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Economic values for ecosystem services: A global synthesis and way forward

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ABSTRACT

This paper presents a global synthesis of economic values for ecosystem services provided by 15 terrestrial and marine biomes. Information from over 1,300 studies, yielding over 9,400 value estimates in monetary units, has been collected and organised in the Ecosystem Services Valuation Database (ESVD). This is a substantial expansion of data since the de Groot et al. (2012) description of the ESVD and provides an important juncture to explore developments in the use of valuation methods and the contexts in which valuations are conducted. In this paper we provide summary values for 23 ecosystem services from 15 biomes to represent the magnitude, variation and gaps in economic values. To enable the comparison and synthesis of values, estimates in the ESVD are standardised to a common set of units (Int$/ha/year at 2020 price levels). This data provides a basis for value transfers to inform decision-making in current policy contexts but requires due consideration and adjustment for context specific determinants of value.

Although the coverage of the ESVD is global, the geographic distribution of data is not even. There is a particularly high representation of European ecosystems and relatively little information for Russia, Central Asia and North Africa. Therefore, the data are not globally representative of biophysical and socio-economic contexts. The distribution of data across ecosystem services is also far from even, with some services very well represented (e.g. recreation, wild fish and wild animals, ecosystem and species appreciation, air filtration and global climate regulation) and others with almost no value estimates (e.g. disease control, water baseflow maintenance, rainfall pattern regulation).

In the past decade, there has been a notable increase in demand for information on the economic value of ecosystem services from both public and private institutions to improve the conservation and management of natural capital. The literature is developing to meet this demand but there is a need for targeted and refined valuation research to ensure sufficient certainty, comparability, and representativeness of the data, and to enable transferability and fill knowledge gaps. This paper concludes by identifying avenues for future development to further increase the amount, quality, representativeness and application of data on economic values for ecosystem services.

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1. Introduction

Ecosystem services (ES) are the direct and indirect contributions of nature to human well-being (Costanza et al., 1997; Daily, 1997; MA, 2005; TEEB, 2010; Haines-Young and Potschin, 2012; Díaz et al., 2018). Globally, there is a declining capacity to provide ES as natural capital continues to be degraded and exploited at unsustainable rates (IPBES, 2019; CBD, 2020; Dasgupta, 2021). In response, public and private sector entities at all levels have made commitments to maintain and manage natural capital, including through Sustainable Development Goals 14 (life below water) and 15 (life on land) (UNGA, 2015), the UN Decade on Ecosystem Restoration (UNGA, 2019) and the Global Biodiversity Framework of the Convention on Biological Diversity (CBD, 2021).

To guide decisions on use, investments, conservation and restoration of natural capital, there is a need for more and better information on the value of ecosystem services (IPBES, 2022; Pascual et al., 2023). Among the diverse conceptualisations of value, economic value provides a measure of the importance of resources and services to human wellbeing (Pearce, 1993; Freeman et al., 2014). The economic value of an ES is the quantified net benefit that people derive from its use, whether there is a market transaction for the ES or not. Economic valuation is one way to quantify and communicate the importance of ES to decision makers, and it can and should be used in combination with other forms of information, e.g. biophysical indicators and social impacts (Jacobs et al., 2023). The comparative advantage of economic valuation is that it conveys the importance of changes in the provision of ES directly in terms of human welfare and uses a common unit of account (i.e., money) so that values can be communicated easily and directly compared across other goods, services, investments and impacts in the economy (Pascual et al., 2010).

Information on the economic value of ES can be used in a variety of decision-making contexts including a) to raise awareness among all stakeholders regarding the importance of natural capital to human wellbeing; b) set priorities across policy targets; c) design policy instruments for environmental management, such as taxes, transferable quotas, certification and labelling, and trade restrictions; d) formulate sustainable financing mechanisms, such as payments for ecosystems services (Daily and Ruckelshaus, 2022); e) evaluate alternative investments in environmental conservation and nature based solutions by means of cost-benefit analysis (van Zanten et al., 2023); f) quantify the distribution of costs and benefits of management decisions among different stakeholders; g) set compensation for damage to nature; h) and enable the generation of monetary ecosystem service accounts (Brander et al., 2022; Grammatikopoulou et al., 2023).

During the past 30+ years, the sub-disciplines of environmental and ecological economics have developed methods and attempted to produce information on the economic value of ES to inform decision making at all levels (Pascual et al., 2010; Freeman et al., 2014) and this body of knowledge now comprises thousands of studies covering all regions of the world and all ecosystem services (de Groot et al., 2012). This information flow has become a "flood of numbers", which to some extent becomes difficult to use for informing policy decisions and raises the need for data management and synthesis (Johnston and Bauer, 2019).

Conducting new primary valuation studies is time-consuming, expensive and generally only feasible for a small number of study sites; whereas the demand for value data is typically for expeditious, low-cost information for, in some cases, large numbers of diverse ecosystems. In consequence, there is substantial policy and research interest in using existing valuation results to inform other policy contexts. Value transfer, or benefit transfer, is the use of research results from existing primary studies at one or more locations (study sites) to predict welfare estimates or related information at other locations or policy contexts (policy sites) (Navrud and Ready, 2007). Value transfer methods provide a means to obtain information quickly at lower cost and are also applicable to large geographic areas to scale up and map values across multiple policy sites (Brander et al., 2012; Schägner et al., 2013). This approach has been employed widely in national and global ecosystem assessments, value mapping applications and policy appraisals. The use of value transfer is widespread but requires careful application (Brander, 2013; Johnston, et al., 2015) and, crucially, sufficient underlying primary valuations on which transfers can be based.

The Ecosystem Services Valuation Database (ESVD) provides an organised collection of estimates of the economic value of ecosystem services expressed in monetary units.[1] The objective of the ESVD is to make these estimates of economic value openly available to help inform decision making on the sustainable use, management and conservation of nature. The ESVD was originally developed in 2010 under The Economics of Ecosystems and Biodiversity (TEEB) initiative hosted by the UN Environment Programme and described in detail in de Groot et al (2012). The ESVD has since been maintained and developed by the Foundation for Sustainable Development[2] and Brander Environmental Economics[3] with funding and support from multiple partners including the UK Department for Environment, Food and Rural Affairs (Defra); the Netherlands Ministry of Agriculture, Nature and Food Quality (LNV); the Joint Research Centre (JRC) of the European Commission, the German Federal Environmental Agency (UBA), the UN Food and Agriculture Organisation (FAO); and the Economics of Land Degradation (ELD) initiative hosted by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ). Since 2019, the ESVD has been recoded in a new structure and substantially expanded. Currently it contains information from over 1,300 studies, yielding over 9,400 value estimates in monetary units for all ecosystem services provided by terrestrial and marine biomes.

This paper provides an overview of the economic values of ecosystem services contained in the ESVD and is structured as follows: Section 2 describes the ESVD structure, content and web-interface; Section 3 provides an overview and summary of ES values per biome; Section 4 outlines how this information can be used to inform decision-making; Section 5 identifies caveats and limitations to the data; Section 6 concludes by identifying avenues for the way forward.

2. The ecosystem services valuation database (ESVD)

2.1. Study retrieval and criteria for inclusion

The process of identifying ecosystem service valuation studies for inclusion in the ESVD involves two main steps: 1. Retrieval of potentially relevant studies through multiple channels of literature search; 2. Screening the identified studies according to specified criteria.

The literature search makes use of multiple channels to retrieve potentially relevant valuation studies including traditional online literature tools and libraries such as Google Scholar, Scopus, ResearchGate, Mendeley, and institutional libraries; calls for studies distributed among relevant networks and associations of researchers in the field; direct contact with recognized ecosystem valuation experts, with a specific focus on locating less visible literature such as theses, dissertations, unpublished reports, and other relevant resources. Publications that provide reviews or synthesis of the valuation literature are also used as a starting point to obtain relevant studies. In addition, the ESVD web interface includes the functionality for users to suggest studies that are not yet included in the database. The purpose of employing these different approaches to literature collection is to ensure a comprehensive and diverse collection of ecosystem service valuation studies for inclusion in the ESVD.

In the process of searching literature databases, a wide range of search terms are used, including: biomes/ecosystems/habitats (e.g., coral reefs, forests, grasslands, wetlands, woodlands); ecosystem

[1] https://www.esvd.info/.
[2] https://www.fsd.nl.
[3] https://lukebrander.com.

services (e.g., fisheries, carbon sequestration, recreation, biodiversity, nature's contribution to people, ecosystem service); valuation methods (e.g., market prices, avoided damage cost, replacement cost, travel cost, etc.); and value terms (e.g., willingness to pay, producer surplus, consumer surplus, total economic value, net present value, benefit).

Potentially relevant studies are collected through this retrieval process and then screened for inclusion in the ESVD using the below criteria, subject to the availability and clarity of information provided in each study:

- Publication type: All types of publications, including journal articles, working papers, conference papers, dissertations, theses, NGO reports, and other forms of grey literature.
- Year of value estimate: Studies and value estimates can pertain to any year, without limitations on the date of study.
- Geographic location and scale: Study sites can encompass any location or scale, ranging from small habitat parcels to global biomes.
- Ecosystem/biome: Studies can address any type of ecosystem or combinations of multiple ecosystem types. Valuations of abiotic natural resources, such as mineral deposits, are not included.
- Ecosystem service: All biotic ecosystem services or combinations of multiple ecosystem services are included. Valuations of abiotic services (e.g., wind, solar) or human inputs into production are not included.
- Valuation metric: Studies reporting values measured in monetary units are included. Valuations measured in other units (e.g., qualitative scales or bio-physical units) are not included.
- Valuation method: Studies applying all types of primary valuation method (e.g., market prices, cost-based methods, stated preferences, revealed preferences etc.) are included. Studies using value transfers are not included. In some cases, value transfer estimates are included when part of a study that also reports primary valuation results.
- Language: Studies published in any language are included in the ESVD. The data, however, is entered in English.

Currently 3,715 relevant valuation studies have been collected, screened and included in a repository of studies. Of these collected studies, 1,223 studies have been coded in the ESVD.

2.2. Structure of the database

The database structure of the ESVD is designed to record detailed information on individual value estimates including the ecosystem service, biome, ecosystem, location, scale of study site, valued change, valuation method, standardised value, review status, and bibliographic details of the underlying study. Each value estimate is assigned to a separate row in the database, and information is coded across more than 166 data fields.

Information on the ecosystem service(s) that are valued is recorded using three widely recognized classification systems that provide standardised frameworks for categorising and understanding different ecosystem services: the TEEB classification (TEEB, 2010), the CICES V5.1 classification (Haines-Young and Potschin, 2018), and the SEEA (System of Economic-Environmental Accounting) classification (UNSD, 2021). These three classifications have been selected for use within the ESVD in order to enable users to identify relevant data using the most appropriate classification to their own applications.

Information on the biome(s) and ecosystem(s) that are valued is recorded using the TEEB classification and an updated classification based on the IUCN Global Ecosystem Typology 2.0 (Keith et al., 2020;) and the FAO Global Ecological Zoning framework (IIASA/FAO, 2012). This updated classification is termed the ESVD 2.0 classification and offers a hierarchical structure consisting of biomes, ecozones, and ecosystems, allowing for more specific disaggregation of ecosystem types within the ESVD (de Groot et al., forthcoming).

Information on the valuation method(s) used is recorded using the categorization of economic valuation methods developed under the ESMERALDA project (Brander et al., 2018). This ensures consistency and allows for the systematic analysis of different valuation approaches.

2.3. Value standardisation

Primary valuation results are coded in the ESVD in the original currencies and units in which they are reported. To compare and synthesise value observations it is therefore necessary to standardise values to a common set of units. Several alternative sets of standard units are feasible depending on the units of the underlying primary values. In the ESVD the units to which values are standardised are International dollars at 2020 price levels, per hectare, per year, for the total number of relevant beneficiaries. The standardisation process involves five steps to address each of these five dimensions: price level, currency, spatial unit, temporal unit, and beneficiary unit.

Values are standardised to a common price level year (2020) to account for differences in price levels over time using GDP deflators obtained from the World Bank – World Development Indicators.[4]

The selected common currency for the ESVD is the International dollar (Int$), which represents the value of the US dollar in the United States in terms of purchasing power. Values reported in other currencies are converted to Int$ using purchasing power parity adjusted exchange rates, which are also obtained from the World Development Indicators.

The standard spatial unit used in the ESVD is hectare. Primary value estimates can be reported for different spatial dimensions of the ecosystem that provides the service, primarily in terms of a unit of area of the ecosystem (e.g. per acre, hectare or km^2), per unit length of the ecosystem (e.g. per mile or km) or for the total spatial extent of the ecosystem. Values that are reported per unit of area or for the total spatial extent of the ecosystem are standardised to a value per hectare since this unit was used in previous versions of the ESVD and also widely used in other value databases and publications. Values that are reported per unit of length of the ecosystem represent a relatively small sub-set of the data (mostly for rivers and beaches) and are not standardised. Similarly, for some ecosystem services (e.g. existence values for migratory birds), the area of the providing ecosystem is not available or measurable and so such values are not standardised to a per hectare value.

The standard temporal unit used in the ESVD is year. Value observations that are reported for other units of time (e.g. per week, month, or multiple years) are annualised. Values reported as present values are annualised using the discount rate and time period specified in the study. In cases where the time horizon and discount rate for a present value are not reported, the sample means of these parameters are used to estimate an annualised value.

The standard beneficiary unit used in the ESVD is the total population of beneficiaries (i.e., the 'market size' or 'economic constituency' for the ecosystem service in question). The majority (61 %) of primary value estimates are reported for the total population of beneficiaries. Primary value estimates reported in different units of beneficiary (e.g. per visitor, person, household) are aggregated using information on the relevant total population of beneficiaries reported in the study. In cases where the study does not report the relevant number of beneficiaries, either secondary sources are used or no standardised value is computed.

Value estimates that cannot be standardised to the selected set of common units are retained and searchable within the ESVD since they are potentially useful for specific research or policy applications but are not included in the computation of summary values.

2.4. Data review process

The data review process consists of two parts: an internal automated

[4] https://datatopics.worldbank.org/world-development-indicators/.

quality check using an R-script and an external review procedure. The automated quality check is developed in R-programming and consists of a series of checks to assess consistent recording of the data between different, but related variables such as country-continent, biome-ecozone-ecosystem, currency-country or valuation year-publication year. For example, if a study is recorded in the Netherlands but in the continent variable 'North-America' is recorded instead of 'Europe', the script notes an error. The script is also used to identify typographical errors and provides a useful first step to ensure the consistency of the coded data. This check cannot, however, validate the interpretation of methods and results from a study.

The second part of the review process to ensure data validity is conducted by external reviewers. The reviewers are scholars and experts in the field of ecosystem services, many of whom are members of the Ecosystem Services Partnership (ESP).[5] Currently the group of reviewers consists of 20–25 external experts. These reviewers voluntarily check data following a specified review protocol. Each reviewer obtains an Excel file with a sub-set of coded ESVD data, a guide to the review process, and PDFs of the studies to review. They return reviewed data to the ESVD Team with suggested corrections. The corrections made during this process may include minor coding errors that the script could not identify or discrepancies in interpretation. The most frequent interpretation differences are related to the ecosystem type, ecosystem services and the units in which the monetary value is reported. Some studies may lack clarity on the valued ecosystem type, making it challenging to classify in the ESVD typology. Similarly, the description of the ecosystem service(s) that are valued, and the diversity of available classifications, can make it challenging to interpret and correctly code the ecosystem service. Interpretation differences in the monetary value often relate to the units in which the value is reported. In particular, there can be ambiguity in the description of temporal, spatial and beneficiary units. Following receipt of reviewed data, the ESVD team then makes the final decision to reject, accept or modify the individual suggested corrections. The revieweŕs name and date of review is recorded and stored for each relevant value estimate in the ESVD. Using this approach allows the ESVD team to ensure clarity and validity on the feedback that is acquired, because each modification is traceable including an explanation whether or not a change was accepted.

2.5. Description of the data

Currently, the ESVD contains over 9,400 records derived from more than 1,300 studies. Approximately 70 % of these value estimates have been standardised to the common set of units described above; and approximately 50 % have undergone expert review (see Fig. 1).

Value estimates are drawn from virtually all parts of the world and Fig. 2 provides a visual representation of the geographic distribution of study sites of the primary valuations included in the ESVD. The data are distributed across all world regions, but some regions have considerably more value estimates than others. There is currently little information in the ESVD for Russia, Central Asia and North Africa. Fig. 3 illustrates the distribution of value estimates by continent and shows that Europe accounts for the largest proportion of value estimates (32 %), followed by Asia (24 %) Africa (16 %), North America (15 %), South America (8 %) and Oceania (5 %). A small number of estimates are for multiple continents or global in scope. We note that this geographic distribution is partially determined by availability of valuation studies but also by the regional interests of the organisations funding the development of the ESVD. The number of value estimates for ecosystems in North America is therefore likely to be much higher than currently represented in the ESVD.

Fig. 4 represents the distribution of value estimates across biomes using the ESVD 2.0 Biomes and Ecosystems classification. The marine biome (including coral reefs) has the highest number of value estimates (21 %), followed by the intensive land use biome (16 %), and coastal systems biome, including mangroves (15 %). Forests are also well represented in the data with 12 % of the value estimates for tropical and subtropical forests and 9 %estimates for temperate forests and woodlands. The biomes with relatively few valuation data are deserts and semi-deserts (1 %), polar-alpine (1 %) and lastly, the subterranean biome is represented by only 0.08 % of the value estimates.

Fig. 5 presents the distribution of value estimates by ecosystem service using a modified version of the TEEB classification (TEEB, 2010), which includes existence and bequest values in line with other classifications such as CICES (Haines-Young & Potschin-Young, 2018) and the SEEA EA reference list (UNSD, 2021). The most prominent ecosystem services include recreation and tourism (19 % of total value estimates), food production (17 %), raw materials (11 %), existence and bequest values (10 %), climate regulation (6 %), air quality regulation (6 %), and moderation of extreme events (4 %). The ecosystem services for which there are relatively few value estimates are maintenance of life cycles, biological control, genetic resources, ornamental resources, and spiritual experience.

Fig. 6 shows the distribution of value estimates across valuation methods. The data provides insights into the different approaches used to assess the economic value of ecosystem services. The main valuation methods employed include market prices (28 %), stated preference methods such as contingent valuation (17 %) and choice modelling (16 %), damage cost avoided (8 %), travel cost (6 %), production function (6 %), net factor income (5 %) and replacement cost (5 %). Methods that are used less extensively include group valuation, input–output modelling, public pricing, opportunity costs, restoration costs and defensive expenditure.

2.6. ESVD web user interface

The ESVD is accessible through an online web-interface, which was developed and launched in 2020 to provide free and convenient access to the data for a variety of user groups.[6] The interface allows users to search the ESVD for valuations with specific characteristics using filters for ecosystem type (ESVD2.0 Biome and ecosystem classification), ecosystem service (TEEB, CICES and SEEA classifications), geographic location (country and continent filters), valuation method, and a free text search. The search output is in tabular format, listing all matching records and information on key variables such as biome, ecosystem, ecosystem service, country, valuation method, site area, and standardised value (if available). The search output can also be viewed and explored on a world map. The interface is able to compute summary statistics for the selected data in terms of mean standardised values and information on the distribution and number of underlying primary value estimates. It is possible to download the search query results or the entire database as a csv file. The ESVD web interface has a large and increasing number of users. As of mid-2023, the total number of registered users is over 3,100, with on average 5 new registrations per day. In March 2023, a user profile functionality was implemented, to gain insight in the different user groups in order to tailor the ESVD user needs. The largest user group (54 %) is from academia and research, followed by business (18 %) and government (14 %). A survey of ESVD users is currently on-going to collect further information on their motivations and needs to inform future development.

[5] https://www.es-partnership.org/.

[6] https://www.esvd.net/.

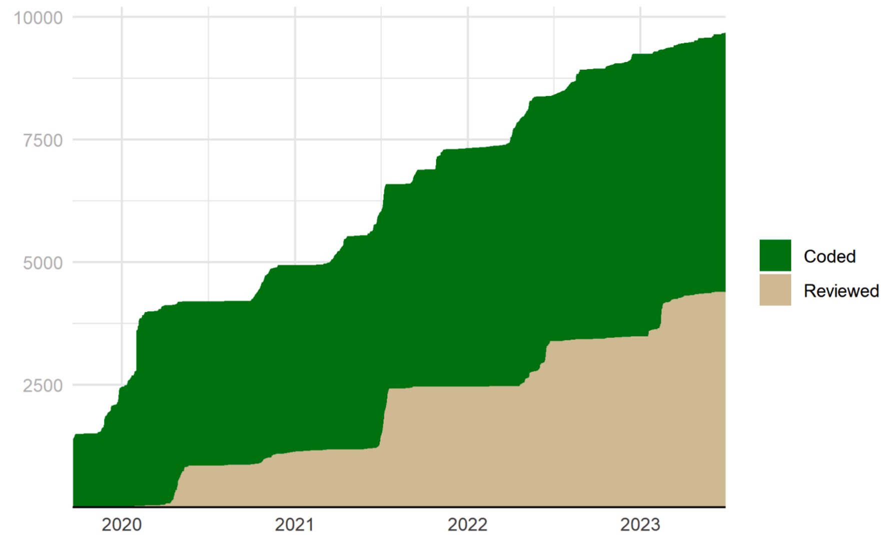

Fig. 1. Number of value estimates coded and reviewed in ESVD since 2019.

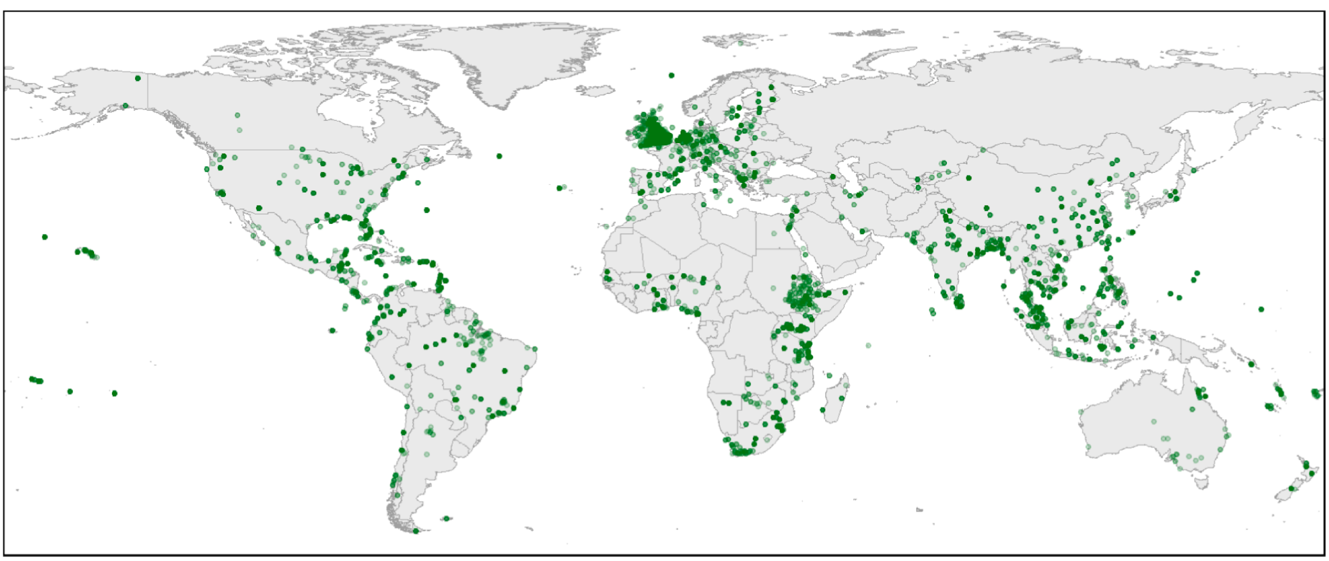

Fig. 2. Location of study sites of the primary valuations included in the ESVD.

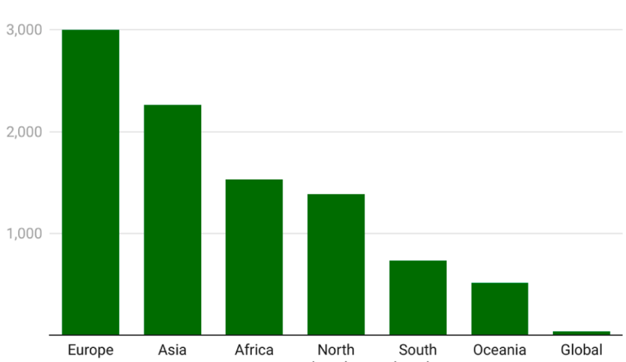

Fig. 3. Number of value estimates in the ESVD by continent.

3. Summary values of ecosystem services per biome

An overview of the average monetary value per service for each biome[7] is provided in Table 1. The summarised values are for single ecosystem services and single biomes, therefore value estimates for bundles of services and/or multiple biomes are excluded from the summary statistics. We also excluded values derived through value transfers to avoid double counting the underlying primary value estimates. Extreme values that might potentially distort the summary values were identified and excluded using a two-step approach: 1. Automated exclusion of statistical outliers defined as values outside 1.5 times the interquartile range of log of transformed values; 2. Manual examination of remaining extreme values and their biophysical and socio-economic contexts to identify highly unrepresentative cases of each biome-ES

[7] Due to the large number of value estimates for coral reefs and mangroves, these ecosystems are split out from their respective biomes (marine and coastal systems) to provide more disaggregated information.

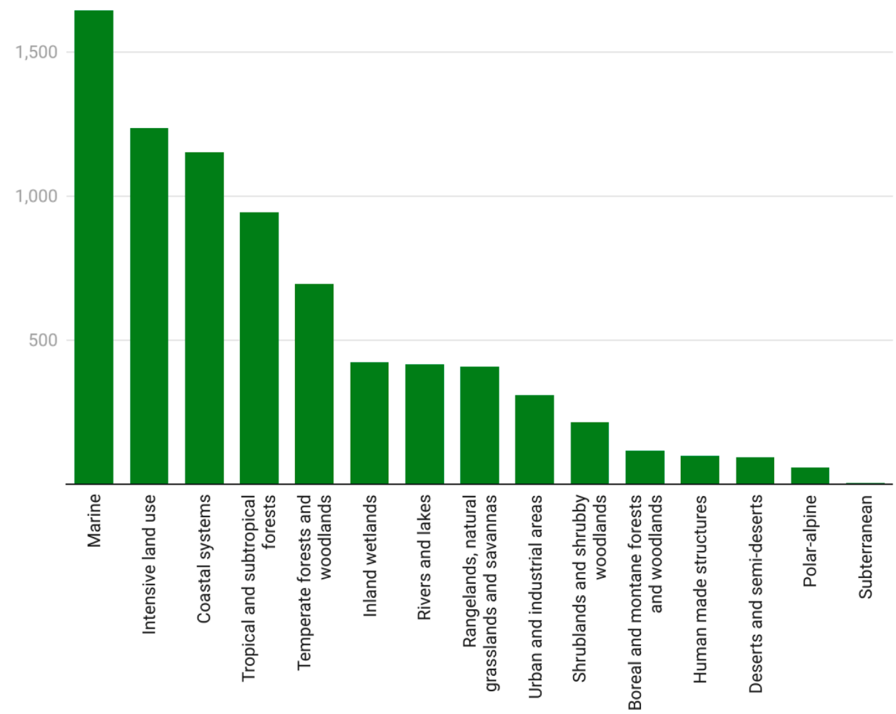

Fig. 4. Number of value estimates in the ESVD by biome.

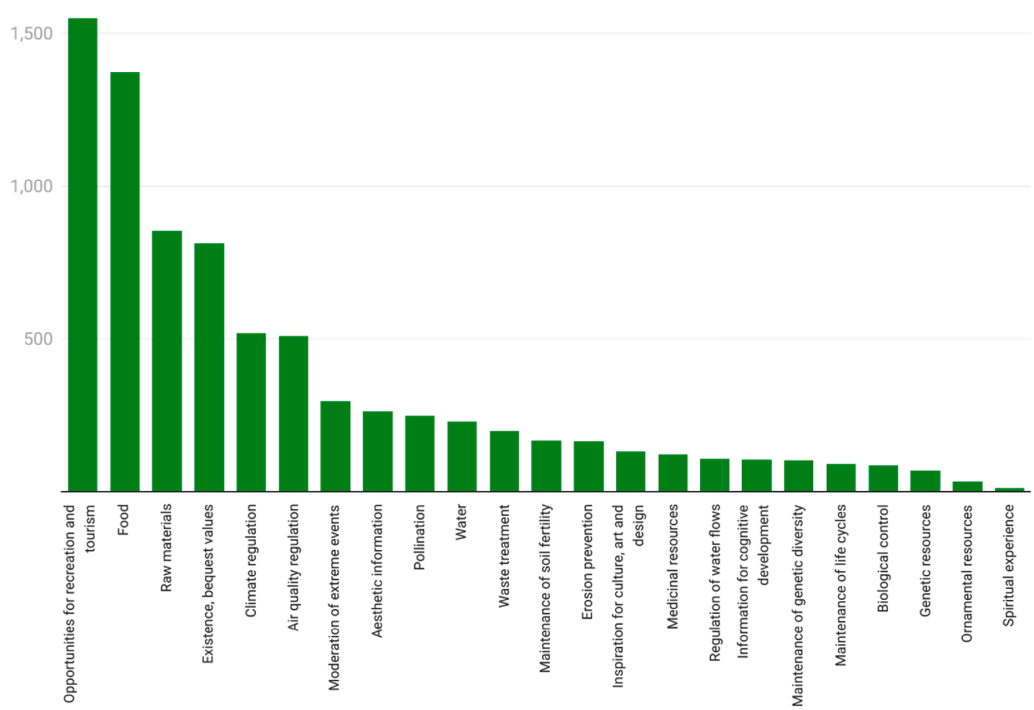

Fig. 5. Number of value estimates in the ESVD by ecosystem service.

combination.

In a small number of cases, the summary values are based on a very small number of available estimates (see number in brackets behind the mean value) and should be treated with caution. In general, however, these values do not form a large proportion of the total economic value for any biome and so do not have a disproportionately large influence on the total values. Note that an empty cell in the table does not mean that the biome in question does not provide the ecosystem service, but rather

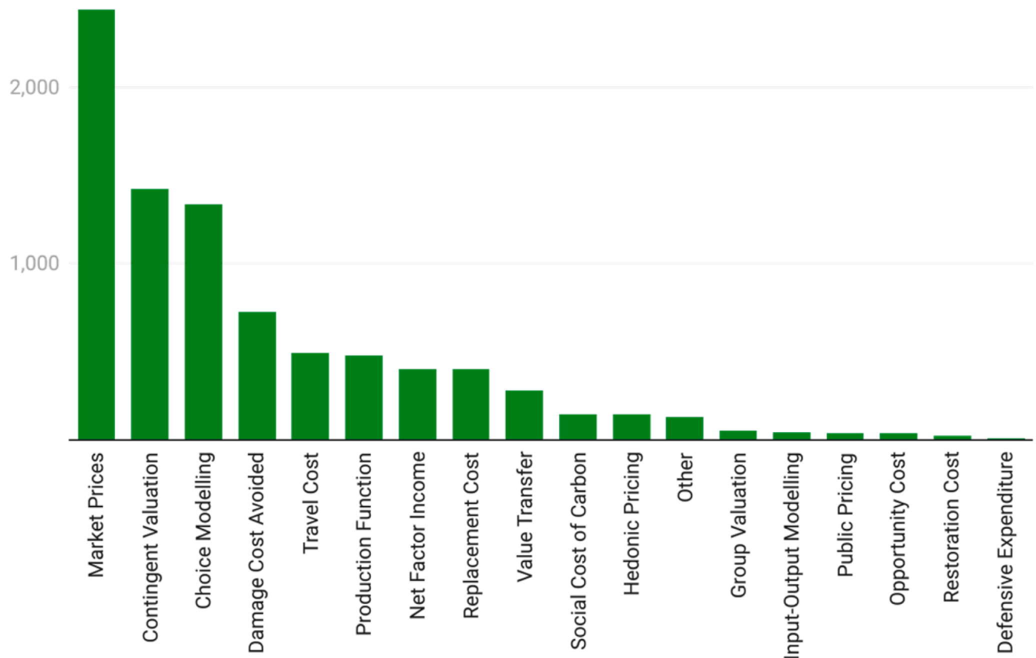

Fig. 6. Number of value estimates in the ESVD by valuation method.

that no value records are currently available within the ESVD.

Table 1 shows that there is large variation in the values of ES across biomes, with very high values for some ES. Considering the total values for the different biomes, the highest values are derived from coral reefs (87,211 Int$/ha/year) mangroves (77,928 Int$/ha/year) and urban and industrial areas (64,167 Int$/ha/year). These high values are derived from different ecosystem services, with coral reefs having particularly high existence and bequest values, mangrove have high values for moderation of extreme events (by mitigating coastal flooding), and urban ecosystems have high values for recreation and aesthetic enjoyment. Other biomes with high mean values (above 30,000 Int$/ha/year) are coastal systems, inland wetlands, and rivers and lakes. We also note that there is substantial variation in the values of ES within biomes (standard deviations are provided in appendix Table A1) reflecting variation in supply and demand across study sites and variation in valuation methods across studies.

This synthesis of value estimates by biome and ecosystem service is also useful to provide an indication of potential research gaps. Intensive land use (i.e., agriculture), mangroves, and temperate forest and woodland are the biomes with the highest number of value estimates, individually exceeding 500 observations, while the polar-alpine and boreal and montane forests and woodland biomes have relatively few value observations. Note that we omitted three biomes from the table for which there are very few value estimates: deserts, subterranean ecosystems, and human made ecosystems.

4. Trends in ecosystem service valuation

Using the de Groot et al (2012) description of the ESVD as a point of comparison, the ecosystem service valuation literature, as represented in the ESVD, has developed dramatically over the past 10 years in terms of the number of studies, methods applied, and diversity of study sites. The total number of studies and value estimates coded in the database increased by 300 % and 600 % respectively. The ESVD now contains approximately 10 times the number of standardised ES values compared to 2012. This is an indication of both the increasing research output in this field over the past ten years (see Fig. 7) and a trend towards an increasing number of value estimates per valuation study, which rose from an average of 4.2 to 7.2. The earlier literature typically comprises of studies that address a single study site and a small set of ecosystem services or a single ecosystem service and a small set of study sites, often applying a specific valuation method. More recently we observe a development towards studies that cover a larger number of ecosystem services and multiple study sites. Concomitantly, individual studies apply multiple valuation methods tailored to the ecosystem services that are addressed, which potentially raises additional within study complexities associated combining results for multiple value concepts and/or derived from different value methods. Similar trends have been identified in systematic reviews of subsets of the ecosystem valuation literature (e.g. Oleson et al., 2018).

Regarding developments in the use of valuation methods, we observe some continuance of earlier patterns and some substantial new developments. Firstly, the use of direct market prices remains the most frequently used method for estimating ecosystem service values. This is particularly the case for the valuation of provisioning services such as food and raw materials and increasingly for climate regulation in the form of market prices for carbon credits. It is also notable that the use of revealed preference methods remains relatively limited, particularly the application of hedonic pricing is likely limited by onerous data requirements. The most dramatic development in the use of valuation methods is the widespread application of choice modelling or discrete choice experiments (DCE). This form of stated preference method, which was hardly represented in the ESVD in 2012, has largely superseded the use of contingent valuation to value a broad range of ecosystem services. The application of DCE valuation, however, generally produces a different type of information. DCE results are largely in the form of marginal WTP for changes in the attributes of the valued ecosystem and/or services. This information facilitates the valuation of alternative policy or management scenarios that deliver changes in the quantity or quality of services in a specific context but does not necessarily enable the valuation of the total ES flow. This presents a challenge for deriving standardised values or comparing across value estimates since it becomes necessary to standardise across often diverse attributes of ecosystems and their services (Rolfe and Brouwer, 2012).

Regarding the diversity of valuation study sites, we observe an increasingly broad geographic coverage of valuation studies. The

Table 1
Mean values (int$ 2020/ha/year) per ecosystem service – biome combination. Number of value estimates in parentheses.

	Marine	Coral reefs	Coastal systems	Man-groves	Inland wetlands	Rivers and lakes	Tropical & sub-tropical forests	Temp-erate forest and woodland	Boreal and montane forests & woodland	Shrubland and shrubby woodland	Rangeland, natural grasslands & savannas	Polar-alpine	Intensive land uses	Urban and industrial areas
Food	71 (4)	741 (68)	2,398 (42)	6,791 (215)	612 (17)	364 (18)	76 (74)	98 (20)	355 (16)	32 (13)	474 (8)	684 (10)	1,409 (82)	1,043 (2)
Water	25 (1)		7,344 (6)	1,623 (3)	873 (8)	8,618 (28)	99 (11)	353 (35)	79 (2)	132 (1)	177 (4)	19 (4)	348 (12)	1,456 (2)
Raw materials	0.34 (1)	18,514 (4)	321 (17)	5,729 (114)	18 (56)	88 (8)	433 (82)	891 (32)	275 (34)	12 (35)	191 (16)	100 (11)	8,750 (73)	514 (3)
Genetic resources			11 (1)		229 (4)		508 (4)							
Medicinal resources							7 (54)		31 (1)	5.6 (4)	1.1 (1)	0.01 (1)	9.9 (3)	
Ornamental resources		34 (2)					0.29 (8)		675 (3)					
Air quality regulation			195 (8)	1,323 (2)	2,485 (9)		15 (1)	1,124 (302)	1,726 (1)		3.1 (8)	1.3 (1)	506 (7)	10,384 (93)
Climate regulation	183 (2)	2 (4)	111 (15)	1,375 (42)	185 (14)	236 (4)	748 (35)	475 (42)	1,425 (9)	54 (6)	414 (12)	671 (5)	515 (79)	870 (15)
Moderation of extreme events		14,369 (17)	7,472 (3)	14,388 (36)	4,969 (20)	8,077 (7)	77 (26)	39 (2)	711 (2)	42 (3)			607 (21)	8,991 (5)
Regulation of water flows			82 (1)	1.6 (2)	1,314 (9)	1,657 (4)	2.5 (7)	940 (3)		115 (1)	36 (6)		649 (27)	620 (4)
Waste treatment	111 (2)	4,078 (8)	1,980 (39)	3,189 (17)	2,603 (18)	2,189 (6)	11 (1)	10 (3)					965 (22)	98 (5)
Erosion prevention		3,418 (11)		7,030 (19)			47 (13)	138 (10)	67 (2)	21 (1)	26 (2)	32 (2)	39 (27)	
Maintenance of soil fertility		1,551 (3)	6,179 (2)	1,028 (5)	812 (1)	23 (2)	1.4 (5)	48 (8)	208 (2)		1,429 (2)	0.53 (3)	410 (79)	
Pollination							260 (67)	8,993 (4)		1 (1)	58 (2)		211 (34)	
Biological control						314 (1)	14 (1)			0.29 (1)			921 (51)	
Maintenance of life cycles		1,385 (2)	77 (7)	4,078 (10)	4,759 (2)	631 (4)	19 (1)					0.11 (1)	1.5 (4)	
Maintenance of genetic diversity		9,432 (5)	40 (1)	5,982 (10)	1,483 (4)		6.8 (4)	323 (4)			117 (6)			
Aesthetic information		5,580 (11)	723 (26)	334 (1)	493 (10)	1,214 (7)		35 (1)		33 (3)	2,114 (1)		86 (12)	17,505 (5)
Opportunities for recreation and tourism	2,022 (116)	6,271 (205)	5,563 (71)	6,118 (63)	12,899 (26)	2,347 (31)	37 (23)	227 (27)	6.7 (6)	56 (4)	238 (14)	3.1 (1)	216 (18)	19,972 (16)
Existence, bequest values	22 (9)	18,793 (108)	2,042 (4)	14,299 (16)	63 (9)	3,420 (2)	5,795 (33)	1,676 (9)		3.7 (3)	225 (4)	257 (1)	1,701 (16)	481 (6)
Inspiration for culture, art and design		917 (1)	0.09 (12)	3,890 (1)	101 (18)	2,672 (5)	2.2 (3)			67 (9)	284 (8)		14 (19)	
Spiritual experience						80 (1)								
Information for cognitive development	0.13 (1)	2,126 (12)	1,488 (12)	749 (6)	120 (3)	1,517 (4)	6.9 (2)	200 (1)		153 (2)	147 (4)	0.62 (1)	1.9 (4)	2,233 (4)
Sum	**2,434** (136)	**87,211** (461)	**36,026** (267)	**77,928** (562)	**34,018** (228)	**33,447** (132)	**8,166** (455)	**15,570** (503)	**5,559** (78)	**728** (87)	**5,934** (98)	**1,769** (41)	**17,360** (590)	**64,167** (160)

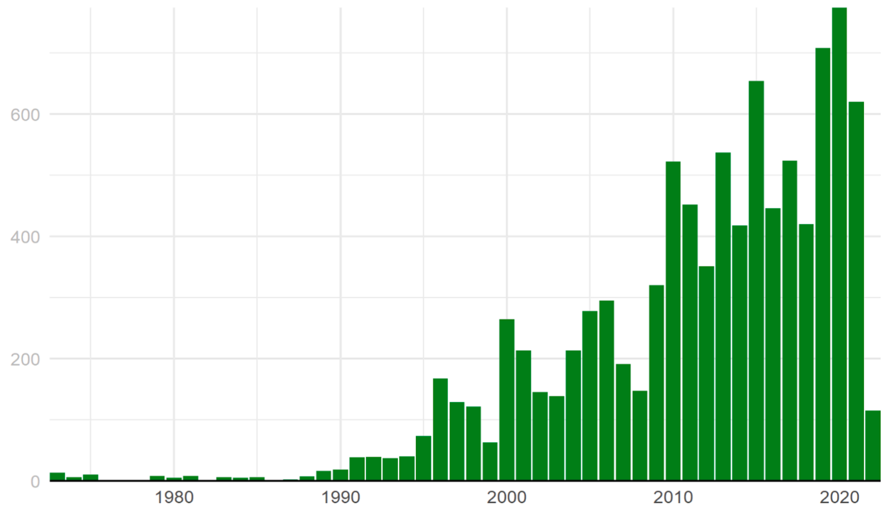

Fig. 7. Publication year of value estimates within the ESVD.

number of individual study sites represented in the ESVD has increased seven-fold to approximately 2,100 and the number of countries represented is now over 140. This is important for the representation of diverse biophysical and socio-economic contexts in the valuation data and the potential for using existing valuations to inform decision-making in new policy contexts. The growing quantity of data means that the sample size for each specific biome is also expanding, which allows for further disaggregation of values across ecozones and ecosystems. The ESVD has also expanded to include information on additional biomes. Of particular importance is the inclusion of values for the biomes 'intensive land use' (including agriculture and aquaculture) and 'urban and industrial areas' (including so-called green–blue infrastructure within urban areas such as city parks and forests). These biomes are not natural ecosystems by definition but can, with appropriate management, deliver highly valuable ecosystem services such as food, raw materials, air filtration and opportunities for recreation.

5. Caveats and limitations

In developing the ESVD, considerable effort has been devoted to ensure that the values in the database are valid in themselves (in terms of research design and methodology) and that they are correctly interpreted and coded in the database. Nevertheless, several caveats and limitations should be kept in mind when using these data.

5.1. Limited value data for some biomes and ecosystem services

Although ESVD now contains over 9,400 unique value records, there remain gaps or limited information for some biomes and ecosystem services. Table 1 shows the number of value estimates underlying each summary value. In principle, as the sample size of value estimates increases, the computed mean values are more likely to be generally representative of the biome and ecosystem service. For some biomes and ecosystem services, there are many value estimates but for others there is very limited data or even none, although the biome or ecosystem is able to provide that service. This means that the total values computed for each biome are likely to be underestimated since values are missing for some relevant ecosystem services. It should also be noted that the summary values presented in Table 1 are based on a restricted set of 4,451 value records and not the full set of 9,400 in ESVD. The main reasons for this limitation are that some reported values are expressed in units that could not be standardised to Int$/ha/year and that many reported values are for multiple ES, which could not be disaggregated to values for individual ES. Although these data cannot be included in the computation of summary values, they are potentially useful for specific research or policy applications and so are retained and searchable within the ESVD.

5.2. Representativeness

The ESVD is a global database containing value observations for all biomes and all ecosystem services. Recent updates have focused on adding data on forests and intensive land uses (agricultural land) and on increasing the representation of regions with relatively little data. The data are not, however, globally representative and the current sample of values reflects the availability of valuation studies, the interests of funding organisations, and the thematic expertise and language skills of the researchers involved in developing the database. From the currently available literature on ES values, the ESVD is likely to have an over-representation of European studies and an under-representation of North and South American studies. This is largely due to the interests of past funding sources and there is potential to increase the representation of other regions with targeted funding, particularly North America for which there is a wealth of ecosystem valuation studies. The implication of the currently skewed sample of valuation studies is that the summary values presented in Table 1 are likely to be more representative of European and Asian ecosystems and socio-economic contexts.

5.3. Data quality and review

The quality and reliability of value data is inherently variable due to variation in the underlying primary valuation studies in terms of valuation methods, implementation and reporting; and due to possible analyst errors in the process of interpreting the studies and coding the data. As explained in section 2.4, the data contained in the ESVD is subject to a two-stage quality control process: an automated check for valid data entries and a review process by invited expert reviewers. The proportion of value records that have been reviewed has greatly increased but currently stands at 50 %. The aim is to eventually increase this to 100 % and potentially to include a qualitative or quantitative indicator of data quality, although such a measure itself faces challenges of consistency across different valuation methods.

5.4. Trade-offs between ecosystem services

In computing total values from each biome, we make the assumption that all ES can be supplied and used simultaneously. In practice there are likely to be trade-offs between some ES. In many cases, the level of sustainable use of one ecosystem service may not be compatible with the sustainable use level of another. For instance, in the case of forests, there is a likely trade-off between the harvesting of timber and use for recreational and other tourist activities. Such trade-offs introduce further complexity to any analysis, since it becomes necessary to consider how the use of one ES affects other uses and values. This has not been possible in the computation of the summary values presented here.

5.5. Average and marginal values

The ESVD contains data on the value of the annual flow of ES (average values) and also data on *changes* in the annual value of ES as the result of some change in the provision of the ES, e.g. due to a change in land use, ecosystem condition, or access (marginal values). As noted in Section 4, valuations using the discrete choice method generally estimate marginal values for some change in ecosystem service provision or ecosystem attributes. The ESVD currently contains limited information to distinguish between the value of flows and changes in flows of ES, so average and marginal values have been summarised jointly in Table 1.

5.6. Differences in value concepts

The ESVD contains value data from a diverse set of valuation methods (Fig. 5), which can be used to estimate different concepts of economic value (e.g., consumer surplus, producer surplus, exchange values, avoided costs). It is recognised that some value concepts are not directly comparable and that certain applications require specific value concepts (Brander et al., 2022). Currently, the ESVD does not record information on the value concept measured by each estimate.

6. Conclusions and way forward

The literature on the economic value of ecosystem services has expanded considerably over the past 10 years to quantify the contribution of natural capital to human wellbeing and inform decision-making on its management and conservation. The ESVD reflects this development and now contains over 9,400 value estimates derived from more than 1,300 studies; with approximately 10 times the number of standardised ES values compared to 2012. The coverage of these data is global and drawn from over 2,000 study sites in over 140 countries. The synthesis of economic values for 23 ecosystem services from 15 biomes presented in this paper shows the large variation in the magnitude of values and the quantity of value estimates. As far as the authors are aware, the ESVD is now the largest freely accessible database of ecosystem service values.

Considering the limitations outlined in Section 5, we conclude by identifying avenues for future development of the ESVD and the way forward for synthesising economic values for ecosystem services.

Continued expansion of the ESVD is needed to fill gaps in the data for regions, biomes and ES that are currently not well represented. Specifically, more value estimates should be added for the continents of South-America, North-America and Africa. The biomes and ecosystems that should be targeted are deserts and semi-deserts; subterranean ecosystems; boreal and montane forests and woodlands; shrublands and shrubby woodlands; polar-alpine; and urban and industrial areas. The ES that require additional (standardised) value data include regulating services, such as regulation of water flows, erosion prevention and biological control. Additionally, several cultural services, which can be difficult to quantify in economic terms and are not well represented in the data, are spiritual experience, and information for cognitive development. Additional value estimates should be included for several provisioning services that potentially have high economic values but for which few estimates are available, such as genetic and medicinal resources. To some extent these gaps can be filled from existing studies that are not yet included in the ESVD, but in some cases there is a need for new primary valuation research.

In the face of an expanding number of published valuation studies and the laborious nature of coding the data, there is interest in the potential use of artificial intelligence (AI) in the process of data development. New technologies such as AI-driven semantic reasoning and machine learning could be used to extract and code information from primary valuation studies at a considerably faster rate and in a more consistent manner. However, given the required interpretation of valuation methods and results to correctly code the data, the use of AI might be limited to coding the more straightforward data fields to be confirmed by analysts and reviewers.

To ensure the quality of the data, there is a need for further development and improvement of the quality control and review process, potentially through greater involvement on the part of the academic and user community. Currently, data checks and an external review procedure as described in section 2.4 are in place. This process is being refined and will eventually be facilitated through the ESVD web interface. To handle the increasing volume of data, so-called Biome Review Groups (BRGs) (a pool of experts on a specific biome) are asked to review the data within the ESVD in a similar manner to the review process used by scientific journals. A BRG-coordinator ('Associate Editor') coordinates the review of ESVD data for a designated biome. Other members in a BRG receive batches of data which are to be reviewed and submitted to the Associate Editor, who decides whether the reviewed values can be included in the ESVD. In addition, measures of inter-coder reliability (ICR) may be implemented to assess the degree of agreement between data coders (O'Connor and Joffe, 2020).

An additional avenue for ensuring data quality is to extend the automated inconsistency checks of the ESVD. The algorithms currently used to check data for potential inconsistencies may be developed further towards database forensics that are based on probabilistic models instead of rule-based algorithms. Similarly, it is important to evaluate changes in the ESVD over time, which may involve data corruption or unintended changes that occur as part of continuous data development.

Aside from expanding the number of value estimates in the ESVD, there is also a need to expand the number of data fields to enrich the information recorded for each estimate. Additional data fields could include information on data validity, value concept, valued change, ecosystem condition, protected status, and policy application. Additional indicators of data validity could include whether the primary study has undergone peer review, stakeholder validation or third party verification. Including additional columns to the ESVD is, however, a time consuming endeavour as it requires modification of both existing and forthcoming data and its feasibility depends on funding opportunities and associated research interests. We consider following fields of information to be of particular high priority: (1) Information on the estimated value concept (e.g. consumer surplus, exchange value etc.) would help explain variation in values and enable filtering values for applications that require specific value concepts (e.g., exchange values in SEEA Ecosystem Accounting). (2) Additional information describing the change that is valued (e.g. land use, management, climate, ecosystem quality etc.) would help to differentiate average and marginal values, and allow filtering for specific forms of change. The possibilities for recording information on the valued change are extensive, ranging from simple categorical variables (e.g. direction of change) to details on the units and quantities of change (e.g. m^3 of water retention, tonnes of crop yield, numbers of visitors), which may help to link valuation data with the outputs of biophysical ES models. Including information on (changes in) ecosystem condition and the protected status of study sites would potentially help to explain how ecosystem degradation, restoration and protection affect the value of ES. (3) Finally, recording details on the policy applications of valuation results would help to evaluate how this information has been taken up in decision-making, which can be useful for developing and promoting the societal impact of valuation research.

Many of these envisaged improvements in the ESVD also require improvements in the underlying literature and particularly the level of detail in which studies report the characteristics of their study sites, methods and results. There is a need for clear guidelines for authors to fully report their methods and findings to ensure they are reproducible and can be synthesised or used in *meta*-analyses. This conclusion is a standard feature of most reviews and *meta*-analyses of the valuation literature and unfortunately remains a valid point. A paper with proposed guidelines for reporting valuation results is currently in preparation by Schaegner et al.

There is also a need for wider reporting of user cases that apply data from the ESVD in value transfers to new policy contexts. This would provide example cases for others to follow and allow evaluation of how valuation data is used in secondary applications. This is particularly relevant for applications in the financial and business sectors, which are generally not published but for which there is growing interest within the sector itself. Many companies and investment institutions are looking for opportunities for sustainable finance, ways to measure their impacts on biodiversity impact, and to 'take nature into account' in operations and investment decisions. Replicable applications and practical tools are, however, still scarce (Van Oorschot & Kok, 2020) and may suffer from a significant credibility deficit (Quatrini and Costanza, 2023). A recent project using data from ESVD analysed biodiversity-related risks of four so-called "positive impact" projects for ASN Bank (in the Netherlands, Madagascar, Paraguay and Nicaragua), quantified the impact of land cover changes on ecosystem services and their monetary values and linked it to the LEAP framework of the Taskforce for Nature-related Financial Disclosure (TNFD).[8]

In using data from the ESVD to estimate values for ecosystem services that are impacted by current policies and investments, it is necessary to adjust the transferred values to reflect the characteristics of the policy/ investment site. Ecosystem service values are inherently highly spatially variable and influenced by site and context characteristics that determine the supply and demand for ecosystem services (Schägner et al., 2013). Direct use of summary values from the ESVD without due consideration of context characteristics can therefore potentially result substantial transfer errors (over or under estimation of values). An improvement on the use of direct unit values transfers is the application of value functions derived through meta-analyses of primary valuations, which enable the estimation of site-specific values. A key advantage of using a meta-analytic value function over other value transfer methods is that it is based on the results of multiple studies and is therefore able to represent and control for greater variation in the characteristics of ecosystems, beneficiaries and also methodological aspects of the underlying primary valuation studies (Brander et al., 2012; Johnston and Bauer, 2020). The progressively expanding literature on the economic value of ecosystem services, and the organisation and synthesis of these data in the ESVD, provides a basis for the development of value functions for an increasing number of biomes and their ecosystem services. This development is part of the process to provide better information and integrate the importance of ecosystems into all relevant policy and investment decisions.

CRediT authorship contribution statement

L.M. Brander: Conceptualization, Data curation, Methodology, Writing – original draft, Writing – review & editing. **R. de Groot:** Conceptualization, Project administration, Supervision, Writing – original draft, Writing – review & editing. **J.P. Schägner:** Conceptualization, Data curation, Formal analysis, Writing – original draft, Writing – review & editing. **V. Guisado-Goñi:** Data curation, Investigation, Writing – original draft, Writing – review & editing. **V. van 't Hoff:** Data curation, Investigation, Writing – original draft, Writing – review & editing. **S. Solomonides:** Data curation. **A. McVittie:** Data curation. **F. Eppink:** Data curation, Validation. **M. Sposato:** Data curation. **L. Do:** Data curation. **A. Ghermandi:** Data curation. **M. Sinclair:** Data curation. **R. Thomas:** Data curation.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Luke Brander reports financial support was provided by Food and Agriculture Organization of the United Nations. Luke Brander reports financial support was provided by United Kingdom Department for Environment Food and Rural Affairs. Luke Brander reports financial support was provided by Netherlands Ministry of Agriculture, Nature and Food Quality. Co-author (Dolf de Groot) is Editor-in-Chief of the Ecosystem Services journal Co-author (Andrea Ghermandi) is an Associate Editor of the Ecosystem Services journal Corresponding author (Luke Brander) is an Associate Editor of the Ecosystem Services journal.

Data availability

Data will be made available on request.

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Appendix

[8] https://www.esvd.info/project-asnbank.

Table A1
Mean values (int$ 2020/ha/year) per ecosystem service – biome combination. Standard error in parentheses.

	Marine	Coral reefs	Coastal systems	Man-groves	Inland wetlands	Rivers and lakes	Tropical & sub-tropical forests	Temp-erate forest and woodland	Boreal and montane forests & woodland	Shrubland and shrubby woodland	Rangeland, natural grasslands & savannas	Polar-alpine	Intensive land uses	Urban and industrial areas
Food	71 (116)	741 (1,321)	2,398 (7,806)	6,791 (22,599)	612 (1,921)	364 (573)	76 (233)	98 (183)	355 (1,215)	32 (69)	474 (698)	684 (1,587)	1,409 (2,956)	1,043 (211)
Water	25 (NA)		7,344 (15,659)	1,623 (2,715)	873 (1,983)	8,618 (21,783)	99 (130)	353 (284)	79 (32)	132 (NA)	177 (303)	19 (24)	348 (731)	1,456 (1,237)
Raw materials	0.34 (NA)	18,514 (21,743)	321 (364)	5,729 (37,458)	18 (56)	88 (161)	433 (1,363)	891 (3,569)	275 (881)	12 (19)	191 (278)	100 (213)	8,750 (32,747)	514 (298)
Genetic resources			11 (NA)		229 (12)		508 (243)							
Medicinal resources							7 (15)		31 (NA)	5.6 (6.5)	1.1 (NA)	0.01 (NA)	9.9 (7.5)	
Ornamental resources		34 (47)					0.29 (0.4)		675 (1,151)					
Air quality regulation			195 (429)	1,323 (1,090)	2,485 (6,079)		15 (NA)	1,124 (1,355)	1,726 (NA)		3.1 (6)	1.3 (NA)	506 (896)	10,384 (10,152)
Climate regulation	183 (175)	2 (3)	111 (121)	1,375 (3,129)	185 (143)	236 (353)	748 (1,194)	475 (596)	1,425 (2,701)	54 (61)	414 (547)	671 (638)	515 (2,563)	870 (458)
Moderation of extreme events		14,369 (44,586)	7,472 (6,374)	14,388 (51,939)	4,969 (6,493)	8,077 (20,514)	77 (115)	39 (47)	711 (352)	42 (12)			607 (1,306)	8,991 (12,239)
Regulation of water flows			82 (NA)	1.6 (1.7)	1,314 (2,855)	1,657 (2,955)	2.5 (2.3)	940 (902)		115 (NA)	36 (42)		649 (491)	620 (279)
Waste treatment	111 (151)	4,078 (2,060)	1,980 (3,467)	3,189 (5,014)	2,603 (5,554)	2,189 (2,211)	11 (NA)	10 (9.1)					965 (1,238)	98 (154)
Erosion prevention		3,418 (6,819)		7,030 (13,274)			47 (88)	138 (138)	67 (34)	21 (NA)	26 (10)	32 (7.3)	39 (37)	
Maintenance of soil fertility		1,551 (969)	6,179 (8,739)	1,028 (980)	812 (NA)	23 (28)	1.4 (15)	48 (56)	208 (288)		1,429 (1,978)	0.53 (0.3)	410 (532)	
Pollination							260 (592)	8,993 (14,462)		1 (NA)	58 (19)		211 (255)	
Biological control						314 (NA)	14 (NA)			0.29 (NA)			921 (1,597)	
Maintenance of life cycles		1,385 (18)	77 (0)	4,078 (7,223)	4,759 (6,711)	631 (687)	19 (NA)					0.11 (NA)	1.5 (2.1)	
Maintenance of genetic diversity		9,432 (17,789)	40 (NA)	5,982 (14,325)	1,483 (1,515)		6.8 (10)	323 (0)			117 (184)			
Aesthetic information		5,580 (1,270)	723 (263)	334 (NA)	493 (574)	1,214 (1,085)		35 (NA)		33 (9.1)	2,114 (NA)		86 (178)	17,505 (20,852)
Opportunities for recreation and tourism	2,022 (9,102)	6,271 (24,128)	5,563 (13,672)	6,118 (26,004)	12,899 (28,202)	2,347 (3,843)	37 (96)	227 (354)	6.7 (4.3)	56 (64)	238 (446)	3.1 (NA)	216 (452)	19,972 (29,219)
Existence, bequest values	22 (27)	18,793 (53,665)	2,042 (1,788)	14,299 (35,185)	63 (46)	3,420 (797)	5,795 (32,157)	1,676 (1,840)		3.7 (3.1)	225 (388)	257 (NA)	1,701 (4,111)	481 (176)
Inspiration for culture, art and design		917 (NA)	0.09 (0)	3,890 (NA)	101 (161)	2,672 (5,633)	2.2 (2.5)			67 (46)	284 (223)		14 (16)	
Spiritual experience						80 (NA)								
Information for cognitive development	0.13 (NA)	2,126 (4,736)	1,488 (0)	749 (1,191)	120 (22)	1,517 (1,168)	6.9 (9.8)	200 (NA)		153 (86)	147 (64)	0.62 (NA)	1.9 (3)	2,233 (859)

References

Brander, L.M., Bräuer, I., Gerdes, H., Ghermandi, A., Kuik, O., Markandya, A., Navrud, S., Nunes, P.A., Schaafsma, M., Vos, H., Wagtendonk, A., 2012. Using meta-analysis and GIS for value transfer and scaling up: valuing climate change induced losses of european wetlands. Environ. Resour. Econ. 52, 395–413.

Brander, L.M., van Beukering P., Balzan, M., Broekx, S., Liekens, I., Marta-Pedroso, C., Szkop, Z., Vause, J., Maes, J., Santos-Martin F. and Potschin-Young M., 2018. Report on economic mapping and assessment methods for ecosystem services. Deliverable D3.2 EU Horizon 2020 ESMERALDA Project, Grant agreement No. 642007.

Brander, L., Schägner, J.P., de Groot, R., 2022. On the potential use of the ecosystem services valuation database for valuation in the system of environmental economic accounting. One Ecosystem 7, e85085.

Brander, L., 2013. *Guidance manual on value transfer methods for ecosystem services*. UNEP https://www.unep.org/resources/report/guidance-manual-value-transfer-methods-ecosystem-services.

CBD, 2020. Global Biodiversity Outlook 5. Convention on Biological Diversity. Montreal.

CBD, 2021. Post-2020 Global Biodiversity Framework. Retrieved from https://www.cbd.int/gbo5/framework/.

Costanza, R., d'Arge, R., De Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'neill, R.V., Paruelo, J., Raskin, R.G., 1997. The value of the world's ecosystem services and natural capital. Nature 387 (6630), 253–260.

Daily, G.C., 1997. Nature's services: societal dependence on natural ecosystems. Island press.

Daily, G.C., Ruckelshaus, M., 2022. 25 years of valuing ecosystems in decision-making. Nature. https://doi.org/10.1038/d41586-022-01480-x.

Dasgupta, P., 2021. The economics of biodiversity: the dasgupta review. HM Treasury, London.

De Groot, R., Brander, L., Van Der Ploeg, S., Costanza, R., Bernard, F., Braat, L., Christie, M., Crossman, N., Ghermandi, A., Hein, L., Hussain, S., 2012. Global estimates of the value of ecosystems and their services in monetary units. Ecosyst. Serv. 1 (1), 50–61.

Díaz, S., Pascual, U., Stenseke, M., Martín-López, B., Watson, R.T., Molnár, Z., Shirayama, Y., 2018. Assessing nature's contributions to people. Science 359 (6373), 270–272.

Freeman III, A.M., Herriges, J.A., Kling, C.L., 2014. The measurement of environmental and resource values: theory and methods. Routledge.

Grammatikopoulou, I., Badura, T., Johnston, R.J., Barton, D.N., Ferrini, S., Schaafsma, M., La Notte, A., 2023. Value transfer in ecosystem accounting applications. J. Environ. Manage. 326, 116784.

Haines-Young, R., Potschin-Young, M., 2018. Revision of the common international classification for ecosystem services (CICES V5. 1): a policy brief. One Ecosystem 3, e27108.

IIASA/FAO, 2012. Global Agro-ecological Zones (GAEZ v3.0). IIASA, Laxenburg, Austria and FAO, Rome, Italy.

IPBES, 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. S. Díaz, J. Settele, E. S. Brondízio E.S., H. T. Ngo, M. Guèze, J.Agard, A. Arneth, P. Balvanera, K. A. Brauman, S. H. M. Butchart, K. M. A. Chan, L. A. Garibaldi, K. Ichii, J. Liu, S. M. Subramanian, G. F. Midgley, P. Miloslavich, Z. Molnár, D. Obura, A. Pfaff, S. Polasky, A. Purvis, J. Razzaque, B. Reyers, R. Roy Chowdhury, Y. J. Shin, I. J. Visseren-Hamakers, K. J. Willis, and C. N. Zayas (eds.). IPBES secretariat, Bonn, Germany. 56 pages.

IPBES, 2022. Methodological Assessment Report on the Diverse Values and Valuation of Nature of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. Balvanera, P., Pascual, U., Christie, M., Baptiste, B., and González-Jiménez, D. (eds.). IPBES secretariat, Bonn, Germany. IPBES (2022).

Jacobs, S., Kelemen, E., O'Farrell, P., Martin, A., Schaafsma, M., Dendoncker, N., Pandit, R., Mwampamba, T.H., Palomo, I., Castro, A.J., Huambachano, M.A., 2023. The pitfalls of plural valuation. Curr. Opin. Environ. Sustain. 64, 101345.

Johnston, R.J., Bauer, D.M., 2020. Using meta-analysis for large-scale ecosystem service valuation: progress, prospects, and challenges. Agricultural and Resource Economics Review 49 (1), 23–63.

Johnston, R.J., Rolfe, J., Rosenberger, R.S., Brouwer, R., 2015. Benefit transfer of environmental and resource values. In: The Economics of Non-Market Goods and Resources, p. 14.

Keith, D.A., Ferrer-Paris, J.R., Nicholson, E., Kingsford, R.T. (Eds.), 2020. The IUCN Global Ecosystem Typology 2.0: Descriptive Profiles for Biomes and Ecosystem Functional Groups. IUCN, Gland, Switzerland.

MA, 2005. Millennium Ecosystem Assessment: Ecosystems and human well-being. Island Press, Washington, DC, p. 563.

Navrud, S., Ready, R.C. (Eds.), 2007. Environmental Value Transfer: Issues and Methods (vol. 1084). Springer, Dordrecht.

O'Connor, C., Joffe, H., 2020. Intercoder reliability in qualitative research: debates and practical guidelines. Int. J. Qual. Methods 19, 1609406919899220.

Oleson, K.L., Grafeld, S., Van Beukering, P., Brander, L., James, P.A., Wolfs, E., 2018. Charting progress towards system-scale ecosystem service valuation in islands. Environ. Conserv. 45 (3), 212–226.

Pascual, U., Balvanera, P., Anderson, C.B., Chaplin-Kramer, R., Christie, M., González-Jiménez, D., Martin, A., Raymond, C.M., Termansen, M., Vatn, A., Athayde, S., 2023. Diverse values of nature for sustainability. Nature 620 (7975), 813–823.

Pascual, U., Muradian, R., Brander, L., Gómez-Baggethun, E., Martín-López, B., Verma, M., Armsworth, P., Christie, M., Cornelissen, H., Eppink, F. and Farley, J., 2010. The economics of valuing ecosystem services and biodiversity. *The economics of ecosystems and biodiversity: Ecological and economic foundations*, pp.183-256.

Pearce, D.W., 1993. Economic values and the natural world. Earthscan.

Quatrini, S., Costanza, R., 2023. No time to lie: Sustainable finance needs nextgen assurance. In: *Sustainable Finance and the Global Health Crisis*. Routledge, pp. 77–99.

Rolfe, J., Brouwer, R., 2012. Design effects in a meta-analysis of river health choice experiments in Australia. Journal of Choice Modelling 5, 81–97. https://doi.org/10.1016/S1755-5345(13)70053-8.

Schägner, J.P., Brander, L., Maes, J., Hartje, V., 2013. Mapping ecosystem services' values: current practice and future prospects. Ecosyst. Serv. 4, 33–46.

TEEB, 2010. The economics of ecosystems and biodiversity: ecological and economic foundations. Routledge.

United Nations General Assembly, 2015. Transforming our world: the 2030 Agenda for Sustainable Development. A/RES/70/1. Retrieved from https://sdgs.un.org/2030agenda.

United Nations General Assembly, 2019. Resolution adopted by the General Assembly on 1 March 2019: 74/224. United Nations Decade on Ecosystem Restoration 2021–2030. Retrieved from https://undocs.org/en/A/RES/74/224.

UNSD, 2021. System of Environmental-Economic Accounting— Ecosystem Accounting: Final Draft.

Van Oorschot, M., van Tulder, R., Kok, M., 2020. Business for biodiversity. Mobilising business towards net positive impact, Policy briefing.

Van Zanten, B.T., Gutierrez Goizueta, G., Brander, L.M., Gonzalez Reguero, B., Griffin, R., Macleod, K.K., Alves, A., Midgley, A., Jongman, B., 2023. Assessing the Benefits and Costs of Nature-Based Solutions for Climate Resilience: A Guideline for Project Developers.