Chapter Eleven

Forensic DNA Evidence and Wildlife Trafficking

Rory McFadden

This chapter explains and discusses the role of wildlife DNA as forensic evidence. It suggests that wildlife DNA evidence is a valuable tool in the investigation and prosecution of wildlife trafficking offences, although as a field it faces particular challenges that may affect its resilience in the courtroom. For this reason, and considering recent trends towards greater scrutiny of forensic sciences as evidence, this chapter argues that wildlife DNA scientists should be prioritising adherence to the external quality standards most palatable by the court.

Table of Contents

 https://doi.org/10.24921/2020.94115945.11

I. Introduction

In contrast to most crime types, the most common question in wildlife trafficking cases is not who has committed the crime, but whether a crime has occurred at all.[1] This question can be complicated because of the types of evidence typical of wildlife trafficking crime scenes, which can make it difficult to identify animals, parts or derivatives as belonging to a certain protected group. Where morphological or other identification methods fail, the forensic analysis of wildlife DNA (desoxyribonucleic acid) can be a useful tool to discover information about the animal, and ultimately determine whether the animal has in fact been trafficked.

Despite its usefulness, forensic wildlife DNA forensics as a science remains somewhat in its infancy, and relatively niche.[2] For this reason, it may be more difficult for wildlife DNA evidence to demonstrate adherence to quality standards expected by the courtroom, and consequently to resist legal challenge. Currently, it is unclear whether and to what extent wildlife DNA evidence is rejected in court or not tendered at all; however, if the goal is to successfully prosecute more perpetrators under wildlife trafficking legislation, it is important that wildlife DNA forensics develops in step with trends and changes in evidence law.

1 M Katherine Moore and Irving L. Kornfield, 'Best Practices in Wildlife Forensic DNA' in Jane E Huffman and John R Wallace (eds), *Wildlife Forensics: Methods and Applications* (2012) 202, 203.

2 John R Wallace and Jill C Ross, 'The Application of Forensic Science to Wildlife Evidence' in Jane E Huffman and John R Wallace (eds), *Wildlife Forensics: Methods and Applications* (2012) 35, 36 – 37.

The available literature regarding wildlife DNA forensics is largely authored by practitioners and aimed at the wildlife forensics community.[3] Many sources contain detailed and technical discussions about best practise and standards internal to wildlife forensics as a science. However, few outline the external standards of the courtroom, which inform the admissibility and assigned probative weight of all types of forensic evidence. Increasingly, courts expect tangible evidence of how reliable a forensic method is, especially where that method is novel or uncommon.

The aim of this chapter is to discuss the function of wildlife DNA as forensic evidence in the investigation and prosecution of wildlife trafficking offenders, and recommend, from a legal perspective, which developments should be prioritised in order to strengthen wildlife DNA as a forensic tool.

Part II of this chapter introduces and explains the basic function of DNA as a forensic science, both in the human crime context and the less familiar wildlife trafficking context. Part III discusses broadly the legal frameworks in place that permit and regulate the use of forensic science as evidence in the courtroom, and outlines some relevant criticisms and trends within this field. Part IV describes some of the methods used by forensic scientists in preparing wildlife DNA evidence. Part V outlines the various forensic applications of wildlife DNA, and part VI looks at particular challenges faced by wildlife forensic scientists in bringing DNA evidence into the courtroom. Part VII discusses possible future directions of wildlife DNA as a robust and reliable forensic science.

3 See, for example, Jane E Huffman and John R Wallace (eds), *Wildlife Forensics: Methods and Applications*, (2012); Brandt Cassidy and Robert Gonzales, 'DNA Testing in Animal Forensics' (2005) 69 *Journal of Wildlife Management* 1454; Arati Iyengar, 'Forensic DNA analysis for animal protection and biodiversity conservation: a review' (2014) 22 *Journal for Nature Conservation* 195; Adrian Linacre and Shanan Tobe, *Wildlife DNA Analysis: Applications in Forensic Science* (2013); Bruce Budowle et al, 'Recommendations for animal DNA forensic and identity testing' (2005) 119(5) *International Journal of Legal Medicine* 119.

II. Scientific background and context

1. DNA

Deoxyribonucleic acid, or 'DNA', is present in the cells of almost every living being. DNA contains sections called 'genes', the structure and sequence of which make up each individual's 'genetic profile'.[4] Genes are, essentially, pieces of code passed down from an individual's parents which contain the requisite instructions for how that individual will develop, function, and reproduce as an organism.[5] Hence, DNA contributes to observable characteristics, such as height and colouring.[6]

An individual's genetic profile stays the same over their lifetime, but genetic profiles vary between all individuals except identical siblings.[7] In humans, about 0.1 % of DNA is different from person to person.[8] This variation makes DNA useful as a forensic science because it can be used to identify or exclude perpetrators and victims from biological material found at crime scenes. In general, DNA provides a significant amount of information about a relevant individual compared to other evidence types. The process of extracting this information is called 'DNA profiling', or 'DNA barcoding'.

2. Defining wildlife DNA

The distinction between human and non-human DNA is not dichotomous. Humans are just one of hundreds of thousands of species on the planet whose DNA may be used for the purposes of investigation. That said, human DNA has been the main focus of DNA forensics since its conception.[9] Forensic practitioners who analyse human DNA have an

4 Peter Cobb, cited in Peter White (ed), *Crime Scene to Court – The Essentials of Forensic Science* (1998) 305; Katherine Cashman, *Lawyers and DNA: Understanding and Challenging the Evidence*, PhD Thesis, The University of Tasmania (2017) 47.

5 Andrei Semikhodskii, *Dealing with DNA Evidence: A Legal Guide* (2007) 3.

6 Ibid 8, 12.

7 Melissa Kidder, 'Human DNA v. Non-Human DNA: A Look at the General Admissibility of Non-Human DNA in the Courts' (2009) 35 *Ohio Northern University Law Review* 397, 399; Semikhodskii (n 5) 8, 12.

8 Kidder (n 7) 399.

9 Ibid 397 – 399.

extensive and detailed appreciation of the entire human genome, which has been meticulously studied, mapped and validated over several decades. It is so well understood, human DNA may even be analysed using widely available and inexpensive commercial 'kits'.[10] A comparatively moderate amount of research has gone into wildlife DNA.

Not only is wildlife DNA forensics nowhere near as developed as its human counterpart, instead of just one species, it encompasses at least the 7,500 species considered endangered or critically endangered on the International Union for Conservation of Nature's (IUCN) *Red List of Threatened Species.*[11] The same lengthy process must be repeated to map out the genome of each new species of interest.[12]

Furthermore, human DNA evidence is much more broadly and frequently employable as evidence in criminal proceedings, since all crime types involve humans, and few involve animals. Crimes which victimise animals are generally regarded as lower priority in comparison to crimes against people and property.[13]

3. DNA analyses

3.1. DNA profiling

A sample of DNA from a known individual may be linked to, for example, a blood stain at a crime scene based on whether the two profiles are identical or not. This is referred to as an exclusionary test, since there is no chance that the profiles came from the same individual if they are not identical. However, if the profiles are identical, there is still an extremely small chance that it is a coincidence. The average probability that two unrelated profiles will randomly match is, theoretically, one in several billion. As such, this analysis comes with a high degree of certainty.[14]

---

10 Moore and Kornfield (n 1) 205.

11 IUCN, 'IUCN Red List of Threatened Species' (Web page, undated).

12 See Robert Ogden, 'Forensic science, genetics and wildlife biology: getting the right mix for a wildlife DNA forensics lab' (2010) 6 *Forensic Science, Medicine and Pathology* 172, 172.

13 Ibid.

14 Kidder (n 7) 397; Semikhodskii (n 5) 22, 49, 108 – 24.

3.2. DNA barcoding

Wildlife DNA is often concerned with matching samples to their 'taxa', the pre-defined groups to which animals belong, rather than to an individual. Because of the hereditary nature of DNA, the DNA profiles of closely related individuals tend to have a high degree of similarity, while more distantly related samples will generally show more dissimilarity. This is because diversity between organisms is caused by genetic mutations occurring over time.[15] The less immediate the relationship between two individuals, the more inherited changes may have accumulated over the course of their respective ancestors descending from their most recent common ancestor.[16] The taxa of the individual, such as family, population or species, are identifiable with reference to particular portions of DNA which are shared with other members of any given taxon, and distinguishable with reference to those portions which vary between them.

By comparing sections of genes known to be shared by all members of a certain taxon, practitioners can infer whether an unknown sample is a part of that group. Before this is possible, the particular section of a gene or number of genes which is both exclusive and common to all members must be identified. This requires extensive examination of samples, called 'reference data', from the relevant taxon to form a 'control population'. The greater the size and diversity of the control population, the more statistically certain it is that the unknown sample is or is not part of the group.[17] The fewer the reference samples, the less conclusive the inference can be.

3.3. Forensic DNA evidence

Criminal justice systems routinely employ DNA analyses as forensic evidence.[18] Generally, DNA profiling is considered to have a sounder

15 George Sensabaugh and D H Kaye, 'Non-Human DNA Evidence' (1998) 39(1) *Jurimetrics* 1, 15.

16 Hassan Ramadan and Nabih Baeshen, 'Biological identifications through DNA barcodes' in Gbolagade Akeem Lameed (ed), *Biodiversity Conservation and Utilization in a Diverse World* (2012) 109, 124 – 125.

17 Budowle et al (n 3) 296 – 298.

18 Semikhodskii (n 5) 1 – 2.

scientific basis than many other forensic techniques.[19] Forensic DNA evidence can be especially advantageous in the investigation of wildlife trafficking. As is discussed below, laws about wildlife trafficking necessitate that the animal in question belongs (or belonged) to a certain taxon which the relevant law seeks to protect. Proving this can be complicated. Seized wildlife and animal derivatives may not be susceptible to morphological or other methods of identification where the sample is, for example: partial; has been processed into a product; or, is in an immature state (such as an embryo).[20] In such instances, DNA barcoding can be useful, since only a tiny amount of any type of biological material is needed. Sometimes protected species have 'lookalike' unprotected species, or parallel legal markets allow trade in certain populations of the same animal. In those cases, DNA may be the only way to distinguish whether or not the particular sample is protected. Related wildlife crimes such as poaching almost always occur outdoors, where evidence is exposed and may decay. DNA is robust; a useable DNA sample may often be extracted from the types of decayed or chemically treated material typical of crime scenes.[21]

III. Legal bases

The form and severity of national wildlife trafficking legislation is ultimately left to individual legislatures. *CITES*, the *Convention on International Trade in Endangered Species of Wild Flora and Fauna*, provides an international framework that seeks to regulate trade in vulnerable species to sustainable levels.[22] For this reason, legislation regarding the protection of endangered species varies widely between jurisdictions, and national wildlife trafficking

19 United States, National Research Council, *Strengthening Forensic Science in the United States: A Path Forward* (2009) 7, 9.

20 Rebecca N Johnson, 'The use of DNA identification in prosecuting wildlife-traffickers in Australia: do the penalties fit the crimes?' (2010) 6 *Forensic Science, Medicine, and Pathology* 211, 211 – 212.

21 Shanan Tobe, James Govan and Lindsey Welch, 'Tackling poaching: Recovery of human DNA profiles from deer remains' (2011) 3 *Forensic Science International: Genetics Supplement Series* e265.

22 Opened for signature 3 March 1973, 993 UNTS 243 (entered into force 1 July 1975).

legislation can encompass a range of criminal behaviours. However, offences generally have the common element that the animal targetted is a member of a protected group.[23]

In defining protected animals, often legislation refers specifically to the *CITES* Appendices, which list some 5 000 animal species whose survival is immediately or potentially threatened by trade. Some jurisdictions include additional species, or provide their own list.[24] Hence the species, origin or individual from which a trafficked sample originates is always a material fact in wildlife trafficking cases.

Although admissibility rules about forensic evidence vary between jurisdictions, there is a fairly consistent approach regarding the standards and thresholds to which forensic evidence must adhere.[25] It is also possible due to the often transnational nature of wildlife trafficking that evidence being collected and prepared within one jurisdiction will be subject to standards set by another.[26]

1. Forensic evidence in the courtroom

1.1. Expert opinion evidence

Expert opinion evidence is admissible as an exception to the rule that witnesses may only give evidence about facts.[27] This opinion rule is generally in place to prevent reliance by the court on unsubstantiated or subjective information, which may prejudice the accused disproportionately to whatever probative value the opinion offers. Expert evidence is excepted because, occasionally, useful evidence is not susceptible to interpretation by a layperson; someone who is capable of its

23 UNODC, *Wildlife and Forest Crime Analytic Toolkit* (rev ed, 2012) 23; Tanya Wyatt, *Wildlife Trafficking: A Deconstruction of the Crime, the Victims and the Offenders* (2013) 106.

24 For example, *Wildlife (Protection) Act 1972* (India) and *Royal Decree for Wildlife Preservation and Protection B.E. 2535 1992* (Thailand).

25 Gary Edmond et al, 'Admissibility Compared: The Reception of Incriminating Expert Evidence (i. e., Forensic Science) in Four Adversarial Jurisdictions' (2013) 3 *University of Denver Criminal Law Review* 31, 31.

26 UNODC (n 23) 34.

27 Craig Adam, *Forensic Evidence in Court: Evaluation and Scientific Opinion* (2016) 2 – 4; Edmond et al (n 25) 33.

interpretation and explanation must give a conclusion based on his or her own expertise. DNA analysis falls into this category.[28]

When the court accepts this type of evidence, it has limited scope to assess its quality. This is because experts make subjective decisions when forming an opinion which the court has no means to evaluate.[29] Since judges can only assess objective evidence, it is important that an enquiry is instead made into the scientific rigour of expert evidence on a case-by-case basis, at both a foundational and an applied level.[30]

1.2. Scientific rigour

In the most comprehensive case, an enquiry into scientific rigour would include an assessment of:

- Whether the discipline generally can provide the kind of information which it purports to (field validity);
- Whether the particular method used is capable of producing the conclusion it purports to (method validity);
- Whether the expert is competent at the method; ie:
    - o Whether he or she possesses the knowledge and skill necessary to employ the method generally (qualification); and,
    - o Whether he or she in fact employed the method competently in the given instance (execution).[31]

While not all admissibility rules address each of these points that can (and should) be expected of forensic scientists, weakness in any of the above aspects of scientific rigour can affect the value the decision-maker assigns the evidence, or form the basis for a legal challenge.[32]

28 United States, President's Council of Advisors on Science and Technology, *Forensic Science in Criminal Courts: Ensuring Scientific Validity of Feature-Comparison Methods*, Report to the President (September 2016), Executive Office of the President (US), September 2016) 1, 23.

29 Rachel Searston and Jason Chin, 'The legal and scientific challenge of black box expertise' (2019) 38(2) *University of Queensland Law Journal* 238, 246, 266.

30 United States, President's Council of Advisors on Science and Technology (n 28) 47 – 49.

31 Samuel Goss and Jennifer Mnookin, 'Expert Information and Expert Evidence: A Preliminary Taxonomy' (2003) 34 *Seton Hall Law Revue* 148, 146 – 149.

32 Edmond et al (n 25) 33.

1.3. Admissibility and weight

While admissibility refers to whether or not the evidence may be tendered at all, the weight of the evidence is its probative value, or the degree to which it should be factored into the verdict.[33] Statutes about admissibility and weight often employ terms such as 'formal qualifications', 'specialised knowledge', 'within a recognised field' and 'training, study and experience'.[34]

An assessment of some or all of these criteria, with empirical evidence supporting them, will inform the trial judge on how to handle the expert evidence. It may be that the judge is satisfied that the science is probative, foundationally valid, and accurately applied and admit it without issue; if not, he or she may discretionarily exclude it in its entirety. The judge may alternatively leave it to the opposing counsel to cross-examine the expert to reveal possible flaws in their assessment, or sometimes simply pick and choose which parts of the evidence meet the threshold and only admit those conclusions.[35] Finally, the judge may admit the evidence in its entirety, but take into account any uncertainty in deciding the weight to assign the evidence.

1.4. Criticisms and future directions

It should be noted that the law of expert opinion evidence, especially in relation to the forensic sciences, has been criticised in many jurisdictions for leniency in admitting and assigning weight to opinions without a thorough examination of the validity of the putative expert's field, methods and competence.[36] For example, courts have been criticised for assessing the weight of forensic evidence using criteria which are more

33 See generally Gary Edmond, 'Legal versus Non-Legal Approaches to Forensic Science Evidence' (2016) 20 *International Journal of Evidence and Proof* 3 – 28.

34 In the United States, scrutinising factors are outlined in *Daubert v Merrell Dow Pharmaceuticals Inc* 125 L Ed 2d 469, 595; in Canada, see *R v Mohan* [1994] 2 SCR 9; in Australia, see for example *Evidence Act 1995* (Cth) s 79. See generally Jason M Chin, 'Abbey Road: The (Ongoing) Journey to Reliable Expert Evidence' (2018) 9(3) *Canadian Bar Review* 422 – 459; Edmond et al (n 25) 31.

35 See, for example, *R v Abbey* (2009) ONCA [62]–[70].

36 See, for example, United States, President's Council of Advisors on Science and Technology (n 28); United States, National Research Council (n 19); Gary Edmond, 'What Lawyers Should Know About Forensic Sciences' (2015) 36 *Adelaide Law Review* 33, 34.

appropriate for assessing admissibility; that is, for allowing weaknesses in scientific rigour to go to the probative value of the evidence, rather than to the perhaps more appropriate question of whether to exclude the evidence entirely.[37]

This is not to imply that wildlife forensic scientists need not bother adhering to a high standard of scientific rigour just because 'most judges under most circumstances admit most forensic science'.[38] On the contrary, these criticisms may be predictive of the direction of expert evidence law generally, and indicative of higher standards courts may (and should) expect of forensic sciences going forward. Additionally, because of the transnational nature of wildlife trafficking as a crime type, experts in any one jurisdiction may be subject to the legal standards of another. This suggests that experts should aim to be operating at the highest standard possible.

IV. Methods

Generally, four different types of facility may undertake wildlife DNA barcoding: a multi-use research laboratory, a university forensics laboratory, a commercial DNA forensics laboratory, or, most rarely, a dedicated wildlife forensics laboratory.[39] Regardless of which of these laboratory types does the testing, strict forensic procedures should be adhered to.

37 Kristy Martire and Gary Edmond, 'Rethinking Expert Opinion Evidence' (2017) 40 *Melbourne University Law Revue* 967, 970; see generally Jason M Chin, 'Psychological science's replicability crisis and what it means for science in the courtroom' (2014) 20 *Psychology, Public Policy, and Law* 225 – 238.

38 Jane Campbell Moriarty and Michael J Saks, 'Forensic Science: Grand Goals, Tragic Flaws, and Judicial Gatekeeping' (2006) 44 *Judges Journal* 16, 28.

39 Ogden (n 12) 175 – 176.

1. Collection and storage

Storage and handling of samples for forensic purposes is held to a notably higher standard than for research purposes.[40] Any material likely to contain DNA evidence should be extracted, isolated, and preserved in a sealed environment at a temperature below –20°C to avoid degradation, especially of softer tissues.[41] Personnel handling evidence should wear clean, protective clothing including gloves, have long hair tied back, and use sterilised or disposable equipment on only one sample at a time to avoid contamination.[42] Best practise would also include archiving a sample of the DNA, in case opposing counsel seek to conduct independent testing.[43] Access to samples, computers, and facilities should be otherwise restricted.[44]

Wildlife DNA may be extracted from a wide range of post-mortal biological material such as blood, flesh, urine, faeces, skin, hair, scales, bone, feathers, claws, teeth, shells, scales, venom, and embryonic tissue, as well as processed products such as cooked meats, furs, tanned leather goods, and medicines.[45] Using modern techniques, trace amounts of DNA may also be amplified to be tested, especially where a sample may contain more than one source, such as in traditional medicines or game sausage.[46] Standard or peer-reviewed techniques for the extraction and purification of DNA from unconventional tissues or under unusual field conditions should be prioritised wherever possible, especially if commercial DNA extraction kits are cost-prohibitive or unavailable.[47]

---

40 See ASTM International Standards E1492 – 05 and E860 – 07 (at http://www.astm.org/).

41 Cassidy and Gonzales (n 3) 1458; Sabrina N McGraw, Shamus P Keeler and Jane E Huffman, 'Forensic DNA Analysis of Wildlife Evidence' in Jane E Huffman and John R Wallace (eds), *Wildlife Forensics: Methods and Applications* (2012) 253, 255.

42 McGraw, Keeler and Huffman (n 41) 255.

43 Moore and Kornfield (n 1) 214.

44 Ibid 213.

45 Iyengar (n 3) 195 – 196; see also Jason Byrd and Lerah Sutton, 'Defining a Crime Scene and Physical Evidence Collection' in Jane E Huffman and John R Wallace (eds), *Wildlife Forensics: Methods and Applications* (2012) 51, 58; Cassidy and Gonzales (n 3) 1458.

46 McGraw, Keeler and Huffman (n 41) 259 – 260.

47 Ibid 253, 254 – 255, 266.

2. Development of method, reference data and validation

Because of the breadth of wildlife that may need to be profiled or categorised, and the reactionary nature of forensic science, scientists must often develop their own specialised tests to answer the investigative question posed.[48]

Broadly speaking, to assign an unknown sample to a taxon, the goal is to find genetic markers that are consistently found within that taxon, but generally not found in the DNA of other taxa. This is done by aligning and comparing reference DNA samples with the support of specialised software.[49] From here it may be inferred, based on the completeness of the reference data, how likely it is that the unknown sample has the identified genetic marker by chance. It is difficult to calculate the statistical significance of a match if the frequency of the genetic marker within the taxon is inferred from a small reference population.[50] This issue is compounded where a taxon is endangered, since the compilation of a large and complete database is hindered by sparsity of the population, laws restricting access to habitats and preventing the extraction of samples, and arduous permit requirements.[51] Specimens listed in the *CITES* Appendices additionally require import and export permits where they need to be transported internationally between States Parties.[52]

The data ideally should be from as many known samples of the relevant taxon and any closely related taxa as possible. Practitioners may have to collect this data themselves, unless the relevant genetic markers can be found in published research or public databases.[53] Although databases should be treated with caution where contributions are unregulated, they can provide comprehensive reference data which improves the certainty of conclusions.[54] The reference population data used should be cited and

48 Linacre and Tobe (n 3) 9.

49 Ibid 127.

50 Kidder (n 7) 415; Cassidy and Gonzales (n 3) 1456.

51 Moore and Kornfield (n 1) 204.

52 *CITES*, arts III, IV, V.

53 See for example GenBank (http://www.ncbi.nlm.nih.gov/genbank/), Barcode of Life (BOL; http://www.barcodeoflife.org/), FishPopTrace (http:// fishpoptrace.jrc.ec.europa.eu/), FishTrace (http://www.fishtrace.org/), and DNA Surveillance (http://www.cebl.auckland.ac.nz:9000/).

54 McGraw, Keeler and Huffman (n 41) 264; Budowle et al (n 3) 299.

publicly available, and any estimates (eg about the rate of inbreeding or mutation) should be disclosed.[55]

Whenever a new set of reference data is developed, it must be validated.[56] Validation is the process of testing a new method or set of markers to evaluate their effectiveness at producing the correct result; ie, how often using that methodology will correctly identify a sample as a part of a given taxon. Validation may include: 'sensitivity, specificity, reproducibility, precision, accuracy, testing the parameters of a method, and analysing samples (mock or nonprobative) commensurate with the intentions for use'.[57] This is especially true given that the majority of wildlife DNA barcoding occurs in an academic environment, so methods and reference data must be carefully reviewed prior to use in casework.

3. Reporting and testimony

After completing an analysis using a validated method, and having followed proper forensic practise, the process and findings should be compiled into a final report along with detailed records of evidence chain of custody, tamper-avoidance procedures, shipping and receiving documentation, relevant emails and phone calls, images, events and bench notes. Reports should be as transparent as possible, and include statements concerning practitioner qualifications and experience, methods, materials, protocols, results and conclusions.[58]

Where appropriate, any conclusions should be qualified by statements about the limitations of the method or process and assumptions made in the interpretation of the evidence.[59] Expert practitioners may additionally be required to conform to legislated reporting formats, including providing a copy of a code of conduct signed prior to beginning any casework, depending on the jurisdiction in which they present their evidence.[60]

55 Budowle et al (n 3) 298.
56 Ibid 295 – 299; McGraw, Keeler and Huffman (n 41) 265.
57 Budowle et al (n 3) 299.
58 Moore and Kornfield (n 1) 225 – 226.
59 Budowle et al (n 3) 300.
60 See, for example, *Supreme Court Rules 1970* (NSW) pt 75 r 3(j); *Uniform Civil Procedure Rules 2005* sch 7.

Estimates of accuracy provided by forensic experts should be quantitative in relation to the particular taxon being tested.[61] Ie, the expert should frame their conclusions as an estimate of how likely it is that the sample in fact originated from a particular taxon, rather than independently identifying its most likely source.[62] Calculating error and match probability is more difficult in DNA barcoding for taxonomic purposes than DNA profiling, since it involves an assessment of an entire taxon rather than two individuals.[63] Because the expert must frame his or her finding in this way, he or she must take care to avoid fallacious statements of probability.[64] This is a particular concern in the context of DNA barcoding due to its high degree of theoretical, but not necessarily practical certainty. Where an expert does not take into account the risk of human or methodological error, random match probabilities, et cetera in calculations of probability, his or her conclusion may be represented to the court as far more certain than it is in reality.[65] Ideally, reports should be reviewed by another knowledgeable party prior to submission and should also be made available to opposing counsel upon request.[66]

In addition to submitting a report, practitioners may also be required to testify in court, especially since wildlife DNA forensics is a relatively seldom-used science, with fewer documented protocols that may be authoritatively cited to in a written report. Practitioners should therefore be trained in expert witness testimony, and expect to be called to give oral evidence having prepared and submitted a report.[67]

---

61 Robert Ogden, 'DNA Applications and Implementation', in Jane E Huffman & John R Wallace (eds), *Wildlife Forensics: Methods and Applications* (2012) 271, 278.

62 Moore and Kornfield (n 1) 278.

63 Ibid 226.

64 Budowle et al (n 3) 298 – 299; for an example of a common fallacious statement, see *R v Doheny and Adams* (1997) 1 Cr App R 369, 372 – 373.

65 Edmond et al (n 25) 36.

66 Moore and Kornfield (n 1) 209 – 210; for an example, see Linacre and Tobe (n 3) 297, 305, 309.

67 Moore and Kornfield (n 1) 229 – 230.

V. Applications

1. Species identification

In the investigation of wildlife trafficking offences, wildlife DNA testing is most commonly used for species identification.[68] This relies on isolating and comparing genetic markers which are generally consistently found within a species, but which vary between species.[69]

Its application is relatively widespread because most protected groups of animals are categorised or referred to in legislation at the species level.[70] Species identification is useful in identifying trafficked products which no longer carry morphologic species traits, such as shark fins[71] and traditional medicines,[72] or trace evidence left at the scene of a suspected poaching or on a suspect's clothing or gear.[73]

Another common use of species identification is where a sample is in an immature state. For example, a 2007 case involved a man wearing a specialised vest designed to conceal and smuggle valuable bird eggs out of Australia. After being told by customs that he would be searched, the man slapped his torso several times, destroying all but two of 38 eggs. DNA analysis was able to determine the number and species of bird embryos contained in both the smashed and remaining eggs, since quarantine laws prevented investigators from allowing the remaining eggs to hatch. The DNA laboratory at the Australian Museum found that each of the bird species were protected under Australian law, and the man was convicted.[74]

---

68 Ogden (n 61) 273.

69 Linacre and Tobe (n 3) 121 – 132.

70 See *CITES*, appendicess I, II, III.

71 See, for example, Mahmood Shivji et al, 'Genetic identification of pelagic shark body parts for conservation and trade monitoring' (2002) 16(4) *Conservation Biology* 1036 – 1047.

72 See, for example, Lindsey Peppin et al, 'A DNA based approach for the forensic identification of Asiatic black bear (Ursus thibetanus) in a traditional Asian medicine' (2008) 53 *Journal of Forensic Science* 1358 – 1362; Jon Wetton et al, 'An extremely sensitive species-specific ARMs PCR test for the presence of tiger bone DNA' (2004) 140 *Forensic Science International* 139 – 145.

73 Ogden (n 61) 273.

74 'Wildlife Forensics', *Catalyst* (Australian Broadcasting Corporation (ABC) Radio, 25 October 2007, presenter: Jonica Newby) <https://www.abc.net.au/catalyst/stories/s2069466.htm>.

2. Origin

In some cases, and for some offences, it is necessary to identify the geographic location from which a sample originates. This is because legislation adheres to political boundaries where a species may not; ie, a species may be distributed across multiple regions, countries or fishing zones, but only be protected by law in some.[75] The method for population assignment is approximately the same as species identification: the unknown sample's DNA profile is assigned to a population if it contains genetic markers frequently observed within only one population.[76]

This method is heavily dependent on the completeness of the reference population, since populations are less likely to be defined by discrete genetic differences than species.[77] It also requires a high degree of genetic variation between geographically distinct populations, and reference data from each potential source population.[78] For these reasons, it may be difficult to carry out this procedure where a large number of populations exist, or where there is significant inter-population breeding.[79] Endangered species are more likely to have small and inbred populations.[80] If, on the other hand, an entire species has been well documented in a database, the use of DNA for population assignment can lead to successful prosecutions, as for example reports involving cases of illegal salmon fishing show.[81]

75 Ogden (n 61) 275.
76 Ibid 278 – 279.
77 Ibid 275.
78 Ibid 277 – 278; for examples see: Lora Ghobrial et al, 'Tracing the origins of rescued chimpanzees reveals widespread chimpanzee hunting in Cameroon' (2010) 10 *BMC Ecology* 2; Samuel K Wasser et al, 'Assigning African elephant DNA to geographic region of origin: Applications to the ivory trade' (2004) 101(41) *Proceedings of the National Academy of Sciences of the United States of America* 14847 – 14852.
79 McGraw, Keeler and Huffman (n 41) 263.
80 Kidder (n 7) 407, 415.
81 Ruth E Withler et al, 'Forensic DNA analysis of Pacific salmonid samples for species and stock identification' (2004) 69 *Environmental Biology of Fishes* 275, 283 – 4; Lisa W Seeb et al, 'Development of a standardized DNA database for Chinook salmon' (2007) 32 *Fisheries* 540, 549.

3. Identification of individuals

Although less common in wildlife and forest crime investigations, in some cases, it may be possible or necessary to exclude or identify a specific animal as the source of a DNA sample found at a crime scene. This may be the case, for instance, where a seized tiger hide must be traced to the carcass of a tiger killed at a zoo,[82] or a poached animal carcass must be linked to meat found in a suspect's vehicle or trophy in his or her home. Individual assignment can also help determine exactly how many animals are involved where it is unclear (eg, where a number of detached shark fins are seized).[83]

Individual identification, or DNA profiling, relies on genetic markers that have a high level of variability even within a given species or population, and are thus likely to differ between individuals.[84] This technique is effective to determine that two samples are not from the same individual where they produce different DNA profiles; however, where two samples produce the same profile, this is only a suggestion that they originate from the same individual. The possibility of closely related samples, especially within inbred populations, may be difficult to displace in some cases.

Individual identification is also used for indexing both protected and non-protected animals, mostly in small populations, to pre-emptively track poached animals or authenticate legal animal products.[85] The latter works by registering all legal specimens as a means to identify illegal samples and has been demonstrated in Norway, at least theoretically, for common minke whales.[86]

---

82 See Sandeep Kumar Gupta et al, 'Establishing the identity of the massacred tigress in a case of wildlife trafficking' (2011) 5 *Forensic Science International: Genetics* 74, 75.

83 McGraw, Keeler and Huffman (n 41) 262.

84 Ogden (n 61) 279.

85 Ogden (n 61) 279 – 280; Per Palsbøll et al, 'DNA Registers of Legally Obtained Wildlife and Derived Products as Means to Identify Illegal Takes' (2006) 20(4) *Conservation Biology* 1284, 1292; Carolyn J Hogg et al, 'Stopping the spin cycle: genetics and bio-banking as a tool for addressing the laundering of illegally caught wildlife as "captive-bred"' (2018) 10(2) *Conservation Genetics Resources* 237, 244 – 5.

86 Palsbøll et al (n 85) 1284; see also *CITES*, appendices I and II.

4. Other applications

In addition to parallel markets, such as when only captive-bred specimens can be legally traded, some species are allowed to be possessed or traded only in certain quantities. This opens up issues where a suspect may claim that some of the specimens in his or her possession are the offspring of a legally obtained specimen, effectively laundering wild-caught animals. Because DNA is directly inherited from the parents, this type of analysis can be done with effective certainty and without a reference population.[87] If approximately half of the genetic markers in the alleged offspring are not shared by the alleged parent, this will generally dispel the claim, subject to the probability of a rare mutation event.[88]

Some legislation protecting wildlife is sex-specific, for instance the poaching of female pheasants in South Korea.[89] Where sexing cannot be done by visual means due to decomposition or processing, immature specimens, or where sex organs are internal (such as in elephants), genetic markers specific to Y-chromosomes can indicate if the specimen is male.[90]

VI. Challenges

In addition to more general issues facing wildlife DNA forensics briefly mentioned above, there are some practical issues relating to the forensic standards increasingly expected by courts.[91] These issues may hinder the use of wildlife DNA forensics in the investigation of wildlife trafficking offences, or else expose experts to challenge in court where they are not properly accounted for, or adequately avoided, prior to testimony.

87 Ogden (n 61) 281.
88 Ibid.
89 Junghwa An et al, 'A molecular genetic approach for species identification of mammals and sex determination of birds in a forensic case from South Korea' (2007) 167(1) *Forensic Science International* 59, 59.
90 McGraw, Keeler and Huffman (n 41) 261.
91 Ogden (n 61) 272.

1. Evidencing scientific rigour

1.1. Pre-trial protocols and quality management

As outlined in Part III, the chief reason for the legal scrutiny under which expert witnesses are placed is the subjective way that experts form opinions. However, this can be limited if experts can show that they have followed a pre-defined method which has been validated and remains susceptible to objective assessment.[92] Where an expert has not followed a documented or recommended procedure in the preparation of evidence, a question may arise as to the integrity of the test itself and the interpretation of the results.

For this reason, it is also important that laboratories undertaking wildlife DNA forensics have demonstrable quality assurance and quality control procedures, which monitor all operational and analytical procedures, training exercises, reporting and review of results.[93] In short, quality assurance aims to prevent errors, or else identify them before they are published.[94] A lack in proper quality assurance and quality control mechanisms may lead to a lack of confidence in the results produced, which in turn may render the evidence weak or inadmissible.[95] General quality assurance standards may be provided by accreditation requirements. For example, laboratories can only become accredited under the gold-standard 'ISO-17025' by the International Organization for Standardization if they are demonstrably in compliance with prescribed quality management standards.

1.2. Certification and accreditation

In its seminal 2009 report on strengthening forensic sciences, the United States National Research Council stated that

> laboratory accreditation and individual certification of forensic science professionals should be mandatory, and all forensic science professionals should have access to a

92 United States, President's Council of Advisors on Science and Technology (n 28) 75 – 81.
93 Moore and Kornfield (n 1) 202.
94 Ogden (n 12) 174.
95 Budowle et al (n 3) 295 – 296.

> certification process. … No person (public or private) should be allowed to practice in a forensic science discipline or testify as a forensic science professional without certification.[96]

This is bolstered by evidence that external qualifications and objective standards are a more meaningful indication of competency because they entail transparency.[97] However, accreditation and certification are uniquely difficult to obtain for laboratories and scientists who perform wildlife DNA forensics, especially those with necessary expertise but who typically only perform research.[98] Acquiring internationally-recognised accreditation (such as ISO-17025) is expensive, arduous and not typically done by university or multi-use laboratories,[99] although it is certainly attainable.[100]

Certification of individual practitioners is more difficult, since the diverse range of specialties under the umbrella of wildlife DNA forensics is spread over few practitioners.[101] Additionally, certification is only a useful indication of professional competence where there is a pre-defined and thorough assessment process; otherwise, it may be vulnerable to legal scrutiny.[102] Currently, the only body that performs individual certification for wildlife forensic practitioners is the Society for Wildlife Forensic Science (SWFS), and currently only in the United States.

Demonstrable training also falls in line with many expert witness provisions,[103] although as a measure of competency it is not sustainable for very long after it is completed.[104] Moreover, there is no specific training that practitioners can undergo to become qualified as wildlife forensic

96 Committee on Identifying the Needs of the Forensic Science Community, cited in United States, National Research Council (n 19) 25, 195 – 200.

97 Edward K Cheng and G Alexander Nunn, 'Beyond the Witness: Bringing A Process Perspective to Modern Evidence Law' (2019) 97(6) *Texas Law Review* 1077, 1115 – 6.

98 Ogden (n 12) 175.

99 Linacre and Tobe (n 3) 15.

100 Edgard O Espinoza et al, 'The Future of Wildlife Forensic Science' in Jane E Huffman and John R Wallace (eds), *Wildlife Forensics: Methods and Applications* (2012) 343, 354.

101 Ibid 354 – 355.

102 Rebecca N Johnson, Linzi Wilson-Wilde and Adrian Linacre, 'Current and future directions of DNA in wildlife forensic science' (2014) 10 *Forensic Science International: Genetics* 1, 9.

103 See, for example, *Evidence Act* (Cth) s 79.

104 Linacre and Tobe (n 3) 16.

scientists.[105] Perhaps more meaningful to a current assessment of competency is the possibility for practitioners to present their ability through proficiency testing results. However, because it would be unrealistic to develop a proficiency test for every taxon that wildlife DNA forensics encompasses, very few such tests are currently available. Publication and presentation of peer-reviewed research within wildlife DNA forensics is often the only available means to demonstrate competency.[106]

2. Funding

Governments in both developing and developed countries appear to be unwilling to commit to funding wildlife trafficking reduction efforts.[107] This is compounded by that fact that casework in wildlife DNA forensics is relatively infrequent, especially where it is specialised, which drives up the cost of developing and maintaining wildlife forensic facilities and personnel significantly.[108] Additionally, and unlike its human counterpart, the majority of wildlife DNA forensics has very little commercial value.[109] Because of this high service cost and lack of commercial viability, government funding is important if laboratories are to operate at satisfactory standards and trained staff are to remain fairly compensated, since low salaries within forensic sciences open up the possibility of corruption and incompetence.

VII. The way ahead

Many of the above challenges could, theoretically, be avoided if all wildlife forensic testing was outsourced to a single, trusted laboratory with

105 Ogden (n 12) 176.
106 Linacre and Tobe (n 3) 16.
107 Anita Sundari Akella and Crawford Allan, *Dismantling Wildlife Crime: Executive Summary* (2012) 8; Melanie Wellsmith, 'Wildlife Crime: The Problems of Enforcement' (2011) 17 *European Journal on Criminal Policy and Research* 125, 137.
108 Ogden (n 12) 174.
109 Ibid.

selective staff. This would also help the ancillary issue that many countries who are most affected by wildlife trafficking are the least equipped to effectively use wildlife DNA forensics.[110] The United Nations Office on Drugs and Crime (UNODC) has stated that

> 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.[111]

The US Fish and Wildlife Service (USFWS) Forensic Laboratory offered over a decade ago to take on any forensic analyses of wildlife trafficking evidence related to the enforcement of *CITES* internationally, free of charge.[112] The USFWS laboratory maintains an ISO-17025 accreditation, and its scientists have testified in court and successfully resisted legal challenge, at least in the United States, based on their 'extensive academic training and experience'.[113]

Despite this, their offer does not appear to have been universally taken up, as most wildlife forensics takes place in domestic university or commercial laboratories.[114] This may be because countries wish to develop their own skills in wildlife forensics, or are unwilling to reveal deficiencies in their own practises or share resources internationally. It may also be that, due to the nature of wildlife forensics, sometimes investigators will encounter an unconventional sample which requires testing by a specialist academic or research laboratory that does not otherwise adhere to forensic standards.[115] Hence, the laborious and expensive practise of wildlife DNA forensics is still dispersed across several laboratories in several countries.

In 2015, UNODC conducted a confidential survey reviewing the capacity of laboratories undergoing forensic wildlife services worldwide.[116] This review

110 Robert Ogden and Jen Mailley, *A review of wildlife forensic science and laboratory capacity to support the implementation and enforcement of CITES* (2015) 30.
111 Ibid 28.
112 Ogden (n 12) 178.
113 *U.S. v Kapp* 419 F.3d 666, 673 – 675.
114 Ogden (n 12) 174.
115 Linacre and Tobe (n 3) 14.
116 Ogden and Mailley (n 110) i–ii.

found that, of the laboratories that had undertaken diagnostic casework, only some were operating in line with internationally accepted forensic standards. For instance, only 44 % of laboratories surveyed indicated that they operated to a minimum quality assurance standard, and only 31 % to an external standard.[117]

This review was revised in 2017 in order to develop and publish a directory of laboratories that are willing and able to conduct wildlife forensics at the requisite standard.[118] The pool of invited participants included those who had participated in the previous survey, plus additional laboratories who had not. Of the laboratories surveyed, 66 % reported that they were operating to a minimum quality assurance standard, and 35 % were subject to external audit. In addition, 68 % of laboratories indicated an intention to improve quality assurance standards over the next three years.

This increase in laboratories claiming to operate at satisfactory quality assurance standards in just a few years is encouraging, and may be indicative of a general positive inclination within wildlife forensics towards more rigorous scientific standards. Given the momentum in evidence law towards a higher standard of scrutiny, it is in the interest of wildlife DNA forensics, and indeed wildlife crime reduction efforts generally, to move towards an externally demonstrable standard of laboratory practise.

VIII. Conclusion

The importance of reducing wildlife trafficking has been enunciated elsewhere, and comprehensively so.[119] Implications such as the extinction of unique and ecologically significant species and the disruption of delicate and vital ecosystems are well documented. Despite this, the prevention of wildlife trafficking is not prioritised to the extent that the seriousness of these consequences suggest it ought to be. The reality is

117 Ibid 21 – 23.

118 Robert Ogden and Simon Dures, Development of an electronic directory of laboratories that conform to a defined minimum standard for conducting wildlife forensic testing' (2017) 23.

119 See, for example Huffman and Wallace (eds) (n 3); Cassidy and Gonzales (n 3) 1454; Iyengar (n 3) 195; Linacre and Tobe (n 3); Budowle et al (n 3) 119.

that efforts to reduce wildlife trafficking are often underdeveloped and underfunded. It is therefore important that the efforts currently in place are strengthened and supported as much as possible.

Regardless of jurisdiction, legislation that catches wildlife trafficking offenders has at least one thing in common: the animal affected by the actions of the perpetrator must belong to a pre-defined group which merits protection. Proving that this is the case is not always straightforward, to the extent that sometimes the only means of proving that the trafficked product or poached animal is protected is by using sciences such as wildlife DNA forensics.[120] Wildlife DNA forensics has the potential to play a vital role in the successful prosecution of wildlife trafficking offenders where other methods of profiling and taxology are, for one reason or another, ineffective.

Wildlife DNA forensics ought to respond to the needs of law enforcement by maintaining and strengthening validity in the courtroom. This can most effectively be done by reference to external standards that speak to both the foundational validity and applied accuracy of the methods used by practitioners. While some laboratories are already operating at a remarkably high standard for a generally under-resourced and immature field, some may run into issues with evidencing the scientific rigour increasingly required in court.

Looking at the literature emerging from this area,[121] in conjunction with the survey results referred to in Part VII, it may be the case that wildlife DNA forensics will continue to improve and mature into a reliable and reputable forensic science on its own. However, without discounting or distrusting the passionate voices within this scientific community who are aware of the developments that need to be made, it is nevertheless important that improvement does not occur in a vacuum. If the goal is to enforce wildlife trafficking legislation, and ultimately to reduce wildlife trafficking in general, then the focus of wildlife DNA forensics should not only be on good science; it should be on demonstrably good science.

120 Peter Cobb, cited in White (n 4) 2.

121 United States, President's Council of Advisors on Science and Technology (n 28); United States, National Research Council (n 19).

Bibliography

Adam, Craig, *Forensic Evidence in Court: Evaluation and Scientific Opinion*, Chichester: John Wiley & Sons, 2016

Akella, Anita Sundari and Crawford Allan, *Dismantling Wildlife Crime: Executive Summary*, Gland: WWF and TRAFFIC, November 2012

An, Junghwa et al, 'A molecular genetic approach for species identification of mammals and sex determination of birds in a forensic case from South Korea' (2007) 167(1) *Forensic Science International* 59

Budowle, Bruce et al 'Recommendations for animal DNA forensic and identity testing' (2005) 119(5) *International Journal of Legal Medicine* 119

Byrd, Jason and Lerah Sutton, 'Defining a Crime Scene and Physical Evidence Collection' in Jane E Huffman and John R Wallace (eds), *Wildlife Forensics: Methods and Applications*, Hoboken, NJ: John Wiley & Sons, 2012, 51

Campbell Moriarty, Jane and Michael J Saks, 'Forensic Science: Grand Goals, Tragic Flaws, and Judicial Gatekeeping' (2006) 44 *Judges Journal* 16

Cashman, Katherine, *Lawyers and DNA: Understanding and Challenging the Evidence*, PhD Thesis, The University of Tasmania, 2017

Cassidy, Brandt and Robert Gonzales, 'DNA Testing in Animal Forensics' (2005) 69 *Journal of Wildlife Management* 1454

Cheng, Edward K and G Alexander Nunn, 'Beyond the Witness: Bringing A Process Perspective to Modern Evidence Law' (2019) 97(6) *Texas Law Review* 1077

Chin, Jason M, 'Abbey Road: The (Ongoing) Journey to Reliable Expert Evidence' (2018) 9(3) *Canadian Bar Review* 422

Chin, Jason M, 'Psychological science's replicability crisis and what it means for science in the courtroom' (2014) 20 *Psychology, Public Policy, and Law* 225

Edmond, Gary et al, 'Admissibility Compared: The Reception of Incriminating Expert Evidence (i. e., Forensic Science) in Four Adversarial Jurisdictions' (2013) 3 *University of Denver Criminal Law Review* 31

Edmond, Gary, 'Legal versus Non-Legal Approaches to Forensic Science Evidence' (2016) 20 *International Journal of Evidence and Proof* 3

Edmond, Gary, 'What Lawyers Should Know About Forensic Sciences' (2015) 36 *Adelaide Law Review* 33

Espinoza, Edgard O et al, 'The Future of Wildlife Forensic Science' in Jane E Huffman and John R Wallace (eds), *Wildlife Forensics: Methods and Applications*, Hoboken, NJ: John Wiley & Sons, 2012, 343

Ghobrial, Lora et al, 'Tracing the origins of rescued chimpanzees reveals widespread chimpanzee hunting in Cameroon' (2010) 10 *BMC Ecology* [not paginated]

Goss, Samuel and Jennifer Mnookin, 'Expert Information and Expert Evidence: A Preliminary Taxonomy' (2003) 34 *Seton Hall Law Revue* 148

Gupta, Sandeep Kumar et al, 'Establishing the identity of the massacred tigress in a case of wildlife trafficking' (2011) 5 *Forensic Science International: Genetics* 74

Hogg, Carolyn J et al, 'Stopping the spin cycle: genetics and bio-banking as a tool for addressing the laundering of illegally caught wildlife as "captive-bred"' (2018) 10(2) *Conservation Genetics Resources* 237

Huffman, Jane E and John R Wallace (eds), *Wildlife Forensics: Methods and Applications*, Hoboken, NJ: John Wiley & Sons, 2012

IUCN, 'IUCN Red List of Threatened Species' (Web page, undated) <https://www.iucn.org/resources/conservation-tools/iucn-red-list-threatened-species#RL_index>

Iyengar, Arati, 'Forensic DNA analysis for animal protection and biodiversity conservation: a review' (2014) 22 *Journal for Nature Conservation* 195

Johnson, Rebecca N, 'The use of DNA identification in prosecuting wildlife-traffickers in Australia: do the penalties fit the crimes?' (2010) 6 *Forensic Science, Medicine, and Pathology* 211

Johnson, Rebecca N, Linzi Wilson-Wilde and Adrian Linacre, 'Current and future directions of DNA in wildlife forensic science' (2014) 10 *Forensic Science International: Genetics* 1

Kidder, Melissa, 'Human DNA v. Non-Human DNA: A Look at the General Admissibility of Non-Human DNA in the Courts' (2009) 35 *Ohio Northern University Law Review* 397

Linacre, Adrian and Shanan Tobe, *Wildlife DNA Analysis: Applications in Forensic Science*, Chichester: Wiley-Blackwell, 2013

Martire, Kristy and Gary Edmond, 'Rethinking Expert Opinion Evidence' (2017) 40 *Melbourne University Law Revue* 967

McGraw, Sabrina N, Shamus P Keeler and Jane E Huffman, 'Forensic DNA Analysis of Wildlife Evidence' in Jane E Huffman and John R Wallace (eds), *Wildlife Forensics: Methods and Applications*, Hoboken, NJ: John Wiley & Sons, 2012, 253

Moore, M Katherine and Irving L Kornfield, 'Best Practices in Wildlife Forensic DNA' in Jane E Huffman and John R Wallace (eds), *Wildlife Forensics: Methods and Applications*, Hoboken, NJ: John Wiley & Sons, 2012, 202

Ogden, Robert and Jen Mailley, *A review of wildlife forensic science and laboratory capacity to support the implementation and enforcement of CITES*, Vienna and Geneva: UNODCA and CITES Secretariat, 2015

Ogden, Robert and Simon Dures, *Development of an electronic directory of laboratories that conform to a defined minimum standard for conducting wildlife forensic testing*, Vienna and Geneva: UNODCA and CITES Secretariat, 2017

Ogden, Robert, 'DNA Applications and Implementation', in Jane E. Huffman and John R. Wallace (eds), *Wildlife Forensics: Methods and Applications*, Hoboken, NJ: John Wiley & Sons, 2012, 271

Ogden, Robert, 'Forensic science, genetics and wildlife biology: getting the right mix for a wildlife DNA forensics lab' (2010) 6 *Forensic Science, Medicine and Pathology* 172

Palsbøll, Per et al, 'DNA Registers of Legally Obtained Wildlife and Derived Products as Means to Identify Illegal Takes' (2006) 20(4) *Conservation Biology* 1284

Peppin, Lindsey et al, 'A DNA based approach for the forensic identification of Asiatic black bear (Ursus thibetanus) in a traditional Asian medicine' (2008) 53 *Journal of Forensic Science* 1358

Ramadan, Hassan and Nabih Baeshen, 'Biological identifications through DNA barcodes' in Gbolagade Akeem Lameed (ed), *Biodiversity Conservation and Utilization in a Diverse World*, Rijeka: IntechOpen, 2012, 109

Searston, Rachel and Jason Chin, 'The legal and scientific challenge of black box expertise' (2019) 38(2) *University of Queensland Law Journal* 238

Seeb, Lisa W, 'Development of a standardized DNA database for Chinook salmon' (2007) 32 *Fisheries* 540

Semikhodskii, Andrei, *Dealing with DNA Evidence: A Legal Guide*, New York, NY: Routledge-Cavendish, 2007

Sensabaugh, George and D H Kaye, 'Non-Human DNA Evidence' (1998) 39(1) *Jurimetrics* 1

Shivji, Mahmood et al, 'Genetic identification of pelagic shark body parts for conservation and trade monitoring' (2002) 16(4) *Conservation Biology* 1036

Tobe, Shanan, James Govan and Lindsey Welch, 'Tackling poaching: Recovery of human DNA profiles from deer remains' (2011) 3 *Forensic Science International: Genetics Supplement Series* e265

United States, National Research Council, *Strengthening Forensic Science in the United States: A Path Forward*, Washington, DC: National Academies Press, 2009

United States, President's Council of Advisors on Science and Technology, '*Forensic Science in Criminal Courts: Ensuring Scientific Validity of Feature-Comparison Methods*, Report to the President, Washington, DC: Executive Office of the Presidentof the United States, September 2016

UNODC, *Wildlife and Forest Crime Analytic Toolkit*, New York, NY: United Nations, rev ed, 2012

Wallace, John R and Jill C Ross, 'The Application of Forensic Science to Wildlife Evidence' in Jane E. Huffman and John R. Wallace (eds), *Wildlife Forensics: Methods and Applications*, Hoboken, NJ: John Wiley & Sons, 2012, 35

Wasser, Samuel K et al, 'Assigning African elephant DNA to geographic region of origin: Applications to the ivory trade' (2004) 101(41) *Proceedings of the National Academy of Sciences of the United States of America* 14847

Wellsmith, Melanie, 'Wildlife Crime: The Problems of Enforcement' (2011) 17 *European Journal on Criminal Policy and Research* 125

Wetton, Jon at al, 'An extremely sensitive species-specific ARMs PCR test for the presence of tiger bone DNA' (2004) 140 *Forensic Science International* 139

White, Peter (ed), *Crime Scene to Court – The Essentials of Forensic Science*, London: Royal Society of Chemistry, 1998

Withler, Ruth E et al, 'Forensic DNA analysis of Pacific salmonid samples for species and stock identification' (2004) 69 *Environmental Biology of Fishes* 275

Wyatt, Tanya, *Wildlife Trafficking: A Deconstruction of the Crime, the Victims and the Offenders*, Basingstoke: Palgrave Macmillan, 2013

'Wildlife Forensics', *Catalyst* (Australian Broadcasting Corporation (ABC) Radio, 25 October 2007, presenter: Jonica Newby) <https://www.abc.net.au/catalyst/stories/s2069466.htm>

Judicial decisions

Daubert v Merrell Dow Pharmaceuticals Inc 125 L Ed 2d 469, 595

R v Abbey (2009) ONCA [62]–[70]

R v Doheny and Adams (1997) 1 Cr App R 369

R v Mohan [1994] 2 SCR 9

U.S. v Kapp 419 F.3d 666