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Visualization analysis of ecological assets/values research by knowledge mapping

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ABSTRACT

Using knowledge mapping tools (CiteSpace), we conducted the visualization analysis on both of international and domestic literatures in relation to ecological assets/values from the Web of Science (WoS) databases and China National Knowledge Infrastructure (CNKI) databases. By combination of the statistical data and visualization mapping, we studied on the research relationship networks and status for the co-authors' institutions, co-authors, co-citation literatures and co-occurring keywords of ecological assets/values based on the sample data from literatures. In the aspects of research on ecological values, our results showed that: (i) main countries of researches on ecological values were the United States, Australia, Canada and China in order, especially the US had the most plenty of literatures in relation to ecological values, and at the same time, literatures from China in this field are in the upper level; (ii) the hotspots of researches on ecological values from the global literatures covered various fields including biodiversity, species richness, ecosystem services, landscape, climate change and dynamic simulation; (iii) as a result of the multidisciplinary integration, the hotspots of researches on ecological values emerge endlessly, so that many high yielding authors and relevant international institutions constantly expanded the research scopes and fields, which promoted the combination of theories and made the significant contribution to themselves; (iv) the mass domestic researches on ecological values began in 1992. The number of posting paper increased obviously and the scopes in relation to ecological value expanded gradually, particularly involved with ecology, economy, even legal and ideology, which illustrated that concepts of "ecological values" had not been only confined to the researches on the traditional science, but also been widely used in many fields of humanity and social science. In the aspect of research on ecological assets, our results showed that: (i) domestic researches on ecological assets had many points in common with ecological values research. In fact, driven from ecological values, researches on ecological assets became gradually characteristic, such as assessment of forest ecological asset, ecological industry and fair value measurement of ecological assets, all of which contained lots of considerable consequences; (ii) the Chinese Academy of Sciences was in the dominant position of domestic research on ecological assets. Other colleges and universities like Beijing Normal University and Nanjing Forestry University were also effective and productive in this field. Their achievements were already improving Chinese academic level; (iii) domestic research teams also changed from different discipline backgrounds to enrich the research scopes of ecological assets. Based on analysis of typical literatures from our results, in the similarity and difference of the concept of "ecological asset" between foreign and domestic literatures, we summarized key points that we should pay attention to: (i) ecological assets included natural resources and ecosystem services; (ii) ecological assets consisted of tangible and intangible parts; (iii) ecological assets were of profitability and public welfare at the same time. Finally, we elucidated that future trend of research on ecological assets would pay more attention to the internal mechanism of changes of ecological assets, determination of the bearing capacity of the ecological environment by such changes, and discovery of accumulation of ecological assets for a stable and sustainable development of the ecosystem, and for harmony between humans and environment.

1. Introduction

In recent years, with the development of economy and technology, ecological assets research has been improved gradually and becomes a new field of ecology and ecological economics. As a multidisciplinary field and focuses on the combination of theory and practice, this broad base of applications of emerging research object thus often leads to confusion regarding the exact semantics of various definitions in the literatures. Numerous scholars often defined the concept of "ecological assets" based on theoretical knowledge and technical methods of their professional disciplines, which may emphasis on different perspectives. From the generalized definitions, the concept referring to ecological

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1872-2032/

assets is obtained from the category of ecological values. This domain is a new branch from ecological values research, so it plays an important role in discovering the status quo and research trends as well as defining explicitly concept of "ecological assets" for subsequent research.

The goal of this article is to use visualization analysis to give a scientometrics overview of international and domestic relevant literatures based on mapping knowledge. To identify key literatures which refer to ecological assets/values domains, we used such visual and scientometrics analytical indicators as the identification, in particular, including institutes and countries of manuscript origin, the top and most highly cited authors, the core literatures and journals, key research hotspots and breakthrough points etc. Then, we presented the comparison between international and domestic definition of "ecological assets". Through analyzing the similarities and differences between different concepts, we summarized the key points that should be paid attention to define "ecological assets". Finally, we concluded the future trends of ecological assets research.

2. Methodology

2.1. Research methodology tools

Knowledge mapping was a relatively new research front of scientometrics. The idea was to use information visualization to represent large amounts of data in research front, such as core structure, overall architecture, development process research status etc. This allowed the viewers to look at a large corpus and to develop deeper insights based on a high level view of the map integrated multidisciplinary theories and methodologies including statistics, applied mathematics, graphics, information science, bibliometrics etc. [1]. Visualization using various network modeling tools had been performed considerately for social network analysis of citation and other complex networks from the huge amounts of information to mine the implicitly effective information with some intelligent analysis methods, such as sequence analysis, clustering analysis, correlation analysis etc. [2]. Scientometrics was a quantitative study of scientific communication. It required a multitude of sophisticated techniques including citation analysis, statistical analysis and other quantitative techniques for mapping and measurement of relationships and flows among academic backgrounds, research results, research hotspots or other knowledge-based entities. In this article, we presented a visualization mapping based systematic analysis of ecological assets/values domain which involved the discovery of various types of co-citation networks as well as the complex network analysis of the overall network using CiteSpace [3,4], a recent tool which had been designed exclusively for citation networks analysis by Chaomei Chen of Drexel University. By color coding the evolution of research, it allowed the examination of some detail relational matrixes between different objects which cannot otherwise be easily captured using other tools (Table 1).

2.2. Data collection

Input data of international literatures were retrieved from the Thomason Reuters Web of Science (WoS), because the supported formats of CiteSpace were a set of bibliographic data files in the field tagged from Institute for Scientific Information (ISI) Export Format. While domestic data from China National Knowledge Infrastructure (CNKI) should be converted into supported text formats using file-format conversion tool by Shengbo Liu of Dalian University of Technology, but CNKI data don't support the citation information, namely references.

2.3. Data processing

After preprocessing all data, we analyzed all relational matrixes supported by CiteSpace using some evaluation methods such as centrality calculation, frequency statistics, clustering coefficient and burst detection. Then, we selected some representative matrix mappings to show in this paper, including five relational matrixes of WoS (co-authors' countries or institutions, co-occurring keywords, co-citation authors, co-citation references and co-citation journals) and three relational matrixes of CNKI (co-occurring keywords, co-authors' institutions and co-authors).

3. Results and analyses

3.1. Literatures of WoS

An exact topic search for "ecological value(s)" resulted 486 records published from Science Citation Index Expanded (SCI-EXPANDED) database from 2002 to 2013 and Social Sciences Citation Index (SSCI) database from 2000 to 2013. We began with some basic parameter settings: (i) Time Slicing. The entire time interval of research was chosen from 2000 to 2013; (ii) Pruning. CiteSpace supported two common network-pruning algorithms. In this article, we concentrated on minimum panning tree pruning; (iii) Links. Strength between nodes and clusters links was processed by a cosine function, and scope type was selected "within slices". Subsequently by using the various options selected by the user, the network could be viewed in different ways and parameters could be analyzed based on centrality as well as frequency.

3.1.1. Analysis of co-authors' countries or institutions

Parameter settings: Years Per Slice: 2; Node Types: Country & Institution: Top N per slice: 20.

The goal of our first analysis was to identify the most important co-authors' country or institution. Based on a time slice of two years, we chose top-20 cited literatures per sliced segment to get a knowledge mapping of co-authors' country or institution network (Fig. 1). Here in Fig. 1, we saw many different sizes of circle nodes which represented different volumes of literatures published by each country/institution. The bigger the nodes were, the more frequency of documents posted [5]. In CiteSpace, the particular centrality was well known to note the ability of a vertex to monitor communication with other vertices [6]. Generally, higher centrality meant more importance of the node which reflected the structure and dynamic essentiality in a particular field. Meanwhile, we collected statistics of co-authors' countries/institutions of international ecological values research (Table 2). Table 2 showed that, in term of frequency, the key publications in the domain originated from USA, which was followed by Australia, Spain, People's Republic of China, England, Canada, Italy and Germany. However, Australia, Spain and Italy had low centralities. These results illustrated that the most collaborations in these three countries came from themselves rather than other different nations. In contrast, high centralities of other countries/institutions such as Germany, USA, US Forestry Service, Brazil and England indicated that they had critical roles in the field of ecological values research. Noteworthy, China had both high frequency and centrality implying that many Chinese researchers had obtained some significant achievements in ecological values domain, especially who came from Chinese Academic of Science.

Table 1
The relational matrixes of CiteSpace support [1].

Relationship	Coupling			Co-author			Co-citation			Co-occurring
Object CiteSpace	Author	Reference √	Journal	Author √	Country √	Institution √	Author √	Reference √	Journal √	Keyword √

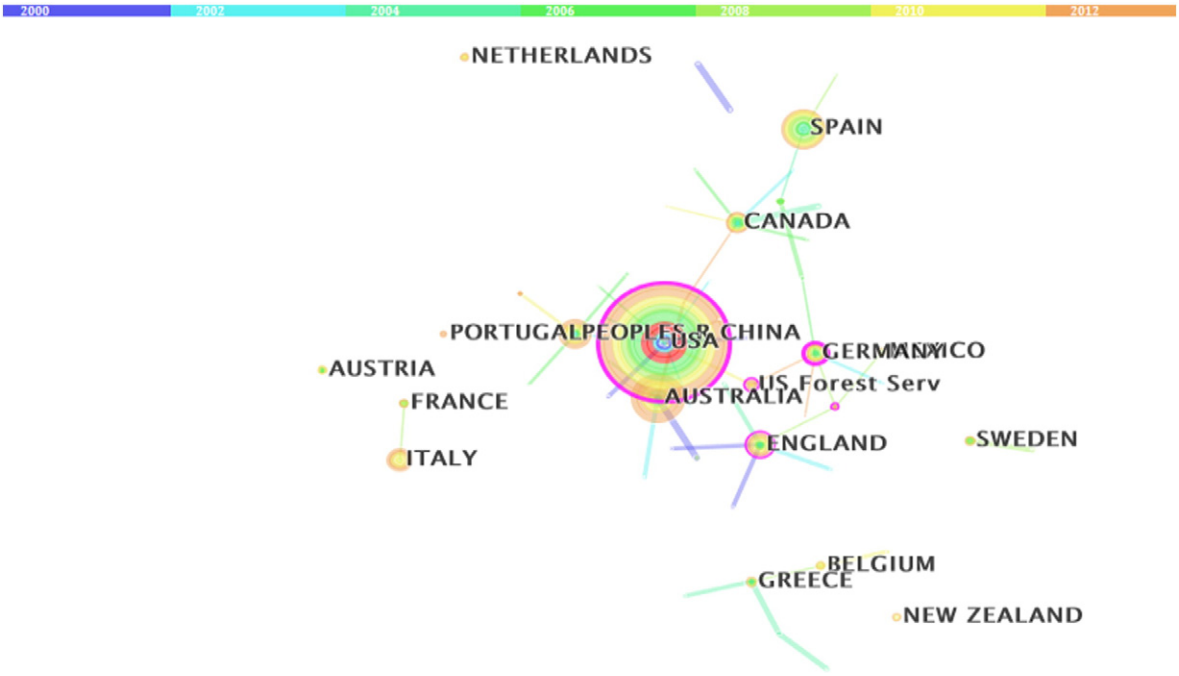

Fig. 1. Mapping on co-authors' countries (institutions) of international ecological values research.

3.1.2. Analysis of co-occurring keywords

Parameter settings: Years Per Slice: 2; Node Types: Keyword: Threshold Interpolation (c, cc, ccv):3, 3, 20.

The scopes of CiteSpace co-occurring keywords analysis not only included the keywords and keywords Plus of the literatures (both called reference keywords), but also tested burst terms. Based on detection results, we could take a further analysis on relevant research hotspots in the field of ecological values. Hotspots involved in ecological values could be delineated in terms of burst terms assigned to each article in the dataset. Fig. 2 showed a portion of a minimum spanning tree of a network of co-occurring keywords, in which the scarlet letter words were delineated in terms of detection keywords and the rest were derived from reference keywords. In combination with data in Table 3, which presented the keywords most frequently assigned by our datasets and the measures of their centralities, our analysis had produced some interesting findings: (i) using CiteSpace to visualize the co-occurring keywords, we obtained three important and popular research objects in ecological values including "species richness", "ecosystem service" and "climate change", all of which were also reference keywords as well as detection keywords in common. (ii) Some of the most frequently used keyword terms also had higher centrality values, for instance, "biodiversity", "vegetation", "landscape", "diversity" and "dynamics" were all frequently assigned as well as high centrality values. (iii) Burst function could identify many keywords of sudden interests in a domain exhibited by the number of co-occurring keywords over a certain period time. Keyword terms detected from burst detection were "landscape", "ecosystem service", "species richness", "nature conservation" and "trees". According to these results, we could observe that the research object of longest lasting time was about "landscape" which was over a four-year period (2005–2008) and "trees" was taken as a research hot topic relatively early (2003–2005). The rest three hotspots in burst terms of ecological values were associated from 2008 to 2009. Along with innovative technologies and development of people's values, as can be seen from Fig. 2 and Table 3, the hot research areas were also in constant innovation. Meanwhile, new publication literatures not only assimilated the classic results, but also took further study on the ecological values from the new perspective.

Table 2
The statistics of co-authors' countries (institutions) of international ecological values research (frequency ≥ 7).

Frequency	Centrality	Country or institution	Frequency	Centrality	Country or institution
95	0.21	USA	14	0.00	Netherlands
43	0.03	Australia	13	0.01	Belgium
39	0.03	Spain	12	0.17	US Forest Ser
32	0.08	People's of China	12	0.00	Austria
27	0.06	England	11	0.00	Portugal
27	0.05	Canada	10	0.00	New Zealand
25	0.00	Italy	10	0.00	Mexico
24	0.22	Germany	9	0.06	Switzerland
17	0.00	Sweden	8	0.00	Poland
14	0.01	Greece	7	0.10	Brazil
14	0.00	France	7	0.00	Chinese Acad Sci

3.1.3. Analysis of co-citation authors and co-citation references

Parameter settings: Years Per Slice: 2; Node Types: Cited Reference: Threshold Interpolation (c, cc, ccv):3, 3, and 20.

In this section, we identified co-citation references network in ecological values domain. This could be seen in Fig. 3 by using a time line especially helped identify the growth of the field. Many palpable concentric circles, size of which was an indicator of the centrality of co-citation reference, were illustrated by separation of years of publications.

Our next work was to analyze the co-citation authors' network of international ecological values research (Fig. 4). Settings parameters: Years Per Slice:1; Node Types: Cited Author; Threshold Interpolation (c, cc, ccv):3, 3, 20. Figs. 3 and 4 showed the visualization of co-citation authors and references of this domain respectively. In spite of few prominent nodes, we could still recognize a number of relatively obvious nodes which represented classical literatures or authoritative scholars in various niches of ecological values domain. Another analysis resulted from these two figures was that many new representative authors or literatures sprang up continuously with strongly cooperative relations in each time slice.

For further comparative analysis, we also analyzed top cited authors and literatures using statistics of citation frequency of greatly influential authors and literatures (Tables 4 and 5). Here, we could observe some

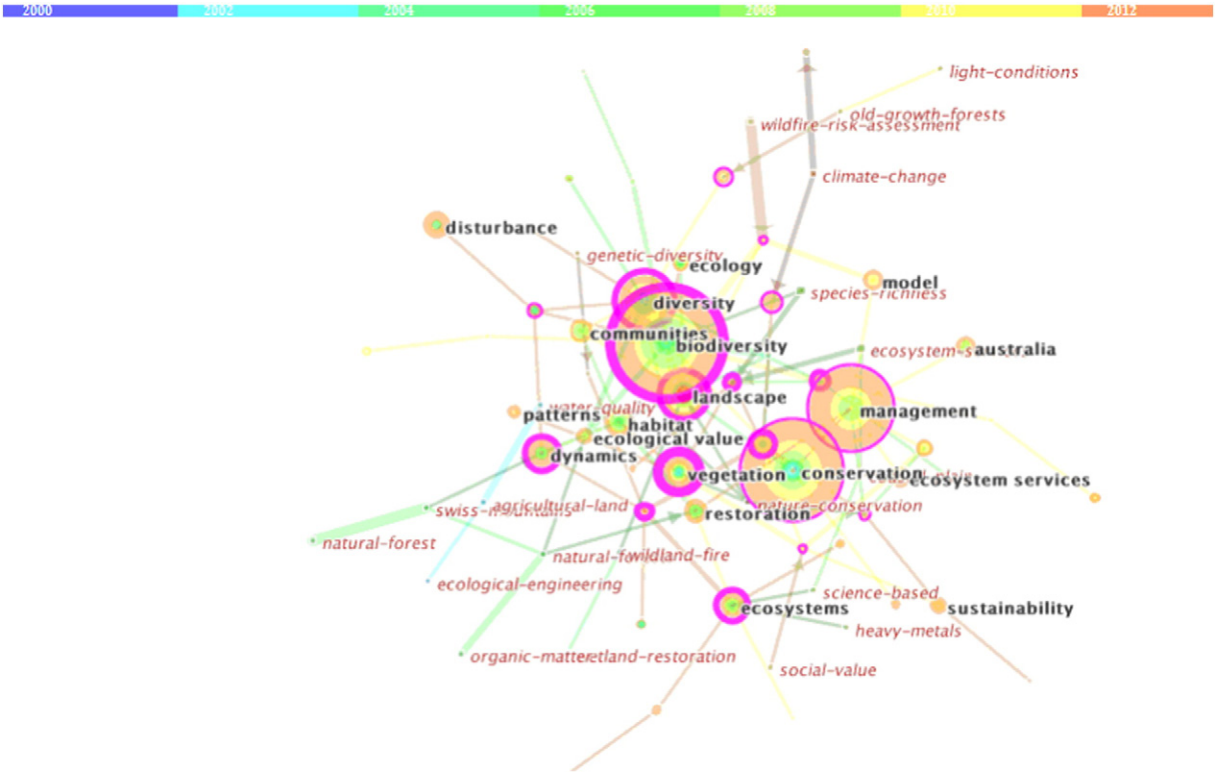

Fig. 2. Mapping on co-occurring keywords of international ecological values research.

Table 3
The statistics of co-occurring keywords of international ecological values research.

Frequency	Centrality	Keyword	Type*	Frequency	Centrality	Keyword	Type
58	0.57	biodiversity	R	7	0.05	protected areas	R
56	0.14	conservation	R	7	0.11	nature conservation	D
50	0.15	management	R	7	0.03	indicators	R
39	0.34	landscape	R	7	0.00	impact	R
33	0.30	diversity	R	7	0.05	fish	R
27	0.10	climate change	R	7	0.00	biodiversity conservation	R
24	0.43	vegetation	R	6	0.07	trees	R
23	0.22	dynamics	R	6	0.08	natural forest	D
22	0.09	ecological value	R	6	0.04	ecosystem services	D
20	0.07	habitat	R	6	0.05	climate change	D
19	0.05	restoration	R	5	0.05	urbanization	R
19	0.33	ecosystems	R	5	0.00	uncertainty	R
18	0.00	ecosystem services	R	5	0.00	soil	R
17	0.00	ecology	R	5	0.00	social value	D
17	0.00	disturbance	R	5	0.00	performance	R
16	0.00	patterns	R	5	0.00	invertebrates	R
16	0.02	model	R	5	0.01	coastal plain	D
16	0.09	communities	R	4	0.05	wildland fire	D
15	0.05	sustainability	R	4	0.00	water quality	D
15	0.00	Australia	R	4	0.00	light conditions	D
14	0.29	growth	R	4	0.13	environments	R
14	0.02	areas	R	4	0.00	agricultural land	D
13	0.24	birds	R	3	0.00	wildfire risk assessment	D
12	0.00	water	R	3	0.00	wetland restoration	D
12	0.05	assemblages	R	3	0.07	swiss mountains	D
11	0.00	policy	R	3	0.02	science based	D
11	0.13	framework	R	3	0.00	organic matter	D
11	0.12	fragmentation	R	3	0.05	old growth forests	D
11	0.00	forests	R	3	0.00	heavy metals	D
10	0.10	species richness	R	3	0.00	genetic diversity	D
10	0.26	responses	R	3	0.13	fuel management	R
9	0.00	community structure	R	3	0.00	ecological engineering	D
8	0.24	land use	R	3	0.00	beech forests	R
8	0.00	classification	R	3	0.05	annotation	R
7	0.02	species richness	D				

*The item of "Type" represents that the keywords are derived from the sources, where R shorts for reference and D shorts for detection respectively.

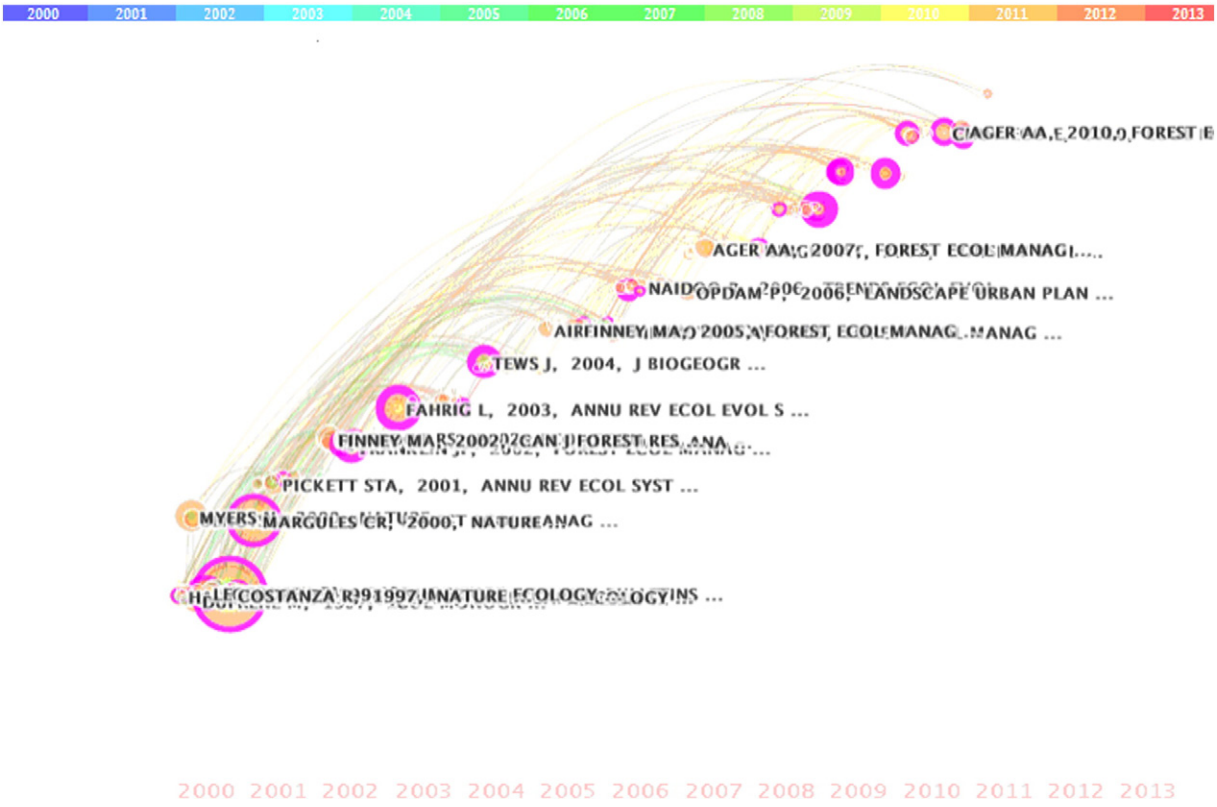

Fig. 3. Mapping on co-citation references of international ecological values research by time series.

top cited literatures which had high frequency or centrality, even both. For example, literatures from Costanza [7], Margules [8], Myers N [9],Fahrig L [10],NOSS RF [11] and Vitousek PM [12] possessed the critical status in ecological values research field. At the same time, it was easy to find, from these two tables, that more and more organizations like Millennium Ecosystem Assessment, International Union for Conservation of Nature and Natural Resources (IUCN), and Food and Agriculture Organization (FAO) also had some valuable results in ecological values

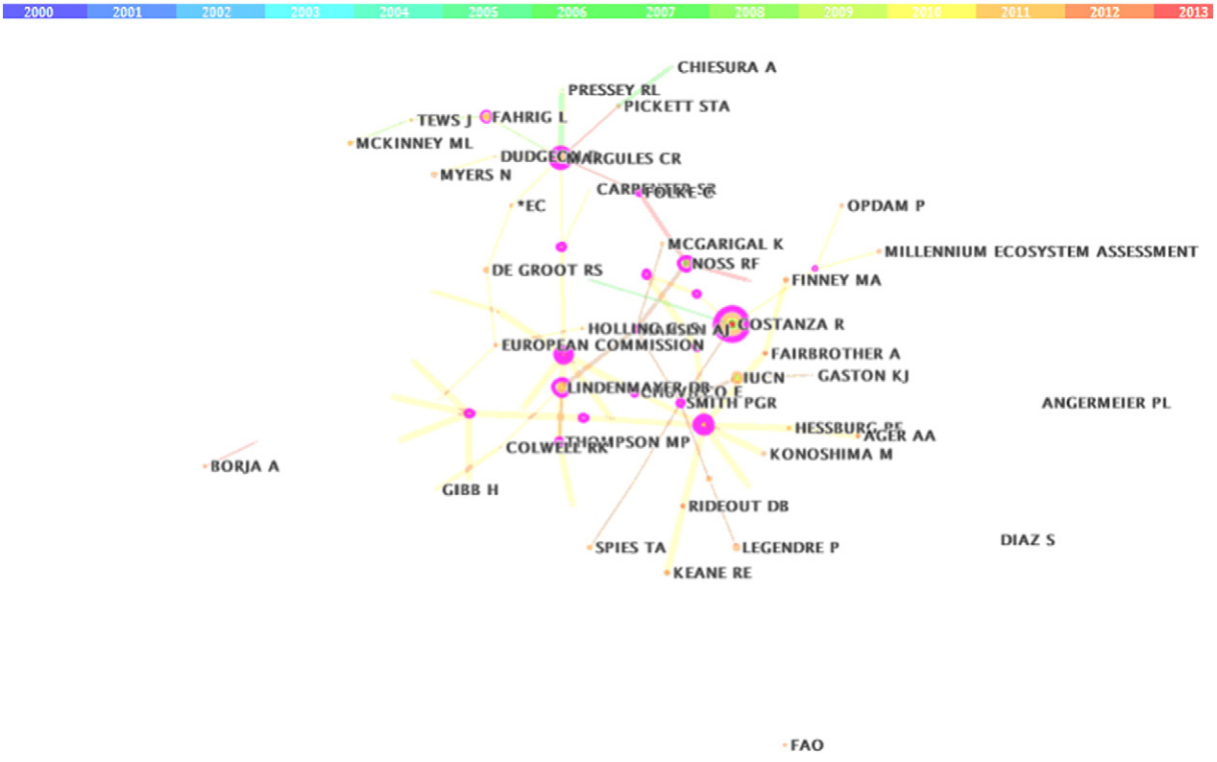

Fig. 4. Mapping on co-citation authors of international ecological values research.

Table 4
The literatures with great influence in co-citation network of international ecological values research (frequency ≥ 7).

Frequency	Centrality	Author	Year	Journal	Volume	Page
20	0.22	Costanza R	1997	NATURE	V387	P253
14	0.28	Margules CR	2000	NATURE	V405	P243
9	0.56	Fahrig L	2003	ANNU REV ECOL EVOL S	V34	P487
9	0.02	Myers N	2000	NATURE	V403	P853
8	0.21	Legendre P	1998	NUMERICAL ECOLOGY (Book)	–	–
7	0.04	Vitousek PM	1997	SCIENCE	V277	P494
7	0.00	Dufrene M	1997	ECOL MONOGR	V67	P345
7	0.00	Fairbrother A	2005	FOREST ECOL MANAG	V211	P28
7	0.05	de Groot RS	2002	ECOL ECON	V41	P393
7	0.00	Finney MA	2002	CAN J FOREST RES	V32	P1420
7	0.16	NOSS RF	1990	CONSERV BIOL	V4	P355
7	0.00	Finney MA	2005	FOREST ECOL MANAG	V211	P97

domain. These organizations played important roles to promote development of a combination of theory and practice. These results also were identical to previous co-occurring keywords analysis results.

3.1.4. Analysis of co-citation journals

Parameter Settings: Years Per Slice: 1; Node Types: Cited Journal; Threshold Interpolation (c, cc, ccv):3, 3, 20.

At last, we mapped the co-citation journals network of international ecological values research (Fig. 5), where we could easily identify many obvious nodes with clarity of connections between each node meaning large quantity of literatures published in many journals. Considering the time slice, most literatures about ecological values were published from 2000 to 2004. After that, continuously new finding appeared every year. Table 6 represented the frequencies and centralities of key journals about ecological values research. In terms of their frequencies of publication, not surprisingly, it could be seen that *Science* was still at the top in most publications refer to ecological values. Other top four frequency journals except *Science* were *Biological Conservation*, *Ecology*, *Nature* and *Conservation Biology*. In addition, here we observed that *Environmental Management* had the highest value of centrality among all the journals. Next four following journals were *Oecologi*, Proceedings of *the National Academy of Sciences* (PNAS), *Ecological economics* and *Ecosystems*. Interestingly, the most influential articles previous section mentioned were published by these journals signifying the great referential values in the field of ecological values research. According to burst detection, there were seven kinds of periodicals to publish a surge number of literature of ecological values in a certain period of time, including *Agriculture* (2006–2007), *Ecosystems & Environment* (2006–2007), *Bioscience* (2004–2006), *Ecological Modeling* (2011), *Forest Science* (2003–2006), *Mountain Research and Development* (2006–2008) and *Water Science and Technology* (2002–2007). The contents of co-citation journals covered widely, not only professional studies in ecology theory, but also various niche area practice researches such as agriculture and forestry, hydrology and mountain region.

Table 5
The authors with great influence in co-citation network of international ecological values research (frequency ≥ 7).

Frequency	Centrality	Author	Frequency	Centrality	Author
26	0.46	Costanza R	9	0.00	Pressey RL
14	0.29	NOSS RF	8	0.00	McGarigal K
14	0.56	Margules CR	8	0.23	Folke C
13	0.06	IUCN	8	0.06	de Groot RS
13	0.26	LINDENMAYER DB	8	0.05	Bengtsson J
12	0.10	Fahrig L	8	0.00	FAO
11	0.00	Myers N	8	0.05	Pickett STA
11	0.00	Finney MA	7	0.05	Fairbrother A
10	0.00	Legendre P	7	0.00	Keane RE
10	0.00	McKinney ML	7	0.00	Borja A
9	0.00	SPIES TA	7	0.00	Opdam P
9	0.08	Holling C. S.	7	0.00	Millennium Ecosystem Assessment

3.2. Literatures of CNKI

Built on domestic data from China Academic Journal Network Publishing Database of CNKI, we retrieved 315 literatures using accurate subject searching for "ecological assets" with time range from 1998 to 2013. At the same time, in order to analyze the relationship between ecological assets and ecological values, "ecological values" was also used to retrieve in title, abstract and keywords. In total, 5421 literatures were found. Then two data samples were exported as format "refworks" so that we could convert data to fit for CiteSpace analyzing. And we only analyzed co-occurring keywords for "ecological value", while not only co-occurring keywords but also two more aspects were analyzed for "ecological assets", co-authors' institutions network and co-authors network.

3.2.1. Analysis of co-occurring keywords

3.2.1.1. Ecological values. Parameter Settings: Time Slicing: Form 1983 to 2013; Years Per Slice: 2; Node Types: Keyword; Threshold Interpolation (c, cc, ccv):15, 15, 10.

In this section, we firstly draw a mapping on co-occurring keywords of domestic ecological values research (Fig. 6). Because we used "ecological values" for the search topic, the frequency of "ecological values" was up to 1109 times (the circle of this node would be much bigger than other nodes). In order to avoid impacting overall visual effect of this mapping, we hid the "ecological values" node. However, there were still many obvious nodes in the mapping, which signified a number of different points of domestic ecological values research, and these were not a great quantity of literatures about ecological values until 1992. Here, in Table 7, we could discover that six keywords, such as ecological values, sustainable development, wetland, ecosystem, ecological civilization and values, located in the top ten no matter from frequency or centrality. It meant that many research contents of domestic literatures involved in these six aspects. And many scholars had achieved certain results. Moreover, we found thirteen keywords should be hotspots in a certain period of time by means of detecting bursts terms (Fig. 7). By analyzing these burst keywords, we could easily determine that they were involved in various fields including ecology, economy, legal, even the ideological and political education. This result illustrated that the meaning of ecological values was not only used in natural science, but also has been extended to multi-disciplinary fields.

3.2.1.2. Ecological assets. Parameter Settings: Time Slicing: Form 1983 to 2013; Years Per Slice: 2; Node Types: Keywords; Threshold Interpolation (c, cc, ccv):2, 2, 20.

Fig. 8 represented co-occurring keywords network of domestic ecological assets research. It showed many palpable nodes in addition to "ecological assets" node. As well as in statistical data (Table 8), we

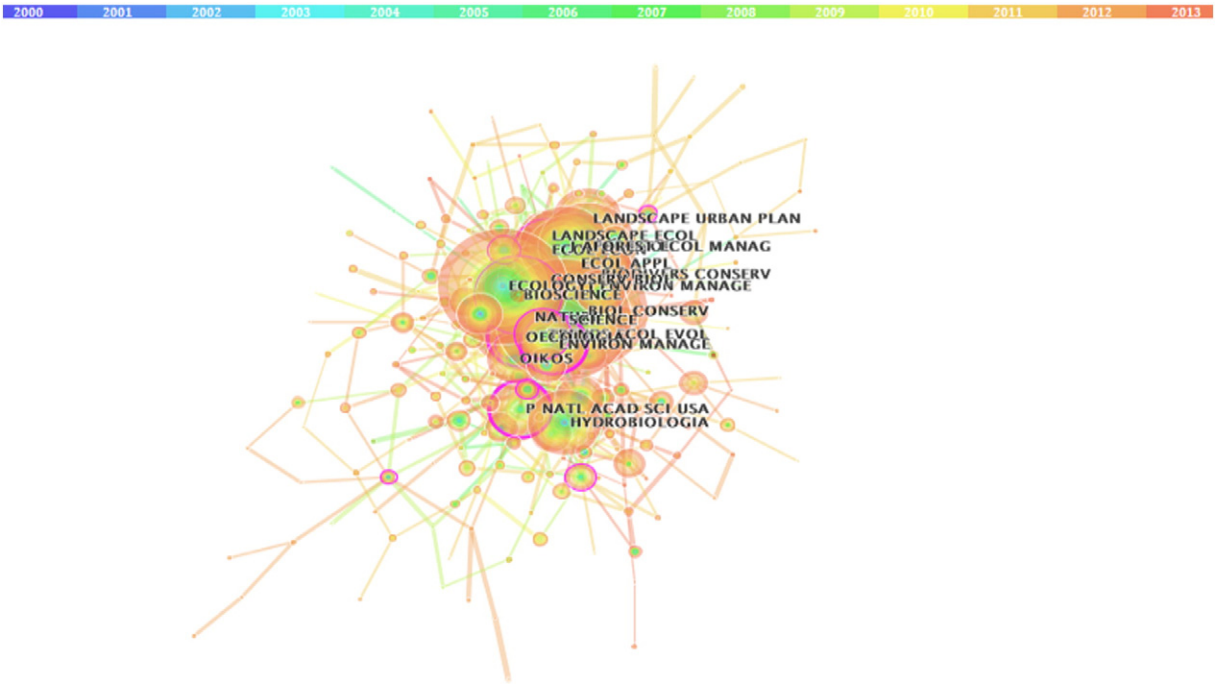

Fig. 5. Mapping on co-citation journals of international ecological values research.

could see frequencies and centralities of keywords represented by these nodes. Coincidentally, top ten frequency keywords had also high centrality even up to top five, which meant these keywords were hotspots in the study of ecological assets, no matter from popularity or importance. We took burst detection to further analyze co-occurring keywords network. The results indicated that three keywords had become research hotpots in a certain period of time, including ecological industry (2000–2003), forest ecological assets (2009–2013) and the fair values (2009–2013). From the view of time slice, we could obtain that many new keywords had always become research hotspots in each time period due to unceasing development of innovative research angles and methods for ecological assets. By being compared with co-occurring keywords of ecological values (Table 9), we found there were fourteen keywords in common. Keywords also revealed internal relations between ecological assets and ecological values. Research points of ecological assets were mostly around research hotspots in the study of ecological values, which focused on the study of sustainable development and ecosystem.

3.2.2. Analysis of co-authors' institutions

Here, in Table 10, we found that the frequency of research achievements of Chinese Academy of Sciences was so much higher than other institutions that meant this institution had absolutely authorities in the field of ecological assets research. Other colleges and universities like Beijing Normal University and Nanjing Forestry University were also effective and productive institutions in this field compared to other universities or colleges. Their achievements were already international, improving the academic level for China.

3.2.3. Analysis of co-authors

Parameter Settings: Time Slicing: Form 1983 to 2013; Years Per Slice: 2; Node Types: Authors; Threshold Interpolation (c, cc, ccv):2, 2, 20.

Fig. 9 showed the co-authors network of domestic ecological assets research in our dataset. This network was comprised of several clusters grouping the collaborative authors. The core researcher was in the center of the cluster, and isolated authors and those on the periphery of the co-authors clusters could be considered less collaborative. Overall, co-authors clusters were dispersedly distributed. Table 11 revealed that the top scholar contributing to ecological assets research was Rusong Wang, who had the most collaborative frequency up to twenty-six times and continuously published literatures about ecological assets. Contents and hotspots of these scholars' researches should be consisted with previous results of co-occurring keywords of ecological assets.

Table 6
The journals with great influence in co-citation network of international ecological values research (frequency ≥ 50).

Frequency	Centrality	Journal	Frequency	Centrality	Journal
119	0.06	SCIENCE	67	0.08	LANDSCAPE URBAN PLAN
118	0.09	BIOL CONSERV	67	0.07	HYDROBIOLOGIA
118	0.10	ECOLOGY	66	0.09	J ENVIRON MANAGE
110	0.02	NATURE	64	0.16	ECOL ECON
105	0.06	CONSERV BIOL	63	0.22	ENVIRON MANAGE
99	0.05	ECOL APPL	59	0.21	OECOLOGIA
88	0.01	FOREST ECOL MANAG	56	0.21	P NATL ACAD SCI USA
79	0.03	J APPL ECOL	56	0.09	OIKOS
78	0.10	BIOSCIENCE	55	0.15	TRENDS ECOL EVOL
74	0.03	BIODIVERS CONSERV	54	0.04	LANDSCAPE ECOL

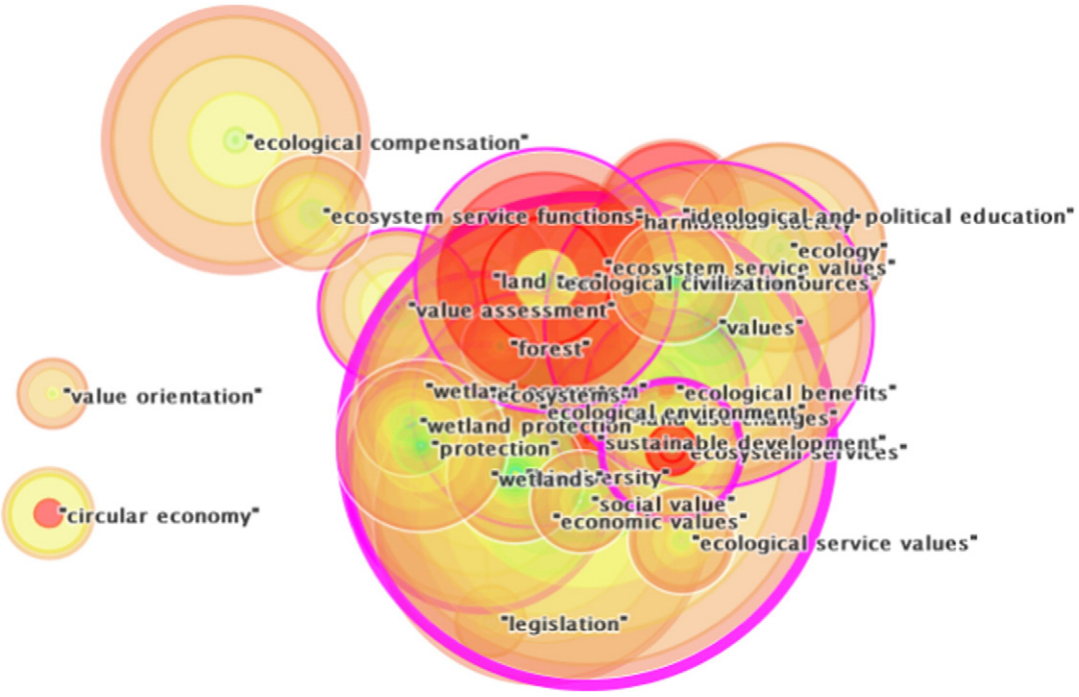

Fig. 6. Mapping on co-occurring keywords of domestic ecological values research.

4. Discussion

4.1. Searching topics of literatures of WoS

When we analyzed literatures from WoS database, the reasons for no choosing "ecological assets" as the topic were as follows: (i) When retrieving the literatures with "ecological assets" as subject words, only 22 literatures could be found. It was not suitable for generating visualization mapping; (ii) In international literatures, the words used to express "ecological assets" did not appear to have reached a consensus, and certain authors used other words to express the meaning of "ecological assets", such as "ecological capitals" or "natural assets". So it was inaccuracy if we only used just "ecological assets" to describe research contents of ecological assets; (iii) When researches about "ecological value" developed to a certain stage, "ecological assets" was generated by multidisciplinary integration. In other words, "ecological assets" was one detail aspect of "ecological values" research categories. Analyzing system structure and development process of ecological values was important in order to establish the macro background knowledge for ecological assets research. Based on the above three factors, we only selected "ecological values" as the research object for the international literatures analyses by using CiteSpace.

4.2. Concepts of "ecological assets"

Through the interpretation of knowledge mapping for ecological assets, it could be observed that scholars studying in different fields had similarities and differences in understanding and researching emphasis of ecological assets so that there were certain discrepancies in term of definition of "ecological balance". And the reasons leading to these discrepancies were mostly in order to coordinate the research methods and analytical technologies of follow-up studies. So it must be of great significance for adequate interpreting a variety of concepts of "ecological assets", summarizing the similarities and differences among various definitions, studying intensively the various academic achievements, and establishing a complete system of disciplines background.

4.2.1. Definitions from literatures of WoS

Although less number of international literatures directly regard "ecological assets" as the research object, on the basis of previous

Table 7
The statistics of co-occurring keywords of domestic ecological values research (frequency ≥ 30).

Frequency	Centrality	Keyword	Frequency	Centrality	Keyword
1109	0.98	ecological values	69	0.00	forest resources
219	0.48	sustainable development	68	0.07	Ideological and political education
156	0.00	economic values	68	0.13	land use changes
150	0.17	values	67	0.05	biodiversity
125	0.00	ecological compensation	66	0.21	ecosystem services
121	0.00	ecological environment	60	0.00	ecosystem service functions
121	0.18	ecological civilization	55	0.00	social value
120	0.31	wetlands	50	0.02	wetland protection
112	0.21	ecosystems	49	0.00	ecological service values
103	0.00	ecology	46	0.00	circular economy
91	0.12	ecological benefits	41	0.00	legislation
80	0.04	protection	41	0.03	forest
76	0.01	ecosystem service values	40	0.00	value orientation
75	0.12	value assessment	34	0.00	wetland ecosystem
70	0.11	land use	30	0.01	harmonious society

keywords	Year	Strength	Begin	End	1983 – 2013
"circular economy"	1983	10.1903	2005	2008	
"ecological civilization"	1983	8.2038	2010	2013	
"ecological benefits"	1983	7.9092	1986	2001	
"ecological environment"	1983	7.1308	1992	2003	
"sustainable development"	1983	6.7737	1998	2001	
"harmonious society"	1983	5.7977	2006	2007	
"ecological values"	1983	5.5054	2006	2006	
"wetland ecosystem"	1983	4.2393	2011	2013	
"ecosystems"	1983	4.1184	1988	1998	
"legislation"	1983	4.0123	2009	2009	
"wetland protection"	1983	3.8518	2003	2003	
"ideological and political education"	1983	3.6372	2009	2013	
"ecosystem services"	1983	3.4961	2003	2007	

Fig. 7. The burst keywords of domestic ecological values research.

knowledge mapping analyses of "ecological value" (Figs. 3 and 4, Tables 4 and 5) we could find that there were still more literatures around researching the general definition of "ecological assets", usually involving in two aspects of "natural resources" and "ecosystem services". The researches about "ecosystem services" were hotspots and emphases in the study of "ecological assets". In some cases, we could consider that the concept of "ecological assets" was due to creating the concept of "ecosystem services", when some scholars attempted to integrate multi-disciplinary knowledge and methodology into research about ecosystem, especially, combining with social and economic domains.

Natural resources could provide all kinds of products for human's living needs, so the study of natural resource values had begun when people used these products. With the development of the society, more and more products from natural resources were used by humans. Then the "ecological assets values" brought about by these resources gradually became the focus of research. However, as changes of the global ecological environments and scientific developments, scholars had realized that all economic, ecological and social benefits from natural resources for humans not only were embodied in the tangible resources, but also reflected on the potential benefits of recessive ecosystem services, which was inevitably ignored for humans and creatures.

The book "*Nature's Services*: *Societal Dependence on Natural Ecosystem*"[13] published by Daily became a cornerstone for studying ecosystem services in Western countries. This book systematically presented

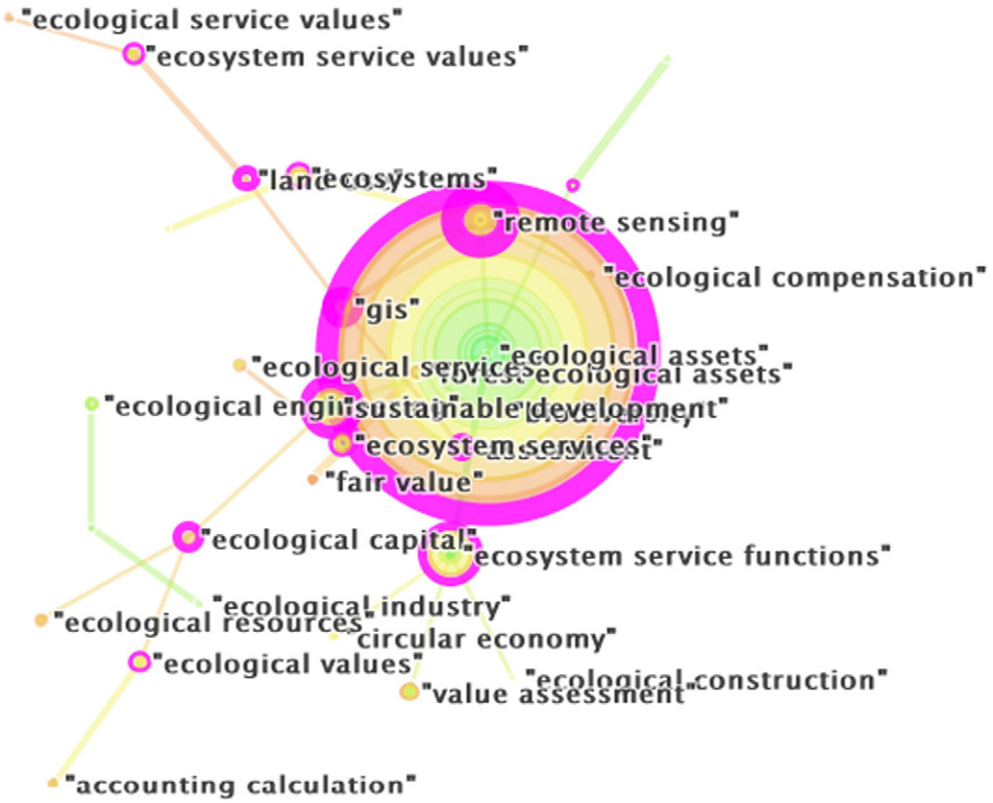

Fig. 8. Mapping on co-occurring keywords of domestic ecological assets research.

Table 8
The statistics of co-occurring keywords of domestic ecological assets research (frequency ≥ 5).

Frequency	Centrality	Keyword	Frequency	Centrality	Keyword
117	0.53	ecological assets	7	0.00	fair value
22	0.29	sustainable development	7	0.07	GIS
19	0.30	remote sensing	7	0.07	ecosystem service functions
15	0.18	ecosystem service functions	7	0.04	eco-agriculture
15	0.04	ecosystems	7	0.01	assessment
14	0.42	value assessment	6	0.01	arid zone
13	0.05	biodiversity	6	0.11	circular economy
11	0.32	ecosystem services	6	0.00	complex ecosystem
10	0.00	ecological environment	6	0.00	ecological compensation
10	0.11	ecological services	6	0.00	accounting calculation
9	0.00	forest ecological assets	6	0.01	ecological benefits
9	0.10	ecosystem service values	6	0.08	urban forest
9	0.00	ecological values	5	0.00	China
8	0.02	ecological industry	5	0.06	grassland ecosystem
8	0.08	ecological capital	5	0.00	land use
8	0.11	ecological resources	5	0.00	ecological economy
8	0.06	ecological engineering	5	0.00	ecological construction
8	0.04	ecological service values	5	0.06	natural capital

the concept of ecosystem services, research process, evaluation methods, regional ecosystem services and all kinds of ecosystem services values. Costanza et al. [7] published an article named "*The value of the world's ecosystem services and natural capital*". The authors suggested to divide the global ecosystem services into 17 types and evaluated ten kinds of ecosystems. After that, more and more scholars started to research ecosystem services and evaluate their values. Scholars studied from various perspectives, like region, basin and individual, introduced classical economics evaluation into ecology domain. As a result, many new words were generated in some overlapping fields. It was also due to this situation, along with concept of "ecological assets" was created, many emerging contents around that were extended out for research, such as green GDP accounting, the national ecological footprint, ecosystem productivity etc. These new hotspots were all elaborations and innovations in ecological assets research.

4.2.2. Definitions from literatures of CNKI

Using cluster analysis to study prominent researchers and publications, Fig. 9 mapped the collaboration among the domestic authors of ecological assets research in our dataset. The co-authors network showed several clusters grouping the most collaborative authors. According to detailed analysis of the literatures published by these groups, we summarized some major definitions of "ecological assets" based on different research perspectives, methods and emphases:

(i) Authors from the largest clustering group, including Hu [14,15], Wang [16], Jiang [17] and Yan [18], determined the definition of "ecological assets" from interdisciplinary explanation between ecology and economics. Ecological assets depended on the reciprocal values between humans (creatures) and environments. Their interaction formed entities serving for ecosystem economic goals. The entities comprised four parts: (a) all kinds of tangible material assets, such as solar energy, atmosphere, hydrology, land, biology, landscape and other natural assets; (b) artificial ecological assets involved in additional human labor, such as water conservancy, environmental protection facilities, roads and green space;(c) intangible ecological assets generated by ecosystem, including ecological niches, combination of geomancy and climate conditions;(d) humanity ecological assets, including logistics, markets and cultures. These assets had clear ownership rights. They focused on expressive forms of ecological assets, and emphasized the ecological asset properties, structure, function as well as some characteristics like value, dynamic and evolutionary.

(ii) Some authors, like Shi [19,20], Pan [21], Zhu [22] and Li [23], considered that ecological assets were the summation of the direct values of biological resources (e.g., food, material, fuel and drug) and the values of ecological service functions (e.g., cleaning the air, soil & water protection and biodiversity conversation) in ecosystems as significant national assets and strategic resources. They assessed the quantities and qualities of ecological assets, especially variation tendency, by using Remote Sensing (RS), Global Position System (GIS) and Geographic Information System (GIS). In their literatures, as we know, the component of ecological assets generally concentrated in the contents and processes which could be quantitative measured by RS-based methods.

(iii) Zhou [24] and Chen [25] also measured ecological assets by using Remote Sensing so that the definition used in their literatures

Table 9
The statistics of co-occurring keywords between ecological assets (I) and ecological values (II).

Keyword	Frequency I	Frequency II	Total frequency	SequenceI	SequenceII
ecological values	9	1109	1118	7	1
sustainable development	22	219	241	1	2
ecological environment	10	121	131	6	4
ecological compensation	6	125	131	11	3
ecosystems	15	112	127	2	5
ecological benefits	6	91	97	12	6
value assessment	14	75	89	3	8
ecosystem service values	9	76	85	8	7
biodiversity	13	67	80	4	10
ecosystem services	11	66	77	5	11
land use	5	70	75	14	9
ecosystem service functions	7	60	67	10	12
ecological service values	8	49	57	9	13
circular economy	6	46	52	13	14

Table 10
The statistics of co-authors' institutions of domestic ecological assets research (frequency ≥ 5).

Frequency	Institution
66	Chinese Academy of Sciences
19	Beijing Normal University
12	Nanjing Forestry University
8	Zhongnan University of Economics and Law
7	Peking University
6	China Agricultural University
5	Chinese Academy of Agricultural Sciences
5	Zhejiang Agriculture and Forestry University
5	Ministry of environmental protection
5	Northeast Forestry University

had some similarities to the previous views. Despite research emphases were both covered resources values and ecosystem service functions values, Zhou et al. divided structure of ecological assets values into four categories including direct use values, indirect use values, option values and existence values. This definition was combined with traditional economic connotation and put forward so as to extensively carry out the measurement of ecological assets based on economic benefits.

(iv) A few other authors, such as Wen [26] and his student Qiao [27] and Liu [28], took into account the aspect of accounting calculation to define the concept of 'forest ecological assets'. The main standpoint was that the forest ecological assets should be considered as all forest ecological resources certificated by relevant authorities due to past transactions or events by forest ecological accounting subjects. The ecological resources were formed by ecological capital circulation, owned or controlled by forest protection units, and could be transacted for property rights with users of forest ecological resources as well as expected economic benefits measured by money in the future. The resources consist of forest ecosystem service functions (e.g., carbon sequestration and oxygen release, cleaning the air, water & soil protection and biodiversity conversation), forest ecological current and fixed assets, and some intangible ecological assets (such as forest harvest and management rights). Though the point given expression to narrow sense of definition of forest ecological assets had limitation on ranges of application because of different divisions between tangible and intangible ecological assets, the study around that also made novel contributions to research ecological assets, for instance, the research illustrated the characteristics of ecological assets and focused on impacts by economy or markets.

(v) In addition to the above opinions, there were still some worthy viewpoints about definitions of 'ecological assets'. Gao [29] thought ecological asset should be included in all can provide humans with services and welfare of natural resources and ecological environment, after a comprehensive analysis on different definitions from Chen [30], Huang [31] and Wang [32]. Services and welfares incorporated not only tangible resource supplies, but also contained intangible ecological services. Physical form of ecological assets could be entered into the market for presenting values, whereas invisible ecological assets could be unable to appraise in the commodity market for public welfare and scarcity attributes. But the effects of these form ecological assets must not be ignored when we evaluated ecological assets.

4.2.3. Key points of "ecological assets" definition

Comprehensive consideration both international and domestic research results of ecological assets, we found that the various views on the definition of "ecological assets" were not completely consistent. In spite of this, we still summarized some connotation characteristics in common: (a) ecological assets were produced within the category of ecological values, combined with unities of natural resources values and ecosystem services values, so we should pay attention to the combination of two aspects at the same time when researched on that;

Fig. 9. Mapping on co-authors network of domestic ecological assets research.

Table 11
The main research results of domestic core scholars (frequency ≥ 5).

Frequency	Author	Research contents
26	Wang Rusong	Chinese ecological assets assessment; construction and management for ecological city; ecosystem engineering; ecological industry; complex ecology and circular economy
9	Shi Peijun	ecological assets assessments; ecological assets quantitative measurement by using remote sensing; biological resources development and ecological construction; region sustainable development
8	Pan Yaozhong	ecological assets quantitative measurement by using remote sensing; ecological construction; region sustainable development
7	Jiang Jushegn	ecosystem values assessments; ecological assets and sustainable development; ecosystem engineering
6	Liu Meijuan	ecological assets of forests; accounting of the fair values of natural resources; forest ecological assets; accounting of biodiversity values
6	Hu Dan	ecological assets assessments; urban ecosystem; ecosystem service function values assessments; complex ecology and circular economy
6	Xie Gaodi	ecological assets assessments; ecosystem service function values assessments; ecological economy; ecological resources
6	Yan Jingsong	ecosystem engineering; ecological construction; ecological industry
6	Wen Zuoming	forest ecological assets; accounting of the fair values of natural resources; accounting of forest ecological values
6	Zhou Kefa	ecological assets quantitative measurement by using remote sensing; ecosystem service function values assessments;
6	Qiao Yuyang	accounting of forest ecological values
6	Zhu Wenquan	ecological assets quantitative measurement by using remote sensing; ecological assets assessments; region sustainable development
5	Chen Xi	ecological assets quantitative measurement by using remote sensing; ecological assets assessments;
5	Zhang Qing	ecological assets quantitative measurement by using remote sensing; ecological assets assessments;
5	Gao Jixi	ecological assets assessments; region ecology
5	Li Jing	ecological assets quantitative measurement by using remote sensing; ecological assets assessments;

(b) ecological assets were constitutive of tangible and intangible assets, even the contents of two aspects were not unanimous due to different understandings in different disciplines, but evaluation of intangible ecological asset was often emphasis and difficulty in this domain; (c) ecological assets had dual natures of economics and publicity. Ecological assets had the ownership following traditional economic values so that should be quantitatively reflected in the market. Nevertheless, ecological assets brought public welfare services to humans (creatures), to some extent, ecological assets owned by all humankind (creatures) in common cannot be measured in the currency markets for their values.

5. Conclusion

In this paper, we had presented a detailed visual and scientometrics survey of ecological assets/values covering all relevant articles from WoS and CNKI from 2000 to 2013. Our approach in this article was based on knowledge mapping tools (CiteSpace). Our analysis had produced some interesting results with statistical data of different objects (e.g., country, author, reference, keyword, and journal). Then, we found out some typical results by interpreting different relational matrixes including co-occurring and co-citation networks. Next, we compared similarities and differences of the definition of "ecological assets" between international and domestic literatures. Sequentially, we concluded key points that should be paid attention when we defined "ecological assets". Finally, we made the prediction about research trends and hotspots in this domain to lay the groundwork for follow-up study.

According to different understandings of concepts of "ecological assets" and research points from domestic and foreign scholars, the trend of ecological assets research had not only confined to evaluate values of natural resources or ecosystem services, but paid more attention to internal mechanism by measuring models and technologies including earning, depleting, losing and transferring of the ecological assets in different regions or ecological economies. By predicting tendencies and internal driving forces of the ecological environment change and analyzing ecological environment carrying capacities, it should seek accumulations of ecological assets. The ultimate goal of ecological assets research was to achieve a stable and sustainable development between humans (creatures) and environmental ecosystems.

All conclusions of this article were based on literatures from WoS and CNKI by using CiteSpace and the aim was to introduce a method for extracting useful information from large scientific literatures. Because of the differences in quantity and quality of analysis samples, some conclusions might be one-sided. So we will continue to enhance this research in the future.

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