Indonesian Society for Science Educators
Journal of Science Learning
journal homepage: ejournal.upi.edu/index.php/jslearning

A Bibliometric Analysis of Biodiversity Education

Mustafa Derman[1]*

[1]Department of Secondary Science and Mathematics Education, Kâzım Karabekir Education Faculty, Atatürk University, Erzurum, Turkey

*Corresponding author: dermanmustafa155@gmail.com

ABSTRACT The importance of biodiversity is one of the most critical issues today, and intense efforts are being made to protect and maintain biodiversity. In this study, biodiversity, which is related to many disciplines, was evaluated in terms of education. A bibliometric analysis was used. The bibliometric method is widely used to reveal the relationship between scientific studies, the effect of the studies, and the effect of the researchers and journals in a particular field. Research findings showed that many articles have been published on biodiversity recently. In education, out-of-school learning activities are used more widely today. Moreover, the USA, China, and Germany are among the countries that publish more articles about biodiversity. Based on the research findings, it was determined that combining the formal education process with out-of-school activities will help students exhibit positive behavior about the environment and biodiversity. Considering the trend in recent years, studies related to climate change, ecosystem service, sustainability, and citizen science can be carried out.

Keywords Biodiversity, Citizen Science, Nature, Outdoor Learning

1. INTRODUCTION

Biodiversity refers to the diversity of life on Earth. Millions of creatures live in our world. Every living thing has an important function in the ecosystem. The concept of biodiversity started to be widely used after the Rio Earth Summit. At the conference in 1992, the definition of the concept of biodiversity was made. Biodiversity education, which is tried to be a part of environmental education, is of an essential effect on a sustainable future (Barker & Elliott, 2000). Environmental education in schools, especially in childhood education, tries to raise awareness and acquire positive attitudes toward the environment (Barraza, 2001). Therefore, educators have made much effort to integrate environmental and biodiversity education into all levels of education (Collins-Figueroa, 2012). Apart from formal education, the importance of biodiversity is brought to people through informal education; TV programs and civil actions are the best examples of this (Slingsby, 2009). Because biodiversity is the responsibility not only of educators and scientists, all should question the reasons for the extinction of biodiversity and its threats (Dreyfus, Wals, & van Weelie, 1999). However, people must first be aware of their environment and nature's biodiversity. Because the formation of awareness includes having sufficient knowledge on this subject, educators are constantly investigating the awareness and knowledge levels of students, teachers, and other members of society by conducting research in this field (Luvison Araújo & Dos Santos Alitto, 2021). One of the places that should be recognized as a priority is the immediate environment. Individuals need information about the living things in the aquatic and terrestrial ecosystems where they live. With outdoor learning activities, students can interact in these environments (Bermudez, Pérez-Mesa, & Ottogalli, 2022); biodiversity is not only the dimension of recognition and awareness.

We can see aspects of biodiversity in every part of our lives. It is a concept associated with health, food, cosmetics, engineering, economics, and many other disciplines. Therefore, the importance of biodiversity should be well understood in all dimensions. Any negativity that may occur in biodiversity, an essential ecosystem component, will negatively affect people in some way (Bilali, Dambo, Nanema, Bassole, & Calabrese, 2022). In other words, human life will become more difficult due to the extinction of living things that exist in the ecosystem or are endangered species (Xu, Xiao, Li, & Wang, 2022). The sustainability of ecosystems depends on biodiversity. Conservation of biodiversity is essential for ecosystems to

Received: 23 September 2022
Revised: 19 January 2023
Published: 20 March 2023

maintain their dynamic structure. For example, an insect's extinction affects pollen transport to plants, and in this case, it may reduce fruit yield (Van Oudenhoven & De Groot, 2012). The protection of biodiversity significantly impacts people's survival and adequate food supply. Therefore, taking action against biodiversity loss is mandatory to leave a sustainable future for future generations (Grant RD, 2007).

One of the essential natural resources is biodiversity. People consume natural resources (or biodiversity) as raw materials. Some researchers express raw material as productivity or ecosystem service. The primary meaning here is nature's benefit to humans (Mace et al., 2012; Worm & Duffy, 2003). Different disciplines have carried out research to reach raw materials. Therefore, biodiversity can be related to many disciplines (Nyaupane & Poudel, 2011; Worm & Duffy, 2003). Health, tourism, food, and clothing industry are among the benefits of biodiversity to people (Nyaupane & Poudel, 2011). In other words, biodiversity also significantly contributes to the world economy and the continuity of healthy ecosystems. Benefits of biodiversity; *biological control agents used instead of pesticides and insecticides*, *recycling of wastes and organic matters*, *soil formation, pharmaceutical raw materials, bioremediation, cleaning of air from carbon dioxide to reduce global warming, genetic source to increase yields, pollination*, and so on. (Adom, Umachandran, Ziarati, Sawicka, & Sekyere, 2019; Pimentel et al., 1997). Situations that affect biodiversity also directly affect productivity (Worm & Duffy, 2003). Therefore, biodiversity conservation and sustainable use are of great importance to humanity. Biodiversity conservation has many dimensions, including social, political, and education (Grace, 2009; Helldén & Helldén, 1970; Menzel & Bögeholz, 2009). Education is one of the most effective ways to protect biodiversity (Yen et al., 2007). Because individuals who are aware of the importance of biodiversity, concerned and sensitive about biodiversity loss will ensure that biodiversity reaches future generations (Montgomery, 2002). Therefore, biodiversity is one of the most critical issues of Education for Sustainable Development (ESD) (Grace, 2009; Helldén & Helldén, 1970; Menzel & Bögeholz, 2009; van Weelie & Wals, 2002). The primary way to build a sustainable future (or sustainable development) is to ensure the maintenance of biodiversity. For biodiversity education to reach its goal and have a sustainable future, it is necessary to increase the whole society's awareness about the extinction of biodiversity. For this reason, local and global projects related to biodiversity education have been carried out in all countries (Gayford, 2000). When people do not have enough information or knowledge about biodiversity, they will not understand the importance of biodiversity in maintaining healthy ecosystems (Hanley, Spash, & Walker, 1995). Therefore, to achieve the goal of sustainable development, it is necessary to improve citizens' knowledge and skills on biodiversity in the formal education process (Grace, 2009). ESD seeks to raise individuals' analysis skills, provide active participation of individuals in protecting biodiversity, produce solutions, and involve people in projects about reducing biodiversity loss (Barraza, 2001). Unfortunately, the main problem in the extinction of many species in nature, the destruction of ecosystems, and the destruction of habitats of living things is the unconscious destruction of nature by anthropogenic impacts. It causes the irreversibility extinction of species in nature (Díaz, Fargione, Chapin, & Tilman, 2006; Gayford, 2000). The researchers pointed out that individuals who know about biodiversity and understand the importance of living things in nature exhibit more sensitive behaviors in protecting the natural environment. Researchers generally emphasize that education has an essential effect on protecting biodiversity (Aivelo & Huovelin, 2020; Beery & Jørgensen, 2018; Gayford, 2000; Hardy & Hardy, 2018; Helldén & Helldén, 1970; Kim, 2019; Schneiderhan-Opel & Bogner, 2020; Schultz & Joordens, 2014; Tuparevska, 2022; Unger, Rollins, Tietz, & Dumais, 2021; Wyner & Doherty, 2021; Zhang, Stevenson, & Martin, 2022). Educators aim to improve students' knowledge and skills about biodiversity by making curriculum revisions (Grace, 2009). It is not only limited to primary schools, but also by integrating biodiversity in university education programs, it is ensured that individuals at all levels of education receive biodiversity education. Because pre-service teachers' having sufficient knowledge and skills on biodiversity will contribute to the development of students' biodiversity values (Lindemann-Matthies et al., 2009). In this way, teaching strategies that increase the interaction of students with the natural environment have developed. Helldén and Helldén (1970) stated that individuals who interact with their natural environment from early childhood exhibit more sensitive behaviors in terms of the protection of biodiversity. Some researchers have also emphasized the necessity of designing school schoolyards in accordance with nature. It was expressed that the schoolyards designed schools that are compatible with the natural environment help the students develop their environmental values (Zhang et al., 2022).

The mentioned literature explains the importance of biodiversity for humanity and sustainable ecosystems. However, biodiversity has decreased over the years, and many species have been extinct. The increasing human population and over-consuming natural resources cause species extinction at a higher rate. (Pimentel et al., 1997). Due to the rapid decrease and extinction of biodiversity, it will be challenging to replace the resources provided by biodiversity. This situation will cause significant damage to both the deterioration of ecosystems and the world economy (Adom et al., 2019). There are approximately 9 million living things on Earth. Humans use many raw materials from biological sources. However, the vast majority of biodiversity loss on Earth has been affected

directly or indirectly by human activities. It was declared at the Earth Summit in Rio de Janeiro in 1992 (Cardinale et al., 2012). Therefore, it brought the protection of biodiversity among the most critical problems in the world.

Considering the existing literature, it is seen that education has an important role in protecting biodiversity and building a sustainable future for the next generation. The growing of individuals who are aware of the protection of natural resources, active participation in preventing the loss of biodiversity, and living as a part of the ecosystem is achieved through education. For this reason, improving students' knowledge and skills about biodiversity through education is one of the essential tools for sustainable development and conservation of biodiversity. Since biodiversity has many benefits for the ecosystem and humanity, much research has been carried out in this area. Previous review studies have evaluated the benefits and impacts of biodiversity in many ways; biodiversity and its importance for human health (Houlden, Jani, & Hong, 2021), relationship between biodiversity and ecosystem service (Mace et al., 2012; Wilson, 2013; Worm & Duffy, 2003), the effects of species extinction on the future of humans (Adom et al., 2019; Alho, 2012; Cardinale et al., 2012; Díaz et al., 2006), monitoring marine ecosystems (Di Ciaccio & Troisi, 2021), pastoralism and biodiversity (Bilali et al., 2022), relationship between the economic benefit of biodiversity and biodiversity loss (Knapp, 2019; Pimentel et al., 1997), the role of zoos in improving citizens' awareness about biodiversity (Wheater, 1995; Whitehead, 1995), the link between biodiversity and ecotourism (Nyaupane & Poudel, 2011), importance of sacred natural sites in terms of biodiversity conservation (Zannini et al., 2021), endangered plants (Xu et al., 2022), trends in landscape change (Hernández, Echeverría, & Nelson, 2021), importance of biodiversity offsetting (Yu, Cui, Xie, Man, & Fu, 2022), and effect of biodiversity on crop sustainability (Grant, 2007). As a result of the analysis related to the review studies, there has been an increase in the subjects of *bibliometric analysis*, *environment, environmental change*, and *human health*. As a result, review studies have increased in recent years.

Furthermore, bibliometric analysis studies were primarily published concerning *ecosystem service*, *sustainability*, *nature-based solutions*, *remote sensing*, *protected areas*, and *biotechnology*. However, unlike previous studies, the educational aspect of biodiversity still needs to be evaluated. Therefore, considering the importance of education in biodiversity conservation, it is crucial to reveal the relationship between biodiversity and education and the trends in biodiversity education. This aim was achieved with studies carried out between 1993-2022. Finally, the place of biodiversity in the field of education was examined.

2. METHOD

To review scientific studies, the bibliometric method was used. The bibliometric method is widely used to reveal the relationship between scientific studies, the effect of the studies, and the effect of the researchers and journals in a particular field. With this method, data can be visualized by bibliometric mapping and heat mapping techniques. Today, many software programs, such as CiteSpace II (Chen, 2006), Network Workbench (NWB) Tool (Börner et al., 2010), and VOSviewer (van Eck & Waltman, 2010), have been used for bibliometric maps. VOSviewer (www.vosviewer.com) was used in this study. VOSviewer is an open-access program used to make large bibliometric maps. Bibliometric maps of authors (or journals) can be constructed based on citations. In addition, researchers can construct maps of keywords in their studies using co-occurrence data (van Eck & Waltman, 2010). The Web of Science (WoS) is one of the most comprehensive database sources. It is used by many researchers to find information and to review special topics in their fields (Xu et al., 2022; Yan & Liu, 2021). Within the scope of the research, two types of searches have been made. First, "Biodiversity education" was chosen as a keyword for the WoS search. All periods and document types were included, and 84 results were reached. The results related to this section were analyzed under the heading "Biodiversity Education." In line with the results obtained, Web of Science Categories associated with biodiversity education was determined. These categories were chosen for use in the second part of the research (Figure 3c). Second, concerning the biodiversity literature, two words were searched in the following terms; "Biodiversity" and "Education," and 23,597 results were found. After that, step-by-step limitations were refined: Document types (Article: 21,236), Languages (English: 20,946), Web of Science Index (SCI-EXPANDED, SSCI, and ESCI: 20,700), and Web of Science Categories (12,727) respectively. The data were downloaded in Tab Delimited File format. Later, these files were combined in the Excel file and saved as a .txt file. The data saved in Excel format and pure science publications were excluded, and 1561 studies related to education and social science were included. The data were saved again in Excel and .txt format. Analyses were made after the data were uploaded into the VOSviewer.

3. FINDINGS

The oldest studies on biodiversity education were published in 1995, with two authors (Wheater and Whitehead) publishing studies in the same journal (Biodiversity and Conservation). The number of publications published between 1995 and 2022 shows a spike in three dates. After 2019, there has been an increase in studies. However, no publications were published on some dates (1996, 2002, 2007, and 2012) (Figure 1a). Most publications in the field of biodiversity education were

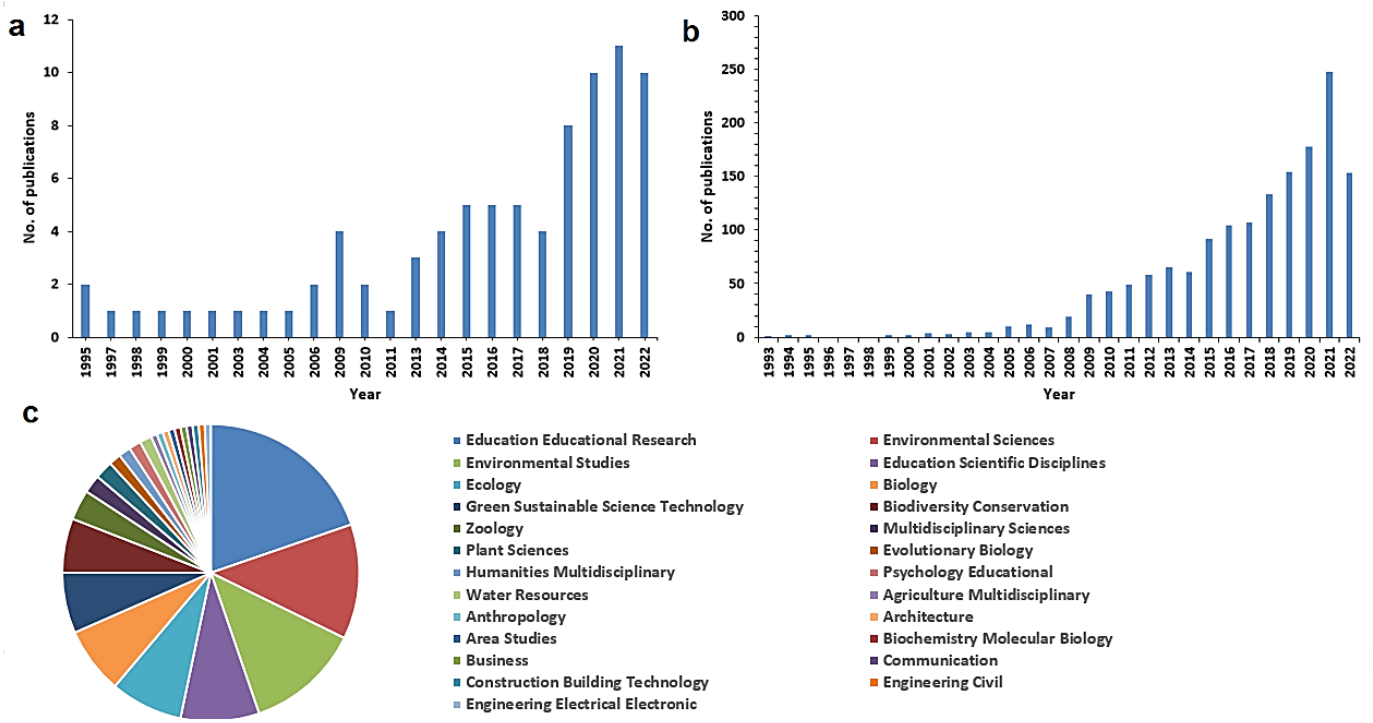

Figure 1 A Summary of studies on biodiversity education: (a) and (b) distribution of the number of publications in "*Biodiversity Education"* and "*Biodiversity" and "Education",* respectively; (c) shows subject areas of biodiversity education.

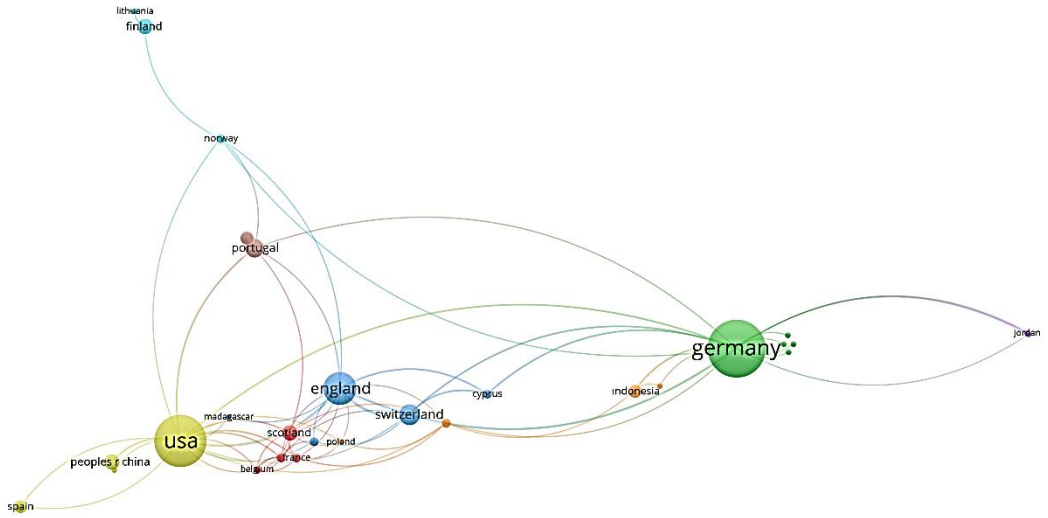

Figure 2 Visualization of co-authorship worldwide

published in the areas of Education, Education Research, Environmental Sciences, Environmental Studies, and Education Scientific Disciplines (Figure 1c). However, in Biodiversity and Education (Figure 1b), the oldest article in this section was published in 1993. A Likert-type scale was used in the research, and it assessed opinions about Kosi Tappu Wildlife Reserve (Heinen, 1993). Only some studies were published between 1993 and 2007. However, as of 2008, there has been an increase in publications in this field. In other words, it is seen that there has been an increase in the publications published in recent years.

3.1 Biodiversity Education

Figure 2 shows studies from different parts of the world. It consists of 8 clusters, each shown in a different color. While at least four countries represent the other clusters, only Cluster 8 (brown) includes two countries. The most significant contribution in this field is the studies carried out in Germany (Documents: 23, Citations: 318, Total link strength: 23), the USA (Documents: 20,

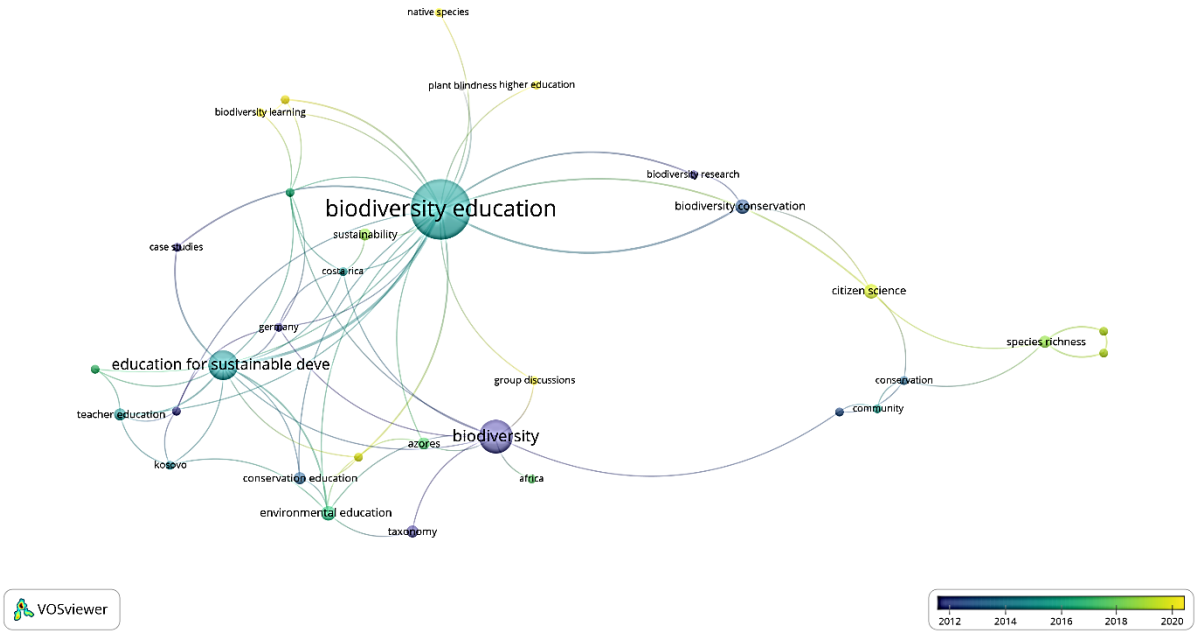

Figure 3 The top keywords used in publications by years

Citations: 732, Total link strength: 27), and England (Documents: 11, Citations: 677, Total link strength: 22). Although Germany had many publications, the USA is the country that cooperated in the highest number of publications with other countries worldwide.

The total number of keywords used in publications was 302. The minimum number of occurrences of a keyword was set as 2. Therefore, 34 words met this criterion. In other words, 34 words were considered in the bibliometric mapping. The most common keywords used were *biodiversity education* (Occurrences: 26, Total link strength: 35), *education for sustainable development* (Occurrences: 10, Total link strength: 20), and *biodiversity* (Occurrences: 12, Total link strength: 10). They are shown with larger circles as seen in Figure 3. Keywords shown in yellow indicate topics that have been studied in recent years (*Biodiversity learning, citizen science, sustainability education, group discussions, place-based education, higher education*, and *native species*) (Figure 3).

3.2 Biodiversity and Education

Co-occurrence and author keywords were chosen to determine the numbers and densities of the keywords used by the researchers in publications. As seen in the figure, clusters shown in different colors were obtained. Each color represents a cluster. As a result of the determined criteria, seven clusters were obtained. Of the 5505 keywords, 53 keywords meet the threshold. *Biodiversity, conservation, ecosystem service, climate change, environmental education, sustainability, protected areas, biodiversity conversation, education*, and *agriculture* are the most used keywords. Considering the concepts to which biodiversity is related, it is seen to be linked to all clusters (Figure 4 and Table 1).

The figure indicates that biodiversity interacts with many disciplines. In other words, there are publications on

Table 1 The ten most-used keywords in biodiversity education

	Keyword*	Occurrences	% of 5505	Total link strength
1	*biodiversity*	223	4.05	176
2	*conservation*	96	1.74	80
	ecosystem	78	1.42	67
3	*service*			
4	*climate change*	67	1.22	65
	environmental	57	1.04	57
5	*education*			
6	*sustainability*	51	0.93	51
7	*protected areas*	52	0.94	49
	biodiversity	53	0.96	44
8	*conversation*			
9	*education*	32	0.58	33
10	*agriculture*	23	0.42	28

*The first ten words were included.

biodiversity in different fields. Biodiversity does not only consist of genetic, species, and ecosystem diversity. Biodiversity has many dimensions: education, sustainability, climate change, species diversity, land use change, agriculture, ecotourism, conversation, ecology, and so on. Studies in the field of biodiversity and climate change are among the issues of recent years. Citizen science (CS) in cluster 2 has recently appeared more widely in biodiversity publications. Figure 3 shows that it is prominently involved in studies published in 2019. One of the main aims of biodiversity education is to raise individuals' sensitivity to the environment. Moreover, it is expected to take an active role in environmental issues. One of the most effective ways depends on individuals' direct interaction with the natural environment. The

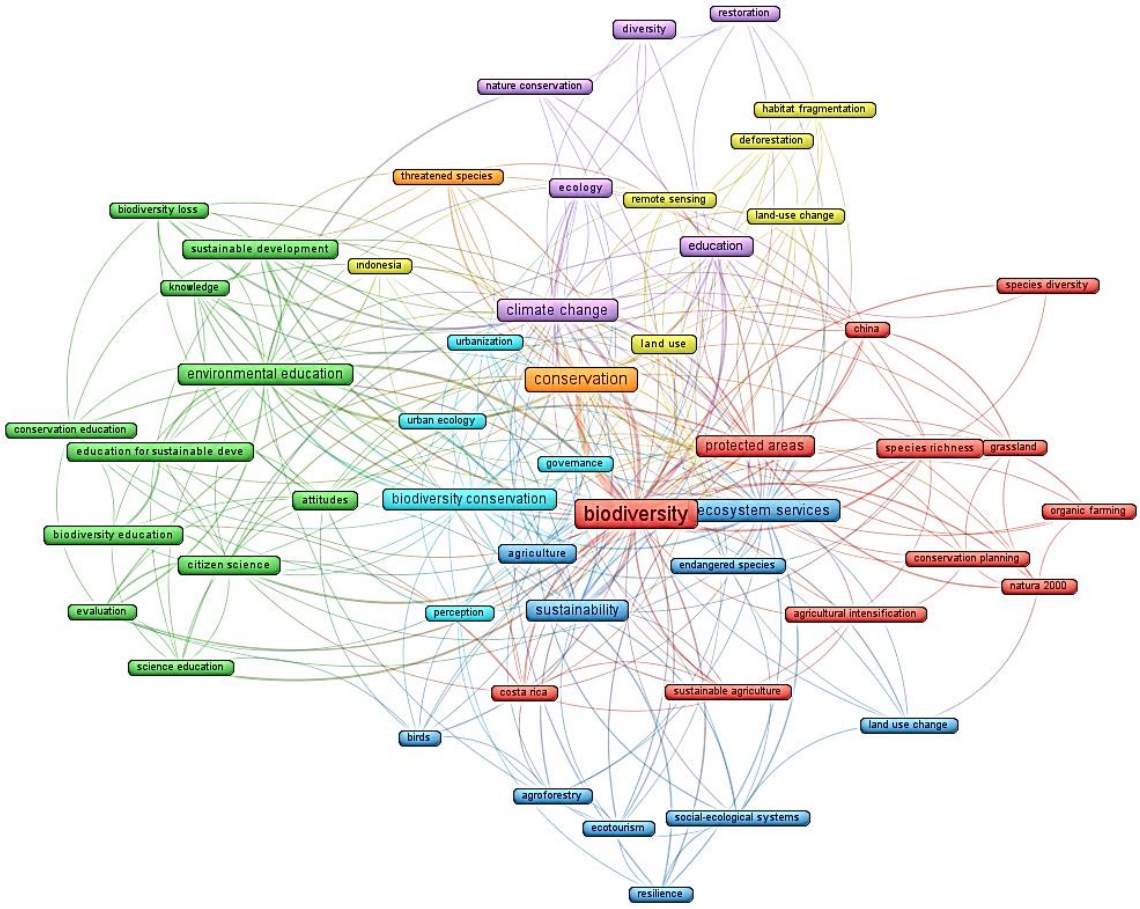

Figure 4 Analyzing keywords in terms of clusters

research indicated that students who spend time in their daily life observing and collecting data about the environment show more sensitive behavior towards the environment (Kim, 2019). A positive correlation was found between childhood nature activities and environmentally sensitive citizen behaviors (Hoover, 2021).

Individuals who interact with the natural environment, even for a brief time, exhibit positive attitudes toward the environment. As a matter of fact, with camp activities, which are a part of informal education, individuals can live in the natural environment and explore nature (Samperiz & Herrero, 2018). Supporting environmental education with informal education, which is a suitable area for field trips and outdoor learning activities, helps to achieve the objectives of environmental education (Jose, Patrick, & Moseley, 2017). With outdoor learning activities, individuals gain more than expected in their experience and learning. Individuals explore their environment and experience the methods used by scientists while collecting data in nature (Jesus-Leibovitz, Faria, Baioa, & Borges, 2017). Therefore, environmental education studies have begun to give more space to outdoor activities in recent years. Activities can be in the form of outdoor learning, citizen science, field trip, or camping.

Biodiversity is related to many fields. It was stated in the studies that these concepts affect each other and have a solid link to each other (Pimentel et al., 1997). Each area's contribution ensures biodiversity's sustainable existence (Worm & Duffy, 2003). The importance of biodiversity has been emphasized in *agriculture, ecosystem service, and protected area* due to the effect of biodiversity on crop yield, biological control (e.g., the use of biological agents instead of chemical agents), and the development of more resistant species. Furthermore, humans derive most of their food supply from plants and animals. Economically, most of the world's raw material resources depend on raw materials derived from biodiversity (Grant, 2007; Knapp, 2019; Mace et al., 2012; Peter, Diekötter, & Kremer, 2019; Pimentel et al., 1997; Wilson, 2013; Worm & Duffy, 2003; Yan & Liu, 2021). Another keyword is *climate change*. One of the most critical problems affecting ecosystems is climate change. Depending on temperature changes (or global warming), the dynamic of ecosystems is negatively affected (e.g., habitat destruction, species migration, or extinction). Therefore, this situation directly affects the diversity of living things in nature (Lovejoy, 2008). One of the most critical problems in the world is the loss of biodiversity. For this reason, *education* and *biodiversity conservation* link to biodiversity. Biodiversity protection can be achieved with a society that is aware of using nature sustainably. The formal and informal education processes try to increase society's awareness of biodiversity (Krombaß & Harms, 2008;

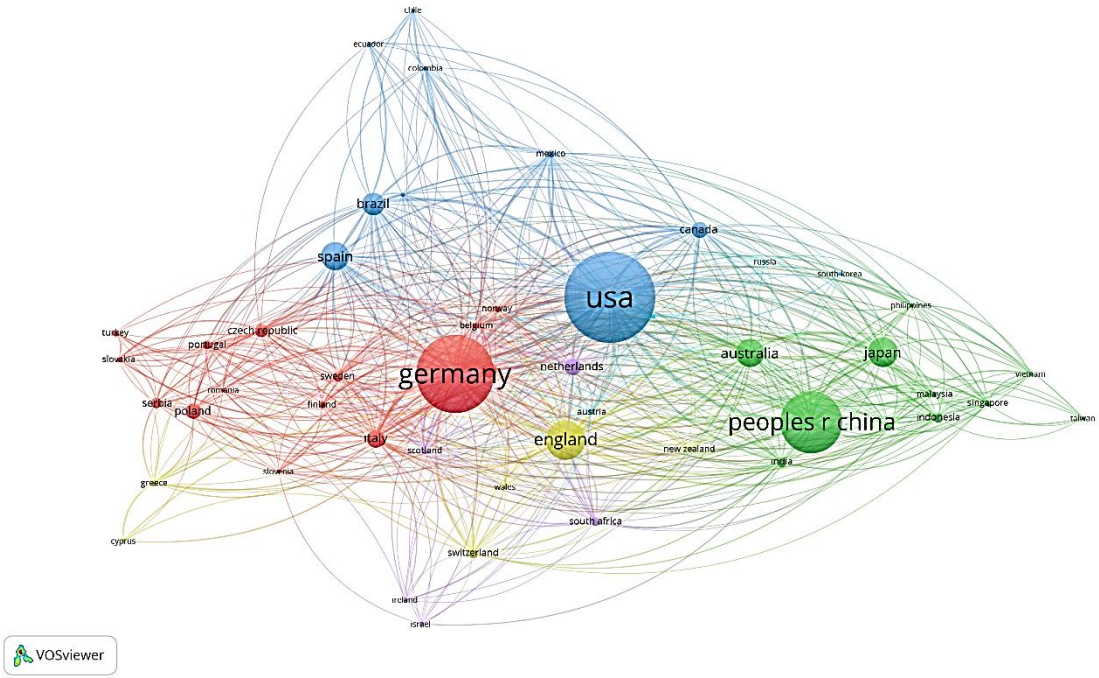

Figure 5 The visualization of co-authorship worldwide

Lindemann-Matthies et al., 2009; Samperiz & Herrero, 2018; Tuparevska, 2022; van Weelie & Wals, 2002). Another important keyword is *sustainability*. It is pointed out that society and ecosystems are seriously affected due to the loss of biodiversity. Therefore, the protection of biodiversity, identification of biological resources, determination of situations that affect biodiversity, and sustainable use of natural resources were considered among the most important objectives of *education for sustainable development* (ESD) (Collins-Figueroa, 2012).

Some of the activities that researchers have used regarding out-of-school activities in recent years are given in Table 2. Studies on the interaction of students with the natural environment are used. In addition, technological developments are also used. Integrating outdoor learning and technology aims to increase students' awareness and sensitivity to biodiversity. Educational scientists point out that the time spent in nature is decreasing more than in previous years. Individuals are estranged from the natural environment. It was emphasized that more interaction with nature would cause us to become aware of the reasons that threaten nature and the ecosystem (Tuparevska, 2022). Positive perceptions of students develop in environments with sufficient facilities in terms of schoolyards. Having natural environment opportunities in a school garden positively reflects individuals' attitudes (Zhang et al., 2022). It was stated that interacting with nature has many benefits regarding environmental attitude, behavior, awareness, sensitivity, and learning. Including out-of-school activities in biodiversity, education allows getting to know nature closely. Therefore, the studies published in recent years have led to the intense involvement of out-of-school activities (Beery & Jørgensen, 2018; Fančovičová & Prokop, 2018; Gormley, Birdsall & France, 2022; Guilherme, Faria, & Boaventura., 2016; Hardy & Hardy, 2018; Jesus-Leibovitz et al., 2017; Kamudu, Rollnick, & Nyamupangedengu, 2022; Krombaß & Harms, 2008; Schultz & Joordens, 2014; Sukhontapatipak & Srikosamatara, 2012; Wyner & Doherty, 2021; Zhang et al., 2022). Although there are no experimental studies that include all of the activities given in Table 2 and compare them with each other, researchers highlighted that the activities engaging the active participation of students (e.g., hands-on, outdoor learning, citizen science, field trip, and camping in nature) have a positive effect on students' success, awareness, attitude, and behavior (Beery & Jørgensen, 2018; Bögeholz, 2006; Bogner, 2018; Braun & Dierkes, 2017; Collado, Corraliza, Staats, & Ruíz, 2015; Jansson, Gunnarsson, Mårtensson, & Andersson, 2014; Kassas, 2002; Kelemen-Finan, Scheuch, & Winter, 2018;

Table 2 Activities for biodiversity education

	Publication	Activity	Participants
1	*Plant biodiversity* (Doup, 2018)	Outdoor learning	Students
2	*Biodiversity literacy* (Schneiderhan-Opel & Bogner, 2020)	Citizen science in class	Students
3	*iNaturalist* (Unger et al., 2021)	Using mobile App	Undergraduate students
4	*Specie variation* (Gormley, Birdsall, France, et al., 2022)	Hands-on activity	5-11 years olds
5	*Sustainable development* (Rodríguez-Loinaz et al., 2022)	Citizen science and ICT tool	Teachers and students

Table 3 Co-authorship worldwide in terms of documents, citations, and total link strength

	Country*	Documents	% of 1561	Citations	Total link strength
1	USA	324	20.76	9595	402
2	Germany	280	17.94	7260	349
3	England	141	9.03	3580	288
4	Australia	101	6.47	2799	182
5	China	223	14.29	2269	164
6	France	55	3.52	2417	141
7	Italy	64	4.10	924	134
8	Spain	101	6.47	2734	133
9	Canada	60	3.84	1412	132
10	Netherlands	61	3.91	1676	132

*The first ten countries were included.

Table 4 The most used sources in terms of documents, citations, and total link strength

	Source*	Documents	% of 1561	Citations	Total link strength
1	BC	236	15.12	9883	137
2	S	282	18.07	1984	118
3	IJSE	21	1.35	433	83
4	RISE	7	0.45	112	72
5	EER	34	2.18	418	70
6	JBE	40	2.56	285	55
7	AEE	131	8.39	3287	54
8	GECCO	106	6.79	809	52
9	EC	42	2.69	888	35
10	JNC	62	3.97	893	31

*BC (Biological conservation), S (Sustainability), IJSE (International Journal of Science Education), RISE (Research in Science Education), EER (Environmental Educatıon Research), JBE (Journal of Biological Education), AEE (Agriculture, Ecosystems & Environment), GECCO (Global Ecology and Conservation), EC (Environmental Conservation), JNC (Journal for Nature Conservation). **The first ten sources were included.

Kossack & Bogner, 2012; Ma & Nickerson, 2006; Navarro-Perez & Tidball, 2012; Prokop, Prokop, & Tunnicliffe, 2007; Randler & Hulde, 2007).

In the present study, which included 133 countries, mapping was made by setting at least ten publications. Regarding cooperation between countries, 6 clusters were obtained (Figure 5 and Table 3). The figure indicates that there is more cooperation between countries where they share the same geography. In addition, countries in Asia, Europe, and America are in cooperation with each other. Many countries represent countries in these clusters (green, red, and blue). The USA, Germany, and China are the most productive countries in terms of biodiversity. The USA, Germany, and England are the countries most closely cooperating with other countries. More than half of the articles published in this field belong to the USA, Germany, and China. In similar studies (Ardoin & Bowers, 2020; Deng, Liang, Li, & Wang, 2021; Haghani, Bliemer, Goerlandt, & Li, 2020), the USA and China rank first among the countries with the most publications. Furthermore, depending on the development of science worldwide, there has been a significant increase in the number of publications. Primarily due to interdisciplinary studies, fields of science now contribute to each other with common study subjects (Haghani et al., 2020; Moosa & Shareefa, 2020).

In recent years, *biological conservation* (documents: 236, citation: 9883, total link strength: 137) and *sustainability* (documents: 282, citation: 1984, total link strength: 118) have come first among the preferred sources of biodiversity. Although the articles were published in journals *journal of biological education* (documents: 40, citation: 285, total link strength: 55), *environmental conservation* (documents: 42, citation: 888, total link strength: 35), and *the Australian journal of the environment* in previous years, as of 2018, the trend in the sources has started to be towards *education science, environmental development, and sustainability, journal of sustainable tourism*, and *international journal of environment*. The journals with the highest publications are BC, S, and AEE. JBE is the journal with the highest number of publications for educational publications (RISE, IJSE, and EER) (Figure 6 and Table 4).

4. DISCUSSION

To summarize the topics where biodiversity is related, the research findings were evaluated under four main

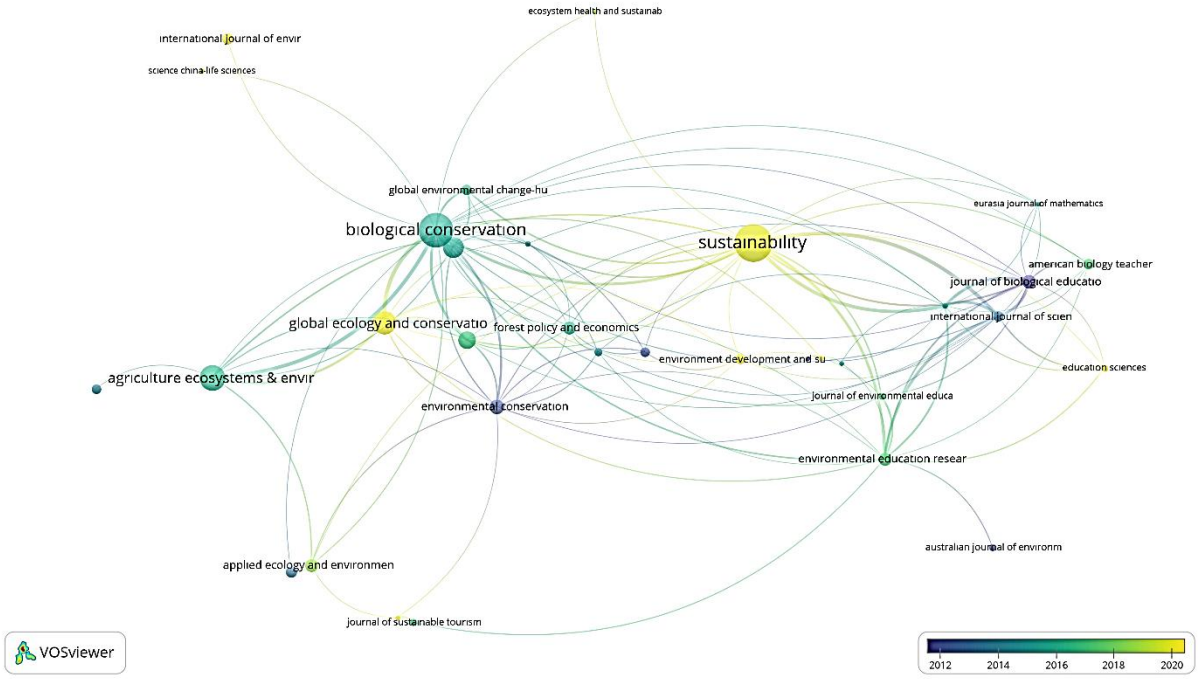

Figure 6 The visualization of journals used in recent years

headings. Findings associated with each main keyword were evaluated considering the keywords identified. Finally, the publications reached in the research were summarized using the sources associated with each heading.

4.1 Education (citizen science and environmental education)

Citizen science (CS) is widely used in biodiversity studies. It has taken a place in this field as a popular keyword in recent years and has different definitions. The most commonly accepted definition is "the participation of society in scientific activities." People use scientific methods to collect, analyze, and interpret data. Only more recently has it been used in educational activities. Students explore and collect data about the environment (Socientize Project, 2013). It is widely used for students' definition of biodiversity and for observing living things in the natural environment (Rodríguez-Loinaz, Ametzaga-Arregi, & Palacios-Agundez, 2022). Practices in this field are not limited to schools but are made with the participation of individuals from different parts of society. People find the opportunity to experience scientific activities by participating in projects. It was pointed out that there are positive reflections on individuals' knowledge, attitudes, and behaviors about biodiversity through citizen science activities (Peter et al., 2019). Students who examine the environment scientifically reach various conclusions in line with the data they have obtained. It was stated that students with opposing views about some living things have positive changes due to citizen science activities (Aivelo & Huovelin, 2020).

Citizen science has made significant contributions to studies on the functioning of ecosystems. The data obtained by citizen scientists provide data on pollution, human impacts on the environment, endangered species, the effects of climate change, and so on. In other words, it provides a large amount of data about the ecosystem by many volunteer and amateur researchers (Dickinson et al., 2012). There is a wide range of research areas from the micro to the macro scale (Bonney et al., 2014). The number of individuals involved in this project is in the millions. These groups, amateur environmentalists, have an essential role in protecting the world and reducing environmental damage (Merenlender, Crall, Drill, Prysby, & Ballard., 2016). In various countries, projects are carried out to observe natural biodiversity changes. These groups of volunteers (students or the public) obtain various data by photographing or observing some species in nature. Data are used to determining the changes that occur in the species over time (Donnelly, Crowe, Regan, Begley, & Caffarra, 2014). Citizen science-based curriculums are designed for students. In such environmental education, students can collect data from nature through fieldwork (Bopardikar, Bernstein, & McKenney, 2021).

With the industrial revolution, environmental problems have become one of the most critical issues in the world due to the damage caused by humans to the environment (or nature). In this context, raising the awareness of individuals on environmental protection was the main agenda of the Stockholm conference in 1972. Environmental problems include all situations that affect the environment and ecosystem. Therefore, the steps to protect biodiversity and to raise individuals related to

biodiversity are given with environmental education (Kassas, 2002). In other words, environmental and biodiversity education's main objectives are to increase citizens' sensitivity to the environment (Kim, 2019). However, the extreme extinction of species due to anthropogenic effects has increased interest in biodiversity protection. Therefore, the concepts of biodiversity and environmental education have been included in all studies. Situations that affect the environment directly or indirectly affect biodiversity (Cardinale et al., 2012; Kassas, 2002). For this reason, all of the behaviors that are tried to be gained by citizens with environmental education will also protect biodiversity and prevent the extinction of species in nature (Kim, 2019).

4.2 Sustainability (ecotourism and ecosystem service)

One of the keywords in the same cluster (blue) is ecotourism (Figure 4). It is a concept that emerged in the 1980s and is based on discovering nature. It is a valuable method for observing nature's diversity and natural beauty. Ecotourism can be thought of as both a trip and an informal learning environment. It has an essential function in protecting ecosystems and biodiversity. Individuals get more positive thoughts about preserving the nature they observe and have experienced (Lengieza, Hunt, & Swim, 2022; Stronza, Hunt, & Fitzgerald, 2022). As of 2007, there has been a substantial increase in the articles published in this field (Stronza et al., 2022). Similar findings were also obtained in our study. There has been an increase in biodiversity publications in recent years. Today, ecotourism and biodiversity are intertwined because these two areas interact intensely. Therefore, it has led to a parallel development with biodiversity studies because the positive and negative effects on biodiversity are addressed in studies on ecotourism (Kiss, 2004; Stronza et al., 2022).

Society is making significant efforts to protect biodiversity by increasing income from ecotourism. As long as the ecosystem, wildlife, and diversity exist, income from ecotourism will continue to rise (Kiss, 2004). Furthermore, governments are developing policies for protecting wildlife. Thus, they hope to generate more benefits from ecotourism (Wilson & Tisdell, 2003). However, scientists constantly express their concerns on this issue. Considering only the income aspect of ecotourism, there will be adverse effects on the ecosystem and biodiversity unless managed sustainably (Goodwin & Swingland, 1996). Ecosystems provide many benefits to humans; ecotourism is only one of them. Tourism and biodiversity are evaluated in publications on ecotourism, and many studies are currently published in this field, introducing the concept of ecotourism to biodiversity studies. The main parameters are tourism, biodiversity, and sustainable management (Stronza & Pêgas, 2008).

One of the most used keywords in biodiversity education is ecosystem service (see Figure 4 and Table 1). Ecosystem services are a concept that covers the benefits of the ecosystem and nature to human beings. Therefore, it constitutes one of the essential concepts that individuals should be aware of in biodiversity education. Citizens who are aware of the resources that biodiversity offers for humanity will take a more active role in preventing the extinction of biodiversity. Therefore, the importance of ecosystem services for humanity should be taught by people through the education process. Scientists assess the benefits of ecosystem services in two ways (regulation and raw material supply). For example, the regulation includes soil formation, sustained fertility, pollination and seed dispersal, climate regulation, and protection against hazards, but raw material supply involves food, medicine, and freshwater (Cardinale et al., 2012; Díaz et al., 2006; Pimentel et al., 1997). The benefits provided in these two ways are necessary not only for ecosystem sustainability but also for the sustainability of the world economy (Adom et al., 2019; Mace et al., 2012).

4.3 Climate change

Climate change has been used extensively in biodiversity publications. It shows the interaction between climate change and biodiversity. It is one of the most critical problems threatening the environment and our world. Changes in the environment affect biodiversity directly or indirectly. The quality of the air deteriorates due to the gases released into the atmosphere. With the increase in the world's temperature, the waters are rising, the glaciers are melting, and living things are negatively affected. Therefore, climate change and biodiversity issues are affected by each other (Lovejoy, 2008; Redlin & Gries, 2021). Scientists have researched the effects of climate change on the ecosystem in the context of the impact of this situation on species (Lovejoy, 2008). Various methods are being developed to prevent the extinction of endangered species. The distribution of species is observed, and efforts are being made to determine how climate change affects the distribution of species in the ecosystem (Midgley, Hannah, Millar, Rutherford, & Powrie, 2002). Unfortunately, observations showed that climate change's effects on living populations are increasing (Root et al., 2003).

4.4 Conversation

At the Rio Earth Summit in 1992, the importance of biodiversity, why it should be protected, its significance for a sustainable future, and how it should be protected were emphasized. Among the objectives of the meeting, the importance of sustainable use of biodiversity resources was stated. It was stressed that biodiversity resources will be used for the people of today and future generations (CDB, 1992). Biodiversity education aims to acquire the importance of natural resources and use them sustainably. With biodiversity education, individuals recognize the functioning of the ecosystem. Thus, they learn about what needs to be done for a sustainable ecosystem. Unfortunately, the ecosystem is declining due to humans'

overuse of natural resources (Lindemann-Matthies et al., 2009). The concept of biodiversity emerged in the sciences and has found its place in many disciplines today. Efforts are made to raise students' awareness of this issue through environmental education (van Weelie & Wals, 2002). Similar to the findings obtained in the study, it was stated that biodiversity is related to many concepts. It was pointed out that all dimensions of this concept should be emphasized in environmental education (Gayford, 2000). Because the importance of biodiversity and why it should be protected will be better understood, enabling students to understand that biodiversity education is not just about species diversity or ecosystem diversity.

5. CONCLUSION

In this study, biodiversity was evaluated in terms of education using the bibliometric analysis method. In this context, the keywords on biodiversity, the related fields, the most cited authors and journals, the most productive countries, and the trends in recent years were compared. Research findings showed that Germany, USA, and England are among the most productive countries in biodiversity education. It was determined that the most used keywords included *biodiversity, conservation, ecosystem service, climate change, environmental education, sustainability, protected area, biodiversity conservation, education,* and *agriculture*. Moreover, recent research results showed that studies related to biodiversity tend to out-of-school (outdoor) activities. In other words, activities that engage the student in interaction with nature (e.g., field trips, citizen science, hands-on activity) were used. Based on the findings and literature discussion, the following suggestions were recommended.

- Countries that are less productive in this area can increase their productivity by co-authorship with more productive countries.
- Researchers are advised to develop activities that involve students interacting more with the environment (nature).
- Considering the trend in recent years, studies related to climate change, ecosystem service, ecotourism, sustainability, and citizen science can be carried out.

REFERENCES

Adom, D., Umachandran, K., Ziarati, P., Sawicka, B., & Sekyere, P. (2019). The Concept of Biodiversity and its Relevance to Mankind: A Short Review. *Journal of Agriculture and Sustainability*, *12*(2), 219–231.

Aivelo, T., & Huovelin, S. (2020). Combining formal education and citizen science: a case study on students' perceptions of learning and interest in an urban rat project. *Environmental Education Research*, *26*(3), 324–340. https://doi.org/10.1080/13504622.2020.1727860

Alho, C. J. R. (2012). The importance of biodiversity to human health : An ecological Perspective. *Estudos Avançados*, *26*(74), 151–165.

Ardoin, N. M., & Bowers, A. W. (2020). Early childhood environmental education: A systematic review of the research literature. *Educational Research Review*, *31*(July), 100353. https://doi.org/10.1016/j.edurev.2020.100353

Barker, S., & Elliott, P. (2000). Planning a skills-based resource for biodiversity education. *Journal of Biological Education*, *34*(3), 123–127. https://doi.org/10.1080/00219266.2000.9655701

Barraza, L. (2001). Environmental Education in Mexican Schools: The Primary Level. *The Journal of Environmental Education*, *32*(3), 31–36. https://doi.org/10.1080/00958960109599143

Beery, T., & Jørgensen, K. A. (2018). Children in nature: sensory engagement and the experience of biodiversity. *Environmental Education Research*, *24*(1), 13–25. https://doi.org/10.1080/13504622.2016.1250149

Bermudez, G. M. A., Pérez-Mesa, R., & Ottogalli, M. E. (2022). Biodiversity Knowledge and Conceptions in Latin American : Towards an Integrative New Perspective for Education Research and Practice. *International Journal of Education in Mathematics, Science, and Technology*, *10*(1), 175–217. https://doi.org/https://doi.org/10.46328/ijemst.2105

Bilali, H. El, Dambo, L., Nanema, J., Bassole, I. H. N., & Calabrese, G. (2022). Biodiversity-pastoralism nexus in West Africa. *AIMS Agriculture and Food*, *7*(1), 73–95. https://doi.org/10.3934/AGRFOOD.2022005

Bögeholz, S. (2006). Nature experience and its importance for environmental knowledge, values and action: recent German empirical contributions. *Environmental Education Research*, *12*(1), 65–84. https://doi.org/10.1080/13504620500526529

Bogner, F. X. (2018). Environmental values (2-MEV) and appreciation of nature. *Sustainability (Switzerland)*, *10*(350), 1–10. https://doi.org/10.3390/su10020350

Bonney, R., Shirk, J. L., Phillips, T. B., Wiggins, A., Ballard, H. L., Miller-Rushing, A. J., & Parrish, J. K. (2014). Next Steps for Citizen Science. *Science*, *343*, 1436–1437. https://doi.org/10.1126/science.1251554

Bopardikar, A., Bernstein, D., & McKenney, S. (2021). Designer considerations and processes in developing school-based citizen-science curricula for environmental education. *Journal of Biological Education*, *Latest articles*, 1–26. https://doi.org/10.1080/00219266.2021.1933134

Börner, K., Huang, W., Linnemeier, M., Duhon, R. J., Phillips, P., Ma, N., Zoss, A. M., Guo, H., & Price, M. A. (2010). Rete-netzwerk-red: Analyzing and visualizing scholarly networks using the Network Workbench Tool. *Scientometrics*, *83*(3), 863–876. https://doi.org/10.1007/s11192-009-0149-0

Braun, T., & Dierkes, P. (2017). Connecting students to nature–how intensity of nature experience and student age influence the success of outdoor education programs. *Environmental Education Research*, *23*(7), 937–949. https://doi.org/10.1080/13504622.2016.1214866

Cardinale, B. J., Duffy, J. E., Gonzalez, A., Hooper, D. U., Perrings, C., Venail, P., Narwani, A., MacE, G. M., Tilman, D., Wardle, D. A., Kinzig, A. P., Daily, G. C., Loreau, M., Grace, J. B., Larigauderie, A., Srivastava, D. S., & Naeem, S. (2012). Biodiversity loss and its impact on humanity. *Nature*, *486*(7401), 59–67. https://doi.org/10.1038/nature11148

CDB. (1992). *Convention on Biological Diversity*. 1–28. https://www.cbd.int/doc/legal/cbd-en.pdf, 24.08.2022

Chen, C. (2006). CiteSpace II: Detecting and Visualizing Emerging Trends and Transient Patterns in Scientific Literature. *Journal of the American Society for Information Science and Technology*, *57*(3), 359–377. https://doi.org/10.1002/asi

Collado, S., Corraliza, J. A., Staats, H., & Ruíz, M. (2015). Effect of frequency and mode of contact with nature on children's self-reported ecological behaviors. *Journal of Environmental Psychology*, *41*, 65–73. https://doi.org/10.1016/j.jenvp.2014.11.001

Collins-Figueroa, M. (2012). Biodiversity and Education for Sustainable Development in Teacher Education Programmes of Four Jamaican Educational Institutions. *Journal of Education for Sustainable Development*, *6*(2), 253–267. https://doi.org/10.1177/0973408212475257

Deng, W., Liang, Q., Li, J., & Wang, W. (2021). Science mapping: a bibliometric analysis of female entrepreneurship studies. *Gender in Management*, *36*(1), 61–86. https://doi.org/10.1108/GM-12-2019-0240

Di Ciaccio, F., & Troisi, S. (2021). Monitoring marine environments with Autonomous Underwater Vehicles: A bibliometric analysis. *Results in Engineering*, *9*(January), 100205. https://doi.org/10.1016/j.rineng.2021.100205

Díaz, S., Fargione, J., Chapin, F. S., & Tilman, D. (2006). Biodiversity loss threatens human well-being. *PLoS Biology*, *4*(8), 1300–1305. https://doi.org/10.1371/journal.pbio.0040277

Dickinson, J. L., Shirk, J., Bonter, D., Bonney, R., Crain, R. L., Martin, J., Phillips, T., & Purcell, K. (2012). The current state of citizen science as a tool for ecological research and public engagement. *Frontiers in Ecology and the Environment*, *10*(6), 291–297. https://doi.org/10.1890/110236

Donnelly, A., Crowe, O., Regan, E., Begley, S., & Caffarra, A. (2014). The role of citizen science in monitoring biodiversity in Ireland. *International Journal of Biometeorology*, *58*(6), 1237–1249. https://doi.org/10.1007/s00484-013-0717-0

Doup, M. L. (2018). Using an Outdoor Activity on Local Plant Biodiversity to Teach Conservation Ecology and Promote Environmentally Responsible Behaviors. *American Biology Teacher*, *80*(5), 359–364. https://doi.org/10.1525/abt.2018.80.5.359

Dreyfus, A., Wals, A. E. J., & van Weelie, D. (1999). Biodiversity as a Postmodern Theme for Environmental Education. *Canadian Journal of Environmental Education, 4*, 155–176.

Fančovičová, J., & Prokop, P. (2018). Effects of hands-on activities on conservation, disgust and knowledge of woodlice. *Eurasia Journal of Mathematics, Science and Technology Education*, *14*(3), 721–729. https://doi.org/10.12973/ejmste/80817

Gayford, C. (2000). Biodiversity education: A teacher's perspective. *Environmental Education Research*, *6*(4), 347–361. https://doi.org/10.1080/713664696

Goodwin, H., & Swingland, I. R. (1996). Ecotourism, biodiversity and local development. *Biodiversity and Conservation*, *5*(3), 275–276. https://doi.org/10.1007/bf00051773

Gormley, K., Birdsall, S., & France, B. (2022). Same, same but different! Exploring children's understandings of within-species variation. *Journal of Biological Education*, *Latest articles*, 1–22. https://doi.org/10.1080/00219266.2022.2081244

Grace, M. (2009). Developing high quality decision-making discussions about biological conservation in a normal classroom setting. *International Journal of Science Education*, *31*(4), 551–570. https://doi.org/10.1080/09500690701744595

Grant, S. M. (2007). The Importance of Biodiversity in Crop Sustainability: A Look at Monoculture. *Journal of Hunger & Environmental Nutrition, 12*(1), 101–109. https://doi.org/https://doi.org/10.1300/J477v01n02_07

Guilherme, E., Faria, C., & Boaventura, D. (2016). Exploring marine ecosystems with elementary school Portuguese children: inquiry-based project activities focused on 'real-life' contexts. *Education 3-13*, *44*(6), 715–726. https://doi.org/10.1080/03004279.2015.1007884

Haghani, M., Bliemer, M. C. J., Goerlandt, F., & Li, J. (2020). The scientific literature on Coronaviruses, COVID-19 and its associated safety-related research dimensions: A scientometric analysis and scoping review. *Safety Science*, *129*, 104806. https://doi.org/10.1016/j.ssci.2020.104806

Hanley, N., Spash, C., & Walker, L. (1995). Problems in valuing the benefits of biodiversity protection. *Environmental & Resource Economics*, *5*(3), 249–272. https://doi.org/10.1007/BF00691519

Hardy, C. R., & Hardy, N. W. (2018). Adapting Traditional Field Activities in Natural History Education to an Emerging Paradigm in Biodiversity Informatics. *American Biology Teacher*, *80*(7), 501–519. https://doi.org/10.1525/abt.2018.80.7.501

Heinen, J. T. (1993). Park-People Relations in Kosi Tappu Wildlife Reserve, Nepal: A Socio-economic Analysis. *Environmental Conservation*, *20*(1), 25–34. https://doi.org/10.1017/S037689290003719X

Helldén, G., & Helldén, S. (1970). Students' early experiences of biodiversity and education for a sustainable future. *Nordic Studies in Science Education*, *4*(2), 123–131. https://doi.org/10.5617/nordina.286

Hernández, C., Echeverría, C., & Nelson, C. (2021). Evolution and emerging research trends in the ecological impacts of landscape change: perspectives from a Chilean biodiversity hotspot. *Landscape Ecology*, *36*(6), 1587–1603. https://doi.org/10.1007/s10980-021-01247-1

Hoover, K. S. (2021). Children in nature: exploring the relationship between childhood outdoor experience and environmental stewardship. *Environmental Education Research*, *27*(6), 894–910. https://doi.org/10.1080/13504622.2020.1856790

Houlden, V., Jani, A., & Hong, A. (2021). Is biodiversity of greenspace important for human health and wellbeing? A bibliometric analysis and systematic literature review. *Urban Forestry and Urban Greening*, *66*, 127385. https://doi.org/10.1016/j.ufug.2021.127385

Jansson, M., Gunnarsson, A., Mårtensson, F., & Andersson, S. (2014). Children's perspectives on vegetation establishment: Implications for school ground greening. *Urban Forestry and Urban Greening*, *13*(1), 166–174. https://doi.org/10.1016/j.ufug.2013.09.003

Jesus-Leibovitz, L., Faria, C., Baioa, A. M., & Borges, R. (2017). Exploring marine biodiversity through inquiry with primary school students: a successful journey? *Education 3-13*, *45*(4), 437–449. https://doi.org/10.1080/03004279.2015.1107612

Jose, S., Patrick, P. G., & Moseley, C. (2017). Experiential learning theory: the importance of outdoor classrooms in environmental education. *International Journal of Science Education, Part B: Communication and Public Engagement*, *7*(3), 269–284. https://doi.org/10.1080/21548455.2016.1272144

Kamudu, B., Rollnick, M., & Nyamupangedengu, E. (2022). Investigating what students learnt about biodiversity following a visit to a nature reserve using Personal Meaning Maps. *Journal of Biological Education*, *Latest articles*, 1–18. https://doi.org/10.1080/00219266.2022.2092190

Kassas, M. (2002). Environmental education : biodiversity. *The Environmentalist*, *22*, 345–351.

Kelemen-Finan, J., Scheuch, M., & Winter, S. (2018). Contributions from citizen science to science education: an examination of a biodiversity citizen science project with schools in Central Europe. *International Journal of Science Education*, *40*(17), 2078–2098. https://doi.org/10.1080/09500693.2018.1520405

Kim, M. (2019). Fostering Environmental Sensitivity by Observing Everyday Environments. *Journal of Geography*, *118*(4), 157–168. https://doi.org/10.1080/00221341.2018.1564351

Kiss, A. (2004). Is community-based ecotourism a good use of biodiversity conservation funds? *Trends in Ecology and Evolution*, *19*(5), 232–237. https://doi.org/10.1016/j.tree.2004.03.010

Knapp, S. (2019). People and plants: The unbreakable bond. *Plants People Planet*, *1*(1), 20–26. https://doi.org/10.1002/ppp3.4

Kossack, A., & Bogner, F. X. (2012). How does a one-day environmental education programme support individual connectedness with nature? *Journal of Biological Education*, *46*(3), 180–187. https://doi.org/10.1080/00219266.2011.634016

Krombaß, A., & Harms, U. (2008). Acquiring knowledge about biodiversity in a museum - Are worksheets effective? *Journal of Biological Education*, *42*(4), 157–163. https://doi.org/10.1080/00219266.2008.9656134

Lengieza, M. L., Hunt, C. A., & Swim, J. K. (2022). Ecotourism, eudaimonia, and sustainability insights. *Journal of Ecotourism*, *Latest articles*, 1–16. https://doi.org/10.1080/14724049.2021.2024215

Lindemann-Matthies, P., Constantinou, C., Junge, X., Köhler, K., Mayer, J., Nagel, U., Raper, G., Schüle, D., & Kadji-Beltran, C. (2009). The integration of biodiversity education in the initial education of primary school teachers: four comparative case

studies from Europe. *Environmental Education Research*, *15*(1), 17–37. https://doi.org/10.1080/13504620802613496

Lovejoy, T. E. (2008). Climate change and biodiversity. *Review of Science and Technology*, *27*(2), 331–338.

Luvison Araújo, L. A., & Dos Santos Alitto, R. A. (2021). Teaching native biodiversity: an exploratory study with Brazilian teachers. *Journal of Biological Education*, *Latest articles*, 1–11. https://doi.org/10.1080/00219266.2021.2006271

Ma, J., & Nickerson, J. V. (2006). Hands-on, simulated, and remote laboratories: A comparative literature review. *ACM Computing Surveys*, *38*(3), 1–24. https://doi.org/10.1145/1132960.1132961

Mace, G. M., Norris, K., & Fitter, A. H. (2012). Biodiversity and ecosystem services: A multilayered relationship. *Trends in Ecology and Evolution*, *27*(1), 19–26. https://doi.org/10.1016/j.tree.2011.08.006

Menzel, S., & Bögeholz, S. (2009). The loss of biodiversity as a challenge for sustainable development: How do pupils in Chile and Germany perceive resource dilemmas? *Research in Science Education*, *39*(4), 429–447. https://doi.org/10.1007/s11165-008-9087-8

Merenlender, A. M., Crall, A. W., Drill, S., Prysby, M., & Ballard, H. (2016). Evaluating environmental education, citizen science, and stewardship through naturalist programs. *Conservation Biology*, *30*(6), 1255–1265. https://doi.org/10.1111/cobi.12737

Midgley, G. F., Hannah, L., Millar, D., Rutherford, M. C., & Powrie, L. W. (2002). Assessing the vulnerability of species richness to anthropogenic climate change in a biodiversity hotspot. *Global Ecology and Biogeography*, *11*(6), 445–451. https://doi.org/10.1046/j.1466-822X.2002.00307.x

Montgomery, C. A. (2002). Ranking the benefits of biodiversity: An exploration of relative values. *Journal of Environmental Management*, *64*(3), 313–326. https://doi.org/10.1006/jema.2002.0553

Moosa, V., & Shareefa, M. (2020). Science mapping the most-cited publications on workplace learning. *Journal of Workplace Learning*, *32*(4), 259–272. https://doi.org/10.1108/JWL-10-2019-0119

Navarro-Perez, M., & Tidball, K. G. (2012). Challenges of Biodiversity Education : A Review of Education Strategies for Biodiversity Education. *International Electronic Journal of Environmental Education*, *2*(1), 12–30.

Nyaupane, G. P., & Poudel, S. (2011). Linkages among biodiversity, livelihood, and tourism. *Annals of Tourism Research*, *38*(4), 1344–1366. https://doi.org/10.1016/j.annals.2011.03.006

Peter, M., Diekötter, T., & Kremer, K. (2019). Participant outcomes of biodiversity citizen science projects: A systematic literature review. *Sustainability*, *11*(2780), 1–18. https://doi.org/10.3390/su11102780

Pimentel, D., Wilson, C., McCullum, C., Huang, R., Dwen, P., Flack, J., Tran, Q., Saltman, T., & Cliff, B. (1997). Economic and Environmental Benefits of Biodiversity. *BioScience*, *47*(11), 747–757. https://doi.org/10.2307/1313097

Prokop, P., Prokop, M., & Tunnicliffe, S. D. (2007). Is biology boring? Student attitudes toward biology. *Journal of Biological Education*, *42*(1), 36–39. https://doi.org/10.1080/00219266.2007.9656105

Randler, C., & Hulde, M. (2007). Hands-on versus teacher-centred experiments in soil ecology. *International Journal of Phytoremediation*, *25*(3), 329–338. https://doi.org/10.1080/02635140701535091

Redlin, M., & Gries, T. (2021). Anthropogenic climate change: the impact of the global carbon budget. *Theoretical and Applied Climatology*, *146*(1–2), 713–721. https://doi.org/10.1007/s00704-021-03764-0

Rodríguez-Loinaz, G., Ametzaga-Arregi, I., & Palacios-Agundez, I. (2022). ICT tools and citizen science: a pathway to promote science learning and Education for Sustainable Development in schools. *Journal of Biological Education*, *Latest art*, 1–17. https://doi.org/10.1080/00219266.2022.2092192

Root, T. L., Price, J. T., Hall, K. R., Schneider, S. H., Rosenzweig, C., & Pounds, J. A. (2003). Fingerprints of global warming on wild animals and plants. *Nature*, *421*(6918), 57-60.

Samperiz, A., & Herrero, J. (2018). Evaluation of a summer camp environmental education program in Spain. *Applied Environmental Education and Communication*, *17*(1), 79–90. https://doi.org/10.1080/1533015X.2017.1366881

Schneiderhan-Opel, J., & Bogner, F. X. (2020). FutureForest: Promoting Biodiversity Literacy by Implementing Citizen Science in the Classroom. *American Biology Teacher*, *82*(4), 234–240. https://doi.org/10.1525/abt.2020.82.4.234

Schultz, J. G. W., & Joordens, S. (2014). The effect of visitor motivation on the success of environmental education at the Toronto Zoo. *Environmental Education Research*, *20*(6), 753–775. https://doi.org/10.1080/13504622.2013.843646

Slingsby, D. (2009). Editorial: Charles Darwin, Biological Education and diversity: Past present and future. *Journal of Biological Education*, *43*(3), 99–100. https://doi.org/10.1080/00219266.2009.9656161

Socientize Project. (2013). Green paper on Citizen Science. Citizen Science for Europe: Towards a society of empowered citizens and enhanced research. *European Commission*, 1–54. https://digital-strategy.ec.europa.eu/en/library/green-paper-citizen-science-europe-towards-society-empowered-citizens-and-enhanced-research, 22.08.2022

Stronza, A. L., Hunt, C. A., & Fitzgerald, L. A. (2022). Ecotourism for conservation? *Routledge Handbook of Ecotourism*, 372–397. https://doi.org/10.4324/9781003001768-28

Stronza, A., & Pêgas, F. (2008). Ecotourism and conservation: Two cases from Brazil and Peru. *Human Dimensions of Wildlife*, *13*(4), 263–279. https://doi.org/10.1080/10871200802187097

Sukhontapatipak, C., & Srikosamatara, S. (2012). The role of field exercises in ecological learning and values education: Action research on the use of campus wetlands. *Journal of Biological Education*, *46*(1), 36–44. https://doi.org/10.1080/00219266.2011.554574

Tuparevska, E. (2022). Learning in nature: an amplified human rights-based framework. *Educational Philosophy and Theory*, *Latest articles*, 1–11. https://doi.org/10.1080/00131857.2022.2035721

Unger, S., Rollins, M., Tietz, A., & Dumais, H. (2021). iNaturalist as an engaging tool for identifying organisms in outdoor activities. *Journal of Biological Education*, *55*(5), 537–547. https://doi.org/10.1080/00219266.2020.1739114

van Eck, N. J., & Waltman, L. (2010). Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics*, *84*(2), 523–538. https://doi.org/10.1007/s11192-009-0146-3

Van Oudenhoven, A. P. E., & De Groot, R. S. (2012). Evidence and people's perceptions of the importance of biodiversity and integrated land use management for ecosystem services and local livelihoods. *International Journal of Biodiversity Science, Ecosystem Services and Management*, *8*(3), 187–189. https://doi.org/10.1080/21513732.2012.716961

van Weelie, D., & Wals, A. (2002). Making biodiversity meaningful through environmental education. *International Journal of Science Education*, *24*(11), 1143–1156. https://doi.org/10.1080/09500690210134839

Wheater, R. (1995). World Zoo Conservation Strategy: a blueprint for zoo development. *Biodiversity and Conservation*, *4*(6), 544–552.

Whitehead, M. (1995). Saying it with genes, species and habitats: biodiversity education and the role of zoos. *Biodiversity and Conservation*, *4*(6), 664–670.

Wilson, C., & Tisdell, C. (2003). Conservation and economic benefits of wildlife-based marine tourism: Sea turtles and whales as case studies. *Human Dimensions of Wildlife*, *8*(1), 49–58. https://doi.org/10.1080/10871200390180145

Wilson, J. B. (2013). Biodiversity theory applied to the real world of ecological restoration. *Applied Vegetation Science*, *16*(1), 5–7. https://doi.org/10.1111/avsc.12008

Worm, B., & Duffy, J. E. (2003). Biodiversity, productivity and stability in real food webs. *Trends in Ecology and Evolution*, *18*(12), 628–632. https://doi.org/10.1016/j.tree.2003.09.003

Wyner, Y., & Doherty, J. H. (2021). Seeing the trees: what urban middle school students notice about the street trees that surround them.

Journal of Biological Education, *55*(2), 155–177. https://doi.org/10.1080/00219266.2019.1667407

Xu, J., Xiao, P., Li, T., & Wang, Z. (2022). Research Progress on endangered plants : a bibliometric analysis. *Biodiversity and Conservation*, *31*, 1125–1147. https://doi.org/https://doi.org/10.1007/s10531-022-02392-y

Yan, H., & Liu, G. (2021). Fire ' s Effects on Grassland Restoration and Biodiversity Conservation. *Sustainability*, *13*(12016), 1–15. https://doi.org/https:// doi.org/10.3390/su132112016

Yen, C. F., Yao, T. W., & Mintzes, J. J. (2007). Taiwanese students' alternative conceptions of animal biodiversity. *International Journal of Science Education*, *29*(4), 535-553. https://doi.org/10.1080/09500690601073418

Yu, S., Cui, B., Xie, C., Man, Y., & Fu, J. (2022). Bibliometric Review of Biodiversity Offsetting During 1992–2019. *Chinese Geographical Science*, *32*(2), 189–203. https://doi.org/10.1007/s11769-022-1265-5

Zannini, P., Frascaroli, F., Nascimbene, J., Persico, A., Halley, J. M., Stara, K., Midolo, G., & Chiarucci, A. (2021). Sacred natural sites and biodiversity conservation: a systematic review. *Biodiversity and Conservation*, *30*(13), 3747–3762. https://doi.org/10.1007/s10531-021-02296-3

Zhang, Z., Stevenson, K. T., & Martin, K. L. (2022). Use of nature-based schoolyards predicts students' perceptions of schoolyards as places to support learning, play, and mental health. *Environmental Education Research*, *28*(9), 1271–1282. https://doi.org/10.1080/13504622.2022.2032612