

A systematic survey of the online trade in elephant ivory in Singapore before and after a domestic trade ban

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Abstract The illegal online trade in wildlife has increased significantly over the last 2 decades. Applying a systematic survey approach, we examined the online trade in elephant ivory before and after the implementation of a domestic trade ban in Singapore, to understand the forms of elephant ivory offered for sale, the e-commerce sites used and the effect of the domestic trade ban. Using elephant ivory and look-alikes in form, shape and colour as proxies for elephant ivory, we found that most of the online listings consisted of bird cages and related accessories such as bird feeding cups and ornaments used to adorn them. After the domestic trade ban in elephant ivory was implemented on 1 September 2021, a 76% drop in total listings was observed. Causal impact analysis indicated a strong causal effect of the domestic trade ban, resulting in an 83% drop in the mean number of new listings found weekly relative to the predicted counterfactual market response based on a Bayesian structural time-series model in the absence of the ban. E-commerce sites play an important role in combatting illegal wildlife trade online by removing flagged listings and sending notifications to raise awareness of the ban. We found textual descriptions of products to be more effective for preliminary differentiation of legal and potentially illegal listings compared to the detection of Schreger lines in images, although this remains a significant challenge for law enforcement. Our findings can inform future efforts to develop automated detection methods for elephant ivory in online markets.

Keywords CITES, domestic trade ban, elephant ivory, enforcement, illegal wildlife trade, internet, Southeast Asia, systematic survey

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Introduction

The illegal wildlife trade is a significant threat to biodiversity conservation (Rosen & Smith, 2010; Baker et al., 2013). The value of this criminal market is estimated to be USD 4–23 billion annually (t Sas-Rolfes et al., 2019). Although illegal wildlife trade remains prevalent in physical markets worldwide, the internet age has brought about a rapid increase in the quantity and diversity of wildlife being traded in the last 2 decades, connecting traders and buyers in unprecedented ways (Zhang et al., 2008; Lavorgna, 2014; Sung & Fong, 2018). The online illegal trade in wildlife first drew global attention after a report was published by the International Fund for Animal Welfare (IFAW) in 2005 (IFAW, 2005, cited in Izzo, 2010). Over 9,000 listings of legally protected live wild animals and derived products were reportedly offered for sale in just 1 week of investigation on English-language websites. Since then, there have been increasing calls for improved monitoring and regulation of illegal online wildlife trade (Sajeva et al., 2013; Hinsley et al., 2016; Martin et al., 2018; Morgan & Chng, 2018) and for conservation assessments such as the IUCN Red List to recognize and account for the internet as a new venue for wildlife exploitation (Jensen et al., 2019).

The monitoring of the illegal online wildlife trade has its own set of challenges compared to monitoring traditional markets. Firstly, there is a large volume of legal wildlife trade online that obscures the illegal trade (Hernandez-Castro & Roberts, 2015). Secondly, there is a considerable and ever-expanding set of multi-language code words, slang terms and misleading names to refer to the diverse wildlife species advertised for sale, disguising the identity of the species and products traded (Sharma et al., 2019; Xu et al., 2019; Alfino & Roberts, 2020). Associated terms could also be generic (e.g. the term ‘ivory’ refers not only to elephant ivory, but broadly to any material from teeth, horn or bone, as well as to an off-white colour; Hernandez-Castro & Roberts, 2015). Thirdly, even with automatic detection enabled by artificial intelligence, any online advertisements identified with the help of such tools still require manual verification (Xu et al., 2019). An advertisement may not reflect actual transactions or may be fraudulent or scam-related (Lavorgna, 2014; Vaglica et al., 2017; IFAW, 2018; Martin et al., 2018). This is a key

challenge facing the regulation of illegal wildlife trade online, where illegality is not self-evident and the point at which an online advertisement flouts the law differs between territorial jurisdictions according to their respective legislations (Wingard & Pascual, 2018; Xu et al., 2019).

Of the many different wildlife taxa illegally advertised for sale online, the trade in elephant ivory has been most studied. Research aimed at understanding the characteristics or improving the monitoring of online ivory trade has focused on Europe and on individual trading sites such as eBay (Hernandez-Castro & Roberts, 2015; Yeo et al., 2017; Alfino & Roberts, 2020; Venturini & Roberts, 2020) or social media platforms such as Twitter (Di Minin et al., 2019; Xu et al., 2019) or Facebook (Xu et al., 2020). Beyond the surface web, illegal wildlife trade has been found to be present (although at a relatively low level) on the dark web (Harrison et al., 2016; Roberts & Hernandez-Castro, 2017; Stringham et al., 2023). Although the existing literature has singled out eBay as a significant online marketplace for elephant ivory in the UK and the European Union (Hernandez-Castro & Roberts, 2015; Yeo et al., 2017; Alfino & Roberts, 2020; Venturini & Roberts, 2020), little information exists regarding elephant ivory in online marketplaces outside Europe, with the exception of some grey literature (Yu & Jia, 2015; Yu, 2018). In a region such as Southeast Asia, where wildlife trade has long been implicated as one of the main factors affecting biodiversity (Sodhi et al., 2004) and where trade is shifting towards online marketplaces (Siriwat & Nijman, 2020; Fink et al., 2021), there is an urgent need to better understand the online trade in elephant ivory.

CITES Parties, including Singapore, have banned the international commercial trade in all forms of elephant ivory products since 1990. Domestic trade, however, remains unregulated in many countries. At the 17th Conference of the Parties in October 2016, a resolution was passed to phase out domestic ivory markets, which can contribute to poaching and illegal trade. In Singapore, based on surveys of physical marketplaces, the domestic ivory market has been described as residual (Webber et al., 2013), being small relative to elsewhere in the region, and ivory craftsmen have been absent from Singapore since the early 1990s (Stiles & Martin, 2002). Nevertheless, the authorities in Singapore launched a public consultation exercise on a proposed ban on the domestic trade in elephant ivory in 2018 (Government of Singapore, 2018). Consequently, in August 2019, Singapore announced its plan to implement a ban on the domestic trade in elephant ivory 2 years later, to go into effect on 1 September 2021 (Menon, 2019). The ban would mean that the sale of elephant ivory and ivory products and the public display of elephant ivory and ivory products for the purpose of sale in Singapore would be prohibited.

In Singapore, the Endangered Species (Import and Export) Act (Cap 92A, 2020 Rev Ed) is the national

legislation giving effect to CITES. Under the Endangered Species (Import and Export) (Prohibition of Sale) Notification, it is illegal to 'sell, offer or expose for sale or display to the public the readily recognisable parts and derivations' of elephants. This includes claims of elephant origins in scam advertisements. In the lead-up to the effective date of the domestic trade ban, the government engaged with key stakeholders to brief them on the upcoming change in legislation. This included visits to the few remaining physical ivory retailers and an online workshop with e-commerce platforms conducted jointly with WWF-Singapore. Our aim was to examine the effect of this policy intervention on the domestic online trade in elephant ivory in Singapore.

We applied a previously described systematic survey approach (Roberts et al., 2021), which follows the well-established systematic evidence review approach (Higgins & Green, 2011), to survey the online trade in elephant ivory on e-commerce sites in Singapore both before and after the ban on domestic trade in elephant ivory was implemented on 1 September 2021. Although e-commerce platforms can be international, we only considered domestic advertisements. A diagnostic morphological feature in elephant and mammoth ivory is the presence of Schreger lines (Baker et al., 2020). As online assessments could not allow for accurate determination of whether a possible elephant ivory item was actually made of elephant ivory, we used listings that looked potentially like elephant ivory in form, shape and colour, with or without Schreger lines, as a proxy for elephant ivory. The objectives were: (1) to determine the forms of elephant ivory offered for sale and the e-commerce sites that sell these in Singapore on the surface web, (2) to compare the differences before and after the domestic trade ban to evaluate its effect, and (3) to distil insights to inform the monitoring of the online domestic trade in elephant ivory that was made illegal after the implementation of the domestic trade ban.

Methods

Online search strategy

Applying a systematic survey approach as described in Roberts et al. (2021), we considered the following nine parameters when developing the search strategy: (1) Product origin: we did not specify in our search whether advertised products were of wild or farmed origin as CITES rules cover both. (2) Geographical origin: we did not specify a geographical origin for the elephant ivory. (3) Survey period: we conducted the survey for 6 months, during June–November 2021, comprising 3 months prior to and after 1 September 2021, the effective start date of the ban on domestic trade in elephant ivory. (4) Trade behaviour: we only considered sellers advertising products for sale and not

potential buyers with adverts regarding items they were seeking to purchase. (5) Population: we did not specify any species or subspecies during the search. (6) Product type: we searched for both raw and worked elephant ivory in a range of products including jewellery, musical instruments and bird cages. (7) Trade platform: during a preliminary survey, we used general search engines but these did not return relevant results and were thus not used for the main survey. Instead, we targeted 10 common e-commerce sites including classifieds, where individuals or companies post advertisements on products they wish to trade. The 10 sites were Adpost, Carousell, Chutku Singapore, eBay Singapore, Facebook Marketplace, Gumtree, Lazada, Locanto, Qoo10 and Shopee (Supplementary Table 1). (8) Country of trade: we were only interested in trade within Singapore. Where applicable, we thus set the location in search filters to Singapore. (9) Origin of trade: we were only interested in trade originating from Singapore. Where applicable, we thus set the shipping source location in search filters to Singapore/Domestic. Supplementary Table 1 details the search criteria and settings used for each platform.

We obtained an initial set of search terms from consultation with David L. Roberts and law enforcement officers in Singapore. Using these terms, we conducted two preliminary searches on Carousell, a popular peer-to-peer e-commerce site in Singapore, as a means of snowball sampling for further possible search terms. We then removed redundant terms, resulting in a set of 21 search terms in English, Simplified Chinese and Malay related to elephant ivory and trade. We conducted a detailed preliminary search on all 21 search terms on all 10 target sites to identify the search terms that resulted in the greatest number and highest percentage of positive hits for elephant ivory and its lookalikes in form, shape and colour (i.e. possible elephant ivory listings). We found that 98% of possible elephant ivory listings were generated by using 14 of the 21 search terms. Out of these 14 search terms, we removed two that generated obvious duplicates with other terms, resulting in a final set of 12 search terms used in this study.

We entered all 12 search terms manually on each target site using the Google Chrome web browser in incognito mode. We analysed all search results if the total number was $\leq 1,000$. Where $> 1,000$ search results were returned or if the total number of results was not shown (applicable to Carousell and Facebook Marketplace), we analysed the first 500 search results. We repeated these searches weekly every Friday during the 6-month study period.

Because it is impossible during an online search to accurately assess whether an item is made of genuine elephant ivory, we included all search results that looked potentially like elephant ivory in form, shape and colour, with or without Schreger lines, for data capture. We used this as a proxy for elephant ivory.

Data capture and cleaning

Data capture combined manual and automated approaches designed to simultaneously collect and clean data (Stringham et al., 2021). We designed custom web scrapers programmed to extract the relevant information from the list of URL addresses captured in the search results. This included the item title, price, description, seller username and any images in the listing. We manually categorized items according to item type and the presence of Schreger lines. Supplementary Table 2 summarizes all of the data variables captured.

In addition, for listings captured during the 13 weeks after the trade ban came into effect, we assessed the titles and descriptions of listings to categorize how each item was described in text. We categorized listings as: (1) explicitly ivory: if 'elephant ivory', 'ivory', the elephant emoji or equivalent was explicitly specified in the listing, (2) implied ivory: if terms such as 'real', 'authentic', 'genuine' or equivalent in the listing implied the product was made of genuine elephant ivory, (3) not ivory: if a non-ivory material was explicitly specified in the listing (e.g. 'cow bone', 'ox bone', 'mammoth', 'resin', 'ivory nut', 'fake ivory', 'not ivory', etc.), (4) neutral: if there was no mention of material in the listing.

When cleaning up the data, we removed all URL tags to prevent query parameters from interfering with the removal of duplicates. When data on the age of the listings were available, we translated these to the date when the listing was posted, for consistency across the data captured. We removed duplicates based on five parameters: trade platform, user name of the seller, advert title, item price and website URL. We separately consolidated and removed duplicates for pre-ban and post-ban listings across 13 weeks each, to obtain unique listings across the pre-ban and post-ban periods. We conducted these data cleaning steps in *Microsoft Excel* (Microsoft Corporation, Redmont, USA).

Data analysis

We used causal impact analysis (Brodersen et al., 2015) to estimate the causal effect of the domestic trade ban on the number of online listings found. This involved the construction of a Bayesian structural time-series model predicting the counterfactual market response that would have occurred if the domestic trade ban had not been implemented (Brodersen et al., 2015). We used Google Trends (Google, 2021) of the same set of 12 search terms in Malaysia and Indonesia, two neighbouring countries in which domestic trade in elephant ivory was unregulated, as covariates in this model. Not all search terms were available in Google Trends for each country, resulting in 13 available covariates. We assumed that the same search terms were used in these two neighbouring countries to look for

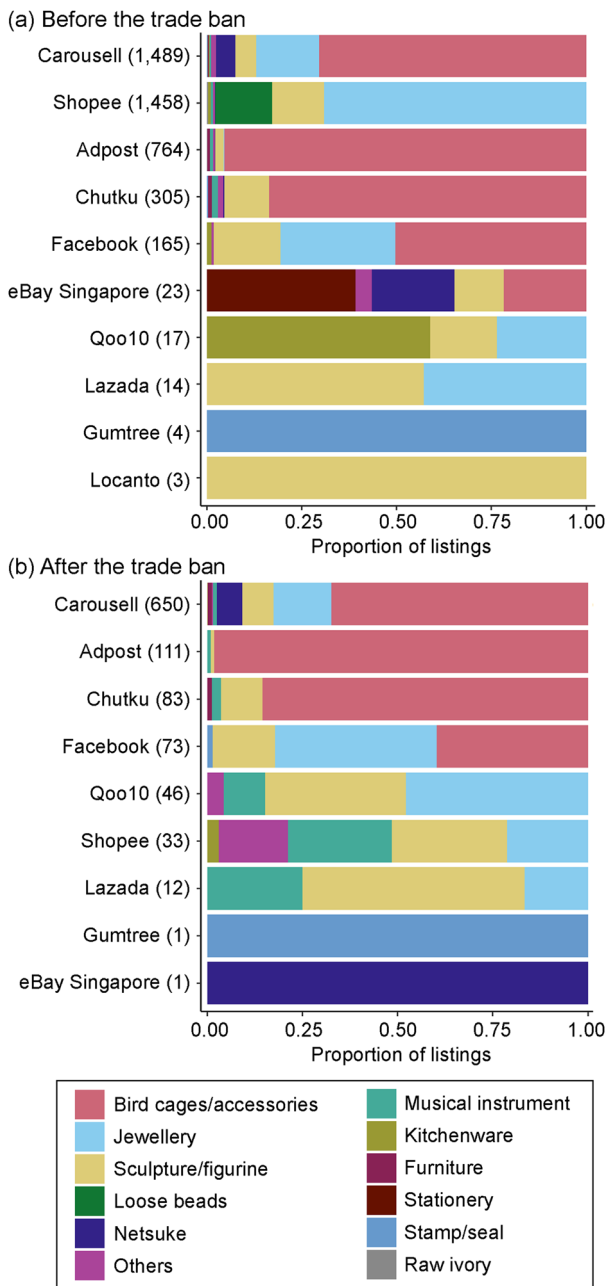


FIG. 1 Characteristics of possible elephant ivory listings found online in Singapore (a) before and (b) after the implementation of the ban on domestic trade in elephant ivory. (a) Before the ban, bird cages and related accessories were the most commonly listed items (50%, $n = 2,121$), followed by jewellery (31%, $n = 1,315$) and sculptures/figurines (9%, $n = 382$). Carousell, Shopee and Adpost accounted for 87% of the total listings. (b) After the ban, most platforms saw a decrease in the number of listings found, although the top three most common item types remained the same: bird cages and related accessories (64%, $n = 647$), jewellery (16%, $n = 161$) and sculptures/figurines (11%, $n = 109$). The numbers in parentheses give the total number of listings found on each platform. (Readers of the printed journal are referred to the online article for a colour version of this figure.)

elephant ivory and hence that the Google Trends should correlate with online ivory trade activity but would not be affected by the domestic trade ban implemented in Singapore. We then compared the actual market trend against the predicted counterfactual to determine the impact of the domestic trade ban. We used the package *CausalImpact* 1.2.7 (Brodersen et al., 2015) in R 4.1.1 (R Core Team, 2021) for this analysis.

Results

Pre-ban: baseline data before the implementation of the domestic trade ban

During the 13 weeks before the domestic trade ban was implemented on 1 September 2021, we found 4,242 unique online listings of elephant ivory and lookalikes in form, shape and colour. We found a weekly mean of 326 new listings. Most listings (90% of the total; $n = 3,797$) had no visible Schreger lines, whereas 10% ($n = 445$) potentially had Schreger lines. The top three most common item types accounted for 90% of all listings found. The most common item type was bird cages or related accessories, comprising 50% of listings ($n = 2,121$), followed by jewellery (31%; $n = 1,315$) and sculptures/figurines (9%; $n = 382$).

In terms of market platform, the top three sites accounted for 87% of all listings found. Carousell and Shopee were the two most prominent sites, accounting for 35% ($n = 1,489$) and 34% ($n = 1,458$) of listings, respectively, followed by Adpost (18%; $n = 764$). The eBay site accounted for only 1% ($n = 23$) of listings. Although the item type listed most frequently on the most prominent websites was bird cages or related accessories, on Shopee, jewellery was the most common item type (Fig. 1a).

Post-ban: after the implementation of the domestic trade ban

After Singapore implemented the ban on domestic trade in elephant ivory on 1 September 2021, we found 1,010 unique online listings of elephant ivory and lookalikes in form, shape and colour, a 76% drop compared to the pre-ban period ($n = 4,242$). We found a weekly mean of 49 new listings. The causal impact analysis predicted this figure to be 286 in the absence of the ban, meaning the effect of the ban was estimated as a decrease of 238 new listings weekly (95% credible interval (CrI): 203–276). In the absence of the ban, the predicted total (cumulative) number of new listings across the post-ban study period would have been 3,723 (95% CrI: 3,283–4,427). However, the actual total number of new listings found was 631, representing an 83% decrease from the predicted value. The ban thus resulted in a substantial drop in

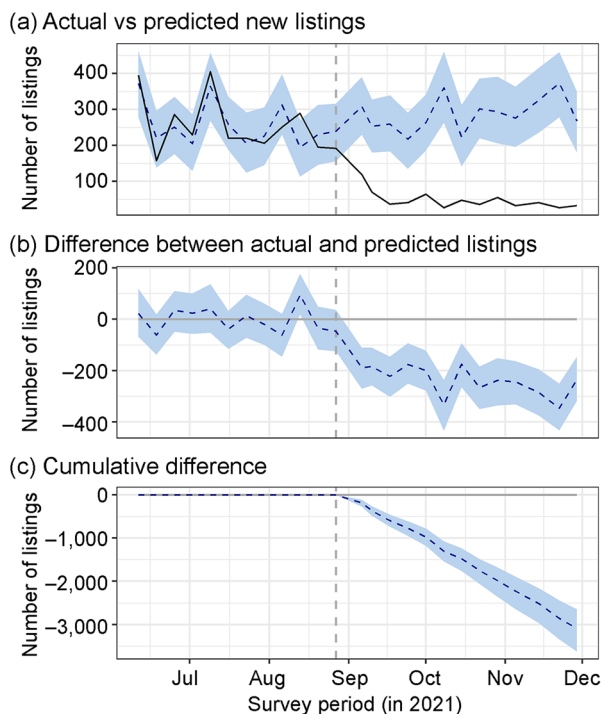


FIG. 2 Impact of the domestic trade ban on online listings of possible elephant ivory products in Singapore. Vertical dashed lines demarcate the effective date of the ban on 1 September 2021. (a) Actual (solid line) vs predicted (dashed line) number of new listings found per week. (b) Difference between the actual and predicted number of listings found per week (a value of zero indicates that the actual number of listings was the same as the predicted number; negative values indicate that fewer listings were found than predicted). (c) Cumulative difference between the actual and predicted number of listings post-ban (a value of zero indicates that the actual number of listings was the same as the predicted number; negative values indicate that fewer listings were found than predicted). The shaded areas represent the 95% credible intervals in all graphs.

the mean number of weekly new listings compared to the expected figure (estimated tail-area probability = 0.001; i.e. there is a 0.1% chance that in the absence of the ban there would have been a negative effect at least as large as that observed; Fig. 2).

The vast majority (98%; $n = 990$) of the post-ban listings had no visible Schreger lines; only 2% ($n = 20$) potentially had Schreger lines. During the post-ban period, 12% ($n = 119$) of listings were described explicitly as elephant ivory, 7% ($n = 72$) were implied to be elephant ivory, 33% ($n = 337$) were described explicitly as not being ivory or as being made of a different material, and 48% ($n = 482$) of listings did not indicate the material (Fig. 3). Of the 191 listings described as elephant ivory explicitly or implicitly, 97% ($n = 186$) provided no images or provided images with no observable Schreger lines.

The pre-ban top three most common item types accounted for 91% of all possible elephant ivory listings found post-ban (Fig. 1b): bird cages or related accessories (64%;

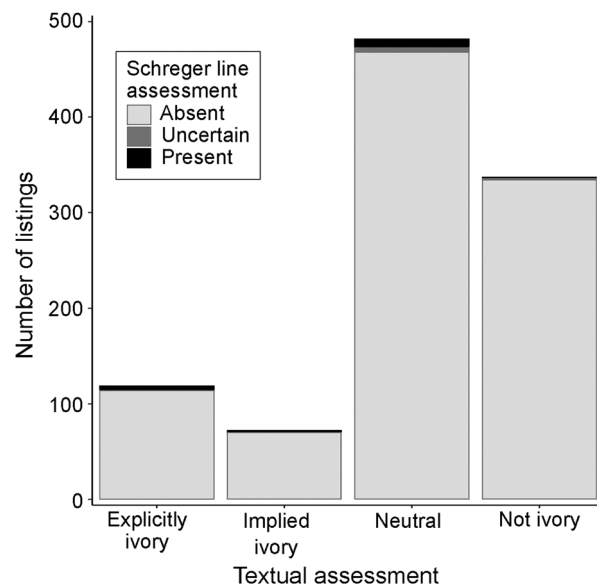


FIG. 3 Of the 1,010 unique elephant ivory and lookalike listings found after the implementation of the domestic trade ban in elephant ivory in Singapore, only 2% ($n = 20$) contained images with potential Schreger lines. We found textual assessment to be a stronger differentiating factor, with 12% ($n = 119$) of listings explicitly mentioning elephant ivory and 7% ($n = 72$) implying items to be made of elephant ivory.

$n = 647$), jewellery (16%; $n = 161$) and sculptures/figurines (11%; $n = 109$). Most platforms saw a decrease in the total number of listings of possible elephant ivory, with the sharpest drop observed on Shopee, from 1,458 listings found pre-ban to just 33 listings found post-ban. Qoo10 was the only site where the number of listings increased post-ban, but the total number remained small, with an increase from 17 to 46 listings.

Across the entire study period of 26 weeks, we found a total of 4,873 unique listings: 27% of these listings had been posted at least 1 year prior to our search and 35% of the listings did not contain details of when they were posted. Thirty-eight per cent had been posted in 2021 (i.e. in the year when we conducted the study, up to 5 months prior to our search).

Discussion

Characteristics of the online trade in elephant ivory in Singapore

Previous studies examining code word usage and the development of automated monitoring of elephant ivory trade on the surface web have focused on the UK or the European Union, and on eBay as a trade platform (Hernandez-Castro & Roberts, 2015; Alfino & Roberts, 2020; Venturini & Roberts, 2020). These previous studies looked specifically at the antiques section of eBay (Hernandez-Castro & Roberts, 2015; Alfino & Roberts, 2020) or used 'netsuke' (a miniature sculpture or small carved ornament) as a search

term on eBay (Venturini & Roberts, 2020). We found this search strategy to be less applicable in the context of Singapore, with eBay accounting for only 1% ($n = 23$) of pre-ban listings of possible elephant ivory across all sites surveyed, and the item type 'netsuke' accounting for only 2% ($n = 90$) of pre-ban listings. This suggests that the findings of these previous studies have limited applicability to the online markets of Singapore.

The online domestic trade in elephant ivory and lookalikes in Singapore consisted predominantly of bird cages and related accessories such as bird feeding cups and ornaments used to adorn bird cages. This indicated keepers of caged birds, especially those keeping songbirds, as an important stakeholder group contributing to the demand for, and online trade in, elephant ivory and its lookalikes, corroborating field observations and past enforcement cases involving the smuggling of ivory products (The Straits Times, 2017). It has been reported previously that the songbird keeper community in Singapore consists predominantly of male, middle-aged members who are likely to be of Chinese ethnicity (Chiok et al., 2022). Links between the ivory and songbird trades in Singapore should be further studied, and proposed conservation interventions aimed at a more sustainable trade in songbirds could concurrently aim to discourage demand for ivory in bird cage accessories.

We found Carousell to be the most important e-commerce site for ivory trade in Singapore, and recommend that authorities focus their engagement efforts on the e-commerce platforms with the largest market share. It is worth noting that Carousell is predominantly a peer-to-peer marketplace rather than a business-to-consumer marketplace, suggesting that it facilitates second-hand trade in bird cages and related accessories that could be of lesser conservation concern compared to new supplies of elephant ivory entering the domestic market. Our findings indicate the importance of recognizing that different regions may use different e-commerce sites and code words to trade elephant ivory, as customs related to the use and ownership of elephant ivory are dependent on the cultural context. Further research is required to develop tools for the automated detection of online trade in elephant ivory in Southeast Asia. In particular, it is necessary to gain further insights into the structure of the e-commerce market and the various forms of elephant ivory traded in the region, which differ from those in Europe and probably also vary across different Southeast Asian countries.

The impact of the domestic trade ban

The ban on the domestic trade in elephant ivory in Singapore caused a decline in the number of listings of possible elephant ivory products in the online marketplace in Singapore. The decline appears to be more pronounced

than in China, which saw a drop of 27% in the mean monthly number of new elephant ivory advertisements on e-commerce websites following the full implementation of its domestic trade ban in 2018 (Yu, 2018). However, the results of this previous study and our survey are not directly comparable because of differences in the methods used.

The implementation of the ban on domestic trade in elephant ivory in Singapore was well planned, which could explain the significant decrease in the number of listings observed in this study. It was first announced in August 2019, with an effective start date 2 years later on 1 September 2021. During the interim period, the authorities and NGOs such as WWF-Singapore proactively engaged with e-commerce sites to raise awareness of the upcoming change in legislation. When the domestic trade ban took effect on 1 September 2021, elephant ivory advertisements became prohibited. The authorities worked with owners of e-commerce sites to remove flagged listings found after 1 September 2021, and with selected site owners to tailor notifications to online sellers to increase awareness of the newly implemented ban. Keywords were also provided for feeding into the artificial intelligence-based systems of trading sites to block inappropriate posts. Over the 13-week post-ban survey period, many listings of elephant ivory and lookalikes were removed by the sites because of these active interventions. Further research is required to ascertain whether the online market activity will shift towards the dark web because of the increased monitoring and enforcement following the implementation of the ban (Harrison et al., 2016).

However, the majority of unique listings found overall (62%) were either posted at least 1 year prior to the study or contained no information on when they were posted. Only 38% of listings found were known to be posted in the study year (i.e. in 2021), suggesting that the turnover rate for elephant ivory and lookalike products in the online marketplace in Singapore was low even before the ban, which aligns with similar observations in the physical marketplace (Webber et al., 2013).

The systematic framework adopted here (Roberts et al., 2021) could be replicated for use with comparative data over a longer period of time and also across different geographical regions in future studies.

Textual assessments to differentiate between legal and illegal listings

To circumvent the challenges of accurately determining whether elephant ivory listed for sale online is authentic (Xu et al., 2019), which would include identifying potentially fraudulent or scam listings (Lavorgna, 2014; Vaglica et al., 2017; IFAW, 2018; Martin et al., 2018), we used listings of elephant ivory and lookalikes as a proxy to examine the online trade in elephant ivory in Singapore. This is useful for understanding the online trade in general and for

studying the effects of the trade ban. To be effective for law enforcement purposes, however, illegal listings need to be differentiated from the large volume of legal online trade (Hernandez-Castro & Roberts, 2015). In countries such as Singapore, where legislation is clear regarding explicit claims of elephant origins in scam advertisements, and where such claims are also an offence and punishable in the same manner as attempts to sell authentic elephant ivory, the detection of elephant ivory through the presence of Schreger lines and of listings with explicit claims of elephant origins can help authorities to prioritize listings for investigation.

In this study, however, we found it difficult to determine the presence of Schreger lines in listings because images were often absent, of poor quality or resolution, and/or provided only limited angles of perspective of the item pictured. Difficulties in observing Schreger lines in small, worked elephant ivory products are to be expected regardless of image quality. For the small proportion of the listings that showed visible lines that could potentially be Schreger lines (pre-ban: 10%, $n = 445$; post-ban: 2%, $n = 20$), we could not conclude that those with Schreger lines were elephant ivory based on assessment of the images alone. In addition, some of the post-ban listings with potential Schreger lines were physically examined by law enforcement officers, who found the items not to be of elephant origin.

After the ban on the domestic trade in elephant ivory was implemented, we found textual assessment to be a stronger differentiating factor between elephant ivory and lookalikes than the presence of Schreger lines, as 19% ($n = 191$) of post-ban listings mentioned elephant ivory explicitly or implicitly in the titles or item descriptions, but only 2% ($n = 20$) featured images with potential Schreger lines. Of the listings identified as potential elephant ivory products by textual assessment, 97% ($n = 186$) contained images without observable Schreger lines or had no images at all. These findings suggest that authorities should consider textual assessments along with examination of any images for the presence of Schreger lines when prioritizing listings for enforcement efforts, even if the textual descriptions are implicit. Further research, in partnership with law enforcement officers who are empowered to seize and inspect the products listed online, is needed. This also has implications for developing tools for the automated detection of elephant ivory in online listings for surveillance and enforcement purposes, suggesting that resources should be focused on natural language processing algorithms rather than image-based machine learning algorithms to detect Schreger lines.

The role of e-commerce sites in combatting illegal wildlife trade

Given the challenges involved in identifying and verifying elephant ivory products offered for sale online by state-

based, centralized regulatory systems (Wingard & Pascual, 2018; Xu et al., 2019), company policies targeting the illegal wildlife trade in online marketplaces could add a valuable market-based layer to regulatory processes, thereby facilitating effective interventions. We observed that policies of different e-commerce sites in Singapore vary regarding their definition of inappropriate content to be removed. For example, the listing of all animals and animal products is prohibited under the policies of some e-commerce sites. This would mean that elephant ivory lookalikes such as products made of cow or ox bone would be subject to content removal, as well as those made of real elephant ivory. However, other e-commerce sites stipulate that only items prohibited by law will be removed. This requires the e-commerce site to verify that a product listed is made of elephant ivory before the listing can be removed, which presents greater challenges for the implementation of a trade ban. To effectively regulate wildlife trade in the internet age, authorities and e-commerce sites will have to continuously review and update their policies as this trade evolves.

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Conflicts of interest All authors were under employment or internship with the National Parks Board during the duration of this study.

Ethical standards This research abided by the *Oryx* guidelines on ethical standards.

References

- ALFINO, S. & ROBERTS, D.L. (2020) Code word usage in the online ivory trade across four European Union Member States. *Oryx*, 54, 494–498.
- BAKER, S.E., CAIN, R., VAN KESTEREN, F., ZOMMERS, Z.A., D'CRUZE, N. & MACDONALD, D.W. (2013) Rough trade: animal welfare in the global wildlife trade. *BioScience*, 63, 928–938.
- BAKER, B., JACOBS, R., MANN, M., ESPINOZA, E. & GREIN, G. (2020) *Identification Guide for Ivory and Ivory Substitutes*, 4th edition (ed. C. Allan). World Wildlife Fund, Washington, DC, USA, and CITES Secretariat, Geneva, Switzerland.
- BRODERSEN, K.H., GALLUSSERY, F., KOEHLER, J., REMY, N. & SCOTT, S.L. (2015) Inferring causal impact using Bayesian structural time-series models. *Annals of Applied Statistics*, 9, 247–274.
- CHIOK, W.X., LEE, R.Y.Y., LEE, J.G.H. & JAIN, A. (2022) The dynamics of songbird ownership and community interconnectedness in Singapore. *Bird Conservation International*, 32, 573–589.

- DI MININ, E., FINK, C., HIIPPALA, T. & TENKANEN, H. (2019) A framework for investigating illegal wildlife trade on social media with machine learning. *Conservation Biology*, 33, 210–213.
- FINK, C., TOIVONEN, T., CORREIA, R.A. & DI MININ, E. (2021) Mapping the online songbird trade in Indonesia. *Applied Geography*, 134, 102505.
- GOOGLE (2021) *Google Trends*. Google, Mountain View, USA. trends.google.com/trends [accessed November 2021].
- GOVERNMENT OF SINGAPORE (2018) *Proposed Ban on Sales of Elephant Ivory and Ivory Products in Singapore*. reach.gov.sg/participate/public-consultation/agrifood-veterinary-authority-of-singapore/proposed-ban-on-sales-of-elephant-ivory-and-ivory-products-in-singapore [accessed 17 March 2023].
- HARRISON, J.R., ROBERTS, D.L. & HERNANDEZ-CASTRO, J. (2016) Assessing the extent and nature of wildlife trade on the dark web. *Conservation Biology*, 30, 900–904.
- HERNANDEZ-CASTRO, J. & ROBERTS, D.L. (2015) Automatic detection of potentially illegal online sales of elephant ivory via data mining. *PeerJ Computer Science*, 1, e10.
- HIGGINS, J.P.T. & GREEN, S. (eds) (2011) *Cochrane Handbook for Systematic Reviews of Interventions*, version 5.1.0 [updated March 2011]. The Cochrane Collaboration, London, UK.
- HINSLEY, A., LEE, T.E., HARRISON, J.R. & ROBERTS, D.L. (2016) Estimating the extent and structure of trade in horticultural orchids via social media. *Conservation Biology*, 30, 1038–1047.
- IFAW (2005) *Caught in the Web: Wildlife Trade on the Internet*. International Fund for Animal Welfare, London, UK. ifaw.org/uk/resources/wildlife-trade-on-internet [accessed June 2023].
- IFAW (2018) *Disrupt: Wildlife Cybercrime*. International Fund for Animal Welfare, London, UK. ifaw.org/international/resources/disrupt-wildlife-cybercrime [accessed June 2023].
- IZZO, J.B. (2010) PC pets for a price: combating online and traditional wildlife crime through international harmonization and authoritative policies. *William & Mary Environmental Law and Policy Review*, 34, 965–998.
- JENSEN, T.J., AULIYA, M., BURGESS, N.D., AUST, P.W., PERTOLDI, C. & STRAND, J. (2019) Exploring the international trade in African snakes not listed on CITES: highlighting the role of the internet and social media. *Biodiversity and Conservation*, 28, 1–19.
- LAVORGNA, A. (2014) Wildlife trafficking in the internet age. *Crime Science*, 3, 1–12.
- MARTIN, R.O., SENNI, C. & D'CRUZE, N.C. (2018) Trade in wild-sourced African grey parrots: insights via social media. *Global Ecology and Conservation*, 15, e00429.
- MENON, M. (2019) Singapore to ban domestic trade in elephant ivory from September 2021. *The Straits Times*, 12 August 2019. straitstimes.com/singapore/singapore-to-ban-domestic-trade-in-elephant-ivory-from-september-2021 [accessed June 2023].
- MORGAN, J. & CHNG, S. (2018) Rising internet-based trade in the Critically Endangered ploughshare tortoise *Astrochelys yniphora* in Indonesia highlights need for improved enforcement of CITES. *Oryx*, 52, 744–750.
- R CORE TEAM (2021) *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing, Vienna, Austria. [R-project.org](https://r-project.org) [accessed June 2023].
- ROBERTS, D.L. & HERNANDEZ-CASTRO, J. (2017) Bycatch and illegal wildlife trade on the dark web. *Oryx*, 51, 393–394.
- ROBERTS, D.L., MUN, K. & MILNER-GULLAND, E.J. (2021) A systematic survey of online trade: trade in Saiga antelope horn on Russian-language websites. *Oryx*, 56, 352–359.
- ROSEN, G.E. & SMITH, K.F. (2010) Summarizing the evidence on the international trade in illegal wildlife. *EcoHealth*, 7, 24–32.
- SAJEVA, M., AUGUGLIARO, C., SMITH, M.J. & ODDO, E. (2013) Regulating internet trade in CITES species. *Conservation Biology*, 27, 429–430.
- SHARMA, C.P., KUMAR, A., VIPIN, SHARMA, V., SINGH, B., KUMAR, G.C. & GUPTA, S.K. (2019) Online selling of wildlife part with spurious name: a serious challenge for wildlife crime enforcement. *International Journal of Legal Medicine*, 133, 65–69.
- SIRIWAT, P. & NIJMAN, V. (2020) Wildlife trade shifts from brick-and-mortar markets to virtual marketplaces: a case study of birds of prey trade in Thailand. *Journal of Asia-Pacific Biodiversity*, 13, 454–461.
- SODHI, N.S., KOH, L.P., BROOK, B.W. & NG, P.K.L. (2004) Southeast Asian biodiversity: an impending disaster. *Trends in Ecology and Evolution*, 19, 654–660.
- STILES, D. & MARTIN, E.B. (2002) The trade in African and Asian ivory in South and South East Asia. *Pachyderm*, 33, 74–87.
- STRINGHAM, O.C., MAHER, J., LASSALINE, C., WOOD, L., MOCAYO, S., TOOMES, A. et al. (2023) The dark web trades wildlife, but mostly for use as drugs. *People and Nature*, 5, 999–1009.
- STRINGHAM, O.C., TOOMES, A., KANISHKA, A.M., MITCHELL, L., HEINRICH, S., ROSS, J.V. & CASSEY, P. (2021) A guide to using the internet to monitor and quantify the wildlife trade. *Conservation Biology*, 35, 1130–1139.
- SUNG, Y.-H. & FONG, J.J. (2018) Assessing consumer trends and illegal activity by monitoring the online wildlife trade. *Biological Conservation*, 227, 219–225.
- THE STRAITS TIMES (2017) Man fined \$10,000 for smuggling ivory products into Singapore. *The Straits Times*, 2 August 2017. straitstimes.com/singapore/courts-crime/man-fined-10000-for-smuggling-ivory-products-into-singapore [accessed June 2023].
- T SAS-ROLFES, M., CHALLENGER, D.W.S., HINSLEY, A., VERÍSSIMO, D. & MILNER-GULLAND, E.J. (2019) Illegal wildlife trade: scale, processes, and governance. *Annual Review of Environment and Resources*, 44, 201–228.
- VAGLICA, V., SAJEVA, M., NOEL MCGOUGH, H., HUTCHISON, D., RUSSO, C., GORDON, A.D. et al. (2017) Monitoring internet trade to inform species conservation actions. *Endangered Species Research*, 32, 223–235.
- VENTURINI, S. & ROBERTS, D.L. (2020) Disguising elephant ivory as other materials in the online trade. *Tropical Conservation Science*, 13, 1–9.
- WEBBER, L., SHEPHERD, C.R. & KRISHNASAMY, K. (2013) Reduction in demand for ivory in Singapore, but transit trade vigilance needed. *Traffic Bulletin*, 25, 79–84.
- WINGARD, J. & PASCUAL, M. (2018) *Catch Me if You Can: Legal Challenges to Illicit Wildlife Trafficking over the Internet*. The Global Initiative Against Transnational Organized Crime, Geneva, Switzerland. globalinitiative.net/analysis/legal-challenges-to-preventing-iwt-online [accessed June 2023].
- XU, Q., CAI, M. & MACKAY, T.K. (2020) The illegal wildlife digital market: an analysis of Chinese wildlife marketing and sale on Facebook. *Environmental Conservation*, 47, 206–212.
- XU, Q., LI, J., CAI, M. & MACKAY, T.K. (2019) Use of machine learning to detect wildlife product promotion and sales on Twitter. *Frontiers in Big Data*, 2, 1–8.
- YEO, L.M., MCCREA, R.S. & ROBERTS, D.L. (2017) A novel application of mark-recapture to examine behaviour associated with the online trade in elephant ivory. *PeerJ*, 5, e3048.
- YU, X. (2018) *China's Ivory Market after the Ivory Trade Ban in 2018*. TRAFFIC, Cambridge, UK. traffic.org/site/assets/files/11150/chinas-ivory-market-post-ban.pdf [accessed June 2023].
- YU, X. & JIA, W. (2015) *Moving Targets: Tracking Online Sales of Illegal Wildlife Products in China*. TRAFFIC, Cambridge, UK. traffic.org/site/assets/files/2536/moving_targets_china-monitoring-report.pdf [accessed June 2023].
- ZHANG, L., HUA, N. & SUN, S. (2008) Wildlife trade, consumption and conservation awareness in southwest China. *Biodiversity & Conservation*, 17, 1493–1516.