sustainability

MDPI

Review

Progress in Ecosystem Health Research and Future Prospects

Jingwei Wang [1,2], Jinhe Zhang [1,2,*], Peijia Wang [1,2], Xiaobin Ma [1,2], Liangjian Yang [1,2] and Leying Zhou [1,2]

[1] School of Geography and Ocean Science, Nanjing University, Nanjing 210023, China
[2] Huangshan Park Ecosystem Observation and Research Station, Ministry of Education, Huangshan 245899, China
* Correspondence: zhangjinhe@nju.edu.cn

Abstract: Since the Anthropocene, drastic changes in the relationship between humans and the earth have prompted human beings to pay more attention to the living environment. As a metaphor to reveal the state of humanity and nature, ecosystem health has gradually become an important issue closely related to global sustainable development ever since it was widely discussed in the 1990s. This study reviewed 4354 publications about ecosystem health from the Web of Science Core Collection by using CiteSpace software. In addition, 135 empirical papers were selected to further analyze the evaluation methods and characteristics of ecosystem health. This study was able to answer four questions: (1) What are the definitions, research content, and characteristics of ecosystem health? (2) Are there any features during the different periods of the development of the ecosystem health? Are there geographical differences in the research? (3) What are the methods and cases selected for studying ecosystem health, and under what kind of conditions do they apply? Are there any patterns or characteristics in the use of these methods? (4) What are the gaps and deficiencies in ecosystem health research, and where should we set our focus on in the future? In general, this study combined bibliometric analysis with a systematic review method, aiming to summarize the current status of ecosystem health research, make up for the deficiencies in the current review, and put forward new insights regarding the concept cognition, evaluation, and future outlook of ecosystem health research.

Keywords: ecosystem health; ecosystem health assessment; ecological ethics; bibliometrics; systematic review; CiteSpace

check for updates

Citation: Wang, J.; Zhang, J.; Wang, P.; Ma, X.; Yang, L.; Zhou, L. Progress in Ecosystem Health Research and Future Prospects. *Sustainability* **2022**, *14*, 15814. https://doi.org/10.3390/su142315814

Academic Editor: Changwoo Ahn

Received: 25 October 2022
Accepted: 25 November 2022
Published: 28 November 2022

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Copyright: © 2022 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

Since the 18th century, the global human–land relationship has changed dramatically, and the Anthropocene has arrived [1]. With the rapid development of human society driven by the Industrial Revolution, the continuing degradation of global ecosystems has become a pressing problem [2,3]. According to the 2000 Millennium Ecosystem Assessment (MA), about 60% of the world's ecosystems have been degraded [4], and concerns about the deterioration of the global ecological environment, and the integrity and stability of the biosphere, as well as the desire for sustainable ecological development have grown. The ecosystem is not only the environmental basis for human survival but also the place where human activities occur. It can also provide a variety of ecosystem services for human beings, which are divided into four categories (provisioning, regulating, supporting, and cultural services) according to the Millennium Ecosystem Assessment Classification Framework [4], providing humans with fresh water, food, medicinal source products, and industrial and agricultural production material, as well as aesthetic, educational, and other cultural values [5]. When disturbances reduce or exceed the regulatory capacity of the system itself, the ecosystem also limits the sustainable growth of human well-being by providing lower-quality ecosystem services [6]. Therefore, the status of ecosystem health is closely related to sustainable human development [2], and the assessment and management of it are particularly important.

The study of ecosystem health originated in North America in the 1980s [7], and scholars all over the world have since initiated substantial research on the concept of ecosystem health and related concerns after more than 10 years [8]. As a metaphor to reveal the state of the human–land relationship, ecosystem health has emphasized the integration of ecological, economic, and human processes [9] and measures of sustainability and system resilience [10]. In 1994, along with the first International Symposium on Ecosystem Health and Medicine held in Ottawa, Canada, the International Society for Ecosystem Health (ISEH) was established, aiming to provide a conceptual and methodological basis for evaluating the state of the earth's ecosystem and to encourage people to understand the important links among human activities, ecological changes, and human health [11], which marked a new stage of development in the understanding of and attention given to ecosystem health [12]. Although the ISEH disintegrated in 2002, scholars have been paying close attention to ecosystem health for more than 30 years, and the academic perspectives, theories, and methods of evaluation have experienced different stages of development.

Currently, because of the importance of ecological sustainability for human society, an increasing number of related studies have shown that ecosystem health is receiving continual attention. In prior ecosystem health research review studies, some reviews have been based on descriptive analyses using bibliometric software. For example, Yang et al. systematically analyzed the development process, literature sources, and related authors of ecosystem health by using CiteSpace software [13]. Some other reviews have been carried out from one single aspect of ecosystem health research; for example, Rocha et al. took the freshwater ecosystem in Argentina as their research object and summarized the ecological indicators that were used to measure ecosystem health [14]. O' Brien et al. reviewed the research on the measurement of ecosystem health and focused on ecosystem health assessments and the selection of the indicators in fresh water and estuaries [10]. Soubry et al. reviewed the field and remote measurement methods used for forest and grassland ecosystem health based on remote sensing and GIS, and a more comprehensive way to measure the health of forest and grassland ecosystem was proposed [15]. Fu et al. summarized the methods of ecosystem measurement [16]. These reviews summarized the research into ecosystem health from a certain point of view, but their overall contribution to ecosystem health research was insufficient. We need to provide a reference for ecosystem health research through a comprehensive and multi-angle analysis. Bibliometric analysis can provide a pathway for the analysis of a large number of documents and identify the hotspots and evolutionary characteristics of previous studies [17,18]. However, there are limitations in terms of insufficient accuracy and the inability to analyze the content of the literature more specifically, but empirical analysis can make up for the lack of bibliometric analysis in specific content analysis. For example, Yang et al. reviewed the progress of research into ecosystem cultural services using a combination of two methods [19]. Therefore, this study combined bibliometric analysis with a systematic review method from the two aspects of overall and small-sample empirical analysis, aiming to explore the following points: (1) discovering the current research status, research hotspots, and characteristics of the development stages of ecosystem health research; (2) analyzing the research methods and objects of ecosystem health to summarize their characteristics of it; and (3) discussing the deficiencies of ecosystem health research and thinking about future research prospects. Through macro-bibliometric analysis and specific empirical literature analysis, this paper systematically reviewed and summarized the origin, development process, research content, and measurement methods of ecosystem health, hoping to summarize the commonalities and rules of existing research, and then find out the gaps and shortcomings of the research, so as to provide reference for the future research and development of ecosystem health.

2. A Brief Introduction to Ecosystem Health

2.1. The Development History of the Ecosystem Health Concept

The concept of "health" was originally derived from medicine and was first used to describe the human body in a good physical, psychological, and social state and then applied to animals and plants. In 1941, the American ecologist Aldo Leopold proposed the concept of "land disease" when studying land issues [20]. In the 1970s and 1980s, Odum [21], Holling [22], Karr [23], and other scholars explained what a healthy ecosystem is, emphasizing the integrity and organicity of a healthy ecosystem, the stability of a healthy ecosystem in response to external disturbances, and the need for less external management. Schaeffer et al. related ecosystem health to human and nonhuman animal health and explored the difficulties in defining ecosystem health [7]. In 1989, Rapport first proposed the concept of ecosystem health. Ecosystem health refers to the situation when the ecosystem is stable and sustainable, that is, it has the ability to maintain its organizational structure, self-regulation, and recovery under stress, which can be evaluated in terms of three aspects: vigor, organization, and resilience [24]. In 1992, Costanza summarized the existing concepts of ecosystem health and expressed ecosystem health in terms of six characteristics: (1) homeostasis, (2) no disease, (3) diversity or complexity, (4) stability or recoverability, (5) vitality or growth space, and (6) balance among the constituents [9]. Mageau et al. extended the concept of ecosystem health to human activity, arguing that "a healthy ecosystem is capable of supporting human communities with ecosystem services such as food, fibre, capacity to absorb and recycle waste, drinking water and clean air" [25].

How to define "health" is the core issue of exploring the conceptual framework of ecosystem health. It is worth mentioning that although it has been fully discussed, the concept of ecosystem health has not yet been finalized. However, in recent years, scholars have discussed the rationality of this concept less. To some extent, it can be considered that a tacit understanding of the concept of ecosystem health has been formed, and more efforts have been made to seek a more comprehensive and reasonable way to explain and measure ecosystem health. Costanza proposed in 2011 that both organisms and ecosystems are complex, and there are many similarities between biological systems and ecosystems. The concept of "health" can be extended to more complex systems, which is also conducive to the assessment of human health [26]. In general, the concept of ecosystem health can be transferred from the medical field to the ecological field, which focuses on the health of various species in the ecosystem, the stability and resilience of the ecosystem as a whole, the service function of the ecosystem, and the interaction with the human community. Exploring ecosystem health fully emphasizes the core meaning of identifying and protecting the state of the ecological environment.

2.2. Ecosystem Health from Different Ecological Perspectives

There are differences in the paradigm and background behind the understanding of ecosystem health between the East and the West if we trace it back to the original view of nature and ecological ethics. In the epistemology of nature, Western philosophical thinking emphasizes the separation between things and the self. From the ancient Greek philosophers, who stressed the difference between humans and nature, to Kant's "artificial natural legislation," Western philosophy has long viewed humans as the subject and nature as the object, leading to a long period of dualism, which advocated that the natural world is "for my use." In the traditional Oriental culture represented by China, Chinese Confucianism advocates that humanity is an integral part of nature, which means man has been consciously regarded as a member of nature and, like all other things in the world, a product of nature; Zhouyi believes that "same virtue of Heaven, Earth and Man," and advocates that humanity and nature are mutually inclusive; Chinese Taoism believes that nature and man are in a complete system, not in division, such as "Unity of Man and Nature, things and man are one"; Chinese Buddhism advocates that "all creatures are equal," and both Han Buddhism and Tibetan Buddhism hold that all things in the world are generally connected so that they all affect each other. Reflected in the ecological protection,

it is advocated in the love of nature in the pursuit of freedom [27,28]. From the perspective of ecological ethics, there are also differences in the understanding of ecosystem health within the frameworks of anthropocentrism, biocentrism, and ecocentrism. Table 1 shows the understanding of ecosystem health under different ecological ethics.

Table 1. Ecosystem health under different ecological ethics.

Ecological Ethics	Focal Point	Main Content	Epistemology	The Key to Assessing Ecosystem Health
Anthropocentrism	Humans	(1) Humans have priority in natural ecosystems. (2) The whole, sustainable, and healthy development of human beings is the center, and human interests and values are the starting point for understanding and transforming nature.	Dualism	The healthy development of human groups and human societies
Biocentrism	Living organisms	(1) People are opposed to being born superior to other species and believe that people are equal to all creatures in the ecosystem. (2) All living things in nature depend on each other.	Monism	The health of all living species in the ecosystem
Ecocentrism	Overall ecosystem	(1) The harmony between humans and nature is emphasized, claiming a community with a shared future. (2) Humans' evaluation of the value of nature should not be based on humans' own interests but should be fully based on objective facts.	Monism	The health and development of the ecosystem overall

3. Materials and Methods

3.1. Data Selection

This review included two parts. The first part involved summarizing the research on ecosystem health, and the second part was a specific analysis of the empirical research literature related to ecosystem health.

In the first part, for the bibliometric analysis, studies published between 1 January 1980 and 30 June 2022 with the search terms "ecosystem health" in the titles, keywords, and abstracts were obtained from the Web of Science Core Collection, with the literature type selected as "article" or "review." In total, 4354 publications were retrieved.

In the second part, for the empirical analysis to further understand the research related to ecosystem health, the 4354 retrieved articles were refined and the search conditions were set as follows: Web of Science Core Collection, 1 January 2000 to 30 June 2022; literature type, article; language, English; TI = "Ecosystem health" AND "assess *" OR "evaluate *" in the title. An asterisk (*) was inserted at the end of the words "assess" or "evaluate" to include terms such as "assessment" and "evaluation." In total, 166 articles were retrieved, and the literature was further refined to screen out nonempirical papers. Finally, 135 articles were selected as the research object. The research methods and characteristics of ecosystem health were quantitatively counted, reviewed, and analyzed by reading the studies one by one.

3.2. Methods of Analysis

3.2.1. CiteSpace

CiteSpace is a bibliometric analysis software package based on Java developed by Dr. Chaomei Chen [29], which can be used to generate visualizations of a knowledge domain. It addresses several issues compared to earlier visualization tools [30,31]. CiteSpace has four core concepts: burst detection, betweenness, centrality, and heterogeneous networks. Based on these concepts, co-occurrence analysis, co-citation analysis, and citation burst analysis are important tools of CiteSpace, which are widely used in quantitative literature reviews [29,32]. Keywords are groups of words that reflect the core content of a text. An analysis of keywords' co-occurrence can reflect the focus, regulation, and characteristics of a specific research field and sort out the context of a discipline's development. Citation burst analyses of keywords can reflect changes in interest in a professional field, thereby revealing research hotspots in different periods [33], which is helpful for better understanding the research content. Therefore, this study analyzed the research hotspots and frontiers of

ecosystem health through the keyword co-occurrence and keyword citation burst tools of CiteSpace software.

3.2.2. Statistics of the Empirical Papers

Research objects are an important component of empirical research, and researchers choose different research areas and objects on the basis of their research backgrounds and methods [34]. Identifying the research objects is conductive to ensuring the reliability and readability of the results of the empirical analysis. The selected articles were statistically analyzed from five aspects: the evaluation methods, the location of the selected case sites, the ecosystem types, the scale of the case sites, and the publication time. Among these, the ecosystem types of the cases were divided into aquatic ecosystems and terrestrial ecosystems according to the geographic classification method. Aquatic ecosystems include marine ecosystems (coasts, gulfs, mangrove forests, etc.) and freshwater ecosystems (rivers, lakes, wetlands, reservoirs, etc.), whereas terrestrial ecosystems include ecosystems with lower human disturbance, such as forest ecosystems, grassland ecosystems, and desert ecosystems, and ecosystems with higher human disturbance, such as city ecosystems and rural ecosystems. The scale of the case sites were classified into global, national, regional, urban or rural, and smaller landscape scales according to the scale of the administrative division.

4. Results

4.1. Overview of General Articles

4.1.1. Annual Variations in Publications

The annual number of publications during 1988–2021 is shown in Figure 1. Changes in the number of published articles can reflect researchers' concerns about ecosystem health. The research literature on ecosystem health has increased rapidly since 1988, especially in the most recent 10 years. In 1988, the American scholar Schaeffer published the first relevant research study [7], and the number of publications grew slowly for the next 10 years. After the establishment of the International Society for Ecosystem Health in 1994, the number of documents showed a rapid growth trend. After the disintegration of the ISEH in 2002, the International Conference on Health Ecosystem Management was held in 2003, and the number of articles presented a small peak in 2003. After 2005, the number of publications gradually increased. In 2013, there was a short peak in the number of publications again. The number of publications between 2005 and 2021 accounted for 87.1% of the total number of publications in the past 40 years.

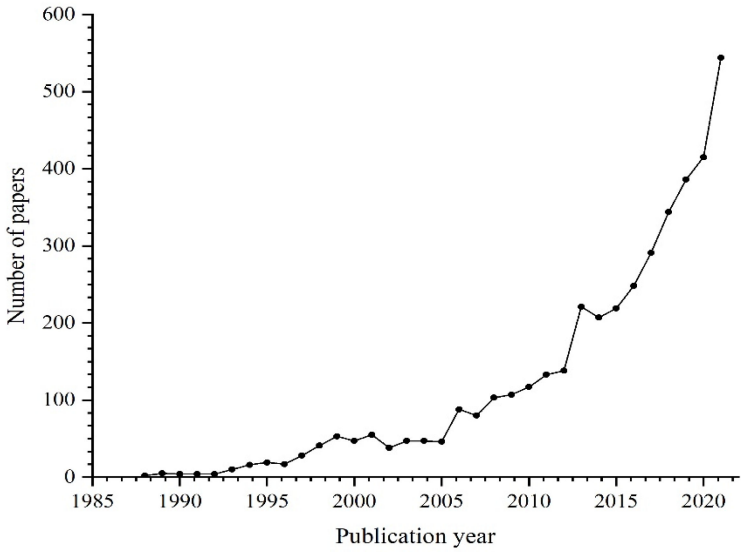


Figure 1. Number of ecosystem health publications from 1988 to 2021.

4.1.2. Geographic Differences in the Publications

There was an obvious geographical difference in the publications on ecosystem health. The number of publications from the top 30 countries is shown in Figure 2. The United States ranked first, accounting for 22.65% of the whole. China ranked second, with the number of Chinese publications accounting for 12.56% of the total, and Australia was third with 7.65%, followed by Canada and the United Kingdom, accounting for 6.96% and 6.87%, respectively. In addition, Germany, France, Spain, Italy, and India rounded out the top 10. Moreover, the number of articles published shows a clear break. The total number of articles published by the top 10 countries accounted for 69.70% of the total number of articles published by 150 statistical countries and were mostly concentrated in North America, Asia, Oceania, and Europe, and fewer studies originated from South America and Africa.

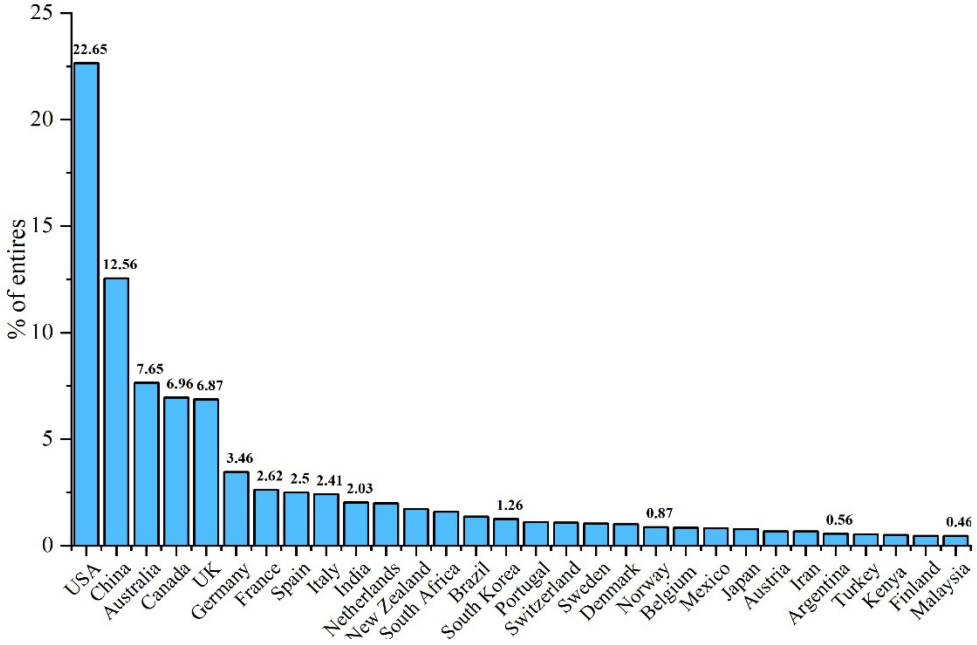


Figure 2. Geographic distribution of the publications on ecosystem health (percentage of the 150 countries).

Research into ecosystem health originated in the United States and Canada. The American scholar Schaeffer and the Canadian scholars Rapport and Costanza et al. are the pioneers and founders of ecosystem health research. From 1990 to 2000, US and Canadian scholars published papers to explain the concept of ecosystem health. In 1994, they took the lead, taking the five major lake areas of Canada as the research object to carry out empirical analysis into diagnosing ecosystem health [35]. In around 1995, Australian and British scholars began to pay attention to ecosystem health; around 2000, the concept of ecosystem health was gradually introduced to China and other European countries.

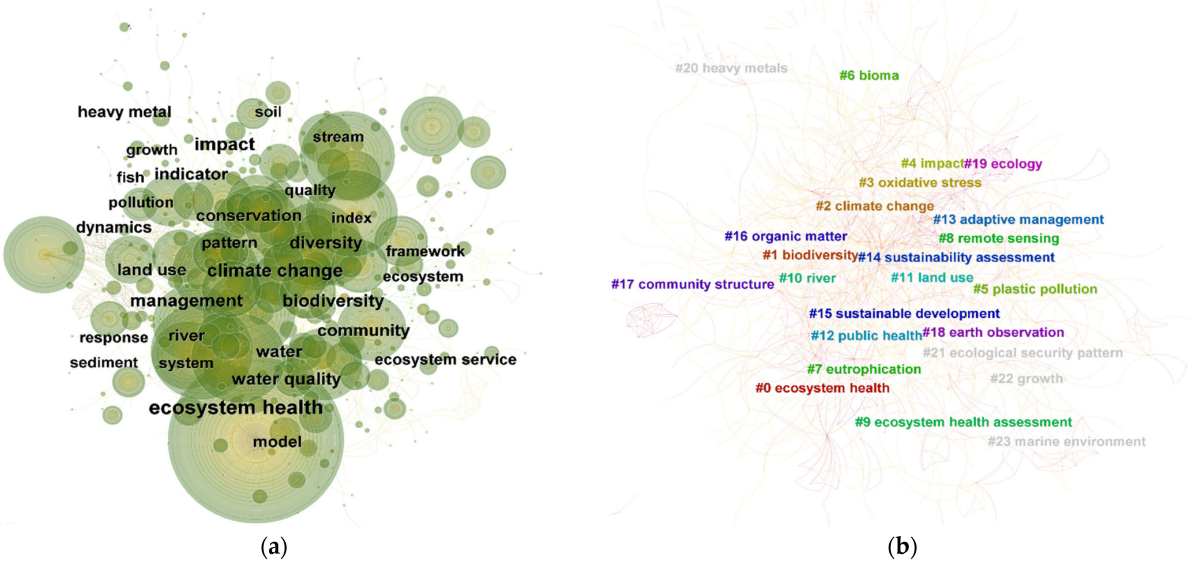
4.1.3. Keywords and Cluster Analysis

To further understand the topics of the research literature, Figure 3 shows the co-occurrence map and clustering map of the keywords of 4354 articles on ecosystem health. The size of the nodes reflects the strength of the keywords in the relevant literature. The larger the node, the greater the strength of the keywords. Further clustering of the keywords and naming the clusters according to keywords enable a general understanding of ecosystem-health-related research. We found that these studies were carried out with a focus on 23 clusters, which can be summarized into four themes (Table 2). The first involves the evaluation and modeling of ecosystem health (clusters 8, 9, and 14). Empirical measurements of ecosystem health have long been the focus of research. Among these areas, land use is the intuitive basis of human–land relationships and is a key element for analyzing

ecosystem health, and research has also been carried out on land use. Additionally, remote sensing is the key technology used for measuring ecosystem health (clusters 10 and 11). Among the different types of ecosystems, research has especially focused on the assessment and protection of the ecological environment of oceans, rivers, and other aquatic ecosystems (clusters 6, 16, 17, and 23) [36,37]. The second theme is environmental pollution and protection (clusters 5, 7, 13, 18, 20, and 21), which includes a variety of assessments of environmental pollution, such as soil and water pollution. Environmental pollution is an important ecological problem that threatens ecosystem health. This branch of the research has focused on heavy metal pollution of the soil and water [38,39], plastic pollution [40], water eutrophication [41], etc. The third theme is that of human health (cluster 12). An ecosystem's health is closely related to public health. Incorporating human health into the assessment of ecosystem health research is an important part of a deeper understanding of the human–land relationship, focusing primarily on urban ecosystem health [42,43]. The fourth theme is sustainable development. On the whole, ecosystem health is closely related to the sustainability of the ecological environment, and this research involves global issues such as biodiversity (cluster 1), climate change (cluster 2), and sustainable development (cluster 15).

Table 2. Themes of ecosystem health research.

Theme	Cluster ID	Keywords	Size	Mean (Year)
Assessment and modeling of ecosystem health	Cluster 9	Ecosystem health assessment	36	2009
	Cluster 14	Sustainability assessment	30	1999
	Cluster 8	Remote sensing	38	2006
	Cluster 11	Land use	33	2007
	Cluster 10	River	35	2005
	Cluster 23	Marine environment	13	2001
	Cluster 6	Biomass	38	2008
	Cluster 17	Community structure	24	2005
	Cluster 16	Organic matter	28	2004
Environmental pollution and protection	Cluster 5	Plastic pollution	40	2007
	Cluster 20	Heavy metals	20	2006
	Cluster 7	Eutrophication	38	2008
	Cluster 18	Earth observation	23	2015
	Cluster 21	Ecological security pattern	19	2014
	Cluster 13	Adaptive management	30	2002
Human health	Cluster 12	Public health	32	2011
Sustainable development	Cluster 15	Sustainable development	29	2010
	Cluster 1	Biodiversity	55	2008
	Cluster 2	Climate change	47	2009



(**a**) (**b**)

Figure 3. Keywords and clusters of ecosystem health research. (**a**) for co-occurrence map and (**b**) for clustering map of the keywords.

4.1.4. Keywords of the Citation Bursts

Table 3 shows the keywords with stronger citation bursts in different periods. This can reflect the emphasis and patterns of change in research topics related to ecosystem health in different stages. The table shows the first occurrence time, end time, and burst intensity of the keywords. The blue lines in the last column of the table represent the entire study period selected (1988–2022), and the red lines represent the duration of the citation burst [44]. To better understand the patterns and focus of the development of ecosystem health research presented by the emergence of keywords, this paper tried to divide the research time into three stages: ecosystem health management based on anthropocentrism (1989–1999), single-ecosystem health diagnoses based on biocentrism (2000–2014), and human–earth interactive exploration based on ecocentrism (2015–2022).

Table 3. Keywords with stronger citation bursts in different periods.

Period	Keyword	Strength	Beginning	End	1988–2022
1988–1999	Stress	10.20	1990	2002	
	Ecosystem management	9.16	1994	2007	
	Adaptive management	6.00	1994	2013	
	Ecosystem health	45.11	1995	2004	
	Integrity	8.75	1997	2010	
	Perspective	5.02	1997	2000	
	Population	8.31	1999	2008	
2000–2014	Ecological indicator	8.69	2000	2012	
	Habitat	7.28	2006	2012	
	River	6.88	2006	2012	
	Fish	5.25	2007	2016	
	Infectious disease	5.16	2007	2009	
	United States	5.28	2010	2011	
	Regime	6.37	2013	2016	
	Oxidative stress	6.14	2014	2016	
2015–2022	Multiple stressor	5.09	2015	2017	
	Disturbance	4.97	2015	2017	
	Emission	4.83	2015	2016	
	Identification	4.86	2016	2018	
	Vulnerability	5.98	2018	2022	
	City	5.29	2019	2022	
	Surface sediment	5.05	2019	2022	
	Mechanism	4.77	2019	2022	
	Service	11.44	2020	2022	
	Urbanization	7.41	2020	2022	

(1) Ecosystem health management based on anthropocentrism (1989–1999)

This was the first decade of the development of the ecosystem health concept, and it was also the decade in which the concept of ecosystem health was debated and gradually accepted. During this period, many scholars fully explored the concept of ecosystem health, and some scholars pointed out the serious limitations of this concept [11]. During this period, in addition to "ecosystem health" (45.11), which was the strongest keyword, the emergence of keywords such as "stress" (10.20) and "population" (8.31) indicates the origin of ecosystem health research. Since the development of the Industrial Revolution brought great convenience to the world, the intense human activities and the rapid increase in the global population have also created great ecological environment pressure. Humans regarded themselves more as "ecological rescuers" after environmental pressures and threats had been faced by "ecological reformers," emphasizing ecological and biological

integrity (8.75), ecosystem management (9.16), and adaptive management (6.00). The fundamental starting point of the research was maintaining the health of the ecological environment for the sustainable development of human society.

(2) Single ecosystem health diagnoses based on biocentrism (2000–2014)

The period from 2000 to 2014 saw 15 years of rapid development of ecosystem health research. During this period, scholars no longer focused on the rationality of the concept and turned their focus to the evaluation of different ecosystems, mainly focusing on a single ecosystem type. The assessment of different types of ecosystem health was widely discussed, such as rivers, forests, wetlands, and other natural ecosystems. The keywords "ecological indicator" (8.69) and "habitat" (7.28) in this stage reflect how scholars paid more attention to ecosystem health from the perspective of bioecology, starting from the internal composition and structure of the ecosystem, seeking suitable indicator species to evaluate the health status of the ecosystem, and paying attention to biological habitats, which are important for species' survival. The keywords "river" (6.88) and "fish" (5.25) show that the aquatic ecosystem represented by rivers was the main target. This shows that the most direct and effective approaches to and the means of diagnosing ecosystem health were sought for after the concept of ecosystem health had been accepted. This stage played a connecting role implicit in the transformation process studies on ecosystem health.

(3) Exploration of human–earth interactions based on ecocentrism (2015–2022)

The second stage of the rapid development of ecosystem health research began in 2015. During this period, with the further transformation of the understanding of the relationship between humans and the ecological environment, the study of human–environment interactions entered a new period. Researchers began to pay attention to multiple stressors (5.09), disturbance (4.97), and emissions (4.83), and the focus of ecosystem health research shifted from focusing on single ecosystem types to composite ecosystems. At the same time, researchers began to pay more attention to ecosystem services. "Service" (11.44), as the most prominent keyword in this stage, implies that people began to pay attention to the function of ecosystems, in addition to focusing on the structure of the ecosystem itself. At the same time, "urbanization" (7.41) and "city" (5.29) were also keywords with a high burst intensity. The relationship between urbanization and ecosystem health is a new focus of researchers. Briefly, we believe that after 2015, human beings began to re-examine the relationship with the ecological environment and regarded human society as closely related to the ecosystem, whether attention was given to urban ecosystems or ecosystem services. These concerns show that research into ecosystem health has begun to consider the health and development of the ecosystem as a whole, and it agrees with the need for harmony between humanity and nature.

4.2. Systemic Review of Empirical Research

4.2.1. Measures of Evaluating Ecosystem Health

Figure 4a shows the statistical results of 135 empirical studies on the methods of measuring ecosystem health. It can be seen that the common methods used for measuring ecosystem health mainly include biological indicator methods and index systems, accounting for 88.3% of the literature, and only 11.7% publications used other methods. A brief description and collation of common ecosystem measurement methods is listed in Table 4.

The biological indicator method is a method closely related to biology. Key species or indicator communities in ecosystems are selected as indicators to evaluate the ecosystem's health. It is mostly used in aquatic ecosystems, such as marine ecosystems or freshwater ecosystems. Common indicator species include plankton [45–47], macroinvertebrates [48–51], and fish [52–54]. Among these, plankton include zooplankton and phytoplankton, and diatoms are common indicator species of phytoplankton [55–57]. Macroinvertebrates are species that live in specific aquatic ecosystems, such as crustaceans or mollusks, including shrimps, oysters, and mussels [58–61]. In addition, for different types of ecosystems, some scholars have chosen ants and seagrass as indicator species [62–64] (Table 4).

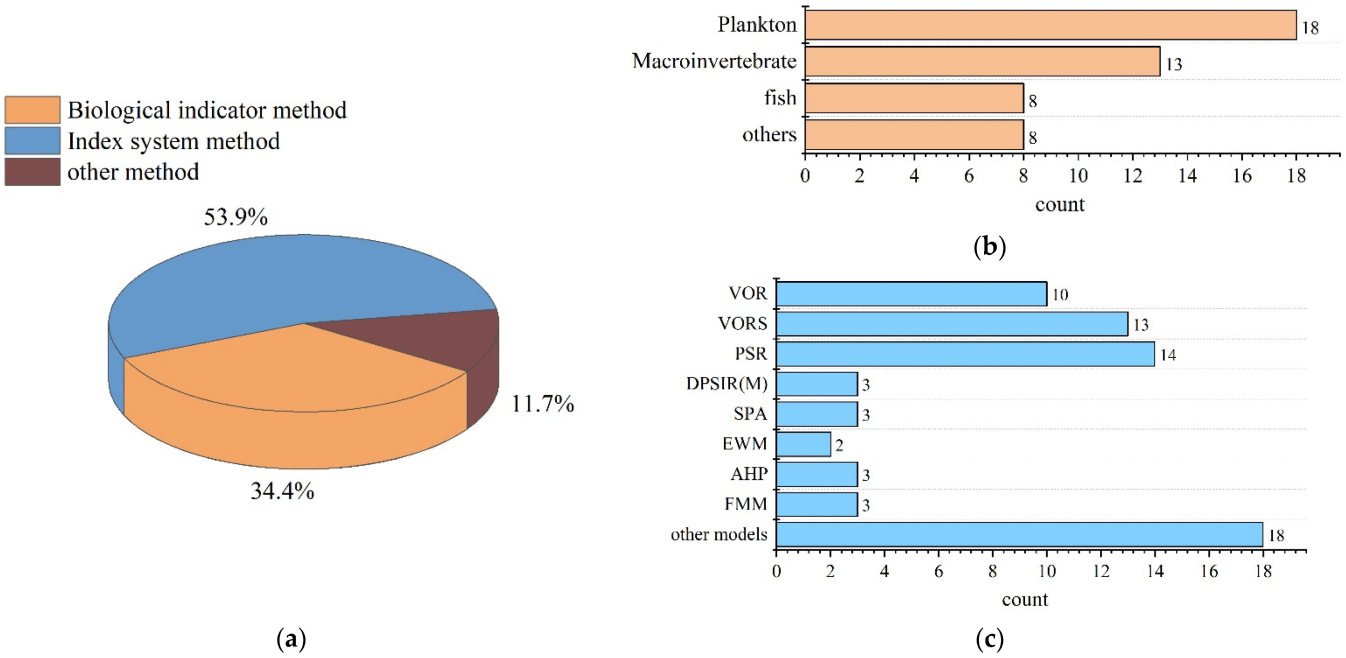


Figure 4. Summary of the methods used to evaluate ecosystem health in empirical publications. The studies were classified as those with biological indicator methods, index systems, and other methods (**a**). The biological indicator methods (**b**) and the index systems (**c**) were stratified further.

The index system method is an approach that constructs different evaluation systems for different types of ecosystems, covering many aspects of the ecological environment and the social environment. An index system can better reflect the characteristics and processes of the composite ecological and social system. Common index systems method include the vigor–organization–resilience (VOR) model [65–68], the pressure–state–response (PSR) model [69–72], the analytic hierarchy process (AHP) [73], the entropy weight method (EWM) [74,75], the fuzzy mathematics method (FMM) [76–78], and set pair analysis (SPA) [79–81] (Figure 4c). Among these, the VOR model and the PSR model have been the most widely used. With the continuous development of research, scholars have expanded their focus to interpreting the meanings of ecosystem health more comprehensively by adding driving forces (D) and impact results (I) to the PSR model (driving–pressure–state–impact–response, DPSIR) [82,83]. At the same time, scholars have paid much attention to ecosystem services and added the element of ecosystem services to the VOR model (vigor–organization–resilience–service, VORS) [84–88]. In evaluations of urban ecosystem health, new indicators, such as population health and ecosystem cognition, have been added to the basic evaluation indicators of VORS [89,90]. There are other evaluation models; for example, the technique for order preference by similarity to the ideal solution (TOPSIS) is to evaluate the land ecosystem's health [91–93], the back propagation neural network (BPNN) is used to evaluate the ecosystem's status [94], and the back propagation neural network model optimized by the genetic algorithm (GA-BPANN) has been improved [95].

Figure 5 shows the annual time series of the changes in the biological indicator methods and index systems used in the empirical literature. This shows that there were few empirical studies before 2008. For the biological indicator method, since 2000, the species indicator method has been used by researchers and the number of articles published annually has fluctuated greatly. However, the use of index systems showed an obvious upward trend after 2015, and such publications have increased year by year. The index system method is more suitable for composite social–ecological systems, indicating that the focus of ecosystem health research has shifted from a single ecosystem to a composite ecosystem.

Table 4. Major measures used to evaluate ecosystem health.

Methods	Contents	Core Elements	Ecosystem Type of Case Location	Author (Year)
Biological indicator method	Plankton (phytoplankton and zooplankton)	(1) Structural indicators: the interconnections between the components of an ecosystem (2) Functional indicators: the overall activity of the ecosystem	Aquatic (marine)	Kim et al. (2019) [45]
	Macroinvertebrates		Aquatic (river)	Kabore et al. (2016) [49]
	Fish		Aquatic (river)	Wu et al. (2014) [96]
	Ants		Terrestrial (mountain)	Bharti et al. (2016) [62]
Index system method	VOR model	(1) Vigor: the primary productivity or metabolism of an ecosystem (2) Organization: diversity and connectivity of ecosystems (3) Resilience: the ability of an ecosystem to withstand or recover from damage	Terrestrial (grassland)	Li et al. (2013) [97]
			Terrestrial (urban)	Atak et al. (2020) [98]
			Terrestrial (urban)	De Toro et al. (2018) [67]
			Aquatic (river)	Suo et al. (2008) [65]
	VORS model	The ecosystem service index (S) added to the VOR model	Terrestrial (grassland)	Wang et al. (2020) [99]
			Terrestrial (urban)	Mallick et al. (2021) [100]
			Aquatic (lake)	Tehrani et al. (2022) [86]
	PSR model	(1) Pressure: external factors that threaten the ecosystem (2) State: the current state of the ecosystem (3) Response: what ecosystems can do in response to pressure	Aquatic (wetland)	Sun et al. (2016) [101]
			Aquatic (wetland)	Subhasis et al. (2020) [102]
			Terrestrial (urban)	Wang et al. (2018) [72]
	DPSIR model	The driving force index (D) and the impact index (I) added to the PSR model	Terrestrial (urban)	Wang et al. (2013) [82]
	Analytic hierarchy process (AHP)	These index systems include economic, resource, and environmental dimensions and comprehensively represent the level of development and degree of coordination of regional ecosystem health.	Aquatic (watershed)	Ekumah et al. (2020) [73]
	Entropy weight method (EWM)		Terrestrial (urban)	Li et al. (2014) [74]
	Fuzzy mathematics method (FMM)		Terrestrial (forest)	Tao et al. (2019) [76]
	Set pair analysis (SPA)		Terrestrial (urban)	Su et al. (2009) [80]

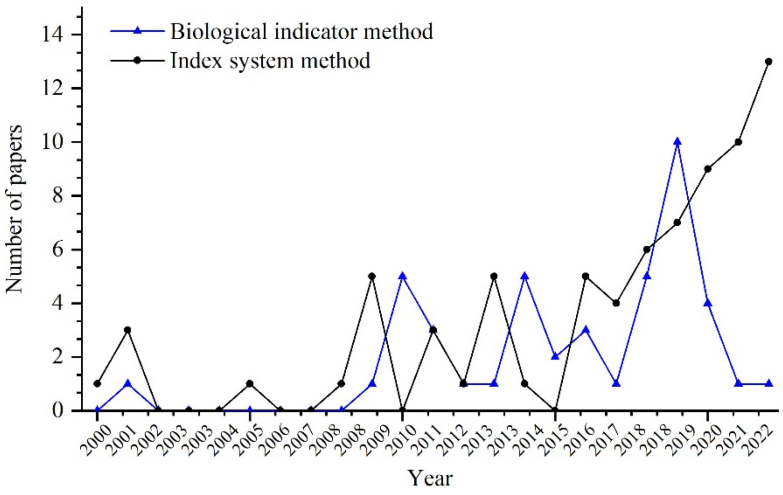


Figure 5. Temporal variation of biological indicator methods and index systems (2000–2022).

For both the biological indicator method and the index system method, the two most important parts in the application of the method are the determination of the indicators and the construction of the evaluation system. The construction of the evaluation system has been summarized before. As for the determination of indicators, it is found that there is no absolutely unified standard for the evaluation of ecosystem health. It is determined based on the understanding and interpretation of the concept connotation of ecosystem health, combined with previous research results and specific ecosystem types selected by the researchers, which is highly subjective. The European Environment Agency has divided indicators into four groups (descriptive indicators, performance indicators, efficiency

indicators, and total welfare indicators [97]), and researchers usually abided by the principle of integrity, simplicity, and dynamic response [70]. Based on the vigor–organization–resilience conceptual model to interpret the connotation of ecosystem health by Rapport [24], these three terms are not as indicators but as macro-dimensions within which to understand the drivers to which the appropriate reference indicators correspond, including social, economic, ecological, environmental, and institutional aspects [67]. For example, as for the VOR model, researchers often took the normalized difference vegetation index (NDVI) to represent the vitality of the ecosystem, but the net primary productivity (NPP), fraction of photosynthetic active radiation, or leaf area index were also selected to represent ecosystem vigor [66,86,103]. For the PSR model, indicators were selected as comprehensively as possible that can fully represent the state of the ecosystem and strived to be sufficient and complete, covering social, economic, and cultural aspects. For instance, researchers added the fishing amount, wastewater discharge, tidal flat disturbance index, and other indicators to the research on the coastal ecosystem [104] and added the GDP, road density, population destiny, etc., to the research on the urban ecosystem [105]. The numbers of indicators are varied at the same time, and some can even reach 33 [91].

4.2.2. Levels of Ecosystem Health

Ecosystem health assessment and monitoring assess the state of ecosystem health through scientific methods. With the intensification of human activities and the great changes in the humanity–nature relationship, how to define the level of ecosystem health is important. For the index system method, there are a series of indicators and the dimensions are different, so maximum–minimum normalization arithmetic is always used to convert the original data into the standard dataset within the range of 0–1 to unify the indicators [101]. In addition, some studies have not determined the threshold for assessing health status but have only explored variation trends in ecosystem health at specific time scales [66,67,98,103]; others have classified the state of ecosystem health into different levels, such as three-level series (e.g., unhealthy, sub-healthy, healthy) [70,97,106], four-level series (e.g., poor, moderate, good, best) [71], and five-level series (e.g., very weak, weak, average, good, very good) [100,107–109]. Equal interval techniques (equal spacing method) and the natural fracture method are mostly used as division methods. For the biological indicator method, it was mostly used in the aquatic ecosystem. Some studies took the direct measurement method, through direct observation of indicators of species, such as species size, cell size [58,110], muscle heavy metal content [111], and population density [46], with "low" or "high" directly characterizing the level of ecosystem health. Some studies constructed an ecological index model, establishing an ecological model through the design of a conceptual diagram, developing model equations, and estimating model parameters. In addition to indicator species, physical and chemical factors, such as water quality and sediment quality, were also added into the model. The Marine Biotic Index (MBI) and the Index of Biotic Integrity (IBI) are popular indexes [112–115], and a large number of studies also combined the geographical location and characteristics of the ecosystem to select specific indicator species indicators. There were also two treatment methods for the results: One was not to divide the dimension of ecosystem health, only exploring the change trend [116], while the other was to divide it into three, four, or five levels according to certain standards. However, the way of division is different from that of the index system, taking the water quality standard of the U.S. Environmental Protection Agency (U.S. EPA) (1993) as a standard, or adopting a statistical method, taking the 25% quantile of the specific value of a reference site as the standard for the health evaluation [39,117–120], which was originally developed by Karr (1981) and applied to the lake/reservoir bioassessment [121].

In general, there is no uniform standard for the division of the ecosystem health level in existing studies. The level of ecosystem health varies due to different research methods, types and geographical location of the ecosystem, research scale, and time series. Not only are there differences in the selection of specific indicators and construction of the model when assessing a specific ecosystem, there are also unique characteristics in different

ecosystem types. For example, human activities and disturbances in urban ecosystems are strong, and the vitality of zooplankton and phytoplankton in aquatic ecosystems will be affected by seasons. Therefore, it is difficult to have a unified delimitation standard to determine the threshold and inflection point of ecosystem health. We believe that the ecosystem health in this study is a relative concept, which means the relative ecosystem health under a specific spatial location and time series has been measured.

4.2.3. Features of Ecosystem Health

By classifying and statistically analyzing the cases selected in the empirical literature, it was found that ecosystem health has type features and scale features.

The type features of ecosystem health refer to the differences in the evaluation criteria of ecosystem health for different types of ecosystems. For different types of ecosystems, it is difficult to use the same indicators or evaluation systems to treat them uniformly. Attention to different types of ecosystem health has always been the focus of researchers. This study found that 64.4% of the studies were on aquatic ecosystems. Among these, marine ecosystems (including coasts, bays, gulfs, offshore areas, and mangrove ecosystems), river ecosystems, and lake ecosystems made up the majority, and studies on wetland ecosystems have been relatively few. Of the terrestrial ecosystems, the selected research objects were mainly urban ecosystems (Figure 6). According to the main body of the ecosystem, the ecosystem types can be divided into three categories (Figure 7a). The first type is the class of water-body-dominated ecosystems, such as oceans, rivers, lakes, and wetlands, and the second class is the organism-dominated ecosystems, such as forests and grasslands. The third class is human-dominated ecosystems, such as urban agglomerations, cities, villages, farmland, and mining areas. The evaluation of the first two types of ecosystems is usually closely related to biological indicator species, community succession, and environmental monitoring in environmental science. Therefore, more biological indicator methods were selected for this research, especially for water-body-dominated ecosystems. In human-dominated ecosystems, humans are an inseparable part of such ecosystems and are also an active and key element. The interaction between humans and the environment is a process that cannot be ignored, involving the human social environment, human survival, and various economic activities. For this kind of ecosystem, an index system is more suitable (Figure 7b).

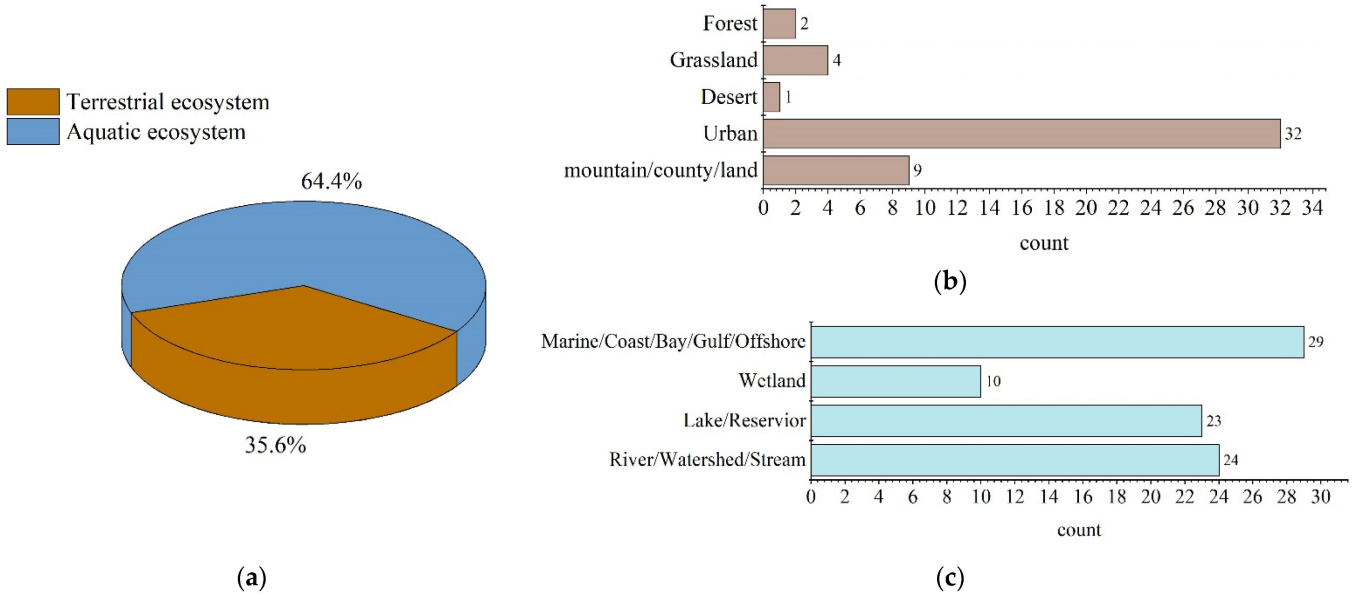


Figure 6. Summary of the types of ecosystems in the empirical publications on ecosystem health. Studies classified as those on terrestrial ecosystems and aquatic ecosystems (**a**). The terrestrial ecosystems (**b**) and aquatic ecosystems (**c**) were stratified further.

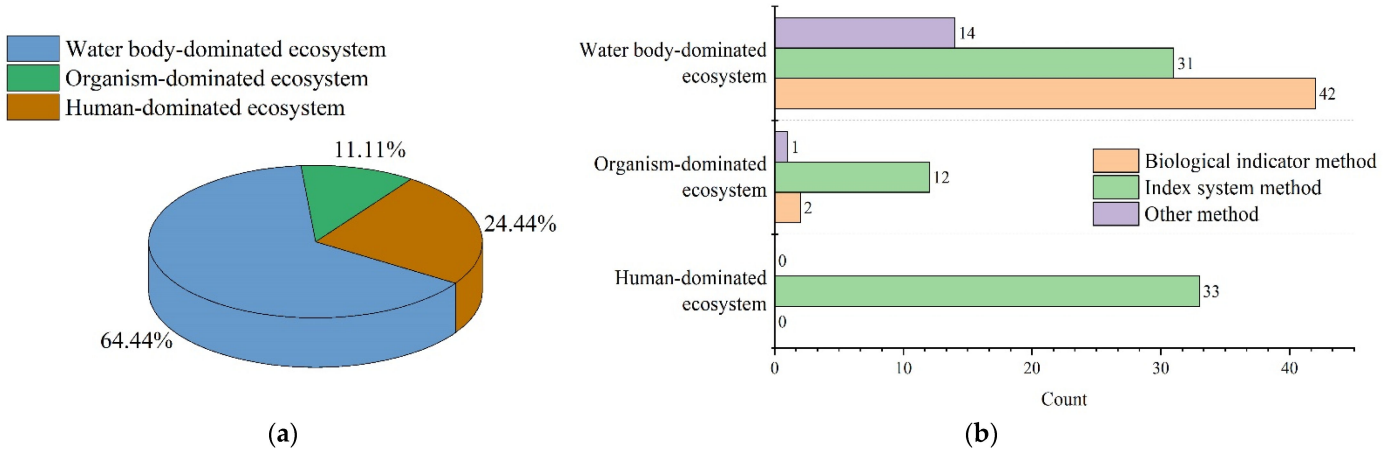


Figure 7. Summary of the types of ecosystem health in the empirical publications. The studies were classified as water-body-dominated ecosystems, organism-dominated ecosystems, and human-dominated ecosystems (**a**). Measures used for the three types of ecosystems (**b**).

Ecosystem health also has scale features. An ecosystem has the characteristics of integrity, complexity, and dynamics; therefore, there are also differences in the evaluation and measurement of ecosystem health at different scales. The measurement of ecosystem health can be conducted from multiple scales, such as global, national, regional, urban, and the landscape (Figure 8). Within the empirical studies, on the global scale, ecosystem health is closely related to climate change, biodiversity conservation, and other issues; these areas have become an important part of global sustainable development and also consider the links among ecosystem health and the food needed for human survival, the socio-cultural environment on which it depends, and public health [88]. At the regional scale, researchers have mostly chosen typical representative areas, such as areas of rapid urbanization [85,102,109,122], coastal areas [58,104,123–125], and areas with typical topographic gradients, such as mountains and plateaus [65,70,92,126], to evaluate ecosystem health. At the urban or rural scale, researchers usually have chosen representative cases, such as national capitals, coastal cities, tourist destinations, or energy-based cities, as case studies [127,128]. Some studies have refined the research units to county units [70]. There are a large number of studies at the scale of landscapes, such as lake landscapes, wetland landscapes, natural reserves, and other small-scale cases [66,86,129].

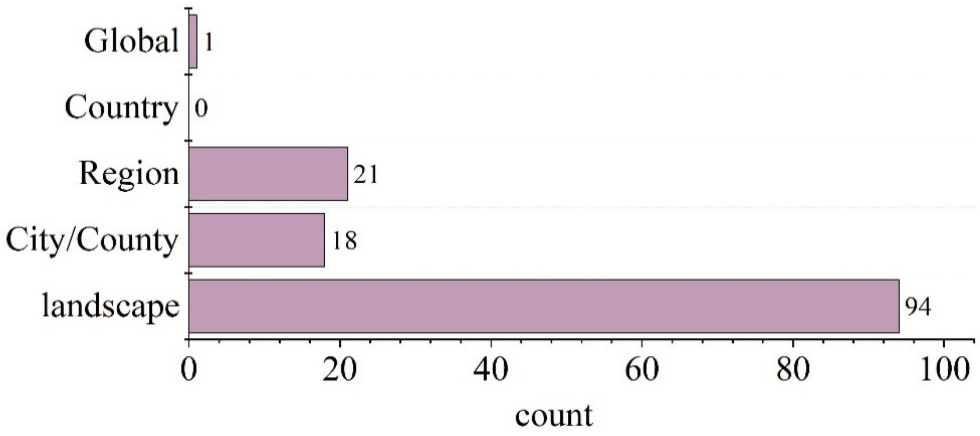


Figure 8. Summary of the scales of ecosystem health in the empirical publications.

5. Discussion and Conclusions

5.1. The Meaning and Development of Ecosystem Health

The study of ecosystem health began in North America in the 1980s and has developed rapidly in the past 15 years since 2005. From the initial debate on the concept to the widespread emergence of empirical research in recent years, ecosystem health has gradually received extensive attention from researchers and is considered an important concept related to global sustainable development. This paper reviewed the research content and development trends in ecosystem health using CiteSpace software, and the research topics could be divided into four themes: modeling and measurement of ecosystem health, ecological and environmental pollution and protection, human health, and sustainable development. The development process could be divided into three stages. The first was the management of ecosystem health based on anthropocentrism (1989–1999), which was the early stage of understanding the concept of ecosystem health, emphasizing the dual relationship between humans and the land. The next stage involved ecosystem health diagnoses based on biocentrism (2000–2014); this stage was the exploration stage of various empirical methods. The latest stage is that of exploring of human–earth interactions based on ecocentrism (2015–2022). As the research object has shifted from a single ecosystem to a composite ecosystem, the exploration of the human–land relationship has also turned a new page, focusing more on the integrity and harmony of humans and the ecological environment and shifting from dualism to monism.

Entering the 21st century, the degree of global integration has accelerated, population mobility has intensified, and international trade has developed rapidly. Global public health emergencies have occurred frequently, including the current COVID-19 pandemic. The focus on more complex ecosystems also indicates that the definition of the concept connotation now aims to pay attention to the human community on the basis of ecological and environmental health. The concept of ecosystem health itself is the product of interdisciplinary research. Therefore, the study of ecosystem health requires multi-angle and multi-disciplinary cross-combinations. At the same time, with today's dramatic changes in the relationship between humans and the land, it is difficult to define whether the human or the natural environment has a more significant impact on the ecosystem. Measurements of elements such as ecosystem services, human health, and ecosystem cognition have indicated that human activities have become an increasingly non-negligible part of studies on ecosystem health.

5.2. Geographical Differences and Characteristics of Ecosystem Health

According to the number of papers published in different countries, it was found that there are significant regional differences in the number of studies on ecosystem health. From 1988 to 30 June 2022, the United States and China accounted for 35.2% of the total number of studies published, and the top 10 countries accounted for 69.70% of the total number of studies published by 150 countries. However, when the empirical literature was analyzed, it was found that although the researchers' nationalities were different and there were differences in the origins of ecological ethics between the East and the West, the content of empirical research and the methods selected were basically the same. It is worth mentioning that after 2015, index systems have received increasingly more attention. This paper also pointed out that ecosystems have type and scale characteristics. For ecosystems with different types and different research scales, the evaluation of ecosystem health is different. In addition, there were also certain subjectivity and relativity in measuring ecosystem health. Although there is no big difference in the overall framework of ecosystem health evaluation among researchers all over the world, the evaluation results will not be exactly the same, due to the differences in evaluation methods and research objects when it comes to individual cases. Therefore, the threshold and inflection point for determining the state of ecosystem health vary according to the type of ecosystem and geographical location. As O'Brien mentioned, given the broad use of the term, it seems impractical to have an

overarching definition of ecosystem health; rather, an approach that is able to define and measure health on a case-by-case basis is preferable [10].

From the perspective of this research discipline, discussions on the meaning of ecosystem health mainly include two perspectives: bioecological perspectives and the ecological economics perspective. Bioecology focuses on the biological structure and attributes of ecosystems, while ecological economics focus more on the service function and value of ecosystems. The biological indicator method and the index system method are the corresponding embodiment of the two disciplinary perspectives of bioecology and ecological economics. The biological indicator method can more intuitively reflect the health status of the ecosystem itself, but it is more suitable for a single type of natural ecosystem, and it needs to be based on the type of ecosystem under study, its geographical location, and targeted selection of the indicator species. The index system method can be adapted to a wider range of ecosystem types, and the ecosystem itself and data sources have fewer restrictions [12].

5.3. Reflection on and Prospects for Ecosystem Health Research

After 30 years of development, ecosystem health research has made positive progress. At the same time, according to the bibliometric and empirical analysis of the relevant research, we also believe that there are still some deficiencies in ecosystem research.

In terms of research perspectives, the current research on ecosystem health has mainly started from the perspective of bioecology or ecological economics and has focused on a single aspect, such as the organism itself or the impact of human activities. In recent years, although researchers have chosen more complex ecosystems, such as urban agglomerations, as their research objects, the facts of human–land interaction have still been insufficiently explained. In the process of evaluating ecosystem health, human activities play an increasingly important role, but there is still a gap in the understanding of monism between humans and ecosystems. In the future, more empirical cases may be needed to enrich the relevant research results. For example, more diverse case sites that can reflect human–earth interactions, such as natural landscape tourism sites or natural heritage protection sites, should probably be selected for research.

In terms of the research methods, this research mainly adopted the biological indicator method and the index system method. The biological indicator method is suitable for single ecosystem types. Although the index system method depends on the land use, it still has a certain subjectivity and greater uncertainty in the classification of indicators. Most researchers have directly used the existing research models, but there may be deviations in the understanding of the connotation of the model, and there are also problems of model application and mixing caused by an unclear definition of model dimensions. For example, in the application of the PSR model, to understand the content of "pressure," "state," and "response," there are many differences from different researchers, which means there is no unified standard up to now. In addition, few have combined both the biological indicator method and the index system method. In recent years, some researchers have made some improvements and attempts in this regard, trying to add new research indicators and adopt new models for evaluation. However, there is still less discussion of the applicability, rationality, pertinence, and innovation of the model. In the future, how to select models and construct more pertinent evaluation systems for ecosystem health, how to quantify the credibility and effectiveness of the methods of analysis, and how to determine the effectiveness of indicator selection may be the focus.

In terms of research content, there has been insufficient discussion of the results of ecosystem health evaluations. At present, research is more focused on the verification of existing evaluation systems and methods. Since the beginning of the 21st century, the harmonious coexistence between humanity and nature is the cultural basis for solving ecological and environmental problems. With the gradual promotion and recognition of global issues and concepts such as "a community with a shared future of mankind" and "one health" [130], more attention may be paid to the role of human health or even

animal health in the conceptual system of ecosystem health. In the context of sustainable development, the topics of ecosystem health and human well-being, the spatial differentiation of ecosystem health, the influencing factors and the influencing mechanisms of ecosystem health, and the management and maintenance path of ecosystem health need to be continuously explored.

Author Contributions: Conceptualization, J.Z. and J.W.; methodology, J.W., X.M. and L.Y.; software, J.W.; writing—original draft preparation, J.W., P.W. and L.Z.; writing—review and editing, J.W. and J.Z.; funding acquisition, J.Z. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Natural Science Foundation of China (NSFC; grant number 42271251).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Ecosystem health publications from 1 January 1988 to 30 June 2022 in this study were derived from the ISI Web of Science (https://www.webofscience.com/wos/).

Acknowledgments: We are grateful to the editors and the reviewers for their helpful comments.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Oldfield, F.; Barnosky, A.D.; Dearing, J.; Fischer-Kowalski, M.; McNeill, J.; Steffen, W.; Zalasiewicz, J. The Anthropocene Review: Its significance, implications and the rationale for a new transdisciplinary journal. *Anthr. Rev.* **2014**, *1*, 3–7. [CrossRef]
2. Wolf, K.L.; Blahna, D.J.; Brinkley, W.; Romolini, M. Environmental stewardship footprint research: Linking human agency and ecosystem health in the Puget Sound region. *Urban Ecosyst.* **2013**, *16*, 13–32. [CrossRef]
3. Wang, H.; Zhou, S.; Li, X.; Liu, H.; Chi, D.; Xu, K. The influence of climate change and human activities on ecosystem service value. *Ecol. Eng.* **2016**, *87*, 224–239. [CrossRef]
4. Corvalan, C.; Hales, S.; McMichae, A. *Ecosystems and Human Well-Being: Health Synthesis: A Report of the Millennium Ecosystem Assessment*; World Health Organization: Geneva, Switzerland, 2005.
5. Lawton, J.H.; Daily, G.C. (Eds.) *Nature's Services. Societal Dependence on Natural Ecosystems*; Island Press: Washington, DC, USA, 1997; Cambridge University Press: Cambridge, UK, 1998.
6. Villnas, A.; Norkko, J.; Hietanen, S.; Josefson, A.B.; Lukkari, K.; Norkko, A. The role of recurrent disturbances for ecosystem multifunctionality. *Ecology* **2013**, *94*, 2275–2287. [CrossRef] [PubMed]
7. Schaeffer, D.J.; Herricks, E.E.; Kerster, H.W. Ecosystem health: I. measuring ecosystem health. *Environ. Manag.* **1988**, *12*, 445–455. [CrossRef]
8. Daily, G.C. Developing a Scientific Basis for Managing Earth's Life Support Systems. *Ecol. Soc.* **1999**, *3*, 45–49. [CrossRef]
9. Rapport, D.J.; Costanza, R.; McMichael, A.J. Assessing ecosystem health. *Trends Ecol. Evol.* **1998**, *13*, 397–402. [CrossRef] [PubMed]
10. O'Brien, A.; Townsend, K.; Hale, R.; Sharley, D.; Pettigrove, V. How is ecosystem health defined and measured? A critical review of freshwater and estuarine studies. *Ecol. Indic.* **2016**, *69*, 722–729. [CrossRef]
11. Rapport, D.J.; Bohm, G.; Buckingham, D.; Cairns, J.; Costanza, R.; Karr, J.R.; de Kruijf, H.A.M.; Levins, R.; McMichael, A.J.; Nielsen, N.O.; et al. Ecosystem health: The concept, the ISEH, and the important tasks ahead. *Ecosyst. Health* **1999**, *5*, 82–90. [CrossRef]
12. Liu, Y.X.; Peng, J.; Wang, A.; Xie, P.; Han, Y.N. New research progress and trends in ecosystem health. *Acta Ecol. Sin.* **2015**, *35*, 5920–5930.
13. Yang, H.; Shao, X.X.; Wu, M. A Review on Ecosystem Health Research: A Visualization Based on CiteSpace. *Sustainability* **2019**, *11*, 4908. [CrossRef]
14. Rocha, L.; Hegoburu, C.; Torremorell, A.; Feijoo, C.; Navarro, E.; Fernandez, H.R. Use of ecosystem health indicators for assessing anthropogenic impacts on freshwaters in Argentina: A review. *Environ. Monit. Assess.* **2020**, *192*, 1–26. [CrossRef] [PubMed]
15. Soubry, I.; Doan, T.; Chu, T.; Guo, X.L. A Systematic Review on the Integration of Remote Sensing and GIS to Forest and Grassland Ecosystem Health Attributes, Indicators, and Measures. *Remote Sens.* **2021**, *13*, 3262. [CrossRef]
16. Fu, S.K.; Zhao, L.; Qiao, Z.; Sun, T.; Sun, M.; Hao, Y.Y.; Hu, S.Y.; Zhang, Y.C. Development of Ecosystem Health Assessment (EHA) and Application Method: A Review. *Sustainability* **2021**, *13*, 11838. [CrossRef]
17. Pauna, V.H.; Picone, F.; Le Guyader, G.; Buonocore, E.; Franzese, P.P. The scientific research on ecosystem services: A bibliometric analysis. *Ecol. Quest.* **2018**, *29*, 53–62. [CrossRef]
18. Sun, S.K.; Jiang, Y.T.; Zheng, S.N. Research on Ecological Infrastructure from 1990 to 2018: A Bibliometric Analysis. *Sustainability* **2020**, *12*, 2304. [CrossRef]

19. Yang, L.; Cao, K. Cultural Ecosystem Services Research Progress and Future Prospects: A Review. *Sustainability* **2022**, *14*, 11845. [CrossRef]
20. Leopold, A.P. Wilderness as a land laboratory. *Living Wilderness* **1941**, *6*, 3.
21. Odum, E.P. The status of three ecosystem-level hypotheses regarding salt marsh estuaries: Tidal subsidy, out-welling, and detritus-based food chains. In *Estuarine Perspectives*; Academic Press: Cambridge, MA, USA, 1980; pp. 485–495.
22. Holling, C.S. Resilience and Stability of Ecological Systems. *Annu. Rev. Ecol. Syst.* **1973**, *4*, 1–23. [CrossRef]
23. Karr, J.R. Biological monitoring and environmental assessment: A conceptual framework. *Environ. Manag.* **1987**, *11*, 249–256. [CrossRef]
24. Rapport, D.J. What constitutes ecosystem health? *Perspect. Biol. Med.* **1989**, *33*, 120–132. [CrossRef]
25. Mageau, M.T.; Costanza, R.; Ulanowicz, R.E. Quantifying the trends expected in developing ecosystems. *Ecol. Model.* **1998**, *112*, 1–22. [CrossRef]
26. Brüll, A.; van Bohemen, H.; Costanza, R.; Mitsch, W.J.; van den Boomen, R.; Chaudhuri, N.; Heeb, J.; Jenssen, P.; Kalin, M.; Schonborn, A. Benefits of ecological engineering practices. In Proceedings of the Ecological Engineering: From Concepts to Applications, Paris, France, 2–4 December 2009; pp. 16–20.
27. Li, D.; Qiu, Z.H. The Study on Ecological Ethics of "Unity of Man and Nature". In *Environmental Protection and Resources Exploitation, Proceedings of the 2013 International Conference on Advances in Energy and Environmental Science (ICAEES 2013), Guangzhou, China, 30–31 July, 2013*; Trans Tech Publications Ltd.: Zurich, Switzerland, 2013; pp. 906–909.
28. Jiang, W.; Zhang, H.R. Traditional Chinese Culture and the Construction of Ecological Civilization: From Cultural Genes to Practical Behaviors—Case Studies in Confucianism, Buddhism and Taoism. *Chin. J. Urban Environ. Stud.* **2020**, *8*, 2050011. [CrossRef]
29. Chen, C.M. CiteSpace II: Detecting and visualizing emerging trends and transient patterns in scientific literature. *J. Am. Soc. Inf. Sci. Technol.* **2006**, *57*, 359–377. [CrossRef]
30. Chen, C.M. Searching for intellectual turning points: Progressive knowledge domain visualization. *Proc. Natl. Acad. Sci. USA* **2004**, *101*, 5303–5310. [CrossRef] [PubMed]
31. Fang, Y.; Yin, J.; Wu, B.H. Climate change and tourism: A scientometric analysis using CiteSpace. *J. Sustain. Tour.* **2018**, *26*, 108–126. [CrossRef]
32. Liu, S.; Sun, Y.P.; Gao, X.L.; Sui, Y. Knowledge domain and emerging trends in Alzheimer's disease: A scientometric review based on CiteSpace analysis. *Neural Regen. Res.* **2019**, *14*, 1643–1650. [CrossRef] [PubMed]
33. Chen, C.M.; Hu, Z.G.; Liu, S.B.; Tseng, H. Emerging trends in regenerative medicine: A scientometric analysis in CiteSpace. *Expert Opin. Biol. Ther.* **2012**, *12*, 593–608. [CrossRef] [PubMed]
34. Cheng, X.; Van Damme, S.; Uyttenhove, P. A review of empirical studies of cultural ecosystem services in urban green infrastructure. *J. Environ. Manag.* **2021**, *293*, 112895. [CrossRef]
35. Munawar, M.; Munawar, I.F.; Weisse, T.; Leppard, G.G.; Legner, M. The significance and future potential of using microbes for assessing ecosystems health: The Great Lakes example. *J. Aquat. Ecosyst. Health* **1994**, *3*, 295–310. [CrossRef]
36. Tampo, L.; Kabore, I.; Alhassan, E.H.; Oueda, A.; Bawa, L.M.; Djaneye-Boundjou, G. Benthic Macroinvertebrates as Ecological Indicators: Their Sensitivity to the Water Quality and Human Disturbances in a Tropical River. *Front. Water* **2021**, *3*, 662765. [CrossRef]
37. Wells, P.G. Biomonitoring the health of coastal marine ecosystems—The roles and challenges of microscale toxicity tests. *Mar. Pollut. Bull.* **1999**, *39*, 39–47. [CrossRef]
38. Park, B.Y.; Lee, J.K.; Ro, H.M.; Kim, Y.H. Effects of heavy metal contamination from an abandoned mine on nematode community structure as an indicator of soil ecosystem health. *Appl. Soil Ecol.* **2011**, *51*, 17–24. [CrossRef]
39. Yang, T.; Chen, J.; Li, X.P.; Wu, T.; Hu, Z.J.; Wang, S. Ecological risk by heavy metal contents in sediments within the Wei River Basin, China. *Environ. Earth Sci.* **2019**, *78*, 1–12. [CrossRef]
40. Giles, R.K.; Nguyen, C.A.T.; Ho, T.T.Y.; Nguyen, C.V.; Ngo, N.T.; Rochman, C.M. Source-Specific Patterns of Marine Debris and Associated Ecological Impacts in the Red River Estuary of Xuan Thuy National Park, Vietnam. *Front. Environ. Sci.* **2021**, *9*, 679530. [CrossRef]
41. Deininger, A.; Frigstad, H. Reevaluating the Role of Organic Matter Sources for Coastal Eutrophication, Oligotrophication, and Ecosystem Health. *Front. Mar. Sci.* **2019**, *6*, 210. [CrossRef]
42. Su, M.R.; Zhang, Y.; Liu, G.Y.; Xu, L.Y.; Zhang, L.X.; Yang, Z.F. Urban Ecosystem Health Assessment: Perspectives and Chinese Practice. *Int. J. Environ. Res. Public Health* **2013**, *10*, 5874–5885. [CrossRef] [PubMed]
43. Weindl, I.; Ost, M.; Wiedmer, P.; Schreiner, M.; Neugart, S.; Klopsch, R.; Kuhnhold, H.; Kloas, W.; Henkel, I.M.; Schluter, O.; et al. Sustainable food protein supply reconciling human and ecosystem health: A Leibniz Position. *Glob. Food Secur. -Agric. Policy Econ. Environ.* **2020**, *25*, 100367. [CrossRef]
44. Qiu, H.-H.; Liu, L.-G. A Study on the Evolution of Carbon Capture and Storage Technology Based on Knowledge Mapping. *Energies* **2018**, *11*, 1103. [CrossRef]
45. Kim, Y.O.; Shim, W.J.; Baek, S.H.; Choi, J.W.; Kim, D.; Choi, H.W. Coastal Ecosystem Health Assessment in Korea: Busan Case Study. *Ocean Sci. J.* **2019**, *54*, 165–182. [CrossRef]

46. Zhang, H.Y.; Duan, Z.D.; Wang, Z.Y.; Zhong, M.F.; Tian, W.; Wang, H.L.; Huang, H. Freshwater lake ecosystem health assessment and its response to pollution stresses based on planktonic index of biotic integrity. *Environ. Sci. Pollut. Res.* **2019**, *26*, 35240–35252. [CrossRef]
47. Shao, N.F.; Yang, S.T.; Sun, Y.; Gai, Y.; Zhao, C.S.; Wang, F.; Yin, X.; Dong, B. Assessing aquatic ecosystem health through the analysis of plankton biodiversity. *Mar. Freshw. Res.* **2019**, *70*, 647–655. [CrossRef]
48. Wolmarans, C.T.; Kemp, M.; de Kock, K.N.; Roets, W.; van Rensburg, L.; Quinn, L. A semi-quantitative survey of macroinvertebrates at selected sites to evaluate the ecosystem health of the Olifants River. *Water SA* **2014**, *40*, 245–254. [CrossRef]
49. Kabore, I.; Moog, O.; Alp, M.; Guenda, W.; Koblinger, T.; Mano, K.; Oueda, A.; Ouedraogo, R.; Trauner, D.; Melcher, A.H. Using macroinvertebrates for ecosystem health assessment in semi-arid streams of Burkina Faso. *Hydrobiologia* **2016**, *766*, 57–74. [CrossRef]
50. Phillips, I.D.; Davies, J.M.; Bowman, M.F.; Chivers, D.P. Macroinvertebrate communities in a Northern Great Plains river are strongly shaped by naturally occurring suspended sediments: Implications for ecosystem health assessment. *Freshw. Sci.* **2016**, *35*, 1354–1364. [CrossRef]
51. Tampo, L.; Lazar, I.M.; Kabore, I.; Oueda, A.; Akpataku, K.V.; Djaneye-Boundjou, G.; Bawa, L.M.; Lazar, G.; Guenda, W. A multimetric index for assessment of aquatic ecosystem health based on macroinvertebrates for the Zio river basin in Togo. *Limnologica* **2020**, *83*, 125783. [CrossRef]
52. Li, T.; Huang, X.; Jiang, X.; Wang, X. Assessment of ecosystem health of the Yellow River with fish index of biotic integrity. *Hydrobiologia* **2018**, *814*, 31–43. [CrossRef]
53. Lee, S.J.; Lee, E.H.; An, K.G. Lotic Ecosystem Health Assessments Using an Integrated Analytical Approach of Physical Habitat, Chemical Water Quality, and Fish Multi-Metric Health Metrics. *Pol. J. Environ. Stud.* **2018**, *27*, 2113–2131. [CrossRef]
54. Mieiro, C.L.; Pacheco, M.; Pereira, M.E.; Duarte, A.C. Mercury distribution in key tissues of fish (Liza aurata) inhabiting a contaminated estuary-implications for human and ecosystem health risk assessment. *J. Environ. Monit.* **2009**, *11*, 1004–1012. [CrossRef]
55. Xue, H.; Zheng, B.H.; Meng, F.S.; Wang, Y.Y.; Zhang, L.S.; Cheng, P.X. Assessment of Aquatic Ecosystem Health of the Wutong River Based on Benthic Diatoms. *Water* **2019**, *11*, 727. [CrossRef]
56. Oeding, S.; Taffs, K.H. Are diatoms a reliable and valuable bio-indicator to assess sub-tropical river ecosystem health? *Hydrobiologia* **2015**, *758*, 151–169. [CrossRef]
57. Bennion, H.; Kelly, M.G.; Juggins, S.; Yallop, M.L.; Burgess, A.; Jamieson, J.; Krokowski, J. Assessment of ecological status in UK lakes using benthic diatoms. *Freshw. Sci.* **2014**, *33*, 639–654. [CrossRef]
58. Aguirre-Rubi, J.; Luna-Acosta, A.; Ortiz-Zarragoitia, M.; Zaldibar, B.; Izagirre, U.; Ahrens, M.J.; Villamil, L.; Marigomez, I. Assessment of ecosystem health disturbance in mangrove-lined Caribbean coastal systems using the oyster Crassostrea rhizophorae as sentinel species. *Sci. Total Environ.* **2018**, *618*, 718–735. [CrossRef] [PubMed]
59. Ahn, J.E.; Ronan, A.D. Development of a model to assess coastal ecosystem health using oysters as the indicator species. *Estuar. Coast. Shelf Sci.* **2020**, *233*, 106528. [CrossRef]
60. Raftopoulou, E.K.; Dimitriadis, V.K. Assessment of the health status of mussels Mytilus galloprovincialis along Thermaikos Gulf (Northern Greece): An integrative biomarker approach using ecosystem health indices. *Ecotoxicol. Environ. Saf.* **2010**, *73*, 1580–1587. [CrossRef] [PubMed]
61. Marigomez, I.; Garmendia, L.; Soto, M.; Orbea, A.; Izagirre, U.; Cajaraville, M.P. Marine ecosystem health status assessment through integrative biomarker indices: A comparative study after the Prestige oil spill "Mussel Watch". *Ecotoxicology* **2013**, *22*, 486–505. [CrossRef]
62. Bharti, H.; Bharti, M.; Pfeiffer, M. Ants as bioindicators of ecosystem health in Shivalik Mountains of Himalayas: Assessment of species diversity and invasive species. *Asian Myrmecol.* **2016**, *8*, 65–79. [CrossRef]
63. Wike, L.D.; Martin, F.D.; Paller, M.H.; Nelson, E.A. Impact of forest seral stage on use of ant communities for rapid assessment of terrestrial ecosystem health. *J. Insect Sci.* **2010**, *10*, 77. [CrossRef] [PubMed]
64. Purvaja, R.; Robin, R.S.; Ganguly, D.; Hariharan, G.; Singh, G.; Raghuraman, R.; Ramesh, R. Seagrass meadows as proxy for assessment of ecosystem health. *Ocean Coast. Manag.* **2018**, *159*, 34–45. [CrossRef]
65. Suo, A.N.; Xiong, Y.C.; Wang, T.M.; Yue, D.X.; Ge, J.P. Ecosystem health assessment of the Jinghe River Watershed on the Huangtu Plateau. *Ecohealth* **2008**, *5*, 127–136. [CrossRef] [PubMed]
66. Wang, H.; Hou, P.; Jiang, J.B.; Xiao, R.L.; Zhai, J.; Fu, Z.; Hou, J. Ecosystem Health Assessment of Shennongjia National Park, China. *Sustainability* **2020**, *12*, 7672. [CrossRef]
67. De Toro, P.; Iodice, S. Ecosystem Health Assessment in urban contexts: A proposal for the Metropolitan Area of Naples (Italy). *Aestimum* **2018**, *72*, 39–59. [CrossRef]
68. Das, M.; Das, A.; Mandal, A. Research note: Ecosystem Health (EH) assessment of a rapidly urbanizing metropolitan city region of eastern India—A study on Kolkata Metropolitan Area. *Landsc. Urban Plan.* **2020**, *204*, 103938. [CrossRef]
69. Yu, G.M.; Yu, Q.W.; Hu, L.M.; Zhang, S.; Fu, T.T.; Zhou, X.; He, X.L.; Liu, Y.A.; Wang, S.; Jia, H.H. Ecosystem health assessment based on analysis of a land use database. *Appl. Geogr.* **2013**, *44*, 154–164. [CrossRef]
70. Liu, D.L.; Hao, S.L. Ecosystem Health Assessment at County-Scale Using the Pressure-State-Response Framework on the Loess Plateau, China. *Int. J. Environ. Res. Public Health* **2017**, *14*, 861. [CrossRef]

71. Sun, R.; Yao, P.P.; Wang, W.; Yue, B.; Liu, G. Assessment of Wetland Ecosystem Health in the Yangtze and Amazon River Basins. *Isprs Int. J. Geo-Inf.* **2017**, *6*, 81. [CrossRef]
72. Wang, Z.Y.; Tang, L.N.; Qiu, Q.Y.; Chen, H.X.; Wu, T.; Shao, G.F. Assessment of Regional Ecosystem Health-A Case Study of the Golden Triangle of Southern Fujian Province, China. *Int. J. Environ. Res. Public Health* **2018**, *15*, 802. [CrossRef] [PubMed]
73. Ekumah, B.; Armah, F.A.; Afrifa, E.K.A.; Aheto, D.W.; Odoi, J.O.; Afitiri, A.R. Geospatial assessment of ecosystem health of coastal urban wetlands in Ghana. *Ocean Coast. Manag.* **2020**, *193*, 105226. [CrossRef]
74. Li, Y.F.; Li, D. Assessment and forecast of Beijing and Shanghai's urban ecosystem health. *Sci. Total Environ.* **2014**, *487*, 154–163. [CrossRef] [PubMed]
75. Yang, Q.; Lin, A.W.; Zhao, Z.Z.; Zou, L.; Sun, C. Assessment of Urban Ecosystem Health Based on Entropy Weight Extension Decision Model in Urban Agglomeration. *Sustainability* **2016**, *8*, 869. [CrossRef]
76. Tao, N.; Liu, D.; Wu, J. Assessment of Forest Ecosystem Health Based On Fuzzy Evaluation Method-A Case Study Of Forest Ecosystem In Liangshui Natural Reserve. *Rev. Int. De Contam. Ambient.* **2019**, *35*, 159–164. [CrossRef]
77. Cheng, W.J.; Xi, H.Y.; Sindikubwabo, C.; Si, J.H.; Zhao, C.G.; Yu, T.F.; Li, A.L.; Wu, T.R. Ecosystem health assessment of desert nature reserve with entropy weight and fuzzy mathematics methods: A case study of Badain Jaran Desert. *Ecol. Indic.* **2020**, *119*, 106843. [CrossRef]
78. Hou, Q.H.; Zhu, W.T.; Liu, X.Y.; Zhang, X. Urban Ecosystem Health Assessment Inside Xi'an By Multivariate Data. *J. Environ. Prot. Ecol.* **2018**, *19*, 1016–1025.
79. Su, M.R.; Yang, Z.F.; Chen, B. Set pair analysis for urban ecosystem health assessment. *Commun. Nonlinear Sci. Numer. Simul.* **2009**, *14*, 1773–1780. [CrossRef]
80. Su, M.R.; Yang, Z.F.; Chen, B.; Ulgiati, S. Urban ecosystem health assessment based on emergy and set pair analysis-A comparative study of typical Chinese cities. *Ecol. Model.* **2009**, *220*, 2341–2348. [CrossRef]
81. Su, M.R.; Yang, Z.F.; Liu, G.Y.; Chen, B. Ecosystem Health Assessment and Regulation for Urban Ecosystems: A Case Study of the Yangtze River Delta Urban Cluster, China. *J. Environ. Inform.* **2011**, *18*, 65–74. [CrossRef]
82. Wang, C.; Qu, A.Y.; Wang, P.F.; Hou, J. Estuarine ecosystem health assessment based on the DPSIR framework: A case of the Yangtze Estuary, China. *J. Coast. Res.* **2013**, *165*, 1236–1241. [CrossRef]
83. Zhang, F.; Zhang, J.Q.; Wu, R.; Ma, Q.Y.; Yang, J. Ecosystem health assessment based on DPSIRM framework and health distance model in Nansi Lake, China. *Stoch. Environ. Res. Risk Assess.* **2016**, *30*, 1235–1247. [CrossRef]
84. Pan, Z.Z.; He, J.H.; Liu, D.F.; Wang, J.W.; Guo, X.A. Ecosystem health assessment based on ecological integrity and ecosystem services demand in the Middle Reaches of the Yangtze River Economic Belt, China. *Sci. Total Environ.* **2021**, *774*, 144837. [CrossRef]
85. Kang, P.; Chen, W.P.; Hou, Y.; Li, Y.Z. Linking ecosystem services and ecosystem health to ecological risk assessment: A case study of the Beijing-Tianjin-Hebei urban agglomeration. *Sci. Total Environ.* **2018**, *636*, 1442–1454. [CrossRef]
86. Tehrani, N.A.; Shafri, H.Z.M.; Salehi, S.; Chanussot, J.; Janalipour, M. Remotely-Sensed Ecosystem Health Assessment (RSEHA) model for assessing the changes of ecosystem health of Lake Urmia Basin. *Int. J. Image Data Fusion* **2022**, *13*, 180–205. [CrossRef]
87. Xu, D.; Cai, Z.; Xu, D.; Lin, W.P.; Gao, J.; Li, L.B. Land Use Change and Ecosystem Health Assessment on Shanghai-Hangzhou Bay, Eastern China. *Land* **2022**, *11*, 867. [CrossRef]
88. Ran, C.; Wang, S.J.; Bai, X.Y.; Tan, Q.; Wu, L.H.; Luo, X.L.; Chen, H.; Xi, H.P.; Lu, Q. Evaluation of temporal and spatial changes of global ecosystem health. *Land Degrad. Dev.* **2021**, *32*, 1500–1512. [CrossRef]
89. Xie, X.F.; Pu, L.J. Assessment of Urban Ecosystem Health Based on Matter Element Analysis: A Case Study of 13 Cities in Jiangsu Province, China. *Int. J. Environ. Res. Public Health* **2017**, *14*, 940. [CrossRef] [PubMed]
90. Liu, P.D.; Rong, L.L.; Teng, F. The Evaluation of Ecosystem Health Based On Hybrid Todim Method For Chinese Case. *Technol. Econ. Dev. Econ.* **2019**, *25*, 542–570. [CrossRef]
91. Zeng, C.; Deng, X.Z.; Xu, S.; Wang, Y.T.; Cui, J.X. An integrated approach for assessing the urban ecosystem health of megacities in China. *Cities* **2016**, *53*, 110–119. [CrossRef]
92. Zhang, Z.X.; Liu, Y.; Li, Y.; Wang, X.G.; Li, H.Z.; Yang, H.; Ding, W.H.; Liao, Y.P.; Tang, N.B.; He, F.F. Lake ecosystem health assessment using a novel hybrid decision-making framework in the Nam Co, Qinghai-Tibet Plateau. *Sci. Total Environ.* **2022**, *808*, 152087. [CrossRef]
93. Xu, W.; Dong, Z.C.; Ren, L.; Ren, J.; Guan, X.K.; Zhong, D.Y. Using an improved interval technique for order preference by similarity to ideal solution to assess river ecosystem health. *J. Hydroinformatics* **2019**, *21*, 624–637. [CrossRef]
94. Wang, C.; Qu, A.Y.; Wang, P.F.; Hou, J.; Ao, Y.H. Development Of A Multi-Index Ecosystem Health Assessment Model Using Back-Propagation Neural Network Approach: A Case Study Of The Yangtze Estuary, China. *Environ. Eng. Manag. J.* **2017**, *16*, 1551–1561.
95. Li, Y.Z.; Wu, Y.X.; Liu, X.G. Regional ecosystem health assessment using the GA-BPANN model: A case study of Yunnan Province, China. *Ecosyst. Health Sustain.* **2022**, *8*, 2084458. [CrossRef]
96. Wu, W.; Xu, Z.X.; Yin, X.W.; Zuo, D.P. Assessment of ecosystem health based on fish assemblages in the Wei River basin, China. *Environ. Monit. Assess.* **2014**, *186*, 3701–3716. [CrossRef]
97. Li, Y.Y.; Dong, S.K.; Wen, L.; Wang, X.X.; Wu, Y. Three-Dimensional Framework of Vigor, Organization, and Resilience (VOR) for Assessing Rangeland Health: A Case Study from the Alpine Meadow of the Qinghai-Tibetan Plateau, China. *Ecohealth* **2013**, *10*, 423–433. [CrossRef] [PubMed]
98. Atak, B.K.; Tonyaloglu, E.E. Monitoring the spatiotemporal changes in regional ecosystem health: A case study in Izmir, Turkey. *Environ. Monit. Assess.* **2020**, *192*, 385. [CrossRef]

99. Wang, Z.; Yang, Z.P.; Shi, H.; Han, F.; Liu, Q.; Qi, J.W.; Lu, Y.Y. Ecosystem Health Assessment of World Natural Heritage Sites Based on Remote Sensing and Field Sampling Verification: Bayanbulak as Case Study. *Sustainability* **2020**, *12*, 2610. [CrossRef]
100. Mallick, J.; AlQadhi, S.; Talukdar, S.; Pradhan, B.; Bindajam, A.A.; Islam, A.M.T.; Dajam, A.S. A Novel Technique for Modeling Ecosystem Health Condition: A Case Study in Saudi Arabia. *Remote Sens.* **2021**, *13*, 2632. [CrossRef]
101. Sun, T.T.; Lin, W.P.; Chen, G.S.; Guo, P.P.; Zeng, Y. Wetland ecosystem health assessment through integrating remote sensing and inventory data with an assessment model for the Hangzhou Bay, China. *Sci. Total Environ.* **2016**, *566*, 627–640. [CrossRef] [PubMed]
102. Das, S.; Pradhan, B.; Shit, P.K.; Alamri, A.M. Assessment of Wetland Ecosystem Health Using the Pressure-State-Response (PSR) Model: A Case Study of Mursidabad District of West Bengal (India). *Sustainability* **2020**, *12*, 5932. [CrossRef]
103. Wang, Z.J.; Liu, Y.; Li, Y.X.; Su, Y. Response of Ecosystem Health to Land Use Changes and Landscape Patterns in the Karst Mountainous Regions of Southwest China. *Int. J. Environ. Res. Public Health* **2022**, *19*, 3273. [CrossRef]
104. Sun, B.D.; Tang, J.C.; Yu, D.H.; Song, Z.W.; Wang, P.G. Ecosystem health assessment: A PSR analysis combining AHP and FCE methods for Jiaozhou Bay, China. *Ocean Coast. Manag.* **2019**, *168*, 41–50. [CrossRef]
105. Song, Z.; Sun, Y.; Chen, P.; Jia, M. Assessing the Ecosystem Health of Coastal Wetland Vegetation (Suaeda salsa) Using the Pressure State Response Model, a Case of the Liao River Estuary in China. *Int. J. Environ. Res. Public Health* **2022**, *19*, 546. [CrossRef] [PubMed]
106. Han, H.; Li, H.M.; Zhang, K.Z. Urban Water Ecosystem Health Evaluation Based on the Improved Fuzzy Matter-Element Extension Assessment Model: Case Study from Zhengzhou City, China. *Math. Probl. Eng.* **2019**, *2019*, 7502342. [CrossRef]
107. Das, M.; Das, A.; Pereira, P.; Mandal, A. Exploring the spatio-temporal dynamics of ecosystem health: A study on a rapidly urbanizing metropolitan area of Lower Gangetic Plain, India. *Ecol. Indic.* **2021**, *125*, 107584. [CrossRef]
108. Li, W.; Xie, S.; Wang, Y.; Huang, J.; Cheng, X. Effects of urban expansion on ecosystem health in Southwest China from a multi-perspective analysis. *J. Clean. Prod.* **2021**, *294*, 126341. [CrossRef]
109. Xie, X.; Fang, B.; Li, X.; He, S.S. Urban ecosystem health assessment and obstacle factor diagnosis using a comprehensive assessment model for Nanjing, China. *Growth Change* **2021**, *52*, 1938–1954. [CrossRef]
110. Guan, B.H.; An, S.Q.; Gu, B.H. Assessment of ecosystem health during the past 40 years for Lake Taihu in the Yangtze River Delta, China. *Limnology* **2011**, *12*, 47–53. [CrossRef]
111. Aguirre-Rubi, J.R.; Ortiz-Zarragoitia, M.; Izagirre, U.; Etxebarria, N.; Espinoza, F.; Marigomez, I. Prospective biomonitor and sentinel bivalve species for pollution monitoring and ecosystem health disturbance assessment in mangrove-lined Nicaraguan coasts. *Sci. Total Environ.* **2019**, *649*, 186–200. [CrossRef]
112. Cui, W.Y.; Guo, S.Y.; Meng, X.Z.; Kong, F.Q. Application of adapted Benthic Index of Biotic Integrity (B-IBI) for river ecosystem health assessment in Zhanghe River Watershed, China. *Pol. J. Ecol.* **2018**, *66*, 407–415. [CrossRef]
113. Houssou, A.M.; Adjahouinou, D.C.; Bonou, C.A.; Montchowui, E. Plankton Index of Biotic Integrity (P-IBI) for assessing ecosystem health within the Oueme River basin, Republic of Benin. *Afr. J. Aquat. Sci.* **2020**, *45*, 452–465. [CrossRef]
114. Huang, X.Y.; Xu, J.; Liu, B.; Guan, X.; Li, J.S. Assessment of Aquatic Ecosystem Health with Indices of Biotic Integrity (IBIs) in the Ganjiang River System, China. *Water* **2022**, *14*, 278. [CrossRef]
115. Tan, X.; Ma, P.M.; Bunn, S.E.; Zhang, Q.F. Development of a benthic diatom index of biotic integrity (BD-IBI) for ecosystem health assessment of human dominant subtropical rivers, China. *J. Environ. Manag.* **2015**, *151*, 286–294. [CrossRef] [PubMed]
116. Xu, F.L.; Tao, S.; Dawson, R.W.; Li, P.G.; Cao, J. Lake ecosystem health assessment: Indicators and methods. *Water Res.* **2001**, *35*, 3157–3167. [CrossRef] [PubMed]
117. Zhu, G.H.; Abu Noman, M.; Narale, D.D.; Feng, W.H.; Pujari, L.; Sun, J. Evaluation of ecosystem health and potential human health hazards in the Hangzhou Bay and Qiantang Estuary region through multiple assessment approaches. *Environ. Pollut.* **2020**, *264*, 114791. [CrossRef] [PubMed]
118. Lin, B.; Shang, H.; Chen, Z. The assessment of wetland ecosystem health by means of LDI: A case study in Baiyangdian wetland, China. *J. Food Agric. Environ.* **2013**, *11*, 1187–1192.
119. Xia, J.; Zhang, Y.Y.; Zhao, C.S.; Bunn, S.E. Bioindicator Assessment Framework of River Ecosystem Health and the Detection of Factors Influencing the Health of the Huai River Basin, China. *J. Hydrol. Eng.* **2014**, *19*, 1–34. [CrossRef]
120. Chen, J.B.; Wang, Y.J.; Li, F.Y.; Liu, Z.C. Aquatic ecosystem health assessment of a typical sub-basin of the Liao River based on entropy weights and a fuzzy comprehensive evaluation method. *Sci. Rep.* **2019**, *9*, 1–13. [CrossRef]
121. Han, J.H.; Kim, B.; Kim, C.; An, K.G. Ecosystem health evaluation of agricultural reservoirs using multi-metric lentic ecosystem health assessment (LEHA) model. *Paddy Water Environ.* **2014**, *12*, S7–S18. [CrossRef]
122. Meng, L.R.; Huang, J.; Dong, J.H. Assessment of rural ecosystem health and type classification in Jiangsu province, China. *Sci. Total Environ.* **2018**, *615*, 1218–1228. [CrossRef] [PubMed]
123. Muniz, P.; Venturini, N.; Hutton, M.; Kandratavicius, N.; Pita, A.; Brugnoli, E.; Burone, L.; Garcia-Rodriguez, F. Ecosystem health of Montevideo coastal zone: A multi approach using some different benthic indicators to improve a ten-year-ago assessment. *J. Sea Res.* **2011**, *65*, 38–50. [CrossRef]
124. Piroddi, C.; Moutopoulos, D.K.; Gonzalvo, J.; Libralato, S. Ecosystem health of a Mediterranean semi-enclosed embayment (Amvrakikos Gulf, Greece): Assessing changes using a modeling approach. *Cont. Shelf Res.* **2016**, *121*, 61–73. [CrossRef]
125. Tang, D.H.; Zou, X.Q.; Liu, X.J.; Liu, P.T.; Zhamangulova, N.; Xu, X.G.; Zhao, Y.F. Integrated ecosystem health assessment based on eco-exergy theory: A case study of the Jiangsu coastal area. *Ecol. Indic.* **2015**, *48*, 107–119. [CrossRef]

126. Zhang, H.; Sun, J.; Deng, W.; Peng, L. Ecosystem Health: Assessment Framework, Spatial Evolution, and Regional Optimization in Southwest China. *Chin. Geogr. Sci.* **2020**, *30*, 142–156. [CrossRef]
127. Liu, G.Y.; Yang, Z.F.; Chen, B.; Zhang, Y.; Zhang, L.X.; Zhao, Y.W.; Jiang, M.M. Emergy-based urban ecosystem health assessment: A case study of Baotou, China. *Commun. Nonlinear Sci. Numer. Simul.* **2009**, *14*, 972–981. [CrossRef]
128. Li, J.; Shen, W. Spatial Heterogeneity of the Effects of Human Activities On Ecosystem Health Of A Coastal Tourism City—A Case Study Of Rizhao, China. *Appl. Ecol. Environ. Res.* **2021**, *19*, 3029–3051. [CrossRef]
129. Xu, F.L.; Dawson, R.W.; Tao, S.; Cao, J.; Li, B.G. A method for lake ecosystem health assessment: An Ecological Modeling Method (EMM) and its application. *Hydrobiologia* **2001**, *443*, 159–175. [CrossRef]
130. Van Bruggen, A.H.C.; Goss, E.M.; Havelaar, A.; van Diepeningen, A.D.; Finckh, M.R.; Morris, J.G. One Health—Cycling of diverse microbial communities as a connecting force for soil, plant, animal, human and ecosystem health. *Sci. Total Environ.* **2019**, *664*, 927–937. [CrossRef] [PubMed]