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Wildlife crime scene investigation: techniques, tools and technology

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ABSTRACT: Wildlife crime, defined here as the illegal taking, disturbance, possession, trade or movement of animals and or their derivatives, is a growing international problem that threatens the survival of many species. In the investigation of such incidents the 'crime scene' may range from the carcass (or parts) of an animal to terrain that encompasses topography as varied as forest or desert and which may include diverse natural and man-made structures. Often, the location of the wildlife crime scene is isolated, with few facilities for proper investigation and collection of evidence. In poorer parts of the world and in countries experiencing social unrest, these features may present particular challenges. Wildlife crime scene work is such that equipment, investigative techniques and scientific technology all need to be appropriate to, and the best available in, the circumstances. Effective investigation under field conditions is likely to require a combination of portable and easy-to-use laboratory equipment coupled with modern methods of data collection and information transmission. An interdisciplinary approach is essential. Biologists/naturalists and those experienced in health studies, especially epidemiology, can often usefully complement the role of the police, enforcement officials and crime scene specialists.

KEY WORDS: Wildlife · Crime scene · Field techniques · Technology · Forensics

INTRODUCTION

Wildlife crime can be defined as the illegal taking, possession, trade or movement of animals and plants or their derivatives in contravention of international, regional, or national legislation (Cooper & Cooper 2007, Lawton & Cooper 2009). Some add to this definition the infliction of cruelty to and the persecution of wild animals, both free-living and in captivity.

In this paper the term 'wildlife crime' is used in a narrower sense from that given above. The emphasis is on the unlawful taking, possession, trade or movement of animals and their derivatives. When such breaches of the law occur, or are suspected, investigation of the crime scene is central to investigations that may lead to arrest and prosecution. In particular, the proper collection, handling and analysis of evidence gathered at such a site will enhance the chances of securing a conviction and/or preventing/discouraging further breaches of the law.

The wildlife crime scene presents many special, sometimes unusual and unexpected, challenges, some of which are very different from those pertaining to other legal investigations. Nevertheless, careful planning, systematic and meticulous examination, coupled with the use of the correct and properly calibrated equipment, deployment of appropriate field techniques and the selective application of modern technology, can go a long way towards countering the difficulties.

THE WILDLIFE CRIME SCENE

Background. The international nature of wildlife crime means that the 'scene' may encompass several countries and include locations ranging from tropical forest, isolated coastline, desert or tundra (where animals have been hunted), to establishments such as the

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premises of an animal dealer, a traditional market, a zoological collection, or a private home. It may even comprise websites on which live or dead species or their derivatives are offered for sale. This diversity adds weight to the argument that the collection of evidence in conservation cases often necessitates working under conditions where the facilities for efficient *in situ* study are greatly restricted. In this paper, therefore, the emphasis is very much on the different physical locations where wildlife crime needs to be investigated and how best to perform well under adverse conditions.

A crime scene visit (sometimes termed a site visit) to the location where a wildlife offence is alleged to have occurred is the prelude to: (1) collection, transportation, storage and submission of evidence; (2) documentation and record keeping, including the taking of photographs; (3) production of a report; and (4) (if the matter proceeds) preparation for and the presentation of evidence in court. This list is familiar to anyone who has been involved in routine crime scene work and indicates that investigation of wildlife offences is not, essentially, markedly different from other forms of forensic activity. However, investigation of wildlife offences can present unusual, sometimes unique, difficulties and may necessitate the use of techniques that are tailored to work in the field.

In wildlife crime scene work, as in other areas of forensic endeavour, it is vital that the investigations are meticulous, that detailed records are kept and that a proper 'chain of custody' (the continuity of evidence) is maintained for each item of evidence. Such a chain will minimise the chance of loss or substitution of material and helps to prove the origin and veracity of specimens or exhibits. The chain should always be as short as possible and ideally it should not include anyone who is unwilling to appear in court or is unlikely to be a reliable witness. This cannot always be determined beforehand. Wildlife cases can be contentious and divisive, especially when someone's livelihood, freedom or reputation is at stake.

In our experience (see also Lawton & Cooper 2009), the following are usually helpful in a wildlife crime scene investigation:

• Accurate information about the circumstances of the alleged offence (a 'history'), preferably in the form of a written record. This should include details of the relevant legislation (Cannings 2000, Cooper & Cooper 2008a).

• Discussion with those involved in reporting the incident, initiating the investigation or in bringing charges. This, too, should be covered in a written statement wherever possible. Standard reporting forms (Cooper & Cooper 2007) may already be in use — for instance, in the UK, where the National Wildlife crime Unit (NWCU) has produced such a form to help collate information from those who may have witnessed a possible wildlife crime offence.

• Correct identification of the species of animal(s) involved.

• A site visit to the location where the offence is alleged to have occurred (the 'crime scene') or the premises where (for example) live animals need to be viewed or dead animals/their derivatives can be examined.

• Immediate recording of environmental parameters, including weather data (Merck 2007).

• Proper collection, holding, transportation, storage and submission of evidence and trace evidence and the relevant accompanying statements and records. A problem when visiting crime scenes is that 'contamination' — the introduction of extraneous, irrelevant, material — can easily occur.

• Careful documentation and record keeping, including appropriate photographic records, leading to production of a report.

Ultimately, if the matter proceeds, it will be necessary to prepare evidence for, and possibly appear in, a court of law.

The holding of evidence can be particularly problematic in wildlife cases, especially under field conditions. The holding of live animals that are evidence or confiscated as 'seizures' can present major difficulties, as these will need to be properly housed and provided with adequate care. Often, especially in poorer countries, facilities for holding such specimens either do not exist or are inadequate.

Preparation for a crime scene visit. Certain basic preparation is vital. Advice is available from textbooks (see, for example, Townley & Ede 2004, White 2004, Merck 2007) and from specific guidelines or 'rules of investigation' produced usually by governmental bodies.

Rapid access to the wildlife crime scene is usually imperative. Delay may result in destruction or spoiling of evidence because of rain, wind or other climatic factors, or the activities of humans, domesticated livestock (e.g. grazing cattle) or wild animals (including scavengers). Therefore equipment, ranging from protective clothing to specimen containers, must be prepared and ready beforehand (see Tables S1 & S2 in the electronic supplement at www.int-res.com/articles/suppl/esr00204_app.pdf).

Those investigating wildlife crime may be fortunate enough to have access to people who are experienced in such work — in the UK, for example, Forensic Science Managers (FSMs), Scenes of Crime Officers (SOCOs) and Crime Scene Investigators (CSIs).

Personnel. Specialists in crime scene management, together with police officers, staff of enforcement bodies and others, including those with experience of the

species in question, usually have a major role to play in investigations. However, others often have much to offer in wildlife work, especially in the field. There are 2 major groups of people who can often assist; (1) amateurs, such as field naturalists, bird-ringers (bird-banders), game-keepers and trackers who often have detailed knowledge of the location and who can assist in such tasks as the recognition and identification of animal footprints, hair, feathers, droppings and (bird) pellets; and (2) medical and veterinary personnel experienced with epidemiological field studies.

In addition to these 'extras,' forensic wildlife work can and should incorporate such specialists as ecologists, entomologists, botanists, veterinarians, pathologists, molecular biologists and toxicologists.

The vagaries of wildlife crime are such that a relatively inexperienced biologist, veterinarian or field conservationist may find him/herself in the position of having to take the lead in securing a crime scene and instituting the collection of evidence. So what attributes are those so involved likely to need? Some important traits include:

• Genuine interest in wildlife and, preferably, a background of involvement in natural history. At a crime scene where, for example, illegal use or disposal of chemicals is suspected, it may be the naturalist who notes dying caterpillars or unusual numbers of fish on the surface of a lake and who provides the important initial clues that can lead to a prosecution.

• Broad knowledge of taxonomy, behaviour and animal biology. Conservation crime can relate to taxa as different as crustaceans and chimpanzees. Correct identification is always a key part of a forensic investigation and appreciating how animals live and behave can play an important part in elucidating the sequence of events in a wildlife case.

• Some understanding of the various specialised techniques, such as microbiology, toxicology and DNA studies, which are likely to be needed when investigating wildlife crime.

Coordinating work in the field can be difficult, especially if SOCOs or their equivalent are unavailable to assist. Simple matters such as establishing and maintaining a crime scene can present problems if those first at the site have limited experience of such matters. The situation can be made easier if advice is sought from people who have experience of containing an area and controlling those working within it, albeit for a different reason. Two examples of those who fall into this category are biologists with experience of dealing with stranded marine mammals, and government veterinary officials who have to respond promptly and efficiently to reports of suspected notifiable diseases, such as anthrax or Newcastle disease, in domesticated animals.

Often, however, as stressed above, a relatively unqualified person has to take the lead. This paper is primarily orientated towards such people, with a strong emphasis on the difficulties of managing a crime scene in more isolated areas or in countries where the infrastructure and organization are poor and dedicated resources are not available.

Establishing a wildlife crime scene. The person who is coordinating activities must:

• Establish a proper command structure and responsibility by introducing him/herself to others present.

• Ascertain the size and location of the crime scene, if possible using GPS.

• Demarcate the crime scene by using barrier tape or its equivalent supplemented with markers, flags, canes and other standard crime-scene security items.

• Maintain a record of entry to a crime scene, of those persons for whom it is necessary to enter. There should be no unnecessary admittance.

• Ensure safety of the scene — for example, by moving bystanders away from buildings that may collapse or animals that may bite.

• Plan collection and holding of evidence.

• Arrange photographic and other records.

• Maintain a proper chain of custody.

Precautions at the crime scene. A crime scene has a legal significance and should be disturbed as little as possible (Townley & Ede 2004, Lawton & Cooper 2009). Anyone who enters a crime scene leaves something at the site and takes something away — this is a concept based on the work and writings of Edmond Locard (1877–1966) and explained succinctly by Gallop & Stockdale (2004).

Some useful rules when entering a crime scene are as follows:

• Prepare what you need beforehand in order to avoid entering and leaving the scene unnecessarily. A checklist is important.

• If you are initially visiting the crime scene alone, be sure to inform other people. Wildlife cases, especially visits to crime scenes, can take a long time and may prove hazardous. It is important that someone knows where you have gone and for what reasons.

• If a SOCO, CSI, police officer or equivalent is present, follow his/her rules and instructions.

• Minimise all disturbance to the site. Touch nothing unnecessarily, stand still when movement is not required, carry everything you need (and do not put it on the ground).

• Remember the basic rule that observation is the all-important prelude to action. Supplement this with photography, video and tape recording.

Legal considerations at the crime scene. There must be strict adherence to international, national and local laws. This should be supplemented with protocols,

standard operating procedures (SOPs) and codes of practice, which, while not necessarily legally binding, help to ensure a professional and ethical approach to the work. Local officials and community leaders may need to be consulted about traditional practices and culture.

Some legislation may limit what can and cannot be done. For instance, in certain countries, if investigations involve live animals, a registered veterinary surgeon (veterinarian) needs to be present to carry out specific procedures. In the UK, for example, if blood has to be taken from an animal for DNA testing, it is a veterinarian who carries out the sampling but s/he must be accompanied by a government wildlife inspector.

Health and safety are always important and may be covered by legislation. Wild animals, whether alive or dead, present certain dangers, such as those associated with physical attack (bites, scratches, goring), infectious diseases (zoonoses) and envenomation. Crime scene work in the field may also expose personnel to injuries (e.g. from rough or dangerous terrain or, in war-torn areas, unexploded ordnance) and to assault by poachers, guerillas, hostile witnesses or others. Those who handle or examine material at the crime scene should be issued with personal protective clothing (see Tables S1 & S2 at www.int-res.com/articles/suppl/esr00204_app.pdf) (PAW 2005).

The key to minimising dangers at the scene is a properly formulated Risk Assessment, a legal requirement in some countries but not necessarily carried out routinely in forensic investigations in many others (ME Cooper 2008). This is based on: (1) identification of the hazards; (2) an assessment as to who might be harmed and how; (3) evaluation of the risks and which precautions are appropriate; (4) recording of results of the evaluation and implementation of precautions; and (5) a regular review and update.

Working in the field. Fieldwork is usually an integral part of wildlife crime scene investigation and is therefore the main focus of this paper. The term fieldwork can be considered to refer to any forensic procedures that are performed away from the investigator's usual place of work, be it an office, laboratory or veterinary clinic (Cork & Halliwell 2002). Fieldwork usually involves a change of environment and often implies less than optimal equipment or backup facilities. Such activities necessitate careful assessment of the locations in which one is to work and making special provisions or adaptations that are required in order to operate successfully under non-standard conditions (Cooper 2004).

A frequent dilemma is how much of the forensic investigation to perform *in situ* — that is, at the crime scene — as opposed to collecting samples and transporting them back to a well-equipped laboratory, *ex situ*. Much depends upon the circumstances: the location of the crime scene and its accessibility, the type of investigations that are likely to be needed and the equipment and personnel (both at the crime scene and back in the laboratory) that are available. Sometimes, especially in high profile cases, safety, security and press (media) interest have also to be taken into account.

Some forensic investigations can only be carried out adequately in the field — the examination of animal footprints in sand or in mud are obvious examples. Others can, if necessary, be performed back in the laboratory — for example, faeces can be packaged and transported to a laboratory — but often it is only in the field that certain observations (e.g. the temperature or smell of those faeces) can be accurately assessed. Mobile medical and veterinary clinics can be purchased or constructed and may permit, for example, the performance of such useful forensic tasks as *in situ* radiography of specimens and storage of tissues at –70°C.

Permits or other written authority should be obtained in order to take possession of material from the crime scene or relevant to the investigation, where such possession is regulated.

Each situation really has to be judged on its merits.

In the succeeding text, we discuss the equipment, techniques and technology that are central to the performance of high quality, professional, wildlife crime scene work.

Equipment. Pepper (2005) detailed the numerous, varied, objects that may be needed for crime scene investigation, many of which are applicable to wildlife cases. Lawton and & Cooper (2009) expanded on this in the context of cases involving reptiles and amphibians.

Some basic tips regarding equipment are to compile your own checklist of items that you wish or need to take with you; there are standard ingredients that are always likely to be needed regardless of the circumstances (see Tables S1 & S2 at www.int-res.com/articles/suppl/esr00204_app.pdf). Also, you should always include spectacles, medication (a comprehensive first-aid kit) and other domestic items that can make life in the field more comfortable. However, be cautious about substances (e.g. mosquito repellent) that might contaminate evidence. All items to be taken on the scene must be scrupulously clean. This should be documented and may become evidential, e.g. where contamination by investigators is alleged. On leaving, after checking that evidence has not been removed, everything must be thoroughly cleaned and decontaminated.

Record keeping at the crime scene. Notebooks for written information are essential. These can be supple-

mented with a micro-cassette tape recorder, which can be used for dictated notes and to record sounds of interest. Inserting the tape-recorder into a sock or enveloping it in a cloth or a thin polyurethane foam sleeve will minimise wind noise.

Video recording is another useful way of assembling information at a crime scene. It should, whenever possible, be supplemented with photography, tape recording and the writing of contemporaneous notes.

Electronic data collection is increasingly important but is not always feasible in poorer countries. A hand-held computer can be invaluable in terms of its relative cheapness, compactness, long battery life, substantial digital data storage, ability to transfer stored data between the computer and a notebook or desktop personal computer and — often of great value at a crime scene — the making of tapeless digital recording of sounds.

Photography. Photographing and examining dead animals and other sensitive material at the crime scene is of great importance. It is best carried out without the attention of onlookers or the press. Privacy may be ensured by using canvas or sacking and aluminium poles or strong bamboo canes. Sometimes a lightweight tent can be used, especially where there is a need to protect items from rain, snow or sand.

All aspects of crime scene investigation are facilitated if a range of photographs is taken, but the photography must be of a high standard (Hart & Budgen 2008). However, any photographs from lay witnesses may have evidential value, where they can be provenanced. Digital cameras are invaluable. It must always be remembered that usually all that a court of law has for reference relating to the crime scene is photographs and evidence. Occasionally, however, a visit may be made to the crime scene to familiarise those adjudicating with the terrain and surroundings. The value of such an approach to wildlife crime cases is increasingly being recognised; an example was a case in France, when both a magistrate and his lawyer visited the site where a bear had been killed (Penketh 2005).

Cameras should be kept in the shade and protected from excessive moisture, particularly immersion in water. Seawater and alkaline (soda) water are especially harmful to photographic equipment. Spare batteries must be packed. If a film camera is being used, every effort should be taken to protect both exposed and unexposed photographic film from adverse environments. A padded container offers satisfactory protection for photographic equipment, provided the container is shaded. In the tropics, an alternative is to wrap the film container in banana or taro leaves, which provide excellent insulation.

Nowadays, in human forensic work, photography is usually a specialised discipline; this is in marked contrast to the situation in wildlife work where a professional photographer is not always accessible.

Specialised equipment. An advantage of having ornithologists and other naturalists involved in wildlife crime scene work (see 'Personnel') is that they often already have relevant equipment (such as that used for bird watching) that can readily be adapted to forensic studies. Examples include waterproof and submersible cameras and cases, night-vision kits, monitoring devices, GPS equipment and hand-held radios. If the investigations are likely to involve the capture and handling of animals, specialised items may be needed — for example, gloves, nets, bags, capture and restraining devices, binoculars, reference texts, avian ring (leg-band) pliers and remover, a magnifying glass and scales or balance.

Portable equipment. If wildlife forensic investigations are to be carried out under field conditions, it may be necessary to transport what would usually be considered standard equipment into difficult terrain. This may mean working far from roads or ready means of communication, with little or no access to clean water and without mains electricity (Cooper & Samour 1997). The climate may provide added challenges rather different from those of an air-conditioned or centrally heated laboratory. In poorer countries this can all be further complicated by shortage of fuel, unavailability of vehicles and poor or non-existent access to the internet and other forms of communication.

Under these circumstances wildlife forensic work may require:

- The preparation and use of portable field kits.
- The use of equipment, including microscopes and endoscopes, that can function mechanically, on solar energy or by using batteries.
- The construction of well-defined areas in forests, deserts, or elsewhere, where standard tasks such as necropsies can be carried out efficiently and safely.
- Ingenuity in the development of local environmentally friendly materials for laboratory and other investigations.
- Adaptability and resourcefulness on the part of those carrying out the work.
- A means of communication — or example, cell or satellite phones or radios.
- A well-rehearsed plan to deal with natural or anthropogenic dangers.

Modern scientific methods, especially those that are DNA-based, permit more and more information to be obtained from smaller and smaller samples. However, there is a paradox in this. As such forensic technology becomes more advanced, getting it out into the field where it is needed can be problematic because of the inaccessibility of the places where so many wildlife

crimes take place. This is particularly true in countries and regions that have suffered disruption because of war, social strife or natural disaster.

This is where portable field kits are so valuable. They provide the means to span the gap between modern (especially electronic and molecular) forensic technology and the isolated environment where such state-of-the-art science is sought. The design of a portable field kit depends upon its purpose. An essential feature is compactness; kits should be as lightweight as possible if they are likely to be carried by hand. The successful use of such technology in veterinary fieldwork has been described elsewhere (Frye et al., 2001) and much of the experience gained can be applied to forensic activity. Those involved in wildlife crime investigations likely to necessitate fieldwork should be prepared to put together, in advance, items for kits that can readily be transported and used even under adverse conditions.

Microscopes and other equipment that usually runs on electricity can and should be used in the field. In the past the McArthur microscope has proved ideal but this is no longer available commercially and a new, comparable, instrument is needed. One possibility is the Millennium Health Microscope (MHM), currently in preparation in Cambridge, UK. Battery-operated or solar-powdered (direct sun or solar panels) equipment that can be used for wildlife crime scene investigations in isolated locations includes miniaturised otoscope (auriscope), ophthalmoscope, rigid endoscope, colorimeter, electrocautery, blood-pressure monitor, respiratory monitor and pulse oximeter, minicentrifuge, miniphotometer, and refractometer. Lightweight flexible solar panels are commercially available. They can be folded or rolled and inserted into protective tubes for transportation to the field.

Technology. PAW (2005) is a useful guide to the use of forensic and other specialist techniques in the investigation of wildlife crime, especially in the UK. It includes information on specimen identification, poisoning and pesticide analysis, forensic veterinary pathology, taxidermy, DNA technology and other laboratory-based procedures. Some techniques that play a part in wildlife crime scene investigations are also discussed by Cooper & Cooper (2007) and Lawton & Cooper (2009) (Table 1). Some of these are discussed in

Table 1. Some techniques used in wildlife crime scene investigations

Category	Examples	Comments
Identification and morphological studies	Species determination using bones, skins, hair, feathers, scales and other organs and tissues	Involves gross, microscopic, isoelectric focusing (Lawton & Sutton 1982) and DNA-based techniques
Pathological studies	Examination of whole carcasses, organs and tissues from dead animals, and of samples from them and from live animals (see below)	Can include various supporting tests (e.g. radiology and other scanning techniques) and laboratory investigations (e.g. cytology and bacteriology) (Cooper & Cooper 2007, Munro & Munro 2008)
Clinical work	Examination and sampling of live animals	Supporting tests, as above, and others. Live animals should, whenever possible, be monitored using non-invasive or minimally invasive methods (Cooper 1998)
DNA technology	Species, sex and parentage determination, other investigations as above	A very important component of most investigations
Other laboratory tests, such as analysis of stable isotopes, trace elements, chemical residues and soil or sediments	Background information on the history and health of an animal, including its diet and (often) its movements	These and other methodologies are rapidly becoming available for use in both ecological and forensic studies. Various secondary specialists can be used, such as forensic geoscientists (Morgan et al. 2006)
Standard 'crime investigation'	Studies on ballistics, debris from explosions and fires, fingerprints, blood spatter, tyre marks, etc., plus tests on items that are more specific to wildlife crimes, such as non-ballistic weapons, nets and traps	These investigations are usually performed by police and specialists. Non-ballistic weapons are used to kill or to maim wildlife in many parts of the world. Even in North America, arrows (fired with a conventional bow or crossbow) are used to kill deer. In poorer parts of the world arrows, spears and catapults may be standard means of taking animals

more detail below, with particular reference to their applicability to the field.

Identification and morphological studies. In all wildlife crime investigations there is a need for accurate identification of animal products or derivatives (PAW 2005). Sometimes the species or its parts (derivatives) are readily recognisable as coming from a particular taxon, e.g. a dead parrot, a snakeskin, antlers of deer. Identification in such cases usually involves morphological studies — for example, examination of bones (Cooper & Cooper 2008a) or hair (Yates 1999), coupled with such DNA technology as PCR and sequencing, to identify certain especially cryptic taxa. When tiny portions of muscle, blood, bile or other body products are seized, DNA analysis is likely to be essential (Wolfes et al. 1991, Wolf et al. 1999). Often it strengthens the argument in a legal case if a number of techniques have been applied — for example, shahtoosh (the wool of the Tibetan antelope) is identified using both microscopical and DNA techniques (PAW 2005).

Identification of whole animals or their parts is facilitated if a range of photographs is taken at the outset. This is particularly true of species such as cetaceans, amphibians and fish, which will rapidly change in morphology as they decompose, become bloated or are scavenged. Photography should be accompanied by morphometrics (weighing and measuring). It should be followed by the collection of gross specimens as evidence and for 'reference collections' (see 'Reference material') and the selection of tissues for DNA and other studies.

Molecular diagnostics have revolutionised the investigation of wildlife crime (McDowall 2008). They permit the detection and differentiation of substances from different species (Wolfes et al. 1991) and provide information on genetic diversity that can assist in the conservation of endangered animal species (Zhang et al. 2002). PCR is particularly valuable in forensic investigation as it enables tiny samples to be identified. PCR is relatively inexpensive, but requires expensive equipment and specially trained staff. For reliable results (essential in a legal case), a designated clean area is required, together with barrier methods, including laboratory coats and disposable gloves.

Despite the high sensitivity and specificity of PCR, no one method should be relied upon absolutely when considering forensic evidence. Morphological methods of identification and additional molecular-based approaches must be an adjunct to it.

Notwithstanding these constraints, DNA-based and other molecular techniques are increasingly being applied to work in the field and thereby provide an alternative to transporting sensitive, sometimes pathogenic, material back to the laboratory. Much of the impetus towards developing such *in situ* tests has come from the need, in both human and veterinary medicine, to develop field diagnostic techniques. Thus, following the 2001 outbreak of foot-and-mouth disease (FMD) in the UK, when some diagnoses were being made only on clinical signs, rapid and accurate field techniques were investigated. As a result, a portable PCR instrument for FMD has been developed that can generate a result within 60 min (King et al. 2008). Similar methods are available for other diseases of humans and animals and the technology involved is increasingly applicable also to forensic studies.

Studies on ancient DNA have illustrated the importance of understanding how, and under what circumstances, degeneration of DNA occurs (Graham 2007). Sometimes even standard procedures such as freezing can render samples unsuitable for analysis because of loss of DNA integrity. Tissues that are fixed in formalin — sometimes the only fixative taken into the field — are likely to become denatured. Alcohol-based fixatives are preferable and can sometimes be compounded from local products. The ideal substrates for forensic DNA analysis are fresh samples of tissue (blood, muscle, etc.) collected using sterile techniques (not always easy in the field) from living or recently dead animals and preserved at –20°C in a dedicated freezer. However, this is rarely possible in forensic investigations and forensic samples frequently include small quantities of material, much of which is contaminated, of indeterminate age and obtained from an environment where conditions are less than ideal for the preservation of nucleic acids. In these cases, investigators may have to compromise by choosing the molecular markers most likely to provide the most meaningful data. Of particular consideration in this respect is the relative rate of degradation of nuclear DNA when compared with that of mitochondrial DNA, making the latter of value in studies on, say, hair, feathers and other keratinous structures (Wolf et al. 1999, McDowall 2008).

Pathological studies. Some investigations in the field seek not just to identify carcasses and tissues of animals but also to discern the circumstances of death. Some important examples, of especial relevance to endangered species, are given below. Post-mortem examinations should, whenever possible, be performed by an experienced comparative pathologist (Munro 1998, Cooper & Cooper 2007, 2008b, Cooper 2008).

The detection of lesions, wounds, bruises, abscesses and scars can be pivotal in determining how and when a wild animal died, or its health status prior to death. Samples will need to be taken but, in addition, photographs must be obtained as supporting evidence in court. Digital imaging enables the sending of pictures to experts in other parts of the world.

Post-mortem change (autolysis) can hamper investigation of carcases but, if properly investigated and analysed, can also provide useful information on when the animal died and the environmental features at the time. Gross and histological examination are often coupled with the investigation of invertebrates that are present within, on, or in the vicinity of the animal's body — so-called 'forensic entomology' (see below).

Wild animals killed or injured by humans need to be differentiated from those attacked by predators, e.g. a free-living raptor or mongoose or a domesticated dog or cat. This may not be easy. Some mammalian predators can be responsible for mass killings of ground-roosting or nesting birds; under such circumstances detective work, including detection of tracks (Ennion & Tinbergen 1967) will be needed to determine the sequence of events. Tooth, beak or claw/talon marks may assist in determining which predator killed the animal, as may the scene of the killing — for instance, whether portions of the prey are scattered or cached.

Post-mortem scavenging needs to be distinguished from ante-mortem predation. This is not always easy although basic criteria, such as that bleeding can only occur before death, can assist.

In investigations where carcases need to be collected for examination, scavenging and disturbance by wild, feral and domesticated animals can hamper collection of bodies and make counting difficult (Bumann & Stauffer 2002). In ecological studies the use of dogs has been advocated in order to increase the rate of recovery of carcases (Homan et al. 2001). However, caution must be exercised in forensic investigations as dogs will damage and destroy other evidence.

Traps, nets and snares are often used to catch wild animals. However, this is not necessarily, per se, illegal. Different species are trapped because they are pests, or for food or as part of scientific study. Traps, nets and snares can cause characteristic traumatic injuries, as well as stress and pain. Trauma is usually characterised by 'patterned injuries.' Traps produce crushing lesions; nets and snares cause strangulation or impairment to blood flow. Marine mammals have been the subject of much relevant research — for example, on the recognition and differentiation of net marks and of tooth (rake) damage (see, for example, Kuiken et al. 1994, Ross & Wilson 1996).

Poisoning of wildlife (including invertebrates) is widespread and its investigation can necessitate the input of scientists of different disciplines. Acute poisoning cases are usually most likely to be detected in the field because animals are found dead or dying.

Forensic entomology. A wide range of invertebrates, not all of them insects, can contribute to forensic studies. The best-known example is the association of certain species of dipterous larvae (maggots), carrion beetles and other taxa, usually as a faunal succession, with dead bodies and derivatives. Invertebrates may also be transported on an animal's body or be found in its bedding or container. Collection of invertebrates for study and as evidence requires strict adherence to well-established protocols. These include standard operating procedures to ensure that, for example, specimens are kept fresh (alive) for taxonomic studies and for possible rearing to adult stage as well as being fixed in alcohol (Cooper & Cooper 2007).

Maintaining a chain of custody is as important in forensic entomological studies as it is in any other field of forensic work.

Submission of evidence. How specimens and other evidence are submitted from the field to the laboratory can be critical to the success of a case (PAW 2005, Cooper & Cooper 2007, 2008b). Samples must be documented, properly packed, labelled and transported, with attention throughout to both ensuring the quality and integrity of the material and maintaining the chain of custody (Hart & Budgen 2008, Lawton & Cooper 2009).

Reference material. Properly prepared and catalogued collections of material from animals (e.g. feathers, hair or bones) are of great value in the investigation of wildlife crime. In addition to their use as sources of reference in court cases, they are important aids to teaching and research.

Very few collections relate specifically to animal forensics. The United States Fish and Wildlife Service (USFWS) has an excellent range of reference material at its National Fish & Wildlife Forensics Laboratory in Oregon, USA, and there are smaller, comparable, collections in the UK, Australasia and probably elsewhere. Bearing in mind some of the legal obstacles to moving specimens internationally (ME Cooper 1996), there would appear to be merit in each country or region having its own reference collection of wildlife material for forensic reference purposes.

This means that every effort should be made to collect relevant specimens and to establish reference collections. This is not an easy task and there may be advantages to join forces with conservation and other bodies that are collating 'voucher' material for other scientific purposes (Cooper et al. 1998).

CONCLUSIONS

Wildlife crime scene work is exacting. Working as a team is essential. Whenever possible, a planning meeting is advisable — an opportunity to bring everyone together and to minimise the risk of inadequate com-

munication before the investigation commences (Lawton & Cooper 2009). One person has to be in charge and brief the investigative team (see 'Personnel') but everybody must have an opportunity to speak and to comment. A systematic plan will ensure that all those involved are aware of the steps that will be taken, that the scene of the alleged crime is fully examined and that potential evidence is not lost or missed during the process.

It is essential to prepare well for site visits and fieldwork and to ensure that those involved are familiar with the necessary rules, SOPs and codes of practice. This is particularly important when backup or direction from the police or other experienced people is not available.

Training sessions provide an opportunity to plan crime scene work beforehand in a place that is readily accessible, such as a large garden, an area of forest or a disused building site.

Investigating wildlife crime is never easy. Many offences take place far from urban areas where enforcement agencies are usually based and where laboratories and scientific expertise are most likely to be found. Poorly equipped countries face particular problems and may have very limited facilities even *ex situ*. Richer nations are in a strong position to help but must do so in a sensitive way and as partners, not supervisors. They can, for example, offer training and provide necessary equipment (such as global information systems [GIS] and digital cameras) that will allow better detection of wildlife crime. Advances in tele-imaging methods that are now widely used for distant diagnosis of human and animal diseases, are increasingly allowing electronic data to be sent elsewhere for analysis rather than flying in expensive personnel. The opportunities for collaboration, especially in fieldwork, are great and should augur well for species protection.

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