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Geographical spread of the invasive species *Kellicottia longispina* (Kellicott, 1879) and *K. bostoniensis* (Rousselet, 1908): A scientometric approach

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ABSTRACT. Processes related to biological invasion of inland waters have become a major issue due to the increasing number of cases associated with the potential effects of invasions. *Kellicottia bostoniensis* and *K. longispina* are rotifer species originating from North America and have become invasive in several continents. In this sense, this study carried out a scientometric analysis to analyze the geographical distribution and identify patterns of occurrence as well as to fill gaps on the knowledge of these species. The survey was based on articles indexed in databases from 1896 to 2014. There is a greater scientific knowledge of these species in the temperate region, and these are present in many different environments. In Brazil, there is a very small number of studies, and no record of *K. longispina*. Therefore, it is noteworthy the importance of studies on the occurrence and abundance of these species in poorly studied areas, such as subtropical and tropical regions, for a better understanding of their invasive potential, given the potential effects on different communities, which can affect the structure and dynamics of environments.

Keywords: Rotifera, zooplankton, dispersal potential, time trend.

Dispersão geográfica das espécies invasoras *Kellicottia longispina* (Kellicott, 1879) e *K. bostoniensis* (Rousselet, 1908): uma abordagem cienciométrica

RESUMO. Os processos relacionados à invasão biológica de águas continentais tornaram-se uma questão importante, por causa do crescente número de casos associados aos potenciais efeitos das invasões. As espécies *Kellicottia bostoniensis* e *K. longispina* são originárias da América do Norte e tornaram-se invasoras em vários continentes. Nesse sentido, o objetivo deste estudo foi realizar uma análise cienciométrica para verificar a distribuição geográfica e, consequentemente, identificar padrões de ocorrência e preencher lacunas sobre o conhecimento dessas espécies. A pesquisa foi realizada com base em artigos indexados em bases científicas, considerando o período de 1896 a 2014. Foi possível observar que há maior conhecimento científico sobre as espécies na região temperada, e estas estão presentes nos mais diferentes ambientes. No Brasil, foi registrado um número muito reduzido de estudos, e ausência de *K. longispina*. Portanto, ressalta-se a importância de estudos sobre ocorrência e abundância dessas espécies em regiões pouco estudadas, como as subtropical e tropical, para o melhor entendimento de seu potencial de invasão, pelos potenciais efeitos sobre as diferentes comunidades, podendo afetar a estrutura e dinâmica dos ambientes.

Palavras-chave: Rotifera, zooplâncton, potencial dispersor, tendência temporal.

Introduction

Invasive species have a wide spatial distribution related to their high potential for dispersal and their phenotypic and ecological plasticity (Espínola & Julio, 2007; Sakai et al., 2001). Biological invasions have become a common subject due to the growing number of reports of occurrence of these species (Boltovskoy & Correa, 2015; Simões et al., 2009) besides the ecosystem imbalance caused by their establishment in several environments (Agostinho Thomaz, & Gomes 2005; Clavero; García-Berthou, 2005; Thomaz, Mormul, & Michelan, 2015; Vitousek, 1990).

Geographic isolation is the first filter to the spread of invasive species, but human actions may facilitate the breach of this natural barrier (Espínola; Julio, 2007; Moyle & Light, 1996; Parkes & Duggan, 2012), favoring the spread of species. As a result, systems become susceptible to the effects of these invasions, which can lead to the extinction of native species, changes in trophic dynamics, in environmental processes (Vooren, 1972; Vitousek, 1990), and even losses of biodiversity

(Moyle & Light, 1996; Agostinho et al., 2005; Clavero & García-Berthou, 2005).

Some cases of biological invasions in the zooplankton community have been reported, involving different continents, countries and types of environments (Lopes, Lansac-Tôha, Vale, & Serafim 1997; José de Paggi, 2002; Serafim, Bonecker, Rossa, Lansac-Tôha, & Costa, 2003; Simões et al., 2009; Zhdanova, & Dobrynin, 2011). Among the rotifers, we find the wide occurrence of *K. bostoniensis* and *K. longispina*, both from North America (Edmondson, 1959).

In 1943, Carlin first recorded the presence of these species in Europe (Sweden) and since then, several studies have reported their presence in other countries, such as the Netherlands (Leentvaar, 1961), Czech Republic (Devetter & Seda, 2006), Russia (Zhdanova & Dobrynin, 2011) among others. In South America, it has been found the occurrence of *K. bostoniensis* in Brazil (Lopes et al., 1997) and Argentina (José de Paggi, 2002). Arnemo, Berzins, Gronberg, & Mellgren, (1968) suggest that the spread of these invasive rotifers occurs by ballast water of ships. However, Lopes et al. (1997) attributed the dispersal of this genus in the Neotropics to the transport of resting eggs of these individuals by migratory birds.

Kellicottia bostoniensis and *K. longispina* have exhibited a successful dispersal in various environments (Almer, Dickson, Ekström, Hörnström, & Miller 1974; Havens, 1991; Urbach, Vergin, Young, & Morse, 2001; Mello, Maia-Barbosa, & Santo, 2011), however, there is still little known about the geographical spread of these invasive species. Rotifers are often considered opportunistic, since they have rapid growth and quickly respond to environmental fluctuations (Pontin & Langley, 1993).

Given the above, this study aimed to determine the geographical distribution of *K. bostoniensis* and *K. longispina* through a scientometric analysis in order to identify the preferences of occurrence that lead to the possible establishment in aquatic systems and also to fill gaps on the invasiveness potential of these species in the different environments.

Material and methods

As the genus *Kellicottia* is made up of only *K. longispina* and *K. bostoniensis*, and the two species are invasive, the literature review included only the word "*Kellicottia*". Thus, the survey was conducted in March 2015, based on articles indexed in Thomson Reuters bases (www.isiwebofknowledge.com), SciVerseScopus (www.scopus.com) and Jstor (www.jstor.org), considering the period from 1896 to 2014. We used the bibliographic production cataloged as an indicator of results.

The selected articles were classified according to the year of publication, country of origin, climatic zones (temperate, tropical, subtropical, polar), continent, environment (lake, river, reservoir), addressed approach (ecological, zoological, including taxonomic and biological studies, paleontological and molecular), design used (descriptive studies were comparative, predictive studies, or those based on the prediction model with presence or absence of ecological theories, experimental studies were those conducted in laboratory with controlled environmental conditions, and review were the studies of literature) and we also gathered data of the average abundance of *K. bostoniensis* and *K. longispina* to analyze their establishment in different continents. The studies in Brazil were also divided according to the regions (North, Northeast, Central-West, Southeast and South).

In total, 241 articles were found, 65 at the Thomson Reuters database, 73 at Scopus and 103 at Jstor. Articles citing "*Kellicottia*" only in the discussions and with no data on geographical distribution no were considered, and studies that occurred in more than one database were considered only once. Thus, scientometric analysis was performed with 197 scientific papers.

The years of publication were grouped into five-year intervals from 1896 (the first year of record that was analyzed separately because of the distance from the other years) to 2014. Thus, the analysis had 15 intervals, namely: 1896, 1947-1951, 1952-1956, 1957-1961, 1962-1966, 1967-1971, 1972-1976, 1977-1981, 1982-1986, 1987-1991, 1992-1996, 1997-2001, 2002-2006, 2007-2011, 2012-2014.

For data analysis, a regression tree (MRT) was performed (De'ath & Fabricius,2000) with response the variable *year* in order to examine how the number of published articles was distributed over time (between 1896 and 2014), and when the number of publications was enough to make an effective change in the scenario of studies on *Kellicottia* in the scientometric survey.

Results

The first five time intervals showed a lower number of articles published (from one to five). As confirmed by the MRT, the separation threshold was in 1977, and from this year, there was a growing number of publications over the years. The interval with the greatest scientific production was 1987-1991 (n = 31) (Figure 1).

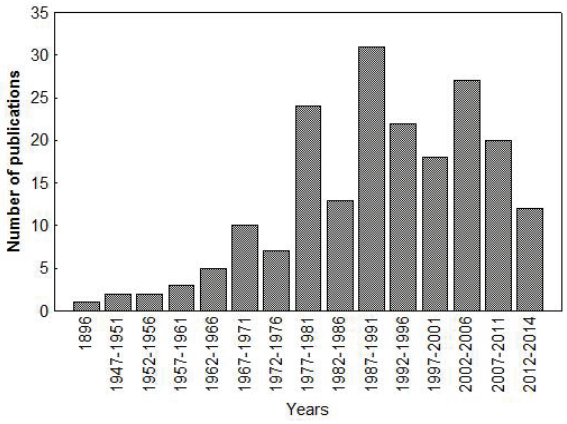

Figure 1. Number of publications indexed in Thomson, Scopus and Jstor databases, addressing studies on *K.* during the scientometric survey.

Regarding the geographical location of the studies, North America was the continent that produced the most, with 113 articles (*K. longispina* n = 70, *K. bostoniensis* n = 43), followed by Europe with 65 (*K. longispina* n=55, *K. bostoniensis* n = 10), South America, with 10 (all with *K. bostoniensis*), Asia, with 8 (all with *K. longispina*) and Antarctica with 1 (*K. longispina*). No publication records were found for the African continent, Oceania and the Arctic. Studies in North America and Europe were dominant until the interval between 1977-1981, it was only between the years 1982-1986 that were the first works in Asia, and between 1997-2001 in South America, the only work of the continent Antarctic was between 2012-2014 (Figure 2).

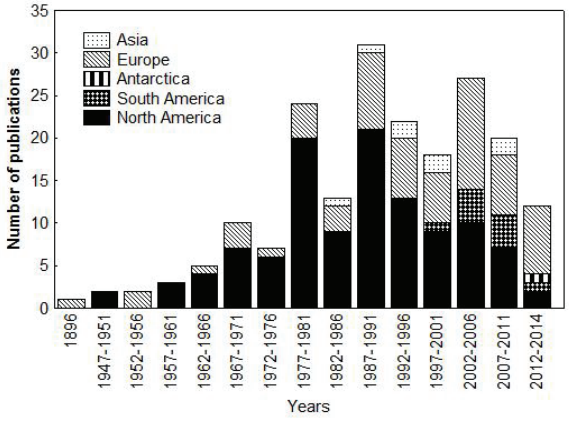

Figure 2. Number of publications recorded for each continent during the period considered in the scientometric survey.

As for the species distribution related to climatic zones, most of the studies were conducted in temperate regions, 182 papers (*K. longispina* n = 130, *K. bostoniensis* n = 52), followed by environments the subtropical climate, 14 (*K. longispina* n = 2, *K. bostoniensis* n = 12) and only one in polar climate (*K. longispina*), none in tropical climate. A higher occurrence of the species was observed in lakes (n = 161, *K. longispina* n = 118, *K. bostoniensis* n = 43), followed by reservoirs (n = 25, *K. longispina* n = 8, *K. bostoniensis* n = 17) and rivers(n= 7, *K. longispina* n = 3, *K. bostoniensis* n = 4), and besides these, four articles did not mention the studied environment. Studies in the subtropical climate zone emerged from the interval between 1977-1981, and the polar climate in the range of 2012-2014.

Most articles used an ecological approach (n = 191, *K. longispina* n = 130, *K. bostoniensis* n = 61), followed by zoological studies (n=5, *K. longispina* n = 3, *K. bostoniensis* n = 2) and molecular studies (n = 1, *K. longispina*). Also, the studies indexed in the research bases presented exclusively ecological approach, in the interval between 1896-1971, 1977-1986, and 2002-2014. The zoological focus was registered in the intervals 1972-1976, 1987-1991 and 1992-1996, and only at the end of the 90's that arose a single work in the molecular area. Still, it can be seen that the ecological studies remained present during all time intervals, and in contrast, there was no study with palaeontological focus throughout the study (Figure 3).

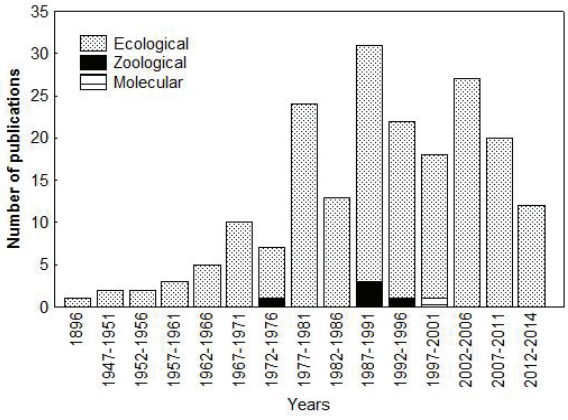

Figure 3. Number of publications classified according to the central focus of the article during the period of the scientometric survey.

In relation to the design used in the articles, the descriptive (n = 85, *K. longispina* n = 60, *K. bostoniensis* n = 25) and predictive studies (n=65, *K. longispina* n = 20, *K. bostoniensis* n = 45) comprised the majority of publications, with articles published in almost all intervals, except for the interval 1952-1965 for descriptive studies and 1896, 1962-1966 for predictive studies. Experimental studies (n = 43, *K. longispina* n = 20, *K. bostoniensis* n = 23) started in the late 70's and early 80's, and thereafter were found in all time intervals. The

studies regarding literature review (n = 4, *K. longispina* n = 2, *K. bostoniensis* n = 2) were found only in the periods between 1952-1956, 1982-1986 and 1992-1996, and also presented the lowest number of publications than other designs used during the period (Figure 4).

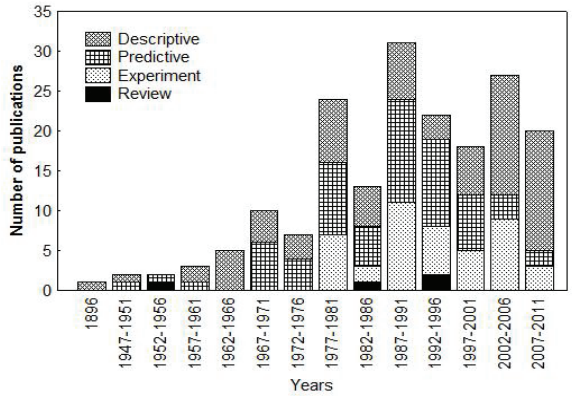

Figure 4. Number of articles classified according to the design employed in studies conducted in the period of the scientometric survey.

The highest average abundance of *K. bostoniensis* was recorded in Europe (73376.3 ind. m^{-3}), followed by South America (64.69 ind. m^{-3}) and North America (10.97 ind. m^{-3}). In turn for *K. longispina*, we observed higher average values than for *K. bostoniensis*, with the highest values of abundance of the first species verified in Asia (82271.67 ind. m^{-3}), followed by Europe (14007.8 ind. m^{-3}), North America (116.45 ind. m^{-3}) and Antarctica (0.050 ind. m^{-3}). The other continents presented no data of abundance for the mentioned species (Figure 5).

In Brazil, there were only nine articles with *K. bostoniensis*, as there was not yet record of *K. longispina* in the country. These articles were restricted to the Southeast (n = 6), South (n = 2) and Central West (n = 1) regions, with descriptive design in the Southeast and Central West regions, and a descriptive study and another predictive study in the South region. All Brazilian studies had an ecological approach (Figure 6).

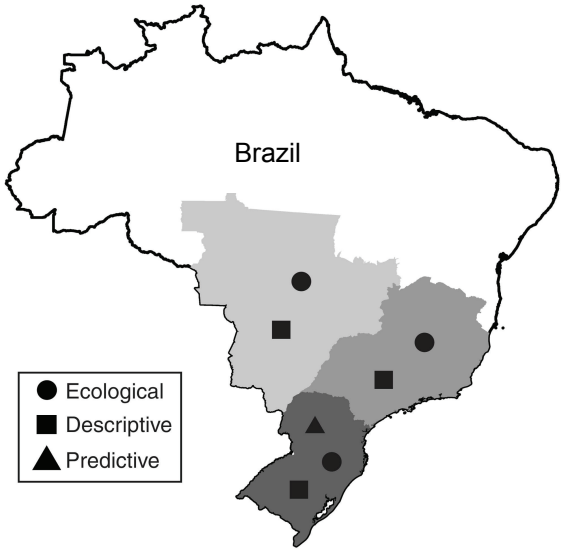

Figure 6. Map of Brazil highlighting regions with studies on *K. bostoniensis*, indicating the design used and the focus addressed in the studies.

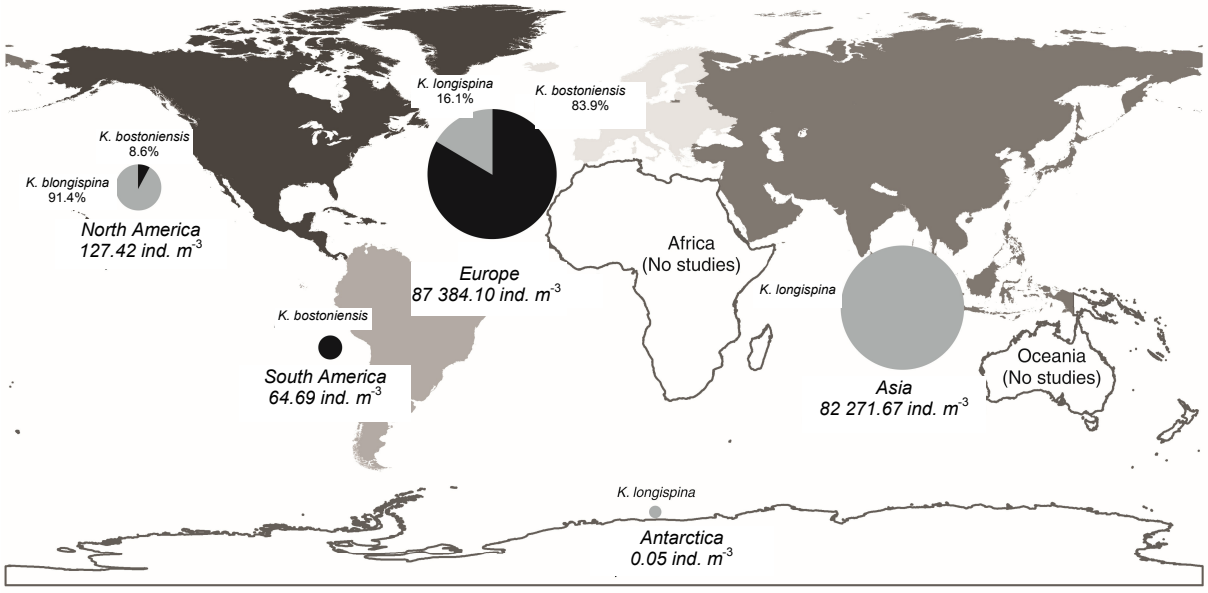

Figure 5. World map with the distribution of abundance of *K. longispina* and *K. bostoniensis* in the continents, data found in the articles analyzed by scientometric analysis. The circles increase proportionally with the amount of the abundance of individuals.

Discussion

The growing number of publications on *Kellicottia* over the years may be indicative of the dispersal potential of the genus. The survey showed that along with the increase in the number of publications over the years, it was also observed an increased occurrence of the species in different continents.

North America is the continent with the highest number of published works on *Kellicottia* possibly because it is the native continent of the species, followed by the European continent. These continents contain the countries with more developed research in the world, with the greatest number of active universities and researchers (Beyens & Meisterfeld, 2001), which may explain the higher number of articles found.

Moreover, these continents are the major world powers with regard to the economy, and for centuries most of the exports and imports of products took place through merchant ships, which are responsible for unwittingly transporting aquatic species in their water ballast tanks (Carlton, 1996; Minchin, Gollasch, Cohen, Hewitt, & Olenin, 2009; Ruiz, Fofonoff, Carlton, Wonham, & Hines, 2000; Ruiz, Fofonoff, Ashton, Minton, & Miller, 2013). As suggested by Arnemo et al. (1968) water ballast tanks can be a source of dispersal of *K. longispina* and *K. bostoniensis* between North America and Europe, as this second continent was the first to report the occurrence of these species outside the continent of origin, due to more intense commercial transactions between these continents. Gray, Johengen, Reid and Macisaac, (2007) reported this fact in an experiment where *K. bostoniensis* resisted the exchange of ballast water at sea, and came to the Great Lakes region of Europe coming from North America. In addition, there was the subsequent spread to other continents, by increasing the commercial trade on a global scale, leading the previously isolated species to overcome geographical barriers and present potential to establish themselves in other regions of the world (Peixoto, Brandão, Valadares, & Barbosa, 2010; Ricciardi & Maclssac, 2000).

For the Neotropical region, the likely route of entry of the species and consequent spread occurred by means of resting eggs transported by migratory birds (Lopes et al., 1997; Figuerola, Green, & Santamaria, 2003), or, eggs transported by the wind or rain (Jenkins; Underwood, 1998). Thus, these eggs remained viable in the sediment of aquatic environments for a long period of time, and hatched out in this region when environmental conditions became favorable for the species (Jenkins; Underwood, 1998). Studies show that resting eggs of rotifers can remain viable for decades and even centuries, resisting desiccation and other adverse weather conditions (Garcia-Roger Carmona, & Serra, 2005).

With respect to climate zones, the temperate region hold more than 90% of the studies, possibly because the continents that showed the highest number of publications are located in this region. However, *K. bostoniensis* has also been recorded in the subtropical region with high abundance and frequency of occurrence (F. Palazzo and A. P. C. Fernandes, personal communication, June, 2014).

The wide distribution of these species in different regions of the world reflects their adaptation to different climates. Therefore, they can be found in various environments such as rivers (José de Paggi, 2002; Serafim et al., 2003), lakes (Serafim et al., 2003; Bezerra, Aguila, Landa, & Pinto-Coelho, 2004), reservoirs (Lopes et al., 1997; Landa, Aguila, & Pinto-Coelho, 2002), and in sites with a wide range of environmental conditions, including those most adverse, such as acidified environments (Almer et al., 1974; Havens, 1991), oligotrophic (Laxhuber, 1987; Urbach et al., 2001), eutrophic (Cooper & Vigg, 1985; Mello et al., 2011) and anoxic (Miracle & Alfonso, 1993); thus confirming their wide potential for ecological and phenotypic adaptation (Arnemo et al., 1968; Bezerra-Neto et al., 2004; José de Paggi, 2002).

This high ecological and phenotypic plasticity that species present in different environments and the expected success in the invasion of aquatic environments arouse the interest in the knowledge of their characteristics. As a result, it was observed a great number of publications on interactions between species of *Kellicottia* (Hofmann, 1983) with environmental preferences (Swadling, Pienitz, & Nogrady, 2000) and resistance to adverse environmental conditions (Almer et al., 1974; Havens, 1991), thus explaining the greatest number of articles with an ecological approach.

Most world studies with *Kellicottia* used descriptive and predictive models. Schwind et al. (2013) suggested that these methods are related to the search for basic knowledge, that is, the first step is observation and report (description) and then, from the observations, assumptions about the subject are drawn (predictive), and subsequently with the development of scientific work, hypothesis testing become more intense, allowing the emergence of more studies with experimental design.

Abundance data of different species showed a wide range of occurrence, with low and high number of individuals, in ecologically distinct

environments, in five continents. In this way, during this survey, it was not possible to detect a single pattern of abundance distribution in relation to the evaluated aspects. Although North America is the native continent of the species, these did not occur at greatest abundance therein, suggesting a successful establishment of these species in other continents, as well as the expressive abundances in the subtropical region, reaffirming their phenotypic and ecological plasticity (Arnemo et al., 1968; Edmonson, 1959).

Some studies consider the abundance as an indicator of success in the establishment of a species in the environment (Shea & Chesson, 2002; Havel & Medley, 2006). Nevertheless, its frequency of occurrence is also another aspect to be considered, as in a long time series, its permanence in the environments, even at low densities, can evidence a successful establishment in certain places (Thomaz et al., 2015).

Regarding Brazil, the low number of published articles and the lack of studies conducted in much of the country suggest that researches on invasive species addressed in this study are still under development. Also, other studies were developed with *K. bostoniensis* (Lopes, 1997; Lansac-Tôha et al., 2004), but they are indexed in scientific databases different from those consulted in this survey (or are theses, dissertations and books), which may underestimate the number of articles on *Kellicottia*, especially the perspective of biological invasion process of this genus.

Conclusion

Our findings show that the growing number of publications on *Kellicottia* over the years is indicative of the dispersal potential of the genus. So, we emphasize the importance of studies aimed at increasing knowledge about the occurrence and geographical distribution of these species and their possible effects on the communities and environmental dynamics.

In contrast, the scientometric survey is considered very important, however, not all studies are available in the databases, as well as some journals are not indexed. Therefore, the number of articles on *Kellicottia* may be underestimated, and especially, the perspective of biological invasion process of this genus.

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