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Microwave effect: analyzing citations from classic theories and their reinventions—a case study from a classic paper in aquatic ecology—Brooks & Dodson, 1965

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Abstract
Citations play an essential role in creating a knowledge network and recognizing relevant contributions during the process of scientific production. Despite the citations establishing the links between new evidence and the preceding ideas, classic articles may not be cited adequately. Our aim is to identify if classic studies are cited over time and if the recent studies are producing new knowledge or just "giving a new look" to pre-existing ideas. We evaluated whether the theory proposed by Brooks and Dodson (Science 150(3692): 28–35, 1965)-*Size-efficiency Hypothesis* was referenced in studies on the subject since its publication. Through the analysis of 1480 scientific papers, we quantified—from 1965 to 2018—the citation index (CI) of the original article considering the number of articles produced on the topic per year and the number of citations to other authors (intermediaries). We observed that 60% of the papers and 59% of the intermediaries do not refer to the original article. The CI was low and negatively affected by the age of the original article, showing that the frequency of citation was lower than the rate by which articles on the topic were published. There is a tendency to cite more recent articles and articles that corroborate their own findings. Our data illustrated the *microwave effect*, in which pre-existing ideas and theories are "reheated" by more recent articles where little of the original idea is modified. The *microwave effect* can create the impression of scientific advancement when there is little being added to the knowledge already produced.

Keywords Uncitedness · Scientometric · Citation window · Scientific production

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Introduction

Such a hard and struggling task to start a story-telling about citations in scientific writing, especially for young and eager scientists. However, as Einstein (1936) so brilliantly points out: "The whole of science is a refinement of everyday thinking". Such refinement may be associated with building scientific knowledge from a systematic model, which guides the way we make science: the scientific method. However, the scientific method, as we know it, was perfected through the centuries. Adding to Aristotle, Herophilos (cc 300 BC), Avicene and Alhazen (cc 1000 AC), Grosseteste and Robert Bacon (cc 1250 AC), Francis Bacon (1561–1626) and René Descartes (1596–1650) consolidated the scientific method, unifying the methodology to investigate and produce scientific knowledge (Voit, 2019). Since then, the predominantly pattern sought in making Science is set out by high standards, systematic observation, testing and formulating grounded hypotheses. Thus, a broad definition of science can be: an effort to better understand the world through observation, comparison, experimentation, analysis, synthesis and contextualization (Mayr, 1997).

Throughout scientific development, the way in which discoveries are disseminated, mainly in the form of scientific articles, it has been the subject of several studies (Doubleday & Connell, 2017; Tahamtan & Bornmann, 2018; van Mil & Green, 2017). Publishing a scientific article is an important step to presenting new ideas and results first to the academic community but also for the society as a whole. The rules and advices for writing a good scientific article range from the use of language (e.g., use of certain words and tenses) to the number and way of referencing (Nicolaisen & Frandsen, 2020; Penders, 2018; Weinberger et al., 2015). However, there is no consensus on which characteristics of an article and their respective references will guarantee that the study will be more or less recognized by its peers (Mammola et al., 2021; Padial et al., 2010; Weinberger et al., 2015). In general, scientists hope to find in any scientific article a well-written text, with clear ideas, robust data and a good theoretical framework of the existing literature (Penders, 2018). Then, during the process of science production, citations play an essential role in creating a knowledge network and recognizing the most relevant contributions. They point to possibilities and limits for new results and, therefore, they support further advances.

Traditionally, original research considerably increases their consistency and impact when they are based on previously published references, but with the evolution of methodologies and continuous research on the same topic, additional scientific evidence is gathered and a previous theory or hypothesis may be remodeled (Das & Panjabi, 2011). However, it is still appropriate to cite the classical papers that originated the remodeled idea because citations represent links to the foundations of a topic and provide aspects of the works' historical context (Kostoff, 1998). The partial transformation of an idea over time, which may even suggest that it is a new idea, contributes to erasure of the original authorship. This can also occur, among other reasons, because of the difficulty in accessing the original document. Such situations can favor an inadequate referencing of a particular idea or knowledge. A common form of inadequate referencing is the acknowledgement of the origin of an idea, where an author A, who cited a work of an author B, is then cited by other authors and recognized as the source of the idea (Ellery, 2008). This type of citation gives the impression that more recent articles have developed ideas that were originally older, but in fact they are just "reheating" ideas. Such phenomenon we named the *microwave effect*. The *microwave effect* is particularly evident when review articles are used as the original source of ideas that have just been summarized in the review paper. This is especially important considering the increase of review papers and works based on

synthesis, which are commonly one of the preferred types of citation (Glanzel et al., 1992; Nicolaisen & Frandsen, 2019).

Other factors can enhance the *microwave effect*, such as the phenomenon of *sleeping beauty* in which innovative ideas for your time spend years dormant before being rediscovered and correctly cited (Van Raan, 2004). In addition, the difficulty of accessing classic and older articles that were previously available only in the printed version can also be a factor that induce authors to cite more recent articles and the *sleeping beauty* phenomenon. However, nowadays many changes have made scientific articles accessible in a few seconds over the internet. In the past, older literature could only be accessed in libraries or by correspondence between researchers (which could take months to happen). Today, many published articles are 'Open Science', having no cost to the readers and, after the creation of platforms like Sci-hub, even paid articles can be accessed without cost (Van Noorden, 2013; Wang et al., 2015). In addition to accessibility, the creation of databases such as Scopus, Web of Science and PubMed allowed access and search more quickly and efficiently through search tools and centralization of databases (Falagas et al., 2008; Martín-martín et al., 2018; Yang & Meho, 2006). With all these changes, science has become more agile and new forms of studies have emerged combining different fields of data science. These new tools have been changing the paradigms of how data is made available by scientists, with many repositories like Github or even personal pages leaving a lot of public information and creating increasingly complex and efficient collaboration networks (Assante et al., 2016; Lin et al., 2020). Therefore, with all these access tools and the availability of classic articles in the databases, inappropriate citations should be unusual.

From this context, our aim is to identify if classic studies are properly cited over time and if the recent studies are in fact producing new knowledge or just "giving a new look" to old ideas (*microwave effect*). Our purpose is to subsidize the debate on scientific knowledge production giving information based on quantitative data obtained from a study case in aquatic ecology. Through a broad search, we evaluated whether the classic theory proposed by Brooks and Dodson (1965)—*Size-Efficiency Hypothesis* was properly referenced in studies on the subject since its publication to the present. Through the analysis of 1480 scientific papers, we quantified and evaluated the different ways in which scientific theories can be remodeled in order to appear like new ideas.

Materials and methods

Search for articles in the databases

Initially we chose the theory proposed by Brooks and Dodson due to its great importance for the studies of trophic ecology and ecological relations in aquatic environments. Brooks and Dodson are recognized by the numerous publications on the subject, being authors of great relevance in limnology, plankton ecology and aquatic biology in general. In addition, due to the growth of studies addressing the functional role of species in aquatic environments and their effects on the ecosystem functioning, the *Size-Efficiency Hypothesis* has great relevance for the development of current studies.

The search for articles on the *Size-Efficiency Hypothesis* was carried out in the main collection of the Web of Science database using the following combination of keywords: predation, plankton, rotifer, cladocera, copepoda and size. These keywords were chosen because they are strongly related to the classical theory proposed by Brooks and Dodson

(1965) and to the group of organisms in which it was initially tested (zooplankton). However, the way by which the keywords were included in the search retained studies with other groups and different kinds of ecosystems and ecological approaches. The keywords were inserted in the search as follows: (predat* AND (*plank* OR rotif* OR cladocer* OR copepod*) AND size). The search was carried out for the period from 1965 (date of publication of S*ize-Efficiency Hypothesis*) until 2018.

Papers selection, data quantification and analysis

The first search returned a total of 3886 articles. However, a considerable part of them had no relation to the proposed subject. Therefore, we made a second selection among the articles retained by the initial search. Only articles published in journals with a scope in aquatic ecology, limnology, oceanography, aquatic biology, marine ecology, aquaculture among other topics related to aquatic environments, were considered (Table S1—Supplementary Material). From this second selection, 482 articles were retained and analyzed.

The 1482 articles were assessed as to the approach used. Articles that addressed *Size-Efficiency Hypothesis* in any way were considered to further analysis when met at least one of the criteria: (1) articles that directly test the *Size-Efficiency Hypothesis*; (2) articles that use the idea to justify their findings or results, even if they have not directly tested this; (3) synthesis articles, scientometrics and meta-analyzes on the topic. All articles were evaluated by two researchers (double blind review) and in case of discrepancy between the two reviewers, the article was evaluated by a third reviewer. In this way, we guarantee that all articles analyzed in fact addressed the topic of the *Size-Efficiency Hypothesis*.

In all selected articles were identified excerpts throughout the text that referred to all or part of the premises of *Size-Efficiency Hypothesis*. From this, the number of citations to the original article by Brooks and Dodson (1965), the number of citations to other articles (hereinafter referred to as intermediaries) and the non-citations (unreferenced excerpt) were counted. The intermediary articles were registered (title and authors) for the second step of analysis. When different excerpts in the same article were identified by each of the reviewers or when the same excerpt had several intermediaries mentioned, only the oldest citation was considered. The year of publication of selected articles and intermediaries was also recorded for temporal analyzes. In the second step of analysis, we checked whether the intermediaries cited the original article by Brooks and Dodson (1965). We also checked which articles were most cited and which authors were most cited as intermediaries (with one or more articles as the first author). The entire search and selection procedure as well as the number of articles evaluated in each phase of this study can be seen in Fig. 1.

We calculate the Citation Index (CI) for each year of the period evaluated. Simply counting the number of citations can generate biased conclusions since the number of publications is affected by trends in the publication rates of the literature on the topic. Thus, calculating the CI allows us to minimize these effects and increase our ability to detect differences over time in the number of citations. The CI was calculated from the modification of Activity Indexes (AI) widely used in scientometric studies (such as Caliman et al., 2010; Kumari, 2006). We obtained the CI value according to the following formula:

$$CI = \frac{(\frac{CY}{CT})}{(\frac{TY}{TT})},$$

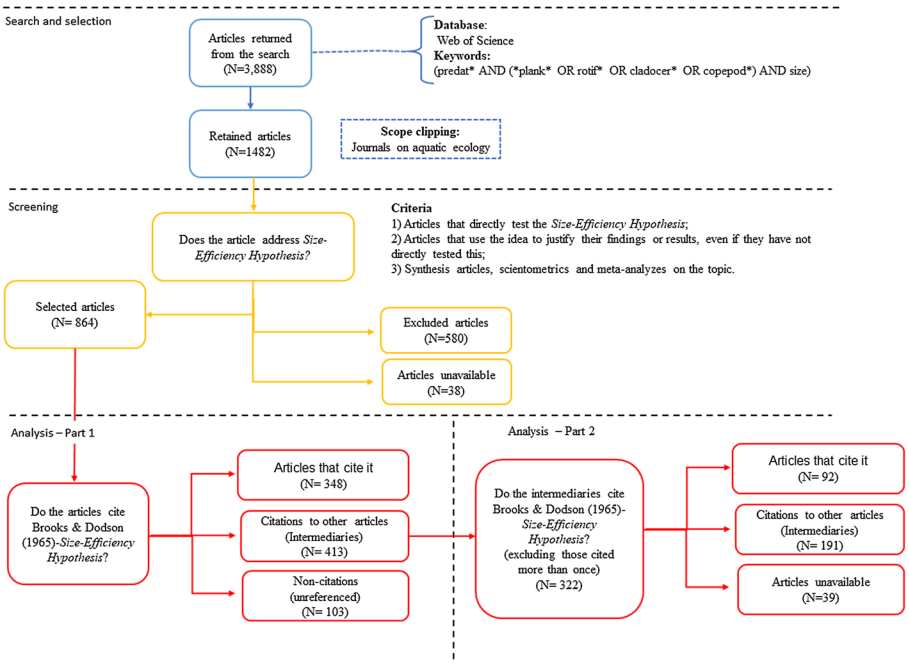

Fig. 1 Flow diagram showing the procedure used for search and select studies on the Size-Efficiency Hypothesis, as well the number of articles evaluated in each phase of this study. The articles were found in the Web of Science database between 1965 and 2018

where CY is the number of citations of the original article by Brooks and Dodson (1965) in a respective year; CT is the total number of citations to the original article by Brooks and Dodson (1965); TY is the total number of articles published in a year; and TT is the total number of articles published for all years studied. When CI = 1, the number of citations follows the same relative rate of publication on the topic. When CI > 1, the frequency of citation is higher than the relative rate of publication and when CI < 1 the frequency of citations is lower than the rate of publication on the topic.

We verified the variation of the CI over time from the year of publication of the article until the year 2018. In addition, we verified the effect of the article's age on the CI and on the number of citations per year using linear regressions. The data were checked for test assumptions. To check whether authors tend to cite more recent articles instead of the old original reference, we calculated Pearson's correlations between $AA_{B\&D}$ and $IA_{B\&D}$, where AA is the difference in years between the analyzed article and the original publication of Brooks and Dodson and IA is the difference in years between the intermediary article cited and the original publication of Brooks and Dodson. Statistical analyzes were performed using the R software and the graphics in the Excel program from Office 2016.

Results

In general, our initial search was able to retain many articles ($N=3888$) and, even after clipping for journals whose scope includes aquatic ecosystems, many articles were also selected ($N=1482$) for evaluation in full (Fig. 1). We found that approximately 39% (or 580) of the articles retained after clipping by the journal scope, did not address the theme originally proposed in *Size-Efficiency Hypothesis*. This was the case for many studies on genomics, taxonomic descriptions and unrelated ecological approaches, such as parasitism ecology, conservation biology, pollution studies, among others. Therefore, after the first full analysis, 864 (or 58%) articles met at least one of the inclusion criteria (Figs. 1, 2). In addition, 38 articles were not analyzed because they were unavailable at the time of the analysis.

We observed that of the 864 articles, only 348 (40%) articles cited Brooks and Dodson (1965). The other 516 (60%) articles did not mention the original reference, even though they addressed the *Size-Efficiency Hypothesis* in part or entirety. Of these, 413 articles cited other studies (intermediaries) and 103 referred to the theory but did not mention anyone (Fig. 2). In relation to intermediary articles (Table S2—Supplementary Material), excluding those cited more than once (total = 322), we observed that 191 (59%) do not refer to the original article even though they were mentioned in other studies when the *Size-Efficiency Hypothesis* was addressed. Therefore, although they are recognized when the subject in question is addressed, they do not cite the original article by Brooks and Dodson (1965) in their own text. Only 92 (29%) intermediaries that were referenced when the *Size-Efficiency Hypothesis* was addressed, cited the original article in their texts (Fig. 2). Unfortunately, 39 (12%) could not be evaluated, as they were unavailable at the time of the analysis.

Regarding the temporal variation, we observed that the number of publications on the topic and the number of citations to Brooks and Dodson (1965), remained reasonably

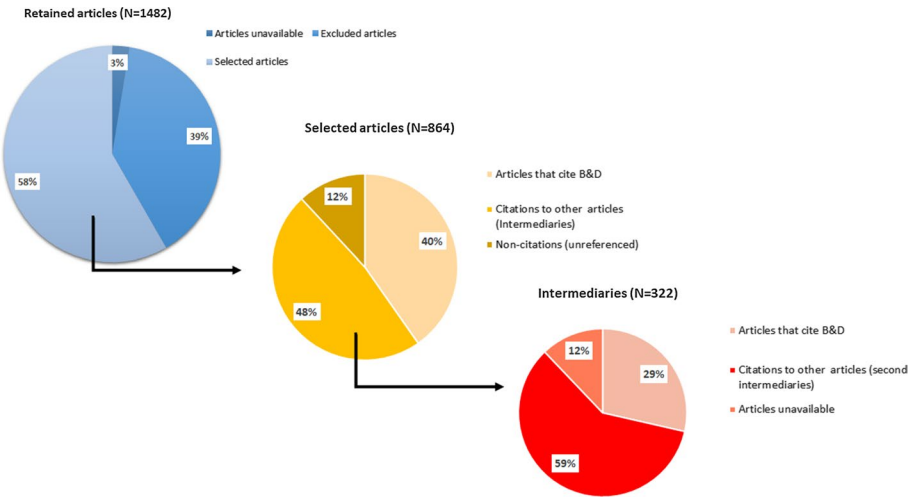

Fig. 2 Pie chart showing proportions of selected articles (top graph in blue), proportion of citations to the original article by Brooks and Dodson (1965) among selected articles (center graph in yellow) and proportion of citations to the original article by Brooks and Dodson (1965) among the intermediate articles (bottom graph in red). The articles were found in the Web of Science database between 1965 and 2018. (Color figure online)

stable over time (Fig. 3). Despite being published in 1965, the first citation among the articles retained in our search occurred in 1968 and is a self-citation. In addition, between 1974 and 1989, publications on the topic were very scarce: we found only 5 articles on the topic in this period. Therefore, we chose to evaluate these years (1974 to 1989) together. From the 1990s onwards, there has been a significant increase in the number of publications up to the present day (Fig. 3). However, for almost the entire period, the proportion of articles published on the topic that cite Brooks and Dodson (1965) does not exceed 40%. Only in 2010, more than 50% of the articles published on the topic in fact mention their original authors. As for CI values, the pattern is the same. Since its publication in 1965, the citation index of the *Size-Efficiency Hypothesis* has not exceeded the value of 1 for most of the time, i.e., although the topic is being addressed frequently, the frequency of citation of the original article is lower than the rate by which articles are published (Fig. 3). We found significant and positive effects of the age of the original article by Brooks and Dodson, on the number of citations ($R^2 = 0.484$, $p < 0.0001$, Fig. 4). However, for the CI the effects were negative ($R^2 = 0.22$, $p < 0.0044$, Fig. 4), i.e., as the article "aged", the citation index was lower.

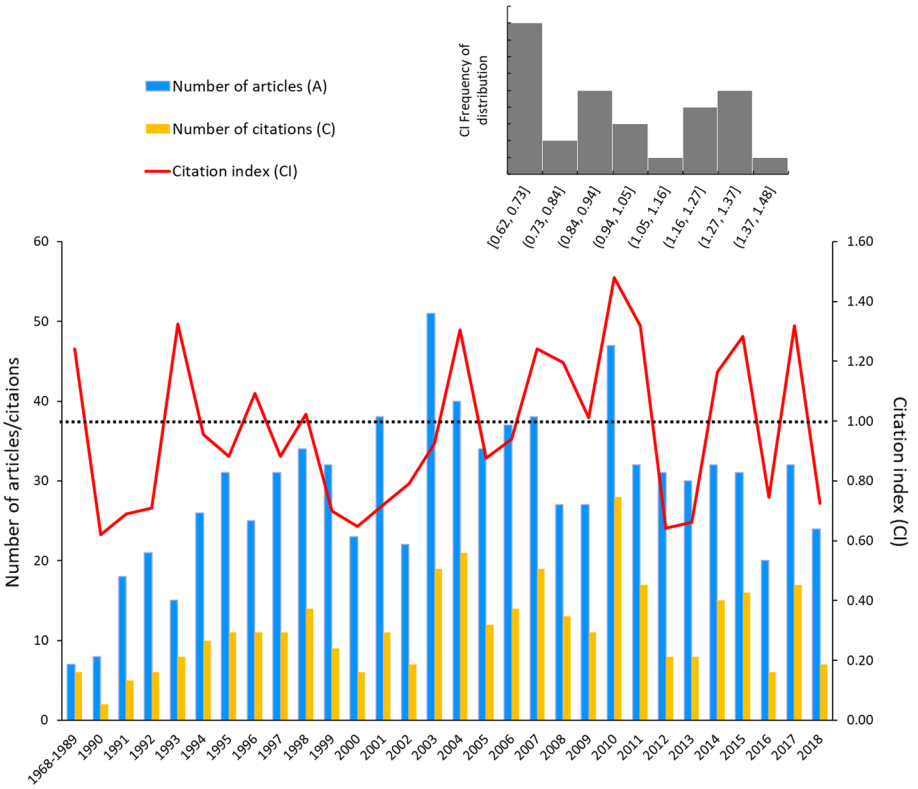

Fig. 3 Temporal variation in the number of articles (A) published on the *Size-Efficiency Hypothesis* by Brooks and Dodson (1965), in the number of citations (C) and citation index (CI) of the original article by Brooks and Dodson (1965). Top right, histogram of frequency distribution of CI values. The articles were found in the Web of Science database between 1965 and 2018. (Color figure online)

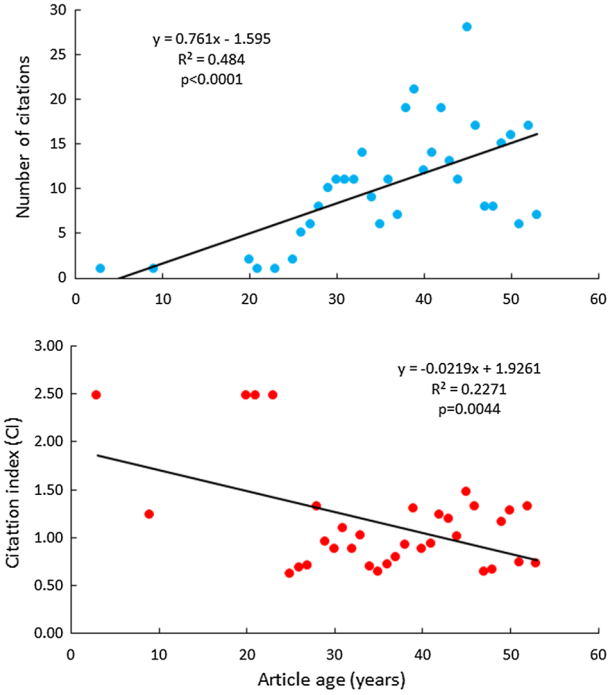

Fig. 4 Linear regressions between the number of citations to the original article by Brooks and Dodson (1965) (top graph in blue) and citation index (bottom graph in red) and it respective age in years

When we carefully evaluated the intermediaries, we found 322 different articles being cited 413 times (Fig. 1), since some of these articles were cited more than once (Table 1). Among the most cited intermediaries most are review articles or book chapters that compile ideas on the topic (Table 1). The book *Predation and Freshwater Communities* by Zaret (1980) was the most cited intermediary followed by the review chapter authored by Gliwicz and Pijanowska (1980) published in the book *Plankton Ecology* (Sommer, 1989). We also highlight that among the intermediaries more cited, we find three articles published individually by Brooks or Dodson, which essentially deal with enhancements or tests of the *Size-Efficiency Hypothesis* (Table 1). However, even if considered together, the number of individual citations from Brooks or Dodson makes up a tiny percentage of the total of intermediary citations (3.8%). In fact, we observed a great variability of intermediaries in which about 84% of them were cited twice or only once. Regarding the tendency of articles to cite more recent articles, we found positive and significant correlations between $AA_{B\&D}$ and $IA_{B\&D}$ ($r = 0.41$, $p < 0.0001$, Fig. 5). This result shows that the more distant a publication is from the original publication on the topic, the more likely it is to cite a contemporaneous publication.

Among the most cited authors, we note that Gliwicz, Z. M. appears first with 24 citations, followed by Zaret, T. M. with 21 citations and Dodson, S. I. with 13 citations (Table 2). These same authors appear as authors of the most cited intermediaries (Table 1), although each of them has contributed with more than one article as the first author. Therefore, we note that some intermediary authors are more cited than others with different articles on the same topic. In addition, we observed that at least seven articles older than the original *Size-Efficiency Hypothesis* were cited (Table 3). Among these, most represent novel articles (for their time) or primary research on the topic.

Table 1 List of the most cited studies in papers on the *Size-Efficiency Hypothesis* found in the Web of Science database between 1965 and 2018, replacing the original article by Brooks and Dodson (1965), referred as "intermediaries" in this study

Title	Authors	Year	No of citations	Does it cite B&D?
Predation and Freshwater Communities	Zaret, T. M.	1980	14	Yes
The role of predation in zooplankton succession	Gliwicz, Z. M. and Pijanowska, J.	1989	10	Yes
Zooplankton competition and predation: an experimental test of the *Size-Efficiency Hypothesis*	Dodson, S. I.	1974	6	Yes
The *Size-Efficiency Hypothesis* and the size structure of zooplankton communities	Hall, D. J., Threlkeld, S. T., Burns, C. W., and Crowley, P. H.	1976	5	Yes
The effects of prey-size selection by lake planktivores	Brooks, J. L.	1968	4	Yes
Adaptive change in zooplankton morphology in response to size-selective predation: a new hypothesis of cyclomorphosis	Dodson, S. I.	1974	4	No
Effects of alewife predation on zooplankton populations in Lake Michigan	Wells, L.	1970	4	Yes
Prey vulnerability and size selection by *Chaoborus* larvae	Pastorook, R. A.	1981	4	Yes
The predator–prey interaction of planktivorous fish and zooplankton	O'Brien, W. J.	1979	4	Yes
Vertical migration in zooplankton as a predator avoidance mechanism	Zaret, T. M. and Suffern, J. S.	1976	4	No

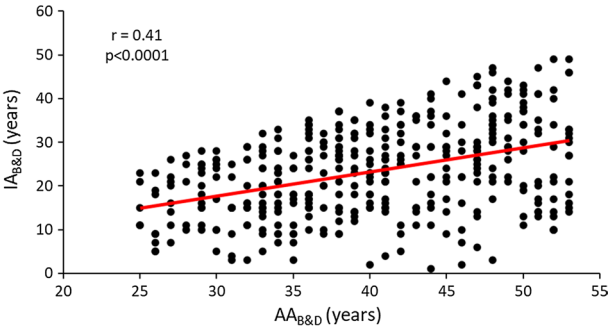

Fig. 5 Pearson's correlation between $AA_{B\&D}$ and $IA_{B\&D}$, where AA is the difference in years between the analyzed article and the original publication of Brooks and Dodson and IA is the difference in years between the intermediary article cited and the original publication of Brooks and Dodson

Table 2 List of the most cited authors in papers on the *Size-Efficiency Hypothesis* found in the Web of Science database between 1965 and 2018, replacing the original authors Brooks and Dodson (1965), referred as "intermediary authors" in this study

Authors	Citations as first Author	No of articles cited
Gliwicz, Z. M.	24	14
Zaret, T. M.	21	5
Dodson, S. I.	13	5
O'Brien, W. J.	11	7
Kerfoot, W. C.	7	5
Pastorook, R. A.	5	2
Hall, D. J.	5	1

Discussion

From our results we could verify that classic ideas are not always properly cited over the years. We observed that there is a tendency to cite more recent articles for pre-existing ideas, instead of their original articles, generating a type of "scientific reheating" of an idea. At least for the field of study addressed (aquatic ecology), we observed that most studies on the topic of *Size-Efficiency Hypothesis*, do not mention the original article that defined and systematized it, being neglected by more recent articles. Our results are surprising as they demonstrate that many ideas may be presented or referenced as newer and innovative than they really are. In this sense, our data indicate that the path taken by science can be much more curvilinear and cyclical than progressive and forward oriented and clearly illustrate the phenomenon we describe as the *microwave effect*.

Studies have shown that the uncitedness ratio of an article may be related to factors such as the identity of the journal in which the work was published, the time window for the first citation, language and readability, the scientific moment in which the work is published, type of document and field study or discipline (Burton, 1960; Hamilton, 1991; Kamat, 2018; Nicolaisen & Frandsen, 2019). Our results have shown that most of the evaluated articles do not properly cite the original reference and even for articles that are cited in place of the original article, the majority also do not cite the original reference. In the case of the data that we evaluate here, there is a clear substitution of the original reference for more recent articles that are more likely to confirm specific results mainly because they studied the same group or environment. May (1967) already pointed to the tendency of authors to cite papers that confirm their findings and, to our data, this is particularly

Table 3 List of cited articles older than the original Brooks and Dodson (1965) article found in the Web of Science database between 1965 and 2018

Title	Authors	Year
Research on the biology of northern pike larvae and some related problems	Montén, E.	1948
The medusa Craspedacusta in Australia	Thomas, I. M.	1950
Benthic productivity as influenced by fish predation	Hayne, D. W. and Ball, R. C.	1956
Estimated sizes of various forage fishes largemouth bass can swallow	Lawrence, J. M.	1957
Fish stock as a protective agent in the occurrence of slow-developing dwarf species and strains of the genus *Daphnia*	Hrbacek, J. and Hrbackova-Esslova, M	1960
Demonstration of the effect of the fish stock on the species composition of zooplankton and the intensity of metabolism of the whole plankton association	Hrbacek, J., Dvorakova, M., Korinek, V. and Prochazkova, L.	1961
Variation of incidence, size and fertility of plankton Crustacea in space and time	Weglenska, T.	1964

evident since we found that more than 80% of intermediaries were cited only once or twice. Therefore, for the field of study evaluated here, it does not seem to us that the uncitedness of Brooks and Dodson (1965) is related to issues such as the journal's identity (since it was published in a high-impact journal—*Science*) or language, but rather at the moment when the article was published and the fact that some authors cite intermediaries only as an example that agrees with the own data.

It is interesting to notice that some of the intermediaries replacing Brooks and Dodson (1965) were either a book chapter or a review paper. Since books have fewer limitations of space, they may provide more details, evidence, or information to support the main theory, so, they also may receive more attention and citations. Moreover, citing prestigious authors and/or detailed publications is considered a key factor to convince the readers of the authors own findings (Tahamtan & Bornmann, 2018). In a similar way, a review paper represents the synthesis of a research theme based on other literature previously published and it may not report new and original results. Some narrative reviews, for example, just compile the results of different studies in a qualitative way and may reflect subjective views of the reviewer. This kind of research help readers to have an idea about the existing knowledge on a topic without the need to read an extensive list of published literature in a field. Furthermore, the tendency to cite reviews instead of the original articles is widely reported (Kamat, 2018; Mammola et al., 2021; Nicolaisen & Frandsen, 2019).

However, despite the several different reasons that can justifies articles citation (Bornmann & Daniel, 2008; Erikson & Erlandson, 2014; Garfield, 1962; Tahamtan & Bornmann, 2018), classicals documents, as the ones accepted as foundation of a theory or method, due its originality and innovative characteristics, are expected to be preferentially cited (Wang & White, 1999). Such expectations rest on important reasons. Paying credit to pioneer research is an important reason to cite a published paper (Garfield, 1962; Tahamtan & Bornmann, 2018) because it not only helps to keep track of the scientific knowledge, but also solidifies the construction of hypotheses and theories, which is also pivotal to good practices in science. Additionally, citing classical documents can increase the persuasive power to papers citing them (Erikson & Erlandson, 2014), which, according to Gilbert (1977), is more important than proper idea's acknowledgement, as inferred as citation main goal. It also denotes familiarity with literature and can be used to expose orthodoxy, iconoclasm, or eclecticism in one subject, which can be relevant to scientific self-image (Erikson & Erlandson, 2014). This does not mean that a review or a book should not be cited at all, but the focus of its citations must be for what it innovates, maps, or points out as new discoveries and not solely as a source of previously published information.

Hicks and Potter (1991) argued that through citation, part of the credits of a work is transferred from citing author to cited ones, which can be viewed as an obstacle to new publications revealing substantial contributions and advances in a topic of study. Under this perspective, there is a possible advantage in omitting a citation to gain credits with a "reheated" idea, that indeed, seems more than balanced by the risk of expressing insufficient familiarity with literature (Erikson & Erlandson, 2014). Another possible reason for inadequacies in citing can be rested on the model of science production. Considering the pressure to publish in the fastest time and the tendency to cite the most recent literature (Mammola, 2020), it is reasonable to understand why an author eventually does not cite an older classic article. In academic life, in order to obtain a relevant publication, young scientists are trained to search, read and cite. In this last one, they are oriented to consider recent papers and those published in high-impact journals (Mammola, 2020). However, the balanced choice between up-to-date references capable of providing timeline information supporting the novel findings and old classic articles

is not always made. On the contrary, many of the up-to-date references that replace the classics do not show great advances in the original theory. In our results, for example, we observed articles that cite intermediary authors on mechanisms of non-visual prey selection, demonstrating a little bit different interactions compared to Brooks and Dodson's original idea. Although it is important to cite the article that first described the phenomenon, some authors choose to read articles on hot topics that are more easily available.

An interesting aspect of Brooks and Dodson's paper is that it remained almost unnoticed for many years until became recognized in the 1990s, as observed through the increase in citations from this decade onwards. In part, this apparently unappreciation can be attributed to scarcity of published papers on this topic until this decade, that may suggest some "prematurity" of the subject on its field of science, since being 'ahead of time' can also represents lack of contemporary appreciation (see Stent, 1972) and delayed recognition, or *sleeping beauties* in science (van Raan, 2004). This phenomenon is not particularly exceptional, whereas many works can *sleep* (i.e., receive few or no citations per year for a long time after published) for more than 50 years (Ke et al., 2015; Li & Ye, 2012), until they *awake* (i.e., suddenly experiences a boost in citations), becoming appreciated and recognized (van Raan, 2004). Despite emblematic examples of delayed recognition, and most of such publications are founded in physics, chemistry, and mathematics, biology and ecology also integrate the ranking of top 20 disciplines that most generate *sleeping beauties* in science (Ke et al., 2015). For Brooks and Dodson's article, this phenomenon is particularly interesting, as the first citation to the work occurred after a reasonable period of time and was a self-citation.

Among our results, we observed that the two most cited intermediaries, Zaret (1980) and Gliwicz and Pijanowska (1980), are a book and a book's review chapter, the last one published a few years before the *awakening* of Brooks and Dodson's paper. According to (Nash et al., 2018), in marine and freshwater sciences, being cited by books have strong positive effects over long-term citations (10 years). The authors suggested that it happens probably due high visibility promoted by such citation and the indicative of being an influential publication in a field of science. Therefore, despite Zaret (1980) and Gliwicz and Pijanowska (1980) had gained part of Brooks and Dodson's credits, their works had probably "compensated" the authors directing part of their audience to the original source, and so, acted as the *prince's kiss* that *awakened* the seminal paper. Also, the likely positive effect of visibility promoted by these intermediaries seems relevant especially considering that Brooks and Dodson's paper was firstly cited in 1968, which apparently had a weak effect on subsequent years' citations (Fowler & Aksnes, 2007; Nash et al., 2018).

Another interesting aspect to be discussed is the fact that Brooks and Dodson (1965) developed their own theory based on existing pillars, provided by previous articles and some of these older studies were cited. These authors, while building the *Size Efficiency Hypothesis* in their article, highlight the effectiveness of three previous articles: Hrbáček et al. (1961), Hrbáček (1962) and Pennington (1941). These important foregoing researches allowed for the hypothesis testing and discussion by Brooks and Dodson and are equally important historical landmarks. Hrbáček et al. (1961), for example, aimed to test whether there was an effect of fish stock (Hrbáček, 1958) on plankton compositional differences and throw some light on the mechanism behind this effect. In this example we can observe the phenomenon was carefully observed and the mechanism underlying the observational findings were discussed, though Hrbáček et al. (1961) did not set out to unify knowledge in the form of a general hypothesis. This organic flow of citations, mechanisms' description and hypothesis building is the most interesting aspect in scientific maturation, since it

prepares the scientific ground for future debates aiming to consolidate scientific knowledge in unified theories (Scheiner & Willig, 2005).

However, for the dataset we analyzed, the most evident pattern that emerges from the intermediary citations is the tendency to cite articles where the theory of *Size-Efficiency Hypothesis* is applied in a particular taxonomic group (or a near group). That is, many times, when referring to the hypothesis, the authors seek to cite those authors who carried out a study, experiment or evaluation with the same group of species or in the same model environment, instead of referring to the authors of the hypothesis, in order to only exemplify similar or divergent results from their own. This effect can be potentiated with the social network of authors (Case & Higgins, 2000) and restricted circles of scientific collaboration. The bias of citation of ecology theories in works with a delimited taxonomic group is commonly observed (Taborsky, 2009). Moreover, factors like nationality of author's, number of authors (Leimu & Koricheva, 2005) and journal reputation (Judge et al., 2007) can influence in the chances of the article being cited. In the case of the *Size-Efficiency Hypothesis* the requirements for wide disclosure are positive, leading to believe that one of the main reasons for not to cite the main article is the taxonomic and social network bias.

Finally, in an increasingly technological and globalized world, advances in the communication process and the speed in exchanging information are also potential factors influencing scientific production. On the website of the Science journal, in Info and Metrics, we verified that Brooks and Dodson's article was digitally published in 2006. Despite the volume of available scientific information on virtual platforms has grown exponentially (Landhuis, 2016), the effect of the on-line publication on the increase in citations was not as relevant as we expected. Certain factors can interfere in the citation process, such as the number of references, pages, and authors, as well as the year of publication (Tahamtan & Bornmann, 2018). The possibility of discovering older articles decreases significantly over the years (Lynn, 2014). There is a negative relationship between the year of publication and the number of citations (Padial et al., 2010). Publications tend to be cited more frequently in the first few years and after they reach a peak, citations decline in frequency (Tahamtan et al., 2016). Therefore, it seems to us that the online publication of Brooks and Dodson's article occurred so long after its original publication that it no longer made so much difference in providing an increase in the number of citations because a large volume of other articles were published online in this period and achieved greater visibility for the reasons mentioned before.

In summary, our study showed through a quantitative and qualitative analysis some aspects rarely explored in scientometric studies. We were able to verify some phenomena and patterns related to the form of citation of classic articles and understand some of the mechanisms that reveal how and why these articles are not properly cited. We observed what we call the *microwave effect*, in which pre-existing ideas and theories are "reheated" by more recent articles where the original idea is not mentioned and little modified. There is a tendency to cite more recent articles and articles that corroborate their own findings or that used the same species and/or environment. The *microwave effect* can create the impression of scientific advancement when there is actually little being added to the knowledge already produced. Therefore, we highlight the importance of an adequate citation so that we walk new steps in the construction of scientific knowledge.

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