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Timber harvesting and conservation status of forest species in the Ecuadorian Amazon

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This study focuses on the Ecuadorian Amazon, a crucial region for forest biodiversity and conservation of native species, which faces challenges due to timber extraction. The research objective was to characterize timber harvesting during 2012 to 2021, focusing on the ten most harvested forest species in terms of volume and provincial distribution, as well as their conservation status according to the IUCN. For the methodology, data were extracted and analyzed from Ecuador's Forest Management System (SAF), focusing on timber extraction in six provinces and assessing 210 species. The results revealed that, from 2,627,659.17 m^3 authorized, 2,296,238.08 m^3 were harvested, representing 54.17% of the national timber harvest from native forests. Species of the Fabaceae family predominated in number and volume, with yields varying from 0.5 m^3/ha in Orellana to 2.8 m^3/ha in Zamora Chinchipe. Analysis of the IUCN categories showed that 67.6% (142 species) are Least Concern (LC), while 3.3% (7 species) are Vulnerable (VU), and 1% (2 species) Endangered (EN). Two species were listed as Data Deficient (DD), one as Critically Endangered (CR) and one as Near Threatened (NT). It is crucial to note that, of the 210 species analyzed, 55 species (26.2%) are not included in the IUCN database, highlighting the importance of more detailed assessments for their conservation and distribution.

KEYWORDS

tree species, conservation status, forest extraction, forest resources, forest trade

1 Introduction

Ecuador stands out as one of the world's biodiversity hotspots (Noroozi et al., 2018; Raven et al., 2020), boasting an impressive array of 91 ecosystems, including 65 forest ecosystems. Within its borders, nearly half of the land (49.99% or 12.4 million hectares) is covered by forests (MAATE, 2023b), underscoring its profound importance in global biodiversity conservation efforts (Tilman et al., 2017). Within this expansive green realm, the 44.7% of this area dedicated to wood production sourced from both native forests and forestry plantations (Castillo-Vizuete et al., 2023). The trajectory of the forestry industry in Ecuador reflects a consistent upward trend (Veintimilla et al., 2021). As of 2019, a reported total of 161 companies were actively engaged in wood-related activities, contributing directly to the creation of approximately 1,598 jobs (Castillo-Vizuete et al., 2023).

The Ecuadorian Amazon Region (EAR) is recognized as a global biodiversity treasure (Bass et al., 2010; Funk et al., 2012; Noroozi et al., 2018; Trew and Maclean, 2021), distinguished for its exceptional richness in vascular plant species (Neill, 2012; Mateo et al., 2013; Guevara-Andino et al., 2019) that contribute to the global significance of the Andean Amazon hotspot (Myers, 1988; Bass et al., 2010). In terms of forest area, the EAR comprises 73.99% (9,209,197 ha) of the country's total forested area (MAATE, 2023b). Beyond its ecological importance, these forests play a pivotal role in the sustenance of rural Amazonian households (Angelsen et al., 2014), serving as a vital resource base. The utilization of wood resources is deeply ingrained in the livelihoods of these communities, drawing from native forests (Torres et al., 2018), as well as relict and planted trees integrated into the diverse land uses such as the traditional chakra system (Vera et al., 2019; Torres et al., 2022). This relationship between the local populace and the forest underscores the intricate interdependence that defines the socio-ecological aspects of the Ecuadorian Amazon. The EAR stands as a testament to an enduring connection between its inhabitants and the rich landscape, echoing back thousands of years. Recent archaeological findings in the Upano Valley reveal a pre-Hispanic urban network dating from around 500 BCE to 300–600 CE (Rostain et al., 2024). The relationship between the local populations and the forest, as observed in the present, is reflected in the archaeologically unveiled patterns of human settlement and infrastructure. This interdependence not only defines the socio-ecological aspects of the modern Ecuadorian Amazon but also reflects an enduring legacy rooted in the EAR's rich cultural and environmental history.

While the longstanding relationships between the EAR and its inhabitants have endured for millennia, the specter of climate change (Fajardo et al., 2023) poses a formidable threat to this intricate interdependence. As the region grapples with shifting weather patterns and rising temperatures, the time-tested bond between the local populace and the forest faces unprecedented challenges. In addressing these contemporary threats, conservation measures and sustainable silviculture practices emerge as imperative strategies (Günter et al., 2012). The forests of the EAR stand as repositories of immense ecological potential, offering a myriad of ecosystem services crucial for environmental sustainability and human well-being. These services encompass carbon sequestration (García-Cox et al., 2023), the sustainable provision of timber and non-timber products (Mejía and Pacheco, 2014), soil regulation (Bravo et al., 2021), water regulation (Dib et al., 2023), and the fostering of social cohesion (Carrus et al., 2020), among others. Recognizing and effectively managing these diverse ecosystem services present unique opportunities, particularly in promoting carbon capture initiatives (Schneider et al., 2018). Noteworthy conservation programs, such as the *Socio Bosque Program* (De Koning et al., 2011; Soto-Pinto and Jiménez-Ferrer, 2018), exemplify the commitment to native forest preservation. Operating under the innovative model of providing payments to forest owners, this initiative not only safeguards biodiversity but also supports the livelihoods of local communities. The intrinsic value of forest resources extends beyond ecological benefits, playing a pivotal role in stimulating the economy (Angelsen et al., 2014).

The EAR is politically divided into six provinces: Sucumbíos, Orellana, Napo, Pastaza, Morona Santiago and Zamora Chinchipe. These provinces play a fundamental role in the supply of wood, mainly for the national market (Castillo-Vizuete et al., 2023). Most of the wood recorded in the EAR comes from the provinces of Sucumbíos and Orellana, while smaller-scale harvesting is conducted in the central and southern provinces of the Amazon (Mejía and Pacheco, 2014). The utilization of wood resources in these provinces is linked to various factors, including the construction of roads associated with oil extraction activities (Llerena-Montoya et al., 2021), unplanned population growth (Huera-Lucero et al., 2020; Fischer et al., 2021; Kleemann et al., 2022; Noh et al., 2022), accelerated increase in the agricultural frontier (Kleemann et al., 2022; Noh et al., 2022), mining (Mestanza-Ramón et al., 2022), illegal logging activities (Vasco et al., 2017) and the increase in poverty (Torres et al., 2018). These multifaceted dynamic underscores the complex interplay of socio-economic and environmental factors that drive the demand for and utilization of forest resources in the EAR.

Official reports indicate a notable surge in wood harvesting within the EAR, escalating from 357 to 458 thousand m^3 in 2007 and 2011, respectively (Mejía and Pacheco, 2014). This use satisfies the demand of the industry focused on the production of furniture and construction works in large Ecuadorian cities such as Quito, Cuenca and Ambato belonging to the Andean region (Mejía and Pacheco, 2014; Schlotzhauer and Torres, 2015). Furthermore, it is important to highlight that 56% of the logging exploitation of native forests originates from the EAR (Castillo-Vizuete et al., 2023). Beyond its economic impact at the regional level, wood harvesting plays a pivotal role in the livelihoods of rural households within the EAR. On average, wood harvesting contributes between 14 and 21.23% of the total monetary income of rural households (Mejía et al., 2015). However, when households are classified according to their livelihood strategies, wood harvesting in indigenous rural communities represents more than 50% of their total income in households oriented to wood harvesting as part of their livelihood strategy (Torres et al., 2018). This underscores the profound dependence on forest resources as a central element of the household livelihoods of certain communities within the EAR.

Despite the evident importance of forest resources, the sustainable use of these invaluable assets in the EAR encounters formidable challenges. A significant impediment arises from the dearth of updated information concerning the utilization, marketing and economic indicators of wood (Arías and Robles, 2011). This information gap not only hampers effective planning but also restricts the execution of timber harvesting activities (Wamsler et al., 2020). Consequently, the native forest in the EAR faces a decline, exacerbated by practices like illegal logging (Bonilla-Bedoya et al., 2017; Vasco et al., 2017). Illegal logging, particularly selective harvesting focusing on high-demand and high-value wood species in national and global level markets (Mejía and Pacheco, 2014), poses a critical threat. Species such as *Cordia alliodora* (Ruiz & Pav.) Oken, *Cedrelinga cateniformis* (Ducke) Ducke, and *Ceiba insignis* (Kunth) P.E.Gibbs & Semir are prime targets for their commercial value. For instance, until 2011, *C. alliodora* alone represented 17.3% of the total volume mobilized from the EAR (Mejía and Pacheco, 2014). This selective exploitation further exacerbates the strain on already vulnerable ecosystems, emphasizing the urgent need for comprehensive and updated data to inform sustainable forest management strategies.

While *C. alliodora* holds an official conservation status, classified as Least Concern (LC) according to the International Union for Conservation of Nature (IUCN) criteria (IUCN, 2023), it is crucial to highlight that *C. catenaiformes* and *C. insignis* lack official evaluations and are currently designated as Not Evaluated (NE). This underscores the imperative for further research and evaluation to ascertain the conservation status of these species within the EAR. In the broader context of the EAR, a recent study by Guevara-Andino et al. (2019) encountered that 89% of lowland tree species in the EAR are currently designated as NE. This alarming trend is not unique to the EAR, as globally, an estimated 115,291 plant species are currently listed as NE (Brummitt et al., 2015). These figures emphasize the pressing need to intensify efforts to aimed at comprehensively understanding the risk of extinction for all plant species worldwide (Betts et al., 2020) and specifically within the unique ecosystems of the EAR (López-Tobar et al., 2023). Given the preceding challenges and gaps in conservation evaluations, there is a clear imperative to furnish the scientific community and decision-makers with updated information on the harvested volumes, particularly focusing on the most traded species in the EAR. It is important to emphasize that this study represents a continuation of previous research focused on understanding the botanical collection patterns of the most traded forest species in the EAR, their protection coverage in conservation initiatives and finally their IUCN conservation status (López-Tobar et al., 2023).

In this context, the present study is designed with three objectives. Firstly, for the first to our knowledge, it seeks to characterize timber harvesting activities in the EAR over a ten-year period (2012–2021). This longitudinal analysis provides a better understanding of trends and patterns in timber harvesting in the EAR, providing a perspective on how these practices have evolved over the course of a decade. Furthermore, it is important to note that the data used represents an important milestone, as it is the first time that official information from the Forest Administration System (SAF) of the Ministry of Environment, Water and Ecological Transition of Ecuador (MAATE) has been analyzed for this period. These data provide a unique opportunity for a detailed and evidence-based study of timber extraction in the region, allowing for an accurate and up-to-date analysis of these activities in the forest ecosystems of the EAR.

Secondly, this study explores into an in-depth analysis of the ten most harvested forest species, examining their prominence and distribution at the provincial level. This level of granularity ensures a localized perspective that can inform targeted conservation and management strategies. Finally, the study serves to illuminate the current conservation status of these key forest species by reporting their categorization within the IUCN framework (IUCN, 2023). By addressing these objectives, the study aims to contribute valuable insights into the sustainable management of forest resources in the EAR, fostering both ecological resilience and socio-economic well-being.

This research has significant implications for various stakeholders, including conservation organizations, policy makers, and local communities. Conservation organizations can use the findings to develop targeted strategies for protecting vulnerable species and ensuring sustainable forest management. Policymakers will benefit from updated and accurate data to formulate effective regulations and policies that balance economic development with environmental conservation. Local communities, who are directly dependent on forest resources for their livelihoods, will benefit from the promotion of sustainable practices that ensure the long-term availability of these resources.

Additionally, this study contributes to the 2030 Agenda for Sustainable Development, particularly Goal 15: Life on Land, which aims to protect, restore, and promote sustainable use of terrestrial ecosystems, manage forests sustainably, combat desertification, and halt and reverse land degradation and halt biodiversity loss. By providing a detailed analysis of timber harvesting and the conservation status of forest species, this research supports efforts to achieve sustainable forest management and biodiversity conservation in the Ecuadorian Amazon.

2 Materials and methods

2.1 Study area

The study is focused on the EAR, with an area of 116,687 km^2 (MAATE, 2023b), including six provinces: Sucumbíos, Orellana, Napo, Pastaza, Morona Santiago, and Zamora Chinchipe (Figure 1). In climatic terms, it is characterized by an average annual precipitation that varies between 2,000 and 5,000 mm (Amatulli et al., 2018) and an average annual temperature of 24°C, making it a region with a hot and humid climate (Fick and Hijmans, 2017). Furthermore, in terms of land coverage, the EAR has a coverage of 78.6% of native forest, being the highest percentage in comparison to the other regions of continental Ecuador (MAATE, 2023b).

2.2 Data provenance

The data used for the analysis were obtained through the SAF of the MAATE (MAATE, 2023a). Initially, in order to carry out the first objective, information related to timber forest species harvested and their respective volumes for the period from 2012 to 2021 was considered. These data were filtered considering only the six provinces of the EAR and all the species reported for this period. Finally, 210 timber forest species were considered for second and third objectives as they were recorded at the species level.

2.3 Data analysis

To address the different analysis, the database was filtered in order to obtain the total volume reported and the number of species authorized for use for each province in each of the years analyzed. Subsequently, the 10 species with the highest volume harvested in the six provinces evaluated were identified. Finally, the current conservation status of the species traded in the EAR according to the IUCN were analyzed, using the "iucn_summary" function of the taxize package (Chamberlain and Szöcs, 2013). It should be noted that all analyzes were performed using the R version 4.1.2.

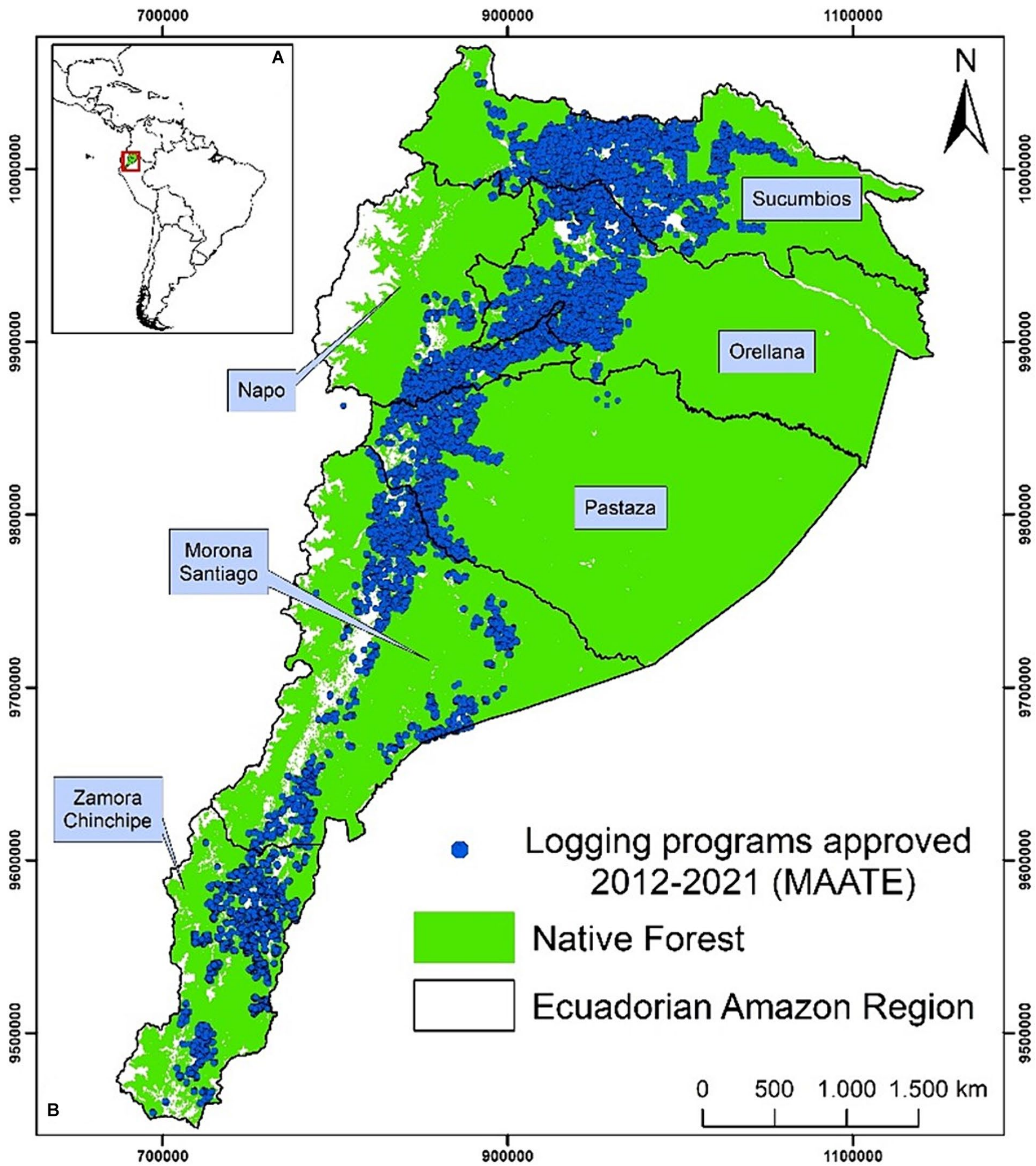

FIGURE 1
(A) Study area location in South America; **(B)** Ecuadorian Amazon Region (EAR). The blue dots represent the distribution of the logging programs officially authorized by MATTE for harvesting (2012–2021).

3 Results

3.1 Characterization of timber forestry exploitation at the provincial level in the EAR

Within the EAR, a total of 2,627,659.17 m^3 of timber was officially authorized for harvesting. However, the actual harvested volume over the period from 2012 to 2021 was 2,296,238.08 m^3, constituting 87.4% of the initially authorized volume. Remarkably, the harvested timber in the EAR constitutes a substantial proportion of the national totals. Specifically, it accounts for 46.13% of the total volume authorized for harvesting nationwide and an even more considerable 54.17% of the total volume effectively harvested at the national level. These proportions underscore the notable contribution of the EAR to the overall timber industry in Ecuador, emphasizing the region's pivotal role in meeting national demands.

In Sucumbíos province, located in the northern Ecuadorian Amazon, the largest volume of authorized timber is reported, totaling 890,193.2 m^3, of which 87.72% was effectively harvested. The number of authorized species remained stable, with 51 species in 2012 and 102 in 2014, slightly decreasing to 84 in 2021. Similarly, in Orellana province, the second largest volume of authorized timber was 837,088.6 m^3, with 88.77% harvested. Furthermore, in the central Ecuadorian Amazon, Napo province reported an authorized timber volume of 261,345.4 m^3, achieving a harvest rate of 91.6%. Pastaza province followed with an authorized volume of 355,067.9 m^3 and a harvest rate of 89.4%. In the southern part of the Ecuadorian Amazon, Morona Santiago province reported 175,669.6 m^3 of authorized timber, with a harvest rate of 74.58%. Meanwhile, Zamora Chinchipe province had an authorized volume of 117,596.8 m^3, with a harvest rate of 84.13% (Table 1; Figure 2).

3.2 Main forest species harvested in the EAR (2012–2021)

In this section, we meticulously examined 210 species with comprehensive species-level data, focusing on current IUCN categories. Table 2 provides an overview of timber harvesting values across different provinces, highlighting the number of species, their harvested volumes, and respective IUCN categories.

In Sucumbíos, *Erisma uncinatum* Warm. (Vochysiaceae) was the most harvested at 77,253.50 m^3 (2.93% of the total), while *Acacia glomerosa* Benth. (Fabaceae) had a significant volume of 46,669.05 m^3 but is listed as NE. Meanwhile, in Orellana, *E. uncinatum* and *Ceiba pentandra* (L.) Gaertn. (Malvaceae) led with 61,104.57 m^3 (2.32%) and 62,017.31 m^3, respectively, both classified as LC. Conversely, in Napo, *C. pentandra* was the most harvested at 18,456.39 m^3 (0.70%), followed by *Campsiandra cateniformis* (Fabaceae) and Erisma uncinatum with 13,063.57 m^3 and 13,215.85 m^3, respectively, all LC. In Pastaza, *C. cateniformis* and *E. uncinatum* were predominant with 26,662.64 m^3 and 23,838.38 m^3, respectively, both LC, while *Ceiba insignis* (Malvaceae) with 13,726.34 m^3 is NE. Similarly, in Morona Santiago, *Trattinnickia glaziovii* Swart (Burseraceae) had the highest volume at 29,769.08 m^3 (1.13%), followed by *C. cateniformis* with 23,469.35 m^3, both LC. Lastly, in Zamora Chinchipe, *Poulsenia armata* (Miq.) Standl. (Moraceae) was the most harvested at 20,047.43 m^3 (0.76%), with *T. glaziovii* and *Podocarpus oleifolius* D. Don (Podocarpaceae) at 7,176.95 m^3 and 7,711.43 m^3, respectively, all LC, while *Prumnopitys montana* (Podocarpaceae) is considered VU.

3.3 Harvested timber species (2012–2021) and their category according to the IUCN

Figure 3 provides a visual representation of the percentage and number of species in each IUCN conservation category across the six provinces of the EAR. The analysis reveals that a majority of species, 67.6% (142 species), are classified as Least Concern (LC). However, seven species (3.3%) are classified as Vulnerable (VU), including *Cedrela odorata*, *Prumnopitys montana*, *Amburana perutilis*, *Hyeronima procerum*, *Guarea cartaguenya*, *Jacaranda mimosifolia*, and *Nectandra guadaripo*. Additionally, two species (1.0%) are classified as Endangered (EN), specifically *C. odorata* and *Carapa guianensis*. Two species (1.0%) fall into the Data Deficient (DD) category: *Prioria copaifera* and *Platymiscium pleiostachyum*. Furthermore, a single species (0.5%) is classified as Critically Endangered (CR), *C. odorata*, and another single species (0.5%) is designated as Near Threatened (NT), *Manilkara bidentata*. Notably, 55 species (26.2%) are currently not assessed in the IUCN database and thus do not fall into any conservation category.

In Sucumbíos province, 153 species were recorded. The LC category had the highest representation with 106 species (69.3%), followed by the Not Evaluated (NE) category with 35 species (22.9%) and the VU category with six species (3.9%). One species was classified as CR, two as DD, and two as EN. In Orellana province, 132 species were found, with the LC category leading at 97 species (73.5%), followed by NE with 29 species (22.0%), and two species each in the EN and VU categories (1.5% each). One species each was found in the CR and NT categories (0.8% each). Furthermore, in Napo province, 98 species were reported, with 73 species (74.5%) in the LC category and 23 species (23.5%) in the NE category. One species each was found in the EN and NT categories (1.0% each).

Moving to Pastaza province, 135 species were recorded, with 98 species (72.6%) in the LC category, followed by 31 species (23.0%) in the NE category. Two species were found in the EN category (1.5% each), three in the VU category (2.2%), and one in the NT category (0.7%). In Morona Santiago province, 156 species were evident. The LC category showed the highest representation with 111 species (71.2%), followed by NE with 38 species (24.4%). One species each was found in the CR, DD, EN, NT, and VU categories (0.6% each). Finally, in Zamora Chinchipe, 120 species were detected. The LC category had the highest representation with 84 species (70.0%), followed by NE with 31 species (25.8%). One species each was found in the CR, EN, and NT categories (0.8% each), and two species in the VU category (1.7%).

4 Discussion

This study is a comprehensive exploration of timber exploitation in the Ecuadorian Amazon, revealing findings on the forest species exploited during the period 2012–2021. Timber extraction is analyzed across all provinces, highlighting the influence of the practices of indigenous communities and settler concessionaires, and raising crucial questions about the sustainability of these activities. The assessment of the conservation status of species according to the IUCN classification reveals a duality of encouraging and worrying aspects. While the majority of species are classified as LC, indicating the potential for balanced and sustainable forest management, the significant presence of species in the VU, EN and DD categories highlights the need for more nuanced approaches to conservation. Furthermore, the finding that 26.2% of the species analyzed are not assessed in the IUCN database highlights a critical gap in our current understanding.

4.1 Trends in the use of forest species

The observed disparities in the volumes of timber exploitation among the provinces of the EAR prompt a critical examination of the underlying trends and contributing factors. Sucumbíos and Orellana

TABLE 1 List of the most important tree species with their volume approved for harvesting, percentage of volume harvested and mean harvesting rate in m³/ha (2012–2021).

Year	Sucumbíos			Orellana			Napo			Pastaza			Morona Santiago			Zamora Chinchipe		
	Approved volume (m^3)	Harvested volume (%) /#sp.	Mean* m^3/ha	Approved volume (m^3)	Harvested volumen (%) / #sp.	Mean* m^3/ha	Approved volume (m^3)	Harvested volumen (%) / #sp.	Mean* m^3/ha	Approved volume (m^3)	Harvested volumen (%) / #sp	Mean* m^3/ha	Approved volume (m^3)	Harvested volumen (%) /#sp	Mean* m^3/ha	Approved volume (m^3)	Harvested volumen (%) / #sp	Mean* m^3/ha
2012**	7,905.8	96.5 / 51	1.4	1,768.4	80.7 / 30	0.5	566.7	88.7 / 15	1.4	3,370.2	96.4 / 52	2.4	1,028.5	52.6 / 22	0.8	736.2	95.9 / 14	1.4
2013	59,736.7	88.1 / 111	0.9	67,406.8	90.4 / 98	0.9	20,711.6	92.2 / 69	1.8	37,892.6	91.3 / 109	2.1	22,619.3	76.5 / 103	1.1	9,272.1	87.6 / 75	1.2
2014	178,621.3	86.5 / 102	0.7	175,361.9	87.9 / 87	0.9	39,365.0	90.0 / 66	1.7	92,628.1	90.1 / 108	1.6	33,456.8	82.1 / 101	1.2	22,049.0	84.1 / 80	1.3
2015	86,027.9	83.3 / 93	0.8	87,511.2	88.9 / 81	0.8	26,105.5	92.7 / 59	1.8	59,178.4	81.6 / 100	1.4	28,439.5	75.5 / 98	0.9	17,997.9	85.6 / 86	1.4
2016	81,078.1	88.1 / 91	0.9	68,833.5	91.5 / 80	0.9	31,865.5	86.5 / 59	1.7	34,808.9	88.0 / 92	1.4	14,218.3	69.8 / 71	1.3	10,172.2	87.0 / 53	2.2
2017	91,770.8	91.5 / 88	1.0	86,125.4	92.6 / 85	0.9	33,860.3	91.7 / 53	1.3	29,985.1	91.8 / 92	1.2	16,316.4	82.9 / 71	2.0	16,526.1	82.6 / 66	1.5
2018	122,057.4	89.9 / 96	0.9	109,955.3	89.7 / 88	1.1	39,681.0	95.0 / 66	1.6	33,444.0	94.3 / 87	1.2	22,322.8	78.2 / 72	2.4	14,420.0	80.4 / 79	1.9
2019	927,40.6	84.4 / 98	0.7	81,530.5	90.6 / 71	1.0	29,136.1	95.9 / 47	1.5	23,299.0	94.3 / 73	1.1	15,319.5	78.0 / 72	1.7	11,141.9	84.7 / 63	2.1
2020	70,832.2	90.4 / 77	0.8	55,240.6	91.8 / 59	1.1	12,608.3	96.4 / 44	1.6	12,864.7	97.7 / 65	1.2	6,795.7	80.0 / 48	1.4	7,523.3	90.3 / 54	2.8
2021	99,422.5	78.5 / 84	0.8	103,355.0	83.7 / 88	0.9	27,445.4	86.8 / 65	1.4	27,596.9	68.3 / 74	0.9	15,152.8	70.3 / 70	1.0	7,758.0	63.2 /50	1.4
Total	890,193.2	-	0.9	837,088.6	-	0.9	261,345.4	-	1.6	355,067.9	-	1.5	175,669.6	-	1.4	117,596.8	-	1.7

*Mean volume harvested; ** Data reported correspond to the last 3 months of 2012, due to issues of the national forestry administration.

emerge as provinces with consistently higher exploitation volumes throughout the period spanning 2012–2021, while Zamora Chinchipe and Morona Santiago exhibit comparatively lower volumes. These differences could be related to the findings reported by Torres et al. (2018), who reported divergent subsistence strategies and economic income generation approaches among indigenous communities and migrant settlers, respectively. The nuanced dynamics in timber extraction volumes over the years raise intriguing possibilities. Indigenous communities use forest resources in a more balanced and sustainable approach given their traditional knowledge of how to use resources without depleting them (Parrotta and Agnoletti, 2012; Wali et al., 2017; Hill et al., 2020; Abas et al., 2022). However, it may also be related to the availability of road infrastructure and human settlements generated in the north of the EAR since the discovery of oil in 1967 (Bilsborrow et al., 2004; Sellers et al., 2017; Durango-Cordero et al., 2018).

The harvesting rate, ranging from 0.5 to 2.8 m³/ha, along with the logging ratio, illuminates a landscape marked by substantial variability in the efficiency of timber harvesting with the EAR. This intriguing variability prompts a more in-depth exploration, considering factors such as transactional costs and the pervasive informality in harvesting practices, as highlighted by Mejía and Pacheco (2014). The deficiencies in traceability processes, as noted by Morán et al. (2019), also emerge as critical factors warranting closer scrutiny.

The study sheds light on distinct patterns of timber extraction, notably observing relatively lower volumes in provinces like Napo and Pastaza, when juxtaposed with the higher extraction rates in Sucumbíos and Orellana. This discrepancy prompts an exploration into the intricate socio-economic dynamics influencing harvesting practices. In this regard, Vasco et al. (2017) have previously highlighted a compelling correlation between low income and illegal logging, suggesting a plausible link to the observed variations. The complex interplay unfolds as small landowners facing economic constraints may find themselves compelled to engage in illegal logging practices as a means to augment their income. This economic pressure, possibly rooted in limited alternatives, could, in turn, contribute to the underreporting of timber extraction volumes officially recorded by MAATE in these provinces.

The timber harvesting landscape in the EAR unfolds with notable distinctions in the reported amounts of wood authorized by the Ministry of the Environment (MAATE) across the provinces. Particularly, Morona Santiago (175,669.6 m³) and Zamora Chinchipe (117,596.8 m³) stand out as provinces with comparatively lower authorized wood harvesting volumes. This disparity finds its roots in the challenging geographical features characterizing the south-eastern part of the EAR. Marked by mountainous terrains and dense jungles (Clark et al., 2010; Velázquez et al., 2015; MAATE, 2023b), this region poses formidable obstacles to accessing extraction areas and subsequently transporting timber to markets. These geographical characteristics are able to be difficult to access extraction areas and the subsequent transportation of wood to markets, in addition to increasing costs and logistical difficulties, which could discourage further timber harvesting (Pokorny et al., 2012). Additionally, the influence of mining activities in these provinces further complicates the timber harvesting patterns. Mining operations often lead to environmental degradation and land-use conflicts, which can restrict access to forested areas and prioritize land for mineral extraction over sustainable forestry practices (Mestanza-Ramón et al., 2022). The dual

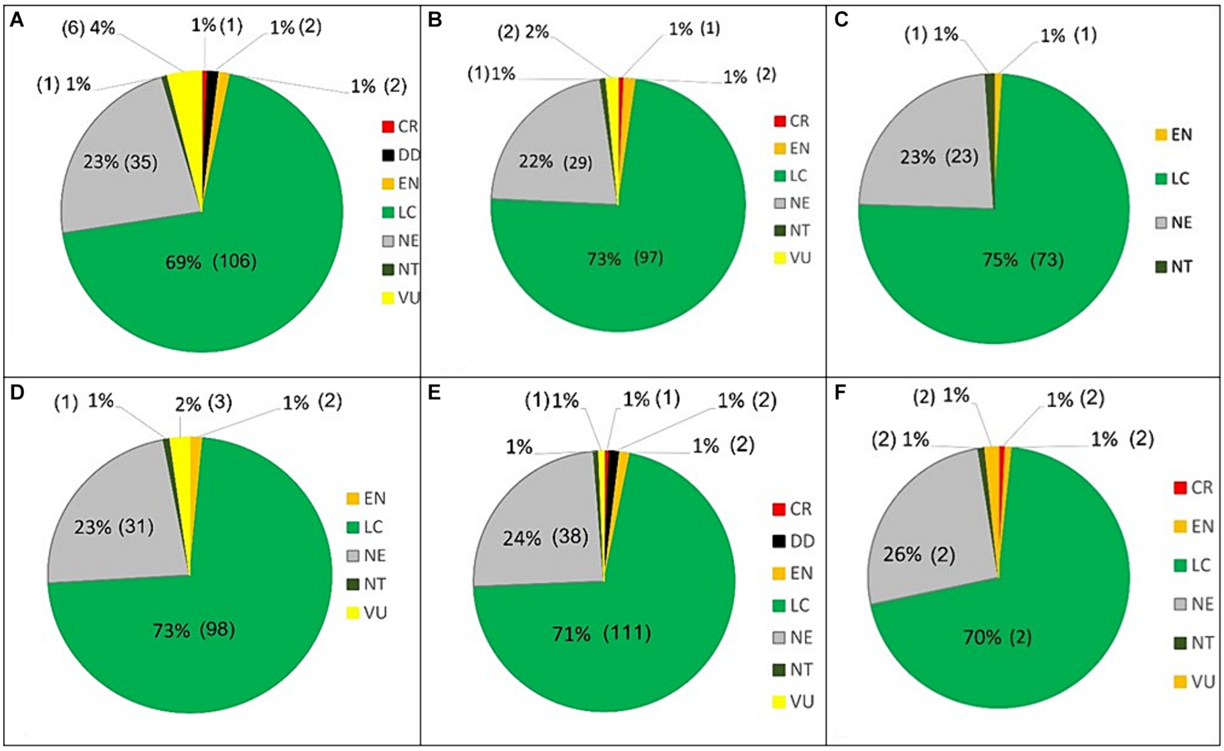

FIGURE 2
Percentage (%) and absolute number species (n) for each of the IUCN conservation categories. Provinces of the EAR: **(A)** Sucumbíos; **(B)** Orellana; **(C)** Napo; **(D)** Pasta; **(E)** Morona Santiago; **(F)** Zamora Chinchipe. Categories: CR, critically endangered; EN, endangered; VU, vulnerable; NT, near threatened; LC, least concern; DD, data deficient; NE, not evaluated.

pressures of difficult terrain and mining activities highlight the complex interplay of factors influencing timber extraction in Morona Santiago and Zamora Chinchipe.

4.2 Ten species with the greatest trade in the provinces of the EAR

The focus on the ten species driving timber trade within the provinces of the EAR unveils *E. uncinatum* from the Vochysiaceae family and *C. cateniformis* from the Fabaceae family as pivotal players. These species consistently emerge with the highest extraction volumes across all EAR provinces, aligning with findings reported by Mejía and Pacheco (2014), who reported that these species are among the eleven most mobilized in the EAR in an analysis performed between 2007 and 2011. These species stand out for their importance in the production of materials used for the manufacture of doors and floors in the construction and fine cabinetmaking industry (Carrasco et al., 2014; Mejía and Pacheco, 2014). Furthermore, various studies estimate that approximately 56% of the timber harvesting of native forests was performed mainly in the EAR (Sierra, 2013; Bonilla-Bedoya et al., 2017).

Both *E. uncinatum* and *C. cateniformis*, central players in timber trade within the EAR, currently bear the classification of LC according to the latest update from the IUCN (IUCN, 2023). This categorization, while indicative of their current non-critical status, warrants cautious interpretation. The extensive exploitation of these species, despite their LC status, raises concerns about potential future implications. It is crucial to recognize that this LC classification does not equate to a license for intensive extraction, as a decline in populations could precipitate a shift in their conservation category (Cazalis et al., 2023). Rather, these results suggest the need for further research into population status of these species, considering the intensified extractive activities they have been subjected to. The choice of certain species for harvesting could depend on several factors, such as availability, wood quality, commercial demand and forest management regulations (Mejía and Pacheco, 2014). Examining the IUCN conservation categories for the most commercialized species reveals critical gaps in our understanding. Notably, *P. montana* has the VU classification, while three species (*A. glomerosa, O. gordoniifolia* and *C. insignis*) lack a formal evaluation of their conservation status in accordance with the criteria established by the IUCN. The results presented in this research suggest that, despite the intense level of exploitation of these three species, their conservation status still remains unknown.

This research accentuates the pressing need for specific investigations to determine the status of these species` populations and resilience against the pressure exerted by extractive activity. In this context, field studies addressing population status, regeneration rates and susceptibility to harvesting could provide vital insights into the sustainability of current harvesting practices. Furthermore, analysis of natural regeneration, growth rates and the long-term effects of harvesting on these populations could shed light on their viability over the time horizon. Likewise, research focused on elucidating the

TABLE 2 List of the most important tree species with their volume approved for harvesting (2012–2021) in absolute and relative values and their IUCN category in the Ecuadorian Amazon.

Family	Species	Common name	Volume		Category IUCN
			(m^3)	(%)	
Sucumbíos					
Vochysiaceae	*Erisma uncinatum* Warm.	Arenillo, Pondo	77,253.50	2.93	LC
Fabaceae	*Acacia glomerosa* Benth.	Guarango, Yonrunta	46,669.05	1.77	NE
Malvaceae	*Ceiba pentandra* (L.) Gaertn.	Ceibo, Ceibo rojo	42,399.91	1.61	LC
Fabaceae	*Cedrelinga cateniformis* (*Ducke*) Ducke	Chuncho, Seique	42,308.65	1.60	LC
Myristicaceae	*Osteophloeum platyspermum* (A.DC.) Warb.	Loteria	36,659.32	1.39	LC
Meliaceae	*Guarea kunthiana* A.Juss.	Colorado, Tucuta	24,473.21	0.93	LC
Mimosaceae	*Cojoba arborea* (L.) Britton & Rose	Dormilon, Guarango	19,180.47	0.73	LC
Combretaceae	*Terminalia oblonga* (Ruiz & Pav.) Steud.	Guayabillo, Yuyun	16,919.49	0.64	LC
Burseraceae	*Trattinnickia glaziovii* Swart	Copal, Anime	14,710.30	0.56	LC
Phyllanthaceae	*Hieronyma alchorneoides* Allemão	Mascarey, Calum	13,856.81	0.53	LC
Subtotal			334,430.71	12.68	
Orellana					
Vochysiaceae	*Erisma uncinatum Warm.*	Arenillo, Pondo	61,104.57	2.32	LC
Malvaceae	*Ceiba pentandra* (L.) Gaertn.	Ceibo	62,017.31	2.35	LC
Fabaceae	*Cedrelinga cateniformis* (Ducke) Ducke	Chuncho, Seique	55,426.06	2.10	LC
Burseraceae	*Trattinnickia glaziovii* Swart	Copal, Anime	25,690.91	0.97	LC
Fabaceae	*Acacia glomerosa* Benth.	Guarango, Yonrunta	15,216.97	0.58	NE
Myristicaceae	*Osteophloeum platyspermum*	Loteria	13,633.33	0.52	LC
Fabaceae	*Dussia lehmannii* Harms	Poroton, Porotillo	13,057.52	0.50	LC
Meliaceae	*Guarea kunthiana* A.Juss.	Colorado, Tucuta	10,987.31	0.42	LC
Moraceae	*Brosimum utile* (Kunth) Oken	Sande, Sandi	11,980.07	0.45	LC
Phyllanthaceae	*Hieronyma alchorneoides* Allemão	Mascarey, Calum	9,160.37	0.35	LC
Subtotal			278,274.43	10.55	
Napo					
Malvaceae	*Ceiba pentandra* (L.) Gaertn.	Ceibo	18,456.39	0.70	LC
Fabaceae	*Cedrelinga cateniformis* (Ducke) Ducke	Chuncho, Seique	13,063.57	0.50	LC
Vochysiaceae	*Erisma uncinatum* Warm.	Arenillo, Pondo	13,215.85	0.50	LC
Meliaceae	*Guarea kunthiana* A.Juss.	Colorado, Tucuta	9,137.42	0.35	LC

(Continued)

TABLE 2 (Continued)

Family	Species	Common name	Volume		Category IUCN
			(m^3)	(%)	
Burseraceae	*Dacryodes peruviana* (Loes.) H.J.Lam	Copal, Anime	9,439.02	0.36	LC
Moraceae	*Brosimum utile* (Kunth) Oken	Sande, Sandi	6,282.22	0.24	LC
Burseraceae	*Trattinnickia glaziovii* Swart	Copal, Anime	4,536.35	0.17	LC
Bignoniaceae	*Jacaranda copaia* (Aubl.) D.Don	Jacaranda	3,809.15	0.14	LC
Phyllanthaceae	*Hieronyma alchorneoides* Allemão	Mascarey, Calum	3,362.30	0.13	LC
Myristicaceae	*Otoba gordoniifolia* (DC.) A.H.Gentry	Sangre De Gallina	2,262.27	0.09	NE
Subtotal			83,564.53	3.17	
Pastaza					
Fabaceae	*Cedrelinga cateniformis* (Ducke) Ducke	Chuncho, Seique	26,662.64	1.01	LC
Vochysiaceae	*Erisma uncinatum* Warm.	Arenillo, Pondo	23,838.38	0.90	LC
Meliaceae	*Guarea kunthiana* A.Juss.	Colorado, Tucuta	14,274.06	0.54	LC
Malvaceae	*Ceiba insignis* (Kunth) P.E.Gibbs & Semir	Ceibo, Ceibo rojo	13,726.34	0.52	NE
Malvaceae	*Ceiba pentandra* (L.) Gaertn.	Ceibo	9,398.31	0.36	LC
Combretaceae	*Terminalia oblonga* (Ruiz & Pav.) Steud.	Guayabillo, Yuyun	6,896.86	0.26	LC
Phyllanthaceae	*Hieronyma alchorneoides* Allemão	Mascarey, Calum	6,327.95	0.24	LC
Burseraceae	*Trattinnickia glaziovii* Swart	Copal, Anime	5,194.30	0.20	LC
Moraceae	*Brosimum utile* (Kunth) Oken	Sande, Sandi	4,674.37	0.18	LC
Urticaceae	*Pourouma minor Benoist*	Uva de monte	3,232.02	0.12	LC
Subtotal			114,225.23	4.33	
Morona Santiago					
Burseraceae	*Trattinnickia glaziovii* Swart	Copal, Anime	29,769.08	1.13	LC
Fabaceae	*Cedrelinga cateniformis* (Ducke) Ducke	Chuncho, Seique	23,469.35	0.89	LC
Meliaceae	*Guarea kunthiana* A.Juss.	Colorado, Tucuta	4,783.89	0.18	LC
Malvaceae	*Ceiba insignis* (Kunth) P.E.Gibbs & Semir	Ceibo, Ceibo rojo	3,728.88	0.14	NE
Malvaceae	*Ceiba pentandra* (L.) Gaertn.	Ceibo	3,007.39	0.11	LC
Moraceae	*Poulsenia armata* (Miq.) Standl.	Damagua, Majagua	2,716.19	0.10	LC
Combretaceae	*Terminalia amazonia* (J.F.Gmel.) Exell	Yumbingue	2,663.67	0.10	LC

(Continued)

TABLE 2 (Continued)

Family	Species	Common name	Volume		Category IUCN
			(m^3)	(%)	
Moraceae	*Clarisia racemosa* Ruiz & Pav.	Moral bobo	2,656.73	0.10	LC
Urticaceae	*Pourouma minor* Benoist	Uva de monte	2,643.06	0.10	LC
Phyllanthaceae	*Hieronyma alchorneoides* Allemão	Mascarey, Calum	1,801.38	0.07	LC
Subtotal			77,239.61	2.93	
Zamora Chinchipe					
Moraceae	*Poulsenia armata* (Miq.) Standl.	Damagua, Majagua	20,047.43	0.76	LC
Burseraceae	*Trattinnickia glaziovii* Swart	Copal, Anime	7,176.95	0.27	LC
Podocarpaceae	*Podocarpus oleifolius* D.Don	Podocarpus	7,711.43	0.29	LC
Podocarpaceae	*Prumnopitys montana* (Humb. & Bonpl. ex Willd.) de Laub.	Romerillo	6,055.61	0.23	VU
Fabaceae	*Cedrelinga cateniformis* (Ducke) Ducke	Chuncho, Seique	4,649.71	0.18	LC
Vochysiaceae	*Vochysia braceliniae* Standl.	Bella Maria	3,264.87	0.12	LC
Burseraceae	*Dacryodes peruviana* (Loes.) H.J.Lam	Copal, Anime	2,037.10	0.08	LC
Sapotaceae	*Pouteria caimito* (Ruiz & Pav.) Radlk.	Caimito	1,652.82	0.06	LC
Lythraceae	*Lafoensia acuminata* (Ruiz & Pav.) DC.	Guararo	1,775.51	0.07	LC
Lauraceae	*Endlicheria gracilis* Kosterm.	Forastero	1,341.44	0.05	LC
Subtotal			55,712.87	2.11	

exploration of the socioeconomic and environmental implications of the use of these species in local communities stands as a relevant component for sustainable management.

4.3 IUCN conservation categories

Within the EAR, our investigation into the IUCN conservation categories illuminates a nuanced distribution. A substantial 67.6% (142 species) of the examined forest species are in the LC category, 3.3% (7 species) as VU, and 1% (2 species) as EN. These findings align with Guevara-Andino et al. (2019) database of lowland trees in the EAR, where 106 species were found in LC, 78 in VU, and 16 in EN.

An interesting parallel emerges when considering global patterns Brummitt et al. (2015), propose that approximately 65% of plant species worldwide may find themselves in the LC category, a trend echoed in the EAR. On the other hand, one species (0.5% of 210) cataloged as CR was identified, being *C. ochroxylum*. This agrees with the previous findings, where a single species in this category was reported of lowland trees in the Amazon (Guevara-Andino et al., 2019). Moreover, 1.0% of the species in our study were classified as DD, suggesting that the available information is insufficient to determine their threat level. This aligns with global patterns, where 8.1% of evaluated plant species worldwide (66,468 species) find themselves in the DD category due to a lack of necessary information. In the case of Ecuador, 6.7% of the species (5,512) are in this category (IUCN, 2023). At the EAR level, Guevara-Andino et al. (2019) reported nine tree species as DD.

Furthermore, in a global context, a total of 390,287 plant species remain to be assessed (Bachman et al., 2019). Meanwhile, the most recent global assessment of the threat status of plants (Brummitt et al., 2015) suggests that as many as 115,291 plant species are currently classified as NE. In this regard, a significant finding of our research is that 26.2% (55 spp.) of the analyzed forest species do not have an IUCN assessment. At the EAR level, this lack of assessments was also observed by Guevara-Andino et al. (2019), who reported that 89% of lowland tree species in EAR have not been assessed by the IUCN.

With regard to NE species, it is important to underline that, in addition to knowing their current IUCN category, it is

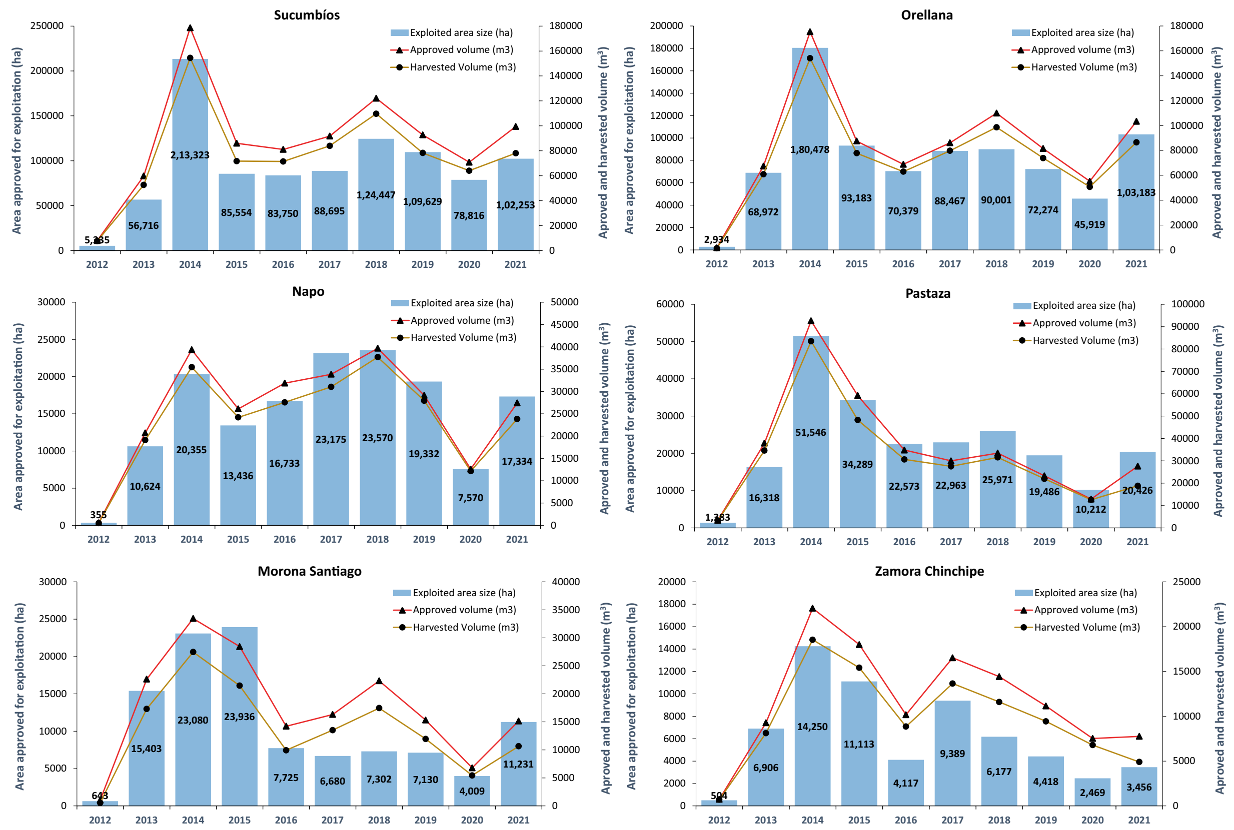

FIGURE 3
Area in hectares affected by timber harvesting and the volume (m³) approved by the Ecuadorian forestry authority (MAATE) and harvested by the executor during the years 2012 to 2021 in the six provinces of the EAR.

necessary to classify whether these species are common or rare. In this regard, recent findings reported by Enquist et al. (2019) suggest that about 36.5% (species with less than or equal to five observations) of the approximately 435,000 plant species on Earth are extremely rare, and there is very little geographic information on the botanical collection patterns of each species. Under this consideration, taking into account the number of observations proposed by Enquist et al. (2019) and considering the geographic database previously reported by López-Tobar et al. (2023) in a recent research focused on the analysis of botanical collection patterns of the most traded species in the EAR, it could be determined that 49.1% (27 spp.) of the NE species would currently be considered as rare due to their limited number of reported observations (less than or equal to 5 observations).

The inherent vulnerability of species classified as rare accentuates their susceptibility to population declines and heightened extinction risk (Engemann et al., 2015; Enquist et al., 2019). It is essential to promote botanical sampling and digitization of herbarium specimens in the EAR to improve the understanding of collection patterns of these species (Guevara-Andino et al., 2019; Davis, 2023). It is also crucial to establish and promote continuous monitoring of these species through initiatives such as the National Forest Inventory of Ecuador (ENF, 2020). To address these issues, it is necessary to use methodologies that allow the identification of optimal areas from both a geographical and ecological point of view (Nuñez-Penichet et al., 2022), thus facilitating the documentation of a greater number of specimens with less economic investment and human effort, leading to the creation of a more complete and enriched database (Soberón and Llorente, 1993). In conclusion, fostering synergy between increased botanical collection efforts, digitization of herbarium collections, and the implementation of continuous monitoring initiatives is poised to yield a more complete and up-to-date understanding of the distribution patterns of wood species classified as NE and considered rare due to the limited number of reported geographical observations. This holistic approach forms the bedrock for informed conservation strategies, ensuring the preservation of biodiversity within the EAR.

The need to evaluate the risk of extinction of plant species at both a global and local level has been widely highlighted in various studies (Guevara-Andino et al., 2019; Betts et al., 2020). However, the IUCN Red List faces substantial challenges in its attempt to keep assessments up to date and decrease the proportion of data-deficient species (Cazalis et al., 2023). Within this perspective, automated evaluations based on geographical occurrence records available in digital format could acquire vital importance, since they would allow the detection of species or groups that face a greater risk of extinction. This would guide manual evaluation efforts toward those species that have a greater need for care (Zizka et al., 2021).

In view of these results, it becomes imperative to chart a course for future research that delves into the evaluation of forest species hitherto unassessed by the IUCN. This becomes especially crucial for species dwelling in the shadow of unidentified threats, urging a meticulous examination of their conservation status. The implications of this research extend beyond academic realms, resonating with government institutions responsible for the conservation of natural resources and biodiversity, as well as environmental organizations. The actionable insights derived from this research can serve as a compass for informed decision-making and the formulation of more effective conservation strategies. By honing in on species potentially at the greatest risk and those that await evaluation, stakeholders can channel their efforts toward safeguarding the rich biodiversity of the Ecuadorian Amazon Region. This strategic approach not only fortifies conservation initiatives but also fosters a proactive stance in the face of emerging threats and uncertainties.

4.4 Conclusions and recommendations

This study undertook a meticulous analysis of timber volumes associated with the most traded species in the EAR spanning 2012–2021. Concurrently, we delved into the contemporary conservation status of these species, as classified by the International IUCN. In this context, our main findings show a picture of timber utilization in the EAR. From an authorized harvest volume of 2,627,659.17 m^3, the harvested counterpart stood at 2,296,238.08 m^3, signifying 54.17% of the national timber harvest from native forests. The Fabaceae family takes the spotlight, boasting the largest species count and a cumulative volume of 305,548.5 m^3, closely trailed by the Malvaceae family.

However, the landscape of timber harvesting is marked by notable variations in average yields, spanning from 0.5 m^3/ha in Orellana (2012) to 2.8 m^3/ha in Zamora Chinchipe (2020). Navigating the IUCN categories, approximately 67.6% of scrutinized forest species are designated as LC. Intriguingly, species within more imminent threat categories—VU, EN, and CR—also make their presence felt. A compelling facet surfaces in the form of 55 species eluding assessment to date, with 49.1% potentially classified as rare due to scant recorded occurrences, showcasing the imperative for intensified assessments to decipher their conservation status and distribution.

The data provided in this study can be used by conservation organizations to develop specific strategies for species identified as VU, EN and CR. In addition, these results can inform public policy by highlighting the importance of sustainable logging practices and stricter regulations to combat illegal logging. Integrating this knowledge into policy frameworks can improve the effectiveness of conservation efforts and contribute to the 2030 Agenda for Sustainable Development, in particular Goal 15, which aims to protect, restore and promote sustainable use of terrestrial ecosystems. The study highlights the need for comprehensive monitoring and assessment to update the conservation status of lesser-known species, thereby supporting the ecological resilience and socio-economic well-being of the region.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

Author contributions

RL-T: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. RH-F: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. FG-R: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. RM: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. BT: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

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Conflict of interest

Author BT was employed by company Ochroma Consulting and Services S.A. B.I.C.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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