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Research on the ecology and impacts of invasive alien species on biodiversity: a systematic literature review

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Abstract

The spread of species worldwide, previously governed by natural processes, is now largely influenced by globalization, trade development, and human movement. Some species become invasive, causing major concerns due to their negative impacts on natural ecosystems and biodiversity. This study employs a methodological approach combining bibliometric analyses and the PRISMA protocol. Using VOSviewer and R, we analyzed scientific literature on invasive alien species. Results reveal a sustained growth in scientific publications, reflecting researchers' increasing interest in this issue. However, a crucial observation emerges: most research is not integrated into national policies with concrete management measures. The results shows a growing scientific focus on invasive species, indicating their significance as a research subject. Despite this academic attention, a critical gap exists between fundamental research and practical management strategies. An urgent need exists to bridge the divide between scientific research on invasive species and practical management programs at local, regional, and national levels. This approach is essential to safeguard biogeographical regions already impacted and preserve non-invaded areas.

Keywords

bibliometric; biological diversity; environmental science; impacts ; invasive species

INTRODUCTION

Invasive alien species can be defined as alien species whose introduction causes or is likely to cause enormous harm (Olson 2006). When an alien species is introduced, becomes established and is dispersed, it is likely to cause multiple impacts (Gren 2008). The impacts observed are generally due to the absence of control measures that the species naturally have in the places where they are native, such as predators or climatic

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factors (Burgiel and A. 2010). In addition, behavior, biological factors and ecological characteristics make invasive species more efficient in resource use compared to native species (Kowarik 2011). The different impacts of invasive alien species can be classified into several classes. Indeed, these impacts are ecological, economic, environmental and societal (Peterson and Orden 2008). The factors generally favoring these impacts are land use change, exploitation, invasive alien species, climate change and pollution (Waage 2005). There are many factors that facilitate the introduction of invasive alien species into new habitats. For example, the globalization of human transport has greatly contributed to the dispersal of these species (Pimentel et al. 2005). Rapid changes in climatic conditions and severe habitat degradation lead to considerable loss of biodiversity and also contribute to the establishment and dispersal of invasive alien species into new habitats (Sax and Brown 2000; Mack and Lonsdale 2001; McKinney 2006; Kowarik 2011).

Invasive alien species are a major factor in the ongoing global environmental changes, exerting profound pressure on biodiversity by causing species declines and extinctions, severely degrading natural ecosystems, and disrupting the essential services they provide (Fandohan et al. 2015). The research carried out brings new elements to inform and shed light on the ecological and economic consequences of these species. New approaches are emerging to describe and assess the impacts of invasive alien species. The establishment and spread of invasive alien species are recognized and taken into account (Pyšek et al. 2008; Wagner 2017). The harmful effects of biological invasions are increasingly recognized throughout the world and several programs are in place in many regions of the world to reduce their current and future impacts. In addition, biological invasions have negative socio-economic and health impacts (Roy et al. 2016). Screening protocols to reduce new introductions are becoming increasingly accurate and have proved cost-effective (Hulme 2013). To mitigate the effects of these species, several policies and risk assessments are now in place to regulate their spread in different ecosystems (Pötzelsberger et al. 2020).

The spread of species around the world is traditionally governed by natural processes. However, globalisation, the expansion of trade and human movements have considerably accelerated this phenomenon, leading to the establishment of invasive plant species with negative effects on ecosystems and local biodiversity. Unfortunately, these problems are often detected late. This study adopts a global perspective, integrating in its analysis's articles from Africa, Europe, America and Asia over the period 2000 to 2023. In this study, we carried out a systematic literature review of knowledge on ecology and impacts of invasive alien species.

MATERIALS AND METHODS

In this study, we consider an invasive alien species to be categorized as a species that has reached new geographical areas and causes major impacts on the environment or society (Blackburn et al. 2011).

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Research strategy description

The Scopus bibliographic database (https://www.scopus.com/) was selected and used as the preferred source of information for this study. This choice is explained by the established reliability of Scopus, the completeness of its data and its broad thematic coverage (Houetohossou et al. 2023). Searches were carried out using key words. An initial search was carried out using the keywords "impact" OR "effect" AND "invasive species". Then, the keywords "ecology" AND "biodiversity" AND “introduced species” AND “ecology” were added in order to obtain an exhaustive list of the various works carried out on the subject. Research results were exported as CSV files, then imported into R software via the bibliometrix package and VOSviewer software for data analysis and visualization (Fig. 1). This study is based on bibliometric analysis and the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) protocol for analysing, identifying, and selecting publications (Page et al. 2020). Bibliometric methods were used to analyze trends in terms of countries, main research organizations, types of journals, etc. in order to provide detailed information (Malapane et al. 2022). Bibliometric analysis is a quantitative method for studying and analyzing scientific publications (Szomszor 2021). It uses statistical and mathematical indicators to describe and quantify publication and citation processes within a research field (Szomszor and Adie 2022). Bibliometric analysis examines the distribution of publications over time, their geographical origin, the scientific journals involved, collaboration between authors, institutions and countries, and the impact of publications through the number of citations received (Selçuk 2019). This enables us to map and understand changes in the structure and dynamics of research on a given subject. PRISMA is a standardized protocol for conducting systematic literature reviews. It is based on a four-stage flow chart (identification, selection, eligibility and inclusion) to select relevant publications for inclusion in the analysis (Selçuk 2019) (Fig. 2).

RESULTS AND DISCUSSION

Publication trends and full-text literature review

Fig. 3 and Fig. 4 show the evolution of the number of relevant scientific publications and the average number of citations per year between 2000 and 2023, respectively. The results show a steady increase in the publication rate. This trend demonstrates the interest of researchers in considering invasive alien species as a relevant research topic. However, most of this research is not well articulated in a national policy, which includes actions to be implemented by the government. Thus, a research priority should focus on increasing the number of relevant studies to link baseline information on invasive alien species to local, regional and national management programs and policies. This represents a challenge in the development and implementation of policies focused on the success of the mitigating the potential damage from invasive alien species.

Throughout the reviewed literature, several studies have addressed the effects or impacts of invasive alien species. The expansion of invasive alien species into new habitats has

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adverse consequences for ecological and economic systems (Wilcove et al. 1998; Simberloff 2003). However, the ecological impacts of plant invasions are still much debated (Chabrerie et al. 2006). Most studies on invasive plants focus to theoretical approaches (Higgins and Richardson 2014; Cannas et al. 1999) and few measurements and field experiments have shown their negative effect on wealth specificity and composition of plant communities (Costello et al. 2010). On a planetary scale, invasive species that increase the flammability of ecosystems seem to have the most adverse impacts (D'Antonio and Meyerson 2002). Biological invasion occurs when a non-native species is introduced into a new environment (ecosystem or habitat) and spreads, causing damage to the native biodiversity being conserved (Sher and Hyatt 1999). For invasive damage to occur, a species that is not represented in the vegetation of an area must enter it from "outside", survive and reproduce, spread from its point of introduction, naturalize and spread further, ultimately causing damage (Mazza et al. 2014). Invasive species can be animals, plants or micro-organisms (including disease agents), but in the case of most protected areas in mainland Africa, it is invasive plants that cause the most damage to native species and wild or production ecosystems (Sachs et al. 2009). There are very few invasive mammals among the native fauna and flora of African protected areas (Fandohan et al. 2015). Invasive exotic reptiles and amphibians are equally rare on the continent, while several exotic species of fish, intentionally introduced for food production, are invasive in some cases (Oumorou et al. 2010). The damage caused to native species or ecosystems by invasive alien species is usually the result of certain characteristics of the invaders which allow them to compete with the dominant local species and alter their habitat (Simberloff 2019). These invasive plants have several key characteristics. They grow faster than native species and spread rapidly due to their exceptional expansion abilities. Their high reproductive capacity allows them to produce large quantities of seeds. They also tolerate a wide range of environmental conditions, unlike native species, which are often restricted by temperature, rainfall, and soil type. Additionally, they compete effectively with local species for water, nutrients, light, and space.

To improve understanding of the management of biological invasions, greater emphasis should be placed on studying the economic costs generated by invasive alien species (Pyšek et al. 2008). This will make invasive species prevention and control programs more effective. One of the main challenges of studies on the impacts of invasive alien species is to better understand the multidimensionality of these impacts. These negative impacts have a major impact on human well-being, in particular the drop in agricultural yield. The loss of certain local species also leads to a decrease in biodiversity and involves indirect economic impacts (Ramírez-Albores et al. 2019). The problems and challenges related to invasive alien species are diverse and complex and need to be tackled from several angles, with a multidisciplinary approach.

Fig. 5 shows the average citations per year, beginning in 2000 for approximately two decades. The years 2009, 2012 and 2014 show the highest average number of citations per year. This exceptionally high citation rate suggests that the publications in these years (2009, 2012 and 2014) may have had a significant impact on the study of invasion

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phenomena around the world. This may reveal temporal trends, with key years in which certain subjects or works have had a greater impact, possibly linked to specific events, discoveries or conditions in those years. This variation in the average impact of publications from year-to-year merits more in-depth analysis to understand the underlying factors and dynamics.

The average citations per year about invasive alien species has increased substantially in recent years, as the analyses and results show. This trend towards an increase in scientific publications dealing with this phenomenon is corroborated by other researchers whose work warns of the harmful consequences engendered by these species introduced into new ecosystems (Ciampitti and Cavagna 2014). The increase in scientific publications on invasive alien species is justified by several factors. The worldwide expansion of biological invasions is one of the main factors contributing to the boom in scientific publications on this subject. The globalisation of trade and transport has led to an increase in the number of accidental or intentional introductions of exotic species, resulting in an upsurge in cases of species becoming invasive in new territories (Polce et al. 2023). Faced with the amplification of this phenomenon, the scientific community has logically given increasing attention to this subject of study. Another decisive factor in the growth of scientific publications on this subject is the growing awareness of the considerable ecological and economic impacts caused by invasive alien species (Walsh et al. 2016). It has been observed that these biological invasions can lead to the extinction of native species, the disruption of ecosystems, major damage to agricultural activities and expensive management costs (Simberloff et al. 2013). This increased understanding of the major issues associated with this problem and motivated sustained investment in research efforts in this area.

In addition, the study of biological invasions has gradually established itself as a field within ecology, benefiting from the emergence of its own concepts, methodologies and theoretical models (Fried et al. 2017). This development and structuring of 'invasion ecology' as a specific disciplinary field has undeniably contributed to stimulating the scientific production associated with this theme. Growing environmental awareness since the 1970s has also played a major role in this dynamic (Ehrenfeld 2003). The threat posed by invasive alien species to native biodiversity has given rise to growing interest and more substantial funding for research in this field, from both government agencies and non-governmental organisations (Bradley et al. 2019). This heightened ecological awareness has greatly stimulated the scientific efforts devoted to this issue. Finally, research into invasive alien species now calls for multi- and interdisciplinary approaches, involving not only ecology, but also other disciplines such as genetics, economics, sociology, etc (Vaz 2018). This diversity of analytical approaches, and variety of disciplinary fields involved, multiplies the research perspectives on this theme; leading to an increase in the number of scientific publications devoted to it (Latombe et al. 2023). The fact that this subject is open to cross-disciplinary and complementary viewpoints means that the scientific output around it is substantially increased.

Keywords co-occurrence

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Fig. 5 presents an analysis of the most frequently used keywords in the literature on the ecology and impacts of invasive species. There are 4 main groups of keywords, represented by the colors green, blue, red and yellow. The green group constitutes the central core, closely linked to the concept of invasive alien species. It concerns the processes of invasion, the ecology of these species and their impacts. The publications in this group explore their effects on biogeography, the distribution of native species, biodiversity, and conservation. The study of their geographical distribution could lead to specific solutions. The blue group, the second largest, is linked to the observed processes of biological invasions, climate change, the concept of the ecological niche, the distribution of populations, risk assessment and niche modelling. The red group deals mainly with the management of ecosystems in the face of introduced species, considering population densities and environmental impacts. Finally, the yellow group deals with population dynamics, detection of species presence and interspecific relationships.

Scientific studies on invasive alien species use a wide range of key words (Meyerson et al. 2019). First of all, these allochthonous organisms spreading into new ecosystems are commonly referred to as "invasive alien species", "biological invasion" and "introduced" or "allochthonous species" (Fried and Panetta 2016). The central themes of these publications relate to the ecological and economic consequences in colonised environments, addressed by keywords such as "ecosystem disruption", "impact on biodiversity" and "agricultural damage" (Vilà 2011). Key concepts such as "pathways of introduction", "dispersal", "interspecific competition" and "niche models" are used to understand the underlying processes (O'Loughlin et al. 2019). In addition, a major strand of research focuses on the "management" or " invasions control", "eradication", "biosecurity" and "prevention of invasion risks", highlighting the issues of "conservation" and "biotic homogenisation" (Barney et al. 2013). This diversity of terminology illustrates the multidisciplinary nature of the field of "biological invasion" and its many dimensions.

Geographical distribution of the studies

Invasive alien species represent a major threat to biodiversity and natural ecosystems across the globe. Many countries have become aware of this problem and are investing considerable research efforts to better understand and combat this phenomenon (Fig. 6). The United States is one of the world leaders in terms of scientific publications on this subject. With vast continental and island territories, the country is faced with numerous biological invasions threatening its unique ecosystems. Canada, Italy, Spain, France, China and other countries are also investing increasing research efforts in response to the threats posed by invasive alien species to their rich national biodiversity. Australia, rich in endemic species, is also a major player in research into invasive species. Island environments are particularly vulnerable to the accidental or involuntary introduction of allochthonous species. The United Kingdom, New Zealand, and Portugal are also among the most prolific countries in terms of publications on this issue. In these countries, the problems of biological invasions are exacerbated by trade and the importance of transport. In Africa, a number of countries, most notably South Africa, Ethiopia, Kenya, Nigeria, and Benin, have also become aware of the problem and are investing

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commendable efforts in the field of ecology and invasive alien species impacts. It is important to note that, although the phenomenon of invasive species is widespread on a global scale, the degree of involvement varies from country to country in terms of dedicated scientific research, often correlated with specific national or regional problems.

Research into biological invasions that threaten biodiversity and natural ecosystems is motivated by several factors. Countries facing serious problems in this area, such as the United States, Australia, and New Zealand, are being encouraged to investigate the subject more closely. Similarly, nations with particularly rich biodiversity, such as South Africa and Mexico, attach great importance to studying these threat factors (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. 2023). In addition, the capacity for funding and the existence of high-performance research infrastructures facilitates the publication of scientific work on this subject, which explains the involvement of the major economic powers (Liu et al. 2023). Some governments, such as New Zealand, which have made invasive species an environmental priority, are also stimulating these research efforts. The increased vulnerability of islands to biological invasions is encouraging island countries to take an interest in this issue (Pérez et al. 2022). Finally, when these phenomena have an impact on major sectors of the national economy, such as the agro-industry in Brazil, there is inevitably renewed scientific interest in the subject (Polce et al. 2023).

The publication of scientific articles on invasive species is of crucial importance for countries, firstly because it enables them to understand and document the impact of these exotic species on their territories (Latombe et al. 2023). The research carried out and published helps to quantify and qualify the ecological, economic and health consequences of these biological invasions (Simberloff et al. 2013). This provides a solid knowledge base for raising awareness among the general public, the economic players involved and political decision-makers of the seriousness of this environmental problem and the urgent need to take action to counter it (Cook et al. 2013). In addition to understanding the impacts, scientific publications also play an essential role in identifying the pathways and vectors for the introduction of invasive alien species (Esler et al. 2010). By studying how these undesirable organisms manage to establish themselves in a new territory, whether through trade, transport, tourism or other channels, research can help to develop preventive measures and stricter regulations to limit the risks of future biological invasions (Pauchard et al. 2016). Publishing on invasive species also helps to advance knowledge of solutions for managing, controlling, eradicating or containing these problematic species (Vallecillo 2019). Numerous articles describe and evaluate the effectiveness of different methods, be they physical, chemical, biological or other. By sharing these discoveries, scientists around the world can learn from each other's best practices in combating invasions in their respective territories (Convention on Biological Diversity 2010). Publication also plays an essential role in the surveillance and monitoring of invasive species over the long term. It is crucial to regularly document changes in the populations of these species, their geographical expansion or the emergence of new outbreaks (Diagne et al. 2021). This provides an early warning of new

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threats and enables management strategies to be adjusted accordingly. Scientific articles provide reliable references to support this monitoring.

From another point of view, published research is essential to inform and guide national and international public policy on biosecurity, biodiversity conservation and the sustainable management of invasive alien species (Dickie et al. 2014). Publications provide the factual basis and scientific data needed by decision-makers to develop appropriate and effective regulations, action programmes and strategies to combat this global environmental scourge (Essl et al. 2019). The publication of high-quality articles on invasive species is therefore an essential investment for any country wishing to better document, understand, prevent and combat biological invasions that represent major threats to its natural ecosystems and economic interests.

CONCLUSION

This literature review highlighted the extent of research carried out on invasive alien species and their ecological impacts in various regions of the world. The studies analyzed demonstrate the profound disruption these species can cause to native ecosystems, threatening biodiversity and leading to sometimes irreversible imbalances. While the mechanisms of introduction and spread vary depending on the species and environments concerned, one common observation remains: invasive species represent one of the greatest threats to the integrity of global ecosystems. Faced with these major challenges, the scientific community is making sustained efforts to expand knowledge, develop effective management strategies, and raise public awareness. However, many uncertainties persist, particularly regarding the complex interactions between invasive species and their host environments. Further research is needed to better understand the factors driving biological invasions and their long-term consequences. To mitigate the impact of invasive species, it is crucial to implement proactive conservation and management strategies. These should include early detection and rapid response mechanisms, habitat restoration programs, stricter biosecurity measures to prevent new introductions, and the promotion of native species resilience. Additionally, interdisciplinary collaboration between scientists, policymakers, and local communities is essential to designing and implementing adaptive management plans. Public engagement and education also play a key role in preventing the unintentional spread of invasive species. Only a comprehensive, coordinated approach to this issue can offer hope of curbing this growing phenomenon, which has severe environmental and economic repercussions.

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Conflicts of interest

The authors have declared that no competing interests exist.

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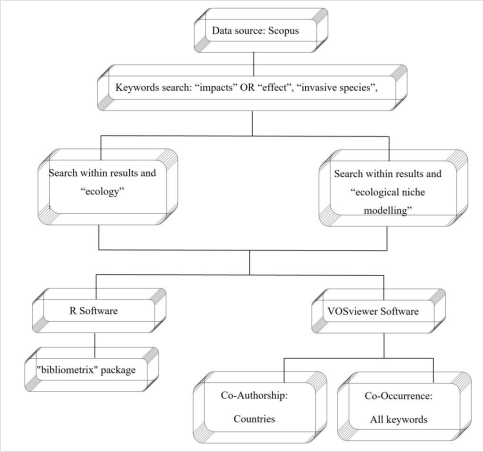

Figure 1.

The systematic bibliometric review flowchart.

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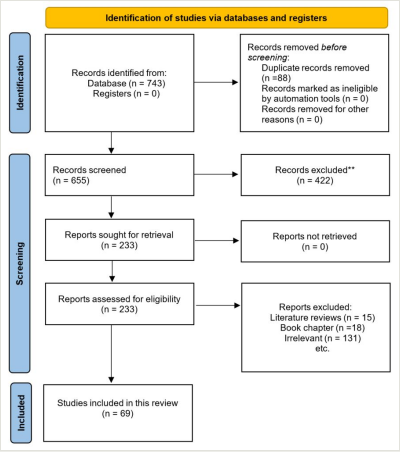

Figure 2.

Selection process flowchart, based on PRISMA.

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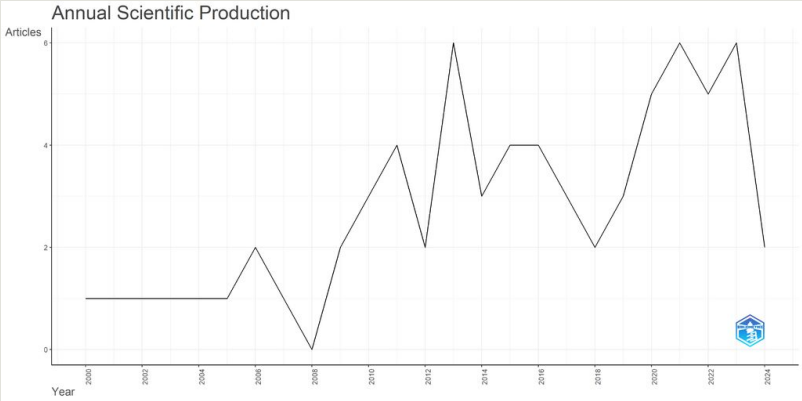

Figure 3.

Number of related papers published on ecology and impacts of invasive species from 2000 to 2023.

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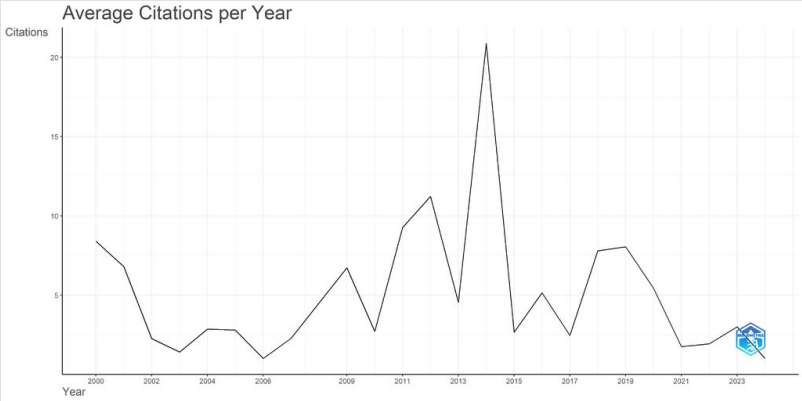

Figure 4.

Average citations per year.

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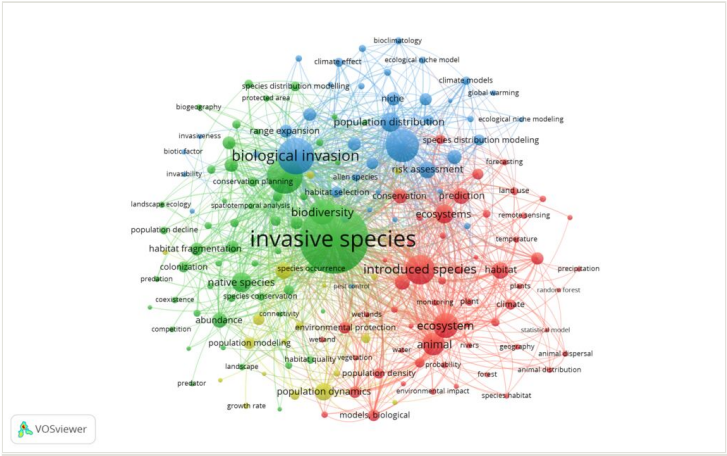

Figure 5.

Graphical representation depicting the interconnected relationships among frequently co-occurring keywords.

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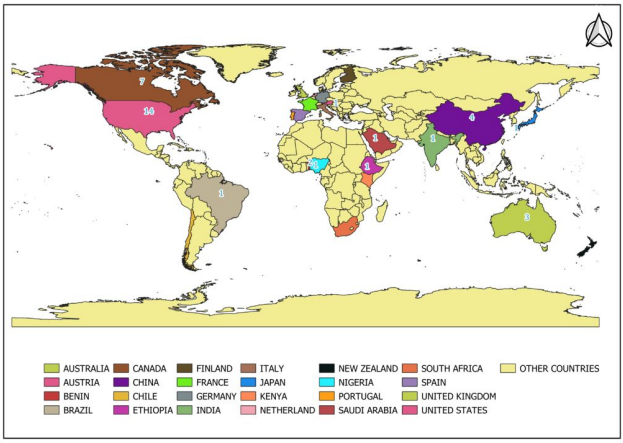

Figure 6.

Country-level distribution of scientific article production