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Review article

What is it vs Who did it? A review of the lack of human focused forensic evidence in the context of wildlife crime

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ABSTRACT

Wildlife crime suffers from low prosecution and conviction rates, with a lack of evidence and resources cited as hurdles to enforcement. Forensic evidence is used in human-on-human crimes to identify perpetrators and link individuals to criminal activity. Forensics approaches in the context of wildlife crime are heavily focused on non-human evidence using DNA barcoding to establish species and geographical origins. In human-on-human crime fingermarks and DNA profiling are two of the most recognisable forensic evidence types, both with significant global infrastructure, which contribute to prosecutions and convictions. Wildlife products can be the only physical evidence type available in a wildlife crime but attempts to recover human forensic evidence from them is a relatively unexplored area. The research that does exist demonstrates fingermark and touch DNA evidence can be collected in many contexts from several different species. Despite this there has been only one report of utilisation of this type human evidence recovery in wildlife case work. Failure to consider all potential evidence types has a negative impact on wildlife crime investigations. There is a need to experimentally assess the benefits and limitations associated with the collection of human evidence from wildlife items. This article introduces key factors that affect the recovery of human fingermarks and touch DNA evidence before focussing on the limited number of instances where these methods have been applied to wildlife forensic research and what considerations should be taken when developing further work in this field.

Introduction

Wildlife crime consists of a broad spectrum of activities, geographic ranges, and species of interest. The illegal wildlife trade (IWT) is one of the most recognisable iterations of wildlife crime and stands as a global crisis. Over 140 countries have reported incidences of either illegal import, export or transit of at least 6000 species [1]. Other well documented examples of wildlife crimes include, illegal poaching/-hunting/fishing [2], animal persecution [3,4] and nest/roost destruction [5]. Contributing to biodiversity loss [6], zoonoses risks [7], and violence [8], wildlife crime and its impacts are firmly on the radar of governments, NGO's and law enforcement agencies. However, despite its recognition, wildlife crime may still be underestimated or misreported in its scale, not wholly understood in its subtleties [9], and suffers from low prosecution/conviction rates [10,11], and failed interventions [12].

The UK, and elsewhere, tend to focus their interventions on critically endangered charismatic megafauna and the IWT [13,14]. Neither these species, nor the IWT, are fully representative of the diversity within wildlife crimes and evidence shows that species designated by IUCN as 'least concern' are still the target of illegal activities, such as human-wildlife conflict [15,16] or specimen collection [17]. Policies have often failed to make a positive impact on broader wildlife crime or at the domestic level, perhaps as a result of such hyperfocus on flagship species [13]. There are both proactive and reactive approaches to tackling wildlife crime. Proactive approaches focus on deterrence tactics; educational programmes, community engagement, alternative livelihoods, policies, and legislation aim to prevent and deter wildlife

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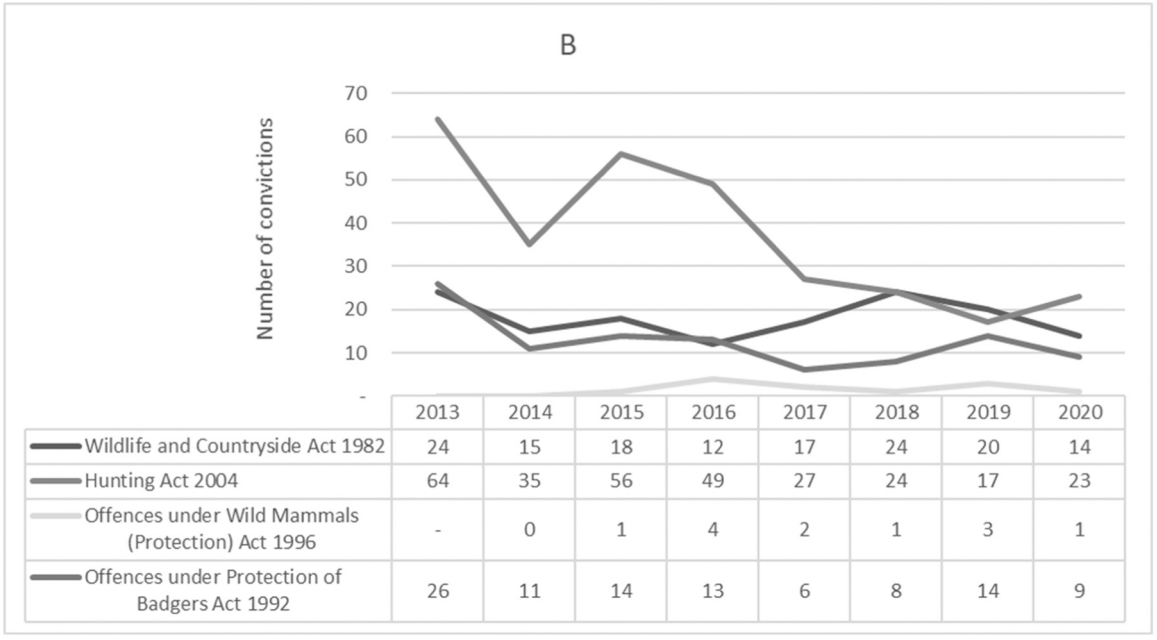
crimes from being carried out in the first instance. Reactive approaches include investigating crimes which have already been committed, enforcing the extensive national legislation and international agreements that exist and gathering intelligence which can feedback into more proactive work.

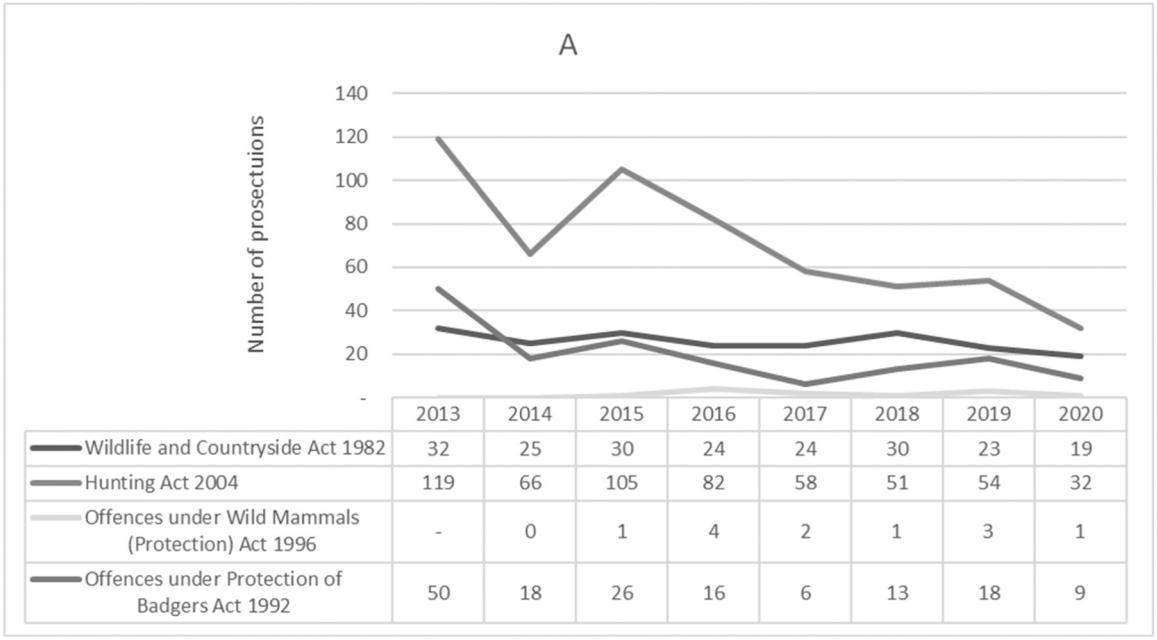
Enforcement success in wildlife crime has been varied; high profile arrests such as that of the "Ivory Queen" [18] suggest promising developments in targeting principal players in trafficking rings. However pre-pandemic seizure rates remained consistent or are increasing for a range of species [19], indicating such arrests are not acting as sufficient deterrents. Nations with high risk species have been found to struggle [20] while lenient sentencing is a repeated concern [11,21]. Suggested underlying factors that impede enforcement include; 1) limited resources, 2) overwhelming scale, 3) corruption, 4) apathy, and 5) ineffective deterrents [22]. These challenges lead to an inference that wildlife crime is a low risk, high reward activity [21,23].

A lot of wildlife crime discussion focuses on highly biodiverse low-income nations as key exporters of wildlife goods. However, enforcement problems are not isolated to these areas and high income nations which play a large role in imports also lack in this arena [11]. For example, the UK is well placed to support wildlife crime investigations; it has a government funded National Wildlife and Rural Crime Unit (NWRCU), stakeholder involvement through the Partnership for Action Against Wildlife Crime (PAW), as well as a clear policy describing their priority areas [6]. Though lauded for their contribution to international efforts to tackle wildlife crime, such as the IWT challenge fund, a recent UN report recommend the UK strengthen their domestic policies and efforts [24]. Advice underscored by the increased number of reports of crimes against badgers and bats, two priority species, [25] but decline in prosecutions and convictions under key wildlife legislation (Fig. 1a and b).

Across all nations and crimes, law enforcement seeks to achieve



	2013	2014	2015	2016	2017	2018	2019	2020
Wildlife and Countryside Act 1982	24	15	18	12	17	24	20	14
Hunting Act 2004	64	35	56	49	27	24	17	23
Offences under Wild Mammals (Protection) Act 1996	-	0	1	4	2	1	3	1
Offences under Protection of Badgers Act 1992	26	11	14	13	6	8	14	9



	2013	2014	2015	2016	2017	2018	2019	2020
Wildlife and Countryside Act 1982	32	25	30	24	24	30	23	19
Hunting Act 2004	119	66	105	82	58	51	54	32
Offences under Wild Mammals (Protection) Act 1996	-	0	1	4	2	1	3	1
Offences under Protection of Badgers Act 1992	50	18	26	16	6	13	18	9

Fig. 1. Number of prosecutions (A) and convictions (B) under four key pieces of UK wildlife legislation between 2013 and 2020.

positive and accurate identification of the human criminal(s) responsible, and the production of robust evidence to inform and direct criminal investigations. Evidence types are vast but one consistent evidence type utilised in criminal investigation for identification purposes is forensic evidence [26]. In the context of wildlife crime, forensics has seen significant investment in recent decades. Whilst veterinary forensic pathology has been regularly implemented to ascertain cause of death [27,28], species identification, through the use of DNA barcoding, has been the main focal area for identity forensics [29]. This work addresses the need to positively identify the species of wildlife and their derivatives for both case work and intelligence gathering, particularly in the absence of morphological characteristics. From it has stemmed the existence of databases containing animal barcode data, including the Barcode of Life Data Systems (BOLD) [30], GenBank [31], and ForCyt [32] as well as international and domestic collaborations including the African Wildlife Forensic Network [33] and PAW forensic working group [34]. The discipline has demonstrated its value by contributing to several wildlife crime investigations [16,35]. A natural progression from species identification has been the need for individual identification or parentage analysis. This has been used to help link individual wildlife parts to crime scenes [36], to link shipments [37], to identify individual animals from private collections [38] or to camera trap records [39], and to establish the number of individual animals that are victims in a crime [36]. Species identification and individual identification in wildlife crimes commonly employ mitochondrial DNA (mtDNA), and Short Tandem Repeat (STR) profiles of nuclear DNA (nDNA) respectively [29]. Within species identification universal primers have been developed for several mtDNA loci however the cytochrome *b* (cyt *b*) gene and the cytochrome oxidase 1 (COI) gene, are most commonly utilised [40]. STR typing uses the same concepts as human DNA profiling with multiple STR loci identified, in the case of humans 17–24 loci, and analysed to establish their size allowing a profile to be built. The sequencing of the human genome has allowed for human DNA profiling to become standard practice and multiple commercial kits be produced. To make STR typing as common in wildlife forensics it would require a similar rigorous approach to identifying suitable STR loci including a representative sample from the population; this is a daunting prospect for the thousands of species that fall victim of wildlife crimes many of which are critically endangered [41,42]. As such there are a minimal number of wildlife species STR typing has been developed for and due to the extensive resources required progression in this area is significantly slower [36]. One pressing limitation with the area is the need for high standards to be met, within both laboratories and practitioner communities, for wildlife forensic science to be taken seriously within the wider forensic and law enforcement community [43]. ISO/-IEC 17025 and 17020 accreditation is the internationally recognised standard, and often legal requirement, for forensic laboratories and practitioners to prove their competency to collect process forensic evidence [44,45]. A 2016 CITES and UNODC commissioned survey of 110 wildlife forensic associated laboratories found just 22 were externally audited under these standards [44]. Though a lack of accreditation does not equate to a lack of capability or skill, it may result in associated evidence collected or processed at/by these establishments/individuals being bought under scrutiny.

A more traditional use of forensics in criminal investigation is the application of human identity testing, often presented as fingermark or DNA evidence [26]. Global infrastructure for human identity testing, including accredited laboratories, is constantly growing [46] and a wealth of research, knowledge, techniques and tools exist for utilisation by law enforcement. Despite ongoing contributions to solving human-on-human crime the literature suggests its application and development, is low in wildlife crime contexts (Fig. 2). This is interesting given the theory and concepts behind both fingerprints and human DNA profiles have both been applied in wildlife crime contexts. Possible reasons for a lack of application and research in this area include i) the observed separation between practitioners of human and wildlife forensics, ii) a lack of awareness/interest by researchers as to the cross-applicability of the methods, iii) unpalatable costs associated with human forensic methods when investigations only lead to small penalties or iv) the methods are not applicable in most wildlife crime cases.

Regardless of the reason, the main aim of any criminal investigation is to identify a suspect and establish a link between the suspect and the illegal activity under investigation. Whilst species or individual identification of wildlife can establish if a crime has been committed and is of

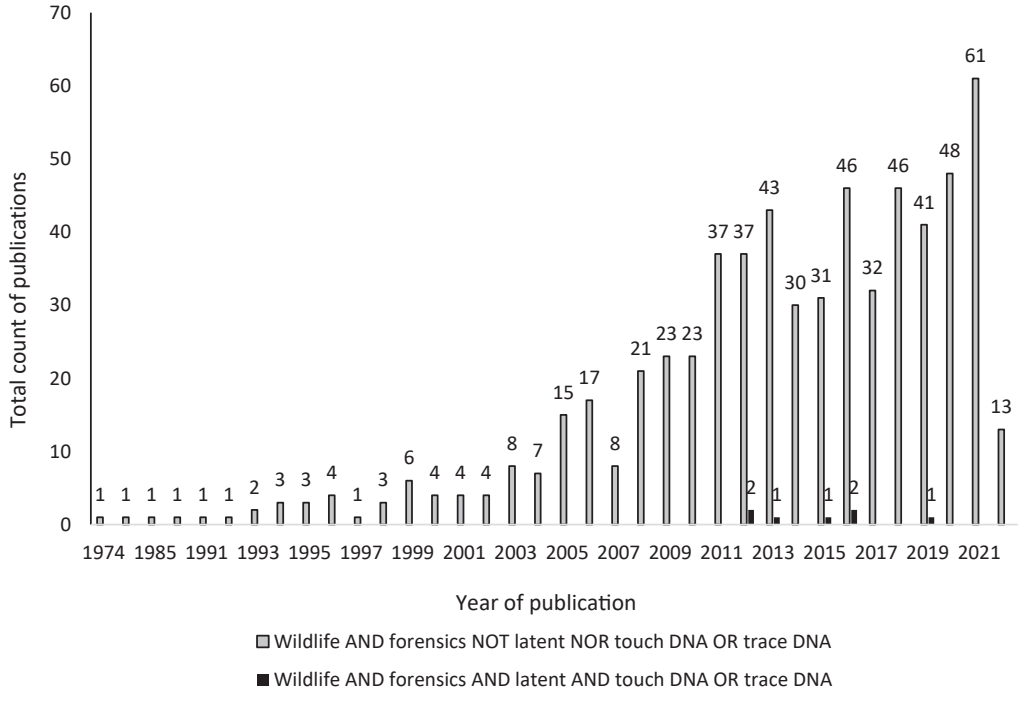


Fig. 2. Number of hits from a literature search using the Boolian terms “Wildlife” AND ”forensics” NOT ”latent” NOR ”touch DNADNA” OR ‘trace DNA’ and a literature search using the Boolian terms "wildlife AND forensics" AND including "latent” OR “touch DNA” OR “trace DNA”.

value in seizures where a suspect is claiming goods are of legal origin, it cannot always provide this link. Two recent UK cases of raptor and badger persecution demonstrate this phenomenon. In both cases carcasses, of white tailed eagles and a badger respectively, were reported to law enforcement with the condition of the carcasses rendering morphological assessment possible for species identification [47,48]. Both incidents occurred in rural areas with no immediate suspects and with the carcasses themselves appearing to be the only tangible evidence available. The position of the carcasses strongly indicated human involvement or handling. These types of cases suggest a logical need to increase the amount of human identity testing in wildlife crime investigation. Through this approach opportunity should present itself to increase the amount of evidence directly linking an individual to an associated crime, strengthening such cases where insufficient evidence is presented to identify a suspect or garner a conviction. Unlike species identification human based identification may also unearth links to other crimes, including those non-wildlife related, shedding light on the suspected crossovers in organised criminal networks [49].

This article reviews the two main forms of evidence used in human identity testing, fingermarks, and DNA evidence, and highlights the limited number of instances where they've been applied in wildlife crime research and investigations. This review was carried out in a traditional approach combining several evidence gathering methods including the identification of relevant stakeholders in the field; a review of UK government and policing related policy and guidance documents; identification through UKAS of common forensic methods used in human identification; and a trawl of the existing scientific literature of the most common methods.

Fingermarks: background and composition

All fingermarks are made up of a finite number of characteristics which present themselves as a unique pattern on an individual's fingertips. Once enhanced or recovered from evidence or crime scenes unidentified marks of sufficient quality can be compared against fingerprints of known individuals or against other unidentified marks to establish a match. Their composition changes almost immediately upon deposition, with time, environmental exposure and the substrate type (porous vs non-porous) all influencing longevity [50–52]. They are composed of an amalgamation of secretions (eccrine, sebaceous, and apocrine) coupled with skin or environmental contaminants (i.e. beauty products, food grease, pollen, dust) [53]. The immediate change to fingermarks occurs with the evaporation or absorption (dependent on surface type) of water and volatile lipids. Water loss results in a "waxier" fingermark as the remaining organic and inorganic compounds become concentrated. Salts will also crystallise and become vulnerable to physical erosion and UV exposure [52]. Over the course of around thirty days most lipid components of sebaceous secretions will reduce significantly; squalene and unsaturated fatty acids are lost first with saturated fatty acids and non-volatile lipids including wax esters and triglycerides being more durable [54–56]. As well as water, temperature, humidity, UV exposure and other forms of radiation contribute to the longevity of latent fingermark constituents [56–59]. Despite this volatility fingermarks have been recovered decades after deposition [50,60] and after days or weeks of environmental exposure [61,62].

For processing of unknown marks the Analysis, Comparison, Evaluation, Verification (ACE-V) approach is widely adopted [63]. Historically each phase was carried out by hand however increasingly countries are utilising biometric Automated Fingerprint Identification Systems (AFIS) in their workflows [64]. A traditional AFIS functions via algorithms focused on identifying and tagging fingerprint minutiae, specifically bifurcations and ridge endings (Fig. 3a), creating a "map" for comparison [65]. Three countries hosting large biometric databases, China, the USA, and the UK are notable players within wildlife crime either as import [66], export or transit countries [67] or as vocal advocates for improved international efforts [68]. The transnational nature of wildlife crimes is well documented and in this vein INTERPOL hosts an international AFIS accessible to member nations [69].

Fingermarks: crime scene and laboratory enhancement methods and photography

Latent fingermarks, those invisible to the naked eye, are the most common type of fingermark encountered at crime scenes with no reason to believe wildlife crimes would be an exception [71]. Initial detection of fingermarks allows for more targeted application of enhancement methods, conserving resources, and time. This is commonly achieved through multispectral forensic light sources or simple oblique lighting [72]. Once detected enhancement treatments, chemical, physical or a combination, allow for the visualisation of the fingermark. Treatments do not have to be used in isolation but due to the potential interactions between sequential treatments a strict order of approaches is followed [73]. A breakdown of the most common fingermark enhancement methods is provided in Table 1. For further analysis, and their utilisation and preservation as evidence, a record of an enhanced fingermark must be obtained, one of sufficient quality for repeated reference and identification. Photography using Digital Single Lens Reflex (DSLR) cameras is the most consistently used documentation approach, however with

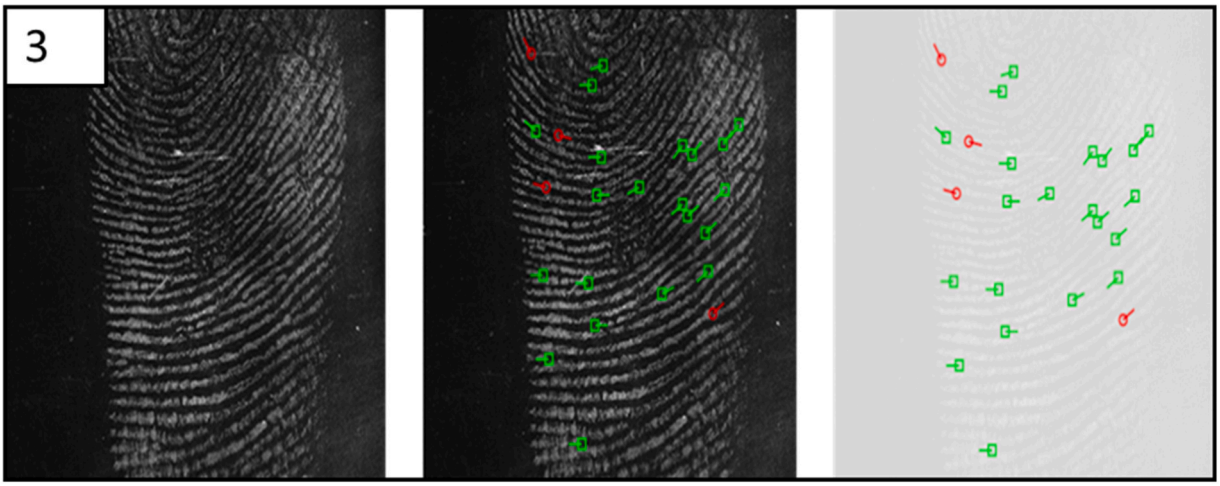


Fig. 3. (left) Latent fingermark with no mark-up in original state; (middle) Highlighted bifurcations and ridge endings as would be placed by an AFIS; (right) A "map" of minutiae that would be searched against. (2a). Images generated using Fingerprint Minutiae Viewer (FpMV) software [70].

Table 1
Common fingermark enhancement methods presented in order of their recommended sequential application.

Enhancement method	Theory	Practical limitations	Porosity	Physical or Chemical
Fluorescent examination	Exploitation of fluorescing constituents either within fingermarks or substrates to provide contrasting illumination.	Requires a dark environment which can be difficult to achieve outside laboratory conditions.	Non-porous, semi-porous, porous	Physical
Powder	Applied directly to a substrate with the design of having a stronger affinity to fingermark constituents comparable to the surface they have been deposited on	Poor application technique can result in damage to the fingermark.	Non-porous, semi-porous	Physical
Powder suspensions	Fine powder incorporated through a solution of detergent and water believed to interact with eccrine and sebaceous components of fingermarks.	Requires a water wash step after application which can be messy and impractical to contain at a scene.	Non-porous, Semi-porous	Physico-chemical
Vacuum metal deposition (VMD)	Functions via the sequential evaporation of metals (gold, zinc) onto a surface within a vacuum. Fatty acids within fingermarks inhibit the layering process so that they become visible within the coated substrate.	An expensive process requiring specialist equipment and training. Irregular shaped objects can be difficult to process if areas are shielded from direct line of evaporation vessels	Non-porous, semi-porous	Chemical
Ninhydrin	Targets the amine group within amino acids and constituents within eccrine sweat triggering a colour change reaction known as Ruhemann's purple.	Optimal process conditions are difficult to achieve at scene and humidity oven size in laboratory limits the size of items which can be processed.	Semi-porous, porous	Chemical
Basic Violet 3	A staining process which targets sebaceous sweat constitutes, shed skin cells and other contaminants to produce a purple mark.	The rinsing step can make containment of the hazardous dye difficult at scenes	Non-porous	Chemical
Cyanoacrylate (superglue) fuming	Polymerisation of ethylcyanoacrylate (superglue) triggered by water within eccrine sweat results in the accumulation of a "noodle-like" structure presenting as a white residue onto a fingermark	Optimal process conditions are difficult to achieve at scene and cabinet size in laboratory limits the size of items which can be processed.	Non-porous, semi-porous	Chemical
1, 8 – Diazalfluoren – 9 – one (DFO)	Reacts with amino acids within a fingermark resulting in a fluorescence which must be subsequently viewed using fluorescent examination	The reaction is initiated through heating making it problematic to carry out at scene.	Semi-porous, porous	Chemical
Physical developer	Fingermark constituents trigger a disturbance within a stable silver-based solution resulting in deposition of silver at the disturbance site.	Highly impractical to implement at scene. Cannot not be followed up by subsequent enhancement techniques.	Semi-porous, porous	Chemical

Source: Adapted from the Fingermark Visualisation Manual [73].

the ever increasing availability of affordable high quality smart-phone cameras research is being done surrounding their use as a tool in latent print photography [74]. Alternatively the use of physical tools, including tape, gellifters and silicone, allows for the removal of the fingermark from the substrate itself [73]. Successful fingermark lifting is of particular importance on curved, irregular, or highly reflective surfaces where photography can be problematic [75,76].

Fingermarks: application of methods in wildlife crime

Much of existing fingermark recovery research has been focused on "traditional" crime scenes and evidence types; these include vehicles, weapons, clothing and household goods or infrastructure such as doors and window frames. This focus has spilled over into the wildlife crime context with fingermark recovery attempted on similar substrates in environments associated with wildlife crime activity [77]. A less traditional evidence type but one of vital importance in wildlife crime are animals and their derivatives. Comparative to "traditional" evidence types there has been minimal research of fingermark recovery in this area. The research that does exist can be loosely grouped into surface type and are as follows; leathers and skins inclusive of mammalian and reptile species, ivory, horn, antlers, feathers, eggs, fur, and pangolin scales (Table 2).

Fingermarks: leather and skins

Leather and animal skins are commonly encountered animal products most often seen in the guise of accessories such as wallets or belts and upholstery such as car seats. As such they are regularly encountered in non-wildlife case work and enhancement of fingermarks from these items are among some of the earliest associated work in this hybrid area. Leather is considered a problematic substrate due to its texture, porosity, and the multiple process stages it may be encountered in [73]. Despite the regularity in which leather items are encountered in criminal investigations success in fingermark retrieval is lacking [87]. Vacuum metal deposition (VMD), superglue fuming, iron oxide powder suspension, a combination of superglue and iodine fuming and the development of a novel fingerprint development membrane (FDM) with a ninhydrin developing agent have all proved successful [77,87–89] at developing identifiable marks on a range of leather types. However, results are often inconsistent, and many marks enhanced of poor quality. Due to the intensive processes involved in its creation, including tanning and dyeing, the properties of leather differ from the raw original skins it is derived from. The only work carried out retrieving fingermarks from raw animal skins is through the substitution of domestic pig skin for human skin in associated research [90,91]. Black magnetic powder and cyanoacrylate fuming have both proved successful in recovering fingermarks off pig skin, even after environmental exposure but the onset of putrefaction quickly deteriorates marks [92]. Although there are few similar "hairless" mammals that these methods could be trialled on the ones that do exist, including hippo (*Hippopotamus amphibius)* and elephant *(Elephantidae sp.),* are high value targets within IWT [93,94]. However, movement of such large species into laboratory environments for chemical enhancement techniques such as cyanoacrylate fuming is unfeasible.

Reptiles represent one of the most trafficked wildlife groups, entering both legal and illegal markets as live specimens destined for the exotic pet trade and coveted reptile skins/leathers for high-end fashion markets [95–97]. Studies indicate that despite appearances reptile skin has some degree of permeability to contaminants and water [98,99] and likely fall under the "semi-porous" category. As a surface type for retrieving fingermarks there is additional complexity with background patterning and scale structure risking interrupting ridge lines, however marks have been successfully enhanced on both snake and lizard species [100]. Notably this work was conducted on both live and deceased specimens, making it applicable to both live seizures and worked goods.

Table 2
Breakdown of existing studies investigating methods of fingermark recovery from wildlife specimens.

Group	Substrate type	Deposition method	Deposition type	Enhancement	Visualisation, Collection & Photography	Variables	Specificity	Maximum grade achieved	Reference
Avian	Feather	Undirected	Ungroomed	Black magnetic powder (BMP), Black magnetic powder (BMP), magneta flake, red and green magnetic fluorescent, aluminium flake and magnetic bi-chromatic powders and cyanoacrylate fuming	Nikon D5100 digital SLR camera with an 18–55 mm lens or a 60 mm micro-Nikon lens + Mason Vectron Quasar 2000/30 connected to an Integrated Rapid Imaging System (IRIS)	Time	Positive enhancements obtained using red and green magnetic fluorescent up to 21 days after deposition.	4/4	[78]
Avian	Egg	Undirected	Ungroomed	BMP, Black magnetic powder (BMP), magneta flake, red and green magnetic fluorescent, aluminium flake and magnetic bi-chromatic powders and cyanoacrylate fuming	Nikon D5100 digital SLR camera with an 18–55 mm lens or a 60 mm micro-Nikon lens + Mason Vectron Quasar 2000/30 connected to an IRIS	Time	Usable prints obtained using black magnetic + magnetic bi-chromatic up to 14 days after deposition	4/4	[78]
Avian	Egg	Consistent pressure 10 s	Ungroomed	Cyanoacrylate fuming + Basic yellow 40 dye	Variable light sources + DSLR camera + Mason Vactron Quaser 40 MH + Canon EOS 5D Mark II with a 100 mm f/2.8 L-series macro lens	None	Usable prints obtained, with an increase in grade achieved through the use of viewing filters.	3/4	[79]
Avian	Feather	Consistent pressure 2 s	Groomed + Ungroomed	Green magnetic fluorescent powder	Blue Crime-Lite 82 S (10 % bandwidth 420–470 nm with a 445 nm peak) + yellow long pass filter (1 % cut-on point – 476 nm) + Nikon D200 with 40 mm f2.8 Nikon micro lens	Time + Environmental exposure	Usable prints obtained up to 60 or 14 days after deposition when stored indoors or outdoors respectively	4/4	[80]
Mammal	Ivory	Undirected	Ungroomed	BMP, Small particle reagent (SPR), cyanoacrylate fuming, BMP and VMD	Undescribed	Time	Usable prints obtained after two weeks using cyanoacrylate fuming	Not described	[81]
Mammal	Ivory	Medium pressure 1–2 or 10 s	Ungroomed, sebaceous and amino acid pads	Supranano Black Magnetic and Black Powder, Jet Black magnetic powder and cyanoacrylate fuming	Adhesive tape and a Nikon D4 camera fitted with a 105 mm Macro Nikkor lens and a 532 nm laser	Time + Sensitivity	Powders with particle sizes < 40 μm performed best, with usable prints recovered up to 1 week after deposition and positive enhancement achieved ridge up to 28 days post deposition	6/6	[82]
Mammal	Antler/ Horn	Undescribed	Deposited in blood	Vapour phase cyanoacrylate + R. A.M stain, leucocrystal violet	Forensic light source + photography	None	Positive enhancement achieved using both described techniques	Not described	[83]
Mammal	Antler	Undescribed	Undescribed	Cyanoacrylate fuming + Volcano Black granular fingerprint powder, iodine fuming, ninhydrin, silver	Copy stand lighting + 4 × 5 Crow Graphic Camera	Moisture + Temperate + Time	Usable prints obtained using magnetic fingerprint powders up to 16 h after deposition	Not described	[84]

(*continued on next page*)

Table 2 (*continued*)

Group	Substrate type	Deposition method	Deposition type	Enhancement	Visualisation, Collection & Photography	Variables	Specificity	Maximum grade achieved	Reference
				nitrate, magnetic fingerprint powders					
Mammal	Scale (pangolin)	Undirected 5 s	Ungroomed	None	Gelatin Lifters + GelScan + Photoshop	Time	Usable prints obtained up to four months after deposition	4/4	[85]
Reptile	Scale	Undescribed	Sebaceous	Cyanoacrylate fuming + rhodamine stain, white or black fingerprint powder	Polilight w/ 590 m barrier filter + photography	None	Usable prints obtained using both methods on a range of species	Not described	[86]

On live specimens Lightning White Fingerprint Powder® showed the most success, likely due to the contrast it produced against the patterned scale coloration of many species tested. Lightning Black Fingerprint Powder® successfully enhanced marks on more uniform light reptile skins such as the ventral side of alligator (*Alligator mississippiensis*). Cyanoacrylate fuming coupled with rhodamine fluorescing stain examined using 530 nm wavelength viewed through a 590 nm barrier filter was effective at enhancing marks on multiple deceased species specimens. These same species also had marks successfully enhanced by fingerprint powders. In keeping with existing knowledge of surface type influence on fingermark retrieval it was reported the smaller and rougher the scales the more limited the enhancement success. In this research the movement of live specimens either led to the destruction of powdered marks or problems with image capture. Within the IWT trade transport conditions of live reptiles is often poor [101]. When subjected to transport conditions it has been found reptiles can demonstrate periods of prolonged inactivity [102]. Though improving the welfare of the animal would be of an immediate priority, this temporary period of inactivity could prove useful for fingerprint powdering in cases of seized reptiles. The issue of movement could also be overcome by use of newly developed techniques such as gellifters which could recover enhanced marks from the body of the animal in a non-invasive manner.

Fingermarks: feathers

Globally it is suspected that avian trafficking is underreported and that a significant proportion of animals are trafficked live for the pet trade [103]. Other species, particularly raptors, are persecuted for their perceived threat to livestock or game species such as grouse [104]. Feathers are a unique structure amongst birds and with their interlocking barbs and barbules resembling fabric weave, which at a macro level renders them as a porous material. Unlike fabric, feathers are at a high risk of disturbance from handling or environmental exposure with barbules readily separated. Coupled with the often-flamboyant colours and patterns on feathers which hinder the ability to render strong contrasts between mark and background, it makes them a difficult surface type for fingermark retrieval. There have been just two complimentary pieces of research looking into fingermark retrieval from feathers [105,106]. For fabrics, VMD and cyanoacrylate fuming are the recommended approaches for fingermark retrieval with VMD the favoured approach on natural materials; powders of any kind are suggested as ineffective [73]. VMD has not been attempted on feathers but cyanoacrylate fuming has, and been found to be one of the least effective approaches [105]. It was postulated this was due to the hydrophobic nature of feathers but as cyanoacrylate is regularly used on non-porous and inherently hydrophobic surfaces it is more likely the porosity of the feathers was a contributing factor as superglue fuming is not recommended on porous materials. Fluorescent magnetic powders, specifically red and green were found to be the most consistently successful enhancement technique under controlled conditions.

The species trialled in these studies, kestrel, sparrowhawk, buzzard, red kite, and golden and white-tailed eagles have similar colour plumage, and as fabric comparisons were the underlying theory of approach plumage weave count rather than colour was a key focus. However, if fluorescent powder enhancement is to be a continued line of research plumage colour may be an important future consideration. Birds light sensitivity range sits between 300 and 700 nm, this is inclusive of the UVA (320–400 nm) end of the UV spectrum (100–400 nm) [107]. Feathers of several bird species, including heavily trafficked brightly coloured parrots and songbirds, have been found to fluoresce under UV light [108,109]. This may impact the ability of a fluorescing mark to stand out against a fluorescing background and considerations should be taken when considering which colour powders and subsequently wavelengths to use during enhancement and photography.

The second piece of research looking at fingermark recovery from feathers focused on environmental effects over time on green magnetic fingerprint powder development [106]. Marks were recovered up to 21 days after deposition with the location of the feathers, semi-protected or not from the elements, and precipitation having a significant effect on the success rates of recovery. Some relationship was also seen between both soil and air temperature and successful mark recovery. Marks recovered from control feathers left indoors were recovered up to 60 days after deposition. As noted by the author happening upon a singular feather, as used in this study, is an unlikely scenario in case work. A whole, or part, carcass is commonly seen in raptor persecution cases. These are at risk of scavenging and the likelihood of feathers and thus marks being disturbed. Even in these instances knowledge that identifiable marks can be recovered after such long periods is beneficial; even if minutiae detail has been disturbed there is still opportunity to identify handling sites for subsequent swabbing for DNA recovery. For live trafficking, the nature in which birds are often packaged, stuffed in tubes or bottles [110], and the inevitable movement of the birds themselves mean chances of mark recovery from feathers will be greatly diminished and there are greater opportunities for mark recovery from the packaging. It is important to consider these types of contexts when deciding which types of wildlife specimens to trial forensic techniques on.

Fingermarks: eggs

Egg theft and egg smuggling is a separate vein of avian associated wildlife crimes [111]. Eggs are easily concealed and have been known to be worn on a person's body for transport purposes [112]. Therefore sophisticated trade routes are not always a requirement and individual criminals can have devastating impacts [113–115]. Egg shells are widely diverse in size, shell thickness, and surface pattern, and importantly to fingermark enhancement shells are porous. This porosity, which varies inter and intra species [116,117] allows the exchange of oxygen and carbon dioxide and is an important consideration for potential enhancement treatments if dealing with live eggs. Research on

fingermark recovery from eggs as a food item initially found limited success with small particle reagent (SPR), a type of powder suspension [118]. A later study concluded cyanoacrylate fuming followed by rhodamine 6 G treatment was the most effective treatment but found best results when the egg had been refrigerated for fifteen minutes prior [119]. Both these studies require potential life-threatening interference with the egg, submersion, refrigeration, and exposure to toxic substances and as such not suitable for application in many wild egg theft crimes.

Research in this area with a focus on wildlife crime found black magnetic powder had a 96 % success rate at positively developing fingermarks on bird of prey eggs with enhancement possible up to 14 days after deposition [105]. The authors considered eggs as a non-porous material but with the knowledge of the inherent porosity of bird's eggs, a semi-porous designation is also appropriate. Given this, powder suspensions become a viable option for attempts at enhancement however the involvement of surfactants and need to wash the object makes their application to live trade limited. The only other study investigating fingermarks on non-domestic avian eggs also utilised cyanoacrylate fuming but with a subsequent Basic Yellow 40 dye treatment [120]. Different wavelengths were used to excite fluorescent components within the fingermarks but resulted in maximum grades of just one and two (on a scale of zero – four). When viewing filters were applied marks increased in quality up to grade three overcoming the patterned background of lapwing and grey partridge eggs. Despite their light uniform coloration, the same results were not achieved on Canada goose and White-tailed eagle eggs. These species possesses more notably porous egg surfaces, and the failure was attributed to the potential for the eggs to absorb the Basic Yellow 40 dye across its whole surface obscuring latent prints. In these studies no effort was made to lift the fingermarks despite the smooth uniform surface of eggs being an ideal candidate for attempts with gellifters. If the quality of the fingermark can be retained during the lifting process, analysis may be significantly easier as the problematic patterned background factor would be removed without the need for cycling through various wavelengths.

Fingermarks: ivory, horn, and antler

Ivory, horn, and antler are commonly associated with a wide variety of wildlife crime activities, with deer poaching being one of the UKs priority areas. Some of the earliest studies focusing on contextual fingermark retrieval from wildlife parts were on deer antlers related to poaching cases [121]. Mature antlers are exposed, regenerative, porous, rough bone which exist in different developmental states including a velveteen stage. On mature antlers, black magnetic fingerprint powder was found to be the superior method for consistent fingermark retrieval compared with cyanoacrylate fuming, ninhydrin or granular powders [121]. Over several days fingermarks became increasingly more difficult to enhance, presumed to be due to the porosity of the antlers causing absorption of constituents. Work on latent print enhancement on human bone drew similar conclusions also finding black magnetic powder the favoured technique [122]. Chemical enhancement was hindered due to the reactions with organic material within the antler, with ninhydrin turning the entire surface area of the antler purple rendering any contrast to surface and ridge detail minimal. A similar phenomenon was seen with leather [88] demonstrating a theme with the application of chemical enhancement methods on organic materials. Further work expanded to include enhancement of bloody fingerprints on both antler and horn, a keratin based substance [123]. The study concluded cyanoacrylate fuming followed by fluorescent dye stains to be a viable technique for latent fingermark enhancement differing from the conclusions drawn in the first study. It should be noted no attempt at comparisons with other enhancement techniques were attempted and no description of the maturity of the antlers given. The porosity of antlers decreases over time making their growth stage of vital importance to viable fingermark enhancement techniques [124].

A perceived issue of fingermark enhancement for many animal products is their rough surface, as generally the smoother the surface the easier it becomes. Of all high risk trafficked animal products the smooth surface of polished ivory appears an appropriate case study to trial techniques. Whilst the term ivory is most commonly attributed to elephant tusks the term itself is applicable to several commercially traded mammalian teeth or tusks including elephant, walrus, narwhal, some toothed whales, hippo, and warthog [125]. Several of which have recently been included in the UK's Ivory Act 2018 [126]. Ivory is porous, comprised almost entirely of dentine with a thin layer of cementum, and in both elephants and walrus tusk tips are coated in enamel but this is eventually worn away and absent in older animals [125]. Hippo ivory is sourced from both their upper and lower canines and their enamel layer is more permanent covering about 2/3 of the tooth. To date there are two published studies investigating latent fingermark enhancement on ivory, both elephant, conducted 15 years apart [127,128]. Both studies found Black Magnetic Powder (BMP) (standard and reduce scale powder respectively) suitable enhancement techniques including in a field setting. The main development seen between studies was increased success rate for longer intervals between deposition and enhancement, with the reduced scale (Supranano™) powder successfully enhancing prints up to 28 days after deposition. As an indicator of the continued focus on megafauna, this research has spawned the largest uptake in interest in application of fingerprinting techniques in wildlife crime cases and demonstration of its value. Kits have been produced and distributed both domestically and overseas with NGO support, with reports that use of these techniques have directly led to arrests [129].

Fingermarks: pangolin scales

Pangolin scales have recently become a high profile evidential item in IWT, in response countries have carried out actions specific to the pangolin species [130]. Despite this and several other international interventions to curb it, historical and continued demand has resulted in seizures containing tens of thousands of individual scales, representing thousands of individual pangolins [131]. Though the number of seizures continues to increase these are not synonymous with conviction and arrest rates [10,132]. Pangolin scales are keratin based, overlapping to form a protective layer on the dorsal side. The surface presents as a smooth material with shallow grooves running vertically from the tip to the base. Under scanning electron microscope they have been revealed to be non-porous, opening up the number of enhancement methods available to them [133].

One attempt has been made to retrieve latent prints from pangolin scales using gelatin lifters [133]. Gelatin lifters are used to recover both treated and untreated latent marks, then subsequently scanned or photographed and enhanced using software such as Photoshop™ [134]. Latent marks on pangolin scales were retrieved up to four months post deposition and whilst the mean grade failed to reach over two point five for any time frames over 28 % of all grades were three or above, and as such considered of forensic interest. There is sound logic behind the proposed use of gelatin lifters as a tool for use in wildlife investigations; they are affordable, portable, durable, and pliable, allowing them to be applied to uneven surfaces and used in field settings where chemical or traditional powdering techniques are unsuited and in nations with minimal resources. Limitations for this method start to creep in surrounding documentation of the latent prints. Optimum photography is carried out using specialised GLScan equipment, a large stationary scanning machine. As it currently stands to achieve best results practitioners would be required to collect marks in-situ and transport to the nearest lab with a GLScan machine which could be a significant distance or even located in a different jurisdiction. The research proposed the use of smart phones as an alternative, a method which is increasingly being investigated [135,136]. A second limitation is the fact that individual scales, such as those used in this study, are usually recovered in large quantities. With minimal resources available to wildlife crime case

workers analysis of hundreds or thousands of individual scales is impractical. Live or whole pangolins are traded on a smaller scale [137] and present a more practical example of case work where gelatin lifters could be applied. However due to the overlapping scales on whole specimens there is higher opportunity for latent marks to bridge multiple scales or be destroyed from friction of rubbing scales. Application of gelatin lifters also relies on an informed idea of the existence and positioning of a latent mark, without this a gel may be applied in a manner which cuts through a mark. As such this work would benefit from a preliminary step of investigating techniques for visualising latent marks, through oblique lighting, forensic light sources, or powdering.

Touch DNA - background and composition

Like fingermarks, DNA profiles are used in forensic investigation to identify an individual and can be full or partial in nature [138]. The laboratory pipeline for the processing of human DNA evidence is well established with validated methods and instrumentation available. The aim of forensic DNA analysis is to generate a STR profile amplified from a series of known loci, each displaying a maximum of two alleles in a single source profile (Fig. 4). The data is reduced into a string of allele repeat numbers that can be compared to a reference sample or searched against a national or international DNA databases. During criminal investigations, DNA may be sampled from sources including blood, hair, saliva, and semen left behind at crime scenes. However, in non-violent crimes where injury or physical human-human abuse has not occurred, touch DNA, that which is transferred from person to object via physical contact, may be recovered [139,140]. Like fingermarks, the factors that affect the presence and retrieval of touch DNA include pre-factors such as the donor, handling time, surface type and post-factors like time since deposition and environmental exposure [141–143]. This is not to imply that as evidence types they are one of the same; although DNA can be recovered from fingermarks [144], fingermarks can exist without detectible DNA, and touch DNA can exist independent of fingermarks. Current understanding of the cellular contents and origins of touch DNA is limited with many possible origins noted including cell free DNA [145], anucleate corneocytes [146], nucleated epithelial cells from hands [142] and fragmentary cells [147]. More recently, it has been proposed that touch DNA originates from various locations or bodily fluids, specifically shed keratinocytes from the outer layers of an individual's hand, nucleated epithelial cells from fluids (e.g. eyes, saliva, nasal fluids) or body parts in contact with hands and cell free DNA either endogenous to the hands (e.g. sweat) or transferred onto the hands [142].

Touch DNA – crime scene recovery methods

To maximise the chance of obtaining a full DNA profile it is important to use a device that can provide an efficient and selective collection of traces, to preserve their integrity by limiting contamination and degradation and to allow an effective recovery of biological material. A large number of collection methods exist including, wet/dry single or double swabbing [148,149], taping [150,151], FTA paper [152], scraping [153], vacuum sampling [154] and cutting [155]. The efficacy of the methods varies based on the substrate and therefore, like fingermarks, become important factors to consider when collecting human touch DNA.

Swabbing

Swabbing is the most widely used method of collection due to its versatility and ability to sample in hard-to-reach areas. The number of swab types and manufacturers producing vastly different products and researchers with varying results conducted in controlled conditions raises questions about the suitability of swab types, whether they meet scientific criteria and are the best choice for specific sample type and

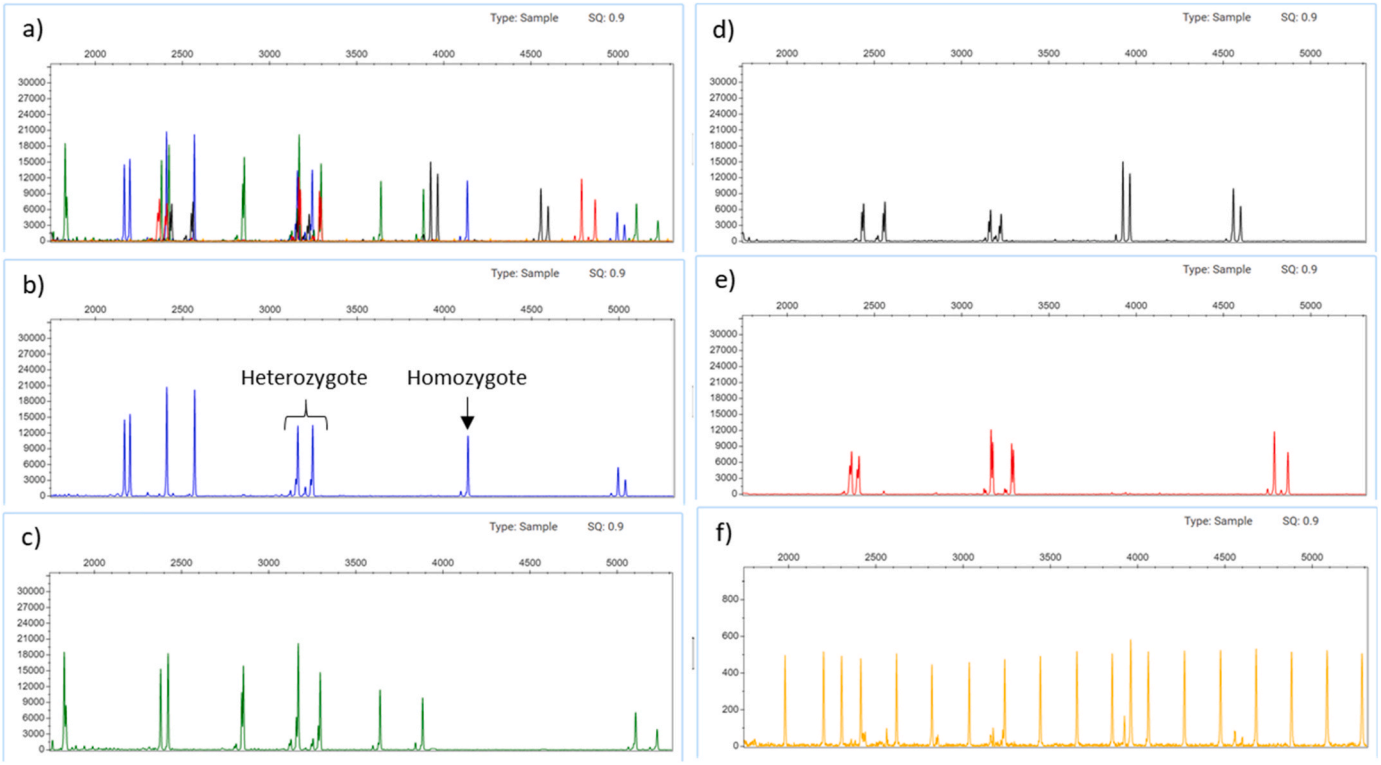


Fig. 4. A single source human STR profile viewed on Genemapper software with Relative Fluorescent Units (RFU) on the Y-axis and fragment size (base pairs) on the x-axis. (5a) Overlay of five channel spectra showing all full STR profile. (5b) Five STR loci amplified in blue channel showing example heterozygote and homozygote alleles at loci. (5c) Five STR loci and Amelogenin amplified in green channel. (5d) Four STRloci amplified in yellow channel. (5e) Three STR loci amplified in red channel. (5 f) Size standard used to identify fragment length of STR alleles presented in orange channel.

substrate. The effectiveness of a swab is influenced by several factors: the material, the thickness and length, how tightly the material is wound, the shape, design and whether the swab or transport tube preserves the DNA [156]. The double swabbing wet/dry method [157] has been suggested as the most effective swabbing technique with data showing that blood from a singular substrate (glass) can be collected using a range of swab types following this technique [158]. This method has also been identified as usable for touch DNA from both primary and secondary transfer [159,160]. Cotton swabs are most used due to their low cost, simplicity of use and ease of transportation for police and forensic departments although nylon flocked swabs and foam swabs are both well researched alternatives. Research looking into the most effective swab type assessed the Prionics cardboard evidence collection kit, COPAN 4N6FLOQSwabs, Puritan FAB-MINI-AP and Sarstedt Forensic Swab with data suggesting that the Copan flocked swabs presented the best overall performance [161]. The type of buffer solution used to wet the swab has been reported to affect the ability to dislodge and recover touch DNA bound to surfaces [162,163].

Adhesive lifting tapes

Lifting tapes are commonly in use today for the recovery of textiles fibres, hair, shoeprints, fingerprints, gunshot residues, cellular material and DNA as they are efficient non-destructive methods for obtaining concealed DNA [164] and can be used similarly to swabs for sampling specific locations on items or larger areas [165]. Taping for trace evidence consists of repeatedly pressing the sticky side against a material or surface and lifting for subsequent DNA extraction and comparison to swabs suggests Minitapes recover higher DNA concentrations except when used on non-porous surfaces [161]. This is also observed in other research which has shown that BVDA Gellifters and Scenesafe FAST tape outperform traditional cotton swabs when sampling fingerprints from 100 % cotton [149]. The conclusion being that BVDA Gellifters and Scenesafe FAST tape could be used as a substitute for cotton swab as they perform equally or better than cotton swabs particularly when collecting touch DNA samples. Further work has shown higher DNA recovery rates for mini-taping and scraping sampling methods independent of the substrates [148]. It can be seen from these studies that tape lifting is a suitable method of collection for both fabrics and non-porous surfaces such as plastic. Although it has been proven that stronger adhesion leads to higher yield of touch DNA, the tack complicates the extraction process leading sampling to be labour intensive.

For the processing of both swabs and lifting tapes DNA can be lost at both the extraction and quantification steps [166,167]. With the already low levels present in touch DNA it therefore becomes important to choose the most efficient workflow for processing samples. In this regard direct PCR amplification is increasingly being used for touch DNA samples so that potential loss of DNA can be circumnavigated by avoiding the extraction, purification, and quantification steps [168].

Touch DNA: application of methods in wildlife crime

Touch DNA: deer

Like fingermark research some of the earliest attempts at human touch DNA retrieval in the context of wildlife crime was conducted in response to deer poaching. Mini-tapes, a common tool used for touch DNA retrieval from clothing [150], were tested for use on limbs of deer handled by hunters [169]. The method was successful but due to the low levels of DNA recovered the researchers were forced to use a modified protocol adapted for low copy number (LCN) during amplification. In a second iteration of the study the LCN approach was overcome through pooling of samples [170]. However, the authors had the luxury of knowing their combined samples should have come from the same "perpetrator" as this was a controlled study. Whilst a single individual handling a carcass may be true for small scale crimes such as deer poaching, in reality the supply chains of many wildlife crimes are complex and several individuals may be involved either along the whole chain or within just one of the links [95,171]. Mixed source DNA is considered complex and combined with the already problematic low levels of DNA in trace samples future studies should include several donors to better emulate real life cases. However with over a decade of development in the area of touch DNA recovery techniques such as direct polymerase chain reaction (PCR) make processing of challenging samples more accessible [168]. As such this work is worthwhile repeating, with un-pooled samples, but using modern direct PCR techniques.

Touch DNA: bird of prey, corvid, and rabbits

In many cases of wildlife crime, the carcass, either whole or in parts, is a commodity therefore encountering a carcass as evidence at a crime scene which has been exposed to the elements, may be less common than encountering it in transit or on a person. In contrast, carcasses of species which are targeted for persecution have no value to the offender and may be left or concealed at the scene of the crime. This is common in crimes against birds of prey whose carcasses are regularly found outside having been exposed to the elements for undetermined amounts of time [172]. The impact of prolonged elemental exposure on touch DNA recovery has been investigated and evidence shows temperature and humidity both impact the persistence of DNA however whether this is positively or negatively is concurrent with the type of surface the DNA has been deposited on [141]. In one study, mini-tapes were chosen to remove human DNA from rabbit (a common bait), corvid and bird of prey carcasses in both controlled and exposed conditions [173]. Profiles were obtainable form corvid and rabbit after two days of elemental exposure including heavy rainfall and up to ten days on carcasses kept in controlled indoor conditions with the rapid decomposition of the carcasses cited as a contributing factor to the decreasing ability to recover DNA. Bird of prey carcasses had only one day of exposure with rainy conditions but found significant difference in success depending on the species. Other external factors such as scavengers or invertebrates associated with decomposition may also contribute to the decline in available DNA. This was suspected to be true in a study of touch DNA recovery from pig skin submerged in water [174]. Both this study and that detailed in [173] managed to produce full DNA profiles from carcasses after being exposed to water. Once conclusion was that touch DNA persisted longer in cold, standing water but a full profile was still retrievable after one day of immersion in running water which is in keeping with [173] who retrieved reportable DNA samples from corvid carcasses exposed to rain after two days. Effects of rain exposure on touch DNA retrieval in wildlife cases deserves more research, given poaching incidents in certain countries peak during rainy seasons, as poachers attempt to capitalise on rangers inability to navigate flooded protected areas and the lack of tourists [175].

Summary

Several key themes flow through human identification in wildlife crime. To begin with the data shows it is possible to recover human evidence with standard techniques without any need to deviate from the general recommended procedures. When considering the wildlife item as any other type of evidence encountered in a criminal investigation it is subject to the same rules of porosity, texture and environmental exposure that must always be considered. Colourful, patterned skins, and coats of animals can be a challenging factor in producing a good contrast between substrate background and fingermark. For species destined for the pet trade or as ornamental these flamboyant features are a driving factor behind their demand, therefore overcoming this problem is imperative. Very few of the studies reviewed here attempted a duality or comparison of enhanced mark quality on the substrate comparable to lifted marks, despite this simulating standard procedure by forensic investigators. Chemical enhancements often failed potentially because raw animal products are organic material which react in

conjunction with fingermark residue rendering any contrasts that do occur of minimal quality. The techniques that do work, powders and gelatin lifts particularly, can be cost effective, field deployable and in the case of powders do not require expensive laboratory infrastructure for analysis. This makes them ideal candidates for take up in by those investigating wildlife crime who cite a lack of resources as a stumbling block to enforcement. Notably researchers have placed no consideration the downstream impacts of fingermark enhancement techniques on potential DNA recovery, human or animal. Dual evidence recovery from fingermarks is an increasing consideration by practitioners for both fresh and archived marks [144,176,177] and the techniques employed can have significant impact on ability to recover DNA profiles. Magnetic powders, one of the most successful fingermark recovery techniques found in this review, have been found to have minimal impact on subsequent DNA recovery [176], making this work an ideal candidate for expansion into touch DNA recovery studies. This also feeds into the need for proper forensic training for wildlife crime scene first responders in the theory and practical application of general evidence handling including contamination minimisation and prioritisation of different evidence types. There are instances where media images of wildlife seizures show law enforcement handling goods without gloves suggesting even basic forensic practices are not being employed [178,179].

Despite decades of successful proofs of concepts on several species there has been only one recorded instance of translation of findings into applied work. One explanation behind this is that there has been no real need for recovery of such evidence types. Wildlife crime investigations can often begin from a "caught red handed" scenario, whereby an individual is found in possession of wildlife products, commonly seen during seizures at borders. As such the need to link an individual to the crime is superfluous. This is a weakness in the continued chronicling of making IWT synonymous with all wildlife crime and thus focusing efforts on highly trafficked species. By assuming this narrative and failing to establish robust methods of linking individuals to wildlife crimes a whole subset of cases is being ignored. It does injustice to the equally pressing matter of domestic, non-trade related, wildlife crimes such as seen in the USA and the UK who have a poor track record in wildlife crime conviction rates [11,25]. Persecution and human-wildlife conflict cases in these countries may rarely see an individual caught in possession of a wildlife product as the wildlife product itself is not a target for commercial gain. The small-scale nature of these crimes, the comparably high resources available, including accredited laboratories and well-established databases, place such nations in prime position to lead in human evidence recovery in wildlife crimes. Ignoring human evidence also fails to consider the additional intelligence it can bring to investigations. For example, DNA barcoding with ivory has resulted in linking shipments and thus identifying supply chains and trafficking routes. This could also be achieved through the presence of repeated instances of the same human DNA profile or fingermark on multiple shipments identifying a repeat offender or common link in supply chains.

It is evident from increasing rates and simultaneous decrease in convictions that current attempts to tackle wildlife crime are fraught with problems. Along the way forensic solutions posed have focused on the wildlife rather than the perpetrator. This work, specifically individual identification of wildlife has important applications, but they are limited by resources, lack of accreditation, need on a large scale and the sheer volume of wildlife species involved. By contrast human identity testing in forensic applications is a globally established industry, with recognised and well-rehearsed best practice methods. Human identity testing benefits from existing databases and infrastructure, particularly in the global north, but with more and more global south stakeholder countries developing in this area, such as India's new National AFIS [180] and Kenya's new forensic laboratory [181].

Any prosecution team will benefit from having an much evidence as possible at their disposal. Recovery and presentation of human trace evidence in wildlife crime cases provides clear links of perpetrators to wildlife products that other types cannot provide. As such it is recommended that more research is conducted looking into human trace evidence recovery from common substrates encountered in wildlife crime cases. Whilst this article has focused on wildlife products and their derivatives the work can be expanded to include traps, snares, weapons, transportation boxes and vehicles. For several of these evidence and material types there will be existing research or guidance on best practice methods but work is needed to contextualise them into the world of wildlife crime. Considerations should be made dependent on the seizure type or crime scene location. For example seizures from shipping containers will have undergone different environmental exposure and time frames since deposition comparative to air cargo, similarly crime scenes in an arid desert environment will have had significantly less moisture exposure than those in tropical humid environments affecting recommended recovery methods.

Fingermark work should look beyond just enhancement on substrates and investigate effective methods of mark retrieval to overcome problems in establishing contrast on patterned backgrounds. Touch DNA work in this area is very much in its infancy but will benefit from including mixed profile scenarios, more modern processing techniques and interactions with fingermark recovery techniques. It is important that such research is completed in appropriate contexts. To do this researchers must work closely with law enforcement to understand their resource limitations, what types of evidence they most commonly encounter at wildlife crime scenes, what national priorities are, and the practicality of applying developed techniques.

Finally, there needs to be recognition of the complimentary nature of species identification and human identification forensic work. What species identification lacks in terms of accreditation and recognition within the wider forensic community, human identification possesses in abundance. Species identification benefits from ample examples of proof-of-concept work as well as media, funding, and research interest whereas in these areas human identity work is in its infancy. Encouraging these veins to work together could result in robust forensic investigation in wildlife crimes, with the recovery and analysis of several streams of forensic evidence being possible. The idea of paired wildlife and human forensic labs who agree to take on relevant evidence processing from wildlife crime cases at their respective crime scenes could be considered. As well as utilising each institutions unique skill set it will strengthen the relationship between the wildlife and human forensic community potentially increasing knowledge sharing opportunities and more cohesive and streamlined case work. A challenge will be the need for human forensic laboratories to find the time and resources to process wildlife crime related evidence. Efforts to access these resources will be strengthened by demonstration of the impacts of wildlife crimes on the economy, communities and biodiversity. Better recording of wildlife crimes should be a first step in this area, as is being called for in the UK within campaigns to make wildlife crimes notifiable [182] and recommendations for centralised wildlife databases within the EU for better monitoring [183]. Ultimately it is recommended that wildlife crime scene first responders receive high quality training in forensic techniques and that subsequently wildlife crime scenes be processed the same as any other high priority crime. This includes the same considerations being taken surrounding evidence collection and handling and best practice forensics. Even if resources do not allow immediate processing of evidence it opens avenues for utilisation of archival evidence when circumstances allow in the future. This has the potential to improve prosecution and conviction rates and act as a serious deterrent to wildlife criminals, providing in a part a solution to the ongoing crisis of wildlife crime.

Ethical statement

The authors declare no ethical approval was necessary for the creation of this review manuscript. The data presented represents the authors understanding of the subject matter gathered through personal research and stakeholder discussions.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this review article.

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