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Disentangling the deforestation-environmental crime nexus in Latin America

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ABSTRACT

Deforestation and natural resource extraction are well-known threats to biodiversity conservation, environmental justice, livelihoods, ecosystem services and can even result in crimes to, and harassment of, environmental defenders. Such punitive actions against environmental defenders can influence both economic development and forest conservation efforts. Yet, little is known about this nexus and the complex relationships between environmental impacts, such as deforestation, and environmental crimes across space and time in many regions such as Latin America. We explored these complex relationships using a database of environmental crimes, threats, and harassment (ECTH) affecting environmental defenders, as well as forest loss data, and municipal-level socioeconomic indicators for nine Latin American countries over a period of eleven years. We found that as deforestation increased, there was a large increase in ECTH episodes related to agricultural activity, while in highly populated municipalities there were more ECTH episodes related to energy production, transportation, and urbanization activities. Overall, the percentage of annual deforestation had a strong influence, which varied according to municipal wealth, population density (PD), and geographical context. Statistically significant increases in violent crimes were found with increasing deforestation, but only in Honduras, Guatemala, and Mexico, and in municipalities with lower population densities. Conversely, higher income, more populated municipalities were characterized by judicial harassment, as opposed to violent crimes, indicating a type of Environmental Crime Kuznets Curve relationship. A structural equation model where deforestation was driven by the number of ECTHs, as well as percent forest area, PD, latitude, and country showed that the number of ECTH events and country were significant drivers of deforestation. Understanding these complex social-ecological dynamics shows the profound effects that deforestation and unsustainable, and unjust, environmental impacts and conflicts can have across forests and ecosystems of the Global South in terms of social justice and conservation, and thus merits increased protection of environmental defenders in Latin America.

1. Introduction

Latin America is one of the most biodiverse regions in the world, yet several land use and natural resources extraction related activities are driving habitat conversion and biodiversity loss at accelerated rates (Albert et al., 2023; UNEP-WCMC, 2016). Deforestation, for example, is affecting key ecosystem services (e.g. climate regulation and water provisioning; Boers et al., 2017), increasing the risk of disease outbreaks (Feged-Rivadeneira et al., 2022; MacDonald and Mordecai, 2019), and ultimately impacting the security and well-being of communities (Alkama and Cescati, 2016). Deforestation is particularly affecting tropical, low and medium-income nations (Crespo Cuaresma et al., 2017), which are also often characterized by unstable political and governance systems, weak economies, and an unequal distribution of wealth (ECLAC, 2021). In such countries, economic development in the form of resource extraction has been widely used to address many of these issues, yet this has come at environmental and socio-economic costs. Specifically, deforestation does not only affect conservation efforts and natural capital but is also creating impacts to vulnerable and indigenous communities, their traditional knowledge, and non-timber forest product-based livelihoods (Bebbington et al., 2018).

Deforestation is also impacting the local and regional-level socio-

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political stability and overall well-being of communities. For example, in Latin America the transition from agricultural to industrial and service-based economies is leading to more frequent environmental conflicts, which are exacerbated by weak governance and governability systems (Martinez-Alier, 2021). Key to these conflicts are environmental crimes perpetuated on community-level individuals and organizations by actors with vested interests in extracting natural resources (Larsen et al., 2021). We define 'environmental crimes, threats, and harassment' (ECTH) as a set of punitive actions that can include both violent and non-violent crimes or "violations of criminal laws designed to protect the health and safety of people, the environment or both" (Gibbs et al., 2010). Typical activities that can lead to these outcomes include land-grabbing, illicit cropping and mining, and enterprise lobbying (Scheidel et al., 2020) and even the consequences of war and armed conflict (Rawtani et al., 2022; Suarez et al., 2018). Such punitive actions against communities or individuals can also include threats that lead to intimidation or internal displacement of people (Zuñiga-Upegui et al., 2019) as well as judicial harassment or strategic legal and/or judicial strategies to silence and intimidate critics (BHRRC, 2020), or other forms of "slow violence" (Nixon, 2011). Actors perpetuating these crimes can be individuals, private organizations, institutions, criminal groups, and even governments, among others.

In turn, the targets of such crimes are frequently organizations, communities, and more increasingly individuals often referred to as social and environmental defenders (Verweijen et al., 2021). These individuals are often vulnerable and members of minority groups, but can also include environmental activists and advocates, small landholders, Non-Governmental Organization staff, union leaders, journalists or others who are directly or indirectly defending community rights and resources and are involved in actions to safeguard recognized common goods (Verweijen et al., 2021). Such environmental defenders are "people who take peaceful action to protect land or environmental rights, whether in their own personal capacity or professionally" (Ghazoul and Kleinschroth, 2018); as such these actions, by definition, are a type of conflict over not just land or resources but also environmental conservation and protection. Furthermore, vulnerable communities and indigenous groups often experience higher rates of violence relative to other groups (Bebbington et al., 2018).

Using the Environmental Justice Atlas (EJ Atlas) Scheidel et al. (2020) characterized such punitive actions on environmental defenders globally and documented not only high rates of criminalization (20% of studied cases), but also physical violence and murders (30% of cases). These data were also used to characterize the types of conflicts and actors involved, and vocabulary used, in environmental movements and indicated an increasing trend in such conflict over time (Martinez-Alier 2016). Jeffords and Thompson (2016) also analyzed the relationship between income and fatal crimes against environmental defenders while controlling for "rule of law", governance, and natural resource extraction factors and found a Kuznets-type curve between fatalities and per capita income across 34 countries from 2002–2013. Weak rule of law and corruption are also associated with patterns of crimes against environmental defenders globally (Butt et al., 2019; Shytov, 2023).

In terms of regional or national-level analyses, studies have been used to elucidate the magnitude and occurrence of such punitive actions in the form of ECTH against communities and individuals (Zeng et al., 2022; Le Billon and Lujala, 2020; Rodrigues et al., 2022). According to GlobalWitness (2022) in 2021 alone, 200 environmental defenders were murdered worldwide, with more than half of these deaths occurring in three Latin America countries: Mexico, Colombia, and Brazil. Since 2012, Brazil had the largest number of murders of environmental defenders (342) followed by Colombia where 322 deaths have been reported. Several other non-lethal types of punitive actions have also been identified, and include physical violence, forced displacement, threats, defamation campaigns, and judicial abuses (ISHR, 2015). These studies present evidence and document who environmental defenders are, the environmental conservation and resource protection or preservation motives for their actions and advocacy, and the magnitude of the link between different economic sectors and types of environmental impacts and conflicts.

However, despite recent findings and studies, there is less evidence and understanding of the multi-scale and bi-directional relationships among environmental impacts such as deforestation and other natural resource extraction activities, socioeconomic conditions, types of resources being protected and ECTH against environmental defenders in regions of the Global South. Therefore, to better understand these dynamics, we analytically explored the nexus between deforestation, ECTHs, and socioeconomic indicators across several Latin American countries during 2009–2019. Specifically, we (i) characterized the occurrence and types of ECTHs perpetuated on environmental defenders; (ii) analyzed the spatio-temporal relationships among ECTHs, municipal-level socioeconomic indicators, and environmental impacts, including deforestation extent, and (iii) explored whether deforestation is a driver of ECTH against environmental defenders.

2. Materials and methods

2.1. Study area

Our study area consisted of nine Latin American countries: Mexico, Guatemala, Honduras, Colombia, Brazil, Peru, Ecuador, Bolivia, and Argentina. The countries represent a variety of cultures, climates, and biomes and contain some of the most biodiverse areas in the world (Myers et al., 2000). Socio-politically they are mostly medium income democracies and are all considered part of the Global South. During this analysis period of 2009–2019 several of these countries, particularly Mexico and Honduras, experienced a spike in narcotics-related ECTHs (Pérez-Llorente et al., 2019; Devine et al 2021), while other countries like Colombia, Brazil and Peru experienced rapid rates of deforestation and increased environmental health issues associated with agriculture expansion and urbanization (Feged-Rivadeneira et al., 2022; Vancutsem et al., 2021; Silva Junior et al., 2021). Other countries such as Argentina, Bolivia and Ecuador have reported several high-profile environmental conflicts related to agriculture, mining, hydroelectric projects, and other extractive industries that affect the environment and biodiversity conservation (Orihuela and Thorp, 2011; Walter and Wagner, 2021).

2.2. Data processing

Geo-referenced ECTH event data were obtained from the 'Tierra de Resistentes' (TDR, 2022) database (https://tierraderesistentes.com/es/datos/). The database is a collaborative and cross-border project that has been investigating the phenomena of violence perpetrated on Latin-American environmental defenders from twelve different countries. The nine countries used in this study were selected based on the availability of the variables necessary for analysis at a municipal and annual basis for the analysis period. The TDR (2022) database reports several variables related to ECTH events including the date of the event and its coordinates, resource type being protected, the environmental impact activity that generated the ECTH event, and the specific type of ECTH. Each incident was reported as a single record, which often resulted in multiple ECTH events (i.e., multiple persons impacted and/or multiple types of events). The victim's gender and ethnicity were also collected, but only on a subset of records, and thus were not included in the analyses. Data were filtered to include only records with full geographic information to allow for linking environmental and socio-economic data during the analysis period (2009–2019). All ECTHs events were then grouped into 3 major ECTH types (Table 1).

For our first and second objective, we characterized the distribution and extent of forest loss using the Global Forest Change dataset v.1.9 (GFC; Hansen et al., 2013) and extracted data on the annual amount of municipal-level deforestation using cloud computing in Google Earth Engine (GEE; Gorelick et al., 2017). A baseline forest cover for the year

Table 1
Environmental crimes, threats, harassments (ECTH) classes filtered from the Tierra de Resistentes database (TDR, 2022), the aggregated classes, and definition sources used in this study.

ECTH types	Number of Records	Number of Events	Aggregated ECTH class (Source definition*)
Judicial harassment	400	21,343	Judicial Harassment (JH; BHRRC, 2020; Nixon, 2011)
Criminalization/ slander	103	1211	
Other	37	777	
Threats	613	6425	Threats-Internal Displacement
Displacement	21	200	(TID; Feged-Rivadeneira et al., 2022; Zuñiga-Upegui et al., 2019)
Murder	580	13,354	Violent Crimes (VC; Gibbs et al., 2010; Scheidel et al., 2020)
Assault	338	6554	
Disappearance	17	128	
Sexual assault	5	375	
(Missing)	5	160	(Missing)
Total	**2119**	**50,527**	

* Please refer to the second paragraph of the Introduction and references for ECTH definitions

2000 was used by defining two thresholds for a 'forest pixel' (30 x 30 m) as percent tree cover ≥ 30% and ≥ 50%. This baseline variable is a proxy for the initial potential of land that can be deforested. Preliminary analyses showed that both thresholds led to identical conclusions; thus, we opted for the ≥ 30% threshold to present results. Annual statistics by municipality were obtained using GEE and adopting the Second-Level FAO- Global Administrative Unit Layers (GAUL) (FAO, 2015). This layer was used to derive all multi-annual municipal-level statistics, including extent of annual deforestation and total deforestation over 2009–2019. We also included the crime event's latitude as a proxy to explore north-south regional differences.

Deforestation and ECTHs can also be influenced by national and regional-level socioeconomic dynamics (Crespo and Cuaresma et al., 2017); accordingly, we accounted for two socioeconomic factors in our analyses. First, we used annual population density (*PD*; persons km^{-2}) obtained using the 3-arc (approximately 100 m x100 m at the Equator) UN-adjusted population counts from gridded layers available from WorldPop (2018) that were derived from a random forest-based dasymetric redistribution mapping estimation approach (Lloyd et al., 2019). Municipal *PD* was calculated by dividing population counts (*P*) by the corresponding area of the municipality (km^2) as derived from FAO-GAUL data. Secondly, a proxy measure of annual estimated wealth (*MW*) was calculated for each municipality by using annual national Gross Domestic Product (*GDP*) per capita data from World Bank (2020), in US$, and annual population, *P*, using Eq. (1) where *i* indicates the year and *m* the municipality:

$$MW_{i,m} = GDP_i * P_{i,m} \quad (1)$$

All ECTHs were aggregated into three classes: Judicial harassment (JH), Threats and internally displaced people (TID), and Violent crimes (VC) (See Table 1 for source definitions for these classes). Types of environmental impact activities that led to ECTHs were also aggregated into five classes of environmental impacts: Agricultural activity (AA), Over-exploitation (OE), Energy production (EP), System modification/ Urbanization/ Pollution/ Transport (SMU), and Narcotrafficking (NT; Table 2).

A spatial join in a GIS environment (ESRI, 2016) was performed to merge all ECTHs and related attributes, as well as deforestation and socioeconomic data at the municipal level. Overall, our final database included 2119 records of 50,527 ECTHs observed in 560 municipalities across nine countries. The TDR database also included a variable describing the environmental resource or amenity the defenders were protecting (TDR, 2022) and these resource types included: water (n=353), air (n=3), forest (n=304), biodiversity (n=16) and land (n=1443). The final dataset used in this study is available from https://figshare.com/articles/dataset/All_ecth_yr_csv/23394107 .

Table 2
Numbers of records and ECTH events by type of environmental impact activities filtered from the Tierra de Resistentes (TDR, 2022) database and the aggregated environmental impact classes used in this analysis: Agricultural activity (AA), Energy production and mining (EP), Narcotrafficking/War/Human disturbance (NT), Over-exploitation (OE), and System modification/Urbanization/ Pollution/Transport (SMU).

Environmental impact activities	Number of Records	Number of Events	Environmental impact class
Agro-industry	701	28,953	AA
Forestry	232	3145	
Energy	53	856	EP
Petroleum	68	255	
Mining	292	3146	
Narcotrafficking	159	898	NT
Hunting/biodiversity trafficking	10	83	OE
Fishing	17	95	
Logging	123	1416	
Real estate speculation	11	57	SMU
Hydroelectric*	164	3215	
Infrastructure	201	7715	
Garbage/waste	8	36	
Tourism	1	3	
(Missing)	79	654	(Missing)
Total	**2119**	**50,527**	

* Hydroelectric was included as a System Modification environmental impact since it is a renewable natural resource as opposed to mining and petroleum which are non-renewable, extractive natural resources.

2.3. Statistical analyses

We developed generalized linear models (GLMs) to determine the drivers of numbers of ECTHs associated with different environmental impact activities by year. We specifically used municipality-level data where at least one ECTH event was recorded and that was associated with an environmental impact activity during the analysis period; thus models are conditional on the existence of at least one ECTH event associated with one environmental impact activity that occurred during the analysis period.

Potential explanatory variables used in the analysis were: baseline forest extent (year 2000), annual estimated municipal wealth (MW), estimated annual population density (PD), and amount of annual deforestation. Since deforestation was hypothesized to be a multi-year disturbance (i.e., a decade) and a cumulative driver of ECTHs, we also calculated the total area of deforestation over the 11-year analysis period. Total area forested and area deforested in each year and in total were divided by the municipality area to make proportional (%) input variables for the models.

The TDR (2022) data gives a listing of locations and years where a ECTH event occurred. Thus, we inferred that years without entries, were those where no ECTH event occurred and created a dataset that included years with and without events, such that each municipality had one observation with the number of ECTH events per year. This dataset could be used to better understand the conditions under which an ECTH is more or less prevalent in municipalities experiencing such events, answering the question: *given that a location has experienced an ECTH, under what conditions are these events more/less prevalent*? However, this approach could not be used with explanatory variables for gender and resource type variables, as they were missing in years with no events.

As an initial exploratory analysis, we investigated the distribution of ECTH categories (i.e., JH, TID, VC), the environmental impact (i.e., AA, EP NT, OE, SMU), and the resource type (e.g., water, forest biodiversity) by country, area deforested (%), area forested (%), MW, PD, and latitude. Because the response data were categorical and the distributions of the predictor variables tended to be skewed, we analyzed these relationships using quartile categories. This allowed us to use Chi-square Tests of Independence to determine if each ECTH category, environmental impact class, and resource type class was independent of each predictor via the SAS procedure PROC FREQ (Version 9.4).

2.4. Models of ECTH as a function of deforestation

Models were developed to better describe the number of ECTH events at each municipality as a function of a set of quantitative and categorical input variables. Since data are counts, a GLM with Poisson response was first formulated via the SAS procedure PROC GLIMMIX. However, a negative binomial distribution better described the excess zeroes found in the data. As a preliminary step, Pearson correlation coefficients were computed between pairs of all quantitative variables (Appendix Table A.1). This resulted in the population (number of persons) variable being removed from further analyses. Quantitative variables included in the model were: % annual deforestation, % forested (year 2000), PD, MW by year, and a municipality's latitude. We then tested models of the number of ECTHs per year as a function of the current year's deforestation, as well as with the amount deforested in the previous and second previous years, and models that included the total deforestation over the analysis period. We explicitly accounted for repeated measures in subsequent years by location, and tested residuals for the presence of spatial autocorrelation.

Models with annual deforestation over the study period consistently performed better, and thus we retained this variable for all subsequent models. Categorical variables for country and latitude were also included. All two-way interactions were included as predictors in models, except those involving country, as uneven counts among countries led to a lack of convergence. Quantitative variables were first standardized (mean 0, standard deviation 1) to promote model stability and year of ECTH was included as a random effect. Models of the number of ECTH per year in each municipality were fit for all types of ECTH together, as well as separately for each ECTH type. A modified backwards stepwise elimination procedure was used whereby the least significant effect was dropped if the Akaike Information Criteria (AIC) did not increase. Simple effects remained in the model if interactions were significant ($p<0.10$). Model residuals were tested for spatial autocorrelation using the SAS procedure PROC VARIOGRAM; however, there was no evidence of significant spatial autocorrelation.

2.5. Modeling drivers of deforestation and ECTH occurrence

We used Structural Equation Modeling (SEM) to explicitly test our third objective regarding the direct and indirect effects among deforestation, forested extent, population density, and municipal-level wealth to better understand the causal relationship between the number of ECTHs and deforestation. Structural Equation Modeling is a statistical technique for quantifying relationships among observed and latent variables. While similar to GLMs in that it examines linear causal relationships among variables, SEM assumes that there is an underlying mechanism which leads to a theoretical covariance structure among variables (Malaeb et al., 2000). Thus all SEMs were based on the hypothesized relationships and results of GLMs.

Specifically, SEM was used to explicitly test two possible relationships between ECTH, municipal-level socioeconomic indicators, and environmental impacts. First, we tested the direct and indirect effects of forested area, PD and MW on the number of ECTHs via deforestation. Then we formulated an alternative model to test deforestation via the number of ECTHs. We designed SEMs using the *lavaan* package in R (R Core Team, 2021). We used the function *sem* to fit models, and the function *modificationindices* to explore the improvement to fit obtained by including additional covariates. The R function *semPaths* in library *semPlot* was used to visualize the model. Categorical variables and non-normal distributions are not supported by these SEM procedures, and thus total ECTH events and percentage deforested data were transformed using the quartic root. Based on preliminary analyses showing that Honduras was significantly different than other countries, country was represented as an indicator for Honduras (HN) versus all others. Model fit was assessed via the Vuong test (Vuong 1989).

3. Results

3.1. Distribution of data across type of ECTH, resource type, and environmental impact activity

In general, the distributions of ECTH events by aggregated ECTH class were significantly different (Chi-square Tests of Independence, $p<0.01$) by % deforested, % forested (2000), MW, PD, and Latitude. Thus, the distribution of ECTH events depended on these variables. Results showed that as deforestation increased, there was a large increase in ECTH events related to agricultural activity (AA); however, ECTH types in most other activity classes decreased (NT, OE; Appendix, Fig. A.1). Also, there were more JH (judicial harassment) and VC (violent crime) events when deforestation was above the median value. When % forested (2000) was at its highest values, there were fewer JH events and more VC (violent crime) and TID (Threats/Internally displaced People) events; and less events related to SMU (System Modification/Urbanization/Pollution/Transport) (Appendix, Fig. A.2). There were also more TID events and less JH events when MW (Municipal Wealth) was high, and as MW increased above the median, ECTH events related to land resource types decreased while those related to water and forest resource types increased (Appendix, Fig. A.3). Conversely, as PD increased there were in general more ECTH events related to land and water resources, and less so for forest-related resource types (Appendix, Fig. A.4). When PD was at its lowest values, there were more TID events, and when it was at its highest values, there were more JH events. Similarly, there were less JH and more TID events at lower latitudes (Appendix, Fig. A.5). At higher latitudes, there were many more SMU events and those related to land resource type.

The numbers of ECTH varied by country and municipality (Table 3; Fig. 1). The chi-square tests indicated that in Brazil and Peru, there were proportionally more TID events than versus other types of ECTH, whereas in Honduras and Ecuador there were proportionally more JH events, and in Mexico and Colombia, proportionally more VC events (Table 3; Appendix, Fig. A.6). These tests further indicated that Brazil, Peru, and Honduras had proportionally more crimes related to AA versus other environmental impact classes, whereas Ecuador, Guatemala, Colombia, Argentina and Mexico had more crimes related to EP (Energy production and mining). Colombia also had proportionally higher crimes associated with NT (Narcotrafficking/War/Human disturbance) and Bolivia had high crimes associated with SMU. Results also indicated that there were proportionally more crimes associated with defending Forest resources in Peru, whereas Brazil, Bolivia, and Honduras had more crimes associated with actions defending land resources.

3.2. Generalized linear models for the drivers of ECTH events

Models characterizing the relationships between ECTH and deforestation show that the number of annual events was significantly related to deforestation ($p<0.01$; Table 4). However, the relationship depended on latitude, MW, and PD. At higher latitudes (i.e. Mexico, Guatemala, and Honduras), there were more crimes with more deforestation and municipal wealth (MW), while the effect was non-significant at low latitudes (South American countries) and low values of MW (Figure 2a; Fig. 2d). At lower levels of PD the number of ECTHs increased with deforestation, and at high levels of PD, the opposite was true (Fig. 2b). We also found that the number of annual ECTHs was significantly related to the extent of forest area in year 2000, specifically as % forested increased, the number of ECTH events increased (Fig. 2c).

Table 3
Number of environmental crimes, threats, and harassment (ECTH) events by environmental impact and ECTH class by country.

	ECTH class*				Environmental Impact class**						
Country	JH	TID	VC	(missing)	AA	EP	NT	OE	SMU	(missing)	**Total**
Argentina	65	1	4	0	1	64	0	0	5	0	70
Bolivia	47	24	8	0	0	17	0	1	61	0	79
Brazil	701	4995	3237	0	6084	1571	136	548	222	372	8933
Columbia	18	303	611	0	53	455	344	26	30	24	932
Ecuador	418	104	60	0	12	566	0	0	4	0	582
Guatemala	483	134	353	25	9	541	0	425	6	14	995
Honduras	21,294	617	14,887	135	25,716	3636	37	64	7238	242	36,933
Mexico	294	366	1148	0	78	604	378	502	244	2	1808
Peru	11	81	103	0	145	18	3	28	1	0	195
Total	23,331	6625	20,411	160	32,098	7472	898	1594	7811	654	50,527

* Judicial Harassment (JH), Threats-Internal Displacement (TID), Violent Crimes (VC)
** Agricultural activity (AA), Energy production and mining (EP), Narcotrafficking/War/Human disturbance (NT), Over-exploitation (OE), and System modification/Urbanization/ Pollution/Transport (SMU).

We also analyzed the relationship between deforestation and the three different ECTH types (JH, TID, VC; Table 4), and found that the number of annual JH events varied significantly by country, with Argentina having significantly more events than all other countries. While % forested (2000) had no significant impact on the number of JHs, % annual deforested had a strong impact that varied according to MW, PD, and latitude. In areas with low MW or in low- to mid-latitudes, annual deforestation was not significantly related to JHs (Fig. 3a, 3c, 3d). However, when MW was high or latitude was high (Guatemala, Honduras, and Mexico), there was a strong increase in JH events as deforestation increased. Similar to the effect seen with the model of all ECTH events, when PD was low, there was a strong increase in JH events as deforestation increased, but the opposite was true when PD was high (Fig. 3b). Fewer significant drivers were found for TID crimes; numbers of TID crimes were significantly higher in Honduras versus other countries and increased with increasing MW and increasing % forested. The number of VC crimes was also significantly different by country, with Brazil and Honduras having significantly greater events than Colombia when accounting for differences in other drivers (% deforested, MW, etc.). Overall, we found that there were significant increases in violent crimes (VC) with increasing deforestation, but only at high latitudes (Mexico, Guatemala and Honduras) and when PD was lower (Figs. 4a, c). Conversely, when PD was very high, VCs were not significantly related to deforestation and VCs decreased with PD when MW was at its highest levels (Fig. 4b).

3.3. Causal models of deforestation and ECTH occurrence

A structural equation model was developed to test to alternative models. First, we investigated if indeed the number of ECTHs were a function of deforestation. Additionally, to better understand interactions among socio-ecological variables, we also developed an alternative model to test if deforestation was a function of the number of ECTHs. The AIC statistics indicated that both models had equal support. The first model where ECTHs were driven by deforestation, % forested (2000) and the effect for Honduras, did not show that deforestation was a strong driver of ECTHs ($p=0.066$). However, in the second model where deforestation was driven by the number of ECTHs, % forest, PD, latitude, and Honduras ($p<0.01$), the number of events was a significant driver of deforestation ($p=0.022$), though not as strong as the effect for Honduras, latitude, and PD (all $p<0.001$). While explanatory effects in the second model appear stronger, goodness of fit statistics are slightly better in the first model. Moreover, there is less evidence to support this latter model based on the Vuong test for non-nested models ($p<0.001$).

4. Discussion

This study used available data to better understand the complex and interactive dynamics between several resource extraction activities and environmental conflicts on ECTH against environmental defenders in 9 countries of the Global South. Results show the profound effects of economic development and deforestation on issues of social justice, weak governability, and the need for increased efforts in the protection of environmental defenders. Indeed, findings might indicate a type of Environmental Crime Kuznets Curve that shows how the nature and magnitude of ECTHs change according to municipal and national level wealth. Below, we discuss these relationships for 9 countries in Latin America (Fig. 1).

Our first objective was to characterize the types and number of ECTH that were perpetuated on environmental defenders according to environmental impact activity, the resource type they were protecting, municipal-level socioeconomic characteristics, and deforestation levels (Appendix Fig A1-A5). Overall, we found that more forested municipalities had more events involving more violent type crimes such as TID (Table 4). Jeffords and Thompson (2016) also discussed a “nexus” between environmental impact activities related to economic development and violent crimes. However, the authors examined how other confounding factors, such as climate change and "information spread”, can also exacerbate ECTHs against environmental defenders. Despite this, Scheidel et al. (2020) found that according to the global Environmental Justice Atlas, in 11% of cases environmental defenders were key in halting “destructive and socially conflictive” projects that detrimentally affected the environment and livelihoods. Although we did not specifically study the socio-demographics of the ECTH victims, Martinez-Alier (2021) and Butt et al. (2019) also found that environmental defenders dealing with environmental impact activities significantly experienced greatest ECTHs when indigenous groups were involved.

More regionally, in Andean countries environmental impact activities related to Over-exploitation (OE), Energy production (EP), System modification/Urbanization/Pollution/Transport (SMU), specifically mining, fossil fuels and logging, have been documented to result in more violent ECTHs, particularly against Afro-descendant and rural, lower income communities (Perez-Rincón et al., 2019). In our study we did not analyze for ethnicity; however, we observed that at increasing levels of deforestation, there was an increasing number of ECTH events related to agricultural activities (Fig. 2, 3, 4). Indeed, in Latin America agricultural expansion, especially involving extensive ranching, is often carried out by criminal groups through land grabbing and slash and burn practices that occurs frequently on or near indigenous reserves or subsistence farmers’ lands (e.g. in Brazil and Colombia); and this has repeatedly led to violent clashes with the original landowners or occupiers (Clerici et al., 2020; Silva-Junior et al., 2023). Trajber Waisbich et al. (2022)

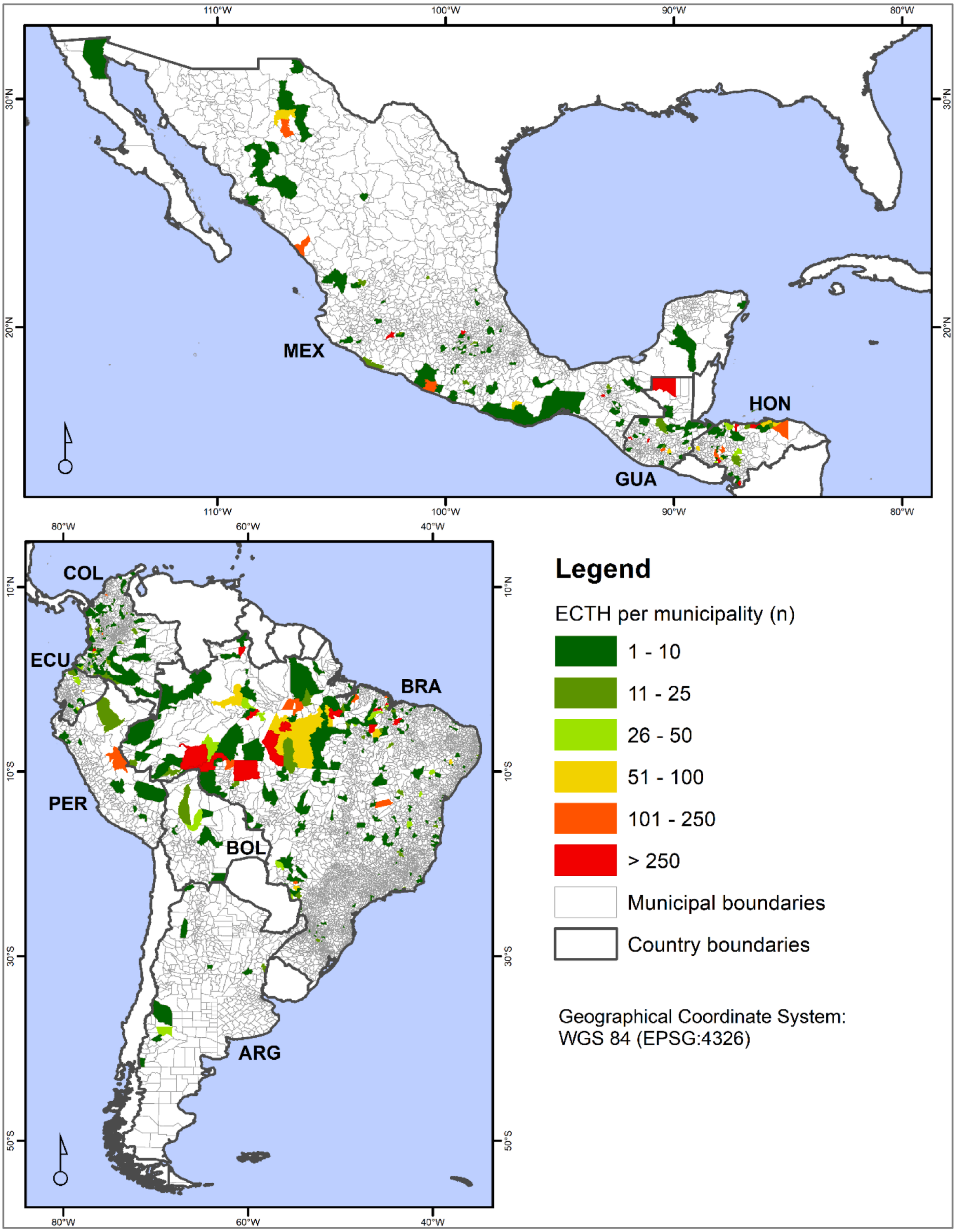

Fig. 1. Environmental crimes, threats, and harassment (ECTH) per municipality for the nine Latin American countries in our study. Note: MEX (Mexico), GUA (Guatemala), HON (Honduras), COL (Colombia), ECU (Ecuador), BRA (Brazil), PER (Peru), BOL (Bolivia), ARG (Argentina).

also report that in the Brazilian Amazon, criminal investigations involving land grabbing are often associated to deforestation-related crimes. Accordingly, our findings and these other studies indicate that efforts at protecting vulnerable and indigenous people in societies undergoing economic development, represent a key governability, social justice, and human rights necessity for sustainable development and biodiversity conservation goals (Dawson et al., 2021).

We also found that at very low PD there were more TID events; however at very high PD, there were more JH events. There were also less JH and TID events at lower latitudes. In places such as Colombia, greater population densities are associated with urban centers and their related infrastructure, and this in turn is related to less forested area in peri-urban areas (Feged-Rivedeneira et al., 2022). This transition from agriculture to industrial or service -based economies can therefore

Table 4
Estimated effects, and their standard errors and p-values for models of environmental crimes, threats, harassment events: all, judicial harassment (JH), threats/ internally displaced people (TID), and violent crime (VC). Estimated effect and standard error not shown for categorical effect by Country. Note: est, estImate; SE, standard error; MW, municipal wealth; PD, population density; ann, annual; Def. deforested.

	All (n=6391)			**JH** (n=1386)			**TID** (n=2761)			**VC** (n=4015)		
Effect	Est.	SE	Pr > |t|	Est.	SE	Pr < |t|	Est.	SE	Pr < |t|	Est.	SE	Pr < |t|
Country			<0.0001			0.004			<0.0001			0.000
% Forested	0.156	0.053	0.003	0.200	0.124	0.110	0.271	0.070	0.0001	0.149	0.064	0.020
Annual % Deforested	0.079	0.054	0.142	-0.079	0.143	0.579				0.081	0.062	0.192
MW	0.877	0.189	<0.0001	1.241	0.509	0.015	0.131	0.069	0.0592	0.463	0.157	0.003
PD	-0.253	0.113	0.025	-0.753	0.293	0.010				-0.095	0.095	0.316
Latitude	0.016	0.009	0.067	0.068	0.019	0.001				0.016	0.011	0.166
% Forested x MW	0.303	0.121	0.013									
Ann. % Def. x MW	0.417	0.228	0.068	1.502	0.710	0.035						
Ann. % Def. x PD	-0.325	0.182	0.074	-1.020	0.474	0.032				-0.281	0.155	0.071
Ann. % Def. x Latitude	0.007	0.004	0.068	0.015	0.008	0.047				0.013	0.005	0.007
MW x Latitude	0.019	0.006	0.001	0.032	0.019	0.085						
MW x PD										-0.061	0.020	0.002

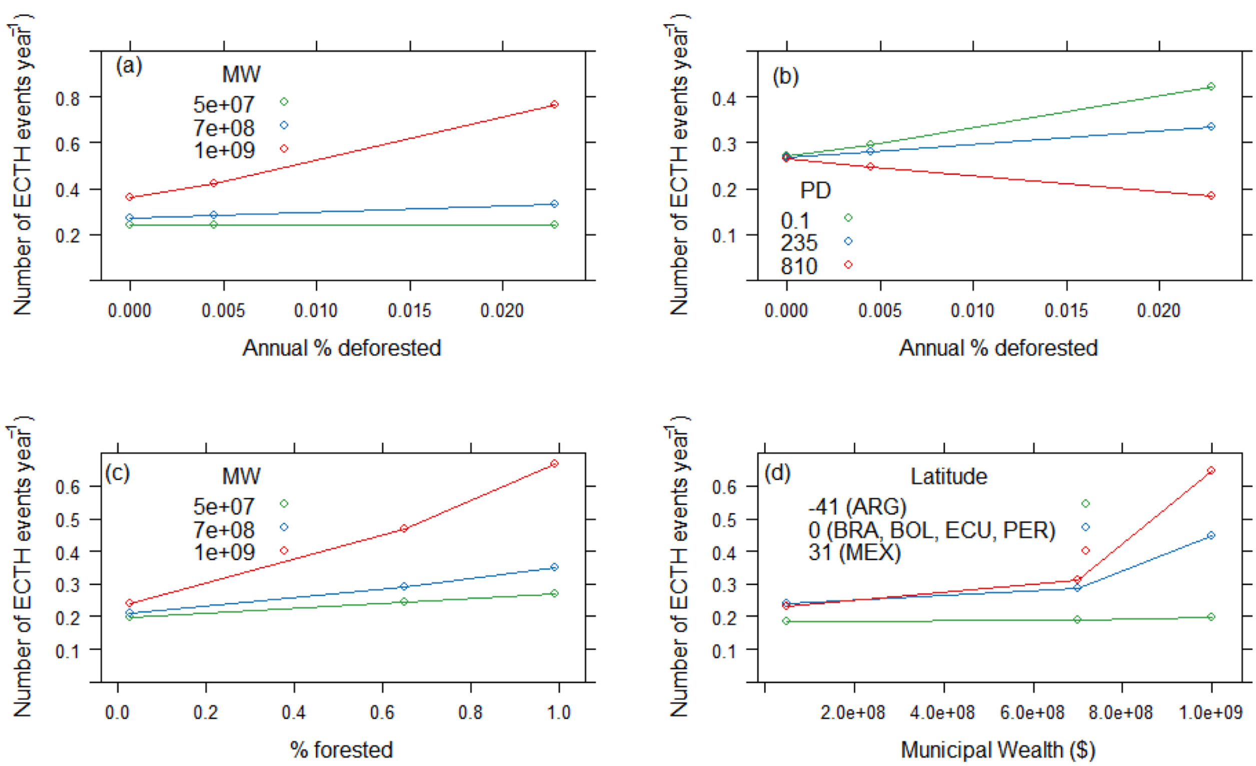

Fig. 2. Estimated marginal mean values of the total number of ECTH events by annual deforestation % at: (a) three levels of Municipal Wealth (MW), ranging from \$50 million US, to \$9 billion US, (b) three levels of Population Density (PD), ranging from 0.1 person per km^{-2} to 810 persons per km^{-2}; by percent forested at (c) three levels of MW; by MW at (d) three levels of latitude, ranging from 41° South to 31° North, controlling for country. ARG=Argentina, BRA= Brazil, BOL= Bolivia, ECU= Ecuador, PER= Peru, MEX= Mexico. Values computed with all other variables in the model at their average values.

represent a shift in demand for land and water resource types. This is common in more urbanized and populated areas (i.e., higher PD) where there is often better governability and thus less VC and TID, and more JH, or a shift in the type of crimes according to development and wealth levels as observed by Jeffords and Thompson (2016) in the Global South, and even in Italy (Germani et al., 2020).

Our second objective was to analyze incidences of ECTHs across countries in the region by municipal-level socioeconomic characteristics and different types of environmental impacts with a focus on deforestation. Again, we found that municipalities with lower population densities (i.e., more rural) and with increasing deforestation during the analysis period, did indeed experience more violent types of ECTHs (Table 4; Fig. 4). This might indicate that in more highly forested countries and possibly municipalities, ECTHs are a more acute problem and might be amplified by environmental impact activities aimed at increasing economic development and this might result in increased demand for forested lands as part of land grabbing, agricultural and ranching development, or logging-related activities (Cuerpo-Cuaresma et al., 2017).

Conversely, ECTHs in higher income countries were characterized by judicial harassment, as opposed to violent crimes, threats, and internal displacement relative to lower income countries. These findings indicate that the types of ECTHs change with the level of wealth of a country or municipality (Figs. 2, 3 and 4) and associated types of environmental impact activities. In general, less wealthy countries experience violent crimes associated with Agricultural Activities and System modification, Urbanization, Pollution, and Transport type activities, whereas high income experience judicial harassment type ECTHs associated with Energy production, Over-exploitation, and Narco-trafficking/warfare (Table 4; Appendix, Fig. A3 and Fig. A4). Studies such as Zeng et al.

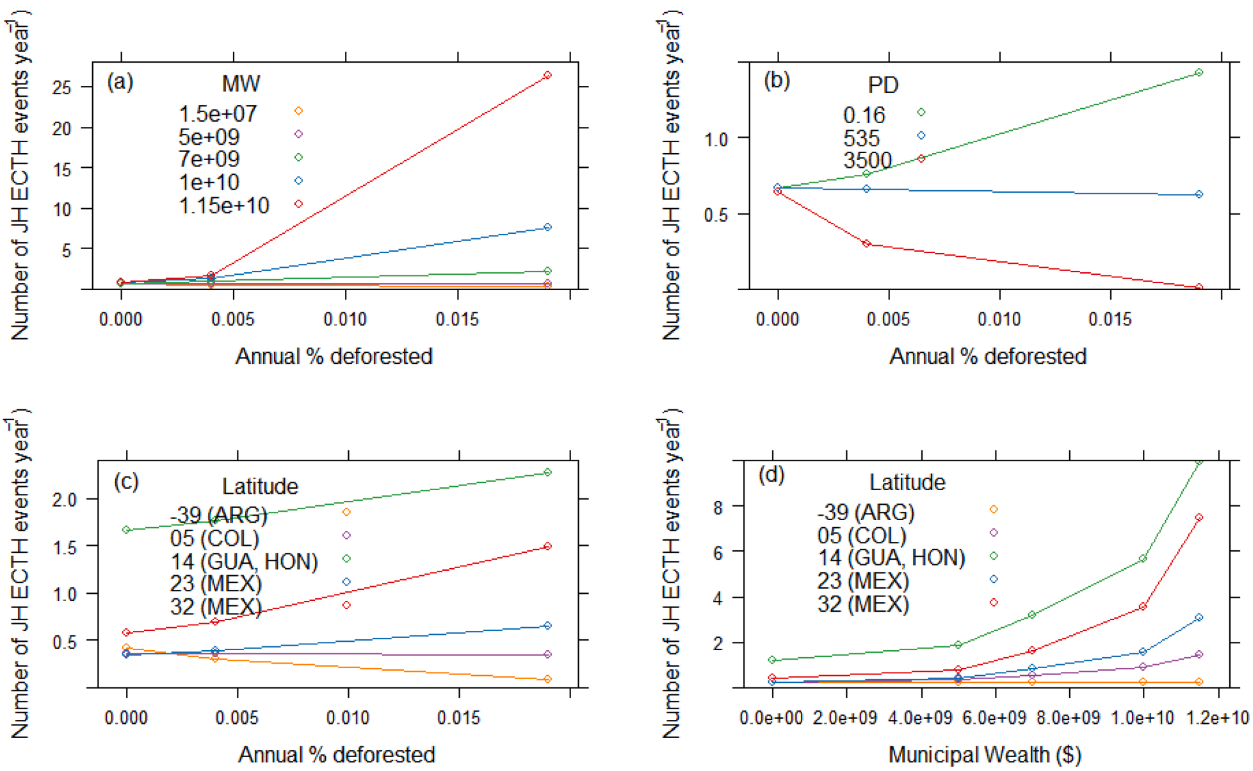

Fig. 3. Estimated marginal mean values of the number of Judicial Harassment (JH) Environmental Crimes, Threats, Harassment (ECTH) events by annual deforestation % at (a) five levels of Municipal Wealth (MW), ranging from \$15 million to \$11.5 billion, (b) three levels of Population Density (PD), ranging from 0.16 persons km^{-2} to 3500 persons per km^{-2}; at five levels of latitude, ranging from 39° South to 32° North, controlling for country (c) by annual deforestation % and (d) by MW. ARG= Argentina, COL= Colombia, GUA= Guatemala, HON= Honduras, MEX= Mexico. Values computed with all other variables in the model at their average values.

(2022) have also documented the importance of socioeconomic processes in driving more violent types of ECTHs and that the highest rates of murders were in the Americas, particularly in 2016. Indeed, these authors also found higher rates of violent crimes were more common in areas with scarce or underutilized resources.

Our socio-ecologically based method and results for our first and second objective mirrors the environmental management, economics, and development literature related to how specific environmental impacts change according to wealth and development metrics. Specifically other literature has also found such a relationship in that a society's type of pollutants change according to its socioeconomic wealth and this is often referred to as an Environmental Kuznets Curve (Buonanno et al 2017; Germani et al., 2020). Accordingly, our findings as applied to different types of ECTH and crime in general – as opposed to environmental pollutants - might also indicate an Environmental Crimes Kuznets Curve like that observed by Jeffords and Thompson (2016).

For our third objective, we explored whether deforestation was a driver of ECTHs perpetuated on environmental defenders. The first of our SEMs tested whether ECTHs were driven by deforestation, % forested land, and country; however, results showed that deforestation was not a strong driver of ECTHs ($p=0.066$). But as explained in Section 3.3, to better understand the two-way interaction, we also tested a second alternative model where deforestation was instead driven by the number of ECTHs, as well as % forest, PD, latitude, and country. Indeed we found that the number of ECTH events was a stronger and significant driver of deforestation ($p=0.022$) as was country ($p<0.01$). Honduras, in both these models was significantly different from the other countries as it experienced more ECTH events and deforestation (Fig. 3). The very high number of ETCHs for Honduras can be also possibly due to an overreporting with respect to the other countries or simply the reality of an increased spike in narcotics-related societal impacts and crimes (Pérez-Llorente et al., 2019; Devine et al 2021).

The term "environmental defenders" was first used in the 1970s, but as of the 2000s has gained relevance in many United Nations Human Rights programs and activities (Verweijen et al., 2021). Indeed, increased media reports have recently, and in the past, documented the changing rates of violent crimes being perpetuated on environmental defenders of biodiversity and different resource types, particularly from certain areas in the Latin American region (BHRRC, 2020; Larsen et al., 2021; Scheidel et al., 2020). Thus, our data-driven findings that link more violent types of ECTHs and deforestation in certain municipalities and contexts (Table 4, Figs. 2–4) corroborates this literature.

However, we do note some limitations in our study. For example, documenting ECTH occurrences in the TDR database does not follow a systematic protocol, but rather depends on the different efforts by local journalists and other non-Governmental Organizations (TDR, 2022). Similarly, impunity, corruption, weak governability, and trust can lead to victims not reporting ECTHs (Shytov, 2023). These realities can therefore potentially lead to increased over- and under-sampling and occurrences of ECTHs. We were also not able to analyze for ethnicity, "vulnerability", and other complex socio-ecological drivers of deforestation and ECTHs. Similarly, given the scale of our analysis and 9 study countries' complexity in terms of biomes, biodiversity, and socioeconomic development - as well as their 560 disparate municipalities - we could not delve into the municipal-level variation in ECTHs within individual countries. Finally, we also note that even though the GFC dataset uses a global algorithm to detect deforestation and has been widely used in large scale analyses, it can however produce over- and underestimations of forest loss in specific localized contexts (Kinnebrew et al., 2022).

That said, our findings show how not only changing wealth of economies, but governance and "the rule of law", will affect the type of resource being defended and the types of ECTHs against these environmental defenders (Martinez-Alier, 2021; Shytov, 2023). Indeed the

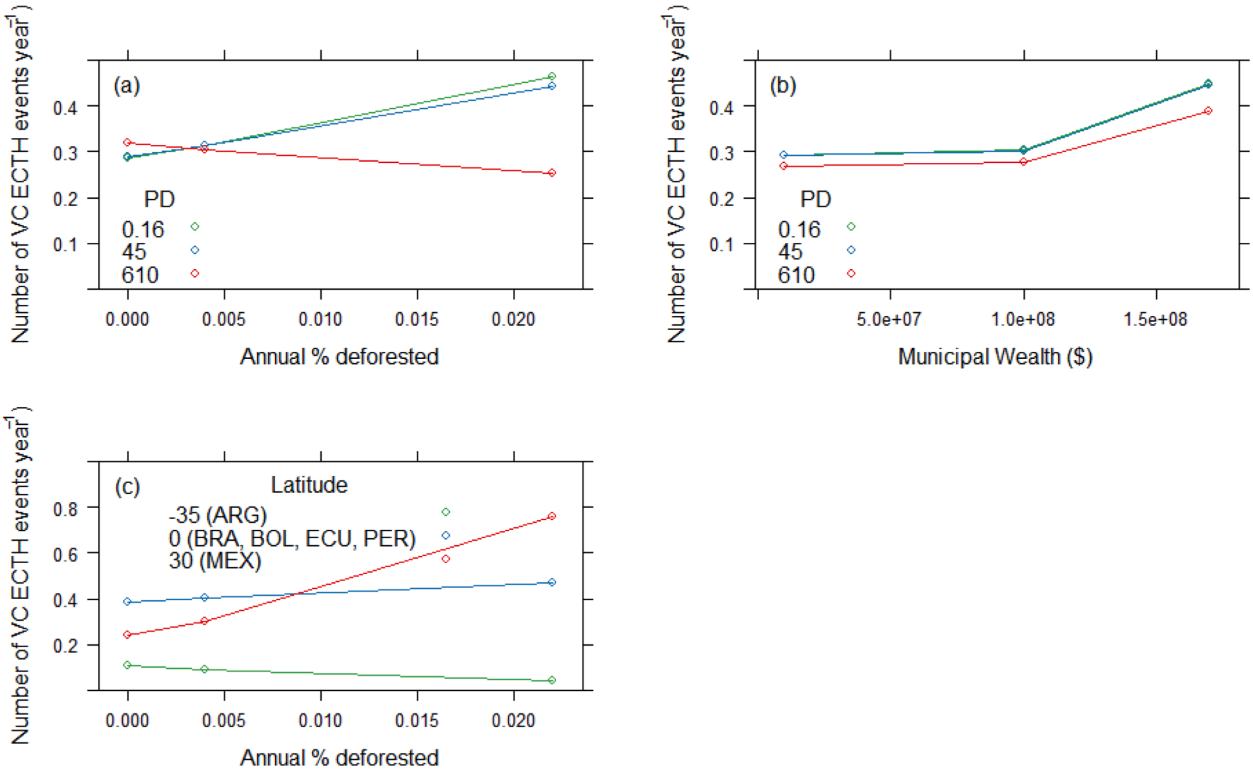

Fig. 4. Estimated marginal mean values of the number of Violent Crimes (VC) Environmental Crimes, Threats, Harassment (ECTH) events at three levels of Population Density (PD), ranging from 0.1 person per km^{-2} to 810 persons per km^{-2} by (a) annual deforestation % and (b) Municipal Wealth (MW); and (c) by annual deforestation % at three levels of latitude, ranging from 35° South to 30° North, controlling for country. ARG= Argentina, BRA= Brazil, BOL= Bolivia, ECU= Ecuador, PER= Peru, MEX= Mexico. Values computed with all other variables in the model at their average values.

socio-economic drivers we studied indicate that improved proxies for governance (i.e., trust, transparency, corruption) and governability (e.g. law enforcement, human rights metrics) and methods such as network analyses and supply chains might merit future research to better analyze and identify who needs protection, and where, in areas experiencing environmental conflicts related to economic development based on natural resource extraction activities (Martinez-Alier 2021; Suarez et al., 2018; Zuñiga-Upegui et al., 2019).

5. Conclusion

Findings such as the ones we present in this study, contribute to a better understanding —and documentation— of the complex and interactive socio-political mechanisms in the ECTH-environmental impact nexus, and how this research can be used to address the impacts of deforestation and other environmental conflicts on individuals and communities, as well as document the need for increased efforts in the protection of environmental defenders. Such controls and protections can likely have substantive benefits on not only promoting conservation efforts but also in advancing human rights and environmental justice outcomes that are increasingly being prioritized. More specifically, documenting and identifying ECTHs on environmental defenders can influence socio-political and economic interest groups, the media, and can even change norms and shifts in societal attitudes and behavior towards conservation efforts.

This study is another step in disentangling the complex and multivariate relationships between ETCHs against environmental defenders and deforestation and other environmental impacts in Latin America. That said, further research is needed to uncover the relationships with other socioeconomic, governance, and governability covariates that can modulate this nexus. For example, more regional deforestation models could incorporate different socio-political variables such as ethnicity, impunity, social media use, and environmental literacy in the ETCHs statistics. Such an approach could elucidate how high-intensity deforestation hotspots are not just issues of concern in terms of biodiversity and ecosystem services, but also potential emerging issues related to human rights, environmental justice and even the media's coverage of these. As such, the debate about deforestation and conservation at large should implicitly integrate the realities of violence and human rights into conservation decision-making. The recently proposed Escazú Agreement, for example, is one mechanism that addresses the rights and protection of defenders in "environmental matters" (López-Cubillos et al., 2021).

In both the Global South and North, there is a growing concern about the increasing persecution being faced by environmental defenders. The media, as well as a large body of literature, discuss the key role environmental defenders are playing in protecting ecosystems, conserving biodiversity, and sustaining ecosystem services and their resilience against criminal actors and unsustainable extractive industries. However, science and evidence-based documentation alone is insufficient. Key issues for addressing environmental conflicts and injustices, as well as recognizing and protecting the role of environmental defenders includes addressing weaknesses in environmental and anti-corruption laws, recognize land rights and titles, addressing the impunity of perpetrators (including corporations), ensuring the participation of environmental defenders and vulnerable communities in the formulation of policies and laws that also address underlying socio-economic inequities and inequalities (Khanna and Le Billion, 2021; Suarez et al., 2018).

The data-driven quantitative analysis approach we undertook to studying environmental-related crimes and violence, we hope, could lead to changes in terms of protecting environmental defenders via law enforcement, policy formulation, and even social transformations at large. Indeed, the environmental defenders analyzed in this study represent important pillars in nature conservation and protection of human rights, and as such, deserve more concerted efforts aimed at their protection and recognition. By unveiling the relationships between environmental impacts such as deforestation and crimes committed on environmental defenders, the need for implementation and enforcement of policies aimed at lowering deforestation is evident, and this in turn should result in less violence towards environmental defenders. The "wicked" nature of these problems was evident in our Environmental Crimes Kuznets Curve-like findings in that extractive activities across different types of resources and levels of wealth and development can result in not only *unsustainable* environmental activities but also *environmentally inequitable* and *unjust* outcomes.

The importance of investigative work such as the 'Tierra de Resistentes' initiative is key not only for researchers and the media but for policy-makers in addressing and communicating environmental justice outcomes and conservation goals. Such organic efforts as those of the Tierra de Resistentes are commendable and serve to unveil these crimes and could also contribute towards disclosing to national and international audiences, the underlying criminal dynamics involved with the environmental impacts. These dynamics could also include issues such as unethical business practices, corruption, environmental injustices and impunity of criminal groups associated with illicit natural resources extraction. Further studies such as ours, and the ones we present in our Introduction, contribute to the growing literature that seeks to understand the role of environmental defenders in nature conservation. It also sheds light on the changing relationship between socio-economic indicators, environmental impact levels and resource loss that are driving ETCHs of environmental defenders. Indeed, such realities merit increased efforts by governments in both the Global South and Global North, to create effective policies and laws to protect environmental defenders and implement sustainable development based on robust environmental justice principles.

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CRediT authorship contribution statement

Nicola Clerici: Writing – review & editing, Writing – original draft, Visualization, Methodology, Formal analysis, Conceptualization. **Christina Staudhammer:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Conceptualization. **Francisco J. Escobedo:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

We have shared the links of the data in the manuscript

Acknowledgments

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Appendix

Fig. A.1, Fig. A.2, Fig. A.3, Fig. A.4, Fig. A.5, Fig. A.6, Table A.1

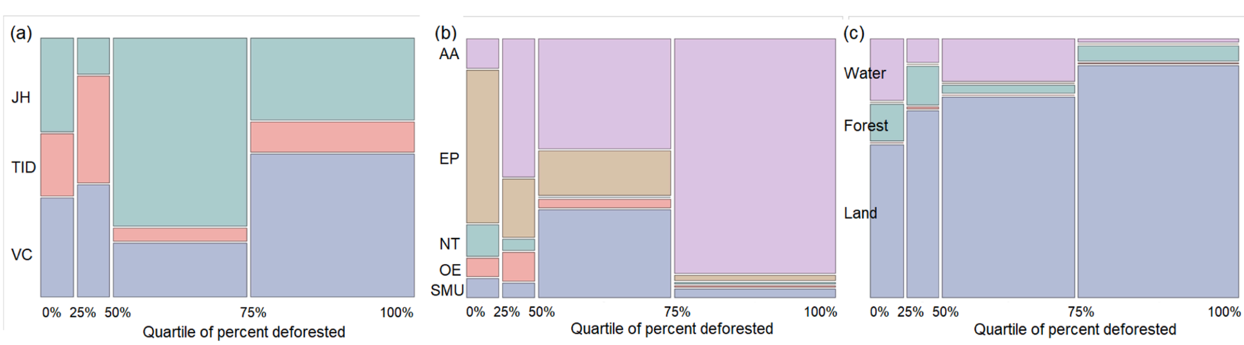

Fig. A.1. Distribution of numbers of ECTHs by quartile of the distribution of deforested and (a) type of ECTH class (JH=Judicial Harassment. TID= Threats-Internal Displacement, and VC=Violent Crimes), (b) environmental Impact class (AA=Agricultural activity, OE=Over-exploitation, EP=Energy production and mining, NT=Narcotrafficking/War/Human disturbance, and SMU=System modification/Urbanization/ Pollution/Transport), and (c) resource type defended.

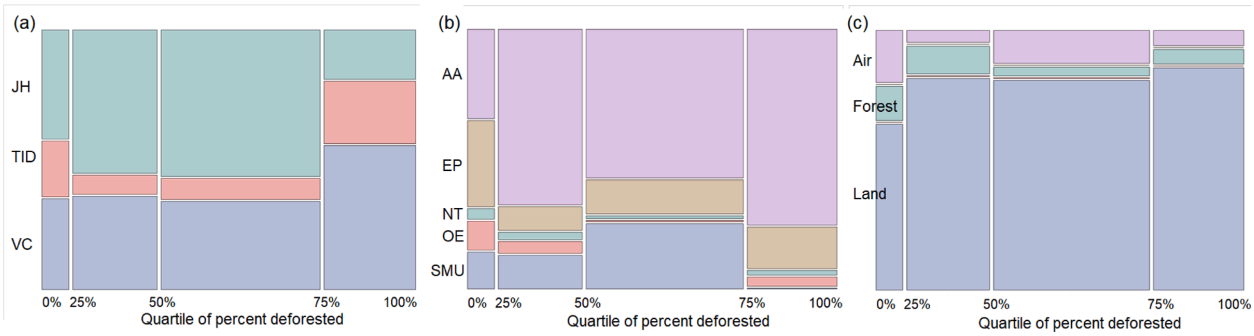

Fig. A.2. Distribution of numbers of ECTHs by quartile of the distribution of annual percent deforested and (a) type of ECTH class, (b) environmental Impact class, and (c) resource type defended. See Fig. A.1 caption for additional acronyms.

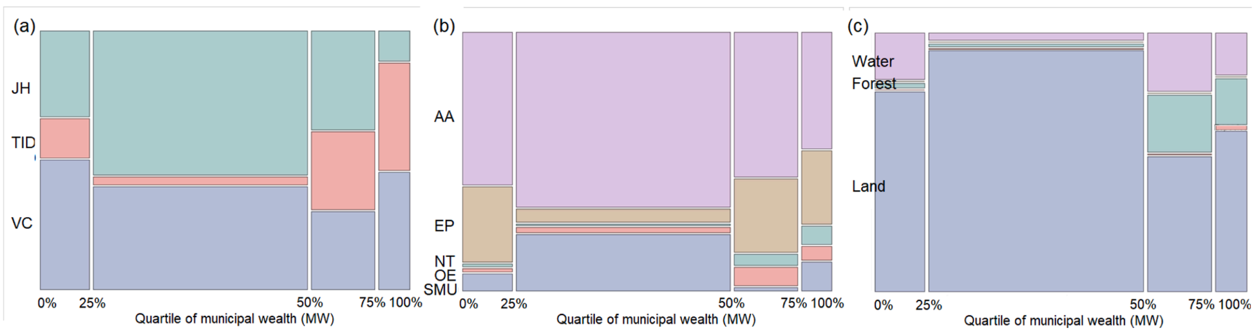

Fig. A.3. Distribution of numbers of ECTHs by quartile of the distribution of municipal wealth and (a) type of ECTH class, (b) environmental Impact class, and (c) resource type defended. See Fig. A.1 caption for additional acronyms.

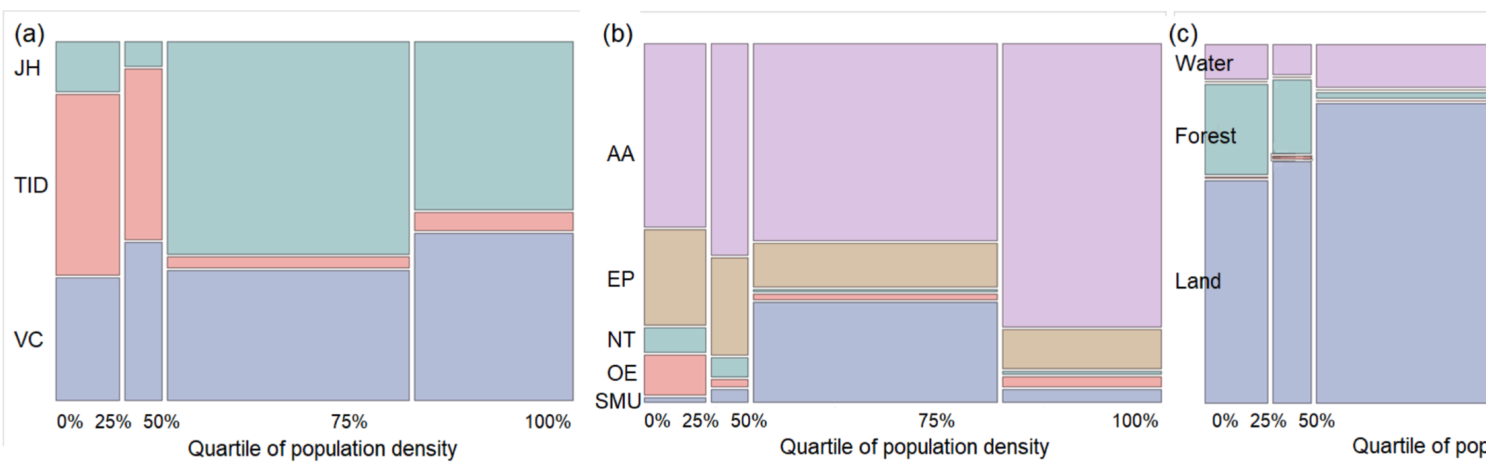

Fig. A.4. Distribution of numbers of ECTHs by quartile of the distribution of population density and (a) type of ECTH class, (b) environmental Impact class, and (c) resource type defended. See Fig. A.1 caption for additional acronyms.

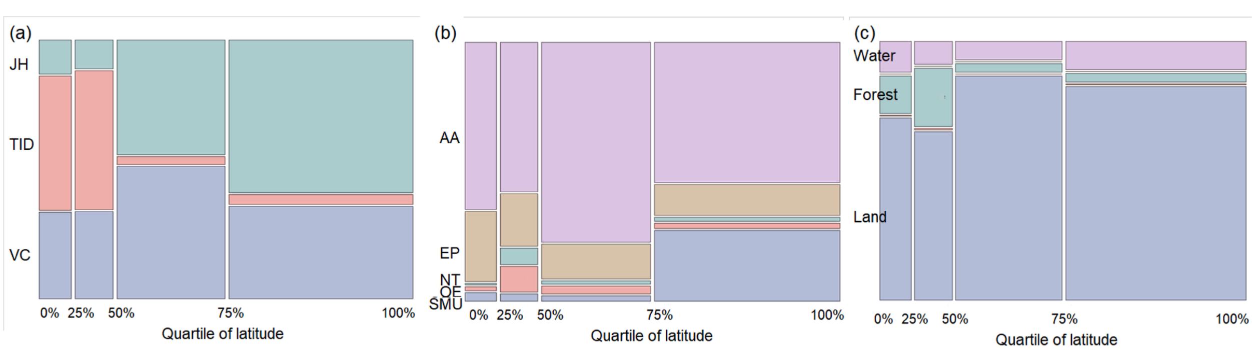

Fig. A.5. Distribution of numbers of ECTHs by quartile of the distribution of latitude and (a) type of ECTH class, (b) environmental Impact class, and (c) resource type defended. See Fig. A.1 caption for additional acronyms.

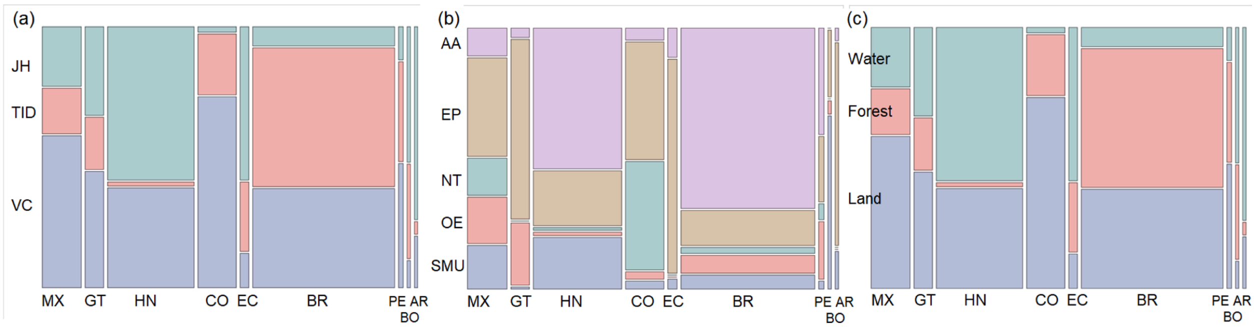

Fig. A.6. Distribution of numbers of ECTHs by country and (a) type of ECTH class, (b) environmental Impact class, and (c) resource type defended. Note: MX (Mexico), GT (Guatemala), HN (Honduras), CO (Colombia), EC (Ecuador), BR (Brasil), PE (Peru), BO (Bolivia), AR (Argentina). See Fig. A.1 caption for additional acronyms.

Table A.1
Pearson Correlation coefficients between all pairs of explanatory variables.

	Population (P)	Population density (PD)	Annual estimated wealth (MW)	% Forested	Total % deforested	Annual % deforested
Population density (PD)	0.61					
Annual estimated municipal wealth (MW)	0.97	0.60				
% Forested	-0.14	-0.21	-0.14			
Total % deforested	-0.07	-0.10	-0.07	0.18		
Annual % deforested	-0.05	-0.07	-0.05	0.13	0.70	
Latitude	-0.07	0.00	-0.09	0.10	-0.12	-0.08

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