Postprint: Effectiveness Analysis of the National Specimen Information Infrastructure (NSII) in Supporting Biodiversity Research

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Abstract

With the rapid development of biodiversity informatics, an increasing amount of open biological data is being utilized by researchers. Analyzing research hotspots and development trends in China's biodiversity field through the lens of a public data platform enables biodiversity workers and decision-makers to gain timely understanding of the current status and directions of biological research in China, providing decision-making support for biodiversity conservation. This paper conducted a full-text search on CNKI and Google Scholar for literature from 2013 to 2023 using the "National Specimen Information Infrastructure (NSII)" and related terms as search objects, retrieving a total of 1,070 NSII-supported documents, including journal articles (822), dissertations (233), popular science articles (5), conference papers (6), and reports (4). Based on the 822 NSII-supported journal articles, this study employs bibliometric methods and techniques to investigate the current status, hotspots, and trends of biodiversity research supported by NSII from perspectives such as publication patterns, research themes and hotspots, and research institutions. Keyword co-occurrence network mapping analysis reveals that biodiversity research hotspots based on data platforms concentrate in five areas: species distribution analysis and modeling, climate change, taxonomy, biodiversity research, and research platform construction. Currently, the field of biodiversity informatics in China is developing rapidly; future efforts should focus on enhancing data source construction, resource integration, sharing capabilities, operational capacities, and international cooperation to continuously advance biodiversity scientific research.

Full Text

Preamble

Analysis of the effectiveness of the National Specimen Information Infrastructure (NSII) in supporting scientific research on biodiversity

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Abstract: With the rapid development of biodiversity informatics, an increasing amount of open biological data has become available to researchers. Analyzing research hotspots and development trends in China's biodiversity field through the lens of a public data platform can help biodiversity workers and decision-makers stay informed about the current status and directions of biological research in China, providing decision support for biodiversity conservation efforts.

This study conducted a full-text search on CNKI and Google Scholar for literature from 2013 to 2023 using search terms related to the National Specimen Information Infrastructure (NSII), retrieving a total of 1,070 NSII-supported documents, including journal articles (822), dissertations (233), popular science articles (5), conference papers (6), and reports (4).

Based on the 822 NSII-supported journal articles, this paper employs bibliometric methods to investigate the current status, hotspots, and trends of biodiversity research supported by NSII from perspectives including publication patterns, research topics and hotspots, and research institutions. Keyword co-occurrence network analysis reveals that biodiversity research based on data platforms concentrates on five areas: species distribution analysis and modeling, climate change, taxonomy, biodiversity research, and platform construction. While biodiversity informatics is developing rapidly in China, future efforts must focus on improving data source construction, resource integration, sharing capabilities, professional competencies, and international cooperation to continuously advance biodiversity scientific research.

Keywords: biodiversity informatics, biodiversity research, National Specimen Information Infrastructure (NSII), data

1.1 Data Sources

This study utilized CNKI and Google Scholar as source databases, focusing on Chinese and English literature related to NSII. Based on a comprehensive investigation of the current status of biological research and knowledge application, the search terms were determined to be: "National Specimen Resource Sharing Platform," "National Specimen Sharing Platform," "National Herbarium," "National Specimen Repository," "National Specimen Platform," "National Specimen Resource Platform," "nsii.org.cn," "NSII," and "National Specimen Information Infrastructure." The search covered literature published between 2013 and 2023, including journal articles, dissertations, popular science articles, conference papers, and reports, with the search conducted up to April 1, 2023. After deduplication, cleaning, and manual verification, 1,070 documents were finalized as the research corpus for the NSII-supported literature database. The database's main fields include title, year, document type, journal name, first author, corresponding author, nationality, research type, geographical scale, research object type, funding source, etc. (The database is available at http://nsii.org.cn/2017/dataservice.php).

1.2 Analytical Methods

This study employs Excel and VOSviewer software for bibliometric and visualization analyses. Excel was used for structured storage, management, and statistical analysis of literature information, enabling direct extraction and analysis of publishing journals, funding sources, research teams, research institutions, and keywords. The geographical scales mentioned in the literature were manually identified and annotated to analyze the spatial scope of research objects. Research objects were manually identified and categorized to analyze the taxonomic groups of interest to researchers. Other databases mentioned in the literature were also manually identified and annotated to analyze the connectivity among biological databases.

Keywords can directly reflect the research objects or themes of literature, and analyzing keyword clustering can reveal research hotspots. The keyword co-occurrence network maps generated using VOSviewer software provide visual representations of keyword clustering, thereby revealing research hotspots. In these maps, nodes represent keyword frequency, node size indicates occurrence count, and connecting lines represent relationships between keywords (van Eck & Waltman, 2010).

2.1 Basic Publication Patterns

From 2013 to 2023, NSII supported the publication of 822 journal articles, 233 dissertations, 5 popular science articles, 6 conference papers, and 4 reports. As journal articles better represent the research level within a discipline, this study analyzed the distribution of NSII-supported papers across different journals. The results show that *Biodiversity Science*, *Frontiers in Plant Science*,

Guihaia, and *Research Information Technology and Application* published the most articles. The top 20 journals by publication count are listed in Table 1 .

Among the 822 NSII-supported journal articles, 767 mentioned funding sources. To analyze funding patterns, these sources were categorized into six types: ministry and research institution projects, provincial/municipal projects, university projects, international cooperation projects, enterprise projects, and other types. Ministry and research institution projects funded the most papers (628), followed by provincial/municipal projects (355). University and international cooperation projects funded fewer papers (83 and 22, respectively). Funding sources not belonging to the above five categories were classified as other types, supporting 59 papers.

2.2 Research Geographical Scales

Through manual annotation, the 822 journal articles were statistically analyzed by research geographical scale. The results show that NSII supported 80 global-scale, 267 national-scale, 327 regional-scale, and 148 other-scale studies. In this study, global scale refers to research areas involving two or more countries; national scale refers to studies covering an entire country; regional scale refers to study areas at or above the county level but below the national scale; and other scale refers to studies that did not mention or clearly specify the research area.

2.3 Research Object Types

Through manual annotation, the 822 journal articles were statistically analyzed by research object type. The results show that NSII supported research on plants (670 articles), animals (45 articles), organisms (42 articles), microorganisms (9 articles), and other object types (such as meteorites, museums, vegetation, etc.) (56 articles). Plant research accounted for 81.51% of the total journal articles. For a given paper, if the research objects included two or three categories among plants, animals, and microorganisms, it was classified as "organisms"; if it involved only one category, it was not classified as "organisms."

2.4 Research Hotspots and Their Evolution

To finely investigate the hotspot directions of NSII-supported research, this study analyzed keywords from 402 Chinese journal articles and 420 English journal articles (referring to articles published in Chinese or English language academic journals, respectively). Based on keyword co-occurrence network maps (Figure 1 [Figure 1: see original paper], Figure 2 [Figure 2: see original paper]), the hotspot research themes in biodiversity supported by NSII from 2013 to 2023 can be summarized into five areas: species distribution analysis and modeling, climate change, taxonomy, biodiversity research, and platform construction.

Quantitative analysis of keyword frequencies in Chinese and English articles

reveals that papers containing keywords such as MaxEnt model and climate change were the most numerous. MaxEnt model belongs to the species distribution analysis and modeling theme, which also includes keywords like potential distribution, distribution pattern, species distribution, geographical distribution, and ArcGIS. The climate change theme includes keywords such as climate change, climate factors, habitat, suitable area, and environmental factors. Taxonomy theme keywords include new records, plant classification, herbarium specimens, and phylogeny. Biodiversity research theme keywords include species diversity, biodiversity, biodiversity conservation, and endangered species. Platform construction theme keywords include digitization, database, and citizen science. The top 30 keywords by frequency in NSII-supported Chinese and English journal articles from 2013 to 2023 are presented in Table 2 and Table 3 .

Analysis of annual keyword evolution (Table 4 and Table 5) shows that the top five keywords in Chinese journal articles over the past five years were: MaxEnt model, climate change, potential distribution, distribution pattern, and geographical distribution. Temporal analysis indicates that MaxEnt model and climate change showed an upward trend in Chinese publications from 2018 to 2021, with a slight decline in 2022. The top five keywords in English journal articles over the past five years were climate change, MaxEnt model, phylogeny, China, and biodiversity conservation. Temporal analysis shows that MaxEnt model and climate change maintained an upward trend in English publications from 2018 to 2022. Overall, MaxEnt model and climate change are hotspot keywords in both Chinese and English articles and across years, representing key research hotspots supported by NSII.

2.5 Research Team Profiles

This study conducted statistical analysis of research teams and nationalities in NSII-supported journal articles. Using corresponding authors and first authors as team representatives, the study analyzed Chinese and English journal article teams separately (Figure 3 [Figure 3: see original paper], Figure 4 [Figure 4: see original paper]). English names among the top 20 most productive corresponding authors were translated to merge identical authors.

Statistical results show that the most prolific users of NSII data were teams led by He Xingjin, Wang Zhiheng, Ma Keping, Huang Linfang, and Pan Kaiwen. The top 20 research teams by publication count are listed in Table 6 .

Research team nationalities were determined based on the country of affiliation of all authors in each paper. Analysis of all researchers from the 822 journal articles revealed contributions from 50 countries, including China, the United States, Australia, the United Kingdom, and Germany. The top 20 countries by publication count are shown in Table 7 . Team compositions were categorized into domestic teams, Chinese-foreign collaborative teams, and foreign teams, accounting for 670 articles (81.51%), 139 articles (16.91%), and 13 articles (1.58%),

respectively.

2.6 Major Research Institutions

Analysis of the 822 NSII-supported journal articles identified the top 10 research institutions by publication count, as shown in Table 8 , including University of Chinese Academy of Sciences, Institute of Botany (Chinese Academy of Sciences), Kunming Institute of Botany (Chinese Academy of Sciences), Peking University, and Sichuan University. These top 10 institutions collectively contributed 338 articles (41.12%).

Note: Since a single paper may involve multiple research institutions and thus be counted separately by different institutions, the 338 articles do not equal the sum of articles from the 10 institutions in Table 8.

2.7 Connectivity with Similar Databases

Based on whether NSII data were cited, NSII-supported papers can be divided into two categories: those that cited NSII data and those that only mentioned NSII. If a paper cited NSII data while also citing other similar databases, these databases were considered to have connectivity.

Statistical results show that among the 822 journal articles, 651 (79.20%) cited NSII data, with 491 (59.73%) also citing other similar databases. Among the other databases cited, the Chinese Virtual Herbarium (CVH), Global Biodiversity Information Facility (GBIF), Plant Photo Bank of China (PPBC), and Chinese Field Herbarium (CFH) appeared most frequently, in 347 (42.21%), 266 (32.36%), [text incomplete in original]

3.2 Multi-Dimensional Use of NSII Data

The term biodiversity inherently carries biogeographical implications, primarily encompassing three levels of diversity: genetic, species, and ecosystem (Ma, 1993). Among NSII-supported journal articles, 79.20% directly cited NSII data. In terms of research scales supported by the data, NSII data have played a role across different geographical scales, from county-level and below (Zhou et al., 2019; Xue et al., 2020) to global scales (Liu et al., 2021; Du et al., 2023).

The ability of NSII data to support biodiversity research at different geographical scales is related to the characteristics of NSII data. NSII is currently the largest biological specimen data platform in China, collecting various types of biological specimen data. The distribution data records on NSII biological specimens contain relatively detailed geographical locations or even latitude and longitude coordinates, and most have been identified by taxonomists, ensuring high data quality. This important species information and corresponding distribution data form the foundation for supporting biodiversity research across different geographical scales.

In terms of research objects, NSII data have supported studies on various taxonomic groups including plants (Guo et al., 2020; Liu et al., 2023), animals (Jiang et al., 2019; Huang et al., 2021), and microorganisms (Wei et al., 2021; Sun et al., 2021), covering research levels from genetic (Tong et al., 2016; Wang et al., 2021) and species (Wang et al., 2019; Mou et al., 2019) to ecosystem scales (Yu et al., 2019; Liu et al., 2022). NSII-supported plant research significantly outnumbers animal and microbial research, with more teams and personnel studying plants (Figure 3, Figure 4, and Table 8). This is not only related to the quantity and quality of NSII's plant data but also because the leading unit of NSII is the Institute of Botany, Chinese Academy of Sciences, which has conducted more promotion in plant-related fields.

3.3 NSII-Supported Research Hotspots

Based on 822 NSII-supported journal articles as the data source, this study used VOSviewer software to analyze research hotspots and development trends. The results identify MaxEnt model and climate change as two current hotspots in biodiversity research.

MaxEnt model is a type of species distribution model widely applied in species resource management and sustainable utilization (Liu et al., 2018), species conservation decision-making (Miao et al., 2020; Ye et al., 2022), invasive species prevention and control (Du et al., 2021; Chen et al., 2021; Xu et al., 2022), and studies on climate change impacts on species distribution (Zhou et al., 2021; Niu et al., 2021; Chen et al., 2022).

Climate change represents the most severe environmental challenge facing humanity. The IPCC Fifth Assessment Report indicates that global temperature increases may exceed 1.5°C by the end of the 21st century compared to 1850-1900, potentially surpassing 2°C under RCP6.0 and RCP8.5 scenarios (Stocker et al., 2014). Climate change profoundly affects plant growth, geographical distribution, and population sizes (Pounds et al., 2006). Growing evidence suggests that climate warming may reduce suitable habitat ranges for plants, forcing migration to higher altitudes and latitudes. However, climate change impacts vary among plant species, making studies of plant responses crucial for biodiversity conservation. With advancing climate change research and geographic information science, species distribution models have become essential tools for investigating climate change impacts on species distributions (Zhao et al., 2019).

In summary, MaxEnt model and climate change represent key data application directions among NSII-supported research hotspots. Species distribution data form the foundation for MaxEnt model applications and studies on climate change-induced distribution shifts. The construction of specimen-based species distribution data has benefited significantly from biodiversity informatics development. Biodiversity informatics is an emerging discipline that collects, organizes, integrates, analyzes, predicts, and disseminates biodiversity-related data to inform conservation and sustainable use decisions (Hardisty & Roberts, 2013).

Data constitute the foundation of biodiversity informatics, with species names and distribution information being most critical. China's species data core includes biodiversity inventories, specimen data, color photographs, literature and floras, and data generated from major projects. Analyzing NSII-supported papers also represents an analysis and prediction of research hotspots supported by biological distribution data.

3.4 International Impact of NSII Data

The statistics on Chinese and English journal articles and research teams demonstrate NSII's significant international influence. Many domestic research teams prefer to publish English papers using NSII data, such as the teams of He Xingjin and Wang Zhiheng. Meanwhile, teams proficient in publishing English papers using NSII data rarely attempt to publish Chinese papers with NSII data. Chinese scholars publishing English papers has enhanced NSII's international influence.

From 2013 to 2019, NSII specimen data experienced rapid growth, with annual increments of 600,000 to 1 million records (Figure 5 [Figure 5: see original paper]). High-quality data (Qian et al., 2018), an open sharing philosophy, and continuously growing data resources form the foundation for NSII data's broad application.

Data growth and continuous promotion have increased NSII's influence, with more domestic and international institutions and teams using NSII data to support research. From 2013 to 2023, the number of journal articles supported by NSII data has shown a yearly increasing trend (Figure 6 [Figure 6: see original paper]). NSII data have become more closely connected with similar foreign databases. Among papers citing NSII data, over one-third also cited GBIF data, with some papers primarily using GBIF data as their research object (Qian et al., 2022; de Araujo et al., 2022).

As data continue to be opened, NSII specimen data are increasingly integrated with GBIF data. As of May 4, 2023, NSII had achieved interoperability with GBIF for 4.5 million specimen records. Over the past decade, the number of papers citing GBIF data has grown steadily, with nearly four papers per day currently citing GBIF data. With GBIF's development, NSII data will be accessed and freely downloaded by more researchers worldwide.

Beyond GBIF, data from foreign platforms such as the US specimen digitization platform (iDigBio) and the Australian biodiversity information system (ALA) were also co-used in journal articles citing NSII data (Raes et al., 2020; Fawcett et al., 2022). From an institutional perspective, NSII data are increasingly used by foreign institutions for biodiversity research, particularly studies on China's biodiversity. NSII data's international influence has been further enhanced.

The availability of biodiversity data and information, along with the ability to effectively utilize them, will become important indicators of future scientific

research. Developing capacity to "mobilize, manage, publish, and use biodiversity data" can support biodiversity strategies, which require reliable and accurate data (Parker-Allie et al., 2021). Biodiversity strategies are rooted in numerous international conventions, including the Convention on Biological Diversity (CBD), Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), United Nations Convention to Combat Desertification (UNCCD), United Nations Framework Convention on Climate Change (UNFCCC), Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), and Sustainable Development Goals (SDG).

Analysis of NSII data-supported papers reveals that China has established a relatively standardized data platform serving biodiversity research with certain influence both domestically and internationally. Future data platform construction still requires multi-dimensional efforts to strengthen the data foundation. First, enhance national-level top-down design, emphasizing the integration of biodiversity big data resources to form more powerful comprehensive information platforms. Specifically, strengthen multi-source data integration and sharing, establish data sharing coordination mechanisms and models, and further break down data silos between different departments and institutions based on joint data cataloging and API interactions. Increase data sharing efforts, as Asia's current data sharing level lags significantly behind Europe and North America. Explore mutually beneficial multi-party cooperation mechanisms domestically (including academic institutions, government agencies, publishers, citizen science platforms, and social media) to promote a "soft environment" where data stakeholders mutually recognize each other's value.

Second, continuously advance original data digitization and sharing, establishing strong connections between big data platforms and data sources, as only continuous data sources can keep data updated. Although China has digitized over 16 million animal and plant specimens for online sharing, the digitization rate needs substantial improvement relative to total specimen collections (Xiao et al., 2018). Additionally, herbarium literature resources contain substantial survey, observation, and distribution data awaiting organization and mining.

Third, increase data openness and design and develop data products. Reference international biodiversity data platforms such as GBIF, Biodiversity Heritage Library (BHL), and Encyclopedia of Life (EOL), and learn from their analytical interface designs for R and Python languages. Develop products for different data application scenarios, including scientific research, government decision-making, enterprise innovation, and public science education. Promote data use through multiple channels and optimize data circulation and service methods through user feedback.

Fourth, strengthen capacity building in biodiversity informatics and develop professional academic communities, including cultivating practitioners' capabilities across the entire data lifecycle through technical training and project implementation, particularly in data mining. Encourage the application of new technologies and methods throughout the data lifecycle, such as infrared camera

technology, audio-video recording, remote sensing, environmental DNA, artificial intelligence, and scientific workflow technologies.

Fifth, enhance regional and international cooperation. In Asia, actively "go global" through channels such as the Chinese Academy of Sciences' overseas science and education centers, the national Belt and Road cooperation network, and the newly established Kunming Biodiversity Fund from COP15 to expand China's cooperative scale and influence in Asia. For global cooperation, actively participate in international projects and affairs through platforms such as GBIF, International Union for Conservation of Nature (IUCN), BHL, and Botanic Gardens Conservation International (BGCI), contributing China's biodiversity data and case studies toward the SDGs.

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Note: Figure translations are in progress. See original paper for figures.