

“The Statistical Analysis of Compositional Data” by John Aitchison (1986): A Bibliometric Overview

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Carolina Navarro-Lopez¹, Salvador Linares-Mustaros²,
and Carles Mulet-Forteza¹ 

Abstract

This paper presents a complete bibliometric analysis of Aitchison’s 1986 seminal book “The Statistical Analysis of Compositional Data.” We have set three objectives. The first is to analyze the academic structure of Aitchison’s 1986 book. Results reveals that although the work has received citations uninterruptedly since its publication, the number of these has increased very significantly over the past 4 years. This is due to the significant increase in the number of publications on the theme of “Compositional Data Analysis” in fields related to “geoscience” over the last few years. The second objective is to determine which main journals Aitchison’s book has been cited in. The results highlight that the main journals are indexed under the following WoS category: “Geosciences, Multidisciplinary” and “Ecology.” Of these, “Mathematical Geosciences” and “Computers, Geosciences” stand out. The third objective is to determine the main topics analyzed in the principal papers published by authors citing Aitchison’s book. Our results show that the keywords in the main papers to have cited Aitchison’s 1986 book originate from the geoscience field, since many of them are related to concepts directly linked to this field and refer to terms related to “biodiversity,” “geodiversity,” “geoheritage,” and “georesources.” Lastly, the analysis shows how the CoDA methodology is now in a phase of exponential growth, expanding to other fields. This implies that geoscience is becoming consolidated in the scientific literature as one of the branches of modern science that has given rise to a new mathematical theory of great impact.

Keywords

John Aitchison, bibliometrics, citation structure, journal ranking, hot topics, VOSviewer

Introduction

Compositional data are positive data that carry only relative information and in the most common situations they sum up to a constant (Filzmoser & Hron, 2009). They are frequent in geology and chemistry, for example, since total amounts are trivially related to the size of the soil or chemical sample, so that only relative importance is of interest. Using standard statistical techniques with compositional data can produce inconsistent results due to a set of undesirable problems, including the problem of spurious correlation of ratios (Pearson, 1897), dependency on scale, appearance of outliers and asymmetry, out-of-range forecasts (negative or above the constant sum) or inconsistency of the sub-composition (Aitchison, 1986). The lack of a solution to the problems inherent in compositional data led Miesch (1969) to state that the problem of the constant sum was one of the most important and most difficult problems encountered when analyzing and interpreting geochemical data. In 1986, Aitchison presented a book entitled *The Statistical Analysis of*

Compositional Data (Aitchison, 1986), which detailed a whole set of techniques based on compositional data, the results obtained being consistent when based on solid mathematical foundations (e.g., Daunis-i-Estadella et al., 2011; Graffelman et al., 2018; Thomas & Aitchison, 2005; Tolosana-Delgado et al., 2019; Verma et al., 2006). At present, despite the proliferation of other manuals analyzing the foundations postulated in Aitchison’s work (see, e.g., Filzmoser et al., 2018; Greenacre, 2018; Pawlowsky-Glahn et al., 2015; Van Den Boogaart & Tolosana-Delgado, 2013), said foundations are still valid, and provide a solid basis for

¹University of the Balearic Islands, Ctra. Valldemossa, Palma de Mallorca, Spain

²University of Girona, Catalunya, Spain

Corresponding Author:

Carles Mulet-Forteza, Department of Business Administration, University of the Balearic Islands, Edificio Jovellanos, Ctra. Valldemossa, Km 7, 5, Mallorca 07122, Spain.

Email: carles.mulet@uib.es



validating results, which is why Aitchison's (1986) book is universally considered to be both essential and seminal.

Consolidation of the statistical methods compiled in Aitchison's book for the field of geoscience (Chakraborty et al., 2020; Hron et al., 2021; Mikšová et al., 2020; Pawlowsky-Glahn & Egozcue, 2020; Pospiech et al., 2021) and the current expansion of these techniques to new scientific fields, such as chemistry, biology, medicine, psychology, education, communication, demography, geography, and other social science disciplines (Batista-Foguet et al., 2015; Belles-Sampera et al., 2016; Blasco-Duatis et al., 2018; Carreras Simó & Coenders, 2020; Carreras-Simó & Coenders, 2021; Coenders & Ferrer-Rosell, 2020; Ezbakhe & Pérez Foguet, 2020; Ferrer-Rosell et al., 2015; Kogovšek et al., 2013; Linares-Mustarós et al., 2018; Muller et al., 2018; Ortells et al., 2016; Rodrigues et al., 2011; Sanz-Sanz et al., 2018) explains the exponential growth in the number of citations of the book, while at the same time confirming the claim that geoscience is establishing itself in the scientific literature as a branch of modern science that has adopted a new mathematical theory of great impact.

This paper presents a bibliometric analysis of the aforementioned book, "The Statistical Analysis of Compositional Data," with the aim of studying the relationships existing between this seminal publication in the field of geoscience and modern science. In the first part of this analysis, we present an overview of the academic structure of publications that have cited Aitchison's work, while in the second part we present a study of the main journals and research topics to have been addressed in articles by authors who have cited it, with the aim of providing an answer to the following research questions (RQ):

RQ1: What is the academic structure of Aitchison's 1986 book?

RQ2: In which main journals has Aitchison's book been cited?

RQ3: What main topics are analyzed in the principal papers published by authors citing Aitchison's book?

This paper makes several important contributions. First, the bibliometric analysis contributes to the growing literature of articles summarizing the achievements and trends in research fields over long periods of time. Identifying the citation structure, origins and evolution of the main topics addressed, as well as the main sources used by authors citing Aitchison's research, will help us to determine intellectual connections in academic fields that use CoDA in their field of research (Koseoglu et al., 2019; Köseoglu et al., 2019; Shafique, 2013). In respect of this, mapping intellectual connections aids the creation of new theories and the development of existing theories, providing a glimpse of future directions that scientific research may take (Köseoglu et al., 2021). Thus, conducting an academic analysis of such developments can help researchers identify the potential impacts

theories may have on society. In addition, these processes also provide valuable information for both academics and practitioners (Torraco, 2016), by providing them with a study that helps to have an outline of the status quo of CoDA, especially for those who are not very familiar with CoDA but are interested in it (Jiang & Fan, 2022). Second, the bibliometric study provides a comprehensive picture of specific research fields and allows researchers to focus on unique areas to add new results and knowledge to the literature (Ghorbani et al., 2021). Then, this paper contributes to a better understanding of the current status, development and future lines of research in the field, supporting researchers and other experts in identifying research areas, and selecting the most appropriate journals to publish their own findings (Sajovic & Boh Podgornik, 2022). Thirdly, the research conducted delves into intellectual connections across a large body of research covering various fields related to geoscience. Fourthly, the work encompasses a long time horizon, allowing researchers to obtain a complete picture of the field addressed, as well as its evolution. Fifthly, the document citation networks are analyzed and reference citation bursts detected in order to provide information on research topics and assess trends over time from different perspectives, which will be of great use for future research; in other words, this study helps to provide an orchestration of knowledge in the field. And finally, the present work focuses on documents that have passed the strict refereeing process, meaning that the results obtained are highly reliable.

Bibliometrics and Social Network Analysis

Bibliometrics entails the quantification of academic production based on certain classifications that project indirect indications on its perception (Huang et al., 2019). Multiple definitions of the term exist, although the modern version is usually attributed to Alan Pritchard. Pritchard (1969) defined bibliometrics as "the application of mathematical and statistical methods to books and other means of communication." More recently, other authors have provided further definitions, however. For example, Zupic and Čater (2015) posited that bibliometrics constitutes a tool for evaluating the evolution of research areas based on social, intellectual, and conceptual structures. Therefore, we can assume bibliometrics is a discipline that aims to evaluate and map scientific progress through classification using statistical techniques (Diodato, 1994; Jappe, 2020; McBurney & Novak, 2002).

As for methodology, bibliometrics focuses exclusively on measuring publications. However, the term "publication" is relatively ambiguous, since, among other documents, it may include book chapters, journal articles, and proceedings in conference volumes. Therefore, before starting a bibliometric research project, it is important to clearly define what is being measured and what type of publication should serve as the basis for the bibliometric analyses to be carried out, since

bibliometrics should provide information about all the key components of a research project.

Bibliometric analysis is a fundamental statistical instrument for analyzing the state of knowledge in a given scientific area, given that it measures the number of documents published and the number of citations received for those documents. In addition, bibliometrics allows the results of the analysis to be mapped through spatial visualization of the findings with respect to the structure and dynamics of scientific fields (Boyack & Klavans, 2014; Zyoud & Fuchs-Hanusch, 2020). Its main objective is to create a representation of the network structure of a research field that highlights the connections between the main journals, publications, etc. and the topics and other key features of the analyzed field (Bruns et al., 2020; Gumpfenberger et al., 2012; Vogel, 2014).

A further aim of bibliometrics is to evaluate the quality of research (Bornmann & Leydesdorff, 2014; Segura-Robles et al., 2020). At present, two main methods are used to this end: a qualitative (by peers) and a quantitative review (bibliometrics) (Feng, 2020). In this respect, the former includes particular, non-quantifiable evaluations made by experienced experts, while the latter considers a publication to be more relevant the more citations it receives.

Today, new alternatives to the classic “citation” have emerged to assess the importance of a scientific document, such as libmetrics and altmetrics. Libmetrics establishes a connection between the importance of a scientific article or book and its availability in a library by measuring how often it is acquired or borrowed from the library, for example. Altmetrics generates new knowledge by combining all of the data available online and applying big data technologies. This allows for bibliometric approaches to focus on correlations rather than causalities, since it should permit the analysis of new connections that have not previously been weighted or questioned. These alternative bibliometric methods are based on free online content, most of which is taken from social networks, which complement the data offered by bibliometrics based on conventional databases, such as the Web of Science (WoS) or Scopus.

Literature Review

Analyzing an academic discipline or scientific field is common practice nowadays, since it helps researchers develop new theories and journal editors foresee research trends (Gatrell & Breslin, 2017; Post et al., 2020; Torraco, 2016; Webster & Watson, 2002). There is therefore a growing interest in and demand for investigations into the intellectual structure of research areas or scientific fields in order to highlight progress in this regard (Kunisch et al., 2018; Torma & Thøgersen, 2021).

Bibliometrics, the main objective of which is to measure scientific output (Wang et al., 2019), emerged in the early 20th century, when psychologists began to collect statistics on publications related to their field of research (Godin,

2006). However, it was the exponential growth in academic publications in the 1950s that first saw American chemist Eugene Garfield begin to evaluate and carry out systematic counts of publications based on the literature used and cited.

One application of bibliometric methods is their use as a tool to evaluate any research that has been conducted (Bornmann & Leydesdorff, 2014; Karakus et al., 2021; Moral-Muñoz et al., 2020). This is the easy part of bibliometrics, since it provides direct information and does not require assumptions for its production. Trying to assess the quality and importance of published papers is a much more complex and less obvious task, however. Researchers have essentially used two methods to carry out this type of analysis of an academic field. The first comprises a qualitative evaluation by researchers (Lopes & Martins, 2021; Zupic & Čater, 2015). This method has several drawbacks, among which can be highlighted its subjectivity and a lack of transparency, which negatively impacts on its reliability and validity (Cook et al., 1997; Szomszor et al., 2021). The second is to conduct bibliometric analyses, and more specifically, analyzing the co-citation of documents (Lopes & Martins, 2021; Zupic & Čater, 2015), which entails identifying the intellectual structure of a scientific field by means of mathematical and statistical methods (Culnan, 1986; Hou et al., 2018). This second approach is the one most used by researchers (Hota et al., 2020; Lampe et al., 2019; Zhao et al., 2018), since it allows the tracking of practically all aspects of scientific collaboration networks (Vasilyeva et al., 2021; Ye et al., 2013).

We can therefore state that bibliometrics is a discipline that aims to assess and map the progress made in scientific fields through the classification of data. This entails, among other methods, the use of statistical techniques to analyze research performance by individuals, institutions, countries, mapping the structure of the analyzed field, etc. (Karakus et al., 2021).

The discipline has since evolved and is now used to evaluate the impact of publications, journals, authors and institutions in order to determine patterns of influence (Biemans et al., 2010; Clark et al., 2014; Post et al., 2020; Sarin et al., 2018).

Bibliometric documents have expanded into several fields (Butt et al., 2021), including accounting (Merigó & Yang, 2017), computer science (Chen et al., 2020; Garousi & Fernandes, 2017), energy (Liu et al., 2020), ecology (Jankó et al., 2017; Zhang et al., 2017), health care sciences services (He, Fang, Chen, et al., 2020; He, Fang, Wang, et al., 2020), hospitality (García-Lillo et al., 2016), medicine (Fan et al., 2020), tourism (Mulet-Forteza et al., 2019), and social media (Leung et al., 2017).

There are also bibliometric works that, rather than focusing on a specific field, analyze the publications of a particular country, institution or author. Thus, for example, Salisu and Salami (2020) analyzed publications by Nigerian authors between 1901 and 2016, Ahmad et al. (2020) analyzed the performance of publications by the University of the Punjab, and Haustein and Peters (2020) analyzed the publications made by the researcher Judit Bar-Ilan. These are just a few

examples of these types of bibliometric analyses. To the best of our knowledge, however, no bibliometric work has yet been carried out that focuses on one specific source in the bibliometric literature, making this paper a starting point for future bibliometric studies.

The results of bibliometric studies provide very useful information for policymakers and academic decision-makers in universities, research centers and governments, as they are considered reliable and relevant sources of results, and are often used to justify decisions on research policies, job offers and promotions, as well as to direct and support research projects (Bornmann & Leydesdorff, 2014; Gatrell & Breslin, 2017; Gläser & Laudel, 2015; Post et al., 2020). In addition, both public and private research funding agencies often ask researchers to either provide certain indications of quality to fund their research or to demonstrate that the research to be carried out has the potential to impact society (Bornmann, 2014; Brueton et al., 2014; Smits & Champagne, 2020). By way of example, in the United Kingdom bibliometrics has been considered for assessing the quality of research output within the country's framework for research excellence. Finally, we would like to point out that bibliometrics can also help journal editors evaluate past publications, design new policies and make future editorial decisions.

Methodology

The statistical data used in this paper were compiled from the WoS database in November 2019. According to Merigó et al. (2015), the WoS comprises information from over 15,000 sources and 50,000,000 documents ranked according to over 250 categories and 150 research areas. It is widely considered to be the most influential in the world.

The bibliometric data used in this work were obtained as follows. First, the "Cited Reference Search" option in the WoS database was used. Subsequently, the "Cited work" option was selected and the following text entered: "The Statistical Analysis of Compositional Data." The search yielded a total of 69 records, which were reduced to 58 once the records that do not make specific reference to the paper "The Statistical Analysis of Compositional Data by Aitchison (1986)" were eliminated. The 11 deleted records, seven primarily referred to another work by Aitchison (1982), in which he first introduced the concept of Compositional Data Analysis, although in a much shorter form and with less impact than the work published in 1986. The remaining four deleted records referred to another work by John Aitchison entitled "Logratios and natural laws in compositional data analysis," published in the journal *Mathematical Geology* in 1999. Once these 11 records had been eliminated, the remaining 58 were selected, which do make explicit reference to the paper "The Statistical Analysis of Compositional Data by Aitchison (1986)." These 58 records returned a total of 2,636 papers that had cited Aitchison's 1986 book. Finally, the number of documents was reduced to 2,426 after limiting the search to

only those that had passed a strict arbitration process, including papers, reviews and letters (Merigó et al., 2019).

In the following step, the option "Cited work" was selected and the following text entered: "The Statistical Analysis of Compositional Data." In this paper, we have considered a wide range of bibliometric methods to represent the bibliographical data analyzed. First, we considered the number of publications and citations, which are the most popular methods according to Ding et al. (2014). Whereas the number of citations generally measures influence, productivity is measured by the number of documents (Svensson, 2010). Another indicator we used here refers to the most influential keywords (Mulet-Forteza et al., 2019).

The VOSviewer Software was used to map the consulted bibliographic data for co-occurrence of author keywords and co-citations (Van Eck & Waltman, 2010, 2014). Such maps allow several aspects of a scientific field to be monitored (Noyons et al., 1999; Su et al., 2019), providing a clearer view of the results obtained (Merigó et al., 2016). Keyword co-occurrence refers to the most common keywords used to develop a research field or a scientific document (Callon et al., 1983; Ding et al., 2001; Huang et al., 2019; McCain, 1986, 1991; Zhang et al., 2019), while co-citation assumes that there is some kind of association between two documents jointly cited by a different third one (Boyack & Klavans, 2014; Hoque et al., 2021; McCain, 1990; Ramos-Rodríguez & Ruíz-Navarro, 2004; Small, 1973).

Before we could perform the graphical analysis with the VOSviewer Software, we had to clean up the data collected from the WoS. In order to carry out the co-citation analysis of journals, the names of the journals with different designations had to be unified. By way of example, data appearing under the names "j roy stat soc b" and "j roy stat soc b m," those appearing under the names "soil sci" and "soil sci s," or those appearing under the names "behav ecol" and "behav ecol s" were unified under the same name. Journals that changed their names during the period were also unified, such as "*Mathematical Geology*," which changed its name to "*Mathematical Geosciences*" in 2008.

The same had to be done in the co-occurrence of author keyword analysis. In this case, keywords that appeared simultaneously in the singular and plural, such as "stream sediment" and "stream sediments" or "ternary diagram" and "ternary diagrams," keywords that appear with or without a hyphen, such as "particle size distribution" and "particle-size distribution" or "isometric log-ratio transformation" and "isometric logratio transformation," and keywords that are written differently in American and British English, such as "foraging behavior" and "foraging behavior," had to be cleaned.

The combination of methods used in this paper allowed us to collect data using "full counting" and "fractional counting" methods. With the former, a publication co-authored by several researchers is assigned to each researcher with a full weight of one, while the "fractional counting" method (VOSviewer software) divides the authorship of the

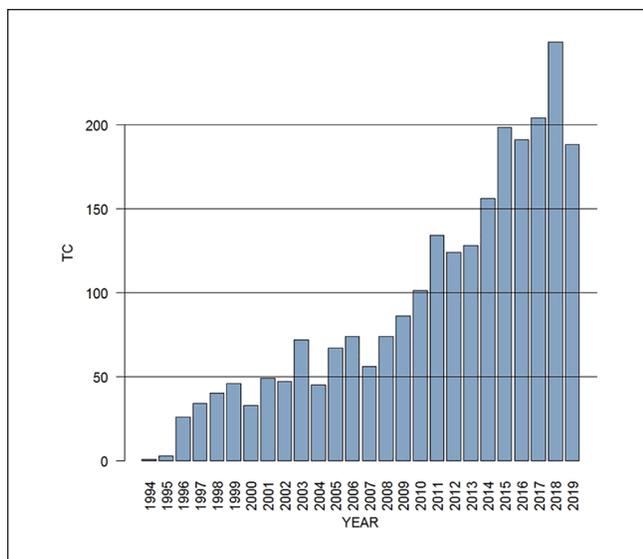


Figure 1. Annual number of citations received by Aitchison's 1986 book.

Source. Authors, WoS database, 1986 through November 2019.

Note. TC = total citations.

document among the number of authors (Mulet-Forteza et al., 2019). In this regard, it should be borne in mind that developing bibliometric networks is not a trivial process and, depending on how this is done, they can yield very different results, as Perianes-Rodriguez et al. (2016) showed for the case of journal network analysis. These authors argued in favor of the “fractional counting” method for producing bibliometric maps of journals, based on the fact it awards the same influence to each reference cited in a publication.

Thus, they considered it more reasonable to use analyses based on the idea of treating each reference cited in a publication as equally representative, as is the case using the aforementioned “fractional counting” method. Although this justification seems plausible to us, as far as we are aware, the reality is that researchers have traditionally preferred to use the “full counting” method in their bibliometric map analysis. That being said, it is not our intention to take a position in favor of one method or the other here, and we therefore provide the results using both methods, which will allow us to compare the results obtained by both systems of data collection.

Bibliometric Study of Aitchison's (1986) Book

We will now address the different research questions posed in our paper.

Academic Structure of Aitchison's (1986) Book

Regarding the first question (RQ1), Figure 1 presents the evolution of citations received by Aitchison's 1986 book.

Table 1. Sections of a documents in which the Aitchison's (1986) book has been cited.

Sections of a document	TP
Introduction	229
Literature review	535
Methodology	688
Results and discussion	305
Conclusion	183
Total	1,940

Source. Authors.

Note. The same document can cite the Aitchison's (1986) book in two or more sections. TP = total papers.

The above figure shows how Aitchison's 1986 book entitled “The statistical analysis of compositional data” has received citations uninterruptedly since 1994. It also shows how different periods can be distinguished for the number of citations received. Thus, between 1994 and 2007, with ups and downs, the average annual number of citations remained at around 42. However, from 2008 onward, the annual number of citations generally increased each year, with notable jumps in 2011 and 2015. This increase in the number of citations received by the book is due, among other aspects, to the significant increase in the number of publications on the theme of “Compositional Data Analysis” in fields related to “geoscience” over the past few years and is likely to continue in the future.

We have delved into the reasons for citing Aitchison's 1986 book. First of all, we downloaded the documents citing this reference. In this regard, we would like to point out that we only had access to 1,529 of the 2,426 references citing Aitchison's 1986 book, which represents 63% of the total. The remaining 897 references could not be analyzed because the databases of the universities of the different authors who have written this document do not have access to all the journals. Even so, we consider that we have analyzed a significant percentage of references that validate the comments made above.

Table 1 shows where Aitchison's 1986 book has been cited in the paper.

Table 1 shows how most of the documents citing Aitchison's 1986 book have used CoDA in their methodologies. Specifically, 35% of the documents analyzed cite Aitchison's 1986 book in the methodology, while 16% do so in the results and discussion section. It is also noteworthy that 28% of the analyzed papers cite it in the literature review, while only 12% and 9% cite it in the introduction and conclusion, respectively.

It is also interesting to carry out a temporal analysis to determine if there is a period of time after which CoDA methodology has started to be used effectively in the papers (Table 2).

Table 2 shows how during the first period analyzed (1994–2000) the citations obtained by Aitchison's 1986 book were

Table 2. Sections of a document in which the Aitchison's (1986) book has been cited. Temporal evolution.

	1994–2000	2001–2010	2011–2019
Introduction	35	55	139
Literature review	28	169	338
Methodology	24	245	419
Results and discussion	18	102	185
Conclusion	16	71	96

Source. Authors.

Note. The same document can cite the Aitchison's (1986) book in two or more sections.

concentrated in the introduction of the documents that cite it. On the other hand, during the period 2001 to 2010 it can be seen how these are distributed, in percentage terms, in a similar way between the literature review, methodology and results, and discussion sections, although the conclusion section is the one which, in percentage terms, has the highest number of citations. Finally, during the period 2011 to 2019 it can be observed, also in percentage terms, how the conclusion section loses weight when citing Aitchison's 1986 book, while the rest of the sections increase their percentage when citing this document. All this shows that, during the last period analyzed, the CoDA is analyzed both from a literature review and from the use of this methodology, which indicates that this technique already enjoys a notable maturity and scientific applicability.

Main Journals Citing Aitchison's (1986) Book

In this section, we will address the second question (RQ2) posed in our paper. Firstly, Table 3 shows the main journals to have most cited Aitchison's (1986) book.

Table 3 shows how most of the documents that have cited Aitchison's (1986) book are published in the *Journal of Geochemical Exploration* and *Mathematical Geosciences*, followed by *Plos One* and *Applied Geochemistry*. Table 3 also shows how the aforementioned journals, together with *Ecology*, *Geochimica et Cosmochimica Acta*, *Journal of Chemical Ecology*, *Chemical Geology*, and *Evolution International Journal of Organic Evolution* are the ones that present the most important strength of connections. In this regard, Figure 2 provides further details of the 500 most important connections occurring between the journals that have cited the book. Table 3 also shows that nine journals on the list are directly related to the field of "geoscience." Specifically, here we are referring to the journals "Mathematical Geosciences," "Computers Geosciences," "Archaeometry," "Journal of Archaeological Science," "Palaeogeography Palaeoclimatology Palaeoecology," "Catena," "Quaternary International," "Quaternary Science Reviews," and "Journal of Quaternary Science."

A map was conducted to reflect the main relationships established between the journals citing the book. In addition, Figure 2 shows the 500 main co-citation links between the principal journals citing the book.

Figure 2 reveals six main clusters, each represented by the same color. Larger clusters include a greater number of journals that have cited Aitchison's book. The distance between two clusters shows the relationship of the clusters in terms of citations, where the clusters located close to each other tend to be related, and vice versa. Within one cluster, the size of a circle represents the number of times a journal has cited the book, larger circles therefore indicating journals that have cited it a greater number of times. The thickness of the curved lines between the clusters represents the number of citations between two journals, whether they belong to the same cluster or not. And finally, the name of each circle (or label) indicates the name of the journal. In this regard, it should be noted that the VOSviewer Software aims to avoid overlapping labels, meaning that the labels are not visible for some journals in Figure 2. The above description also applies to Figures 3 to 6.

The first cluster in Figure 2, in red, comprises 95 journals indexed mainly under the WoS categories "Geochemistry & Geophysics" and "Chemistry." What the research carried out in these categories has in common, among other aspects, is that it usually considers a large number of variables in its analysis. In these cases, the CoDA methodology improves the results obtained from these analyses, as the proportionality features of abundance data are fully taken into account, thereby enhancing their relative multivariate behavior (Buccianti et al., 2015). These particular features made these fields pioneers in applying statistical methods based on CoDA applications, especially by members of the International Association for Mathematical Geosciences. The second cluster, in green, is composed of 94 journals indexed mainly under the WoS categories "Multidisciplinary Sciences" and "Ecology." These fields are similar to those of the first cluster, as they are ones in which studies of different species abound and in which percentages are widely used to infer the ecological preferences found among species. In this case, CoDA allows for the elimination of inconsistencies that occur when determining percentages, which later become false correlations (Guerreiro et al., 2015).

The third cluster, in dark blue, comprises 54 journals indexed mainly under the "Statistics & Probability" and "Mathematics" categories. Logically, these categories form the central axis of Figure 2, CoDA applications being very useful in these fields for eliminating all kinds of mathematical and statistical inconsistencies that can be caused by working with percentages. The fourth cluster, in yellow, is composed of 45 journals indexed basically under the categories "Soil Sciences" and "Environmental Sciences." The fifth cluster, in purple, is composed of 39 journals indexed mainly under the category "Ecology." And finally, the last cluster, in blue, is composed of 33 journals indexed mainly under the category "Zoology." These last three clusters maintain certain characteristics similar to the first two clusters described above, hence their widespread use of CoDA methodology. Therefore, we observe that Aitchison's 1986 book has

Table 3. Main journals that have cited Aitchison's (1986) book.

R	Journal	TP	TLS
1	Journal of Geochemical Exploration	82	1,203.31
2	Mathematical Geosciences	68	2,074.38
3	Plos One	47	745.01
4	Applied Geochemistry	45	659.41
5	Sedimentary Geology	34	617.42
6	Journal of Chemical Ecology	33	841.81
7	Journal of Archaeological Science	27	324.76
7	Science of the Total Environment	27	748.14
9	Computers Geosciences	24	622.50
9	Evolution International Journal of Organic Evolution	24	804.62
11	Journal of Wildlife Management	23	476.07
12	Archaeometry	22	359.94
12	Journal of Applied Statistics	22	146.48
12	Journal of Evolutionary Biology	22	292.49
15	Animal Behaviour	20	657.30
15	Geoderma	20	424.32
17	Geochemistry Exploration Environment Analysis	19	386.76
18	Ore Geology Reviews	18	433.21
19	Palaeogeography Palaeoclimatology Palaeoecology	16	383.33
20	Behavioral Ecology	15	690.50
21	Catena	14	175.55
21	Geochimica et Cosmochimica Acta	14	989.86
21	Wildlife Biology	14	58.41
24	Austrian Journal of Statistics	13	77.45
24	Bird Study	13	117.12
24	Environmental and Ecological Statistics	13	62.65
24	Journal of the American Statistical Association	13	688.75
24	Proceedings of the Royal Society B Biological Sciences	13	654.84
24	Quaternary International	13	291.26
24	Stochastic Environmental Research and Risk Assessment	13	203.98
31	American Naturalist	12	686.88
32	Behavioral Ecology and Sociobiology	11	82.38
32	Environmetrics	11	192.29
32	Insectes Sociaux	11	274.49
32	Journal of Sedimentary Research	11	243.79
32	Quaternary Science Reviews	11	616.78
32	Statistical Modelling	11	84.27
38	Chemical Geology	10	824.22
38	Ecology	10	1,051.88
38	Journal of Insect Physiology	10	265.43
38	Journal of Quaternary Science	10	267.56
38	Oecologia	10	411.18

Source. Authors, WoS database, 1986 through November 2019.

Note. The records of the journals that have changed their name during the analyzed period have been unified under the most recent name of the journal, such as "Mathematical Geology" which changed, in 2008, its name to "Mathematical Geosciences." R=ranking; TP=total papers; TLS=total link strength.

received citations in a multitude of WoS categories, although most are fields related to "geoscience."

Since Figure 2 is very difficult to read, given the large number of journals appearing in it, we have produced a new one, Figure 3, which presents the same results, but mapped with a higher threshold in order to observe the journals that cite the book in greater detail.

In this case, Figure 3 is composed of five main clusters, which are further detailed in the following two figures.

Figure 3 distributes the journals among five clusters, the first consisting of 25 journals, the second 18, the third 11, the fourth ten and the third nine. This more detailed view provided by the previous three figures, especially Figures 4 and 5, allows us to take a closer look at the main

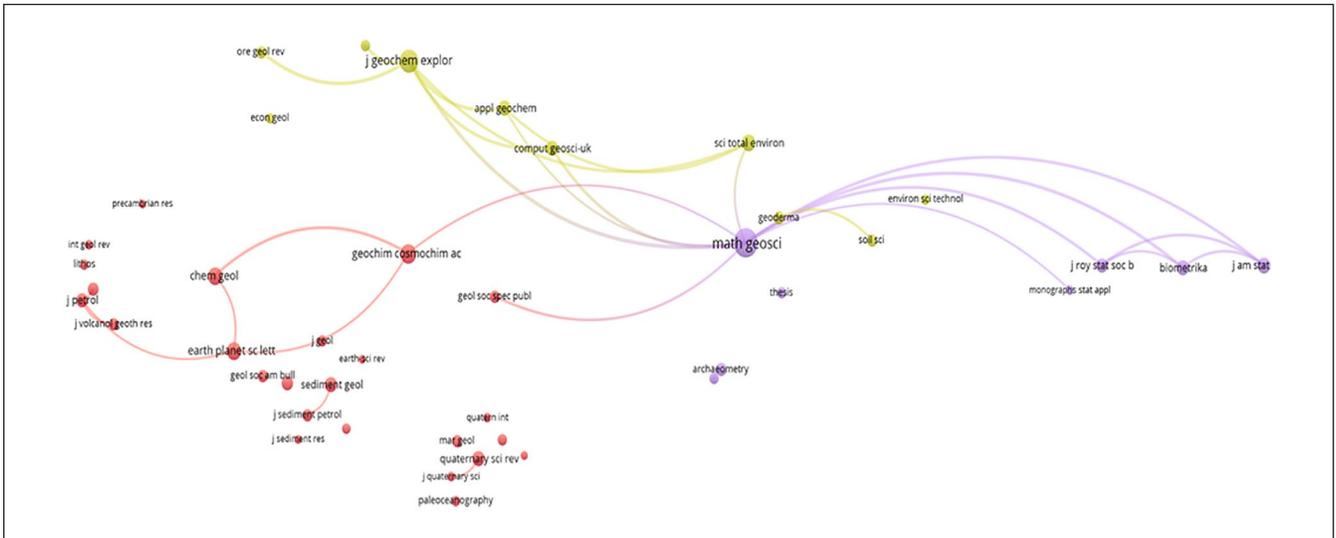


Figure 4. Co-citations of journals that have cited Aitchinson's (1986) book. Red, yellow and lilac clusters. Citation threshold of 250 and showing the 50 most representative co-citation connections.
 Source. Authors, based on WoS database; figure created using VOSviewer Software.

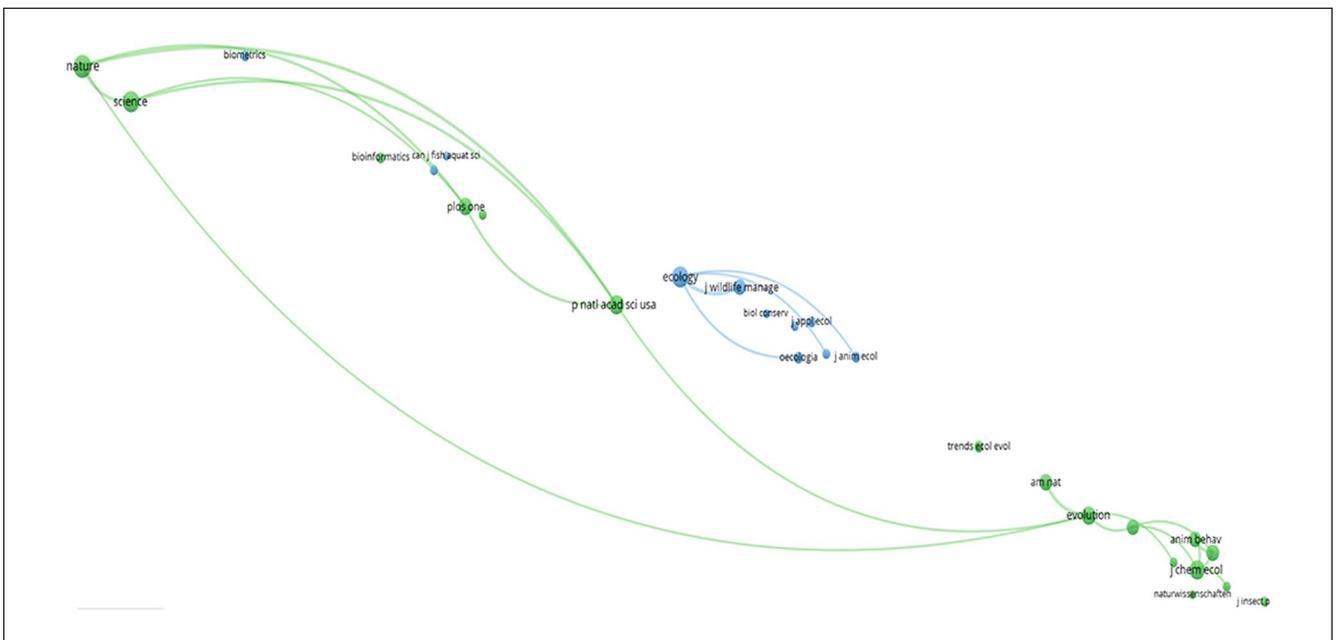


Figure 5. Co-citations of journals that have cited Aitchinson's (1986) book. Green and blue clusters. Citation threshold of 250 and showing the 50 most representative co-citation connections.
 Source. Authors, based on WoS database; figure created using VOSviewer Software.

12 keywords each. In the first cluster, the words “principal component analysis,” “log-ratio” and “simplex” stand out. In Cluster 2, the most important words are “soil,” “microbiome” and “fatty acids.” Clusters 3 and 4 also coincide in terms of number, having 10 keywords each. Cluster 3 ranks third in number of citations, and has “cuticular hydrocarbon,” “sexual selection” and “mate choice” among its most

important keywords. In Cluster 4, which is secondary, the words “multivariate,” “cluster analysis” and “geostatistics” stand out. Although this cluster has a high number of words, the total occurrence is relatively low. As for Cluster 5, it has nine keywords, with the main words being “geochemistry,” “provenance” and “statistics.” Cluster 6 has five keywords; despite the smaller number of words, it becomes a core

Table 4. Main WoS categories that have cited Aitchison's (1986) book.

Categories of Wos	Total journals
Geosciences, Multidisciplinary	23
Ecology	19
Geochemistry & Geophysics	16
Statistics & Probability	9
Environmental Sciences	7
Evolutionary Biology	6
Geography, Physical	6
Geology	6
Multidisciplinary Sciences	6
Zoology	5
Biology	4
Mathematical & Computational Biology	4
Mathematics, Interdisciplinary Applications	4
Mineralogy	4
Entomology	3
Genetics & Heredity	3
Oceanography	3
Palaeontology	3
Soil Sciences	3
Behavioral Sciences	2
Biochemical Research Methods	2
Biochemistry & Molecular Biology	2
Biodiversity Conservation	2
Engineering, Environmental	2
Marine & Freshwater Biology	2
Microbiology	2
Water Resources	2
Automation & Control Systems	1
Biotechnology & Applied Microbiology	1
Chemistry, Analytical	1
Chemistry, Inorganic & Nuclear	1
Computer Science, Artificial Intelligence	1
Computer Science, Interdisciplinary Applications	1
Earth Sciences	1
Energy & Fuels	1
Engineering, Civil	1
Fisheries	1
Instruments & Instrumentation	1
Mining & Mineral processing	1
Physiology	1

Source. Authors based on the WoS database and the VOSviewer Software.

Note. The same journal can be indexed in two or more WoS categories.

network clarifies the distribution of core journals. With regard to the third research question (RQ3), our results show how the keywords in the main papers to have cited the book correspond to the year 2010, coinciding with the period that had the greatest number of citations.

Our study presents several findings that allow us to understand the evolution and advances that are taking place in the CoDA field through an analysis of the citations received by

Table 5. Most common author keywords occurrences in journals that have cited Aitchison's (1986) book.

R	Keyword	Occurrences	Total link strength
1	Compositional Data Analysis	364	174.00
2	Cuticular Hydrocarbon	109	58.00
3	Principal Component Analysis	72	48.00
4	Log-Ratio	70	54.00
5	Geochemistry	67	42.00
6	Simplex	64	48.00
7	Multivariate	57	40.00
8	Provenance	43	25.00
9	Sexual Selection	41	27.00
10	Aitchison Geometry	36	32.00
11	Isometric Log Ratio	32	23.00
12	Cluster Analysis	30	24.00
13	Dirichlet Distribution	29	18.00
14	Origin	28	27.00
15	Age	27	26.00
15	Climate	27	27.00
15	Climate-Change	27	23.00
15	Heavy-Metals	27	27.00
15	Preference	27	24.00
15	Soils	27	27.00
21	China	26	26.00
21	Profiles	26	26.00
23	Geostatistics	25	17.00
23	Habitat Selection	25	15.00
23	Constraints	25	24.00
23	Elements	25	25.00
23	Geostatistics	25	24.00
23	Impact	25	25.00
23	Natural-Selection	25	25.00
23	Statistics	25	23.00
31	Bayesian	24	7.00
31	Soil	24	15.00
31	Bayesian	24	20.00
31	River	24	23.00
31	Sea	24	20.00
31	Social Insect	24	24.00
31	Systems	24	22.00
31	Uncertainty	24	21.00
39	Archaeometry	23	22.00
39	Holocene	23	20.00
39	Missing Values	23	23.00
39	Organic-Matter	23	23.00
39	Predation	23	22.00
39	Xrf	23	22.00

Source. Authors, WoS database, 1986 through November 2019.

Note. R = ranking.

Aitchison's (1986) book, a seminal text in both the field of geoscience and modern science. Firstly, the present work paints a collective picture of the academic structure cited in the book. Secondly, there has been a significant increase in

Our document contributes to the body of relevant literature by systematizing the CoDA literature through the application of VOSviewer software as a visualized analytical tool for bibliometric analysis, providing valuable references for researchers wishing to delve deeper into this area of knowledge. In addition, it reflects CoDA's network maps and information tables in a more comprehensive way, providing a clear orientation to follow the development and then recognize emerging trends. Thirdly, it shows the most influential journals in the discipline, allowing researchers to perform precise journal searches. Finally, it can also guide scholars on how to approach a study involving knowledge mapping with the applicable analytical element of publications (Liu et al., 2022).

This paper has some limitations. The first concerns the database used to carry out the study, that is, the WoS database. For example, the WoS does not include all academic journals, and therefore journals included in other databases, such as those included in the "Emerging sources citation index," have not been considered. Another limitation of this database is that it uses a "full counting" method to collect data. In order to resolve this limitation, our research also incorporated the "fractional counting" method, using the VOSviewer software to detect the co-occurrence of author keywords and co-citations of journals. The third limitation is that not all documents indexed in the WoS were considered: only those subject to a strict process of arbitration. A further limitation is that the results are dynamic and will inevitably change over time. Despite these limitations of our analysis, we consider that this paper can be regarded as an overview of the relationships that occur between Aitchison's book and the geoscience field, as well as modern science, expanding on what is already known about the beginnings of CoDA in journals (Navarro et al., 2021).

This document also provides a starting point for future studies, as our results can be complemented by those obtained in other journals that choose to include journals appearing in the "Emerging sources citation index," as these journals offer less experienced researchers a good opportunity to publish their results. This can also lead to the development of emerging themes and new research trends (Mulet-Forteza et al., 2019) in the field of CoDA through the comparing of results, which, in turn, can lead to the development of new conceptual frameworks (Mulet-Forteza et al., 2021). It may also prove interesting to repeat this work using several databases, and not only the WoS, in order to compare the results obtained from the use of several databases. In addition, such research could highlight some of the limitations of the different databases, some of which are discussed in this paper. Finally, it is also proposed that a literary review be conducted of the main documents that cite Aitchison's (1986) book in the main scientific fields highlighted in this paper, as this will provide very relevant information on how scientific research in CoDA may progress in these fields.

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ORCID iD

Carles Mulet-Forteza  <https://orcid.org/0000-0002-3904-8314>

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