Trends and Biases in Global Climate Change Literature

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Abstract

The purpose of this study is to conduct a scientometric analysis of the global climate change (GCC) literature to identify the patterns, trends and biases in this research field. Data were obtained using the Thomson ISI database. A total of 5,444 articles on GCC were recorded, showing a temporal increase in the number of articles ($r = 0.84$; $P < 0.0001$). Most the articles look at the impact of climate change on geophysical variables, humans and vegetation. Few studies look at fungi, amphibians or reptiles ($H = 24.6$; $P < 0.0001$, $N = 27$). Principal component analysis revealed a temporal difference in the keywords associated with each article. In the first years we observed that the most frequent keywords indicated worry about the main causes of global climate change, but this shifted in more recent years towards keywords indicating concern with the effects of climate change on biodiversity. We argue that this scientometric study can help guide future climate change research and contribute to our understanding of several poorly studied areas.

Key words: Scientometric, Temporal Trend, Climate, Niche Model.

Introduction

It is widely recognized that the problem of Global Climate Change (GCC hereafter) has occupied, in recent years, a central position in scientific literature and public understanding (including newspapers and television) (Parmesan 2006). Scientific understanding of GCC contributed to the debate among environmentalists and political groups concerned with economic growth (Gleick *et al.* 2010; Dessler & Parson 2010). Moreover, the topic of global climate change has been included in the agendas of political institutions of many countries (Velders *et al.* 2007; Cohen *et al.* 2009). In many ways, the debate about the impacts of GCC has affected political and economic actions at broad scales (for example, the United Nations Framework Convention on Climate Change – Kyoto Protocol or United Nations Conference on Sustainable Development – Rio +20).

Questions about the real impacts of GCC on biodiversity and some aspects of human security have been the main focus of the scientific community in recent years (Karl & Trenberth 2003; Gleick *et al.* 2010). For example, several studies highlight the impact of global climate change on food security (e.g., Lobel *et al.* 2008), economic use of species (e.g., Nabout *et al.* 2011), conservation planning (Garcia & Araújo 2010), spread of diseases (e.g., Lafferty 2009), invasive species (e.g., Bradley *et al.* 2010) and economic parameters (e.g., Torres *et al.* 2012). However, the large body of literature on this topic makes difficult to achieve a general and global view of results, trends and biases in the research fields involving climate change (Stanhill 2001).

The quantitative analysis of research literature has led to a new technique called “bibliometric” or “scientometric” review, which contributes to the understanding of the state of the art within a scientific field (Hood & Wilson 2001). In this context, understanding the state of the art of the publications dealing with the impacts of GCC is essential to formulate future research strategies (Stanhill

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2001; Li *et al.* 2011; Siqueira *et al.* 2009). The purpose of this study was to analyze the literature on GCC to identify the patterns, trends and biases in this area of research. More specifically, we assessed i) the number of papers that have been published about GCC across the years, and if there temporal trends in this research field; ii) the scientific journals, the geographical scale (local, regional or global), the environment (atmospheric, aquatic, marine or terrestrial), geophysical variable and/or taxonomic groups that were studied and iii) the temporal variability of keywords. Our scientometric analyses of GCC differs from previous ones (e.g. Li *et al.* 2011; Siqueira *et al.* 2009) because here we evaluated multiple levels and components (i.e., socio-economic, biodiversity, geophysics) and performed an exhaustive investigation of all papers about GCC found in the search (see details in method). Hopefully, this type of review can help researchers to manage and prioritize the types of projects that need to be pursued to fill the gaps in GCC research.

Methods

The literature used in this study was obtained from Thomson ISI (www.isiknowledge.com) online database. The analysis was based on papers published in all time periods available in this database until December 2011. We used as keywords in titles the words: "Global change*" OR "Global climate* change*" OR "Global biologic* change*" OR "Global Warming" OR "Global Weather Change".

For each paper, we identified the i) the year of publication, ii) the journal of publication, iii) the geographical scale (local, regional or global), iv) the approach employed (theoretical, observational or experimental), v) the environment: atmospheric, aquatic (continental waters), marine (ocean and coastal waters) or terrestrial, vi) the taxonomic group or geophysical variable studied and, vii) the keywords.

Considering the "topic iv", it is important to note that "experimental" papers included the studies where the authors developed some experiments in laboratory or field stations, including microcosms and mesocosms. "Observational" papers incorporated articles where some empirical data were analyzed and described, including secondary data, while "theoretical" papers included mainly review articles. Taking into account the "topic vi", papers were grouped into 11 categories based on the taxonomic group or geophysical variable studied: (i) "Geophysics" parameters included the variables associated with global climate change such as carbon and nitrogen, (ii) "Humans" variables included the studies that investigated the effect of climate change on food security, human health and vectors of disease, (iii) "Vegetation", "Invertebrates", "Microorganisms" (photosynthetic or non-photosynthetic eukaryotes and prokaryotes and viruses), and (iv) "Bird", "Fish", "Amphibian", "Mammal" (except humans), "Reptile" and "Fungi".

To evaluate trends in the number of papers, it was necessary to account for the general increase in the number of papers

for the years under consideration (Peters 1991). To achieve this goal, the number of papers published on GCC each year was divided by the total number of articles found in the database for that year.

We initially applied a Pearson correlation to evaluate the temporal trend of number of paper by geophysical or taxonomic group. We also applied a non-parametric test (Kruskal-Wallis) to compare the number of papers that studied the different approaches, environments and taxonomic groups. If a difference ($P < 0.05$) was detected, we also applied a post-hoc test (Mann-Whitney) (Zar 2010).

A Principal Component Analysis (PCA) based on the correlation matrix among 134 keyword frequencies (see below) and followed by a Varimax rotation of axes was used to verify the temporal trend in keywords (e.g., Carneiro *et al.* 2008; Nobis & Wohlgemuth 2004). The main use of PCA is to reduce the dimensionality of multivariate data (Legendre & Legendre 2004), considering that new variables (principal components) are created as linear combinations of the original variables (i.e., keyword frequency). The components allow us to plot the observations (i.e. years) in a new reduced space and to see how the keywords are related along the years. For this paper, synonymous keywords were grouped (leaving a total of 134 variables for PCA). Counting keywords can be affected by the total number of papers published per year, and it is worth noting that more papers have been published in recent years. To take this into account, we divided the number of papers with a specific keyword by the number of papers that occurred in that same year, which gives the keyword frequency. The keywords used in the Thomson-ISI search were removed from the PCA because of their high frequency and to avoid circularity.

Results

Between 1971 (when the first identified paper on GCC was published) and 2011, our search allowed recording a total of 5,444 papers on indexed journals. The number of GCC papers shows a significant temporal increase ($r = 0.67$, $P < 0.0001$, $N = 36$) with a peak in the 1990 (Figure 1a; see the patterns in raw data - without standardized the number of papers - in the Figure S1 of Additional Supporting Information, available at www.abeco.org.br).

In total, 1,115 journals published articles about GCC. Despite the large number of journals in which articles were published, 30 journals comprised 34% of the publications (Figure S2 in the Additional Supporting Information). The journals publishing more papers on the subject were *Nature* (150 articles), *Science* (128 papers), *Climatic Change* (121 papers) and *Chemical & Engineering News* (99 papers). Most studies were at global scale (1350 papers, or 45%), followed by regional (1127 papers or 37%) and local scale (513 papers or 17%).

Most of the articles were theoretical (3,314 papers, or 67% of the total), followed by observational (1,427 papers,

or 28%) and experimental (209 papers, or 4%) ($H = 26$; $P < 0.0001$, $N = 35$). The Mann-Whitney test showed a significant difference between these three approaches. Research about GCC was performed mainly in terrestrial systems (52%), followed by atmospheric systems (26%). Only 9% of the papers addressed aquatic systems. We observed a significant difference between the different types of systems ($H = 17.3$, $P < 0.001$, $N = 36$). However, there was no difference between terrestrial and atmospheric systems (Mann-Whitney; $U = 0.95$, $P = 0.15$, $N = 36$).

There was also a difference among the taxonomic groups and geophysical variables studied ($H = 24.6$; $P < 0.0001$, $N = 27$). Most of the articles looked at the impact of climate change on geophysical variables (44%), humans (21%) and vegetation (19%) (Table 1). However, only “invertebrate”, “microorganism”, “bird”, “mammal”, “reptile” and “amphibian” evidenced significant temporal increases (demonstrated by positive Pearson correlation).

The PCA revealed a temporal change in the keywords related to GCC (but the first two axes of PCA accounted for only 23.8% of the total variance). The keywords taken from the papers published in the 1990s were distinct from the keywords taken from the papers published between 2003 and 2011. Between 1991 and 2000, the most frequent keywords were “biochemistry”, “vegetation” and “forests”, while in recent years the most common keywords were “temperature”, “adaptation”, “niche model”, “biodiversity” and “conservation” (Figure 2) (See also PCA scores in the Additional Supporting Information).

Discussion

Scientific production

The increase in the overall number of papers over the years indicates the interest of the scientific community on GCC (Siqueira *et al.* 2009; Li *et al.* 2011). Moreover, it also reflects an increase in the number of researchers working in this research field (Abt 2007). In fact, scientometric

Table 1. Number of papers and temporal trends of the geophysical variables and taxonomic groups obtained on GCC papers. To analyze the temporal trends we performed a Pearson correlation between number of paper and year of publication (bold value significant; $P < 0.05$). The temporal trend was firstly standardized by dividing the number of papers published each year by the total number of papers found in the entire database for that year.

Variables	Number of papers	Pearson correlation
Geophysical	1544	-0.04
Humans	747	-0.27
Vegetation	690	0.06
Invertebrate	170	0.75
Microooganism	107	0.59
Fish	66	0.11
Bird	62	0.55
Mammal	61	0.67
Reptile	16	0.66
Amphibian	12	0.43
Fungi	1	0.33

Figure 1. Temporal trends in the number of papers in the Thomson ISI database about global climate change. The values recorded were previously standardized (see details in Material and Methods).

Figure 2. Scores from varimax rotated Principal Component Analysis (PCA) using the keyword frequencies from articles about GCC. The listed keywords were those that most contributed to the composition of the first two axes. These components evidenced how the keywords are related with the years (dots).

studies have shown a continuous increase in scientific publications over the years in different areas of research (Hood & Wilson 2001), even considering biological research, such as studies of phytoplankton (Carneiro *et al.* 2008), macrophytes (Padial *et al.* 2008), biodiversity (Bini *et al.* 2005; Caliman *et al.* 2010) and genetic studies with use of flow cytometry (Quixabeira *et al.* 2010).

The increase on GCC literature can be explained by increases in investments and scientific grants as well. Institutions have also been encouraged to support and involve the scientists to work on this field, considering the concern about the future of natural resources (e.g., Pereira *et al.* 2010) and human security (e.g., Berrang-Ford *et al.* 2011). Besides, this involvement can ensure policy impact or fashion science (Crane 1969). However, the studies on GCC experienced a decrease in number of papers after 1994. This decrease can be explained by skepticism or uncertainties about the predictions of climatic changes (Peck & Teisberg 1993). In contrast, since the year 2000, the increase in the number of publications is most likely a response to empirical tests of climatic changes and the development of new technologies (i.e., computer programs) to simulate and predict new conditions under different climate scenarios (IPCC 2007).

In the more recent years, the scientific production on GCC had a significant growth (despite another reduction after 2008). The great visibility of these papers can be also demonstrated by the number of publications in high-impact journals, such as *Science* and *Nature*. Indeed, the variety of journals that published on GCC supports its importance to

other scientific fields (not only Ecology), such as Politics, Agriculture and Human Health.

Publications trends and biases

Our scientometric analysis showed that most papers about GCC are theoretical and at global geographical scale. In fact, in the last years, the studies applying niche modeling techniques and remote sensing, in a global view, have been an important contribution to understanding the potential effects of GCC (Kerr *et al.* 2007). On the other hand, it is important to note that the first articles were observational and local, searching for global warming evidence (i.e., Kopec 1971). Even considering that experimental and observational studies with a focus on GCC are often conducted at the local/regional scale (Kerr *et al.* 2007), some authors affirm that, for GCC, local, regional and global processes are related (Grimm *et al.* 2008). Furthermore, in our analysis, the proportions of global, regional and local studies are quite similar (for example, in 2011, 35% of the total papers were global, while 38% were regional and 25% were local).

We found a bias towards terrestrial and atmospheric studies. Indeed, the high number of scientific publications studying terrestrial environments are also discussed in others studies (Caliman *et al.* 2010; Siqueira *et al.* 2009). Atmospheric studies mainly focused on the causes of climate change and not on its impacts (contrary to what we see for terrestrial, aquatic or marine research; e.g. Jan Stevenson & Sabater 2010). Despite evidence of the significant impacts of climate change on biodiversity (Sala *et al.* 2000), it is

clear that there is only a few research focusing on aquatic ecosystems, particularly with respect to biodiversity (e.g., Hoegh-Guldberg *et al.* 2007) or physical and chemical processes (i.e., acid waters; e.g., Doney *et al.* 2009). Even considering that few studies were about fungi, fish, bird, mammal, reptile and amphibian, we can observe that the researches focusing in these taxonomic groups are increasing over the years (see Table 1). This increase may be an indicative of the interest of scientific community to investigate the effects of GCC on biodiversity on more general grounds (see discussion below) (e.g., Sala *et al.* 2000; Parmesan 2006; Hoegh-Guldberg *et al.* 2007; Pereira *et al.* 2010; Collevatti *et al.* 2011).

The multivariate analysis indicated a temporal trend in the keywords found in each article. This temporal change of keywords has also been showed in others scientometric studies (Carneiro *et al.* 2008; Nobis & Wohlgemuth 2004), revealing the dynamics of scientific researches (e.g. Ortega *et al.* 2011; Carneiro *et al.* 2008). Considering the GCC literature, in the first years the most frequent keywords indicated the main causes of global climate change and, indeed, at that time most papers were discussing the evidences of human activities in the climate changes (Grimm *et al.* 2008; Gleick *et al.* 2010). In more recent years, the most frequent keywords indicated concern about the effects of climate change on biodiversity, including the geographical distribution of species and effects on their physiology and phenology. In this context, we can highlight the keyword “niche models”. The niche models, or species distribution models, are generated based on an empirical relationship between points of occurrence and environmental data (i.e., correlative models). This association allows mapping suitable regions of the species and, assuming that environmental niches were correctly estimated and will not shift, it is possible to predict how suitable areas will change after GCMs (Peterson *et al.* 2011). Therefore, the wide availability of species occurrence data, environmental data with different resolutions and computational tools have contributed to the widespread use of niche models. In fact, some papers highlights the importance of niche models in macroecological studies (Kerr *et al.* 2007), including those defining guidelines for research in particular regions (i.e., the Neotropical regions – see Kamino *et al.* 2012), discussing the implications for establishing conservation strategies (Araújo *et al.* 2011), aspects of biological invasions (Bradley *et al.* 2010) and the spread of diseases (Lafferty 2009).

In summary, our scientometric analysis showed that the growing number of articles about GCC is indicative of the significant interest of the scientific community and the general public on this research field. Although the influence of human activities for the GCC were previously understood (Grimm *et al.* 2008), there are uncertainties in projections of future climate changes (Deser *et al.* 2012). Several recent papers have evaluated the impacts of GCC, but it is important to highlight that there are still gaps in

knowledge of biodiversity (e.g., Linnean and wallacean shortfall; Bini *et al.* 2006) and about socio-economic issues that may be aggravated by global climate change (Torres *et al.* 2012).

Concluding remarks

We hope that this scientometric study will be useful to guide future research on climate change. Furthermore, our analysis indicated some gaps that need more attention, including : i) reducing uncertainty in climate and niche models (e.g. Deser *et al.* 2012; Pereira *et al.* 2010); ii) direct the taxonomic and ecological studies towards fields that are still poorly understood (i.e., aquatic systems and taxonomic groups, like, fungi, fish, bird, mammal, reptile and amphibian); iii) establish strategies for future conservation and analysis of the viability and efficiency of current conservation areas (e.g. Araújo *et al.* 2011), iv) indicate socio-climatic hotspots regions (e.g. Torres *et al.* 2012), and; iv) reduce human impacts that promote the GCC (IPCC 2007).

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