Scientific evidence in biodiversity conservation rarely crosses language barriers in citation networks

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ABSTRACT

Using relevant scientific evidence is crucial to effectively conserve species and ecosystems worldwide. Currently, evidence that is available only in non-English languages is severely underutilised. To understand most underutilised languages of evidence and factors that facilitate the use of non-English-language evidence, this study analyses the citation patterns of articles testing the effectiveness of conservation actions, published in English and 15 non-English languages. Our results showed that non-English-language articles received significantly fewer English citations than English-language articles. Hungarian, Polish, Korean, and Russian articles were particularly under-cited in English. Despite lower English citations, many non-English-language articles had high citations within their own languages, indicating their value within local conservation communities. Non-English-language articles with English abstracts received more English citations. The content of the article, such as having a more robust study design or assessing threatened species, was not significantly associated with the number of English citations received. Our findings highlight the importance of increasing the visibility and recognition of non-English-language articles, especially those in currently underutilised languages, for a more comprehensive understanding of global conservation challenges. Providing a translated English abstract has a potential to increase the readership of an article by increasing the accessibility to those who can understand English.

Keywords

Evidence-based conservation, evidence synthesis, language barriers, language bias, conservation science, citation patterns, non-English language literature, metascience

INTRODUCTION

Conservation science intends to generate evidence that informs conservation decision-making (Wilson *et al.*, 2016). Evidence-based conservation focuses on implementing a 'best-practice' approach, based on evidence documented in the scientific literature as well as other types of knowledge, such as traditional and local ecological knowledge (Sutherland *et al.*, 2004; Gillson *et al.*, 2019; Hosen, Nakamura and Hamzah, 2020; Jessen *et al.*, 2022). The need for effective conservation intervention cannot be overstated, with a 69% global decline in monitored vertebrate populations since 1970, and 1 million species threatened with extinction (Brondizio *et al.*, 2019).

Evidence-based conservation builds on evidence synthesis—the systematic collation of relevant scientific evidence from multiple sources. However, successful evidence synthesis, and therefore successful evidence-based conservation requires a reliable evidence base (Christie *et al.*, 2021). Biases within the evidence collated through evidence synthesis can be detrimental to environmental outcomes since it is not always appropriate to make generalizations or apply research from one particular context to another (Gillson *et al.*, 2019; Christie *et al.*, 2021). To develop a comprehensive evidence base, evidence synthesis needs to search for evidence in as many relevant sources as possible (*Guidelines and Standards for Evidence synthesis in Environmental Management (Version 5.1)*, 2022).

Although the global dominance of English as the common language of science has fostered a greater capacity for global information sharing and collaboration (Di Bitetti and Ferreras, 2017), it has also led to information in other languages being undervalued and underutilised (Lynch *et al.*, 2021; Hannah *et al.*, 2024). Non-English-language literature is an important information source in conservation science, providing alternative descriptions or different cultural understandings within the scientific discourse (Díaz-Reviriego *et al.*, 2024). Non-English-language literature can also provide scientific evidence on species, regions and ecosystems that may be otherwise undocumented in English language literature alone (Angulo *et al.*, 2021). Similarly, studies published in lower impact factor journals, such as much non-English language literature, can be an important recourse in informing domestic conservation decisions (Amano, Berdejo-Espinola, *et al.*, 2023; Choi *et al.*, 2024). Omitting non-English-language literature from evidence synthesis can lead to bias in the resulting datasets and mislead conservation decision-making (Konno et al., 2020). Therefore, it is important to ensure that all available evidence has been collected, including evidence across multiple languages, to ensure the best possible environmental outcomes are being achieved.

Many English-language reviews with a global scope tend to only cite literature published in English (Lynch *et al.*, 2021; Hannah *et al.*, 2024) often based on the assumption that any important scientific information is available in English-language literature (Amano, Berdejo-Espinola, *et al.*, 2021). If non-English-language literature is being frequently cited by English-language literature (Fig. 1A) this tendency may be inconsequential. In this case, the relevant evidence is being transferred from non-English languages to English, and then to global reviews, which are often intended to inform international decision-making and conservation outcomes (Cook, Possingham and Fuller, 2013). In contrast, if non-

English-language literature is not being highly cited by English-language literature (Fig. 1B), there may be a divide between languages, indicating that the scientific evidence being produced in non-English languages may not be reaching global reviews, which will limit its application in decision making and conservation outcomes, as their evidence base can be incomplete and biased (Christie *et al.*, 2021).

Few studies to date have assessed the flow of scientific evidence on biodiversity conservation between languages, although investigating this can be a key component in understanding how language barriers impact evidence-based conservation. Cross-language citations can indicate the degree of transfer of scientific evidence between languages. Comprehension of these interactions between languages will allow stakeholders to understand which languages may be underrepresented in informing conservation decisions. For instance, it can be assumed that languages with lower rates of cross-language citations could produce information largely unknown to the international scientific community. Understanding this information flow can help reduce the resources needed to assess conservation literature in multiple languages.

Using a global database of primary studies on the effectiveness of conservation interventions, published in English and 15 non-English languages (Sutherland *et al.*, 2019; Amano, *et al.*, 2021), this paper addresses this knowledge gap by investigating the language patterns that exist within citation networks for conservation articles of global importance. The specific objectives of this paper are three-fold: (i) assessing the strength and direction of citational links between different languages to understand how conservation-related evidence flows among different languages, (ii) identifying any largely isolated languages that receive few cross-language citations, and (iii) investigating factors that influence the international visibility of non-English language literature, as measured by the number of English-language citations. This study will allow us to test the assumption that non-English-language literature does not need to be directly cited in global reviews, as the information filters through by being cited in English language literature (Fig. 1A). Ultimately, the global information flow within conservation science is an important process that should be understood to ensure that non-English language literature is being appropriately utilized, and to understand any gaps and barriers that may exist.

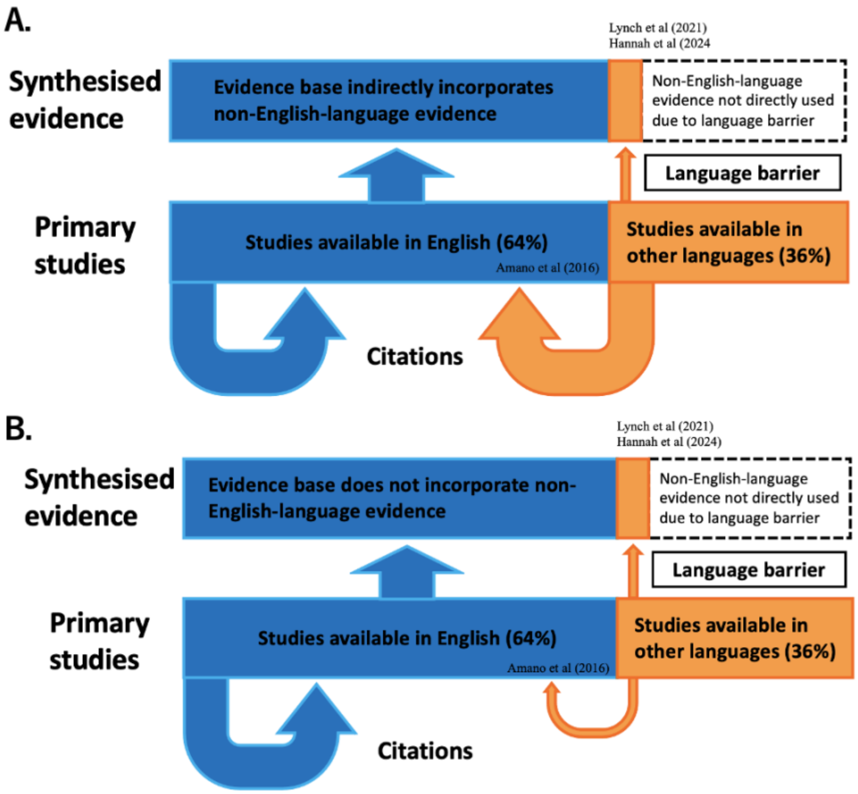

Figure 1: The importance of assessing citations across multiple languages. A. A system wherein scientific evidence published in non-English languages is well represented by English language studies, which are predominantly cited in reviews with a global scope. B. A system wherein evidence published in non-English languages is not widely cited by English language studies, meaning that this information is rarely present in evidence bases underpinning global reviews.

Methods

Database

This paper analyses articles published in English and non-English languages providing evidence on the effectiveness of conservation interventions. The database of non-English-language articles was established in Amano et al., (2021), and contains 1,234 scientific articles written in 16 different non-English languages. Using a discipline-wide literature search method (Sutherland *et al.*, 2019), these articles were manually screened from a range of relevant journals. Articles were included in the database if they met pre-defined inclusion criteria; A: articles that measure the effect of an intervention that might be done to conserve biodiversity, and B: articles that measure the effect of an intervention that might be done to change human behaviour for the benefit of biodiversity (see Amano, Berdejo-Espinola, *et al.*, 2021 for more details). Articles in this database range from 1915 to 2020, with the median year of publication being 2009. The inclusion criteria did not specifically limit articles based on species. Therefore, the database covers a wide range of species, including terrestrial and aquatic plants and animals. This study utilised a subset of the articles from this database; we selected journal articles that assessed the three taxa: birds, mammals, and amphibians to allow for comparison between taxa (n = 329 total articles). These articles spanned from 1963 – 2020, with a median year of publication of 2009. Our database for analysis contained articles across 15 different languages, with the largest number of articles being Japanese (n = 93), followed by German (n = 55), Spanish (n = 39) and Russian (n = 28).

We also used a discipline-wide literature database provided by Conservation Evidence (https://www.conservationevidence.com/), which contained 11,847 articles, predominantly written in English, but also containing a number of non-English-language papers. This database contained journal articles, as well as theses. The inclusion criteria for this database are the same as described for the non-English-language database (Sutherland *et al.*, 2019). Articles in this database range from 1912 to 2022, with the median year of publication being 2006. Similar to the non-English-language database, the inclusion of articles is not based on the species covered by the study, so a wide range of species are covered within this database. To allow for more manageable data extraction, a random sample of papers within the three taxonomic categories was taken from the Conservation Evidence database, rather than investigating all articles. A sample size of 171 English-language articles was determined by using the sample formula in the R package *samplingbook* (Manitz *et al.*, 2021), assuming a confidence interval of 0.15, an expected proportion of English-language citations being 50% of total citations. Because citation patterns may vary over time, we attempted to maintain the same temporal structure as the non-English-language database within each taxonomic group (birds, mammals, amphibians). To achieve this, we performed stratified random sampling, where articles were randomly selected within decade / taxon combinations (e.g. 3 articles from the time period 1990 – 2000 in the category birds). The articles in this sample ranged from 1971 to 2019, with a median publication year of 2007.5.

Both databases already contained general metadata relating to each article, such as the title, author names, year and journal name. The non-English language database also contained information relating to the language of the article.

Data Extraction

Each article was individually searched on Google Scholar (https://scholar.google.com.au/) by looking up either English language or non-English language titles (if applicable) between 9/6/2023 and 29/8/2023. If an article could not be found using Google Scholar, it was also searched using Google (https://www.google.com/) and the University of Queensland institutional library (https://www.library.uq.edu.au/). If found on these platforms, the article was searched again in Google Scholar using the DOI, the non-English-language title or any other identifying information to obtain the citation information from the Google Scholar platform. Articles that were still unable to be located were marked as such and were excluded from the analysis (n = 14 articles in the non-English-language database). For the non-English-language articles, the article was assessed to determine if any English-language title or abstract was provided. Next, the number of citations received by the article was recorded based on information provided on Google Scholar. The citations were then evaluated to determine if there were any self-citations. Self-citations were recorded if any author of the original article appears as an author of the citing article. Finally, each article that had cited the focal article was individually accessed to determine its language. The language of each citing article was determined by pasting either the title of the article or a portion of the main text into Google Translate (https://translate.google.com/) and using its language detection feature. The number of citations by language was recorded for each article.

The lexical distance between each non-English language and English was recorded using an online linguistic distance calculator from eLinguistics.net (http://elinguistics.net/), with a lower value indicating a language is more related to English. The non-English-language database also included lists of the species studied in each article. These species were cross-referenced against the International Union for Conservation of Nature (IUCN) Red List of Threatened Species version 2023-1 (https://www.iucnredlist.org/) to determine the conservation status of the species studied in each article. All data extraction was performed from June to August of 2023.

Analysis

Three multivariate models were developed in R Version 2023.06.0+421 (R Core Team, 2019) using the full database of English and non-English-language articles.

First, to assess the difference in citation numbers between English and non-English-language articles we ran a negative binomial generalised linear model (GLM) with the number of English citations (i.e., citations by English-language articles) as the response variable, and the language of articles as the explanatory variable. English was used as the reference category. Next, we ran the same GLM but with the total number of citations (i.e., citations by articles in any languages) as the response variable.

The third analysis assessed the factors that explain variation in the number of citations by English-language articles. This analysis only used the non-English-language database. The response variable was the number of English citations and the explanatory variables were: year of publication, the availability of an English abstract (yes/no, no is the reference category), study design (more complex/less complex, less complex is the reference category. After, Before-After, and Control-Impact designs were categorised as being less complex, and Before-After-Control-Impact and Randomised Controlled Trial were categorised as more complex, following Christie et al 2019), IUCN status of the study species (threatened/not threatened, not threatened is the reference category. Least Concern and Near Threatened were defined as not threatened, and Vulnerable, Endangered, and Critically Endangered as threatened), taxonomic group (birds/mammals/amphibians, birds is the reference category), lexical distance of article language from English, and the total number of same language citations received by an article.

We hypothesised that articles providing their abstracts in English and those in languages that are linguistically closer to English would receive a higher number of citations from English-language article. We used other explanatory variables to control for their impacts. The year of publication of an article would be negatively associated with a higher number of English citations, since older articles have more time to receive citations. Also non-English-language articles that have a larger number of same-language citations are considered of higher importance and may thus also have a higher number of English citations. Articles that focus on threatened species are also expected to have a higher number of English citations due to the conservation importance of the studied species. Non-English-language articles with a more robust study design are also expected to receive a higher number of English citations, since these articles may be perceived as more valid and worth citing.

The Variance Inflation Factor (VIF) was sufficiently small (< 2.96, calculated with the package *car* in R (Fox and Weisberg, 2019)) for all explanatory variables in the models.

Results

The number of English citations among the 329 articles written in non-English languages was generally low, with a median of 0 (range 0 – 26, Figure 2). Articles in Hungarian, Polish, and Russian in particular received few English citations, ranging between 0 and 2. In contrast, English-language articles received a median of 37 English citations (range 0 – 356), and the number of English citations was significantly lower for articles in all non-English languages compared to English-language articles (Figure 2, Table S1).

While there was little difference between the number of English citations and the total number of citations for English-language articles, the total number of citations was consistently higher than the number of English citations for articles in all non-English languages (Figure 2). Most of the non-English-language citations were from the same language as the original article (Figures 3 and 4). For example, 28% (n=74) of the assessed non-English-language articles only contained citations within the same language, and 47% (n=124) contained over 50% of their citations within the same language. This suggests that many of the non-English-language articles are discovered more from researchers using the same language than from English. Although the total number of citations received by an article was still significantly lower for all non-English languages compared to English (Figure 2, Table S1), this result suggests that the extremely low number of English citations for non-English-language articles is not solely due to the lack of the importance of the study, but at least partly due to the lack of visibility, or lack of searching effort resulting from language barriers

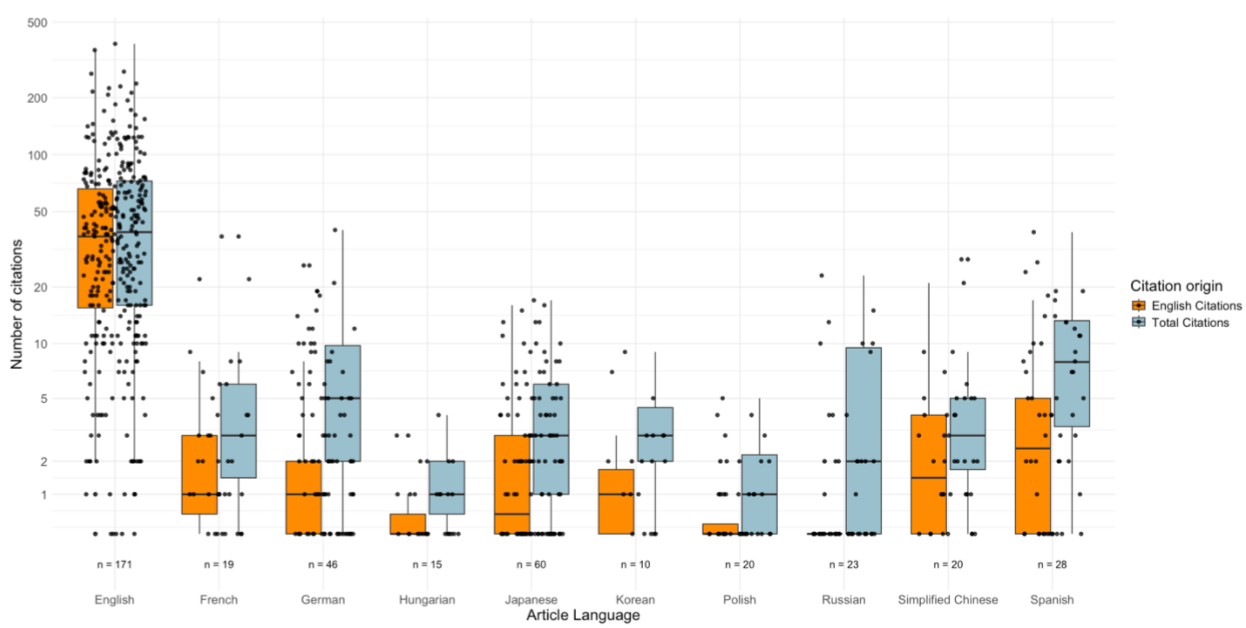

Figure 2: The number of English citations (orange) and the total number of citations (blue) received by articles written in different languages. The middle line within each box represents the median value. The top and bottom of the box denote the first (Q1) and third quartiles (Q3), respectively, indicating the interquartile range (IQR). The whiskers extend to the smallest and largest values within 1.5 times the IQR

from the Q1 and Q3. All individual articles are also plotted as dots. The y-axis has been log10-transformed.

When assessing citations to all articles in each non-English language, an average of 56.8% and median of 60% of total citations (range: 0% - 100%) were from the same language as the original article (Figures 3 and 4). Alternatively, an average of 37.8% and median of 33% of citations (range: 0% - 100%) were from English (Figures 3 and 4). For all languages, other non-English cross-language citations (i.e. articles in languages other than their own or English) was generally very low at 4.3% on average, and a median of 0% (range: 0% - 100%. Russian clearly showed the lowest proportion of English citations, followed by Hungarian and Polish (Figure 3). These languages may be considered the most isolated, with limited sharing of their findings internationally. In contrast, French and three East Asian languages (Japanese, simplified Chinese, and traditional Chinese) showed a particularly high proportion of English citations overall (54%, 61%, 62%, and 67%, respectively).

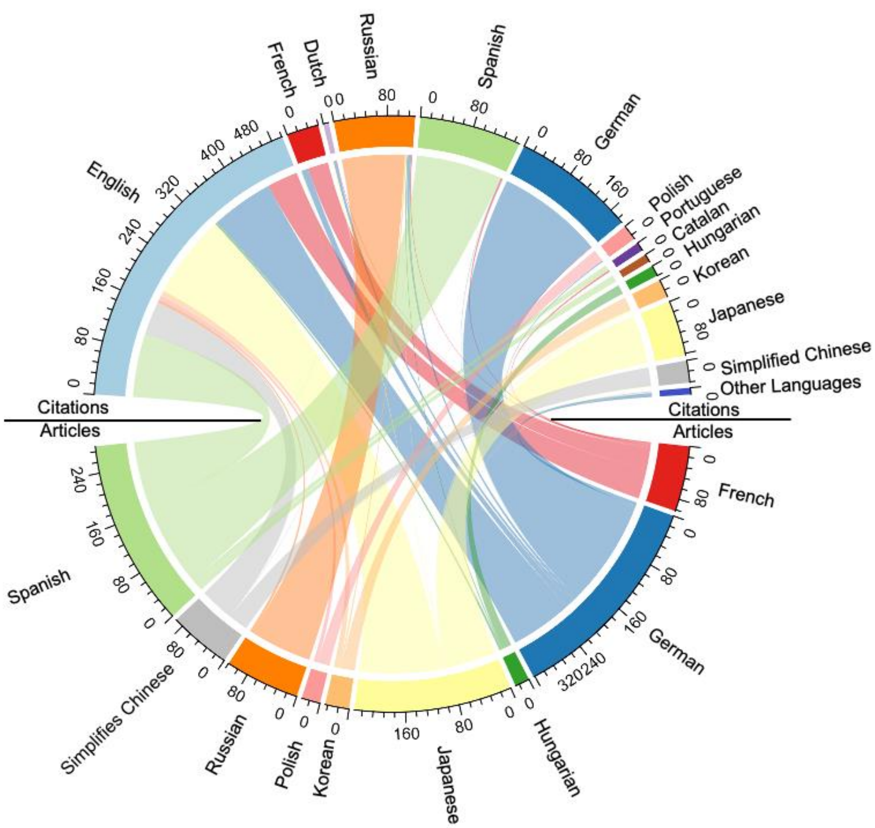

Figure 3 – Language patterns of citations for non-English language articles. Figure shows the number of citations received in each language. Excludes languages with <10 articles.

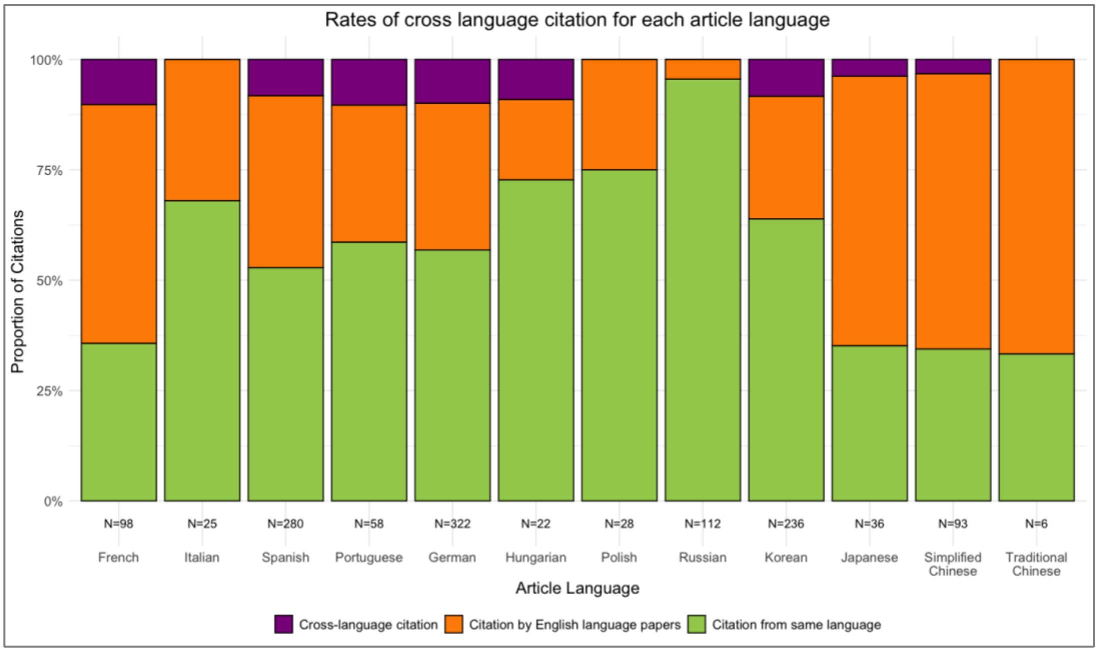

Figure 4: The proportion of total citations received by an article split into three groups: citations from the same language as the article (green bottom section), English (orange middle section), or another non-English language (purple top section). The number of citations received by articles in each language is displayed in the figure.

As hypothesised, non-English-language articles that included an English-language abstract received a significantly higher number of English citations when controlling for other factors (Figure 5, Table S2). Contrary to our hypothesis, articles in languages that are more linguistically distant from English received a significantly higher number of English citations (Figure 6, Table S2). As expected, articles that were published in older years and had more citations from the same language also attracted a higher number of English citations (Figure 5, Table S2).

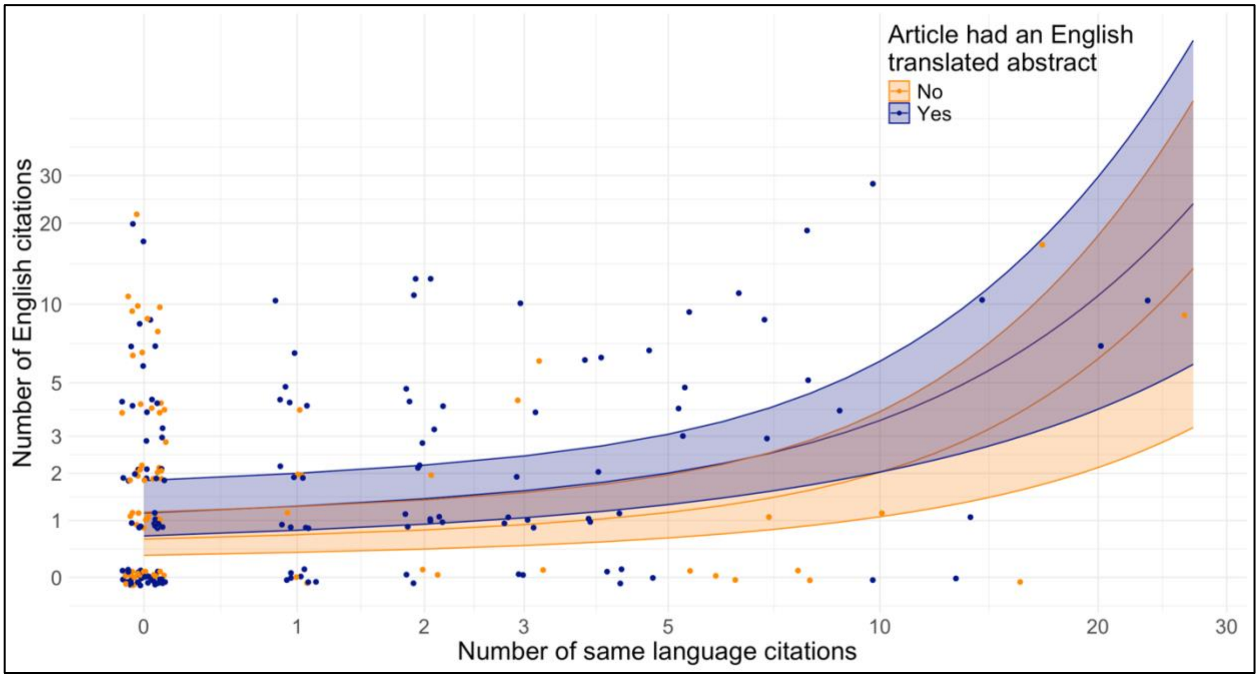

Figure 5: Relationship between the number of same-language citations and the number of English language citations received by non-English language articles with (blue, n=140) and without (orange, n=79) an English-language abstract. The regression lines are based on the fitted negative binomial generalised linear model (Table S2) with 95% confidence intervals shown as shaded areas. Jitter is used to show all data points. The x and y-axis have been log10-transformed.

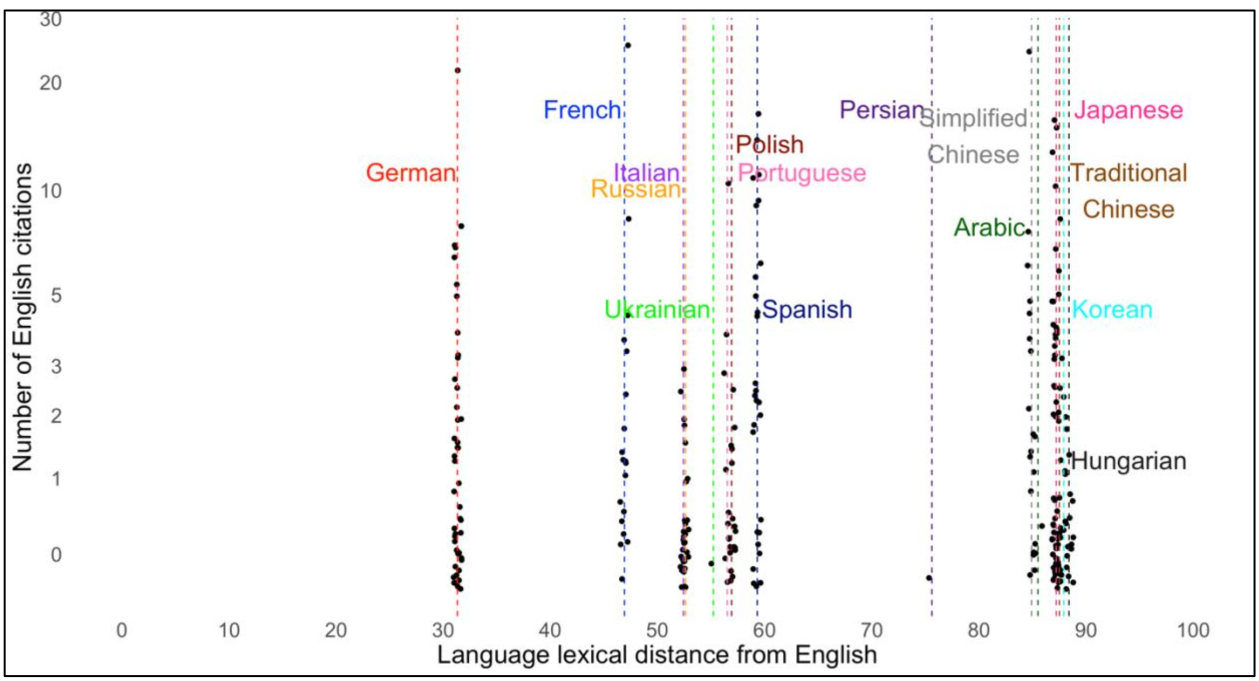

Figure 6: Relationship between the linguistic distance from English of the language of a non-English language article and the number of English language citations received by the article. Jitter has been used to show all points. The y-axis has been log10 transformed.

Our analysis showed that 91% of citations for all articles in the English-language database were from English-language articles (Supplementary Figure 1). Out of the non-English-language citations, the highest number of citations was from Spanish, followed by German and Portuguese, though these languages only accounted for small percentages (1.73%, 0.66% and 0.65% respectively) due to the overwhelming dominance of English citations. 24.86% (n=43) of articles only contained English language citations. Only 10 English-language articles in our sample had an abstract that was translated into another language. Abstracts were found to have been translated into only Spanish (n=8) or French (n=2).

DISCUSSION

Our study found that non-English-language literature received significantly fewer citations than English-language literature, and specifically, fewer citations from English language articles. Our analysis also revealed that the total number of citations is consistently higher than the number of English citations in all non-English languages, meaning that citations to non-English-language articles are primarily from the same language. This suggests that the limited number of citations from English-language articles must be at least partly due to the effects of language barriers, wherein these articles are overlooked or inaccessible due to their language (Amano, González-Varo and Sutherland, 2016; Hannah *et al.*, 2024).

There were several isolated languages for which English-language citations were notably rare, including Hungarian, Polish, Korean and Russian (Figure 3). This suggests that scientific evidence being produced in those languages may not reach a broader audience, such as researchers, policymakers, and conservation practitioners in different regions, despite the relevance or importance of the science. Russian, for example, was the most isolated study in our database, with an average of 94.8% of citations being in the same language. Russia is known to have high scientific output (Mokhnacheva and Tsvetkova, 2019), however this information is rarely used internationally. Russian-language articles may also be particularly important in conservation due to the country's vast and unique landmass, which is home to a number of rare endemic species as well as migratory species (Kirpotin *et al.*, 2021). These articles may provide essential insights into these species and ecosystems, contributing to both conservation efforts and the global understanding. However, due to the isolation of the Russian-language articles, much of this information remains underutilised by the international community. Although the database of non-English-language articles used in this study covers the top 16 non-English languages in terms of scientific publications (Amano et al. 2016), we can't dismiss the possibility that there are other languages in which important evidence for conservation is published yet rarely used internationally.

Having an English-language abstract was positively associated with the number of English citations in non-English-language articles (Figure 5, Table S2). Although there may be other confounding factors (e.g., non-English-language articles indexed on a well-known literature search system may be more likely to have English-language abstracts), this suggests that providing an English-language abstract in a non-English-language article can increase its international visibility, potentially increasing its impact. Importantly, our model found that non-English-language articles with a more robust study design or those assessing species of greater conservation concern did not necessarily receive more English citations. This may indicate that scientific rigour and global importance are not necessarily the key elements in gaining article attention, and instead language-related visibility and accessibility are crucial. Many of the non-English language articles assessed in this study adopt robust study designs to test the effectiveness of conservation actions for threatened species (Amano, *et al.*, 2021), some of which may not have been fully utilised in conservation simply due to language barriers. For example, the study by Shizhou, Shengqiao, & Wu (2013), a randomised control trial investigating the critically endangered South China Tiger, which has only received 3 citations.

Contrary to our hypothesis, the number of English citations was higher in articles written in languages that are more linguistically distant from English. This may indicate that languages that are further from English, such as Japanese, simplified Chinese, and traditional Chinese, may have greater recognition by both international and domestic communities as an important source of evidence for informing conservation science. Japanese has the largest number of papers in our database (60), sourced from 12 different journals. These journals and papers seem to be recognised as an important source of evidence both domestically and internationally.

Sharing scientific information across languages is key to gaining a comprehensive understanding of conservation challenges and performing conservation actions based on relevant and robust evidence. Incorporating greater diversity in the language of sources can reduce bias (Konno et al 2020) and offer unique perspectives and regional/local knowledge (Amano, *et al.*, 2021). For example, regions with rich biodiversity but limited resources for research are often underrepresented in conservation science, leading to an incomplete understanding of ecosystems, hindering effective conservation strategies (Amano, Lamming and Sutherland, 2016; Wilson *et al.*, 2016). Language gaps further compound the issue, as English is not widely spoken in many of the regions with rich biodiversity, and research published in languages other than English there often struggles to reach a global audience (Di Bitetti and Ferreras, 2017). Similarly, information needs to flow between different non-English languages to avoid wasted resources and incomplete understandings (Buxton *et al.*, 2020). If cross-language citations are rare, the research produced within a language may lack these alternative viewpoints, risking the formation of echo-chambers. While sometimes research may only apply to a small area or locally relevant topic, reliance on same-language citations can limit the global impact and interrupt the exchange of knowledge.

Our results suggest that providing English-language abstracts of non-English-language articles may increase the visibility and use of the articles. However, simply recommending that authors publishing in non-English languages include English-language abstracts may further burden those whose first language is not English, as these authors already face significant time and resource costs (Amano *et al.*, 2023). A potential solution could be the implementation of machine translation technologies. While the quality of machine translation including artificial intelligence is still not perfect and varies between languages (Esperança-Rodier and Frankowski, 2021; Mohamed *et al.*, 2024; Moneus and Sahari, 2024), publishers, journals, and literature search systems should start considering its implementation on their platforms to multilingualise scientific publications. These measures are especially important when it comes to the more isolated languages, such as Russian, Korean, Polish and Hungarian, where there are a limited number of English citations.

Conservation science, being a discipline with global application, benefits from a diverse range of perspectives, methodologies, and findings. While it can be difficult to assess information in multiple languages, research teams should endeavour to proactively search and include evidence that is available only in non-English languages to ensure that all relevant evidence is considered. Ultimately, the integration of multilingual information into conservation science can benefit both the scientific community and the natural world that we seek to conserve.

Funding and Data Availability

This work is supported by the Australian Research Council Future Fellowship FT180100354 and The University of Queensland Research Training Program Scholarship.

The data used in the analysis is provided as Supplementary Data S1. All codes used in the analysis are available at https://github.com/KHannah12/MultilingualCitations/.

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