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# Bibliometric analysis of biological invasions research during the period of 1991 to 2007

HAO QIU,[a,b] YI-FENG CHEN[a]

[a] *Laboratory of Biological Invasion and Adaptive Evolution, Institute of Hydrobiology, Chinese Academy of Sciences, Wuhan 430072, P. R. China*
[b] *Graduate School of Chinese Academy of Science, Beijng, P. R. China*

The objective of this study is to conduct a bibliometric analysis of all biological invasions-related publications in the Science Citation Index (SCI) from 1991 to 2007. The indicator citation per publication (CPP) was used to evaluate the impact of articles, journals, and institutions. In the 3323 articles published in 521 journals, 7261 authors from 1905 institutions of 100 countries participated. As the most productive country of biological invasions research, the US will benefit from more collaboration between institutions, countries, and continents. In addition, analysis of keywords was applied to reveal research trends.

## Introduction

Biological invasions is a pervasive and costly environmental problem that threaten biodiversity in almost all ecosytems [CARLTON & GELLER, 1993; VITOUSEK & AL., 1996]. Encompassing new human pathogens, weeds or pests in terrestrial systems, and dominant alien species in freshwater or marine aquatic systems, they are second most important proximate cause of biodiversity loss worldwide, only inferior to direct habitat transformation [SOULÉ, 1990]. Therefore, biological invasions have been the focus of intense management and research activities worldwide over the past half century.

Biological invasions research has grown at a frenetic pace in the past few dacades, and rapidly become one of the hottest topic in ecology [LODGE, 1993; RICHARDSON, 2006]. The scientific recognition that some species, when introduced outside their native range, cause a decline in indigenous species, go back to at the writings of Charles Darwin. In the 1950s another British biologist, Charles Elton, wrote the first book, *The Ecology of Animal and Plant Invasions* [ELTON, 1958], attempting to describe the biology of invasive organisms. It was not until the 1980s, partly as a result of international SCOPE programme on biological invasions [DRAKE & AL., 1989], did biological invasions really start their migration to centre in the theatre of mainstream ecology. This trend has resulted from two forces: the development of the scientific basis

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*Address for correspondence*:
YI-FENG CHEN
E-mail: chenyf@ihb.ac.cn

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for invasion biology based on a substantial and accumulating literature, and the urgency of the invasive species issue because increased world trade and travel are increasing the frequency of invasions [REICHARD & WHITE, 2003].

As biological invasions research reports begin to further develop worldwide, the massive increase in the number of publications dealing with aspects of invasions will need to be collected before future research strategies can be formulated. Knowledge of past invasiveness elsewhere is a key component of early warning [WITTENBERG & COCK, 2001] and is important in assessing the potential risks from new introductions. Sharing information and expertise internationally on the ecology, impacts, and management of invasive alien species is a essential to reduce the risks of further invasions and mitigate the impacts of those that have already happened [CLOUT & POORTER, 2005]. The purpose of this study, was to bibliometrically analyze the literature published in this field from 1991 to 2007, in order to provide insights into the characterstics of the literature and identify patterns, trendencies, or irregularities that may exist in the rapid growth of biological invasions research. Greater investments in improved technology and management practices would be more than repaid by reduced damageds from current and future invasive species [LODGE & AL., 2006]. Therefore, investiments should aim at supporting institutions that have a proven record of success in biological invasions research, particularly in regions where little research has been published.

## Methodology

Documents used in this study were based on the online database of the Science Citation Index (SCI) retrieved from the ISI Web of Science, Philadelphia, PA, USA. "Bio*-invasion*" and "invasive-species" were used as keywords to search titles, abstracts and keywords.

Documents were analyzed according to their type, language of publication, publication output, distribution of subject category, publication patterns, authorship, institution information, country of publication, and distribution of author keywords. The records were downloaded, and additional coding was manually performed for the number of authors, country of origin of the collaborators, and impact factors of the publishing journals. Papers orginating from England, Scotland, Northern Ireland, and Wales were grouped under the UK heading. Impact factors were taken from the *Journal Citation Report* (JCR) published in 2007.

To assess the visibility of an article, the number of times it was cited was used as an indicator. However, the numbers of times cited for an article is highly correlated with the length of time since its publication. To adjust for bias due to differences in the length of time since the publication of the articles, variables of TC2 (times cited before year 2) and CPP (citation per publication) were used [HSIEH, 2004]. Figure 1 shows the

relationship between the average number of times cited per paper and the number of years since its publication for 3323 articles. It shows that the frequency of being cited was higest in the 2nd full year since its publication, and began to decrease rapidly after that. Thus, TC2 was used to assess the visibility of articles instead of just times cited since publication. Another variable CPP for articles published in a particular year was calculated as TC2 divided by the number of articles published in that year. Therefore, CPP is reported for articles published in the period from 1991 to 2005 because paper published from 2006 to 2007 do not accumulate 2 full year citation records thus were excluded from the analysis.

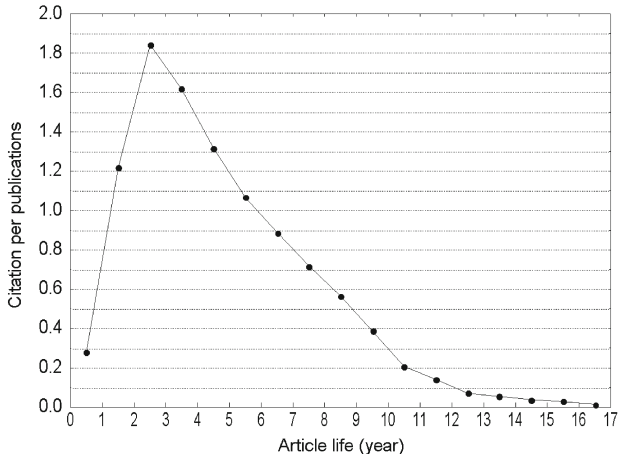


Figure 1. Citation per publication by article life

## Results

*Language of publication*

The nine languages in which the documents were published were dominated by English (3743; 99%) followed distantly by French (21; 0.56%), spanish (8; 0.21%), German (3; 0.08%), Chinese (2; 0.05%), Japanese (2; 0.05%), Portuguese (2; 0.05%), Hungarian (1; 0.03%), and Russian (1; 0.03%).

*Types of documents*

From this analysis, 10 document types were found. The articles, comprising 88% (3323) of the total production, was the most-frequently used document type, followed distantly by reviews (293; 7.7%) and editorial material (92; 2.4%). Meeting abstract (26; 0.69%), news item (25; 0.66%), letter (14; 0.37%), correction (5; 0.13%), book

review (3; 0.08%), biographical-item (1; 0.03%), and note (1; 0.03%) showed much-lesser significance. Articles were the most-commonly contributed document type, and 3323 articles were analyzed in the following study.

*Article output*

As Figure 2 displays, the number of biological invasions articles published has significantly increased since 1991. There were only 14 articles in 1991, smoothly increased to 79 in 1999. In 2006, it reached 669 articles, and 618 in 2007. The trend of the past 10 years (1998–2007) has increased at a quicker pace.

The fluctuation of TC3 and CPP values from 1991 to 2005 are also showed in Figure 2. The average CPP was 4.8. The CPP was lowest in 1993, 1991, and 1994 at 1.7, 2.3, and 2.4, respectively, but was highest in 1997, 2004, and 2003 at 6.1, 5.4, and 5.3, respectively. Using 3-year periods to minimize the year-to-year fluctuations, the average CPP values for 1991–1993, 1994–1996, 1997–1999, 2000–2002, 2003–2005 were 2.4, 3.5, 5.1, 4.1, and 5.3, respectively. Although a slight decrease of CPP values appeared between 2000 and 2002, the visibility of articles published after 1997 have significantly increased compared to articles published in previous years.

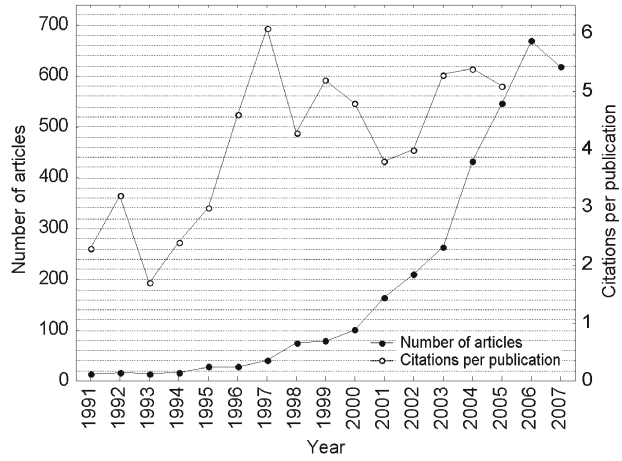


Figure 2. Output of articles and citations per publication (CPP) by year

*Distribution by subject categories*

In total, 3323 articles were published in 87 ISI subject categories. Out of the 87 ISI subject categories, 23 (26%) subject categories contained only 1 article, and 8 (9.2%) subject categories contained 2 articles. Table 1 shows the 10 ISI subject categories with

the most publications including the number of articles, percentage of total articles, and CPP. The total number of publications displayed was greater than 3323, because some publications belonged to more than one subject category.

Table 1. Number of articles and CPP by subject category

| Ranking | Subject category | P | P% | CPP |
|---|---|---|---|---|
| 1 | Ecology | 1726 | 52.0 | 5.7 |
| 2 | Biodiversity Conservation | 553 | 17.0 | 5.1 |
| 3 | Environmental Sciences | 512 | 15.0 | 4.5 |
| 4 | Marine & Freshwater Biology | 493 | 15.0 | 3.5 |
| 5 | Plant Sciences | 455 | 14.0 | 3.2 |
| 6 | Entomology | 280 | 8.4 | 3.4 |
| 7 | Forestry | 161 | 4.8 | 2.7 |
| 8 | Zoology | 144 | 4.3 | 2.4 |
| 9 | Evolutionary Biology | 137 | 4.1 | 6.0 |
| 10 | Oceanography | 131 | 3.9 | 2.8 |

P: Number of publications; CPP, citations per publication.

*Publication patterns*

Table 2. Journals publishing biological invasions articles

| Journal title | Article | CPP (ranking) | IF (ranking) | ISI category | Position |
|---|---|---|---|---|---|
| *Biological Invasions* | 172 | 6.5 (6) | 2.125 (10) | Biodiversity conservation | 10/27 |
| | | | | Ecology | 45/116 |
| *Diversity and Distributions* | 109 | 7.4 (3) | 2.965 (8) | Biodiversity conservation | 7/27 |
| | | | | Ecology | 29/116 |
| *Ecology* | 96 | 11.2 (1) | 4.822 (2) | Ecology | 7/116 |
| *Biological Conservations* | 80 | 4.1 (10) | 3.296 (6) | Ecology | 21/116 |
| *Ecological Applications* | 76 | 6.4 (7) | 3.571 (5) | Ecology | 19/116 |
| *Oecologia* | 75 | 6.9 (5) | 2.973 (7) | Ecology | 28/116 |
| *Marine Ecology Progress Series* | 63 | 4.4 (9) | 2.546 (9) | Marine & Freshwater Biology | 10/79 |
| *Conservation Biology* | 59 | 5.7 (8) | 3.934 (4) | Biodiversity conservation | 3/27 |
| | | | | Ecology | 15/116 |
| | | | | Environmental Sciences | 8/160 |
| *Journal of Applied Ecology* | 52 | 7.3 (4) | 4.220 (3) | Ecology | 14/116 |
| *Molecular Ecology* | 45 | 7.6 (2) | 5.169 (1) | Biochemistry & Mol. Biol. | 47/263 |
| | | | | Ecology | 6/116 |
| | | | | Evolutionary Biology | 5/35 |

N=3323; CPP, citations per publication; IF, impact factor.

In total, 3323 papers were published in 521 journals including specialty journals, but also journals of other disciplines. Out of the 521 journals, 205 (39%) journals contained only 1 article, and 89 (17%) journals contained 2 articles. The 100 most productive journals published 2365 (71%) articles, and the left 958 (29%) articles were published by other 421 jounals. Table 2 shows the title of the most 10 productive journals, the number of articles published by these journals, CPP, ranking order of CPP, IF, and ranking order of IF.

*Authorship*

Of the 3323 articles that were published, there were 7261 authors, The average number of authors per article from 1991 to 2007, was 3.2. Of the 3323 articles with author information, 5532 authors (76%) were credited in 1 article, followed distantly by 1041 (14%) in 2 articles, 327 (4.5%) in 3 articles.

Table 3 shows the top 10 most productive authors between 1991 and 2007. Seven of these authors were from the US, the other three were from South Africa, Canada, and the Czech Republic. Compared with authors from the US, authors from other countries had higher proportion of international co-authorship.

Table 3. The top 10 most-productive authors between 1991 and 2007

| Ranking | Author | Institution | P | CPP | ICA(%) |
|---|---|---|---|---|---|
| 1 | Richardson, DM | University of Cape Town, South Africa | 41 | 10.9 | 18 (44) |
| 2 | Macisaac, HJ | University of Windsor, Canada | 27 | 8.6 | 10 (37) |
| 3 | Holway, DA | University of California San Diego, USA | 24 | 11.3 | 2 (8.3) |
| 4 | Suarez, AV | University of California San Diego, USA | 20 | 12.3 | 3 (1.5) |
| 5 | Lodge, DM | University of Notre Dame, USA | 19 | 8.6 | 6 (32) |
| 6 | Pysek, P | Academy of Sci. of the Czech Republic | 19 | 8.5 | 8 (42) |
| 7 | Carlton, JT | Williams College, USA | 18 | 5.5 | 3 (17) |
| 8 | Dantonio, CM | University of California, Berkeley, USA | 17 | 8.4 | 4 (24) |
| 9 | Ruiz, GM | Smithsonian Enviromental Reaearch Center, USA | 16 | 5.5 | 6 (38) |
| 10 | Stohlgren, TJ | Colorado State University, USA | 16 | 4.0 | 0 (0) |

P: Number of publications; CPP, citations per publication; ICA, international co-authorship.

*Institutional comparisons*

There were 15 (0.45%) articles without institution information on the ISI Web of Science. Of the 3323 articles, totally 1905 institutions participated in. Table 4 shows the number of articles and the number of co-institution articles for institutions that had published at least 45 articles from 1991 to 2007. All of the top 10 institutions are located in the US which evolved as the strongest leader in the field.

Table 4. Institutional comparisons

| | Total articles | | Co-institution articles | | |
|---|---|---|---|---|---|
| Institution | No. (%) | CPP | No. (%) | No. of co-inst. | CPP |
| United States Department of Agriculture | 152 (4.6) | 4.0 | 107 (70) | 141 | 4.4 |
| University of California, Davis | 129 (3.9) | 7.2 | 87 (67) | 111 | 7.8 |
| U.S. Geological Survey | 79 (2.3) | 4.7 | 66 (84) | 85 | 5.2 |
| University of California, Berkeley | 63 (1.9) | 7.0 | 54 (86) | 66 | 7.0 |
| Colorado State University | 61 (1.8) | 8.1 | 51 (84) | 65 | 10.1 |
| University of Florida | 52 (1.6) | 5.5 | 37 (71) | 57 | 5.8 |
| University of Wisconsin | 52 (1.6) | 4.6 | 37 (71) | 52 | 4.1 |
| Stanford University | 50 (1.5) | 8.3 | 36 (72) | 47 | 9.5 |
| Cornell University | 46 (1.4) | 9.2 | 33 (72) | 56 | 8.0 |
| University of Minnesota | 45 (1.4) | 10.9 | 27 (60) | 43 | 11.2 |

N=3323; CPP, citations per publication.

In the total articles published by the top 10 institutions, the average percent of co-institution articles was 73%. In other words, only 27% of total articles were single-institution articles. The CPP values for total articles and co-institution articles of UMN were the highest, and also the ability to independently conduct research of UMN was highest, with 40% single-institution articles.

*Country of publication*

In total, of the 3323 articles were included in this analysis, for there were 14 (0.42%) articles without author address information on the ISI Web of Science. Out of the 100 countries of publication, 20 countries produced only 1 article, 16 countries produced 2 articles, and 62 countries produced less than 10 articles. Among the 3309 articles with author address information published from 1991 to 2007, 1894 (57%) articles were international collaborations and 1415 (43%) were independent publications, with the most articles originating form the US (1878; 57%), France (252; 7.6%), and Australia (248; 7.5%). The G7 countries (Canada, France, Germany, Italy, Japan, UK, US) were all ranked in the top 10, except for Japan (Figure 3).

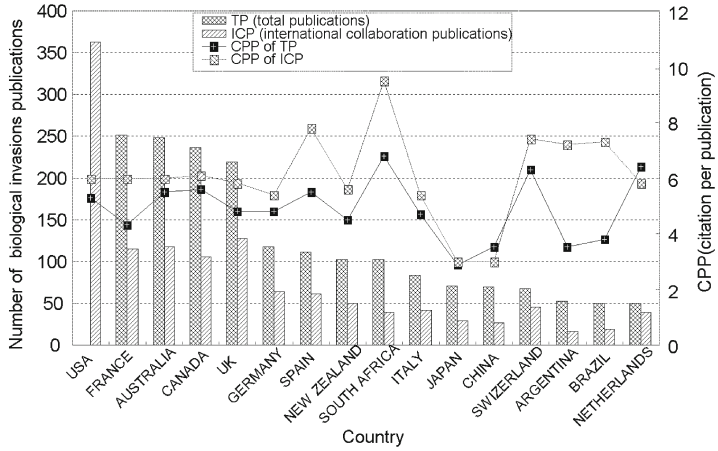


Figure 3. Publication activity of countries from 1991 to 2007
(USA's outputs (TP=1878) was not represented in the figure.)

It is notable that New Zealand, South Africa, and Argentina ranked in the top 15 of publication position, which were better rankings than seen in other research fields [GAUFFRIAU, 2009]. It is also notable that South Africa had higer CPP values compared to other world regions, including the US and Western Europe. As the two curves shown in Figure 3, the CPP values of international collaboration publications (ICP) were significant higher than that of total publications (TP), especially for some Latin American countries like Argentina and Brazil. In contrary, some Asian countries, such as Japan and China, didn't benefit a lot from international collaboration.

Table 5. Publication distribution by region

| | TP | No. country | CPP | IP(%) | ICP | No. co-country | CPP |
|---|---|---|---|---|---|---|---|
| Americas | 2134 | 14 | 5.2 | 1647 (77) | 287 | 27 | 5.9 |
| Europe | 938 | 36 | 3.9 | 662 (71) | 276 | 47 | 5.8 |
| Asia | 213 | 21 | 3.5 | 110 (52) | 103 | 30 | 4.7 |
| Oceania | 341 | 6 | 5.1 | 203 (60) | 138 | 31 | 6.1 |
| Africa | 144 | 16 | 5.7 | 71 (49) | 73 | 33 | 6.6 |

TP: Total publications; IP: single continental publications; ICP: intercontinental collaboration publications.

Table 5 shows a wide regional scatter of publications, due to the fact that every region is uniformly affected by biological invasions. The current mass invasions event is without precedent and shoule be regarded as a unique form of global change. The Americas produced the most publications (2134; 64.2% of 3323), and European had the most countries (36 countries from Europe, 47 countries from other continents) to participated in this field, the CPP value for Africa was the highest. Among the five continents, Africa produced the least publications, but 51% of them were intercontinental collaboration publications. In contrast, as high as 77% of Americas' publications were single-continental.

*Distribution of author keywords*

For each paper dealing with biological invasions, original author keywords (as given in the paper) were examinated. Among the 15,264 keywords used, 13,804 (90.4%) keywords appeared less than 5 times, 841 (5.5%) keywords appeared between 5 and 10 times, 523 (3.4%) keywords appeared between 10 and 50 times, and only 96 (0.63%) keywords appeared at least 50 times. As high as 90.4% of author keywords used less than 5 times, which probably indicates a lack of continuity in research and a wide disparity in biological invasions research focuses.

Table 6 shows the frequency of keywords appeared in four subcategories of biological invasions: location, habitat, plant invasions, and animal invasions. 13 of the top 20 hot research area were located in Americas. Habitat studied most was grassland, followed by forest, islands, and wetlands. Aquatic ecosystems, including fresh water, marine (bay, sea, ocean), river, and ballast water, were also important fields of biological invasions research. Because they are among the most vulnerable systems, which are being challenged worldwide by invading species.

Studies on plant invasions contributed more to the total number of keywords than animal invasions. The topics of vegetation, forests, weeds, and grasses were more emphasized in botanical studies; insects, fish, birds, and crustacea were more studied in animal invasions. It seemed that studies of grasslands and marine environment were the most frequently concerned in botanical and zoological studies, respectively. Studies on plants and animals are to some extent complementary, and that this may contribute to the development of more general theories on biological invasions in the future [PYSĚK, 2006].

Table 6. Frequency of keywords used in different aspects

| Location | Habitat | Plant invasions | Animal invasions |
|---|---|---|---|
| United States (256) | Grassland (157) | Plants (257) | Hymenoptera (78) |
| North-America (204) | Forest (99) | Vegetation (175) | Fish (72) |
| California (140) | Islands (85) | Forests (147) | Birds (59) |
| New-Zealand (126) | Wetlands (68) | Weeds (108) | Zebra mussel (57) |
| Great-lakes (99) | Water (61) | Plant-communities (67) | Argentine ant (43) |
| Australia (85) | Soil (56) | Seed-dispersal (56) | Crustacea (42) |
| Hawaii (67) | Fresh-water (49) | Herbivory (54) | Fire ants (38) |
| Florida (46) | Marine (48) | Grasses (49) | Insects (34) |
| Europe (41) | River (47) | Plant-disversity (48) | Coleoptera (30) |
| San-francisco bay (38) | Ballast water (47) | Tree (45) | Herbivores (29) |
| British-Isles (32) | Rain-forest (38) | Alga (31) | Zooplankton (27) |
| South-Africa (32) | Estuary (37) | Spotted knapweed (28) | Lepidoptera (27) |
| Southern California (32) | Salt-marsh (36) | Purple loosestrife (24) | Invertebrates (24) |
| Mediterranean Sea (29) | Tallgrass prairie (30) | Phytoplankton (22) | Diptera (21) |
| New York (29) | Bay (29) | Macrophyte (20) | Native ants (20) |
| Northern California (28) | Sea (25) | Woody-plants (20) | Decapoda (18) |
| Argentina (24) | Field (24) | Centaurea (19) | Parasites (18) |
| China (21) | National-park (23) | Common reed (17) | Social insects (16) |
| Baltic Sea (18) | Ocean (23) | Shrub (17) | Hemiptera (15) |
| Ontario (17) | Nature reserves (20) | Amur honeysuckle (15) | Crayfish (14) |

## Conclusions

Our bibliometric analysis indicated the output of biological invasions articles has significantly increased since 1991, especially with a quicker pace in the past 10 years (1998–2007). The visibility of articles published, measured by an indicator CPP, has significantly increased after 1997. In the 3323 articles published in 521 journals, 7261 authors from 1905 institutions of 100 countries participated. Articles published in the category of evolutionary biology and ecology had higher CPP values. The journal that published the greatest number of articles was *Biological Invasions*.

The geographical pattern of scientific literature not only partly corresponds to the degree to which invasions are preceived as a problem in different parts of the world, but also reflects differences in the amount of funding allocated [LEIMU & KORICHEVA, 2005]. The US dominated publication production followed by France, Australia, and Canada, the seven major industrial countries still comprised the majority of the total production. Seven of the top 10 productive authors were from the US, and the 10 most productive institutions were all located in the US. The Americas produced the most publications and had the lowest proportion of intercontinental collaboration. Especially for the US, high proportion of single-country publications indicated the collaboration between institutions, countries, and continents need to be further strengthed, because invasive alien species do not respect national borders. To be effective in preventing the spread of invasive alien species, initiatives to address the prevention, eradication, or control an invasive species also must be able to cut across political boundaries [CLOUT & POORTER, 2005].

Another issue deserves attention is the quality of scientific literature produced by Asia, where is one of the world's hotspots of biodiversity. International collaboration of biological invasions research in Japan and China, is not as effective as that in South Africa and Latin America, based our CPP study. As for China, one consequence of rapid economic development is that the diversity and the effects of invasive species are rapidly growing. Although some funding has provided to support the research and management of invasive species, a national campaign against biological invasions is still in its infancy. Because for most local governments, the prime goal is GDP growth, not environmental protection [DING, 2008]. Institutions in developed countries can be encouraged and supported to lead research involving developing countries. This involvement can ensure not only technical capacity, but also a more appropriate research process leading to effective policy impact.

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