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The dark web trades wildlife, but mostly for use as drugs

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19 **Abstract**

20 Contemporary wildlife trade is massively facilitated by the Internet. By design, the dark web is one
21 layer of the Internet that is difficult to monitor and lacks thorough investigation. Here, we accessed a
22 comprehensive database of dark web marketplaces to search across c. 2 million dark web
23 advertisements over 5 years using c. 7k wildlife trade-related search terms. We found 153 species
24 traded in 3,332 advertisements (c. 600 advertisements per year). We characterized a highly
25 specialized wildlife trade market, where c. 90% of dark-web wildlife advertisements were for
26 recreational drugs. We verified that 68 species contained chemicals with drug properties. Species
27 advertised as drugs mostly comprised of plant species, however, fungi and animals were also traded
28 as drugs. Most species with drug properties were psychedelics (45 species), including one genera of
29 fungi, *Psilocybe*, with 19 species traded on the dark web. The native distribution of plants with drug
30 properties were clustered in Central and South America. A smaller proportion of trade was for
31 purported medicinal properties of wildlife, clothing, decoration, and as pets. Our results greatly
32 expand on what wildlife species are currently traded on the dark web and provide a baseline to track
33 future changes. Given the low number of advertisements, we assume current conservation and
34 biosecurity risks of the dark web are low. While wildlife trade is rampant on other layers of the
35 Internet, particularly on e-commerce and social media sites, trade on the dark web may still increase
36 if these popular platforms are rendered less accessible to traders (e.g., via an increase in
37 enforcement). We recommend focussing on surveillance of e-commerce and social media sites, but
38 we encourage continued monitoring of the dark web periodically to evaluate potential shifts in
39 wildlife trade across this more occluded layer of the Internet.

40

41

42 **Resumen**

43 *La web oscura comercializa vida silvestre, pero principalmente como drogas*

44 El internet facilita enormemente el comercio contemporáneo de vida silvestre. Por diseño, la web
45 oscura es una capa de Internet que es difícil de monitorear y carece de una investigación exhaustiva.
46 Aquí, accedimos a una base de datos completa de mercados de la web oscura y buscamos a través c.
47 2 millones de anuncios web oscuros durante 5 años utilizando c. 7k términos de búsqueda
48 relacionados con el comercio de vida silvestre. Encontramos 153 especies comercializadas en 3332
49 anuncios (c. 600 anuncios por año). Caracterizamos un mercado de comercio de vida silvestre
50 altamente especializado, donde c. el 90% de los anuncios de vida silvestre en la web oscura eran de
51 drogas recreativas. Verificamos que 68 especies contenían químicos con propiedades
52 farmacológicas. Las especies anunciadas como medicamentos se componen principalmente de
53 especies de plantas, sin embargo, los hongos y los animales también se comercializaron como
54 medicamentos. La mayoría de las especies con propiedades farmacológicas eran psicodélicos (45
55 especies), incluido un género de hongos, *Psilocybe*, con 19 especies comercializadas en la web
56 oscura. La distribución nativa de plantas con propiedades farmacológicas se agruparon en América
57 Central y del Sur. Una proporción más pequeña del comercio fue para las supuestas propiedades
58 medicinales de la vida silvestre, la ropa, la decoración y como mascotas. Nuestros resultados
59 amplían en gran medida qué especies se comercializan actualmente en la web oscura y
60 proporcionan una línea de base para rastrear cambios futuros. Dada la baja cantidad de anuncios,
61 asumimos que los riesgos actuales de conservación y bioseguridad de la dark web son bajos. Si bien
62 el comercio de vida silvestre prolifera en otras capas de Internet, particularmente en el comercio
63 electrónico y los sitios de redes sociales, el comercio en la web oscura puede aumentar si estas
64 plataformas populares se vuelven menos accesibles para los comerciantes (por ejemplo, a través de
65 un aumento en la aplicación). Recomendamos enfocarse en la vigilancia de los sitios de comercio
66 electrónico y redes sociales, pero alentamos el monitoreo continuo de la web oscura
67 periódicamente, para evaluar los posibles cambios en el comercio de vida silvestre a través de esta
68 capa más ocluida de Internet.

69

70 Introduction

71 Wildlife trade can present severe conservation, biosecurity, and ethical problems (‘t Sas-Rolfes et al.
72 2019; Fukushima et al. 2020; Cardoso et al. 2021). Increasingly, the Internet facilitates wildlife trade
73 in ways that were not previously possible (Lavorgna 2014; Siriwat & Nijman 2020). Thus, monitoring
74 the Internet for wildlife trade is a conservation and biosecurity priority (Stringham et al. 2021b;
75 Fukushima et al. 2021; Whitehead et al. 2021). Most Internet wildlife trade occurs on publicly
76 viewable websites, known as the *open web* (e.g., e-commerce sites (Heinrich et al. 2019; Ye et al.
77 2020)); but increasingly, wildlife trade also occurs on the *deep web*, which consists of social media
78 and private messaging apps (e.g., Facebook (Van et al. 2019) and WhatsApp (Sánchez-Mercado et al.
79 2020)). Prior research has found very small amounts of wildlife traded on the *dark web*, which
80 remains the most obscure section of the Internet (Harrison et al. 2016; Roberts & Hernandez-Castro
81 2017).

82 The dark web is different from other layers of the Internet in several ways (Stringham et al. 2021b).
83 First, the dark web requires special software to access, making it more obscured and difficult to
84 navigate compared to the open and deep web. Further, no search engine exists for the dark web and
85 thus, users must know a website address (i.e., URL) beforehand to be able to visit a site. The purpose
86 of the dark web is to provide anonymity to users; although several successful law enforcement
87 operations suggest that anonymity is not guaranteed (Décary-Hétu & Giommoni 2017; Hiramoto &
88 Tsuchiya 2020; Zhuang et al. 2021). Some of the most well-known and “popular” dark-web sites are
89 marketplaces that sell drugs and other illicit items (Aldridge & Décary-Hétu 2014; Soska & Christin
90 2015; Cunliffe et al. 2017).

91 There are currently no known marketplaces specifically dedicated to wildlife trade on the dark web,
92 unlike the open and deep web where wildlife marketplaces are plentiful (e.g., 151 websites trading
93 reptiles (Marshall et al. 2020)). However, some wildlife has been traded on dark-web drug
94 marketplaces and prior studies monitored 5 marketplaces from 2014 to 2017; finding cacti (sold as
95 drugs for their hallucinogenic properties), reptile-skin handbags, and a handful of advertisements for
96 ivory and rhino horns (Harrison et al. 2016; Roberts & Hernandez-Castro 2017).

97 Here, we provide an extensive examination of wildlife trade on high-traffic portions of the dark web.
98 We accessed the most comprehensive dark-web database available to academic research, consisting
99 of nearly 2 million advertisements from 51 marketplaces spanning from 2014 to 2020. We identified
100 advertisements that traded wildlife, and analysed which taxa are traded and for what purposes. Our
101 study sets out to answer what wildlife is currently being traded on the dark web.

102

103 Methods

104 We accessed a dark-web database collected by the DATACRYPTO software (described in (Décary-
105 Hétu & Aldridge 2015)). At the time we accessed DATACRYPTO (May 2021), the database spanned c.
106 5.6 years (2014 July 29 to 2020 March 6) and contained c. 1.94 million advertisements across 51
107 marketplaces (i.e., dark-web websites). Each advertisement contained the following information: a
108 unique identifier, a marketplace identifier, a seller identifier, the date, the title of advertisement,
109 and the text description taken directly from the advertisement. The names of the marketplaces and
110 the identities of the sellers were de-identified by DATACRYPTO prior to us obtaining the data.

111 We generated 6,959 keywords related to the scientific names, common names, and use-types
112 involved in the illegal wildlife trade (derived from (Stringham et al. 2021a)); a full list of search terms

113 is provided in Appendix S1). These keywords are derived from seizures records of wildlife on three
114 global wildlife trade databases, which encompass over 3,000 species. We composed our keywords to
115 be in English to correspond with the knowledge that most dark web marketplaces on DATACRYPTO
116 are predominately in English (Décarry-Héту et al. 2016). We searched the dark web database for
117 these keywords, returning advertisements that ‘fuzzy’ matched to our keywords (i.e., words within a
118 Levenshtein distance of 2 or less, see Appendix S2). This search returned 1,232,462 advertisements.
119 We used a variety of semi-automated and manual methods to identify if advertisements were selling
120 wildlife (Appendix S2). Ultimately, we identified 3,332 advertisements that traded wildlife. We
121 excluded taxa that are used in common agricultural, aquaculture, or farming operations (see
122 Appendix S3 for a list of excluded species). We did not analyse the quantity traded within an
123 advertisement (e.g., mass, volume, number of products, or number of individuals), which were
124 hugely inconsistent both within and across taxa; instead we measured the number of
125 advertisements.

126 We identified advertised taxa to the most specific rank possible (e.g., species, genus, family). We
127 used the Global Biodiversity Information Facility database (GBIF 2022) to standardize taxonomy and
128 to obtain upstream taxonomic information. For each taxon in each advertisement (i.e., taxon-
129 advertisement combination), we identified the category of wildlife traded: live, dead/raw, or
130 processed/derived (see Appendix S4 for definitions) and the purpose the taxon was being traded for
131 (e.g., drugs, medicinal, pets, decorative), which we called the ‘use-type’ (See Appendix S5 for full list
132 and definitions of use-types). For some taxon-advertisement combinations, we assigned more than
133 one use-type. For instance, several plants were advertised both for their use as drugs and for their
134 medicinal properties. For species advertised as drugs, we conducted a structured literature search to
135 identify the category of drug (e.g., stimulant, hallucinogen) and the chemical(s) responsible for
136 producing the drug effect (e.g., DMT, psilocybin) (Appendix S6). We did not verify the accuracy of
137 claimed medicinal properties, but simply reported this use-type as (purported) medicinal.

138 We obtained the IUCN Red List status for each species (IUCN 2021). We determined if the species or
139 taxa was listed in the Appendices of the Convention on International Trade in Endangered Species of
140 Wild Fauna and Flora (CITES) (UNEP-WCMC 2022). We used the Global Invasive Species Database to
141 designate if a species is invasive (GISD) (Invasive Species Specialist Group 2015). For each taxon-
142 advertisement combination, we recorded if the seller specified that the specimen was harvested
143 from the wild. For plant species, we obtained their native distributions using the World Geographical
144 Scheme for Recording Plant Distributions (WGSRPD; see Appendix S7 for more details) (Brummit
145 2001).

146 We performed exploratory summary analyses on wildlife advertisements, describing taxonomic
147 trends, use-type trends, number and identity of species, and number of advertisements. We
148 examined species that were of conservation concern (i.e., IUCN status, CITES-listed, wild harvested)
149 or invasive (i.e., listed in GISD). We quantified geographic hotspots for traded plants using
150 geographic level three of WGSRPD (Appendix S7). Finally, we performed exploratory summaries on
151 the markets and sellers that traded wildlife.

152 We performed data analysis and data visualization using R (version 4.1.0; *R Core Team* 2022) and
153 used the following packages: *tidyverse* (version 1.3.1) (Wickham et al. 2019); *sf* (version 1.0-7)
154 (Pebesma 2018); *janitor* (version 2.1.0) (Firke 2021); *gsheet* (version 0.4.5) (Conway 2020); *glue*
155 (version 1.6.2) (Hester & Bryan 2022); *lubridate* (version 1.7.10) (Grolemund & Wickham 2011);
156 *ggalluvial* (version 0.12.3) (Brunson 2020); *patchwork* (version 1.1.1) (Pedersen 2020); *networkD3*
157 (version 0.4) (Allaire et al. 2017); *htmlwidgets* (version 1.5.4) (Vaidyanathan et al. 2021); *flextable*

158 (version 0.6.6) (Gohel 2021a); and *officer* (version 0.3.18) (Gohel 2021b). To obtain upstream
159 taxonomic information, we used the *taxize* package (version 0.9.99; Chamberlain & Szöcs 2013).

160

161 **Results**

162 *Overall characteristics*

163 We identified 153 species traded from 3,332 advertisements of wildlife, at an average rate of 595
164 advertisements per year (Figure 1a; Appendix S8). Most advertised taxa were identifiable to the
165 species level (82% of taxa, 90% of advertisements; Appendix S9). In total, we detected 188 unique
166 taxa (i.e., including upper level taxon; Appendix S10 for full list of species and taxa) and 4,368 taxon-
167 advertisement combinations (Figure 1b). The most common use-type of wildlife was drugs,
168 consisting of 90% of all advertisements and 96 species (62% of the recorded species). However, we
169 could only verify that 68 species actually contained chemicals with known drug properties (Appendix
170 S10). Psychedelics were the most common class of drugs measured by number of advertisements (n
171 = 2,403) and species (n = 41 species). The next most common use-type was for purported medicinal
172 use, consisting of 8% of advertisements and 60 species (39% of species). Half of all traded species
173 (excluding Bacteria) have not been assessed by the IUCN (74 species), while 55 species were
174 categorized as Least Concern and 19 species are threatened (Vulnerable, Endangered, or Critically
175 Endangered). There are 17 species and three upper-level taxa (1 genus and 2 families) listed in CITES
176 Appendix I or II. Nine traded species are categorized as invasive by the Global Invasive Species
177 Database (GISD); although none of those species were traded live.

178

179 *Taxa-use trends*

180 The majority of species traded were plants (Plantae; n = 101 species), followed by fungi (Fungi, n =
181 28), and animals (Animalia; n = 18) (Figure 1). Plants were the most commonly traded kingdom, with
182 2,513 taxon-advertisements (58% of total), followed closely by fungi with 1,721 taxon-
183 advertisements (39%), while animals made up only 126 taxon-advertisements (3%) (Figure 1).

184 Plant species were the most taxonomically diverse kingdom, represented by 55 families and 94
185 genera (Appendix S10; Appendix S11). Overall, most plants were advertised for their use as drugs
186 (88% of plant advertisements) (Figure 2). Of the 70 plant species advertised as drugs, we verified
187 that 45 of them contained chemicals with known drug properties. Psychedelics were the most
188 common class of drugs with 21 plant species and 947 advertisements (Appendix S12). Likewise, the
189 most commonly traded plant species contained chemicals with known drug properties (Table 1). For
190 example, *Mimosa tenuiflora*, the most common plant traded (n=551 advertisements), contains
191 methyltryptamine (DMT), a psychedelic (Table 1). Three plant species were drug facilitators,
192 meaning they contain a chemical that enables a different drug to become chemically active when
193 ingested (Brito-da-Costa et al. 2020). Other plants were traded for their purported medicinal
194 properties (10% of species; 46 species). Most plants were traded as processed/derived (61% of plant
195 advertisements; 72 species), followed by dead/raw (i.e., dead parts: 30% plant advertisements; 58
196 species), and few were living plants (9% of advertisements, 15 species) (Appendix S13). Five of the
197 traded plant species are at risk of extinction, including peyote (*Lophophora williamsii*), goldenseal
198 (*Hydrastis canadensis*), and catuaba (*Erythroxylum vacciniifolium*); each listed as Vulnerable by the
199 IUCN. Seven plant species and one genus (*Dalbergia*) are listed in CITES Appendix I or II, including
200 one orchid species (*Dendrobium nobile*), four cacti (*L. williamsii* and 3 species in *Echinopsis*), *H.*

201 *canadensis*, and *Panax quinquefolius*. According to the GSID, seven traded plant species are invasive,
202 including coltsfoot (*Tussilago farfara*) and Formosan koa (*Acacia confusa*). The native distributions of
203 traded plants were geographically diverse, spanning every continent except Antarctica (Figure 3).
204 Traded plant species with drug properties had native distributions mostly in Central and South
205 America, while other plant species had native distributions mostly in Europe and parts of Western
206 and Southern Asia (Figure 3; Appendix S14).

207 The most common fungi species were from the *Psilocybe* genus (83% of fungi advertisements, 1,381
208 advertisements, 17 species), where *P. cubensis* (commonly referred to as ‘magic mushroom’) was
209 the most popular species in this study, with 1,189 advertisements (Table 1). Almost all fungi were
210 sold as drugs (96% of listings; Figure 2). Of the 22 species advertised as drugs, we verified that 21 of
211 them contained chemicals with known drug properties. The most common drug class for fungi was
212 psychedelics, found in 19 species and 1,400 advertisements (Appendix S12). The active chemical
213 psilocybin is a psychedelic found in every traded species of *Psilocybe*. There were 11 species
214 advertised for their purported medicinal properties and three species traded as food, including the
215 black truffle (*Tuber melanosporum*). Most fungi were traded as dead/raw (54% of fungi
216 advertisements, 23 species), followed by processed/derived (31% fungi advertisements, 14 species),
217 then live (15% fungi advertisements, 16 species) (Appendix S13). One fungus species, the caterpillar
218 fungus (*Ophiocordyceps sinensis*), is categorized as Vulnerable by the IUCN as it is used and traded
219 for medicinal purposes locally, nationally and internationally. No other traded fungi species were
220 evaluated by the IUCN (except for *Hericium erinaceus*; Least Concern), no fungi were listed in CITES
221 appendices, and no traded fungi were classified as invasive.

222 Animals were more taxonomically diverse than fungi, having 14 families represented (10 families in
223 the phylum Chordata, 3 in Arthropoda, 1 in Echinodermata). Animals were traded for a range of use-
224 types, including clothing (i.e., furs, skins), drugs, decorative purposes, pets, medicine, and food. The
225 two most common animal species were the racoon (*Procyon lotor*), traded for clothing (i.e., racoon
226 fur), and the Sonoran Desert toad (*Incilius alvarius*), traded because its secretions contain
227 psychoactive properties (i.e., psychedelic). There were three live species advertised as pets (12
228 advertisements): the African grey parrot (*Psittacus erithacus*), hyacinth macaw (*Anodorhynchus*
229 *hyacinthinus*), and goliath beetle (*Goliathus goliatus*). Nine traded animal species are listed as
230 Threatened by the IUCN and one traded animal was categorized as Extinct (western black
231 rhinoceros, *Diceros bicornis longipes*). The nine Threatened species included two parrots (*A.*
232 *hyacinthinus* and *P. erithacus*), 6 mammals (*Panthera leo*, *Panthera tigris*, *Acinonyx jubatus*,
233 *Loxodonta africana*, *Hippopotamus amphibius*, and *Rangifer tarandus*), and *Apostichopus japonicus*
234 (Japanese spiky sea cucumber). All traded mammals (except for *P. lotor* and *R. tarandus*) and the
235 two Threatened parrots were also listed in CITES Appendix I or II. Further, three animal taxa traded
236 at the family level are listed in CITES Appendix I or II: Elephantidae, Rhinocerotidae, and Pythonidae.
237 Two traded animal species are classified as invasive (*P. lotor* and *R. tarandus*), although neither were
238 traded as live specimens.

239 We recorded 17 traded species that were specified by sellers to be harvested from the wild, in 52
240 advertisements (median 3 wild-harvested advertisements per species; Appendix S15). Three wild-
241 harvested species are listed as at risk of extinction by the IUCN: *A. japonicus* (Japanese spiky sea
242 cucumber; Endangered), *L. williamsii* (peyote; Vulnerable), and *Ophiocordyceps sinensis* (caterpillar
243 fungus; Vulnerable).

244 We observed some animals traditionally implicated in the illegal wildlife trade being advertised in
245 low quantities. This included the tusks of species in the elephant family (Elephantidae) (i.e., ivory,

246 n=22 ads), horns of species in the rhinoceros family (Rhinocerotidae, n=13), and the teeth and skins
247 of tigers (*P. tigris*, n=4) and lions (*P. leo*, n=3).

248 We found several traded taxa that did not fit the traditional definition of wildlife trade. Specifically,
249 there were five species of bacteria traded as potential bioweapons, including *Corynebacterium*
250 *diphtheriae* (causes diphtheria), *Staphylococcus aureus* (causes a variety of infections), and
251 *Clostridium botulinum* (causes botulism).

252

253 *General market & seller characteristics*

254 Wildlife advertisements constituted a small proportion (0.2%) of all dark web advertisements.
255 Advertisements of wildlife were found in 47 of the 51 marketplaces searched (92%), although the
256 majority of marketplaces (>50%) contained less than 30 wildlife advertisements (Appendix S16). The
257 number of species traded in a given marketplace generally increased as the number of wildlife
258 advertisements in a marketplace increased (Appendix S17). Less than 1% of all dark-web sellers
259 advertised wildlife (1,222 of 155,094 sellers). The majority of sellers listed only a single
260 advertisement of wildlife and thus, a single taxon (>50% of sellers, Appendix S16). The number of
261 wildlife advertisements remained relatively stable over time (Appendix S18).

262

263 **Discussion**

264 Our results greatly expand on the number of wildlife species known to be traded on the dark web
265 (Harrison et al. 2016; Roberts & Hernandez-Castro 2017). At the same time, our findings suggest that
266 the dark web is a highly specialized wildlife trade market, consisting primarily of plants, fungi, and
267 animals traded for their properties as recreational drugs. We speculate that other species which
268 meet this criteria may become ensnared in future wildlife trade on the dark web, such as plants that
269 contain methyltryptamines (i.e., DMT containing plants; (Bussmann 2016)), *Psilocybe* fungi, plants
270 with drug properties in Central and South America, or frogs that contain bufotoxin (de Greef 2022)
271 (Figure 3). Further, we observed other types of wildlife trade occurring in much smaller amounts, for
272 use as medicine, clothing, decor, rituals, and pets. While this trade is currently minimal, there is
273 always the possibility of this trade expanding in the future.

274 The quantity of wildlife and number of species traded on the dark web appears to be vastly lower
275 than the open and deep web. We observed c. 600 advertisements of wildlife per year on the dark
276 web across 47 marketplaces. While not directly comparable, other studies with different wildlife-
277 trade contexts (i.e., public e-commerce sites) had a rate of three to over 300 times as many
278 advertisements for a *single* website (i.e., from 2k to 67k advertisements per year: (Xu et al. 2020; Ye
279 et al. 2020; Olden et al. 2021)). Further, while we found 154 species traded on the dark web, other
280 non-dark-web online-trade studies have observed over 2,600 species from one taxonomic kingdom
281 or class (e.g., plants (Humair et al. 2015) and reptiles (Marshall et al. 2020), respectively). This
282 comparison reinforces the notion of the dark web as a highly specialized and small niche market for
283 wildlife as drugs. However, we note that we did not capture the volume of wildlife in a given
284 advertisement and some advertisements may contain tens to hundreds of a given species/product
285 or may represent an ongoing supply of the wildlife. For example, we observed the sale of 200kg of
286 powered *Mimosa tenuiflora* root bark (DMT containing) in one advertisement. Thus, we note that
287 the number of advisements we measured is a conservative measure of any given taxa traded on the
288 dark web.

289 Given the small number of advertisements and low species diversity, we assume that the current
290 trade on the dark web is unlikely to be a major conservation threat. Nevertheless, we identified
291 trade of three species threatened and harvested from the wild (*Apostichopus japonicus*, *Lophophora*
292 *williamsii*, and *Ophiocordyceps sinensis*), which is of potential conservation concern and warrants
293 further investigation. For the same reason, the dark web is unlikely to be a biosecurity concern
294 currently, or is at most of low concern for invasive species. We found nine species traded that are
295 known invasive species (7 plants, 2 animals); however, none were traded alive (i.e., only dead or
296 derived products) and therefore of low biosecurity concern. We note that the database we used for
297 categorizing invasive species (GISD) does not include many regionally invasive species. Thus, we may
298 have missed categorizing some invasive species traded on the dark web. Yet, of the live specimens
299 traded (31 species), most occurred in limited numbers (i.e., the median number of advertisements
300 was three), which is why we consider this trade to be a low concern for invasive species (Cassey et
301 al. 2018). We did not evaluate the disease risk of traded taxa, which can potentially be hosts or
302 reservoirs for wildlife or human pathogens (Calisher et al. 2006; Liebhold et al. 2012; Fu & Waldman
303 2022).

304 In terms of legality, we were unable to quantify if traded species were illegal because we did not
305 know what jurisdictions the trades occurred in (Fukushima et al. 2021). Thus, it is possible that some
306 of this trade may be illegal from an environmental (i.e., conservation/biosecurity) legislative
307 standpoint. In particular, species listed in CITES Appendices (n =17) are illegal to trade between
308 international borders (assuming dark web sellers do not have a permit). However, it is more likely
309 that many of these species are regulated for their drug properties. For example, the most common
310 species on the dark web, the magic mushroom (*Psilocybe cubensis*), is currently illegal to sell or
311 possess in most of the United States (Pollan 2019).

312 We did not attempt to verify the validity of dark web advertisements. In general, the validity of any
313 online wildlife advertisement is difficult to verify (i.e., determine if the advertisement is genuine or
314 fraudulent). This is especially true in the case of the dark web, particularly without the help of law
315 enforcement agencies (Stringham et al. 2021b). Prior studies of wildlife trade on the dark web have
316 attempted to verify advertisements (Harrison et al. 2016; Roberts & Hernandez-Castro 2017),
317 however, since we identified substantially more advertisements, this was not feasible during our
318 study. Therefore, it is possible that some advertisements we found were falsified (e.g., fake
319 rhinoceros horns found in advertisements in prior studies (Harrison et al. 2016; Roberts &
320 Hernandez-Castro 2017).

321 Due to the nature of the dark web, we cannot rule out the possibility that there are other sites
322 (marketplaces or forums) where wildlife is traded. This is a serious limitation of monitoring the dark
323 web where unlike on the open and deep web, either a search engine can find relevant websites, or a
324 company keeps records of what is being sold (e.g., eBay), the dark web keeps no such records. Thus,
325 we very likely did not capture the entirety of wildlife trade on the dark web, although we used the
326 most comprehensive dataset of the dark web available, DATACRYPTO (Décary-Héту & Aldridge
327 2015). Further, the sites monitored by DATACRYPTO are the most accessed dark web sites on the
328 Internet. Therefore, if there are other sites on the dark web where wildlife trade is occurring, then
329 we speculate that trade volume is even lower than what we observed on the general illicit
330 marketplaces covered by DATACRYPTO. Finally, the search terms we used to search through
331 DATACRYPTO were not as targeted as we initially assumed because c. 1.2 out of c. 1.9 million
332 advertisements (c. 60% of the entire database) were returned. Thus, we suspect that we did not miss
333 many advertisements in DATACRYPTO that traded wildlife.

334 We provide a baseline of wildlife trade to be compared against future trade on the dark web. If
335 wildlife trade increases on the dark web in the future, we should turn our collective efforts to
336 reporting illegal trade and enforcing trade regulations. Nevertheless, current wildlife trade is thriving
337 on the open (e-commerce) and deep web (social media, messaging apps) (Hinsley et al. 2016;
338 Sánchez-Mercado et al. 2020; Sung et al. 2021). Thus, in the limited resource landscape of
339 conservation and biosecurity efforts related to wildlife trade (World Bank Group 2016), we
340 recommend most monitoring and enforcement resources be focused on the open and deep web;
341 especially considering the massive amount of trade occurring on social media sites, such as Facebook
342 (Xu et al. 2020). At the same time, we recommend continued regular surveillance of the dark web
343 and encourage new efforts to find any dark-web marketplaces or websites that trade wildlife, but
344 which are not currently known.

345 **Data Availability**

346 The data used in this paper can be downloaded at
347 https://figshare.com/articles/dataset/The_dark_web_trades_wildlife_but_mostly_as_drugs/200637
348 [26](#).

349

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494

495

496 **Tables**497 *Table 1.*

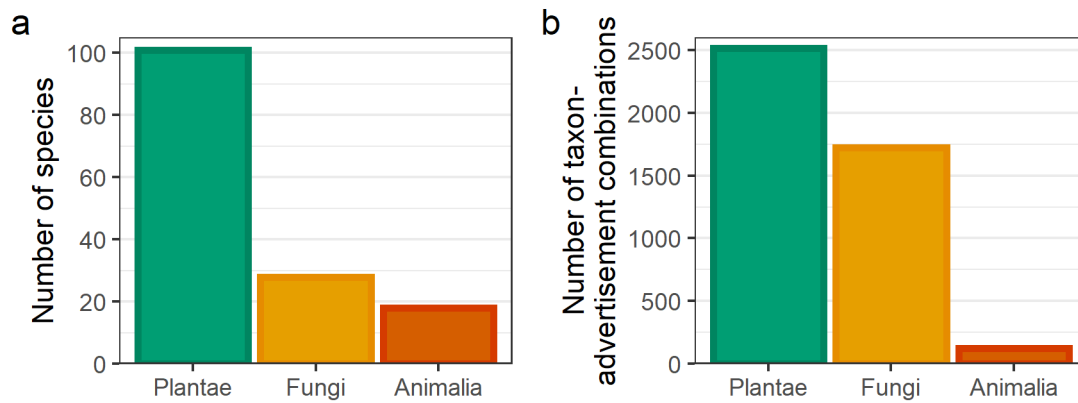
498 The twenty most commonly traded species on dark web marketplaces by number of advertisements.
 499 Sixteen of the top twenty species contain chemicals with known drug properties or chemicals that
 500 facilitate (i.e., activate) the intake of another chemical with drug properties. For one species,
 501 *Mitragyna speciosa*, the drug class depends on the dosage of the active chemical ingested
 502 (mitragynine). Four of the twenty species were not found to be drugs but have medicinal properties
 503 (labelled as Medicinal in Drug Class). See Appendix S6 for our methods on identifying the drug class
 504 and active chemical of each species.

Species	Common name	Kingdom	Drug Class	Number of ads
<i>Psilocybe cubensis</i>	Magic mushroom	Fungi	Psychedelic	1,189
<i>Mimosa tenuiflora</i>	Jurema	Plantae	Psychedelic	551
<i>Mitragyna speciosa</i>	Kratom	Plantae	Stimulant, Depressant	237
<i>Banisteriopsis caapi</i>	Yage	Plantae	Facilitator	233
<i>Peganum harmala</i>	Syrian rue	Plantae	Facilitator	151
<i>Nymphaea nouchali</i>	Blue lotus	Plantae	Depressant	101
<i>Salvia divinorum</i>	Salvia	Plantae	Dissociative	100
<i>Passiflora incarnata</i>	Passion flower	Plantae	Medicinal	87
<i>Echinopsis pachanoi</i>	San Pedro cactus	Plantae	Psychedelic	66
<i>Acacia confusa</i>	Formosan koa	Plantae	Psychedelic	63
<i>Calea ternifolia</i>	Dream herb	Plantae	Medicinal	61
<i>Verbascum thapsus</i>	Mullein	Plantae	Medicinal	58
<i>Turnera diffusa</i>	Damiana	Plantae	Anxiolytic	54
<i>Lophophora williamsii</i>	Peyote	Plantae	Psychedelic	52
<i>Psilocybe tampanensis</i>	Magic truffles	Fungi	Psychedelic	50
<i>Diplopterys cabrerana</i>	Chaliponga	Plantae	Psychedelic	43
<i>Psychotria viridis</i>	Chacrana	Plantae	Psychedelic	38
<i>Psilocybe subaeruginosa</i>	Gold tops	Fungi	Psychedelic	33
<i>Erythroxylum coca</i>	Coca plant	Plantae	Stimulant	32

Species	Common name	Kingdom	Drug Class	Number of ads
<i>Handroanthus impetiginosum</i>	Pau d'arco	Plantae	Medicinal	31

505

506 **Figures**

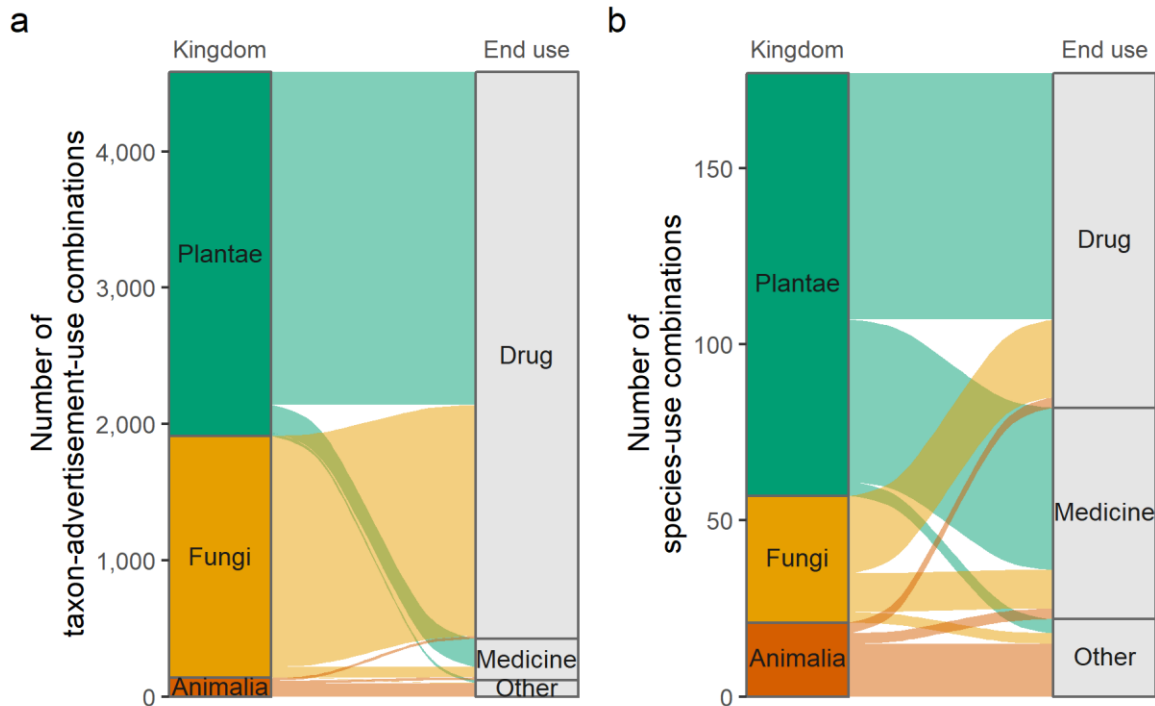


507

508 *Figure 1.*

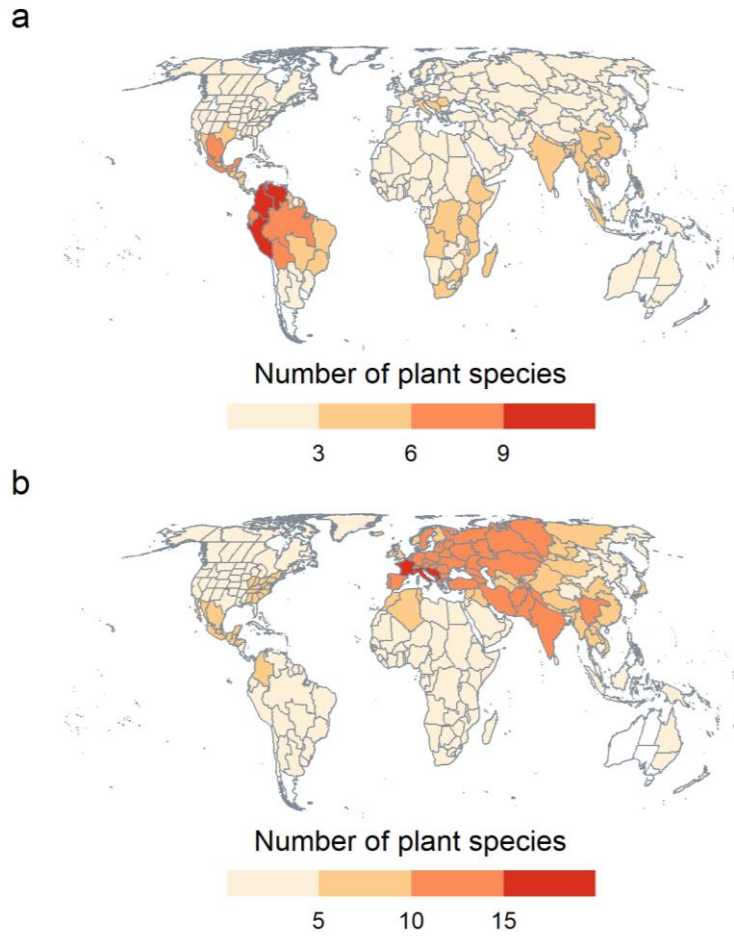
509 (a) The number of species traded on the dark web and (b) the number of taxon-advertisement
510 combinations (i.e., some advertisements listed more than one taxon), stratified by taxonomic
511 kingdom.

512



513
514 *Figure 2.*

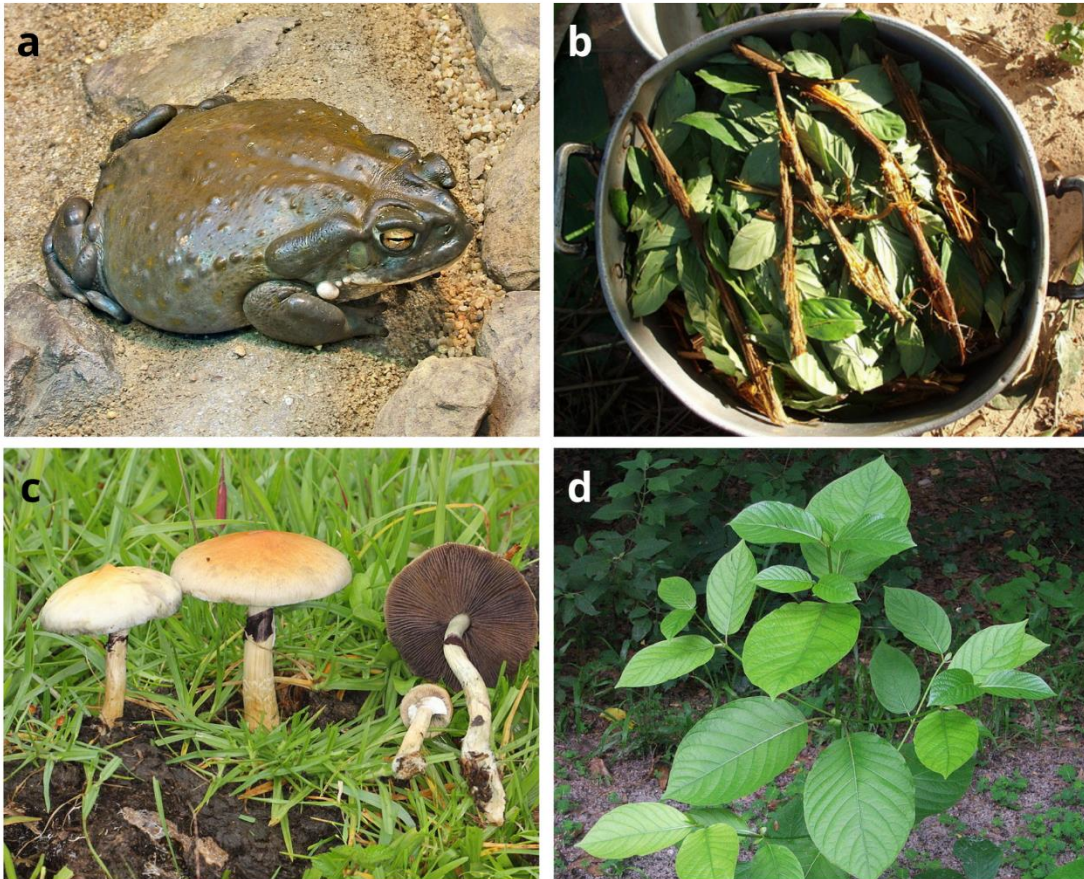
515 End use characteristics of wildlife traded on the dark web. (a) Number of taxon-advertisement
516 combinations stratified by end use and (b) number of species stratified by end use. Note that some
517 taxon-advertisement and species had more than one end use. End use definitions can be found in
518 Appendix S5. Advertisements and species of Bacteria are not shown (4 advertisements; 6 species).



519

520 *Figure 3.*

521 The native distribution of plant species traded on the dark web stratified by (a) if the plant has
 522 verified drug properties (n = 45) and (b) all other traded plants species (n = 56). The number and
 523 colours correspond to the number of species in each geographic area. Geographic area borders
 524 mostly correspond to either country or country subdivisions (see Appendix S7 for details). White
 525 indicates no species having native distributions. There were no traded plant species native to
 526 Antarctica. Note this map only shows traded plant species, not fungi or animals.



527

528 *Figure 4.*

529 A sample of species traded on the dark web for their properties as drugs. (a) Sonoran Desert toad
 530 (*Incilius alvarius*), whose poison in the parotoid glands contains 5-MeO-DMT, a known psychedelic.
 531 (b) A preparation of Ayahuasca containing *Psychotria viridis*, a source of DMT, and *Banisteriopsis*
 532 *caapi*, a liana that contains monoamine oxidase inhibiting alkaloids (MAOIs). (c) *Psilocybe cubensis*
 533 contains the psychedelic compound psilocybin. (d) *Mitragyna speciosa* can have stimulant effects in
 534 low doses or opioid-like effects in higher doses. Photo credits: (a) Wildfeuer; (b) Awkipuma; (c) Alan
 535 Rockefeller; (d) Uomo vitruviano.

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Appendix to:

The dark web trades wildlife, but mostly for use as drugs

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- Appendix S4. Wildlife advertisement category definitions
- Appendix S5. Wildlife advertisement end use definitions
- Appendix S6. Methods for drug verification and classification
- Appendix S7. Methods to obtain native plant distributions
- Appendix S8. Dataset of taxon-advertisement combinations
- Appendix S9. Detailed results of number of taxa and advertisements by taxonomic rank
- Appendix S10. Dataset of taxa traded on the dark web and their characteristics
- Appendix S11. Detailed results of taxonomic diversity
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- Appendix S14. Dataset of plant species richness by geographic areas
- Appendix S15. Detailed results on species advertised as wild harvested
- Appendix S16. Detailed results on market and seller characteristics
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- Appendix S18. Detailed results of taxonomic trends over time

569 **Appendix S1: Full list of search terms**

570 Refer to csv file named "Appendix_S01_dark_web_search_terms.csv" for the full list of search terms
571 supplied to search through DATACRYPTO.

572 **Appendix S2: Semi-automated and manual methods to detect if advertisements were trading**
573 **wildlife**

574 *Overview*

575 We processed the collected advertisements from DATACRYPTO to identify if wildlife were traded.

576 First, we removed exact duplicates, which we defined as advertisements with the exact same text
577 description. Next, we removed fuzzy duplicates within sellers, which we defined as advertisements
578 that were greater than 80% similar based on Levenshtein distance (using the “ratio” function from
579 the python package “python-Levenshtein”, version 0.12.0). For fuzzy duplicates, we only compared
580 advertisements by the same seller. Exact and fuzzy duplicates may have occurred due to cross-
581 marketplace postings of the same seller or sellers with different usernames posting the same
582 advertisements. After removing both exact and fuzzy duplicates, 354,635 advertisements remained.

583 We then searched the remaining advertisements for exact matches to the keywords supplied
584 originally to the database (see Methods in main text). We manually examined these advertisements
585 to determine if wildlife was traded.

586 Since the remaining unexplored advertisements were numerous (>300k), we used topic modelling, a
587 natural language processing method (Griffiths and Steyvers 2004), to categorize advertisements
588 based on their topics (see below for detailed methods of topic modelling). This process resulted in
589 47 topics and we removed advertisements that belonged to topics we deemed as not related to the
590 wildlife trade (e.g., bank account information or prescription drugs). This topic modelling process
591 removed 134,596 advertisements.

592 Next, we removed listings based on a separate list of keywords generated as the most common
593 unigrams and bigrams. This removed a further 130,020 advertisements. Finally, for the remaining
594 82,114 advertisements, we manually scanned to detect if wildlife was traded, resulting in 3,332
595 advertisements.

596

597 *Details of Topic Modelling and Topic Labelling*

598 The purpose of the topic modelling was to identify topics that did not involve the trade of wildlife
599 and exclude advertisements categorized to these topics from further investigation.

600 First, we performed standard text cleaning methods to prepare the text for topic modelling. We
601 converted all text to lower case, removed punctuation, removed extra spaces, and removed
602 numbers. Then, we removed English stop words (from python package “nltk”, version 3.4.5). Next,
603 we stemmed words using the Porter stemmer (from “nltk” package).

604 We tokenized by unigrams and excluded unigrams found in greater than 95% of advertisements and
605 also excluded unigrams found in less than 5% of advertisements. This was achieved using the
606 “CountVectorizer” function from the python package “scikit-learn” (version 1.0.1).

607 Next, we performed topic modelling using a Latent Dirichlet Allocation (LDA) model. We tuned the
608 model, testing multiple values for the number of topics, ranging from 1 to 85 topics. We chose the
609 model with the lowest log-likelihood score (Griffiths and Steyvers 2004), which was, in our case, 58
610 topics. To implement the LDA modelling, we used the “LatentDirichletAllocation” function from the
611 “scikit-learn” package.

612 We assigned each advertisement a topic determined by the LDA prediction with the highest
613 proportion (of a topic) for a given advertisement. To determine a label for a topic (e.g., prescription
614 drugs or banks accounts), we first randomly sampled advertisements from each topic. We chose to
615 restrict sampling to advertisements with over 0.5 proportion of a topic. We manually determined
616 the topic by scanning through a sample of advertisements for a given topic. Examples of topics we
617 determined were: credit card numbers, computer software, e-books, cannabis/THC vapes, Viagra
618 and other prescription drugs, and LSD. We removed from consideration topics that we suspected
619 could include wildlife or that included advertisements with wildlife in the sample. For example, one
620 topic included peyote, which is a small cactus. Other topics we did not consider contained a mixture
621 of different drugs that we could not rule out if wildlife was traded or not. Overall, we did not
622 consider 11 topics, leaving 47 topics for further investigation for removal.

623 We performed sampling for each remaining topic, stratified by the predicted proportion an
624 advertisement was (from LDA) from that topic (e.g., 10 samples from 0.5 to 0.6 predicted
625 probability, 10 samples from 0.6 to 0.7, etc.). We then labelled each advertisement sampled as being
626 relevant to the given topic. Next, for each topic, we identified the predicted probability that it
627 contained all relevant advertisements. For example, if advertisements from the topic “e-books” were
628 only relevant if the predicted proportion of the topic was 0.7 or greater, we only selected
629 advertisements with over 0.7. Overall, this topic modelling process resulted in excluding 134,596
630 advertisements from further analysis for wildlife trade from 47 topics.

631

632 *References*

633 Griffiths TL, Steyvers M. 2004. Finding scientific topics. PNAS. 101: 5228–5235.
634 doi:[10.1073/pnas.0307752101](https://doi.org/10.1073/pnas.0307752101)

635 **Appendix S3: Taxa found traded on the dark web but were excluded from analysis**

636 Refer to csv file named “Appendix_S03_excluded_taxa.csv” for the full list of taxa we found traded
637 on the dark web but we excluded from our analyses because they are commercially produced for
638 either agricultural, forestry, aquaculture, or apiculture reasons. Refer to Table S3 for a description of
639 the columns. Note, we excluded all species of the genera *Cannabis*, who trade was widespread on
640 the dark web (>100k advertisement’s) and is also produced commercially. Finally, we excluded two
641 advertisements trading human (*Homo sapiens*) skulls, because humans are not traditionally
642 considered being part of wildlife trade.

643 Table S3. Column descriptions for the data file “Appendix_S03_excluded_taxa.csv”

Column	Description
gbif_name	The name of the taxon according to GBIF
gbif_rank	The taxonomic rank of the taxon (i.e., species, genus) according to GBIF
gbif_id	GBIF’s unique identifier for the taxon
reason_excluded	The reason why the taxon was excluded from our analysis.
kingdom	The taxonomic kingdom of the taxon according to GBIF
phylum	The taxonomic phylum of the taxon according to GBIF
class	The taxonomic class of the taxon according to GBIF
order	The taxonomic order of the taxon according to GBIF
family	The taxonomic family of the taxon according to GBIF
genus	The taxonomic genera of the taxon according to GBIF
species	The taxonomic species of the taxon according to GBIF

644

645 **Appendix S4: Wildlife advertisement category definitions**

646 Table S4. Categories of traded wildlife. Each taxon-advertisement combination was assigned one of
647 four categories: raw/dead, processed/derived, by-product, or live.

Category	Definition	Example
raw/dead	Wildlife is in its natural physical form, representing either the whole organism or parts/section of the organism that has not been altered extensively.	Dried leaves, whole mushroom, feathers
processed/derived	Wildlife was altered and not immediately recognisable as the wildlife product	Toad poisons, powdered substances
by-product	A product that wildlife externally produces, i.e. secondary product	Honey
live	Wildlife specimen is alive	Whole plants, plant cuttings, live animals (e.g., parrots)

648

649

650 **Appendix S5: Wildlife advertisement end use definitions**

651 Table S5. End use categories of traded wildlife. We assigned each taxon-advertisement an end use
 652 depending on what was being advertised and how the seller specified the traded taxon. For some
 653 advertisements, we assumed the end use based on the context of the advertisement. For example,
 654 we assumed live parrots were for the end use of being a household pet. Another common example
 655 includes when a seller advertises a plant for its drug properties but doesn't explicitly mention it's for
 656 recreational drug use. In these cases, we assumed the advertisement's end use was 'drug'.

End use	Definition	Example
Drug	Chemical or natural substances taken for enjoyment or leisure purposes rather than medical reasons. We included drug precursors in this category.	Magic mushrooms, DMT from <i>Mimosa tenuiflora</i> rootbark
Medicine	A substance that is claimed/purported to be beneficial for the treatment of disease, illness or injury, including food supplements.	Natural Viagra, lung tonic
Food (raw)	Food product consisting of just the one wildlife specimen, unadulterated and in its natural form.	Honey, animal meat
Food (processed)	Food product containing of at least one wildlife specimen, altered so it is no longer in its natural form	Meat jerky
Cosmetic	Wildlife products and/or their derivatives being used with the intention of altering someone's appearance	Botox, breast growth 'supplements'
Accessory	Fashion accessories or any fashion apparel items that aren't clothing	Belt, handbag, shoes, briefcase
Clothing	Wildlife products that are used as an item of clothing	Snakeskin jacket, fur coat
Pet	A live animal is being sold for the purpose of pet trade	Macaw parrot
Decorative	Wildlife product advertised for decorative purposes	Elephant ivory, African dan masks, animal skins
Ritual	Wildlife that does not have any health benefit and is not taken for enjoyment or leisure. Has historical records of being used for ritual/religious practices.	Kambo (secretions of the Giant monkey frog)
Poison	Substance used with the intent to cause death, injury or harm. Includes incapacitating agents (i.e., date rape drugs: Devil's breath). Includes venom.	Ricin, Devil's breath
Weapon	A bioweapon, physical weapons used with the intention of causing physical harm	Diphtheriae, E. coli
Drug paraphernalia	Any equipment, product or accessory intended for making, using or concealing drugs.	Wooden marijuana grinder box

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658

659 **Appendix S6: Methods for drug verification and classification**

660 We identified the drug classes (Table S6a) and active substances (Table S6b) of the taxa sold as drugs
 661 on the dark web. We distinguished taxa with known pharmacological effects from those with
 662 unsubstantiated effects. We classified the drug class (e.g., depressant, stimulant, psychedelic) and
 663 identified the main active substance(s) of a taxon from the scientific peer-reviewed literature (See
 664 Table S6c for full list of references). We found that some taxa did not have known pharmacological
 665 effects or had different effects. For example, sellers advertising *Tagetes lucida* claimed it to be a
 666 hallucinogenic, however the literature did not support this and instead indicated sedative properties
 667 (Pérez-Ortega, González-Trujano et al. 2016). Several plants did not have known active drug
 668 chemicals but instead contained a chemical, considered to be a ‘facilitator’, meaning it causes
 669 another chemical to become activated. For example, we classified the chemical harmine as a
 670 facilitator due to its use in ayahuasca to enable the psychedelic compound DMT to be orally active
 671 (Brito-da-Costa, Dias-da-Silva et al. 2020). We recorded the facilitated chemical as their own
 672 separate drug class. Other taxa contained precursor chemicals used to manufacture a drug (e.g.,
 673 safrole harvested from *Sassafras albidum* to manufacture MDMA (Kemprai, Protim Mahanta et al.
 674 2020)). For these taxa with precursors, we classified the drug class based on the what the precursor
 675 becomes (i.e., MDMA for *Sassafras albidum*) and recorded the precursory chemical found in the taxa
 676 separately.

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687

688 Table S6a. The classes of drugs that were known to be in plants, fungi, and animals traded on the
 689 dark web.

Drug class	Definition	Example
Depressant	Slow down the functions of the central nervous system. Lower doses generally induce relaxation and sedation. High doses may cause unconsciousness. Depressants can also produce euphoria.	Alcohol, cannabis, valium, opioids
Stimulant	Speed up the message between the body and your brain. Increases heart rate, blood pressure and body temperature. Makes you feel more alert and energetic.	Cocaine, ecstasy, nicotine
Psychedelic	A class of hallucinogenic drugs that can cause visual and auditory hallucinations, and often a substantially altered state of consciousness.	Mescaline, LSD, psilocybin, and DMT

Deliriant	Causes delirium and hallucinations.	Datura, Brugmansia, Benadryl
Toxin	A harmful organic substance.	Grayanotoxin
Dissociative	Distorts sensory perceptions and produces a feeling of detachment from the self and the environment.	Ketamine, Salvia divinorum
Facilitator	Facilitates the uptake of another chemical with desired effects.	Harmine allows DMT to be orally active.

690

691 Table S6b. The active substance/s, precursor chemical, or facilitating chemical found in taxa traded
692 on the dark web as drugs.

Chemical	Notes
Apigenin	Antianxiety effects.
Arecoline	Parasympathomimetic stimulant.
Atropine	An anticholinergic that can cause deliriant hallucinations.
Caffeine	A central nervous system stimulant.
Cathinone	Stimulant effects, found in Khat.
Cocaine	Natural alkaloid in Coca plants, extracted to make cocaine (crack)
Coumarins	Aromatic organic compounds found in many plants.
Cytisine	A toxic alkaloid found in certain plants of Fabaceae.
Ephedrine	A stimulant which occurs in the plant genus Ephedra.
Ergine	Ergoline alkaloid, psychedelic effects.
Grayanotoxin	A group of neurotoxins produced in some plant species of the Ericaceae family.
Harmine	Hallucinogenic alkaloid found in Caapi & syrian rue (harmaline is its hydrogenated form)
Ibogaine	A psychedelic described as having oneirogenic and dissociative effects.
Kavalactones	A group of lactone compounds found in kava roots
Lactucin	Analgesic and sedative properties
Leonurine	A pseudoalkaloid that has been isolated from Leonotis leonurus.
MDMA	MDMA, found in some sassafrass plants
Mescaline	A psychedelic compound found in certain cacti species.
Methyltryptamines	Organic compounds that are serotonin analogues and produce psychedelic effects. Examples include NMT, DMT, 5-MeO-DMT, and Bufotenin.
Mitragynine	Induces mild stimulating effect at low doses and opioid-like effects at higher doses.
Multiple	Multiple chemicals present without clear indication of a sole active substance.
Muscimol	Found in Amanita muscaria.

Nicotine	An alkaloid found in the Solanaceae family that has stimulant and anxiolytic effects.
Nuciferine	A sedative found within <i>Nymphaea</i> and <i>Nelumbo nucifera</i> .
Opiates	Alkaloid compounds found in the opium poppy including morphine and codeine.
Psilocin	A serotonergic psychedelic substance similar to LSD and DMT found in certain mushroom species.
Psilocybin	A psychedelic prodrug compound of psilocin found in certain mushroom species.
Safrole	A precursor to MDMA.
Salvinorin A	A dissociative hallucinogen found in <i>Salvia divinorum</i> .

693

694 Table S6c. References used to verify and categorize drug classes and main active substance(s) of taxa
695 advertised as drugs. The citation for each individual taxon can be found in Appendix S10, in the
696 'reference' column.

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698 **Appendix S7: Methods to obtain native plant distributions**

699 To obtain the native distributions of traded plants, we used the Kew Plants of the World Online
700 database (POWO 2022). POWO, utilises the World Geographical Scheme for Recording Plant
701 Distributions (WGSRPD) (Brummitt 2001). The WGSRPD, has four geographic units for recording
702 plant distributions. POWO, uses the 'level 3' geographic unit which records distribution at the
703 country scale or by political subdivisions for large countries. Large countries that are subdivided are:
704 Argentina, Australia, Brazil, Canada, Chile, China, India, Mexico, South Africa, USA, and Russia. The
705 shapefiles and geographic unit codes were obtained from the WGSRPD Github repository (Desmet
706 and Page 2007).

707 For each traded plant species we used scientific names to retrieve Life Sciences Identifiers (LSID)
708 from POWO. This was done by using the 'get_pow' function from the 'taxize' package (Chamberlain
709 & Szöcs 2013). We manually verified species with more than one result, by using the POWO
710 database to determine the accepted species name. We then retrieved native distributions from
711 POWO with the 'pow_lookup' function from 'taxize' (Chamberlain & Szöcs 2013). We cross
712 referenced this data with the 'level 3' shapefile data from the WGSRPD Github repository (Desmet
713 and Page 2007).

714

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723 on the Internet; <http://www.plantsoftheworldonline.org/> [Accessed 1/4/2022].

724 **Appendix S8: Dataset of taxon-advertisement combinations**

725 Refer to csv file named “Appendix_S08_taxon_advertisement_dataset.csv” for the full dataset of
726 each taxon-advertisement combination. Refer to Table S8 for a description of the columns.

727

728 Table S8. Column descriptions for the data file “Appendix_S08_taxon_advertisement_dataset.csv”

Column	Description
gbif_name	The name of the taxon according to GBIF
ad_id	A unique identifier for the advertisements. Taxon-advertisements from the same advertisements with have the same ‘ad_id’.
market_id	A unique identifier for the marketplace the advertisement was advertised in
seller_id	A unique identifier for the seller who listed the advertisement
date	The date the advertisement was recorded by DATACRYPTO
category	The category of the taxon-advertisement. See Appendix S4 for category definitions.
end_use	The end use of the taxon-advertisement. See Appendix S5 for end use definitions.
how_processed	How the wildlife was processed.
what/physical	What physical component of the wildlife was being advertised.
wild_harvested	If the wildlife was being advertised as wild harvested.

729

730 **Appendix S9: Detailed results of number of taxa and advertisements by taxonomic rank**

731 Table S9. The number of taxa and advertisements for each taxonomic rank. There were occasionally
 732 multiple taxa per advertisement, thus, what is displayed is the number of taxon-advertisement
 733 combinations, which is greater than the total number of advertisements.

Taxonomic rank	Number of taxa	Cumulative proportion of all taxa	Number of taxon-ad combos	Cumulative proportion of all taxon-ad combos
subspecies	2	0.011	14	0.003
species	152	0.819	3,902	0.897
genus	17	0.910	102	0.920
family	10	0.963	58	0.933
order	4	0.984	236	0.987
class	1	0.989	4	0.988
kingdom	2	1.000	52	1.000

734

735 **Appendix S10: Dataset of taxa traded on the dark web and their characteristics**

736 Refer to csv file named “Appendix_S10_taxa_key.csv” for the traded taxa and their characteristics,
 737 including: taxonomy, drug information, IUCN status, and GISD status. Refer to Table S10 for a
 738 description of the columns.

739

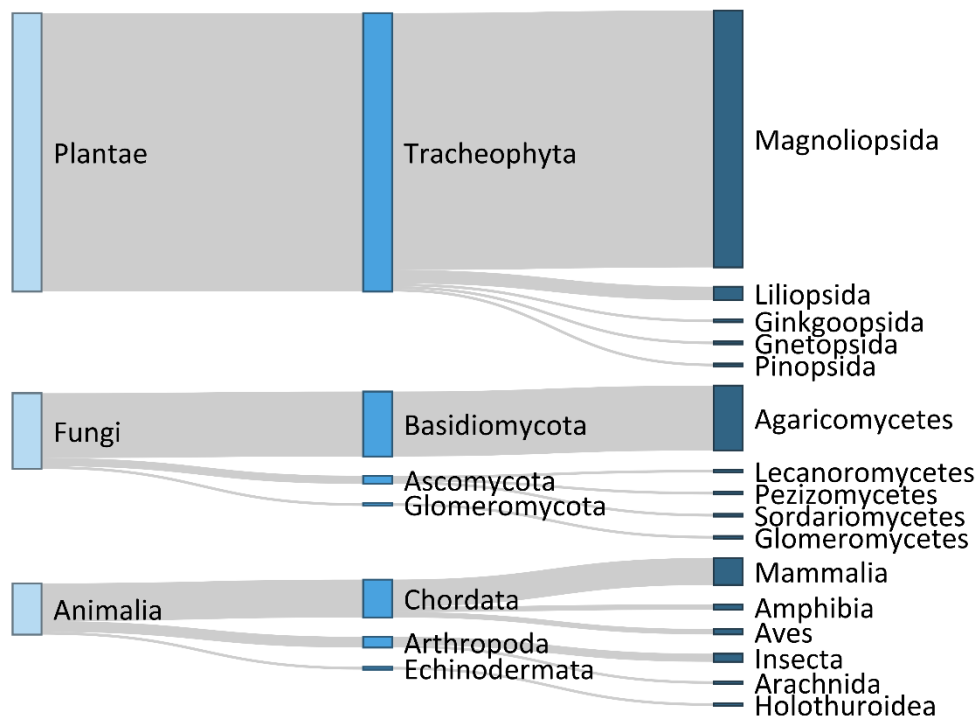
740 Table S10. Column descriptions for the data file “Appendix_S10_taxa_key.csv”

Column	Description
gbif_id	GBIF’s unique identifier for the taxon
gbif_name	The name of the taxon according to GBIF
gbif_rank	The taxonomic rank of the taxon (i.e., species, genus) according to GBIF
kingdom	The taxonomic kingdom of the taxon according to GBIF
phylum	The taxonomic phylum of the taxon according to GBIF
class	The taxonomic class of the taxon according to GBIF
order	The taxonomic order of the taxon according to GBIF
family	The taxonomic family of the taxon according to GBIF
genus	The taxonomic genera of the taxon according to GBIF
species	The taxonomic species of the taxon according to GBIF
subspecies	The taxonomic subspecies of the taxon according to GBIF
iucn	The IUCN Red List status for each species. NA indicates the taxon is not a species while NE indicates the species has not been evaluated by the IUCN to date.
iucn_threat	The level 5 (Biological resource use) IUCN threat code for a species. For more information, see https://www.iucnredlist.org/resources/threat-classification-scheme
gisd_listed	If the species is listed as invasive in the GISD.
drug_class	The drug class of the species, if it is a verified drug. See Appendix S6 for methods.
drug_chemical	The active chemical of species, if it is a verified drug. See Appendix S6 for methods.
drug_precursor	If the species contains a precursor, the precursor chemical is listed in this column. See Appendix S6 for methods.
drug_chemical_facilitated	If the species contains a chemical that is a facilitator, the facilitator chemical is listed in this column. See Appendix S6 for methods.
drug_reference	The citation to a peer-reviewed research article verifying the species contains a chemical that is a drug. See Table S6c for the full reference.

741

742

743 **Appendix S11: Detailed results of taxonomic diversity**



744

745 Figure S11.

746 Taxonomic diversity of species traded on the dark web. Bar widths correspond to the number of
 747 species found traded (n = 154). The first column represents taxonomic kingdom, middle column
 748 represents the phylum, and rightmost column represents the order. Taxa identified to a rank above
 749 species are not displayed. The six species of bacteria traded are not displayed.

750 **Appendix S12 Detailed results of species with known drug properties**

751 Table S12a. The number of advertisements and species with verified drug properties by drug class,
 752 stratified by taxonomic kingdom. See Appendix S6 for methods to derive drug classes and Table S6a
 753 for definitions of drug classes.

Kingdom	Drug Class	Number of ads	Number of species
Fungi	psychedelic	1,440	19
Plantae	psychedelic*	963	22
Plantae	facilitator	393	3
Plantae	depressant	378	9
Plantae	stimulant	321	11
Plantae	dissociative	100	1
Plantae	anxiolytic	77	6
Fungi	deliriant	25	1
Fungi	depressant	25	1
Animalia	psychedelic	15	1
Plantae	deliriant	9	2
Animalia	toxin	2	2

754 * Three species of plants contained a precursor (i.e.,
 755 safrole) to a psychedelic (MDMA): *Cinnamomum camphora*
 756 (3 ads), *Cinnamomum parthenoxylon* (14 ads), and
 757 *Sassafras albidum* (16 ads). See Appendix S6 for more
 758 information on drug classification.

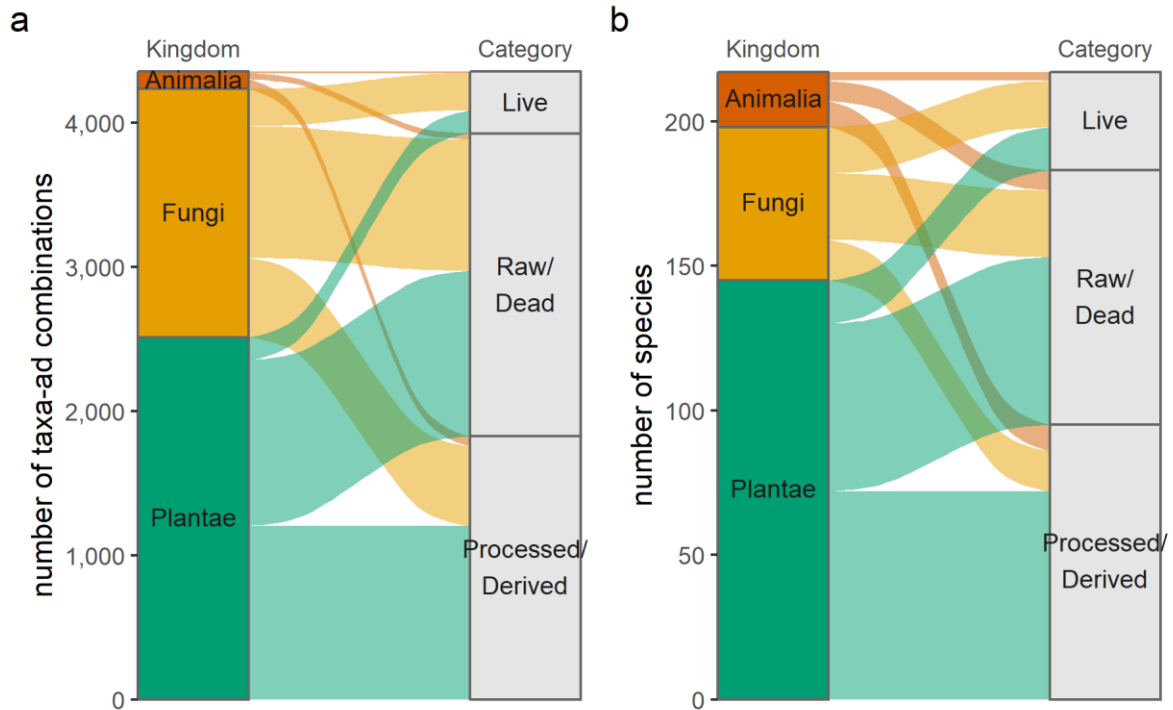
759

760 Table S12b. The number of advertisements and species with verified drug properties by active
 761 chemical, stratified by taxonomic kingdom. See Appendix S6 for methods to derive drug classes and
 762 Table S6a for definitions of drug classes. Note, harmine is the only chemical on this list that is a
 763 facilitator.

Kingdom	Active chemical	Number of ads	Number of species
Fungi	Psilocybin	1,440	19
Plantae	Methyltryptamines	752	10
Plantae	Harmine	393	3
Plantae	Mitragynine	238	2
Plantae	Mescaline	141	4
Plantae	Nuciferine	121	2
Plantae	Salvinorin A	100	1
Plantae	Apigenin	54	1
Plantae	Cocaine	38	2
Plantae	MDMA	33	3
Fungi	Psilocin	30	5
Plantae	Ibogaine	26	2
Fungi	Muscimol	25	1
Animalia	Methyltryptamines	15	1
Plantae	Ergine	11	3
Plantae	Atropine	9	2
Plantae	Several candidates	9	3
Plantae	Coumarins	7	1
Plantae	Lactucin	6	1
Plantae	Leonurine	6	1
Plantae	Kavalactones	4	1
Plantae	Nicotine	4	1
Animalia	Grayanotoxin	2	2
Plantae	Cathinone	1	1
Plantae	Ephedrine	1	1

764

765 **Appendix S13: Detailed results of advertisement category by taxonomic kingdom**



766

767 Figure S13. Characteristics of the 'category' of wildlife traded on the dark web. (a) The number of
 768 taxon-advertisement combinations stratified by category and (b) number of species stratified by end
 769 category. Note that some taxon-advertisement and species had more than one category. Category
 770 definitions can be found in Appendix S4. Advertisements and species of Bacteria are not shown (4
 771 advertisements; 6 species). Also, advertisements with the category of by-product are not shown,
 772 which consisted of 4 advertisements, 2 species (*Apis laboriosa* and *Apis dorsata*), one Family
 773 (Bufonidae), and one Order (Scorpiones).

774 **Appendix S14: Dataset of plant species richness by geographic areas**

775 Refer to csv file named “Appendix_S14_plant_spp_richness” for the data file containing the plant
 776 species native richness by geographic area. See Appendix S7 for methods. Refer to Table S14 for a
 777 description of the columns.

778

779 Table S14. Column descriptions for the data file “Appendix_S14_plant_spp_richness”

Column	Description
LEVEL3_COD	The code of the country/subdivision according to WGSRPD. See Appendix S7 for details.
LEVEL3_NAM	The name of the country/subdivision according to WGSRPD. See Appendix S7 for details.
n_spp	The number of plant species native to the given location. See Appendix S7 for details.
category	The category of what the ‘n_spp’ value refers to: <ul style="list-style-type: none"> • “All species” indicates this row represents the species richness of <i>all</i> plant species in the given location. • “Drug species” indicates this row represents the species richness of all species <i>with</i> verified drug properties in the given location. • “Non-drug species” indicates this row represents the species richness of all species <i>without</i> verified drug properties in the given location.

780

781 **Appendix S15: Detailed results on species advertised as wild harvested**

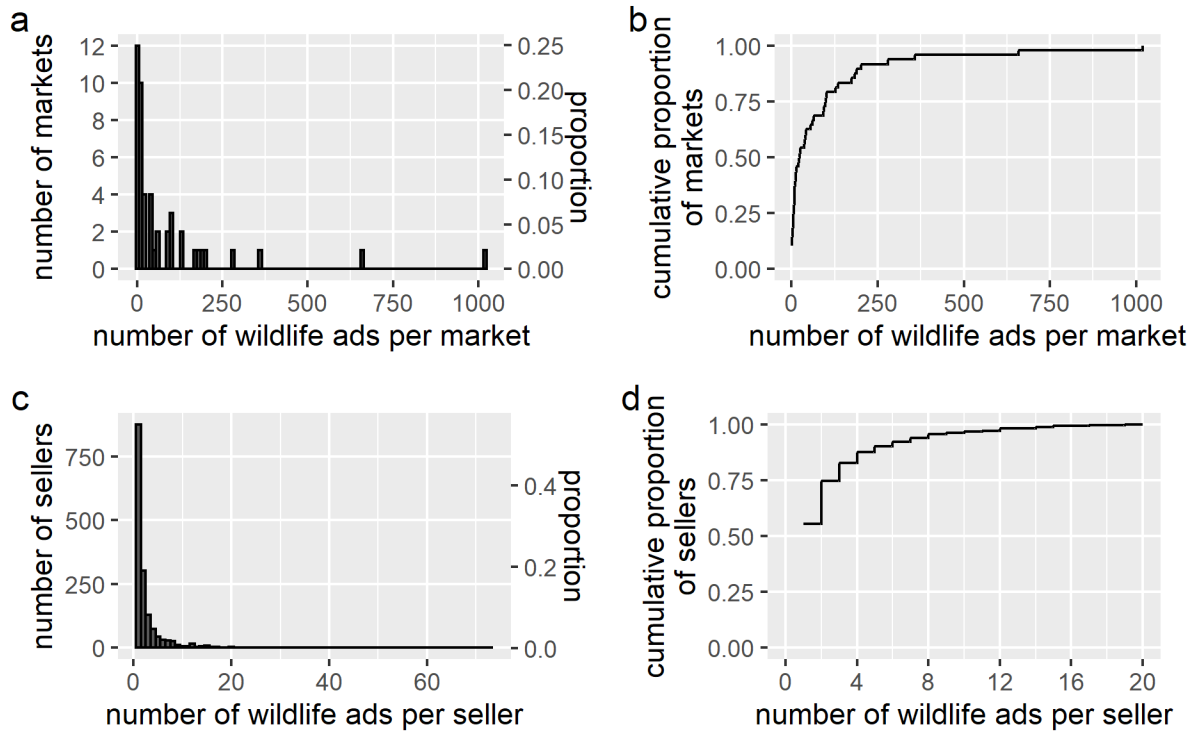
782 Table S15. Species traded on the dark web that are described by sellers as wild harvested along with
 783 their IUCN red list status. The number of advertisements in this table indicates the number of
 784 advertisements that a seller describes this species as wild harvested.

Species	Kingdom	Number of ads	IUCN
<i>Psilocybe cubensis</i>	Fungi	8	NE
<i>Psilocybe subaeruginosa</i>	Fungi	8	NE
<i>Amanita muscaria</i>	Fungi	6	NE
<i>Psilocybe semilanceata</i>	Fungi	6	NE
<i>Mitragyna speciosa</i>	Plantae	5	LC
<i>Lophophora williamsii</i>	Plantae	3	VU
<i>Tabernanthe iboga</i>	Plantae	3	LC
<i>Mimosa tenuiflora</i>	Plantae	2	LC
<i>Panaeolus cyanescens</i>	Fungi	2	NE
<i>Psilocybe cyanescens</i>	Fungi	2	NE
<i>Apis dorsata</i>	Animalia	1	NE
<i>Apis laboriosa</i>	Animalia	1	NE
<i>Apostichopus japonicus</i>	Animalia	1	EN
<i>Craterellus cornucopioides</i>	Fungi	1	NE
<i>Ophiocordyceps sinensis</i>	Fungi	1	VU
<i>Psilocybe mexicana</i>	Fungi	1	NE
<i>Psilocybe subcubensis</i>	Fungi	1	NE

785

786

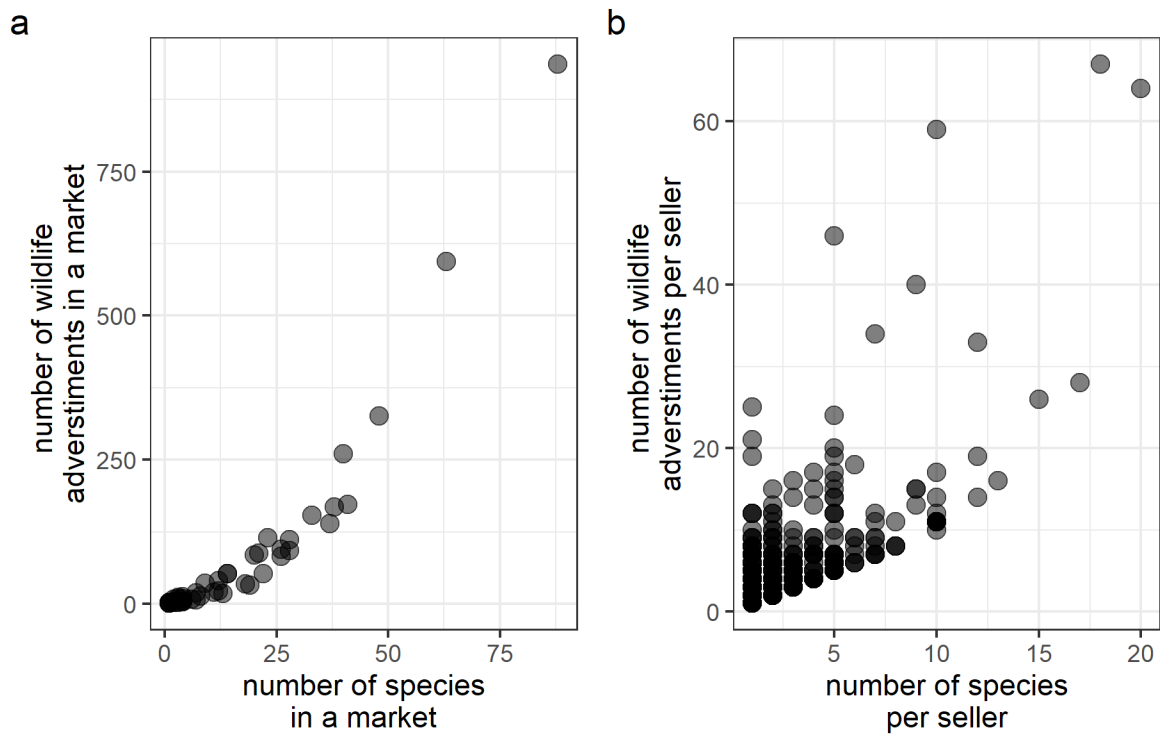
787 **Appendix S16: Detailed results on market and seller characteristics**



788

789 Figure S16. (a) Distribution of the number of wildlife advertisements per marketplace, where the bin
790 width is 10 advertisements. (b) The cumulative distribution of the proportion of marketplaces by the
791 number of wildlife advertisements in each marketplace. (c) Distribution of the number of wildlife
792 advertisements per seller, where the bin width is 1 species. (d) The cumulative distribution of the
793 proportion of sellers by the number of wildlife advertisements per seller.

794

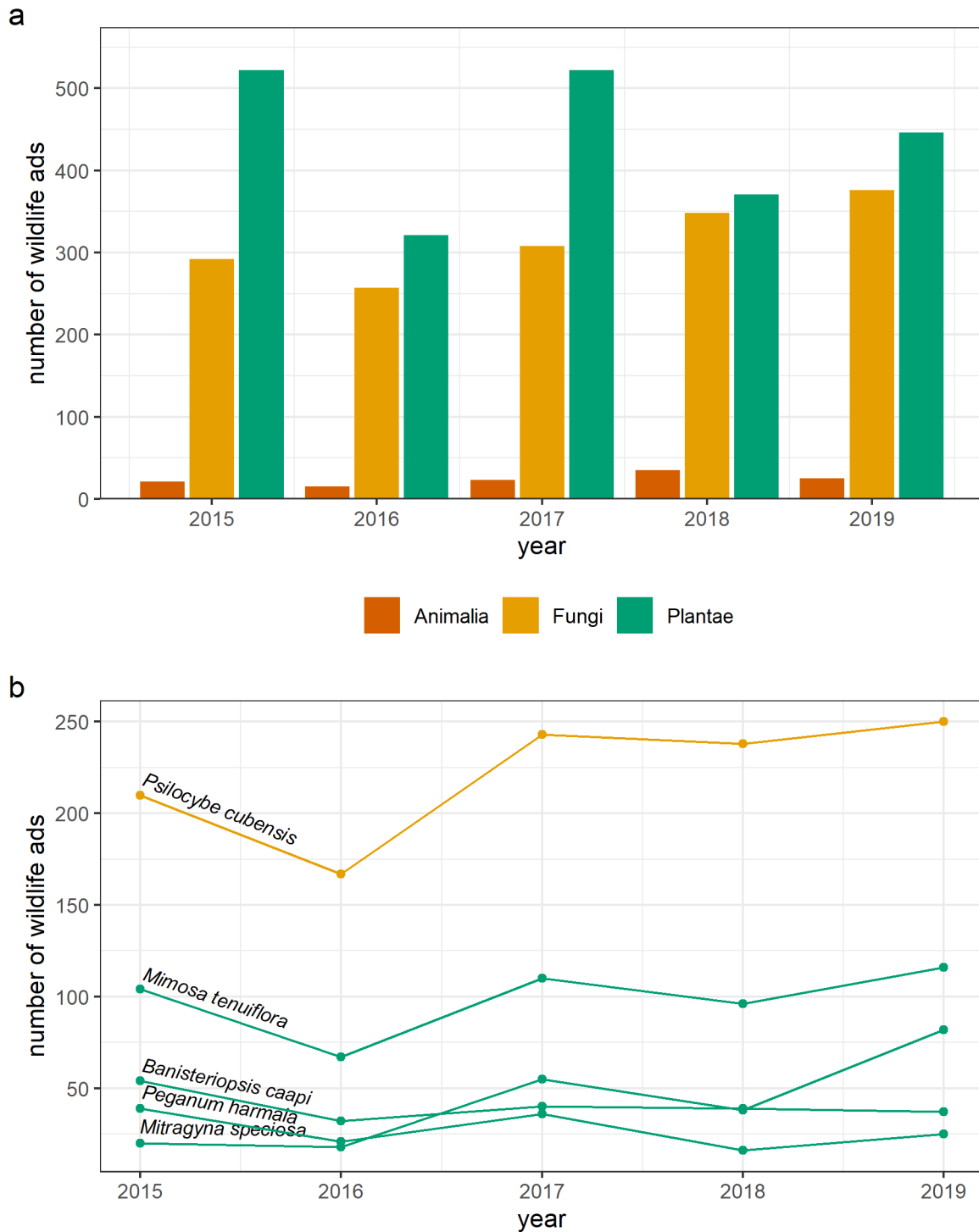


796

797 Figure S17. The relationship between (a) the number of species in a marketplace compared to the
 798 number of wildlife advertisements in a marketplace, and (b) the number of species per seller
 799 compared to the number of wildlife advertisements per seller. In general, the number of species
 800 found in a given marketplace was positively correlated with the number of wildlife advertisements
 801 found in a marketplace. Also, the number of species traded by a given seller was positively
 802 correlated with the number of wildlife advertisements for a seller. Yet, most sellers only had 1
 803 advertisement, and thus one species (Appendix S16).

804

805 **Appendix S18: Detailed results of taxonomic trends over time**



806
 807 Figure S18. Time series aggregated by number of advertisements per year, (a) by kingdom and (b)
 808 for the top 5 traded species. Years 2014 and 2020 were excluded due to incomplete data for the
 809 years. Bacteria were not visualized here because they were advertised in 4 advertisements.

810

811