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Quantifying interregional flows of multiple ecosystem services – A case study for Germany

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ABSTRACT

Despite a growing number of national-scale ecosystem service (ES) assessments, few studies consider the impacts of ES use and consumption beyond national or regional boundaries. Interregional ES flows – ecosystem services "imported" from and "exported" to other countries – are rarely analyzed and their importance for global sustainability is little known. Here, we provide a first multi-ES quantification of a nation's use of ES from abroad. We focus on ES flows that benefit the population in Germany but are supplied outside German territory. We employ a conceptual framework recently developed to systematically quantify interregional ES flows. We address four types of interregional ES flows with: (i) biophysical flows of traded goods: cocoa import for consumption; (ii) flows mediated by migratory species: migration of birds providing pest control; (iii) passive biophysical flows: flood control along transboundary watersheds; and (iv) information flows: China's giant panda loan to the Berlin Zoo. We determined that: (i) Ivory Coast and Ghana alone supply around 53% of Germany's cocoa while major negative consequences for biodiversity occurred in Cameroon and Ecuador; (ii) Africa´s humid and sub-humid climate zones are important habitats for the majority of migratory bird species that provide natural pest control services in agricultural areas in Germany; (iii) Upstream watersheds outside the country add an additional 64% flood regulation services nationally, while Germany exports 40% of flood regulation services in neighboring,

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[1] Our esteemed colleague Dr. Sebastian Arnhold sadly passed away in November 2017. We appreciate his valuable contributions to this work and remember him as an enthusiastic researcher.

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downstream countries; (iv) Information flows transported by the pandas were mainly related to political aspects and - contrary to our expectations - considerably less on biological and natural aspects. We discuss the implications of these results for international resource management policy and governance.

1. Introduction

Ecosystem services (ES), the flow of benefits from ecosystems to people, are fundamental to human well-being. These essential flows can be transferred across long distances in multiples ways (Liu et al., 2016; López-Hoffman et al., 2010; Schröter et al., 2018). Through this transfer, ES flows couple social-ecological systems across space through a process called telecoupling (Liu et al., 2013). However, these long-distance ES flows have rarely been quantified (Koellner et al., 2018). Interregional ES flows result from the exchange of ecosystem-derived matter, energy or information between a sending system, e.g., the origin of the ES flow, and the receiving system that benefits from the ES flow, and often cross the borders between countries (López-Hoffman et al., 2010). We have recently developed a conceptual typology of four classes of interregional ES flows (Schröter et al., 2018):

(i) *Biophysical flows of traded goods* are mostly related to flows of provisioning ES and the trade of food or biomass, such as timber, soy beans, coffee or fish from distant ecosystems (Boerema et al., 2016; Drakou et al., 2018; Kastner et al., 2011).
(ii) *Flows provided through migrating or dispersing species* (López-Hoffman et al., 2017) e.g., pest control by migratory bats (López-Hoffman et al., 2014) or cultural ES flows through migrating monarch butterflies (Semmens et al., 2018).
(iii) *Passive biophysical flows* are mediated by riverine, oceanic or atmospheric currents and primarily provide provisioning and regulating ES, e.g., freshwater provision (Turpie et al., 2008) or flood control (Watson et al., 2016).
(iv) *Information flows* are received through cognition of information across distances and predominantly consist of cultural ES, e.g., derived from social media to provide the basis for psychological experiences (Hausmann et al., 2018) or for developing a sense of place for a landscape (Pastur et al., 2016).

ES flows depend not only on natural capital, but are usually co-produced by human, social, manufactured, and financial capital (Díaz et al., 2015; Fischer et al., 2016; Palomo et al., 2016; Rieb et al., 2017). For example, transboundary flood protection can be improved by spatial planning and joint governance as social capital, built infrastructure as manufactured capital, and floodplain restoration as natural capital. Moreover, in many cases of interregional ES flows, the amount and quality of the ES flow is determined by other embedded ES in the sending system (Schröter et al., 2018), e.g., pollination as a precondition to enable provision and trade of agricultural products (Klein et al., 2007).

Interregional ES flows between countries are often vital to national economies and the well-being of a country's citizens. Approaches to quantify different ES flow types with interregional influence are, however, urgently needed (Koellner et al., 2019). National ecosystem assessments are often limited to national boundaries and most often neglect interregional ES flows (Schröter et al., 2016) apart from a few examples (Kissinger et al., 2018; UK NEA, 2011). Similarly, the System of Environmental-Economic Accounting-Experimental Ecosystem Accounting framework, developed by the United Nations and being applied worldwide to quantify the contributions of ES to national economic measurement (UN, 2017) has not yet addressed interregional ES flows, in part because of the novelty of needed assessment methods. The scientific community has recently begun to quantify interregional ES flows (Koellner et al., 2019; Schirpke et al., 2019; Xie et al., 2019), but most interregional analyses remain focused on the analysis of provisioning ES flows through traded goods (e.g., Boerema et al., 2016; Kastner et al., 2011). Traded goods are the most straightforward interregional flow to quantify due to data provided by national statistics. Knowledge is often lacking for other interregional ES flow types. Most assessments are still largely conceptual, though a few empirical examples exist (Bagstad et al., 2019; Liu et al., 2013, 2016; López-Hoffman et al., 2017, Semmens et al., 2018). In addition, many analyses of interregional ES flows only consider one ES flow type (e.g., López-Hoffman et al., 2017). Very recently, a few studies have assessed interregional flows across larger spatial scales and for several ES and flow types. For example, Schirpke et al. (2019) show a range of interregional flows for the European Alps, including grassland biomass (traded good, according to the classification in Schröter et al. 2018), water supply, landslide protection, and carbon sequestration (physical flows), outdoor recreation and symbolic plants and animals (information flows). Xie et al. (2019) assess interregional flows for Inner Mongolia, considering livestock production (traded good), wind erosion prevention, water provision, and carbon sequestration (physical flows). Neither of these are national-scale studies.

Recent studies on interregional flows largely omit the systematic consideration of environmental justice issues. By highlighting access, benefit and distribution of ES between nations, interregional ES flows raise issues of environmental justice (Sikor et al., 2014). Global inequalities exist for many natural resources (Giljum and Eisenmenger, 2004). The Global South is rich in natural resources, while the Global North largely profits from the extraction (Acosta, 2017). Environmental and social problems accompanying these activities are left within the country of extraction. These interrelationships have multiple effects on ecosystems and human well-being. Interlinkages between the Sustainable Development Goals (SDGs) and interregional ES flows potentially exist in 12 of the 17 SDGs for at least one ES flow type (Koellner et al., 2019). Interregional ES flow assessments – particularly those encompassing multiple flow types – thus improve our understanding of, for example, the links between global trade and local well-being. This is particularly important to reach the SDGs of “no poverty” (SDG 1), “zero hunger” (SDG 2) and “good health and well-being” (SDG 3). There is, hence, a critical need to assess interregional ES flows received and across international borders in order to identify interregional dependencies, assess the responsibilities of a given country for the cross-border impacts of their ES use and most importantly to reduce global environmental inequalities.

In this paper, we assess four telecoupled, interregional ES flows that are used by people in Germany and that are affected abroad by land and natural resource use within Germany and sending system nations. We selected Germany as an example of a high-income country of the Global North that is interconnected through diverse interregional ES flows to both its neighbors and to the Global South in ways that are critical for its national prosperity and sustainability. Employing selected case studies, for the assessment of (i) *biophysical flows of traded goods*, we quantify the amount of embedded ES in cocoa production and therefore the associated impacts of Germany's cocoa import on biodiversity in other countries. For (ii) *flows mediated by species through migration and dispersal*, we assess the region of origin and number of migratory bird species that provide natural pest control for agricultural areas in Germany. For (iii) *passive biophysical flows*, we evaluate the interdependency of supply and demand for flood regulation in Germany and neighboring countries in five transboundary watersheds (Rhine, Elbe, Oder, Danube, and Wiedau). Finally, to assess (iv) *information flows*, we use the example of the giant panda loan by the Chinese Government to the Berlin Zoo. We quantify the flows of services by the frequency of news reports and internet searches. We synthesize the results to identify research frontiers and governance options to address the dependencies between one nation and its partner countries and to suggest pathways towards global environmental equity.

2. Methods

Germany presented a well-suited case for studying interregional ES flows. While no comprehensive national ecosystem assessment exists yet for Germany (Albert et al., 2017), several national-scale ES studies have been conducted (Albert et al., 2016; Dittrich et al., 2017; Rabe et al., 2016; Wüstemann et al., 2015). However, none of these assessments systematically measure interregional ES flows between Germany and other world regions, despite often substantial remote impact. For instance, half of Germany's demand for cropland is based outside the country (Fischer et al., 2017). In 2013, Germany's ecological footprint exceeded its biocapacity by 143% (Global Footprint Network, 2017).

Koellner et al. (2019) provided technical guidance on how to structure and conduct an assessment of interregional ES flows, including relevant methods and metrics, which we used as basis of analysis. Quantification of interregional ES flows can be complex and data intensive. Koellner et al. (2019) elaborated three tiers for such analyses, with different complexity and feasibility levels (Grêt-Regamey et al., 2015; Tallis and Polasky, 2009). The first tier involved the development of straightforward, proof-of-concept methods and simple indicators that could be widely applicable, even in settings with relatively low data availability. Tier 1 thus primarily makes use of existing databases, approaches and literature. Tier 2 pairs existing databases with additional data and uses models with intermediate levels of complexity. Tier 3 includes highly complex models that are time and data intensive for most applications (Grêt-Regamey et al., 2015; Tallis and Polasky, 2009). Here, we developed a "tier 1.5" approach for the assessment of four interregional ES flow types (Table 1), providing a first estimate of Germany's multiple ES connections to the rest of the world. This methodology combined tiers 1 and 2 complexity and feasibility levels.

2.1. Cocoa trade

Cocoa (*Theobroma cacao*) is an important traded good in Germany and is mainly imported from West Africa (Mayer et al., 2018). Cocoa is only grown in tropical countries, and therefore consumption in northern countries is fully dependent on imports. For consumption, we used the apparent consumption (domestic production plus imports and minus exports) as a proxy. Cocoa production largely depends on embedded ES, for example, on a restricted list of species of wild pollinators. These pollinators account for about 95% of the crops' yield, making cocoa production highly pollinator dependent (Gallai et al., 2009; Kaufmann, 1975). In Germany, cocoa imports increased by 34% from 2008 to 2015 (to 1,103,000 tonnes in 2015) (Mayer et al., 2018). Ivory Coast and Ghana are currently the largest cocoa producers in the world, together producing 56% of the global and 80% of the African cocoa production in 2017 (FAOSTAT, 2019). Cocoa production plays an important role for social structure, local economies, rural livelihoods and development in West Africa (Gockowski and Sonwa, 2011). However, large-scale cocoa cultivation and expansion has also made cocoa production a major driver of land degradation and deforestation (Ruf et al., 2015; Wessel and Quist-Wessel, 2015). Therefore, it is useful to consider the impact of cocoa trade on biodiversity in an interregional ES flow analysis. We discuss the wider context of cocoa trade and its implications in Appendix A.

We combined established methods and datasets to account for the flows of cocoa, of embedded ES and of related impacts on biodiversity, i.e., species expected to have disappeared through habitat loss attributed to current cocoa production. First, we identified the sending

Table 1
Brief overview of the four selected ecosystem services flow types with Germany as receiving system.

Ecosystem services flow	Biophysical flow of traded goods: Cocoa trade	Flow by migrating or dispersing species: Pest control by migratory birds	Passive biophysical flow: Transboundary flood regulation	Information flow: Giant panda loan
Analysis	Import of cocoa to Germany, embedded services, and cropland embedded in cocoa production	Number and distribution range of migratory bird species providing pest control in agricultural areas in Germany	Flood risk, flood regulation supplied by vegetation and soils, and flood regulation demand in Germany and its change over time	Content and frequency of information flow in newspapers and Google on the giant panda loan to the Berlin Zoo
Sending system	Ivory Coast, Ghana, Nigeria, Cameroon, Togo, Ecuador, Indonesia and other countries (minor cocoa exports to Germany)	Europe, Asia and Africa	Poland, Czech Republic, Austria, France, Liechtenstein, Luxembourg, Switzerland, Belgium	China
Spatial resolution	5 arcmin (~9.25 km at the equator)	Combination of 100 m land cover information and vector data of bird occurrence ranges	300 m	n/a
Time period of analysis	2010	2012 (CORINE for Germany)	2000, 2006, 2012	April 2016 to August 2017

systems that supply most of the cocoa to Germany. Following Kastner et al. (2011), we traced cocoa embedded in processed products or traded as beans back to their countries of origin. This approach relies on a global dataset showing national-level production (in our case, cocoa) and trade flows between individual countries (Kastner et al., 2011). It employs matrix algebra to link countries of consumption (here, Germany) to the countries of crop cultivation. In doing so, the approach eliminates countries of transit, which are not relevant to our question. For instance, large quantities of cocoa products are imported to Germany from Belgium and the Netherlands. As these countries do not grow cocoa, the method establishes clear links between the imports to Germany and the countries of cultivation (Table 2). We then accounted for co-production factors embedded in the cocoa flows to Germany (cropland use for cocoa cultivation; Kastner et al., 2014), by dividing the cocoa flows by cocoa yields reported at the national level (FAOSTAT, 2019); we also assessed pollination dependence as an example of embedded ES (Wolff et al., 2017) and biodiversity loss as an example for environmental impacts (Chaudhary and Kastner, 2016) related to cocoa production. Cocoa yields depend about 95% on pollinators (Gallai et al., 2009). Pollination dependence was calculated as the additional area that would be needed in the absence of pollinators. This was done by lowering the reported crop yields by the dependency ratio to calculate the area that would be needed to meet Germany's production demand. The biodiversity loss estimate relies on the countryside species-area relationship model (Pereira and Daily, 2006) that depicts how overall species richness changes in response to shifting land cover and land use in a given territory. In this way, we estimate how many species disappear in a landscape with cocoa cultivation as compared to natural landscapes. In addition, we followed the methods of Fridman and Kissinger (2019) to map cocoa flows to specific sub-national regions and represented the origin of Germany's cocoa consumption at a 5 arcmin spatial resolution. They disaggregate trade data given at the national level to a moderate spatial resolution global grid using spatial production weights. The weights are based on global production maps from Spatial Production Allocation Model (SPAM) dataset (IFPRI and IIASA, 2016) and represent the share of production in each grid cell relative to the national production.

2.2. Pest control by migratory birds

Birds and other predators living in and around farmland can provide valuable natural pest control that reduces the need for pesticide use (Civantos et al., 2012; Pejchar et al., 2018). While there is increasing awareness of the dependency of species providing pest control on natural habitat (Karp et al., 2018), there is little knowledge on the interregional interlinkages of this ES (López-Hoffman et al., 2017). Migratory species also depend on suitable habitats outside the areas that benefit from the ES, and birds often migrate across large distances that connect their breeding and wintering habitats (Bauer and Hoye, 2014). In order to quantify ES dependencies of one country on other countries' ecosystems, it is hence necessary to understand both the type and amount of ES provided by a migratory species and its habitat dependence across that species' different migratory regions (Semmens et al., 2011).

We mapped receiving and sending systems for migratory bird species providing control of invertebrate crop pests. These migratory birds move between seasonal areas of occurrence, i.e., breeding, non-breeding, or stopover habitats. For this analysis of spatial linkages, we considered Germany as a receiving region and all outside regions as sending regions. As bird migration is cyclical, receiving agricultural regions in Germany can also be considered to be sending regions for other regions within the flyway, should future analyses address, e.g., pest control outside of Germany. These biophysical flows may therefore often be reciprocal, cyclical and lead to interactive exchange between regions.

We based the analysis on a review of bird species providing control of invertebrate crop pests in Europe (Civantos et al., 2012). We extracted occurrence data (range maps) for these 50 listed bird species (BirdLife International and Handbook of the Birds of the World, 2016). A similar approach using range maps has been used for analysing interregional flows of the ES birdwatching (Schröter et al., 2019). We first excluded 23 species that were resident species in Germany. We assumed that no interregional ES flow takes place for these resident species. The other 27 species had partial seasonal occurrence both inside and outside of Germany.

We then selected all species that had at least one type of habitat (breeding, non-breeding and stopover) exclusively outside Germany to identify sending systems. This ensured that we excluded those species that had both breeding and non-breeding habitats within Germany (i.e., year-round resident species), assuming that for these cases no major interregional flow takes place between Germany and outside areas. This was the case for the mistle thrush (*Turdus viscivorus*) and meadow pipit (*Anthus pratensis*). We additionally excluded resident habitats outside of Germany (assuming no interregional flow takes place for those areas). By excluding these species, 25 species were left for our analysis. We included the northern lapwing (*Vanellus vanellus*) in the analysis even though it had both breeding and non-breeding habitats in Germany. Only a small fraction of this species' total non-breeding habitat is located in Germany; hence, the species can be considered as migratory. We included all individual delineated habitat regions in the BirdLife database that overlapped with at least one of the two flyways crossing Germany, the East-Atlantic flyway and the Black Sea/Mediterranean flyway (Kirby, 2010). This ensured that populations outside the flyways were excluded and the only populations included were those that are likely to spend part of their annual lifecycle in Germany. Subsequently, we excluded seasonal habitats of two species in Greenland and parts of

Table 2
Ecosystem services and related resource use and impacts due to cocoa trade for selected countries to Germany in 2010: flows of cocoa for consumption in Germany, associated cropland use, additional land that would be required for cocoa provision in the hypothetical absence of wild pollinators, and number of species disappearing due to German cocoa consumption.

Sending system	Cocoa flow (tons)	Cropland used for cocoa cultivation for German consumption (hectares)	Additional area required in hypothetical absence of wild pollinators (hectares)	Biodiversity impact (species disappearing in respective ecoregions)
Ivory Coast	123,939	238,607	5,388,525	0.38
Ghana	62,280	179,170	3,404,221	0.45
Nigeria	43,397	161,739	3,073,036	0.96
Cameroon	39,031	111,995	2,127,906	3.39
Togo	27,172	43,345	823,564	0.24
Ecuador	14,936	26,702	507,336	1.88
Indonesia	13,476	29,285	556,415	0.22
Other countries (36 additional countries)	24,395	95,476	1,814,037	1.25
Total for German consumption	**348,626**	**931,318**	**17,695,037**	**8.78**

the Arctic based on a literature review. We assume that no major migration from these areas to Germany takes place for these species (northern wheatear, *Oenanthe oenanthe,* based on Lyngs, 2003; horned lark, *Eremophila alpestris,* based on Encyclopedia of Life, 2018). We prepared a spatial overlay of occurrence data for the final selection of 25 migratory, pest-controlling bird species (Appendix Table B.1). We selected all individual delineated seasonal habitats of the 25 species to identify receiving systems within Germany. To delineate receiving systems, we selected agricultural areas in Germany (grassland, cropland, permanent crops, mixed classes including agriculture) from the CORINE 2012 land cover dataset (Coordination of information on the environment – CORINE; EEA, 2016a) and created a spatial overlay of the extent of species occurrence data.

2.3. Transboundary flood regulation

Germany borders nine countries and shares five major rivers with other nations (most notably the Danube, Elbe, and Rhine; GEF, 2016). Significant floods in recent decades included those on the Rhine (1993 and 1995), the Elbe and Danube (2002), and major floods in 2013 that affected nearly all of Germany's major rivers (Thiekeh et al., 2016). Floods in 1993, 1995, and 2002 spurred major changes to national flood policies and cooperation in flood management with neighboring countries (Becker et al., 2007; Thiekeh et al., 2016). While the importance of transboundary flood management is recognized in Germany, relevant cross-border datasets are limited (Uhlemann et al., 2010), making transboundary assessments of flood mitigation as an ES both a scientific and practical challenge.

Germany “imports” flood regulation supplied on the Elbe, Oder, and Rhine Rivers from nine upstream nations, and “exports” flood regulation on the Danube, Oder, Rhine, and Wiedau Rivers to four adjacent nations (plus many additional downstream nations in the Danube Watershed, Appendix Figure C.1). We quantified three metrics–flood risk, flood regulation supplied by vegetation and soils, and flood regulation demand–for all of Germany plus its five transnational watersheds (Rhine, Danube, Elbe, Oder, and Wiedau, Appendix Figure C.1). These were based on ‘Tier 1.5’ flood regulation assessment metrics developed by Martínez-López et al. (2019). First, to estimate flood risk, we generated a ranked value as the weighted average of (i) mean annual precipitation, (ii) modified topographic wetness index to estimate surface-water permanence based on slope and contributing area (Beven and Kirkby, 1979), and (iii) average rainy season temperature, to account for the Clausius-Clapeyron relationship between temperature and rainfall intensity, adapted for mid-latitude environments (Utsumi et al., 2011). Second, we estimated flood regulation supply by calculating runoff reduction based on the curve number method, with flood risk reduced in proportion to the curve number values; low curve numbers provide greater flood regulation (Ferrer-Julià, 2003). Third, we produced an estimate of flood regulation demand by intersecting population density data with the location of the 10-year floodplain (Alfieri et al., 2014), providing a conservative estimate since green infrastructure's impact on the reduction of large floods is likely to be small (Brauman et al., 2007).

We used CORINE land cover data to estimate changes in flood regulation supply for the years 2000, 2006, and 2012 (EEA, 2016a) and population count data from Gridded Population of the World for 2000, 2005, and 2010 to estimate flood regulation demand (CIESIN, 2016). By calculating percent change in these metrics over the years, a temporal analysis makes more meaningful use of index-based ES indicators. Lastly, we summed the amount of flood regulation supplied by upstream / ”exporting” countries and flood regulation demand by downstream / ”importing” countries, and quantified that change over time. For rivers that formed the boundary between two countries (e.g., the Oder River between Germany and Poland), we summarized imports and exports from both nations, as ecosystems provide flood regulation benefits to people and property at risk of flooding on both river banks. We ran our analysis at 300 m spatial resolution and summarized input data in the supplemental information (Appendix C). Model code was adapted from a public repository (https://github.com/integratedmodelling/im.aries.global; Villa et al., 2014); we ran the models in R 3.4.4 (R Core Team, 2018).

2.4. Information flows from giant pandas at the Berlin Zoo

In Germany, giant pandas *(Ailuropoda melanoleuca)* are a favorite species for public viewing in zoos (DW, 2018). The panda is a charismatic species that can serve as an instrument for nature conservation through informing the public about endangered wildlife species and pressure on their habitats (Kontoleon and Swanson, 2003; Liu et al., 2015). However, terms such as “panda diplomacy” (Buckingham et al., 2013) show that multiple meanings are attributed to pandas, including considering pandas as a means of the Chinese Government to shape their political and diplomatic relationships with other nations. As the latter aspects have not yet been systematically explored, we put an emphasis on how information flows from pandas also represent political aspects in our analysis.

Our analysis focused on the lending of two giant pandas by the Chinese Government to the Berlin Zoo in July 2017. The pandas came from a breeding station close to the City of Chengdu in southwestern China. We interpret the pandas as carriers of information flows that create a connection between a sending system (China) and a receiving system (Germany). Newspapers operate as agents in the receiving systems that disseminate relevant information (Liu et al., 2015). We used a mixed qualitative-quantitative approach for our analysis. Initially, we conducted a frequency analysis in Google Trends to explore the popularity of the two pandas in the Berlin Zoo. The use of Google Trends in scientific analysis has become recognized recently, e.g., Nghiem et al. (2016) to reflect the frequency (i.e., popularity) of search terms used by search engine users. We gathered the total search volume in Google for the terms “panda” AND “Berlin” AND “zoo.” We normalized the results to the total search volume for the term during the requested period (Choi and Varian, 2012).

We also used a content analysis of newspaper articles about the panda loan to identify the type and amount of information about ES (e.g., habitat value) and which related political, economic, and cultural aspects were covered in the newspaper articles. While the quantitative analysis explicates *how often* the topic of interest (lending of pandas to the Berlin Zoo) was covered, the qualitative analysis explored *what* is reported in newspapers (i.e., information about ecosystems, cultural or political aspects). We focused on the receiving system by collecting a sample of German newspapers. The sample covered the period from April 2016 to August 2017 (preparation of loan, actual move and arrival on July 6, 2017, as well as the acclimatization) to analyze how the frequency of information flows changed over time. We derived the sample using the Lexis-Nexis database service (Nexis Database, 2018) “German Language News,” which provides full-text articles to newspapers, news agencies, and specialized press from 269 sources. Given the quantity of potential newspaper articles, we selected five major national newspapers plus three local newspapers published in Berlin. All national newspapers are widely read and distributed and represent both conservative (Bild, Die Welt) and liberal perspectives (Frankfurter Rundschau, Spiegel and taz). We included local newspapers to analyze how local and national coverage differ. We used the words in German for “panda” AND “Germany” in the keyword query to search for relevant articles. In addition, we used the term “politics” to capture to what extent newspaper articles also report about political aspects. Our sample included a total of 56 articles. Appendix Table D.1 lists the newspapers and number of articles that were considered in the content analysis.

We included deductive and inductive steps in the content analysis (Mayring, 2000) using the MAXQDA 12 software (Kaefer et al., 2015). We defined a first set of deductively derived categories prior to the analysis of the newspaper coverage. These were rather broad and were meant to gather information about "natural," "economic," "cultural," and "political" aspects of the panda loan. After reading all articles, we further refined these general categories by adding subcategories. For example, we included the subcategories "information about pandas in general" or "information about their habitat" under the main category "natural aspects." During this step, we also generated new categories inductively to be able to include relevant information that were not yet covered by the previously developed categories. The additional categories were meant to include information about the "Two pandas," the "Berlin Zoo," as well as information about "scientific," "historical," "organizational-logistic," and "emotional" aspects. In a final step, we analyzed all articles by attributing categories to specific codes in the newspaper articles. Codes usually represent a unit of meaning that can be part of a sentence, a full sentence or an entire paragraph.

3. Results

3.1. Cocoa trade

In 2010, Germany was the second largest cocoa consumer in the world, with consumption estimated at more than 348,500 tons of cocoa beans equivalent (Table 2). Over 90% of the cocoa supplied to Germany originates from seven countries, of which five are located in West and Central Africa (Ivory Coast, Ghana, Nigeria, Cameroon, and Togo; providing approximately 85% of cocoa supply) and one each in South America (Ecuador) and Southeast Asia (Indonesia). Ivory Coast and Ghana alone supplied around 53% of Germany's cocoa. Cropland for Germany's cocoa consumption totals 931,318 hectares globally (Table 2), of which almost 800,000 hectares (84%) are in West African countries. In Ivory Coast, Ghana and Togo, cocoa is mostly grown in southern regions. Hotspots of cocoa production exported to Germany in 2010 are concentrated within the Guinean rainforest ecoregion in Ghana and occur more sparsely in the Congolian rainforests in Cameroon (Fig. 1).

We quantified pollination as an embedded ES, as the additional land required for cocoa provision in the hypothetical absence of wild pollinators accounted for almost 17.7 million hectares. Finally, we quantified biodiversity impacts associated with Germany's cocoa consumption, i.e., species expected to have disappeared through habitat loss from cropland, totaled to 8.78 regional species extinctions (Table 2). Major impacts on biodiversity occurred in Cameroon (3.39 species disappearing) followed by Ecuador (1.88 species disappearing), which together account for about 60% of all regional extinctions associated with German cocoa imports. In contrast, the main suppliers of Germany's cocoa, Ivory Coast and Ghana accounted for 0.38 and 0.45 species extinctions, respectively.

3.2. Pest control by migratory birds

Our spatial analysis showed that the majority of migratory bird species that provide pest control to German agricultural areas migrate between Germany and Africa´s humid and sub-humid climate zones, especially in the Great African Rift and the Savanna Zone (Fig. 2; per country in Appendix Table B.2). About 10 to 12 bird species migrate from those areas to Germany, e.g., the common swift (*Apus apus*), red-backed shrike (*Lanius collurio*), northern wheatear (*Oenanthe oenanthe*), and European nightjar (*Caprimulgus europaeus*). In addition, these and other species stay or rest in the Nile Delta and along the Mediterranean coast of Africa. Fewer bird species that we assessed (about 1 to 3 species) migrate between Germany and other European countries, Russia, the Near East and Middle East, and northern India.

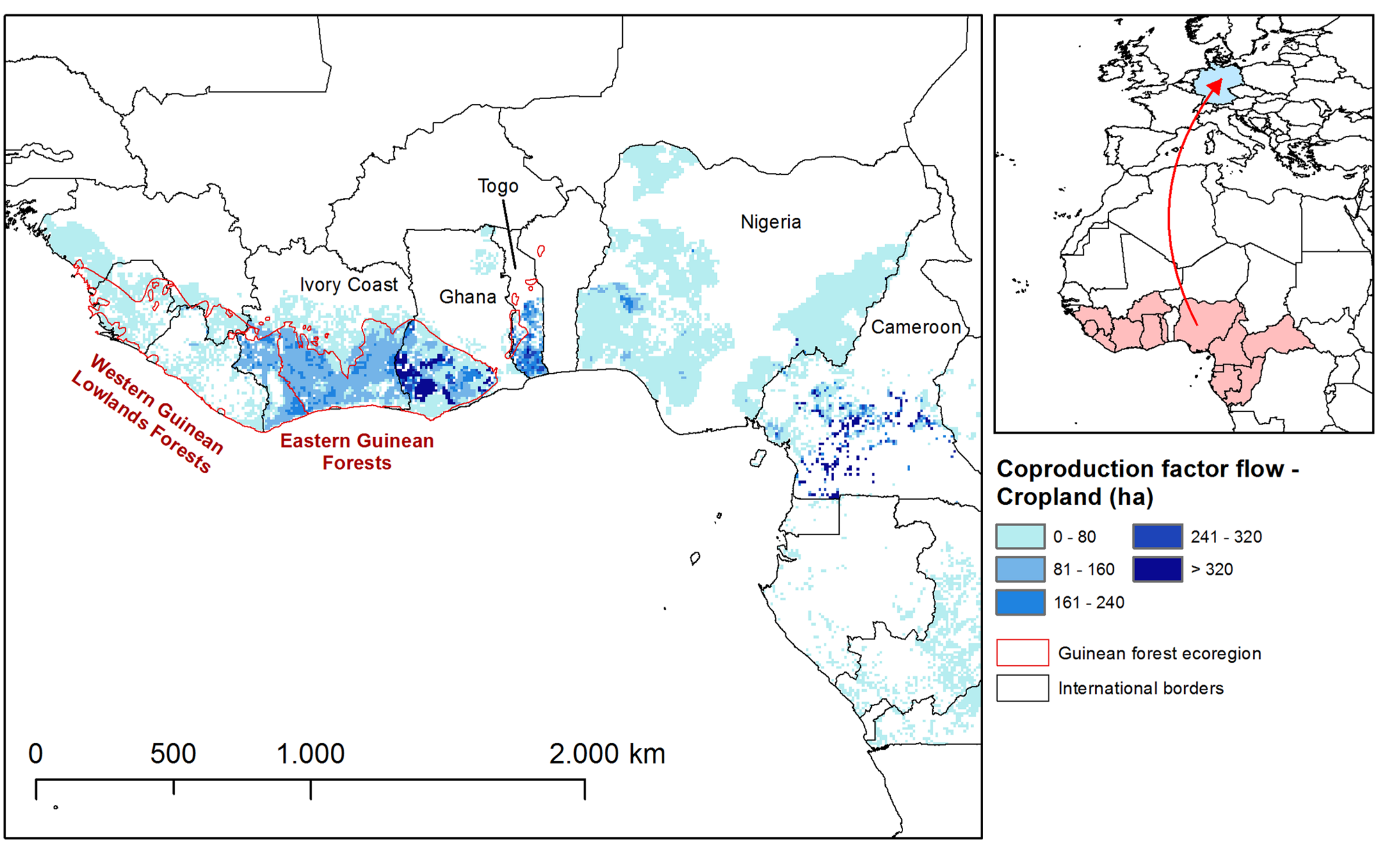

Fig. 1. Areas in West Africa exporting cocoa to Germany in 2010. Sending countries are shown in pink, and the receiving country (Germany) in light blue. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

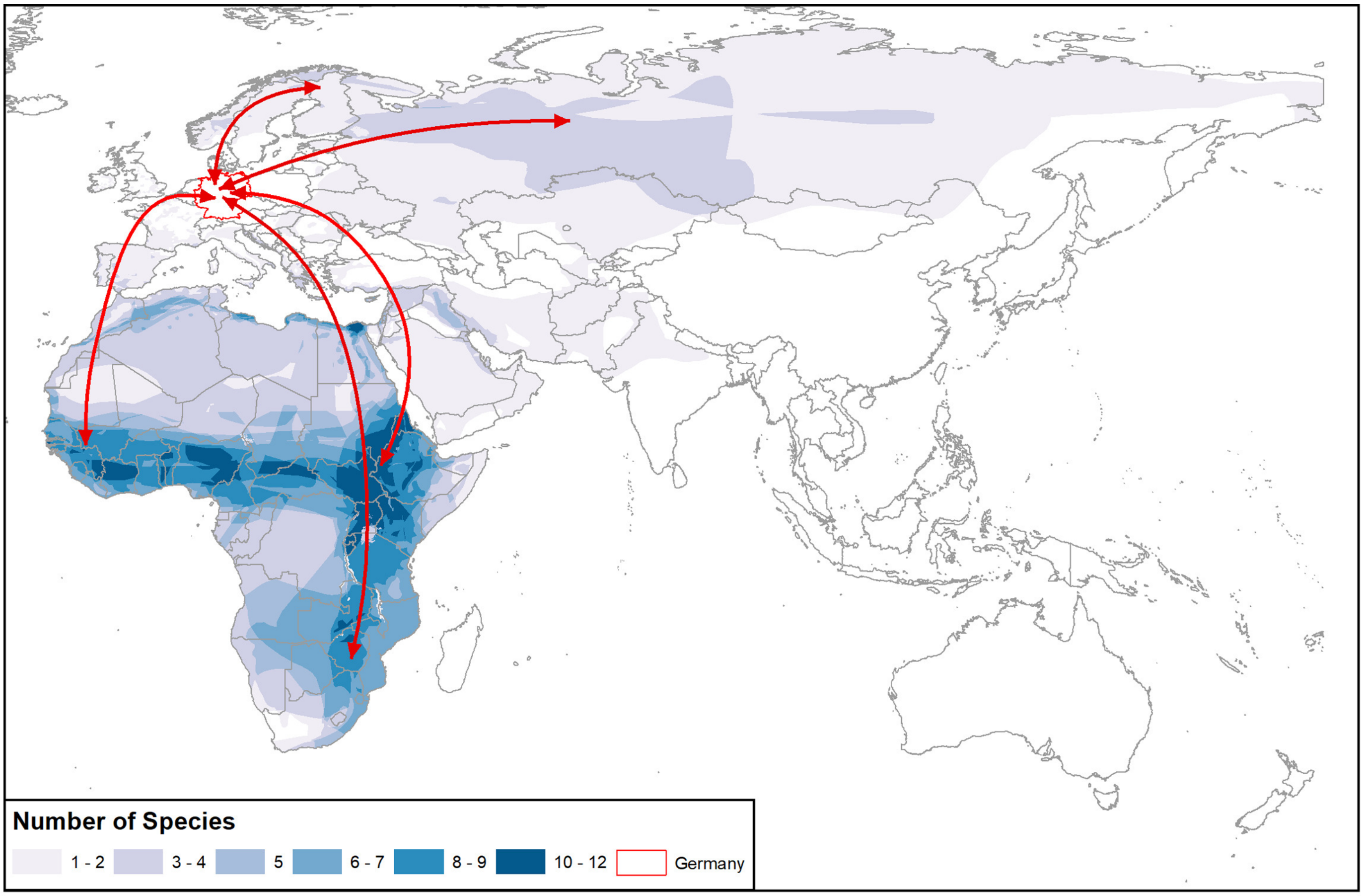

Fig. 2. Sending system: migratory habitat for birds providing pest control in Germany.

Within Germany, the greatest overlap of assessed migratory bird species providing pest control for agriculture was 10 to 12 species, primarily in the eastern states of Brandenburg and Saxony (Fig. 3). Examples of bird species include Eurasian skylark (*Alauda arvensis),* whinchat (*Saxicola rubetra*), and corn bunting (*Emberiza calandra*). In Bavaria, North Rhine-Westphalia, Lower Saxony and Baden-Wuerttemberg, higher occurrence levels are scattered. Areas with the lowest occurrence levels of one to six migratory bird species per pixel are located in Schleswig-Holstein and Mecklenburg-Western Pomerania.

3.3. Transboundary flood regulation

Of the modeled, nationwide flood regulation supplied by ecosystems in Germany, about 40% is exported to downstream nations with shared watersheds (Fig. 4; Appendix Table C.1 and Appendix Figure C.2, C.3 and C.4)–primarily to the Netherlands on the Rhine River (58.5% of exports) and Austria and other downstream nations on the Danube (36.5%), with much smaller exports to Poland on the Oder (4.8%) and Denmark on the Wiedau (0.2%). Nations upstream of Germany provide additional flood regulation to beneficiaries in Germany, adding an additional 64% of the national total for flood regulation services from upstream watersheds. These imports come from the Oder (61.5% of total imports, primarily from Poland), with roughly equal imports on the Elbe (19.9%) and Rhine (18.6%).

From 2000 to 2012, flood regulation supplied by ecosystems declined by 1.6% across Germany due to an increase in urban, industrial and cultivated areas (EEA, 2016b). This led to a decrease of 2.9% in total exported flood regulation over the 12-year period, which ranged from a large decrease in flood regulation exports on the Wiedau (16.8% decline), to small declines on the Rhine and Danube watersheds (3–4%), to a small increase in flood regulation exports on the Oder (1.9%). Similarly, land cover change in adjacent nations led to a decrease of 0.6% in total flood regulation imports by Germany. Flood regulation supplied by upstream nations to Germany declined in the Rhine (0.5%) and Oder (1.0%) watersheds but increased by 0.7% in the Elbe watershed.

Demand for flood regulation across Germany declined by 0.6% from 2000 to 2010, reflecting slight national-scale population decline by 0.5% from 2000–10 and 2.2% from 2000–12 (World Bank, 2018). About 62% of Germany's flood regulation demand occurs in downstream locations on the Elbe, Oder, and Rhine where Germany imports flood regulation from upstream nations. Flood regulation demand is greatest in the Rhine watershed (53.5% of national demand from transboundary watersheds), less on the Elbe (44.6%), and minimal on the Oder (2%). Flood regulation demand in Germany's transboundary watersheds declined by 1.5% from 2000 to 2010; declines ranged from 2.9% in the Elbe, to 7.7% in the Oder to zero in the Rhine. Flood regulation demand by Germany's adjacent downstream neighbors is about 68% of Germany's total domestic demand. Demand is greatest by the Netherlands in the Rhine (47.8% of total demand in adjacent downstream nations), followed by Poland in the Oder (32.7%), and Austria in the Danube (19.5%) Total demand grew by 3.6% from 2000 to 2010, with demand increasing by 5-6% for Austria and the Netherlands, while declining for Poland (-0.8%) and Denmark (-14.3%).

3.4. Information flows from giant pandas at the Berlin Zoo

The information flow analysis showed a notable increase in Google searches and media coverage on the panda loan to the Berlin Zoo in July 2017. The main reason for this peak is the arrival of the pandas on

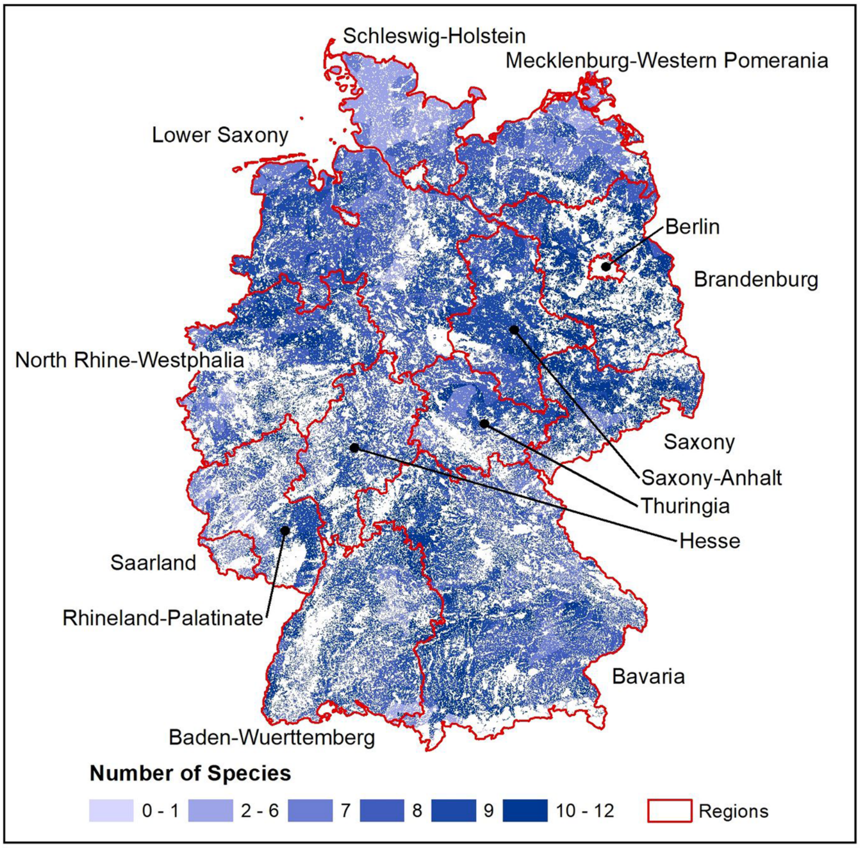

Fig. 3. Receiving system: seasonal extent of area populated by migrating birds that potentially provide pest control in German agricultural areas.

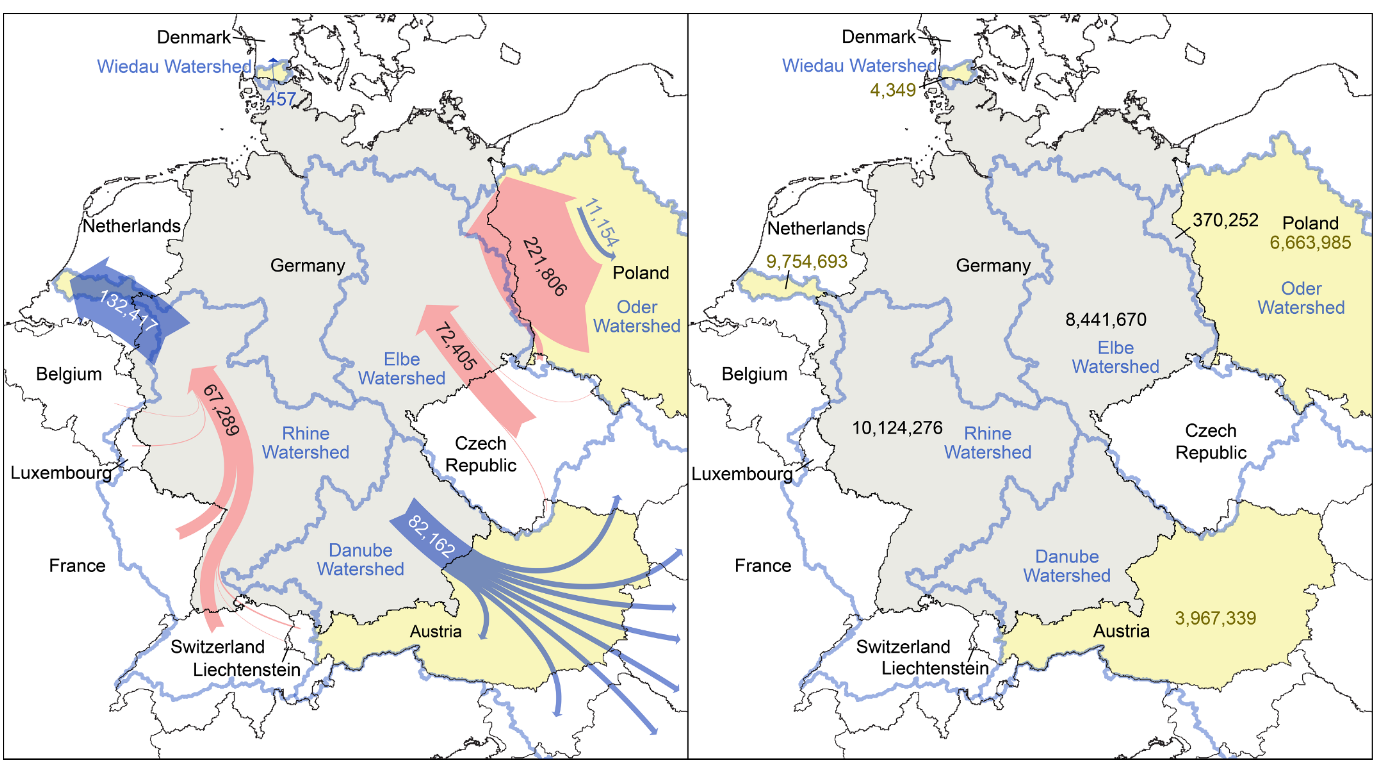

Fig. 4. Flood regulation supply by upstream countries to downstream countries, with Germany's imports shown in pink and exports shown in blue (left); flood regulation demand by downstream countries (right). All values are cell-level index numbers (0-1). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

July 6th (see Appendix Fig. D.1). This increase of media attention is also reflected in the newspaper sample gathered in the receiving system (Germany). In addition, the content analysis shows that emblematic animals such as a giant panda allow media agents to generate and attribute many different meanings to pandas (see Appendix Table D.2 for an overview). The number of codes attributed to a single category include information about the two giant pandas themselves ("The Pandas"; $n = 49$), i.e., where they come from, their characteristics as well as their appearance, but it also includes information about their natural habitat and the different pressures (e.g., population pressure, climate change) resulting in the reduction of wild panda populations ("natural aspects"; $n = 31$, Fig. 5). Such information can help to increase awareness among the public in the receiving system about pandas as an endangered species but also provides relevant insights on how their ecosystems of origin are at risk. At the same time, newspaper articles included information about breeding programs set up to stop the extinction of giant pandas ("scientific aspects"; $n = 15$, Fig. 5). Since two relevant research institutions supporting international breeding programs are located in Berlin, local newspapers generated a greater amount of information (about 87% of the total information on scientific issues) than national newspapers. In addition, about 73% of the information specifically on the two pandas came from local newspapers.

The analysis also revealed that media agents took the opportunity to inform the public about other aspects in reports about the pandas. This includes historical information ("historical aspects"; $n = 23$) about previous panda sending to the Berlin Zoo in 1980 located in the former Western part of Berlin, which were organized as a donation (and not as a loan), as well as the donation of pandas by the Chinese Government to other zoos around the world. Reports also refer to information about the economic relationship between China and Germany ("economic aspects"; $n = 32$). Locally, a high share of information was provided about the organizational, logistical and financial details of the lending ($n = 45$). This also includes reports about how German politicians and experts repeatedly visited breeding stations in China and about the share of money generated by the lending fee that was spent on species conservation (about 70%) (BZ, 2017).

Most information was provided on political aspects ($n = 116$; Fig. 5), which is an expected result considering the search terms (see Section 2.4). This highlights how political interests are shared between the sending and receiving systems (e.g., climate change and energy transition). The newspaper articles particularly highlight the relative stability of the political relationship between China and Germany at the time of the panda loan. In this context, pandas are framed as a symbol that affirms the relationship between both nations. The notion of panda diplomacy is also referenced, including how China uses pandas as friendly ambassadors by which strategic interests are reached more easily than by classical diplomatic means. However, the reports about the panda are also used to engage critically with the political situation in China; some articles point particularly to the lack of human rights and basic democratic principles.

4. Discussion

4.1. Interpretation of the findings

Uncovering how interregional flows affect synergies and tradeoffs between ES and biodiversity in distant systems can enable the assessment of the sustainability of ES management practices (Pascual et al., 2017). Taking the example of cocoa, the increase of German consumption of this traded good supplied by Cameroon and other countries can lead to enhanced business opportunities and employment in the farming areas. If managed unsustainably, however, cocoa trade also leads to loss of pristine forest and species in the country of origin (Table 2). Therefore, while cocoa production provides income to local farmers, a (distant) country's demand for cocoa also serves as a driver of land degradation and deforestation in the country of origin (Ruf et al., 2015; Wessel and Quist-Wessel, 2015). Forest loss in cocoa-producing

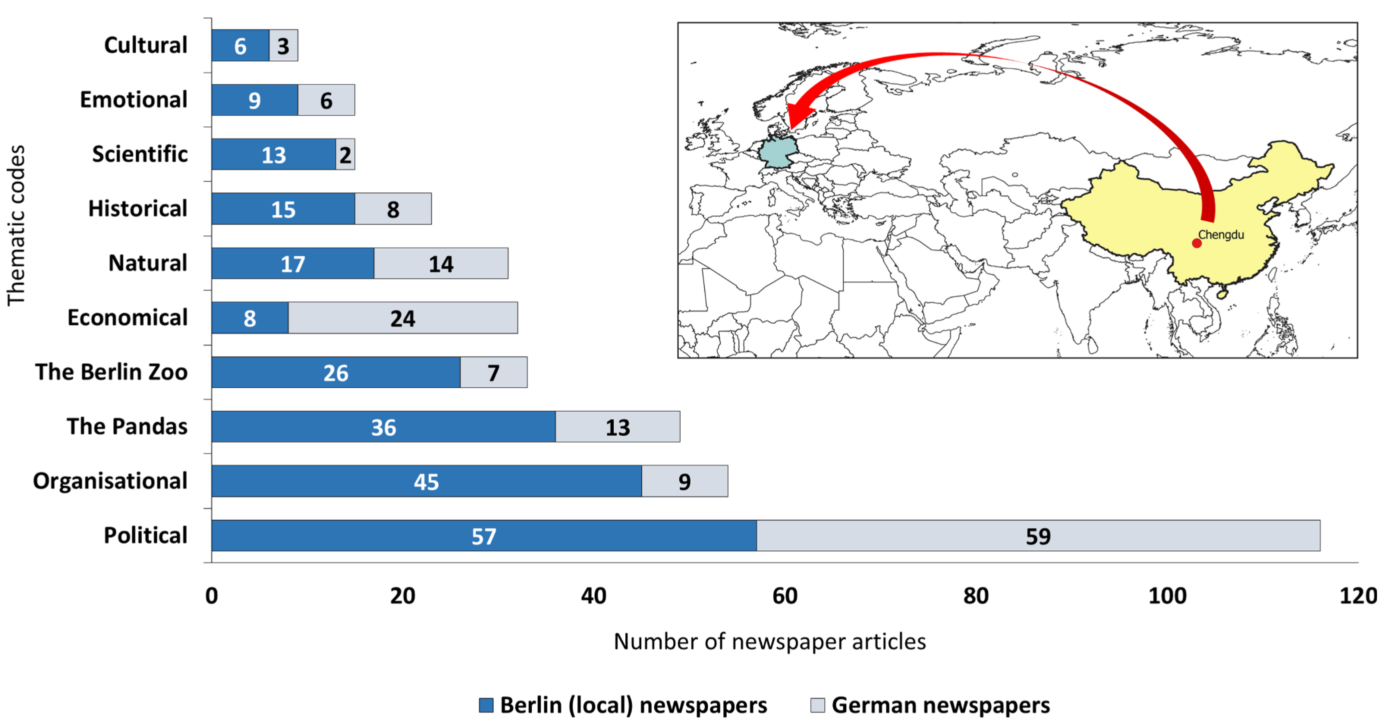

Fig. 5. Thematic codes and number of newspaper articles on the loan of two pandas from the Chengdu reserve to the Berlin Zoo (see inset map) in national German newspapers and local Berlin newspapers.

areas can have negative effects on local provisioning services, including food, fuel, fiber, and medicine, thus affecting the livelihoods of local communities (Gockowski and Sonwa, 2011). In addition, forest clearing has led to the deterioration of regulating services, such as soil fertility, maintenance of habitats, and micro-climate regulation (Ruf et al., 2015). This may have not only local but also distant effects. For example, a loss of birds in Cameroon due to the expansion of cocoa farming and thereby loss of wintering bird habitat might have negative impact on the provision of pest control in Germany as this regulating service strongly relies on migratory birds from the African tropical zone (Fig. 2). Within Europe, similar tradeoffs may exist between floodplain farming and floodplain restoration for natural flood control (Rouquette et al., 2011). A full accounting for a nation's agricultural imports and exports, coupled with an understanding of which imported and exported crops are grown in floodplains, could enable a tradeoff analysis for interregional flows of transboundary flood protection and food provision. These examples show that tradeoffs between different ES can happen not only locally, but also between distant regions.

On the other hand, institutional agreement between two connected countries can foster synergies related to the ES that are shared between both countries. For example, the cultural ES of experience and inspiration provided by the giant panda in the Berlin Zoo might support the maintenance of habitats that leads to further nature-based tourism in China. In fact, the panda loan includes an annual payment from Germany to preserve the species' habitat in China. Liu et al. (2015) noted that the preservation and restoration of giant panda habitat can also promote the provision of cultural ES in China, such as the physical experience of wildlife-based tourism. We expected therefore to see substantially enhanced information about panda ecology and conservation following their loan. However, we did not identify these findings from Liu et al. (2015) in our results.

Joint species conservation arrangements to secure ES flows are rarely agreed upon (but see López-Hoffman et al., 2017), and the example of migratory birds providing pest control in Germany did not yet lead to a greater awareness and willingness to protect wintering habitats in Africa, where habitats are threatened by climate and land-use change (Bairlein, 2016; Jetz et al., 2007). In fact, Runge et al. (2015) found that 91% of habitats of migratory bird species have inadequate protection status for habitats in at least one part of their annual cycle. This may have serious implications for ES provision in countries on their migratory route (Hulina et al., 2017). These analyses can help to highlight the need for transboundary conservation for migratory species and the ES they deliver (Bagstad et al., 2019; Lopez-Hoffman et al., 2017).

4.2. Caveats and approaches to improve interregional ES assessments

We presented a first national-scale, quantitative analysis with selected case studies for the four interregional ES flow types. While our analysis of four interregional ES is partial, it is substantially more complete than studies evaluating a single flow type (e.g., trade goods or migratory species-driven flows) and systematic (addressing all flow types) than past national-scale analyses. It also points the way toward comprehensive national-scale analyses addressing interregional ES flows (following Koellner et al., 2019). Analysis of trade goods and their impacts can be prioritized based on a nation's most important imports, generally following the methods and data sources we used. Broader-scale analysis of migratory species-derived ES can proceed following consultation with wildlife ecologists to identify migratory taxa that provide important ES within a country. In an example application, Schröter et al. (2019) provide a complementary analysis to our research by evaluating the origin of migratory species valued for birdwatching and information flows on existence and bequest values in Germany. ES derived from biophysical flows can be prioritized by evaluating a country's geographic position within watersheds, airsheds, and oceanic currents and important environmental stressors. This drove our selection of flood regulation as an initial focus for Germany. Analysis of dust regulation in areas with wind erosion problems (Xie et al., 2019) or transboundary water supply in water-stressed areas might emerge as initial priorities elsewhere. To evaluate important information flows, analysts can identify charismatic species of importance to the nation that originate from beyond the country's borders. Schröter et al. (2019) provide an example analysis for information flows from charismatic species valued by residents of Germany and the Netherlands. Finally, by using a tiered assessment framework (Koellner et al., 2019), assessments can be tailored to the data availability and decision contexts in a given country.

Interregional flows of ES are manifold and highly diverse, and quantification of all ES flow types was not feasible with the same level of detail. For example, analyses of ES flow changes were only possible for transboundary flood regulation due to data limitations. Similarly, due to a lack of available data, we could not conduct extensive uncertainty analyses. However, we acknowledge the importance of uncertainty analyses in future interregional ES assessments (Bryant et al., 2018; Hamel and Bryant, 2017; Koellner et al., 2019). Knowledge also varies for the different ES and flow types. For example, the assessment of biophysical flows of traded goods is much more scientifically developed (e.g., Life-Cycle Assessment, multi-regional input-output analysis, human appropriation of net primary production, ecological, water, and carbon footprints) than the assessment of cultural ES flows (Koellner et al., 2019). Complexity is a challenge in highly interdisciplinary studies, and often places limits on analyses (Green et al., 2005).

The assumptions and simplifications required to represent complicated and data-scarce interregional flows (Appendix Table E.1) and the use of proxy indicators to evaluate ES flows and embedded ES add uncertainty to the results. For cocoa trade, for example, we assumed that the embedded ES pollination is provided equally across space, although it is a complex process (Young, 1982, 1983). Cocoa production relies on a balance and temporal synchronization between the abundance of wild pollinators (various species of midges) and flowers. These factors are regulated by natural climatic conditions and management practices, e.g., the shade levels are a very important factor for midge survival (ibid.). Some management factors, such as the shade level, can be spatially modeled, while lack of pollinator abundance data with sufficient temporal resolution will remain a limiting factor for more detailed pollination analyses. Habitat suitability models could be employed to advance future research for ES flow analyses allowing for spatial differentiation of embedded services using various models and simulations, such as the Integrated Modeling of Ecosystem Services Tradeoffs (InVEST; Nelson et al., 2009) and Artificial Intelligence for Ecosystem Services (ARIES; Villa et al., 2014) modelling toolkits, and the Telecoupling Toolbox (McCord et al., 2018; Tonini and Liu, 2017).

The approach for migratory species focused on the spatial delineation of potential occurrences of these species. Models that further specify potential habitat within range maps could be developed (Rondinini et al., 2011). The relatively coarse range maps contain uncertainty about the actual distribution of species and hence the number of overlapping species (Hurlbert and Jetz, 2007). Considering species' abundance and typical levels of consumption of crop pests would be the next steps to quantifying the importance of a species for pest control (López-Hoffman et al., 2014). These assessments could also be improved by considering abundance of individual populations of the species or observed or modeled pest control services. Our assumption that different parts of a species' range are equally important masks spatial heterogeneity related to the distribution and quality of habitats for migratory birds within the ranges (Bieri et al., 2018). While this may lead to overestimation of the extent of the sending system, delineation of all potential habitat areas adheres to the precautionary principle. For transboundary flood regulation, the employed simple index number approach could be enhanced by using a formal hydrologic or event-based model. Additionally, while the curve number method provides a theoretical basis for the role of vegetation and soils in absorbing water, for very large flood events, ecosystems' flood-regulation capacity can be much more limited. More sophisticated modeling approaches can be used to quantify flood regulation where data and capacity allow (Stürck et al., 2014). For the analysis of interregional information flows, a limitation was the focus on political aspects in search terms. Codes were potentially double counted due to overlapping content. Furthermore, we did not include other media, e.g., Twitter and TV news, in the analysis. In addition, the spatial dimension of information flows could be considered by proxy indicators for spatial characteristics.

Flows from one nation to another can relate both to the benefits that ES provide and to "ecosystem disservices" (Shackleton et al., 2016). For example, impervious surfaces can increase runoff and downstream flood risk; similar to our flood regulation analysis, it is possible to quantify impervious surfaces in upstream "sending" nations (Table C.2). Similarly, certain migratory species might cause crop damage, which could be quantified for comparison with ES benefits. Interestingly, some telecoupled ES flows may be two-way, such as those triggered by migratory species, which obviously provide cyclical flows where benefits and disservices may occur in all affected countries (Pejchar et al., 2018). For instance, species may provide pest control in one country and may act as crop grazers, prey, or predators for species providing ES or disservices in other countries. As such, countries may be considered both as sending and receiving nations (data limitations made the evaluation of Germany as a receiving nation most feasible for all but our flood regulation analysis, where Germany is both a sending and receiving nation). Information flows may also be reciprocal, and the interactive effects of sending and receiving countries could be assessed in other cases. We consider the selected panda example to be a one-way flow, as ecological information on their habitats would unlikely appear at higher rates in Chinese media due to the Berlin Zoo loan. Furthermore, flows may also have a temporal component and may change over time, as shown for the flood example, possibly due to interactive effects of ES flows in sending and receiving systems, e.g., through changes in demand patterns or management and policy responses. These suggestions add both realism and complexity to interregional ES flow analyses. However, they should not deter initial analyses such as those presented here and elsewhere (Schirpke et al., 2019; Xie et al., 2019) in building our still early understanding about the importance of interregional ES flows.

4.3. Implications of interregional flows of ecosystem services for governance and management

Assessments of interregional, telecoupled ES flows across distances are a crucial first step towards the creation of globally sustainable environmental governance and decision making regimes. Because the use of ES in a receiving location can have adverse effects on ecosystems in the sending system, and sending system natural resource management decisions can affect telecoupled nations, assessments of interregional flows are ultimately assessments of environmental equity across international borders. Remote responsibilities emerge and need to be accounted for. Costs of land management and associated land degradation are usually borne by the local providers in sending systems, while the benefits of consumed goods, climate or water regulation, opportunities for using cultural services such as birdwatching or hunting as well as education or other information flows are distributed at larger scales (Bagstad et al., 2019; Liu et al., 2015). Trade in provisioning ES, one type of interregional flow, is often linked to tradeoffs in the sending system, such as habitat destruction and loss of species (Chaudhary and Kastner, 2016; Mayer et al., 2005; Marques et al., 2019). The results of this study suggest how assessments of interregional ES flows can more comprehensively inform the design of international management and policy actions that account for a nation's offsite ES burdens (Pascual et al., 2017) in distant sending regions. This knowledge can then be used to design governance instruments to manage externalities related to ES flows.

Interregional ES flows are influenced by local and distant governance regimes, creating an overarching but connected complex governance system (Oberlack et al., 2018; Paavola, 2007). As a consequence, interregional ES flows require polycentric governance mechanisms that are neither local nor entirely global (Oberlack et al., 2018). While local institutions and actors might be willing to sustainably manage ES provision in the sending system, these institutions are influenced by other institutional arrangements operating in distant places and across large spatial scales (Martín-López et al., 2019). Therefore, local institutions of sending systems may not be able to handle the processes driven by receiving systems. On the other hand, global institutions, such as United Nations conventions (e.g., Convention of Migratory Species) and global trade agreements may be unable to manage the consequences of interregional flows on local sending and receiving systems (Challies et al., 2014; Lenschow et al., 2016). For these reasons, governance mechanisms that operate at a single level, such as local communities or global agreements, might fail to sustainably manage ES. Clearly, if interregional ES flows connect distant places and different organizational levels (from local to global), then their management necessarily requires the consideration of institutional theories of polycentrism (Andersson and Ostrom, 2008; Nagendra and Ostrom, 2012). Governance of telecoupled ES flows should align and strengthen governance beyond single governance levels and increase accountability and legitimacy across those institutions engaged with interregional ES flows (Biermann et al., 2012). Conservation actions, supported by, e.g., payments for ES or other policy instruments such as pollution control, might be needed to protect ecosystems abroad, which can require broader discussions about equity issues related to ES supply and demand and opportunity costs of conservation. In fact, the consideration of interregional ES flows and the recognition of globally distributed natural resource use might contribute to stronger identification and examination of environmental justice issues. By unravelling how ES use is unevenly distributed among actors across places (i.e., distributional justice) and how ES-related decision-making is also unevenly distributed among actors across governance levels (i.e., procedural justice) (Martín-López et al., 2019), increased understanding about interregional flows may help to inform such policy instruments to promote environmental justice. Overall, nations need to be able to identify, understand, and map their use of global resources and associated ES flows to embrace and act on their remote responsibilities for sustainable development.

Our analysis also demonstrates how embedded ES flows and related co-production flows do not necessarily align with impacts. While the Ivory Coast and Ghana are the most prominent sending systems in the cocoa trade to Germany, the highest biodiversity impacts were identified in Cameroon and Ecuador. Sustainable certification schemes, such as Fair Trade and Rainforest Alliance (EU Commission, 2009; FAO, 2003), have been shown to have a positive effect on biodiversity and ES of the sending systems for trade goods flows, even though pathways for improved biodiversity outcomes are not yet fully clarified (Tscharntke et al., 2015). These or other policy instruments could be spatially targeted to regions affected negatively by interregional ES trade flows. For flood regulation, several transboundary flood management agreements already exist for Germany and other European nations (e.g., the Convention on the Protection of the Rhine, 1999), while for migratory species transnational payment schemes exist for northern pintail ducks between the U.S. and Canada and could be expanded to other species and regions (Bagstad et al., 2019; Lopez-Hoffman et al., 2017). Regarding information flows, examples of mechanisms to compensate international ES flows occur not just in the panda loan fees but also the Nagoya Protocol on Access and Benefit Sharing of genetic information (Nagoya Protocol, 2014).

One of the crucial advantages of interregional ES flow assessment is to explicitly recognize that ES provision is often determined not only by local socio-environmental conditions in the sending system, but also by the ES demand (quantity and quality) in the receiving system. Therefore, actions to ensure sustainable ES management need to also address ES use, consumption, preferences, and demand patterns in the receiving systems as key drivers that often lead to land degradation, as mentioned by the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES, 2018). Possible policy tools include increased transparency in information about the products consumed and their telecoupled ecological impact as well as social effects such as land tenure conflicts and equity issues. In response, governance systems need to be designed that may involve multi-stakeholder partnerships of producers and consumers in the sending and receiving systems, nongovernmental organizations and governments to design more sustainable trade and management strategies and policy options for telecoupled ES flows (Smith, 2008).

Finally, an increased societal awareness of benefits received from abroad, such as food or water supply, flood control, or benefits provided by migratory or charismatic species, could help to build support for international conservation efforts (López-Hoffman et al., 2017). For example, the interregional flows of information by photographs of polar bears are used to build awareness of climate change's effects on Arctic ecosystems (National Geographic, 2018). Similarly, images of orangutans can inform the public about the destruction rainforests and consequences of palm oil plantation expansions (National Geographic, 2017).

5. Conclusion

As one of the first studies to systematically assess different selected interregional ES flow types for one nation, we show how interregional ES flow assessments can unravel interdependencies of countries triggered through ES demand in distant places. We analyzed different aspects of interregional ES flows, covering sending and receiving systems, embedded ES, and co-production flows. Such advancements in methodological approaches can help improve national efforts to assess and account for ES while considering interregional ES flows. An understanding of such flows can also help to assess the interconnectedness of local and global drivers for ES provision and associated pressures leading to land degradation and biodiversity loss. Considering a multitude of interregional ES flows in both sending and receiving regions can guide the assessment and development of consumption patterns, resource management practices and governance options of ES flows between regions. Such assessments of interregional ES flows and the understanding of their socio-ecological implications and governance are crucial to sustain ES provision and human well-being in our deeply interconnected world.

CRediT authorship contribution statement

Janina Kleemann: Conceptualization, Methodology, Investigation, Formal analysis, Validation, Writing - review & editing. **Matthias Schröter:** Conceptualization, Methodology, Investigation, Formal analysis, Validation, Writing - review & editing. **Kenneth J. Bagstad:** Conceptualization, Methodology, Investigation, Formal analysis, Validation, Writing - review & editing. **Christian Kuhlicke:** Conceptualization, Methodology, Investigation, Formal analysis, Validation, Writing - original draft. **Thomas Kastner:** Conceptualization, Methodology, Investigation, Formal analysis, Validation, Writing - review & editing. **Dor Fridman:** Conceptualization, Methodology, Writing - original draft, Writing - review & editing, Software, Visualization. **Catharina J.E. Schulp:** Conceptualization, Methodology, Investigation, Formal analysis, Validation, Writing - review & editing. **Sarah Wolff:** Conceptualization, Methodology, Investigation, Formal analysis, Validation, Writing - review & editing. **Javier Martínez-López:** Conceptualization, Methodology, Investigation, Formal analysis, Validation, Writing - review & editing. **Thomas Koellner:** Conceptualization, Methodology, Investigation. **Sebastian Arnhold:** Conceptualization, Methodology, Formal analysis, Writing - review & editing. **Berta Martín-López:** Conceptualization, Methodology, Validation, Writing - review & editing. **Alexandra Marques:** Conceptualization, Methodology, Validation, Writing - review & editing. **Laura Lopez-Hoffman:** Conceptualization, Methodology, Validation, Writing - review & editing. **Jianguo Liu:** Conceptualization, Methodology. **Meidad Kissinger:** Conceptualization, Writing - review & editing. **Carlos Antonio Guerra:** Conceptualization, Methodology. **Aletta Bonn:** Conceptualization, Methodology, Investigation, Formal analysis, Validation, Writing - review & editing.

Declaration of Competing Interest

The authors of the manuscript “Quantifying interregional flows of multiple ecosystem services – a case study for Germany” declare that there is no conflict of interest.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.gloenvcha.2020.102051.

Appendices

Appendix A - Biophysical flows of traded goods: Context and governance of cocoa trade

Cocoa production in West Africa is situated in the Guinean eastern forests and western lowland forests ecoregions. Extensive cultivation methods by smallholder farming (with farm sizes of about two to four hectares) is the dominant production system, keeping average yields low. Changing rainfall patterns and rising temperatures in the past 20 years have increased the occurrence of pests and diseases (ICCO, 2008). In combination with aging cocoa trees, a lack of soil nutrients and poor shade management, the productivity of cocoa crops in both regions continues to be low, leading to low incomes for many cocoa farmers. At the same time, high farm-gate prices, high input prices relative to income, and restricted access to loans and credits limit the possibility to afford inputs such as fertilizers. As a consequence, production gains are predominantly derived from relocating farms to new forest zones where soil fertility is still high (Wessel and Quist-Wessel, 2015).

West African countries are very important trading partners for cocoa in the Western world. In West Africa itself, cocoa production plays an important role for social structure, local economies, rural livelihoods, and development, connecting over two million households to global markets (Gockowski and Sonwa, 2011). Cocoa farms are predominantly family run, with men and children supplying most of the farm labor. In the cocoa-producing regions, production revenues provide a major contribution to household income. This has been associated with higher school enrolment compared to other rural districts where cocoa is not produced (Bøås and Huser, 2006). In Ghana, it is estimated that cocoa supports the livelihoods of more than 800,000 farm households, making 25-30% of Ghanaian population dependent on the cocoa value chain (The World Cocoa Foundation, 2017). Cocoa production also attracts migrant workers from other parts of the country (ICCO, 2008; Ruf et al., 2015). About 60% of all the agricultural labor force in Ghana is employed in the cocoa industry (Bøås and Huser, 2006).

A negative aspect of cocoa cultivation and expansion is that the relocation of farms to new forest zones has made cocoa production a major driver of land degradation and deforestation (Ruf et al., 2015; Wessel and Quist-Wessel, 2015). Most of this deforestation is happening within the Guinean rainforest, one of the most severely threatened forest systems in the world (CILSS, 2016). The Guinean rainforest is a global biodiversity hotspot due to its high levels of species richness and endemism; it is estimated that about 9,000 species of vascular plants occur in the hotspot, including 1,800 endemic species (Mittermeier et al., 2004). Forests in the cocoa production areas provide invaluable ES for local communities, including food, fuel, fibers, and medicine. In addition, the forest provides an important carbon sink. As a consequence, forest clearing has led to large-scale losses of biodiversity and release of carbon emissions into the atmosphere. Land clearing has also been contributing to reduced soil fertility, disturbance and fragmentation of habitats, and changes in micro-climates (Ruf et al., 2015). Structural problems of the cocoa sector, combined with effects of climate change result in poverty and economic decline in many of the cocoa-producing regions. This has made farmers inclined to employ child labor, in particular, in times of economic crisis. This is leading to child trafficking and migration (Bøås and Huser, 2006).

Even though there is an impact on local biodiversity due to global trade, traditional cocoa agroforests demonstrate relatively high biodiversity depending on factors such as landscape structure and interaction with natural forest, land-use intensiveness, multi-crop systems and shade-canopy simplification as well as on the taxa and geographic location (Schroth and Harvey, 2007). The relative role of pollinators and supporting ecosystems on cocoa production in West Africa is still vague because studies are limited (Frimpong et al., 2011). But it is assumed that the large dependency of cocoa on pollinators makes the region highly vulnerable to a loss of pollinators.

In order to protect biodiversity, ES and improve local livelihoods, cocoa certification schemes/standards (Fair Trade, UTZ and Rainforest Alliance) have shown to have predominantly positive effects on both social and environmental conditions in the sending country (ICCO, 2012). These include positive effects on climate change mitigation, improvement of energy efficiency, waste disposal and restrictions on the use of genetically modified organisms (ICCO, 2012). However, schemes are currently limited with regard to specific criteria on biodiversity conservation (Tscharntke et al., 2015). This is also problematic as the scale on which certification schemes become effective are not always the scale on which ecological processes operate (e.g., farm vs. landscape scale). In addition, the certification schemes have different focal areas. Where certification schemes have limitations, the sending system can become active in working on initiatives that go beyond their standards. For example, measures for pollinators can be improved, such as more diversified farming systems based on principles of organic agriculture or agroecology and the promotion of habitat connectivity through agroforestry or intercropping hedgerows (IPBES, 2016).

Appendix B - Flows mediated by species through migration and dispersal

Table B.1
Final selection of migratory bird species providing pest control

• Alauda arvensis
• Apus apus
• Caprimulgus europaeus
• Corvus frugilegus
• Cuculus canorus
• Delichon urbicum
• Emberiza calandra
• Emberiza hortulana
• Eremophila alpestris
• Falco subbuteo
• Falco vespertinus
• Lanius collurio
• Lanius excubitor
• Lanius senator
• Lullula arborea
• Merops apiaster
• Oenanthe oenanthe
• Otus scops
• Saxicola rubetra
• Saxicola torquatus
• Sturnus vulgaris
• Tachymarptis melba
• Turdus pilaris
• Upupa epops
• Vanellus vanellus

Table B.2
Number of migratory bird species providing pest control species to Germany, with habitat in sending system countries

Continent	Country	Number of migratory bird species providing pest control to Germany with habitat in that country
Africa	Democratic Republic of the Congo	12
	Ethiopia	12
	Kenya	12
	Nigeria	12
	South Sudan	12
	Sudan	12
	Uganda	12
	Burundi	11
	Cameroon	11
	Egypt	11
	Eritrea	11
	Guinea	11
	Rwanda	11
	United Republic of Tanzania	11
	Benin	10
	Burkina Faso	10
	Central African Republic	10
	Chad	10
	Gambia	10
	Ivory Coast	10
	Liberia	10
	Mali	10
	Senegal	10
	Togo	10
	Zambia	10
	Zimbabwe	10
	Botswana	9
	Djibouti	9
	Ghana	9
	Guinea-Bissau	9
	Libya	9
	Malawi	9
	Mauritania	9
	Mozambique	9
	Niger	9
	Sierra Leone	9
	South Africa	9
	Somaliland	8
	Algeria	7
	Angola	7
	Morocco	7
	Namibia	7
	Republic of the Congo	7
	Gabon	6
	Somalia	6
	Swaziland	6
	Tunisia	6
	Equatorial Guinea	5
	Lesotho	5
	Western Sahara	4

(*continued on next page*)

Table B.2 (*continued*)

Continent	Country	Number of migratory bird species providing pest control to Germany with habitat in that country
Asia	Israel	6
	Lebanon	6
	Iran	5
	Iraq	5
	Jordan	5
	Syria	5
	Kazakhstan	4
	Kuwait	4
	Saudi Arabia	4
	Turkey	4
	China	3
	Mongolia	3
	Qatar	3
	United Arab Emirates	3
	Afghanistan	2
	India	2
	Oman	2
	Pakistan	2
	Turkmenistan	2
	Uzbekistan	2
	Yemen	2
	Kyrgyzstan	1
	Nepal	1
	Tajikistan	1
Europe	Cyprus	6
	Russia	5
	Albania	4
	Bosnia and Herzegovina	4
	Croatia	4
	Finland	4
	Montenegro	4
	Portugal	4
	France	3
	Greece	3
	Italy	3
	Norway	3
	Slovenia	3
	Spain	3
	Sweden	3
	Belarus	2
	Estonia	2
	Ireland	2
	Macedonia	2
	Malta	2
	Ukraine	2
	United Kingdom	2
	Belgium	1
	Bulgaria	1
	Hungary	1
	Kosovo	1
	Latvia	1
	Lithuania	1
	Moldova	1
	Poland	1
	Republic of Serbia	1
	Romania	1
	San Marino	1
	Slovakia	1
	Switzerland	1
	Vatican	1

Appendix C - Biophysical flows

Fig. C.1. Transboundary watersheds of Germany included in our analysis (GEF, 2016). Germany's border is indicated with a thick black line; transboundary watersheds are in blue cross-hatching. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

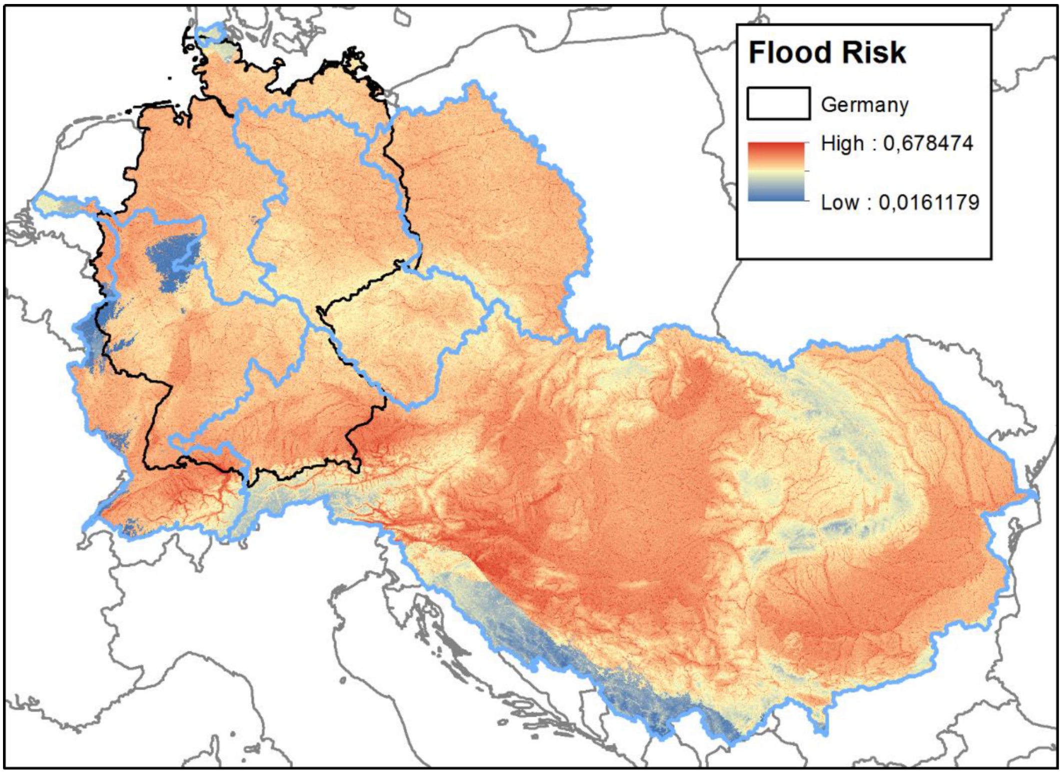

Fig. C.2. Modeled flood risk for Germany and adjacent transboundary watersheds based on cell-level index numbers. Transboundary watersheds are outlined in light blue (GEF, 2016). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

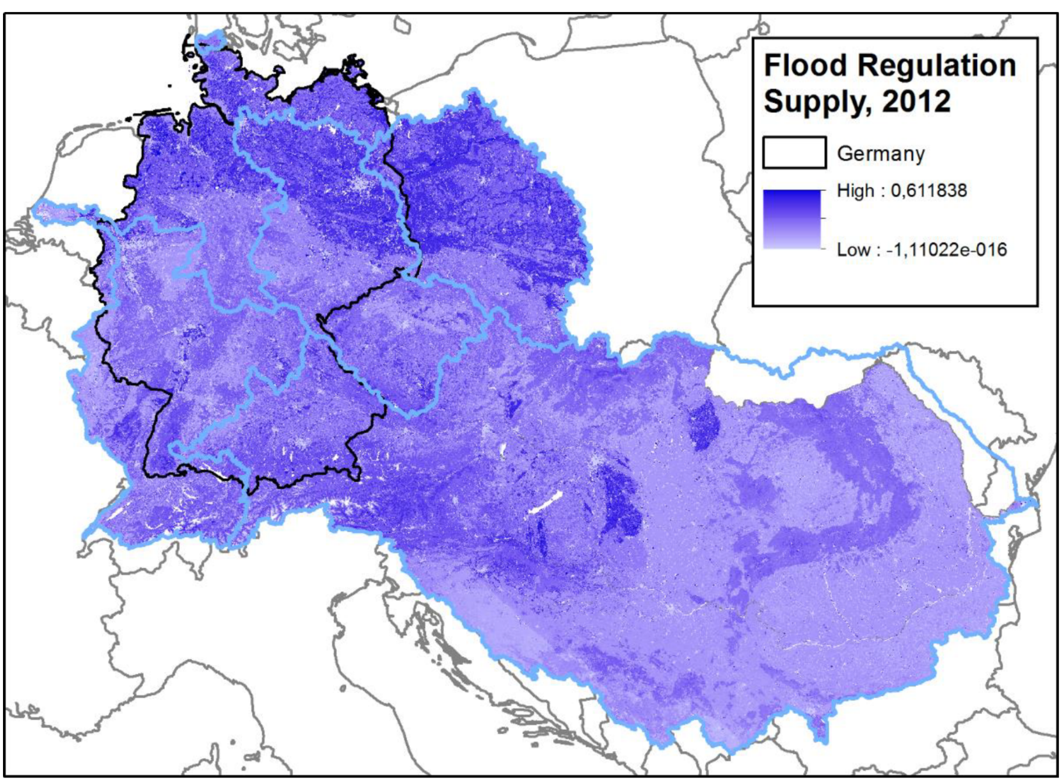

Fig. C.3. Modeled flood regulation supply for Germany and adjacent transboundary watersheds based on cell-level index numbers. Transboundary watersheds are outlined in light blue (GEF, 2016). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

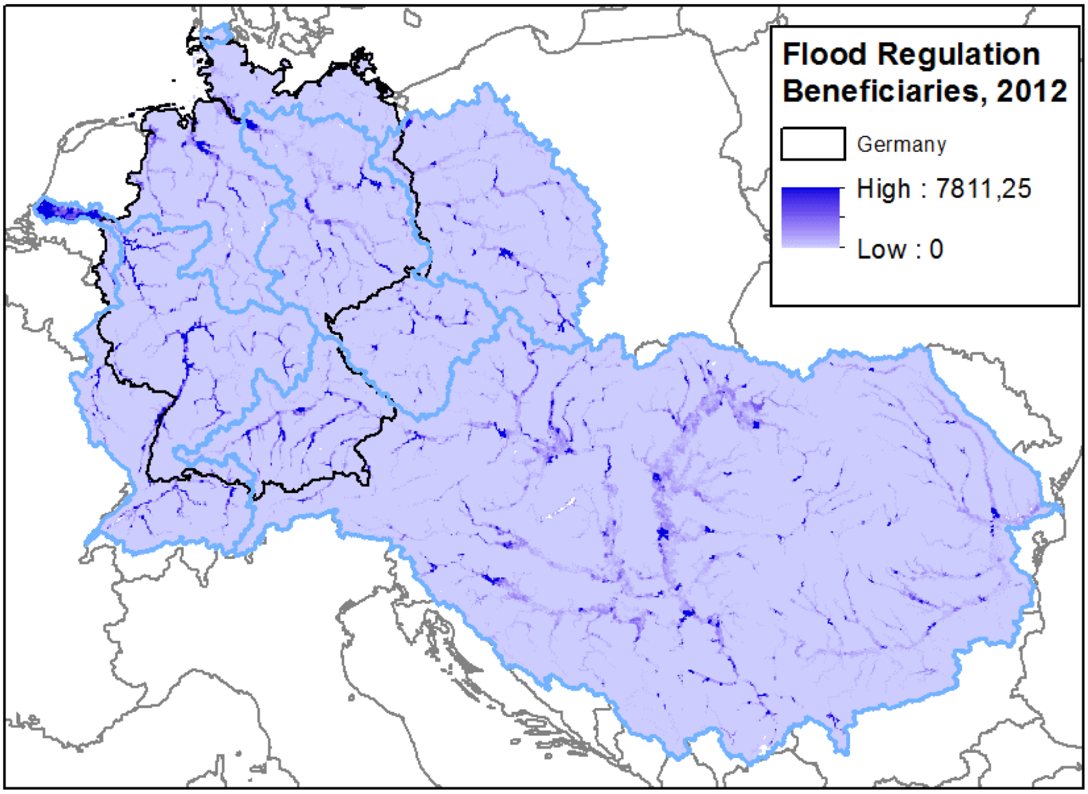

Fig. C.4. Modeled flood regulation beneficiaries for Germany and adjacent transboundary watersheds based on cell-level index numbers. Transboundary watersheds are outlined in light blue (GEF, 2016). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table C.1
Modeled flood regulation imports (from upstream nations) and exports (to downstream nations) for Germany, 2000-2012, based on summed cell-level index numbers.

Exports of flood regulation as an ecosystem service from Germany								
			Flood regulation supplied by Germany			**Flood regulation service demanded in downstream nation**		
		Flood risk in Germany	**2000**	**2006**	**2012**	**2000**	**2005**	**2010**
Danube	Austria & other downstream nations	231,422	85,190	84,995	82,162	3,841,941	3,971,337	4,088,738
	TOTAL EXPORTS	**231,422**	**85,190**	**84,995**	**82,162**	**3,841,941**	**3,971,337**	**4,088,738**
Oder	Poland	25,158	10,950	10,960	11,154	6,692,438	6,658,600	6,640,916
	TOTAL EXPORTS	**25,158**	**10,950**	**10,960**	**11,154**	**6,692,438**	**6,658,600**	**6,640,916**
Rhine	Netherlands	407,222	136,352	135,936	132,417	9,477,038	9,777,123	10,009,919
	TOTAL EXPORTS	**407,222**	**136,352**	**135,936**	**132,417**	**9,477,038**	**9,777,123**	**10,009,919**
Wiedau	Denmark	1136	549	536	457	4693	4334	4020
	TOTAL EXPORTS	**1136**	**549**	**536**	**457**	**4693**	**4334**	**4020**
GRAND TOTAL EXPORTS		**664,938**	**233,041**	**232,427**	**226,190**	**20,016,110**	**20,411,394**	**20,743,593**
Imports of flood regulation as an ecosystem service to Germany								
River / Country		**Flood risk upstream nation**	**Flood regulation supplied by upstream nation**			**Flood regulation service demanded in Germany**		
			2000	**2006**	**2012**	**2000**	**2005**	**2010**
Elbe	Austria	3680	1746	1643	1642	8,565,250	8,445,642	8,314,118
	Czech Republic	196,104	69,757	70,030	70,361			
	Poland	881	392	400	402			
	TOTAL IMPORTS	**200,665**	**71,895**	**72,073**	**72,405**	**8,565,250**	**8,445,642**	**8,314,118**
Oder	Czech Republic	28,639	10,327	10,428	10,487	385,213	370,166	355,377
	Poland	458,157	213,688	211,482	211,319			
	TOTAL IMPORTS	**486,796**	**224,015**	**221,910**	**221,806**	**385,213**	**370,166**	**355,377**
Rhine	Austria	8777	3311	3297	3298	10,120,403	10,132,615	10,119,811
	Belgium	1706	684	683	683			
	France	92,462	28,185	27,975	27,947			
	Liechtenstein	644	226	224	224			
	Luxembourg	6077	2009	1966	1963			
	Switzerland	107,804	33,237	33,176	33,174			
	TOTAL IMPORTS	**217,470**	**67,652**	**67,321**	**67,289**	**10,120,403**	**10,132,6158**	**10,119,811**
GRAND TOTAL IMPORTS		**904,931**	**363,562**	**361,304**	**361,500**	**82,197,142**	**1,897,416**	**81,394,910**

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Table C.1 (*continued*)

Exports of flood regulation as an ecosystem service from Germany				
Totals within Germany	1,487,367	571,480	570,803	562,206
% of within-German flood regulation supply exported	44.7%	40.8%	40.7%	40.2%
% of imported flood regulation relative to that supplied within Germany	60.8%	63.6%	63.3%	64.3%

Table C.2
Upstream impervious surface based on CORINE land cover data (EEA, 2016a): example of an “ecosystem disservice” provided by upstream nations (impervious areas include CORINE classes 1.1 and 1.2, which are primarily impervious surfaces; 1.3 is construction/mining/dump sites and 1.4 is developed green space, neither of which are primarily impervious surfaces). For ecosystem services demand, floodplains were mapped based on Alfieri et al. (2004), using 10-yr floodplains as a conservative definition of green infrastructure's flood mitigation capability.

Imports of flood regulation "disservice" to Germany (km^2 impervious surface in upstream nation)				
River	Country	Flood regulation "disservice" (km^2 impervious surface in upstream nation)		
		2000	**2006**	**2012**
Elbe	Austria	33,9	46,8	47,9
	Czech Republic	2.550,2	2.609,3	2.733,4
	Poland	3,9	4,5	5,3
	TOTAL IMPORTS	2.588,1	2.660,6	2.786,6
Oder	Czech Republic	587,6	597,5	619,1
	Poland	357,6	362,8	367,5
	TOTAL IMPORTS	945,1	960,2	986,5
Rhine	Austria	166,8	170,5	179,8
	Belgium	41,5	41,9	42,7
	France	1.744,1	1.867,8	2.027,6
	Liechtenstein	17,9	19,8	20,6
	Luxembourg	191,7	217,8	230,1
	Switzerland	1.968,3	1.990,0	2.051,0
	TOTAL IMPORTS	4.130,3	4.307,8	4.551,6
GRAND TOTAL IMPORTS		**7.663,5**	**7.928,6**	**8.324,8**
Imports of flood regulation "disservice" to Germany (km^2 impervious surface in upstream nation)				
River	Country	Flood regulation "disservice" (km^2 impervious surface in upstream nation)		
		2000	**2006**	**2012**
Danube	Austria & other downstream nations	2.900,5	3.050,4	3.494,4
	TOTAL EXPORTS	2.900,5	3.050,4	3.494,4
Oder	Poland	357,6	362,8	367,5
	TOTAL EXPORTS	357,6	362,8	367,5
Rhine	Netherlands	1.744,1	1.867,8	2.027,6
	TOTAL EXPORTS	1.744,1	1.867,8	2.027,6
Wiedau	Denmark	11,9	13,7	18,2
	TOTAL EXPORTS	11,9	13,7	18,2
GRAND TOTAL EXPORTS		**5.014,1**	**5.294,6**	**5.907,6**

Appendix D - Information flows: Thematic codes for media content analysis

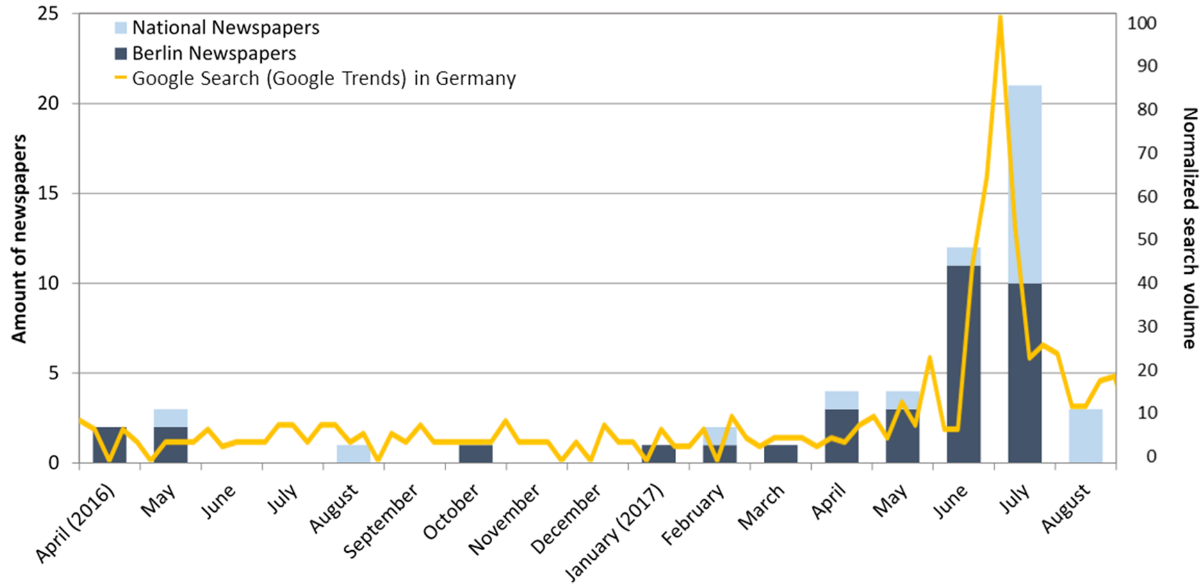

Fig. D.1. Frequency of search terms used by Google search engine users and newspaper articles in German newspapers to estimate popularity of the giant pandas in the Berlin Zoo. Yellow line reflects the queries in Germany in Google Trends ``panda” AND “Berlin” AND “zoo" in April 2016 to end of August 2017 as normalized search volume (right *y*-axis). There were no results in Google Trends for “panda” AND “Germany” AND “politics.” Data from Google Trends. Bar charts show the number of Berlin and national newspaper articles published on the panda loan to the Zoo of Berlin over the same period. The giant pandas arrived in the Berlin Zoo on July 6, 2017. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table D.1
National and local (Berlin) newspapers included in the content analysis.

Newspaper	Number of articles
National Newspapers	
Der Spiegel	1
Bild Bund	1
Die Welt	6
Frankfurter Rundschau	7
Taz, die Tageszeitung	5
Berlin Newspapers	
Berliner Kurier	8
Der Tagesspiegel	8
Berliner Zeitung	20
Total	56

Table D.2
Thematic codes for the content analysis.

Thematic code	Subcategories and description
The pandas	• **Origin of pandas:** Chengdu; • **Description of pandas:** age, weight, name, appearance, pubescent; • **Actions of pandas:** eating, shewing, sleeping, inspecting compound walking backwards; • **Characterization of the two pandas:** Friendly, gleaming, relaxed, calm, patient, dominant, difference in character.
Scientific	• **International breeding programs and research:** Cooperation between Berlin Zoo and Leibniz Institute for Zoo and Wildlife Research and with the Berlin Natural Science Museum, research on reproduction and genes; • **Policy analysis:** Relationship Germany-China, explicit reference to panda diplomacy as a field of research
Historical	• **Historical examples of Pandas in Berlin:** Previous pandas in Berlin Zoo, examples for 'panda diplomacy', Donation of pandas in the context of the 'Cold War'; • **Historical examples of pandas internationally:** examples for 'panda diplomacy'
Details about loan and transfer	• **Contractual details:** Duration of loan, costs for loan, return of offspring, keeping conditions, controlling, negotiation of details, usage of loans (species conversation); • **Opening Ceremony:** Preparation of opening ceremony, invited guests, when pandas will be shown to the public, ceremony itself; • **Transfer:** first class flight, quarantine, arrival; • **Preparation:** journeys to China by representatives of Zoo (living conditions, reproduction, breeding, building trust)
Emotional	• **Description of pandas in general with a strong emotional connotation:** cuddly, sweet, cute, fluffy, button eyes, lazy, ravenous, likeable
Cultural	• **Opening ceremony as a cultural event:** Chinese music, food, dances, decoration, tea ceremony; • **Cultural relationship between China and Germany**
Economic	• **Economic relationship between China and Germany:** long-term, reliable relationships, complementary economic portfolio (technique – market), difficult access to Chinese market, Germany most important trading partner of China, China most important trading partner for Germany worldwide, preparation of free-trade agreement, signing of bilateral contracts (e.g., AIRBUS, water dam projects), pandas as a gratification for good economic relations
Political	• **G20** • **Panda diplomacy:** historical examples, pandas as means for policy; (observation 1st and 2nd order), policy as a means to get panda from A to B–including stats action, diplomacy, negotiations, 'soft power,' pandas as friendly ambassadors, donation/loan as a state act, pandas as a gratification; • **Relation China Germany:** Stable relationship, important partner, shared interests (e.g., climate change, energy transition), strategic partnership, pandas as symbol for close relationship between Germany and China, pandas/animals representing specific ideals, • **Political situation in China:** Lack of human rights and democratic principles in China: Political situation in China: Liu Xiaobo–oppression of opposing voices, lack of democracy, human rights
Natural	• **Information about pandas:** Reproduction, food, amount of flood, maverick, fertility of female pandas • **Pandas as threatened species:** Number of pandas living worldwide both in natural habitat and in breeding stations • **Pandas as symbols for species conservation**

Appendix E - Methodological shortcomings and approaches for improvement

Table E.1
Assumptions and shortcomings of the analysis and approaches to improve the assessment of the respective ecosystem service (ES) flow type.

ES flow type	Assumptions and shortcomings in this study	Approaches to improve the assessment
Cocoa trade	• Ranking of sending system will differ depending on the chosen indicator. This makes objective selection of focal regions difficult. Different rankings[1] between different indicators. • Assumption on cocoa production areas: spatial disaggregation assumed that each grid cell's exports to Germany is proportional to the national share. Disaggregation follows 2005 production data • Knowledge gap on the role of pollinators in the sending region. • Analysis of embedded services (pollination) assumed that pollination is equally provided across space. • Species loss: cropland flows are general indicators derived from the countryside SAR[2] of agricultural areas (specifically, permanent crops).	• Scoping the sending system for the purpose of literature review should be based upon the results of multiple indicators (e.g., not only in terms of highest production dependency but also impact of production on biodiversity or other embedded ES). Integration of habitat suitability and other ES models (tier 3) would enable spatial differentiation of embedded services.
Pest control by migratory birds	• Species range data are global estimates. • Approach focuses on spatial delineation of potential occurrences of these species. • Abundances of the species and actual observed or modelled pest control were not considered. • All seasonal areas are treated equally; hence, differences in pest control during breeding, wintering or passage were not considered. • Only agricultural areas were considered as receiving areas. However, non-agricultural areas in proximity are also relevant as habitat for migratory species and are part of interregional flows. • Germany is also sending system in the life cycle of migratory species.	• Analyze the abundance of pest-controlling bird species, quantity of insects consumed, and saved costs for / environmental damage by insecticides in order to quantify the importance of each bird species for pest control (e.g., López-Hoffman et al., 2014).
Trans- boundary flood regulation	• Index number indicator approach for flood regulation (like most large-scale flood risk maps). • Not a formal hydrologic/flood event model. • Does not account for the role of "grey infrastructure" in flood	• A more data and computationally intensive approach could use hydrologic/event based models coupled with agent-based models to quantify ES flows; this is a tier 3 approach (Koellner et al., 2019).

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Table E.1 (*continued*)

ES flow type	Assumptions and shortcomings in this study	Approaches to improve the assessment
	control–e.g., dams, levees. • Once soils are saturated, more limited ability for ecosystems to provide flood mitigation (e.g., large floods under climate change). Justification for use of small watersheds in analysis, not considering e.g., the impacts of German flood regulation on countries located far downstream on the Danube (see Bagstad et al., 2014). • The analysis for Danube did not extend beyond Austria due to uncertainty about how far downstream conditions in Germany affect nations in a large watershed (see above point).	
Panda loan	• Due to language barriers, the content analysis focused on German newspapers; newspaper articles from the sending systems (China) and how they report about the panda loan to the Berlin Zoo were not included. • Potential double counting of codes due to overlapping content. • The selection of search terms emphasized political aspects. • The specific context of Google searches was unknown. • Other media, e.g., Twitter and TV news, was not included.	• Consider proxy indicators for spatial characteristics of data of information flows in order to look more specifically at spatial aspects.

[1] By rankings we mean that the area of interest (i.e., sending system with the highest metric value) varies across metrics.
[2] Countryside species-area relationship, e.g., see Chaudhary et al. (2015) and Pereira & Daily (2006).

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