Abstract

Ecosystem services flow interregionally between sending and receiving regions and their consumption can have impacts on ecosystems in distant regions. Global trade of wild species comprises a multitude of ecosystem services. We identify ecosystem service flows provided by traded species and delineate main sending and receiving regions through species range maps, based on bilateral trade entries in the database of CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora) from 2014 to 2018. We found that 65% of species represent the service class 'Science' (1378 species), 14% 'Decoration and pets' (293), 9% 'Entertainment' (188), 4.7% 'Conservation' (96), 4.6% 'Education' (95) and 2.7% 'Medicine' (54). Sending regions are predominantly located in the 'global South' and receiving regions in the 'global North'. Of the traded species 12.3% are threatened and 83.9% may become so without regulation. Of the main sending regions 24.1% are protected. Results show that main sending and main receiving regions differ depending on the ecosystem service. By linking actual trade data from CITES with different types of services, traded service-providing species can be directly assigned to service classes. Through the novel approach of identifying sending regions based on species-specific range maps, the study enables spatial analyses down to a 100x100km scale within countries and regions globally for more targeted conservation actions.

Keywords

telecoupling; interregional flows; service-providing units; trade; conservation; endangered species

1. Introduction

As a result of increasing globalization, our world is characterized by regional and interregional exchanges of people, goods and information. These increasing exchanges also affect interregional flows of ecosystem services (ES) (Schröter et al., 2018), which arise from the movement of material, energy or information between regions (Liu et al., 2013). These interregional flows occur through traded goods, species migration and dispersal, passive biophysical flows through currents of rivers, oceans and the atmosphere, as well as through information flows (Schröter et al., 2018). ES flow interregionally between sending and receiving regions. Sending regions are defined as regions in which interregional ES flows originate. Receiving regions are destination areas where interregional ES flows are obtained from the sending region and in which people benefit through, e.g., consumption or environmental risk reduction. The provision and actual use of ES can be separated by large distances (Koellner et al., 2019; Schröter et al., 2018; Liu et al., 2016). As a consequence, the use of ES and subsequent management decisions in one geographical region can have major impacts on biodiversity and ecosystems in distant regions, a process called telecoupling (Koellner et al., 2019). It is therefore important to consider interregional flows of ES in national and regional assessments to account for important implications for local and global sustainability (Koellner et al., 2019). To date, only a few assessments have explicitly studied interregional flows of ES (e.g. Kleemann et al., 2020; Koellner et al., 2019; Schirpke et al., 2019) and there is a need for method development.

Within this field, the trade of provisioning services like food and feed (Fridman and Kissinger, 2018; Boerema et al., 2016) or timber (Yu et al., 2013; Kastner et al., 2011) is particularly well studied. Several studies have outlined that consumption of traded ES in one region can have major impacts on ecosystems in another region and that biodiversity loss can be linked to interregional flows of ES (IPBES, 2018; Moran and Kanemoto, 2017). A particular type of trade that underlies interregional ES flows has, however, so far been studied to a much lower extent. The global trade of animal and plant species (CITES, 2019a; Nijman, 2010), for which bilateral data on trade transactions between sending and receiving regions exists, comprises a multitude of ES. Traded species can either be sourced from captivity or the wild. Wildlife trade is defined as the total sum of "all sales or exchanges of wild animal and plant resources by people" (Nijman, 2010, p. 1102). It involves live animals and plants as well as parts and products, such as skins, extracts, and medicinal ingredients.

This study examines the wildlife trade of endangered species as listed in the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) trade database (CITES, 2019b). The traded endangered species, hereinafter referred to as exported species, contribute to a range of ES. With the first official zoos and circuses in the 19th century, species became part of entertainment and education (van Uhm, 2018). The 21st century has been categorized by a rising demand for luxury items, e.g. pets, and traditional Asian medicine (Challender et al., 2015). Today, species are being traded for various purposes. They contribute to entertainment and relaxation or as companion animals (Bush et al., 2014). Furthermore, traded species are being used for educational, and medical and scientific purposes (van Wyk and Prinsloo, 2018; Nijman and Bergin, 2017; Wolff et al., 2017; Ferreira et al., 2013). Many rural people and communities, primarily people in developing countries, rely on trade of wild species, including timber species, medicinal plants and living or parts of vertebrates (Roe, 2002). Unsustainable trade of species taken from the wild may pose major threats to global biodiversity if species are overexploited (Ribeiro et al., 2019). The quantification of these flows of traded ES is important for managing the prevention of overexploitation and for assuring of a fair distribution of opportunity costs of conservation (Schröter et al., 2018).

To prevent overexploitation and to thereby ensure legal and sustainable trade, CITES was enacted in 1975. CITES regulates the international trade in threatened and potentially-threatened species through a licensing-system which registers exports and imports of the currently 183 Parties. Traded species are categorized into three 'Appendices', according to the degree of protection they need because of overexploitation through international trade. Each Party is required to submit an annual report of trade, containing a summary of information on quantities and terms of traded specimens, the importing countries, etc. (CITES, 2013). The submitted trade reports include information on the purpose of trade for each traded specimen which provides crucial information on the respective ES that each specimen provides for the importing country. With more than 1 million records added annually (Robinson and Sinovas, 2018), the CITES Trade Database is a useful tool for understanding and monitoring wildlife trade, although the database only comprises trade of species that are listed in CITES. In recent years, there has been an increasing number of studies focusing on trade monitored by CITES (e.g. Scheffers et al., 2019; Harfoot et al., 2018; Bush et al., 2014), most of which primarily analyzed the trade of taxonomic groups (e.g., Hinsley et al., 2018; Auliya et al., 2016; Harrington, 2015) or the trade of species from a specific geographical region (e.g., Challender et al., 2015; Natusch and Lyons, 2012; Schlaepfer et al., 2005). Until now, however, to the best of our knowledge, no study has linked the global trade of species with an analysis of interregional ES flows.

To better assess the contributions of single species to ES provision and the consequences of population changes to ES provision, Luck et al. (2003) developed the concept of 'service-providing units'. A 'service-providing unit' is defined as the group of individuals of a traded species that provides a particular ES. The analysis of ES through globally traded species in this study is based on this concept. The respective supporting habitats of these exported species can be used to spatially delineate sending regions from which interregional ES flows originate (Kleemann et al., 2020; Koellner et al., 2019; Schröter et al., 2019). Ceausu et al. (2021) have recently pointed to the need of a stronger consideration of species richness when quantifying and mapping ES. Using such approaches would also allow to better estimate to what extent ES and biodiversity align spatially (Cimon-Morin et al., 2013; Maes et al., 2012), which in turn would increase knowledge on the operability of inclusive conservation approaches searching for synergies between the protection of biodiversity and the needs of people (Mace, 2014; Tallis and Lubchenco, 2014). An analysis of interregional flows of ES and the respective protection status of the sending regions could help to understand to what extent areas important for the provision of ES (for use in distant regions) could show such synergies. The aim of this study is to identify global interregional flows of ES provided by exported species as registered in the CITES database and to spatially delineate the main sending and receiving regions of this wildlife trade, building on a regional structure by the Intergovernmental Science-Policy-Platform on Biodiversity and Ecosystem Services (IPBES). We use richness of exported species as a proxy for interregional flows. Furthermore, in order to better understand the current state of sending regions, we aim to characterize located hotspots of exported species by their degree of threat and protection within sending regions. We here strive to advance the field of interregional flows of ES and telecoupling by presenting a new method to assess flows of ES globally that combines trade records with range maps building on species as service-providing units.

2. Methods

Our analysis consisted of three major steps, adapted from Koellner et al. (2019) who provided a general guidance for the assessment of interregional ES flows: identification of relevant ES flows, characterization of sending and receiving regions, and quantification of interregional ES flows. The following analysis is based on this guidance structure.

2.1 Identification of relevant ecosystem service flows provided by exported species

Provided services were identified by assigning ES classes, following the classification of Díaz et al. (2018), to related purposes of use of traded species. When trading a CITES-listed species, the Parties are requested to submit the intended use of the traded species in the importing country in the trade report (CITES, 2013). CITES categorizes the submitted records of traded species into twelve different purpose codes: B: Breeding in captivity or artificially propagation, E: Educational, G: Botanical garden, H: Hunting trophy, L: Law enforcement/judicial/forensic, M: Medical – including biomedical research, N: Reintroduction or introduction into the wild, P: Personal, Q: Circus and travelling exhibitions, S: Scientific, T: Commercial, Z: Zoo. For this study, ten of the twelve purpose codes were considered. The purposes of use in law enforcement/judicial/forensic (L) and commercial use (T) were excluded. The use of species in criminal and court proceedings could not be assigned to a respective ES, as this category does not represent an ES classified by Díaz et al. (2018). As for the commercial use of traded species, there was not sufficient information about the intended usage in the importing country available (Robinson and Sinovas, 2018) and the general description of a commercial purpose could be assigned to several ES. The remaining purpose codes were assigned to related ES as shown in Table 1.

The following six classes (adapted, renamed and specified from Díaz et al., 2018) will be used throughout the study:

1) **Decoration and Pets** (derived from “Materials, companionship and labor”): Production of materials derived from organisms for ornamental purposes, e.g. hunting trophies, such as horns, tusks, ivory, etc.; live organisms being directly used for decoration, company, transport and labor, e.g. ornamental plants in households, pets.

2) **Science** (“Medicinal, biochemical and genetic resources”): Production of genes and genetic information used for plant and animal breeding and biotechnology, e.g. specimens, derivatives, skins.

3) **Medicine** (“Medicinal, biochemical and genetic resources”): Production of materials derived from organisms used for medicinal, veterinary and pharmacological purposes, e.g. specimens, derivatives, skins.

4) **Education** (“Learning and inspiration”): Organisms used for education and acquisition of knowledge, e.g. skeletons, skulls, feathers, live organisms.

5) **Entertainment** (“Physical and psychological experiences”): Organisms enabling physically and psychologically beneficial activities, including relaxation, leisure, tourism and aesthetic enjoyment, e.g. zoo and circus animals, such as parrots, elephants, crocodiles, and plants on display in botanical gardens.

6) **Conservation** (“Maintenance of options”): Present and future benefits associated with the continued existence of a high biodiversity of species, e.g. conservation of ecosystems, possibility of an on-going biological evolution, options for yet unknown discoveries, such as new medicines and materials.

Table 1: Purpose codes used in trade reports of CITES and related ES categories (based on Díaz et al., 2018). The shortened term for each ES category which will be used hereafter is shown in brackets in the left column.

Ecosystem service categories	Purpose code
Decoration and pets (Materials, companionship and labor)	H: Hunting trophy
	P: Personal
Science (Medicinal, biochemical and genetic resources)	S: Scientific
Medicine (Medicinal, biochemical and genetic resources)	M: Medical (including biomedical research)
Education (Learning and inspiration)	E: Educational
Entertainment (Physical and psychological experiences)	G: Botanical garden
	Q: Circus and travelling exhibitions
	Z: Zoo
Conservation (Maintenance of options)	B: Breeding in captivity or artificially propagation
	N: Reintroduction or introduction into the wild

2.2 Data preparation

2.2.1 Trade data

Trade reports were obtained from the CITES Trade Database (CITES, 2019b), with the following variables: Year, exporting and importing countries, source, purpose, term and taxon (i.e. genus, species or subspecies). Trade reports were obtained for the period 2014-2018, with 2018 being the most recent data available for analysis. Since new Parties join every year, the last five years represent a time period with only few new members (CITES, 2019a) and therefore, only minor errors will be made by combining trade volumes of the single years. For this time period, the recorded trade events of all exporting and importing countries with trade of wild species (source code = ‘wild’) were downloaded, regardless of the respective terms of trade. In this context, the term ‘wild’ refers to the legal removal and trade of species from the wild, in contrast to, for example, artificial propagation or breeding in captivity. All terms of trade, e.g. live species as well as skins, feathers, extracts, etc., were included, since the aim of this study was to analyze the number of different species traded and not the number of traded individuals for each species. Note that a quantification on the species level was the most feasible analysis, as standardized units to aggregate trade volumes are lacking in the CITES database (see discussion). The purpose codes ‘law enforcement/judicial/forensic’ and ‘commercial’, comprising of 121 and 96664 trade reports, respectively, for the specified time period, were excluded from the download, as they did not clearly match the classification of the selected ES in this study.

Before further analyzing the traded endangered species from the CITES Database, the trade data table had to be edited as there were undesired and incomplete reports. Reports were removed if information about the importing country or the country of origin was missing (ISO-Code ‘XX’) or reported as ‘various’ (ISO-Code ‘XV’). If there was no entry in the cell for the country of origin, the exporting country, if recorded, was assumed as country of origin. If, however, the country of origin was recorded as ‘unknown’ (XX) or ‘various’ (XV), the assumption was made that the recorded exporting country was not the country of origin (i.e. occurrence of re-export, which would confound our aim of identifying sending regions) and that the country of origin had not been recorded. In this case, the report was removed from the data table. Additionally, exporting countries or countries of origin recorded as ‘introduction from the sea’ (ZZ) were excluded, since the analysis only includes the trade of terrestrial species. Furthermore, the data table still contained reports with source ‘unknown’ or with no entry, which were removed as well as reports with incomplete scientific species names (‘spp.’). The initially downloaded data contained 37469 report entries with 3435 different species, the complete and curated dataset contained 32878 report entries with 2755 different species. A detailed listing of the number of removed entries can be found in Appendix B.

2.2.2 Characterization of sending and receiving regions

Distribution data of species was requested from the IUCN (International Union for Conservation of Nature) Red List of Threatened Species, BirdLife International, and GIFT (Global Inventory of Floras and Traits). These datasets contain vector data of range maps delineating the extent of occurrence for each analyzed species. A range map describes the smallest polygon that includes all known occurrences of a species in which no internal angle exceeds 180 degrees (Bland et al., 2015).

As data on the distribution of species is limited, we included data for six well-studied species groups: amphibians, birds, insects, terrestrial mammals, plants, and reptiles. Data on the distribution of amphibians, insects, terrestrial mammals, and reptiles was retrieved from the IUCN Red List of Threatened Species (IUCN, 2019). Data on the distribution of plants from IUCN does not include the majority of traded species in the CITES dataset, and hence data from the Global Inventory of Floras and Traits (GIFT) was requested (Weigelt et al., 2019). This dataset covers most of the traded plant species and was therefore suitable for subsequent analysis. Furthermore, data on the distribution of birds was received from BirdLife International (BirdLife International and Handbook of the Birds of the World, 2018).

Range maps from the IUCN Red List of Threatened Species and from BirdLife International contained information on 'presence', 'origin' and 'seasonal' occurrence of the respective species. Following the selection of Schröter et al. (2019), only entries with the presence-code 'extant', 'probably extant' or 'possibly extant' were included in order to identify the most probable ranges of service-providing species. In addition, the origin of species was limited to 'native' and 'reintroduced' and the seasonal classification was set to 'resident', 'breeding season' and 'non-breeding season'. The data table from GIFT contained information on the status of the native occurrence of the listed plant species. We only included range maps with the native distribution of the respective species. All range maps of the traded species were spatially divided into five geographical regions, as defined in the following.

Building on the regional structure that IPBES identified for the assessment of biodiversity and ecosystem services (IPBES, 2015), the following five regions were selected and defined as sending and receiving regions: Europe and Central Asia, Asia and the Pacific, Africa, South- and Mesoamerica, and North America. This regional structure of IPBES was used in order to define clear units for the representation of the interregional ES flows at an appropriate aggregated level (since our aim was not to analyze flows between single countries, but rather at global level between regions). There is also reason to assume that future regional and global assessments will use the established IPBES regional classifications. For this study, the IPBES defined region of 'the Americas' was further divided into two regions because of major differences in exporting and importing trade volumes. The complete list of all countries used and their allocation to the respective region can be found in Appendix A. Sending regions were defined as regions within range maps of exported species. Receiving regions were defined as regions which import species (importing countries of exported species).

2.3 Quantification of ecosystem service flows

2.3.1 Spatial analyses

The reports of the CITES data table were assigned to the respective region by joining the data table with the list of countries allocated to the five regions.

Taking up on the limited distribution data, the trade dataset was narrowed down to the six species groups (amphibians, birds, insects, terrestrial mammals, plants, reptiles), thereby twelve other species groups were removed (*Actinopteri, Anthozoa, Arachnida, Bivalvia, Cephalopoda, Coelacanthi, Dipneusti, Elasmobranchii, Gastropoda, Hirudinoidea, Holothuroidea, Hydrozoa*). This resulted in another removal of 1843 report entries for which no distribution data was available (details in Appendix B). The remaining species names listed in the trade data table were compared with the remaining species names listed in the data tables of the range maps. This was done by running the function 'Join by attributes' in ArcMap (ESRI, Version 10.7) with the respective columns. To prevent the removal of entries with mismatch concerning the spelling of species names, added subspecies suffixes or because of outdated names these irregularities were corrected prior joining the two data tables. To check for alternative names, the online data from IUCN (IUCN, 2019) and GBIF (GBIF, 2019) were used. Only entries in the trade data table were adjusted. Any changes that were made during this step were documented (Appendix C). As a result, a dataset for the global trade of a total number of 26456 report entries with 1699 different species was obtained.

Note that for the analysis imports back into the sending region were excluded, since the aim of this study was to analyze interregional flows of ES. Interregional flows are flows of ES between differing sending and receiving regions, whereas intraregional flows describe the flows of ES within the same region. This led to another reduction of the final number of trade reports and traded species used for the analysis. This final dataset contained 21861 report entries with 1552 different species.

To quantify the trade amount of exports or imports for each region, each species was only considered once per sending and receiving region. Similarly, the analysis of sending and receiving regions was done for each ecosystem service category individually.

For sending regions, exported species richness was analyzed by overlaying the range maps of included species. Range maps of traded species were converted into a raster format in RStudio (RStudio Inc., Version 1.2.1335) with a resolution of 100x100 km by using a raster grid as mask (Amatulli et al., 2018). This coarse resolution was applied, since fine resolutions have been shown to overestimate actual species occurrences (Hurlbert and Jetz, 2007). Cells within the species range were assigned the value 1 and cells outside the species range the value 0. Then, the range rasters for included species (see Section 2.2) were added up. As a result, cell values of the added range rasters showed the number of species with ranges existent in the respective raster cell. For receiving regions, the total numbers of different species that were imported into each country were summed.

2.3.2 Identification of hotspots

Hotspots of exported species were defined as areas with high numbers of exported species occurring per cell. Cell values of the upper 10% of the grid cells of sending regions, a commonly used percentage to delineate hotspots (Schröter and Remme, 2016), were taken as a threshold for hotspot identification. This method, commonly described as 'top richest cells method', divides the grid cells, after ranking them from high to low, into classes with an equal number of cells. The class with the highest value is then defined as a hotspot (Schröter and Remme, 2016).

Hotspots of endangered species (hereinafter referred to as vulnerability hotspots) were defined by only selecting species categorized as VU (vulnerable), EN (endangered) or CR (critically endangered) within IUCN categories (Baillie et al., 2004). The dataset on the global distribution of plants does not provide information about the vulnerability of included species. Therefore, vulnerability of plant species was taken from the CITES reports, when they were listed in Appendices I (species threatened with extinction) and II (species which may become threatened with extinction) (CITES, 1973). In addition, plant species included in the IUCN dataset of plants and listed as VU, EN or CR were included as endangered species (IUCN, 2019). These two datasets together represent an adequate overview over globally threatened plant species. Vulnerability hotspots were identified similarly as hotspots of all exported species, but with restricting the analyzed species to endangered ones. Identified hotspots for all exported species were compared with vulnerability hotspots. This was done by calculating the Cohen's Kappa statistic of agreement of the spatial raster data in RStudio (RStudio Inc., Version 1.2.1335) with the package 'fmsb' (Nakazawa, 2019). For comparison, the range maps of the identified hotspots of exported species and vulnerability hotspots were converted into a raster format with a resolution of 100x100km. Cells within a hotspot were assigned the value 1, cells outside a hotspot the value 0.

The protection status of identified hotspots of exported species was evaluated by comparing the coverage of hotspot regions with protected areas with the coverage of total sending regions with protected areas. Since hotspots of exported species are exclusively located in Africa and South- and Mesoamerica, the total sending regions used for this analysis were sending regions from only these two regions. Protected areas information were taken from the World Database on Protected Areas (UNEP-WCMC and IUCN, 2020). The protected area categories 'Not Reported', 'Not Applicable' and 'Not Assigned' were included in the analysis, following the recommendation of the UNEP-WCMC (UNEP-WCMC, 2017), since these categories do not imply that respective areas are less well managed than categorized areas.

Figure 1 displays a visual representation of the methodology after the appropriate trade reports from the CITES trade database were selected.

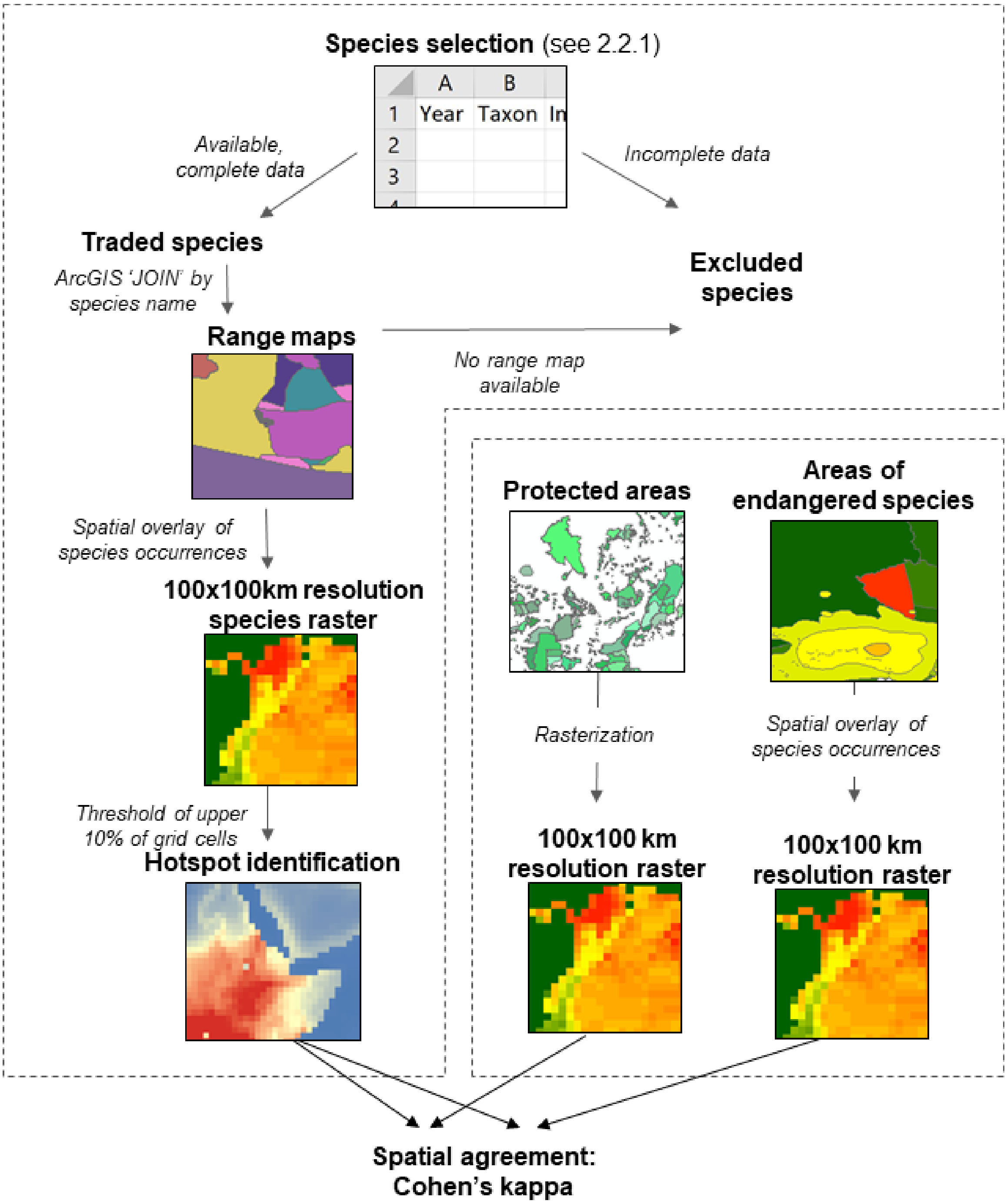

Figure 1: Visual representation of the methodology described in section 2.3.

3. Results

3.1 Global trade in exported species

Exported species of the six included species groups included in the analysis are composed of 41% bird species, 22% mammal species, 17% plant species, 16% reptile species, 4% amphibian species and less than 1% insect species.

We found that 65% of all species (1552 unique species) represented the ES class ‘Science’ (1378 species), 14% ‘Decoration and pets’ (293 species), 9% ‘Entertainment’ (188 species), 4.7% ‘Conservation’ (96 species) 4.6% ‘Education’ (95 species) and 2.7% Medicine (54 species). Some species were counted double if they were traded for more than one ES. The largest part of global exports, calculated as number of species exported, originated from South- and Mesoamerica (46%), followed by Africa (24%), Asia and the Pacific (19%), Europe and Central Asia (6) , and North America (5%) (Fig. 2).

The main receiving regions, calculated as number of different species imported, were North America (41%), followed by Europe and Central Asia (33%), Asia and the Pacific (14%), South- and Mesoamerica (8%), and Africa (4%) (Fig. 2).

Concerning the degree of threat of the species included in this study, 12.3% were assigned to Appendix I (‘species threatened with extinction). 83.9% of the species were registered in Appendix II (‘species which may become threatened with extinction’) and 3.2% in Appendix III (‘species that fall under regulations within the jurisdiction of any CITES member’). For less than 1% no Appendix was entered in the database.

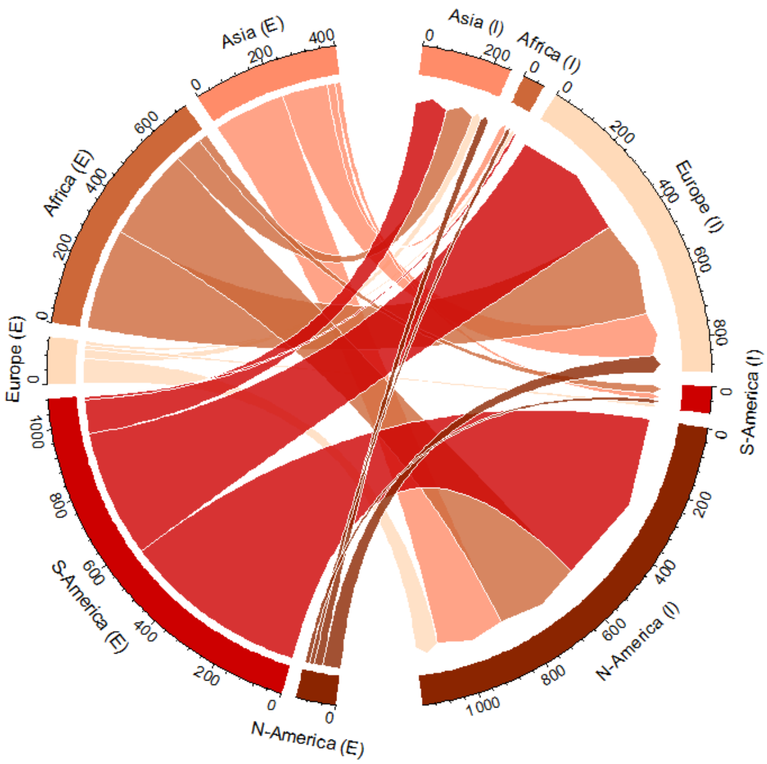

Figure 2: Global exports (left) and imports (right) of exported species to the five global regions: Asia = Asia and the Pacific, Africa = Africa, Europe = Europe and Central Asia, S-America = South- and Mesoamerica, N-America = North America. (E) refers to export regions, (I) refers to import regions. Numbers refer to the quantity of different species. Diagram was created with package ‘circlize’ (Gu et al., 2014).

3.2 Identification of sending regions

Sending regions for all ES combined can be found on a global scale, except for the interior of Greenland (Fig. 3). Main sending regions were identified in Mesoamerica, the Northern part of South America, and Southeast Africa. The highest number of overlapping species range maps is 247 for regions in South America. Figure 3 shows the sending regions of exported species which are displayed on the left side in Figure 2.

Figure 4 shows the globally distributed sending regions for each ES category individually. The sending regions for the ES ‘Decoration and pets’, ‘Science’ and ‘Education’ are to a large extent globally

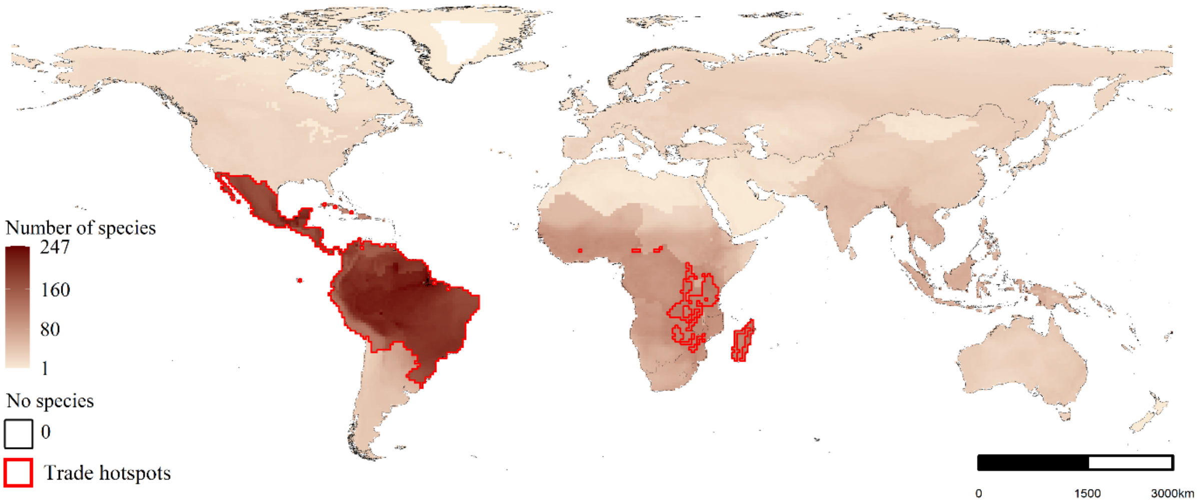

Figure 3: Global sending regions and hotspots of exported species. Color scale represents the species richness within a raster cell (quantity of species abundant per cell). Coordinate System: WGS 84, EPSG: 4326.

distributed with few exceptions in Greenland, Northern Africa and Southwestern Asia. The global distribution of sending regions of the ES categories ‘Medicine’, ‘Entertainment’ and ‘Conservation’ is patchy, especially in Europe and Asia and for ‘Conservation’ in America as well. Main sending regions are located in South- and Mesoamerica for ‘Science’, ‘Medicine’, ‘Entertainment’ and ‘Conservation’ and in Southeast Africa for ‘Decoration and pets’ and ‘Education’.

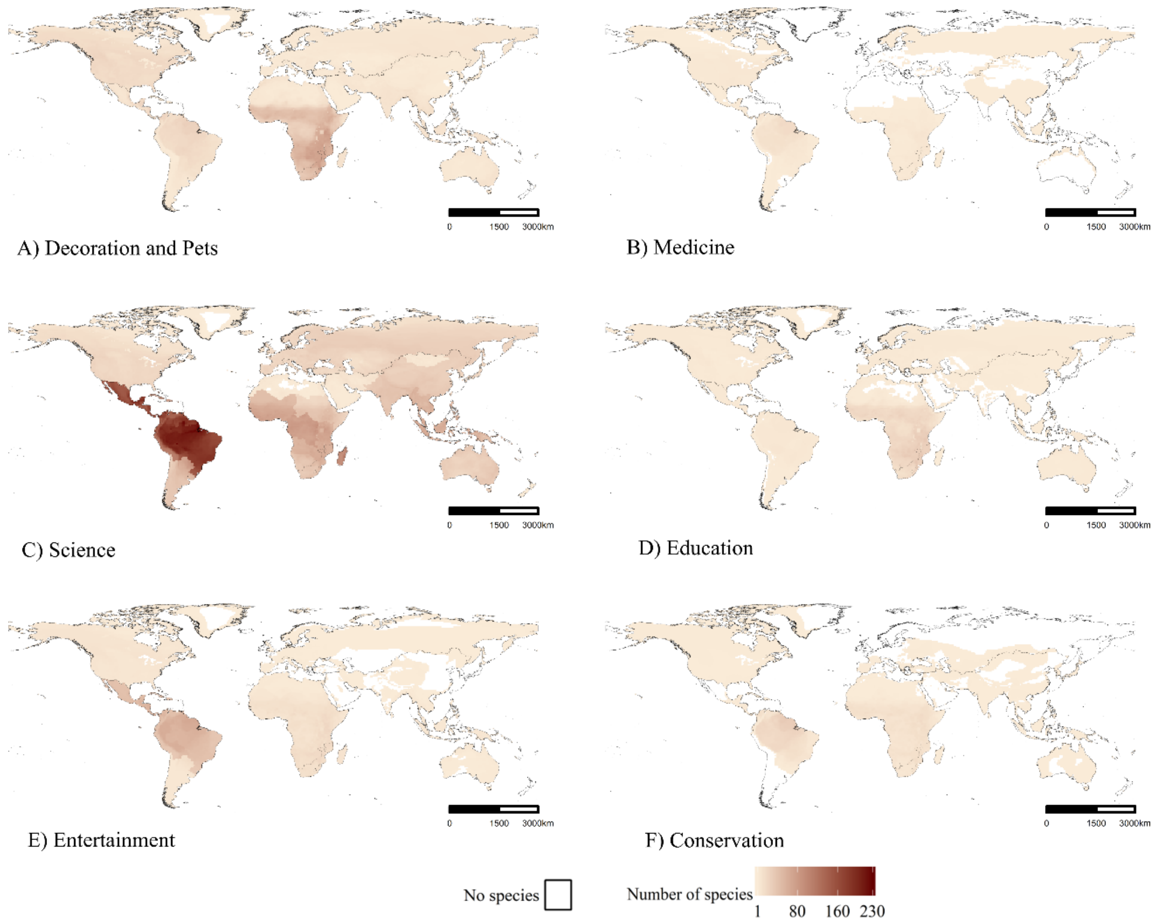

Figure 4: Global sending regions of exported species for the ecosystem service categories individually. Color scale represents the species richness within a raster cell (quantity of species abundant per cell). Coordinate System: WGS 84, EPSG: 4326.

The exported species for each ES category are subdivided into the species groups as displayed in Table 2. Amphibian species are almost exclusively exported for ‘Science’. Birds and mammals show a lower species export ratio for ‘Science’ and a higher species export ratio for ‘Decoration and pets’ than plants and reptiles. Insect species are mainly exported for ‘Decoration and pets’ and ‘Science’.

Table 2: Quantity of exported species per species group for the ecosystem service categories individually. Species were counted double if exported for more than one ecosystem service category.

	Decoration and pets	Science	Medicine	Education	Entertainment	Conservation	Total
Amphibians	0	62	0	0	1	1	64
Birds	164	547	22	50	58	50	891
Insects	3	3	0	1	0	0	7
Mammals	91	309	26	37	44	32	539
Plants	5	227	1	1	61	0	295
Reptiles	30	230	5	6	24	13	308
Total	293	1378	54	95	188	96	

3.3 Identification and characterization of sending hotspots

Hotspots of exported species are located in parts of Africa and South- and Mesoamerica (Fig. 3). These areas encompass 21,720,000 km^2 (9.9%) of the total sending area, i.e. globally distributed sending areas with at least one traded species present.

Hotspots of exported species were compared with vulnerability hotspots (Appendix D). Of the hotspots of exported species 91% fall into vulnerability hotspot areas. The Cohen's Kappa statistic was 0.89 ($p < 0.001$, 95% confidence level: [0.88; 0.90]) which represents an almost perfect agreement. High congruence in hotspots of exported, service-providing hotspots and vulnerability hotspots exists in South- and Mesoamerica and along the coast in Madagascar. Regions of hotspots of exported species without identified vulnerability hotspots are located in Southeast Africa. Vulnerability hotspots without identified hotspots of exported species can be found in Southeast Asia.

24.1% of the hotspots of exported species fall into one of the IUCN Management categories for protected areas (Appendix E), whereas only 17.2% of total providing regions, i.e. regions of Africa and South- and Mesoamerica, are protected (Table 3). Within hotspots of exported species, 1.0% of the area is classified as category Ia which represents the highest degree of protection. Within total sending regions only 0.4% of the area is classified as category Ia. Higher proportions of hotspot areas of exported species fall into categories II, V and VI compared to the proportions of areas of total sending regions that fall into these categories

(Table 3). Lower proportions of hotspot areas of exported species compared to total sending areas fall into categories III and IV (Table 3).

A high coverage of hotspots of exported species with protected areas can be identified in the Amazon forest. Less coverage can be found South of the Amazon rainforest in the central parts of South America and, additionally, in Mesoamerica. Identified hotspots of exported species in Southeast Africa are to a fair amount covered by protected areas, as well as hotspots of exported species in Madagascar.

Table 3: Coverage of hotspots of exported species and of total sending regions with protected areas and respective proportions divided into IUCN Management categories (UNEP-WCMC, 2017).

IUCN Management category	Proportion within hotspot area covered with protected area (in %)	Proportion within total sending area covered with protected area (in %)
Ia (Strict Nature Reserve)	1.0	0.4
Ib (Wilderness Area)	< 0.1	< 0.1
II (National Park)	5.9	3.6
III (Natural Monument or Feature)	0.4	0.2
IV (Habitat/Species Management Area)	0.3	1.2
V (Protected Landscape/Seascape)	2.8	1.0
VI (Protected area with sustainable use of natural resources)	7.2	3.6
Not Reported	4.7	4.8
Not Applicable	1.8	2.4
Not Assigned	0	< 0.1
Total	**24.1**	**17.2**

3.4 Identification of receiving countries

Receiving regions are displayed as receiving countries, since this represents the most detailed information available. Receiving countries are globally distributed with few exceptions in Africa (Fig. 5). Main receiving countries are the United States of America with a total number of 1049 different imported species, followed by Germany with 430 different species, the United Kingdom with 286 different species and Canada with 272 different species (Table 4).

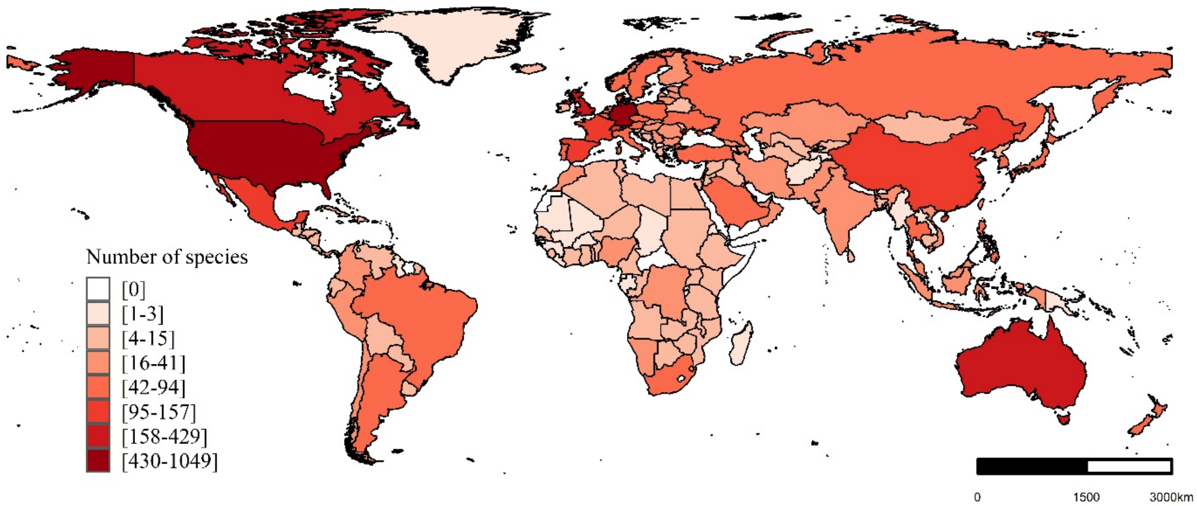

Figure 5: Global receiving countries of traded species. Color scale represents the quantity of imported species per country. Data clustering was done based on the Jenks optimization method (Jenks, 1967). Coordinate System: WGS 84, EPSG: 4326.

Table 4 displays the top four importing countries of each ecosystem service category, in means of total number of different imported species for the respective service category.

Table 4: Top four main importing countries of service-providing species for the ES categories individually. Species were included more than once if imported for more than one ES.

Ecosystem service category	Country	Number of imported species
All six ES	United States of America	1049
	Germany	430
	United Kingdom	286

	Canada	272
Decoration and pets	United States of America	214
	United Kingdom	136
	Canada	94
	Switzerland	93
Science	United States of America	934
	Germany	352
	Canada	208
	United Kingdom	166
Medicine	United States of America	32
	China	12
	United Kingdom	11
	Netherlands	10
Education	United States of America	47
	China	44
	Zaire	14
	Germany	11
Entertainment	United States of America	86
	China	56
	Germany	48
	Turkey	20
Conservation	China	43
	Philippines	31
	Thailand	29
	Russia	28

4. Discussion

4.1 Main sending and receiving regions

Our results quantify and spatially delineate where traded service-providing species underpin interregional ES flows between sending and receiving regions across the world. Comparisons with results of studies that determined absolute trade quantities of individuals should only be seen in terms of general tendencies (as we have used species numbers as a proxy). Whereas parts of South- and Mesoamerica and regions in Southeast Africa serve as hotspots of exported species, North America, and Europe and Central Asia are evidently the major importers of these exported species. This indicates a distinction in exporter and importer regions between the ‘global South’ and the ‘global North’ (Reuveny and Thompson, 2007). South- and Mesoamerica, and Africa, the main exporting regions of exported species, represent to a majority the ‘global South’ (Reuveny and Thompson, 2007) which is, in general, suggested to be a source of resources (Givens et al., 2019). The role of poorer countries as exporter on the global wildlife market is therefore affected by multiple factors. First of all, both legacy and current economic dependencies result in the role of ‘southern countries’ as suppliers (Givens et al., 2019; Giljum and Eisenmenger, 2004). Due to their economically less diversified and less developed economies, countries from the ‘global South’ are more dependent on trade with developed regions from the ‘global North’. After the initial approach of establishing regional markets to substitute imports and reduce external dependencies did not reach its goal, ‘southern countries’ increasingly aimed to get access to international markets during the 1990 to improve their economic situation on the international market (Krapohl, 2020). Additionally, countries within the ‘global South’ tend to be main exporting countries of species, since they possess the majority of global biodiversity, e.g. hotspots like the Amazon rainforest or the Coastal Forests of Eastern Africa (Mittermeier et al., 2011) and species native to these regions are in high demand on a global scale (Scheffers et al., 2019; Symes et al., 2018; Harrington, 2015). And finally, high export volumes due to increasing demand lead to higher numbers of threatened species (BirdLife International, 2018; Harris et al., 2017; Fernandes-Ferreira et al., 2012).

North America, and Europe and Central Asia, the main importing regions of traded wildlife, represent to a majority the ‘global North’ (Reuveny and Thompson, 2007). Lenzen et al. (2012) found similar results after quantifying international trade of various commodities and foreign consumption as a driver of threats to species. Their findings show that developed countries tend to be major importers whereas developing countries find themselves threatening biodiversity for providing exports. The favorable position within the global economy enables wealthier countries to shift the externalities associated with their consumption in ES provided by traded species onto poorer countries. Pascual et al. (2017) emphasized that ecosystem assessments tend to neglect these externalities, i.e. burdens, which effect ecosystems and people in sending regions and they suggested the recognition and quantification of these ecosystem service burdens.

When focusing on the country-level, five main importer countries can be identified: the United States of America, Canada, Germany, the United Kingdom, and China. The United States of America have already been identified as a major importer (Symes et al., 2018; Lenzen et al., 2012), and with a rising economy and growing international trade connections, China plays an important role on the global market as well (Sun and Heshmati, 2010).

4.2 Geographical distribution of ecosystem service-providing regions

Figure 4 shows that, besides the geographical difference between sending and receiving regions, there is also a difference between sending regions for each individual ES.

The ES falling into the categories of 'Science', 'Entertainment' and 'Conservation', which are mainly provided with species from South- and Mesoamerica, are to a majority (>75%) composed of bird, mammal and plant species (Table 2). This coincides with global species richness of the three classes which is located in South- and Mesoamerica (Jenkins et al., 2013; Brooks et al., 2006). In addition, species native in South- and Mesoamerica might be relatively more demanded for the above three ES than species native to other regions.

Africa represents the main sending region for species providing the ES of the categories ‘Decoration and pets’ and ‘Education’. Exported species are mainly (>85%) composed of bird and mammal species (Table 2) which have also been found to have a high general and traded species richness in Africa (Scheffers et al., 2019; Grenyer et al., 2006). Bush et al. (2014) also identified main trade routes from Africa to interregional destinations for mammals and birds used as pets which supports the findings of this study. In addition, Africa is known as a popular region for hunting activities and subsequently the export of hunting trophies (Vigne, 2013; Abensperg-Traun, 2009). Species used for educational purposes are predominantly exported from Africa which may indicate that species native to Africa are more valuable for education than species from elsewhere.

4.3 Protection status of sending regions

In line with inclusive conservation approaches that search for a balance between the protection of biodiversity for its own sake and for the benefit of people (Mace, 2014), the question has arisen to what extent areas important for ES are spatially matching areas important for biodiversity (Cimon-Morin et al., 2013). We found a relatively high percentage of non-protected hotspot areas, i.e. areas important for the provision of ES elsewhere. This can, on one side, indicate that despite high export numbers of service-providing species for the global trade these areas still do not need protection. On the other side, this might point to areas of importance for ES provisioning which have so far not been protected. Systematic conservation planning is increasingly considering information on ES next to that of biodiversity (e.g. Villarreal-Rosas et al., 2020). Future studies could include spatially explicit information on sending regions important for ES used elsewhere in the world in the prioritization of new protected areas. Moreover, such approaches could search for ways to finance these conservation efforts by receiving regions who might have a responsibility to protect distant regions important for ES (Schröter et al., 2018; Pascual et al., 2017). Examples for such conservation financing approaches are already in place for migratory species which connect distant sending and receiving regions (López-Hoffman et al., 2017).

Our results also state that the proportion of protected areas within hotspots of exported species is higher than within total sending regions (within hotspots: 24.1%; within total sending regions: 17.2%). Total terrestrial protected areas as listed in the WDPA cover just under 15% of global land area (UNEP-WCMC, IUCN and NGS, 2018). In comparison, a considerably higher proportion of hotspots of exported species are protected. This implies that regions with a higher number of (service-providing) species have already been acknowledged as priority areas of protection. The results also show higher percentages of areas within hotspots of exported species classified as categories Ia, II and III which represent the highest degrees of protection, than within total sending regions. This supports the conclusion and emphasizes that areas within hotspots of exported species are also more likely to have a higher degree of protection than areas outside the hotspots. This could be due to the fact that they are rich in species, which might also drive the number of exported species taken from the wild.

One fact that draws attention is the very low congruence of hotspots of exported species and vulnerability hotspots in Africa (Appendix D). If these regions experience high pressure on local biodiversity because of global trade, while assessments mainly concentrate on general vulnerability hotspots, these impacted areas might be overlooked, especially since these regions are not entirely covered with global protected areas as well (Appendix E).

In contrast, the results showed vulnerability hotspots in Southeast Asia, but no hotspots of exported species were identified in this region, even though Southeast Asia has been highlighted several times before as highly threatened region (Nijman, 2010; TRAFFIC, 2008; Sodhi et al., 2004). Nevertheless, it is important to be aware that this study excluded a fair amount of species, especially marine species, which have been found to be a major export product from Southeast Asia (Nijman, 2010).

Additionally, it has to be taken into account that, by excluding intraregional trade flows, hotspots of species that were traded within a region were not identified in this study.

4.4 Relation of trade of wild species to sustainability

Sustaining ES provided by exported species over the long term may be achieved through reduction of demand in luxury goods, through trade management as offered by CITES or through replacement of traded species by less threatened species or other provisioning possibilities. Some species traded globally for the provision of ES may be replaced by artificial products, e.g. new medicines from chemical compounds, or modern technology, e.g. computer-modelling techniques in research centers. Nevertheless, some ES cannot be provided elsewhere, e.g. genetic diversity (Díaz et al., 2019). As a consequence, it is not only necessary to identify services provided by exported species that can be replaced or limited, but it is also crucial to ensure sustainable trade of those species linked to ES that are non-replaceable.

In this context, we have to be aware of the fact that all traded species listed in the CITES database are to some extent affected by international trade and are in need of protection from over-exploitation (CITES, 2019a). Of the species included in this study 12.3% are already threatened with extinction (‘Appendix I’) and 83.9% of the species may become so without strict regulations (‘Appendix II’).

ES should only be used within ecological limits to guarantee the provision of such for human well-being of present and future generations (Schröter et al., 2017). International trade which leads to ES flows has become indispensable for meeting human needs and wants, since support of populations of one region on local resources has become impossible due to a growing world population (Kissinger and Rees, 2010). Nevertheless, with an increasing separation of sending and receiving regions, beneficiaries of ES are spatially distant from many effects of consumption (Kissinger and Rees, 2010) and, hence, have to be made aware of consequences related to their demand and consumption of ES. Sustainability, therefore, also includes a fair distribution of costs related to conservation efforts that have to be taken in order to maintain service provision (Schröter et al., 2018). This includes the compensation of countries that are providing ES to protect ecosystems and correspondent service-providing species.

Besides the negative consequences linked with wildlife trade, it also benefits people. The trade of species generates income and employment in sending regions and provides valued goods and services in receiving regions. To maintain beneficial effects and reduce negative consequences of international trade, trade has to be managed (Kissinger and Rees, 2010) in a way, that guarantees the maintenance of wildlife on one side and maintains the services provided by traded species in both exporting and importing countries in the long term on the other side.

4.5 Uncertainties of the analysis

We analyzed the number of traded species to identify interregional flows and sending hotspots. The CITES Database also offers information about the quantities of traded individuals per report entry. However, since quantities of traded individuals are entered in different units, e.g. grams, liters, square meters, pieces, etc., and parts of one single individual can be entered for different terms, e.g. horn, skin, teeth, etc., which may lead to double counting, the conversion of these information into numbers of traded individuals is challenging to implement. Future studies should aim for the analysis of quantities of traded individuals of each species and the respective abundance in native ranges in order to better outline regions threatened with biodiversity loss. One possible approach could be the definition of general standardized units that can be used for every traded species, e.g. grams or liters. Subsequently, the quantity of traded individuals per species could be determined based on the average weight or volume of a species' individual. Another approach for the quantification of ES flows could be the definition of flows in terms of price values of exported species which are, unfortunately, not included in the CITES trade reports. We suggest that CITES reconsiders its monitoring to include this information in a standardized way.

Of the total number of trade entries in the CITES trade database for the time period 2014-2018 11% were analyzed in this study. Due to limited distribution data about species, a significant number of traded endangered species had to be excluded from the subsequent analysis. In addition, reports from the CITES trade database had to be excluded, because of missing information. This especially led to an underrepresentation of plant and mammal species compared to the initial proportions of the analyzed species (Appendix F). Nevertheless, the final dataset of traded endangered species covers 58% of the trade reports and 45% of the respective species based on the delimitated dataset (only species taken from the wild, unspecific purpose codes 'law enforcement/judicial/forensic' and 'commercial' excluded) we initially downloaded from the CITES trade database. The aim of this study was to analyze clearly definable purposes for species trade which can then be linked to ES. Therefore, not all purpose codes were suitable for the analysis and especially the removal of the purpose code 'commercial' led to a significant reduction of trade reports.

Moreover, intraregional flows, thus exporting and associated importing countries located in the same region, were excluded. As a consequence, trade transaction between countries of the same region were not included in the analysis.

The distribution of species used in the analysis is based on range maps which by definition also includes areas that are not inhabited by these species in between actual distribution areas of species. Therefore, the identified sending regions and hotspots of exported species may also contain areas where traded species are non-existent. Nevertheless, this approach offers the identification of sending regions based on ecosystems rather than on entire countries. The analysis was also restricted to terrestrial species. Several studies already stated that trade in marine species, legal and illegal, poses a fair amount of globally traded species (e.g. Kuo and Vincent, 2018; D'Cruze and Macdonald, 2016; Nijman, 2010). Our results only cover the legal trade of species taken from the wild that was documented in CITES. Nevertheless, it must be assumed that the illegal removal of species from the wild represents a second major part of global wildlife trade (D'Cruze and Macdonald, 2016; Bush et al., 2014) and that our analysis only display parts of the total volume of globally traded wildlife. Even though CITES offers information about confiscated species in their database, it must be assumed that these reports are by far not complete and that an analysis of this data would only be fragmentary.

5. Conclusion

This study has analyzed the interregional flows of ES provided by exported species. The results delineate main sending and receiving regions. Moreover, we have provided an overview over the degree of threat and protection of ecosystems that host traded native species in sending regions.

Countries of the 'global North' have been identified as major importing countries and within these countries, main trade volumes result from only few receiving countries. Countries of the 'global South' have been identified as major exporting countries and within the countries of the 'global South', different regions provide different ES. Hotspots of exported species are proportionally more protected than total sending regions. Still, only a quarter of hotspot areas is designated as protected area. This may highlight areas of concern, because of high impacts due to interregional wildlife trade and little protection through assessments that may be worth looking at in future assessments for conservation management.

By considering the interregional flows of ES provided by exported species, this study displays a possibility to identify differences in sending and receiving regions. Through the linkage of the actual trade data from CITES with different types of ES - a novel approach of this study - the traded species can be directly assigned to the services they provide. By identifying the sending regions based on the species-specific range maps, the study additionally enables accurate spatial analysis down to a 100x100km scale within countries and regions globally for more targeted conservation actions.

6. References

Abensperg-Traun, M., 2009. CITES, sustainable use of wild species and incentive-driven conservation in developing countries, with an emphasis on southern Africa. Biol. Conserv. 142, 948–963. https://doi.org/10.1016/j.biocon.2008.12.034

Amatulli, G., Domisch, S., Tuanmu, M.-N., Parmentier, B., Ranipeta, A., Malczyk, J., Jetz, W., 2018. A suite of global, cross-scale topographic variables for environmental and biodiversity modeling. Sci. Data 5, 180040. https://doi.org/10.1038/sdata.2018.40

Auliya, M., Altherr, S., Ariano-Sanchez, D., Baard, E.H., Brown, C., Brown, R.M., Cantu, J.-C., Gentile, G., Gildenhuys, P., Henningheim, E., Hintzmann, J., Kanari, K., Krvavac, M., Lettink, M., Lippert, J., Luiselli, L., Nilson, G., Nguyen, T.Q., Nijman, V., Parham, J.F., Pasachnik, S.A., Pedrono, M., Rauhaus, A., Córdova, D.R., Sanchez, M.-E., Schepp, U., van Schingen, M., Schneeweiss, N., Segniagbeto, G.H., Somaweera, R., Sy, E.Y., Türkozan, O., Vinke, S., Vinke, T., Vyas, R., Williamson, S., Ziegler, T., 2016. Trade in live reptiles, its impact on wild populations, and the role of the European market. Biol. Conserv. 204, 103–119. https://doi.org/10.1016/j.biocon.2016.05.017

Baillie, J.E.M., Hilton-Taylor, C., Stuart, S.N., 2004. 2004 IUCN Red List of Threatened Species. A Global Species Assessment. IUCN Gland Switz. Camb. UK 191.

BirdLife International, 2018. State of the world's birds: taking the pulse of the planet. Cambridge, UK: BirdLife International.

BirdLife International and Handbook of the Birds of the World, 2018. Bird species distribution maps of the world. Version 2018.1 [WWW Document]. URL http://datazone.birdlife.org/species/requestdis (accessed 10.30.19).

Bland, L.M., Keith, D.A., Miller, R.M., Murray, N.J., Rodríguez, J.P. (Eds.), 2015. Guidelines for the application of IUCN Red List of ecosystems categories and criteria. IUCN International Union for Conservation of Nature. https://doi.org/10.2305/IUCN.CH.2016.RLE.1.en

Boerema, A., Peeters, A., Swolfs, S., Vandevenne, F., Jacobs, S., Staes, J., Meire, P., 2016. Soybean Trade: Balancing Environmental and Socio-Economic Impacts of an Intercontinental Market. PLOS ONE 11, e0155222. https://doi.org/10.1371/journal.pone.0155222

Brooks, T.M., Mittermeier, R.A., da Fonseca, G.A.B., Gerlach, J., Hoffmann, M., Lamoreux, J.F., Mittermeier, C.G., Pilgrim, J.D., Rodrigues, A.S.L., 2006. Global Biodiversity Conservation Priorities. Science 313, 58–61. https://doi.org/10.1126/science.1127609

Bush, E.R., Baker, S.E., Macdonald, D.W., 2014. Global Trade in Exotic Pets 2006-2012: Exotic Pet Trade. Conserv. Biol. 28, 663–676. https://doi.org/10.1111/cobi.12240

Ceaușu, S., 2021. Ecosystem service mapping needs to capture more effectively the biodiversity important for service supply. Ecosyst. Serv. 10.

Challender, D.W.S., Harrop, S.R., MacMillan, D.C., 2015. Understanding markets to conserve trade-threatened species in CITES. Biol. Conserv. 187, 249–259. https://doi.org/10.1016/j.biocon.2015.04.015

Cimon-Morin, J., Darveau, M., Poulin, M., 2013. Fostering synergies between ecosystem services and biodiversity in conservation planning: A review. Biol. Conserv. 166, 144154. https://doi.org/10.1016/j.biocon.2013.06.023.

CITES, 2013. A guide to using the CITES Trade Database. Version 8.

CITES, 1973. Text of the Convention.

CITES, 2019a. CITES [WWW Document]. URL https://www.cites.org/eng/ (accessed 1.29.20).

CITES, 2019b. CITES trade statistic derived from the CITES Trade Database, UNEP World Conservation Monitoring Centre, Cambridge, UK [WWW Document]. URL https://trade.cites.org/

D'Cruze, N., Macdonald, D.W., 2016. A review of global trends in CITES live wildlife confiscations. Nat. Conserv. 15, 47–63. https://doi.org/10.3897/natureconservation.15.10005

Díaz, S., Pascual, U., Stenseke, M., Martín-López, B., Watson, R.T., Molnár, Z., Hill, R., Chan, K.M.A., Baste, I.A., Brauman, K.A., Polasky, S., Church, A., Lonsdale, M., Larigauderie, A., Leadley, P.W., van Oudenhoven, A.P.E., van der Plaat, F., Schröter, M., Lavorel, S., Aumeeruddy-Thomas, Y., Bukvareva, E., Davies, K., Demissew, S., Erpul, G., Failler, P., Guerra, C.A., Hewitt, C.L., Keune, H., Lindley, S., Shirayama, Y., 2018. Assessing nature's contributions to people. Science 359, 270–272. https://doi.org/10.1126/science.aap8826

Díaz, S., Settele, J., Brondízio, E., Ngo, H.T., Guèze, M., Agard, J., Arneth, A., Balvanera, P., Brauman, K., Watson, R.T., Baste, I.A., Larigauderie, A., Leadley, P., Pascual, U., Baptiste, B., Demissew, S., Dziba, L., Erpul, G., Fazel, A., Fischer, M., María, A., Karki, M., Mathur, V., Pataridze, T., Pinto, I.S., Stenseke, M., Török, K., Vilá, B., 2019. Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services 45.

Fernandes-Ferreira, H., Mendonca, S.V., Albano, C., Ferreira, F.S., Alves, R.R.N., 2012. Hunting, use and conservation of birds in Northeast Brazil. Biodivers Conserv 24.

Ferreira, F.S., Fernandes-Ferreira, H., Léo Neto, N.A., Brito, S.V., Alves, R.R.N., 2013. The trade of medicinal animals in Brazil: current status and perspectives. Biodivers. Conserv. 22, 839–870. https://doi.org/10.1007/s10531-013-0475-7

Fridman, D., Kissinger, M., 2018. An integrated biophysical and ecosystem approach as a base for ecosystem services analysis across regions. Ecosyst. Serv. 31, 242–254. https://doi.org/10.1016/j.ecoser.2018.01.005

GBIF, 2019. GBIF Home Page [WWW Document]. URL https://www.gbif.org/ (accessed 11.7.19).

Giljum, S., Eisenmenger, N., 2004. North-South Trade and the Distribution of Environmental Goods and Burdens: a Biophysical Perspective. J. Environ. Dev. 13, 73–100. https://doi.org/10.1177/1070496503260974

Givens, J.E., Huang, X., Jorgenson, A.K., 2019. Ecologically unequal exchange: A theory of global environmental *in* justice. Sociol. Compass 13, e12693. https://doi.org/10.1111/soc4.12693

Grenyer, R., Orme, C.D.L., Jackson, S.F., Thomas, G.H., Davies, R.G., Davies, T.J., Jones, K.E., Olson, V.A., Ridgely, R.S., Rasmussen, P.C., Ding, T.-S., Bennett, P.M., Blackburn, T.M., Gaston, K.J., Gittleman, J.L., Owens, I.P.F., 2006. Global distribution and conservation of rare and threatened vertebrates. Nature 444, 93–96. https://doi.org/10.1038/nature05237

Gu, Z., Gu, L., Eils, R., Schlesner, M., Brors, B., 2014. circlize: Implements and enhances circular visualization in R. Bioinformatics. http://cran.r-project.org/web/packages/circlize/.

Harfoot, M., Glaser, S.A.M., Tittensor, D.P., Britten, G.L., McLardy, C., Malsch, K., Burgess, N.D., 2018. Unveiling the patterns and trends in 40 years of global trade in CITES-listed wildlife. Biol. Conserv. 223, 47–57. https://doi.org/10.1016/j.biocon.2018.04.017

Harrington, L.A., 2015. International commercial trade in live carnivores and primates 2006-2012: response to Bush et al. 2014: Trade in Live Carnivores and Primates. Conserv. Biol. 29, 293–296. https://doi.org/10.1111/cobi.12448

Harris, J.B.C., Tingley, M.W., Hua, F., Yong, D.L., Adeney, J.M., Lee, T.M., Marthy, W., Prawiradilaga, D.M., Sekercioglu, C.H., Suyadi, Winarni, N., Wilcove, D.S., 2017. Measuring the impact of the pet trade on Indonesian birds: Bird Declines from Pet Trade. Conserv. Biol. 31, 394–405. https://doi.org/10.1111/cobi.12729

Hinsley, A., de Boer, H.J., Fay, M.F., Gale, S.W., Gardiner, L.M., Gunasekara, R.S., Kumar, P., Masters, S., Metusala, D., Roberts, D.L., Veldman, S., Wong, S., Phelps, J., 2018. A review of the trade in orchids and its implications for conservation. Bot. J. Linn. Soc. 186, 435–455. https://doi.org/10.1093/botlinnean/box083

Hurlbert, A.H., Jetz, W., 2007. Species richness, hotspots, and the scale dependence of range maps in ecology and conservation. Proc. Natl. Acad. Sci. 104, 13384–13389. https://doi.org/10.1073/pnas.0704469104

IPBES, 2018. Summary for policymakers of the regional assessment report on biodiversity and ecosystem services for Europe and Central Asia of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. IPBES secretariat, Bonn, Germany. 38.

IPBES, 2015. Report on the regional scoping progress for a set of regional and subregional assessments (deliverable 2 (b)). IPBES/3/6.

IUCN, 2019. The IUCN Red List of Threatened Species. Version 2019-3 [WWW Document]. IUCN Red List Threat. Species. URL https://www.iucnredlist.org/en (accessed 10.28.19).
Jenkins, C.N., Pimm, S.L., Joppa, L.N., 2013. Global patterns of terrestrial vertebrate diversity and conservation. Proc. Natl. Acad. Sci. 110, E2602–E2610. https://doi.org/10.1073/pnas.1302251110
Jenks, G.F., 1967. The Data Model Concept of Statistical Mapping. Int. Yearb. Cartogr. 7, 186–190.
Kastner, T., Erb, K.-H., Nonhebel, S., 2011. International wood trade and forest change: A global analysis. Glob. Environ. Change 21, 947–956. https://doi.org/10.1016/j.gloenvcha.2011.05.003
Kissinger, M., Rees, W.E., 2010. An interregional ecological approach for modelling sustainability in a globalizing world—Reviewing existing approaches and emerging directions. Ecol. Model. 221, 2615–2623. https://doi.org/10.1016/j.ecolmodel.2010.07.003
Kleemann, J., Schröter, M., Bagstad, K.J., Kuhlicke, C., Kastner, T., Fridman, D., Schulp, C.J.E., Wolff, S., Martínez-López, J., Koellner, T., Arnhold, S., Martín-López, B., Marques, A., Lopez-Hoffman, L., Liu, J., Kissinger, M., Guerra, C.A., Bonn, A., 2020. Quantifying interregional flows of multiple ecosystem services – A case study for Germany. Glob. Environ. Change 61, 102051. https://doi.org/10.1016/j.gloenvcha.2020.102051
Koellner, T., Bonn, A., Arnhold, S., Bagstad, K.J., Fridman, D., Guerra, C.A., Kastner, T., Kissinger, M., Kleemann, J., Kuhlicke, C., Liu, J., López-Hoffman, L., Marques, A., Martín-López, B., Schulp, C.J.E., Wolff, S., Schröter, M., 2019. Guidance for assessing interregional ecosystem service flows. Ecol. Indic. 105, 92–106. https://doi.org/10.1016/j.ecolind.2019.04.046
Krapohl, S., 2020. Games regional actors play: dependency, regionalism, and integration theory for the Global South. J. Int. Relat. Dev. 23, 840–870. https://doi.org/10.1057/s41268-019-00178-4.
Kuo, T.-C., Vincent, A., 2018. Assessing the changes in international trade of marine fishes under CITES regulations – A case study of seahorses. Mar. Policy 88, 48–57. https://doi.org/10.1016/j.marpol.2017.10.031
Lenzen, M., Moran, D., Kanemoto, K., Foran, B., Lobefaro, L., Geschke, A., 2012. International trade drives biodiversity threats in developing nations. Nature 486, 109–112. https://doi.org/10.1038/nature11145
Liu, J., Hull, V., Batistella, M., DeFries, R., Dietz, T., Fu, F., Hertel, T.W., Izaurralde, R.C., Lambin, E.F., Li, S., Martinelli, L.A., McConnell, W.J., Moran, E.F., Naylor, R., Ouyang, Z., Polenske, K.R., Reenberg, A., de Miranda Rocha, G., Simmons, C.S., Verburg, P.H., Vitousek, P.M., Zhang, F., Zhu, C., 2013. Framing Sustainability in a Telecoupled World. Ecol. Soc. 18, art26. https://doi.org/10.5751/ES-05873-180226
Liu, J., Yang, W., Li, S., 2016. Framing ecosystem services in the telecoupled Anthropocene. Front. Ecol. Environ. 14, 27–36. https://doi.org/10.1002/16-0188.1
López-Hoffman, L., Chester, C.C., Semmens, D.J., Thogmartin, W.E., Rodríguez-McGoffin, M.S., Merideth, R., Diffendorfer, J.E., 2017. Ecosystem Services from Transborder Migratory Species: Implications for Conservation Governance. Annu. Rev. Environ. Resour. 42, 509–539.
Luck, G.W., Daily, G.C., Ehrlich, P.R., 2003. Population diversity and ecosystem services. Trends Ecol. Evol. 18, 331–336. https://doi.org/10.1016/S0169-5347(03)00100-9
Mace, G.M., 2014. Whose conservation? Science 345, 1558–60. https://doi.org/doi: 10.1126/science.1254704.
Maes, J., Paracchini, M.L., Zulian, G., Dunbar, M.B., Alkemade, R., 2012. Synergies and trade-offs between ecosystem service supply, biodiversity, and habitat conservation status in Europe. Biol. Conserv. 155, 1–12. https://doi.org/10.1016/j.biocon.2012.06.016.
Mittermeier, R.A., Turner, W.R., Larsen, F.W., Brooks, T.M., Gascon, C., 2011. Global Biodiversity Conservation: The Critical Role of Hotspots, in: Zachos, F.E., Habel, J.C. (Eds.), Biodiversity Hotspots. Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 3–22. https://doi.org/10.1007/978-3-642-20992-5_1
Moran, D., Kanemoto, K., 2017. Identifying species threat hotspots from global supply chains. Nat. Ecol. Evol. 1, 0023. https://doi.org/10.1038/s41559-016-0023

Nakazawa, M., 2019. fmsb: Functions for Medical Statistics Book with some Demographic Data. Japan. https://cran.r-project.org/package=fmsb.
Natusch, D.J.D., Lyons, J.A., 2012. Exploited for pets: the harvest and trade of amphibians and reptiles from Indonesian New Guinea. Biodivers. Conserv. 21, 2899–2911. https://doi.org/10.1007/s10531-012-0345-8
Nijman, V., 2010. An overview of international wildlife trade from Southeast Asia. Biodivers. Conserv. 19, 1101–1114. https://doi.org/10.1007/s10531-009-9758-4
Nijman, V., Bergin, D., 2017. Reptiles traded in markets for medicinal purposes in contemporary Morocco. Contrib. Zool. 86, 39–50. https://doi.org/10.1163/18759866-08601003
Pascual, U., Palomo, I., Adams, W.M., Chan, K.M.A., Daw, T.M., Garmendia, E., Gómez-Baggethun, E., de Groot, R.S., Mace, G.M., Martín-López, B., Phelps, J., 2017. Off-stage ecosystem service burdens: A blind spot for global sustainability. Environ. Res. Lett. 12, 075001. https://doi.org/10.1088/1748-9326/aa7392
Reuveny, R., Thompson, W.R., 2007. The Limits of Economic Globalization: Still Another North–South Cleavage? Int. J. Comp. Sociol. 48, 107–135. https://doi.org/10.1177/0020715207075397
Ribeiro, J., Reino, L., Schindler, S., Strubbe, D., Vall-llosera, M., Araújo, M.B., Capinha, C., Carrete, M., Mazzoni, S., Monteiro, M., Moreira, F., Rocha, R., Tella, J.L., Vaz, A.S., Vicente, J., Nuno, A., 2019. Trends in legal and illegal trade of wild birds: a global assessment based on expert knowledge. Biodivers. Conserv. 28, 3343–3369. https://doi.org/10.1007/s10531-019-01825-5
Robinson, J.E., Sinovas, P., 2018. Challenges of analyzing the global trade in CITES-listed wildlife: CITES data. Conserv. Biol. 32, 1203–1206. https://doi.org/10.1111/cobi.13095
Roe, D., 2002. Making a Killing Or Making a Living: Wildlife Trade, Trade Controls, and Rural Livelihoods. IIED.
Scheffers, B.R., Oliveira, B.F., Lamb, I., Edwards, D.P., 2019. Global wildlife trade across the tree of life. Science 366, 71–76. https://doi.org/10.1126/science.aav5327
Schirpke, U., Tappeiner, U., Tasser, E., 2019. A transnational perspective of global and regional ecosystem service flows from and to mountain regions. Sci. Rep. 9, 6678. https://doi.org/10.1038/s41598-019-43229-z
Schlaepfer, M.A., Hoover, C., Dodd, C.K., 2005. Challenges in Evaluating the Impact of the Trade in Amphibians and Reptiles on Wild Populations. BioScience 55, 256. https://doi.org/10.1641/0006-3568(2005)055[0256:CIETIO]2.0.CO;2
Schröter, M., Koellner, T., Alkemade, R., Arnhold, S., Bagstad, K.J., Erb, K.-H., Frank, K., Kastner, T., Kissinger, M., Liu, J., López-Hoffman, L., Maes, J., Marques, A., Martín-López, B., Meyer, C., Schulp, C.J.E., Thober, J., Wolff, S., Bonn, A., 2018. Interregional flows of ecosystem services: Concepts, typology and four cases. Ecosyst. Serv. 31, 231–241. https://doi.org/10.1016/j.ecoser.2018.02.003
Schröter, M., Kraemer, R., Remme, R.P., van Oudenhoven, A.P.E., 2019. Distant regions underpin interregional flows of cultural ecosystem services provided by birds and mammals. Ambio. https://doi.org/10.1007/s13280-019-01261-3
Schröter, M., Remme, R.P., 2016. Spatial prioritisation for conserving ecosystem services: comparing hotspots with heuristic optimisation. Landsc. Ecol. 31, 431–450. https://doi.org/10.1007/s10980-015-0258-5
Schröter, M., Stumpf, K.H., Loos, J., van Oudenhoven, A.P.E., Böhnke-Henrichs, A., Abson, D.J., 2017. Refocusing ecosystem services towards sustainability. Ecosyst. Serv. 25, 35–43. https://doi.org/10.1016/j.ecoser.2017.03.019
Sodhi, N.S., Koh, L.P., Brook, B.W., Ng, P.K.L., 2004. Southeast Asian biodiversity: an impending disaster. Trends Ecol. Evol. 19, 654–660. https://doi.org/10.1016/j.tree.2004.09.006
Sun, P., Heshmati, A., 2010. International Trade and Its Effects on Economic Growth in China. ZA Discuss. Pap. Inst. Study Labor IZA 5151, 39.
Symes, W.S., McGrath, F.L., Rao, M., Carrasco, L.R., 2018. The gravity of wildlife trade. Biol. Conserv. 218, 268–276. https://doi.org/10.1016/j.biocon.2017.11.007
Tallis, H., Lubchenco, J., 2014. A call for inclusive conservation. Nature 515, 27–28.

TRAFFIC, 2008. “What’s Driving the Wildlife Trade? A Review of Expert Opinion on Economic and Social Drivers of the Wildlife Trade and Trade Control Efforts in Cambodia, Indonesia, Lao PDR and Vietnam”. East Asia and Pacific Region Sustainable Development Discussion Papers. East Asia and Pacific Region Sustainable Development Department, World Bank, Washington, DC.
UNEP-WCMC, 2017. World Database on Protected Areas User Manual 1.5. UNEP-WCMC: Cambridge, UK. Available at: http://wcmc.io/WDPA_Manual.
UNEP-WCMC and IUCN, 2020. Protected Planet: The World Database on Protected Areas. Version 01-2020. Cambridge, UK [WWW Document]. URL www.protectedplanet.net (accessed 1.16.20).
UNEP-WCMC, IUCN and NGS, 2018. Protected Planet Report 2018. UNEP-WCMC, IUCN and NGS: Cambridge, UK; Gland, Switzerland; and Washington, D.C., USA.
van Uhm, D.P., 2018. The social construction of the value of wildlife: A green cultural criminological perspective. Theor. Criminol. 22, 384–401. https://doi.org/10.1177/1362480618787170
van Wyk, A.S., Prinsloo, G., 2018. Medicinal plant harvesting, sustainability and cultivation in South Africa. Biol. Conserv. 227, 335–342. https://doi.org/10.1016/j.biocon.2018.09.018
Vigne, L., 2013. Recent findings on the ivory and rhino-horn trade in Lao People’s Democratic Republic 9.
Villarreal-Rosas, J., Sonter, L.J., Runting, R.K., Dade, M.C., Possingham, H.P., Rhodes, J.R., 2020. Advancing Systematic Conservation Planning for Ecosystem Services. Trends Ecol. Evol. 35, 1129–1139. https://doi.org/10.1016/j.tree.2020.08.016
Weigelt, P., König, C., Kreft, H., 2019. GIFT – A Global Inventory of Floras and Traits for macroecology and biogeography. J. Biogeogr. 47, 16–43. https://doi.org/10.1111/jbi.13623
Wolff, S., Schulp, C.J.E., Kastner, T., Verburg, P.H., 2017. Quantifying Spatial Variation in Ecosystem Services Demand: A Global Mapping Approach. Ecol. Econ. 136, 14–29. https://doi.org/10.1016/j.ecolecon.2017.02.005
Yu, Y., Feng, K., Hubacek, K., 2013. Tele-connecting local consumption to global land use. Glob. Environ. Change 23, 1178–1186. https://doi.org/10.1016/j.gloenvcha.2013.04.006

Appendix

Appendix A

Table A.1: Examined countries and respective ISO-A2 abbreviations with their assigned sub-regions and regions.

Country	**Sub-Region**	**Region**	**ISO_A2**
Albania	Central Europe	Europe and Central Asia	AL
Bosnia and Herzegovina	Central Europe	Europe and Central Asia	BA
Bulgaria	Central Europe	Europe and Central Asia	BG
Croatia	Central Europe	Europe and Central Asia	HR
Cyprus	Central Europe	Europe and Central Asia	CY
Czech Republic	Central Europe	Europe and Central Asia	CZ
Estonia	Central Europe	Europe and Central Asia	EE
Hungary	Central Europe	Europe and Central Asia	HU
Latvia	Central Europe	Europe and Central Asia	LV
Lithuania	Central Europe	Europe and Central Asia	LT
Macedonia	Central Europe	Europe and Central Asia	MK
Montenegro	Central Europe	Europe and Central Asia	ME
Poland	Central Europe	Europe and Central Asia	PL
Romania	Central Europe	Europe and Central Asia	RO
Serbia	Central Europe	Europe and Central Asia	RS
Slovakia	Central Europe	Europe and Central Asia	SK
Slovenia	Central Europe	Europe and Central Asia	SI
Turkey	Central Europe	Europe and Central Asia	TR
Yugoslavia	Central Europe	Europe and Central Asia	YU
Andorra	Western Europe	Europe and Central Asia	AD
Austria	Western Europe	Europe and Central Asia	AT
Belgium	Western Europe	Europe and Central Asia	BE
Denmark	Western Europe	Europe and Central Asia	DK
Faroe Islands	Western Europe	Europe and Central Asia	FO
Finland	Western Europe	Europe and Central Asia	FI
France	Western Europe	Europe and Central Asia	FR
Germany	Western Europe	Europe and Central Asia	DE
Gibraltar	Western Europe	Europe and Central Asia	GI
Greece	Western Europe	Europe and Central Asia	GR
Guernsey	Western Europe	Europe and Central Asia	GG
Holy See	Western Europe	Europe and Central Asia	IT
Iceland	Western Europe	Europe and Central Asia	IS
Ireland	Western Europe	Europe and Central Asia	IE
Israel	Western Europe	Europe and Central Asia	IL
Italy	Western Europe	Europe and Central Asia	IT
Jan Mayen	Western Europe	Europe and Central Asia	SJ
Jersey	Western Europe	Europe and Central Asia	JE
Liechtenstein	Western Europe	Europe and Central Asia	LI

Country	Sub-Region	Region	ISO_A2
Luxembourg	Western Europe	Europe and Central Asia	LU
Malta	Western Europe	Europe and Central Asia	MT
Man, Isle of	Western Europe	Europe and Central Asia	IM
Monaco	Western Europe	Europe and Central Asia	MC
Netherlands	Western Europe	Europe and Central Asia	NL
Norway	Western Europe	Europe and Central Asia	NO
Portugal	Western Europe	Europe and Central Asia	PT
San Marino	Western Europe	Europe and Central Asia	SM
Spain	Western Europe	Europe and Central Asia	ES
Svalbard	Western Europe	Europe and Central Asia	SJ
Sweden	Western Europe	Europe and Central Asia	SE
Switzerland	Western Europe	Europe and Central Asia	CH
United Kingdom	Western Europe	Europe and Central Asia	GB
Armenia	Eastern Europe	Europe and Central Asia	AM
Azerbaijan	Eastern Europe	Europe and Central Asia	AZ
Byelarus	Eastern Europe	Europe and Central Asia	BY
Georgia	Eastern Europe	Europe and Central Asia	GE
Moldova	Eastern Europe	Europe and Central Asia	MD
Russia	Eastern Europe	Europe and Central Asia	RU
Ukraine	Eastern Europe	Europe and Central Asia	UA
USSR	Eastern Europe	Europe and Central Asia	RU
Kazakhstan	Central Asia	Europe and Central Asia	KZ
Kyrgyzstan	Central Asia	Europe and Central Asia	KG
Tajikistan	Central Asia	Europe and Central Asia	TJ
Turkmenistan	Central Asia	Europe and Central Asia	TM
Uzbekistan	Central Asia	Europe and Central Asia	UZ
American Samoa	Oceania	Asia and the Pacific	AS
Australia	Oceania	Asia and the Pacific	AU
Cook Islands	Oceania	Asia and the Pacific	CK
Federated States of Micronesia	Oceania	Asia and the Pacific	FM
Fiji	Oceania	Asia and the Pacific	FJ
French Polynesia	Oceania	Asia and the Pacific	PF
Guam	Oceania	Asia and the Pacific	GU
Kiribati	Oceania	Asia and the Pacific	KI
Marshall Islands	Oceania	Asia and the Pacific	MH
Nauru	Oceania	Asia and the Pacific	NR
New Caledonia	Oceania	Asia and the Pacific	NC
New Zealand	Oceania	Asia and the Pacific	NZ
Niue	Oceania	Asia and the Pacific	NU
Norfolk Island	Oceania	Asia and the Pacific	NF
Northern Mariana Islands	Oceania	Asia and the Pacific	MP
Pacific Islands (Palau)	Oceania	Asia and the Pacific	PW
Papua New Guinea	Oceania	Asia and the Pacific	PG
Pitcairn Islands	Oceania	Asia and the Pacific	PN

Country	Sub-Region	Region	ISO_A2
Solomon Islands	Oceania	Asia and the Pacific	SB
Tokelau	Oceania	Asia and the Pacific	TK
Tokelau	Oceania	Asia and the Pacific	TK
Tonga	Oceania	Asia and the Pacific	TO
Tuvalu	Oceania	Asia and the Pacific	TV
Vanuatu	Oceania	Asia and the Pacific	VU
Wallis and Futuna	Oceania	Asia and the Pacific	WF
Western Samoa	Oceania	Asia and the Pacific	WS
Brunei	South-East Asia	Asia and the Pacific	BN
Cambodia	South-East Asia	Asia and the Pacific	KH
Cocos (Keeling) Islands	South-East Asia	Asia and the Pacific	CC
East Timor	South-East Asia	Asia and the Pacific	ID
Indonesia	South-East Asia	Asia and the Pacific	ID
Laos	South-East Asia	Asia and the Pacific	LA
Malaysia	South-East Asia	Asia and the Pacific	MY
Myanmar (Burma)	South-East Asia	Asia and the Pacific	MM
Philippines	South-East Asia	Asia and the Pacific	PH
Singapore	South-East Asia	Asia and the Pacific	SG
Thailand	South-East Asia	Asia and the Pacific	TH
Vietnam	South-East Asia	Asia and the Pacific	VN
China	North-East Asia	Asia and the Pacific	CN
Hong Kong	North-East Asia	Asia and the Pacific	CN
Japan	North-East Asia	Asia and the Pacific	JP
Macau	North-East Asia	Asia and the Pacific	MO
Mongolia	North-East Asia	Asia and the Pacific	MN
North Korea	North-East Asia	Asia and the Pacific	KP
Paracel Islands	North-East Asia	Asia and the Pacific	PF
South Korea	North-East Asia	Asia and the Pacific	KR
Spratly Islands	North-East Asia	Asia and the Pacific	PG
Taiwan	North-East Asia	Asia and the Pacific	TW
Afghanistan	South Asia	Asia and the Pacific	AF
Bangladesh	South Asia	Asia and the Pacific	BD
Bhutan	South Asia	Asia and the Pacific	BT
British Indian Ocean Territory	South Asia	Asia and the Pacific	IO
Christmas Island	South Asia	Asia and the Pacific	CX
India	South Asia	Asia and the Pacific	IN
Iran	South Asia	Asia and the Pacific	IR
Maldives	South Asia	Asia and the Pacific	MV
Nepal	South Asia	Asia and the Pacific	NP
Pakistan	South Asia	Asia and the Pacific	PK
Sri Lanka	South Asia	Asia and the Pacific	LK
Bahrain	Western Asia	Asia and the Pacific	BH
Gaza Strip	Western Asia	Asia and the Pacific	PS
Iraq	Western Asia	Asia and the Pacific	IQ
Jordan	Western Asia	Asia and the Pacific	JO

Country	Sub-Region	Region	ISO_A2
Kuwait	Western Asia	Asia and the Pacific	KW
Lebanon	Western Asia	Asia and the Pacific	LB
Neutral Zone	Western Asia	Asia and the Pacific	IQ
Oman	Western Asia	Asia and the Pacific	OM
Palestine	Western Asia	Asia and the Pacific	PS
Qatar	Western Asia	Asia and the Pacific	QA
Saudi Arabia	Western Asia	Asia and the Pacific	SA
Syria	Western Asia	Asia and the Pacific	SY
United Arab Emirates	Western Asia	Asia and the Pacific	AE
West Bank	Western Asia	Asia and the Pacific	PS
Yemen	Western Asia	Asia and the Pacific	YE
Comoros	East Africa and adjacent islands	Africa	KM
Djibouti	East Africa and adjacent islands	Africa	DJ
Eritrea	East Africa and adjacent islands	Africa	ER
Ethiopia	East Africa and adjacent islands	Africa	ET
Kenya	East Africa and adjacent islands	Africa	KE
Madagascar	East Africa and adjacent islands	Africa	MG
Mauritius	East Africa and adjacent islands	Africa	MU
Mayotte	East Africa and adjacent islands	Africa	YT
Reunion	East Africa and adjacent islands	Africa	RE
Rwanda	East Africa and adjacent islands	Africa	RW
Seychelles	East Africa and adjacent islands	Africa	SC
Somalia	East Africa and adjacent islands	Africa	SO
South Sudan	East Africa and adjacent islands	Africa	SD
Tanzania, United Republic of	East Africa and adjacent islands	Africa	TZ
Uganda	East Africa and adjacent islands	Africa	UG
Angola	Southern Africa	Africa	AO
Botswana	Southern Africa	Africa	BW
Bouvet Island	Southern Africa	Africa	BV
French Southern & Antarctic Lands	Southern Africa	Africa	TF
Glorioso Islands	Southern Africa	Africa	TF
Heard Island & McDonald Islands	Southern Africa	Africa	HM
Lesotho	Southern Africa	Africa	LS

Country	Sub-Region	Region	ISO_A2
Malawi	Southern Africa	Africa	MW
Mozambique	Southern Africa	Africa	MZ
Namibia	Southern Africa	Africa	NA
South Africa	Southern Africa	Africa	ZA
Swaziland	Southern Africa	Africa	SZ
Zambia	Southern Africa	Africa	ZM
Zimbabwe	Southern Africa	Africa	ZW
Burundi	Central Africa	Africa	BI
Cameroon	Central Africa	Africa	CM
Central African Republic	Central Africa	Africa	CF
Chad	Central Africa	Africa	TD
Congo	Central Africa	Africa	CG
Equatorial Guinea	Central Africa	Africa	GQ
Gabon	Central Africa	Africa	GA
Sao Tome and Principe	Central Africa	Africa	ST
Zaire	Central Africa	Africa	CD
Algeria	North Africa	Africa	DZ
Egypt	North Africa	Africa	EG
Libya	North Africa	Africa	LY
Mauritania	North Africa	Africa	MR
Morocco	North Africa	Africa	MA
Sudan	North Africa	Africa	SD
Tunisia	North Africa	Africa	TN
Western Sahara	North Africa	Africa	EH
Benin	West Africa	Africa	BJ
Burkina Faso	West Africa	Africa	BF
Cape Verde	West Africa	Africa	CV
Gambia, The	West Africa	Africa	GM
Ghana	West Africa	Africa	GH
Guinea	West Africa	Africa	GN
Guinea-Bissau	West Africa	Africa	GW
Ivory Coast	West Africa	Africa	CI
Liberia	West Africa	Africa	LR
Mali	West Africa	Africa	ML
Niger	West Africa	Africa	NE
Nigeria	West Africa	Africa	NG
Senegal	West Africa	Africa	SN
Sierra Leone	West Africa	Africa	SL
St. Helena	West Africa	Africa	SH
Togo	West Africa	Africa	TG
Argentina	South America	South- and Mesoamerica	AR
Bolivia	South America	South- and Mesoamerica	BO
Brazil	South America	South- and Mesoamerica	BR
Chile	South America	South- and Mesoamerica	CL
Colombia	South America	South- and Mesoamerica	CO

Country	Sub-Region	Region	ISO_A2
Ecuador	South America	South- and Mesoamerica	EC
Falkland Islands (Islas Malvinas)	South America	South- and Mesoamerica	FK
French Guiana	South America	South- and Mesoamerica	GF
Guyana	South America	South- and Mesoamerica	GY
Paraguay	South America	South- and Mesoamerica	PY
Peru	South America	South- and Mesoamerica	PE
South Georgia and the South Sandwich Is	South America	South- and Mesoamerica	GS
Suriname	South America	South- and Mesoamerica	SR
Uruguay	South America	South- and Mesoamerica	UY
Venezuela	South America	South- and Mesoamerica	VE
Anguilla	Mesoamerica	South- and Mesoamerica	AI
Belize	Mesoamerica	South- and Mesoamerica	BZ
Costa Rica	Mesoamerica	South- and Mesoamerica	CR
El Salvador	Mesoamerica	South- and Mesoamerica	SV
Guatemala	Mesoamerica	South- and Mesoamerica	GT
Honduras	Mesoamerica	South- and Mesoamerica	HN
Mexico	Mesoamerica	South- and Mesoamerica	MX
Nicaragua	Mesoamerica	South- and Mesoamerica	NI
Panama	Mesoamerica	South- and Mesoamerica	PA
Antigua and Barbuda	Caribbean	South- and Mesoamerica	AG
Aruba	Caribbean	South- and Mesoamerica	AW
Bahamas, The	Caribbean	South- and Mesoamerica	BS
Barbados	Caribbean	South- and Mesoamerica	BB
Bonair, Sint Eustatius and Saba	Caribbean	South- and Mesoamerica	VE
British Virgin Islands	Caribbean	South- and Mesoamerica	VG
Cayman Islands	Caribbean	South- and Mesoamerica	KY
Cuba	Caribbean	South- and Mesoamerica	CU
Curaçao	Caribbean	South- and Mesoamerica	VE
Dominica	Caribbean	South- and Mesoamerica	DM
Dominican Republic	Caribbean	South- and Mesoamerica	DO
Grenada	Caribbean	South- and Mesoamerica	GD
Guadeloupe	Caribbean	South- and Mesoamerica	GP
Haiti	Caribbean	South- and Mesoamerica	HT
Jamaica	Caribbean	South- and Mesoamerica	JM
Martinique	Caribbean	South- and Mesoamerica	MQ
Montserrat	Caribbean	South- and Mesoamerica	MS
Netherlands Antilles	Caribbean	South- and Mesoamerica	AN
Puerto Rico	Caribbean	South- and Mesoamerica	PR
Saint Barthélemy	Caribbean	South- and Mesoamerica	AI
Saint Martin (French Part)	Caribbean	South- and Mesoamerica	AI
Sint Maarten (Dutch Part)	Caribbean	South- and Mesoamerica	AI
St. Kitts and Nevis	Caribbean	South- and Mesoamerica	KN
St. Lucia	Caribbean	South- and Mesoamerica	LC

Country	Sub-Region	Region	ISO_A2
St. Vincent and the Grenadines	Caribbean	South- and Mesoamerica	VC
Trinidad and Tobago	Caribbean	South- and Mesoamerica	TT
Turks and Caicos Islands	Caribbean	South- and Mesoamerica	TC
Virgin Islands	Caribbean	South- and Mesoamerica	VI
Baker Island	North America	North America	UM
Bermuda	North America	North America	BM
Canada	North America	North America	CA
Greenland	North America	North America	GL
Howland Island	North America	North America	UM
Jarvis Island	North America	North America	UM
Johnston Atoll	North America	North America	JT
Juan De Nova Island	North America	North America	UM
Midway Islands	North America	North America	MI
St. Pierre and Miquelon	North America	North America	PM
United States	North America	North America	US
Wake Island	North America	North America	UM

Appendix B

Data processing of downloaded trade dataset

Table B.1: Number of report entries in the downloaded trade dataset after each step of data processing. In addition, numbers of species after main process steps and further information about removals.

Step	Report entries	Species	Details
Downloaded/Original dataset	37469	3435	
Importing country = ‚XX‘ or ‚XV’	37010		
Country of origin = ‘XX’ or ‘XV’ or ‘ZZ’	35647		
Exporting country = ‚ZZ‘ or ‚XX’	35460		
Source = ‚U‘ or blank	34777		
Species ending = ‚spp.‘	32878		
Excluded species groups	31035	1843	12 species groups removed: - Actinopteri - Anthozoa - Arachnida - Bivalvia - Cephalopoda - Coelacanthi - Dipneusti - Elasmobranchii - Gastropoda - Hirudinoidea - Holothuroidea - Hydrozoa
No extent of occurrence available	26456	1699	
Intraregional trade → Final dataset	21861	1552	Removed entries from each region: Europe/Central Asia: 886 Asia and the Pacific: 1173 Africa: 1038 Central/South America: 384 North America: 1114

Excluded codes of range maps obtained from IUCN and BirdLife International

- presence: 4 – possibly extinct, 5 – extinct, 6 – presence uncertain

- origin: 3 – introduced, 4 – vagrant, 5 – origin uncertain, 6 – assisted colonization

- seasonal: 4 – passage, 5 – seasonal occurrence uncertain

Appendix C

Table C.1: List of species names as entered in CITES database (second column) that were removed after comparison with species names as entered by IUCN (2019-3) or BirdLife International (2018). Third column shows species names as found to be entered in datasets of IUCN or BirdLife International. Fourth column shows species names as used in the analysis. Empty cells display species for which no different term was found in the datasets of IUCN or BirdLife International and were, therefore, removed from the analysis. Alternative species names, based on the names entered in the CITES database, were searched for in the online data of IUCN (IUCN, 2019) and GBIF (GBIF, 2019).

Species group	Species name in CITES	Species name in IUCN (2019-3) or BirdLife International (2018)	Species name as used in analysis
Amphibians	Epipedobates darwinwallacei		
	Oophaga histrionica		
	Ranitomeya toraro		
Birds	Accipiter cirrhocephalus	Accipiter cirrocephalus	Accipiter cirrocephalus
	Accipiter francesii	Accipiter francesiae	Accipiter francesiae
	Accipitridae hybrid		
	Aglaiocercus kingi	Aglaiocercus kingii	Aglaiocercus kingii
	Amazilia rondoniae		
	Amazona mercenaria	Amazona mercenarius	Amazona mercenarius
	Anthracothorax recurvirostris	Avocettula recurvirostris	Avocettula recurvirostris
	Aquila clanga	Clanga clanga	Clanga clanga
	Aquila pomarina	Clanga pomarina	Clanga pomarina
	Aratinga aurea	Eupsittula aurea	Eupsittula aurea
	Aratinga canicularis	Eupsittula canicularis	Eupsittula canicularis
	Aratinga erythrogenys	Psittacara erythrogenys	Psittacara erythrogenys
	Aratinga leucophthalma		
	Aratinga mitrata	Psittacara mitratus	Psittacara mitratus
	Aratinga pertinax	Eupsittula pertinax	Eupsittula pertinax
	Aratinga wagleri	Psittacara wagleri	Psittacara wagleri
	Asturina nitida	Buteo nitidus	Buteo nitidus
	Buteo leucorrhous	Parabuteo leucorrhous	Parabuteo leucorrhous
	Buteo magnirostris	Rupornis magnirostris	Rupornis magnirostris
	Buteo polysoma	Geranoaetus polysoma	Geranoaetus polysoma
	Calliphlox evelynae		

Species group	Species name in CITES	Species name in IUCN (2019-3) or BirdLife International (2018)	Species name as used in analysis
	Calyptorhynchus baudinii		
	Calyptorhynchus funereus		
	Calyptorhynchus latirostris		
	Carduelis cucullata	Spinus cucullatus	Spinus cucullatus
	Chalcopsitta sintillata		
	Cyanopsitta spixii		
	Diphyllodes magnificus	Cicinnurus magnificus	Cicinnurus magnificus
	Eos rubra	Eos bornea	Eos bornea
	Epimachus fastuosus		
	Eriocnemis alinae	Eriocnemis aline	Eriocnemis aline
	Eupodotis vigorsii		
	Falco hybrid		
	Falco peregrinus anatum	Falco pergrinus	Falco pergrinus
	Grus antigone	Antigone antigone	Antigone antigone
	Grus canadensis		
	Grus rubicunda		
	Gymnoglaux lawrencii	Margarobyas lawrencii	Margarobyas lawrencii
	Gyps rueppellii		
	Hieraaetus fasciatus	Aquila fasciata	Aquila fasciata
	Hieraaetus spilogaster	Aquila spilogaster	Aquila spilogaster
	Hylocharis sapphirina	Amazilia sapphirina	Amazilia sapphirina
	Milvago chimango	Phalcoboenus chimango	Phalcoboenus chimango
	Nandayus nenday	Aratinga nenday	Aratinga nenday
	Northiella haematogaster narethae	Northiella haematogaster	Northiella haematogaster
	Nyctea scandiaca	Bubo scandiacus	Bubo scandiacus
	Orthopsittaca manilata	Orthopsittaca manilatus	Orthopsittaca manilatus
	Otus albogularis	Megascops albogularis	Megascops albogularis
	Otus asio	Megascops asio	Megascops asio
	Otus barbarus	Megascops barbarus	Megascops barbarus
	Otus choliba	Megascops choliba	Megascops choliba
	Otus colombianus	Megascops colombianus	Megascops colombianus
	Otus ingens	Megascops ingens	Megascops ingens
	Otus koepckeae	Megascops koepckeae	Megascops koepckeae
	Otus marshalli	Megascops marshalli	Megascops marshalli

Species group	Species name in CITES	Species name in IUCN (2019-3) or BirdLife International (2018)	Species name as used in analysis
	Otus petersoni	Megascops petersoni	Megascops petersoni
	Otus roboratus	Megascops roboratus	Megascops roboratus
	Otus watsonii	Megascops watsonii	Megascops watsonii
	Paradisaea rudolphi	Paradisornis rudolphi	Paradisornis rudolphi
	Pionopsitta aurantiocephala	Pyrilia aurantiocephala	Pyrilia aurantiocephala
	Pionopsitta barrabandi	Pyrilia barrabandi	Pyrilia barrabandi
	Pionopsitta caica	Pyrilia caica	Pyrilia caica
	Pionopsitta pyrilia	Pyrilia pyrilia	Pyrilia pyrilia
	Poephila cincta cincta		
	Psephotus dissimilis	Psephotellus dissimilis	Psephotellus dissimilis
	Psephotus dissimilis		
	Psephotus varius	Psephotellus varius	Psephotellus varius
	Psittacula echo	Psittacula eques	Psittacula eques
	Psittacus erithacus timneh	Psittacus erithacus	Psittacus erithacus
	Pterocnemia pennata	Rhea pennata	Rhea pennata
	Ptiloris magnificus		
	Rhea americana albescens	Rhea americana	Rhea americana
	Strix albitarsis	Ciccaba albitarsis	Ciccaba albitarsis
	Strix virgata	Ciccaba virgata	Ciccaba virgata
	Tauraco porphyreolophus	Gallirex porphyreolophus	Gallirex porphyreolophus
	Thalurania fannyi		
	Torgos tracheliotus	Torgos tracheliotos	Torgos tracheliotos
	Trochilus hybrid		
Insects	Bhutantitis mansfieldi		
	Bhutantitis thaidina		
	Parnassius apollo		
	Agrias amydon		
Mammals	Alouatta seniculus		
	Arctocepalus tropicalis		
	Arctocephalus australis		
	Arctocephalus forsteri		
	Arctocephalus galapagoensis		
	Arctocephalus gazella		
	Arctocephalus pusillus		
	Ateles geoffroyi frontatus		
	Axis procinus annamiticus		

Species group	Species name in CITES	Species name in IUCN (2019-3) or BirdLife International (2018)	Species name as used in analysis
	Bison bison athabascae		
	Callicebus aureipalatii	Plecturocebus aureipalatii	Plecturocebus aureipalatii
	Callicebus brunneus	Plecturocebus brunneus	Plecturocebus brunneus
	Callicebus cupreus	Plecturocebus cupreus	Plecturocebus cupreus
	Callicebus discolor	Plecturocebus discolor	Plecturocebus discolor
	Callicebus donacophilus	Plecutrocebus donacophilus	Plecutrocebus donacophilus
	Callicebus purinus	Cheracebus purinus	Cheracebus purinus
	Callicebus torquatus	Cheracebus torquatus	Cheracebus torquatus
	Callithrix argentata	Mico argentatus	Mico argentatus
	Callithrix humeralifera	Mico humeralifera	Mico humeralifera
	Callithrix pygmaea	Cebuella pygmaea	Cebuella pygmaea
	Canis aureus		
	Canis lupus crassodon	Canis lupus	Canis lupus
	Canis lupus irremotus	Canis lupus	Canis lupus
	Canis lupus monstrabilis	Canis lupus	Canis lupus
	Canis lupus pallipes	Canis lupus	Canis lupus
	Capra falconeri megacros		Canis falconeri
	Capra hircus aegagrus	Capra aegagrus	Capra aegagrus
	Capra hircus	Capra aegagrus	Capra aegagrus
	Cebus apella	Sapajus apella	Sapajus apella
	Cebus capucinus		
	Cebus flavius	Sapajus flavius	Sapajus flavius
	Cebus libidinosus	Sapajus libidinosus	Sapajus libidinosus
	Cebus nigritus	Sapajus nigritus	Sapajus nigritus
	Cebus olivaceus		
	Cebus xanthosternos	Sapajus xanthosternus	Sapajus xanthosternus
	Cephalophus brookei		
	Cerathoterium simum simum	Cerathoterium simum	Cerathoterium simum
	Ceratotherium simum cottoni	Cerathoterium simum	Cerathoterium simum
	Cercopithecus kandti	Cercopithecus albogularis	Cercopithecus albogularis
	Cercopithecus lhoesti	Allochrocebus lhoesti	Allochrocebus lhoesti
	Cercopithecus mitis	Cercopithecus albogularis	Cercopithecus albogularis
	Cercopithecus pogonias		
	Cercopithecus wolfi		
	Damaliscus hybrid		

Species group	Species name in CITES	Species name in IUCN (2019-3) or BirdLife International (2018)	Species name as used in analysis
	Damaliscus pygargus pygargus	Damaliscus pygargus	Damaliscus pygargus
	Dugong dugon		
	Equus hemionus hemionus	Equus hemionus	Equus hemionus
	Equus przewalskii	Equus ferus	Equus ferus
	Equus zebra hartmannae	Equus zebra	Equus zebra
	Equus zebra zebra	Equus zebra	Equus zebra
	Felis silvestris lybica	Felis silvestris	Felis silvestris
	Galago demidoff	Galagoides demidoff	Galagoides demidoff
	Galago thomasi	Galagoides thomasi	Galagoides thomasi
	Herpestes javanicus auropunctatas	Herpestes javanicus	Herpestes javanicus
	Hexaprotodon liberiensis	Choeropsis liberiensis	Choeropsis liberiensis
	Hippotragus niger variani	Hippotragus niger	Hippotragus niger
	Leopardus jacobitus		
	Lynx hybrid		
	Lynx rufus escuinapae		
	Manis gigantea	Smutsia gigantea	Smutsia gigantea
	Manis temminickii	Smutsia temminckii	Smutsia temminckii
	Manis tetradactyla	Phataginus tetradactyla	Phataginus tetradactyla
	Manis tricuspis	Phataginus tricuspis	Phataginus tricuspis
	Mazama temama cerasina	Mazama temama	Mazama temama
	Mirounga leonina		
	Monachus monachus		
	Monachus schauinslandi		
	Nasua nasua solitaria	Nasua nasua	Nasua nasua
	Nomascus annamensis		
	Odobenus rosmarus		
	Oreonax flavicauda		
	Ovis ammon severtzovi	Ovis ammon	Ovis ammon
	Ovis aries		
	Ovis aries cycloceros		
	Panthera tigris altaica	Panthera tigris	Panthera tigris
	Phitecia irrorata		
	Profelis aurata	Caracal aurata	Caracal aurata
	Puma concolor couguar	Puma concolor	Puma concolor

Species group	Species name in CITES	Species name in IUCN (2019-3) or BirdLife International (2018)	Species name as used in analysis
	Puma yagouaroundi		
	Saiga borealis		
	Samiri collinsi		
	Trichechus inunguis		
	Trichechus manatus		
	Trichechus senegalensis		
	Uncia uncia	Panthera uncia	Panthera uncia
	Ursus americanus emmonsii	Ursus americanus	Ursus americanus
	Zaglossus bruijni		
Reptiles	Amblyrhynchus cristatus		
	Amyda catilaginea		
	Boa constrictor	Boa imperator	Boa imperator
	Caiman crocodilus crocodilus	Caiman crocodilus	Caiman crocodilus
	Caiman crocodilus fuscus	Caiman crocodilus	Caiman crocodilus
	Caiman crocodilus yacare	Caiman crocodilus	Caiman crocodilus
	Candoia bibroni		
	Candoia carinata		
	Candoia paulsoni		
	Candoia superciliosa		
	Centrochelys sulcata		
	Chelonoidis carbonarius		
	Chelonoidis chilensis		
	Chelonoidis denticulatus		
	Clelia clelia		
	Conolophus subcistatus		
	Corallus grenadensis		
	Cordylus angolensis		
	Cordylus machadoi		
	Cordylus nyikae		
	Cordylus tropidosternum		
	Corucia zebrata		
	Crocodylus cataphractus	Mecistops cataphractus	Mecistops cataphractus
	Crotalus durissus		
	Cuora amboinensis		
	Cyclura carinata		

Species group	Species name in CITES	Species name in IUCN (2019-3) or BirdLife International (2018)	Species name as used in analysis
	Cyclura cornuta		
	Cyclura cychlura		
	Cyclura nubila		
	Cyclura pinguis		
	Cyclura ricordi		
	Cyclura rileyi		
	Daboia russelii		
	Dogania subplana		
	Emydoidea blandingii		
	Epicrates cenchria	Epicrates crassus	Epicrates crassus
	Epicrates cenchria		
	Epicrates chrysogaster		
	Epicrates exsul	Chilabothrus exsul	Chilabothrus exsul
	Epicrates gracilis		
	Epicrates striatus	Chilabothrus striatus	
	Eretmochelys imbricata bissa	Eretmochelys imbricata	Eretmochelys imbricata
	Eretmochelys imbricata imbricata	Eretmochelys imbricata	Eretmochelys imbricata
	Erymnochelys madagascariensis		
	Eunectes murinus		
	Eunectes notaeus		
	Glyptemys insculpta		
	Gongylophis colubrinus		
	Gopherus agassizii		
	Graptemys geographica		
	Graptemys ouachitensis		
	Graptemys pearlensis		
	Graptemys pseudogeographica		
	Heosemys spinosa		
	Homopus boulengeri	Chersobius boulengeri	Chersobius boulengeri
	Homopus signatus		
	Indotestudo ferstenii		
	Karusaurus jordani		
	Karusaurus polyzonus	Karusasaurus polyzonus	Karusasaurus polyzonus
	Kinixys belliana		
	Kinixys erosa		
	Kinixys homeana		
	Kinixys spekii		

Species group	Species name in CITES	Species name in IUCN (2019-3) or BirdLife International (2018)	Species name as used in analysis
	Kinixys zombensis		
	Liasis machloti		
	Macrochelys temminckii		
	Malaymemys subtrijuga		
	Mauremys japonica		
	Mauremys mutica		
	Mauremys reevesii		
	Naja naja		
	Namazonurus campbelli	Cordylus campbelli	Cordylus campbelli
	Namazonurus namaquensis		
	Namazonurus pustulatus		
	Natator depressus		
	Pelochelys bibroni		
	Phelsuma dubia		
	Platysternon megacephalum		
	Podocnemis sextuberculata		
	Podocnemis unifilis		
	Psamobates ooculifer		
	Pseudemydura umbrina		
	Ptyas mucosus		
	Python molurus		
	Python sebae		
	Rafetus swinhoei		
	Salvator rufescenz		
	Shinisaurus crocodilurus		
	Siebenrockiella leytensis		
	Stigmochelys pardalis		
	Terrapene carolina		
	Testudo graeca		
	Testudo horsfieldii		
	Trachemys scripta elegans	Trachemys scripta	Trachemys scripta
	Tupinambis teguixin		
	Uromastyx acanthinura		
	Uromastyx dispar		

Species group	Species name in CITES	Species name in IUCN (2019-3) or BirdLife International (2018)	Species name as used in analysis
	Varanus albigularis		
	Varanus dalubhasa		
	Varanus dumerilii		
	Varanus niloticus		
	Varanus ornatus		
	Varanus rudicollis		
	Xenochrophis		

Appendix D

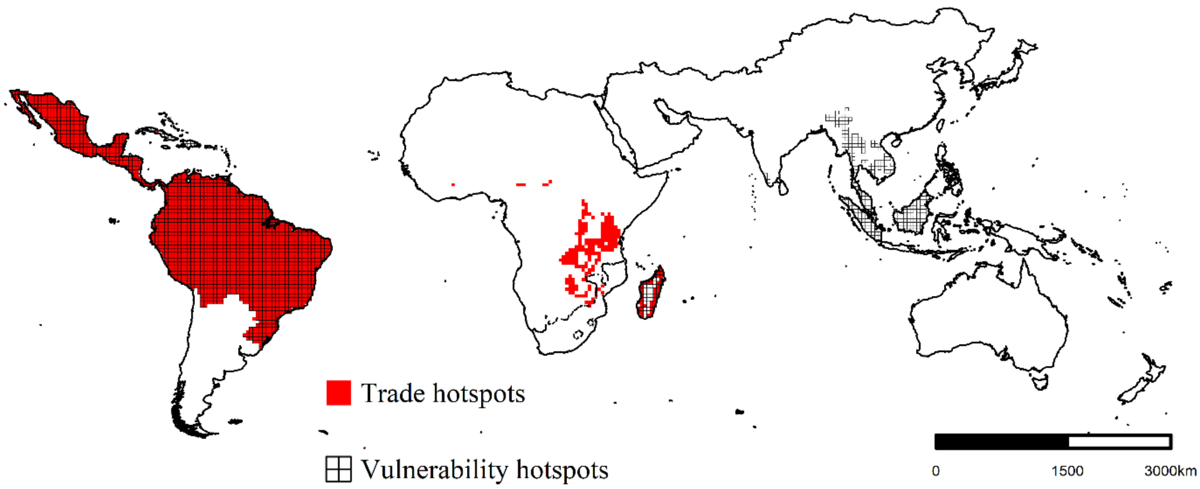

Figure D.1: Global hotspots of exported, service-providing species and vulnerability hotspots. Hotspots of exported, service-providing species represent raster cells with 110 or more species abundant per cell. Vulnerability hotspots represent raster cells with 97 or more species abundant per cell. Coordinate System: WGS 84, EPSG: 4326.

Appendix E

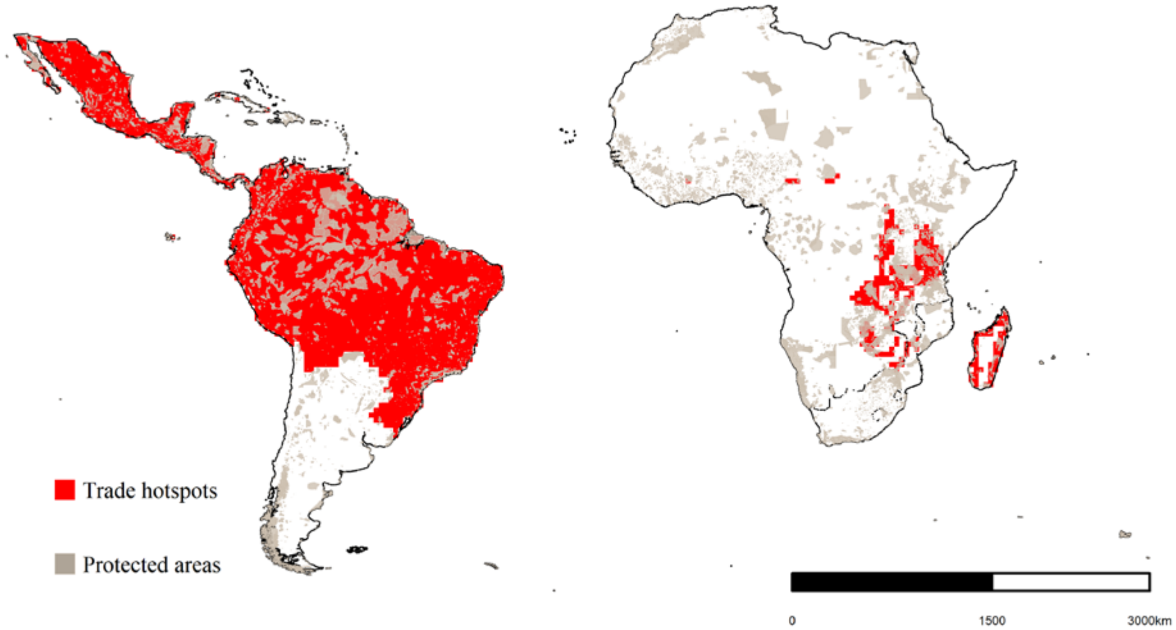

Figure E.1: Global hotspots of exported, service-providing species and protected areas located in South- and Mesoamerica, and Africa (UNEP-WCMC and IUCN, 2020). Hotspots of exported, service-providing species represent raster cells with 110 or more species possibly present per cell. Coordinate System: WGS 84, EPSG: 4326.

Appendix F

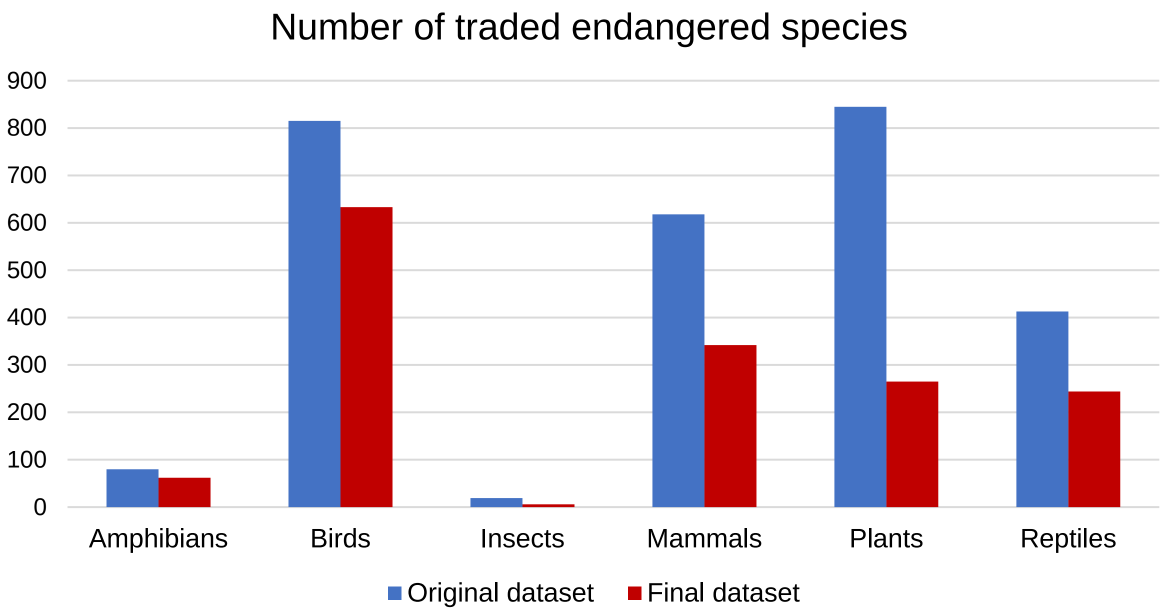

Figure F.1: Composition of exported, service-providing species of the six examined species groups.