Measuring the scientific impact of FishBase after three decades

by

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Submitted: 27 Jan. 2022
Accepted: 2 Aug. 2022
Editors: F. Teletchea, A. Tilley

Key words
Open access
Citation analysis
Highly cited
Scientometrics
Infometrics

Abstract. – FishBase (www.fishbase.org) is a global, open access information system about fishes that contains published scientific data on topics such as physiology and behaviour, life-history characteristics, and species distributions. Since its creation in the late 1980s, FishBase has evolved into a highly dynamic and versatile tool for scientists and the public. The goal of this study is to quantify the impact of FishBase using citation analysis. We used three sources to count the number of times FishBase has been cited and the ways in which it has been used: Scopus for citations in peer-reviewed journals, Google Scholar for citations by a variety of items on the Internet, and Google Books for citations in books. Our findings reveal that FishBase has received more than 10,000 citations in total from 1994 to 2020 (up to 1,229 annual citations in 2020) across hundreds of peer-reviewed journals in Scopus, while Google Scholar attributed nearly 15,000 total citations to FishBase, with an average of 1,200+ citations per year from 2017 to 2021. Regions that use FishBase the most are in Europe, United States of America, Brazil, and Australia. Some of the top authors citing FishBase come from fields in agricultural (*i.e.*, aquaculture), biological and environmental sciences, and work on fisheries biology and management, as well as parasitology, among others. Most citations of FishBase use it as a source of data for information on diet composition, fish sizes and length-weight relationships, taxonomy, or fish habitat. With a cumulative number of citations in the peer-reviewed literature exceeding 10,000 in Scopus and 15,000 in Google Scholar, FishBase is in the top 1% of all cited items published in this and the previous century.

Résumé. – Mesurer l'impact scientifique de FishBase après trois décennies.

FishBase (www.fishbase.org) est un système d'information mondial en libre accès sur les poissons qui contient des données scientifiques publiées sur des sujets tels que la physiologie et le comportement, les caractéristiques de l'histoire de vie et la répartition des espèces. Depuis sa création à la fin des années 1980, FishBase est devenu un outil très dynamique et polyvalent pour les scientifiques et le public. L'objectif de cette étude est de quantifier l'impact de FishBase en utilisant l'analyse des citations. Nous avons utilisé trois sources pour compter le nombre de fois où FishBase a été cité et les façons dont il a été utilisé : Scopus pour les citations dans les revues évaluées par les pairs, Google Scholar pour les citations par une variété d'articles sur Internet, et Google Books pour les citations dans les livres. Nos résultats révèlent que FishBase a reçu plus de 10 000 citations au total de 1994 à 2020 (jusqu'à 1 229 citations annuelles en 2020) dans des centaines de revues évaluées par des pairs dans Scopus, tandis que Google Scholar a attribué près de 15 000 citations totales à FishBase, avec une moyenne de plus de 1 200 citations par an de 2017 à 2021. Les régions qui utilisent le plus FishBase sont l'Europe, les États-Unis d'Amérique, le Brésil et l'Australie. Certains des principaux auteurs citant FishBase proviennent de domaines de l'agriculture (c'est-à-dire l'aquaculture), des sciences biologiques et environnementales, et travaillent sur la biologie et la gestion des pêches, ainsi que sur la parasitologie, entre autres. La plupart des citations de FishBase l'utilisent comme source de données pour des informations sur la composition du régime alimentaire, les tailles des poissons et les relations longueur-poids, la taxonomie ou l'habitat des poissons. Avec un nombre cumulé de citations dans la littérature évaluée par des pairs dépassant 10 000 dans Scopus et 15 000 dans Google Scholar, FishBase se situe dans le top 1% de tous les articles cités publiés au cours de ce siècle et du siècle précédent.

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INTRODUCTION

Citation analysis as an approach to measure the impact of scientific papers, and later of scientists and scientific institutions, was invented by Eugene Garfield (1925-2017) as a byproduct of a method to better index the scientific literature and thus improve its searchability (Garfield, 1955). Based on this insight, E. Garfield founded a company, which indexed much of the world's peer-reviewed scientific literature, the Institute for Scientific Information (ISI; now 'Clarivate'). Through multiple comparisons of citation scores with other measures of scientific impact (scientific awards, membership in prestigious societies, peer evaluations, etc.), he then established citations as a measure of scientific impact (see contributions in Garfield's 15-volume 'Essays of an Information Scientist, 1962-1993; www.garfield.library.upenn.edu/essays.html). This work became the basis of the overlapping fields of scientometrics (*the analysis of publications*) and bibliometrics (*the quantitative study of published units, such as journal articles and books chapters*), as well as culturomics (*the quantitative analysis of text*). These computational methods can be applied to identify temporal changes in research fields (Broadus, 1987; Silber-Varod *et al*., 2016; Kim *et al*., 2018), highlight trends in different research topics, measure the impact of scientists, institutions, or specific works, and infer their quality (Nicolaisen, 2008; Bohannon, 2011). Citation analysis in particular, studies the relationships between citing and cited documents, *i.e*., research papers that acknowledge prior publications by referencing (or citing) them (Smith, 1981). After all, no scientific paper is an island, rather it is a part of the literature about a particular subject. For consistency, the term "citation analysis" will be hereon used to describe the analyses conducted in this study.

FishBase (www.fishbase.org; Froese and Pauly, 2021) was developed in the late 1980s and is an open access global database on fishes that offers a wide variety of biological information; it includes a plethora of data, covering all levels of biological organization for the known 34,700+ fish species (Fig. 1). As of August 2021, FishBase contains information on 15,833 marine species, 15,848 freshwater species, and ~2,000 that are diadromous or prefer brackish waters. These data are derived from more than 59,000 published sources (journals, books, conference/symposia proceedings, reports, grey literature, etc.), 61,000+ photos, and over 2,440 collaborators. All data, including relevant statistical programs, an online ichthyology course, and even a FishBase book, are freely available to any user with Internet access. Given the struggle of institutions in developing countries to cover costly journal subscriptions that limit access to published material (Arunachalam, 2003), FishBase's fundamental service is to provide freely accessible data to scientists and the general public in all countries of the world. This commitment is highlighted by an interface that can be changed from English to 15 other languages, including Arabic, Chinese, French, Hindi, Russian, and Thai.

FishBase, and the data contained within the database, is not subjected to a formal peer-review process. However, since its development in the late 1980s it has undergone several reviews by experts, notably McCall and May (1995). In response, FishBase is constantly being adapted to meet suggestions and new needs (Froese and Pauly, 2000; Palomares and Bailly, 2011). In the annual meeting of the FishBase Consortium, the members of the consortium review the annual achievement and decide on the work for the year ahead, which may include changing of regional and/or thematic emphasis for encoding new information into the database, or adding new fields and modifying existing ones. For example, FishBase recently added multiple observed values of the micronutrients content in fishes (Hicks *et al.,* 2019), and a Bayesian tool which, based thereon, computes an estimate of calcium, iron, selenium, zinc, vitamin A, total omega

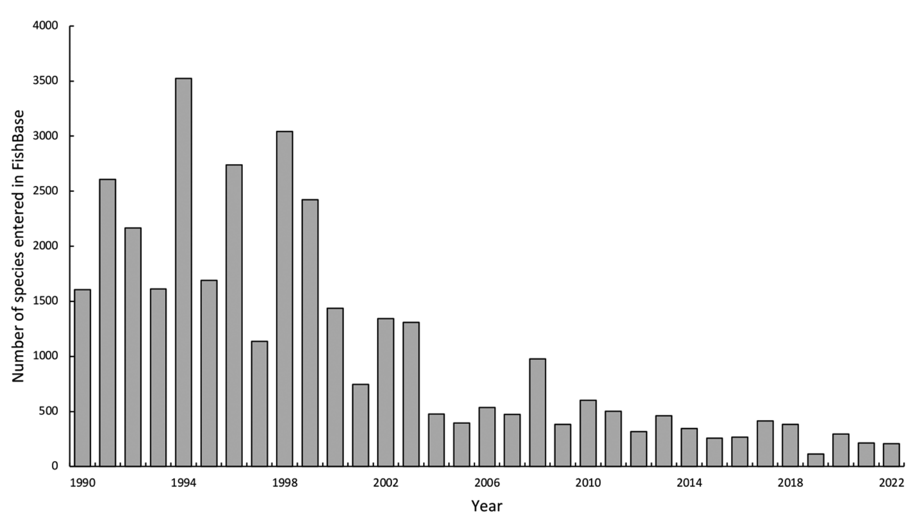

Figure 1. – The number of new fish species being encoded in FishBase each year since its creation in the late 1980s.

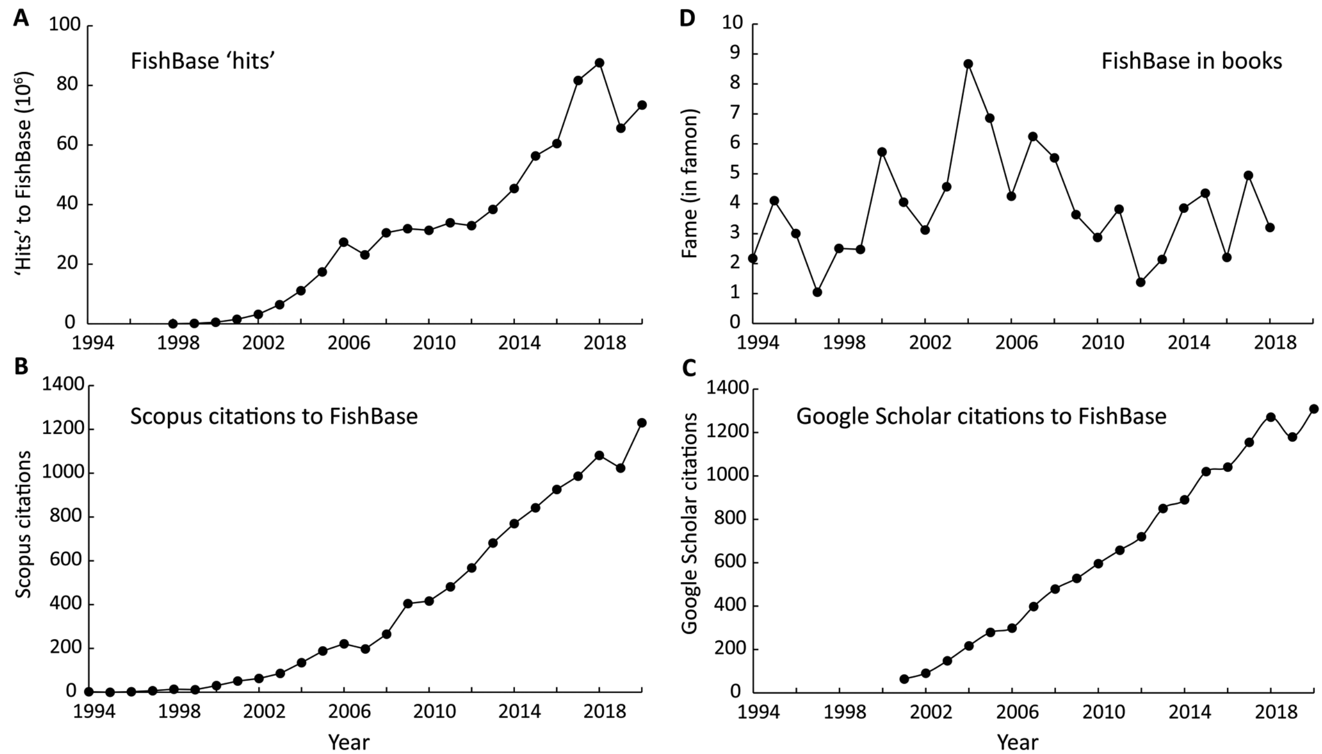

Figure 2. – Four indicators for the impact of FishBase. **A**: Annual number of 'hits' that the FishBase webpage has been receiving since 1998. Data derived from https://www.fishbase.se/WebUse.php?yr=All. *'hits' are defined as all requests made to the server and are used as a representation of FishBase usage. The number of substantial user sessions is by default considerably lower, *i.e.*, around 1 million per month in 2020. **B**:Annual number of citations to FishBase, based on data from Scopus (www.scopus.com, accessed on August 16, 2021). **C**: Annual number of citations to FishBase, based on data from Google Scholar (www.scholar.google.com, accessed on January 13, 2021). **D**: Occurrence in famons (1 famon = 10-6 relative % Ngram frequency: Stergiou, 2017) of the term "fishbase" (case insensitive) in the corpora of English (American and British), French, and Spanish books published between 1994 and 2018, based on data from the Google Books Ngram Corpus (http://books.google.com/ngrams; accessed on October 2, 2021).

3 fatty acids, and protein values for all species of fishes lacking observed values (https://www.fishbase.org/Nutrients/NutrientSearch.php).

The usage of FishBase has proven critical for dealing with global issues (*e.g.*, Pauly *et al.*, 1998; Froese and Pauly, 2000; Froese and Binohlan, 2001, 2003; Christensen *et al.,* 2003; Froese *et al.,* 2005; Froese, 2006; Cheung *et al.,* 2010) and its success is demonstrated by the large number of 'hits' (more than 80 million hits per month as of August 2021, with the number of hits increasing through time; Fig. 2A), derived from all continents and from a variety of users including individuals, colleges and universities, museums, research institutes, governmental and non-governmental organizations (Nauen, 2006; Froese and Pauly, 2021). However, visualizing the scientific impact of a work requires the establishment of measures of impact, *i.e.*, "[s]cience employs a knowledge filter that slowly separates the wheat from the chaff" (Bauer, 1992). Such a filter acts at different steps: a scientific finding is subjected to peer-review; if peers find it useful then it gets published in the primary literature; if other scientists also find it useful, it is cited; if it is cited a lot, it gets into review articles, monographs, and books; eventually it is cited in textbooks (Bauer, 1992). Thus, citation analysis is a reliable method of measuring the scientific impact of a particular piece of work.

In this paper, we expand on previous works (Stergiou and Tsikliras, 2006a; Palomares and Bailly, 2011) to evaluate the scientific impact of FishBase after three decades of operation and development. We use citation analysis on FishBase citations in Scopus, Google Scholar, and Google Books to showcase the great success of the database based on remarkably high values of 'traditional' bibliometric indices. This analysis aims to provide quantitative and qualitative long-term evidence of the impact of FishBase and the breadth of its impact on the scientific literature.

MATERIALS AND METHODS

For many years, Clarivate's Web of Science (WoS: www.webofscience.com/; previously Thomson ISI's Citation Index) was the only source of citation analysis. However,

Table I. – Main characteristics of the three major citation analysis tools: Web of Science (WoS; core collection), Google Scholar, and Scopus (sources: Wooster Campus Research Library of the Ohio State University and University Library of Iowa State University; data updated in January 2019).

	WoS	**Google Scholar**	**Scopus**
Subject focus	Science, technology, social sciences, arts & humanities	All subject areas (including technical and business documents)	Health, physical, life, and social science, arts & humanities
Developer/Producer	Clarivate Analytics	Google / Alphabet	Elsevier
Coverage	~13,000 journals	Unknown, but likely higher than both other sources	~22,000 journals
Timespan	1900-present (With the purchase of Century of Science)	Unknown (Theoretically, all that is available on the Web)	1970-present
Data and report export	Export to MS Excel and text	Difficult – copy/paste only	Robust – many options
Strengths	Coverage back to 1900	Includes all types of documents, including non-traditional sources not covered by WoS & Scopus – *e.g.*, tutorials, posters, presentations, theses, conference papers	Visually stunning author and citation reports
	Organization name unification	Finds more & newer citations in most subject areas	International and specialized disciplinary coverage
	Publisher-neutral (they are an info provider, not a publisher)	Book coverage via Google Books and free online publications	Downloadable reference list
	While controversial, its journal citation reports, impact factors, and h-index are most widely used	International, multi-lingual, interdisciplinary coverage	Includes in-press articles
Weaknesses	Covers only “journals of influence”	Questionable content quality (stray citations)	Narrower timespan
	Difficulty searching unusual author name formats: hyphenated, compound names, umlauts, etc.	Few sorting options & limited search features	Still weak in sociology and physics/astronomy
	Punctuation issues – *e.g.*, ampersands in journal titles	Inflated citation counts due to many non-peer-reviewed sources	Typographical errors in records
	Can lead to low citation counts due to errors in citations provided by authors, and different citation styles used by journals	Difficult to export citations & reports	
		Difficult to narrow down common author name searches	
		Weeding irrelevant hits is time consuming	

in 2004, two other bibliographic services became available, Google Scholar (Butler, 2004; www.scholar.google.com/) and Scopus (www.scopus.com), which were found to perform as well as the WoS (*e.g.*, Google Scholar: Pauly and Stergiou, 2005; Scopus: Vieira and Gomes, 2009). However, each tool has different advantages and disadvantages (Tab. I). Here, we chose to use Scopus (accessed on August 16, 2021) rather than WoS because *i)* it covers more sources than WoS with higher content quality than Google Scholar (Mongeon and Paul-Hus, 2015; Lukman *et al.,* 2018; Martín-Martín *et al.,* 2018); *ii)* it provides easily-obtained, downloadable, and comprehensive citation reports and metadata (Martín-Martín *et al.,* 2018); and *iii)* since we were interested in citations no earlier than the 1990s, the narrower timespan of Scopus was not an obstacle. However, given the ubiquity of Google Scholar, we also use it as a database for this citation analysis. These two sources were complemented with information derived from the Google Books Ngram Corpus (http://books.google.com/ngrams; accessed on October 2, 2021).

Scopus (Burnham, 2006) is an expertly curated abstract and citation database that covers more than 23,000 peer-reviewed journals from more than 5,000 international publishers, including over 75 million records of Open Access and in-press articles, conference papers, and book series. Scopus also provides tools for citation overview, result analyses, h-index, and author evaluation (Scopus fact sheet https://www.elsevier.com/solutions/scopus; accessed on November 11, 2021). Google Scholar provides a simple way to search for scholarly publications from the literature. This includes sources such as peer-reviewed articles, theses, books, abstracts and court opinions, from academic publishers, professional societies, online repositories, univer-

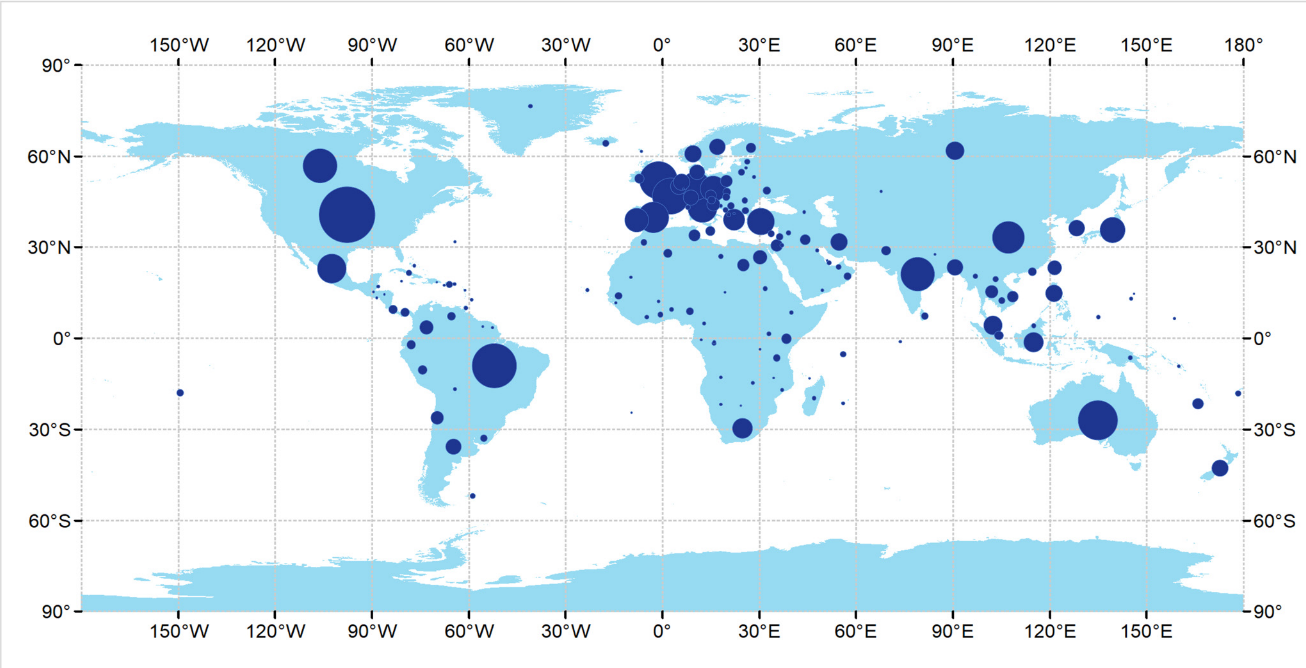

Figure 3. – Bubble map visualization of the global distribution of FishBase citations for the period 1994-2020, based on data from Scopus (www.scopus.com, accessed on August 16, 2021). Bubble size is relative to the number of documents citing FishBase (maximum number: 2,022 documents produced by the United States of America).

sities and other web sites. The Google Books Ngram Corpus (Michel *et al.,* 2011; Lin *et al.,* 2012) is a database that contains over 8 million books, or 6% of all books ever published, and consists of words and phrases (*i.e.*, Ngrams) and their usage frequency over time.

We searched all fields in Scopus, including the title, abstract, keywords, authors, references and more, using the keyword "fishbase". The same keyword was used to search Google Books (including English, French, and Spanish). The search in all sources was case-insensitive and thus returned results for "fishbase", "FishBase", "Fishbase", and "FISHBASE". The citation data were analyzed by year, author, journal, country, and discipline or subject using the "Analyze search results" tool of Scopus and they were exported into separate .csv files by the researcher. We also analyzed the context in which FishBase was cited for the top 107 most highly cited research articles (1% of the total FishBase citations from 1994 to 2020, based on Scopus). Each paper was downloaded and scanned by a researcher for excerpts mentioning FishBase. The context of each reference was characterized as "neutral" (or "technical"), "positive", or "negative" based on the wording used throughout the text. For example, a simple reference to FishBase as a source of data was characterized as "neutral" or "technical": "To determine the richness of coastal species, we extracted habitat association data for each of the 13,049 species from FishBase…" (Tittensor *et al.,* 2010). The use of positive words within the examined paper such as "highly successful" or "comprehensive" was considered as "positive" context: "We assembled body size data for 6,760 species from FishBase, the most comprehensive source of biological data on the world's fishes" (Rabosky *et al.,* 2013). Finally, criticism and characterizations such as "incomplete" were considered as "negative" context: "The FishBase is not a perfect instrument…" (Zenetos *et al.,* 2005).

For citations attributed to FishBase by Google Scholar (GS), we used the GS profile of D. Pauly, which groups all citations to the various editions of the 'FishBase Book', from 1996 to 2000 in English, Chinese, French and Portuguese (see Froese and Pauly, 2000) and the citations to the database itself (*i.e.*, Froese, R. and D. Pauly (eds) [variable dates] FishBase. World Wide Web electronic publication. www.fishbase.org); these data are like those in R. Froese's GS profile.

Certain limitations to our methodology should be considered. First, only items published in English were considered for the Scopus analysis. Second, Scopus only indexes journals which themselves are highly cited and often leaves out regional journals. Finally, citation analysis assumes that authors cite their references to give credit to the source information. In the case of FishBase, where it is not a specific journal article but rather a database containing natural history information on fishes from other sources, biased citing is likely.

Figures 1 and 3 were made using the programming language R, while Fig. 2 was made in Microsoft Excel. However, the base map in Fig. 2 was made with the mapping software ArcGIS (version 10.2).

RESULTS

The citation analysis based on data from Scopus revealed a total of 10,685 FishBase citations for the period 1994-2020 (Supplementary Table S1), implying an average citation rate of around 400 citations per year (ranging from 1 to 1,229 citations in 2020). FishBase citations exhibited a near linear increase since 2000, with 2020 delivering 1,229 citations (Fig. 2B), while Google Scholar exhibited a smooth increase of citations attributed to FishBase, from 64 in 2001 to an average of 1,200 per year from 2017 to 2021, resulting in a cumulative total of nearly 15,000 citations (Fig. 2C). Contrary to these clear trends, intense fluctuations were recorded through the Google Books Ngram Corpus (Fig. 2B). The term "fishbase" was increasingly found in Google Books from 1994 to 2004, while the frequency of occurrence dropped until 2012, and then increased at a slower rate up to 2018 (Fig. 2D). Most of the documents citing FishBase, and found through Scopus, originate from the Global North, except for Brazil (Fig. 3). The United States of America was the country producing the highest number of documents citing FishBase (2022), followed by Brazil (1268), Australia (1005), the United Kingdom (916), and France (851).

The vast majority of the 10,685 documents citing FishBase in Scopus (9,661; 90%) were peer-reviewed journal articles presenting original data, while 448 (4%) were reviews, 250 (2%) were books and book chapters, 218 (2%) were conference papers, and the rest were other gray literature items, such as reports, theses, proceedings, and periodicals. Based on Scopus, FishBase has been cited in documents published in more than 150 different scientific journals. The top 30 journals that cited FishBase produced 3,902 citations (37% of the total citations) (Tab. II). Ten out of the 30 top journals (33%) were dedicated to ichthyology, fishes, and fisheries accounting for 1,721 citations, while 5 out of the top 30 journals (17%) were parasitology journals (Tab. II). The remaining 15 (50%) journals specialized in marine or generally aquatic sciences (10/30, 33%), or were more general (*e.g.*, No. 2 and 28).

The documents citing FishBase belonged to diverse scientific fields (Fig. 4A). Most citations originated from the agricultural (*i.e.*, aquaculture) and biological sciences (7,976; 45%), environmental sciences (3,157; 18%), and earth and planetary sciences (1,585; 9%). Nevertheless, researchers in the fields of mathematics (*e.g.*, ecological network analyses studies: Caputo *et al.*, 2021), economics (*e.g.*, fisheries economic sustainability studies: Jimenez *et al.*, 2021), physics (*e.g.*, hydroacoustic technology studies: Jaya *et al.*, 2019), nursing (*e.g.*, nutrition studies: Goswami and Manna, 2020), and psychology (*e.g.*, behavioural studies: Dolado *et al.*, 2014) have also cited Fish-

Table II. – The top 30 journals that have published documents citing FishBase from 1994 to 2020, based on data from Scopus (www.scopus.com, accessed on August 16, 2021).

No.	Journal	Number of documents
1	Journal of Applied Ichthyology	709
2	PLoS ONE	282
3	Systematic Parasitology	244
4	Journal of Fish Biology	205
5	Marine Ecology Progress Series	197
6	Zootaxa	185
7	Acta Ichthyologica et Piscatoria	181
8	Fisheries Research	125
9	Acta Parasitologica	107
10	Journal of Ichthyology	107
11	Folia Parasitologica	104
12	ICES Journal of Marine Science	92
13	Journal Of Parasitology	90
14	Cybium	89
15	Environmental Biology of Fishes	88
16	Estuarine Coastal and Shelf Science	85
17	Parasitology Research	81
18	Fish and Fisheries	79
19	Marine Biology	77
20	Indian Journal of Geo Marine Sciences	76
21	Journal of the Marine Biological Association of the United Kingdom	74
22	Marine Biodiversity Records	74
23	Frontiers in Marine Science	73
24	Reviews in Fish Biology and Fisheries	72
25	Mitochondrial DNA	71
26	Hydrobiologia	70
27	Marine Pollution Bulletin	70
28	Scientific Reports	66
29	Turkish Journal of Fisheries & Aquatic Sciences	66
30	Ecological Modelling	63

Base over the years, albeit to a lesser extent (less than 215 citations in total, *i.e*. < 2%).

Analysis of the 107 most highly cited papers that reference FishBase (or 1% of the total FishBase citations from 1994 to 2020, based on Scopus) revealed that the vast majority did so in a neutral/technical (89 papers; 83%) or positive (15 papers; 14%) way, while only a few were negative (3 papers; 3%) (Fig. 4B). Neutrality was mostly expressed as a simple reference of FishBase (37 of the 107 analyzed citations; 35%) or as usage of the database as a source of data (70 of the 107 analyzed citations; 65%) (Fig. 4C).

The main research interests of the top 30 authors who cited FishBase in their publications from 1994 to 2020, based on data from Scopus, were fisheries, fisheries biology and management, and stock assessments, followed by parasitology, marine ecology and conservation, fish biology and ecology, coral reef ecology, and systematics and taxonomy (Tab. III). Four out of the 30 (13%; Tab. III) top authors citing FishBase (Daniel Pauly, Konstantinos Stergiou, Rainer Froese, and Athanassios Tsikliras) are members of the FishBase Consortium and are involved in the development of FishBase in some form. Twenty out of the 30 top authors (67%) came from or worked in Australia (13%), Brazil (13%), France, Greece, the UK, and USA (10% each). The Czech Republic (represented by the Institute of Parasitology, Biology Centre CAS) and Greece (represented by the Aristotle University of Thessaloniki and the Hellenic Center for Marine Research) were more highly represented in the top 30 authors list despite the countries' smaller relative size. Research institutes (Czech Academy of Sciences, French National Centre for Scientific Research, Chinese Academy of Sciences, French National Research Institute for Sustainable Development), universities (James Cook University, University of British Columbia, University of Montpellier, the University of Queensland), and museums (Natural History Museum London, French National Museum of Natural History) were among the entities that produced the most documents citing FishBase.

The different types of data extracted from FishBase mainly included diet composition and trophic level, size and length relationships (*e.g*., maximum length, length-weight and length-length relationships), taxonomy and species diversity, species distribution data (*e.g*., depth, geographical

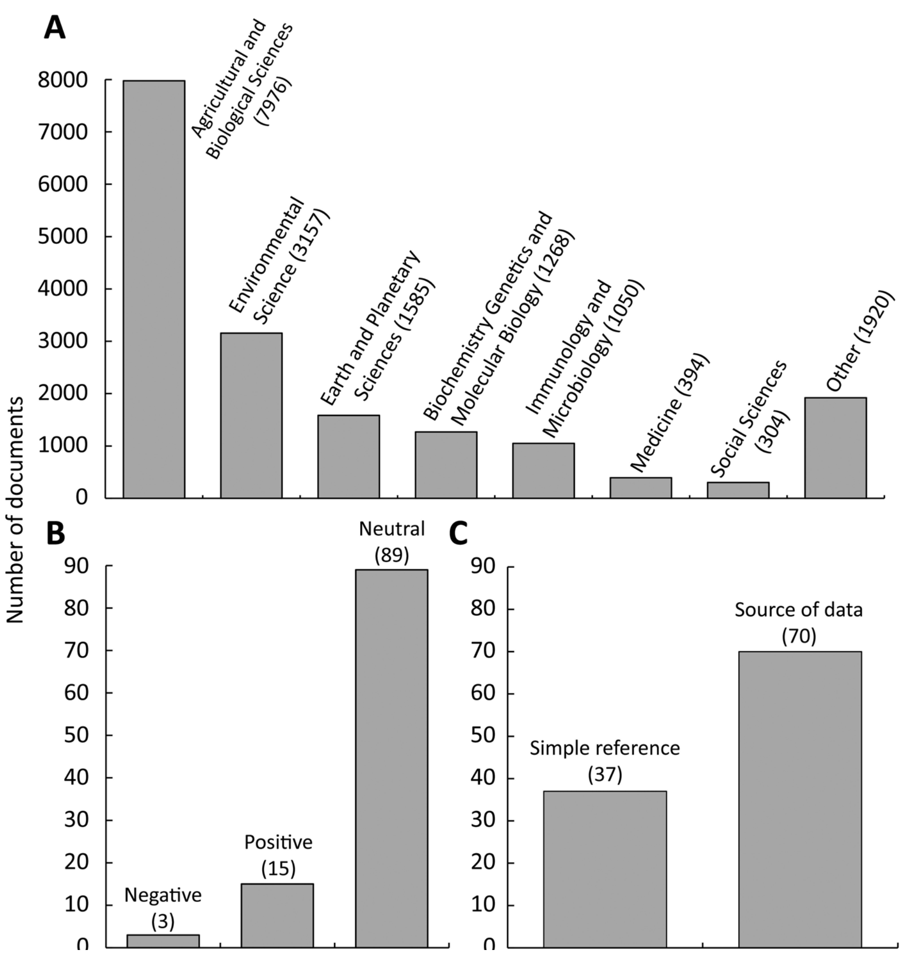

Figure 4. – Subject areas and context of FishBase citations. **A**: Number of documents citing FishBase by subject area, based on data from Scopus (www.scopus.com, accessed on August 16, 2021). Note that documents may fall into more than one category. **B**: Context in which the 107 most highly cited papers (1% of the total FishBase citations from 1994 to 2020, based on Scopus) reference FishBase (neutral/technical, positive, negative) and **C**: How they use it (as a source of data or a simple reference to it).

Table III. – The top 30 authors who cited FishBase in their publications (“docs”) from 1994 to 2020, based on data from Scopus (www.scopus.com, accessed on August 16, 2021), and their main research interests.

Author (docs)	Affiliation	Country	Research topic
Moravec F (182)	Institute of Parasitology, Biology Centre CAS	Czech Republic	Biology, ecology, and diversity of nematodes, fish parasites
Scholz T (81)	Institute of Parasitology, Biology Centre CAS	Czech Republic	Fish parasites, helminths, biology and taxonomy of trematodes and fish tapeworms
Justine JL (77)	National Museum of Natural History, Paris	France	Parasitology, systematics, biodiversity, Monogenea, comparative spermatology
Pauly D (72)	University of British Columbia	Canada	Fisheries, marine ecosystems, conservation biology
Luque JL (68)	Federal Rural University of Rio de Janeiro	Brazil	Fish parasitology, parasite ecology
Hossain MY (66)	University of Rajshahi	Bangladesh	Fisheries management, aquatic resource conservation, stock assessment, fish biology and ecology, climate change, fisheries
Bray RA (63)	Natural History Museum London	UK	Parasitic worms, systematics, phylogeny, biology
Graham NAJ (53)	Lancaster University	UK	Coral reef ecology, resilience, climate change, social-ecological systems
Cribb TH (51)	The University of Queensland	Australia	Parasitology
Tavares-Dias M (51)	Embrapa Amapá	Brazil	Fish parasitology, fish farms
Nagasawa K (47)	Hiroshima University	Japan	Parasitic crustaceans, parasitic helminths, pelagic sharks, Pacific salmon
Bellwood DR (42)	James Cook University	Australia	Marine biology, coral reef fish, ecology
Stergiou KI (42)	Aristotle University of Thessaloniki	Greece	Fish biology, fisheries, fisheries ecology, fisheries management, marine ecology
Kritsky DC (41)	Idaho State University	USA	Parasitology
Kulbicki M (40)	Research Institute for Development	France	Macro-ecology, reef fish ecology, stable isotopes
Wilson SK (40)	James Cook University	Australia	Coral reef fish ecology, climate change
Ohtomi J (39)	Kagoshima University	Japan	Fisheries biology, aquatic bioproduction science, life sciences
Akyol O (38)	Ege University	Turkey	Fisheries, fisheries biology, fishing technology
Boxshall GA (38)	Natural History Museum London	UK	Copepods, parasitic crustacea
Harvey ES (38)	Curtin University	Australia	Fish ecology, marine ecology stereo-video, fisheries ecology, marine conservation
Jawad LA (38)	Auckland Fish Biodiversity Consultancy	New Zealand	Fish taxonomy
Mouillot D (37)	Montpellier University	France	Ecology, coral reefs, statistics
Friedlander AM (36)	University of Hawaii	USA	Fisheries ecology, marine protected areas, coral reefs, community-based fisheries management
Floeter SR (34)	Federal University of Santa Catarina	Brazil	Reef fish, biogeography, evolution, ecology, macroecology
Froese R (34)	GEOMAR Helmholtz Centre for Ocean Research Kiel	Germany	Fish, fisheries, biodiversity, life history strategies, bio-informatics
Adriano EA (33)	Federal University of São Paulo	Brazil	Parasitology, fish, myxozoa, taxonomy
Tsikliras AC (33)	Aristotle University of Thessaloniki	Greece	Fish biology, fisheries stock assessment, fisheries management, marine ecosystems
Mohapatra A (32)	Zoological Survey of India	India	Marine fish taxonomy, ecology
Sala E (32)	National Geographic Society	USA	Ecology, conservation biology, marine biology, food webs, fisheries
Karachle PK (31)	Hellenic Center for Marine Research	Greece	Fisheries, fish feeding, fish ecomorphology, non-indigenous species, stakeholder involvement

range), data on the environment/habitat, growth, fecundity, as well as nomenclature (Supplementary Table S2).

DISCUSSION

The cumulative citation number for FishBase in Scopus as of August 16, 2021, is 10,685[1], which puts it in a very small group of highly cited published items, or the top 1% of all publications. This is in part because from the *ca*. 38 million scholarly items that have been published from 1900 to 2005, half have not been cited at all. Also, from the remaining half that have been cited at least once, only 5,063 items (0.03%) have been cited more than 1,000 times (see Garfield, 2005). Indeed, FishBase is the fourth most cited fisheries reference after the classic overview of fishes of the world by Nelson (1976), the review of early zebrafish development by Kimmel *et al*. (1995), and the handbook of quantitative fisheries research by Ricker (1975). Only two other databases are among the most highly cited fisheries references (Branch and Linnell, 2016) and those are the Catalog of Fishes (place 27; Eschmeyer *et al.,* 1998) and the FishStat database of global fisheries landings (place 98; FAO, 1998). In recent years, FishBase has received more citations annually than any other fisheries reference, thus justifying its characterization as "the one indispensable fisheries database, … [which] summarizes every scrap of information on every species of fish in the world…" (Branch and Linnell, 2016).

'Hits' and citations to FishBase have been increasing through time, while the number of new fish species encoded in the database followed an opposite decreasing pattern over time, with most new species being entered during the first ten years of operation, as expected. More than half of the sources citing FishBase come from 'general' scientific journals, such as the interdisciplinary journals *PLoS ONE, Scientific Reports,* and *PeerJ*. Additionally, disciplines such as immunology and microbiology had over 1,000 citations to FishBase. For example, FishBase was cited in a metagenomic shotgun analysis of the intestinal microbiomes of codfishes published in the journal *Applied and Environmental Microbiology* (Riiser *et al.,* 2020). This clearly indicates that FishBase has a good reputational breadth, having just as many citations with fish-specific disciplines, such as applied sciences, as with more basic disciplines like taxonomy [*e.g*., paper regarding problems in nomenclature and taxonomy affecting the legal governance of tuna and other migratory fishes (Serdy 2004)], as well as other disciplines such as parasitology [*e.g*., paper on the taxonomy of parasitic helminths of freshwater fishes (De Len and Choudhury, 2010)].

The journal that cited FishBase the most, *Journal of Applied Ichthyology*, had an arrangement with the database for many years as an outlet for papers with fish trait information that were then entered in FishBase. Numerous such papers have been about length-weight relationships (*e.g*., Terra *et al.,* 2017; Qamar and Panhwar, 2018), growth parameters and mortality rates (*e.g*., García and Duarte, 2006; Liang and Pauly, 2017), size at maturity (*e.g*., Raharinaivo *et al.,* 2020), fish maximum size (*e.g*., Sprem *et al.,* 2010), and fish diet composition (Headly *et al.,* 2009). Other journals that feature high citations of FishBase include the open access interdisciplinary journal *PLoS ONE*. The journal *Systematic Parasitology* also has a high number of FishBase citations primarily with papers using it for basic biological characteristics of fishes as it pertains to parasites, such as a synopsis of the most speciose group within the phylum Myxozoa, *i.e*., the genus *Myxobolus*, that primarily infects fish (Eiras *et al.,* 2014).

It is also important to mention the diffusion of FishBase into undergraduate university textbooks (*e.g*., Stergiou and Tsikliras, 2015) and more general ecological books (*e.g*., Clarke, 2017; Taylor, 2017; Newman, 2019), especially given the strong gap between terrestrial and aquatic ecologists (Stergiou and Browman, 2005) who read, cite, and publish in different journals. Nevertheless, even if primarily targeting the students and researchers of the world, FishBase does have a much higher audience than academia, reinforcing the importance of not only the database, but also of the ever-growing FishBase project. Such broader audience is not related to scientific publications, but includes librarians, aquarists, anglers, divers, translators, illustrators, or consultants (Froese, 2001).

The success of FishBase is also corroborated by the context of its citation which, in most cases, was neutral/technical using FishBase as a source of data, or even positive and praising the database. Adjectives with a positive connotation, such as "comprehensive", "popular", "recognized", "hugely successful", "fundamental", "key", "major" or "largest" were perceived as a positive reference to FishBase (*e.g*., Worm *et al.,* 2006; Rabosky *et al.,* 2013; Song *et al.,* 2014). On the other hand, three papers criticized the trophic level estimates provided by FishBase (Essington *et al.,* 2006), the accuracy of the nomenclature (Zenetos *et al.,* 2005), and the availability of site-specific data (Claudet *et al.,* 2010). Despite their criticism, the former papers (Zenetos *et al.,* 2005; Essington *et al.,* 2006) still used the scientific names and trophic level estimates from FishBase, respectively. The latter paper (Claudet *et al.,* 2010) was partly a misconception since fish life history and ecological traits, such as maximum body size and depth, are site-specific when looking beyond the general species summary page into the specific tables and related references.

[1] It is worth mentioning that this number has increased to 12,746 by July 8th, 2022, during the revision of the manuscript.

Certain limitations to our methodology should be considered when interpreting the results. Regarding the language, we are aware of several other publications (including books: *e.g.*, Stergiou *et al.,* 2011) that have cited FishBase in other languages apart from English, which was the only one considered with Scopus. Moreover, the fact that Scopus often leaves out regional journals can lead to underrepresentation of scholars from the tropics (Pauly, 1984) where much of their work may either not be in English journals or indexed by Scopus; this is a reason why we also used Google Scholar (Stergiou and Tsikliras, 2006b; Harzing and van der Wal, 2008). Even so, our results are likely a conservative estimate of actual FishBase usage since, in many cases, authors may cite the source from which FishBase extracted the data (*e.g.*, maximum length of *Siganus sutor* is 45 cm based on Woodland [1990]) instead of FishBase itself, which is incidentally the approach that is recommended in Froese and Pauly (2000), at least for limited information.

The citation analysis presented here demonstrates the major scientific impact of FishBase and its continuous growth throughout the years. FishBase is in the top 1% of all scientific sources in citation count, irrespectively of discipline, but has a widespread impact that goes beyond the academic research community. These findings are valuable evidence that can be included in research grant proposals and when promoting FishBase to prospective funders. Securing continuous support, in financial terms, but also in terms of supporters and content contributors, will ensure that FishBase continues to grow, is maintained, and kept up to date thanks to the invaluable work of all encoders, IT team members, and collaborators under the guidance of the current and potential future FishBase Consortium members. It takes a village to keep up with the scientific progress and growing number of publications, new methods, data, and tools pertaining to fish. FishBase hopes to keep getting the support of colleagues throughout the world in the continuous effort to improve and offer its content to all users for free.

Acknowledgements. – We would like to express our appreciation and gratitude to all encoders and IT team members of FishBase and SeaLifeBase in the Philippines for their continuous work on the databases. We also thank Elaine Chu of the Sea Around Us for the multi-panel figures. The authors thank two anonymous reviewers for their useful comments.

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Online supplementary materials

Table S1. – The 10685 documents citing FishBase from 1994 to 2020, based on data from Scopus (www.scopus.com, accessed in August 2021).
Available at https://sfi-cybium.fr/sites/default/files/supplementary-files/Humphries%20FB2%20Tab%20S1.xlsx
Table S2. – The 107 (1% of the total FishBase citations from 1994 to 2020, based on Scopus) most highly cited papers that reference FishBase, the context in which they cite it (neutral, positive, negative), the use (source of data, simple reference), and the types of data they extracted from it.
Available at https://sfi-cybium.fr/sites/default/files/supplementary-files/Humphries%20FB2%20Tab%20S2.xlsx