Octopus Biological Studies

Subjects: Agriculture, Dairy & Animal Science
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Increasing effort in research involving octopuses with a greater number of journals reporting research on these animals, as well as countries, institutions, and researchers involved. Some research themes lost importance over time, while some new themes appeared recently. Current data provide significant insight into the evolving trends in octopuses studies.

Keywords: cephalopods ; model species ; bibliometrix ; bibliometric analysis ; science mapping

1. General information

The octopuses and their close relatives, cuttlefishes, squids, and nautiloids are representatives of Cephalopods, with around 800 living species described to date [1]. Cephalopods possess interesting biological characteristics such as short lifespan, rapid growth, developmental plasticity, large brain, and sophisticated sense organs with the capacity for learning and memory, which are associated with the ability of rapid adaptation to environmental challenges (both natural and anthropogenic), and made them a resilient group, which may benefit from a changing ocean environment. Therefore, their global sharp increase is not surprising in terms of population in the context of rapid environmental changes in the last six decades [2]. Cephalopods are both important predators and prey in many marine environments and important fishery resources in many countries [3], which together with their peculiar biological features, attracted scientific interest making them optimal models for studies in several different fields of scientific inquiries [4]. Indeed, since the first half of the 20th century, cephalopods also started to play a pivotal role in scientific research, with a steadily growing body of research dealing with various aspects of their biology, including genetics, aquaculture, welfare, behavior, cognition, neurobiology, neuroethology, and the effects of climate change (see [4][5][6][7][8][9][10]).

Among cephalopods, interesting “model organisms” are octopuses. They include about 300 species belonging to several genera [1]. Octopuses have an exceptionally large, well-developed brain (the largest brain-body mass ratio among invertebrates), and flexible high-order cognitive behaviors (e.g., tool use, problem-solving), with a high degree of brain plasticity, learning, and memory [5][11][12][13]. They are active predators, owing to their peculiar sensorial system [14], which could be the evolutionary force-drive behind the development of their unique “abilities” [15]. The combination of very interesting features has fueled an increasing interest by the researchers making them an ideal “model species” not only for inferring brain functioning but also to gain general biological insight and understanding [16]. To date, a worldwide trend in scientific research on octopuses has never been explored using a bibliometric approach [17], while the evaluation of scientific research has become increasingly important in recent years. The bibliometric analysis is a useful tool for measuring the output of scientific research, using specific indicators to obtain information about trends in different fields [18][19].

The present study aims to provide a bibliometric analysis of biological research related to sources, countries, and affiliations dealing with research on octopuses. Furthermore, the structure of the topic was defined both at a conceptual level, by analyzing the co-occurrence network and thematic maps, and at the social structure level, through the analysis of collaboration networks and world maps. The most frequent and impactful journals, countries, research institutes, and their social and conceptual relationship were also identified. We provide a bibliometric analysis of the collection of scientific studies available to these authors related to octopuses from 1985 to 2020 (i.e., 36 years). The period was split into two blocks, comprising roughly the same number of scientific products, to analyze the evolution of the research topics over time. In this work, we provide data helping a wide range of users, not only scientists but also editors, in the choice of topics of emerging and major interest in octopuses studies.

The comprehensive science mapping analysis was performed by using Bibliometrix, a new and powerful R-tool [20] that offers various options for importing bibliographic data from scientific databases and performing bibliometrics analysis related to different items.

2. Conceptual Structure

The KWP analysis in the EP identified five clusters, represented in a thematic map, according to their centrality and density ranking (Figure 1).

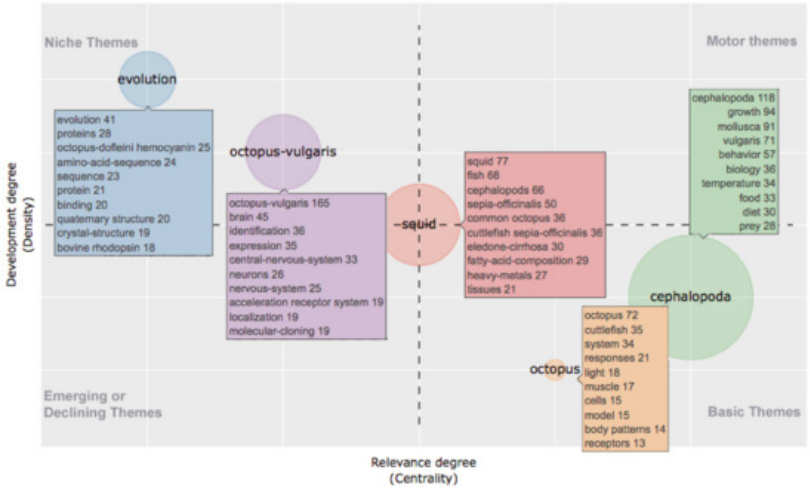

Figure 1. Thematic map showing clusters and the KeyWords Plus from 1985 to 2010 (“earlier period”) identified by the co-occurrence network. The *X*-axis represents the centrality (i.e., the degree of interaction of a network cluster in comparison with other clusters) and gives information about the importance of a theme. The *Y*-axis symbolizes the density (i.e., measures the internal strength of a cluster network, and it can be assumed as a measure of the theme’s development). Accordingly, the first quadrant identifies motor themes (i.e., well developed and important themes for the structuring of a research field); in the second quadrant are plotted highly developed and isolated themes (i.e., themes of limited importance for the field); the third quadrant contains emerging or declining themes (i.e., themes weakly developed and marginal); in the fourth quadrant fall basic and transversal themes (i.e., they concerns general topics that are transversal to different research areas of the field).

In this period there were no motor themes, while two basic themes located in the fourth quadrant showed high centrality and average density. One of them included “cephalopoda”, “growth” and “molluca” as the most co-occurring KWP, and also “food”, “diet” and “prey” which draw a research theme in “*growth and nutrition*”. The other theme had as indicative KWP “system”, “muscle”, “cells”, “body patterns” and “receptors” which are related to “*morphology*”. At the center of the graph there was a cluster characterized by taxonomic terms, but also containing KWP such as “fatty-acid-composition”, “heavy-metals” and “tissues” suggesting a topic related to “*pollution impact*” studied comparatively in different taxa. Two niche themes, with low centrality and high density, were located in the second quadrant. One of them was linked to “*biochemistry*” as it contained the KWP “proteins”, “amino-acid-sequence”, “sequence”. However, the presence of “evolution” as relevant KWP indicates that such studies were mainly aimed at modeling evolutionary patterns. The other one identified a theme on “*neurobiology*” and contained “brain”, “central nervous system” and “neurons” as the most occurring KWP. In the RP the KWP analysis identified four clusters as the result of the emergence/decline of some themes, in terms of gain/loss of centrality and density (Figure 2).

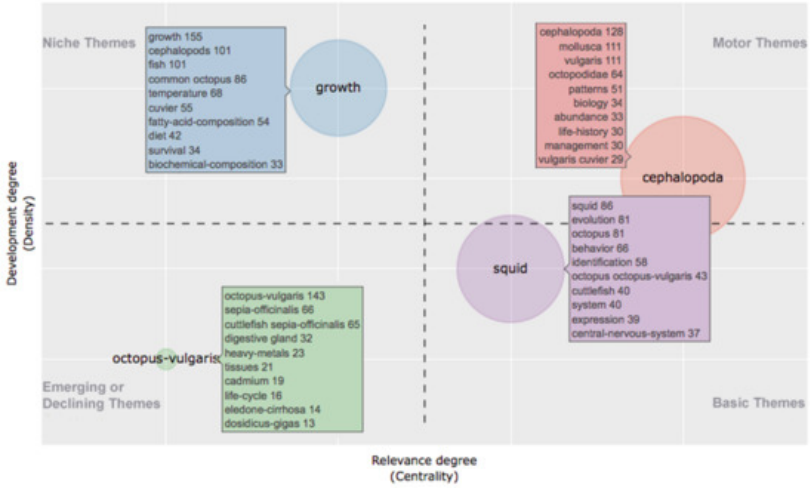

Figure 2. Thematic map showing clusters and the KeyWords Plus from 2011 to 2020 (“recent period”) identified by the co-occurrence network. The *X*-axis represents the centrality (i.e., the degree of interaction of a network cluster in comparison

with other clusters) and gives information about the importance of a theme. The *Y*-axis symbolizes the density (i.e., measures the internal strength of a cluster network, and it can be assumed as a measure of the theme's development). Accordingly, the first quadrant identifies motor themes (i.e., they are well developed and important for the structuring of a research field); in the second quadrant are plotted highly developed and isolated themes (i.e., they are of limited importance for the field); the third quadrant contains emerging or declining themes (i.e., they are weakly developed and marginal); the fourth quadrant includes basic and transversal themes (i.e., themes concerning general topics transversal to different research areas of the field).

One cluster was positioned in the first quadrant as motor themes in octopuses studies characterized by a high centrality and density. The most occurring KWPs were taxonomic terms, further than "biology", "abundance" and "life-history", identifying a theme on "*ecology*". In the second quadrant (niche themes) there was a cluster characterized by the KWP "growth", "cephalopods", "fish", as well as "temperature", "fatty-acid-composition" and "diet", drawing a topic on "*growth and nutrition*". A cluster in the third quadrant was characterized by low centrality and density, which means that it was weakly developed and marginal and included taxonomic terms, and also "heavy-metals", "tissue", "cadmium", identifying a research theme on "*pollution impact*". The fourth cluster contained "squid", "evolution" and "octopus" as the most common KWP, and also "behavior", "identification", "expression" and "central nervous system". It appears to delineate a research theme dealing with "*genes, behavior, and evolution*" and was a basic theme.

3. Social Structure

The UK with Ireland, USA with Canada shared the higher number of publications, followed by Spain and Portugal and Spain and France in EP. In the RP, after a visible increase in the collaboration network (Figure 3 and Figure 4), Spain with Portugal were the leading countries, with the highest frequency of shared publications. In the second position, Spain showed a higher frequency of collaboration also with the UK and, in the third position, there was the frequency of collaboration between UK and Portugal.

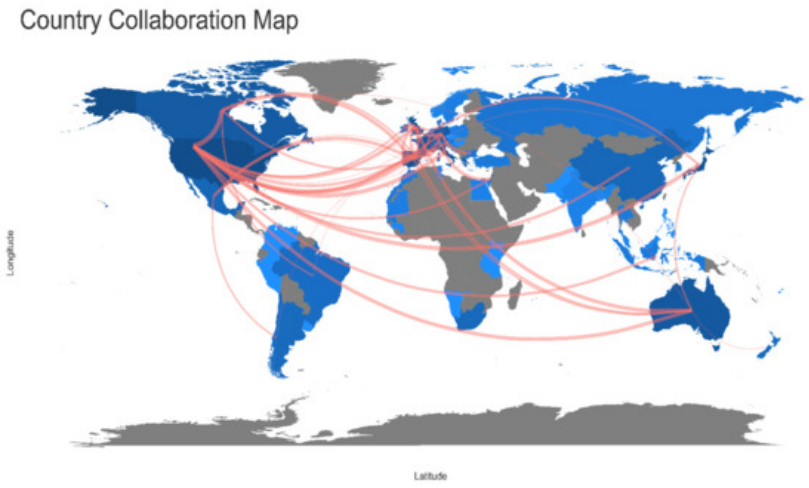

Figure 3. World map showing research collaborations among countries from 1985 to 2010 ("earlier period"). Brighter blue color indicates a higher collaboration rate. Connectors do not show countries with less than three shared papers.

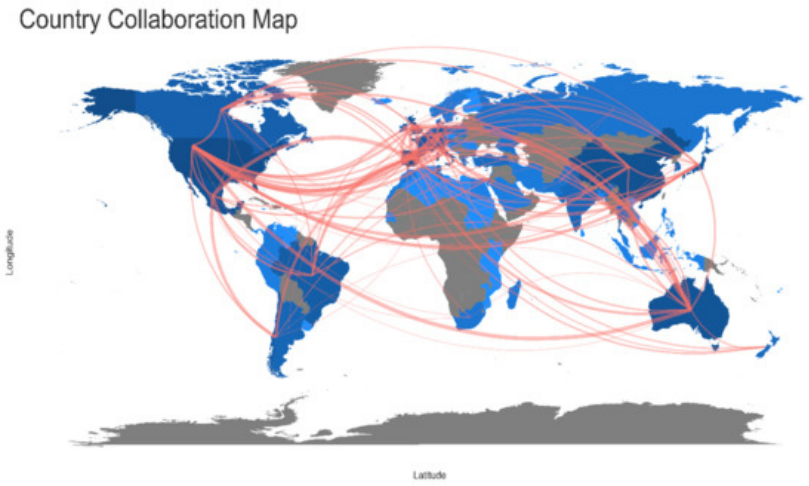

Figure 4. World map showing research collaborations among countries from 2011 to 2020 ("recent period"). Brighter blue color indicates a higher collaboration rate. Connectors do not show countries with less than three shared papers.

4. Comments

The data relating to the scientific production of studies on octopuses showed a steady increase from the starting point (i.e., 1985) with less than 10 papers per year, to about 100 in the current times and with annual growth of up to 10%. Our bibliometric analysis highlighted a strong increase in the number of authors, author appearances, and authors of multi-authored documents in the more recent period analyzed. Furthermore, in parallel with the increasing number of researchers involved in studies on octopuses, the number of countries and affiliations contributing to the studies has also increased. The statistic “documents per Author” had a negative variation (EP 0.52, RP 0.32), meaning that, while the number of co-authors per publication increased (EP 3.40, RP 5.09), the “annual publication rate per author” decreased (EP 0.30, SP 0.26). In other words, the research effort by each researcher has generally decreased over time. This is not in line with the general trend of scientific studies showing that the contribution of a researchers’ individual publication rate remained unchanged [21]. Despite the decreasing research effort provided by a single researcher over the last decade, the general increase in people (EP 2741, RP 4235) and affiliation collaborations per year (EP 0.119, RP 0.267) can explain the rising trend in studies on octopuses.

Our data show that the most productive countries using octopuses as “model organisms” in different research fields were the same in both periods examined, keeping their contribution almost unchanged. However, some countries, such as Japan, France, and the UK, have shown a decrease in their involvement. The reasons could be the increased commitment of some other countries such as Chile, in the last decade, but also the social and political impact, especially in European countries, due to the recent laws that consider octopuses, along with other cephalopods, “sentience animals” and consequently protected species [22]. Noteworthy, looking at the total number of publications by corresponding authors we obtained a different picture with Spain as the main contributor in the EP, while in the RP no substantial differences emerged with a proportion of corresponding authors around one-third for almost all countries listed in the first ten positions.

Unlike countries, affiliations saw a stronger turnover, with most of the affiliations different in the top ten positions in the two periods considered in our study. The Spanish Institute of Oceanography (Spain) was an important and constant contributor in both periods studied. The University of Texas (USA) and University of Tasmania (Australia), which were listed among the top positions in the EP, have left their position, while emerging affiliations in the last decade, such as the National Autonomous University of Mexico and the Ocean University of China increased their efforts in studying octopuses.

A sharp increase over the past decade has also been observed in the collaboration network, in which the UK, Spain, and Portugal became the leading countries. The general increase in collaboration networks could be beneficial for the dissemination of scientific knowledge at different levels. Articles resulting from international collaborations have been shown to have a higher growth rate than those resulting from national collaborations [23]. Moreover, articles by international co-authors are even more cited [24], which partially explains the increased citation trend of octopuses studies.

In parallel with the rise in research efforts, the number of sources involved in octopuses studies has also increased. Considering the number of citations it is evident that there was a strong turnover comparing the two periods of study and important journals such as “Science” and “Nature” were highly ranked only in the RP. However, they published only a few studies, and indeed they did not receive a high h-index and the other bibliometric indicators. Based on h-index, only a few journals remained high-ranked in both periods, such as “Aquaculture” but others have significantly changed their rankings. Of note, “Marine Biology”, the journal with the highest h-index value in the EP, was not even listed in the top sources in the last decade and “Marine Ecology Progress Series” the journal with the third-highest h-index, was in the ninth position in the RP Contrariwise, the “Journal of Experimental Marine Biology and Ecology” gained a higher rank in recent times. It should be noted that the h-index alone cannot be indicative of the relevance of a journal. Moreover, it is noteworthy that some journals were inaugurated after 1985, as in the case of “PLoS One” that was launched in 2006, and it is, therefore, logical that it was only slightly represented in the old period.

According to the methodology for measuring themes development by strategic maps [25] (the research fields as clustered by the KWP), two themes were present in both periods of study, namely “*growth and nutrition*” and “*pollution impact*”. Both were subjected to a decreased interest, considering the Callon centrality and density measures [25]. Particularly, “*pollution impact*” became a declining theme in RP, while “*growth and nutrition*” lost centrality, passing from motor themes in the EP to niche themes in the RP.

In the past decade, “*morphology*”, “*biochemistry*” and “*neurobiology*” themes disappeared, probably partly incorporated in other themes, while “*ecology*” and “*gene, behavior, and brain evolution*” appeared as new themes, the first as a motor

theme and the latter as a basic theme. It should be emphasized that this picture comes from the most occurring KWP, which does not exclude the possibility of the existence of other lines of research that, however, not being sufficiently developed did not cluster in a specific theme. Noteworthy, in several clusters, appeared other cephalopod species, indicating that many studies have addressed specific issues using a comparative approach.

A recent review on the state-of-the-art of cephalopods research explored the scientific production in different fields ranging from genetics, aquaculture, climate change, anthropogenic impact, and animal welfare in captivity, also including behavior, cognition, and neurobiology [4]. The authors using the research topics mentioned above as keywords (e.g., “aquaculture”, “behavior”, “cognition”, etc.) associated with the term “cephalopod” have provided the number of publications per decade between 1986 and 2015 as derivative from research on Clarivate Web of Knowledge Core Collection (WoS). In the three decades examined (1986–1995; 1996–2005; 2006–2015), the studies in the field of aquaculture and behavior prevail by far, compared to those of genetics and neuroscience/neurobiology, to which only more recently are associated those relating the climate change, the cognition, and welfare. Our study on octopuses articles seems to provide a somewhat different picture of the research topics addressed, which means that octopuses are used as model studies often in different fields from the other cephalopods or with a different degree of involvement. However, it should be mentioned that O’Brien and collaborators restricted their research to some specific keywords, while our search strategy took into consideration all fields of octopuses studies. This could be another explanation why the octopuses studies do not exactly match with that of the whole group of Cephalopods [26], thus making it difficult to compare with the current data.

It should be emphasized that our algorithm clusters the most frequent KWP, which does not exclude that octopuses are involved in other research. Important themes such as “*genetics*” and “*genomics*” described for Cephalopods [4] appear still poorly developed in octopuses with respect to other themes to be evident in our analysis. However, this does not exclude that this theme could become an emergent theme as proved by recent papers that link genes expression to behavior [5] [12].

In this paper only articles from Web of Science (WoS) were considered, thus our data does not cover the entire literature on octopuses (i.e., grey literature). However, this is a general limitation since no scientific database is comprehensive, and each of them has its power and weaknesses [27]. Furthermore, since our academic subscription to the WoS collection did not allow electronic access to researches published before 1985, our study was limited to the last 36 years. However, although the number of items considered in this study might not precisely reflect the worldwide biological research activity on octopuses the current data provide significant insight into the evolving trends in octopuses studies.

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