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Data Paper

Dataset of Biodiversity Loss in Global Staple Food Trade, 1995-2022

Zhuofan Huang‡, Zhenglei He‡, Zelin Xing‡

‡ Guangdong Basic Research Center of Excellence for Ecological Security and Green Development, Key Laboratory for City Cluster Environmental safetyand Green Development of the Ministny of Education, School of Ecology, Environment and Resources, Guangdong University of Technology, Guangzhou, China

Corresponding author: Zhenglei He (hezhenglei@gdut.edu.cn)

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Abstract

Understanding the intricate link between global food trade and ongoing biodiversity loss is critical, yet comprehensive datasets visualising this relationship remain scarce. To address this, we developed a novel global staple food trade biodiversity loss network dataset spanning 1995-2022. This dataset uniquely integrates global trade data with agricultural production metrics to quantify the embodied biodiversity loss associated with the trade of four major crops: wheat, soybean, rice and maize, across 157 countries and encompassing up to 91414 trade relationships. By constructing this dynamic network framework, our work provides a comprehensive resource for analysing the complex interplay between food trade and biodiversity loss. This dataset offers crucial insights for identifying key countries, trade relations and risk transfer mechanisms, thereby serving as a foundational tool for providing information for the development of sustainable food trade policies and fostering interdisciplinary research in this vital area.

Keywords

staple food, biodiversity loss, trade, complex network analysis

Overview and background

As a key pillar for maintaining global food security, global food trade plays an indispensable role in meeting the needs of a growing population (Godfray et al. 2010, Kinnunen et al. 2020). However, with the deepening of globalisation, the scale and scope of food trade are also continuing to expand. While the global food supply brings convenience, it also brings unprecedented challenges to biodiversity (Lenzen et al. (2012), Cabernard et al. (2024), Li et al. (2024a)). Issues such as changes in land use, habitat destruction, and species extinction are increasingly becoming major threats to the health of global ecosystems (Newbold et al. 2015, Ortiz et al. 2021, Marsh et al. 2025). The growing demand for food will increase the production of food-producing countries and the over-use of land will further increase biodiversity loss (Marques et al. 2019, Cabernard et al. 2024, Keck et al. 2025). Biodiversity loss will be transferred from exporting countries to importing countries through international trade (Lv et al. 2022, Boakes et al. 2024). International trade is a major driver of biodiversity loss (Wilting and van Oorschot 2017), about 25% of global species lost (Marsh et al. 2025) and 30% of global species threats are driven by international trade (Lenzen et al. 2012). Globally, agricultural activities, particularly cropland expansion, are primary drivers of biodiversity loss, accounting for over 90% of such losses, with 72% specifically attributable to cropland expansion (Cabernard et al. 2024). Staple food crops, including soybeans, maize, rice and wheat, play a pivotal role in this dynamic. Their expanding global cultivation, frequently encroaching upon biodiverse habitats, exerts a disproportionately significant impact on biodiversity (Kato et al. 2018, De Vos et al. 2024, Fan et al. 2024). Consequently, an exhaustive quantification of the nexus between global food trade and biodiversity loss is imperative for the formulation of effective conservation strategies.

Although existing studies have explored food trade and biodiversity loss, there are still some limitations. For example, Beyer and Manica (2021) have established global and country-level datasets of the biodiversity footprints of 175 crops and pastures and have estimated three common biodiversity measures for the world's mammals, birds and amphibians - species richness, endangered species richness and range rarity. Eskew et al. (2020) provide data on 15 years of the USA imports of wildlife and its derived products (2000-2014). The datasets include 2 million shipments of wildlife or wildlife products, representing 60 biological categories and 3.2 billion living organisms. These data will be of broad help to scientists and policy-makers in better understanding the quantity, source, biological composition and potential risks of the global wildlife trade. However, to date, there is still a lack of datasets that quantify the impact of global staple food trade on biodiversity loss, as well as analytical methods that can reveal the dynamic relationship between the two. To address these gaps, this work developed a biodiversity loss network dataset, based on global staple food trade from 1995 to 2022. This dataset aims to quantify the contribution of food trade to biodiversity loss and evaluate the vulnerability in the global staple food trade network.

The dataset's construction integrates staple food trade volumes with biodiversity loss indicators to form a global network. Furthermore, it employs complex network analysis, utilising metrics, such as network modularity, clustering coefficient and average path length, to elucidate the relationship between food trade and biodiversity loss. The dataset also analyses the dynamic evolution of the network, thereby revealing the potential risk of biodiversity loss. The dataset has a wide range of application value and can provide important references for fields such as ecology, economics, geography and policy research, helping to assess the impact of trade policies and predict the trend of biodiversity loss (Zhang et al. 2024, Li et al. 2024b, Sun et al. 2025).

By constructing and analysing this biodiversity loss dataset, it aims to provide new perspectives and tools for studying global food trade and biodiversity loss, provide a scientific basis for formulating biodiversity conservation and sustainable food trade policies and contribute to achieving global sustainable development goals.

Materials and Methods

This study constructed a global staple food trade biodiversity loss network and analysed the impact of global staple food trade on biodiversity loss from 1995 to 2022. The network was constructed, based on global staple food trade data and biodiversity loss intensity factors. There are 157 network nodes (countries), edges represent bilateral trade relations and edge weights represent the amount of biodiversity loss caused by trade. This article calculates the loss of biodiversity in inter-state staple food trade using the following formula:

$$F_{ij} = \sum_{j=1}^{n} W_{ijk} \times B_k$$

Amongst these variables, F_{ij} represents the quantity of biodiversity loss transferred from country *i* to country *j*. W_{ijk} represents the weight of the *k* staple food commodity traded from country *i* to country *j*. B_k represents the unit biodiversity loss intensity factor for the *k* food commodity. *n* represents all types of traded food commodities. This methodology transforms abstract staple food trade flows into concrete flows of biodiversity loss, establishing a solid foundation for subsequent network analysis.

This study used a complex network analysis method and calculated network indicators, such as average degree, graph density, clustering coefficient, average path length, number of communities, modularity and standard deviation. Complex network analysis has its strengths in revealing the complex relationships within large interconnected systems and is suitable for analysing the flow of global trade. Based on this network, the following network metrics were calculated (CHEN and CHEN 2023, Li et al. 2024a, HUANG et al. 2025):

Average degree: The average number of connections amongst all nodes in a network. It provides insights into the extent to which countries are involved in trade relationships that contribute to biodiversity loss.

Graph density: The ratio of the number of edges that actually exist in a network to the maximum possible number of edges. The metric helps understand the intensity of trade links and their potential impact on biodiversity. The graph density is calculated as follows:

$$D = 2m/(n(n-1)),$$

where D is the density of the network, m is the number of edges in the network and n is the number of nodes.

Clustering coefficient: A measure of how clustered nodes are in a network. It helps identify potential trade blocs or regional patterns of biodiversity loss. The clustering coefficient is calculated as follows:

$$C = 2E/(k(k-1)),$$

where E represents the number of edges between the k neighbours of node and k represents the degree of node.

Average path length: The average of the shortest path lengths between any two nodes in a network. It helps understand how quickly biodiversity loss impacts can propagate. The average path length is calculated as follows:

$$L = 1/(1/2N(N+1)) \sum_{(i \geq j)} d_{ij}$$

where d_{ij} represents the shortest path length between node i and node j and N represents the total number of nodes in the network.

Number of communities: The number of communities in the network provides insights into the overall complexity of the network's organisation, indicating distinct trading blocs or regions with similar biodiversity loss patterns.

Modularity: A measure of the strength of community divisions in a network. High modularity indicates strong community structure, implying that countries within the same community exhibit similar biodiversity loss patterns due to shared trade relationships. The modularity (Q) is calculated as follows:

$$Q = 1/2m \sum_{(i,j)} (A_{ij} - k_i k_j/2m)\delta(c_i, c_j)$$

where m is the total number of edges in the network, A_{ij} is the weight of the connection between node i and node j (considering direction in directed graphs), k_i is the degree of node i, k_j is the degree of node j, c_i is the community to which node i belongs, c_j is the community to which node j belongs, δ (c_i,c_j) is an indicator function that if $c_i = c_j$ (i.e. nodes i and j belong to the same community) and 0 otherwise.

Standard deviation: This metric measures the dispersion of biodiversity loss values across countries, indicating the degree of inequality in biodiversity loss distribution.

Steps

This study employed a multi-step data processing workflow to construct a global staple food trade biodiversity loss network.

Step one: Data collection

1. Global staple food trade data: Trade data for wheat, soybeans, rice and maize were extracted from UN Comtrade (https://comtrade.un.org). Using 6-digit Harmonised System (HS) codes, ensuring detailed categorisation of trade flows. This database was chosen for its comprehensive coverage of international trade data.

2. Biodiversity loss intensity factor: Biodiversity loss intensity factors were obtained from the study of Cabernard et al. (2024) (https://doi.org/10.1038/s41893-024-01433-4). This study provides robust estimates of biodiversity loss associated with agricultural production, making it a reliable source for our analysis.

3. Staple food production per unit area data: Data on staple food production per unit area (annual yield) were sourced from the Food and Agriculture Organisation of the United Nations (FAOSTAT) database (https://www.fao.org/faostat/zh/#data/QCL). FAOSTAT was selected for its authoritative and comprehensive agricultural production statistics.

Step two: Data processing

1. Normalisation of biodiversity loss factors: Biodiversity loss was quantified using the Potential Disappeared Fraction (PDF), an indicator that measures the impact of land-use change on species richness. PDF values represent the proportion of species richness lost due to land use (Chaudhary et al. 2016). To standardise for regional variations in agricultural productivity, this paper divided the biodiversity loss intensity factor derived from Cabernard et al. (2024) by the annual production per unit area of each staple food provided by FAOSTAT. This adjustment produced a quality adjusted biodiversity loss factor, enabling a more precise comparison of biodiversity impacts across years.
2. Following the calculation of biodiversity loss per unit of production, this value was multiplied by the annual volume of staple food trade between countries. This multiplication yielded the total embodied biodiversity loss associated with each trade flow. Specifically, for each directed trade link between countries, the normalised biodiversity loss factor was multiplied by the corresponding annual trade volume of wheat, soybeans, rice and maize. This process was performed for each year from 1995 to 2022, resulting in a time-series dataset representing the global staple food trade biodiversity loss network.
3. Network construction: A weighted directed network was constructed, with nodes representing countries and directed edges representing bilateral trade flows. Edge weights were calculated as the magnitude of biodiversity loss embodied in the traded goods. The network's growth over time is depicted in Fig. 1, which shows a linear increase in the number of edges from 1895 in 1995 to 91414 in

2022, indicating a 47-fold increase. This trend highlights the expanding interconnectedness of the global food trade network and its potential implications for biodiversity loss.

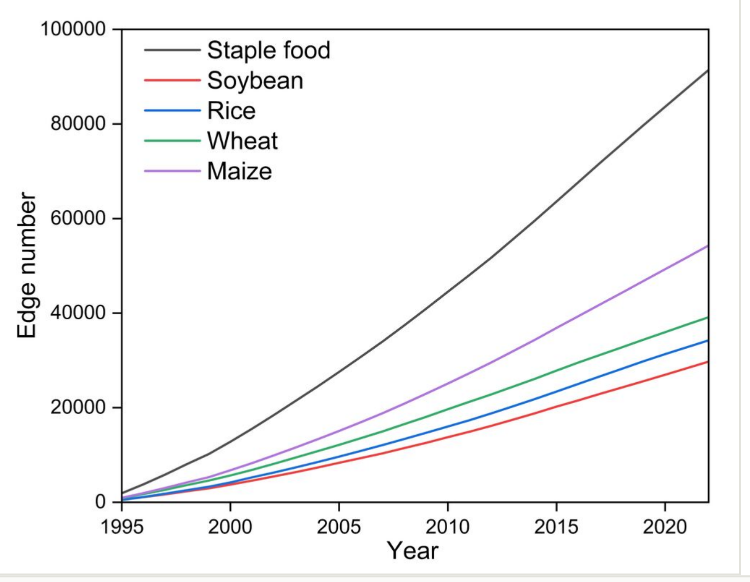

Figure 1.

Number of edges in the network of biodiversity loss in global staple food trade. Graph showing the number of edges in the network of biodiversity loss in global soybean, rice, wheat and maize trade from 1995 to 2022.

Quality control

Data quality control included addressing missing trade data within the UN Comtrade database. Specifically, a minor percentage of total potential trade flows were reported as incomplete, meaning a trade relationship existed, but the specific volume was missing, preventing the calculation of the corresponding embodied biodiversity loss. Consequently, these incomplete trade records were excluded from the final dataset to ensure data integrity and the consistency of the biodiversity loss metric.

This exclusion addresses data incompleteness, which is distinct from "zero trade" (where no trade occurred, resulting in no biodiversity loss transfer). Given the extremely small proportion of missing data and the absence of any systemic concentration across specific years or countries, we suggest that this exclusion has a negligible impact on the overall macro-structure of the network and the primary conclusions of the study. The biodiversity loss embodied in these excluded flows is considered too insignificant to alter the major findings or the dynamic evolution of the network presented in this dataset. Additionally, consistency checks were performed across data sources to ensure data accuracy. All data processing was performed using Stata 16.

Limitations and uncertainty

Biodiversity Loss Intensity Factor (BLIF) Uncertainty: The BLIFs sourced are based on complex modelling approaches and associated assumptions, meaning they inherently carry a degree of modelling uncertainty. These factors represent the best available robust estimates, but are not absolute values.

Normalisation and Data Source Integration: We normalised the BLIF by FAOSTAT's annual yield data to account for regional productivity variations. This step, while crucial for enhancing cross-regional comparability, introduces the potential for propagation of errors or uncertainties existing within the FAOSTAT agricultural production statistics.

Indicator Selection: Our use of PDF focuses specifically on species richness loss due to land-use change. While PDF is a widely recognised and robust indicator in life cycle assessment (LCA) studies, it does not capture all aspects of biodiversity loss, posing a limitation on the scope of the derived loss metric.

Implications for Sensitivity: Given these multi-source uncertainties, future work should ideally employ a Multi-Regional Input-Output (MRIO) framework or similar scenario analysis to rigorously assess the sensitivity of our primary findings. This could involve testing the network dynamics and country rankings against the upper and lower bounds of the reported BLIFs or simulating changes in key trade volumes. However, we maintain that, despite these inherent data limitations, this dataset provides the most comprehensive and dynamic quantification of biodiversity loss embodied in global staple food trade to date, offering a reliable foundation for macro-level policy analysis.

Dataset description

The main purpose of the dataset is to quantify the evolution of the contribution of global staple food trade to biodiversity loss, thereby revealing the complex relationship between food trade and biodiversity. Currently, global staple food trade plays a key role in ensuring food security, but its rapid growth also threat to biodiversity. This dataset aims to fill the research gap on staple food trade networks and biodiversity loss and provide data support for multidisciplinary cross-disciplinary research.

Staple food trade data from 157 countries, covering the period 1995 to 2022, were compiled and subsequently transformed to represent embodied biodiversity loss. Alongside this data compilation, a comprehensive analysis of the resulting network structures across these 28 years was conducted. Table 1 provides a description of the labels used within the dataset (further details are available in Supplementary Materials 1-17, Suppl. materials 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17).

As illustrated in Fig. 2, the biodiversity loss embodied in global staple food trade increased substantially during the period from 1995 to 2022. Amongst the four analysed crops, the biodiversity loss driven by soybean cultivation experienced the most rapid growth, increasing by a factor of 6.35, from $1.61 \times 10\text{^}{-6}$ PDF in 1995 to $1.02 \times 10\text{^}{-5}$ PDF in 2022. This rate of increase significantly surpassed that of the other crops: rice (3.29-fold), wheat (1.69-fold) and maize (3.07-fold). Historically, wheat accounted for the largest proportion of the total biodiversity loss embodied in global staple food trade; however, soybeans gradually overtook wheat to become the dominant contributor to total embodied biodiversity loss in 2022.

Table 1.

The explanation of the labels in the dataset.

Column label	**Column description**
t	Reports year of data.
i	Indicates the country of export.
j	Indicates the country of import.
q	The quantity of trade product.
country_code	The standard code for the country.
country_name_abbreviation	Abbreviation of country name, used to concisely represent a country in a limited space.
iso_3digit_alpha	A three-letter country code, part of the ISO 3166-1 standard.

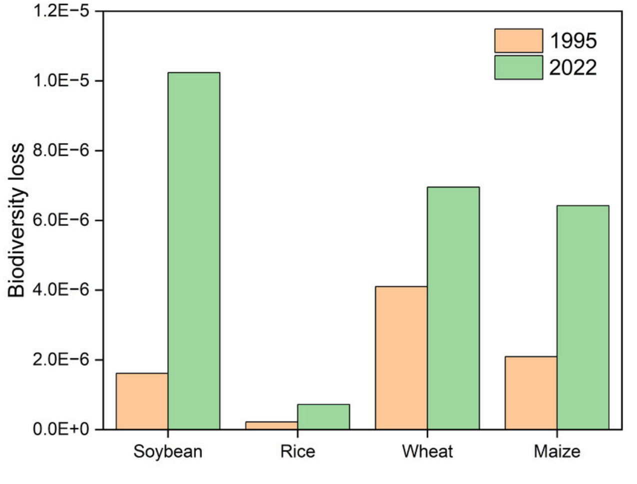

Figure 2.

Evolution of biodiversity loss in global staple food trade. Graph showing the evolution of biodiversity loss in global soybean, rice, wheat and maize trade in 1995 and 2022.

The geographical scope of this dataset is global, encompassing the aforementioned 157 countries, with country boundaries and names adhering to UN Comtrade standards. Fig. 3 illustrates the average embodied biodiversity loss associated with imports and exports for these 157 countries between 1995 and 2022. The results indicate that countries with substantial agricultural trade, such as the USA, Brazil, China, Australia and Argentina, experience the most significant impacts of global staple food trade on their biodiversity loss.

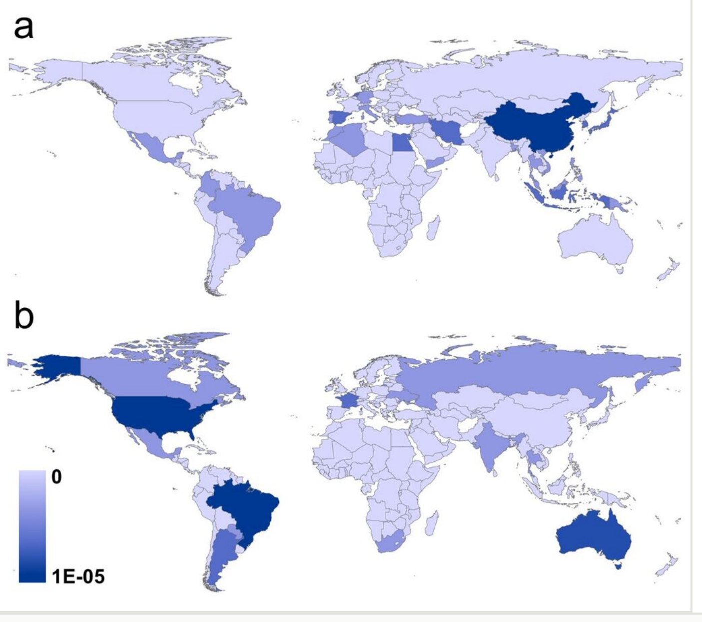

Figure 3.

Key countries in the average loss of biodiversity in global staple food trade. The maps shading indicate the average loss of biodiversity in imports (a) and exports (b) by key countries in 1995-2022. The units of the volumes are PDF.

Fig. 4 highlights the key bilateral trade relationships through which biodiversity loss is conveyed within global staple food trade flows. The findings reveal that trade linkages between major agricultural producing and consuming nations serve as critical pathways for the transfer of embodied biodiversity loss.

Conclusion

This study successfully introduces the first comprehensive and dynamic network dataset quantifying the embodied biodiversity loss in global staple food trade (wheat, soybeans, rice and maize) over the period from 1995 to 2022. By integrating detailed trade flows from UN Comtrade, agricultural productivity data from FAOSTAT and the robust PDF indicator, this work bridges a critical data gap in the quantitative analysis of the environmental impacts of international food supply chains. The dataset, covering 157 countries and documenting the dynamic evolution of tens of thousands of trade relationships, serves as a powerful instrument for system-level analysis. Network analysis results, including the trends in average path length and modularity, reveal the expanding interconnectedness of the global food system and highlight key producer countries, as well as the specific trade pathways that concentrate and transfer biodiversity loss risk across borders. This resource functions as a critical data infrastructure for researchers and policy-makers. It is designed to facilitate rigorous quantitative analysis of environmental responsibility, support the formulation of equitable and sustainable food trade policies and ultimately contribute to achieving global biodiversity conservation targets and Sustainable Development Goals 15.

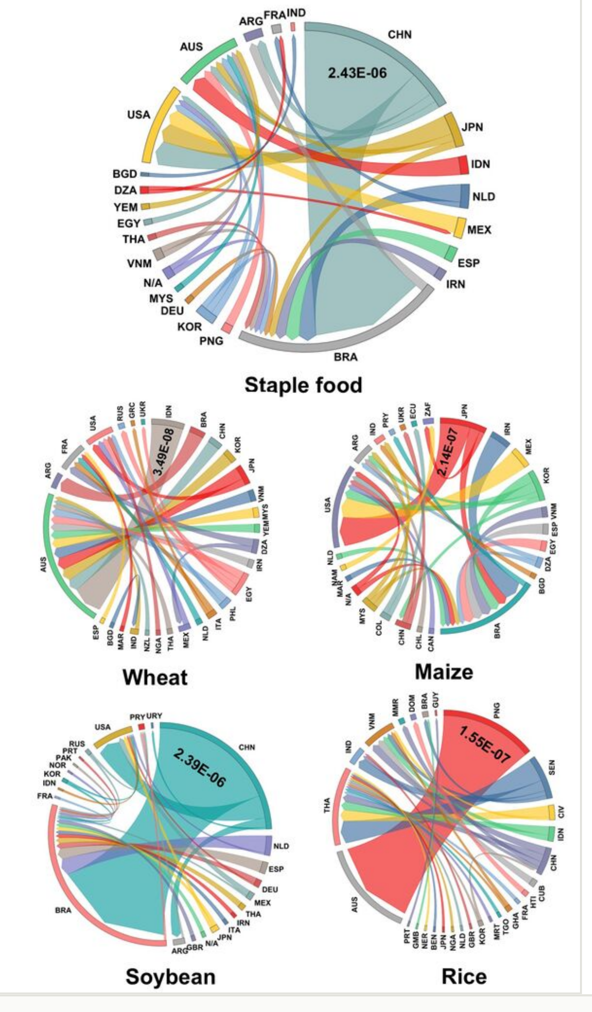

Figure 4.

The trade-based global staple food average biodiversity loss networks topology between 1995-2022. The units of the volumes are PDF. The origins and destinations of trade are each assigned a colour and represented by the circle's segments. As the flow width is non-linearly adapted to the curvature, it corresponds to the flow size only at the beginning and end points. For clarity, this paper displays only the links that account for the top 30 of the total flow.

Format names and versions

The dataset is stored in CSV format.

Creation dates

March 2025

Dataset creators

Zhuofan Huang and Zhenglei He

Dataset contributors

See list of co-authors

Language

English

Licence

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Repository location

This paper (Suppl. Material)

Re-use potential

Any re-use of these data must cite this source. The authors may be contacted in case of doubts with the use and the interpretation of the data.

Details for replicability and reproducibility

The data processing, network construction and analysis presented in this study were conducted using R version 4.1.2. All custom scripts and code developed for this research are publicly available and can be accessed on GitHub at the following repository: https://github.com/ZhuofanH/Biodiversity-Loss.

Acknowledgements

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Author contributions

In this study, Zhenglei He conducted the overall design. Zhuofan Huang collected the data and performed the calculations. Zhuofan Huang and Zhenglei He led the analysis. Zhuofan Huang and Zhenglei He also participated in the writing.

Conflicts of interest

The authors have declared that no competing interests exist.

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Supplementary materials

Suppl. material 1: Soybean trade matrix (1995-2022) doi

Authors: Zhuofan Huang and Zhenglei He
Data type: Metadata
Brief description: Trade matrix of soybean from 1995 to 2022, in tonnes, with 28 tables in total.
Download file (986.15 kb)

Suppl. material 2: Rice trade matrix (1995-2022) doi

Authors: Zhuofan Huang and Zhenglei He
Data type: Metadata
Brief description: Trade matrix of rice from 1995 to 2022, in tonnes, with 28 tables in total.
Download file (1.86 MB)

Suppl. material 3: Wheat trade matrix (1995-2022) doi

Authors: Zhuofan Huang and Zhenglei
Data type: Metadata
Brief description: Trade matrix of wheat from 1995 to 2022, in tonnes, with 28 tables in total.
Download file (1.68 MB)

Suppl. material 4: Maize trade matrix (1995-2022) doi

Authors: Zhuofan Huang and Zhenglei He
Data type: Metadata
Brief description: Trade matrix of maize from 1995 to 2022, in tonnes, with 28 tables in total.
Download file (2.66 MB)

Suppl. material 5: Biodiversity loss coefficient of staple food (1995-2022) doi

Authors: Zhuofan Huang and Zhenglei He
Data type: Metadata
Brief description: Biodiversity loss coefficients for soybean, wheat, rice and maize from 1995 to 2022, in PDF/km^2.
Download file (219.76 kb)

Suppl. material 6: World staple food production (1995-2022) doi

Authors: Zhuofan Huang and Zhenglei He
Data type: Metadata
Brief description: World staple food production per unit area from 1995 to 2022, unit is kg/ha.
Download file (11.31 kb)

Suppl. material 7: Total loss of biodiversity of staple food (1995-2022) doi

Authors: Zhuofan Huang and Zhenglei He
Data type: Metadata
Brief description: Total biodiversity loss from staple food trade from 1995 to 2022, unit is PDF.
Download file (11.09 kb)

Suppl. material 8: Average degree (1995-2022) doi

Authors: Zhuofan Huang and Zhenglei He
Data type: Network structure indicators
Brief description: The average number of connections between all nodes in the staple food biodiversity loss network from 1995 to 2022 was counted.
Download file (10.08 kb)

Suppl. material 9: Average clustering coefficient (1995-2022) doi

Authors: Zhuofan Huang and Zhenglei He
Data type: Network structure indicators
Brief description: The clustering degree of nodes in the staple food biodiversity loss network from 1995 to 2022 was counted.
Download file (9.86 kb)

Suppl. material 10: Average path length (1995-2022) doi

Authors: Zhuofan Huang and Zhenglei He
Data type: Network structure indicators
Brief description: The ratio of the actual number of edges to the maximum number of edges in the staple food biodiversity loss network from 1995 to 2022 was counted.
Download file (9.90 kb)

Suppl. material 11: Graph density (1995-2022) doi

Authors: Zhuofan Huang and Zhenglei He
Data type: Network structure indicators
Brief description: The clustering degree of nodes in the staple food biodiversity loss network from 1995 to 2022 was counted.
Download file (9.84 kb)

Suppl. material 12: Modularity (1995-2022) doi

Authors: Zhuofan Huang and Zhenglei He
Data type: Network structure indicators
Brief description: Statistics on the strength of community divisions in the staple food biodiversity loss network from 1995 to 2022.
Download file (9.86 kb)

Suppl. material 13: Network diameter (1995-2022) doi

Authors: Zhuofan Huang and Zhenglei He
Data type: Network structure indicators
Brief description: The maximum distance between any two nodes in the staple food trade biodiversity loss network from 1995 to 2022 was counted.
Download file (9.46 kb)

Suppl. material 14: Number of communities (1995-2022) doi

Authors: Zhuofan Huang and Zhenglei He
Data type: Network structure indicators
Brief description: The number of communities in the staple food trade biodiversity loss network from 1995 to 2022 was counted.
Download file (9.54 kb)

Suppl. material 15: Number of edges (1995-2022) doi

Authors: Zhuofan Huang and Zhenglei He
Data type: Network structure indicators
Brief description: The number of edges in the staple food trade network biodiversity loss from 1995 to 2022 was counted.
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Suppl. material 16: Standard deviation (1995-2022) doi

Authors: Zhuofan Huang and Zhenglei He
Data type: Network structure indicators
Brief description: Statistics on differences in biodiversity loss in staple food trade between countries from 1995 to 2022.
Download file (11.02 kb)

Suppl. material 17: Country codes doi

Authors: Zhuofan Huang and Zhenglei He
Data type: List of country
Brief description: The country and territory code standards defined by the International Organisation for Standardisation (ISO).
Download file (13.68 kb)