Methodological Annex to the 2nd edition of the World Wildlife Crime Report: Trafficking in protected species

Introduction

This document describes the methodological approach developed for the World Wildlife Crime Report analysis and to integrate different data sources into a consolidated database, namely the UNODC World WISE Database. It explains the aggregation techniques, the methodology to estimate trafficking flows and illicit financial flows and produce related maps, and the methodology adopted for the field research, product conversion rates, and price data. It also presents and discusses the case studies included in the 2020 World Wildlife Crime Report.

The information presented in the World Wildlife Crime Report is based on both qualitative and quantitative data, including data available from the following sources:

- CITES Trade Database
- CITES Monitoring the Illegal Killing of Elephants (MIKE) Programme
- CITES Elephant Trade Information System (ETIS)[1]
- International Union for the Conservation of Nature - Species Survival Commission (IUCN-SSC) population data
- National administrative records
- Trade statistics, including those from UN COMTRADE and the International Tropical Timber Organization
- TRAFFIC
- Wildlife Justice Commission
- EIA - Environmental Investigation Agency
- EAGLE - Eco Activists for Governance and Law Enforcement
- LAGA – Last Great Ape Organisation
- UNODC forensic data
- World Bank Development Indicators
- Fieldwork conducted by UNODC in Benin, Burkina Faso, Cameroon, Central African Republic, Chad, the Democratic Republic of the Congo, Gabon, Gambia, Guinea-Bissau, Germany, Indonesia, Japan, Kenya, Madagascar, Mali, Malaysia, Mexico, Nigeria, United Republic of Tanzania, Senegal, South Africa, Thailand, Togo, Uganda, USA, and Viet Nam.
- UNODC World WISE wildlife seizures database

The updated UNODC World WISE Database includes the following data sources:

- CITES Annual Illegal Trade Reports (from 2017)
- CITES Annual reports, CITES Biennial Reports, CITES Special Reporting Requirements and other CITES reports
- EU-TWIX
- World Customs Organization, Customs Enforcement Network Database (WCO-CEN)
- United States Fish and Wildlife Service LEMIS database

[1] UNODC appreciates the collaboration of TRAFFIC regarding the provision of ETIS data on West and Central Africa.

- EIA – Environmental Investigation Agency *(for pangolins, rhinos, elephants and big cats only)*
- ASEAN Wildlife Enforcement Network
- AFTTS - GORE
- Australian Permits Administration Database
- COBRA3 Operation
- COFIS/IBAMA
- EAGLE
- Environment South Africa
- Hong Kong Customs
- LAGA – The Last Great Apes Organisation
- Lusaka Agreement Taskforce Secretariat
- Mexican National Data
- NECER - National Environmental Compliance & Enforcement Report
- Philippines National Data
- WAPPRIITA - Wild Animal and Plant Protection and Regulation, Canada
- WCCB - Wildlife Crime Control Bureau, India
- WPSI - Wildlife Protection Society of India

Assembling the World WISE Database

The way that each country records its crime data, including its seizure incidents, was independently devised. The domestic laws pertaining to wildlife also vary greatly between countries, so both the format and the content of wildlife seizure records are diverse. The creation of global crime databases is greatly facilitated by the existence of global agreements, which can include definitions (since there is no global agreement on the definition for wildlife crime) and, over time, standardised formats for recording violations. Up until the creation of the CITES Annual Illegal Trade Reports in 2016, there was no standard template under which wildlife seizure incidents were recorded.

As a result, the World WISE Database was assembled from a number of independent databases that were not designed to be compatible. Fortunately, however, the CITES system has been highly influential in the way that Parties record their seizure data, and many of the same abbreviations and recording conventions appear in both CITES permit databases and the wildlife seizure databases integrated to create World WISE. The extent of this convergence varies between countries, so the amount of adaptation required to integrate each national or regional database into World WISE varies.

With the 2016 implementation of the CITES Annual Illegal Trade Report requirement, countries now report seizure data in a standard format that includes the following information:

- Date of seizure
- Species
- Quantity & unit
- Location of incident
- Detecting agency
- Reason for seizure

- Means of transport
- Method of concealment
- Alleged country of origin
- Country(ies) of transit
- Alleged final destination
- Estimated value in country (optional)
- Nationality of offenders (optional)
- Law under which charges were brought (optional)
- Sanction (desirable)
- Disposal of confiscated specimens (desirable)

Even if a system with a standardised set of codes (for example for the description of the specimens) is in place,[2] unfortunately, there appears to be a lot of variation in the way these codes are applied. This implies that a share of the observed seizure records is unusable. While some of these appear to be simple mistakes, others reflect the limited capacity of the reporting authorities to identify precisely seized specimens. Species are often reported with generic names (e.g. "elephant") or scientific names correspond to high taxonomic levels. For example, some seizures are listed under the family "*Anguillidae*", which includes several types of eel species, some of which are not CITES listed. Moreover, the description of the specimens is not always available, and units are sometimes employed that do not properly capture the quantity seized. For example, timber seizures may be associated with a count, and it is unclear what "six timber" represents. An additional complication is represented by the misalignment in the reporting of the seizure dates, which complicated the detection of duplicated entries.

As said, in order to guarantee the widest possible coverage of seizure events, the World WISE Database integrates multiple data sources. In recent years, UNODC had access to several data sources covering, in some cases, the same seizure events. For countries with rich data, a pre-selection of data sources was carried out (for example, for EU Member States, EU-TWIX data were used instead of AITRs). For those reporting a more limited number of cases, all possible data sources were put together, even when covering the same years. Therefore, a duplicates cleaning process was implemented to remove duplicated cases.

To minimize the risk of duplicated entries and maximise the data coverage, a duplicates cleaning process was designed and implemented in three stages:

1. A first stage consisted of the removal of identical observations, that is records reporting the exact same information for all fields.
2. The second stage consisted of the selection of a subset of key variables and a removal of identical observations based on these variables only. Records were removed when reporting identical information on the following variables:
    - Country of seizure
    - Date of seizure
    - Species scientific name
    - Description of specimen
    - Quantity
    - Unit
    - Corresponding count

[2] See CITES Guidelines for the preparation and the submission of the CITES Annual Illegal Trade Reports: https://cites.org/sites/default/files/notif/E-Notif-2019-072-A2.pdf

    - Corresponding mass (converted to the same multiples – like grams to kilograms)

   The location of the incident was not considered, as reporting standards for the locations vary widely. The routing was also not taken into account, as many data sources do not report such information.

3. The third, more sophisticated duplicates cleaning algorithm is based on a similarity criterion. The same seizures are, in fact, often reported by the authorities with different but similar dates, or with similar quantities (for example, 133 kilograms and 130 kilograms), therefore some similarity criteria were set up to remove these entries.

Aggregation techniques

To speak about "wildlife crime" as a whole, it is essential to aggregate the many different products and many different species that are commonly seized. The World WISE Database contains seizures of some 6,000 species, and many of these can appear as a range of different products. Some seizures matter more than others, due to a combination of the quantity of material seized and the significance of the species per quantity.

To discuss trends in wildlife crime, or to perform comparisons between species products, some standard units are essential. A first challenge in the aggregation of the quantities emerges by the fact that authorities do not use a common unit of measurement to report the quantity of seized specimens, and count units are used as frequently as mass units. For example, in some cases the quantity of elephant tusks seized are reported in kilograms, whereas in others they are expressed in number of tusks seized. Only for a very limited number of data sources are both the number of seized specimens and the corresponding mass available (like in the EU-TWIX Database).

In order to standardize the unit of measurement and therefore to aggregate the quantities of seized items, two types of units have been created:

- **Mass equivalent (kilograms)**
  Conversion formulae were generated to combine useable categories and to convert compatible mass units. Seizures already expressed in ounces, milligrams, and tons were converted into kilograms. Then, seized quantities expressed in counts or number of pieces were converted to mass using a count-to-mass conversion factor. For more details on the conversion factors, see the case studies by species below.

- **Live equivalent**
  In the species analysis, as discussed below, the most common product categories were also converted to an additional common unit, a whole/live animal equivalent. In general, the seizure of whole bodies (BOD), live (LIVE), trophy (TRO), skulls (SKU) and full skeletons (SKE) were assumed to be equal to a whole animal.

For the conversion from mass to live equivalent, the PanTHERIA database was used to identify the average adult mass of for most species, except for some of the case studies.[3] The average adult mass of a species was then used to determine the mass-to-live conversion factor for that species. For the seizure records that were reported by genus only, the genus-level average weight (weighted based on the number of seizures of the different species from that genus in the database) was calculated using the following formula:

$$GW = \sum_{i=1}^{N} w_i * W_i$$

GW = Genus-level average weight
W_i = Average weight of the species i
$w_i = \frac{x_i}{X}$, weight factor of the species i
x_i = Total quantity of specimen of the species i
X = Total quantity of specimen of all species in the genus
N = Number of species in the genus

For certain species for which both mass and count were made available by the reporting authorities for a sufficient number of seizure records, conversion factors have been calculated on the basis of these cases. This approach is currently adopted for the cases of elephant ivory and rhino horns. The details and the results of these calculations are discussed in the case studies section below.

Seizures valuation

Comparing and aggregating wildlife seizures is complicated because of the variety of products involved. Organized crime is committed for material gain, and the extent of this gain is of great relevance for traffickers. In addition, the aggregated mass or live equivalent do not say much about the relevance of the illegal market and, in many cases, make direct comparison between different species meaningless. Thus, to capture the criminal significance of a wildlife seizure, it makes sense to assign a monetary value to it. Due to the difficulty in assessing the monetary value of all the seizures included in World WISE, in the present report, the use of this standard unit of measurement was limited to the most commonly trafficked wildlife. Looking at the variation in the value of these markets across time was also useful in demonstrating the volatility of the seizure records.

Of course, wildlife commodities do not have a fixed monetary value. Valuation provided in the illegal trade reports by the authorities is often missing and the reported illegal trade value is often inaccurate. Moreover, the true value of a seizure depends on the point in the supply chain

[3] Jones, K., Bielby, J., Cardillo, M., Fritz, S., O'Dell, J., Orme, C., Safi, K., Sechrest, W., Boakes, E., Carbone, C., Connolly, C., Cutts, M., Foster, J., Grenyer, R., Habib, M., Plaster, C., Price, S., Rigby, E., Rist, J., Teacher, A., Bininda-Emonds, O., Gittleman, J., Mace, G. and Purvis, A. (2009). PanTHERIA: a species-level database of life history, ecology, and geography of extant and recently extinct mammals. Ecology, 90(9), pp.2648-2648. Retrieved from http://esapubs.org/archive/ecol/E090/184/ on March 20, 2019.

the seizure was made. This would seem to pose an insurmountable barrier to valuating each seizure for comparative purposes.

Fortunately, some countries do record the declared values of legal imports and exports of a wide range of wildlife species-products. Since the point is to create a standard unit for comparison, rather than to accurately pinpoint real market value, it makes sense to use a single reference market. It would be best if this reference market were large, with many data points to reference, representing both a significant hub for legal trade and a significant source of wildlife seizures. All these qualities were met in the data (including value data) captured by the Law Enforcement Management Information System of the United States Fish and Wildlife Service (LEMIS). To provide an appropriate valuation, the declared import and export values from LEMIS were statistically assessed and each seizure assigned a monetary value based on this dataset. Where valuation information was not available from LEMIS, mainly for CITES appendix I species, other sources from the literature and UNODC fieldwork were used.

These price data have their weaknesses. The "Declared U.S. Dollar Value" is the amount in United States dollars declared by the trader at the point of export from or import to the United States of America. Often, this information is derived from the invoices associated with the shipment, so the value may represent what the importer paid the overseas supplier, or what the exporter charged the overseas purchaser. The declared value does not, therefore, typically represent the retail value of the traded wildlife, and there may be incentives for under-pricing. In addition, authorities do not routinely verify or validate these values to confirm their accuracy beyond comparing them to other documentation included with the declaration. In those cases where the wildlife was not declared, such as wildlife that was unlawfully imported or exported and subsequently interdicted by the United States Fish and Wildlife Service or another agency, an estimated value for that wildlife was assigned or a value of "0" was entered as the declared value. Zero-value imports were excluded.

Both import and export price data were included in the analysis. The purpose of the trade was limited to breeding, commercial, personal and hunting trophies, excluding all trade related to circuses and traveling exhibitions, botanical gardens, zoos, reintroduction into the wild, enforcement, medical, scientific and educational purposes. After applying all these filters to the dataset, 1,475,558 relevant price records were used for the calculation of average price estimates. Price per taxon per year (2006-2013) was corrected for inflation by using a conversion factor to express prices as estimates of U.S. dollars in 2018.

Genus and higher taxonomic levels were used so that prices would be based on a greater number of records, thus providing a more robust price estimate. The price indices are therefore calculated at the genus level and segregated by type of specimen and unit. Calculations done at the genus level also provided value data for a higher proportion of seizure records. This larger sample comes at a cost, however, as within the genera there can be considerable variation in the value assigned to specific species. For example, the rarer species of parrots can be worth many times their more common relatives. Due to the nature of the distribution of the price data (non-normal, small number of cases, outliers, wide variation), the median was the best measurement to estimate the genus unit price. Price indices for the case studies are detailed below in the relevant sections.

The methodology used to derive the value index is as follows. Each reported value is considered and assigned a weight to the valuation according to the amount of the commodity associated with each seizure record.

Let commodity x have n number of reported declared values; $\{v_1, v_2 \ldots \ldots v_n\}$
Assuming that each report involves several units of the commodity $\{x_1, x_2, \ldots \ldots x_n\}$,
the value assigned to each report is: $\{x_1 * v_1, x_2 * v_2, \ldots \ldots \ldots x_n * v_n\}$
Thus, the value of all the reported amounts of commodity x is: $\sum_{i=1}^{n} x_i * v_i$
The value index for commodity x used for this report is the weighted average

$$vx = \frac{\sum_{i=1}^{n} x_i * v_i}{\sum_{i=1}^{n} x_i}$$

Trafficking flow maps

Individual seizure data have the power to provide rich information on many aspects of the illegal products trafficked. Most wildlife seizure data reporting tools (AITR, WCO, EU-TWIX…) report information not only on nature of the seized specimen (species, product, mass…) and on the seizure event, but also on the routing of the illicit shipment.

Information on the country of origin, transit and destination can help the investigation of transnational trafficking flows and the identification of countries exposed to major trafficking threats, as well as areas where the demand of such products is more relevant.

Trafficking flow maps allow the visualization of aggregated information on the major countries of origin and destination of the trafficked species. The availability of data on origin, transit, and destination countries is the starting point for identification of the trafficking routes and the basis for building flow maps. However, in many cases, this information is not available to the seizing authorities or is not reported in the data collection form.

In the absence of complete information on the routing of seizures, it becomes then crucial to make a number of assumptions on the routing and extrapolate the hidden components, from the partially available information. Since the country of seizure is always known, this information can be useful to supplement missing data on the routing.

Countries where the seized species is native can be considered the origin, while all the others can be considered transit or destination countries. In this way, proxy variables on the origin or destination can be reasonably constructed to extrapolate more information on the routing for the purpose of developing the trafficking flow maps.

Proxy variables for origin and destination country and definition of role of the seizure country in the supply chain

According to the available information on the routes for any individual seizure, it is possible to establish a rule to build proxy variables for missing origin and destination countries and determine the role of the country of seizure in the supply chain. Emphasis is placed on the origin and destination countries, rather than on transit countries. Information on transit countries is often incomplete and generally not reliable enough to be represented on the flow maps. In addition, being the focus on showing origin and final destination of illicitly traded wildlife items, it might result misleading to represent transit countries on the trafficking flow maps. Therefore, the report's flow maps primarily focused on identifying the origin and destination countries.

The following scenarios have been identified to build the proxy variables:

- Scenario 1: Information on country of destination is available, while the origin country is missing. In this case, if the protected species is native[4] in the seizure country, the seizure country is assumed to be the origin. Otherwise, no assumptions can be made on the origin country and it is left as "unknown".

- Scenario 2: Information on the country of origin is available, while the destination country is missing. In this case, the country making the seizure is considered its destination, if this is different from the origin.

- Scenario 3: Both the country of origin and the country of destination have been specified, but the seizure country does not match either the origin or the destination country. Given that the illicit item has been detected in the seizure country, the country of seizure is considered a transit country.

After adopting the above rules to fill in missing information on the trafficking route, all observations still having missing information on the origin or destination were removed. In addition, domestic seizures – defined as seizures where the reported origin corresponds to the reported destination – were also excluded.[5]

Following this rule, it was possible then to assign a role to the seizure country in the trafficking route for most seizures in the WISE Database. Seizures have then been aggregated by country of origin and destination and two trade flow matrices have been created.

Potential and actual flows matrices

The concept of "actual" and "potential" flows is particularly relevant in aggregating individual seizures to produce the final adjusted flows of illicit items to be represented on the map.

The concept of potential and actual flows is based on the idea that some illicit flows *actually* happened when a shipment of illicitly traded products leaves the country of origin and is detected in the country of destination. The situation is different when the country of seizure is the country of origin, where no illicit shipment is detected at the destination because it was seized by the (border or national) authorities in the country of origin. A separate treatment of the two cases was considered necessary so long as some countries may appear as destinations but do not actually record any flow, because the illegal shipment has been seized at the origin.

Even if the situation may be slightly more complex than this, and frequently seizures are detected thanks to bilateral and cooperative efforts of law enforcement authorities in both the exporting and the importing country, differences in border control capacity to detect and report

[4] Species are defined as native in a certain country if the country is mentioned among the ones that are part of the distribution area of a certain species included in the CITES checklist. For more details see the *Full species list* in the website https://checklist.cites.org/#/en.
[5] In this sense, seizures between different Special Administrative Regions of China and China mainland have also been considered as domestic.

seizures are relevant when it comes to estimating the quantity of trafficked species between two countries. Building a map on the basis of the reported seizures may lead to a biased picture. Countries who report more seizures would be incorrectly considered the countries who have imported more illicit items.

Potential and actual flows are then treated and adjusted in a different way, with a correction factor that aims to reflect differences in the law enforcement capacity of each country.

A first matrix, called **matrix of actual flows** is then constructed aggregating all flows that have been detected in the country of destination.

Table 1 - Actual flows matrix

	Destination = Seizure country			
Origin		$destination_1$	$destination_j$	$destination_m$
	$origin_1$	y_{11}	$\dots$	y_{1m}
	$origin_i$	y_{i1}	y_{ij}	y_{im}
	$origin_n$	y_{n1}	$\dots$	y_{nm}

The second matrix, called **matrix of potential flows**, aggregates all flows that were stopped by the authorities before they could be shipped to the destination.

Table 2 - Potential flow matrix

	destination			
Origin = Seizure country		$destination_1$	$destination_j$	$destination_m$
	$origin_1$	x_{11}	$\dots$	x_{1m}
	$origin_i$	x_{i1}	x_{ij}	x_{im}
	$origin_n$	x_{n1}	$\dots$	x_{nm}

The assumption is that the potential flows, despite the fact that they never occurred, might be used to estimate the total amount of illicit items which actually flowed from country i to country j.

For both matrices:

- Separate matrices are created for every group of species (elephants, rhinos, pangolins…), rather than considering bilateral flows of all species together.
- The aggregation corresponds to the sum of the *quantity* trafficked between two countries. For certain species (such as eels), the sum was calculated using live equivalents, whereas for other species (like elephants) the sum was performed using the estimated mass.[6]

[6] For more details on the aggregating variable used for each species, please refer to descriptions and footnotes of the maps in each chapter.

Calculation method

The total estimated illicit flow from country *i* to country *j* includes two components:

$$tot_{ij} = \frac{Potential_{ij}}{k_i} + Actual_{ij}$$

where k is a coefficient that represents the ability of the origin countries to block illicit trafficking before the illicit goods are exported, and is defined as:

$$k_i = \frac{\sum_{j=1}^{m} x_{ij}}{\sum_{j=1}^{m} y_{ij}}$$

Where:
x_{ij} is the potential flow from country *i* to country *j*
y_{ij} is the actual flow from country *i* to country *j*

The better a country is at detecting illicit items before they are exported, the lower the potential flows will be weighted. On the other hand, for those countries that have more difficulty blocking illicit goods before they are exported, the potential flow will be augmented because it will be divided by a number lower than 1.

Case studies

Consultants were commissioned to collect qualitative information on the report's main wildlife markets through key informant interviews. The markets studied included those for rosewood, glass eels, ivory and rhino horn, pangolins, live reptiles, and tigers. The nature of the individual consultancies, species conversion factors, and price indices (if different from the LEMIS price data) used for data analysis are detailed below for each chapter or box found in the report.

Rosewood

For the rosewood case study, data on the tropical hardwood furniture trade, as well as on the rosewood trade, were reviewed. A literature review on the illicit rosewood trade in Madagascar, Southeast Asia, East Asia, Central America, and West and Central Africa was carried out. An initial analysis of the trade data and literature indicated that quite a bit of work had already been done on the illegal rosewood trade in Southeast Asia and Madagascar. Central America, another source of CITES-listed rosewood, had been less studied, but also seemed to be a lesser source of illicit supply based on the seizure record. What had not yet been documented was a growing market for illegal rosewood from West and Central Africa, in particularly *Pterocarpus erinaceus*.

Earlier field research conducted in 2014 and 2015 from West Africa (Benin, Burkina Faso, Mali, Nigeria, and Togo) was partially used for the chapter, but new extensive fieldwork was also conducted in Gambia and Nigeria during 2018. Import/export data were obtained and analysed for all other countries via official statistics (customs, CITES management authorities etc.) and key contacts in-country. Data were also gathered from Senegalese sources close to the border with Gambia, as well as contacts in Guinea-Bissau.

Official statistics were supplemented by information provided during fieldwork by a range of rosewood industry stakeholders. The consultant conducted semi-structured interviews with government forestry staff, national park service staff, customs officials, ports personnel, shipping companies, and market sellers (see the table below for a list of the main people interviewed). These individuals provided information on how rosewood was extracted and then traded (both legally and illegally), how the trade was regulated, and the major sources and markets for rosewood logs.

Table 3 - List of stakeholders interviewed for the rosewood case study

Country	Institution
The Gambia	Department of Forestry
	Department of Parks and Wildlife Management
	University of The Gambia
	Ministry of Agriculture
	Ministry of Interior
	Ministry of Environment, Climate Change, & Natural Resources
	Janne Commission
	West Coast Region (WCR), Forestry Divisional Office
	Lower River Region (LRR), Regional Forestry Office
	Central River Region (CRR), Regional Forestry Officer
	North Bank, Regional Forestry Office
	Upper River Region (URR), Regional Forestry Office
	Gambia Revenue Authority (GRA)
	Gambia Ports Authority
	United Logistics Gambia
	URR
	LRR
	Gambia Ports Authority
	National Environment Agency
	NESERA
Nigeria	Department of Forestry in the Ministry of Environment
	Department of Forestry in the Ministry of Environment
	Federal Customs Department
	Ministry of Finance, Technical Services Department
	Trade and Exchange Dept. Central Bank of Nigeria
	Dei-Dei Market
	National Export Promotion Council
	National Parks Headquarters, National Parks Service, Federal Ministry of Environment
	Federal Ministry of Environment
	ECOWAS Forestry Department
	Ministry of Interior
	Dede Log Market, Abuja
	Central Bank of Nigeria (CBN)
	Apapa Ports, Customs Department
	Nigeria Wood Association
	Tin Can Island Ports, Forestry Inspection Department
	Sagamu Log Market

Rosewood seizures and estimates are expressed in a variety of terms, including weight, volume, log counts, and container counts. It can be difficult to compare between units, or to envisage what these large amounts mean in real terms. For this reason, the following rules of thumb are offered, although they are too imprecise to provide the basis for official estimates.

Rosewood logs are an organic product, and so vary considerably in size. There are differences in average size between species and there are differences within species depending on the age of the trees and the area of harvest. As illegal harvesting continues, the average size of the logs generally decreases, as younger trees are also targeted.

With these caveats in mind, it is still possible to come up with some general figures based on a review of seizures where the weight, the volume, and the number of logs were recorded. The table below shows the conversion factors used.

For data analysis purposes, conversions were applied for log and timber records reported in CON (containers), CUM (cubic meters) and NUM (number). Cubic centimeters were converted to cubic meters, grams were converted to kilograms and milliliters were converted to liters. Based on consultations with timber specialists, the following assumptions and conversions were made: 1 cubic meter is equivalent to 1 ton, 1 container is equivalent to 23 metric tons or 120 logs, 1 timber is equivalent to 1 log, and 2 logs are equivalent to 1 tree. *Pterocarpus erinaceus* data was also used to estimate conversion factors for *Dalbergia spp*.

Table 4 - Conversion factors for rosewood logs or timber by species

<table>
<tr><th rowspan="3">Species</th><th colspan="8">LOG/TIM</th></tr>
<tr><th colspan="2">Container (CON)</th><th colspan="2">Cubic Meter (CUM)</th><th colspan="2">KIL</th><th colspan="2">NUM</th></tr>
<tr><th>Mass 1 CON (kg)</th><th>Ratio</th><th>Mass (kg)</th><th>Ratio</th><th>Mass (kg)</th><th>Ratio</th><th>Mass 1 LOG (kg)</th><th>Ratio</th></tr>
<tr><td>Dalbergia</td><td rowspan="16">23000</td><td rowspan="16">383.33</td><td rowspan="16">1000.00</td><td rowspan="16">383.33</td><td rowspan="16">1.00</td><td rowspan="16">383.33</td><td rowspan="16">191.67</td><td rowspan="16">383.33</td></tr>
<tr><td>• Cearensis</td></tr>
<tr><td>• Cochinchinensis</td></tr>
<tr><td>• Granadillo</td></tr>
<tr><td>• Latifolia</td></tr>
<tr><td>• Madagascariensis</td></tr>
<tr><td>• Melanoxylon</td></tr>
<tr><td>• Nigra</td></tr>
<tr><td>• Oliveri</td></tr>
<tr><td>• Retusa</td></tr>
<tr><td>• Sissoo</td></tr>
<tr><td>• Stevensonii</td></tr>
<tr><td>• Tucurensis</td></tr>
<tr><td>Pterocarpus</td></tr>
<tr><td>• Erinaceus</td></tr>
<tr><td>• Santalinus</td></tr>
</table>

Ratio = live tree equivalent ratio

Assumptions: 2 logs = 1 tree, 1 timber = 1 log (to avoid overestimation)
Source: Environment Investigation Agency, (2018).[7]

For the rosewood price index valuation, rosewood data was not reported in LEMIS, instead data from the legal market prices in China were used to estimate value of rosewood records of type TIM, LOG in KIL, CUM, and NUM. For species with no data, the genus-level average price index was applied.

Ivory and rhino horn

For the ivory and rhino case study, a literature review was conducted and both legal and illicit trade data were analysed.

Ivory

Data collected from earlier field research in 2015 from Kenya, Mozambique, United Republic of Tanzania, and Uganda was used for this report, but because ivory harvested in West and Central Africa is trafficked via other parts of the continent and vice-versa, new fieldwork was conducted both in the region (Cameroon, Gabon, and the Democratic Republic of the Congo) and outside it (Kenya, United Republic of Tanzania, Mozambique, South Africa) from June to September 2018. Semi-structured interviews were carried out with government authorities, NGOs and local resident harvesters/dealers. A selected list of organizations interviewed are provided in the table below.

Table 5 - Selected list of stakeholders interviewed for the ivory case study

Country	Institution
Kenya	Kenya Wildlife Service
	Tsavo Trust
	Ol Pejeta Conservancy
	Lewa Conservancy
	Northern Rangelands Trust
	National Police Reserve
	Save the Elephants
	Aspinall Foundation
	Wildlife Direct
	Offbeat Safaris
United Republic of Tanzania	TANAPA
	TAWIRI
	Wildlife Now
	TRAFFIC
	TAWA
	PAMS

[7] Environment Investigation Agency (2018). GUINEA-BISSAU AUTHORIZED PLUNDER: The Rosewood Stockpile Sale, https://content.eia-global.org/posts/documents/000/000/802/original/EIA_US_Guinea-Bissau_report_0918_US_Format_FINAL_MEDRES.pdf?1547131805.

	Friedkin Conservation Fund
South Africa	SANParks
	Conservation Imperative
	Freeland Africa
	Cape Nature
	University of Cape Town
	Department of Environmental Affairs
	Directorate of Priority Crime Investigation
	DPCI
	State Security Agency
	TRAFFIC
Mozambique	ANAC
	Oxpeckers Center for Investigative Environmental Journalism
Namibia	WWF
Botswana	Mochaba Developments
Gabon	Gabon Parks
	CENAREST
	WCS
	Conservation Justice
	WWF
Cameroon	TRAFFIC
	LAGA

This research involved estimating new ivory entering the market annually. This calculation was based on an estimated number of elephants illegally killed between 2016 and 2018 developed by George Wittemyer (see annex 1 below for his full methodology). Wittemyer produced an update of the model he produced with colleagues in 2014, which estimated the number of elephants poached in three regions of Africa based on data from the CITES Monitoring of the Illegal Killing of Elephants (MIKE) program.[8] This updated model was used for the Central African portions of this report only.

For data analysis purposes in World WISE, conversions were applied to both African elephants (*Loxodonta africana*) and Asian elephants (*Elephas maximus)*. Only TUS (tusk) seizures were used for analysis. According to experts consulted, the count-to-mass conversion factors for tusks vary according to the region of the reporting countries. Accordingly, the average weight of a tusk per region was calculated using World WISE seizures that had both a count and a mass. This allowed for a more accurate representation of the mass of tusks in World WISE seizures since tusks can mean different things to different authorities in different regions. Some for example, only label ivory as a tusk when the full unworked tusk is trafficked; others report tusk pieces as tusks. The tusk-to-live factors is the region-species-specific count-to-mass conversion factors multiplied by 2. See the Table below for conversions.

[8] George Wittemyer, Joseph M. Northrup, Julian Blanc, Iain Douglas-Hamilton, Patrick Omondi, and Kenneth P. Burnhama, ‘Illegal killing for ivory drives global decline in African elephants’. *Proceedings of the National Academy of Sciences*, Vol 111, No 36, 2014. pp 13117–13121.

Table 6 – Whole tusk conversion factors by region for each species[9]

Genus	Species	Conversion Factor (kg)[10]	Mass-to-Live Factor	Region
Loxodonta		3.730224	10.24	Africa
Loxodonta	*africana*	3.730224	10.24	Africa
Elephas		3.730224	10.24	Africa
Elephas	*maximus*	3.730224	10.24	Africa
Elephantidae		3.730224	10.24	Africa
Loxodonta		2.756022	10.24	Asia
Loxodonta	*africana*	2.756022	10.24	Asia
Elephas		2.756022	10.24	Asia
Elephas	*maximus*	2.756022	10.24	Asia
Elephantidae		2.756022	10.24	Asia
Loxodonta		2.590214	10.24	Europe
Loxodonta	*africana*	2.590214	10.24	Europe
Elephas		2.590214	10.24	Europe
Elephas	*maximus*	2.590214	10.24	Europe
Elephantidae		2.590214	10.24	Europe

Source: UNODC calculations based on World WISE Database

Rhino horn

For data analysis purposes, conversions were applied to all rhinos.

The horn mass varies from species to species, therefore, the average weight of a horn per species was calculated using World WISE seizures that had both a count and a mass. This allowed for a more accurate representation of the mass of rhino horns in World WISE seizures. Due to data limitations, only a global conversation ratio was calculated for rhino horns instead of regional ones as was possible for ivory. When no species level identification was possible, the genus average weight was used. The horn-to-live factors of each species was calculated using the average estimated horn weight multiplied by the number of horns of the specific species.

Table 7 - Rhino horn conversion factors for each species

Species	HOR		HOP & HOC	
	Mass (kg)	Ratio	Mass (kg)	Ratio
Ceratotherium	2.183887	2.66	0.5111667	-
• *simum*	2.183887	2.66	0.5111667	-
Diceros	2.183887	5.88	0.5111667	-
• *bicornis*	2.183887	5.88	0.5111667	-
Rhinoceros	2.183887	0.96	0.5111667	-
• *sondaicus*	2.183887	0.96	0.5111667	-

[9] For Americas and Oceania, a common conversion factor was applied, with average mass at 3.012071 and a mass-to-live factor at 10.24.
[10] For specimen types TRO, TUS. For IVP, the average mass globally was 1.346419 and for IVC and IJW it was 0.09922317.

• *unicornis*	2.183887	0.96	0.5111667	-
Rhinocerotidae	2.183887	2.66	0.5111667	-

Source: UNODC calculations based on World WISE Database

For the rhino price index valuation, *Diceros sp*. horn prices were used to estimate *Ceratotherium sp*. horn prices. Since LEMIS did not report prices for horns (HOR) in kg, part of the information used for this estimate came from the Wildlife Justice Commission. The price value was calculated by multiplying the genus (in kg) price index with the genus count-to-mass conversion factor. The price of BOD/LIV/TRO was estimated by the price of the horn multiplied by the number of horns of the genus. The family prices were calculated using the median of the genus price.

Live Reptiles

For the live reptile case study, a literature review on the reptile pet trade was conducted. Both legal and illicit trade data were analysed, and fieldwork was conducted in 12 countries (including the United States of America, Mexico, Germany, Italy, Madagascar, and countries in East and Southeast Asia) over a two-year period from 2017 to 2019, chosen for their disproportionate involvement in the live reptile trade via local end consumers (hobbyists, breeders), animal traffickers, and a strong online influence in the trade. Regions were prioritized by current fads within the reptile trade, particularly rare turtles and tortoises, North American endemic species, and high-value island endemic species.

The consultant attended several reptile shows and markets: three in North America, two in Asia, and two in Europe. Effort was placed to systematically scan each venue, looking for animals with characteristics of being wild-caught or poached, documenting the species, approximate number of individuals, price, overall health, size/age, seller, country of origin, and any deceased animals. Any species likely originating from illicit means or listed on CITES Appendices I or II were documented, even if traded in small numbers. Photos or videos were taken whenever allowed and possible.

The consultant conducted structured interviews either in person or by phone with dealers/traders, zoos, NGOs, scientists, conservationists, and government authorities (see the table below for a list of the main institutions interviewed). These individuals provided information on current and emerging trends in the reptile pet trade including the scope of the trade, current trade routes and methods of concealment, the main players involved in the trade, as well as information on the characteristics of species that made them more attractive to dealers and collectors. Due to the intimate nature of the herpetoculture community, the majority of the interviewees requested to remain anonymous, in order to maintain their relationships with other hobbyists, business relationships, government relationships, and/or retain anonymity for their own market research. The consultant also monitored online social media platforms (Facebook, Instagram, Weibo, classifieds, hobbyist forums, etc.) for data on the illegal reptile trade and monitored messaging app groups for activity and trends of reptile hobbyists and dealers.

Table 8 - List and types of stakeholders interviewed for the live reptile trade case study

Location	Industry actors	Conservation actors
Americas		
	Retail pet stores	San Diego Zoo

United States of America	Breeders	Hainan Normal University
	Dealers, retailers, importers in various states	USFWS
	Hobbyists in various states	IUCN specialist
		Turtle Conservancy
		Turtle Survival Alliance
		Global Wildlife Conservation
		Zoo Curator
		Zoo Director
		TFTSG
		NEPARC
		NC Wildlife Resources
Mexico	Dealers (Mexico City)	Herpetologists (Colima and Chiapas)
	Pet stores (Mexico City) Breeders (Puebla)	
Argentina		IUCN Specialist
Caribbean		Flora and Fauna International
Europe (Italy, Germany, Netherlands, Austria)		
	Dealers	Herpetologists
	Hobbyists	Trade research expert
	Hobbyist	IUCN specialist
		Turtle Island
Africa		
Madagascar	Exporters	DWCT
	Local poachers	SOPTOM
		IUCN specialist
		DREEF
Asia		
Malaysia		TRAFFIC
Indonesia	Dealers and exporters (Timor, Sulawesi, Jakarta, Cesena)	TRAFFIC Field Agent
	Hobbyists (Jakarta)	
China	Hobbyists	Trade research expert
		Kadoorie Farm and Botanic Garden
Viet Nam		WCS
		IUCN specialist
		Asian Turtle Program
Philippines	Local pet retailers (Manila)	KATALA Inc
		PFW

For data analysis purposes, only BOD (bodies) and LIV (live) were considered for illicit data and only LIV were considered for legal trade data. Eggs were not included in the analysis because they are rarely stolen for the pet trade given the natural conditions and temperatures they need to reach maturation and hatch. Bodies were included in the illicit data analysis since high mortality rates are often associated with the live pet trade.

For legal trade however, it was not necessary to include bodies since CITES permits will be issued for live animals in the case of the pet trade. If a CITES permit was issued for bodies, then that shipment would be not be intended for the live pet trade. Almost all legal data for live reptiles were with no units (number of animals), and only three entries were reported as kg for the time frame analysed. These entries were converted to live equivalents using the average body mass of 3.767kg for *Mauremys reevesii* and 0.2685kg for *Furcifer pardalis*.[11] For the illegal reptile trade data from World WISE, the maximum adult body weight for each species was used for the conversions. This information was obtained from Slavenko et al (2016),[12] which contained a database of all extant reptile species' weights. The only exceptions to this are for the following species where the maximum juvenile weight was used because the Slavenko et al measurements grossly overestimated maximum size and these species are often traded as juveniles or subadults: *Crocodylus acutus, Crocodylus moreletti, Aldabrachelys gigantea, Astrochelys radiata, Osteolaemus tetraspis,* and *Boa constrictor*. For *Aldabrachelys gigantea, Astrochelys radiata, Osteolaemus tetraspis,* and *Boa constrictor*. Maximum juvenile weight was obtained from the ZIMS database of the Association of Zoos and Aquariums which aggregates weights and measurements for species across zoo collections. For the others, an average weight was used based on species trade experts recommendations: all *Crocodilians*: 15 kg (also based on Platt et al (2011)[13]); all *Varanus*: 3.5 kg; and all *Pythons*: 8.44 kg.

Over-estimation is expected because of the use of the maximum adult weight in the conversion calculations. The maximum adult weights were used because of data availability constraints. There are further factors that affect the weight estimation such as sexual dimorphism, seasons, etc. Unfortunately, taking these variations into account was not possible given the lack of data for all species on this. The conversions are therefore subject to those limitations.

This particular case study was difficult to analyse since some reptile species are traded for several different reasons which is not stated in the data. For instance, some reptiles are traded live for the meat trade or skin trade, so they are not intended for the pet trade. To complicate matters further some species are used for multiple endpoints (e.g. the meat trade and pet trade) so it is impossible to determine the proportion of reptiles traded for each endpoint. To mitigate for some of these issues, we used all the live and body reptile data in WorldWISE to run the analyses, but then asked the consultant to identify which species were primarily trafficked for the pet trade or were heavily farmed and therefore unlikely to be wild sourced. These species were then excluded from the analysis. The excluded species were:

- The green iguana (*Iguana iguana*) and the ball python (*Python regius*), both of which are heavily farmed and in the top ten species for the legal reptile commercial trade based on number of live specimens, according to the CITES Trade Database.
- *Varanus nebulosus* (Clouded monitor), *Varanus bengalensis* (Bengal monitor), and *Ptyas mucosus* (Oriental rat snake), excluded because they are primarily traded for the skin trade.
- *Amyda cartilaginea* (Asiatic softshell turtle), *Mauremys reevesi* (Chinese pond turtle), *Testudo hermanni* (Hermann's tortoise), and *Naja atra* (Chinese cobra) are primarily consumed for their meat (as well as for traditional Chinese medicine for Chinese cobra), so were also removed.

Pangolin

For the pangolin case study, fieldwork was conducted primarily in two countries: Cameroon and Uganda with some additional fieldwork looking at pangolin product prices in Gabon. For all sites, relevant scientific literature and open sources were consulted for information on

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[11] Slavenko, A., Tallowin, O. J. S., Itescu, Y., Raia, P., & Meiri, S. (2016). Late Quaternary reptile extinctions: size matters, insularity dominates. Global Ecology and Biogeography, 25(11), 1308–1320.
[12] Ibid.
[13] Platt, S.G., Rainwater, T.R., Thorbjarnarson, J.B., Martin, D. (2011). Size estimation, morphometrics, sex ratio, sexual size dimorphism, and biomass of *Crocodylus acutus* in the coastal zone of Belize. *Salamandra, 47(4)*, 179-192.

pangolins and their trade, policies and legal frameworks for their protection, seizures, arrest and conviction records. This information was then supplemented with interview data and field observations.

Interviews focused on how pangolins are located and captured, what and how many individuals are involved in their procurement, where poachers source pangolins, and the prices paid for pangolins and their parts. Additional questions focused on the identity of the buyers, common sales points, destination markets, and known methods of export.

Cameroon fieldwork

For Cameroon, questionnaires were collected from major stakeholders and semi-structured interviews were conducted (via calls and e-mail) of pangolin experts from both government and non-governmental organizations. Data from field observations were also used where appropriate. In many instances, anonymity was ensured especially for actors like poachers and traffickers.

The Cameroon fieldwork was carried out between May 1 and July 30, 2018 in 16 locations within five regions: Centre Region (Yaounde), East Region (Abong Mbang, Bertoua, Lomie, Mambele, Ngoyla, and Yokadouma), Littoral Region (Douala), South West Region (Buea and Limbe), and South Region (Campo, Djoum, Kribi, Meyomessala, Oveng, and Sangmelima).

The main stakeholders contacted for their expert opinion included delegates and staff from:

- The Ministry of Forestry and Wildlife (MINFOF) - in charge of conservation and sustainable management of natural resources in Cameroon.
- The Ministry of Justice (MINJUSTICE) - provided information on court cases and convictions of offenders carrying out the illegal trade of pangolins and their derivative products.
- Other enforcement agencies (Police, Gendarmerie, Customs) - provided information on seizures and arrests as well as on inter-agency collaborations to fight wildlife crime.
- TRAFFIC, the wildlife trade monitoring network – provided information on trade issues with pangolins.
- The World Wildlife Fund for Nature (WWF) – provided expertise on the pangolin trade in South-east Cameroon where they conduct anti-poaching and law enforcement activities in protected areas.
- The Last Great Ape Organization (LAGA) – provided information on pangolin dealers and the primary generators of the illegal trade.
- The Zoological Society of London (ZSL) in cooperation with the U.S. Fish and Wildlife Service's (USFWS) Wildlife Without Borders-Africa Program runs a fellowship program known as MENTOR-POP (Progress on Pangolins) that trains young professionals on pangolin conservation. Their fellows provided additional information on the pangolin trade to complement NGO and government data, as did individuals from the Pangolin Conservation Network (PCN) and the Central Africa Bushmeat Action Group.

Uganda fieldwork

A total of 22 interviews were carried out with pangolin hunters and traders in 4 different locations in Uganda. The selected areas were based on past research and data indicating a high level of illicit trade of wildlife products at these locations, especially for pangolins. Location choice was also refined based on interviewee tip-offs. The locations selected were the districts of Arua, Gulu, Nwoya and Mukono, and their surroundings. Five interviews were carried out in Arua, 12 in the district of Gulu, three in Nwoya district, and two in Mukono district. To protect the anonymity of the interviewees, no names or specific locations are provided.

For data analysis purposes, conversion factors were developed to calculate live equivalents for all eight species of pangolins (*Manis crassicaudata, M. pentadactyla, M. javanica, M. culionensis, M. tetradactyla, M. tricuspis, M. gigantea,* and *M. temminckii).* This was based on the average total scale weight published in the literature, but this was only available for some pangolin species (*Manis crassicaudata, M. pentadactyla, M. javanica, M. tricuspis, M. gigantea*).[14]

The scale weight to body weight ratios were calculated using average total scale weights and the corresponding average adult body mass. *M. culionensis* was recognized as a distinct species from *M. javanica* and, given the lack of data for *M. culionensis*, values for *M. javanica* were applied for scale-to-live factors for *M. culionensis.*[15] For the other two African species (*M. temminckii* and *M. tetradactyla*), ratios were not available in the literature so they were calculated using their respective body mass * average African-species scale to animal ratio (0.157) of the two known African species (see tables below).

In case a pangolin scales seizure did not specify the species scientific name, or it was reported at genus or family level (*Manis spp.* or *Manidae spp.*), different conversion factors were assigned according to the country of origin of the shipment.[16] For seizures originating from Africa, a mass-to-live conversion factor equal to 0.5[17] was applied. In case the country of origin was unknown, a conversion factor of 0.43 was applied (as average between 0.36 and 0.5).

For the pangolin price index valuation, 180 USD/kg was used as an estimate price for MEA.[18]

Table 9 - Body weight of pangolin bodies, live specimens and trophies, by species

Species	**Common name**	**BOD/LIV/TRO**	
		Mass	**Ratio**
Manidae		4.960	4.960

[14] Challender, D., Harrop, S., and MacMillan, D. (2015), Understanding markets to conserve trade-threatened species in CITES. Biological Conservation, Vol 187, 2015, pp 249-259; Challender, D. and Waterman, C. (2017). Implementation of CITES Decisions 17.239 b) and 17.240 on Pangolins (*Manis* spp.). Retrieved from: https://cites.org/sites/default/files/eng/com/sc/69/E-SC69-57-A.pdf on 13 February 2018.
[15] Lagrada, L., Schoppe, S. and Challender, D. (2014). *Manis culionensis. The IUCN Red List of Threatened Species*. Retrieved from: https://doi.org/e.T136497A45223365.
[16] In its proxy version. For the description of the proxy for the country of origin, see the Trafficking flow maps section of this methodological annex.
[17] This conversion factor is based on evidence collected from fieldwork research – interviews conducted with pangolin traffickers in 11 sites in Cameroon in 2018 – and confirmed by consultation with the IUCN pangolin specialist group.
[18] Xu, L. M., Guan, J., Lau, W., & Yu, X. J. (2016). *An Overview of Pangolin Trade in China*. Retrieved from: https://www.semanticscholar.org/paper/An-Overview-of-Pangolin-Trade-in-China-Xu-Guan/330d62859722db36cd3259d0ab6cc0f6eb82e262.

Manis		4.960	4.960
Manis crassicaudata	Indian pangolin	6.500	6.500
Manis culionensis	Philippine pangolin	4.960	4.960
Manis javanica	Sunda pangolin	4.960	4.960
Manis pentadactyla	Chinese pangolin	4.330	4.330
Manis gigantea	Giant ground pangolin	33.000	33.000
Manis temminckii	Ground pangolin	11.900	11.900
Manis tetradactyla	Black-bellied pangolin	2.750	2.750
Manis tricuspis	White-bellied pangolin	1.752	1.752

Ratio = live equivalent ratio
Source: Body masses for BOD (bodies), LIV (live), and TRO (trophies) of Asian species (*M. crassicaudata, M. culionensis, M. javanica,* and *M. pentadactyla*) are all taken from Challender *et al.*, (2015); while body masses for BOD (bodies), LIV (live), and TRO (trophies) of African species (*M. gigantea, M. temminckii, M. tetradactyla,* and *M. tricuspis*) are taken from Jones *et al.*, (2009).[19]

Note: The *Manis tricuspis* body weight is taken from the PanTHERIA database[20] in effort to insure the consistent use of one source for all African pangolin species. A comparison of this weight was done with other studies for the species and the weights quoted for adult individuals ranged from 0.8 to 2.73 kg with the latest paper on the subject by Sodeinde et al (2002)[21] citing 1.27 +/- 0.06 for male adults and 1.02 +/- 0.17 for females. Given that the PanTHERIA value is slightly higher than this, we could be slightly underestimating the number of *M. tricuspis* individuals in trade.

Table 10 - Weight and ratios for pangolin meat and scale, by species

Species	**Common name**	**Region of origin**	**MEA**		**SCA**	
			Mass	**Ratio**	**Mass**	**Ratio**
Manidae		Africa	4.600	4.600	0.010	0.50
		All other regions	4.600	4.600	0.010	0.36
		Unknown	4.600	4.600	0.010	0.43
Manis		Africa	4.600	4.600	0.010	0.50
		All other regions	4.600	4.600	0.010	0.36
		Unknown	4.600	4.600	0.010	0.43
Manis crassicaudata	Indian pangolin	-	5.500	5.500	0.010	1.00
Manis culionensis	Philippine pangolin	-	4.600	4.600	0.010	0.36
Manis javanica	Sunda pangolin	-	4.600	4.600	0.010	0.36
Manis pentadactyla	Chinese pangolin	-	3.760	3.760	0.010	0.57
Manis gigantea	Giant ground pangolin	-	29.400	29.400	0.010	3.60
Manis temminckii	Ground pangolin	-	10.028	10.028	0.010	1.872

[19] Challender *et al.*, 2015; Jones *et al.*, 2009.
[20] Jones, K., Bielby, J., Cardillo, M., Fritz, S., O'Dell, J., Orme, C., Safi, K., Sechrest, W., Boakes, E., Carbone, C., Connolly, C., Cutts, M., Foster, J., Grenyer, R., Habib, M., Plaster, C., Price, S., Rigby, E., Rist, J., Teacher, A., Bininda-Emonds, O., Gittleman, J., Mace, G. and Purvis, A. (2009). PanTHERIA: a species-level database of life history, ecology, and geography of extant and recently extinct mammals. Ecology, 90(9), pp.2648-2648. Retrieve from: http://esapubs.org/archive/ecol/E090/184/ on March 20, 2019.
[21] Sodeinde, O.A., Adefuke, A.A, & Balogun, O.F. (2002). Morphometric analyses of *Manis tricuspis* (Pholidota-Mammalia) from South-Western Nigeria. *Global Journal of Pure and Applied Sciences*, *8*(1), 7-13.

Manis tetradactyla	Black-bellied pangolin	-	2.317	2.317	0.010	0.43
Manis tricuspis	White-bellied pangolin	-	1.392	1.392	0.010	0.36
	Ratio = live equivalent ratio, # of Scale = average number of scale per animal Source: Masses of MEA (meat) records were calculated from body mass - scale mass; masses of SCA (scales) were taken from Mitra, (1998[22]); while number of scales were taken from Ullmann *et al*., (2019).[23] The scale ratios for all Asian species (*M. crassicaudata, M. culionensis, M. javanica, and M. pentadactyla*) are taken from Challender *et al*., (2015). The scale ratios for two African species (*M. gigantea and M. tricuspis*) were taken from Challender and Waterman, (2017); while the other two African species (*M. temminckii, M. tetradactyla*) were not available in the literature so they were calculated using body mass * average African-species scale to animal ratio (0.157).[24]					

Big Cats

For the big cats case study, a literature review was performed with emphasis on the bone trade. Both legal and illicit trade data were analysed, and fieldwork was also conducted in Thailand, Viet Nam, and South Africa. The three countries were visited during early 2019: Thailand (17-25 February), Viet Nam (26 February-8 March), and South Africa (10-15 March). Semi-structured interviews were carried out with government officials, NGOs, and individuals from the private sector involved in the trade. Thirteen captive tiger facilities and five markets were also visited during the fieldwork period (see table below).

Table 11 - Captive tiger facilities and markets selling wildlife products visited during fieldwork

Country	Captive tiger facilities	Markets
Thailand	Bangkok Safari World Pata Zoo, Bangkok Chiang Mai Night Safari Park, Chiang Mai Province Tiger Kingdom, Chiang Mai Province Mae Rim Tiger Kingdom, Chiang Mai Province	Tha Prachan Amulet Market, Bangkok Yaowarat Road, Bangkok
Viet Nam	Soc Son Wildlife Rescue Centre, Hanoi Mai Tai private farm, Thai Nguyen province Bao Son Paradise Park, Hanoi Hanoi Zoo, Hanoi	Old Quarter, Hanoi Lang Ong Street shops, Hanoi
South Africa	Lory Park Zoo, Midrands Mystic Monkeys and Feathers, Limpopo Province Hartbeespoort Dam Zoo, North West Province Rhino and Lion Nature Reserve, Gauteng Province	Faraday Market, Johannesburg

[22] Mitra, S. (1998). On the scale of the Scaly Anteater Manis crassicaudata. Journal Bombay Natural History Society 95(3):495–497.
[23] Ullmann, T., Veríssimo, D., Challender, D.W.S., Evaluating the application of scale frequency to estimate the size of pangolin scale seizures, Global Ecology and Conservation (2019), doi: https://doi.org/10.1016/j.gecco.2019.e00776.
[24] Challender *et al.* (2015); Challender and Waterman (2017).

The seven species referred to as "big cat" were included in the analysis for this chapter*:* lion *(Panthera leo*), jaguar (*Panthera onca*, leopard *(Panthera pardus*), tiger (*Panthera tigris*), snow leopard (*Uncia uncia*), clouded leopard (*Neofelis nebulosi*), and Sunda clouded leopard (*Neofelis diardi*).[25] The assumption was made that a rug, a skeleton, a substantially whole skin, and a skull were each equal to a whole animal killed. While this could lead us to overestimate the live equivalent count slightly if 1 skull and 1 skeleton (without skull) are from the same animal or 1 skin and 1 skull or 1 skeleton (without skull) are from the same animal, given the small sample sizes for skeleton cases (n = 12), this overestimation would be minor. The conversion factors for the BOD (body), LIV (live), or TRO (trophy) specimen types are provided by species in the table below.

Table 12 - Big Cat Conversion Factor by Species

Genus	Species	Conversion Factor (kg)	Mass-to-Live Factor
Panthera	*Panthera spp.*	142.87	142.87
	leo	158.62	158.62
	leo persica	158.62	158.62
	onca	83.94	83.94
	pardus	52.4	52.4
	tigris	161.91	161.91
Neofelis	*Neofelis spp.*	15.1	15.1
	nebulosa	15.1	15.1
	diardi	15.1	15.1
Uncia	*Uncia*	32.5	32.5

Source: All conversions are taken from Jones *et al*. (2009).[26]

Glass Eels

For the glass eels case study, a literature review was conducted on both legal and illicit trade. Legal and illicit trade data were also analysed, and semi-structured interviews were carried out with law enforcement personnel in Europe and China. Information on seized glass eels were compiled from available CITES documents and complemented by media reports. Specific knowledge on the modus operandi was collected through a questionnaire that was prepared and presented to the attending parties at the Europol OP LAKE assessment meeting in Madrid, Spain on 18 and 19 September 2018. The meeting was attended by representatives of enforcement authorities and CITES management authorities from Portugal, Italy, Netherlands, United Kingdom, Germany, Morocco, Romania, Spain as well as the United States of America, Canada and Interpol. A document compiling all glass eel interceptions between 2011 and 2018 was also circulated and enforcement agencies were asked to review the listed data and to include additional cases that might have been missed. Only Italy (Guardia Di Finanzia), Portugal (Maritime Police and CITES Management Authority), the Spanish Environmental Protection Service (SEPRONA) of the Guardia Civil, the French Office de lute contre les atteintes à l'environment et à la santé publique (OCLAESP), the Agence Française pour la Biodiversité (AFB), and Europol completed the questionnaire.

[25] (Kitchener, A.C., et al. (2017). A revised taxonomy of the Felidae: The final report of the Cat Classification Task Force of the IUCN/SSC Cat Specialist Group. *Cat News Special Issue*, *11*, 80 pp.

[26] Jones *et al*., 2009

For data analysis purposes, it was assumed that all LIV (live) records were glass eels and that all BOD (bodies) were fully grown eels unless otherwise specified in the records. The weights of live glass eels were considered to be 0.0002 7kg for *Anguilla anguilla*, and 0.00017 kg for *Anguilla rostrata*. The weights of adult eels (bodies) were considered to be 0.2 7kg for *Anguilla anguilla*, and 0.17 kg for *Anguilla rostrata*. Conversion factors for live equivalents are in the table below.[27] Conversion factors of *Anguilla anguilla* were used in cases with unidentified species.

Table 13 - Eel conversion factor by species

	BOD				**LIV**			
	Juvenile		**(not specified, assumed adult)**		**Adult**		**(not specified, assumed juvenile)**	
	Average mass	**Ratio**	**Average mass**	**Ratio**	**Average mass**	**Ratio**	**Average mass**	**Ratio**
Anguilla	0.00027	0.00027	0.27	0.27	0.27	0.27	0.00027	0.00027
• *anguilla*	0.00027	0.00027	0.27	0.27	0.27	0.27	0.00027	0.00027
• *rostrata*	0.00017	0.00017	0.17	0.17	0.17	0.17	0.00017	0.00017
Anguillidae	0.00027	0.00027	0.27	0.27	0.27	0.27	0.00027	0.00027

Ratio = live equivalent ratio
Source: Appelbaum *et al*. (1998)[28]

For the price index evaluation, an individual adult eel (*Anguilla sp.*) was estimated to be 0.27 kg valuated at USD 4.32 per adult eel; therefore 1 kg of fully-grown eel (BOD records) was valued at 16 USD.[29] An individual glass eel was estimated to be 0.00027kg with a value of USD 0.31; therefore 1 kg of glass eels was valued at 1148 USD. Since the species of *Anguilla* being offered for sale at the markets were unknown in most cases,[30] the above valuation factors were applied to all LIV records.

Boxes

Several text boxes have been included within the chapters to highlight trade in other species. A brief literature review was conducted on both legal and illicit trade for each box. Legal and illicit trade data were also analysed, but no fieldwork was performed. Some conversions, applied for certain species, are explained below.

Seahorses

For data analysis purposes, it was assumed that all the BOD (bodies) records were dried seahorses and all LIV (live) records were live seahorses. The average weight of a dried seahorse was calculated at 0.003kg (a rounded version of 0.00269, which is the average dry weight for

[27] Appelbaum, S., Chernitsky, A., and Birkan, V. (1998). Growth observations on European (*Anguilla anguilla L.*) and American (*Anguilla rostrata Le Sueur*) glass eels. *Bulletin Français de la Pêche et de la Pisciculture, (349)*, 187-193.
[28] *Ibid.*
[29] Shiraishi, H., & Crook, V. (2015). *Eel market dynamics: An analysis of Anguilla production, trade and consumption in East Asia*. Retrieved from https://www.traffic.org/site/assets/files/2482/eel_market_dynamics_report.pdf
[30] Ibid.

seahorses based on regional averages), and the global average wet weight was calculated at 12.5 grams or 0.013kg. These figures were taken from Evanson *et al.*, (2011).[31] Species-level average weights of live seahorses were taken from raw data in O'Gorman and Hone, (2012).[32] The average genus wet weight of 0.013kg using species-specific wet weights from O'Gorman and Hone, (2012) is similar to that of the global average wet weight from Evanson *et al.*, (2011).

Table 14 - Seahorse conversion factor by species

	BOD (Dried)		**LIV (Wet)**	
	Average Mass	**Ratio**	**Max Mass**	**Ratio**
Hippocampus	0.003*	0.003	0.013	0.013
• *abdominalis*	0.003	0.003	0.071	0.071
• *alatus*	0.003	0.003	0.002	0.002
• *angustus*	0.003	0.003	0.016	0.016
• *barbouri*	0.003	0.003	0.005	0.005
• *bargibanti*	0.003	0.003		
• *borboniensis*	0.003	0.003	0.004	0.004
• *comes*	0.003	0.003	0.009	0.009
• *coronatus*	0.003	0.003	0.002	0.002
• *denise*	0.003	0.003		
• *erectus*	0.003	0.003	0.01	0.01
• *fuscus*	0.003	0.003	0.004	0.004
• *grandiceps*	0.003	0.003		
• *guttulatus*	0.003	0.003	0.006	0.006
• *hendriki*	0.003	0.003		
• *hippocampus*	0.003	0.003	0.005	0.005
• *histrix*	0.003	0.003	0.007	0.007
• *ingens*	0.003	0.003	0.043	0.043
• *jugumus*	0.003	0.003		
• *kelloggi*	0.003	0.003	0.035	0.035
• *kuda*	0.003	0.003	0.043	0.043
• *patagonicus*	0.003	0.003		
• *reidi*	0.003	0.003	0.008	0.008
• *semispinosus*	0.003	0.003	0.008	0.008
• *sindonis*	0.003	0.003	0.001	0.001
• *spinosissimus*	0.003	0.003	0.007	0.007
• *trimaculatus*	0.003	0.003	0.016	0.016
• *whitei*	0.003	0.003	0.003	0.003

Ratio = live equivalent ratio

*0.003 is a rounded version of 0.00269, which is the average dry weight for seahorses (based on regional averages) cited by Evanson *et al.*, (2011).
Note: Using this methodology, for several species the actual wet weight is below the average dry weight used, which is obviously impossible. The number of cases that would be affected by this was minimal, so these values

[31] Evanson, M., Foster, S.J., Wiswedel, S., and Vincent, A.C.J. (2011). Tracking the international trade of seahorses (Hippocampus species). https://doi.org/10.14288/1.0348153
[32] O'Gorman, E.J., and Hone, D.W.E. (2012). Body Size Distribution of the Dinosaurs. PLoS ONE, 7(12), e51925. https://doi.org/10.1371/journal.pone.0051925

were left as is instead of calculating a separate dry weight for these species based on the assumption that dried weight = about 23% of wet weight.

Sources: Data conversions for BOD (dried) were obtained from Evanson *et al.*, (2011); while data conversions for LIV (wet) were obtained from O'Gorman and Hone, (2012). The calculations for wet weights are from O'Gorman, but the max fish length used to calculate the wet weights is originally from FishBase: https://www.fishbase.se/search.php. This source calculates the max mass using max fish lengths (a mixture of total lengths, standard lengths, and fork lengths). Therefore, the quantity of seahorses could be underestimated using wet weights.

Sea cucumbers[33]

For data analysis purposes, the vast majority of seizures were of *Isostichopus sp.* Only one CITES listed sea cucumber species (*Isostichopus fuscus*) is currently in the database. However, this will likely change in the near future once the CITES Appendix II listings for four other sea cucumbers will enter into effect on 28 August 2020. The conversion factor for a LIV *Isostichopus sp.* record was estimated at 0.386 kg.[34] The dried weight of an *Isostichopus sp.* is 6% of its wet weight;[35] therefore, the average dried weight of an *Isostichipus sp.* was calculated to be 0.023 kg. In the case of a species with no family specified (i.e. class Holothuroidea), the *Isostichopus sp.* factor was used. Average wet weights of other species of sea cucumber were collected for further referencing purposes.[36] Average species wet-to-dried weight conversion factors were also collected for further referencing purposes.[37]

Table 15 - Sea cucumber conversion factor by species

	BOD		**LIV**	
	Average Mass	**Ratio**	**Average Mass**	**Ratio**
Actinopyga	0.001225	0.001225	0.35	0.35
• *echinites*	0.0315	0.0315	0.3	0.3
• *lecanora*	0.0016	0.0016	0.4	0.4
• *mauritiana*	0.0009	0.0009	0.3	0.3
• *miliaris*	0.0016	0.0016	0.4	0.4
Bohadschia	0.0946	0.0946	1.1	1.1
• *argus*	0.1548	0.1548	1.8	1.8
• *similis*	0.0258	0.0258	0.3	0.3
• *vitiensis*	0.1032	0.1032	1.2	1.2
Holothuria	0.09095	0.09095	0.85	0.85
• *atra*	0.0214	0.0214	0.2	0.2

[33] The results for sea cucumbers is based on the November 28th 2019 version of the UNODC WorldWISE Database, while the remaining analyses in the report are based on the February 18th version of the database.
[34] Herrero-Pérezrul, M. D., Bonilla, H. R., García-Domínguez, F., & Cintra-Buenrostro, C. E. (1999). Reproduction and growth of Isostichopus fuscus (Echinodermata: Holothuroidea) in the southern Gulf of California, Mexico. *Marine Biology, 135(3)*, 521-532.
[35] Hernández, O. A., Pabón, E. A., Montoya, O. J. C., Duran, E. C., Narváez, R. O. C., & Forero, A. R. (2017). Sea Cucumber (*Isostichopus sp. aff badionotus*) Dry-Salting Protocol Design. *Natural Resources, 8(03)*, 278.
[36] Toral-Granda, V., Lovatelli, A., & Vasconcellos, M. (Eds.). (2008). Sea cucumbers: a global review of fisheries and trade (Vol. 516). Rome: Food and Agriculture Organization of the United Nations.
[37] Purcell, Steven & Agudo, Natacha & Gossuin, Hugues. (2009). Conversion of weight and length of sea cucumbers to beche-de-mer: filling gaps for some exploited tropical species. *SPC Beche-de-mer Information Bulletin, 29*, 3-6.

• *coluber*	0.0321	0.0321	0.3	0.3
• *edulis*	0.0214	0.0214	0.2	0.2
• *fuscogilva*	0.2568	0.2568	2.4	2.4
• *fuscopunctata*	0.1605	0.1605	1.5	1.5
• *leucospilota*	0.0214	0.0214	0.2	0.2
• *scabra*	0.0321	0.0321	0.3	0.3
• *whitmaei*	0.1972	0.1972	1.7	1.7
• ***Isostichopus***	0.02316	0.02316	0.386	0.386
• ***Pearsonothuria***	0.0602	0.0602	0.7	0.7
• *graeffei*	0.0602	0.0602	0.7	0.7
• ***Stichopus***	0.0143	0.0143	0.433	0.433
• *chloronotus*	0.0033	0.0033	0.1	0.1
• *herrmanni*	0.033	0.033	1	1
• *horrens*	0.0066	0.0066	0.2	0.2
• ***Thelenota***	0.258	0.258	3	3
• *ananas*	0.215	0.215	2.5	2.5
• *anax*	0.301	0.301	3.5	3.5
Holothuroidea cl.	0.02316	0.02316	0.386	0.386

Ratio = live equivalent ratio

Note: The wet-to-dried conversion factors are from table 2 in Purcell *et al.*, (2009). The table provides mean weight of whole fish and boiled/dried fish. So the wet-to-dried conversion factors are boiled dried weight/whole fish weight. The data are only available for some species. If there is a matched species, the species-specific conversion factor is used. If not, the average genus conversion factor is used.

Sources: All sea cucumber BOD conversions are taken from Purcell *et al.*, (2009), except for *Isostichopus* spp. which is instead taken from Hernández *et al.*, (2017). All sea cucumber LIV conversions are taken from Toral-Granda *et al.*, (2008), except for *Isostichopus* spp. which is instead taken from Herrero-Pérezrul *et al.*, (1999).

Supply and value chains and illicit financial flows from the trade in ivory and rhino horn

Illicit financial flows: definition and measurement framework

SDG indicator 16.4.1. measures the total value of inward and outward illicit financial flows (IFFs) in current United States dollars. IFFs are financial flows that are illicitly generated (e.g., originating in criminal activities or tax evasion), illicitly transferred (e.g., violating currency controls) or illicitly used (e.g., for financing terrorism).

For constructing measurements of IFFs emerging in illicit markets, a bottom-up and direct measurement approach has been developed.[38] Bottom-up methods estimate IFFs directly in relation to the underlying activities and ‘build them up’, departing from the overall illicit income that illegal markets generate. ‘Direct’ refers to an individual measurement of data pertaining to the various stages of the economic processes generating IFFs. The estimations presented in this study followed such a bottom-up, direct measurement approach.

[38] Published in the SDG indicator metadata repository on the SDG website of the United Nations Statistics Division: https://unstats.un.org/sdgs/metadata/files/Metadata-16-04-01.pdf.

Illicit financial flows measure the volumes of illicit income that crosses borders. As all other SDG indicators, the IFF indicator is meant to be produced at the country level. 'Cross-border' means in this context that an exchange is made between a resident[39] and a non-resident of a country, regardless of their geographical location. If a resident of country A transfers funds to a resident of country B, the transaction constitutes an IFF even if both parties are at the same location. At the country level, all such transactions are accounted for when the indicator is measured. To produce the indicator at the regional or global level, all illicit financial flows within a region or globally are aggregated.

To estimate illicit financial flows emerging from illegal markets, the measurement framework of income generating and income management flows has been developed.

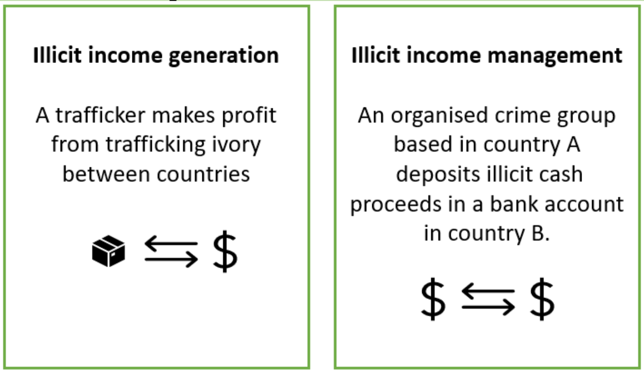
- **Income generation** is the set of transactions that either directly generate illicit income for an actor or that are performed in the context of the production of illicit goods and services.
- **Income management** is the set of transactions related to the use of the illicit income for investment in financial and non-financial assets or for consuming goods and services.

Income generation and income management explained

Illicit financial flows emerging in illegal markets can be measured by distinguishing income generation and income management. In order to explain the concepts of income generation and income management a fictitious **example** is offered.
In a country A, an organized crime group collates a shipment of ivory and sells it onwards. The group sells 40 per cent of the production to traffickers residing in country A for US$35,000, and the other 60 per cent directly to residents of a destination country B for $50,000. The group is moving $5,000 of their net income to offshore accounts.
The following IFF are accounted for in the country A, place of residence of the organized crime group.
IFF from income generation: Inward illicit financial flows of $50,000 accounted for country B (money received from the destination country in exchange for the ivory).
IFF from income management: Outward illicit financial flows of $5,000 accounted for country A, the amount of net income that is moved to offshore accounts.
The transactions worth $35,000 are not cross-border transactions as they occur between residents of the same country (and would not be considered as cross-border

[39] A resident of a country has their centre of economic interest within the country. This definition is different from a legal one and follows the international Balance of Payments statistics, see International Monetary Fund (IMF), *Balance of Payments Manual*, Fifth Edition, 2005, para. 58.

transactions even if both parties were located in different countries) and are therefore not an IFF.



All estimates are based on estimates of overall illicit income, which can be represented by three main aggregates: illicit gross income (or output), intermediate expenditure or intermediate costs, and value added, presented here as illicit net income.

- **Illicit gross income** (market value or sales) is the value of illicit goods and services produced in a given period (for example, a year). The value is determined as quantity multiplied by price, where prices need to correspond to the geographic extension of the market under consideration.

- **Intermediate expenditure** is the value of inputs acquired to produce the illicit goods and services over a given period. The value of inputs is determined as quantity multiplied by price. Intermediate expenditures for poachers may include lodging, transportation, guns or bribes to persons facilitating the trade. Intermediate expenditure for traffickers includes the costs for purchasing raw material (for example, the payments traffickers make to poachers), but also others, such as expenditure for transportation or bribes.

- **Illicit net income** of an actor or a group of actors is the illicit gross income minus intermediate expenditure. Illicit net income is the income available to an actor after accounting for costs.

Illicit gross income and intermediate expenditure are pertaining to the income generation process but include domestically generated income. Illicit net income is the basis for assessing income management flows, as only funds can be used for consumption or investment that are available after accounting for costs.

Estimation of illicit income from the illegal trade in ivory and rhino horn

In a global market, illicit gross income is represented by retail prices and corresponding quantities sold at retail. To estimate illicit gross income information on the estimated, annual amounts consumed and respective prices are needed.

Estimating flows of rhino horn and ivory

Globally, all product entering the illegal market in a year is either consumed, seized by law enforcement, stocked or lost. Product entering the illegal market is either newly sourced (*P*) or enters from stockpiles or inventories (*V*). Consumption (*C*) refers to product purchased by end-consumers, seizures (*S*) is product confiscated by law enforcement, inventories (*V*) are products temporarily (beyond the time period under consideration) held in inventories or stockpiled for speculation, losses (L) include product rendered unusable during transportation and raw material lost during manufacture (e.g., during the carving process).

Therefore, for each time period t, the following holds
$\boldsymbol{P_t + \Delta V = C_t + S_t + L_t}$, **(1)**

where ΔV is the changes in inventories held by all actors along the supply chain, $\Delta V = V_{t-1} - V_t$. ΔV can be positive or negative, if more or less products are entering inventories than entering the illegal market.

Inventories with ivory and rhino horn product can be of significant size and the size of the inventories may change over time (e.g., building up when production exceeds sales and sizing down when sales exceed production), but cannot be measured with the data available. Inventories are therefore not explicitly considered in the present calculations, which implies the assumption that inventories are constant over the time frame considered (three calendar years). Losses are not accounted for because of lack of data.

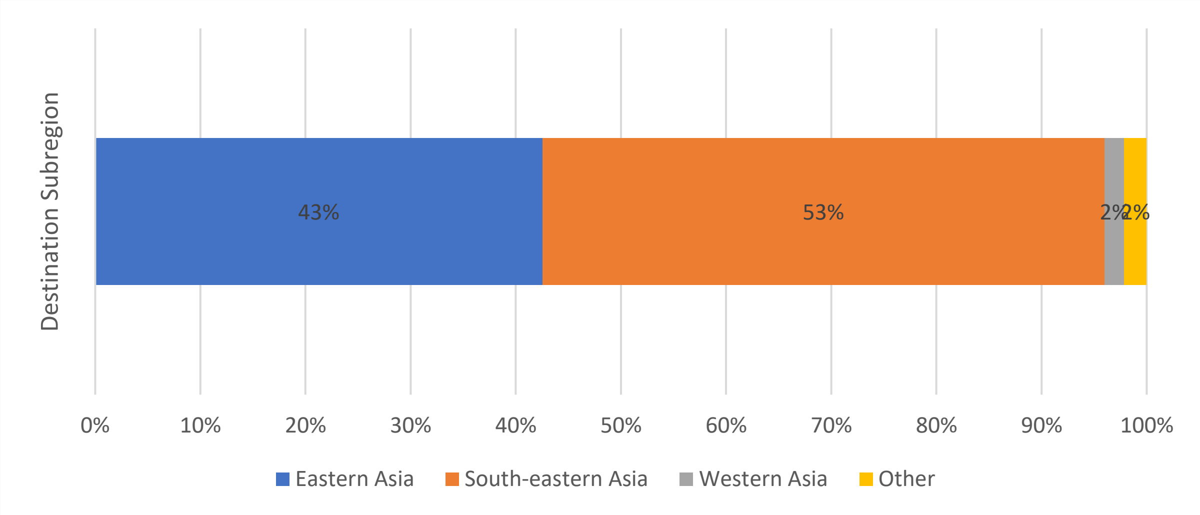
With that, in the time period considered and at the global level, all newly sourced ivory and rhino horn is either consumed or seized by law enforcement:
$P_t = C_t + S_t$. (2)

If two out of three quantities are known, the third one can be deduced. Seizures are obtained from UNODC's World WISE database, production is estimated based on rhino and elephant poaching data. With that, consumption can be calculated as produced amounts minus seized amounts.

To break down global consumption, C_t, into regional consumption levels, $C_{r,t}$, *r=1..n*, seizure data recorded in World WISE is used: in a certain proportion of seizure cases information on the final destination of a shipment was recorded. With the assumption that the final destinations recorded in the seizure data approximate destination and consumption patterns, the regional consumption vector can be estimated. In the case of rhino horn, 98 per cent of all horn was reportedly destined for Asia and less than 2 per cent for other regions, so out of the rhino horn available for consumption, 98 per cent are thought to be consumed in Asia. A similar principle was applied for ivory (86 per cent of the ivory available for consumption are thought to be consumed in Asia).

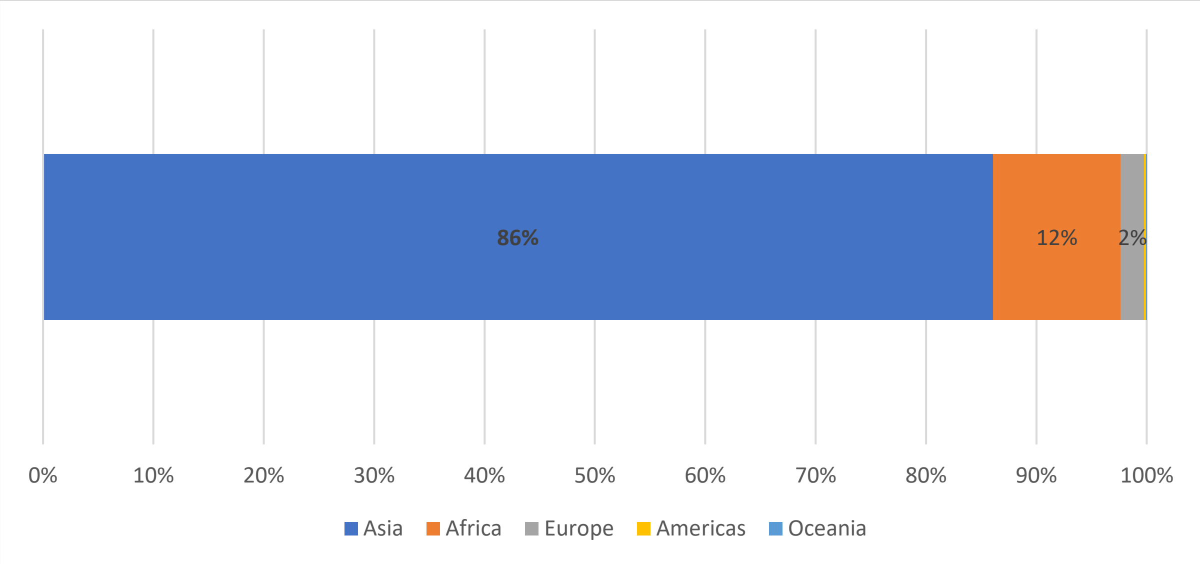
In all seizure data related estimates, an average of 2016 and 2017 was used to represent the 2016-2018 reference period.

Figure 1 - Reported final destination of seized rhino horn, UNODC World WISE database, 2016- 2017



Note: Based on 118 observations between 2016 and 2018. Percentage of total weight seized. Other includes Southern Asia (0.3 per cent).

Figure 2 - Reported final destination of seized ivory, UNODC World WISE database, 2016- 2017



Note: Based on 118 observations between 2016 and 2018. Percentage of total weight seized. Other includes Southern Asia (0.3 per cent).

Breakdown by trade level

The amount of ivory and rhino horn traded by trade level is calculated by using seizure data by region and assumptions on the stage at which most of the products are seized. For calculating illicit income, 4 levels are used: poaching, runners and brokers, international trafficking (comprising exporters, importers, and wholesalers in destination countries) and retail trade in destination countries.

Poachers and runners and brokers are assumed to sell all harvested ivory and rhino horn onwards (it is assumed that no or only very limited seizures take place at this stage). For calculating how much is internationally trafficked, ivory and rhino horn that is not consumed or seized in Africa is taken as basis (that is supplied amounts minus estimated consumption in Africa (if any) minus amounts seized in Africa). The basis for the value of the retail trade are the estimated amounts consumed in Asia. This approach could be made more accurate by estimating the value of ivory/rhino horn consumed outside of Asia.

Price data

In absence of a systematic monitoring of prices by Member States, UNODC undertook field and desk research to collect prices of ivory and rhino horn at various levels of the supply chain. Field work in Africa involved interviews with law enforcement agencies, experts on the illegal wildlife trade from academia and NGOs, and key informant interviews. During field work, 52 interviews were conducted in Central, Eastern and Southern Africa and numerous reference publications were studied.

Price data from destination countries was provided by the Wildlife Justice Commission (WJC)[40] and the Environmental Investigation Agency (UK).[41]

Rhino horn

Depending on the data source, prices were stratified by trade level[42] (see chapter on the organisation of the trade) and according to wholesale or retail level. Prices presented a large variability and despite best efforts, details around certain prices were often missing (e.g., if costs for guns and ammunition was included in the fee for the poacher or not).

Africa

To approximate the time period of 2016-2018, an average of the closest prices in time was used. The following tables show the ranges of prices observed. For exporters, only a single observation was available (only shown in the overview table).

The below ranges reflect minimum and maximum prices observed. Single observations were often only a price range and not a point estimate. To calculate an average price range relevant for the three-year reference period, mid-point estimates were calculated for each observation as simple averages of the minimum and maximum prices observed. This assumed that prices follow a roughly symmetric distribution between the minimum and maximum values. The minimum and maximum values presented in the overview table are the minimum and maximum values observed.

Table 16 - Different rhino horn prices (USD/kilogramme) at the poacher level, Southern and Eastern Africa, by year

Year	Southern Africa	Eastern Africa
2010	493 – 985	
2012	439 - 1,865	
2014	2,559 – 8,422	
2016	1,111- 4,286	3,000
2018	3,462 - 6,154	5,940-9,900

40 https://wildlifejustice.org/
41 https://eia-international.org
42 Maggs, K. (2011). South Africa's National Strategy for the safety and security of rhino populations and other relevant government and private sector initiatives. In Proceedings of the tenth meeting of the IUCN African Rhino Specialist Group held at Mokala National Park, South Africa from 5-10 March 2011 (Ed. C. Dean), pp. 130–146 as quoted in Milliken, T. and Shaw, J. (2012). *The South Africa – Viet Nam Rhino Horn Trade Nexus: A Deadly Combination of Institutional Lapses, Corrupt Wildlife Industry Professionals and Asian Crime Syndicates*. TRAFFIC, Johannesburg, South Africa.

Notes: The years 2014 – 2018 were used to calculate an average price for the refence period. Two outliers excluded: USD/kg 8,197 in 2016 and USD/kg 14,388 in 2014.

Table 17 - Different rhino horn prices (USD/kilogram) at the runner's level, Southern and Eastern Africa, by year

Year	Southern Africa
2012	9149–18,299
2013	6227–12,455
2018	3,793-8,077

Note: The years 2018 was used to calculate an average price for the refence period.

Table 18 - Different rhino horn prices (USD/kilogram) at the middlemen level, Southern and Eastern Africa, by year

Year	Southern Africa
2016	4,643-12,854
2018	9,375-11,538

Asia

For Asia, the data available were observations collected in the field during negotiations or observations in shops and with traders for the years 2015-2017. The observations were therefore not collected as a range, but single price points.

To estimate wholesale and retail prices in Asia, the simple average of all observations available for the years 2015-2017 was taken as approximation for 2016-2018 (29 observations for wholesale and 37 observations in retail). The minimum and maximum values are the minimum and maximum values observed.

Table 19 - Prices of whole horn/horn tips at the whole sale level in Asia, per kilogram, 2015-2017

Values	Average of Price USD	Min of Price USD	Max of Price USD
Wholesale	24,308	15,037	54,054
Worked rhino horn	49,297	4,050	153,610

Table 20 - Average rhino horn prices at the different points in the trade chain Africa and Asia, 2014-2018 (US$/kilogram).

	Mid-point	Minimum	Maximum
Poacher	4,332	1,111	8,422
Runner	5,935	3,793	8,077
Middlemen	9,603	4,643	12,854
Exporter/Importer	16,000	16,000	16,000
Wholesale Asia	24,308	15,037	54,054
Retail Asia	49,297	4,050	153,610

Sources: UNODC field work, Haas & Ferreira 2016, Fenio 2014. Environmental Investigation Agency (UK); Wildlife Justice Commission. Data has been supplemented with estimates outside of the reference period 2015-2017, where needed.

Ivory

Africa

A total of 48 observations for the poacher, broker, dealer and exporter levels was available in the relevant time period. Despite the best efforts of the field data collection, it was not possible to find data points for Southern Africa with the exception for the broker level. To calculate an average relevant for the reference period, data points between 2014 and 2018 were used. The resulting mid-point estimates are an average of the sub-regional values weighted by average numbers of elephants illegally killed between 2014 and 2018. Minimum and maximum values are the minimum and maximum values observed for the relevant time.

Figure 3 - Mid-point estimates of prices per kilogram ivory, by level, sub-region and year, 2010-2018, Africa

	2010	2011	2012	2013	2014	2015	2016	2017	2018
Poacher									
Central	32				178				110
East	43	67	155	168	121	19	51	80	53
Broker									
Central	38				193		138		169
East		224	235						102
Southern								170	102
Dealer									
Central	60		183			190			414
East				350	227	185	200		99
Exporter									
Central					285				572
East							550		178

Asia

For Asia, a total of 245 observations was available. The mid-point estimates are the simple average over all relevant observations, the minimum and maximum values are the minimum and maximum values observed. Ivory tusks prices refer to prices of raw ivory tusks at the wholesale level, "worked ivory" to worked ivory pieces (carvings, bangles, etc) at the retail level.

Figure 4 - Average ivory prices at the different points in the trade chain Africa and Asia, 2014-2018 (US$/kilogram)

	Midpoint	Minimum	Maximum
Poacher	93	26	199
Broker	125	60	168
Dealer	236	106	351
Exporter	387	196	608
Ivory tusks Asia	1,009	633	1,750
Worked ivory Asia	6,346	1,126	15,000

Simulation study

To assess the potential for IFFs from the illegal trade in rhino horn and ivory a Monte Carlo simulation was used. Monte Carlo simulations sample from a probability distribution for each variable to produce a large number of possible outcomes. Its results reflect possible IFFs depending on different model inputs.

The simulation here used two random inputs, the number of supply chain links (groups of actors) involved and the proportion of transferred value that constitute IFFs between each pair of actors. The following details were implemented.

- Supply chains had a randomly chosen length between one and six. A supply chain of length one means that there is only one link (transactions between two actors) that has the potential to generate IFF. A supply chain of length six means that IFFs can occur between all pairs of actors. The possible combinations of actors are chosen with the same probability (e.g., a link between poacher-retailer is chosen with the same probility as a link poacher-intermediary).
- To account for the presumably more complex supply chains in the illegal ivory trade, the number of relevant transactions is on average higher than for rhino horn. The number of cross-border transactions follows a truncated normal distribution with mean 3.5 for rhino horn and 4.5 for ivory, and a standard deviation of 2.
- For each link between two actors that can generate IFF, a randomly chosen percentage (between 20 and 80 per cent with equal probability) of the transactions constitute illicit financial flows.

Moreover,

- Each IFF is only counted once, either as in- or outflow, and not twice.
- There is a minimum amount of IFF, if all rhino horn and ivory is purchased by foreign residents from poachers.
- No additional flows from income management or bribes were considered. Including such flows would increase the IFFs accordingly. The simulations use the point estimates of prices and supply derived in earlier section

Annex 1

Revisiting estimates of elephant poaching across Africa

by George Wittemyer

Abstract

This report presents results from a revised model of the elephant carcass data reported through the CITES Monitoring of the Illegal Killing of Elephants (MIKE) programme. While the previous outputs from this model relied on published birth and death rates for African savanna elephants, I update the model such that estimates for forest elephants are now based on recent published data on forest elephant demography (natural mortality and natality). The model incorporates variation in demographic rates and from the carcass sampling process, but not from population survey data. The model is run on carcass data from MIKE sites that represent over 50% of the extant species in Africa but does not incorporate information from MIKE sites in West Africa due to their lower reporting rates relative to sites in Central, East, and Southern Africa. Results indicate illegal killing of elephants rose to a peak in 2011, and the rate of illegal killing has been declining since 2014. Estimated numbers of illegally killed elephants for the continent and Central, East and Southern Africa are presented.

Introduction

Illegal wildlife trade has emerged as one of the critical conservation issues of the twenty-first century (Sutherland et al., 2014), targeting thousands of species worldwide (IUCN, 2016). Expanding trade volumes suggest relatively sophisticated criminal networks are increasingly engaged in wildlife trade (Bennett, 2015; Underwood, Burn, & Milliken, 2013), driving detrimental impacts to global wildlife populations (Milliken, Emslie, & Talukdar, 2009; Underwood et al., 2013; Walston et al., 2010) with likely cascading effects on ecosystems (Estes et al., 2011) and communities (Lindsey et al., 2013). Recent work suggests the illegal harvest feeding the illegal wildlife trade can have serious economic costs for range nations of charismatic species by compromising the potential for tourism-based revenue generation (Naidoo, Fisher, Manica, & Balmford, 2016). With increasing recognition of the scale of the problem, international policy bodies are increasingly being called to act on this global problem (UNODC, 2016).

The cryptic nature of wildlife trade inhibits information regarding levels of offtake and trafficking (UNODC, 2016), data fundamental to identifying critical areas for intervention and the effectiveness of interventions. While numerous approaches exist to assess survivorship and, therefore, mortality of medium and large bodied species (Royle & Nichols, 2003; White & Burnham, 1999), accurately diagnosing the influence of illegal killing on population processes remains a challenge (Liberg et al., 2012). Few approaches provide robust delineation of mortality drivers, such as between natural and illegal causes (Wittemyer et al., 2014). Typically, identification of illegal harvest via wildlife monitoring is accomplished through direct assessment of known or marked animals, such as tagging animals to assess proportions subjected to poaching (Sampson et al., 2018; Stenglein et al., 2015), or indirectly through assessment of population level status, such as evaluation of trends (Chase et al., 2016) or changes in age structure (Chelliah, Bukka, & Sukumar, 2013). Approaches focused around human activities provide useful insight to general trends in illegal harvest, but rarely can be translated into demographic rates. Downstream assessments through market surveys (Auliya et al., 2016) or enforcement seizure reports (Mendiratta, Sheel, & Singh, 2017; Underwood et al., 2013) can provide insight to general trends and levels of offtake. Increasingly, this entails direct assessment of law enforcement interdictions that provides broad assessment of changes in illegal harvest effort (Haines et al., 2012). Recently, social science approaches focused on surveying human populations have provided insight to the illegal offtake levels, even providing estimates of biomass harvested (Gavin & Anderson, 2007; Rogan et al., 2017). While valuable, quantitative assessment of illegal activity rates or metrics that can be translated into estimates of demographically informative harvest rates are preferred for diagnosing population trends and risks and formulating regulatory frameworks (Milner-Gulland & Akcakaya, 2001; Weinbaum, Brashares, Golden, & Getz, 2013).

The influence of illegal wildlife trade and related poaching of African elephants has increasingly typified this issue, largely due to their iconic status and polarized views around commercial trade in elephant products (Bennett, 2015; Stiles, 2004). As a result, a novel, continental monitoring effort was launched in 2002 by the Convention on the International Trade in Endangered Species (CITES, 2013) to monitor the levels and extent of illegal elephant harvest. The Monitoring the Illegal Killing of Elephants (MIKE) was instituted by CITES initially at over 40 elephant populations (MIKE sites) across Africa to ascertain the impact of legal ivory trade on the species (Burn, Underwood, & Blanc, 2011). The number of sites currently that have submitted MIKE data has since expanded to 56 sites. As a key part of this program, the cause and year of death of all elephant carcasses found during patrolling (by foot, vehicle, air or through informant networks) were recorded by site management authorities. While the results from this program have been equivocal in regards to its original goals (Burn et al., 2011), the monitoring system provides powerful data regarding the site specific relative causes of mortality that has served to indicate regional levels of illegal harvest (CITES, 2013).

Carcass level data on the cause of elephant mortality captured by the MIKE Programme provide an index of ivory poaching pressure across the distribution of the species (Burn et al., 2011). The annually collated carcass data offer the most regular index on poaching levels available. Analysis of these carcass data have been instrumental in identifying the scope and trends in ivory poaching across Africa and factors associated with high levels of illegal killing between 2002-2009 (Burn et al., 2011). Currently these data are analysed to ascertain trends in the proportions of illegally killed elephants (PIKE), which is reported to CITES on an annual or near annual basis. A demographic modelling approach was developed to convert the proportion of carcasses caused by illegal killing into poaching rates, showing poaching rates reached levels that drove a decline in Africa's elephants between 2010-2012 (Wittemyer et al., 2014).

Here, I present model estimates of the number of elephants being poached annually across Africa between 2010-2016. I update a previously developed modelling approach that uses carcass survey data to estimate the proportion of illegally killed elephants (PIKE) by site. This procedure uses the ratio of poached to total carcasses for each MIKE site to estimate the binomial sample proportion of the annual mortality caused by illegal killing and the theoretical variance around this estimate (Wittemyer et al., 2014). This proportion is then used as a multiplier of published natural mortality rates for African elephants to derive probable poaching rates. Here, I summarize the model used to convert MIKE data to estimates of the number of elephants illegally killed, present estimates of the number of elephants illegally killed continentally and regionally, and discuss the assumptions underlying this analysis.

In turn, poaching rates can be combined with estimated annual reproduction and natural mortality rates to derive an estimate of population change. A Monte Carlo approach was employed to sample across the variance introduced both observationally through the sampling of carcasses and naturally due to variation in annual mortality and reproduction (Wittemyer et al., 2014), providing an estimate of the distribution of probable poaching and population growth (lambda) rates. Relating these rates to recently reported estimates of the numbers of African elephants (Chase et al., 2016; Thouless et al., 2016), an estimate of the annual number of elephants illegally killed can be derived. The analysis differs from the previous approach by including recently published estimates of natural mortality and reproduction in forest elephants (A. Turkalo, Wrege, & Wittemyer, 2016).

METHODS

Carcass Data

Monitoring of Illegal killing of elephants data are collated and disseminated publicly through the CITES website (https://cites.org/eng/prog/mike/data_and_reports). Currently these data have been posted from the inception of the program in 2002 through 2016. The sample size and consistency of reporting carcass data became more consistent after 2009, therefore, I focus this analysis on the period 2010-2016. Here, direct modeling of MIKE data was used to estimate trends in the 21 best sampled MIKE populations. These 21 populations constitute 5 populations from Central Africa, for which forest elephant parameters were used in models, and 16 savanna elephant populations (8 from Eastern Africa, and 8 from Southern Africa), where definition of Central, East, and Southern Africa is as specified by the African Elephant Specialist Group and used to organize and present elephant population estimates in the African elephant Status Report (Thouless et al., 2016). In combination, these MIKE sites are thought to comprise approximately 45% of the species (~54% of forest elephants and ~44% of savanna elephants), though total numbers of elephants in Africa remain unknown (Thouless et al., 2016). Of note, the most recent revision of the African elephant Database (AED) estimates a substantially lower population of forest elephants than the 2007 AED estimate. Western Africa, holding <5% of the species, lacked adequate data for modelling and was excluded from this analysis. Among these 21 MIKE sites, a total of 8898 carcasses were reported between 2010-2016, among which 4688 carcasses were assessed as having been illegally killed (Table 1). In this analysis, annual carcass data are used directly and not amalgamated or smoothed over multiple years.

Demographic Parameters

Previous analyses relied on birth and natural death rates published from savanna elephants to model trends using the MIKE data from forest and savanna sites (Wittemyer, Daballen, & Douglas-Hamilton, 2013; Wittemyer et al., 2014). The available, empirical estimates of rates for savanna elephants is re-presented here (Table S1), from the original table published in Wittemyer et al. 2013. Recently published information on forest elephant demography (A. K. Turkalo, Wrege, & Wittemyer, 2018) allow species specific demographic parameters to be used for forest populations that were previously modeled using savanna elephant parameters. Given forest elephant natural mortality and natality is markedly lower than that of savanna elephants, previous assessments reliant on savanna parameters to model illegal killing likely overestimated poaching rates and recovery potential in forest populations (A. Turkalo et al., 2016).

Modelling Approach

The modeling approach used here was based off the broader MIKE program framework of estimating the Proportion of Illegally Killed Elephants from reported numbers of elephant carcasses ascribed a cause of death as either illegally killed or natural. The annual proportion of the population that was illegally killed (PIKE) in any year (p_p) was assumed to be represented by (and therefore calculated as) the proportion of carcasses that were illegally killed $\left(\frac{c_i}{c_t}\right)$ where c_i is the number of carcasses found that were illegally killed, and c_t is the total number of carcasses found. This value was assumed to represent the contribution of illegal killing of the total annual mortality experienced by a population, from which the annual illegal killing mortality can be derived as $m_i = m_t p_p$, where m_t is the total annual mortality and m_i is the illegal killing mortality. During years when illegally killed carcasses were found, it assumed numbers of carcasses were a binomial random variable (the number of illegally killed elephants arises from an underlying probability of being illegally killed, given a certain number of dead elephants). As such, for years when illegally killed carcasses were found and the cause of death assigned (i.e. illegally killed or natural mortality), the estimated proportion illegally killed and corresponding variance ($varp$) was calculated as the binomial sample proportion and variance from the observed carcasses:

$$p_p=\left(\frac{c_i}{c_t}\right) \text{ and } var_p = \frac{p_p \times (1-p_p)}{c_t}$$

For each MIKE site, the proportion of illegally killed carcasses at each site was estimated using a Monte Carlo simulation approach to derive 10,000 random draws from the theoretical binomial distribution calculated by the respective carcass data, from which a mean and variation around the mean PIKE value can be derived. During years when no illegally killed carcasses were observed, the proportion and variance of illegal killing were assumed to equal 0. Because carcass data were available in annual totals, no attempt to control for age structure was conducted.

To estimate the illegal killing rate, a draw from the proportion of illegally killed carcasses at each site was multiplied by a single random draw from a moment matched beta distribution representing an annual natural mortality derived from empirical field studies in savanna populations (7 populations) or forest populations (1 population). For savanna sites, a natural mortality figure of 3.2% (variance = 0.015%) derived from the seven published metrics on the species was used (Wittemyer et al., 2013). For forest sites, a natural mortality figure of 1.8% (variance = 0.001%) derived from the Dzanga population was used (A. Turkalo et al., 2016). The deterministic intrinsic growth rate (λ) was estimated by combining derived mortality with natality drawn from a beta distribution representing the published, 4-year average natality of savanna and forest sites (savanna: 7.4%, standard deviation = 1.4%; forest: 4.3%, standard deviation = 0.1%). Four year average values span the average inter-calf interval for the species and mitigates the high degree of stochasticity in annual rates of this parameter (Wittemyer, Barner Rasmussen, & Douglas-Hamilton, 2007). The approach implemented is specified as:

$$\lambda = 1 - m_p - m_n + R$$

$$m_p = \frac{p_p}{1 - p_p} \times m_n$$

$$m_n \sim Beta(\alpha_n, \beta_n)$$

$$\alpha_n = \frac{\mu_n^2 - \mu_n^3 - \mu_n \sigma_n^2}{\sigma_n^2}$$

$$\beta_n = \frac{\mu_n - 2\mu_n^2 + \mu_n^3 - \sigma_n^2 + \mu_n \sigma_n^2}{\sigma_n^2}$$

$$R \sim Beta(\alpha_R, \beta_R)$$

$$\alpha_R = \frac{\mu_R^2 - \mu_R^3 - \mu_R \sigma_R^2}{\sigma_R^2}$$

$$\beta_R = \frac{\mu_R - 2\mu_R^2 + \mu_R^3 - \sigma_R^2 + \mu_R \sigma_R^2}{\sigma_R^2}$$

Where μ_n and σ_n^2 are the sample proportion and variance of natural mortalities, p_p is the proportion of illegally killed elephants (PIKE - where the mean and variance is calculated for each site using carcass counts as described above) and R is the 4-year running average of recruitment with μ_R an σ_R^2 representing the mean and variance of biologically plausible natality. Values of lambda were estimated using Monte Carlo simulation over 30,000 iterations, from which the median and inter-quartile range for the annual population growth rate were derived.

Simulations were run independently for forest and savanna sites using corresponding mortality and natality figures. Runs for which PIKE exceeded 0.9, the combined mortality from natural causes and poaching ($m_p + m_n$) equaled or exceeded 1, or where lambda < 0 were discarded to ensure the biological integrity of the simulation (see discussion of assumptions below). The distribution of lambda then was used to estimate the median and inter quartile population size for each year, using the latest population count for each population (Thouless et al., 2016) and extrapolating forward or backward in time. Mean survey estimates were used, and error in survey estimates were not incorporated into the analysis. In this procedure the population estimate was assumed to have been collected at the end of the year coinciding with the carcass figure totals for that year (i.e. $N_{t+1} = N_t \times \lambda_{t+1}$). The population size was combined with the estimated poaching rate (as derived above), to estimate the number of elephants illegally killed which was used to adjust subsequent population size estimates. In the absence of illegal killing (i.e. 0 illegally killed carcasses found), our model estimated an average population increase of 4.2% per year in savanna sites and 2.5% in forest sites.

Estimating population and illegal killing trends across MIKE sites

MIKE data have been collected across 56 sites in Africa. However, previously published simulation results indicated that robust assessment of annual PIKE requires 20 carcasses annually, though informative but less certain estimates can be derived from sites averaging 10 carcasses per year (Wittemyer et al., 2014). As such, only sites that averaged over 10 carcasses per year were included in the analysis (Table S2). This approach mirrors the 'empirical' approach implemented in Wittemyer et al. 2014, though is less restrictive by including three sites that averaged less than 20 carcasses per year between 2010-2016 (i.e. 18 sites averaged over 20 carcasses annually during the period of analysis). In total, 21 populations were used in the analysis, which constituted 5 populations from Central Africa, for which forest elephant parameters were used in models, and 16 savanna elephant populations (8 from Eastern Africa, and 8 from Southern Africa) (Table S2 and S3).

As a result of our population estimation procedure (i.e. poaching rates calculated as a function of relative cause of death from sampled carcasses and natural rates), years with illegally killed carcass proportions > 0.968 and > 0.982 resulted in estimates of total population extermination in savanna and forest populations respectively on account of the assumption that natural mortality averaged 3.2% and 1.8% per year. Proportion of illegally killed elephant values higher than these thresholds were predominantly found in forested populations, and likely result from biases in carcass sampling in high density vegetative areas (see discussion below). As a result, excessively high PIKE values were truncated as mentioned previously, where Monte Carlo runs for which PIKE values > 0.9 were discarded and redrawn. This effectively capped maximum annual mortality at 28.8% and 16.2% for savanna and forest populations, respectively. This occurred in 27 of the 145 site years assessed, 16 of which were in the 5 forest sites.

The poaching rate and lambda could not be estimated for years in which no carcasses were reported. Among the 21 sites used, two (Zakoma, Chad and Odzala, Republic of Congo) lacked carcass data during one or two successive years (CITES 2013). During years that lacked carcass data, no population change (i.e. lambda = 1) was assumed.

Population growth rates (lambda) and illegal killing rates were amalgamated to derive regional (Central, Eastern, and Southern Africa) and continental rates. Changes across the sum of the estimated annual site population sizes per region were used to derive regional growth rates, where outputs from each Monte Carlo run were combined to derive the rate distributions. Similarly, the illegal killing rates were amalgamated across the 21 sites by summing the estimated number of poached elephants (illegal killing rate multiplied by estimated population size) across each region and dividing by corresponding regional population sizes. Regional rates were similarly adjusted to estimate continental rates. As such, the regional and continental trends are only representative of those populations for which adequate, unbiased data were available. Because West Africa was not represented in the approach (due to small carcass samples), estimates for the combined central, eastern and southern regions of Africa which contain approximately 95% of extant elephants (Table 1) were presented.

Discussion of assumptions

Application of carcass ratios to estimate population change relies on a number of assumptions, most substantively that mortality events were independent and carcasses were randomly sampled. It is important to summarize the assumptions underlying the presented results and discuss the approaches used to assess or minimize their influence where possible. Assumptions are initially summarized with respect to the demographic parameterization of the model:
(i) The baseline mortality and natality rates derived from the published literature that were used in our models represent conditions in relatively well protected savanna populations. All but one of the seven populations from which parameters were derived are recovering or expanding populations (most likely experiencing density independent conditions), in contrast to populations demonstrating compensatory reductions in growth related to age structure or density (Wittemyer et al., 2013). As such, the underlying natural mortality rate likely represents conditions for a population experiencing robust growth (i.e., having relatively low mortality). Where density is higher, we would expect natural mortality to be greater, which would result in higher estimates of poaching. The underlying model assumes an average growth rate of 4.2% in the absence of poaching, which likely reflects healthy growth for this species. Published rates did not differ between region (southern versus eastern Africa), as such the average across all studies was used. Demographic parameters published for forest elephants are derived from a single population. This population experiences moderate levels of poaching and has been impacted by compression (A. K. Turkalo, Wrege, & Wittemyer, 2013, 2017; A. K. Turkalo et al., 2018). It is unknown how these influence demography and if model parameterization is representative of conditions in other sites.
(ii) The potential effect of density dependence was not included in the model. This was both practical, as there is no logical way to determine carrying capacity for the myriad of sites in different ecosystems represented in our analysis, and ensured our model provided a conservative scenario for population decline (i.e. population growth was not inhibited in our modelling approach). Further, it is assumed most populations of elephants are below ecological carrying capacity as a result of human harvest.
(iii) The underlying demographic data were not adjusted to account for possible influences of illegal killing (e.g. compensatory influences reducing natural mortality or reductions in fecundity). No evidence for a compensatory relationship between natural mortality and illegal killing rates were found in the Samburu study system, with a positive correlation between annual rates of these two types of mortality (Wittemyer et al., 2014).
In addition to these demographic assumptions, our model is dependent on the accuracy of the underlying carcass data. The influence of stochastic variation induced by (a) small sample size and (b) annual variability in natural mortality rates was limited by excluding sites with low samples of carcasses per year and smoothing reproductive rates over four years to reduce stochasticity in demographic parameters. Other potential sources of bias that may affect results include:
(i) Where carcasses were found primarily through acoustic identification of gunshots (e.g. gunshots heard and investigated leading to discovery of a poached carcass) or following poacher trails, lower detection of natural (independent of human sign) carcasses will result in

biasing PIKE estimates high. This is particularly a concern in forested sites where sampling is notoriously difficult (Maisels et al., 2013). Unfortunately, information on patrolling and carcass sampling was not available. To ameliorate the most egregious and likely inaccurate PIKE estimates, high PIKE values $\geqslant 0.9$ were excluded (see previous discussion regarding actual number of site years truncated per analysis). While it is possible to get high PIKE values, particularly in years with low natural mortality, truncation ensured population decrease as estimated in the model could not exceed ~25% during any given year.
(ii) Spatial bias in patrolling relative to elephant distribution or mortality can result in misrepresentative carcass data. Unfortunately, detailed patrol data were not available for any MIKE sites.
(iii) The model presented was not age structured because the reliability of age estimates from carcass data were not known, though it is known that survivorship is age dependent. Using a population average mortality, as done here, was assumed to be representative of mortality across the age classes represented in the carcasses surveyed.
(iv) There are factors that may lead to bias in assessment of carcass causes of death. Mortalities of dependents resulting from the illegal killing of adults may not have been found or assigned as natural (i.e. carcasses without human induced wounds are assumed to be from natural causes), when in fact they are a function of the illegal killing. Similarly, poisoning of elephants may be difficult to diagnose from carcass encounters. Should poisoned elephants have their tusks at the time of detection, the carcass will likely be assigned natural causes. Elephants killed by gunshots that die lying on the side of the gunshot wound may also be misclassified as resulting from natural causes. In contrast, natural deaths from which ivory was harvested prior to detection may be erroneously assigned as caused by poaching. In the MIKE site carcass data analyzed here, carcasses assigned unknown cause of death were assumed to be from natural causes given that no evidence of illegal killing was found. This is the most conservative assessment, but potentially leads to underestimation of true illegal killing rates. While assumptions have been explicitly stated and controlled for when possible, results presented represent a best estimate of the levels and trends in poaching and resulting population changes (Table 2). Unfortunately, the probability of any of these sources of bias in the data compiled by the MIKE program could not be assessed, a function of the large scale of this monitoring program and the importance of its implementation in areas with little research or forensic capacity.

RESULTS

Supporting previous analyses, results show poaching levels have been unsustainable (i.e., exceeding the natural reproduction rate, meaning populations would be in decline) across the best monitored MIKE sites between 2010-2015, with aggregate model derived illegal killing rates averaging 6.4% (C.I. 4.4% - 10.1%) annually between 2010-2015 (Table 1). However, data suggests a marked decline in poaching rates in 2016, when levels dropped to 2.4%. In aggregate, this suggests a general decline of 1.7% annually across these 21 sites between 2010-2016. Given best estimates of the elephant population sizes in these populations, this model estimates over 11,000 elephants were killed annually in these populations alone. Given the lack of certainty on elephant population size, however, converting the derived rates into number of elephants killed is extrapolation, and it is important to note confidence in population size estimates used in the modeling approach were not incorporated into the analysis.
Poaching rates in 2013-2016 are lower than those found in 2011 (the peak poaching year) or 2012 (Wittemyer et al. 2014). Declines were not uniform across sites, with recent poaching rates and trends differing markedly across populations, countries and regions. When collating data from these 21 sites into regional values, poaching rates were likely to have declined to

sustainable levels in Southern Africa by 2013 and East Africa by 2016, but remain persistently high in Central Africa. Despite the continued problems in Central Africa, evidence of successes in stemming poaching in specific populations are emerging, most notably in the Zakouma and Dzanga sites.

While providing systematic insight to poaching levels, the best means to interpret these data are debatable (Jachmann, 2012; Wasser et al., 2015). Carcass survey data is collected and collated by each range state individually, and sampling effort and reporting efforts vary strongly across range states and MIKE sites (Burn et al., 2011). Sampling bias driven by different approaches to locating carcasses has also been identified as a concern (Jachmann, 2012), particularly among forest sites where vegetation greatly limits the surveyed area when performing ground transect sampling methods (Maisels et al., 2013). As such, comparison of site-specific trends or amalgamated trends using the same sites may be more meaningful than contrasts between sites.

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Table: Modelled regional number of elephants illegally killed

Region		2010	2011	2012	2013	2014	2015	2016	2017	2018
Central	Median	3210	4400	4362	3308	4071	2928	1983	2063	1569
	2.50%	1252	2277	2254	1625	2104	1369	890	832	607
	97.50%	7394	7909	7868	6092	7177	5598	4119	4503	3577
Southern	Median	11174	13331	11083	6777	6182	5741	4301	5936	6477
	2.50%	5829	7285	5176	3110	3112	3301	2347	3533	3633
	97.50%	26428	28973	27069	17376	15299	9704	7672	9715	11388
Eastern	Median	6503	12783	6654	10854	6705	7012	2663	1728	3169
	2.50%	3806	6959	4045	5916	3387	3711	1335	793	1596
	97.50%	12502	26331	11529	21549	14434	13190	5136	3669	6063

* 21 sites, annual data (not smoothed), based off of 2015 African Elephant Status Report population numbers. 2016 preliminary for Central Africa, and likely to increase once data set is complete.

Table: Modelled regional lambda

Region		2010	2011	2012	2013	2014	2015	2016	2017	2018
Central	Median	0.970	0.906	0.895	0.915	0.877	0.904	0.937	0.927	0.946
	2.50%	0.951	0.875	0.863	0.886	0.845	0.875	0.913	0.898	0.922
	97.50%	0.984	0.933	0.923	0.939	0.906	0.929	0.957	0.951	0.966
Southern	Median	1.002	0.994	1.002	1.017	1.019	1.022	1.028	1.023	1.022
	2.50%	0.987	0.979	0.986	1.006	1.009	1.014	1.019	1.014	1.012
	97.50%	1.014	1.007	1.014	1.027	1.029	1.031	1.036	1.032	1.031
Eastern	Median	0.982	0.923	0.974	0.929	0.967	0.961	1.011	1.023	1.007
	2.50%	0.966	0.890	0.959	0.902	0.945	0.942	1.002	1.014	0.997
	97.50%	0.995	0.948	0.987	0.951	0.983	0.977	1.020	1.030	1.016

Table: Modelled regional illegal killing rate

Region		2010	2011	2012	2013	2014	2015	2016	2017	2018
Central	Median	0.083956	0.118685	0.129845	0.110032	0.147992	0.121386	0.087736	0.09852	0.079244
	2.50%	0.031691	0.060598	0.068544	0.05728	0.083667	0.064431	0.04583	0.047738	0.037747
	97.50%	0.197412	0.214639	0.228924	0.19202	0.240865	0.207461	0.159428	0.183287	0.150771
Southern	Median	0.039375	0.046898	0.039215	0.023938	0.021475	0.019564	0.014263	0.01924	0.020546
	2.50%	0.02038	0.0258	0.018728	0.011405	0.011347	0.011928	0.008319	0.01235	0.012552
	97.50%	0.093216	0.100804	0.093514	0.059181	0.050749	0.031289	0.023884	0.029312	0.033319
Eastern	Median	0.059648	0.119424	0.067381	0.112828	0.075034	0.081186	0.030484	0.019349	0.035226
	2.50%	0.035273	0.066787	0.043635	0.066511	0.042228	0.048941	0.017575	0.010292	0.020767
	97.50%	0.112452	0.237924	0.109854	0.207971	0.146439	0.136092	0.051944	0.036028	0.058584

Table: Total carcasses

Region	**Site**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Central	**Dzanga-Sangha**	5	10	10	42	17	30	30
Central	**Zakouma**	39	7	0	1	1	4	NA
Central	**Odzala**	NA	123	12	1	7	10	30
Central	**Garamba**	15	14	48	17	121	105	100
Central	**Minkébé**	18	31	27	27	19	22	51
Eastern	**Meru**	40	81	129	55	28	14	4
Eastern	**Samburu/Laikipia**	164	264	310	156	95	151	145
Eastern	**Tsavo**	81	107	238	291	172	127	170
Eastern	**Queen Elizabeth**	11	20	21	37	22	21	10
Eastern	**Katavi Rukwa**	13	29	29	18	14	27	16
Eastern	**Ruaha Rungwa**	28	34	110	57	50	47	27
Eastern	**Selous Mikumi**	195	224	156	118	42	68	30
Eastern	**Tarangire**	42	5	20	6	10	9	10
Southern	**Chobe**	37	42	351	156	239	197	121
Southern	**Niassa**	77	85	117	73	137	66	99
Southern	**Zambezi**	6	29	10	68	76	87	97

Southern	**Etosha**	11	27	14	5	9	13	20
Southern	**Kruger**	14	20	5	17	35	74	165
Southern	**South Luangwa**	49	22	34	21	77	83	85
Southern	**Chewore**	29	51	43	91	52	41	33
Southern	**Nyami Nyami**	19	16	52	36	27	31	15

Table: Poached carcasses

Region	**Site**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Central	**Dzanga-Sangha**	0	1	4	41	6	13	7
Central	**Zakouma**	36	5	0	0	0	3	NA
Central	**Odzala**	NA	118	12	1	7	10	22
Central	**Garamba**	10	13	47	16	119	98	97
Central	**Minkébé**	17	27	24	20	19	19	47
Eastern	**Meru**	28	63	71	33	11	2	3
Eastern	**Samburu/Laikipia**	77	161	225	99	37	54	58
Eastern	**Tsavo**	55	65	136	133	85	42	37
Eastern	**Queen Elizabeth**	4	16	12	10	11	12	5
Eastern	**Katavi Rukwa**	12	25	25	12	11	25	15
Eastern	**Ruaha Rungwa**	16	32	73	48	29	35	10
Eastern	**Selous Mikumi**	108	143	80	87	34	51	12
Eastern	**Tarangire**	21	1	14	6	8	7	1
Southern	**Chobe**	9	14	28	2	23	10	0
Southern	**Niassa**	65	76	114	67	131	63	92
Southern	**Zambezi**	2	17	6	30	27	31	32
Southern	**Etosha**	0	0	0	0	0	0	0
Southern	**Kruger**	0	1	0	0	6	30	46
Southern	**South Luangwa**	26	14	14	15	41	46	50
Southern	**Chewore**	4	34	34	36	9	12	7
Southern	**Nyami Nyami**	19	13	14	8	10	11	4

Region	Site	Population Size	Year of Estimate	Reference
Central	**Dzanga-Sangha**	632	2012	Princée, 2013
Central	**Zakouma**	423	2013	Antonínová et al., 2014
Central	**Odzala**	9292	2012	Maisels et al., 2013
Central	**Garamba**	1718	2014	Mònico, 2014
Central	**Minkébé**	6875	2013	ANPN, 2013
Eastern	**Meru**	747	2007	Mwangi et al., 2007
Eastern	**Samburu/Laikipia**	6365	2012	Ngene et al., 2013
Eastern	**Tsavo**	12182	2011	Ngene et al., 2011
Eastern	**Queen Elizabeth**	2904	2014	Wanyama et al., 2014
Eastern	**Katavi Rukwa**	5616	2014	TAWIRI, 2015
Eastern	**Ruaha Rungwa**	20090	2013	TAWIRI, 2013
Eastern	**Selous Mikumi**	15201	2014	TAWIRI, 2015
Eastern	**Tarangire**	4079	2014	TAWIRI, 2015
Southern	**Chobe**	40767	2006	DWNP, 2006
Southern	**Niassa**	4441	2014	Grossman et al., 2014
Southern	**Zambezi**	13116	2015	Gibson & Craig, 2015
Southern	**Etosha**	2911	2015	Kilian, 2015
Southern	**Kruger**	17086	2015	Ferreira et al., 2015
Southern	**South Luangwa**	3302	2015	DNPW, 2016
Southern	**Chewore**	3303	2015	Dunham et al., 2015
Southern	**Nyami Nyami**	3555	2006	Dunham et al., 2006