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Testing ecosystem accounting in northern China – a case study of SEEA EA in Liaoning Province

Jiayang Ji[a], Tianshu Zhu[a], Changgeng Jia[a], Yu Fan[a] and Youtao Song[a,b]*

[a]*School of Environment, Liaoning University, Shenyang, P.R. China;* [b]*Institute for Finance Research, Faculty of Economics, Shenyang, P.R. China*

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The establishment of ecosystem accounts helps to promote and practice sustainable development. In China, the establishment of ecosystem accounts based on the System of Environmental-Economic Accounting–Ecosystem Accounting (SEEA EA) facilitates government decision-making regarding the ecological transformation of economic and social development. There have been attempts to develop ecosystem accounts in some southern Chinese provinces and cities, but little has been done to develop an ecosystem account for northern China. This study examined the potential and challenges of constructing ecosystem accounts in methods and policies in northern China and promoted the practice of EA accounts by constructing ecosystem extent, condition, ecosystem services supply and use accounts, and biodiversity accounts in Liaoning Province. The testing accounts cover provisioning, water supply, air filtration, water purification, global climate regulation (carbon storage), soil erosion management, and recreation services in 2019. The results show that due to the difference in climate between northern and southern China, there is no accounting for temperature regulation and flood regulation services, but water supply services are considered; Policy, demographic, and socioeconomic factors affect the extent and condition of ecosystems. This study illustrates how ecosystem accounts can contribute to policy and decision-making, foster sustainable development, and inform the application of ecosystem accounts in northern China and other countries and regions. In this paper, we identify difficulties, including data availability and quality, that limit the integration of ecosystem accounting into policy. Future research is suggested to address these gaps and facilitate the implementation of ecosystem accounting.

Keywords: China; ecosystem accounting; natural capital; SEEA EA; sustainability

1. Introduction

The Sustainable Development Goals (SDGs) were adopted by the United Nations General Assembly in 2015 in order to guide public policies and motivate societal actors to promote sustainable development (Biermann *et al.* 2022). They covered society, the economy, and the environment (UNSD 2015c), the three key elements of sustainable development. Natural capital interacts with built, human, and social capital to support and sustain human, economic, and societal well-being (Costanza *et al.* 2017), which is referred to as ecosystem services. Ecosystem services have been estimated in spatially explicit form and are available in several different valuation units, including monetary values (Costanza *et al.* 2016), presenting the integration of social, economic,

*Corresponding author. Email: youtaosong@sina.com

and environmental information. It is essential to monitor these three components of information effectively and sustainably in order to accomplish the SDGs (UNSD 2015b). Therefore, the valuation of ecosystem services can provide useful scientific support for the prevention of ecological harm and improvement of ecosystem quality, hence encouraging sustainable development (Langemeyer *et al.* 2021).

The United Nations has developed the System of Environmental and Economic Accounting (SEEA) as an international standard accounting framework. SEEA can effectively complement economic statistics on the contribution of natural capital by paralleling economic indicators such as GDP (UN 2021). It consists of Central Framework (CF) and Ecosystem Accounting (EA). SEEA CF addresses natural capital from the standpoint of resource stocks (Yang *et al.* 2021). SEEA EA builds on years of experimental practice and was officially introduced in 2021. SEEA EA measures primarily the physical and monetary quantities of ecosystem services and monitors changes in ecosystem size and condition (McMahon *et al.* 2022). Compared to CF, SEEA EA emphasizes ecological fluxes and relates them to human activities in order to depict nature's contribution to humans (Mokany *et al.* 2022). In this regard, the information from SEEA can assist with monitoring and reporting initiatives related to SDGs for their policy relevance, analytical soundness and measurability (Pirmana *et al.* 2019).

However, according to the Global Assessment of Environment Statistics and Environmental-Economic Accounting (UNSD 2007, 2015a; UNCEEA 2018), the development and implementation of SEEA is constrained by the lack of human and financial resources, and the compilation of SEEA accounts is impeded by the availability and quality of data. As of 2018, only 69 countries around the world have environmental economic accounting programs (UNCEEA 2018). The newly released EA has only been implemented by a few countries/regions. Farrell *et al.* (2021) compiled an extent and condition account of a catchment case study in Ireland, highlighting the role of data gathering and stakeholder engagement. Vysna *et al.* (2021) developed extent, condition and service accounts of the European Union, and combined results on crop provision with economic and social variables on agricultural production. Australia addressed the Indigenous perspective on EA (Normyle *et al.* 2022). The Netherlands developed a comprehensive set of accounts and found compiling the ecosystem accounts was a major undertaking, even in a relatively small and data-rich country such as the Netherlands (CBS and WUR 2021).

China compiled EA accounts for Guangxi and Guizhou, which are located in Southern China, a tropical-subtropical zone with high temperatures and rainfall and evergreen seasons. NBS China (2021) found that it impossible to compile an ecosystem service supply and use table because data were collected by different functional departments and organized by administrative division, not by ecosystem type. In addition, EA compilation can be different since climate differences can lead to distinct ecosystem compositions that provide different ecosystem services (Tang *et al.* 2018; Zilio *et al.* 2017). China's latitudes, distance from the sea, terrain heights, landscape types, and mountain ranges create four diverse geographical regions: northern, southern, northwest, and Qinghai-Tibet. Therefore, this study aims to address the gaps in previous studies, compile EA accounts for northern China with a regional applicable manner and conducts a case study in Liaoning Province, the economic heart of Northeast China, one of China's four key economic regions (W. Li *et al.* 2020). In addition, the study uses a land cover dataset with 30 m resolution obtained from

Chinese environmental disaster monitoring satellites (HJ-1A/B) and US terrestrial satellites (Landsat OLI) in order to classify ecosystems to resolve the problem encountered in Guangxi and Guizhou. The development of EA accounts in Liaoning Province not only practices EA standards in Northern China, but it also localizes SEEA EA and highlights the difficulties in compiling SEEA EA accounts in Northern China, thereby facilitating its acceptance within China.

2. Methods and data

2.1. Building ecosystem accounts

The SEEA EA presents accounts that are integrated, internally consistent, and interrelated, as shown in Figure 1. These accounts encompass the extent and condition of ecosystems (in physical terms), the supply and use of ecosystem services (in physical and monetary terms), and ecosystem assets (in monetary terms). Thematic accounts, such as biodiversity and carbon, can be created to address specific policy-relevant concerns or to supplement existing accounts (Edens *et al.* 2022). Moreover, its organization allows it to be utilized equally well in sections (Farrell *et al.* 2021). We have developed four SEEA EA core accounts (ecosystem extent accounts, ecosystem condition accounts, and physical and monetary accounts of ecosystem services) and a thematic account (Biodiversity) in Liaoning. This paper addressed the issues of data availability, data quality, and supply-use table development for the implementation of ecosystem accounting in China by using cross-sectoral data collection, Arc GIS satellite data interpretation, Aries platform accounting, and literature review on the supply and use side of the classification service as much as possible.

An ecosystem extent account was compiled for the year 2019. The ecosystem extent account consists of a map of the ecosystem types in Liaoning (Figure 2) from 2009 to 2019. Land cover data with 30 m resolution from Chinese environmental disaster monitoring satellites (HJ-1A/B) and US terrestrial satellites were utilized to obtain

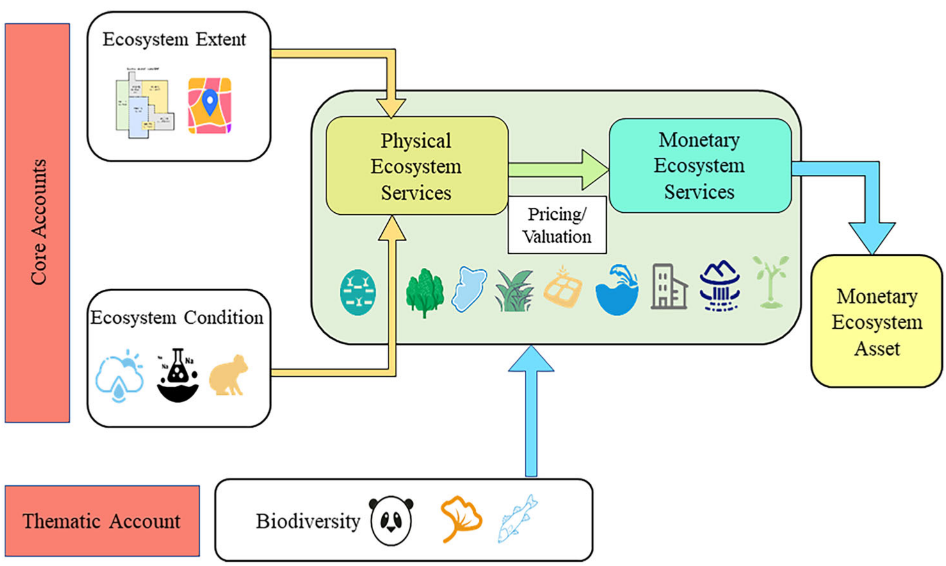

Figure 1. The accounts of the SEEA EA (UN 2021).

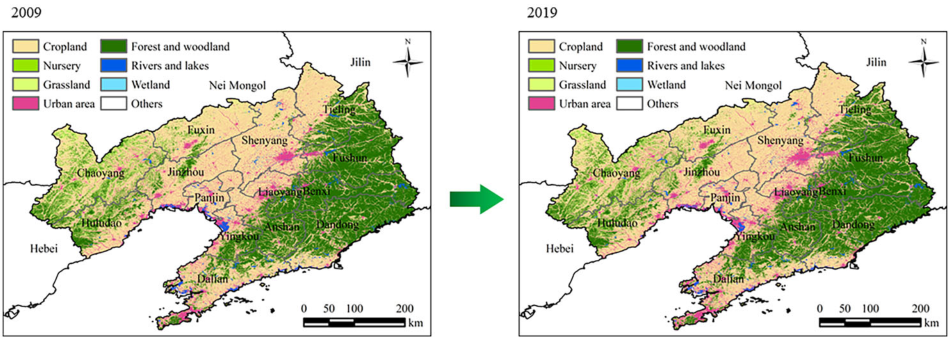

Figure 2. Ecosystem structure of Liaoning Province in 2009 and 2019.

classification information for ecosystems (Landsat OLI). Object-oriented multi-scale segmentation change detection was utilized to classify these remote sensing data. The accuracy of the classification findings from remote sensing was confirmed by sampling at random, and it exceeded 85%. (i) land cover, (ii) land use, and (iii) ecosystem services determined ecosystem types. The second requirement implies that ecosystem types inherently supply multiple services (Hasan *et al.* 2020).

The condition account gives indicators of an ecosystem's general health as well as stressors that have the ability to damage it (UN 2021). State indicators depict the state of the land, air, water, and plants. Indicators of pressure represent environmental pressures such as pollution, groundwater management, and urbanization. Pressures have an effect on ecosystems and, consequently, their capacity to deliver services (Hein *et al.* 2020). In ecosystem accounting, measuring ecosystem condition is of central importance because (i) the monitoring of ecosystem condition is relevant to a wide range of environmental policies, such as those focusing on water quality and biodiversity (Hillebrand *et al.* 2018); and (ii) ecosystem condition is a measure of ecosystems' future capacity to provide ecosystem services (Matasov *et al.* 2020). The most policy-relevant indicators were chosen for the condition accounts based on the *Opinions on Establishing a Mechanism for Realizing the Value of Ecosystem Products* released by the State Council of China. The Liaoning ecosystem condition account relied heavily on existing datasets (such as the data on water quality from the Water Resources Bulletin). For various pressure indicators (such as air pollution and acidification), the current situation was depicted by combining available statistics with reference values from the scientific literature.

The physical supply and use account for ecosystem services details the physical flows of ecosystem services from nature to society (Abdullah-Al-Mamun *et al.* 2017). Flow is the accumulation of an ecosystem service during a particular accounting period, often one year. All selected services were rigorously defined to represent nature's contribution to humanity, and they were quantified using a wide range of metrics and resolutions, with human inputs excluded (UN 2021). However, some ecosystem service definitions are contested in terms of classification. According to Costanza *et al.* (2011), carbon fixation is a type of supporting service, despite being categorized as a regulating service by Ouyang *et al.* (2020). When such controversial ecosystem services are encountered, they are defined in this paper according to the concepts in the SEEA EA, such as defining carbon fixation as a climate regulation service and classifying it as one of the regulating and maintenance services. In this paper, we account for 10 ecosystem services based on data availability and quality according to the government-issued guidelines in China (GEP) and the cross-section of the SEEA EA ecosystem services inventory. Selected services were divided into three categories: provisioning, regulating and maintenance, and cultural, in accordance with the reference list of ecosystem services in the SEEA EA. In addition, it is difficult to distinguish human capital effects from provisioning services; for instance, it is difficult to account for the relative contributions of farmers and ecosystems to cropland yield. Moreover, the limiting physical input to crop provisioning varies considerably based on the type of habitat (e.g. temperature in boreal areas, water in semi-arid areas, plant nutrients in many temperate agroecosystems) (Azeda *et al.* 2021). There is currently no widely acknowledged approach for assessing the contribution of ecosystems to agricultural production in physical terms (Hein *et al.* 2020). Such issues encountered in the physical accounts can be resolved in the monetary account, for example, farmers' inputs which should be excluded from provisioning services can be quantified by the value of fertilizer, pesticides, and labor in the statistical yearbook.

In this study, high-resolution spatial models were developed for a variety of ecosystem services. The modeling of 10 ecosystem services included five provisioning services, four regulating and maintenance services, and one cultural service. These ecosystem services have been researched and mapped. Physical supply tables are generated and evaluated based on the outcomes of the geographical models. We generate an ecosystem services supply table for each ecosystem type. Users, not final goods, were used to describe those who accessed ecosystem services. For instance, the agricultural sector, not the customer who purchases the processed output, is the user of ecosystem services associated with crop provisioning. Unless it was impossible to establish a dominant user group, ecosystem services were normally given to a single user group. The definition of users of location-dependent ecosystem services as landowners.

The monetary ecosystem services account is constructed using the physical ecosystem services account as a foundation. The exceptional feature of SEEA EA is that the monetary valuation is accomplished in accordance with information from conventional national accounts (Vysna *et al.* 2021). This property enables the comparison of ecosystem services to other goods and services and the incorporation of ecological information into typical economic models and evaluations of productivity (Dvarskas 2019). The key notion of both the SNA and SEEA EA is the value transfer mechanisms, which involve the actual exchange of services, labor, assets, or items for money (Tapsuwan *et al.* 2021). This SEEA EA technique is based on the SNA, which excludes consuming surplus but includes producer surplus and manufacturing costs. When utilizing SEEA EA, it is essential to comprehend the relationship between the values of ecosystem services and those currently available in the national account. In the SNA, the value of ecosystem services that are used for production or consumption can already be (partially) included in the value of GDP (Eigenraam and Obst 2018). As described in the physical ecosystem services account, provisioning services make it difficult to discern between the value provided by human civilization and the value provided by natural capital. However, the monetary ecosystem service account would be calculated with greater precision than the physical ecosystem service account due to the monetary quantity data for artificial inputs such as pesticides and fertilizers. The SEEA EA indicates that, in this instance, the ecosystem services can be valued using either a lease price or a resource rent approach. Moreover, ecosystem services may contribute directly to household consumption, such as tourism and recreation that depend on the natural environment (Çetin, Bourget, and Tezer 2021). This (additional) final household consumption, in addition to being included in GDP as measured by the SNA, is indicative of the value consumers assign to an ecosystem service (e.g. recreation). Other ecosystem services can be valued using methodologies other than GDP value transfer (as defined by the SNA). Since ecosystem services with public attributes (e.g. water purification) are used directly for household consumption and government consumption, they are frequently offered for free and are not included in gross domestic product (as defined by the SNA).

The Liaoning Biodiversity Account is constructed in accordance with the SEEA EA and the Convention on Biological Diversity. The Convention on Biological Diversity (CBD) specifies that biodiversity consists of three levels: ecological diversity, species diversity, and genetic diversity. The value of biodiversity primarily consists of use value and non-use value, where the former refers to direct value and indirect value and the latter refers to existence value and selection value (Nobel *et al.* 2020). According to the classification, we can determine that the conservation value of species diversity belongs to the category of non-use value, and that its conservation function is primarily to provide essential species and genetic resources for ecosystem succession and biological evolution, as well as to play a role in the maintenance of ecosystem stability and biodiversity (Wintle *et al.* 2019). It also contributes to the maintenance of ecological processes and stability (Valainis *et al.* 2021). The species variety of trees was considered for account construction in this study. In accordance with the SEEA EA principle, we chose to construct accounts with the more plentiful and valuable tree species that are prominent in the region. For physical quantities, we picked accounting areas based on the availability of data; for value quantities, we accounted for the conservation value of various species using the Shannon-Wiener index (Sun and Ren 2021). The objective of the biodiversity accounts constructed in this paper is to help integrate the conservation of forest-based biodiversity into economic development planning and financial investment decisions, mainstream biodiversity in economic life, and achieve biodiversity conservation goals.

2.2. Data inventory

This study includes 2009 and 2019 data on land usage, administrative boundaries, and nature reserve boundaries in Liaoning Province. The administrative division boundaries and land use statistics for Liaoning Province were collected from the Resource and Environment Science and Data Center of the Chinese Academy of Sciences, where the land use data precision was $30\,m \times 30\,m$. Data on aboveground biomass and vegetation cover were extracted from the National Data Center for Forestry and Grassland Sciences database and utilized in prior research on the national dynamics of ecosystem services. Socioeconomic, hydrological, meteorological, and pollution monitoring data were compiled using the connected province and national government ministries' publicly accessible, official statistics sources. In addition, information on the physical and economic (price-related) components of ecosystem services was acquired from trustworthy data sources and relevant literature. The monetary value of cultural services was determined using data derived from relevant publications.

2.3. Study area

Liaoning is located in the northeast region, one of the four major economic zones in China, with the Yellow Sea and Bohai Sea to the south, a river dividing it from North Korea to the east, and Japan and South Korea across the sea. It is the only coastline and border province in the northeast. The province has a land area of 148,000 km^2, a coastline of 2,292 km, and an offshore water area of 68,000 km^2. The terrain is elevated in the north and low in the south, with hills and mountains separating the east and west. Liaoning has a moderate continental monsoon climate zone with four distinct seasons, making it excellent for a wide range of crops. It is a major national grain-producing region and a vital production region for cattle, fisheries, high-quality fruits, and a wide range of specialty items. There are 14 provincial cities and 100 counties (cities and districts) in the province, which has a total population of 42.71 million people.

3. Results and discussion

3.1. Ecosystem extent and condition account

Figure 2 provides a summary of the study on ecosystem extent, including a map of the ecosystem types in 2009 and 2019. Forest and woodland, rivers and lakes, cropland, urban area, nursery, wetland, grassland, reservoirs and ponds are included in the account. The most notable change during this time period is the 8,831 km^2 rise in cropland in the Liaoning Province and the decrease in grassland. These major changes may be attributable to the development of agriculture and livestock in Liaoning Province as a result of population growth (Duro *et al.* 2020). Moreover, although urban ecosystem accounts for only 5.43% of Liaoning, it has increased by 21.7% since 2009, demonstrating the fast urbanization caused by economic development and population growth (Buhaug and Urdal 2013). There is no alteration to rivers and lakes, and only a slight impact to wetlands and the reservoir.

The aggregated ecosystem condition account for the Liaoning Province in 2009 and 2019 is shown in Table 1. The account comprises three condition groups—abiotic characteristics (physical and chemical states), biotic characteristics (composition, structure, and function), and landscape characteristics—to illustrate the condition of the Liaoning ecosystem in its entirety. This condition report's data collection can aid in identifying an ecosystem's dominant trend (UN 2021). During the accounting period,

Table 1. Ecosystem condition account for Liaoning Province (2009 and 2019).

Condition group	Condition class	Descriptor	Units	2009	2019	Change (% per decade)
Abiotic characteristics	Physical state	Temperature	°C	8.5	10.28	20.94%
	Chemical state	Rainfall	mm/year	566	699.92	23.66%
		SO_2 (Air)	$\mu g/m^3$	43.99	19	−56.81%
		NO_2 (Air)	$\mu g/m^3$	33.00	28	−15.16%
		PM_{10} (Air)	$\mu g/m^3$	88.99	70	−21.34%
Biotic characteristics	Composition	Ecological Index	Index	61.50	67.2	9.27%
	Structure	forest coverage	%	35.13%	39.24%	11.70%
	Function	Vegetation coverage - NDVI	Index	0.467	0.507	8.57%
Landscape characteristics		Non-commercial forest ratio	%	48.40%	53.58%	10.70%

both temperature and precipitation increased by more than 20%, which may indicate global climate change (C. Li *et al.* 2021). Changes in climate can affect the biodiversity and function of aquatic and terrestrial ecosystems (Kløve *et al.* 2014), which can result in alterations to ecosystem services (Weiskopf *et al.* 2020). The advancing desulfurization technology and the implementation of desulfurization price subsidy policy have led to considerable reductions in SO_2 in China (Ai *et al.* 2021). The reduction of NO_2 and $PM_{10,}$ almost entirely driven by wintertime decreases, is indicative of decreasing anthropogenic NOx emissions (Fan *et al.* 2021; Lin *et al.* 2019). The forest coverage and vegetation coverage – NDVI increased by 11.70% and 8.57%, respectively, in this decade due to the Liaoning Province government's supply-side structural reform of forestry. The growth in the proportion of non-commercial forests between 2009 and 2019 demonstrates the positive development of forest ecosystems in Liaoning Province.

Ecological index is a mixture of indicators (biological abundance index, vegetation cover index, water network density index, land stress index, pollution load index, and environmental limitation index) used by the Chinese government to indicate the ecological environment quality status of the evaluated area. Its ecological environment is categorized into five levels based on the condition of its ecological environment: The ecological environment condition index more than or equal to 75 is exceptional, with a high vegetation cover, a rich biodiversity, and a stable ecosystem; 55 to 75 is good, with a high vegetation cover, a rich biodiversity, and an ecosystem suitable for human life. In the range of 35 to 55, the vegetation cover is average, the amount of biodiversity is average, and the environment is more favorable for human existence, but there are limits that are not acceptable for human life. Nevertheless, there are limiting variables that are unsuitable for human existence; $20 \sim 35$ are poor, with inadequate vegetation cover, severe drought and low rainfall, fewer species, and factors that obviously limit human life; less than 20 are extremely poor, with bad conditions and human life being constrained.

The ecosystem extent and condition account show the changes in land use and ecosystem quality in Liaoning Province from 2009 to 2019. Overall, according to the basic characteristics and spatial pattern of the land use change study in China, national macro policies, regional development policies, and socioeconomic development were the main drivers of land use change in China at the beginning of the twenty first century (Liu *et al.* 2010). The improvement in people's living standards and internal restructuring of agricultural land were the main factors leading to the change in cultivated land in northern China (Li *et al.* 2004), which may be the reason for the upward trend in cultivated land area in Liaoning Province from 2009 to 2019. Population growth, poor grassland management and overgrazing may have contributed to the decreasing trend of grassland area in Liaoning Province (Fu *et al.* 2007). Mao *et al.* (2018) found that Eastern China (including Liaoning in northeastern China) lost 2,394 km^2 due to urban expansion, which may be the reason for the decrease in wetland in Liaoning Province from 2009 to 2019. Meanwhile, studies have pointed out that the level of socio-economic development and industrialization is the driving factor of urban area expansion (Wu and Zhang 2012), and the GDP for Liaoning Province increased by 94.5% during 2009-2019, so this may be the reason for the increase in urban land area in Liaoning Province. The decrease in pollution indicators and the increase in ecological indicators in the status account indicate the improvement in ecological quality in Liaoning Province during 2009-2019, which may be due to the adoption of vertical supervision reform in ecological governance by the Chinese government. The vertical supervision reform reduces the financial pressure and improves the capacity of ecological governance, and enhances the authority to regulate enterprises in terms of structural effects, which reduces the local number of polluting enterprises (Lin and Xu 2022).

3.2. Physical ecosystem services account

The physical ecosystem services account comprises accounting tables detailing the supply and usage of each ecosystem service by economic sector. According to the SEEA EA definition, supply and demand are equal in value in this account. Data for biomass provisioning services and cultural services are from the Statistical Yearbook, data for water supply, air filtration and water purification services are from the Government Public Documents, and global climate regulation services and soil erosion control services are accounted for using ARIES for SEEA. The table of physical supply is shown in Table 2 below. The supply table reveals that forests and woodlands provide the greatest variety of ecosystem services, while cropland provides the highest level of global climate regulation service, in part because these ecosystem types cover the greatest areas. More natural ecosystem types (such as wetlands, forests and woods, and rivers) provide a greater diversity of ecosystem services per square kilometer than do fewer natural environment types (urban area). Due to the fact that each service is expressed in distinct indications, it is not possible to sum the quantities of distinct services. The table of physical use is provided in Table 3. The usage account illustrates how economic sectors utilize ecological services. Agriculture uses the most ecosystem services among industry sectors, while the government use the most ecosystem services (6). The government has been allotted the usage of the four regulating services (global climate regulation, air filtration, water purification, and soil and sediment retention) based on land ownership.

3.3. Monetary ecosystem services account

The monetary ecosystem services account documents the monetary value of ecosystem service flows across the accounting period (e.g. one year). Table 4 and Table 5 provide an overview of the ecosystem outcomes. Data for biological supply services were obtained from the Statistical Yearbook (removing the cost of fertilizer, pesticides, and labor, etc.), water supply, air filtration and water purification services were based on physical account data using the replacement cost method, cultural services were accounted for by travel cost, and global climate regulation services and soil and water conservation services were accounted for using ARIES for SEEA. The overall value of the five provisioning services in Liaoning Province was 233,971 million, the value of the four regulating and maintenance services was 1,813.1 million, and the value of the cultural services was 623,263.2 million. The provisioning service is significantly higher than the regulating and maintenance service, most likely because: (i) the soil conditions (soil microorganisms, organic matter, etc.) in Liaoning Province are conducive to crop growth (Zhang *et al.* 2018); (ii) the commercial forests in Liaoning Province are close to 50%; and (iii) the final service being counted in the regulating and maintenance service includes only four major services due to difficulties in data acquisition. The values for nature-related recreation that were determined using the

Table 2. Physical supply table of ecosystem service account for Liaoning province in 2019.

Supply	Units of measure	ECOSYSTEM TYPES									Total supply
		Cropland	Nursery	Forest and Woodland	Grassland	Wetland	Urban	Rivers and Lakes	Reservoirs and Ponds	Ocean	
Provisioning services											
Crop provisioning	Million ton	24.3									24.3
Livestock provisioning	Million ton				8.1						8.1
Wood provisioning	Million m^3			1.1							1.1
Aquaculture provisioning	Thousand ton							39.0		487.0	526.0
Water supply	00 million m^3							102.3	34.3	0.1	136.7
Regulating and maintenance services											
Global climate regulation	Million tons C	12.8	1.3	9.8	0.1	0.0	0.6			0.3	24.9
Air filtration	Million tons SO_2			1.4							1.4
	Thousand tons NO_2			32.0							32.0
Water purification	Million ton					2,353.7					2,353.7
Soil and sediment retention	Thousand ton	1,142.0	369.4	11.9	9.0	2.2				2.7	1,537.3
Cultural services											
Recreation-related services	Million visits			129.8			378.3	40.1	12.3	81.2	641.7

Table 3. Physical use Table of ecosystem service account for Liaoning Province in 2019 (million yuan).

Use	Units of measure	Agriculture	Forestry	Graziery	Fisheries	Industry and construction	Tertiary sector of the economy	Total industry	Government consumption	Household consumption	Total use
Provisioning services											
Crop provisioning	Million ton	24.3						24.3			24.3
Livestock provisioning	Million ton			8.1				8.1			8.1
Wood provisioning	Million m^3		1.1					1.1			1.1
Aquaculture provisioning	Million ton				526.0			526.0			526.0
Water supply	00 million m^3	71.5	9.2			20.1	6.2	107.0	12.3	17.4	136.7
Regulating and maintenance services											
Global climate regulation	Million tons C							0.0	24.9		24.9
Air filtration	Million tons SO_2							0.0	1.4		1.4
	Thousand tons NO_2							0.0	32.0		32.0
Water purification	Million ton							0.0	2,353.7		2,353.7
Soil and sediment retention	Thousand ton							0.0	1,537.3		1,537.3
Cultural services											
Recreation-related services	Million visits							0.0		641.7	641.7

Table 4. Monetary supply table of ecosystem service account for Liaoning province in 2019.

Supply	Ecosystem types									Total supply
	Cropland	Nursery	Forest and Woodland	Grassland	Wetland	Urban	Rivers and Lakes	Reservoirs and Ponds	Ocean	
Provisioning services										233,971.0
Crop provisioning	108,240.1									108,240.1
Livestock provisioning				61,326.6						61,326.6
Wood provisioning			5,489.2							5,489.2
Aquaculture provisioning							731.4		11,046.4	11,777.8
Water supply							35,279.7	11,833.5	24.2	47,137.4
Regulating and maintenance services										1,813.1
Global climate regulation	0.0	0.0	0.0	0.0	0.0	0.0			0.0	0.0
Air filtration SO_2			1,739.9	0.0						1,739.9
NO_2			40.3	0.0						40.3
Water purification					33.0					33.0
Soil and sediment retention	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cultural services										622,263.2
Recreation-related services			125,873.3			36,6822.7	38,927.0	11,933.8	78,706.4	622,263.2

Table 5. Monetary use Table of ecosystem service account for Liaoning Province in 2019.

Use		Agriculture	Forestry	Graziery	Fisheries	Industry and construction	Tertiary sector of the economy	Total industry	Government consumption	Household consumption	Total use
Provisioning services											
Crop provisioning		108,240.1						108,240.1			108,240.1
Livestock provisioning				61,326.6				61,326.6			61,326.6
Wood provisioning			5,489.2					5,489.2			5,489.2
Aquaculture provisioning					11,777.8			11,777.8			11,777.8
Water supply		246.6	31.8			69.2	21.5	369.1	42.3	59.9	471.4
Regulating and maintenance services											
Global climate regulation								0.0	0.0		0.0
Air filtration services	SO_2							0.0	1,739.9		1,739.9
	NO_2							0.0	40.3		40.3
Water purification								0.0	33.0		33.0
Soil and sediment retention								0.0	0.0		0.0
Cultural services											
Recreation-related services								0.0		62,2263.2	62,2263.2

spending method were higher. These costs include transportation to natural regions and park entrance fees (entry fees must be paid for only a few parks, and most of the value is from travel costs). According to the trade-offs and synergies analysis model proposed by Briner *et al.* (2013), the crop provisioning service can increase carbon sequestration (global climate regulation service). Hence, there would be a synergetic effect between crop provisioning service and global climate regulation service. The decrease in livestock provisioning will reduce greenhouse gases. The increase in wood provisioning service can increase the amount of carbon sequestration and increase the soil and sediment retention service. Due to the non-allocatable input characteristic of land, crop provisioning service and cultural service are dependable, which means using land to provide food affects the corresponding landscape's cultural services. There is a need for additional study on the SEEA EA in order to gain a better understanding of which regulating and maintenance services should be selected and how regulating services should be valued. In addition, certain services, such as those connected to marine fishing and coastal protection, are still absent from the accounts. Moreover, in order to further analyze the complexity of ecosystems and their dynamic relationship with human society, the conversion of ecosystem services to human society and methods for accounting for ecosystem service values need to be further investigated.

3.4. Biodiversity account

Table 6 presents an overview of Liaoning's biodiversity accounts, including ecosystem extent and ecosystem values, i.e. the conservation values of endemic species. There are 10 species of natural forests and 18 species of planted forests, with an area ratio of 1.15. The Shannon-Wiener index is a standard diversity index, which can indicate both the species richness and the uniformity of species distribution within a community, which means the higher the number of species, the higher the diversity (Song *et al.* 2016). In this method, the conservation value of species diversity per unit area was calculated using the forestry industry standard of the People's Republic of China. The conservation value of natural forests in Liaoning Province in 2019 is 52.91 billion yuan, and the conservation value of planted forests is 41.67 billion yuan, with a ratio of 1.27 between the two.

3.5. Sustainability in SEEA EA

In addition, SEEA EA can be used to analyze the accounting area's sustainability (UNSD 2021). In sustainability theory, there are two schools of thought: the strong sustainability philosophy and the weak sustainability philosophy. The weak sustainability concept claims that natural capital and man-made capital are interchangeable and that the accumulation of man-made capital may compensate for the loss of natural capital by maintaining a constant total of natural and man-made capital (Gowdy and O'Hara 1997). The capacity to give services to human society can be maintained so long as the sum of natural and man-made capital remains consistent. As long as the total amount of natural and man-made capital remains unchanged, the capacity to continue the flow of services to human civilization can be maintained (Biely, Maes, and Van Passel 2018). In other words, the growth restriction imposed by the depletion of natural capital can be maintained by maintaining constant levels of both natural and created capital. The growth restriction imposed by the depletion of natural capital can be circumvented by

Table 6. Biodiversity account of Liaoning Province in 2019.

Advantageous tree species	Natural forest Area (km^2)	Natural forest Conservation value (million yuan)	Planted forest Area (km^2)	Planted forest Conservation value (million yuan)
Sum	21,292	52,912.0	18,450	41,673.5
Akamatsu	95	190.0	31	62.0
Yaupon	635	1270.0	4076	8152.0
Oak	8115	24,345.0	886	2658.0
Birchwood	190	380.0	0	
Water Hoang	1199	3597.0	32	96.0
Other hard and broad categories	381	1143.0	1639	4917.0
Lime	62	124.0	0	
Other soft broad categories	159	477.0	127	381.0
Broadleaf mix	9982	19,964.0	1074	2148.0
Needle Broad mix	474	1422.0	1326	3978.0
Spruce	0		95	285.0
Larch	0		4454	8908.0
Red pine	0		539	1617.0
Sphagnum pine	0		253	759.0
Black pine	0		31	62.0
Cypress wood	0		95	190.0
Poplar	0		3128	6256.0
Coniferous mix	0		349	1047.0
Other economic forests	0		315	157.5

technological advancement and knowledge innovation. The weak idea of sustainability, which is predicated on the total substitutability of natural and man-made capital, justifies the usage of massive capitalization. The idea of sustainability, which promotes the use of substantial natural resource inputs for national economic development, indicates that natural capital can be monetized. This indicates that natural capital can provide economic production. In the realm of ecosystem services, the Chinese government is supporting the theory of ecological goods value realization. The notion of weak sustainability is the theoretical foundation for the value realization of ecological products, which tries to convert the potential value of ecosystem services into their actual economic worth. Through eco-industrialization and payment for ecosystem services, the objective is to convert the potential value of ecosystem services into actual economic value.

Strong sustainability assumes that certain essential natural capital cannot be replaced by man-made capital, or that the expense of replacing natural capital with man-made capital would be unsustainable. The GEP is founded on the notion of strong sustainability, which quantifies the value of ecosystem products and services in order to effectively incorporate natural capital conservation into economic and social development decisions. The Sanjiangyuan National Park, for instance, is a very important national ecological security barrier, and the value of natural capital is so high and unique that it is difficult to replace it with human or man-made capital, or that it would be costly to do so. Therefore, the fundamental purpose of Sanjiangyuan National Park is to safeguard natural capital, not to convert the value of ecological goods into commercial value. At this time, GEP accounting may play a key role in integrating natural capital conservation into economic and social development decisions by providing scientific support and a reference base.

3.6. Analytic issues and policy implications

In the Liaoning Province case study, the accounting structure can be challenging to implement. As in accounting, the supply and use tables require sufficient and exhaustive data, but there is no structure in place for systematically assembling this database. Inadequate accounting basic data can result in crude and conservative evaluations. A second concern is about context and scale. The accounting region is picked by our researchers, yet there are ecosystem effects that span boundaries. Change can have consequences in one location with one species, and those effects can extend to other locations, regions, species, and ecosystems. In addition, ecosystem services have far-reaching effects that extend beyond the bounds of the region studied (e.g. wind pollination, which can span 101 km (Robledo-Arnuncio 2011). None of these effects can be completely mapped or tallied. This reality is both practical and theoretical. Furthermore, it is impossible to map ecosystem services completely in time and space, both practically and theoretically. Existing research does not provide comprehensive knowledge of the linkages between ecosystems and their relative contributions (Costanza *et al.* 2017). Scholars have been unable to quantify not only the spatial but also the temporal coupling of individual ecosystem processes (La Notte *et al.* 2017). This could result in double counting or undercounting.

In China, ecosystem accounting is in its early and promotional stages, with the government issuing guidelines to encourage localities to propose and practice ecosystem accounting. Currently, the form of ecosystem accounting in China is GEP, which is presented as a separate number. The supply and use table in SEEA EA can be used as a complement to GEP, reflecting how much ecosystem services are provided by different ecosystems to various industries (users). This also means that ecosystem data monitoring and data collection in China is not in the same form as required by the SEEA framework, making account creation difficult.

It is important to note, however, that despite the above challenges and limitations, ecosystem accounting has been identified as having multiple policy uses in relation to energy, biodiversity, green economic growth, and climate change. As a developing country with a rapidly growing economy and abundant natural resources, China has limited environmental regulatory mechanisms. By integrating key information on trends in the extent, condition, ecosystem services and biodiversity into regular ecosystem accounting based on SEEA EA, the Chinese government can assess the sustainability of ecosystem use and progress toward sustainable development (Hein *et al.* 2020). Meanwhile, ecosystem accounts support multiple policy applications related to ecology and planning, and assist in the green transformation of economic and social development. For example, some Chinese provinces are currently practicing ecological resource equity trading, which revolves around the management integration, conversion and upgrading of natural resources, market-based trading and building a platform for sustainable operation. However, the accuracy of the accounting results is a prerequisite to guarantee the effective application of ecosystems. Even though we applied the more detailed maps available and the accounting methods recommended by SEEA EA and Chinese government guidelines, their limited practice does not ensure that they adequately reflect the complexity of ecosystems and the relationship they have with human society. Consequently, with better maps and accounting models, ecosystem accounting may provide more meaningful information to government decision-makers.

4. Conclusion

The application of SEEA EA faces several key trade-offs, especially in terms of which ecosystem services to select. It was difficult to avoid being insufficiently comprehensive when establishing ecosystem accounts for Liaoning Province, so feasibility and conceptual rigor were prioritized based on data availability and quality. This study complements previous experimental SEEA accounts established in southern China. According to the study, there are three differences between the accounts established in the south and the north: (i) Liaoning accounts for water supply services; (ii) it does not account for temperature regulation services; and (iii) it also does not account for flood storage services. It is a consequence of the significant differences in climate between south and north China, with a temperate monsoon climate in the north and a subtropical monsoon climate in the south, which has a major impact on the ecological environment, resulting in more floods in the south and more droughts in the north. Moreover, this study found that there has been an increase in cropland and urban areas in Liaoning province. There was also a decrease in grassland area, a decrease in air pollution, a decrease in forest diversity, and an increase in environmental indicators, such as forest cover. This may be affected by a variety of factors, such as government policies, population growth, socioeconomic development, and others.

Our study tested the SEEA EA application in northern China. It follows the principles of SEEA EA in establishing accounts and selecting accounting methods, and incorporates the Chinese government's pilot guidelines in monetary accounting. We believe that this study brings added value to the pilot ecosystem accounts in China. Just as ecosystem account applications are still in their preliminary stages, further testing of ecosystem accounting will help in exploring the components that need to be enhanced for wider application.

The Liaoning ecosystem accounts can help to clarify many of the linkages between ecosystems and economic systems, and provide a reference for establishing ecosystem accounts in northern China. There are still many data limitations and institutional barriers to developing ecosystem accounts and using them for decision-making. Despite these challenges, we believe ecosystem accounting has great potential for local and national decision-making. Our study in establishing a testing ecosystem account in Liaoning Province provides theoretical and methodological findings and guidance for selecting and organizing data using the SEEA EA framework in the near future as ecosystem accounts are geographically expanded in China.

Disclosure statement

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References

Abdullah-Al-Mamun, M. M., Kazi Mohammad Masum, A. H. M. Raihan Sarker, and Asyraf Mansor. 2017. “Ecosystem Services Assessment Using a Valuation Framework for the Bangladesh Sundarbans: Livelihood Contribution and Degradation Analysis.” *Journal of Forestry Research* 28 (1): 1–13. doi:10.1007/s11676-016-0275-5.

Ai, Hongshan, Zhengqing Zhou, Ke Li, and Zhuang Kang. 2021. “Impacts of the Desulfurization Price Subsidy Policy on SO_2 Reduction: Evidence from China’s Coal-Fired Power Plants.” *Energy Policy* 157 (October): 112477. doi:10.1016/j.enpol.2021.112477.

Azeda, Carla, Nuno Guiomar, Sérgio Godinho, João Paulo Medeiros, and Teresa Pinto-Correia. 2021. “The Ambiguous Role of Agri-Environment-Climate Measures in the Safeguarding of High Nature Value Farming Systems: The Case of the Montado in Portugal.” *Agriculture, Ecosystems & Environment* 319 (October): 107562. doi:10.1016/j.agee.2021.107562.

Biely, Katharina, Dries Maes, and Steven Van Passel. 2018. “The Idea of Weak Sustainability is Illegitimate.” *Environment, Development and Sustainability* 20 (1): 223–232. doi:10.1007/s10668-016-9878-4.

Biermann, Frank, Thomas Hickmann, Carole-Anne Sénit, Marianne Beisheim, Steven Bernstein, Pamela Chasek, Leonie Grob, et al. 2022. “Scientific Evidence on the Political Impact of the Sustainable Development Goals.” *Nature Sustainability* 5 (9): 795–800. doi:10.1038/s41893-022-00909-5.

Briner, Simon, Robert Huber, Peter Bebi, Ché Elkin, Dirk R. Schmatz, and Adrienne Grêt-Regamey. 2013. “Trade-Offs between Ecosystem Services in a Mountain Region.” *Ecology and Society* 18 (3) art35. doi:10.5751/ES-05576-180335.

Buhaug, Halvard, and Henrik Urdal. 2013. “An Urbanization Bomb? Population Growth and Social Disorder in Cities.” *Global Environmental Change* 23 (1): 1–10. doi:10.1016/j.gloenvcha.2012.10.016.

CBS (Statistics Netherlands) and WUR (Wageningen University and Research). 2021. *Natural Capital Accounting in the Netherlands: Technical Report*. Wageningen: Wageningen University & Research. https://edepot.wur.nl/566545.

Çetin, Nüket İpek, Gulhan Bourget, and Azime Tezer. 2021. “Travel-Cost Method for Assessing the Monetary Value of Recreational Services in the Ömerli Catchment.” *Ecological Economics* 190 (December): 107192. doi:10.1016/j.ecolecon.2021.107192.

Costanza, Robert, Lew Daly, Lorenzo Fioramonti, Enrico Giovannini, Ida Kubiszewski, Lars Fogh Mortensen, Kate E. Pickett, Kristin Vala Ragnarsdottir, Roberto De Vogli, and Richard Wilkinson. 2016. “Modelling and Measuring Sustainable Wellbeing in Connection with the UN Sustainable Development Goals.” *Ecological Economics* 130 (October): 350–355. doi:10.1016/j.ecolecon.2016.07.009.

Costanza, Robert, Rudolf de Groot, Leon Braat, Ida Kubiszewski, Lorenzo Fioramonti, Paul Sutton, Steve Farber, and Monica Grasso. 2017. “Twenty Years of Ecosystem Services: How Far Have We Come and How Far Do We Still Need to Go?” *Ecosystem Services* 28 (December): 1–16. doi:10.1016/j.ecoser.2017.09.008.

Costanza, Robert, Ida Kubiszewski, David E. Ervin, Randall Bluffstone, James Boyd, Darrell Brown, Heejun Chang, et al. 2011. “Valuing Ecological Systems and Services.” *F1000 Biology Reports* 3 (1): 14. doi:10.3410/b3-14.

Duro, Juan Antonio, Christian Lauk, Thomas Kastner, Karl-Heinz Erb, and Helmut Haberl. 2020. “Global Inequalities in Food Consumption, Cropland Demand and Land-Use Efficiency: A Decomposition Analysis.” *Global Environmental Change* 64 (September): 102124. doi:10.1016/j.gloenvcha.2020.102124.

Dvarskas, Anthony. 2019. “Experimental Ecosystem Accounting for Coastal and Marine Areas: A Pilot Application of the SEEA-EEA in Long Island Coastal Bays.” *Marine Policy* 100 (February): 141–151. doi:10.1016/j.marpol.2018.11.017.

Edens, Bram, Joachim Maes, Lars Hein, Carl Obst, Juha Siikamäki, Sjoerd Schenau, Marko Javorsek, et al. 2022. "Establishing the SEEA Ecosystem Accounting as a Global Standard." *Ecosystem Services* 54 (April): 101413. doi:10.1016/j.ecoser.2022.101413.

Eigenraam, Mark, and Carl Obst. 2018. "Extending the Production Boundary of the System of National Accounts (SNA) to Classify and account for Ecosystem Services." *Ecosystem Health and Sustainability* 4 (11): 247–260. doi:10.1080/20964129.2018.1524718.

Fan, Hao., Chuanfeng Zhao, Yikun Yang, and Xingchuan Yang. 2021. "Spatio-Temporal Variations of the PM2.5/PM10 Ratios and Its Application to Air Pollution Type Classification in China." *Frontiers in Environmental Science* 9 (June): 5–6. doi:10.3389/fenvs.2021.692440.

Farrell, Catherine, Lisa Coleman, Mary Kelly-Quinn, Carl Obst, Mark Eigenraam, Daniel Norton, Cathal O'Donoghue, Stephen Kinsella, Orlaith Delargy, and Jane Stout. 2021. "Applying the System of Environmental Economic Accounting-Ecosystem Accounting (SEEA-EA) Framework at Catchment Scale to Develop Ecosystem Extent and Condition Accounts." *One Ecosystem* 6 (April): E 65582. doi:10.3897/oneeco.6.e65582.

Fu, Yang, Fengxia Li, Guosheng Zhang, Qiong Yang, and Xiaoqing Zeng. 2007. "Natural Grasslands Degradation and Environmental Driving Factors in Qinghai Province." *Journal of Glaciology and Geocryology* 29 (4): 525–535. doi:10.7522/j.issn.1000-0240.2007.0076. http://www.bcdt.ac.cn/EN/Y2007/V29/I4/525.

Gowdy, John, and Sabine O'Hara. 1997. "Weak Sustainability and Viable Technologies." *Ecological Economics* 22 (3): 239–247. doi:10.1016/s0921-8009(97)00093-1.

Hasan, Shaikh Shamim, Lin Zhen, Md Giashuddin Miah, Tofayel Ahamed, and Abdus Samie. 2020. "Impact of Land Use Change on Ecosystem Services: A Review." *Environmental Development* 34 (June): 100527. doi:10.1016/j.envdev.2020.100527.

Hein, Lars, Roy P. Remme, Sjoerd Schenau, Patrick W. Bogaart, Marjolein E. Lof, and Edwin Horlings. 2020. "Ecosystem Accounting in The Netherlands." *Ecosystem Services* 44 (August): 101118. doi:10.1016/j.ecoser.2020.101118.

Hillebrand, Helmut, Bernd Blasius, Elizabeth T. Borer, Jonathan M. Chase, John A. Downing, Britas Klemens Eriksson, Christopher T. Filstrup, et al. 2018. "Biodiversity Change is Uncoupled from Species Richness Trends: Consequences for Conservation and Monitoring." *Journal of Applied Ecology* 55 (1): 169–184. doi:10.1111/1365-2664.12959.

Kløve, Bjørn, Pertti Ala-Aho, Guillaume Bertrand, Jason J. Gurdak, Hans Kupfersberger, Jens Kværner, Timo Muotka, et al. 2014. "Climate Change Impacts on Groundwater and Dependent Ecosystems." *Journal of Hydrology* 518 (October): 250–266. doi:10.1016/j.jhydrol.2013.06.037.

La Notte, Alessandra, Dalia D'Amato, Hanna Mäkinen, Maria Luisa Paracchini, Camino Liquete, Benis Egoh, Davide Geneletti, and Neville D. Crossman. 2017. "Ecosystem Services Classification: A Systems Ecology Perspective of the Cascade Framework." *Ecological Indicators* 74 (March): 392–402. doi:10.1016/j.ecolind.2016.11.030.

Langemeyer, Johannes, Cristina Madrid-López, Angelica Mendoza Beltrán, and Gara Villalba Méndez. 2021. "Urban Agriculture: A Necessary Pathway towards Urban Resilience and Global Sustainability?" *Landscape and Urban Planning* 210 (June): 104055. doi:10.1016/j.landurbplan.2021.104055.

Li, Chao, Francis W. Zwiers, Xuebin Zhang, Guilong Li, Ying Sun, and Michael Wehner. 2021. "Changes in Annual Extremes of Daily Temperature and Precipitation in CMIP6 Models." *Journal of Climate* 34 (9): 3441–3460. doi:10.1175/JCLI-D-19-1013.1.

Li, Jinggang, Chunyang He, Peijun Shi, Jin Chen, and Wei Xu. 2004. "Change Process of Cultivated Land and Its Driving Forces in Northern China during 1983-2001." *Acta Geographica Sinica* 59 (2): 274–282. doi:10.11821/xb200402014. http://www.geog.com.cn/EN/Y2004/V59/I2/274.

Li, Weiwei, Pingtao Yi, Danning Zhang, and Ying Zhou. 2020. "Assessment of Coordinated Development between Social Economy and Ecological Environment: Case Study of Resource-Based Cities in Northeastern China." *Sustainable Cities and Society* 59 (August): 102208. doi:10.1016/j.scs.2020.102208.

Lin, Boqiang, and Chongchong Xu. 2022. "Does Environmental Decentralization Aggravate Pollution Emissions? Microscopic Evidence from Chinese Industrial Enterprises." *The Science of the Total Environment* 829 (July): 154640. doi:10.1016/j.scitotenv.2022.154640.

Lin, Nan., Yuxuan Wang, Ying Zhang, and Kai Yang. 2019. “A Large Decline of Tropospheric NO_2 in China Observed from Space by SNPP OMPS.” *The Science of the Total Environment* 675 (July): 337–342. doi:10.1016/j.scitotenv.2019.04.090.

Liu, Jiyuan, Zengxiang Zhang, Xinliang Xu, Wenhui Kuang, Wancun Zhou, Shuwen Zhang, Rendong Li, et al. 2010. “Spatial Patterns and Driving Forces of Land Use Change in China during the Early 21st Century.” *Journal of Geographical Sciences* 20 (4): 483–494. doi:10.1007/s11442-010-0483-4.

Mao, Dehua, Zongming Wang, Jianguo Wu, Bingfang Wu, Yuan Zeng, Kaishan Song, Kunpeng Yi, and Ling Luo. 2018. “China’s Wetlands Loss to Urban Expansion.” *Land Degradation & Development* 29 (8): 2644–2657. doi:10.1002/ldr.2939.

Matasov, Victor, Luca Belelli Marchesini, Alexey Yaroslavtsev, Giovanna Sala, Olga Fareeva, Ivan Seregin, Simona Castaldi, Viacheslav Vasenev, and Riccardo Valentini. 2020. “IoT Monitoring of Urban Tree Ecosystem Services: Possibilities and Challenges.” *Forests* 11 (7): 775. doi:10.3390/f11070775.

McMahon, Joseph M., Syezlin Hasan, Andrew Brooks, Graeme Curwen, Josh Dyke, Chantal Saint Ange, and James C. R. Smart. 2022. “Challenges in Modelling the Sediment Retention Ecosystem Service to Inform an Ecosystem Account – Examples from the Mitchell Catchment in Northern Australia.” *Journal of Environmental Management* 314 (July): 115102. doi:10.1016/j.jenvman.2022.115102.

Mokany, Karel, Chris Ware, Thomas D. Harwood, Rebecca Schmidt, and Simon Ferrier. 2022. “Habitat-Based Biodiversity Assessment for Ecosystem Accounting in the Murray–Darling Basin.” *Conservation Biology* 36 (5): e13915. doi:10.1111/cobi.13915.

China, N. B. S. 2021. *Ecosystem Accounts for China: Results of the NCAVES Project*. https://seea.un.org/node/2808.

Nobel, Anne, Sebastien Lizin, Roy Brouwer, Stephan B. Bruns, David I. Stern, and Robert Malina. 2020. “Are Biodiversity Losses Valued Differently When They Are Caused by Human Activities? A Meta-Analysis of the Non-Use Valuation Literature.” *Environmental Research Letters* 15 (7): 073003. doi:10.1088/1748-9326/ab8ec2.

Normyle, Anna, Bruce Doran, Michael Vardon, Dean Mathews, Julie Melbourne, and Glenn Althor. 2022. “An Indigenous Perspective on Ecosystem Accounting: Challenges and Opportunities Revealed by an Australian Case Study.” *Ambio* 51 (11): 2227–2239. doi:10.1007/s13280-022-01746-8.

Ouyang, Zhiyun, Changsu Song, Hua Zheng, Stephen Polasky, Yi Xiao, Ian J. Bateman, Jianguo Liu, et al. 2020. “Using Gross Ecosystem Product (GEP) to Value Nature in Decision Making.” *Proceedings of the National Academy of Sciences of the United States of America* 117 (25): 14593–14601. doi:10.1073/pnas.1911439117.

Pirmana, Viktor, Armida Salsiah Alisjahbana, Rutger Hoekstra, and Arnold Tukker. 2019. “Implementation Barriers for a System of Environmental-Economic Accounting in Developing Countries and Its Implications for Monitoring Sustainable Development Goals.” *Sustainability* 11 (22): 6417. doi:10.3390/su11226417.

Robledo-Arnuncio, Juan J. 2011. “Wind Pollination over Mesoscale Distances: An Investigation with Scots Pine.” *The New Phytologist* 190 (1): 222–233. doi:10.1111/j.1469-8137.2010.03588.x.

Song, Qingfeng, Bing Wang, Jinsong Wang, and Xiang Niu. 2016. “Endangered and Endemic Species Increase Forest Conservation Values of Species Diversity Based on the Shannon-Wiener Index.” *iForest - Biogeosciences and Forestry* 9 (3): 469–474. doi:10.3832/ifor1373-008.

Sun, Wei, and Chumeng Ren. 2021. “The Impact of Energy Consumption Structure on China’s Carbon Emissions: Taking the Shannon–Wiener Index as a New Indicator.” *Energy Reports* 7 (vember): 2605–2614. doi:10.1016/j.egyr.2021.04.061.

Tang, Zhonglin, Geng Sun, Nannan Zhang, Jing He, and Ning Wu. 2018. “Impacts of Land-Use and Climate Change on Ecosystem Service in Eastern Tibetan Plateau, China.” *Sustainability* 10 (2): 467. doi:10.3390/su10020467.

Tapsuwan, Sorada, Raymundo Marcos-Martínez, Heinz Schandl, and Zefan Yu. 2021. “Valuing Ecosystem Services of Urban Forests and Open Spaces: Application of the SEEA Framework in Australia.” *Australian Journal of Agricultural and Resource Economics* 65 (1): 37–65. doi:10.1111/1467-8489.12416.

UNCEEA (United Nations Committee of Experts on Environmental-Economic Accounting). 2018. “Global Assessment of Environmental-Economic Accounting and Supporting Statistics 2017.”

Document presented at the Forty-ninth session of the United Nations Statistical Commission, New York, March 6. 9. https://unstats.un.org/unsd/statcom/49th-session/documents/BG-Item3h-2017-Global-Assessment-of-Environmental-Economic-Accounting-E.pdf

UN (United Nations). 2021. *System of Environmental-Economic Accounting-Ecosystem Accounting (SEEA EA)*. White cover publication, pre-edited text subject to official editing. https://unstats.un.org/unsd/statcom/52nd-session/documents/BG-3f-SEEA-EA_Final_draft-E.pdf.

UNSD (United Nations Statistics Division). 2007. "Global Assessment of Environment Statistics and Environmental-Economic Accounting." Document presented at the Thirty-eighth session of the United Nations Statistical Commission, New York, February 27–March 2. https://unstats.un.org/unsd/statcom/doc07/Analysis_SC.pdf.

UNSD (United Nations Statistics Division). 2015a. "Global Assessment of Environmental-Economic Accounting and Supporting Statistics 2014." Document presented at the Forty-sixth session of the United Nations Statistical Commission, New York, March 3–6. https://unstats.un.org/unsd/envaccounting/ceea/meetings/eleventh_meeting/BK-11-4a-1_report.pdf.

UNSD (United Nations Statistics Division). 2015b. "SEEA and Transforming Global and National Statistical Systems for Monitoring SDG Indicators." Paper presented at the Tenth Meeting of the UN Committee of Experts on Environmental Economic Accounting, New York, June 24–26. https://unstats.un.org/unsd/envaccounting/ceea/meetings/tenth_meeting/Paper3a.pdf.

UNSD (United Nations Statistics Division). 2015c. "The SEEA as the Statistical Framework in Meeting Data Quality Criteria for SDG Indicators." Paper presented at Tenth Meeting of the UN Committee of Experts on Environmental-Economic Accounting, New York, June 24–25. https://unstats.un.org/unsd/envaccounting/ceea/meetings/tenth_meeting/Paper3b.pdf.

UNSD (United Nations Statistics Division). 2021. *Using the SEEA EA for Calculating Selected SDG Indicators – Project Country Testing Experiences*. United Nations Statistics Division, Department of Economic and Social Affairs, New York. http://creativecommons.org/licenses/by/3.0/igo/.

Valainis, Uldis, Maksims Balalaikins, Juris Soms, Dalia Bastytė-Cseh, Alvydas Gintaras, Adelė Banelienė, Danas Augutis, Marija Žukovskienė, Māris Nitcis, and Maksims Zolovs. 2021. "Ecological Network for Species Dependent on Ancient Broadleaf Trees Using *Osmoderma Barnabita* as a Model Species: A New Approach." *Insect Conservation and Diversity* 15 (2): 273–287. doi:10.1111/icad.12554.

Vysna, Veronika, Joachim Maes, Jan-Erik Petersen, Alessandra La Notte, Vallecillo, Nerea Aizpurua, Eva Ivits, and Anne Teller. 2021. *Accounting for Ecosystems and Their Services in the European Union (INCA): Final Report from Phase II of the INCA Project Aiming to Develop a Pilot for an Integrated System of Ecosystem Accounts for the EU*. 2021 edition. Publications office of the European Union, Luxembourg. doi:10.2785/197909. https://ec.europa.eu/eurostat/documents/7870049/12943935/KS-FT-20-002-EN-N.pdf/de44610d-79e5-010a-5675-14fc4d8527d9?t=1624528835061

Weiskopf, Sarah R., Madeleine A. Rubenstein, Lisa G. Crozier, Sarah Gaichas, Roger Griffis, Jessica E. Halofsky, Kimberly J. W. Hyde, et al. 2020. "Climate Change Effects on Biodiversity, Ecosystems, Ecosystem Services, and Natural Resource Management in the United States." *The Science of the Total Environment* 733 (September): 137782. doi:10.1016/j.scitotenv.2020.137782.

Wintle, Brendan A., Heini Kujala, Amy Whitehead, Alison Cameron, Sam Veloz, Aija Kukkala, Atte Moilanen, et al. 2019. "Global Synthesis of Conservation Studies Reveals the Importance of Small Habitat Patches for Biodiversity." *Proceedings of the National Academy of Sciences of the United States of America* 116 (3): 909–914. doi:10.1073/pnas.1813051115.

Wu, Kai-ya, and Hao Zhang. 2012. "Land Use Dynamics, Built-up Land Expansion Patterns, and Driving Forces Analysis of the Fast-Growing Hangzhou Metropolitan Area, Eastern China (1978–2008)." *Applied Geography* 34: 137–145. doi:10.1016/j.apgeog.2011.11.006.

Yang, Yi., Yuwei Jia, Sun Ling, and Congxu Yao. 2021. "Urban Natural Resource Accounting Based on the System of Environmental Economic Accounting in Northwest China: A Case Study of Xi'an." *Ecosystem Services* 47 (February): 101233. doi:10.1016/j.ecoser.2020.101233.

Zhang, Zhiyong, Siwei Liang, Jingkuan Wang, Xiaoke Zhang, Mohammad Mahamood, Jun Yu, Xiaoping Zhang, Aizhen Liang, and Wenju Liang. 2018. "Tillage and Crop Succession

Effects on Soil Microbial Metabolic Activity and Carbon Utilization in a Clay Loam Soil." *European Journal of Soil Biology* 88 (July–August): 97–104. doi:10.1016/j.ejsobi.2018.07.006.

Zilio, Mariana I., M. Belen Alfonso, Federico Ferrelli, Gerardo M. E. Perillo, and M. Cintia Piccolo. 2017. "Ecosystem Services Provision, Tourism and Climate Variability in Shallow Lakes: The Case of La Salada, Buenos Aires, Argentina." *Tourism Management* 62 (October): 208–217. doi:10.1016/j.tourman.2017.04.008.