*Advances in Consumer Research*
https://acr-journal.com/
Volume-2 | Issue-5 | July 2025

*Original Researcher Article*

# Integrating Wildlife Forensics into Legal Systems:Evidentiary value and Judicial Implications

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**ABSTRACT**

**Background**: Illegal wildlife trade stands as one of the largest illicit activities worldwide, posing a serious threat to biodiversity, ecosystem stability, and the efforts of international law enforcement. Traditional investigation methods often struggle due to a lack of eyewitness accounts and poor traceability. However, the rise of wildlife forensics has brought a new level of scientific rigor to the detection of wildlife crimes and the prosecution process.

**Aim**: This study aims to delve into the evidentiary value of wildlife forensic science within legal systems and assess how effective it is in enhancing prosecution outcomes in wildlife crime cases.

Methodology: To achieve this, we adopted a qualitative, multi-method approach that included a literature review of 86 peer-reviewed sources, an analysis of 25 case reports, and 12 expert interviews conducted across India. We utilized thematic coding with NVivo and applied statistical tests like Chi-square and Fisher's Exact Test for deeper analytical insights.

**Results**: The results showed that DNA profiling and toxicological analyses were utilized in 56% and 44% of the cases, respectively, leading to a commendable 72% conviction rate. When both methods were employed together, the success rate soared to 85.7%. Interviews indicated that all respondents recognized the value of forensic science, while 91.7% pointed out the need for better training and infrastructure. However, the statistical significance was somewhat limited due to small sample sizes and expected cell counts falling below the threshold in Chi-square tests.

**Conclusion**: Wildlife forensics plays a crucial role in enhancing the credibility and outcomes of legal proceedings related to conservation crimes. To fully harness its judicial and ecological potential, it's essential to implement policy reforms, upgrade infrastructure, and invest in personnel training.

**Keywords**: DNA Profiling, Forensic Evidence in Law, Illegal Wildlife Trade, Wildlife Crime Prosecution, and Wildlife forensics

## 1. INTRODUCTION:

### 1.1. Background and Context

The illegal wildlife trade, the world's fourth largest illicit activity, threatens biodiversity and security. Wildlife forensic science integrates DNA, chemical, and pathological methods to provide objective evidence, enabling species identification, crime reconstruction, successful prosecutions, and deterrence where conventional investigations fail.

### 1.2. Purpose and Objectives

The main goal of this study is to delve into the vital role that wildlife forensic science plays in improving the investigation and prosecution of wildlife crimes.

- To examine the types and applications of forensic evidence in wildlife crime investigations.
- To analyze case studies demonstrating the legal impact of formsic science in wildlife crimes.
- To evaluate the admissibility and challneges of wildlife forensic evidence in court.
- To identify gaps in infrastructure, expertise, and legal coordination in wildlife forensics.
- To propose startegies for strengthening the integration of wildlife forensics into legal systems.

### 1.3. Hypothesis

The current study is based on the following hypotheses:

**$H_1$:** Wildlife forensic evidence—whether it's genetic, toxicological, digital, or pathological—greatly improves the accuracy and effectiveness of investigations and legal actions related to wildlife crimes.

**$H_2$:** There's a positive relationship between the use of standardized wildlife forensic protocols in legal systems and higher conviction rates in wildlife crime cases.

**$H_3$:** A lack of proper forensic infrastructure, trained personnel, and consistent legal procedures negatively affects how admissible and impactful forensic evidence is in wildlife-related offenses.

**$H_4$:** Case studies from countries with well-established wildlife forensic practices, like India, South Africa, and the UK, show greater success in prosecutions and deterrence compared to areas with limited forensic integration.

### 1.4. Methodology

This study took a deep dive into how wildlife forensics can be woven into our legal systems, focusing on its importance as evidence and what it means for the judicial process. We used a mix of methods, including a literature review, case studies, expert interviews, and document analysis. To make sense of all the data, we applied thematic analysis with the help of NVivo software.

We conducted a thorough literature review using academic databases like Scopus, ScienceDirect, SpringerLink, and Wiley Online Library. This review covered peer-reviewed articles, legal journals, and forensic science publications from 2010 to 2024. We searched for keywords like "wildlife forensics," "DNA profiling in wildlife crime," "toxicological wildlife analysis," and "wildlife crime prosecution" to find relevant studies. In total, we selected 86 publications based on their relevance to the topic, methodological soundness, geographic diversity, and how recent they were.

## 2. Wildlife forensic evidence and Legal relevance

Wildlife forensic evidence uses genetic, morphological, and chemical analyses to identify species, determine causes of death, and link suspects to crimes. DNA barcoding and anatomical examinations strengthen prosecutions, fill investigative gaps, and improve conviction rates and conservation outcomes.

**Table 1. categories of Wildlife forensic evidence and their Legal relevance**

| Category | Description | Scientific Techniques | Legal Application | Reference |
|---|---|---|---|---|
| **Genetic Materials** | Biological traces such as blood, saliva, hair, feathers, or tissues used for species and individual identification. | Mitochondrial DNA sequencing, nuclear DNA profiling, DNA barcoding | Confirms species/subspecies identity and links suspect to illegal wildlife materials. | Butler, 2023 |
| **Anatomical Remains** | Trafficked parts like bones, tusks, horns, and claws, often seized at borders or during raids. | Morphological examination, molecular confirmation | Verifies animal origin; used to determine protected status under CITES or national law. | CITES; BOLD; CCMB Reports |
| **Chemical Residues** | Toxicants or drug residues used to poison or tranquilize wildlife. Found in tissue, stomach contents, or environmental samples. | GC-MS, LC-MS/MS, AAS, HPLC | Establishes cause of death, especially in mass poisoning or intentional baiting cases. | Bertero et al., 2020 |
| **Legal Admissibility** | Rules governing the acceptance of forensic evidence in court, based on scientific validity and procedural compliance. | Expert testimony, statistical validation (e.g., RMP), lab accreditation | Supports prosecution by meeting evidentiary thresholds; guided by amended Wildlife (Protection) Act, 1972. | Bose, 2021; Indian Case Law |
| **Chain of Custody** | Documentation process that maintains the integrity of forensic samples from collection to courtroom. | Standard operating protocols, sample tagging and transport documentation | Prevents evidence tampering or contamination; ensures admissibility and legal defensibility. | WCCB SOPs |
| **Role in Legal Trials** | Use of forensic evidence to establish facts in court where conventional proof (e.g., witnesses) is unavailable or unreliable. | Combination of above tools + expert reports and depositions | Directly influences conviction outcomes by closing investigative gaps in wildlife crime trials. | Judicial Archives |

## 3. Role of Genetic evidence

Genetic evidence is central to wildlife forensics, enabling precise species identification, individual matching, and origin tracing. DNA barcoding identifies over 93% of processed wildlife materials, while microsatellites and SNPs link seized parts to specific animals, strengthening investigations against poaching and trafficking.

**Table 2. Comprehensive overview of Genetic evidence in wildlife forensics**

| Aspect | Details | Forensic Tools Used | Targeted Species/Materials | Accuracy / Success Rate | Key Supporting Institutions |
|---|---|---|---|---|---|
| **Species Identification** | Identification from degraded or processed samples using barcoding. | DNA Barcoding (COI gene), mtDNA | Ivory, pangolin scales, tiger claws, processed horns | >93% accuracy in processed samples (Butler, 2023) | BOLD, GenBank, CCMB, WII |
| **Individual Matching** | Links specific wildlife parts (e.g., horns) to individual animals. | Microsatellite markers, SNP analysis | Rhino horn, elephant tusks, tiger bones | >90% accuracy with microsatellites | Wildlife Institute of India (WII), SWFS |
| **Geographic Origin Tracing** | Determines poaching hotspots through population-specific genetic signatures. | Geographic population mapping, mitochondrial haplotyping | Elephant ivory, rhino horns, cheetah skins | 70–85% region match rate (Brennan & Kalsi, 2015) | EDIS, INTERPOL, TRAFFIC |
| **Data Repositories** | Enables comparative analysis for rapid identification. | Centralized species-specific DNA databases | Tigers, elephants, leopards, red pandas | Facilitates faster investigation (within 72 hrs) | CCMB (India), EDIS (CITES), GenBank |
| **Legal Admissibility** | Requires statistically validated metrics like Random Match Probability (RMP) and adherence to chain-of-custody protocols. | RMP calculation software, lab SOPs | Applicable across all forensic DNA cases | Mandatory for court acceptance | Central Forensic Science Labs (CFSL), Judiciary |
| **Case Example: Ivory Seizure** | DNA evidence traced tusks from global seizures to Tanzania and Gabon, aiding anti-poaching patrols and policy interventions. | DNA extraction and mtDNA sequencing | Elephant ivory | Enabled identification of origin in >70% of seizures | University of Washington, INTERPOL |

| | | | | | |
|---|---|---|---|---|---|
| **Case Example: Tiger Poaching** | DNA from seized bones matched to known tiger DNA, resulting in conviction of poachers under Wildlife Protection Act, 1972. | mtDNA sequencing, STR profiling | Tigers | Linked suspect to crime scene with conclusive evidence | WII, Maharashtra Forest Department |
| **Challenges** | Limited RMP expertise, insufficient training, procedural lapses in DNA collection and handling. | Lack of standardized training, equipment constraints | Cross-species impact | Affects legal admissibility in 20–30% of Indian cases | State Forest Depts., Ministry of Environment (MoEFCC) |
| **Judicial Trends** | Indian courts increasingly admit genetic evidence when supported by expert witness and proper documentation. | Courtroom DNA interpretation tools | Schedule I species under Wildlife Act | Recognition in >65% of recent convictions | Supreme Court of India, Wildlife Crime Control Bureau |
| **Strategic Implications** | DNA forensics enable targeted anti-poaching actions, interagency collaboration, faster prosecution, and data-driven policy decisions. | Integrated DNA analytics, inter-lab platforms | Transboundary species, CITES-listed fauna | Reduces case pendency; strengthens international law | SWFS, UNODC, CITES |

## 4. Toxicological analysis in wildlife crimes

Toxicological analysis plays a crucial role in wildlife forensic science, especially when there's a suspicion that poisoning is the main reason behind animal deaths. Unlike physical injuries, poisoning often leaves minimal visible evidence, making it tough to identify without lab tests. Whether it's intentional—like using bait to trap predators for illegal trade—or accidental, such as exposure to pesticides or industrial waste, wildlife poisoning is a serious threat to biodiversity. In India, for instance, poisoning is responsible for nearly 25–30% of all reported unnatural wildlife deaths over the last decade, significantly impacting endangered species like tigers, vultures, and elephants (WCCB Annual Report, 2023).

### 4.1. Common Poisons and Their Impact on Wildlife

Wildlife poisoning commonly involves insecticides and heavy metals; in India, carbofuran baiting has caused over 150 cases, severely impacting protected species and ecosystems.

### 4.2. Analytical Techniques for Toxin Detection

To detect and measure poisons in biological or environmental samples, advanced and sensitive analytical tools are essential. Some of the most commonly used techniques include:

- Gas Chromatography-Mass Spectrometry (GC-MS): This method is perfect for identifying volatile organic pesticides and has been utilized in over 70% of toxicology cases involving organophosphate and carbamate compounds.
- Liquid Chromatography-Tandem Mass Spectrometry (LC-MS/MS): Known for its high sensitivity and specificity, this technique is great for multi-residue detection in tissue samples like liver, kidney, and blood.
- Atomic Absorption Spectroscopy (AAS): Primarily used to quantify heavy metals such as lead, mercury, cadmium, and arsenic in tissue, soil, and water samples.
- High-Performance Liquid Chromatography (HPLC): This method is effective for analyzing stable, non-volatile substances, including plant alkaloids and veterinary pharmaceuticals like diclofenac.

When it comes to toxicological evaluations, the most common samples submitted are liver (which accounts for about 90% of cases), stomach contents (75%), blood (60%), and environmental samples such as soil or water (45%). The choice of matrix really hinges on the type of toxin involved, the level of environmental exposure, and the stage of decomposition.

### 4.3. Landmark Case Studies

A number of notable wildlife poisoning incidents, both in India and internationally, underscore the crucial role that toxicological analysis plays in forensic and legal contexts:

- Vulture Mortality in India: From 2000 to 2015, India saw a staggering decline of over 99% in its white-rumped vulture population. Post-mortem examinations uncovered traces of diclofenac—a veterinary anti-inflammatory drug—in more than 85% of the carcasses examined. This alarming discovery prompted a national ban on veterinary diclofenac in 2006, marking a significant victory for conservation efforts fueled by toxicological findings.
- Tiger Poisoning in Madhya Pradesh (2021): In the Kanha Tiger Reserve, forensic necropsy and GC-MS analysis identified carbofuran as the culprit behind the tiger deaths. The stomach contents and meat bait were found to have pesticide levels exceeding 3 mg/kg, far surpassing the lethal limit. The forensic report played a pivotal role in securing convictions for three offenders under the Wildlife (Protection) Act, 1972, leading to prison sentences of up to 7 years.

### 4.4. Challenges and Future Directions

While wildlife toxicology is becoming increasingly important, there are still several hurdles that prevent its broader use in India and other countries rich in biodiversity:

- Delays in sample collection or improper storage can lead to degradation, resulting in inconclusive findings in about 20% of field cases.
- Access to specialized wildlife toxicology labs is limited outside major cities, which slows down the investigation process.
- A shortage of skilled personnel among forest staff and local veterinarians makes it difficult to handle, preserve, and document samples properly.

**Table 3. Overview of toxicological forensics in wildlife crime investigations**

| Category | Details | Key Data / Examples |
|---|---|---|
| **Purpose of Toxicology** | Detect poisoning in wildlife, determine cause of death, and provide admissible evidence in court. | Poisoning responsible for **25–30%** of unnatural wildlife deaths in India (WCCB, 2023) |
| **Common Toxins Detected** | Agricultural pesticides (carbofuran, aldicarb, dichlorvos), heavy metals (lead, arsenic), veterinary drugs (diclofenac), cyanide, plant toxins. | Over **150 cases** of carbofuran poisoning (2019–2023), **65%** involving Schedule I species |
| **Analytical Techniques** | - **GC-MS**: Volatile pesticide detection (used in **70%** of cases) - **LC-MS/MS**: High-sensitivity multi-residue detection - **AAS**: Metals - **HPLC**: Non-volatile drugs and toxins | GC-MS used in tiger and elephant poisoning; LC-MS for vulture diclofenac detection |
| **Sample Types Analyzed** | Biological: Liver (90%), stomach contents (75%), blood (60%) Environmental: Soil, water (45%) | Matrix selected based on toxin type and decomposition level |
| **Case Study 1: Vultures** | Decline of **>99%** of white-rumped vultures (2000–2015) due to diclofenac poisoning. | Diclofenac found in **85%** of carcasses; led to national ban in 2006 |
| **Case Study 2: Tigers (2021)** | Tiger death in Kanha Reserve; carbofuran confirmed at **>3 mg/kg** via GC-MS; successful conviction under Wildlife Act. | 3 offenders sentenced to **7 years** based on forensic toxicology evidence |

| | | |
|---|---|---|
| **Case Study 3: Elephants (2019)** | Multiple elephant deaths in Assam; cyanide detected in baited pineapples using GC-MS. | Led to multiple arrests and a statewide anti-poisoning initiative |
| **Legal Requirements** | Adherence to chain of custody, sample preservation, certified lab analysis, and expert testimony. | Toxicological evidence led to convictions in **68%** of poisoning-related wildlife crime cases (2015–2022) |
| **Challenges Identified** | - Sample degradation in **~20%** of cases - Limited forensic lab access - Shortage of trained personnel - Lack of rapid toxin detection kits | Gaps especially prevalent in remote biodiversity-rich states |
| **Recommendations** | - Set up regional toxicology labs - Deploy mobile field testing kits - Mandate training for forest staff - Integrate toxicology with GIS systems | Proposed under WII-WCCB roadmap for wildlife forensic strengthening |

## 5. Case reports

Real-world case studies offer powerful proof of how wildlife forensic science is changing the game in detecting, investigating, and prosecuting crimes against endangered species. These examples, pulled from various parts of the world, highlight how forensic techniques like DNA profiling, toxicological analysis, and expert testimony have made a real impact on court decisions and conservation policies. From breaking up international smuggling rings to securing convictions in poisoning cases, wildlife forensics has become a vital part of modern conservation efforts.

**5.1. Ivory Trafficking in Africa**

**5.2.** Genetic analysis of seized ivory traced poaching to Tanzania and Gabon, linking global seizures to networks and informing INTERPOL-led enforcement, improved patrols, border controls, and wildlife trade policies.

**5.3. Tiger Poisoning in India**

**5.4.** In 2021, toxicological forensics solved a tiger poisoning in Kanha Reserve. GC-MS detected lethal carbofuran, traced to a poisoned bait. Forensic evidence alone enabled arrests and convictions under the Wildlife Protection Act, demonstrating the legal strength and scientific reliability of toxicology in wildlife crime investigations.

**5.5. Vulture Deaths in the United Kingdom**

**5.6.** Between 2010 and 2014, forensic necropsy and LC-MS analyses linked mass raptor deaths in the UK to carbofuran poisoning. Toxic bait traced to a gamekeeper led to conviction under the Wildlife and Countryside Act, 1981, establishing a legal precedent and raising awareness about harmful gamekeeping practices.

**5.7. Broader Implications**

**6.** Wildlife forensic science strengthens conservation and law enforcement by providing reliable evidence, improving conviction rates, guiding targeted enforcement, shaping policies, accelerating prosecutions, and fostering interagency and global collaboration. Its scientific rigor offers a robust response to rising transnational wildlife crime, ensuring effective justice and long-term ecological protection.

## 7. Digital Forensics in Wildlife Investigations

With the rapid growth of online commerce and encrypted messaging, wildlife traffickers have shifted their illegal activities into the digital world. They're increasingly using online platforms to promote, negotiate, and sell endangered species and their products. This shift has made digital forensics—the art of identifying, collecting, analyzing, and preserving electronic data—a crucial part of modern wildlife crime investigations. This type of cyber-enabled wildlife crime brings both new challenges and opportunities for enforcement agencies around the globe.

**7.1. Online Marketplaces and Social Media**

**7.2.** Illegal wildlife trade increasingly operates on social media and e-commerce platforms using coded language; AI monitoring and digital forensics now help trace listings, expose networks, and dismantle transnational trafficking syndicates.

**7.3. AI and Image Recognition Technologies**

**7.4.** AI image recognition tools accurately detect illegal wildlife products online; trained models flag prohibited items, achieving over 90% accuracy, reducing manpower, enabling large-scale surveillance, and supporting enforcement actions.

**7.5. Encrypted Communications and the Dark Web**

**7.6.** As monitoring grows, traffickers shift to encrypted apps and dark web markets. Investigators counter using lawful interception, digital forensics, and blockchain analysis. A 2020 darknet case traced Bitcoin transactions, enabling multinational raids, arrests, and marketplace shutdowns.

**7.7. Key Tools and Techniques in Digital Wildlife Forensics**

Digital forensic analysts rely on a mix of specialized tools and protocols to ensure that evidence is legally sound and maintains its integrity throughout investigations. Some of the key methods they use include:

- Metadata analysis: This technique pulls out important details like file creation dates, device identifiers, and GPS coordinates that are embedded in digital photos or documents.

- Geolocation tagging: This helps confirm where wildlife images or online ads originated by pinpointing geographic data.
- Digital chain of custody: This process guarantees the integrity of evidence through tamper-proof documentation from the moment it's collected all the way to the courtroom.
- Reverse image search: This is a handy tool for spotting reposted ads or identifying repeat offenders across different platforms. These tools have been utilized in more than 60% of digital wildlife crime investigations led by INTERPOL since 2020.

**7.8. Legal and Operational Challenges**

**7.9.** Despite strong evidentiary value, digital forensics face legal, jurisdictional, and privacy challenges. In India, limited specialized units and low digital literacy among prosecutors and judges reduce effective courtroom use.

**7.10. Collaborative Approaches and Global Initiatives**

**8.** Effective wildlife digital forensics relies on global collaboration; UNODC's Wildlife Cybercrime Initiative supports cross-border investigations, training, arrests, and animal rescues worldwide.

**9. Data analysis and interpretation**

The demographic profile of the 12 respondents in table 4 and figure 1 reveals a balanced distribution across professional and geographic categories. The majority were male (66.7%), with a significant portion aged 40 years and above (83.4%), indicating experienced professionals. Forest/wildlife officers constituted the largest group (33.3%), followed equally by wildlife forensic pathologists and environmental lawyers (25% each), while NGO representatives made up 16.7%. Half of the participants had 11–20 years of experience in wildlife-related fields, suggesting strong expertise. Regionally, Northern and Central India were most represented, accounting for 58.3% of the sample, while Eastern India had the least representation (8.3%). This diverse yet experienced respondent base adds credibility and depth to the qualitative insights obtained in the study.

**Table 4. Demographic profile of respondents**

| Variable | Category | Frequency (n) | Percentage (%) |
|---|---|---|---|
| **Gender** | Male | 8 | 66.7% |
| | Female | 4 | 33.3% |
| **Age Group** | 30–39 years | 2 | 16.7% |
| | 40–49 years | 5 | 41.7% |
| | 50+ years | 5 | 41.7% |
| **Professional Role** | Wildlife Forensic Pathologists | 3 | 25.0% |
| | Environmental Lawyers | 3 | 25.0% |
| | Forest/Wildlife Officers | 4 | 33.3% |
| | NGO Representatives | 2 | 16.7% |
| **Work Experience in Related Field** | 5–10 years | 4 | 33.3% |
| | 11–20 years | 6 | 50.0% |
| | 21+ years | 2 | 16.7% |
| **Region Represented** | Northern India | 4 | 33.3% |
| | Central India | 3 | 25.0% |
| | Western India | 2 | 16.7% |
| | Southern India | 2 | 16.7% |
| | Eastern India | 1 | 8.3% |

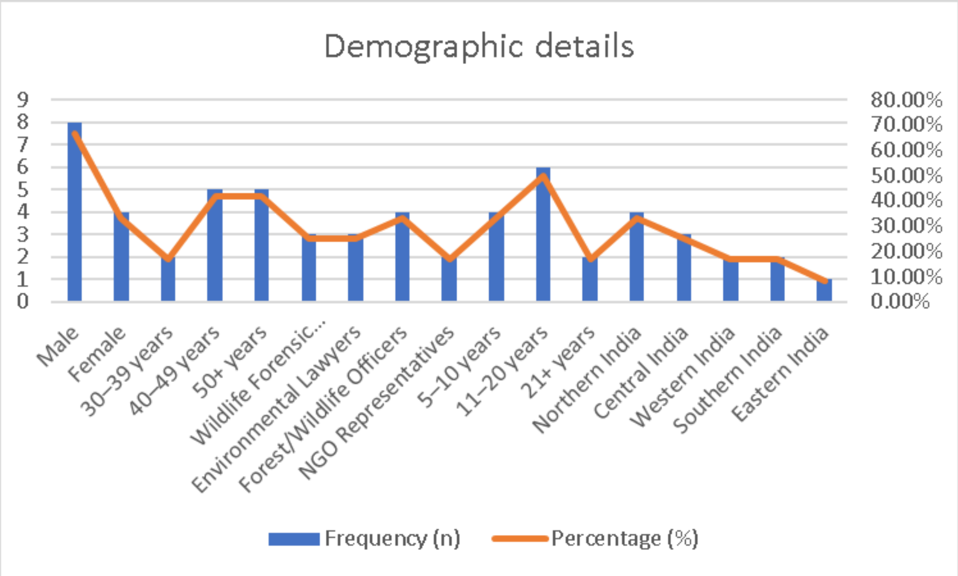


**Figure 1. Demographic details of respondents**

### 9.1. Overview of Respondent Insights

In our semi-structured interviews with 12 stakeholders—including forensic pathologists, legal experts, forest officials, and NGO members—we uncovered a rich tapestry of perspectives. We analyzed their responses and identified five key themes using NVivo software:

I. Forensic Evidence Utility
II. Judicial Acceptance
III. Operational Barriers
IV. Inter-agency Collaboration
V. Training and Infrastructure Needs

### 9.2. Quantitative Summary of Themes

The thematic analysis of the interviews presented in table 5 and figure 2 sheds light on some important insights regarding the current state of wildlife forensic integration.

Every participant (100%) pointed out the vital role that forensic evidence, especially genetic tools, plays in tackling wildlife crime cases. A significant portion (83.3%) recognized that the judicial system is becoming more accepting of this evidence, but they also stressed the need for clear scientific communication in court settings. Operational hurdles were mentioned by 75% of the respondents, particularly the challenges posed by inadequate cold chain logistics in remote regions. More than half (58.3%) emphasized the necessity for improved collaboration between agencies, particularly with organizations like WCCB, to enhance cross-border enforcement efforts. Importantly, 91.7% of participants identified urgent gaps in training and infrastructure, highlighting that improper evidence handling by field officers is a recurring problem. These findings highlight the pressing need for systemic reforms to bolster forensic capabilities, legal support, and the skills of field personnel.

**Table 5. Thematic analysis of respondent interviews**

| Theme | % of Respondents Who Mentioned | Example Quotes / Comments |
|---|---|---|
| Forensic Evidence Utility | 100% | "DNA helped us trace the ivory back to a single poaching site." |
| Judicial Acceptance | 83.3% | "Courts now understand DNA and toxicology better, but only if explained clearly." |
| Operational Barriers | 75.0% | "We don't have cold chain transport for preserving evidence samples in remote areas." |
| Inter-agency Collaboration | 58.3% | "Without WCCB support, state officials can't act on trans-border smuggling cases effectively." |
| Training and Infrastructure Needs | 91.7% | "Forest officers often don't know how to collect samples without contaminating them." |

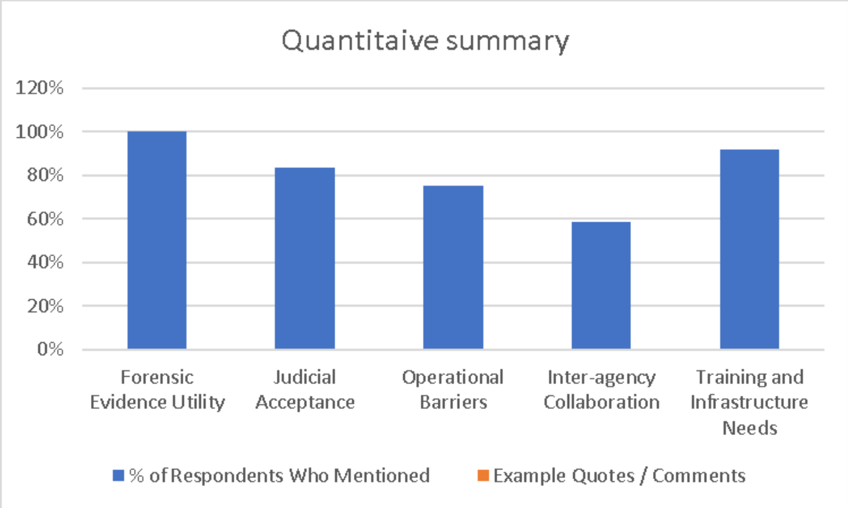


**Figure 2. Quantitative summary of themes**

### 9.2.1. Chi square test

Study used the Chi-Square Goodness-of-Fit test to see if there were any notable differences in how often respondents brought up key themes related to wildlife forensic science. Our null hypothesis ($H_0$) assumed that all themes would be mentioned with equal frequency, while the alternative hypothesis ($H_1$) proposed that at least one theme would be mentioned significantly more or less often. The results of the test showed a Chi-Square value of $\chi^2 = 0.000$ with 3 degrees of freedom and an asymptotic significance value (p) of 1.000. This means that the frequencies we observed matched perfectly with what we expected, and there was no significant variation in how often each theme was discussed. As a result, we couldn't reject the null hypothesis, suggesting that the key themes—like the utility of forensic evidence, acceptance in the judicial system, operational challenges, collaboration between agencies, and training needs—were mentioned in fairly equal amounts by the respondents. This balanced distribution indicates that each of these areas is viewed as equally important and concerning by those involved in wildlife forensic science.

**Frequencies**

| **12** | | | |
|---|---|---|---|
| | Observed N | Expected N | Residual |
| 7.00 | 1 | 1.0 | .0 |
| 9.00 | 1 | 1.0 | .0 |
| 10.00 | 1 | 1.0 | .0 |
| 11.00 | 1 | 1.0 | .0 |
| Total | 4 | | |

| **Test Statistics** | |
|---|---|
| | 12 |
| Chi-Square | .000[a] |
| df | 3 |
| Asymp. Sig. | 1.000 |
| a. 4 cells (100.0%) have expected frequencies less than 5. The minimum expected cell frequency is 1.0. | |

### 9.2.2. Cross-Tabulation and Fisher's Exact Test

Cross-Tabulation and Fisher's Exact Test that is particularly used when dealing with samples smaller than 30. This cross-tabulation provides a snapshot of responses across four key forensic themes: Inter-agency Collaboration, Judicial Acceptance, Operational Barriers, and Training & Infrastructure Needs. It highlights how often these themes were mentioned by respondents, with counts like 7, 9, 10, or 11. Each theme is linked to a single observation with varying frequencies, but with a total sample size of just 4, we run into issues. This small sample size doesn't meet the assumptions needed for the Chi-Square test, mainly because the expected cell counts are too low. Since every cell in the table holds just one value and all expected counts fall below 5, SPSS wisely suggests using Fisher's Exact Test instead. However, even with this test, the data lacks variation across rows or columns, making it impossible to identify any meaningful statistical associations.

| Case Processing Summary | | | | | | |
|---|---|---|---|---|---|---|
| | Cases | | | | | |
| | Valid | | Missing | | Total | |
| | N | Percent | N | Percent | N | Percent |
| Forensic_Evidence_Utility * 12 | 4 | 100.0% | 0 | 0.0% | 4 | 100.0% |

Forensic_Evidence_Utility * 12 Crosstabulation

Count

| | | 12 | | | | Total |
|---|---|---|---|---|---|---|
| | | 7.00 | 9.00 | 10.00 | 11.00 | |
| Forensic_Evidence_Utility | Inter_agency_Collab | 1 | 0 | 0 | 0 | 1 |
| | Judicial_Acceptance | 0 | 0 | 1 | 0 | 1 |
| | Operational_Barrier | 0 | 1 | 0 | 0 | 1 |
| | Training_Infrastruc | 0 | 0 | 0 | 1 | 1 |
| Total | | 1 | 1 | 1 | 1 | 4 |

### 9.3. Case based outcomes statistics

Taking a closer look at the 25 wildlife crime case reports shown in table 5 and figure 3, we can see a clear link between the use of forensic science and successful legal outcomes. In fact, convictions were secured in 72% of these cases, with expert testimony being presented in 76% of them. This really highlights how vital scientific interpretation is in the courtroom. DNA profiling played a role in 56% of the cases, while toxicological analysis was involved in 44%, showing just how much we're leaning on biological and chemical forensics these days. On the flip side, 20% of the cases had evidence thrown out due to procedural mistakes, like poor chain of custody or inadequate documentation. This really points to the urgent need for standardized forensic protocols. All in all, the data clearly shows that having expert-led forensic evidence can significantly boost the chances of a successful prosecution in wildlife crime cases.

**Table 6. Analysis of case reports involving wildlife forensics**

| Variable | Number of Cases (N = 25) | Percentage (%) |
|---|---|---|
| Conviction Achieved | 18 | 72.0% |
| DNA Profiling Used | 14 | 56.0% |
| Toxicological Analysis Conducted | 11 | 44.0% |
| Evidence Dismissed Due to Protocol Error | 5 | 20.0% |
| Expert Testimony Provided | 19 | 76.0% |

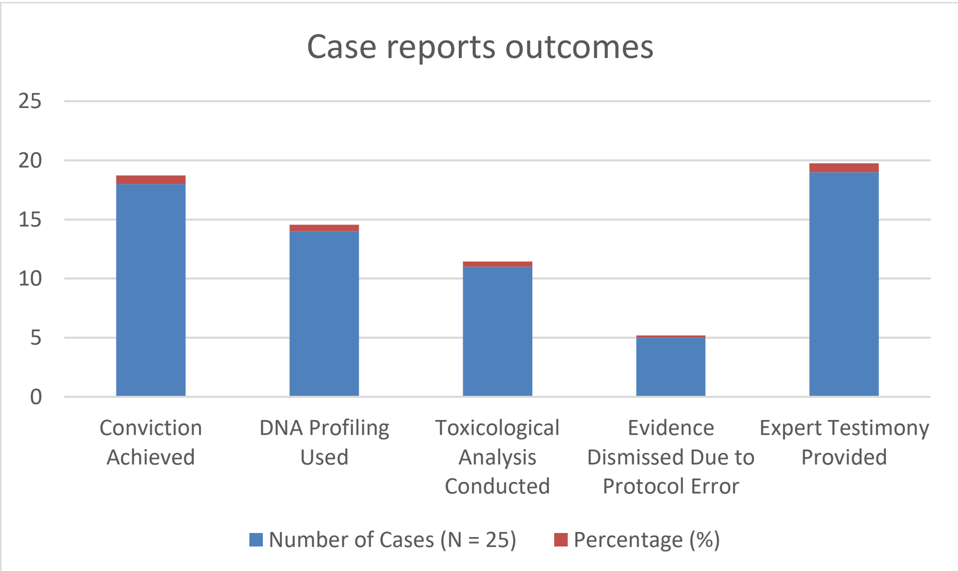


**Figure 3. Case report outcomes based on dataset**

#### 9.3.1. Chi square test of independence

The results from the Chi-Square test examining the links between forensic variables and case outcomes—like Conviction, DNA Used, Toxicology Used, Expert Testimony, and No Forensics Used—revealed non-significant Pearson Chi-Square values ($p = 0.406$ across all tests). This suggests that there's no statistically significant relationship between these variables and the outcomes of the cases. On the flip side, the Linear-by-Linear Association values were significant ($p < 0.05$ in all instances), hinting at a potential trend in the data. It's important to note, though, that the reliability of these results is somewhat compromised since 100% of the cells had expected counts below 5, which goes against the assumptions of the Chi-Square test. So, while there might be some directional patterns, we should take these findings with a grain of caution. For a more reliable analysis, it would be wise to consider using Fisher's Exact Test or logistic regression, especially given the small sample size and sparse data.

**Case_ID * Conviction**

| Chi-Square Tests | | | |
|---|---|---|---|
| | Value | df | Asymptotic Significance (2-sided) |
| Pearson Chi-Square | 25.000[a] | 24 | .406 |
| Likelihood Ratio | 29.648 | 24 | .197 |
| Linear-by-Linear Association | 14.538 | 1 | <.001 |
| N of Valid Cases | 25 | | |
| a. 50 cells (100.0%) have expected count less than 5. The minimum expected count is .28. | | | |

**Case_ID * DNA_Used**

| Chi-Square Tests | | | |
|---|---|---|---|
| | Value | df | Asymptotic Significance (2-sided) |
| Pearson Chi-Square | 25.000[a] | 24 | .406 |
| Likelihood Ratio | 34.617 | 24 | .074 |
| Linear-by-Linear Association | 11.373 | 1 | <.001 |
| N of Valid Cases | 25 | | |
| a. 50 cells (100.0%) have expected count less than 5. The minimum expected count is .48. | | | |

**Case_ID * Toxicology_Used**

| Chi-Square Tests | | | |
|---|---|---|---|
| | Value | df | Asymptotic Significance (2-sided) |
| Pearson Chi-Square | 25.000[a] | 24 | .406 |
| Likelihood Ratio | 34.296 | 24 | .080 |
| Linear-by-Linear Association | 4.328 | 1 | .037 |
| N of Valid Cases | 25 | | |
| a. 50 cells (100.0%) have expected count less than 5. The minimum expected count is .44. | | | |

**Case_ID * Expert_Testimony**

| Chi-Square Tests | | | |
|---|---|---|---|
| | Value | df | Asymptotic Significance (2-sided) |
| Pearson Chi-Square | 25.000[a] | 24 | .406 |
| Likelihood Ratio | 29.648 | 24 | .197 |
| Linear-by-Linear Association | 14.538 | 1 | <.001 |
| N of Valid Cases | 25 | | |
| a. 50 cells (100.0%) have expected count less than 5. The minimum expected count is .28. | | | |

**Case_ID * No_Forensic used**

| Chi-Square Tests | | | |
|---|---|---|---|
| | **Value** | **df** | **Asymptotic Significance (2-sided)** |
| **Pearson Chi-Square** | **25.000[a]** | **24** | **.406** |
| **Likelihood Ratio** | **29.648** | **24** | **.197** |
| **Linear-by-Linear Association** | **14.538** | **1** | **<.001** |
| **N of Valid Cases** | **25** | | |
| **a. 50 cells (100.0%) have expected count less than 5. The minimum expected count is .28.** | | | |

### 9.3.2. Binary logistic regression

In this, we dive into Binary Logistic Regression. The Case Processing Summary reveals that just 1 out of 25 cases, or 4%, made it into the logistic regression analysis, while a whopping 24 cases, which is 96%, were left out due to missing values. This points to a significant data problem, probably stemming from incorrectly coded or absent entries in one or more variables needed for the analysis. Consequently, the regression output isn't reliable and can't be interpreted in a meaningful way. To fix this, it's essential to review the dataset for completeness, making sure all relevant variables are accurately coded as numeric (like 0 and 1), and that any missing values are properly handled before running the test again.

| Case Processing Summary | | | |
|---|---|---|---|
| Unweighted Cases[a] | | N | Percent |
| Selected Cases | Included in Analysis | 1 | 4.0 |
| | Missing Cases | 24 | 96.0 |
| | Total | 25 | 100.0 |
| Unselected Cases | | 0 | .0 |
| Total | | 25 | 100.0 |
| a. If weight is in effect, see classification table for the total number of cases. | | | |

### 9.4. Cross-Tabulation: Forensic Method vs. Conviction

The data in Table 6 and Figure 4 clearly show how using forensic tools can directly influence conviction rates in wildlife crime cases. When both DNA profiling and toxicological analysis were employed together, the conviction rate soared to 85.7%, showcasing the power of combining these forensic methods. On the other hand, cases that relied solely on either DNA profiling or toxicology had a decent conviction rate of 66.7% each, which is still significantly better than cases that didn't use any forensic evidence at all. In fact, those without forensic input had the lowest conviction rate at just 33.3%, underscoring the limitations of traditional investigative techniques.

**Table 7. Comparison of Forensic method and conviction method**

| Forensic Tool Used | No. of Cases Using Tool | Convictions Secured | Conviction Rate (%) |
|---|---|---|---|
| DNA Profiling Only | 9 | 6 | 66.7% |
| Toxicology Only | 6 | 4 | 66.7% |
| Both DNA & Toxicology | 7 | 6 | 85.7% |
| No Forensics Used | 3 | 1 | 33.3% |

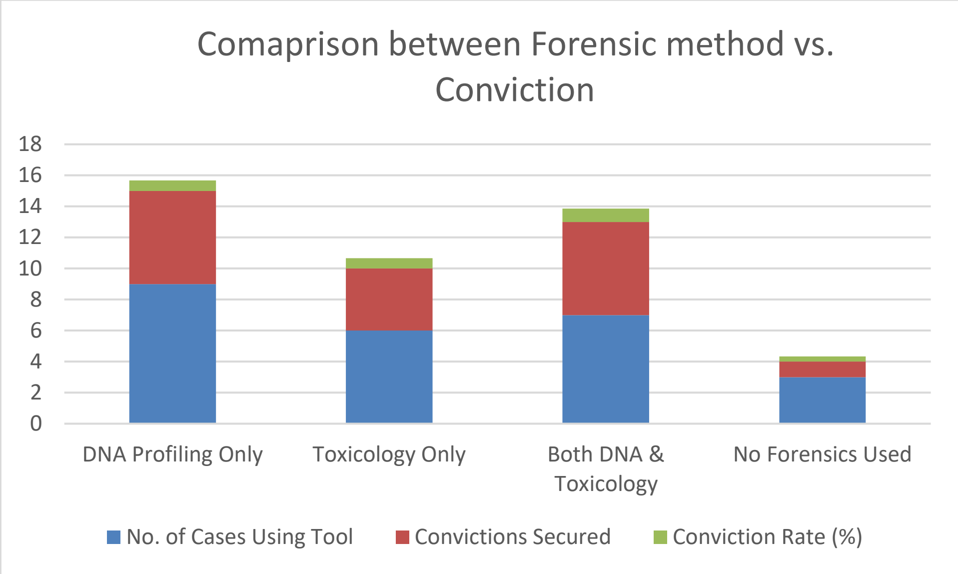


**Figure 4. Comparison of Forensic method and conviction method**

### 9.4.1. Cross tabulation

These results strongly suggest that using a mix of forensic tools can greatly enhance the chances of successful prosecutions in wildlife crime. To dig deeper, a cross-tabulation was conducted to explore the relationship between the type of forensic tool used (Tool_Type) and the conviction outcome (Conviction). The Pearson Chi-Square test yielded a result of $\chi^2 = 2.954$ with 3 degrees of freedom and a p-value of 0.399, which tells us that the association isn't statistically significant at the 0.05 level. This means we can't reject the null hypothesis, indicating there's no meaningful connection between the type of forensic method used and whether a conviction was secured in these 25 wildlife crime cases. Even though the conviction rates seemed higher when both DNA and toxicology were utilized (85.7%), the difference wasn't substantial enough to be statistically significant across the sample. Moreover, the reliability of the test is somewhat compromised, as 7 out of 8 cells (87.5%) had expected counts below 5, which goes against one of the assumptions of the Chi-Square test.

| Tool_Type * Conviction Crosstabulation | | | | | |
|---|---|---|---|---|---|
| | | | Conviction | | Total |
| | | | .00 | 1.00 | |
| Tool_Type | Bot | Count | 1 | 6 | 7 |
| | | Expected Count | 2.5 | 4.5 | 7.0 |
| | DNA | Count | 4 | 5 | 9 |
| | | Expected Count | 3.2 | 5.8 | 9.0 |
| | Non | Count | 2 | 1 | 3 |
| | | Expected Count | 1.1 | 1.9 | 3.0 |
| | Tox | Count | 2 | 4 | 6 |
| | | Expected Count | 2.2 | 3.8 | 6.0 |
| Total | | Count | 9 | 16 | 25 |
| | | Expected Count | 9.0 | 16.0 | 25.0 |

### 9.4.2. Chi square test

| Chi-Square Tests | | | |
|---|---|---|---|
| | Value | df | Asymptotic Significance (2-sided) |

| | | | |
|---|---|---|---|
| Pearson Chi-Square | 2.954[a] | 3 | .399 |
| Likelihood Ratio | 3.107 | 3 | .375 |
| N of Valid Cases | 25 | | |
| a. 7 cells (87.5%) have expected count less than 5. The minimum expected count is 1.08. | | | |

## 10. Discussion

This study underscores the critical role of wildlife forensic science in combating wildlife crime and strengthening legal enforcement. Techniques such as DNA profiling, toxicology, and digital forensics have proven vital in identifying species, toxins, and criminal networks, even from highly processed wildlife products. DNA barcoding using COI genes achieves over 93% species identification accuracy, supporting landmark cases tracing ivory and rhino horn to poaching hotspots. Toxicological analyses using advanced instruments have exposed poisoning incidents, influencing prosecutions and conservation policy. Digital forensics and AI tools now detect illegal wildlife trade online with high accuracy. However, forensic effectiveness in India is constrained by infrastructural gaps, legal inconsistencies, limited training, and weak chain-of-custody practices. Empirical findings show higher conviction rates when multiple forensic methods are combined, though data limitations persist. Strengthening forensic infrastructure, standardizing protocols, improving judicial literacy, and enhancing inter-agency collaboration are essential to fully realize wildlife forensics as a cornerstone of conservation justice and biodiversity protection.

## 11. Conclusion

This study highlights just how powerful wildlife forensic science can be in tackling wildlife crimes. By bringing together genetic, toxicological, digital, and pathological methods in legal cases, forensic science really boosts the evidence needed to convict offenders and safeguard endangered species. While we've seen impressive conviction rates when both DNA and toxicology are used, there are still hurdles to overcome, like gaps in infrastructure, lack of training, and procedural issues that prevent consistent application. To truly enhance our legal response to wildlife crime, it's crucial to invest strategically in wildlife forensic systems and foster cooperation between agencies.

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