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Policing wildlife trafficking in northeastern Mexico: the case of Tamaulipas in 2023-2024

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Illegal wildlife trade is an environmental, economic, and social problem that threatens global public health and the security of countries. It is one of the main drivers of biodiversity loss on a global scale. Mexico is a source and transit nation for trafficked wildlife, so the timely detection by Mexico's governmental institutions is of fundamental importance for combating wildlife trafficking. The present study aims to analyze the factors that facilitate or constrain the police actions taken as first responders to wildlife trafficking in the state of Tamaulipas during the period 2023-2024. Through interviews with police officers, we determined that the prioritization of crimes related to public security has limited police attention to other forms of crime, such as wildlife trafficking. As the outcome is that wildlife trafficking is a largely uninvestigated, unquantified, and unaddressed crime. Further, most police officers are unaware that environmental crimes fall under their jurisdiction, which limits law enforcement and environmental justice in the state.

KEYWORDS

wildlife trafficking, policing, environmental crime, police, green criminology

Introduction

Illegal wildlife trade is an environmental, economic, and social problem that threatens global public health and national security. It is one of the main causes of biodiversity loss on a global scale (UNODC, 2020; Bezerra-Santos et al., 2021; UNODC, 2024). Wildlife trafficking, like other environmental crimes, is socially neglected and economically exploitative, generating global insecurity with widespread consequences for human development (International Police [INTERPOL], 2020). Consequently, human lives and livelihoods, as well as all other life of the planet (Agnew, 1998; White et al., 2013; Brisman, 2014; Carpio-Domínguez, 2023a). Environmental crime exacerbates poverty and weakens society's resilience (INTERPOL, 2020) leading to the reduction of a healthy environment.

Scholars have thus called for an adaptive governance model which should emphasize key law enforcement solutions to wildlife crime (Castro-Salazar et al., 2022).

Environmental justice considers the just treatment and meaningful involvement of all people regardless of income, race, color, national origin, Tribal affiliation, or disability. In agency decision-making and other Federal activities affecting human health and the environment (Environmental Protection Agency, 2024), environmental justice incorporates the ways in which the governments respond to environmental issues, including environmental crimes (Bass, 1998).

Environmental criminal threats are complex and constantly evolving and emerging (Ayling, 2017; Carpio-Domínguez et al., 2022; Duffy, 2022). Among the crimes with a high adaptive capacity to government regulations, wildlife trafficking has been highlighted due to the heterogeneity of its contributing factors (social, environmental, geographic, political, economic and cultural), as well as the creation of social networks that confer permeability to government institutions (t Sas-Rolfes et al., 2019; Wyatt et al., 2020; Anagnoustou, 2021). Key forces addressing wildlife trafficking include government environmental institutions (e.g., environmental agencies, police, experts, universities and research centers, international agreements) and members of civil society (e.g., non-governmental organizations and volunteers) who have collectively joined forces to understand, measure, and prevent wildlife trafficking in different parts of the world (UNODC, 2024).

Police represent the first line of government attention in attending crimes, including cases of wildlife trafficking because, primarily, they are first responders, this refers to an authority with public security functions that first arrives at the scene of a criminal act or where evidence, objects or instruments related to a criminal act were found (Protocolo Nacional de Actuación Primeros Respondientes, 2017). Their capability to identify wildlife trafficking and the forms in which it occurs is strategic in identifying and combating this crime.

Wildlife trafficking in Mexico occurs as organized crime, subsistence activity, and as an activity promoted by cultural tradition (see Sosa-Escalante, 2011; Arroyo-Quiroz and Wyatt, 2019; Alvarado-Martínez and Ibañez-Alonso, 2021; Arroyo-Quiroz et al., 2023; Carpio-Domínguez et al., 2023). It therefore requires a comprehensive and coordinated response from the government and its institutions (Castro-Salazar et al., 2023; Carpio-Domínguez, 2023a), including actions to strengthen the capacities of government officials responsible for the identification, attention, management, and prevention of wildlife crimes (Castro-Salazar and Camacho-García, 2020).

In Mexico, wildlife trafficking is a crime under federal jurisdiction (Art. 420 of Código Penal Federal, 2024). Responsive actions fall to the national Attorney General's Office (Fiscalía General de la República) (FGR) and each State Attorney General's Office in criminal jurisdiction, as well as the Secretariat of Environment and Natural Resources (Secretaría de Medio Ambiente y Recursos Naturales) (SEMARNAT) and the Federal Attorney General's Office for Environmental Protection (Procuraduría Federal de Protección al Ambiente) (PROFEPA) for administrative jurisdiction.

However, constant social and security problems in Mexico have diminished environmental crimes, including wildlife trafficking, from public interest relative to crimes considered "of high social impact" (e.g., homicides, drug trafficking, kidnappings, theft, extortion). As a result, environmental crime does not occupy an adequate place on government agendas (Moreto et al., 2015; Carpio-Domínguez, 2023a) despite the fact that wildlife trafficking often occurs in conjunction with other crimes, such as drug trafficking, kidnapping, human trafficking, and arms trafficking (Carpio-Domínguez et al., 2022, 2023).

The neglect of environmental crimes is particularly apparent in the state of Tamaulipas where, due to its border location with Texas in the United States, phenomena such as human migration, drug trafficking, and organized crime are present and are considered high-impact phenomena (Coss-Noguera, 2012; Moloensnik and Suárez de Garay, 2012; Correa-Cabrera, 2016; Izcarra-Palacios, 2016; París-Pombo, 2016). Government attention and resources are focused on addressing these problems.

Environmental crime in the state of Tamaulipas has not been studied in depth despite the fact that it is located between the Sierra Madre Oriental and the coast on the Gulf of Mexico, making it the northern state of Mexico with the greatest biodiversity (Correa-Sandoval et al., 2014; Gobierno de Tamaulipas, 2024). Nonetheless, wildlife trafficking is documented Tamaulipas and is related to other forms of criminality originating from criminal groups, government officials, and the civilian population (Sosa-Escalante, 2011; Carpio-Domínguez et al., 2018a, b, 2022; 2023b). The factors that facilitate and constrain police action as a first response to wildlife trafficking in the state of Tamaulipas have not previously been investigated.

The state of Tamaulipas has 4,543 police officers, most of whom are preventive police (n=4,307, 94.8%), followed by community police (n=184, 4.1%), reaction police (n=45, 1.0%), and investigation police (n=7, 0.2%) (INEGI, 2023a). To cover the security needs of the state, studies have estimated the need to increase the number of new police officers to 8,400 (Oficina de las Naciones Unidas contra la Droga y el Delito [UNODC], 2020). Tamaulipas ranks thirteenth nationally in the number of police per state, below Mexico City (n=95 161), Estado de México (n= 20 613), Veracruz (n= 11 957), Oaxaca (n= 8 094), Nuevo León (n=7 669), Tabasco (n= 7 617), Chiapas (n= 7 393), Guerrero (n= 7 372), Puebla (n= 6 291), Jalisco (n=6 195), Yucatan (n= 5 398), and Hidalgo (n=5 165).

According to the Secretariat of Public Security of the state of Tamaulipas (Secretaría de Seguridad Pública del estado de Tamaulipas) (SSPT), the mission of the state police is to "prevent the commission of crimes in the state territory, guarantee and maintain public order and peace, protect the integrity of people, their human rights and individual guarantees, governed by the principles of legality, efficiency, professionalism and honesty." Guidelines also envision that police officers are "professional ... with optimal training in various disciplines of police work, supported by modern equipment and technology, to provide an efficient service of quality and warmth to society" (SSPT, 2023). Although the main objective of police is to guarantee peace through the pursuit of justice (Willy, 2023), they are typically the first responders in criminal cases, including environmental crimes.

The aim of our study was to analyze the factors that constrain and facilitate the police actions as first responders to wildlife trafficking in the state of Tamaulipas during the period 2023-2024. In particular, we sought to ascertain how the security, political, social, cultural, and environmental context influences the identification, response, and prevention of environmental crimes such as wildlife trafficking. Ultimately, it is our hope that the project findings will be used to increase the priority for police actions to address wildlife crimes in Tamaulipas and elsewhere, consequently improving policy force capacity for enforcement. Biodiversity conservation is contingent on these improvements in environmental justice.

Methods

Theoretical framework

This study adapts the institutional capacity framework proposed by Rosas-Huerta (2008) which was in turn adapted from Grindle and Hildebrand (1995); Grindle (1997) and Forss and Venson (2002). The framework enables the elucidation of factors that facilitate or constrain police actions as first responders to wildlife trafficking. Capacity is defined as the “ability to perform functions, solve problems and set and achieve objectives” (Fukuda-Parr et al., 2002). Institutional capacity is composed of administrative capacity

and political capacity, and through its processes and organization it seeks to ensure compliance with the public agenda.

Following Grindle’s (1997) framework, institutional capacity has five levels: the individual; the institution; the network of institutions; public governance; and social norms, values and practices. These levels can be regrouped into three levels: micro (the individual), meso (the institution) and macro (the institutional context) (Rosas-Huerta, 2008). Analyzing institutional capacity through these levels provides an understanding of how different factors influence the capacity to perform functions, solve problems and set and meet objectives in the field of public service.

At the micro level are the attitudes and aptitudes, skills, incentives, objectives, and adequacy of the institutions’ staff. Although they are the basis of success for any public policy, individual actions are not sufficient to achieve institutional capacity and are therefore related to the other levels of institutional capacity. The meso level is focused on the institution and considers the clear objectives and goals in the functions and policies implemented, the financial resources to develop its functions, the organizational capacity (organizational culture), the leadership of the institution, as well as the inter-institutional coordination and cooperation to meet objectives. Finally, the macro level refers to the economic, political, and social environment in which the institution performs its functions, and is subject to changes in legislation, political regimes and political and legal changes (Willems, 2004; Rosas-Huerta, 2008) (Figure 1).

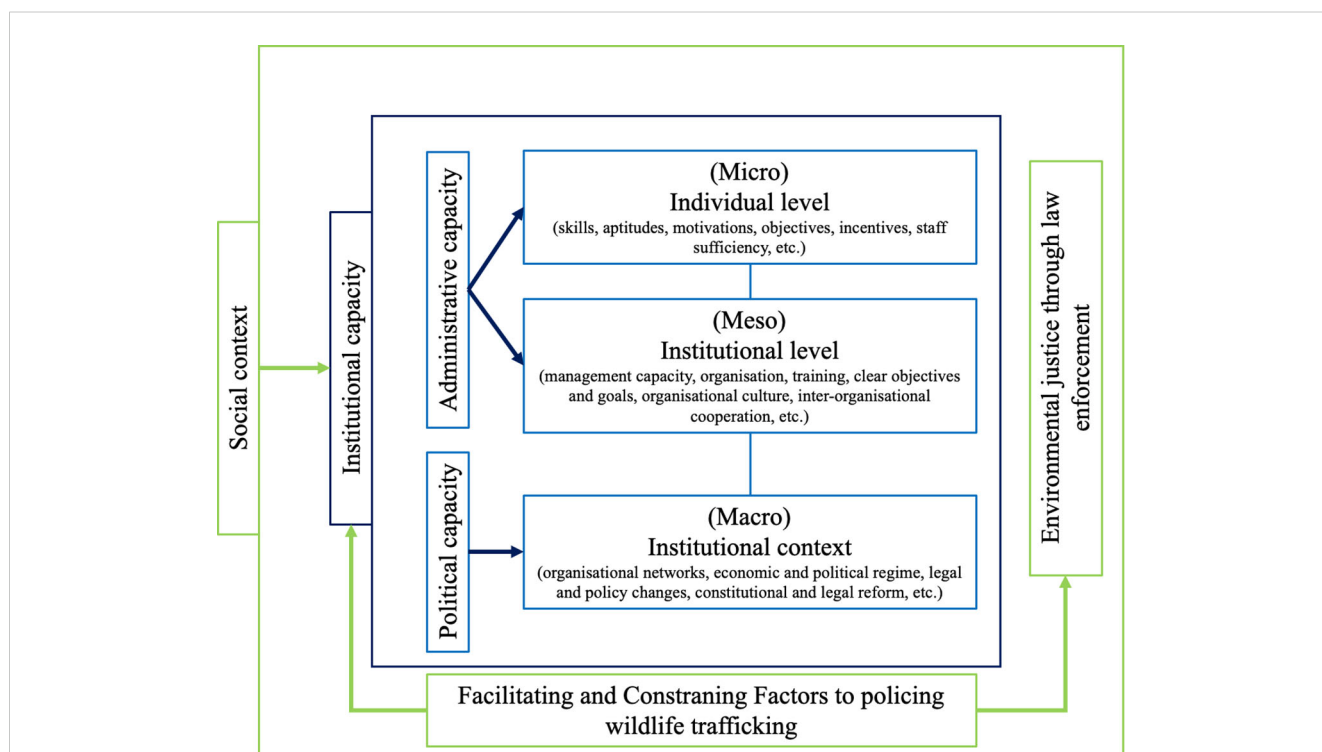


FIGURE 1
The theoretical framework examines institutional capacity for public service. The framework is adapted from Grindle and Hildebrand’s (1995), Grindle’s (1997), Forss and Venson’s (2002), Willems’ (2004) and Rosas-Huerta’s (2008) proposals about institutional capacity. Source: Modified from Rosas-Huerta (2008).

The main objective of adapting this theoretical framework is to understand those factors that not only depend on the self-management and self-organization of institutional capacity to respond to social problems, but also those originated in the social context. In particular, the factors that facilitate and constrain police action in responding to wildlife trafficking as a preliminary study of the police and their relationship in the institutional response to environmental crime in the Mexican context.

This framework incorporates environmental law enforcement from the role of police as first responders in wildlife trafficking as part of the government’s role in achieving environmental justice. It focuses on making visible the government response and the challenges and advantages of achieving environmental justice, considering the social context in which the police institutions operate (Tomkins, 2005).

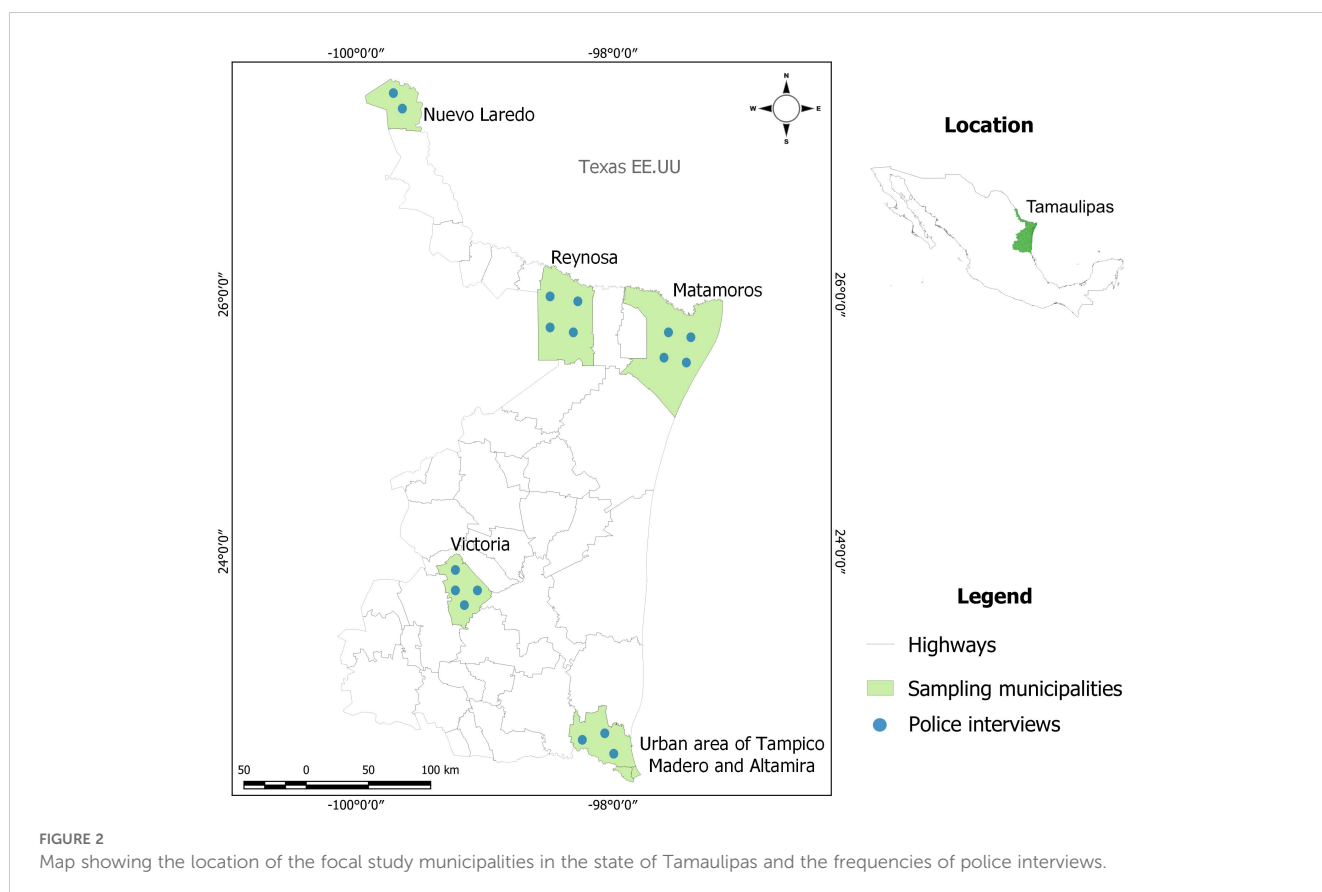
Study area

This study was conducted in seven municipalities within the state of Tamaulipas in northeastern Mexico. The study municipalities were intentionally selected because these municipalities have the largest cities in the state, with the largest populations and with State Guard detachments. To obtain a broader geographical perspective of police response in cases of wildlife trafficking, police from the three regions of the state of Tamaulipas were considered: north, central, and south. This

approach provided insight into the diverse of security, economic, social, and environmental contexts that facilitate or constrain the police activities as first responders in wildlife trafficking in the three regions of the state of Tamaulipas (Figure 2). The distribution of the municipalities in the northern region were Nuevo Laredo (n=2), Reynosa (n=4) and Matamoros (n=4); in the central region the municipality of Victoria (n=4), the capital of the state, was considered, and in the southern region the urban area of the municipalities of Tampico (n=1), Altamira (n=1) and Madero (n=1) was considered.

Research participants

For data collection we requested access to public security offices of the municipalities to conduct interviews with preventive police officers for this study and once authorization was obtained, we proceeded to explain the objective, informed consent process, and scope of this study to the police officers who initially agreed to participate, after which they referred other colleagues who could participate and provide information. This data collection technique, known as snowball sampling, involves identifying potential informants and leading to other informants with the same inclusion criteria (Bernard, 2006) until saturation of the sample is reached. Saturation of the sample was conducted when no new or additional information or issues of interest to the research emerge from the interviews (Krueger and Casey, 2000), thus investigating



the phenomenon and subsequently allowing new research from other angles (Martínez-Salgado, 2012).

Seventeen interviews to preventive police officers were conducted during the period August 2023 to January 2024, achieving sample saturation. Each interview lasted between 30 and 40 minutes and was conducted in person. Regarding the gender of the interviewees, 23.5% (n=4) were women, while 76.5% (n=13) were men; with an average age of 36.6 years and an average of 6.9 years in police service. The police officers interviewed represent four police ranks: Sub-officer (n=4, 23.5%), Police Officer 1° (n=1, 5.9%), Police Officer 2° (n=1, 5.9%) and Police Officer 3° (n=11, 64.7%).

Each police rank develops prevention activities established by the Regulations of the Professional Police Career Service of the Secretariat of Public Security of the state of Tamaulipas (Reglamento del Servicio Profesional de Carrera Policial de la Secretaría de Seguridad Pública del Estado de Tamaulipas, 2021) and these ranks are categorized as follows: (a) Officers and Sub-officers and (b) Basic Scale. The persons interviewed were Sub-officers (higher police rank in this study) engaged in supervisory and liaison activities. While Basic Scale, the police officers (1st, 2nd and 3rd) engaged in law enforcement operations. In addition, each rank is determined by the level of education of each police officer at the time of entry to police institution or the last degree obtained while in the institution (professionalization). The police officers interviewed were from the three regions of the state of Tamaulipas

(see Figure 1): north (n=10, 58.8%), central (n=4, 23.5%) and south (n=3, 17.6%) (Table 1).

Informed consent

Prior to each interview, the written informed consent for this study was read and shared with the participants, and each participant signed it in agreement. In addition, the data collection instrument contains a consent section that participants signed at the end of each interview (see Supplementary Material).

Data collection instrument

An interview guide was designed and applied to preventive police officers in the state of Tamaulipas (see Supplementary Material for detailed interview guide). The interview guide were structured in two categories: (1) the first category explores the factors constraining police response in cases of wildlife trafficking as a first responder, (2) the second category explores the factors facilitating police response in cases of wildlife trafficking, both considering the institutional and instructional perspective (Protocolo Nacional de Actuación Primeros Respondientes, 2017; Código Nacional de Procedimientos Penales, 2024) (National First Responders Protocol and National Code for Criminal Procedures).

TABLE 1 Police officers interviewed to analyze factors constraining and facilitating policing as a first response to wildlife trafficking in Tamaulipas during 2023-2024.

ID Code	Gender	Age (years)	Years in police service	Grade of education	Municipality	Region
POLICETAM01	Male	46	12	Bachelor	Nuevo Laredo	North
POLICETAM02	Male	35	9	High school	Nuevo Laredo	
POLICETAM03	Male	48	10	Bachelor	Reynosa	
POLICETAM04	Female	29	5	High school	Reynosa	
POLICETAM05	Female	33	5	High school	Reynosa	
POLICETAM06	Male	37	6	High school	Reynosa	
POLICETAM07	Male	40	8	High school	Matamoros	
POLICETAM08	Male	39	5	High school	Matamoros	
POLICETAM09	Male	38	7	High school	Matamoros	
POLICETAM10	Male	34	6	High school	Matamoros	
POLICETAM11	Male	47	12	Bachelor	Victoria	Central
POLICETAM12	Male	35	5	High school	Victoria	
POLICETAM13	Female	28	3	High school	Victoria	
POLICETAM14	Male	30	4	High school	Victoria	
POLICETAM15	Male	39	11	Bachelor	Tampico	South
POLICETAM16	Male	32	6	High school	Altamira	
POLICETAM17	Female	33	4	High school	Madero	

The interview guide included sixteen questions on the legal competencies of the police to respond to environmental crimes, knowledge of wildlife trafficking, the country’s environmental legislation, procedures and protocols for document review, seizure and confiscation of specimens and products, the connection between wildlife trafficking and other crimes in the state, as well as the ways in which society participates to prevent and report cases of wildlife trafficking.

Interview analyses

The data obtained from the interviews were systematized and coded using ATLAS.ti software (v.8). The information was selected considering the objective of the study, this process of abstraction of the information involves selecting the information that allows to understand the phenomenon based on the research objective (Miles and Huberman, 1984). The primary axes were the previous categories, allowing the subcategorization of the information, this process involves discovering and identifying connections between concepts following an inductive reasoning (González, 2010) and has an important practical significance, because from this discovery the whole explanatory model is presented in the form of a theory, integrating the secondary categories that appear related to the main categories (Strauss and Corbin, 2002; Penalva-Verdú et al., 2015).

Preliminary coding followed the previous categories for the interview guide: factors that constrain and facilitate policing. In

addition, codes were created to identify relevant information and create subcategories of analysis to identify more specifically the elements that structure each of the previous categories and to understand the phenomenon integrally.

Once the subcategories were obtained from the processing of the interviews, the results were drafted based on the explanatory model obtained and served to thread the structure and syntax of the results based on the previous categories and the subcategories that emerged from the analysis of the interviews.

Incorporating textual quotations in the writing of the results serves to give consistency and support the arguments (see Lingard and Watling, 2021) and make visible the perspective of the police officers interviewed in relation to the policing of wildlife trafficking in the state of Tamaulipas.

Findings

To analyze police actions in the identification and response to wildlife trafficking in Tamaulipas, two main categories were generated to understand the phenomenon: 1) factors that facilitate the identification and response to wildlife trafficking and 2) factors that constrain the identification and response to wildlife trafficking. The analysis of the interviews provided an explanatory model of the phenomenon based on the experiences of the police in the state that considers the social, security, institutional and environmental context of the state of Tamaulipas during 2023-2024 (Figure 3).

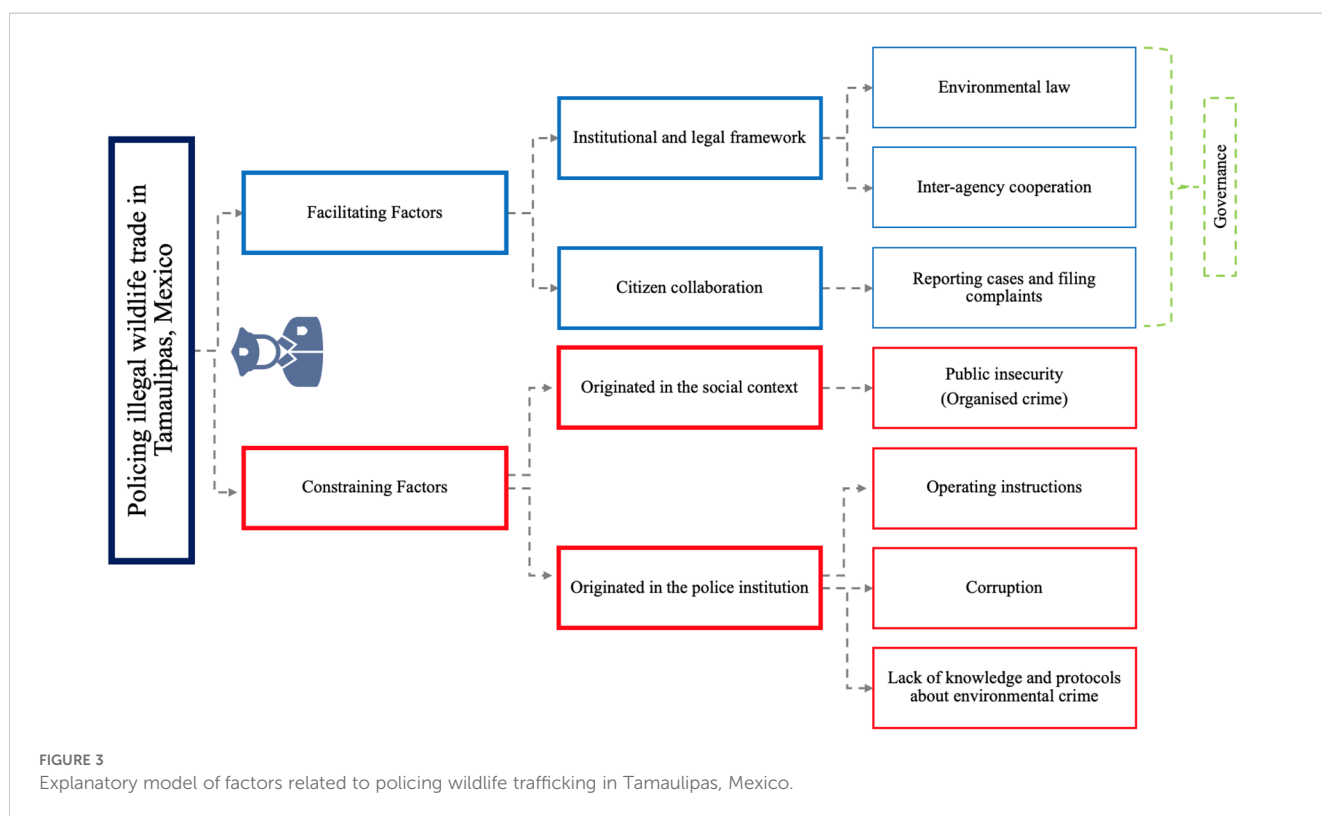


FIGURE 3 Explanatory model of factors related to policing wildlife trafficking in Tamaulipas, Mexico.

Facilitating factors

Three main factors were identified as facilitating the policing of wildlife trafficking: 1) the institutional and legal framework (through environmental law and inter-agency cooperation) and 2) citizen collaboration (through reporting cases and filing complaints) (see [Figure 3](#)).

Institutional and legal framework

Mexico's environmental legislation and its institutions are the core structure of law enforcement. Environmental conservation and protection depend on their functioning and coordination. Mexico has an extensive environmental legislation that includes the regulation of most of the factors that can cause environmental harm (see [Revuelta-Vaquero, 2022](#); [Anglés-Hernández et al., 2023](#)), including wildlife trafficking. This environmental legislation establishes and determines the different forms of participation and cooperation between criminal and administrative institutions in environmental issues ([Noyola-Rodríguez et al., 2024](#)), including the participation of the police.

Environmental law

Environmental legislation in Mexico can be understood from two jurisdictions: criminal and administrative (in other countries it is considered a civil jurisdiction). In the criminal jurisdiction are the crimes contained in the Penal Codes (Federal, in charge of the federal administration and State in charge of each state administration) and violations to these codes are considered crimes and include a punishment (such as imprisonment, reparation of environmental damages and fines) and are judicialized, which means that governmental attention is attended to as criminal acts, due to their social and environmental consequences.

In the administrative jurisdiction are those laws and regulations that regulate the use of natural resources and violations to the laws and regulations are considered administrative offences and are punishable by fines and reparation of social and environmental damage and do not include imprisonment, except in cases where an environmental crime is committed with an administrative offence.

In addition, Mexico is party to various international environmental agreements and treaties (e.g. CITES, Convention on Biological Diversity), which, together with its own legal and institutional system, protect and preserve the environment.

Cases of wildlife trafficking is considered a federal crime punishable under Article 420 bis IV of the Federal Criminal Code ([Código Penal Federal, 2024](#)) and defined as: whoever illicitly captures, possesses, transports, collects, importing into or exporting from the country, any specimen, its products or derivatives and other genetic resources, of a species of wild flora or fauna, terrestrial or aquatic, considered endemic, threatened, in danger of extinction, subject to special protection, or regulated by any international treaty to which Mexico is party. In addition, wildlife trafficking is punishable by one to nine years' imprisonment

plus a financial fine, and the police as first responders can attend to cases of wildlife trafficking in the verification of documentation and for the precautionary confiscation of specimens or products suspected of illegality, and report to the Prosecutor's Office and PROFEPA for specialized attention.

The environmental regulatory framework, in addition to the Penal Codes, also includes two important laws: the General Law on Ecological Equilibrium (Ley General de Equilibrio Ecológico) ([LGEEPA, 2024](#)) and the General Law on Wildlife (Ley General de Vida Silvestre) ([LGVS, 2021](#)). Regarding wildlife trafficking, these two laws establish the legal and administrative criteria for keeping specimens of fauna and flora in captivity and under express authorization (provided they have been legally acquired), as well as preventive activities for wildlife trafficking such as surveillance, monitoring, inspection, the development of alternative productive activities for rural communities and environmental education.

The environmental legal framework is further reinforced by other official instruments such as the National First Responders Protocol ([Protocolo Nacional de Actuación de Primeros Respondientes, 2017](#)) and the National Code for Criminal Procedures (articles 132 and 238, [Código Nacional de Procedimientos Penales, 2024](#)), which establish the faculties and procedures to be followed by public government officials in prosecuting crimes in Mexico, including wildlife trafficking.

Identifying whether conduct is criminal or not is one of the main attributes and responsibilities of the police as first responders. The National First Responders Protocol and the National Code for Criminal Procedures establishes that the police have the obligation to attend to complaints, identify and report possibly criminal conduct to their superior and to the Public Prosecutor's Office, document through the Homologated Police Report with the support of photographs or video recordings. Subsequently police must deliver the scene and seized or confiscated wildlife or products through the Chain of Custody to the Environmental expert (Forensic Sciences Department). Under indication of the Public Prosecutor's Office the specimens must be destined to the competent authority (PROFEPA) for their respective management (e.g. to be sent to zoos, Wildlife Conservation and Research Centre or consult them for referral to Wildlife Conservation Management Units, institutions or persons that fulfil the best conditions for the safety and care of wildlife) (Article 120, [LGEEPA, 2024](#)) ([Figure 4](#)).

The police, as first responders, have the legal authority to investigate the legality of flora and fauna specimens in operations or when attending to complaints, as well as to inform PROFEPA (through Public Prosecutor's Office) about seizures or confiscations of trafficked flora and fauna. In confiscation, specimens or products may be recovered if legal provenance is demonstrated by the possessor, while confiscation is not possible to return specimens or products, because legal provenance is not proven and therefore it is a crime. In the latter scenario, the specimens are placed in the care of an authorized institution (e.g., zoos, environmental management units, wildlife research centers) ([Castro-Salazar et al., 2024](#)), while the products are either stored or destroyed.

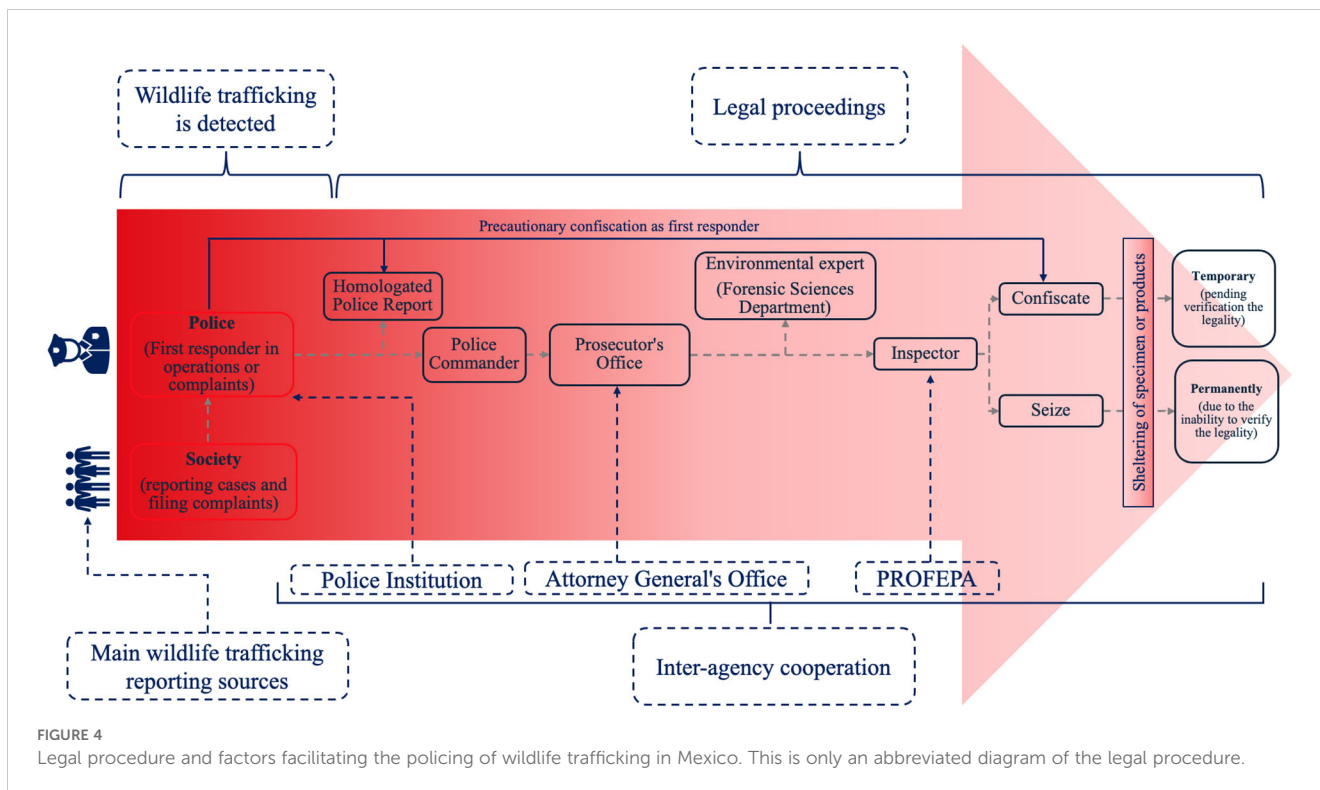


FIGURE 4
Legal procedure and factors facilitating the policing of wildlife trafficking in Mexico. This is only an abbreviated diagram of the legal procedure.

Inter-agency cooperation

One of the primary factors facilitating law enforcement against wildlife trafficking is inter-agency co-operation. When police officers identify cases of wildlife trafficking, they notify the Attorney General’s Office or the State Attorney General’s Office to initiate the criminal investigation, and PROFEPA to secure the specimens (see Figure 4).

When we find animals or things like that where we go on operations, what we do is notify PROFEPA because we do not have jurisdiction over the animals [...] they arrive and check the animal and prepare a form that we attach to our report, obviously with the corresponding photographs (POLICETAM01).

As a commander, I have the duty to inform the Public Prosecutor’s Office about anything related to the environment, I think they supervise that (POLICETAM11).

We always have good communication with other security institutions such as the Army and the Navy, when we are in an armed confrontation, they always come to the call for help to support us [...] we also coordinate with them in the operations (POLICETAM15).

Although some lack of awareness of their specific responsibilities to deal with wildlife trafficking is evident, inter-institutional cooperation partially compensates for this lack of awareness. The

National Code for Criminal Procedures, the National First Responders Protocol, the General Law of Ecological Balance and the General Wildlife Law all promote and encourage collaboration between government agencies and other facilities such as the Wildlife Conservation and Research Centre and Wildlife Conservation Management Units. This is consistent with other studies that establish that collaboration between government institutions, training between institutions and communication can lead to good results in environmental law enforcement (Pink, 2016; Barrett and White, 2017; White and Pink, 2017; Faroque and South, 2022).

When some police colleagues found the tigers [possibly *Panthera tigris*] in the garage of a drug trafficker, they called us to help with a possible armed confrontation, but when the situation calmed down, the commander called PROFEPA, and they came very quickly and seized the tigers (POLICETAM06).

As observed in the interviews and depicted in Figure 4, the police alone are not able to enforce the law against wildlife trafficking –the participation of public security institutions and other governmental entities in environmental issues is necessary. This reflects a strength at the macro level of institutional capacity to consolidate organizational and inter-institutional networks to address social problems (Willems, 2004; Rosas-Huerta, 2008). Strengthening capacities of collaboration between institutions represents the first line of action against wildlife trafficking in Tamaulipas and Mexico.

LGEEPA (2024) establishes that SEMARNAT, as the main environmental authority in Mexico, must provide training and

environmental education to public education institutions (schools of all educational levels) and other facilities. However, it does not consider public security institutions, such as the police, despite being first responders at crime scenes and for the attention of complaints.

Citizen collaboration

Reporting cases and filing complaints

Citizen collaboration through complaints plays a key role in facilitating the policing of wildlife trafficking in Tamaulipas because it incorporates society in response to environmental crimes and, as documented in other studies, environmental complaints are a source of information and an indicator to develop effective public policies (Salgado and Fidélis, 2011; Zeng et al., 2019; Jiao et al., 2021). This is particularly important, as the relationship between citizen participation in denouncing environmental crimes and police reaction has not previously been academically documented in Tamaulipas or Mexico.

The environmental law framework considers different ways to make complaints directly to PROFEPA: 1) by going to the offices, by email, on the website and by phone call (requesting its ratification in writing within three days) (LGVS, 2021; CNPP, 2024; LGEEPA, 2024). Although environmental complaints made directly to PROFEPA belong to the administrative jurisdiction, citizens also report directly to 911 when they identify criminal conduct such as wildlife trafficking, and police officers attend to the complaints to take the necessary steps to enforce the law or to turn the case over to PROFEPA (see Figure 3).

When we have been called about the trade of animals at the flea market, it has been because people report it to 911 and from there they inform us about the location and what the people described in the complaint [...] when we arrive at the place and if we see something strange, for example exotic animals being sold or animals that are not domestic or farm animals, we report it to the Prosecutor's Office so they can check and talk to PROFEPA (POLICETAM03).

In addition, it is necessary to highlight that a greater participation and concern of society for environmental issues is observed, which is evident in the increase of complaints at the national level attended by PROFEPA (see PROFEPA, 2023). The figures on environmental crimes that are judicialized in Mexico are only partially publicly available, as the open access data only show the total number of criminal cases, without specifying the type of crime (wildlife trafficking, deforestation, pollution, etc.), which is particularly problematic for measuring specific environmental crimes at the national or local level (see Castro-Salazar et al., 2023).

The police, as first responders, are one of the primary government officials dealing with complaints, including those related to wildlife trafficking, so effective interaction between the complainant, the 911 service and the police ensures an effective governance and environmental justice (Tomkins, 2005).

When we were informed about people kidnapped in a “safe house” [a place where drugs, weapons, migrants and kidnapped people are illegally kept by criminal groups] the people who made the report told us that there were also exotic animals such as tigers [possibly *Panthera tigris*] and jaguars [possibly *Panthera onca*] in the backyard of the house, this information is as it helps ensure our safety and prepares us to handle such scenarios (POLICETAM10).

About two years ago we received a report through 911 about a person who was selling parakeets [possibly *Amazona oratrix*] on the street, we went and when we arrived we carried out an inspection, we secured the parakeets and we contact to PROFEPA, when they came and checked it was indeed wildlife trafficking [...] we have noticed that more and more people are getting involved in denouncing criminal activities (POLICETAM13).

Considering the importance of the police as first responders to crime, it should be noted that the factors favoring police intervention against wildlife trafficking are based on the legal authority to enforce environmental law, but also on the participation of society in the prevention of wildlife trafficking through the filing of complaints. Although few cases have been identified by police officers who know the protocol for enforcing environmental law, a first step, in addition to training police officers on their faculties, is to promote citizen collaboration through environmental education.

Constraining factors

Policing wildlife trafficking in Tamaulipas is influenced by factors originating in the social and public security context (see Figure 3), such as the fragmentation and consolidation of criminal groups dedicated to trafficking in drugs, arms and migrants; and those originating in the police institution, such as strategies in operations, corruption and lack of knowledge about protocols for law enforcement in environmental crimes (National First Responders Protocol, Homologated Police Report, etc.). All these factors influence how the police operate against wildlife trafficking as first responders.

Originated in the social context in Tamaulipas

Public security conditions in the state of Tamaulipas are historically related to its geographic location. Its proximity to the state of Texas in the United States, and for being the southernmost border of northern Mexico, is a strategic point for different forms of trafficking such as drugs, people and firearms between the two countries, and criminal groups have strengthened and ruled over

many social factors such as politics, the economy and social life, but also determine the state's public security conditions (Coss-Noguera, 2012; Moloensnik and Suárez de Garay, 2012; Correa-Cabrera, 2016; Izcara-Palacios, 2016; Paris-Pombo, 2016) and the ways in which the law is enforced by police and government institutions.

Public insecurity

The main cause of public insecurity in the state of Tamaulipas is organized crime linked to drug trafficking. Criminal groups operating in the region often outgun police forces, hindering effective law enforcement, and due to the weapons equipment of these criminal groups exceeds that of the police forces. This situation stems from the tendency of members of criminal groups to keep exotic animals in captivity in their homes or ranches (farms) as "luxury possessions," mainly felines (*Panthera tigris*, *P. leo* and *P. onca*). Although this phenomenon has been documented in previous studies in the state (Carpio-Domínguez et al., 2018b; 2022; 2023a, b), how the police respond to cases of wildlife trafficking by criminal groups has not been documented and is a factor that originates in the social context of institutional capacity and influences the policing response to wildlife trafficking (Willems, 2004; Rosas-Huerta, 2008).

The conditions of public insecurity in the state have resulted in the police being unable to enforce the law or initiate a criminal investigation even when the crime is committed in flagrante delicto because the organizational structure of response and coordination of criminal groups in armed confrontations outweighs the daily police patrols that are generally manned by 2 or 4 police officers, two in the cab and two in the truck bed.

6 years ago, we stopped a truck on a street in Rio Bravo, when we approached the first thing we saw was a tiger cub [possibly *Panthera tigris*] leaning out of the window and the driver got out of the vehicle with a long gun and asked us [offensively] what was being offered to us and we let him continue, my partner and I could do nothing (POLICETAM08).

This imposition of organized crime on public security institutions has been a historical phenomenon, not only in the state of Tamaulipas, but throughout the country, and it intensified during and after the "war against drugs" in Mexico during the Calderon administration (2006-2012) (Williams, 2010; Buscaglia, 2012; Olinger, 2013; Carpio-Domínguez, 2021). The policy of direct action against drug trafficking was characterized among other things by armed confrontations between state forces (police, Secretaría de la Defensa Nacional [Ministry of National Defense]) and the big drug cartels (e.g. Cartel del Golfo, Cartel del Pacífico, Cartel de Juárez), but also by armed confrontations between the cartels.

This situation led to the fragmentation of the cartels into smaller criminal groups characterized by extreme violence and the diversification of economic activities in addition to drug trafficking, such as kidnapping, extortion, fuel theft, trafficking of

migrants, extortion, among others, and which have remained more than eighty criminal groups in the country (Muedano, 2018; Carpio-Domínguez, 2021).

In the 43 municipalities of Tamaulipas, eleven criminal groups operate: the *Cártel del Golfo*, *Los Zetas Vieja Escuela*, *Cártel del Noreste*, *Tropa del Infierno*, *Los Ciclones*, *Los Escorpiones*, *Los Metros*, *Los Panteras*, *Los Rojos*, *Operativo Gama 16*, *Columna Armada Pedro J. Méndez* and *Cartel de Jalisco Nueva Generación* (Infobae, 2023) (Figure 5). These criminal groups are characterized by activities such as extortion, kidnapping, migrant trafficking, and drug sales, and during police operations to confront them, cases of possession of exotic animals from wildlife trafficking have been identified, such as felines (*Panthera tigris*, *Panthera leo* and *Panthera onca*), oryx (*Oryx dammah*), bears (*Ursus americanus*), deer (*Odocoileus virginianus*), spider monkeys (*Ateles geoffroyi*), also in conservation risk categories (see Carpio-Domínguez et al., 2018b, 2022; Carpio-Domínguez, 2023a, b).

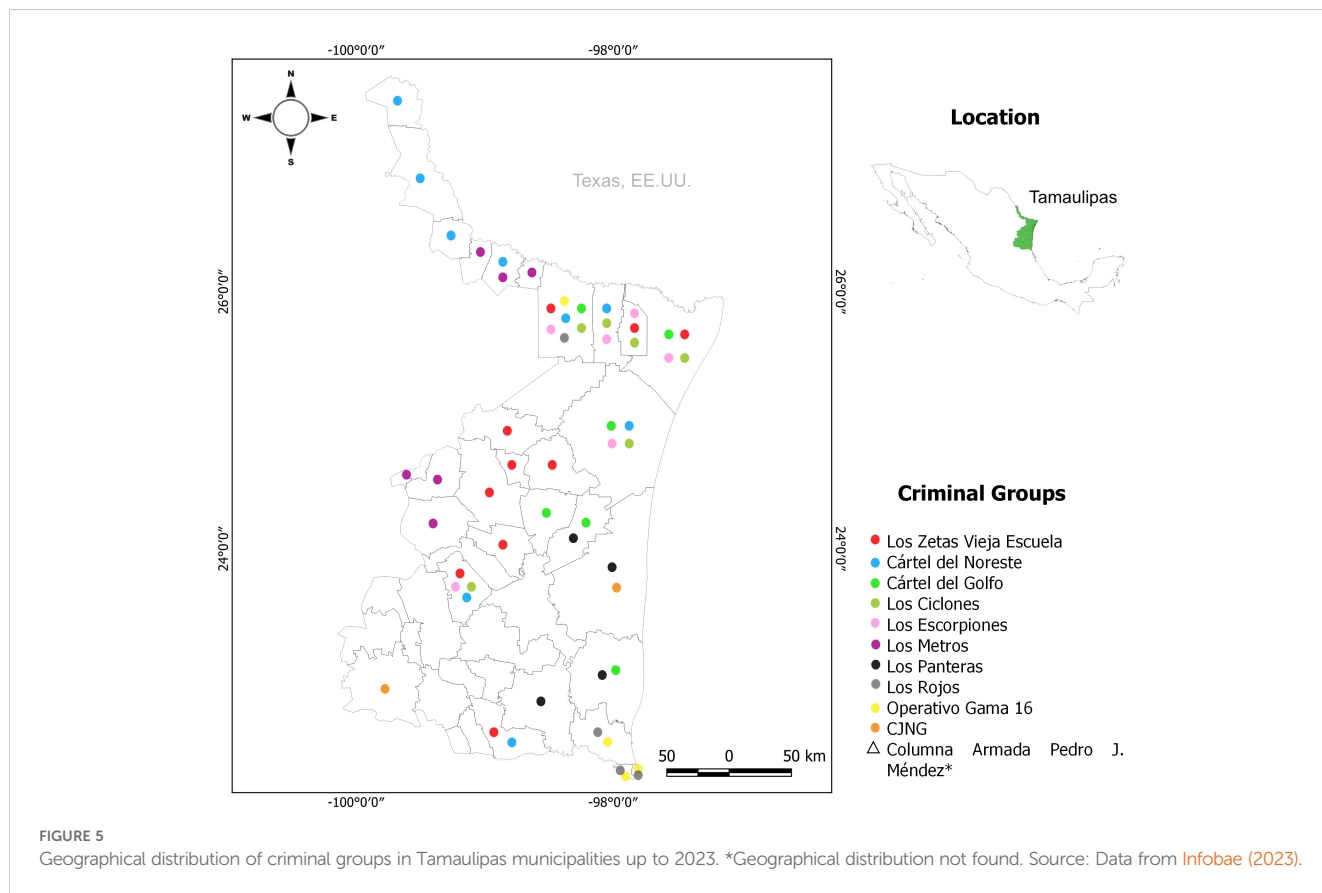
In the logic of police operations against drug trafficking, little attention is paid to other crimes, such as wildlife trafficking, as it is not categorized by the state as a crime of high social impact and are the main target of police operations, so the real rates of wildlife trafficking in the state are unknown (Carpio-Domínguez et al., 2018b, 2022, 2023).

If we see exotic animals in captivity, we cannot do anything, we only go to support the SEDENA (Ministry of National Defense) and in the cases that we have seen crocodiles [possibly *Crocodylus moreletii*], lions [possibly *Panthera leo*] or some other animal, the Commander decides whether to report it to the Prosecutor's Office but this has only happened a few times (POLICETAM12).

Public insecurity negatively influences the implementation of environmental legislation in the country. In Tamaulipas, wildlife trafficking is a crime subordinated to the "big social problems" and has not received adequate attention by the police as first responders at the crime scene, not only due to lack of interest and knowledge in identifying environmental crimes, but also due to the forms of direct and structural violence to which the police are exposed and which have been made visible in other studies on police enforcement in Mexico and other Latin American countries (e.g. Malone and Dammert, 2020; Quintero-Cordero, 2020; Cortés-Fuentes et al., 2023; Monroy-Ojeda, 2023).

Originated in the police institution

The neglect (intentional or unintentional) of environmental crime and harms by the government and its institutions has been documented in other studies at global and national levels (see Tomkins, 2005; Moreto et al., 2015; Castro-Salazar and Luyando-Cuevas, 2020). In Mexico it is exemplified by the reduction of the budget for environmental institutions, which results in a shortage of



staff to attend to environmental complaints (Castro-Salazar and Camacho-García, 2020) but also because of government prioritization of some crimes over others, which means prioritizing attention and resources to crimes of high social impact over environmental crimes, consequently receive less governmental attention and environmental law enforcement institutions receive fewer public resources for hiring personnel and equipment to attend to complaints or conduct inspections. This represents a constraint factor not only for tackling wildlife trafficking, but a constraint for institutional capacity to respond to social problems at the macro level of institutional capacity (Willems, 2004; Rosas-Huerta, 2008). It is also a constraint to accessing environmental justice due to governmental neglect of social and environmental problems (Tomkins, 2005).

Among the factors constraining police action to effectively address wildlife trafficking in Tamaulipas are those originating within the police institution. These factors include operating instructions, corruption and lack of knowledge and protocols on environmental crime.

As police officers we receive frequent training and updates, mostly on protocols, human rights, firearms training and self-defense, but not on environmental crimes. Actually, we have never been lectured about that, if you ask me for a protocol on environmental crimes, I wouldn't know what to answer (POLICETAM04).

Operating instructions

The context of public insecurity, corruption and working conditions such as the high turnover rate of personnel has caused the police to act in a “practical” manner without generating investigative or intelligence activities, limiting them only to responding to instructions from the command center, which is known as “reactive activities” and which, in turn, is determined by the context of public insecurity in the state, therefore police interactions with organized crime are generally sporadic, numerically disadvantaged and often require support from SEDENA or the Navy.

In the raid of a “safe house” we found a panther cub [possibly *Panthera onca*], There was no one present, and no drugs or weapons were found and the Commander instructed us to go and leave the animal there, because there were 8 of us police, if the traffickers returned with reinforcements, we wouldn't have been able to handle it (POLICETAM02).

In Mexico, wildlife trafficking as a federal crime is prosecuted by complaint, so that the police can only act in response to a complaint or when they are involved in special police operations, mainly against drug trafficking. As evidenced in the interviews and as has been reported in other studies in this region (Carpio-Domínguez

et al., 2018b; 2022; 2023) wildlife trafficking is identified within anti-drug trafficking operations, while from the interviews conducted, only two police officer has been commissioned to respond to a citizen complaint about wildlife trafficking.

Only once I had to deal with a 911 report to go to the flea market to check because there was a lady selling those talking parrots (possibly *Amazona oratrix*), but as I did not know what to do, I spoke to my superior and he told me not to do anything, that it was not in our jurisdiction and that I should leave (POLICETAM16).

When we have found animals like lions and so on, we almost always notify our superior, if he tells us to notify PROFEPA we do, otherwise we just report what we came for [weapons, drugs, migrants, etc.] (POLICETAM17).

The only thing I know is that if I see that if we find illegal exotic animals in an operation I have to call to my Commander, he is in charge of that [...] but I personally don't know, I wouldn't even know who to talk to besides the Commander (POLICETAM09).

The police face two critical, interdependent limitations: 1) instructions from superiors not to prosecute environmental crimes, such as wildlife trafficking, have greater weight in the decision not to attend to these crimes than the obligations attributed in the National Code for Criminal Procedures (article 221, *Código Nacional de Procedimientos Penales*, 2024) and 2) the lack of knowledge regarding procedures for addressing environmental crimes, both by the police and their superiors.

Although it seems to be a local phenomenon, other studies have reported that in transnational environmental crime, police cooperation and the lack of homologation of environmental legal frameworks represent a challenge for police enforcement (Spapens, 2013). In addition, the police currently perform a variety of functions spanning administrative, regulatory, social welfare, and law enforcement that are variable depending on the context (Tomkins, 2005). When responding to or identifying environmental crime the workload increases, which is consistent with a lack of knowledge and interest in addressing environmental crime.

Corruption

Corruption also limits the policing of wildlife trafficking, which is related to the widespread public insecurity in the state of Tamaulipas. In Mexico, the levels of perception of corruption are high, according to *Transparency International* (2023) it is 31/100, which places the country in 126/180th place in corruption; while in the state of Tamaulipas 77.4% of the population considers that there is corruption in government institutions (INEGI, 2023b).

To understand how corruption affects the processes of attention, registration, law enforcement, and accounting of environmental crimes in the state, it is necessary to consider that there are relationships between government officials and different criminal associations, or corrupt practices among government officials. Other studies on wildlife trafficking in the state have shown the interrelation government officials and members of criminal groups (see Carpio-Domínguez et al., 2023; 2023b), as well as bribes to allow the smuggling of wildlife across the country (see Carpio-Domínguez et al., 2022).

The relationships of government officials and members of criminal groups are also subject to processes of adjustment and pact-breaking, which has been reported in other studies in Mexico (Pérez-Velazco, 2013; Valencia-Londoño, 2018). This provides insights into the processes of intimidation of government forces towards members of criminal groups and that, in some cases, it is related to wildlife trafficking.

When we handle to the case of a private [illegal] zoo, we were deployed to seize drugs and weapons because the owner was with organized crime, but when we arrived to carry out the raid on the property there was nothing [...] and curiously it wasn't until the third day of guarding the private zoo that three little bags of marihuana, cocaine and a.45 caliber pistol appeared [...] and during the eight days we were guarding the place, the animals were not fed and several tigers [*Panthera tigris*] and a baboon [*Papio hamadryas*] died [...] all this was done to intimidate the malandro [drug trafficker] [...] (POLICETAM05).

Relations between security forces or politicians and members of criminal groups determine how the law is enforced also in cases of wildlife trafficking. If the police deal with complaints or are on operations, the targets are usually known, which means that they know whose house, ranch, or farm it is, and as instructions from superiors are given, police actions are carried out.

During an operation, the commander instructed us not to touch anything in the house such as jewelry, animals from the private zoo (including ostriches (*Struthio camelus*), deer (possibly *Odocoileus virginianus*), parrots (possibly yellow-headed parrots-*Amazona oratrix*), peacocks (possibly *Pavo cristatus*), a tiger cub [possibly *Panthera tigris*] or the luxury vehicles that the malandro [drug trafficker] had [...] we only carried out the operation to comply with Commander's instructions (POLICETAM09).

Corruption not only limits environmental law enforcement, but it also constrains cases of wildlife trafficking from being registered and documented and remaining in unreported figures. According to the *UNODC* (2020; 2024) corruption is an essential factor in all processes of wildlife trafficking (sourcing, transit and export),

however, as observed in this study also in law enforcement. It has been documented that for environmental law enforcement, police officers are the government officials with the highest percentage of corrupt practices (UNODC, 2020) and in environmental crimes, government officials are rarely prosecuted for corruption.

Lack of knowledge and protocols about environmental crime

The context of public insecurity in the state of Tamaulipas and in Mexico more broadly has compelled public security institutions to prioritize prevention and reaction against “traditional” crimes, which can be delimited as human-to-human violence. This implies that professionalization, law education, training, and police enforcement are focused on easily identifying crimes and human-to-human violence, and therefore have not been educated or trained to identify other forms of crime such as environmental crimes, this includes human to non-animal violence and/or harms against biodiversity.

When I was in the police academy, they never talked to us about environmental crimes, I don't think these crimes are not even in our jurisdiction, only the crimes that the Penal Code establishes (POLICETAM07).

I know that there are environmental crimes, but those are handled by PROFEPA, if I wanted to take any case the Commander would scold me, or my colleagues would mock me (POLICETAM04).

We are trained for the worst in society, the violence, the homicides, the shootings, that's what we are prepared for, not to know if a parakeet is legal or not [...] and if I were to handle something involving exotic animals or similar issues, I would just call PROFEPA and that's it. I honestly don't think that the police should deal with environmental crimes because it has nothing to do with people's safety (POLICETAM15).

Although, in practice, not all police officers are aware of their environmental law enforcement role, the National First Responders Protocol (*Protocolo Nacional de Actuación de Primeros Respondientes*, 2017) and the National Code for Criminal Procedures (articles 132 and 238, *Código Nacional de Procedimientos Penales*, 2024) authorized them to report and take custody of wildlife specimens or products until they are collected by PROFEPA. The actions of the police are fundamental to detect wildlife trafficking before any other institution, however, it is still a pending issue in police training in Tamaulipas.

The truth is I don't know much about environmental crimes or wildlife trafficking, we didn't learn about it at the academy, but I know that if I have any doubts, I can ask my Commander [...] in the operations we have seen several exotic animals, but I couldn't say if they are legal or not (POLICETAM14).

Discussion

In general, the police response to wildlife trafficking is influenced by institutional factors, training, and the social context in which police activity is carried out. For example, in the northern region of the state, due to its border location, the influence of organized crime largely determines that police training is focused on combating organized crime, mainly drug trafficking. In addition, preventive patrolling and police operations have identified wildlife trafficking and several police officers have an awareness of what wildlife trafficking in concept, as well as the importance given to the chain of command to resolve procedural doubts on environmental issues (Table 2).

A key starting point is to encourage and promote citizen collaboration in reporting cases of wildlife trafficking, but also to focus efforts on training police (including Commanders) on the procedures and legal competences of the police in environmental issues through the inter-institutional cooperation that already exists between the police and environmental institutions and the Public Prosecutor's Offices. Further, it is essential to create protocols for police attention to wildlife trafficking to guide police response.

In the central and southern regions of the state, factors such as unawareness of environmental law, insufficient training, absence of protocols on environmental crime, and even lack of interest in environmental crime are identified as influencing the police response to wildlife trafficking. However, considering the facilitating factors for policing in these regions (see Table 2), strategies can be implemented at both the societal and institutional levels. At the social level, citizen collaboration should be promoted and encouraged through the reporting of wildlife trafficking cases, while at the institutional level, courses and training should be implemented for the police on the importance of detection and the importance of the police in detecting environmental crimes such as wildlife trafficking, with the aim of raising awareness of the role of the police as the first line of attention for environmental crimes.

Police training academies and universities that offer academic degrees in areas of public security (e.g., criminology, criminalistics, public security), from which people join the police forces in the country, should incorporate subjects related to green criminology and environmental law enforcement (see Carpio-Domínguez et al., 2020). In addition, specialized police environmental manuals and protocols (see Uribe and Ibáñez, 2020) could be developed with the aim of enhance awareness of police capacities to respond to wildlife trafficking that are being denied and made invisible in the police law enforcement in Tamaulipas.

It is necessary to raise awareness across all levels of government of the importance of the police as first responders to environmental crime, not only by faculties conferred by the legal framework, but also the proximity they have with society and what happens on the streets every day (McKenna, 1993; Spapens, 2013). This is an urgently needed strategy that will ensure environmental justice and the prevention of wildlife trafficking.

TABLE 2 Summary of factors facilitating and limiting police intervention as first responders in wildlife trafficking by region in the state of Tamaulipas during 2023-2024.

Municipality	Region	Facilitating	Constraining
Nuevo Laredo Reynosa Matamoros	North	<ul style="list-style-type: none"> Preventive patrolling and identification of wildlife trafficking Interinstitutional cooperation with environmental institutions Citizen collaboration through complaints Attending to complaints related to wildlife trafficking Continuous training by the police institution Awareness of animal abuse in wildlife trade Request instructions from the Commander 	<ul style="list-style-type: none"> Public insecurity caused by criminal groups Unaware about environmental laws Lack of training and protocols on environmental crime Subject to the Commander's instructions
Victoria	Centre	<ul style="list-style-type: none"> Citizen collaboration through complaints Attending to complaints related to wildlife trafficking Interinstitutional cooperation with Prosecutor's Office Interinstitutional cooperation with environmental institutions Request instructions from the Commander 	<ul style="list-style-type: none"> Unaware about environmental laws Public insecurity caused by criminal groups Lack of training and protocols on environmental crime Subject to the Commander's instructions
Tampico Altamira Madero	South	<ul style="list-style-type: none"> Attending to complaints related to wildlife trafficking Preventive patrolling and identification of wildlife trafficking Interinstitutional cooperation Request instructions from the Commander 	<ul style="list-style-type: none"> Unaware about environmental law Lack of interest about environmental crime Subject to the Commander's instructions

Considering the institutional capacity framework (Grindle and Hildebrand, 1995; Grindle, 1997; Forss and Venson, 2002; Willems, 2004; Rosas-Huerta, 2008), it is evident that police as first responders in wildlife trafficking have several limitations at all levels of institutional capacity. At the micro level it is identified that, although they have the legal authority to respond to wildlife trafficking, they are not aware of this competence and even have an attitude of little interest in wildlife trafficking. This is related to other meso-level phenomena such as the lack of training and education on environmental crimes, changes in the administration of the institution and the prioritization of public insecurity crimes, which in turn depend on macro-level factors such as instructions at the federal and state levels to reduce the figures of crimes related to public security.

The factors behind these levels are framed in a social context in which public insecurity derived from organized crime causes environmental crimes to be subordinated to crimes related to public security and, on the other hand, a greater increase in the interest of the civilian population in reporting environmental crimes to which public agencies such as the police must respond.

Conclusions

This study highlights police's capacity to address wildlife trafficking in Tamaulipas in northeastern Mexico. Environmental crimes such as wildlife trafficking are subordinated to those considered as "of high social impact," such as drug trafficking. Police officers erroneously consider that other forms of crime, such as wildlife trafficking, are all outside their jurisdiction, limiting the ability to achieve environmental justice.

The study reveals that the police are unaware of the procedures to deal with wildlife trafficking cases. Therefore, the capacities of the

Tamaulipas police must be complemented with legal and technical-scientific knowledge to be able to identify environmental crimes, including illegal wildlife trafficking and to respond efficiently as a first responder in support of environmental law enforcement. It is important to highlight that citizen collaboration is a fundamental part of wildlife trafficking law enforcement, since it is evident that there is a growing social commitment regarding environmental harms and crimes such as wildlife trafficking.

To improve response capacity to wildlife trafficking, there is a need for inter-institutional collaboration based on training and the elaboration of protocols of attention between the police, the Public Prosecutor's Office, and PROFEPA. These should be oriented towards strengthening the knowledge of environmental crimes of the police as first responders to facilitate the application of environmental justice with the collaboration of the entire institutional system.

Drawing on institutional capacity framework to address these limitations, integral strategies can be implemented to reach all levels of the police institution by: 1) training for the police on environmental crimes; 2) promoting and strengthening inter-institutional cooperation with PROFEPA; 3) implementing policies to improve the institutional management processes of the police; 4) knowledge of all forms of crime that fall under their jurisdiction; 5) establish law enforcement protocols on environmental issues, and clarify the role of the police in the Code of Criminal Procedures in attending to environmental crimes such as wildlife trafficking, and 6) implementing environmental education policies for civil society.

Finally, this study highlights wildlife trafficking as a hidden criminal phenomenon among the crime figures in the state of Tamaulipas and underscores the police's pivotal role in detection, prevention, and law enforcement of wildlife trafficking to achieve environmental justice in Tamaulipas and northeastern Mexico.

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.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent to participate in this study was provided by the participants.

Author contributions

JC-D: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. JC-N: Data curation, Formal analysis, Investigation, Methodology, Validation, Visualization, Writing – review & editing. JC-S: Conceptualization, Formal analysis, Investigation, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing. VM-S: Conceptualization, Formal analysis, Investigation, Methodology, Validation, Visualization, Writing – review & editing.

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Conflict of interest

The 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.

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Supplementary material

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fcosc.2025.1488500/full#supplementary-material>

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