentro del parque. Determinamos que la riqueza, composición y estructura de especies difieren entre las zonas que estuvieron minadas y las no minadas. Encontramos árboles más grandes y una mayor cantidad de árboles maderables en la zona que estuvo minada en comparación con la zona no minada. Nuestros resultados sugieren que las minas antipersonales crearon zonas inaccesibles dentro del parque, donde las actividades como la tala selectiva se interrumpieron durante casi dos décadas. En consecuencia, el conflicto armado favoreció la conservación de los bosques. La información recopilada aquí es relevante para la protección y gestión en el post conflicto.

RÉSUMÉ

Les conflits armés modifient la dynamique des communautés humaines installées à proximité des zones protégées. Cette situation modifie l'intensité d'utilisation des ressources naturelles dans ces zones. En particulier, les zones où se trouvent des mines antipersonnel semblent être des réservoirs de biodiversité car le conflit provoque l'abandon de ces zones et leur exclusion des activités extractives. La Colombie a subi cinq décennies de conflit armé, ce qui a incité les agriculteurs à abandonner les zones rurales et, dans certains cas, a réduit l'exploitation des ressources naturelles dans ces régions, favorisant la conservation des forêts indigènes. Dans cette étude, nous avons cherché à déterminer les effets indirects du conflit armé sur la diversité des arbres du parc naturel national de Selva de Florencia, dans les Andes centrales, en Colombie. Nous avons établi des transects de végétation dans des zones où, pendant le conflit armé, il y avait des mines antipersonnel (zone minée) et des zones exemptes de mines antipersonnel (zone non minée) au sein du parc. Nous avons déterminé que la richesse, la composition et la structure des espèces différaient entre les zones minées et non minées. Nous avons trouvé des arbres de plus grande taille et plus d'arbres à bois dans la zone minée que dans la zone non minée. Nos résultats suggèrent que les mines antipersonnel ont créé des zones inaccessibles au sein du parc, où des activités telles que l'exploitation forestière sélective ont cessé pendant près de deux décennies. En conséquence, le conflit armé a favorisé la conservation de la forêt. Les informations recueillies ici sont pertinentes pour la protection et la gestion post-conflit.