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Global ivory market prices since the 1989 CITES ban☆

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ABSTRACT

Poaching associated with the ivory trade is estimated to cause an 8% annual loss in the world elephant population. Although international trade in ivory was banned by the Convention on the International Trade in Endangered Species in 1989, elephant populations continue to suffer. Together with global price data on ivory transactions, information on ivory product type, weight, region, legality of sale, and year of transaction, were used alongside an ivory Transaction Index (TI) and world gold price to: (1) examine the temporal and geographic trends in ivory price; (2) determine variables associated with ivory price; and (3) propose a predictive equation based on these variables. Results indicate that ivory price has been rising since the CITES ban, with highest values observed across Asia. Determinants significant to ivory market price include: (1) region; (2) type [raw, polished, carved]; (3) TI; and (4) legality. Interaction effects were present between region and legality, and between region and type. The predictive equation successfully explained 72.5% of variation in price. It is hoped that an improved understanding of the market mechanism will lead to more effective policy interventions, which can ensure a secure future for elephants as a species.

1. Introduction

The wildlife trade involves the sale or exchange of wild animals or plants and their derivatives, such as skins, tourist curios, or food products. It is estimated that this global trade is worth up to $350 billion annually, with illegal transactions accounting for approximately $20 billion (TRAFFIC, n.d.; Wyler and Sheikh, 2008; Petrossian et al., 2016; UNODC, 2016). Data on illegal trafficking seizures indicate that the wildlife trade is unevenly distributed across taxa; mammals account for 51% of all wildlife seizures, with ivory being a significant subcategory, making up 25% of mammalian seizures by number (TRAFFIC, n.d.; Petrossian et al., 2016).

By 1976, the ivory trade had pushed elephants to the brink of extinction. Plunging African elephant (*Loxodonta africana)* populations drew international attention, at which point concerns about their long-term survival led to their listing by the Convention on the International Trade in Endangered Species (CITES). By 1989, the African elephant had made its way onto CITES Appendix I, which criminalized all international trade and left individual nations responsible for the regulation of domestic trade activity (Lemieux and Clarke, 2009). In 1999 and 2008, however, several elephant range countries had elephants down listed to Appendix II due to increasing populations, and legally auctioned government-stockpiled ivory to designated Asian trading partners. These two events are known as the “one-off ivory sales” (USFWS, 2013). Up until 2016, China and the US, the two largest ivory markets, still had legal components to the trade. In 2016, however, both countries agreed to shut down markets by the end of 2017. The following analysis assesses market data from 1989 to this 2017 shutdown, which will likely mark a new era for the ivory trade and African elephants.

Almost 600,000 kg of illegal ivory has been seized since 1991 (CITES Secretariat, 2016a, 2016b). Primarily the product of elephant poaching, these seizures represent the death of approximately 50,000 elephants per year, highlighting the grave effects of the trade on remaining African elephant populations, currently estimated at just over 350,000 (Chase et al., 2016).

As is the case for any commodity, the ivory trade (and therefore elephant poaching activity) is driven by demand (Milner-Gulland and Leader-Williams, 1992; Knapp, 2012; Holden and McDonald-Madden, 2017; Holden et al., 2018). Higher ivory market prices lead to higher poaching incentives, and therefore greater numbers of elephants being killed. Previous researchers have studied ivory price at multiple levels

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ranging from local markets to national scale, but the majority of studies suffer from data deficiency or employ a purely qualitative approach.

One of the first analyses examining trends in ivory market price was performed by Wittemyer et al. (2014). The authors collated price information from markets in Samburu, Kenya and demonstrated that observed spikes in ivory price circa 2008 were correlated with increased elephant poaching and ivory seizure rates. This study, although limited to Samburu, was amongst the first to link ivory prices to elephant poaching and illegal seizures (Wittemyer et al., 2014).

Gao and Clark performed a similar analysis in 2014, focusing specifically on price trends in China. The researchers visited Chinese ivory markets to gather information on ivory price, type, and weight, amongst other variables. Through their analysis, Gao and Clark established that illegal ivory prices increased dramatically in the years leading up to 2013, and that illegal raw ivory was approximately ten times more expensive in China than in Africa (Gao and Clark, 2014).

Gao and Clark's (2014) conclusions about increasing prices were supported by 't Sas-Rolfes et al. (2014), who observed significant ivory price increases from 2000 to 2014 in both Africa and East Asia. The researchers noted increases in elephant poaching and ivory seizures around 2008, which supported the findings of Wittemyer et al. (2014).

In 2015, Stiles, Rowan, and Moyle published a study drawing connections between the previously noted price increases and both the one-off ivory sale of 2008 as well as the Global Financial Crisis of 2007/2008. Their analysis also explored relationships between ivory prices and elephant poaching, ivory shipping costs, and macroeconomic indicators such as LIBOR and gold price (Stiles et al., 2015).

The only quantitative approach to analyzing ivory markets was published by Milner-Gulland in 1993. In this paper, Milner-Gulland developed an econometric model to describe consumer demand for ivory and rhino horn in Japan, which was found to be primarily income-driven. This analysis, however, is relatively out of date and limited solely to Japanese markets (Milner-Gulland, 1993).

Each of these publications highlights the multidimensional nature of the ivory trade by integrating variables such as the estimated number of elephant poaching events, global ivory seizure volumes, the type, weight, and legality of ivory, and various macroeconomic indicators. To the best of our knowledge, however, there have been no attempts to integrate these variables with market price data in a systematic manner. There is also a lack of studies exploring market prices both temporally and geographically. The aim of this study, therefore, was to examine a large dataset of ivory market prices, together with information such as ivory product type (raw, polished, carved), weight, region, and legality. Alongside the Transaction Index (TI) (which estimates the number of transactions in a given year) and world gold price, this data will be used to (1) examine the temporal and geographic trends in market price since the 1989 CITES ban, (2) determine factors significantly linked to ivory price, and (3) propose a predictive equation for price based on these factors.

By exposing trends in market price since the 1989 CITES ban and identifying its determinants, it is hoped that better policy decisions can be made with regards to regulation, education, and conservation efforts. This could, for example, be more stringent trade regulation in regions where ivory price, and therefore likely demand, is highest. Ideally, this would lead to decreased poaching incentives and a more secure future for elephants.

2. Methodology

2.1. Data collection

Market data was obtained from two sources. The UK-based non-profit 'Stop Ivory' facilitated the provision of pricing data collected between 1999 and 2004. This dataset contained 320 individual transactions from ivory markets visited across Africa, Europe, as well as South, Southeast, and East Asia. Some historical samples in this dataset stretched back to 1874. This novel unpublished data was collected using the methods described in Martin and Stiles's previous publications (Martin and Stiles, 2000, 2002, 2003, 2005).

A second set of information was collected via literature search. The search for articles was executed using the databases Science Direct, Web of Science, and Google Scholar. Google web searches were also used to find news publications citing ivory prices. Search terms included 'ivory price,' 'ivory market survey,' 'elephant ivory,' 'ivory trade,' and their variations. Prices were recorded only from peer-reviewed publications, globally recognized news sources, or reputable elephant non-profit organizations to ensure price sample reliability. A complete record of collected samples and their information sources is provided in Appendix A.

Ivory prices from both datasets were filtered to only include samples from 1989 onwards. This was done in order to focus on the global market after the 1989 (CITES) ban on the international ivory trade. Once filtered, the first dataset contained 182 samples and the second 109 samples. This filtered data was used for all analyses.

Data from both sets included the following information: market price, product type (raw, polished, or carved), estimated weight of sample, country of transaction, legality of transaction (legal, illegal, or unknown), and the year of the transaction. Raw ivory was defined as tusks that had not been carved, polished, or worked, essentially coming straight from an elephant ($n = 201$); polished ivory was defined as tusks that had been polished but not been worked or carved ($n = 33$); and carved ivory was defined as tusks that had been carved and worked ($n = 48$). Data was also classified by legality as legal ($n = 118$), illegal ($n = 83$), and unknown ($n = 90$), based on the records of the original data collectors.

Prices were calculated in USD against the weight of the ivory piece and then adjusted for inflation using the US Consumer Price Index (CPI). This resulted in the final unit of 2017-equivalent USD per kg. Inspection of the residuals from the statistical models for normality and homogeneity of variance (applied to inflation-adjusted prices) suggested that the natural logarithm of price should be used as the outcome variable to satisfy the modeling requirements. Therefore, all prices hereafter referred to are the natural log of 2017 USD/kg ('LnPrice').

Due to sample size constraints, samples were grouped by region, rather than by country. Regional groupings were maintained as originally assigned by Martin and Stiles (2000, 2002, 2003, 2005) in their market surveys (Table 1).

Finally, the following global-level variables were collected for each year since 1989: ivory Transaction Index (TI) (Milliken et al., 2013; Underwood et al., 2013; CITES Secretariat 2016) and the international price of gold (Macrotrends, n.d.).

Ivory TI was applied to this analysis as an index of transaction activity for a given year. Applied to the trade in 2013 by Underwood, Burn, and Milliken, TI estimates the relative number of transactions of a target good in a given year (Halpern, 1997; Underwood et al., 2013). Ivory TI also takes into account the number of ivory seizures made by

Table 1
Regional grouping with included countries.

Region	N	Definition
Africa[a]	104	Gabon, Cameroon, Central African Republic, Chad, Cote D'Ivoire, Democratic Republic of the Congo, Ethiopia, Nigeria, Senegal, Kenya, Egypt, Tanzania, Zimbabwe
Europe[a]	17	Germany, France, and the United Kingdom
East Asia[a]	47	China, Hong Kong, Japan
South/S. East Asia[a]	17	Thailand, Cambodia, India, Laos, Nepal, Singapore, Myanmar (Burma), Vietnam, Sri Lanka
United States	11	
Online	13	Samples from global online marketplaces
World	5	Citations of general 'world' price in a given year

[a] Regional groupings as assigned by Martin and Stiles (2000, 2002, 2003, 2005).

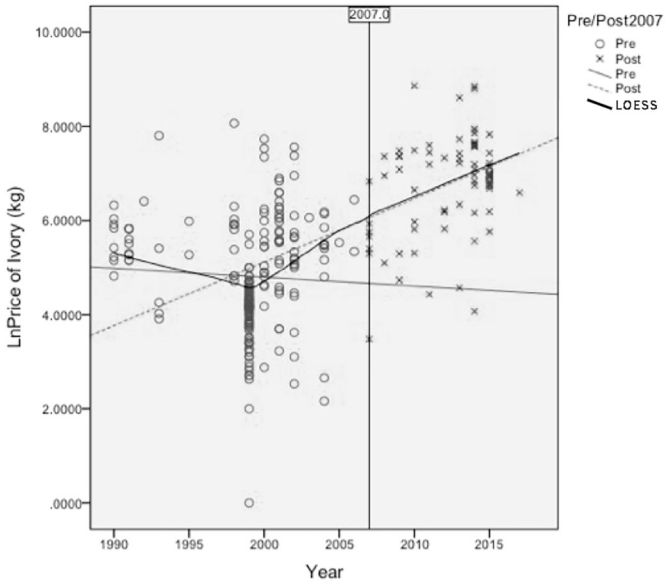


Fig. 1. Global ivory market price data 1989–2017 with best-fit line options (linear split at 2007 and LOESS). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

68 countries for each year from 1996 to 2015 as well as the relative weight of ivory seized.

2.2. Statistical analysis

R v3.5.1 (R Core Team, 2018) was utilized for statistical analyses. A univariate general linear model (GLM) was used to examine temporal and spatial trends and to determine factors significantly associated with the price of ivory. LnPrice was the dependent variable; fixed factors tested within the models included data source (field surveys versus literature search), legality, product type, and region. Covariates tested in the analysis were weight of sample, as well as TI and gold price of the year of transaction. All fixed factors and covariates were assessed for their statistical significance at an alpha of 0.05.

2.2.1. Temporal and geographic analysis

For temporal analysis, price data was initially plotted against time and fit using LOESS (75% points to fit, Kernel = Epanechnikov). The fit of the LOESS suggested splitting the data to fit two linear regression models (Fig. 1). The price data was consequently fit with two linear models to provide a stronger summary of the price trends over time – the location of the split is discussed below.

2.2.2. Price determinants

A series of GLMs were run to test different combinations of fixed factors and covariates. An initial series of GLMs tested for a significant overall difference between the data from the two sources. Because no difference was found, this factor was removed from all subsequent models and the combined dataset was used throughout the remaining modeling process. This modeling process involved running the GLM repeatedly to identify the strongest combination of predictors of ivory price, assessed collectively by adjusted R-squared values and significance levels. All factors in the final model that were statistically significant ($p < 0.05$) were retained. It should be noted that, because of the exploratory nature of this type of study, p-values here should only be seen as a guideline to identify candidate variables that can be assessed as causal factors in future hypothesis-led studies. Amongst the factors tested but subsequently removed were: weight, amount of ivory crushed per year, China's gross national income, and the proportion of elephants illegally killed per year (PIKE).

3. Results

3.1. Temporal and geographic analysis

A LOESS fitted curve was applied to the overall ivory market price data (Fig. 1). The data suggested an initial slow decrease in LnPrice followed by a steep increase after approximately the year 2000. The precise point of inflection is hard to discern, as the LOESS fitted line will

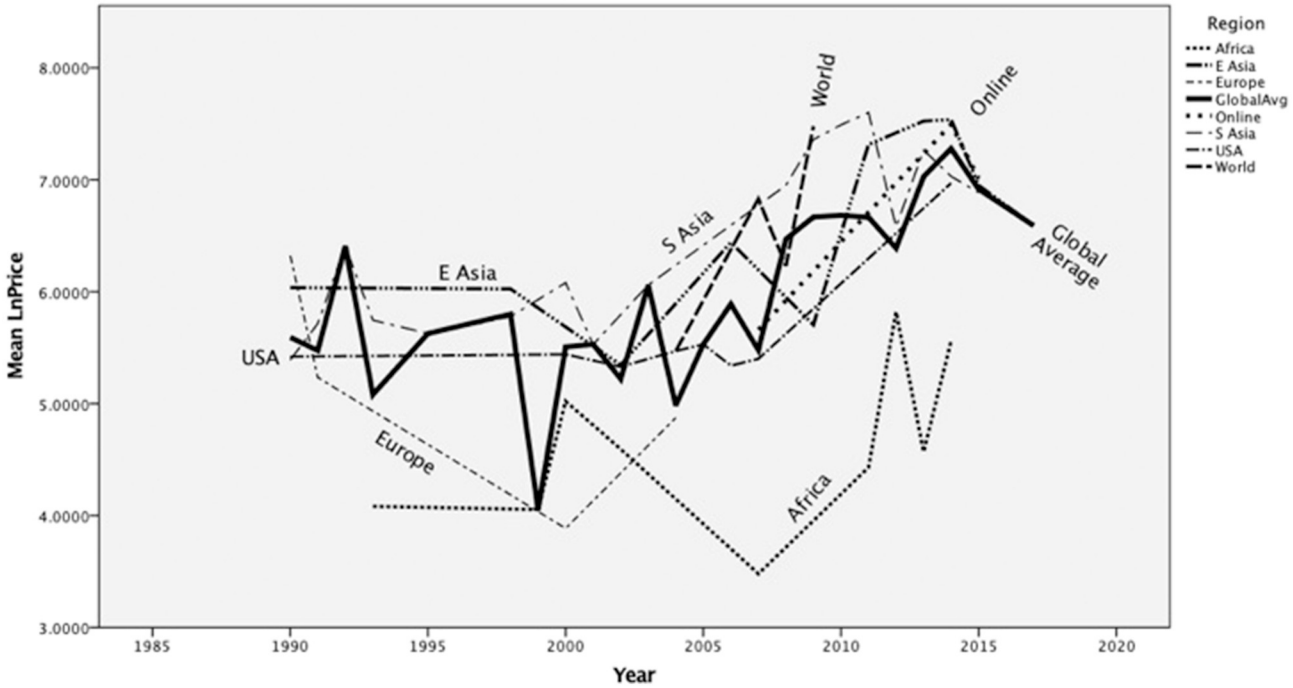


Fig. 2. Regional and global trends of ivory price 1990–2017 based on the mean LnPrice for each year. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 2
The final predictive model of LnPrice showing the significant fixed factors and covariates and their significant interactions together with the parameter estimates, significance and a 95% confidence interval of the estimate.

Term	Estimate	Std. error	Statistic	P-value
Intercept	3.6277	0.3732	9.7196	0.0000
Year As Transaction Index	0.0059	0.0016	3.5940	0.0004
Year As Gold	0.0006	0.0003	2.1660	0.0313
Continent E Asia	4.3084	0.8966	4.8054	0.0000
Continent Europe	1.5355	0.8399	1.8282	0.0688
Continent Online	−0.1124	0.4890	−0.2299	0.8183
Continent S Asia	1.7385	0.8421	2.0645	0.0401
Continent USA	0.2568	0.5163	0.4974	0.6194
Continent World	1.6990	0.4827	3.5199	0.0005
Type Polished	−0.0478	0.2121	−0.2252	0.8220
Type Raw	−0.8909	0.2346	−3.7971	0.0002
Legality Legal	−0.2185	0.3089	−0.7072	0.4801
Legality Unknown	0.8313	0.3045	2.7296	0.0068
Continent E Asia: Type Polished	−0.4767	0.9872	−0.4829	0.6296
Continent Europe: Type Polished	−0.6327	1.1115	−0.5692	0.5698
Continent Online: Type Polished	1.9607	0.6955	2.8189	0.0052
Continent S Asia: Type Polished	0.7469	0.8727	0.8559	0.3930
Continent E Asia: Type Raw	−2.1450	0.8503	−2.5227	0.0123
Continent Europe: Type Raw	−0.2244	0.8658	−0.2592	0.7957
Continent Online: Type Raw	2.0591	0.6386	3.2244	0.0014
Continent S Asia: Type Raw	0.0615	0.8251	0.0745	0.9407
Continent USA: Type Raw	0.5250	0.5729	0.9163	0.3605
Continent E Asia: Legality Legal	−1.0727	0.4367	−2.4567	0.0148
Continent Europe: Legality Legal	−1.5564	0.6265	−2.4842	0.0137
Continent S Asia: Legality Legal	0.5047	0.3918	1.2882	0.1990
Continent World: Legality Legal	0.5353	0.7497	0.7140	0.4759
Continent E Asia: Legality Unknown	−1.0407	0.4227	−2.4624	0.0145
Continent S Asia: Legality Unknown	−0.5872	0.4221	−1.3912	0.1655

be overly influenced by the weight of data from 1999, for which price samples were heavily clustered from Africa. The year 2007 was selected as a break point due to historic, recorded market changes, discussed below. The LOESS fitted line does suggest a slightly earlier point of inflection; however, even if an earlier point of inflection were to be adopted, the slopes of the two fitted lines would remain relatively unaffected. The mean annual price of ivory as LnPrice is graphed by region as well as globally (shown as world means) (Fig. 2).

3.2. Price determinants

There was no statistically significant difference between LnPrice from the two data sources, namely the field survey data and data collected via literature search, therefore, this term was dropped from the model, as was the variable 'estimated weight of ivory,' which proved insignificant to price estimation. The variables retained in the final model included region, type, legality, the region * legality interaction, the region * type interaction, TI and the world gold price (see Table 2 for predictive variables retained in the final model and their levels of statistical significance). Baseline values, or those tied to the intercept in the equation, are the 'Africa' prices, 'carved' ivory type, and 'illegal' legality.

The analysis presented shows that the relationship between the price of ivory and region, legality and type is complex (Table 2). The significant interaction term between region and type indicates that the price differential between the different types of ivory is dependent upon region, and the significant interaction between region and legality indicates that the price differential between the legality categories is also dependent upon region. The model also shows that, on average, for every unit increase in TI (transaction index, i.e. related to the number of transactions in a given year) there was an associated 0.0006 increase in LnPrice and for every unit increase in gold price an associated increase of 0.001 in TI.

Ivory price is depicted as it varies according to legality across regions (Fig. 3a). Overall, illegal ivory was the most expensive. Ivory of unknown legality had intermediate prices, while legal ivory had the lowest prices. Asian (i.e. East as well as South and Southeast Asia) and online illegal ivory had particularly high prices. Africa and Europe, on the other hand, had notably low legal ivory prices. Southeast Asia had almost equal legal and illegal ivory prices, a phenomenon which did not occur in any other region.

The model shows that prices tended to be higher for carved and polished ivory (Fig. 3b). For all types, higher prices were observed across Asia. East Asia had particularly high prices for carved and polished ivory; the significant interaction between region and product type such that the East Asian carved ivory was notably more expensive ($p = 0.007$). Prices for carved and polished ivory were lowest in Africa, with slightly higher prices observed across Europe and the USA.

4. Discussion

4.1. Summary of findings

The price model developed explains approximately 72.5% of the variation in the ivory price (LnPrice) since the CITES ban. Determinants significant to ivory market price included: (1) region; (2) type; (3) Transaction Index; and (4) legality. Interaction effects were present between region and legality, and between region and type. There was a strong positive linear relationship between Transaction Index (which estimates the number of ivory transactions each year and takes into account both the number and weight of ivory seizures made from 1996 through 2015) and year, with a general increase with successive years (see Appendix B).

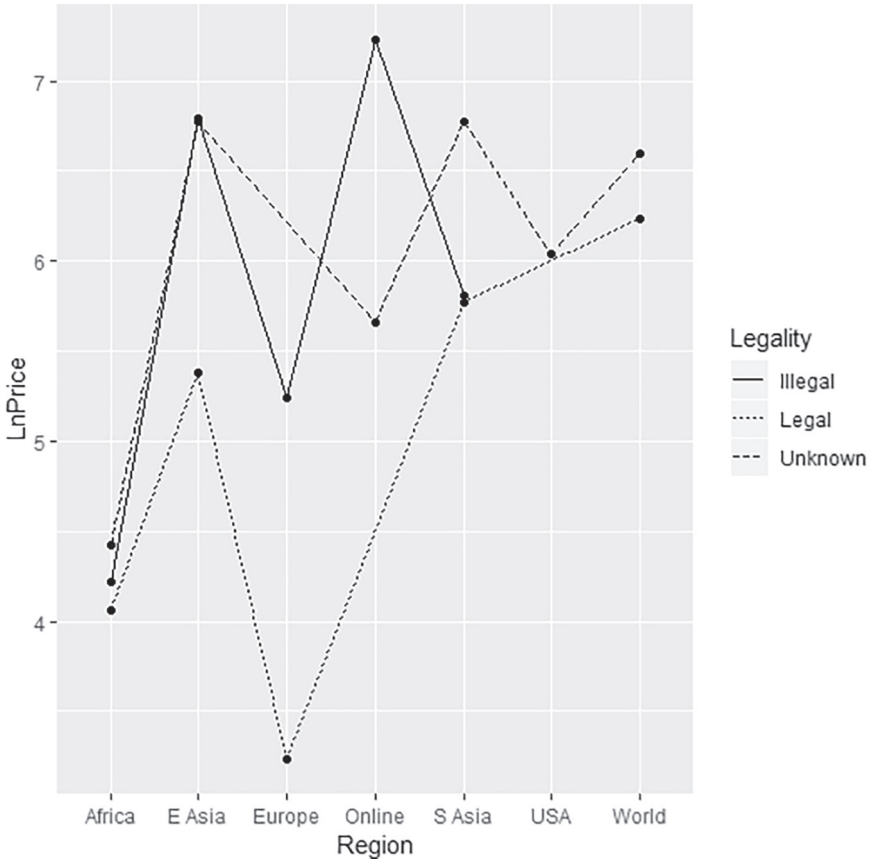
The total weight of ivory at a sale proved a non-significant factor on price per kilogram. Weight in the current dataset ranged from a minimum 0.17 kg to a maximum of 80 kg, with a mean of 5.4 kg and a standard deviation of 7.1 kg. A histogram of the reported sample weights is included within Appendix C. Various publications, including those by CITES, classify weight of each ivory transaction into three categories of: < 10 kg, 10-100 kg, and 100 kg + (Underwood et al., 2013; CITES Secretariat 2016), and deem weight an important factor in the analyses of ivory trade data, with larger pieces generally attracting higher prices per kilogram. It is likely due to the limited weight range and generally low weights in comparison to other reports, that weight was not significant in the present model.

4.2. Identified price determinants

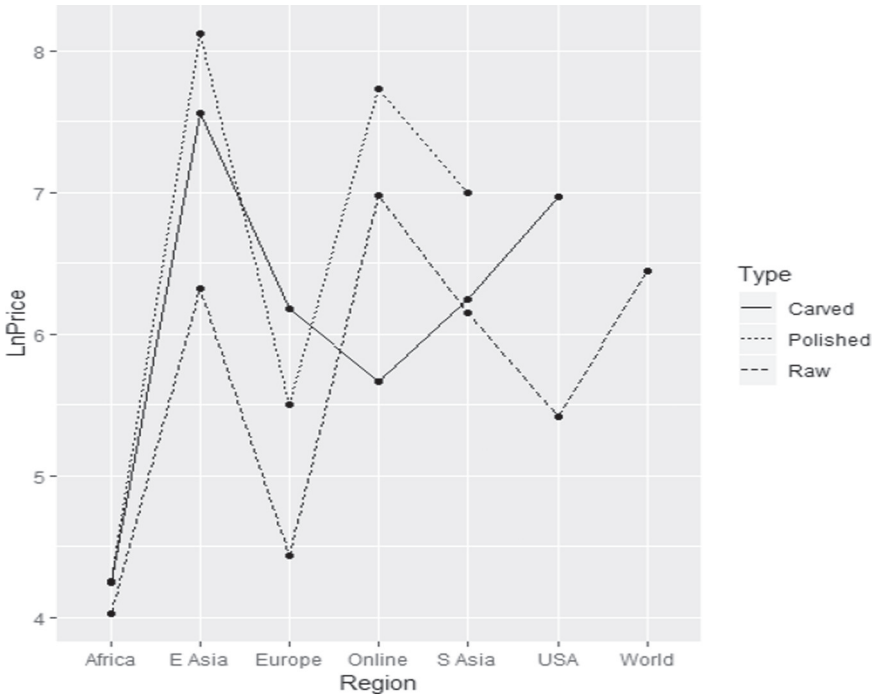
The identified price determinants, such as region, product type, legality, and the interactions between region and legality, as well as region and type, may reflect the sociocultural demand for ivory in its various forms. Regional differences in particular should be representative of social and cultural demand. Regional demand for a type of ivory (raw, polished, carved) may be reflective of the more particular market demands, as well as potentially the existence of domestic ivory processing facilities. For example, high prices across Asia are likely reflective of a local demand, and distinctly higher prices of carved and polished ivory in East Asia (Fig. 3b) may be indicative of particularly strong demand for these products. Legality may also reflect sociocultural attitudes towards ivory or regional enforcement activity. Almost equivalent prices for legal and illegal ivory observed in South Asia may be indicative of a disregard of ivory legality or low risk of law enforcement intervention.

As discussed, TI is indicative of global market size, with more global transactions corresponding to a larger global market and higher prices. The inclusion of TI in the model should account for fluctuations in the global market, therefore more accurately depict sociocultural demand both globally and regionally.

Lastly, world gold price is indicative of global investment into and demand for luxury goods. Gold market prices fluctuate due to interest rates, geopolitical relations, currency markets, inflation and deflation,



a. Ivory Region*Legality Means Plot



b. Ivory Region*Type Means Plot

Fig. 3. Means plots showing the interaction effects of region * legality and region * type on global ivory market price 1989–2017. In Fig. 3a LnPrice is depicted as it varies according to legality across regions, whilst in Fig. 3b the LnPrice is shown as it varies according to type across region (whilst all other predictive variables are held constant). The covariate TI in the model is evaluated at 146.29, and the covariate Gold Price at 661.55. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

investment demand, and equity markets (Gold Price, 2018). The integration of world gold price into the model reflects these factors and the status of the global economy, which would affect the price of ivory, another luxury good.

4.3. Other price determinants

Other variables likely explain the price discrepancies between regions, type, and legality observed and must account for at least some of the 28.1% of variation unaccounted for by the model. These may include corruption-related expenses, shipping costs, speculative investing, production costs, ivory quality, and significant events including signings of international agreements and ivory destructions by authorities.

4.3.1. Corruption

Legal prices were lower than those for illegal ivory across almost all regions (Fig. 3a); the exception is South and Southeast Asia. The prominence of corruption and bribes in South and Southeast Asian regions may account for the difference in price according to legality observed. As the prices of ivory classified as 'unknown' legality were similar to those of illegal ivory in East Asia, it is probable that much of this ivory was also illegal. Bennett (2015) reported that up to $30,000 a day might be disbursed in bribes to officials on the Vietnam-China border. These officials often facilitate the integration of illegal ivory into legal markets and contribute to already poor law enforcement (Martin and Stiles, 2003; Moyle and Conrad, 2014; Bennett, 2015; Vigne and Martin, 2016). Due to the clandestine nature of these activities there is data deficiency preventing the inclusion of corruption into the model.

4.3.2. Shipping costs

Shipping expenses impact both operational costs and market prices. Moyle (2014) demonstrated that shipping costs were correlated with smuggling levels, as indicated by ivory seizures. Specifically, lowered transport costs were correlated with increased ivory seizures indicating larger volumes being transported. If shipping costs influence the volume of ivory smuggled, they are likely to affect market prices indirectly. Because shipping costs have been demonstrated to follow similar patterns to global ivory seizures and global business cycles through the oil price, they were not integrated into the present model and instead were accounted for using TI and gold price.

4.3.3. Speculative investing

It has been reported that the estimated amount of ivory leaving Africa is not fully accounted for in seizures and market sales (Moyle and Conrad, 2014; Stiles et al., 2015). This suggests a leak into an alternative market – likely speculative stockpiling. Stiles et al. (2015) as well as Moyle and Conrad (2014) show that the 37 legal factories in China only had a collective throughput of 28–30 tusks per month from mid 2009 to early 2014. During this same period, up to 200 M tons of ivory could have been entering China per year; at an average of 10 kg per tusk this would equate to 20,000 tusks per year. This large discrepancy is most likely accounted for by speculative stockpiling. This behavior may increase demand for primarily raw ivory, which would in turn affect market prices (Stiles et al., 2015). As with many black market commodities, there is data deficiency when it comes to inventory; the volumes kept for investment each year were unclear and therefore not incorporated into our price model.

Bulte et al. (2003) have further discussed the profitability of speculative stockpiling when it comes to endangered species. Linking the value of this practice to the dynamics of supply and demand, the authors argue that the profitability of such behaviors may be tied to an *active effort* to decrease long-term supply – in the case of elephants, poaching. The large scale killing of certain species (such as elephants) directly increases the value of wild stocks, and therefore fuels a cycles of behavior the authors have coined "banking (or betting) on extinction" (Bulte et al., 2003; Mason et al., 2012).

4.3.4. Production costs

Both polished and carved ivory require work by a craftsman. Martin and Stiles (2003) cite the salary of an experienced craftsman in Tokyo in 2001 to reach $38,400 per year, while an average-earning craftsman in working part time in Hong Kong earned an average $18,000 per year in 2002. These labor costs must be accounted for in the market price of any worked ivory, explaining price discrepancies between raw and worked pieces. However, little other data exists as to ivory craftsman salaries, making it impossible to include in the price analysis. The dummy variable in our model accounts for this difference to some degree (i.e. linearly).

4.3.5. Quality

Quality of ivory, which generally refers to colour and presence of visible cracks, has not been systematically quantified. However, various price citations note differences between low and high quality ivory. In Thailand, for example, high quality ivory was reported to attract as much as double the standard price, or $182 rather than $91 per kilogram (Martin and Stiles, 2002). Differences based on quality were also noted in Cambodia, where prices ranged from $100 to $340 per kilogram around 1994. In 2001, Vietnamese prices fluctuated by approximately $170 per kilogram due solely to quality. Thus, quality could contribute to variations in price for similar types of ivory.

4.3.6. Significant events

Various events since the 1989 ban could have impacted market price. These include two one-off ivory sales, the adoption of the Cotonou Declaration, as well as various major ivory seizures and destructions. In 1999, CITES approved the first one-off ivory sale of Botswanan, Namibian, and Zimbabwean stockpiles to a designated trading partner in Japan (USFWS, 2013). The second one-off sale occurred in 2008 of Botswanan, Namibian, Zimbabwean, and South African stockpiles to China and Japan. These sales added approximately $5 million and $15.5 million worth of ivory into the market, respectively, which likely affected global supply and demand dynamics (USFWS, 2013; Hsiang and Sekar, 2016).

The second one-off sale was followed by the adoption of the Cotonou Declaration by 22 African elephant range states in 2015. The declaration called for a closure of all domestic ivory markets in an effort to end the trade and conserve elephants (WCS, 2016). African market prices are much below the world average and those of other regions (Fig. 2), however, as this declaration was adopted in 2015, the discrepancy is likely due to other factors, such as minimal of shipping costs within Africa as opposed to abroad, and lower labor costs.

This second one-off sale corresponded with the 2007 inflection point applied to display the trends in ivory market prices. The use of 2008, the year of the sale, as the inflection point made little difference to the fit of the lines. The data inflection point also corresponded with the Global Financial Crisis of 2007–2008 (Wittemyer et al., 2014; 't Sas-Rolfes et al., 2014; Stiles et al., 2015).

Since 1989, over 20 countries have crushed and burned > 260 tons of ivory, the majority having been destroyed in the last 5 years (Biggs, 2016; Braczkowski et al., 2018). Not only a symbol of ivory devaluation (Nuwer, 2013; Coghlan, 2015), these destructions remove ivory from potential re-entry into the market, and therefore may affect supply and demand. It is difficult to estimate how much ivory is being crushed or burned from global stockpiles due to the secrecy surrounding government inventory. Based on ETIS global seizure data submitted by participating governments and reports of global ivory destruction retrieved via literature and Google searches for news articles, we estimate that approximately 40% of all ivory seized between 1991 and 2016 has been destroyed. A graph of these destructions by country is available in Appendix D.

't Sas-Rolfes (1997) argued that destroying ivory stockpiles reduces

the potential legal supply relative to demand, thereby increasing the perceived market value of ivory. This could inflate market prices and make trade more lucrative. Ivory destruction was not included in the model due to the inclusion of TI, which accounts for ETIS seizure data, and therefore government holdings. Our supplementary destruction dataset includes records on the total amount of ivory destroyed within a calendar year for nine separate years, the first being 1998. A follow-up two-tailed test for bivariate correlation between the total amount of ivory crushed or burned globally and the price of ivory (LnPrice) was not significant ($r = 0.430$, $p = 0.288$). However, given the small sample size and the magnitude of the correlation, we cannot rule out the possibility that a significant positive relationship would become apparent with a larger sample size.

4.3.7. Other determinants

There are two other potential variables that could not be tested due to data restrictions or redundancy that might account for price discrepancies and/or the unaccounted remaining 27.5% of variation. The first is changes in the trade chain over time, for instance by increased militarization (Duffy et al., 2019) or integration into terrorist or narcotics networks (Wyler and Sheikh, 2008; ADMCF, 2018); the second is natural fluctuations in elephant population ecology which could alter the perceived value of ivory or potentially increase the challenge of poaching (Courchamp et al., 2006; Holden and McDonald-Madden, 2017). Of the two, the latter issue can potentially be addressed by means of bioeconomic modeling using the present data, as discussed in the concluding section.

4.4. Analytical limitations

One of the most cited limitations of studying the ivory trade is data deficiency. The illegal ivory trade and related poaching activity are by nature cryptic. Many researchers have found it difficult to gather data on issues related to the ivory trade and hence study global ivory prices of ivory over time ('t Sas-Rolfes et al., 2014; Wittemyer et al., 2014; Stiles et al., 2015). In the present study, this limitation was partially overcome by incorporating both novel market surveys data from Martin and Stiles, as well as originally collected data into a meta-analysis.

Another potential issue is systematic biases, whereby both ETIS (Elephant Trade Information System) and PIKE (Proportion of Illegally Killed Elephants) datasets are underestimated in some areas as warned by, and therefore may influence TI (Underwood et al., 2013). These biases arise primarily due to the varied but limited abilities of countries to make ivory seizures as well as report those seizures to the ETIS database (Underwood et al., 2013; CITES Secretariat 2016). There are, however, no better estimates of ivory seizures, elephant poaching, or transactions that are currently available.

5. Conclusion

Ivory price data included in this analysis starts in 1989, the time of the CITES ban and reach 2017. Globally, our analysis indicates that prices have been increasing since this ban. Researchers disagree, however, on the effect of the ban on elephant poaching. Some argue that it has reduced or reversed the decline in elephant populations by making international trade illegal and by increasing criminal risks for those partaking (Khanna and Harford, 1996; Lemieux and Clarke, 2009). Others argue that it has stimulated speculative stockpiling, potentially increasing the price of ivory and encouraging poaching activities to continue ('t Sas-Rolfes, 1997). We hope our exploratory analysis can provide some insights into this debate.

The present analysis has provided a global overview of ivory prices since the CITES trade ban, giving both geographic and temporal perspectives. The model depicted overall increasing price trends commencing at some point after 2000, with highest market values in Asia.

It is hoped that by elucidating these trends and the variables relevant to price determination, better decisions can be made with regards to global ivory policies. An understanding of regional price trends and associated demand, alongside a comprehension of which factors influence market price, can inform conservationists, law enforcement, and policy makers on where to focus efforts on ivory trade campaigns, wildlife conservation, and education. For example, focusing limited resources on efforts to more heavily regulate trade in East Asia, where ivory price and therefore demand likely is highest, could lead to decreased poaching incentives and a more secure future for elephants.

Finally, quantitative results from the present study have the potential to contribute to the bioeconomic modeling literature (Bulte and Van Kooten, 1999; Bulte and Swanson, 2003; van Kooten, 2008; Holden and McDonald-Madden, 2017) that examines optimal intervention mechanisms related to elephant population management. For example, existing models could be calibrated, tested and modified with the regional and temporal price trends identified in Section 3 to improve their accuracy and hence derive more effective policy design. This may add evidence to support decisions concerning the CITES ivory ban, national trade regulations, as well as to global stockpile management. A similar framework could also be applied to other endangered species experiencing poaching and illegal trade in their products, such as rhinos and tigers, so as to achieve more orchestrated conservation efforts for global wildlife.

Literature review samples (Appendix A), a graph of transaction index versus year (Appendix B), histogram of ivory sample weights (Appendix C), and a graph of ivory destruction by country from 1989 to 2016 (Appendix D) are available online. The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

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References

't Sas-Rolfes, M., Moyle, B., Stiles, D., 2014. The complex policy issue of elephant ivory stockpile management. Pachyderm 55, 62–77.

ADMCF, 2018. Trading in Extinction: The Dark Side of Hong Kong's Wildlife Trade. https://doi.org/10.13140/RG.2.2.27577.01124.

Bennett, E.L., 2015. Legal ivory trade in a corrupt world and its impact on African elephant populations. Conserv. Biol. 29, 54–60. https://doi.org/10.1111/cobi.12377.

Biggs, D., 2016. Track the impact of Kenya's ivory burn Kenya's. Nature 534, 179. https://doi.org/10.1038/534179a.

Braczkowski, A., Holden, M., O'Bryan, C., Choi, C., Gan, X., Beesley, N., Gao, Y., Allan, J., Tyrrell, P., Stiles, D., Brehony, P., Meney, R., Brink, H., Takashina, N., Lin, M., Lin, H., Salamo, I.I.I.S., Watson, J., Kahumbu, P., Maron, M., Possingham, H., Biggs, D., 2018. Reach and messages of the world's largest ivory burn. Conserv. Biol. 32, 765–773. https://doi.org/10.1111/cobi.13097.

Bulte, E., Swanson, T., 2003. Economic incentives and wildlife conservation. CITES Workshop on Economic Incentives and Trade Policy Geneva Switzerland 47 (2), 1–37.

Bulte, E., Van Kooten, G., 1999. Economic efficiency, resource conservation and the ivory trade ban. Ecol. Econ. 28, 171–181. https://doi.org/10.1016/S0921-8009(98)00048-2.

Bulte, E., Mason, C., Horan, R., 2003. Betting on extinction: endangered species and speculation. Land Econ. 79 (4), 460–471. https://doi.org/10.2307/3147293.

Chase, M.J., Schlossberg, S., Griffin, C.R., Bouché, P.J.C., Djene, S.W., Elkan, P.W., Ferreira, S., Grossman, F., Kohi, E.M., Landen, K., Omondi, P., 2016. Continent-wide survey reveals massive decline in African savannah elephants. PeerJ 4, e2354. https://doi.org/10.7717/peerj.2354.

CITES Secretariat, 2016b. Report on the elephant trade information system (ETIS). Available from. https://cites.org/sites/default/files/eng/cop/17/WorkingDocs/E-CoP17-57-06-R1.pdf, Accessed date: January 2019.

Coghlan, A., 2015. Crushing ivory stockpiles destroys vital evidence of poaching. Science 349 (6243), 84–87. https://doi.org/10.1126/science.aaa2457.

Courchamp, F., Angulo, E., Rivalan, P., Hall, R., Signoret, L., Bull, L., Meinard, Y., 2006. Rarity value and species extinction: the Antrhopogenic Allee effect. PLoS Biol. 4 (12), e415. https://doi.org/10.1371/journal.pbio.0040415.

Duffy, R., Massé, F., Smidt, E., Marijnen, E., Büscher, B., Verweijen, J., Ramutsindela, M., Simlai, T., Joanny, L., Lunstrum, E., 2019. Why we must question the militarisation of conservation. Biol. Conserv. 232, 66–73. https://doi.org/10.1016/j.biocon.2019.01.

013.
Gao, Y., Clark, S.G., 2014. Elephant ivory trade in China: trends and drivers. Biol. Conserv. 180, 23–30. https://doi.org/10.1016/j.biocon.2014.09.020.
Gold price, 2018. URL. https://goldprice.org/live-gold-price.html, Accessed date: January 2019.
Halpern, J., 1997. The transaction index: a method for standardizing comparisons of transaction characteristics across different contexts. Group Decis. Negot. 6 (6), 557–572. https://doi.org/10.1023/A:1008640426690.
Holden, M., McDonald-Madden, E., 2017. High prices for rare species can drive large populations extinct: the anthropogenic allee effect revisited. J. Theor. Biol. 429, 170–180. https://doi.org/10.1016/j.jtbi.2017.06.019.
Holden, M., Biggs, D., Brink, H., Bal, P., Rhodes, J., McDonald-Madden, E., 2018. Increase anti-poaching law-enforcement or reduce demand for wildlife products? A framework to guide strategic conservation investments. Conserv. Lett. 12 (3), e12618.
Hsiang, S., Sekar, N., 2016. Does legalization reduce black market activity? Evidence from a global ivory experiment and elephant poaching data. In: National Bureau of Economic Research (NBER) Working Paper Series, pp. 22314.
Khanna, J., Harford, J., 1996. The ivory trade ban: is it effective? Ecol. Econ. 19, 147–155. https://doi.org/10.1016/0921-8009(96)00043-2.
Knapp, E., 2012. Why poaching pays: a summary of risks and benefits illegal hunters face in Western Serengeti, Tanzania. Tropical Conservation Science 5, 434–445. https://doi.org/10.1177/194008291200500403.
van Kooten, G., 2008. Protecting the African elephant: a dynamic bioeconomic model of ivory trade. Biol. Conserv. 141 (8), 2012–2022. https://doi.org/10.1016/j.biocon.2008.05.016.
Lemieux, A.M., Clarke, R.V., 2009. The international ban on ivory sales and its effects on elephant poaching in Africa. Br. J. Criminol. 49, 451–471. https://doi.org/10.1093/bjc/azp030.
Macrotrends, n.d. Macrotrends LLC. URL Macrotrends.net (accessed January 2019).
Martin, E., Stiles, D., 2000. The Ivory Markets of Africa. West Sussex, United Kingdom and Nairobi, Kenya. https://savetheelephants.org/wp-content/uploads/2016/11/2000IvoryMarketsAfrica.pdf.
Martin, E., Stiles, D., 2002. The South and South East Asian ivory markets. West Sussex, United Kingdom and Nairobi, Kenya. Available from. https://savetheelephants.org/wp-content/uploads/2016/11/2002SouthSEAsia.pdf, Accessed date: January 2019.
Martin, E., Stiles, D., 2003. The ivory markets of East Asia. West Sussex, United Kingdom and Nairobi, Kenya. Available from. https://www.traffic.org/site/assets/files/4194/ivory_markets_of_east_asia.pdf, Accessed date: January 2019.
Martin, E., Stiles, D., 2005. Ivory markets of Europe. West Sussex, United Kingdom and Nairobi, Kenya. Available from. https://savetheelephants.org/wp-content/uploads/2016/11/2005MarketsofEurope.pdf, Accessed date: January 2019.
Mason, C., Bulte, E., Horan, R., 2012. Banking on extinction: endangered species and speculation. Oxf. Rev. Econ. Policy 28 (1), 180–192. https://doi.org/10.1093/oxrep/grs006.
Milliken, T., Burn, R.W., Underwood, F.M., Sangalakula, L., 2013. Monitoring of illegal trade in ivory and other elephant specimens. Doha, Qatar. Available from. https://www.cites.org/sites/default/files/eng/cop/15/doc/E15-44-01.pdf (accessed January 2019).
Milner-Gulland, E.J., 1993. An econometric analysis of consumer demand for ivory and rhino horn. Environ. Resour. Econ. 3, 73–95. https://doi.org/10.1007/BF00338321.
Milner-Gulland, E., Leader-Williams, N., 1992. A model of incentives for the illegal exploitation of black rhinos and elephants: poaching pays in Luangwa Valley, Zambia. J. Appl. Ecol. 29, 388–401. https://doi.org/10.2307/2404508.
Moyle, B., 2014. The raw and the carved: shipping costs and ivory smuggling. Ecol. Econ. 107, 259–265. https://doi.org/10.1016/j.ecolecon.2014.09.001.
Moyle, B., Conrad, K., 2014. Dirty Laundry: Are Chinese Legal Ivory Factories Using Poached Ivory as an Input? https://doi.org/10.2139/ssrn.2516504.
Nuwer, R., 2013. We're crushing tonnes of ivory to discourage poachers. New Scientist 2–4.
Petrossian, G.A., Pires, S.F., van Uhm, D.P., 2016. An overview of illegal wildlife entering the United States. Global Crime 17 (2), 181–201. https://doi.org/10.1080/17440572.2016.1152548.
R Core Team, 2018. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria Available from. https://www.R-project.org/, Accessed date: January 2019.
't Sas-Rolfes, M., 1997. Elephants, Rhinos, and the Economics of the Illegal Trade. Pachyderm. pp. 23–29.
CITES Secretariat, 2016a. Addendum to the Report on the Elephant Trade Information System (ETIS). Available from. https://cites.org/sites/default/files/eng/cop/17/WorkingDocs/E-CoP17-57-06-R1-Add.pdf, Accessed date: January 2019.
Stiles, D., Martin, R., Moyle, B., 2015. Analysis of Ivory Demand Drivers. Available from. http://danstiles.org/publications/ivory/43.Analysis%20of%20Demand.pdf (accessed January 2019).
TRAFFIC, n.d. Wildlife Trade: What Is It?. URL http://www.traffic.org/trade/(accessed January 2019).
Underwood, F.M., Burn, R.W., Milliken, T., 2013. Dissecting the illegal ivory trade: an analysis of ivory seizures data. PLoS One 8. https://doi.org/10.1371/journal.pone.0076539.
UNODC, 2016. World Wildlife Crime Report: Trafficking in Protected Species. Retrieved from UNODC Research website. https://www.unodc.org/documents/data-and-analysis/wildlife/World_Wildlife_Crime_Report_2016_final.pdf.
USFWS, 2013. CITES & Elephants. Available from. https://www.fws.gov/le/pdf/CITES-and-Elephant-Conservation.pdf, Accessed date: January 2019.
Vigne, L., Martin, E., 2016. Vietnam's Illegal Ivory Trade Threatens Africa's Elephants. Save The Elephants. Availble from. https://savetheelephants.org/wp-content/uploads/2016/07/2016_VietnamReportFINAL_0.pdf.
WCS, 2016. CITES CoP17 delegates adopt resolution recommending closure of domestic elephant ivory markets globally. Natl. Geogr. A Voice Elephants. http://voices.nationalgeographic.com/2016/10/02/cites-cop17-delegates-adopt-resolution-recommending-closure-of-domestic-elephant-ivory-markets-globally/.
Wittemyer, G., Northrup, J.M., Blanc, J., Douglas-Hamilton, I., Omondi, P., Burnham, K.P., 2014. Illegal killing for ivory drives global decline in African elephants. PNAS 111, 13117–13121. https://doi.org/10.1073/pnas.1403984111.
Wyler, L., Sheikh, P., 2008. International illegal trade in wildlife: threats and US policy. Congressional Research Service 45.