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A review of wildlife forensic science and laboratory capacity to support the implementation and enforcement of CITES

Review commissioned by the Secretariat of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES)

Review undertaken by the United Nations Office on Drugs and Crime (UNODC)

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COMBATING WILDLIFE AND FOREST CRIME
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Executive Summary

This review represents the first comprehensive attempt to survey global wildlife forensic capacity to support the implementation and enforcement of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). The use of wildlife forensic science to help identify and characterize animal and plant specimens has been established in some countries for decades, however at an international level, the discipline is still in the relatively early stages of development.

Increasing focus on the potential benefits of wildlife forensics, including statements issued at recent CITES meetings, has helped to raise awareness of the forensic applications among the law enforcement and conservation communities. However, detailed understanding of wildlife forensic practice is not widely held by relevant stakeholders and there is no current register of wildlife forensic laboratories or the services they provide.

The purpose of this document is two-fold. First, it provides an introduction to the key aspects of wildlife forensic science relating to CITES. This should be relevant to enforcement agencies, the legal profession and research scientists alike. Second, the review summarizes the findings of a comprehensive international survey of laboratory capacity and practices, in order to provide a snapshot of current wildlife forensic capabilities and to establish a benchmark against which to assess future developments.

The survey was conducted on a confidential basis to encourage responses from all practicing laboratories, including those not yet necessarily operating robust forensic control processes. The survey was distributed to participating laboratories in autumn 2015 though an extensive network of contacts established by the contributors and via a CITES Notification to the Parties.

Survey data were collated from 110 institutions in 39 different countries. Information was recorded on the range of taxa analyzed, the types of investigative question addressed, the principle techniques used, sources of analytical reference materials and the measures employed by laboratories relating to quality assurance and staff training. Additional questions relating specifically to the identification of rhinoceros horn, elephant ivory and timber were included to gather more detailed information on these groups of taxa.

Results revealed an extremely broad spectrum of facilities, offering a diverse range of services, but with relatively few institutions operating in full accordance with recognized international forensic best practice. It should be noted that other than the removal of responses that were considered void, no attempt was made to validate the accuracy of the information provided and the survey results are therefore based entirely on self-declaration.

The database of laboratory responses resulting from this work provides a resource to identify forensic service providers capable of assisting in enforcement activities. The potential to

maintain and update the database through time offers the opportunity to accurately gauge the development of global forensic capacity as well as providing an ongoing source of relevant information for the enforcement community.

Incorporating the survey results into the broader picture of wildlife forensic science, the review concludes with an assessment of seven areas for development within the discipline, covering different aspects of applied forensics from method development to staff training and quality assurance. There is a clear need to develop a coordinated process for prioritizing limited project funding to maximize the impact of wildlife forensics in support of CITES implementation and enforcement.

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Part 1. Introduction

The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) is an international agreement between governments. Its aim is to ensure that international trade in specimens of wild animals and plants does not threaten their survival. CITES works by subjecting international trade in specimens of selected species to certain controls. All import, export, re-export and introduction from the sea of species covered by the Convention has to be authorized through a licensing system.

States that have agreed to be bound by the Convention ('joined' CITES) are known as Parties. Although CITES is legally binding on the Parties – in other words they have to implement the Convention – it does not take the place of national laws. Rather it provides a framework to be respected by each Party, which has to adopt its own domestic legislation to ensure that CITES is implemented at the national level.

Against a backdrop of widespread illegal trade in wildlife that is affecting the conservation of traded species and of biodiversity as a whole, the need for effective wildlife law enforcement is now widely recognized by national governments and inter-governmental organizations, including CITES and the United Nations Office on Drugs and Crime (UNODC).

Wildlife trafficking is a complex issue, often involving multiple actors which operate at different levels, ranging from local poaching or illegal harvest through to international and highly organized criminal networks with established global supply chains. Tackling the illegal wildlife trade requires a well-coordinated, multi-faceted approach, good international cooperation, and the increased use of all the tools and resources available, including forensic applications.

One of the issues routinely faced by enforcement agencies is the definitive identification of wildlife specimens in trade, necessary to demonstrate legal or illegal activity. The identification of evidence in criminal investigations can be achieved through the application of forensic science. The purpose of this review is to summarise the current state-of-the-art in wildlife forensic science and to provide, for the first time, a comprehensive picture of laboratory capacity at the global level, for performing forensic analysis in support of CITES implementation and enforcement.

This document begins by providing relevant background to the subject of wildlife forensic science (Part 2), its use to support enforcement of CITES regulations (Part 3) and a description of the main methods used in wildlife forensics (Part 4). Part 5 provides a summary of the results of the global survey of wildlife forensic capacity. Finally, Part 6 examines possible areas for future development of wildlife forensic capacity and makes general recommendations for resource prioritization.

Part 2. Wildlife Forensic Science

a) What is forensics?

Forensic science is an applied discipline concerned with the controlled use of analytical scientific methods to generate evidence in relation to legal proceedings. The forensic scientist addresses the needs of prosecution or defense investigators, by applying appropriate tools to answer questions that arise during the investigation or prosecution of a case.

In this context, it would normally be incorrect to refer to a particular method as being 'forensic'. For example, DNA profiling methods employed to individually identify a sample (person, animal, plant) can be performed within a university undergraduate project, or to provide compelling evidence to support a murder conviction; but only one of these would be considered forensic analysis. The term 'forensic' refers to the purpose of the analytical method and the way in which that method is performed, rather than the method itself.

b) What is *wildlife* forensics?

In tackling the illegal wildlife trade, investigative questions may relate to both the identification of the perpetrators and, importantly, the identification of the wildlife product in trade. The former is the subject of traditional forensic analyses, such as human DNA profiling or ballistics, while the latter is the subject of wildlife forensics. These categorisations are not entirely fixed within the forensic community, but are generally considered the best rule of thumb.

c) Forensics, intelligence and research

The subject of forensic science has received considerable public attention over the past decade, through exposure in the popular press and entertainment industry. While this widespread interest has benefitted the discipline to some extent, it has also resulted in much misunderstanding about what forensic science is, and what the term 'forensic' means.

In its strictest sense, as described above, the term 'forensic' relates solely to the production of scientific evidence for legal proceedings and the development of tools specifically for that purpose. This sets a very high standard for the methods, data and laboratory procedures employed in any forensic analysis. Each aspect of the analysis must be formally validated to demonstrate fitness-for-purpose and details of the analytical process must be thoroughly documented within an established quality assurance system. All activities involved in the generation of evidence may be subject to legal scrutiny, and in many countries, all personnel involved may be considered as witnesses in the eyes of the law. In this respect, the standard of forensic analysis required to investigate crimes against wildlife is no different to that applied to crime against humans.

The requirements for forensic testing outlined here inevitably restrict the range of tests that may be performed in a forensic investigation. Taking genetic analysis as an example, there are far more DNA identification tests published in the academic literature than there are forensic tests available for law enforcement. This is primarily because of the additional time and costs associated with taking a research method and transferring it into a validated forensic method. The issue is particularly acute in wildlife forensics because of the huge diversity of possible species-specific tests and the fact that, unlike human DNA forensics, there is no commercial market for the development and application of wildlife forensic tests.

The situation inevitably creates a tiered system of test standards, from a novel research method that is largely unproven but may provide powerful identification results in a university lab environment, through to well established methods, such as DNA sequencing, that are routinely applied for species identification in a quality assured forensic laboratory environment[1].

The forensic science community has established standards and guidelines for wildlife forensic testing as will be described in further sections of this review, however, difficult decisions remain as to how to deal with information generated outside of such rigorous standards. The concept of 'intelligence', as opposed to 'forensic evidence' is often used to categorise such information, but its subsequent use by investigators may become fraught with difficulty if the strength of the information is not clearly understood and results are relied upon too heavily as part of a prosecution. A good example of this challenge is with the development of DNA analysis techniques to identify the specific geographic origin of a traded wildlife product[2]. In such applications, identifying the most likely source of origin may be informative, but is not the same as excluding all other options. Such issues can be addressed to a large extent, but most common research approaches to population assignment are not so exacting in their implementation.

At the present time, while there is a well-defined standard for what constitutes forensic analysis for the production of evidence in legal proceedings, there is no such agreed bar against which to measure the reliability of methods and processes for generating intelligence information. The use of wildlife science methods for such applications should therefore be judged cautiously and on a case-by-case basis.

d) The forensic framework

In addition to ensuring that a laboratory can generate forensic evidence using appropriate methods and processes, capacity for wildlife forensic science depends on the broader

[1] Ogden (2010) Forensic Sci Med Pathol. 6(3):172-9
[2] Ogden & Linacre (2015) Wildlife forensic science: a review of genetic geographic origin assignment. For Sci Int Genet. 10.1016/j.fsigen.2015.02.008

organizational framework surrounding its use. Any wildlife forensic investigation extends from the point of evidence collection through to the presentation of analytical findings in court. In the simplest scenario this will still involve issues of evidence preservation, secure collection, storage and transport to the lab, followed by appropriate use of the forensic evidence by investigators and the ability of the judiciary (and jury) to accept and understand the evidence as it is presented. Evaluating the broader forensic framework surrounding individual laboratories is beyond the scope of this review, but it is important to consider this issue, when seeking to identify suitable facilities for forensic analysis, or the development of capacity in this area.

e) Evidence security

It is critical that any material evidence is held securely, under controlled access, at all times from point of collection to conclusion of the analysis. This includes all stages of evidence handling from the crime scene, through transportation and transfer to the laboratory, and within the laboratory itself. This ‘chain of evidence’ (also referred to as the ‘chain of custody’ of the evidence) must not be broken and must be verifiable in order to demonstrate to the court that there has been no possibility of tampering with the evidence at any stage. At all times, it must be possible to identify an individual responsible for custody of the evidence. Evidence security is a key concern of the wider forensic framework (see above) but is also an essential part of the control processes established in any forensic laboratory. The need to guarantee evidential security has implications for the type of laboratory that can readily perform forensic analysis and forms part of the overall quality assurance system required for undertaking such work.

f) Quality Assurance and certification

The level of confidence in any laboratory analytical result relates to the degree of quality assurance (QA) surrounding the production of the data. The QA concept is fundamental to the performance of any test where the results are later relied upon by a third party, such as medical diagnostics or forensics. QA is usually delivered through a Quality Management System, which describes a series of control processes and protocols surrounding the implementation of a test. Quality Management Systems cover all aspects of test implementation, from method performance and validation, through staff training, laboratory operating procedures and the systems in place for reporting and reviewing analytical results. While a Quality Management System is designed to be specific to a laboratory process, general standards have been developed, such as ISO17025 or GLP/GMP, which describe general QA requirements for laboratory testing and under which individual laboratories may choose to become formally accredited.

Laboratory accreditation to the ISO17025 standard has become a requirement for human forensic laboratories in many countries and is considered the gold standard in wildlife forensic testing. However, accreditation to such a standard is time consuming, expensive and may require a level of staffing and infrastructure that is simply not realistic for wildlife forensic laboratories to achieve, irrespective of the quality of their work. To address this issue, the US Scientific Working Group on Wildlife Forensic Methods (SWGWILD), in conjunction with the Society for Wildlife Forensic Science (SWFS), established a set of Standards and Guidelines specifically for several disciplines within wildlife forensics (SWGWILD 2012). At the present time, there is no audit system for laboratories wishing to adhere to these standards, however such a system is expected to be available by 2017.

While a number of wildlife forensic laboratories do hold ISO17025 accreditation, an absolute requirement for laboratory accreditation in wildlife forensic science is an unrealistic expectation at this time. This complicates the job of law enforcement agencies in selecting a suitable laboratory for forensic analysis, and creates difficulties in court when assessing the reliability of evidence. This has been recognized by the International Consortium on Combatting Wildlife Crime (ICCWC),[3] and UNODC, in cooperation with its ICCWC partners, developed guidelines for the analysis of wildlife products to inform investigators, scientists and the judiciary on the respective roles, responsibilities and standards that should be met by different actors in a wildlife crime investigation[4]. At the very least, laboratories conducting wildlife forensic testing should have implemented a Quality Management System and casework documentation system, available for review by investigators and the court.

In addition to laboratory accreditation, it is possible for individual forensic practitioners to become certified as forensic scientists. In wildlife forensics, a certification scheme is run by the Society for Wildlife Forensic Science, in order to assess and approve the quality of individual forensic practice, determined among other things, through a review of historic case files. The certification scheme was originally designed for implementation in North America but is being adapted for use at an international level and considered another indicator of best practice, alongside laboratory quality systems.

[3] https://cites.org/eng/prog/iccwc.php
[4] 'Guidelines on Methods and Procedures for Ivory Sampling and Laboratory Analysis'; 'Guide for Forensic Timber Identification'.

Part 3. The use of wildlife forensic science to support the implementation and enforcement of CITES

a) Common investigative and scientific questions

As in any applied discipline, the development and implementation of forensic tools is driven by the end-user and the challenges they face. In the case of CITES implementation and enforcement the end-users are the government agencies responsible for investigating illegal international trade in CITES-listed species. The investigative questions they need to address in relation to the identification of animals and plants, or their parts and derivatives, can generally be categorized into five groups, concerning:

- i) the species[5] involved;
- ii) the geographic origin of a specimen[6];
- iii) the wild or captive/cultivated source of a specimen;
- iv) the individual origin of a specimen;
- v) the age of a specimen.

The wildlife forensic scientist will address specific investigative questions by formulating an appropriate scientific question that can be answered using the techniques available. For example, a suspicious captive breeding claim may be investigated by the use of DNA profiling to refute claimed parentage-offspring relationships and support an investigation into illegal trade in wild-caught animals. Similarly, radio-carbon dating may be applied to evaluate suspicions that ivory originated from a recently poached elephant, rather than from a historic antique claimed to be a pre-Convention specimen.

Within these five categories of investigative question there are a huge range of specific enforcement needs, some of which can be addressed using generic wildlife forensic methods, others that require a much more specialist approach. In every case, the wildlife forensic scientist needs relevant information concerning the evidence and the investigative point to prove in order to determine the best forensic approach to take. An overview of wildlife forensic methods is provided in Part 4.

b) Investigative need for forensic evidence

The appropriate use of forensic analysis can provide compelling evidence critical for the prosecution of a case. The counterpoint to this is that forensic analysis may not always be necessary or appropriate, or may not deliver a sufficiently accurate, robust result to carry any evidential weight. Ultimately it is the decision of the court to determine the relevance, veracity and strength of any evidence presented to it. It is however the responsibility of both national agencies responsible for wildlife law enforcement and forensic scientists to ensure that

[5] As defined in Article I of CITES
[6] As defined in Article I of CITES

resources spent on forensic analysis are justified in terms of need and impact. This issue also relates to funding research projects that may claim to be capable of delivering novel wildlife forensic applications. At all points in the process, work should be assessed to determine whether or not a particular technique can, or likely will, be used to deliver forensically robust evidence that is relevant to an investigation.

c) CITES and wildlife forensic science

The CITES Conference of the Parties (CoP) and Standing Committee have, in recent years, adopted Decisions, Recommendations and Resolutions that reflect an increased desire to consider and implement wildlife forensic science to tackle the illegal trade. The references to issue-specific forensic applications collated in CITES Notification to the Parties No. 2015/61 dated 20 November 2015, forms the basis for the current review (see Annex I). It is now considered timely to develop an integrated overview of global wildlife forensic capacity, in order to provide a resource for CITES enforcement stakeholders and to determine a baseline from which to coordinate the development of further wildlife forensic services.

Part 4. Overview of Techniques and Materials Used in Wildlife Forensics

Wildlife forensics utilizes a broad spectrum of analytical methods and reference materials to identify biological evidence. Detailed reviews of the development and application of wildlife forensic methods are available elsewhere[7,8]. The following section provides a brief overview of the key techniques and considerations relating to wildlife forensic applications to CITES enforcement. A summary of the Methods is provided in Table 1.

a) Methods

Visual Identification

The use of visible physical characteristics is intuitively the simplest approach to identifying wildlife and wildlife products in trade. In cases where the evidence retains sufficient characteristics and appropriate expertise exists, visual identification is usually the quickest and least expensive form of forensic analysis. Visual identification is normally applied to determine the taxon of origin, at best to species level but often limited to the level of genus or a higher taxonomic level (Table 1). Visual identification is extremely effective as a rapid, affordable screening test, as it is possible to train enforcement officers in the use of identification keys in the field, or obtain initial opinions through the use of digital photography and mobile communications. However, when used in forensic analysis, its application is limited to the availability of experts capable of performing a detailed, objective analysis that is accepted in court. This limitation restricts the use of visual identification in wildlife forensics, particularly in countries lacking well-established natural history institutions with the appropriate reference collections and expert staff. Indeed, courtrooms do appear to be increasingly seeking alternative forms of identification that are perceived as being less subjective, despite the validity of the approach.

Genetic identification

Observed genetic differences among species, populations and individuals can be used to identify and categorise biological evidence. The use of DNA analysis in wildlife forensics is most developed for species identification (including DNA barcoding), where it is now routinely used to identify the taxon of origin. However with the availability of species-specific DNA profiling systems and reference data, DNA analysis can also be used to match samples at an individual level or support/refute parentage claims (Table 1). The use of DNA to identify geographic origin relies on methods that assign the genetic profile of an evidence sample to its genetic population of origin. This requires a large reference database of genetic data from

[7] Huffman & Wallace, eds. 2012. Wildlife Forensics: Methods and Applications. John Wiley & Sons, Ltd., Chichester, West Sussex, UK

[8] Dormontt et al 2015. Forensic timber identification. Biological Conservation doi:/10.1016/j.biocon.2015.06.038

across the species range and for the species to exhibit population genetic structure on a geographic scale that is informative to an investigation. The development of such methods is difficult and in its infancy for most species, however the example of African elephant ivory demonstrates the potential of this approach[9].

DNA analysis is limited by the need to extract a sufficient quantity and quality of DNA from the evidence, which may be problematic for highly processed wildlife derivatives, or materials such as timber. At a global scale, DNA laboratories and analytical staff are widely available, however there is a lack of suitably trained wildlife DNA forensic practitioners.

Chemical identification

The different chemical properties of a biological sample may be analysed using a variety of approaches to identify wildlife. Broadly speaking these approaches can be divided into two: i) analysis of chemical compounds within a sample that reflect the biochemical products of the animal or plant (e.g. proteins), or ii) analysis of stable isotope ratios for specific elements within a sample that reflect the environment in which the animal or plant lived[10]. Both approaches use mass spectroscopy to generate a chemical profile for the sample that may be compared against appropriate reference data to help identify its origin. Chemical profiles derived from biochemical compounds can be used to differentiate species, infer geographic origin, or differentiate wild from captive sources. Chemical profiles composed of isotope ratios can be used to identify likely geographic origin.

The use of chemical identification in wildlife forensics is not as widespread or developed as genetic identification, primarily due to limitations on the availability of laboratory equipment and comprehensive reference data. Further work is also needed to standardize approaches and validate methods across laboratories. This is an active area of research focus and does offer great potential, particularly for timber identification, but at the present time the use of chemical identification in wildlife forensics remains a highly specialized approach with relatively few routine applications.

Radiocarbon dating

Strictly speaking, radiocarbon dating is a form of chemical isotope analysis, however its basis and application to wildlife forensic analysis make it sufficiently distinct to treat as a separate method here. Radiocarbon dating relies on measurement of naturally occurring carbon isotopes, including the radioactive ^{14}C isotope. While the approach is widely used to age organic compounds dating back thousands of years, the elevated levels of ^{14}C caused by atmospheric atomic bomb testing during the 1950s and 1960s, has enabled scientists to estimate the age of organic samples during the past 50 years with much greater precision.

[9] Wasser et al 2015. Science 3;349(6243):84-7.

[10] Additional chemical methods, such as NIRS (near infra-red spectroscopy), which relies on the characterization of molecular absorption spectra, are being trialed in some areas of wildlife identification, e.g. timber, but are not yet widely accepted for forensic analysis.

This approach may be of relevance to CITES enforcement, as Article VII, paragraph 2, of the Convention[11] provides an exemption for specimens acquired before the provisions of the Convention. The use of radiocarbon dating to demonstrate the age of an individual animal or plant may provide compelling evidence to an investigation.

Radiocarbon dating is a highly specialized technique. Only around 150 laboratories perform the technique worldwide with a fraction of these known to perform analysis of wildlife. Nevertheless, the approach is well established and is used on occasion to support CITES enforcement.

[11] https://cites.org/eng/disc/text.php

Table 1 Generalised overview of techniques available to wildlife forensic science and the questions they can be used to address. Note that all analyses are implemented on a case-by-case basis and factors such as the evidence item (type/condition/age) and specific point to prove in an investigation will dictate whether or not any particular method will be suitable.

Technique	Taxonomic ID	Geographic ID	Captive/Wild Source ID	Individualisation	Ageing
Visual analysis	**Yes** [12] – but requires sufficient physical characters, species ID not always possible	**Rarely** (based on taxonomic ID and distribution data – resolution may not be informative)	**Rarely** (based on wild vs captive specific characters)	**No**[13]	**Rarely** [14] (may be useful in ageing of claimed antiques)
DNA analysis	**Yes** – requires DNA recovery from sample type	**Rarely** (based on population genetic variation and data – resolution may not be informative)[15]	**Sometimes** [16] (based on parentage testing and availability of reference parent samples)[17]	**Sometimes** (based on availability of DNA profiling system for target species)[18]	**No**
Chemical analysis	**Rarely** – possible in theory but necessary reference data largely unavailable	**Sometimes** (based on environmental chemical signatures – resolution may not be informative)	**Sometimes** (based on sufficient environmental/diet difference in the specific scenario)	**No**	**No**
Radiocarbon dating	**No**	**No**	**No**	**No**	**Yes** – with some limitations

[12] 'Yes' denotes methods that are widely available and routinely used.
[13] 'No' indicates method applications that are not currently possible.
[14] 'Rarely' indicates methods that are theoretically possible, but have only ever been used in extremely rare cases, or are generally at a research phase in their development.
[15] But see research on determining geographic provenance of African elephant ivory as a working example, Footnote 7.
[16] 'Sometimes' indicates methods that have been developed and demonstrated in specific scenarios/species, but are not widely available, or may require further forensic development.
[17] Parentage testing requires a DNA profiling system (see note 10) and a system of recording legitimate captive bred relationships.
[18] DNA profiling systems exist for certain species, e.g. rhinoceros, tiger etc, and can be readily developed for additional species.

b) Reference materials

As mentioned throughout the Methods section above, wildlife forensic science is heavily dependent on the existence and accessibility of reference materials against which to compare analytical results and identify the evidence. Reference materials are typically in the form of physical samples, but may also be held digitally as reference data.

Physical samples

Authenticated physical samples form the basis of any biological reference system and underpin the development of wildlife forensic tests. Every reference sample must have an unambiguous taxonomic identification along with meta-data appropriate to its use, for example, a specific collection location for geographic origin testing, or a specific age for radiocarbon dating. The collection and curation of reference materials is a huge task and has historically been the role of natural history museums and herbariums around the world. The problem of reference sample availability for CITES enforcement is compounded by the difficulties in obtaining new samples from endangered species.

While many institutions actively support wildlife crime investigations, serious challenges exist when attempting to use such collections as reference materials in wildlife forensic investigations, including ambiguous taxonomy, reluctance to allow destructive sampling, difficulties in transfer of reference materials and the suitability of the sample type available. Furthermore, for certain applications, such as geographic origin assignment, biological collections rarely hold sufficient samples from across a species range to support method development. In such cases, references samples are typically held by research labs involved in generating the baseline data for a particular method. Gaining access to academic reference materials is often even more difficult than materials held in public institutions. While a small number of wildlife forensic laboratories do hold their own reference sample collections, they are in the minority and always face challenges concerning tests on previously unsampled species.

It should be stressed that without authenticated reference materials, it is not possible to categorically identify animals and plants in trade. Improving access to reference samples for wildlife forensic practitioners should be a priority in the development of forensic capacity to support implementation and enforcement of CITES (see Part 6).

Reference data

The use of digital analytical result data as a reference standard may circumvent the issues of physical sample access and allow wildlife forensic scientists in multiple labs to make use of a single reference sample. For example, DNA barcoding involves the production of a standardized DNA sequence from an authenticated reference sample, which is stored and accessible in digital form. DNA barcode sequence data is freely available through an online searchable database that will, for example, allow forensic scientists in Southeast Asia to access the reference data for a sample that has never left Africa. Such remote access to reference data is very useful in wildlife forensic science, but its use must be managed very carefully and may not always be appropriate. Databases usually contain errors, some types of data are very difficult to exchange between laboratories and some countries do not allow the use of reference data generated by third parties in a forensic investigation. These issues are very familiar to practicing wildlife forensic scientists, but may be less obvious to academic researchers or law enforcement officers, for whom an awareness of the limitations of reference data is considered important.

Part 5. Survey of global wildlife forensic capacity

a) The wildlife forensic science community

Wildlife forensic science is a multidisciplinary subject that includes analytical methods developed from biological, biochemical, chemical and physical sciences. While the emphasis is clearly focused on the application of such methods to wildlife law enforcement, the broader wildlife forensic community includes scientists who choose to direct their research towards future forensic applications or the production of data to inform law enforcement on illegal trade issues. This creates an interesting and dynamic community of scientists associated with wildlife forensics, but can also create an often bewildering array of options and divergent opinions for the law enforcement community.

In response to this situation, the Society for Wildlife Forensic Science (SWFS) was established in 2009 to promote standardization, support practitioners and establish wildlife forensic science as a mature discipline. To date, it has members from around 60 laboratories in 20 different countries. In addition, groups such as the European Network of Forensic Science Institutes' Animal, Plant and Soil Traces group (ENFSI-APST), include scientists primarily from human forensic labs who may also be involved in wildlife forensic work. Lastly, in relation to CITES enforcement, individual national CITES Management and Scientific Authorities may rely on additional national laboratory facilities to assist in CITES enforcement investigations. These may include scientists at institutions such as universities, museums or herbaria that do not identify themselves as forensic practitioners but who nonetheless are contributing to the production of forensic evidence. The current review has attempted to include this entire breadth of the wildlife forensics community to generate, for the first time, a global snapshot of capacity to support CITES enforcement.

b) Survey background, aims and methodology

A number of CITES Decisions adopted at the 16th meeting of CoP to CITES and Recommendations adopted by the CITES Standing Committee[19] encourage the increased use of forensic analysis to support the implementation and enforcement of CITES.

To this end, the CITES Secretariat, in collaboration with UNODC and in cooperation with the Society for Wildlife Forensic Science, commissioned a global review of laboratory capacity to identify facilities involved in the development or application of identification techniques, in a forensic context, to support law enforcement and to combat illegal trafficking in CITES-listed species. The overall aim of the review was to generate data about current global capacity of wildlife forensic science for CITES enforcement. Given the developing nature of wildlife forensic science and its broad community of scientific stakeholders, the purpose of the survey

[19] See CITES Notification 2015/61 https://cites.org/sites/default/files/notif/E-Notif-2015-061.pdf

was *not* to judge the quality or performance of any laboratory or practitioner, but to take an inclusive approach and gather information on all ongoing wildlife forensic activities, including applied research.

Data for the review was generated through a survey of wildlife forensic capacity carried out from 1st October to 31st December 2015. The survey is based on the results of a confidential questionnaire that was circulated directly to laboratories known or thought to be involved in wildlife forensic science, and through CITES Notification to the Parties No. 2015/061, requesting CITES authorities to share the survey with relevant forensic facilities and research institutions within their territories (Annex 1).

Questions were designed to cover a range of topics relevant to wildlife forensic science and introduced in the preceding sections, including: the nature of analysis performed, the methods used, the taxa identified, the investigative questions addressed, the reference materials used, the quality assurance systems in place and the level of staff training. To ensure that the review could address Decisions and Recommendations on elephants and rhinoceros from CoP16 and SC65 (see notification for details), the review included specific focus on laboratory capacity for methods associated with the identification of elephant ivory and rhinoceros horn.

A ten-question, self-complete questionnaire was designed using the online survey tool Survey Monkey. The questionnaire was designed to maximise response and completion rates while minimising various quality issues commonly encountered when gathering data using self-reported or self-complete methods (for further detail on questionnaire design, see Annex 3). The questionnaire was distributed via individual emails that explained the purpose of the survey and use of the data.

Over 150 individualized invitations were sent out via email. The questionnaire was also made available to all CITES Parties as an Annex to CITES Notification to the Parties No. 2015/061 dated 20th November 2016. In addition to direct requests to targeted recipients, an unknown number of recipients were also invited to participate through word of mouth between laboratory scientists, thus precise response rates cannot be calculated.

Participants who were individually emailed had a timeframe of approximately 4 weeks to complete the survey, since the online tool was closed on 18th December 2015. The deadline for submitting answers via the CITES Notification to the Parties was 31st December 2015.

The questionnaire responses were entered into Microsoft Excel to enable data cleaning, recoding and analysis. Data recoding consisted of using logic functions in Excel to combine answer options and allow filtering.

The resulting database provides a resource for identifying the capacity and working practices of multiple laboratories working in the area of wildlife forensics across the world. Although a summary of the key results and trends across laboratories is provided in this review, data from individual laboratories will remain confidential. The reasons for this are two-fold: i) the data were submitted on the basis of self-declaration, therefore no validation of individual lab response accuracy has been conducted, nor should be implied; ii) the data were submitted on the basis of anonymity to encourage all laboratories to reply, regardless of whether or not they currently operate according to best practice.

c) Results

Summary of response level

A total of 160 responses were received, however a significant number of these (n=52) lacked contact information (Question 10). The majority of these 52 responses were discarded as likely online submission errors or responses lacking sufficient data, but 13 were retained in the summary analysis as the responses were for the most part complete and in some cases respondents had stated that they wanted anonymity, despite assurances that submissions were confidential. A number of replicate responses were also received from different people at the same laboratories and these were removed. This left a total of 97 named responses and 13 anonymous responses that were subsequently analysed and summarized in the section below. This level of participation was in line with an initial target of up to 100 responses and supported the combined approach of direct laboratory mailing lists and the CITES Notification. The 110 responses analysed included laboratories from 39 different countries distributed across all CITES regions (Annex 2).

Question summaries

The response to each of the nine remaining questions is summarized below. In addition, specific summaries are provided for responses relating to elephant ivory and rhinoceros horn.

Q1. Forensic casework and/or research

[Has your laboratory ever carried out a test that has been used as evidence in a court of law during a wildlife crime investigation?]

A1. Positive responses were provided by 67% of laboratories (n=74).

Q2. Taxonomic groups analysed

[Does your laboratory carry out research or legal casework for the types of biological materials listed? Terrestrial animal; Aquatic animal; Plant; Timber; Rhinoceros horn; Elephant ivory]

A2. The most common taxonomic group analysed was terrestrial animals with more laboratories conducting casework than undertaking research (Figure 2). The opposite trend was shown for aquatic animals and all plant forms, where research activities were more common than casework. Casework for aquatic animals and plants was performed at approximately half the number of laboratories working on terrestrial animals.

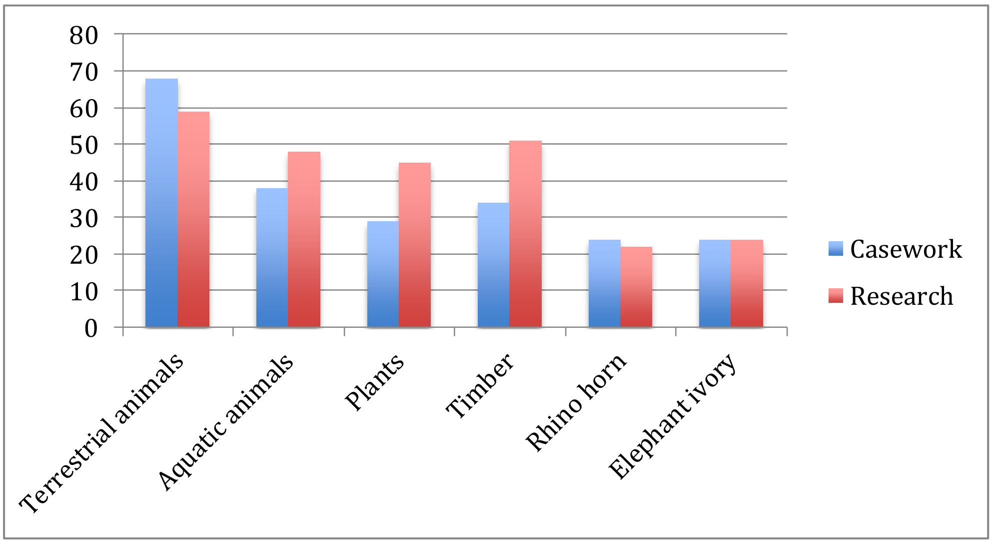

Figure 2a Application type across taxonomic groups

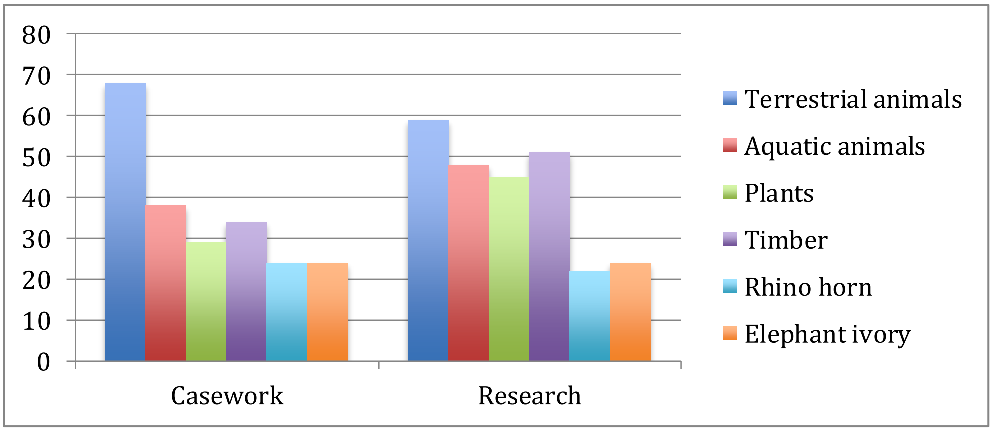

Figure 2b Taxonomic groups by application type (casework & research)

Q3. Analytical Techniques.

[Please tick the casework techniques used in your laboratory for each of the sample types listed: Morphology/ Anatomy; DNA analysis; Immunoassay; Chemical profiling; Stable Isotopes; Other]

A3. DNA analysis was the most common technique used in animals, followed by morphology/anatomy, while this trend was reversed in plants and timber (Figure 3). Chemical profiling was also used widely in analysis of plants (n=11 labs) and timber (n=14 labs).

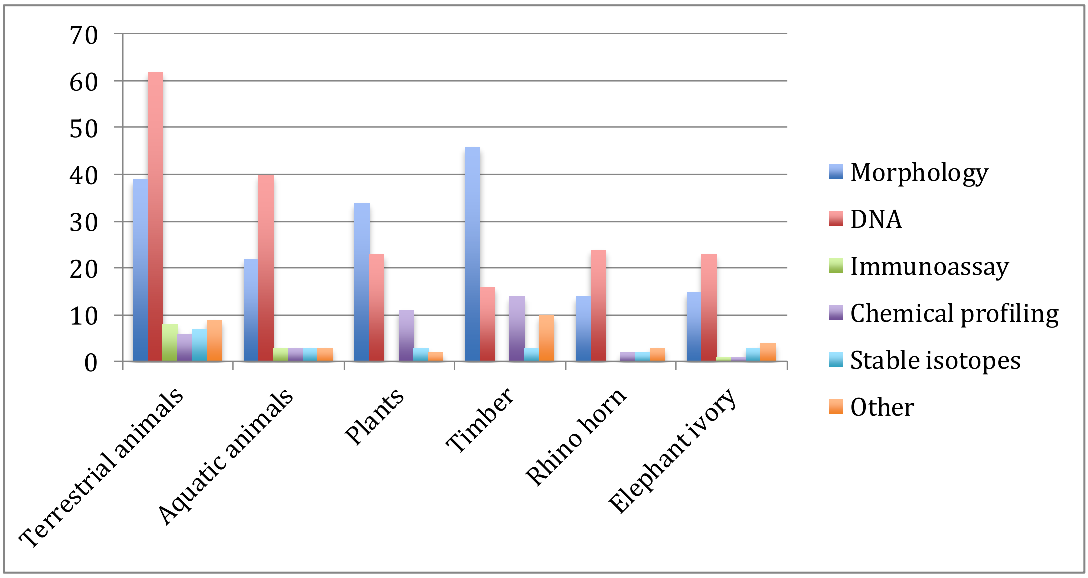

Figure 3a Analytical technique across taxonomic groups

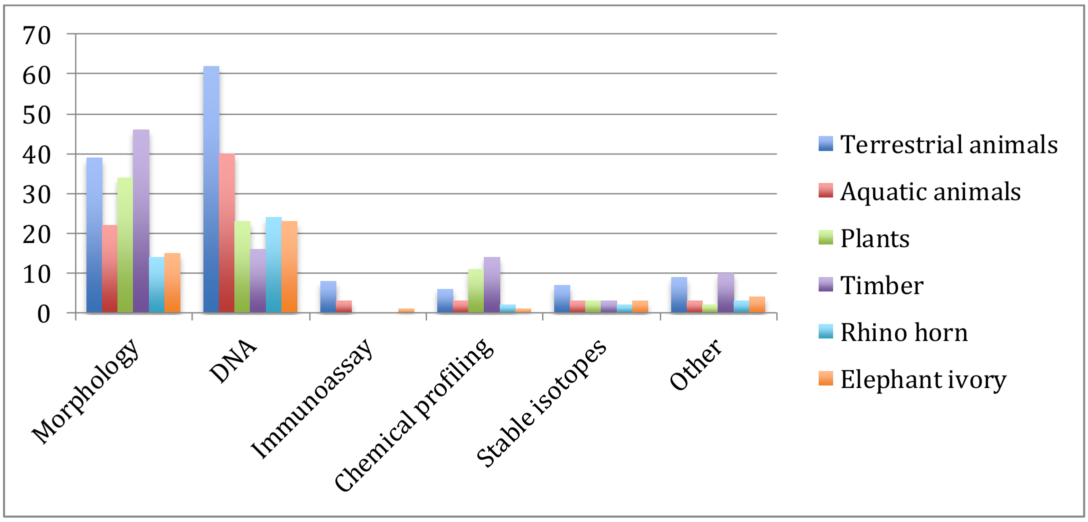

Figure 3b Taxonomic groups analysed with different techniques

Q4. Investigative questions

[For wildlife crime investigations, which identification questions can your laboratory address? Species; Geographic Origin; Individual; Parentage; Age]

A4. Species identification was the most common issues addressed in all taxonomic groups (Figure 4), with parentage and individual identification also performed at around half of the labs, although these results are likely to be for relatively few species in each case. Ageing samples was quite widely available for terrestrial animals and timber (n=18 labs each).

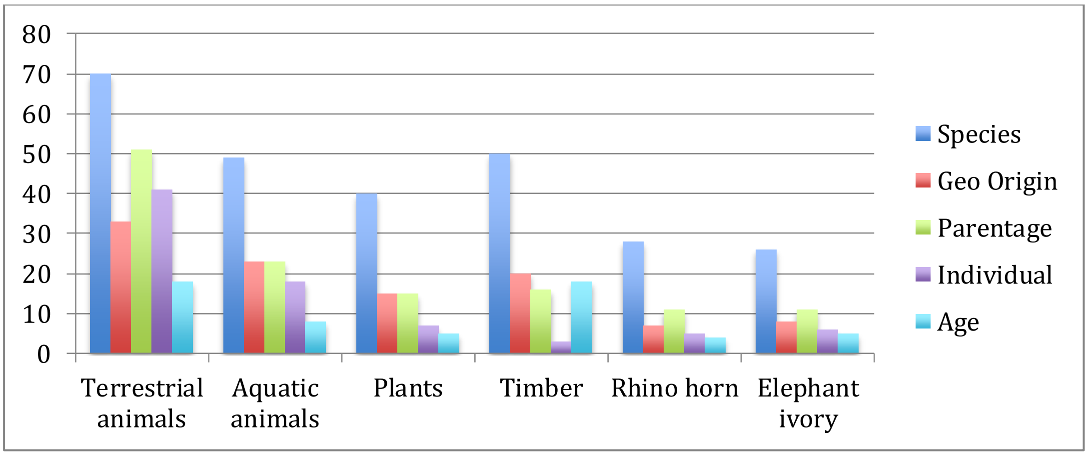

Figure 4a Investigative questions across taxonomic groups

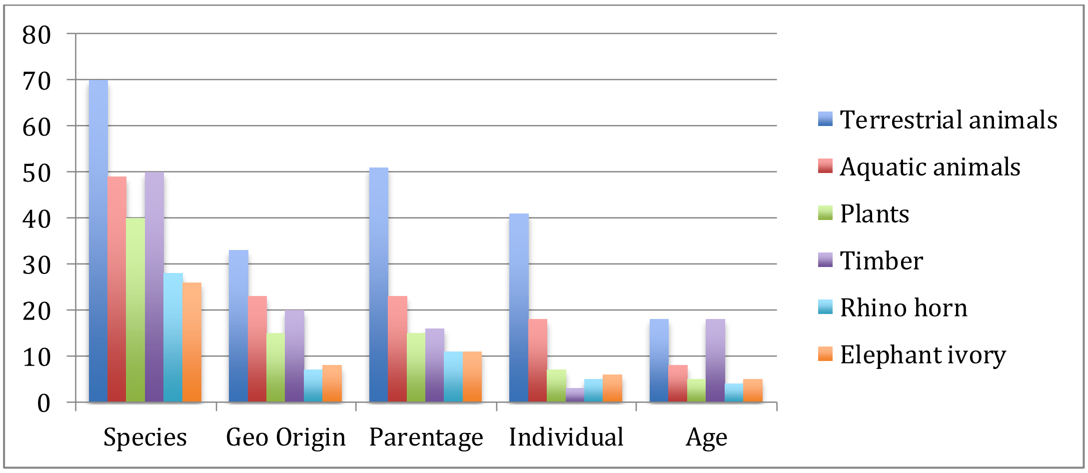

Figure 4b Taxonomic groups analysed to address different questions.

Q5. Cooperation with other countries.

[Is your laboratory able to carry out wildlife forensic casework for other countries?]

A5. Positive responses were provided by 33% of laboratories (n=36). The majority of these appeared to relate the provision of analysis on an ad-hoc case-by-case basis, often to neighbouring countries, rather than the establishment of any long-term cross-border forensic services.

Q6. Reference materials.

[What type of reference materials does your laboratory use to characterise samples in casework? Internal physical samples; external physical samples; internally generated electronic data; externally generated electronic data.]

A6. Physical reference samples were held at 85% of laboratories, with external physical reference collection less frequently used (59%). The opposite trend was observed for electronic data, although the difference between internally generated data (58%) and externally generated data (69%) was smaller. Note that these separate categories are not mutually exclusive and one lab may make use of all four types of reference material.

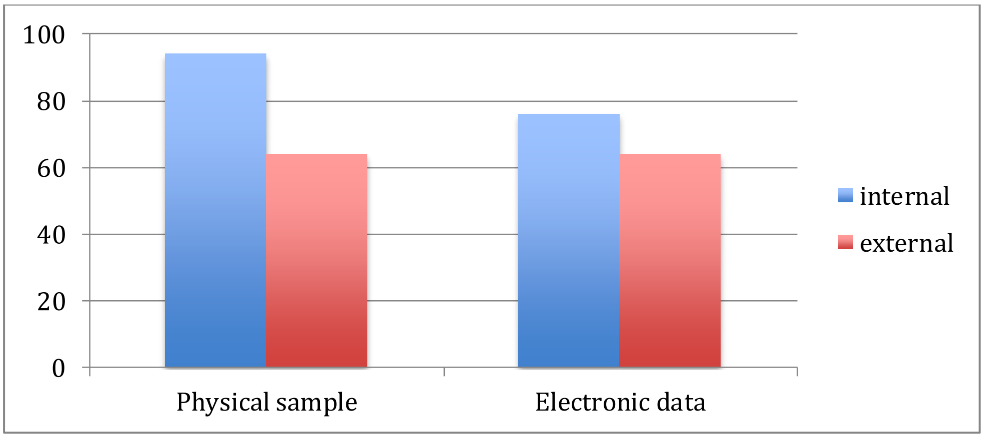

Figure 6 Types of reference material used in different laboratories

Q7. Quality Assurance.

[For casework, what Quality Assurance standards does your laboratory work to? How are you audited?]

A7. Fewer than half of the 110 labs included in the analysis (44%) could identify a Quality Assurance standard to which they operate. Of the remainder, 23 labs (21%) stated that they operated to a standard but could not state which, and 39 labs (35%) did not work to any standard at all.

Of the QA identified labs, 22 are externally audited under ISO17025, considered the gold standard for forensic science. Note that standards are not mutually exclusive, so for example, a single lab may be accredited under ISO9001 (quality management), ISO17025 (analytical testing) and adhere to SWGWILD standards; therefore the total number of responses exceeds 110.

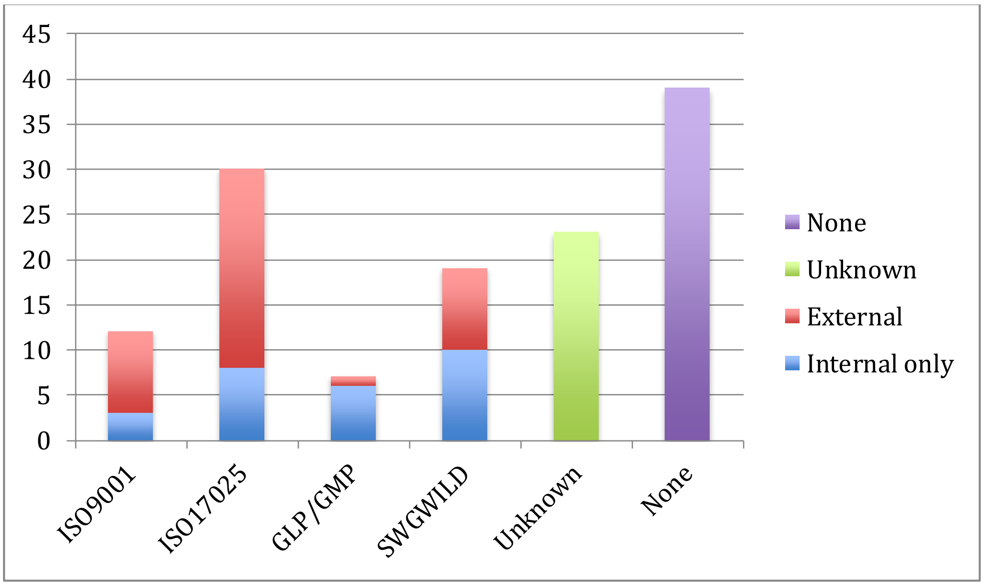

Figure 7 Type of QA standard operated by different laboratories. Labs that are subject to external audit ('External') will also be audited internally. 'Unknown' indicates labs that claim to work to a standard but did not state what that standard was.

Q8. Staff Training

a) Do staff receive training in forensic practice? Yes – 57%

b) Does the lab maintain a staff training record? Yes – 47%

b) Are staff certified to perform forensic casework? Yes – 36%

c) Do lab staff participate in regular proficiency testing? Yes – 38%

Q9. Future Plans.

[Are there plans for your laboratory to expand its capabilities in the next 3 years?]

Improving Quality Assurance Yes - 55%

Developing new techniques Yes – 70%

Increasing staff levels Yes – 41%

Other - answers included increased staff certification and lab collaboration

Elephant ivory (only laboratories providing contact details)

On the specific issue of elephant ivory identification, a total of 20 identifiable laboratories stated that they undertook forensic analysis of ivory samples. This included 10 using a morphological approach, 17 performing DNA analysis and 1 using radiocarbon dating. Across methods, 18 of 20 labs provide species identification, 6 provide geographic origin analysis, 8 provide individualization (sample matching), 5 provide parentage analysis and 5 labs provide estimates of age.

In total, 6 of 24 labs (identifiable and anonymous) operate under externally audited quality assurance schemes, with a further 3 labs stating that they operate under internally audited schemes. Seven labs answered positively to all staff training criteria.

The results raise a number of questions over the laboratory responses. There is a discrepancy between the number of labs conducting radiocarbon dating and those estimating age. This may be due to an alternative form of ageing, or due to a lab having established a service relationship with a separate radiocarbon dating facility. The answers to the geographic origin question suggest that different levels of geographic resolution are being included, likely ranging from continental (Asian/African) origin (essentially a species identification issue) through to relatively fine scale assignment to geographic origin within Africa.

Rhinoceros horn (only laboratories providing contact details)

In the case of rhino horn, a total of 19 identifiable laboratories stated that they undertook forensic analysis of horn samples. This included 9 using a morphological approach, 16 performing DNA analysis and 1 using radiocarbon dating. Across methods, 18 of 20 labs provide species identification, 4 provide geographic origin analysis, 8 provide individualization (sample matching), 4 provide parentage analysis and 3 labs provide estimates of age.

In total, 6 of 24 labs operate under externally audited quality assurance schemes, with a further 5 labs stating that they operate under internally audited schemes. Seven labs answered positively to all staff training criteria.

d) Discussion and Conclusions

Number of active wildlife forensic laboratories

The scale of the survey response, with 110 results received from 39 countries distributed across all CITES regions, provides a good indication that the results obtained are representative of the current situation regarding global wildlife forensics capacity. While it is possible that some laboratories may have not had the opportunity to participate in the survey, it is considered unlikely that these are heavily involved in forensic casework to support CITES enforcement at this time, due to the extensive international network of contacts used to identify laboratories, and the international reach of the CITES Notification. Subsequent updates of this database should achieve full lab representation.

The questionnaire was designed to distinguish between labs undertaking forensic casework from those simply conducting research to support the development of new techniques applicable to forensic analysis. However, it was clear from a number of the responses that this distinction is not necessarily understood by some of the laboratories, as the responses from several were contradictory on this issue. This may be due to the language used in the survey, or because some research labs do not fully appreciate the distinction between research and forensic practice. The latter explanation remains a concern within the wildlife forensic community (see subsequent sections) and is an area that will be informed by the detailed results of this survey.

Regardless of the total number of responses, an estimate of the number of active wildlife forensic laboratories should take into account whether or not the lab operates a Quality Assurance (QA) system, which is fundamental to forensic practice. Of the 74 labs with a history of conducting casework, 30 were unable to identify a quality assurance standard to which they operate. A further 11 lab respondents indicated that a QA system was in place but were unable to state what standard was being followed, which does raise questions about the accuracy of the response. This would indicate that the maximum number of forensic casework labs that may be operating to a minimum level of quality is 41, of which 23 are subject to an external audit of their testing procedures.

This analysis results in a fairly severe reduction in the number of labs available to conduct forensic analysis to support CITES enforcement. However, it should be noted that standardization and implementation of formal QA procedures in wildlife forensic science is in its relative infancy and many laboratories are in the process of addressing this issue, as indicated by 'future plans' provided by respondents. It is anticipated that the number of labs achieving the appropriate level of quality assurance will grow steadily over the next five years.

Scope of investigative questions and taxa that can be addressed

The most common wildlife forensic application was species identification, with more labs providing identification of terrestrial animals than any other taxonomic category. This result reflects the investigative drivers (species ID is the most commonly asked question), the body of background reference data (greater for animals than plants), the technical complexity of the test and the fact that species identification methods are typically generic and applicable across multiple taxa. This is in contrast to parentage, individual and geographic origin identification methods that are typically species specific, requiring much greater laboratory investment to develop and maintain.

Analytical methods were dominated by DNA and morphology, with preference for DNA methods in animals and morphological approaches to plant and timber identification. This is probably due in part to the technical difficulties encountered when conducting DNA analysis from wood. The relative lack of chemical profiling and stable isotope work is likely to reflect both the level of forensic method development for these techniques, for which fewer validation studies have been conducted, and the limited availability of equipment in forensic laboratories, as opposed to research labs.

The results for laboratory capacity to age samples were somewhat ambiguous. No specific option was provided in the survey for radiocarbon dating, and different radiocarbon dating labs appeared to categorize themselves under 'chemical profiling', 'stable isotope' or 'other' in the survey. This should be addressed in future versions of the survey. The current results indicate that between 5 and 10 labs are capable of radiocarbon dating of animal products. A similar number apparently estimate age from sample morphology, or for timber, dendrochronology (tree ring analysis). While radiocarbon dating is never likely to be available in every country, it is infrequently required and with sufficient communication and organization there should be sufficient global capacity to support CITES-related casework.

Wildlife forensic capacity in relation to priority taxonomic groups

The analytical capacities for ivory and rhinoceros horn are very similar with only six labs operating forensic testing under external audited quality systems for these species groups. Nevertheless, a further 18 laboratories surveyed provide analysis of ivory and rhino horn and many of these operate or are developing internal quality assurance schemes, which indicates capacity growth in this area.

For timber, seven of 26 practicing casework labs have stated that they have external accreditation (some will overlap with rhinoceros and elephant above), although it is not certain that all of these claims are entirely accurate. Capacity for applications within species (geographic origin, parentage, individualization) will certainly be restricted to relatively few target species per laboratory.

A detailed analysis of individual laboratory capacity is beyond the scope or remit of this review, however the results do help to identify which laboratories are working on elephant ivory, rhinoceros horn and timber. Taken together with documents such as the recent ivory and timber analysis guidelines developed by UNODC in cooperation with ICCWC, the survey results will enable enforcement agencies to better understand issues relating to the forensic identification of these high values wildlife products.

Part 6. Future Areas of Development in Wildlife Forensics

Opportunities exist to develop many different aspects of wildlife forensic science. Development within the field is often associated with novel technologies or applications. However, while these are usually welcome, it is often more fundamental issues such as the availability of reference materials and staff training that are more urgently required. This section briefly describes the main areas of wildlife forensics in terms of their potential for development, before suggesting some recommendations for how these might be prioritized.

a) Potential areas for development

1. Species methods

Besides a few generic techniques, such as DNA species identification and radiocarbon dating, the majority of wildlife forensic applications are species specific. The huge range of potential target species means that there is an almost endless number of new methods or population datasets that could be developed for CITES-listed species and their lookalikes. Identifying priority species to target for new method development is important to maximize the impact of resources spent in this area.

While a great deal of background research on species methods can be delivered, or may already be available, through the academic science community, the transfer from research to forensic application requires the performance of validation studies; an area that receives relatively little attention or traditional research funding. There is a real need for greater resources to be given to the transfer of existing research into practical forensic applications.

2. Reference resources

Wildlife forensics is hugely reliant upon the use of reference materials and reference data. For some groups of taxa, there is simply not enough taxonomically verified reference material available to develop or apply forensic methods, and for these species (e.g. many timbers), new reference collections are required. However the creation of new reference material collections is often impractical due to the rarity of the target species and their protected status. At a global scale, existing collections will often have the potential to meet the needs of the wildlife forensic community. The challenge lies in identifying and coordinating shared use of such collections, either through sample exchanges or scientific collaboration. Raising awareness of the potential role and responsibility of natural history collections to support CITES enforcement, as well as fundamental research, would be an important first step towards increasing access to reference materials.

3. Technologies

Technological advancement continues to offer new possibilities for forensic science. For certain CITES-listed species there would be significant advantages to be able to identify traded wildlife with greater speed, precision and accuracy than is currently possible. Novel technologies, such as 'electronic noses' for chemical identification of wildlife products, also have the potential to increase access to analytical testing such as point-of-use technologies at border inspection posts or crime scenes. Initiatives such as the Wildlife Tech Challenge[20] have provided drivers for technologists to examine potential wildlife forensic applications and it is important that innovation in wildlife forensic science continues.

There are also a few cautionary notes to consider in the development of novel technologies for wildlife forensics. First, forensic science by its very nature tends to be based on established, tried and tested technologies. It is necessary to have a clear understanding of the limitations and robustness of any equipment or method used to generate forensic evidence and this is usually based on years of collective experience gained in a research environment. Second, technology transfer from research to application can be expensive and is normally funded by commercial organisations looking for a return on their investment. Wildlife forensic and conservation applications do not normally offer any realistic prospect of a financial return, requiring alternative funding models to be developed for tech transfer. Where investments are made by the conservation community, it is vital that a comprehensive and realistic cost-benefit analysis is incorporated into the funding decision. Third, while often presented as a compelling solution to a particular CITES enforcement issue, it is vital that any novel technology is critically examined all the way through to its potential forensic application and inevitable courtroom challenge. A lack of understanding of forensic science and detailed enforcement needs from early stage technology developers can lead to a great deal of effort and resources being wasted on solutions that never had any real prospect of being applied. Good communication between all stakeholders involved in the development and use of new wildlife forensic technologies should ensure that the benefits to CITES-enforcement are maximized.

4. Infrastructure

The creation of laboratories and purchase of new equipment represent significant investments in national or international wildlife forensic programmes. The construction of a dedicated wildlife forensics facility provides not only a scientific centre for performing forensic analysis, but can also act as a catalyst to a country's entire wildlife law enforcement efforts. In the past five years laboratory facilities have been developed in many countries, for example in Southeast Asia (Malaysia, Thailand, Viet Nam) and Africa (Botswana, Kenya,

[20] www.wildlifecrimetech.org

South Africa) and more are planned. It can be argued that there is still insufficient capacity for conducting wildlife forensic casework, particularly in regions with the greatest need for the identification of CITES-listed species in trade. However the most appropriate solution is certainly not for every country to have its own dedicated laboratory. Many countries lack appropriate scientific, enforcement and judicial structures required to support the production and use of forensic evidence. Until these are available, the establishment of a wildlife forensic facility would be premature and have little or no impact. Furthermore, there is insufficient casework demand at present to justify a lab in every country. A number of alternative models have been considered (Ogden 2010) including a system of regional hub facilities providing forensic services to local neighbouring countries. The current UK-funded African Wildlife Forensics Network Project run by UNODC and TRACE is attempting to develop such an approach in southern Africa that should help to maximise access to the wildlife forensic resources in the region.

Overall, new infrastructure remains an important component of any plan to develop international wildlife forensic capacity, but the timing, specifications and remit of any new facility should be considered very carefully within a wider law enforcement framework at least at a national level, and ideally internationally as well.

5. Staff Training

Forensic scientists require training and expertise in their particular scientific discipline and in the general practice of forensic science. In service training and ongoing professional development are also important aspects of forensic science and are usually requirements of laboratory accreditation schemes. While awareness-raising and basic training can be delivered via short-term workshops and courses, training a graduate research scientist to become a capable, confident wildlife forensic practitioner can take many years.

The provision of ongoing training and support to newly established and emerging wildlife forensic facilities is a key issue in international wildlife forensic science capacity building.

There are a number of challenges facing the delivery of wildlife forensic training, beyond simple funding requirements. In relatively new forensic laboratories, there is often significant pressure to undertake casework and deliver results before sufficient training has been completed, potentially exposing inexperienced wildlife forensic scientists to operating beyond their field of expertise. The time available for additional professional training on an annual basis may also be extremely limited. In situations where academic researchers become involved in forensic science, there may not even be a realization that training is required, as the step-change from research to forensic analysis is not appreciated. Lastly, there is very little global capacity to provide wildlife forensic training, due to a lack of experienced wildlife forensic scientists with the time to be engaged on comprehensive training programmes.

None of these challenges is insurmountable and with appropriate support from senior management, a combination of training courses, secondments and scientific exchanges should deliver the necessary training required in most cases. It is noted from the survey responses described in Part 5 that almost all laboratories conducting forensic casework recognize the need for further staff training; prioritizing and resourcing this area is the next step.

Related to staff training, the issue of staff retention is also very important. Many of the newer laboratories around the world are based at government institutions and have been staffed by young, well-qualified, motivated science graduates for whom there are relatively few opportunities for promotion within the wildlife forensic field in their country. This has led to high levels of staff turnover, which in the absence of succession planning has led to previous training investments being lost. The development of human resource capacity in international wildlife forensics should include policies for longer-term retention of expertise.

6. Forensic Standards and Quality Assurance (QA)

Significant advances have been made over the past five years in defining minimum standards applicable to performing a range of analyses for wildlife forensic casework. In parallel, proficiency testing and practitioner certification schemes have also been developed by the Society for Wildlife Forensic Science. All of these initiatives require much broader dissemination and take-up in order to address the very patchy distribution of QA systems that was observed in the survey. There are an alarming number of laboratories that claim to perform forensic casework with either no QA systems, or 'unknown' QA systems in place, which represents a serious issue in relation to evidence admissibility and ultimately the development of global wildlife forensic capacity.

It is the responsibility of each laboratory and its parent institution to ensure that a suitable quality system is in place to ensure the delivery of robust evidence and demonstrate this to the satisfaction of the court. However, supporting laboratories to achieve this through the roll-out of international standards, proficiency, certification and audit schemes is an area where the international community can significantly contribute to the development of global forensic capacity.

7. Communication, awareness raising and stakeholder engagement

Wildlife forensic analysis does not occur in isolation, but as an integral part of a criminal investigation. Any wildlife trafficking case will involve at least one enforcement agency and, if the case proceeds, the public prosecutor and national judiciary. For forensic analysis to be effective, it requires close operational cooperation between the laboratory and investigating agencies as well as a broad understanding on the part of all stakeholders as to what wildlife forensic science can offer and how evidence needs to be handled. The majority of countries suffering most from the illegal wildlife trade are relatively inexperienced in using forensic science of any sort and therefore to fulfill the potential that wildlife forensics has to offer, it is important to raise awareness of the forensic science and educate investigators and the legal profession. This has long been recognized by many organizations involved in developing wildlife forensics capacity and consequently ongoing programmes in Southeast Asia and Africa specifically include activities that foster inter-agency relationships and providing training and materials tailored to non-scientific stakeholders. Similarly, the ICCWC guideline documents on the analysis of ivory and timber explicitly target investigators, scientists and the legal profession, as three equally important target audiences.

Such work needs to continue and expand if wildlife forensics is to succeed in significantly enhancing prosecution rates and ultimately raise the risk of prosecution in the eyes of wildlife traffickers.

b) Prioritizing areas for development

The seven areas of potential development described above indicate the breadth of challenges facing the discipline and the range of opportunities for improvement programmes. Finite resources necessitate a process of prioritization; designing this process itself is arguably one of the most urgent needs. Attempting to identify priority development objectives is beyond the scope of this review, however it is worth considering briefly at this stage the criteria that should govern such a process. Prioritisation should be:

i) Enforcement driven. Forensic science is an applied discipline and the overriding purpose of any development activity should be to improve the ability of forensic science to support law enforcement. This means that resources should be prioritized towards identifiable and justifiable needs, either within the forensic science community (e.g. training, reference materials) or the enforcement community (e.g. addressing an investigative question).

ii) Quality assured. If minimum standards and validation criteria are not being met by a laboratory conducting forensic casework then any investment in a novel technique or piece of equipment is essentially a waste of resources.

iii) Economical. The choice between funding one large scale single-species project versus several multi-species projects; or whether to support basic training in an established technique versus research and development into a novel concept, require careful consideration. The 'Return on Investment' in this instance is likely to be a complicated measure that includes outcomes on different temporal scales, the prioritization of species conservation objectives, enforcement priorities and the impact that a forensic solution will have on any one issue. What is clear is that to date there has been relatively little overarching analysis of the benefits of one development proposal over another, resulting in uncoordinated funding decisions that have not always represented good value nor delivered priority goals. Analysis of cost-benefit should be included in the prioritization process.

Acknowledgements

This review was made possible by the survey participants who took the time to complete the questionnaire, and the feedback received is highly appreciated. The authors would also like to thank Trey Knott (NOAA) and other members of the Society for Wildlife Forensic Science for assistance with survey design and testing.

Annex 1 CITES notification and questionnaire (English)

CONVENTION ON INTERNATIONAL TRADE IN ENDANGERED SPECIES
OF WILD FAUNA AND FLORA

NOTIFICATION TO THE PARTIES

No. 2015/061 Geneva, 20 November 2015

CONCERNING:

Global forensic capacity to address illegal trafficking in wildlife

1. At its 16th meeting (CoP16, Bangkok, 2013), the Conference of the Parties adopted the Decision 16.78 on *Monitoring of illegal trade in ivory and other elephant specimens (Elephantidae spp.)* of which paragraph b) states that the Secretariat shall:

   b) examine and advise about existing DNA-based and forensic identification techniques for sourcing and ageing ivory, identify relevant forensic facilities and research institutions, and consider the need for further research in these areas;

2. At its 65th meeting (SC65, Geneva, July 2014), the Standing Committee in relation to document SC65 Doc. 42.1 on *Elephant conservation, illegal killing and ivory trade*, endorsed Recommendation f) in document SC65 Com. 7 as follows:

   f) request the Secretariat to compile a list of appropriate forensic-analysis facilities capable of reliably determining the age or origin of ivory, or both, for distribution to the Parties;

3. In Resolution Conf. 11.3 (Rev. CoP16) on *Compliance and enforcement*, under *Regarding additional actions to promote enforcement*, the Conference of the Parties recommends that Parties:

   i) promote and increase the use of wildlife forensic technology . . ., in the investigation of wildlife crime offences;

4. A number of other decisions adopted at CoP16 encourage the increased use of forensic analysis to support the implementation and enforcement of CITES. These include among others Decisions 16.84 paragraph d) and 16.89 paragraph b) on *Rhinoceroses (Rhinocerotidae spp.)*, Decision 16.102, paragraph b) on *Snake trade and conservation management (Serpentes spp.)* and Decision 16.136 paragraph a) i) on *Sturgeons and paddlefish (Acipenseriformes spp.)*.

5. To promote and increase the use of wildlife forensic science in the investigation of wildlife crime offences, the CITES Secretariat, in cooperation with the United Nations Office on Drugs and Crime, will undertake a global review of laboratory capacity, in close cooperation with the Society for Wildlife Forensic Science. This work will not only be of benefit in the context of elephants, but also for combating other wildlife crimes more effectively. The purpose of this work is to identify facilities involved in the development or application of identification techniques, in a forensic context, to support law enforcement and to combat illegal trafficking in CITES-listed species.

6. To ensure that a comprehensive review is conducted and to facilitate the provision of information, a questionnaire was prepared which is contained in the Annex (in English only) to the present Notification. The Secretariat invites all Parties to disseminate the questionnaire to any forensic facilities and research institutions that may exist within their territories. The questionnaire is intended to be completed directly by these forensic facilities and research institutions. It can be completed and submitted online at **https://www.surveymonkey.com/r/wildlifeforensics** (in English only), or submitted to the Secretariat via email at info@cites.org.

International Environment House • Chemin des Anémones • CH-1219 Châtelaine, Geneva • Switzerland
Tel: +41 (22) 917 81 39/40 • Fax: +41 (22) 797 34 17 • Email: info@cites.org • Web: http://www.cites.org

7. The information submitted by individual facilities and institutions through the questionnaire will remain confidential and no information will be made public without prior consultation and explicit consent from such facilities and institutions. The submitted information will be used as a first step in conducting the global review of forensic capacity to address illegal trafficking in wildlife, and further consultations with facilities and institutions that submitted completed questionnaires will be conducted as part of this review.

8. Completed questionnaires should be submitted to the Secretariat no later than 31 December 2015.

Notification to the Parties No. 2015/061
Annex (in English only)

GLOBAL FORENSIC CAPACITY TO COMBAT ILLEGAL TRADE IN WILDLIFE

The questionnaire can be completed online and submitted online at https://www.surveymonkey.com/r/wildlifeforensics or submitted to the Secretariat via email to info@cites.org. Parties are requested to submit completed questionnaires no later than 31 December 2015.

1. Has your laboratory ever carried out a test that has been used as evidence in a court of law during a wildlife crime investigation? YES ☐ NO ☐ DON'T KNOW ☐

2. Casework / Research. Does your laboratory carry out research or legal casework for the types of biological materials listed? Please tick all that apply.

	Casework	*Research*	*Neither*
Terrestrial animal	☐	☐	☐
Aquatic animal	☐	☐	☐
Plant	☐	☐	☐
Timber	☐	☐	☐
Rhinoceros horn	☐	☐	☐
Elephant ivory	☐	☐	☐
Other (please specify)			

3. Techniques. Please tick the casework techniques used in your laboratory for each of the sample types listed.

	Morphology/ Anatomy	*DNA analysis*	*Immunoassay*	*Chemical profiling*	*Stable Isotopes*
Terrestrial animal	☐	☐	☐	☐	☐
Aquatic animal	☐	☐	☐	☐	☐
Plant	☐	☐	☐	☐	☐
Timber	☐	☐	☐	☐	☐
Rhinoceros horn	☐	☐	☐	☐	☐
Elephant ivory	☐	☐	☐	☐	☐
Other (please specify)					

4. Applications. For wildlife crime investigations, which identification questions can your laboratory address? Please tick all that apply.

	Species	Geographic Origin	Individual	Parentage	Age	None
Terrestrial animal	☐	☐	☐	☐	☐	☐
Aquatic animal	☐	☐	☐	☐	☐	☐
Plant	☐	☐	☐	☐	☐	☐
Timber	☐	☐	☐	☐	☐	☐
Rhinoceros horn	☐	☐	☐	☐	☐	☐
Elephant ivory	☐	☐	☐	☐	☐	☐
Other (please specify)						

5. Cooperation with other countries. Is your laboratory able to carry out wildlife forensic casework for other countries? YES ☐ NO ☐
If yes, please specify:

6. Reference materials. What type of reference materials does your laboratory use to characterise samples in casework? Please tick all that apply.

Physical sample authenticated at your lab	☐
Physical sample authenticated by a 3rd party	☐
Electronic data generated at your lab	☐
Electronic data obtained from an external database	☐

7. Quality Assurance. For casework, what Quality Assurance standards does your laboratory work to? How are you audited? Please tick all that apply.

Audit:	External audit	Internal audit
ISO 9001	☐	☐
ISO 17025	☐	☐
GLP/GMP	☐	☐
SWGWILD	☐	☐
Don't know	☐	☐

None/ research only (please specify)

8. Staff training for forensic casework (if no casework is performed, tick N/A)

	Yes	**No**	**N/A**
a) Do staff receive training in forensic practice?	☐	☐	☐
b) Does the lab maintain a staff training record?	☐	☐	☐
b) Are staff certified to perform forensic casework?	☐	☐	☐
c) Do lab staff participate in regular proficiency testing?	☐	☐	☐

9. Future plans. Are there plans for your laboratory to expand its capabilities in the next 3 years? Please tick all that apply

Improving Quality Assurance	☐
Developing new techniques	☐
Increasing staff levels	☐

Other/ further information:

10. Contact details
Institute name:
Address:
Principal contact:
Role:
Email:
Telephone:

Thank you for completing this survey. Please email the completed version to info@cites.org

Annex 2 List of countries who supplied survey responses

Note: Not all responses could be included in the data analysis due to incompleteness

CITES Region	Country
Africa	Botswana
	Cameroon
	Kenya
	Liberia
	South Africa
Asia	China
	Hong Kong
	India
	Japan
	Malaysia
	Philippines
	Thailand
	Vietnam
Central and South America and the Caribbean	Brazil
	Cayman Islands
	Chile
	México
Europe	Austria
	Czech Republic
	Denmark
	France
	Germany
	Greece
	Hungary
	Israel
	Italy
	Lithuania
	Netherlands
	Portugal
	Romania
	Russian Federation
	Spain
	Sweden
	Switzerland
	Turkey
	United Kingdom
North America	Canada
	United States of America
Oceania	Australia

Annex 3 Technical considerations in questionnaire design

Questionnaire length was capped at ten questions and the number of compulsory questions was kept to a minimum to maximise completion rates (Brace, 2008; De Vaus, 2002; QB2), and categories such as type of sample (for example, terrestrial animal, aquatic animal, plant, and timber) were always presented in the same order to minimise human error and maximise data validity (QB4); the question order was designed such that a generic and simple question on the topic of wildlife forensics was presented first, in order to get users focused on the topic while avoiding giving away any sensitive information before they had 'settled into' the process (Brace, 2008); similarly, contact and demographic details were left to last; questionnaire wording was kept simple, and acronyms and complex technical terms avoided to cater for users whose first language was not English (De Vaus, 2002; QB4). Issues such as social desirability bias (Fisher, 1993; De Vaus, 2002) (wishing to 'look good' or at least avoid looking inadequate) were hard to counter and to check for because internal quality check questions were not possible given the brevity of the questionnaire. However, it was assumed that most participants were professionals who would have no need to exaggerate their capabilities. Finally, most questions were closed questions, in order to elicit clear, valid and quantifiable data (see for example Brace, 2008), but some open-ended questions with free text fields were included where more detail was required.

References

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