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Trends of scientific literature about ecomorphology as tool in study of fishes

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Abstract

The ecomorphology is an important tool for ichthyologic studies. The present study aimed to evaluate the trends of ecomorphological studies in fish in the scientific literature published between 1980 to 2019 and answer the following questions: Has the use of ecomorphology as a tool in ichthyological studies increased over the years? Which are the main countries and journals that publish scientific studies in this area? Is it possible to identify trends in ecomorphological studies? For this work, scientific studies were used as reference sources made available in the database Thomson ISI Web of Science (ISI WoS, 2019). Searches were performed using the following keywords: ecomorphology, morphology, diet, feeding ecology, ecomorphological attributes and morphology attributes. The number of publications on fish ecomorphology has increased over the years. The country that published the most papers was the USA and the journal Aquaculture. The keywords formed five groups, evidencing temporal changes related to words. Older articles focus only on the description of habitat use and more recent ones seeks to relate to ecomorphology with most broad ecological aspects.

Keywords: biodiversity, fishes, ichthyology, systematic review, scientific knowledge

Tendências da literatura científica sobre ecomorfologia como ferramenta no estudo de peixes. A ecomorfologia é uma ferramenta importante para os estudos ictiológicos. O presente estudo objetivou avaliar as tendências dos estudos ecomorfológicos em peixes na literatura científica publicada entre 1980 a 2019 e também responder as seguintes questões: O uso da ecomorfologia como ferramenta em estudos ictiológicos aumentou ao longo dos anos? Quais são os principais países e periódicos que publicam estudos científicos nesta área? É possível identificar tendências em estudos ecomorfológicos? Para este trabalho foram utilizados, como fontes de referência estudos científicos disponibilizados no banco de dados Thomson ISI Web of Science (ISI WoS, 2019). Foram realizadas buscas utilizando as seguintes palavras chaves: ecomorfologia, morfologia, dieta, ecologia alimentar, atributos ecomorfológicos e atributos morfológicos. O número de publicações em ecomorfologia de peixes aumentou ao longo dos anos. O país que mais publicou trabalhos foi o EUA e a revista Aquaculture. As palavras-chave formaram cinco grupos principais, evidenciando mudanças temporais relacionadas às palavras. Os artigos mais antigos são focados apenas na descrição do uso do hábitat e os mais recentes buscam relacionar a ecomorfologia com aspectos ecológicos mais amplos.

Palavras-chave: biodiversidade, peixes, ictiologia, revisão sistemática, conhecimento científico

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1. Introduction

Ecomorphology is the branch of ecology that aims to relate the morphology of the species with ecological aspects based on quantitative data (SILVA et al. 2012; LEAL et al. 2013). Studies of ecomorphological nature may also reflect important patterns in species phylogenetically distant, and establish ecomorphological differences between related species (SILVA-CAMACHO et al. 2014; PESSANHA et al. 2015), being an area that integrates several fields of biology, such as: zoology, morphology, ecology, physiology, animal behavior and evolutionary biology (ANTUNES-SAMPAIO and GOULART, 2011). Ecomorphological studies generally predict that external morphology is adaptive, he it evolves and diversifies over time by environmental pressures, anthropogenic factors, resources available in the environment, predation and competition (SANTOS et al. 2011).

Due to its predictive approaches, ecomorphology is used in studies of several organisms, as an example in studies involving fish which is the group that have greater morphological variation as available food, habitat structural condition, competition and predation (NORTON and BRAINERD, 1993; TEIXEIRA and BENNEMANN, 2007), and it is believed that ecomorphology is an important tool to describe diversification morphological in fish, which could show morphological variations in relation to behavior and efficiency in captur preys (EVANS et al. 2019; BALDASSO et al. 2019). As a result, these morphological diversifications in fish become essential models for ecomorphological studies, linking the shape of structures with ecological performance (EVANS et. al. 2019; BALDASSO et al. 2019).

It is possible to find in the scientific literature various fish-related ecomorphology studies, with the most diverse approaches and applications, both for the differentiation of the niche (SILVA-CAMACHO et al. 2014; BALDASSO et al. 2019), to relate the body format with the characteristics of the environment (TEIXEIRA and BENNEMANN, 2007; BALDASSO et al. 2019), or to relate feeding to ecomorphological patterns (FREIRE and AGOSTINHO, 2001; TEIXEIRA and BENNEMANN, 2007; SILVA-CAMACHO et al., 2014; BALDASSO et al., 2019).

The evaluation of scientific production is an important issue to determine the evolution of knowledge in a given area of science among different regions of the world (QUIXABEIRA et al. 2010). Therefore, a systematic review becomes essential to understand the evolution of the use of ecomorphology as a tool in ichthyological studies. Thus, considering the great importance that fish have for the balance of an ecosystem and the importance of evaluating scientific production by the academic community, this study aims to systematically analyze trends in ichthyological studies involving ecomorphology through the scientific literature published from 1980 to 2019, seeking answers to the following questions: Is there a significant correlation in the temporal use of ecomorphology in ichthyological studies? Which are the main countries and journals that publish scientific studies in this area? Is it possible to identify trends in ecomorphological studies?

2. Methodology

2.1 Data source

For this study were used, as reference sources scientific studies made available in the Thomson ISI Web of Science database (ISI WoS, 2019), available through the journal portal CAPES (Coordenaçao de Aperfeiçoamento de Pessoal de Nível Superior). 1980 was chosen as the initial year because for believing that the first works in fish ecomorphology have been published

since the 1980s. Searches were performed using the following keywords: "ecomorphology*" OR "morphology*" OR "diet*" OR "feeding*ecology" OR "ecomorphological*attributes" OR "morphology* attributes" (the asterisk is a boolean vector that includes derivations). The main collection of the Web of Science database was used to avoid the duplicity of articles. Thus, the records of each work found in the Web of Science were inserted individually in Software Histcite™ to extract the year of publication, names of journals, country of origin of work, titles of papers, abstracts, keywords/words from the title of each article. Were made spreadsheets with this information for the statistical analyses below.

2.2 Data analysis

To ensure that statistical analyses were not influenced by the increase in publications per year, the standardization of the quantitative data proposed by CARNEIRO et al. (2008) which consists of dividing the total number of articles by the total number of articles published annually, multiplying the resulting by 100. With the standardized data, Pearson's Correlation Analysis was performed to determine trends in the use of ecomorphology as tools in ichthyological studies over the years. A Principal Component Analysis (PCA) was then performed for analyze the temporal trends of title keywords/words in studies ichthyological. For the Principal Component Analysis, the synonymous words were grouped, study areas and species names were excluded, only the 10 most specific words in this field of study were plotted in order to obtain a readable graph (loadings >0.70 to <0.60). After that, was done a qualitative study of some abstracts of articles for discuss the focus of each study and its relationship with the years. A table summarizing this qualitative analysis is presented as appendix (see Appendix A). Finally, a Cluster Analysis (Cluster) was performed using Euclidean Distance to check the clusters of years in relation to the composition of the keywords/ words of the titles. All these analyses were performed in the R Software (R CORE TEAM, 2016).

3. Results and Discussion

There is exponential and significant growth in the global trend of publications on fish ecomorphology in the database ($r= 0.94$; $P <0.001$; Figure 1). The search for articles that contained in the title, in the abstract, in the keywords the terms: ecomorphology, morphology, diet, feeding ecology, ecomorphological attributes or morphology attributes resulted in 66.667 publications (Figure 1).

The global scientific production in studies that include fish ecomorphology is growing over time and this is reflected in the growing number of several works as monographs, dissertations, theses, scientific articles, proceedings papers, reviews, meeting abstract, articles early access, materials editorial, books review published annually in a database. Thus, in this study, it is evident that the number of researchers and the scientific production in this area grow over increase, and there is a positive correlation between the years with the total of articles published and indexed in the database Thomson ISI Web of Science. One of the allies for this advancement is the emergence of new technologies and the facility the dissemination of knowledge, as well as agencies that foster research, cooperation among researchers and assistance from various public and private institutions (SOUZA et al. 2018).

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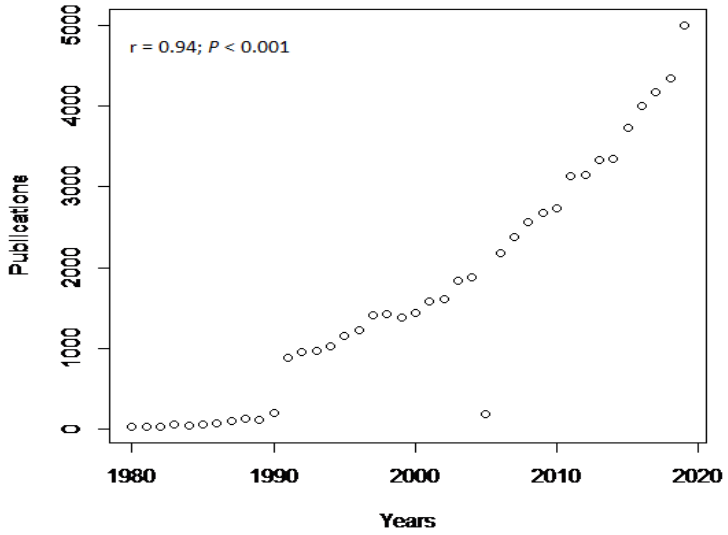

Figure 1- Number of publications by year published in the Thomson ISI Web of Science database, representing the science growth.

The USA was the country with the highest number of publications on fish ecomorphology from 1980 to 2019 (25,8% of published articles) followed by China (7,3%), Canada (7,2%), Spain (5,9%), Japan (5,4%), England (5,4%) and Brazil occupying the seventh position (5,4%)(Figure 2). 501 journals published articles on ecomorphology of fishes sometime between 1980 and 2019. Among them, the most representative were: Aquaculture (3.298 articles, 4,8% of total publications), Aquaculture Research (1.547 publications, 2.2%), Aquaculture Nutrition (1.396 publications, 2%), Journal of Fish Biology (1.057 publications, 1.5%), Fish Shellfish Immunology (820 publications, 1,1%), Plos One (794 publications each, 1,1%) (Figure 2).

The EUA is the leading country in ecomorphological studies on fish, as well as in several other areas of science, such as biodiesel (FERREIRA et al. 2014), in general ecology (LIMA-RIBEIRO et al. 2007), fitoplankton (CARNEIRO et al. 2008) and Zooplankton (SOUZA et al. 2018). This pattern may be a reflection of large investments in research, not only government institutions, but also private companies, in addition to in addition to quality infrastructure and institutions (FERREIRA et al. 2014; BASU et al. 2018; SOUZA et al. 2018). In this way, the EUA stands out for being the country most spent on research and development in the world (about 40% compared to other countries), has about 70% of Nobel Prize winners, as well as the top 40 best universities in the world (GALAMA and HOSEK, 2008; SOUZA et al. 2018). On the other hand, despite small investments in research and education, the Brazil occupies the seventh position of the countries that publish the most in fish ecomorphology.

From the Principal Component Analysis (PCA), it was possible to distinguish the words that are most closely associated with ecomorphologicals works on fish between 1980 and 2019. The first axis explained 35.5% of the variance found and the second axis explained 17%, totaling 52.5% of variation found. The most segregated words on axis 1 were Fish, Function, Shape, Feed, Ecomorphology and Morphology, on axis 2 the main word was Diet (Figure 3; Table 1). The Cluster Analysis generated five different groups (A, B, C, D and E), according to the keywords/words of the title (Figure 4). In

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group A are the years 2015, 2016, 2017, 2018 and 2019; In group B are the years 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, and 2014; In group C are the years 1980, 1981, 1982, 1983, 1984, 1985, 1986, 1987, 1988, 1989 and 1990. In group D are the years 1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998, 1999 and 2000. Finally, in group E are the years 2001, 2002, 2003, 2004 and 2005. In this way, there is a temporal grouping related to words, with the groups C and D concentrating the pioneer works in ecomorphology of fishes, followed by group E, and finally Group A and B, which chronologically groups together the most recent works in ecomorphology of fishes.

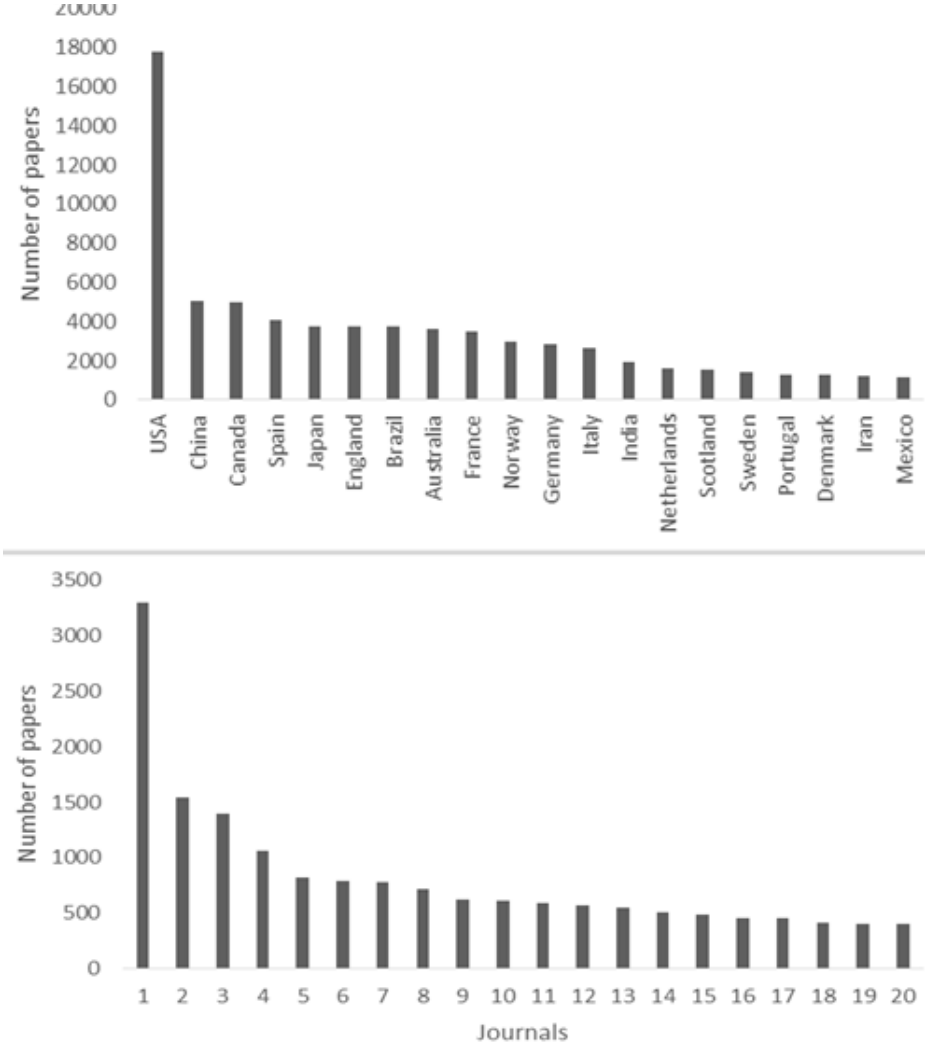

Figure 2- The top twenty countries (above) and the top twenty journals (below) with the highest cumulative numbers of published articles on ecomorphology in fishes from 1980 to 2019. The numbers in the above refer to journals: (1) Aquaculture, (2) Aquaculture Research, (3) Aquaculture Nutrition, (4) Journal of Fish Biology, (5) Fish Shellfish Immunology, (6) Plos One, (7) Marine Ecology Progress Series, (8) Britsh Journal of Nutrition, (9) Journal of Nutrition, (10) Fish Physiology and Biochemistry, (11) Journal of the World Aquaculture Society, (12) Enviromental Biology of Fishes, (13) American Journal of Clinical Nutrition, (14) Lipids, (15) Journal of Applied Ichthyology, (16) Hydrobiologia, (17) Aquaculture International, (18) Canadian Journal Of fisheries and Aquatic Sciences, (19) Science of the Total Enviromental, (20) Marine Biology.

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Table 1. Loadings of words obtained in PCA. In bold are the words most positively related to axis 1 or axis 2 (values ≥ 0.70 to ≤ 0.60) and plotted in Figure 3

Letter/Simbol	Word	PC1	PC2
A	Fish	0.77	-0.09
B	Ecomorphology	0.63	0.19
C	Morphology	0.60	0.36
D	Feed	0.68	0.51
E	Development	0.16	-0.26
F	Trophic	0.44	-0.39
G	Diet	0.34	0.83
H	Variation	0.53	-0.12
I	Shape	0.74	-0.42
J	Function	0.74	-0.41
	EIGENVALUE	3.53	1.70
	% VARIANCE	35.3%	17%

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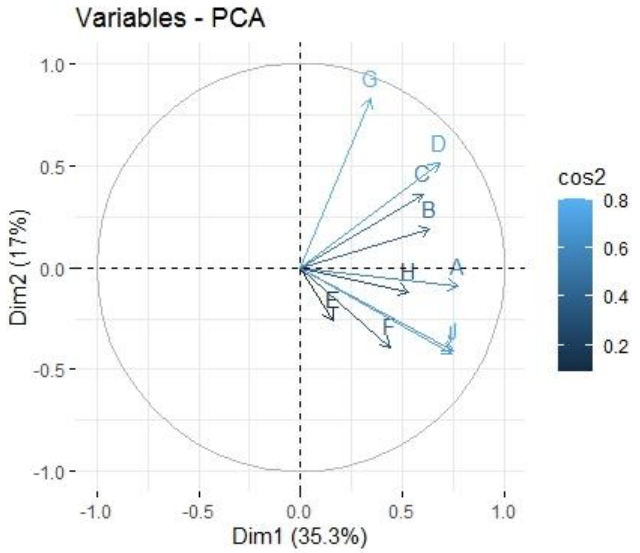

Figure 3- PCA using the keywords/title words (loadings >0.70 to <0.60). (loadings of words; see Table 1).

The PCA performed with the keywords/ words of the title, pointed out that the words that are most associated with ecomorphological works in fish among the years 1980 and 2019 are: Fish, Function, Shape, Feed, Ecomorphology, Morphology and Diet. This result can be explained by the fact that ecomorphological studies in fish vary as to the focus of the study, because according to CARDOSO et al. (2015) ecomorphology can be used to describe only the fish habitat, a theme addressed since 1980; to describe only diet; or habitat and diet together, which explains the wide range and variations of words found in this study. In addition, studies in this area demonstrate a strong relationship of morphology with the use of habitat.

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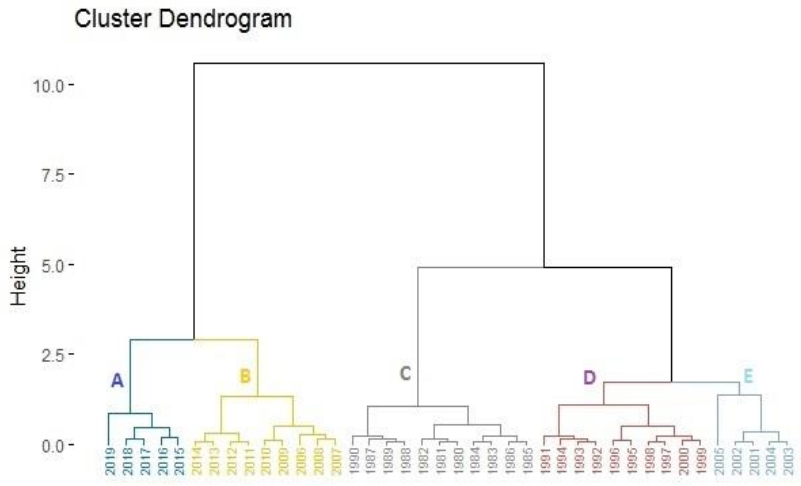

Figure 4- Dendrogram for cluster analysis using the main keywords/title words of articles on ecomorphology of fishes published in the ISI Web of Science database from 1980 to 2019. Cophenetic Correlation Coefficient = 0.80.

The Cluster analysis grouped five main groups who followed a time scale, suggesting a temporal trend with the words used in each time interval. The groups A (2015-2019) and B (2006-2014) concentrate the recent works and focused on the description the use of habitat and diet together. However, in this group, there is also a trend towards broader ecological aspects, such as geographical isolation, environmental quality, ecomorphotypes, conservation, variation intraspecific, and adaptation, coexistence of species, environmental degradation, predation, and deforestation. Finally, it is worth mentioning that, in this last group, it was possible to verify a number significant study focused on environmental issues and conservation of fish habitats (Qualitative analysis, Appendix A). One example is the strong global concern of the impacts of global warming on the environment soil misuse, degradation of ecosystems and their effects on ichthyofauna. The group C (1980-1990) is focuseds in description of the use, lifestyles and niches occupied in the habitat, group D (1991-2000) and E (2001-2005) were most related to works of diet analysis of fish (Qualitative analysis, Appendix A).

4. Conclusion

The number of publications of ecomorphological studies of fish increased over time. Developed countries are the ones that most publish ecomorphological studies; on the other hand, the underdeveloped countries are the least-published ecomorphological studies of fish. In this sense, the relative stability of ecomorphological fish studies indicate that research support policies (including private companies, organizations governmental and non-governmental) are essential for the development of science, since the number of publications is one of the most important measures to qualify and quantify the evolution of science.

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Appendix A- Qualitative analysis of some abstracts that contain the word "ecomorphology", "morphology", "diet", "feeding ecology", "ecomorphological attributes" and "morphology attributes".

Group	Word Influenced	Related to	References
A (2015-2019)	Fish Shape Function Trophic	Partitioning Geographic isolation Environmental quality Conservation Adaptation Coexistence of species; Environmental degradation; Deforestation;	Pessanha et al. (2015); Silva et al. (2016); Siqueira-Souza et al. (2017); Morales and García-Alzate (2018); Soria-Barreto et al. (2019).
B (2006-2014)	Ecomorphology Diet Feed	Potential niche Ecotyping Convergence Ecology Trophic Ecomorphology Feeding Biomechanics	Cunico and Agostinho (2006); Medeiros and Ramos (2007); Hoagstrom and Berry (2008); Souza and Barrella (2009); Antunes-Sampaio and Goulart (2010); Silva et al. (2012); Leal et al. (2013); Silva-Camacho et al. (2014).
C (198O-1990)	Morphology	Character transformation Evolution Assemblage structure Functional anatomy	Kotrschal (1989); Wikramanayake (1990).
D (1991-2000)	Ecomorphology	Morphology Ecology Diet Ontogeny Ecomorphology Size-structured Locomotion	Wainwright (1991); Douglas and Matthews (1992); Norton and Brainerd (1993); Sibbing et al. (1995); Wainwright (1996).Adite and Winemiller (1997); Piet (1998); Peres-Neto (1999); Cutwa and Turigan (2000).
E (2001-2005)	Morphology	Morphology attributes Functional anatomy Habitat use Preference for habitat	Wainwright et al. (2002).Gomes et al. (2003); Oliveira and Bennemann (2004); Piorski et al. (2005); Freire and Agostinho (2001).

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