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The Role of Zoological Evidence in Combating Wildlife Crime: A Comprehensive Review

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

Wildlife crimes, mainly poaching, trafficking, and habitat destruction, are amongst the greatest threats to biodiversity and ecological balance worldwide. The battle against these crimes has given rise to the crucial role of zoological evidence in bridging the gap between science and law. The physical evidence-in the form of bones, skins, and feathers-used along with biological evidence of DNA and tissue samples-provides unchallengeable links with species and geographic origins for successful prosecutions. Advanced technologies such as DNA barcoding, isotope analysis, and satellite tracking have made evidence collection and analysis easier, thereby increasing the reliability and accuracy of forensic investigation.

However, it is not easy to integrate zoological evidence into legal frameworks. Technical barriers, inadequate forensic infrastructure, and a lack of training for enforcement personnel often act as a hindrance in its effective use. Legal systems must also change and accommodate and validate

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Cite as: Chatterjee, Subham, and Tuhin Saha. 2025. "The Role of Zoological Evidence in Combating Wildlife Crime: A Comprehensive Review". UTTAR PRADESH JOURNAL OF ZOOLOGY 46 (2):115-24. https://doi.org/10.56557/upjoz/2025/v46i24768. scientific methodologies in courts. This article discusses the interplay between zoological science and legal frameworks in wildlife crime investigations, focusing on success stories, current limitations, and the way forward. By leveraging scientific advancements and filling policy gaps, this fusion of disciplines can play a transformative role in securing justice and promoting conservation. The collaboration between law and science must be strengthened to prevent wildlife crime and preserve biodiversity for future generations.

Keywords: Wildlife forensics; trafficking; poaching; legal constrains; policy.

1. INTRODUCTION

Wildlife crime, including illegal poaching, trafficking of endangered species, and habitat destruction, has reached the level of a global crisis threatening biodiversity. The illicit wildlife trade is estimated to be worth billions of dollars annually (Hughes, 2021), thrives on the exploitation and trafficking of protected animal and plant species (Woodcock et al., 2023; UNEP-INTERPOL, 2016), ranking it among the top illegal activities worldwide, after drug and human trafficking. This exploitation leads to severe consequences, including biodiversity loss, the spread of diseases, human injuries, reduced animal welfare, and cultural degradation (Breuer et al., 2016; Griffiths et al., 2017; Derkley et al., 2019; Morton et al., 2021; Mohapatra and Menon, 2022; Woodcock et al., 2023). This crisis directly undermines conservation efforts, disrupts ecosystems, and exacerbates species extinction risks (Dawnay et al., 2007; Ogden et al., 2009). Illegal wildlife trafficking takes place across urban, suburban, and rural areas, with a particular focus on regions of high biodiversity Profitable (Cao. 2015). organized crime syndicates have been established in Asia. Africa. and Australia to exploit wildlife, driven by high demand for items such as elephant ivory products (Woodcock et al., 2023; Cao, 2015).

The impact of poaching can have far-reaching consequences at both national and international levels (Sanches et al., 2012). For example, due to extensive poaching, only two northern white rhinoceroses remain in existence, both of which are female, rendering the subspecies functionally extinct (Woodcock et al., 2023; Ryder et al., 2021).

The cultural harm inflicted on local communities by poaching is significant, as it often involves the destruction of their natural environment, including the loss of local wildlife and cultural heritage. Wildlife crime is sometimes regarded as cultural victimization, as many individuals perceive wildlife as an integral part of their identity (Woodcock et al., 2023; Griffiths et al., 2017). The Table 1 provides a non-exhaustive overview of the categories of criminal offences occurring in countries of origin, transit points, and destination countries, along with a list of associated offences (Table 1).

The WWCR3 analytical dataset reveals that between 2015 and 2021, seizures involved the illegal trade of approximately 4,000 wildlife species, with around 3,250 of these listed under the CITES Appendices. The highest number of individual seizures during this period involved corals, crocodilians, and elephants (Fig. 1). To explore the relationship between wildlife crime and extinction risk, an analysis was conducted on the conservation status and threats faced by wildlife species recorded in recent seizure data provided to UNODC. Among the four species groups, approximately 50% of the species documented in seizures are listed in the IUCN Red List database as being under ongoing threat from intentional harvesting. This proportion is higher for mammals at 73% and lower for birds at 31% (Fig. 2). In India, the conviction rate for wildlife crimes remains alarmingly low, less than 5%, highlighting significant gaps in enforcement iudicial processes. Weak evidence. and inadequate forensic training, and limited technological resources further compound the issue, with many crimes remaining unresolved (United Nations Office on Drugs and Crime [UNODC], 2022). Such a situation calls for strong mechanisms to bridge scientific evidence with legal enforcement effectively. Forensic zoology has become a significant tool in combating wildlife crime through scientific input to the investigation. Techniques like DNA barcoding, morphological analysis, and species identification allow investigators to draw solid between seized specimens links and endangered species, which makes evidence that can be reliably prosecuted (Sanctuary Nature Foundation, 2022) Such global initiatives as the Wildlife Crime Working Group underpin the need to add forensic science to wildlife protection laws

to enhance the frameworks of enforcement (Biodiversity Links, 2023). The authorities are in a position to not only strengthen the legal outcomes of such cases but also work towards global conservation by boosting the use of zoological evidence in wildlife crime investigations. This article explores how forensic zoology can serve as a link between processes and deliver conservation justice in the rapidly changing landscape.

Table 1. Wild	llife, forest and a	associated o	offences at	origin,	transit and	destination	points
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	Wildlife Offences	Forest Offences	Associated Offences			
Origin	Poaching (Illegal Hunting)	Illegal logging and	Corruption			
	Use of prohibited hunting	harvesting	Tax evasion and non-			
	equipment or methods	Illegal possession	payment of fees			
	Taking of restricted prey	Illegal processing of	Document fraud			
	(breeding females, young,	plant material	Money-laundering			
	protected species)	Illegal export				
	Violation of seasonal restrictions					
	Illegal possession					
	Illegal processing of animal					
	material					
	Illegal export					
Transit	Illegal import	Illegal import	Corruption			
	Illegal possession	Illegal possession	Tax evasion and non-			
	Illegal supply and sale	lllegal supply and sale	payment of fees			
	Illegal processing	Illegal processing	Document fraud			
	Illegal export	Illegal export	Money-laundering			
Destination	Illegal import	Illegal import	Corruption			
	Illegal processing	Illegal processing	Tax evasion and non-			
	Illegal possession	Illegal possession	payment of fees			
	Illegal supply and sale	lllegal supply and sale	Document fraud			
	Illegal consumption	Illegal consumption	Money-laundering			
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Fig. 1. Percentage share of seizure records by species group2015-2021 Source: UNODC report, 2024

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Fig. 2. Percentage of species recorded in seizures identified in the IUCN red list database as subject to ongoing threat from intentional harvest 2015-2021 Source: UNODC report, 2024

The IUCN Red List Categories reflect the assessment of how close a species is to extinction. Threatened species are those categorized as Critically Endangered, Endangered, or Vulnerable. Species listed as Near Threatened are considered close to meeting the criteria for a threatened category or are likely to qualify for one shortly. Those classified as Least Concern have been evaluated and found not to meet the criteria for Threatened or Near Threatened status, although some may still have declining populations

2. METHODS

Using a qualitative methodology, this study integrated a thorough literature analysis of current legal frameworks, international treaties, and case studies pertaining to indigenous rights and animal conservation. Key trends and difficulties in striking a balance between conservation initiatives and legitimate ownership rights were found using thematic analysis. In order to provide best practices and policy recommendations for upcoming projects, the study also looked at particular instances of effective partnerships between conservation organizations and indigenous populations.

3. TYPES OF ZOOLOGICAL EVIDENCE IN WILDLIFE CRIME INVESTIGATION

Wildlife crime investigations involve zoological evidence to untangle illegal activities, protect endangered species, and strengthen conservation laws. The two types of evidence are physical evidence and behavioral evidence, both of which are important in the determination of species identity, origins, and crime patterns.

3.1 Physical Evidence

Physical evidence is the core of wildlife crime investigations and can be in the form of tangible

materials such as animal skins, bones, tusks, horns, quills, feathers, and scales. These artifacts are confiscated from poachers or illegal traders and analyzed to determine species, origin, and the legality of possession. The common examples of physical evidence includes:

- a) Skins and Fur: Skins from the tigers and snow leopards are often involved in illegal trade. Patterns of stripes and spots on skins offer essential identification marks (Wildlife Conservation Trust, 2023).
- b) Bones and Tusks: Elephant ivory and rhino horns, highly valued for decorative or medicinal purposes, are traced back through advanced imaging techniques and isotopic analysis of the geographic origin (Challender et al., 2019).
- c) Feathers: Feathers from exotic birds, like parrots or eagles, are subjected to morphological and chemical tests to identify protected species under wildlife trade laws (Hebblewhite & Haydon, 2010).
- d) Scales and Shells: Pangolin scales and turtle shells are key evidence in trafficking cases. Morphology combined with genetic tests, such as DNA barcoding, ensures accurate species verification (Kumar et al., 2015).

Physical evidence plays a decisive role in judicial proceedings, providing concrete proof of wildlife crime that can stand the test in courtrooms. It also offers investigators crucial leads to dismantle trafficking networks.

3.2 Behavioral Evidence

Behavioral evidence includes data regarding habitat patterns, species movement, and abnormalities of natural behaviors caused by human disturbances. Although indirect, it augments the information related to wildlife crime and identifies hotspot crime areas.

- a) **Habitat Patterns:** Analyzing natural habitats allows investigators to predict the routes of poaching and trafficking. For example, creating a map of the pangolin's native range and cross-referencing confiscated scales with these habitats helps enforcement agencies trace the origin of the trade (McKeown, 2017).
- b) Movement Data: Tracking technologies, such as GPS collars and satellite telemetry, have been a revolution in wildlife crime prevention. For instance, elephant migration monitoring has helped reveal areas that are vulnerable to ivory poaching. Similarly, movement data from tagged tigers in India's reserves has revealed human-wildlife conflict zones where illegal activities are frequent (Milliken & Shaw, 2012).
- c) Behavioral Anomalies: Human-induced disturbances, such as poaching or habitat fragmentation, result in observable behavioral changes. Changes in the behavior of elephants that avoid their migration routes or pangolins with altered feeding habits can indicate habitat encroachment or trafficking activities. Such deviations provide crucial leads for onground enforcement efforts (Nijman et al., 2016).

Behavioral evidence is especially useful in preventive conservation strategies. Identifying changes in wildlife behavior helps authorities take proactive measures to mitigate threats to species before crimes take place. Combinations of physical and behavioral evidence provide a strong base for wildlife crime investigations. While physical evidence can directly and concretely place someone at the scene of the crime, behavioral evidence supplies situational context and understanding of how the crime was committed. Advancements in forensic technology, including genetic databases and telemetry systems, have rendered further refinement of zoological evidence in the fight against wildlife crime (Ripple et al., 2014).

Addressing challenges such as cross-border wildlife trafficking needs the complete integration of zoological evidence within the legal framework. This cooperation enhances conservation laws while establishing justice for the exploited animal species.

4. TECHNIQUES FOR COLLECTION AND ANALYSIS OF DATA

Wildlife crime investigations require precision in collecting and analyzing evidence, especially in that this evidence must withstand legal scrutiny. Advanced field collection and laboratory analysis technologies are vastly improving enforcement and prosecution abilities. Newer technologies such as Artificial Intelligence (AI) are bringing in a fundamental change in approaches.

Wildlife crime investigation focuses on field collection, beginning with the crime scene, on preserving the chain of custody-a critical legal requirement. Wildlife officers are trained to collect physical evidence, including tusks, feathers, and scales, with a minimum chance of contamination. Blood, tissue, or excreta DNA samples are collected with the use of swabs, placed in temperature-controlled containers, and kept intact until laboratory analysis (Waits & Paetkau, 2005).

Several others have introduced forensic science into activism and law enforcement. In Africa, evidence collection and presentation are streamlined through cooperative engagements by field experts and forensic labs (Mozer et al., 2021). In addition, legal experts always remind to meticulously document every important detail that would guarantee the evidence finds its way into the court with full adherence in terms of the gathered evidence with the current codes prescribed in the criminal justice system (INTERPOL, 2023).

Laboratory methodologies have been honed to analyze genetic and morphological features of contraband wildlife samples. DNA analysis and microsatellite genotype analysis have been routinely applied for the identification of species and geographical origin. For example, in Germany, the FOGS Project is developing SNP-STR markers, which offer high specificity and reliability in answering kinship and species origin questions, especially in court cases (Ecole Polytechnique Fédérale de Lausanne [EPFL], 2022). DNA-based databases are available to store genetic information for various species, aiding in identifying the origin of wildlife samples. These databases help determine the species to which a sample belongs, trace its geographical location, detect individual species within mixed samples, and provide insights into sex ratios (Pérez-Espona, 2021). Additionally, DNA from mixed samples has been utilized to study individual organisms and analyze gene flow, which refers to the transfer of genetic material between populations (Woodcock et al., 2023; Pérez-Espona et al., 2008).

Wildlife crime laboratories not only work with prosecutors in interpreting forensic results but also ensure that the evidence fulfills the required legal standards in the court. Such a coordination stresses the need for validation studies and quality control to prove findings that will underpin conviction and withstand review in judicial proceedings. Machine learning and artificial intelligence are increasingly revolutionizing wildlife forensics through the rapid processing of vast data sets. Machine learning models can identify individual species within photographic evidence, track the movements of wildlife from satellite imagery, and investigate the patterns of illicit activity in trade networks (Tuia et al., 2022). Such Al-based tools also prove useful in assessing digital evidence, mostly from online wildlife trafficking trade, which remains an important piece of evidence in trafficking-related cases.

The legal framework needs to once again conform to these technologies. For example, there must be a set convention in delineating what constitutes the admissibility of AI evidence in courts. Ethical issues related to maintaining transparency and fairness with respect to algorithmic processes should be highlighted in public setting confidence upon these technologies (Koenig et al., 2023). A sound legal framework is sine qua non for wildlife crime investigations. International treaties like CITES and India's Wildlife Protection Act form the basis for actions. However, there are still considerable discrepancies in realizing the standardization of forensic evidence in nearly all jurisdictions. Improving inter-agency coordination and training programs is instrumental in addressing these inconsistencies. Emerging technologies like AI also proffer additional challenges, such as the question of liability for lapses arising from

automated analyses. Developments in evidence collection, laboratory analysis, and AI offer optimism for combating wildlife crime. The effectiveness of evidence depends on how seamlessly they are integrated into the legal framework. Connecting scientific innovations with judicial requirements could pave the way to global conservation justice, wherein wildlife crime and its perpetrators are held accountable.

5. LEGAL FRAMEWORKS TO ADDRESS THE WILDLIFE CRIMINAL INVESTIGATIONS

The admissibility of zoological evidence in courts has become a crucial tool in the prosecution of wildlife crimes, integrating scientific findings into the legal framework to enhance justice. In this regard, the national legal provision, for instance, the Wildlife Protection Act, 1972, in India, and international laws, such as CITES (the Convention on International Trade in Endangered Species of Wild Fauna and Flora), are the backbone of acceptance of zoological evidence in the courts across the world.

The Wildlife Protection Act, 1972, forms the basis by which zoological evidence is generally permitted in the Indian court system. Under this Act, it is mandatory that every evidence connecting wildlife trafficking or whatever the crime may be, should be scientifically validated, if that evidence is to stand admissible in the courts (Wildlife Forensic Science Network, 2023). According to Singh (Wildlife Forensic Science Network, 2023), the Act prohibits are illegal trade of wildlife and prescribes extremely well-defined methods of collection. preservations, and presentations concerning biological evidence like DNA samples from animals, which is essential for most wildlife prosecutions (India Wildlife Protection Act, 2022). It is through the very same integration of DNA profiling with forensic genetics envisioned within this Act that species and individuals associated with the unlawful acts could be traced back, thus directly linking the illicit intention with the persons accused of it (CITES Secretariat, 2023).

Internationally, CITES sets important standards for forensic evidence used in wildlife crime prosecutions. CITES requires the member states to adopt forensic methods for the identification and provenience in court of species, which makes evidence acceptable across national boundaries. One of the benefits, as noted by INTERPOL (2023), as a result of the incorporation of CITES regulations into national laws is that the cross-border admissibility of forensic evidence greatly facilitates wildlife crime investigations and prosecutions by countries working together. Thus, the application of CITES by different countries in effect standardizes the scientific techniques used for wildlife crime investigations to bolster the strength and legal defensibility of zoological evidence (INTERPOL, 2023).

Zoological evidence strengthens prosecution by laying down a direct connect between wildlife products and crime. For instance, DNA analysis can indicate to which geographic area the seized ivory originated, and correlates directly to certain poaching events (Mozer et al., 2021). This link between evidence and crime works not only towards isolating the crime but also serve as a deterrent as per the conviction of poachers in Africa in DNA evidencing from elephant ivory, tracing specific wildlife populations (Koenig et al., 2023). Also, most importantly, this admissibility ensures that such evidence is not dismissed lightly and hence strengthens the prosecution's case in a court of law (Raman, 2023).

Zoological evidence has powerfully pointed to the roles that conviction landmark cases demonstrated. For instance, in Kenva, a DNA profiling of rhino horns linked evidence from seizures to the poaching syndicate and led to the conviction of several poachers who were behind the illegal trade (Ecole Polytechnique Fédérale de Lausanne [EPFL], 2022). This case emphasizes the role of rigorous forensic science in linking physical evidence directly to criminal activity, supporting its legal credibility. Likewise, DNA analysis of confiscated pangolin scales determined the species and proved the illegal trade, thereafter resulting in serious sentences for the traffickers in the US (FOGS Project, 2023).

It has become imperative to integrate zoological evidence into relevant legal frameworks, since such an account can give an important impetus for the prosecution of the wildlife crimes. Statutory laws in India, such as the Wildlife Protection Act and international conventions like CITES provide the necessary legal backdrop for admissibility of forensic evidence. Here, scientific techniques like DNA profiling and isotope analysis can link the criminal intent with wildlife crime thus improving chances for a successful prosecution. Continued development and validation of such methods keep zoological evidence as an essential weapon in the war

against wildlife crime, both at the national and global levels.

6. CHALLENGES IN USING ZOOLOGICAL EVIDENCE

The use of zoological evidence in wildlife crime investigations has a few challenges that may hinder its effectiveness in court dependent on how such evidence is being handled. These are technical challenges, operational setbacks, and other legal complications that must be managed carefully enough for such evidence to be admissible and credible.

The various challenges that exists in using zoological evidence are as follows:

- a) Technical Challenge: One of the most challenging technical tasks is the complexity of forensic strategies. Sure, DNA and isotope analysis can work great but mandate specialized instruments and expertise. DNA profiling, for example, consists of collecting, amplifying, and sequencing DNA from samples such as hair, scales, or bones. This must be conducted under strict conditions to avoid contamination, which arises as a relatively critical issue from studies as far back as the FOGS project, highlighting the need for careful handling and processing of biological evidence (Wildlife Protection Act, 1972). Also, these techniques sometimes depend on both some astounding computing tools for interpreting the genetic data: such tools may not be ordinarily available in every jurisdiction.
- **Operational Issues:** On the operational b) side, complications present themselves in how evidence is collected and stored. Forensic protocols must be followed with scrupulous attention for each piece of evidence collected from the crime scene to the courtroom to maintain the integrity of that evidence during the period of investigation. Crucial is the maintenance of the "chain of custody", which is the documentation that tracks handling and transfer of exhibits and samples. A breach in the process by way of contamination or tampering during collection or analysis will raise questions about the authenticity of the evidence, which could seriously jeopardize a case (Koenig et al., 2023). In short, the need for specialized training and resources for law enforcement officers, forensic scientists, and other associated

personnel makes the introduction of these new techniques into different regions extremely difficult.

c) Legal Constraints: Legal constraints might be among the most significant barriers that hinder effective use of zoological evidence. The legal system must possess the required instruments for interpreting and thus accepting scientific accordance evidence in with the established rules. Issues such as admissibility of evidence in court demand that the techniques used in forensic sciences are scientifically validated and standardized so as to meet legal standards set out for forensic evidence (INTERPOL, 2023). Queries arise as not all countries have standardized regulations regarding forensic evidence; hence, this would result in a little difficulty in wildlife crime investigations where the same iustifications are expected in the same judicial system (Singh, 2022). More importantly, the courts might find it prohibitive to interpret jargon or technical complexity in forensic results (Mozer et al., 2021). Therefore, it is imperative that expert witnesses translate scientific results into re-constructable legal arguments that make sense to juries.

7. SUGGESTIVE REFORMS

In addressing the challenges in the use of zoological evidence in wildlife crime investigations, some proposals can be suggested:

- a) Through facilitation of capacity-building programs for enforcement agents and forensic scientists on proper collection, handling, and analysis of zoological evidence, a drastic change can be brought in (Ecole Polytechnique Fédérale de Lausanne [EPFL], 2022). This includes setting standardized protocols for field laboratory collection methods and analysis, ensuring a standard level of independence and accuracy for comparison between cases.
- b) By providing adequate funding for the development of advanced forensic technologies such as DNA sequencing and isotope analysis, and artificial intelligence (AI) tools will improve the precision of wildlife identification. There should also be continued research into newer methods, which should be prioritized to keep pace

with new techniques developed by wildlife criminals.

- c) There is strong need to amend national wildlife protection laws such as the Wildlife Protection Act of 1972 in India to include the latest developments in forensic science. This could include adopting standards set by international treaties such as CITES to make sure forensic evidence in wildlife crime prosecution is accepted worldwide.
- d) International cooperation for harmonization in terms of forensic standards is strongly encouraged. This will provide the platform for data bases be shared, training organized jointly, and even mutual recognition of forensic evidence in enhancing global enforcement of wildlife protection laws (FOGS Project, 2023). This shall also lead to better coordination in combating transnational wildlife crimes.
- e) The public should be made generally aware of the usable zoological evidence to combat wildlife crime, thus promoting community engagement in reporting illegal actions and ensuring the collection of evidence by the authorities.

8. CONCLUSION

The array of scientific proofs of zoological concepts brought into the legal system for investigations relating to poaching is an infusion into wildlife crime detection for the gaining edge malfeasance for wildlife against trade. Connecting forensic science with various types of legal purposes, including national legislation like India's Wildlife Protection Act of 1972 and international acts like CITES, consequently provides an enormous tool in the hands of the legal system for linking wildlife crime to other criminal activities. Other challenges include: scientific and technical issues, socio-economic aspects, operational inefficiencies, and legal constraints. In order to tackle such challenges, multiple areas of reform need to be done. Examples include improving law enforcement capacity, enhancing technological integration, and encouraging cross-jurisdictional cooperation. If effectively put into practice, such changes will again strengthen the legal process but will also serve as a more potent deterrent to wildlife crime, thereby improving prospects for global significantly. conservation The future of prosecution for wildlife crime lies in unifying science and the law, and that forensic evidence should remain a credible and invaluable tool to deliver justice for conservation.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative Al technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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