Science: tackling the illegal wildlife trade

TECHNOLOGY UPDATE

THE ROYAL SOCIETY

Science: tackling the illegal wildlife trade
Issued: September 2018 DES5360
ISBN: 978-1-78252-360-4

This report can be viewed online at:
royalsociety.org/illegal-wildlife-trade

Cover image Pangolin © Vicky Chauhan.

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Foreword

Image
Professor Andrew Hopper CBE FREng FRS, Treasurer and Vice-President of the Royal Society.

The Illegal wildlife trade is a pressing global issue damaging natural capital, cultural heritage, livelihoods and sustainable economic development. It is fuelled by criminality and corruption; the proceeds raise nearly $23 billion a year and threaten some of the world's most iconic species.

The Society was invited to explore potential new ways in which emerging science might be applied to stopping the trade. It therefore took an experimental approach, working with practitioners and experts but also deliberately including Fellows who were expert in their fields but who had not had previous experience in this area.

These discussions surfaced a range of ideas with further potential, across several technological and scientific fields. This policy briefing outlines five interventions which might offer feasible opportunities for implementation and impact. In taking such ideas forward it will be essential for them to be considered in the wider social, user and operational contexts in which they will be developed and applied.

The Society carried out this project informed by discussions with the FCO and Defra, and in order to make a contribution to the London 2018 Illegal Wildlife Trade Conference hosted by the UK Government. We trust that those working to stop the trade will find this briefing of interest and that it will contribute to further conversations about the benefits of science to tackling real world issues.

Professor Andrew Hopper CBE FREng FRS
Treasurer and Vice-President of the Royal Society.

Joint ministerial preface

The illegal wildlife trade (IWT) is an urgent global issue. It has contributed to dramatic falls in the numbers of many endangered species, from rhinos and pangolins to sturgeon and rosewood. Worth up to £17 billion a year globally, it is a highly organised, sophisticated criminal industry.

This illegal trade is not just damaging to endangered species. The immense profitability of IWT fosters corruption. This feeds insecurity in local communities and undermines good governance and the rule of law, which can hamper economic growth. IWT is also a great threat to national and regional security, as the networks that support it are all too often the very same that enable money laundering, modern slavery and people trafficking.

Faced with these threats, the UK is committed to playing a leading role in fighting IWT, and working with partners from around the world to end this scourge. We need to ensure that we are leveraging the scientific and technological expertise available to work with our international partners in the fight against the illegal trade. We have been clear that governments must work together with academia, the private sector and civil society to harness the innovation and technology present in all sectors to tackle IWT.

We can already see how technology is being used to fight IWT on the ground. Thermal cameras have been deployed in Kenya and have helped rangers capture dozens of poachers. British scientists at King’s College London have developed a kit that ensures fingerprints on ivory can be identified for up to 28 days. Technology has a key role to play in giving law enforcement and border officials the tools they need to detect and disrupt illegal trade. More advanced technology could also help us to bypass human error and corrupt officials in detecting IWT.

We must be mindful that IWT occurs globally including in some of the poorest and most remote parts of the world, and therefore any technological solutions must be cost-effective and practical.

The illegal wildlife trade was a relatively new area for the Royal Society, and they have applied their scientific expertise to a real world issue to come up with some innovative solutions. We are very grateful to the Royal Society for their collaboration with the government and various other interested organisations in compiling this report and the five technological interventions they have identified and laid out as possible tools for tackling IWT. This Royal Society report is a valuable addition to the global effort to end this scourge.

Dr Thérèse Coffey MP
Parliamentary Under Secretary of State
for the Environment

Rt Hon Mark Field MP
Minister of State,
Minister for Asia and the Pacific

Image top
Dr Thérèse Coffey MP, Parliamentary Under Secretary of State for the Environment

Image bottom
Rt Hon Mark Field MP, Minister of State, Minister for Asia and the Pacific

Summary

Advances in science and technology offer major opportunities to tackle the illegal wildlife trade. Promising tools are emerging from many different fields, from novel fingerprinting kits for ivory, artificial intelligence to spot suspect cargoes, to portable devices that use genetics to identify wildlife products in the field. While science and technology could have an important impact, no one approach will tackle every part of it as the trade is a complex system that involves many species, environments and actors.

To demonstrate the potential of science and technology to tackle wildlife crime, this briefing describes five potential interventions:

- **Risk profiling through interrogation of shipping documentation**
  Big data analysis and forms of artificial intelligence including machine learning can be used by border agencies to analyse trade documents to predict and determine illegal wildlife trade activity with increased accuracy and speed.

- **Smart shipping container technologies**
  Novel design and inbuilt computers, beacons and sensors connected to the internet of things can make shipping containers 'smarter' – more secure and able to detect illegal wildlife products inside.

- **Optical recognition approaches**
  A range of advanced text and optical image search and recognition techniques, allied to artificial intelligence and machine learning can be employed to detect illegal wildlife goods at borders, to track the movement of poachers through protected areas or to disrupt illegal online wildlife marketing.

- **Development of biological and chemical identification capability for use in the field**
  Devices that are smaller, more portable, faster, easier to use and cheaper than today's can be developed to improve law enforcement efforts by providing faster intelligence and detection.

- **Environmental isotope analysis**
  Deeper understanding of the relationship between the environment and the chemical composition of organisms can be used to obtain intelligence on their geographical origins and age, useful for law enforcement.

For scientific and technological interventions to have impact and avoid unintended consequences, it is crucial to consider the context in which they will be developed and used, including social factors, the technological landscape and user needs. Action also needs to be co-ordinated, suitably resourced and encouraged by policy-makers. Consequently, this briefing identifies four cross-cutting themes that could help make the interventions identified more successful:

- **Accessible, affordable innovation and fit-for-purpose products**
  Making simple yet innovative solutions and more complex technologies as affordable as possible. Tailoring them to their users and environments through iterative testing, and integrating them into existing systems and providing support.

- **Wildlife crime as a technological test bed**
  Marshalling greater resources and expertise by demonstrating that technologies to tackle wildlife crime can offer wider commercial and public benefits to industry and government.

- **Digital infrastructure and global technology platforms**
  Ensuring developing countries can draw upon otherwise inaccessible digital capabilities from elsewhere.

- **Open data and databases**
  Better collection, storage and sharing of data as well as accessible, secure and curated databases.

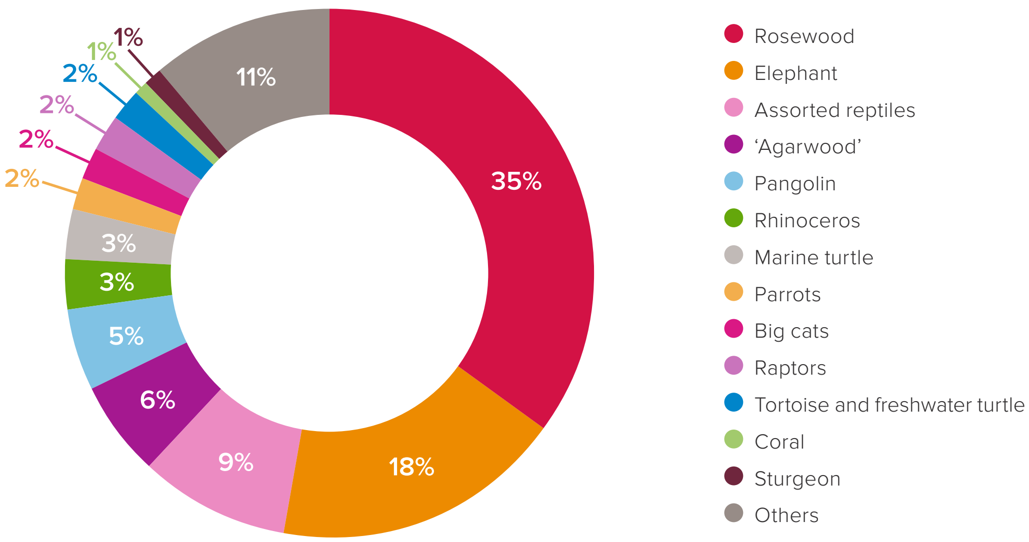
The illegal wildlife trade

The illegal wildlife trade is an urgent global issue. The trade damages natural capital, cultural heritage, livelihoods, sustainable economic development and investment[1]. Fuelled by criminality and corruption, the proceeds average $23 billion a year and threaten some of the world's most iconic species[2]. A wide variety of organisms are affected, including plants, animals, birds, fish and reptiles. Examples of the impact of the trade are shown in box 1, while the type of seizures and trends in the poaching of rhinos and elephants in Africa are given in figures 1 – 3.

Trade in wildlife is governed by domestic and international laws and rules. These include the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), an international agreement between governments that aims to ensure that international trade in specimens of wild animals and plants does not threaten their survival[3].

FIGURE 1

Share of type of wildlife among total seizures 2005 – 2014.

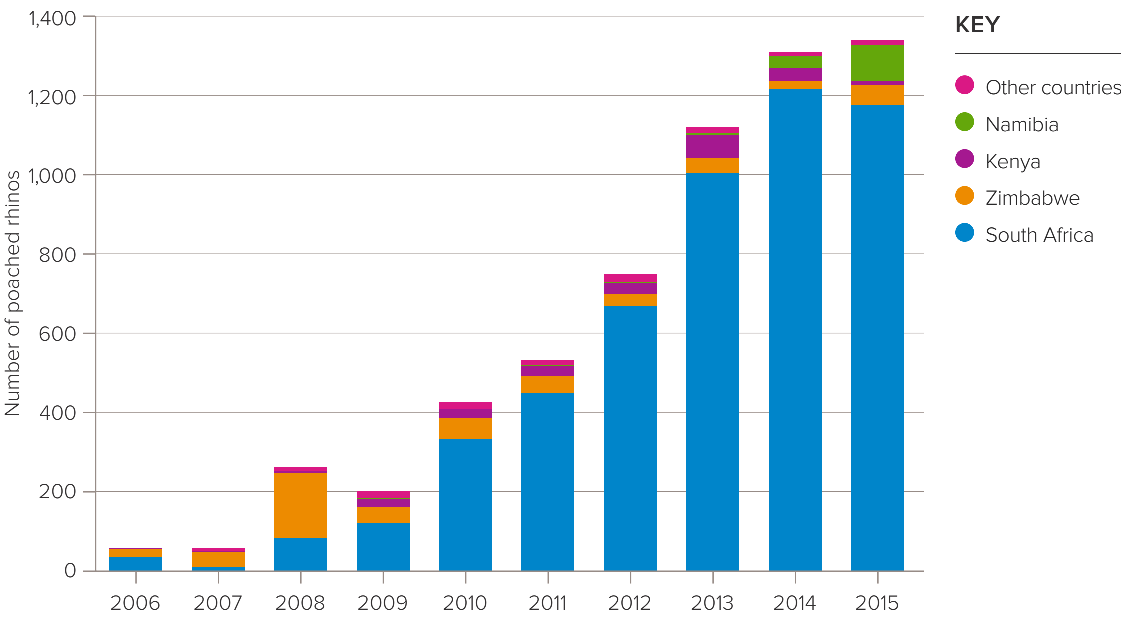


Source: UNODC. 2016 World wildlife crime report. Trafficking in protected species.
See: https://www.unodc.org/documents/data-and-analysis/wildlife/World_Wildlife_Crime_Report_2016_final.pdf

1. Defra (Department for the Environment, Food and Rural Affairs), DfiD (Department for International Development), FCO (Foreign and Commonwealth Office) and Home Office. 2014 London Conference on the illegal wildlife trade declaration. 12-13 Feb. Declaration See https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/281289/london-wildlife-conference-declaration-140213.pdf (accessed 24 September 2018).
2. Africa Wildlife Foundation. 2015 World Wildlife Day Highlights Severity of Wildlife Crime. See https://www.awf.org/news/world-wildlife-day-highlights-severity-wildlife-crime (accessed 24 September 2018).
3. See the CITES website: https://www.cites.org/

FIGURE 2

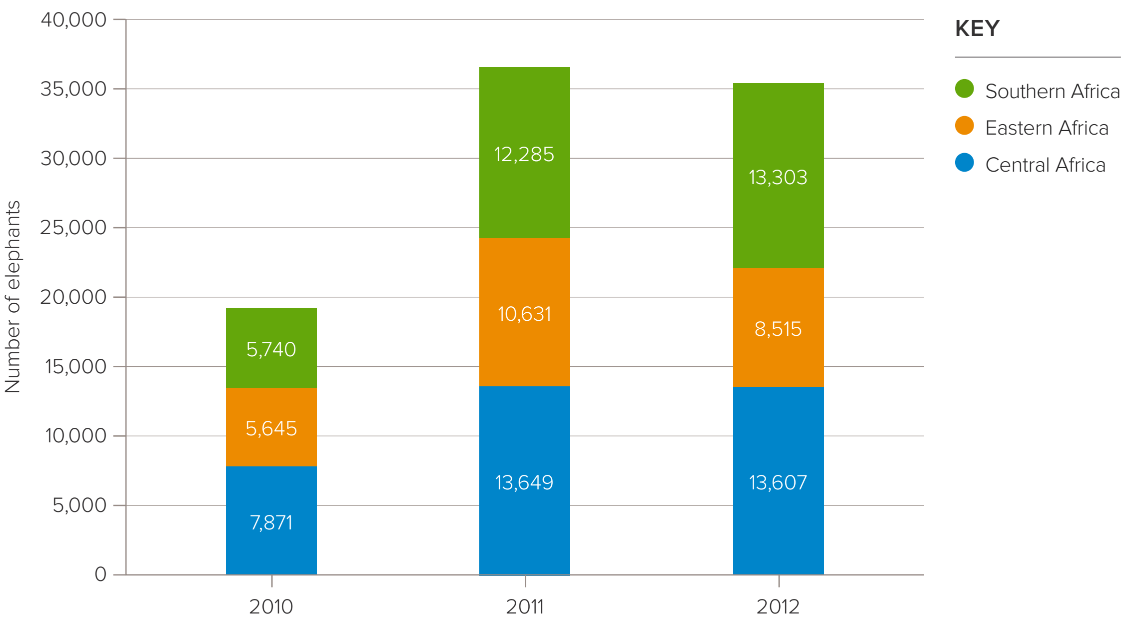
Trends in poaching of rhinos in Africa.



Source: UNODC. 2016 World wildlife crime report. Trafficking in protected species.
See: https://www.unodc.org/documents/data-and-analysis/wildlife/World_Wildlife_Crime_Report_2016_final.pdf

FIGURE 3

Trends in poaching of elephants in Africa.



Source: UNODC. 2016 World wildlife crime report. Trafficking in protected species.
See: https://www.unodc.org/documents/data-and-analysis/wildlife/World_Wildlife_Crime_Report_2016_final.pdf

BOX 1

Examples of impact of the illegal wildlife trade

The impact of the illegal wildlife trade is diverse in terms of species, trade routes and transport modes. The following examples and estimates illustrate the complexity and scale of the issue[4]:

Iconic species
1054 rhinos were poached in South Africa in 2016, up from 13 in 2007[5].

Human
The lives of those working hard to protect endangered wildlife are also at risk; in the last year, over 100 rangers have died in the line of duty, many at the hands of poachers[6].

Aquatic
Tens of millions of seahorses are traded each year (98% dried and only 2% alive) with 87 countries involved in this trade for traditional medicines, curios and aquarium displays[7].

Trade routes
In the last decade, more than one million pangolins are estimated to have been trafficked, primarily to China and Vietnam where their meat is considered a delicacy and their scales used in traditional medicines[8,9].

Plants
Rosewood (for furniture) and agarwood (cosmetics and perfume) are estimated at 35% and 6% respectively by standard value of total wildlife seizures between 2005 and 2014[10].

Collateral damage
The population of the vaquita porpoise has fallen by an estimated 80% between 2011 and 2015 as a result of bycatch in nets, many of which were intended to illegally catch an endangered fish called the totoaba[11].

Value
The estimated street value of one illegal shipment of glass eels seized at Heathrow in 2017 was £1.2 million[12].

4. Worldwise. World Wildlife Crime Report. World wildlife seizures (worldwise) database. See https://www.unodc.org/documents/data-and-analysis/wildlife/WLC16_Chapter_2.pdf (accessed 6 February 2018).
5. Save the Rhino. Poaching statistics. See https://www.savetherhino.org/rhino_info/poaching_statistics (accessed 6 February 2018).
6. The Thin Green Line Foundation. 2018 World Ranger Day 2018 – Ranger Roll of Honour 2018. In Memoriam. See https://www.internationalrangers.org/world-ranger-day/ (accessed 24 September 2018).
7. ZSL (Zoological Society of London). Infographic: Illegal Wildlife Trade. See https://www.zsl.org/zsl-london-zoo/news/infographic-illegal-wildlife-trade (accessed 6 February 2018).
8. ZSL (Zoological Society of London). Illegal wildlife trade crisis> Pangolin Conservation. See https://www.zsl.org/conservation/threats/illegal-wildlife-trade-crisis/pangolin-conservation (accessed 24 September 2018).
9. UNODC. 2016 World wildlife crime report. Trafficking in protected species. See: http://globalinitiative.net/world-wildlife-crime-report-trafficking-in-protected-species/ (accessed 24 September 2018)
10. UNODC. 2016 World wildlife crime report. Trafficking in protected species. See: http://globalinitiative.net/world-wildlife-crime-report-trafficking-in-protected-species/ (accessed 24 September 2018)
11. Environmental Investigation Agency. 2016 Collateral damage: How illegal trade in totoaba swim bladders is driving the vaquita to extinction See: https://eia-international.org/wp-content/uploads/EIA-Collateral-Damage-FINAL-mr.pdf (accessed 16 February 2018)
12. Home Office. 2017 Eels seized at Heathrow airport. See https://homeofficemedia.blog.gov.uk/2017/03/03/home-office-in-the-media-3-march-2017/ (accessed 6 February 2018).

The role of science and technology

Science and technology offers major opportunities to help tackle the illegal wildlife trade. Progress has already been made by initiatives such as Zoohackathon, the Wildlife Crime Tech Challenge and Wildlab.net (see box 2), and there are many examples of new technologies in use now such as ivory fingerprinting kits (see case study 1). This policy briefing outlines potential scientific and technological interventions and introduces insights from different fields and sectors to complement existing work.

The illegal wildlife trade involves many different species, locations and actors, some of which are outlined in table 1. Scientific and technological interventions can have an important impact but no single intervention or group of interventions will tackle every challenge or part of the system. When developing interventions it is important to consider the social context to avoid unintended consequences, mindful that advances in science and technology can potentially facilitate as well as reduce the trade.

The interventions that follow are a potential source of feasible opportunities that have a reasonable chance of implementation and impact. Rather than representing an exhaustive list of every option they are intended to illustrate the range of opportunities that exists across different scientific disciplines, environments, species and time frames of development. Often technologies might be used in combination such as risk profiling shipping documents and smart containers. Other technologies not detailed, such as remote sensing, often help underpin those that are covered and interventions should seek to address both demand and supply. The use of human networks alongside technology could be especially important where Non-Governmental Organisations (NGOs) and wider civil society are partnered with enforcement officers. The Society is not aware of a single, reliable, curated source of data on the illegal wildlife trade as a whole. The development of such a database would present an opportunity to identify where interventions would be most useful.

BOX 2

Examples of science and technology initiatives to tackle wildlife crime

Zoohackathon

Zoohackathon is a project supported in part by the US Government's Task Force on Combating Wildlife Trafficking to reduce demand for endangered species and increase international cooperation. It has quickly grown to encompass efforts by many of those involved in conservation and technology from around the world.

Through Zoohackathon, leading conservation technology zoos worldwide welcome coders and programmers for sessions aimed at developing solutions to problems put forward by international wildlife experts. At the end of the hackathons, teams pitch their ideas to an expert panel of judges. Local winners receive prizes and winners from each site are also eligible to compete for global prizes.

In 2017 both the London and Global Zoohackathons were won by a UK product that processes images from camera traps in the field and immediately flags the presence of elephants or people to rangers. This would allow poaching to be identified and addressed more swiftly.

For further details see zoohackathon.com

The Wildlife Crime Tech Challenge

The Wildlife Crime Tech Challenge rewards innovative science and technology solutions that tackle specific wildlife trafficking issues. In early 2016, the Challenge selected Prize Winners to receive Prize Packages of $10,000 in addition to promotional and networking opportunities and technical assistance to scale or accelerate their solutions. Prize Winners were also eligible to compete for one of up to four Grand Prizes worth as much as $500,000. The Challenge used Grand Prizes to target and invest in the most promising solutions, and announced four Grand Prize Winners in September 2016. They featured technologies to identify illegal trading online and in the field, including artificial turtle eggs fitted with tracking devices to reveal trafficking routes.

The Wildlife Crime Tech Challenge is an initiative of the US Agency for International Development (USAID) in partnership with the National Geographic Society, the Smithsonian Institution, and TRAFFIC.

For further details see wildlifecrimetech.org/index

Wildlabs.net

Supported by Google and ARM, Wildlabs is an open source facility for those working against illegal wildlife crime. Wildlabs was established to build an online community among those involved in conservation and develop technological solutions. It also provides for sharing of skills and networking. The intention is to cut costs and raise effectiveness of technology-based approaches for those active in combating illegal trade, making them practical for small, relatively poorly funded groups to access.

Within its first year, Wildlabs grew to a community of over 1300 global members. Areas in which they are actively collaborating to develop new hardware technologies include an open-source acoustic monitoring device for tracking wolves and an automatic elephant detector using machine learning. They are also crowd-sourcing answers to questions ranging from low-cost wildlife tracking tags to self-powered camera traps.

For further details see wildlabs.net/about-wildlabsnet

CASE STUDY 1

Development of an ivory fingerprinting kit

One example of a recent technology developed to help tackle the illegal wildlife trade is a fingerprinting kit for ivory created through a collaboration between King's College London and the Metropolitan Police Service. Until recently, fingermarks could only be recovered from ivory two to three days after deposition using traditional powdering techniques.

Investigation of new, smaller scale magnetic powder materials enabled recovery of fingermarks on ivory with better definition and for up to 28 days. This extended period allows more time to gather evidence on those who have handled the ivory and potentially those responsible for organising poaching. The powder and method of application are also relatively affordable and user-friendly, with any excess powder able to be recycled. The International Fund for Animal Welfare (IFAW) have now supported and funded provision of these kits internationally. Most recently, they have been successfully used to catch poachers and traders in Kenya and other ivory crime hotspots.

The technique has been integrated with DNA profiling to identify poachers from their powdered fingermarks on ivory. There may also be opportunities in the future for the use of this technology on other hard semi-porous wildlife products, such as animal claws, and a gel format is being developed to stop the powder being blown away in the field.

TABLE 1

Environment	Examples of illegally traded species
Deserts	• In the last 15 years at least 50% of the population of the desert dwelling Peruvian cactus *Echinopsis pampana* has disappeared through illegal collection for the ornamental plant trade[13]. • Domestic and international nurseries are the destinations for many illegal cacti. • Other desert species at risk include snakes, plants and reptiles.
Forests	• Rosewood refers to a number of different species of tropical hardwood used in furniture, some of which are CITES listed. • Rosewood represented over a third of the total standard value of seizures between 2005 and 2014[14]. • Other forest species at risk include tigers, primates, wild birds and orchids
Fresh water	• The Ganges River Dolphin is an endangered species that is threatened by a range of human activity including the illegal wildlife trade[15]. • The dolphin is targeted for its meat and oil that are used as medicines and to attract catfish. • Other freshwater species at risk include turtles and fish.
Oceans	• Wildaid and Sharksavers have estimated that manta ray populations have declined by between 56% and 86% in recent years[16]. • Manta rays are caught for their gill plates that are used for purported medicinal properties in East Asian markets. • The gill plates are shipped to China's southern province of Guangdong where they can fetch $500 per kilo. • Other marine species at risk include corals, sharks, turtles, sea cucumbers, abalone and seahorses.
Savannas	• Poaching has led to around 30% of Africa's savannah elephants being wiped out between 2007 and 2014[17]. • Ivory is moved by land, sea and air to Asian markets, often concealed by lower value fillers; such as fish. • Other savannah species at risk include lions and other big cats, rhinos and tortoises.

13. International Union for the Conservation of Nature (IUCN) Red List. Illegal trade contributes to placing cacti among world's most threatened species. See http://www.iucnredlist.org/news/cacti-assessment (accessed 6 February 2018)

14. UNODC. 2016 World wildlife crime report. Trafficking in protected species. See: https://www.unodc.org/documents/data-and-analysis/wildlife/World_Wildlife_Crime_Report_2016_final.pdf

15. World Wildlife Fund. Dolphins and porpoises. Ganges River Dolphin. See https://www.worldwildlife.org/species/ganges-river-dolphin (accessed: 19 February 2018)

16. Wildaid and Sharksavers. Manta rays worth more dead than alive. See http://www.sharksavers.org/en/blogs-news/shark-savers-blog/for-immediate-release-manta-rays-worth-more-alive-than-dead/ (accessed 6 February 2018).

17. Great Elephant Census. Great Elephant Census Final Result. See http://www.greatelephantcensus.com/final-report (accessed 6 February 2018).

Image
© Pierre-Yves Babelon.

Risk profiling through interrogation of shipping documentation

Big data analysis, and forms of artificial intelligence including machine learning, can be used by border agencies to analyse trade documents to predict and determine illegal wildlife trade activity with increased accuracy and speed.

Point of intervention

Trade flows across borders rely on effective risk assessment. This allows the smooth passage of legitimate trade consignments while ensuring there is a high probability that cargoes containing illicit goods, whether live animals or products, will be further investigated. Risk analysis of trade documents, such as shipping manifests, customs declarations and business invoices, enables border agencies to decide how to allocate staff resources; when to seek further information or advice on a particular consignment; and whether to subject goods to physical inspection.

Basic text scanning can be allied with more sophisticated machine learning techniques to read documents, identify anomalies and flag concerns. This could substantially reduce the scope for human errors arising from fatigue, overwork or susceptibility to corruption and free up border officials' time for other investigatory purposes. Case study 2 illustrates this approach.

Science and technology

Technologies are already being deployed to analyse trade documentation (see case study 3). These include:

- open ended natural language processing and optical character recognition – to convert unstructured or semi-structured information in electronic or paper form to useable datasets;
- artificial intelligence techniques including machine learning methods – applied to analyse substantial volumes of data at high speeds (replicating techniques for detecting irregularities in financial transactions); and
- open source material – available to assist analysis of particular risks, such as so-called 'dual use' components in making gun parts.

The World Customs Organisation encourages and supports member countries to implement a Cargo Targeting System that focuses on advance receipt and analysis of shipping manifest documentation and a systems approach, built on electronic documentation and risk profiling. This system allows manifests to be sent electronically from the port of departure to the port of entry to allow more time for analysis during transit. The International Air Transport Association and the CITES secretariat also lead initiatives to increase the uptake of electronic documents, such as e-permitting. Electronic documents significantly reduce fraud by separating documentation from physical goods, enabling machine analysis and inhibiting falsification of documents.

CASE STUDY 2

Detect IT – Fish

TRAFFIC, World Wide Fund for Nature (WWF) and Hewlett Packard Enterprise have developed an automated tool using publicly available import and export data (mass and value) to highlight potentially illegal fish trade. Detect IT: Fish provides an automated comparison of fisheries trade data between countries, identifying discrepancies in reported import and export data to highlight potential trade in illegal products.

The tool brings high level transparency and can be used by:

- governments in policy initiatives around particular wildlife goods or trade routes;
- border/fisheries agencies as intelligence to investigate trade anomalies; and
- NGOs and civil society in targeting their work.

The tool has already highlighted anomalies in abalone and lobster exports from South Africa to the Far East that are now under investigation by TRAFFIC alongside South African and neighbouring border authorities.

For further details see detect.trade

CASE STUDY 3

Analysing shipping documentation to detect illegal aquatic wildlife

The Anderson Cabot Center for Ocean Life at the New England Aquarium and Roger Williams University have developed software to electronically scan shipping documents related to aquatic cargoes. Use of analysis from around 30,000 previous shipments enables machine learning to flag anomalies based on criteria such as price, weight and country of origin.

Working prototypes of handheld scanning devices using the software have utilised information for around 40,000 marine species. The devices have received positive feedback from wildlife inspectors, both for the speed and efficiency of document processing in practical border situations and for their user-friendly information interface and alert system.

More advanced risk profiling and machine analysis of trade documentation is routinely used by UK border forces for all incoming cargoes. This includes natural language processing and machine learning approaches to detect suspect cargoes, including those containing illegal wildlife goods. Substantive debriefs follow all customs seizures and are a key part of the risk management system, helping to understand changing practices of illicit goods traffickers and tailor intelligence approaches to disrupt them.

Barriers and opportunities

Technological approaches enabling deeper analysis of shipping documentation require substantial investment in both hardware and personnel. Such systems also need to be maintained and upgraded as the trade evolves.

Algorithmic approaches to trade document analysis require historic information on legitimate trade and illegal wildlife seizures to develop training sets for machine learning systems to enable them to successfully identify anomalies. Creating banks of data specifically on illegal wildlife trade is entirely feasible, but highly resource intensive. There are also very practical limitations. As an example, while there are developed taxonomic databases for wildlife, these are not replicated in terms of species detail by the Harmonised System (an internationally standardised system to classify traded products) or other approaches to trade classification.

There is also the potential to generate large numbers of false positives from algorithmic analysis. Machine learning and game theory approaches have been trialled in environments with limited variables, for instance, in open country to predict poacher behaviour and inform enforcement approaches by rangers.

However, when applied to the large number of trade transactions, even a very small percentage of anomalies unconnected with illicit cargo would generate many false positives that could be indistinguishable from the signals generated by illegal trafficking. This might be ameliorated by integration of information, for instance the combination of analysis of sensor data with manifest analysis to expose mismatches.

Machine-based techniques could be piloted in relation to illegal wildlife goods by interested parties including governments, border agencies, businesses, international organisations and NGOs. Successful aspects of that pilot could be applied more widely to other types of illicit cargo such as weapons or revenue avoidance. Equally, systems developed to analyse trade documents at speed and volume might find other commercial or social uses such as in establishing patterns and anomalies in health care returns or survey information.

Conclusion

Much of the technology and scientific understanding to improve risk assessment based on trade document analysis is already available. Software programs to enable algorithmic risk evaluation, assisted by optical character recognition, are currently used in a variety of settings, both at borders and in other domains. There is, however, scope to apply electronic documentation analysis more consistently and to expand risk profiling internationally. There is also an opportunity to think creatively about strengthening risk analysis by extending more sophisticated strategies to a wider suite of documentary or electronic evidence, such as financial documentation or even social media.

Image
© donvictorio.

Smart shipping container technologies

Novel design and inbuilt computers, beacons and sensors connected to the internet of things can make shipping containers 'smarter' – more secure and able to detect illegal wildlife products inside.

Point of intervention

Shipping containers reduce the cost of freight by enabling end-to-end transport of cargoes, by sea, road or rail[18]. They play a ubiquitous role in global trade supply routes: around 20 million containers transport $4 trillion worth of goods across the world each year, accounting for 90% of global trade[19].

The growth of 'smart shipping containers', driven by commercial pressures, could have a role in detecting illegal wildlife goods. Recent advances include sensors delivering real-time information about the whereabouts and contents of a container and enhanced physical security through smart design. The use of smart shipping containers to tackle the illegal wildlife trade depends on the uptake of such containers in the marketplace.

Science and technology

Key challenges arise as a consequence of the shipping container environment itself. Sensors have to be able to detect materials throughout the sizeable interior volume of the container. The shipping vessel and surrounding containers create an almost impenetrable Faraday cage inhibiting wireless communication. Also, durable power sources are needed for an independent power supply, perhaps through lithium-ion batteries or by harvesting power from the environment.

Commercially available containers already use sensors to provide continuous information on their location, temperature and humidity. (see case study 4). Theoretically, smart container sensors could be configured to detect or track any particular type of wildlife species for which there was a unique signature identifier. Carbon dioxide sensors are already deployed in container environments to test for breathing and more advanced sensors are being developed that could detect chemicals or movement within containers.

Containers could also be equipped with Radio Frequency Identification (RFID) sensors, already widely available to protect goods in stores, to provide alerts to the presence of tagged illegal wildlife goods.

18. Gittens R. 2006 How the invention of a box changed our world. *The Sydney Morning Herald*. 12 June 2006. See https://www.smh.com.au/business/how-the-invention-of-a-box-changed-our-world-20060612-gdnqf0.html (accessed 24 September 2018).

19. Secure Systems. SecureSystem® Brings Patented Smart Shipping Container Technology to North America. See https://www.securesystem.net/securesystem-brings-patented-smart-shipping-container-technology-north-america/ (accessed 24 September 2018).

CASE STUDY 4

Maersk 'reefer' containers

The global transport and logistics company, Maersk, is the world's largest transporter of 'reefer' (refrigerated) containers. It has introduced a reefer technology known as Remote Container Management (RCM) whereby sensors installed inside the container enable remote monitoring of the container's location, temperature and power supply. Data from the sensors are relayed via a proprietary communication system on board Maersk vessels using GSM 2G and antennae. The technology allows customers to monitor their cargo in real time and alerts Maersk onshore support teams whenever the conditions inside a container change or the reefer malfunctions.

In terms of physical security, sensors are fitted to some containers to detect whether or not it has been entered. More complex digital locking devices are also available which, through password protection, enable containers to record where, when and by whom a container was entered.

CakeBoxx Technologies[20] have developed a 'door-less' solution to prevent unauthorised entry to containers. Containers using the system consist of a flat open plate, with access on all sides to facilitate loading, on to which a lid (including the container's sides) is lowered (like a cake box) by crane or forklift truck. This means illicit items cannot be removed or inserted from the container in most transport and storage situations as it is impractical to lift the lid before the final destination is reached.

Technologies are being trialled to investigate potential security breaches at containers parked in railway sidings using inspection drones whose launch is triggered by smart container alarms which provide precise location coordinates. Such automated security functions are invisible to criminals and can be maintained in place, requiring minimal human intervention. The open platforms needed to share the required information between commercial, security and enforcement agencies could be developed from existing systems as patterns in routes, cargoes and individual carriers or businesses are already analysed for commercial reasons, such as to compare cargo prices. If shared with border authorities, such information could be used to enhance risk analysis, potentially linked to algorithmic analysis of trade documents to highlight suspect cargoes.

20. See http://cakeboxx-technologies.com/about/ (accessed 12 February 2018)

Barriers and opportunities

A principal barrier to the use of smart shipping containers in disrupting illegal wildlife trade is the limited extent of market penetration of such containers. Illegal wildlife traffickers can simply use containers that are not protected by smart detectors.

Factors that might drive commercial uptake of smart shipping containers include: visibility for just-in-time delivery; information to deal with insurance issues; and assurance regarding container contents for health and safety purposes. Smart containers may become prevalent where high value goods are being sent to high risk destinations or for goods that have stringent health or regulatory controls, such as refrigerated food or pharmaceuticals. Additionally, if border authorities saw the extra security provided by smart containers as a contributory factor in granting fast-track clearance of goods, this will drive industry uptake.

Taking smart shipping containers into the realm of genuinely innovative internet of things solutions requires substantial development of the architecture for sharing and analysing data. This includes platforms for sharing data between sources. It also raises governance issues related to the security, ownership and value of information.

Conclusion

For smart shipping containers to be more widely adopted they need to be tailored to the practices of carriers, shipping lines and the commercial pressures driving the evolution of trade. Smart shipping containers represent a longer-term opportunity to stem the illegal wildlife trade. There may, however, be circumstances, such as the investigation of specific trade routes or wildlife cargoes, where the existing technologies can assist law enforcement agencies.

Image
© jezphotos.

Optical recognition approaches

A range of advanced text and optical image search and recognition techniques, allied to artificial intelligence and machine learning can be employed to detect illegal wildlife goods at borders, to track the movement of poachers through protected areas or to disrupt illegal online wildlife marketing.

Point of intervention

Optical recognition approaches can be systematically deployed to tackle the illegal wildlife trade, at the border, in the field and in the wider marketplace. The range of techniques includes: automatic text analysis online; high-speed analysis of images produced by scanning equipment at borders; and more sophisticated deep learning techniques to identify images of humans and wildlife in the field or online (see case study 5).

Science and technology

Greater speed, accuracy and expanded data banks (to train machines) are enabling optical recognition and machine learning techniques to be deployed in fields as diverse as medical imagery and self-driving vehicles. Examples of applications to tackle wildlife crime include the following.

Detecting wildlife signifiers at border posts

These techniques could be utilised at the border. For instance, data already captured on scanners used to detect weapons in passenger baggage could be subjected to high speed optical recognition analysis to identify wildlife signifiers such as bones. Critically, such interventions could be designed to increase the effectiveness of existing border infrastructure rather than requiring the installation of substantial new hardware, although this could still be resource intensive and would need to align with other priorities.

CASE STUDY 5

Development of optical recognition technologies

The Zoological Society of London and Google have been collaborating to create image recognition models that can be highly accurate in identifying wildlife and humans from the thousands of camera trap images captured in the field. A platform and algorithms have been developed to speed up processing from months to just seconds.

The partnership is working to optimise these recognition models so that they can be downloaded and embedded on lower power imaging devices to detect illegal activity in the field. This means that wildlife populations and movements can be easily monitored and law enforcement teams alerted if poachers are spotted.

The collaboration has included the development of Cloud Auto ML Vision, which aims to democratise artificial intelligence by allowing organisations and individuals with limited machine learning expertise to train their own advanced image recognition models for their own use regardless of their technological knowledge. The project aims to make these models accessible to anyone from anywhere, and available for use by any implementing partner and solution developer.

A key barrier is the cost of Google's tools to implementing partners. Credits are required to host and run advanced models and while these have been waived for some, they present big barriers to others who could benefit from these advanced technologies.

CASE STUDY 6

Enforcement Gaps Interface

New York University and partners have applied data mining approaches (natural language processing and machine learning) to identify gaps in enforcement in the internet wildlife trade. A computational model mines nearly a hundred commercial sites for CITES Appendix I listed fauna (699 species of protected wildlife). Critical to the project has been interdisciplinary working between computer and environmental scientists.

Compared to human searches, the system has been shown to generate far higher hit rates of illegal wildlife sites and at far greater speed. Slightly reduced levels of accuracy in searches can be remedied by final human review. The project will provide illegal wildlife trafficking and marketing information through a secure interface to enforcement agencies to target their investigations.

For further details see wildlifecrimetech.org/winners

In-field detection of illegal activity and wildlife movements

Image recognition tools are currently being used to process data feeds from a range of camera imaging devices, from thermal imagery, to camera traps, to radar. Machine learning systems are being used to give law enforcement teams real-time intelligence on illegal activity in protected areas. Image recognition algorithms can quickly analyse the vast amount of optical data coming in from surveillance streams and give teams an early warning of any threats so they can respond. The algorithms can differentiate between wildlife and human presence. This helps small teams understand where the wildlife is positioned and potential intrusions so they can target resources effectively.

Detecting illegal wildlife goods online

Data science can already be used on a massive scale to search for marketing or trade of illegal wildlife goods online. Case study 6 illustrates how such techniques are currently being applied in a pilot project. Application of such search approaches to analyse images is more complex. Illegal wildlife goods are diverse in nature including live animals, fur, teeth, claws, skin, furniture and medicines. More advanced technologies need to be used alongside image recognition to avoid an excessive burden of returns relating to legitimate retail items. Convolutional neural networks, a type of machine learning, are one means by which relatively little pre-processing or prior knowledge can build finely honed algorithms.

So-called 'social machines' engage individuals as 'sensors' to achieve impact at scale through their wide geographical spread and networks. Data enrichment approaches, such as providing annotations and context on images received, can help to reduce erroneous or misleading data inputs and intuitive user interfaces enable extensive participation. Social machines could generate sizeable photographic libraries to act as training sets to improve the accuracy of image recognition models in detecting illicit goods.

Barriers and opportunities

Optical recognition technologies will only help halt wildlife crime if the results lead to action. For instance, research indicates that there are low levels of activity related to the illegal trade of wildlife on the dark web[21], contrasting with open and increasing trade on the surface web. This may show limited interest or incentive to remove the trade from mainstream websites. Equally stark, state of the art scanning technology is of no avail against illicit traffic when sensors are bypassed through corruption.

Application of sophisticated image recognition techniques at the border requires substantial investment in infrastructure. Even where it is possible to build on existing border infrastructure, such as scanning and X-ray devices, there are risks of undermining border priorities, notably security.

Additionally, such innovations typically lead to a cycle of technological deployments followed by attempts by traffickers to circumvent them. Algorithms designed to detect illegal wildlife goods through image recognition will be met with photographs in black and white, shot in poor lighting conditions or distorted by reflections intended to defeat the web scraper technologies. Continuous support and development will be required to adapt, update and refine machine-driven approaches.

For in-field detection the key barrier is the number of false positives arising from application of some recognition tools. This leads to false alarms and operational fatigue. The challenge is being overcome as optical recognition models are becoming more advanced and accurate. This is helped by the aggregation and application of more training data. However this is still costly to host and models can be expensive.

Conclusion

A range of image recognition technologies, including text and image searches and web scrapers, are capable of being deployed now against online marketing of illegal wildlife goods. The information derived can be used to disrupt online trade by enabling authorities to take enforcement action or online service providers to curtail marketing activities. In slightly longer time horizons, advanced analysis and machine learning tools could be used on image data generated by existing border infrastructure. It is more difficult to envisage practical deployment of computer vision and deep learning techniques at the border which are more suited to wildlife population observation in the field.

21. Harrison JR, Roberts DL & Hernandez-Castro J. 2016 Assessing the extent and nature of wildlife trade on the dark web. *Conservation Biology*. http://dx.doi.org/10.1111/cobi.12707 (accessed 6 February 2018).

Image

Development of biological and chemical identification capability for use in the field

Devices that are smaller, more portable, faster, easier to use and cheaper than today's can be developed to improve law enforcement efforts by providing faster intelligence and detection.

Point of intervention

Field collection of samples is a vital step in the process of preserving evidence and acquiring a presumptive test[22] to identify species that may be traded illegally. Identification techniques typically associated with laboratory analysis, such as handheld devices capable of DNA analysis, are being developed for forensic testing in the field. Many of these technologies are not new but there are opportunities for those in the early stages of development, or not typically used in wildlife crime, to be applied across a targeted range of traded species and at various points in the system including crime scenes, at point of sale, or border control.

There is potential for significant impact if handheld and portable technologies could be harnessed and used for a wide array of species. The greatest benefit is likely to be the ability to hamper illegal trade whilst allowing legal trade to continue. Border officials and others would be able to quickly discern illegal products from legal ones when examining consignments, providing the ability to make faster decisions, although there might be the need for extensive training if a wide variety of tools are used.

As well as the benefits for rapid testing at the border, this intervention could ultimately provide rapid testing of evidence at wildlife crime scenes, and for trading standards. To achieve this goal, devices need to be highly portable, robust and affordable to ensure they can be immediately available to enforcement officers who might require them.

Science and technology

There are a number of different scientific techniques that might be used and developed for field use. The following examples are by no means exhaustive but rather illustrate the range of potential technologies at various stages of development.

The ParaDNA system developed by LGC labs is a portable DNA detection device typically used in crime scene forensics to identify human samples. The device is easy to use for non-experts and uses a direct Polymerase Chain Reaction (PCR) approach. It analyses a small amount of a sample by copying the DNA within it until there is enough to read. Whilst such devices are not new, the system sets new standards in speed and ease of identification[23]. The system is already used for field testing though not yet for the illegal wildlife trade. However, a proof of concept study has demonstrated that the system could correctly identify 92.7% of cod samples used in highly processed food samples as being from a single species[24].

22. A presumptive test establishes whether a sample is not a suspected substance or if the sample probably is the suspected substance. Presumptive tests will generally still need to be followed by confirmatory tests.

23. For further information see: https://www.lgcgroup.com/cn/products/paradna-technology/paradna-field-portable-instrument/#.W6f8OEVKg_U

24. Dawnay, N. *et al*. 2016 Species detection using HyBeacon1 probe technology: Working towards rapid onsite testing in non-human forensic and food authentication applications. *Forensic Science International: Genetics*, **20**, 103-111.

It could be developed to carry out presumptive tests for a suite of species, for example to test for endangered species being offered in traditional medicines. For each new application a developmental phase would be required to set up the system and add the relevant reference data to the software. This developmental phase takes around a year from the laboratory level to the provision of the assay.

Oxford Nanopore Technologies have developed a mobile phone sized DNA sequencer, the MinION, which determines the order of the four chemical building blocks in a DNA chain by the characteristic fluctuation each induces in an electric current as they pass sequentially through a nanoscale pore. Species are identified by comparing the DNA sequence to a validated reference database. The single method applied using this device can identify a broad range of species, and uses an existing global database of DNA from over 250,000 species[25]. To use the MinION, various protocols must be applied using components that require different temperatures so it is predominantly currently used in labs. However, components that are able to withstand ambient temperatures are being developed for field use. The MinION can fit in a pocket, is relatively low cost and whilst current protocols require additional equipment and a degree of expertise, the process is being simplified with the aim of allowing anyone to use it in any location with minimal extra equipment or training[26]. The timescale to reach this level of refinement is likely to be several years.

Electronic Noses (e-noses) are handheld devices that use sensors to mimic a dogs' olfactory system to identify chemical odours. The University of Technology in Sydney (UTS) are developing the devices to be rapid and easy to use, though they are at least five years from deployment. UTS has created a prototype but it has not yet been developed and validated for use in the field. It is hoped the device will be able to distinguish between species and items. Sensitivity is currently the biggest challenge, as generally speaking, the greater the sensitivity the less portable the device becomes. Nanosensors could represent one way to increase sensitivity and they are in the early stages of investigation[27].

Barriers and opportunities

Many of the barriers, downsides and risks are technology specific, for instance the reliance of e-noses on adequate sensitivity. However, there are a variety of common barriers that exist across these technologies.

The technologies, whilst adapted for field use, only provide presumptive rather than confirmatory tests and unless field tests are 100% accurate, lab confirmation tests will still need to be carried out, as with any forensic science[28]. Similarly, no technologies can identify a species without sufficient reference data, which requires the collection of samples for comparison, stored in reliable and sharable reference databases. International efforts to generate a comprehensive robust database of species identifying DNA sequences are continuing apace and will soon cover most species of relevance to the illegal wildlife trade.

25. For further information see: http://www.barcodinglife.org/

26. For further information see https://nanoporetech.com/products/minion

27. For further information see https://web-tools.uts.edu.au/projects/detail.cfm?ProjectId=2015001376

28. Tests typically require a benchmark of 95% accuracy to be classed as diagnostic.

All forensic technologies require significant validation. This is the key for field devices and the examples given demonstrate the need for real-world validation to identify a threshold of acceptability. Validation can be a lengthy and time-consuming process.

Device users, such as border staff, are often overburdened with the number of technologies in which they might need to be trained. Training non-experts, whether border force or crime scene investigators, can also require significant resources. This raises additional questions about the standardisation of training programmes and the level of knowledge and expertise needed for good evidence collection. Standards and quality control can be compromised if people are not sufficiently trained in using tools appropriately to gain quality results. There are a number of programmes that train non-experts to use equipment in the field, though as with any new technologies training and dissemination takes time.

Economies of scale can push down costs for handheld and portable devices, though costs can be quite high in the early stages for new technologies.

Conclusion

There are many opportunities to develop technologies for identification capability in the field. It is likely that a variety of tools or techniques will be needed to identify one or more species, at different points in the system, and across different environments. The priority may be to understand the exact needs of the users and in doing so create devices that are smaller, faster, easier to use and cheaper than today's, as well as sufficiently validated with a cache of reliable reference data.

Image
© lcswart

Environmental isotope analysis

Deeper understanding of the relationship between the environment and the chemical composition of organisms can be used to obtain intelligence on their geographical origins and age, useful for law enforcement.

Point of intervention

Isotope analysis has been applied widely in human forensics to advance criminal investigations and in the food industry to authenticate the origin of food products such as wine and meat. This approach is based on two principles: first, different environments have predictable isotopic signatures, stable or radioactive, and second, these signatures are embedded into the tissues of organisms through their diets[29]. Samples of tissue (such as hair, feathers, tusks and leaves) may be analysed for different isotopic markers, providing valuable information on their history. For example, the movement of Atlantic salmon has been traced by looking at the ratio of the chemicals strontium 87 to strontium 86 in the ears (otoliths)[30].

The underlying techniques are generally well established but new applications specific to the illegal wildlife trade will require further research and demonstration. Already, stable isotope analysis for geographic tracing has been applied to plant and animal species including orchids, cycads[31], and crocodile lizards[32]. Radioactive isotope analysis is useful in determining the age of animal species that have parts amenable to this technique, such as elephant tusks[33].

Isotope studies may also be well suited to certain places in the trafficking chain. First, where illegal specimens have been seized, stable isotope studies might provide insights into their origin, while radioactive isotope dating might establish how long ago they were obtained. (see case study 7). Second, stable isotopes may be applied to test claims of origin within 'legal' wildlife supply chains to ensure they are not in fact being used to trade illegal wildlife.

CASE STUDY 7

IvoryID

IvoryID is applying both stable and radioactive isotope analysis in the fight against elephant poaching and the illegal ivory trade. It utilises stable isotope methods validated by researchers from WWF Germany and works with partners from the University of Regensburg who analyse radioactive isotopes to determine the age of ivory.

The website includes a free and readily accessible reference database of over 700 samples of ivory from African and Asian elephant range states, and was handed over to the international CITES community at COP 17 in 2016.

For further details see ivoryid.org/

29. Rubenstein DR & Hobson K. 2004 From birds to butterflies: animal movement patterns and stable isotopes. *TRENDS in Ecology and Evolution* **19**, 1, 256-263.
30. Barnett-Johnson R et al. 2008 Tracking natal origins of salmon using isotopes, otoliths, and landscape geology. *Limnology and Oceanography*., **53**(4), 1633–1642.
31. Retief K, West A & Pfab M. 2014 Can Stable Isotopes and Radiocarbon Dating provide a forensic solution for curbing illegal harvesting of threatened cycads, *Journal of Forensic Sciences* **59**, 6,. 1541-1551.
32. van Schingen M *et al*. 2016 Can isotope markers differentiate between wild and captive reptile populations? A case study based on crocodile lizards (Shinisaurus crocodilurus) from Vietnam. *Global Ecology and Conservation*, **6**, 232-241.
33. Cerling T *et al*. 2016 Radiocarbon dating of seized ivory confirms rapid decline in African elephant populations and provides insight into illegal trade, *PNAS*, 1-6.

Science and technology

Isotopes are atoms of one element with the same number of protons but differing number of neutrons. They may be stable, such as carbon-12, 12C, or unstable/radioactive, such as carbon-14, 14C. Isotope analysis often uses a mass spectrometer to measure the ratio of different isotopes in a sample. The isotopes are ionised through the loss of electrons to electrically charge them, allowing them to be deflected by a magnetic field. A difference in mass causes the lighter ions to deflect more than the heavier ones, separating them and allowing the presence of different isotopes in the sample to be measured, see figure 4.

Stable isotope studies are useful in geographic tracing of samples and have the potential to work in most environments provided there is sufficient isotopic variation. The isotopic signatures of plants generally show stronger correlation to their environment because they do not move in contrast to animals. Organism isotopic signatures also tend to move further from the original environmental signature the higher up they sit in the food chain – with carnivores experiencing larger shifts than herbivores.

Different stable isotopes convey different information, for example:

- Carbon and hydrogen – organism interactions with their environment (ecology)
- Nitrogen – aridity (dryness)
- Oxygen – temperature
- Sulphur – proximity to the ocean
- Strontium – underlying geology on which plants grow.

Some stable isotope applications utilise the distinct isotopic signatures of certain locations to infer origin of species[34], while others apply the variance of sample isotopic signatures to differentiate between wild and captive-bred organisms[35]. In the latter case, the generally widely varied diets of wild organisms are distinguishable from the more restrictive diets of captive-bred specimens.

Radioactive dating is based on the predictable decay of radioactive elements and has been used to date samples over thousands of years, by using known reference isotope ratios. One such reference applied to the illegal wildlife trade is the spike of 14C in the atmosphere in the 20th century. Since then, the ratio of 14C /12C has steadily declined, as represented in figure 4. Using this reference, the age of a sample can be deduced by analysing its 14C content[36].

Alongside ‘passive’ tracing of environmental isotopes there are also more ‘active’ applications that involve tagging of wildlife or wildlife parts by deliberately changing their isotopic signatures. The precision, as well as social and ecological implications of these methods are not well understood and would require further research to verify their safety for use.

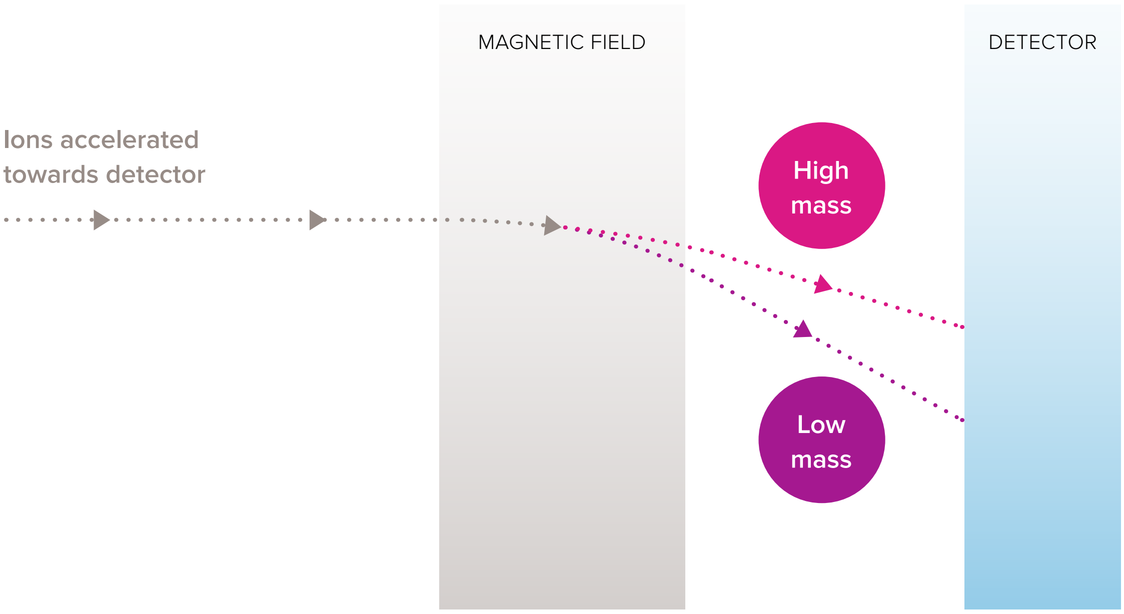
34. Bowen G, Wassenaar L & Hobson K. 2005 Global application of stable hydrogen and oxygen isotope to wildlife forensics. *Oecologia*, **143**, 337-348.

35. van Schingen, M. et al. 2016. Can isotope markers differentiate between wild and captive reptile populations? A case study based on crocodile lizards (Shinisaurus crocodilurus) from Vietnam. *Global Ecology and Conservation*, **6**, 232-241.

36. The 14C spike is from historical atmospheric nuclear testing.

FIGURE 4

How a mass spectrometer works.



Source: gcsescience.com/f29.htm

Barriers and opportunities

Implementation of isotope analysis requires the development of comprehensive global reference databases – a substantial data collection effort that might be initiated by targeting priority areas. These databases should be freely accessible and searchable, and developments in big data analytics might further aid their development and maintenance[37].

Current developments utilising both physical measurements and simulations to model isotopic signatures over large geographic areas known as isoscapes may improve the prospects for developing such reference databases[38]. Isoscapes reduce the number of physical samples required, and are a useful tool for visualising isotope variations over large areas.

Isotope analysis uses specialist equipment like mass spectrometers that are expensive and which require stable power supplies and temperature control. These may not be available in some developing countries where wildlife trafficking is prevalent, hence requiring partnerships with more developed countries where samples can be tested. However this may be complicated by CITES rules which prohibit movements of certain materials.

Spectrometers for detecting light isotopes, such as carbon, nitrogen, hydrogen, oxygen and sulphur, are often somewhat more affordable and easily deployed than those used to detect heavier isotopes. Portable devices are currently available from some manufacturers but they are generally less precise than lab-based instruments, as well as requiring power that is often supplied through batteries in the field, and needing to be robust and easily usable by local enforcement teams. Ideally, a device would be small, precise, robust, portable and affordable, particularly as cost remains a major barrier for the use of these techniques by law enforcement agencies. It might be simpler to engineer such an instrument that focused on only one or two isotopes.

While stable isotope analysis can provide insights about the geographical origin of samples, the technique is not precise because several geographical areas may share similar isotopic signatures. Precision may be improved through combination with other types of tracing, and users should have an understanding of the limitations of this method. Practitioners would have to adhere to strict standards for the results of these techniques to be used as evidence in court.

Radioisotope dating using 14C may only be possible until around 2035, after which radiocarbon from the 14C spike will have decayed to very small values. Thereafter this method may need to rely on new or more sensitive techniques.

Conclusion

Environmental isotope analysis presents opportunities for tackling the illegal wildlife trade both now and in the future as the science is developing and the techniques will improve. Stable isotope analysis might be useful in differentiating between wild and captive-bred samples while radioactive isotope analysis might provide information into when samples were harvested. The development of reference geographic databases of stable isotopes, facilitated by recent developments in isotope variation modelling, would further enable the application of this technique.

37. Pauli JN *et al*. 2017 Opinion: Why we need a centralized repository for isotopic data. *Proc. Natl. Acad. Sci. U.S.A.* **114**, 2997-3001.

38. Bowen GJ & West JB. 2008 Isotope landscapes for terrestrial migration research. In: Hobson KA & Wassenaar LI (eds) *Tracking Animal Migration with Stable Isotopes*, Amsterdam: Elsevier.

Conclusions

The tools described in this briefing offer rich opportunities to combat the illegal wildlife trade. While none represent a comprehensive solution, each could make an important contribution if developed and deployed in a context-sensitive manner. In researching the areas of science and technology presented, four cross cutting themes emerged that could help make the interventions identified more successful:

Accessible, affordable innovation and fit-for-purpose products

The illegal wildlife trade often takes place in complex settings with limited resources or harsh environments such as isolated border posts or busy ports. In such circumstances technologies need to be affordable, reliable, easy to use and tailored to their environment[39]. Users should be involved in development from an early stage, and provided with training and continuous long-term support. New technologies also need to be integrated into existing operations, their rollout supported and interventions fashioned so that evidence and data can be correctly collected. While there is a strong need for simple yet innovative solutions, there is also a place for more sophisticated approaches that may become more widely available over time as research and economies of scale make technologies more accessible.

Wildlife crime as a technological test bed

Limited resources are available to stop wildlife crime. It is not the business of most corporations and only one of many responsibilities for governments. However, the challenges posed by the trade can serve as test beds for technologies with much wider commercial or public application. For example, digital risk profiling of shipping documentation could be used to stop many different sorts of smuggling. This has parallels with the successful development of the predictive text system found in millions of mobile devices before smartphones, which was developed alongside more niche work on eye tracking products for people with disabilities[40].

Digital infrastructure and global technology platforms

The recent rapid growth in digital technologies has been accompanied by the creation of global digital infrastructure and technology platforms. These can provide access to free resources that can help stop wildlife crime such as global positioning through satellites, instant messaging and cloud computing. Global digital networks potentially allow developing countries to draw upon previously inaccessible digital capabilities from elsewhere, providing the right basic infrastructure is in place[41]. Citizens too have a role in helping to develop and implement technological interventions through digital means, as demonstrated by the work of WildLab.net using images. (see box 2).

39. See for example SMART conservation software that has been refined, supported and promoted by nine implementation partners: http://smartconservationtools.org/

40. Ganapati P. 2010 T9 predictive text inventor dies. *Wired*. 24 September 2010. See http://www.wired.co.uk/article/t9-predictive-text-inventor-dies (accessed 6 February 2018).

41. Economist. 2017 What technology can do for Africa. See https://www.economist.com/news/special-report/21731038-technology-africa-making-huge-advances-says-jonathan-rosenthal-its-full (accessed 6 February 2018).

Open data and databases

To analyse shipping manifests or images, machine learning systems need to be trained on large pools of examples, while reference databases are required for many chemical sensing and identification techniques to work. In some cases data exists but is not easily accessible and in others it has yet to be collected. One study found that only 5% of datasets meet a 'gold standard' needed for effective biodiversity conservation[42]. The development of new and emerging technologies to help tackle the illegal wildlife trade would be enhanced through better collection, storage and sharing of secure data, as well as accessible, secure and curated databases. Such progress would also help us to better understand the trade.

Rapid recent scientific and technological advances across many fields from digital to DNA profiling have opened a wealth of possibilities for tackling wildlife trafficking. Considerable progress has already been made through the hard work of NGOs, academia, industry, governments, citizens and others. In identifying the interventions in this briefing, the Society hopes to showcase some further potential gains while recognising that these are only part of the solution to what is a complex problem. A number of technologies, such as detection of environmental radioactive isotopes in ivory, are closer to deployment than others, such as smart shipping containers. If properly tailored to the environment and users, the technologies covered here present powerful additions to the toolkit for stopping wildlife crime.

42. Joppa LN *et al*. 2016 Filling in biodiversity threat gaps. *Science*, **352**, 6284, 416-418.

Appendix

Chair

Chair
Professor Andy Hopper CBE FRS FREng, Treasurer, Royal Society

Review panel

This report has been reviewed by seven independent experts. The Review Panel members were not asked to endorse the conclusions of the report, but to act as independent referees of the technical content and presentation. Panel members acted in a personal capacity. The Royal Society gratefully acknowledges the contribution of the reviewers.

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Acknowledgements

This project would also not have been possible without contributions from a range of individuals through interviews, workshops and roundtables. We wish to particularly thank:

Acknowledgements
Sir David Attenborough OM CH CVO CBE FRS
Professor Dame Sue Black, Professor of Anatomy and Forensic Anthropology, University of Dundee (until July 2018)
Professor Richard Catlow FRS, Foreign Secretary, Royal Society
Naomi Doak, Head of Conservation Programmes, United for Wildlife
Dr Tim Harrison, Science Teacher, Farlingaye High School
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9 781782 523604

ISBN: 978-1-78252-360-4
Issued: September 2018 DES5360