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RESEARCH PAPER

Trends in the scientific literature on phytoplankton

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Abstract The use of scientometric techniques can assist in evaluating the importance of a subject, author or article, and also emphasize the trends and contributions of a discipline, scientist or research group, institution or country regarding world-wide scientific and technological advances. We applied scientometric analysis to papers in the Thomson ISI database, in order to understand temporal trends in phytoplankton research. From the years 1991 through 2005, the number of articles on this topic increased. We found 19,681 articles containing the word "phytoplankton" in the title, keyword and/or abstract. Principal components analysis (PCA) was used to summarize changes in the focus of papers published from 1991 to 2005. The keywords gradually changed, in the earliest years indicating descriptive study, whereas in recent years (2000 and after), the keywords became more diversified and related to aspects of technology, genetics, evolution and public health.

Keywords Phytoplankton · Scientometric analysis · Scientific development · Temporal trend

Introduction

Regardless of the criteria used to measure scientific growth (e.g., number of articles, scientific journals, PhDs), it is now widely acknowledged that this growth is exponential (King 2004). Considering the astonishing number of articles published each year, it is becoming difficult for scholars to follow the progress of their scientific fields (Garfield 1992). Even a basic question such as "What are the main questions pursued by scholars in a given scientific field?" is difficult to answer.

Scientometric studies allow us to observe the progress of science and technology, and have been widely used to satisfy the need for a global view of research activities (Garfield 1992; Dalpé 2002; Strehl and Santos 2002). In ecology, there have been a few attempts in this direction (Budilova et al. 1997; Duarte 1999; Pinto et al. 2002; Melo et al. 2006; Bini et al. 2005; Fazey et al. 2005; Lawler et al. 2006).

In this study, we carried out a broad analysis of papers published in peer-reviewed journals in which the term phytoplankton was used. Thus, scientometric data were used to quantify and describe spatial and temporal (over the past 15 years, 1991–2005) patterns in phytoplankton research. Specifically, we asked the following questions: (1) How rapidly is the number of scientific articles focused on phytoplankton biology increasing? (2) What countries are the major publishers on phytoplankton? (3) Can we recognize a temporal trend in the investigated issues through the articles' keywords? (4) Based on the keywords analysis, is it possible to identify trends in the type of questions that the authors pursued?

Methods

The source of the data was the Thomson ISI Web of Science (http://portal.isiknowledge.com). The analysis was based on all the papers that contained the word "phytoplankton" in the article's title, abstract or keywords,

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published from 1991 to 2005. The data were collected from the Thomson ISI in August 2006.

For each paper, we identified the year of publication, the first author's country, the journal, the number of citations, the keywords, and the journal impact factor (obtained from the Journal Citation Reports—JCR, published in 2005). The number of articles with the word phytoplankton was standardized through time, by dividing the number of phytoplankton articles by the total number of articles in the database in a given year, and multiplying the result by 100.

The impact factor (IF) of journal X for a particular year t is defined as the number of citations received in year t by all documents published in X in the years $t - 1$ and $t - 2$, divided by the number of documents published in X during years $t - 1$ and $t - 2$ (Garfield 1972). Despite many criticisms (Rossner et al. 2007), the journal impact factor (IF) has been used for ranking and evaluating journals and as a surrogate for judging the quality and importance of researches' publications (Carvalho et al. 2005). This index is published annually by the Journal of Citation Reports.

The diversity of journals that published papers with the word "phytoplankton" each year (1991–2005) was estimated by the Shannon–Wiener diversity index (H'). Some authors have also used ecological indexes in scientometric studies (Rousseau 1998; Carvalho et al. 2005). A Principal Components Analysis (PCA), based on the correlation matrix (Legendre and Legendre 1998), was performed to analyze the temporal trend in keywords. First, keywords with similar meanings were grouped. To remove the influence of the total number of articles published each year, we analyzed the proportion of the number of articles with a specific keyword to the total number of articles appearing in that year. Keywords such as phytoplankton, area of study and species names were excluded from this analysis. The term "phytoplankton" was not used in the PCA due to its high frequency.

Results

A total of 19,681 articles contained the word "phytoplankton" between 1991 and 2005, accounting for 80% of the total number of articles with that term in the Thompson ISI (from 1945 to 2005). The number of publications increased significantly during this period ($R^2 = 0.61$, $P < 0.05$; Fig. 1). In 2005, the production of articles decreased compared with the total number of papers in the Thomson ISI database.

Most studies were published in the form of articles (94.3%) and reviews (3.61%) in 978 journals. A high proportion of articles on phytoplankton were published in the *Marine Ecology Progress Series* (7.26%), *Hydrobiologia* (6.39%), *Limnology and Oceanography* (5.55%) and the *Journal of Plankton Research* (4.66%) (Fig. 2a). Only

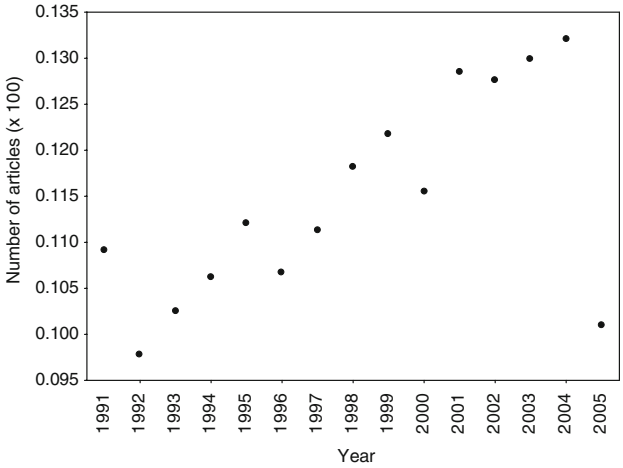

Fig. 1 Temporal trend in the standardized number of articles (multiplied by 100) that contained the word "phytoplankton" in the ISI database. To standardize the number of paper containing the word phytoplankton, the number articles for each year was divided by the total number of articles in the ISI database of the same year. These values were then multiplied by 100

19 journals accounted for 50.13% of all articles published in the database with the word phytoplankton (472 journals). The diversity of journals publishing articles on phytoplankton biology is continuously increasing (Fig. 2b; $r = 0.94$, $P < 0.01$).

Approximately, 31.7% of scientific production using the word "phytoplankton" came from institutions in the USA, followed by Canada and several European countries (Fig. 3). Few papers were often cited, whereas 11.5% of the articles on phytoplankton were never cited, and 31% of the articles were cited only 1–5 times (Fig. 4a).

The most cited article was by Charlson et al. (1992), with 1,058 citations. Three other articles were heavily cited, receiving more than 500 citations: Trenberth and Hurrell (1994; 676 citations), Coale et al. (1996; 582 citations) and Smith et al. (1992; 517 citations). We observed that the highly cited articles were published a long time ago (Fig. 4b), and that the most-cited articles were mainly from 1992 to 1994. In general, there was a decrease in the IF through the years of the journals that published on phytoplankton (Fig. 5).

As revealed by the principal components analysis (Fig. 6), the most frequent keywords during 1991 and 1998 were rather general (e.g., atmospheric aspects such as aerosol, basin, density and productivity). The keywords related to quadrants II and III are associated with the most recent years. The difference between quadrants II and III and the other quadrants is probably due to the fact that in this period there was a development of key concepts in phytoplankton biology (e.g., functional groups) and words such as "trophy" and "bloom". Phytoplankton studies focusing on phylogeny, genetics or technologies (e.g.,

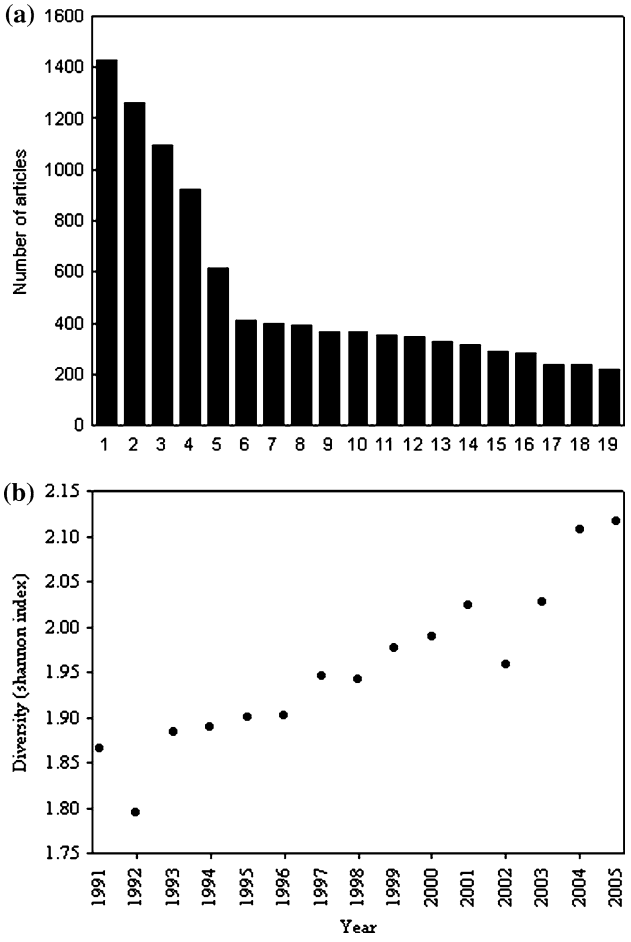

Fig. 2 **a** Journals with the highest number of articles, the *number* represent the journal (*1* Mar Ecol Prog Ser, *6* J Phycol, *11* Mar Biol (NY), *16* J Mar Sys, *2* Hydrobiologia, *7* J Geophys Res, *12* Can J Fish Aquat Sci, *17* J Exp Mar Biol Ecol, *3* Limnol Oceanogr, *8* Aquat Microb Ecol, *13* Arch Hydrobiol, *18* Polar Biol, *4* J Plankton Res, *9* Freshw Biol, *14* Deep-Sea Res Part I Oceanogr Res Pap, *19* Ecol Model, *5* Deep-Sea Res Part II Top Stud Oceanogr, *10* Estuar Coast Shelf Sci, *15* Mar Chem). **b** Diversity (*H'*) of the journals in which the word "phytoplankton" was cited between 1991 and 2005

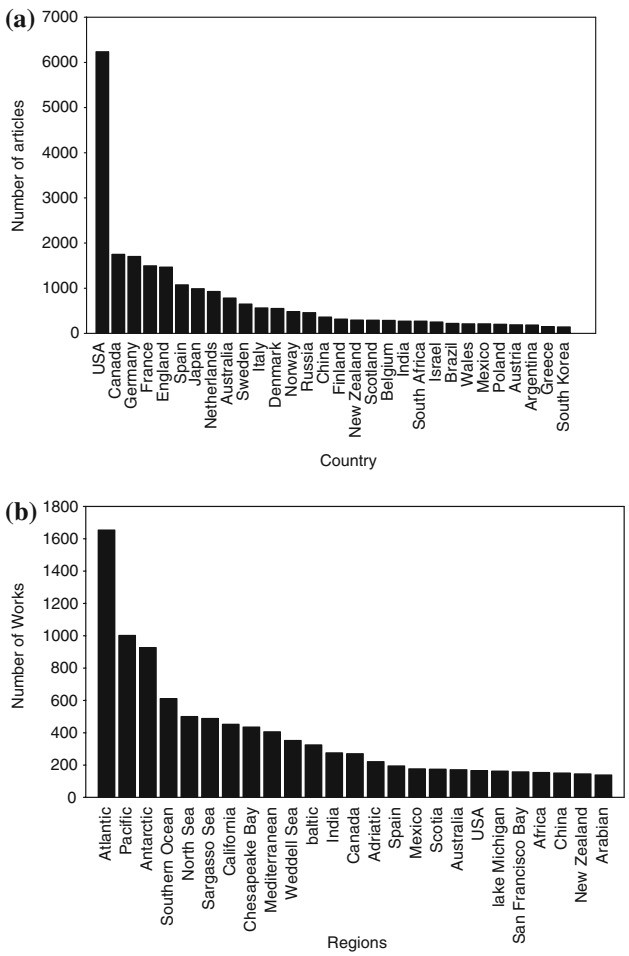

Fig. 3 **a** Nationality of the authors and **b** regions with high number of studies

remote sensing, CHEMTAX) are scarce and appeared only recently; the word "conservation" does not appear in these analyses.

Discussion

The increase in the number of publications during the period studied probably indicates an increase in the number of researchers interested in phytoplankton biology. However, limnological studies involving only algae have decreased markedly over the last three decades (Irfanullah 2006). In 2005, the production of articles slowed compared with the total number of papers in the Thomson ISI database. However, in that year, the total number of articles in the Thomson ISI database increased much more in regard to the previous years. On the other hand, the total number of articles with phytoplankton decreased, leading to a decrease in the proportion.

In general, the journal in which the article is published can be used as a criterion to evaluate the field of research knowledge (Vanti 2002). The journals that frequently publish research on phytoplankton biology belong to the subject categories of oceanography and limnology. More phytoplankton studies were concentrated in the limnology–oceanography area, rather than in specific journals. Although the majority of the articles were published in a relatively few journals, the diversity of journals publishing articles on phytoplankton biology has increased continuously through the years.

The greatest number of publications by North American authors reflects the local investment in infrastructure and research (May 1998). Presently, scientific activity is highly concentrated in a few industrialized countries (Jappe 2007). The scientific production of Latin American countries has grown in the past 20 years, mainly in Brazil, Mexico,

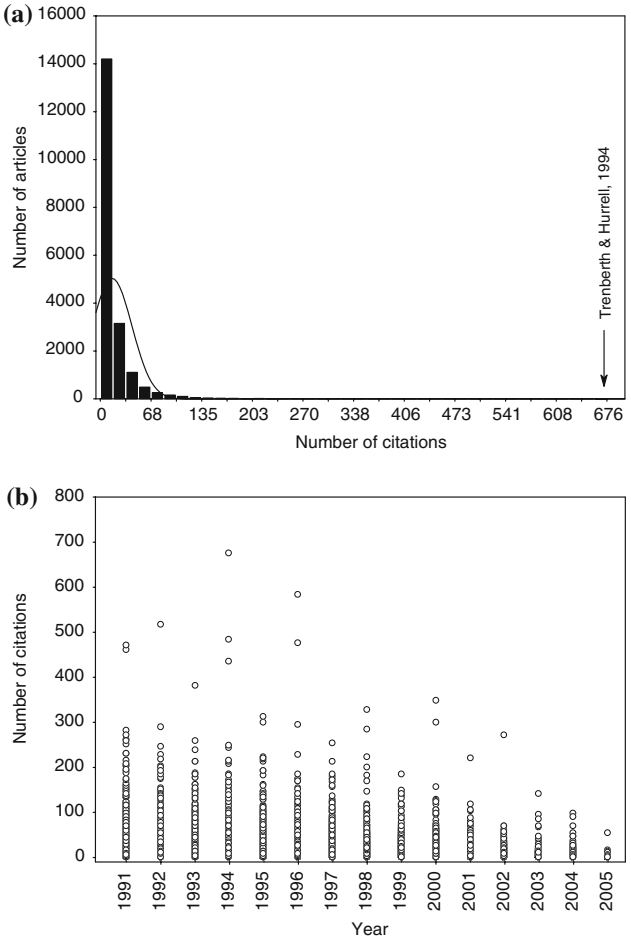

Fig. 4 **a** Citation distribution and **b** temporal variation of the number of citations ($n = 19{,}680$). Charlson et al. (1992), with 1,052 citations, was not included

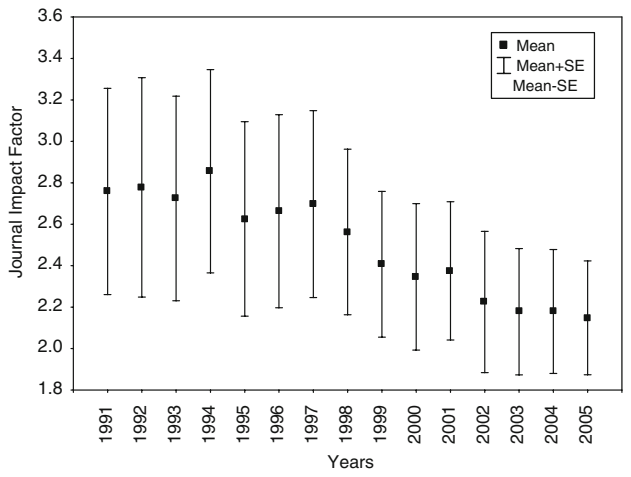

Fig. 5 Mean impact factor (±SE) of the journals that published research on phytoplankton biology

Argentina and Chile (Hill 2004). Nowadays, the number of publications per dollar invested in research and development is higher in Latin America than in the USA and

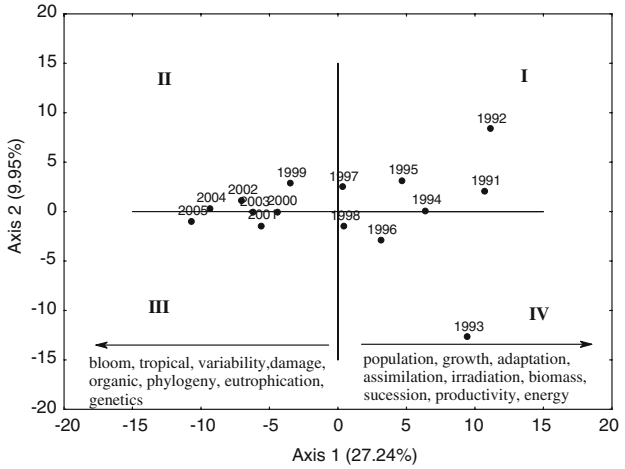

Fig. 6 Principal component analysis (PCA) using the keywords found in the articles. Inserted keywords were those that most contributed to the formation of the axes

Canada (Holmgren and Schnitzer 2004) Even so, during the period studied, Brazil, Mexico and Argentina contributed only 4.33% of the papers published on phytoplankton in 1991 through 2005. The predominance of publications by authors from higher-income countries is a pattern also found in other fields of biology (Fazey et al. 2005). Besides the paucity of investment, the low scientific contribution of scientists from lower-income countries may be also accounted for by other factors (e.g., low salaries and language barriers; Fazey et al. 2005).

The frequency with which a work was cited by others is one of the criteria for scientific evaluation (Dastidar 2004). The number of citations is a tool to identify the impact of a work in the scientific community, and it can also be used to assess the scientific performance of research institutes, departments and faculty members, as well as to indicate the scientific quality of an article (Leimu and Koricheva 2005). Most published articles are either not cited at all, or cited only a few times (Colquhoun 2003; Leimu and Koricheva 2005).

The most-cited article was by Charlson et al. (1992), who wrote about the impact on climate of anthropogenic aerosols and their relationship to greenhouse gases. This article considered marine phytoplankton as the principal natural emitters of dimethylsulfide (DMS). Three other articles were also heavily cited; these considered the effect of global change such as El Niño, La Niña and increased ultraviolet (UVB) radiation on phytoplankton communities, and also the impact of fertilization experiments on marine phytoplankton. Knowledge about the effects of climate change on marine environments brings many economic and societal advantages (Dastidar 2004). Further, future studies with phytoplankton, envisaging climate change, will be projected through simulation (Irfanullah 2006).

Due to the time lag between the publication of an article and its citation in other papers, the most-cited articles in this study were from 1992 to 1994. In general, the number of citations depends heavily on the year of publication (Yu and Li 2007). Therefore, old articles tend to be cited more than the most recent. Despite the increasing number of articles, these have been published in journals with low IF, but the increase in the number of journals could reinforce the fall in the IF. In general, the majority of papers on a given subject are published in journals with low impact factors (Valiela and Martinetto 2005). Therefore, the impact factor reflects the broad interests of the scientific community and not necessarily the quality of the science (Bini et al. 2005).

As revealed by the principal components analysis, the most frequent keywords from 1991 through 1998 had a descriptive character. In most developing countries, limnological studies are still largely descriptive, with substantial taxonomic considerations (Irfanullah 2006). Words such as "trophy" and "bloom" associated with the most recent years indicate the increased concern of the scientific community with studies on water quality. In fact, in recent years, the occurrence of pervasive phytoplankton blooms, often dominated by Cyanophyceae, has stimulated a significant amount of public, political and scientific actions. These facts probably resulted in a large increase in publications on this subject (Huszar et al. 2000).

The relationship between phytoplankton growth and water-quality problems is widely known (Reynolds 2006). Also, these environmental problems (e.g., water quality) are much more frequent in lower-income countries (Hardoy et al. 1992). Thus, despite the likely societal benefits of scientific knowledge of this area, few efforts have been made by the governments of lower-income countries to reverse this situation.

In recent years, key concepts in phytoplankton biology have been developed (e.g., functional groups). Further, studies focusing on phylogeny, genetics or technologies (e.g., remote sensing, chemtax) are scarce and have appeared only recently. The word "conservation" does not appear in these analyses, paralleling the results of Lawler et al. (2006), who reported a low frequency of conservation-oriented studies in aquatic ecosystems.

The number of publications increased significantly between 1991 and 2005. During this period, changes in the approach of phytoplankton studies were evidenced in the literature. We consider that phytoplankton studies have a dynamic behavior, with interest shifting among subjects, such as the present focus on genetics, evolution and ecology. However, some subjects (keywords) were infrequent, evidenced by few studies in those areas, and therefore there are gaps in phytoplankton studies.

It is encouraging that phytoplankton researchers are widening their focus on questions of broad scientific interest in recent years. However, descriptive studies are still frequent. Studies on freshwater ecosystems are much less frequent than are those on marine ecosystems, despite the importance of freshwater for life. Scientometric analyses, as performed here, may be important to evaluate the growth of a field of expertise, and also to identify imbalances, which could be resolved at different levels (e.g., creation of specific journals, changes in editorial priorities and governmental investments for the formation of human resources in a given area with few specialists).

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