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# UTILIZATION OF SHELLFISH AND MARICULTURE RESIDUES: SYSTEMATIC LITERATURE REVIEW WITH META-ANALYSIS

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## ABSTRACT

Present in most coastal areas, shellfish and mariculture generate a large amount of shellfish residues, which can be applied in various industries, due to their high calcium content. The goal of this study was to investigate the worldwide scientific production in the Scopus database, about the use of these residues. From the application of the PRISMA methodology, ten articles were selected, which underwent bibliometric and bibliographic analyzes. These were published in portuguese and english, in seven different countries, between 2006 and 2019, which suggests a short time to address the topic. Each researcher was only the author or co-author of a single article. The least cited articles were published in the last three years, and the most cited was the oldest of the analysis. The works dealt with the application of shellfish residues in the water and sewage, energy, agriculture and civil construction industries. As benefit of the application, the abundance of waste, energy savings and the reduction of environmental impacts resulting from the extraction of new raw materials and inappropriate disposal were highlighted. The meta-analysis proved to be effective in this investigation, and showed that there are still few studies in the area, but with different approaches. Thus, more research is suggested, dealing with the improvement of techniques for the use of these residues, and more political and economic incentive to use them.

**KEYWORDS:** shellfish, calcium, industry, bibliometry, PRISMA.

# APROVEITAMENTO DE RESÍDUOS DA MARISCAGEM E DA MARICULTURA: REVISÃO SISTEMÁTICA DA LITERATURA COM META-ANÁLISE

## RESUMO

Presentes em boa parte das zonas costeiras, a mariscagem e a maricultura geram uma grande quantidade de resíduos de concha de mariscos, que podem ser aplicados em diversas indústrias, devido ao seu grande teor de cálcio. O objetivo deste estudo foi investigar a produção científica mundial na base de dados Scopus, acerca do aproveitamento destes resíduos. A partir da aplicação da metodologia PRISMA, foram incluídos 10 artigos, que passaram por análises bibliométricas e bibliográficas. Estes foram publicados em português e em inglês, em sete países distintos, entre 2006 e 2019, o que sugere pouco tempo de abordagem do tema. Cada pesquisador só foi autor ou coautor de um único artigo. Os artigos menos citados foram publicados nos três últimos anos, e o mais citado foi o mais antigo da análise. Os trabalhos versaram sobre a aplicação dos resíduos de concha de mariscos nas indústrias de águas e esgotos, energia, agricultura e construção civil. Como benefício da aplicação, foi destacada a abundância do resíduo, a economia energética e a diminuição dos impactos ambientais decorrentes da extração de novas matérias-primas e do descarte inadequado. A meta-análise se mostrou eficaz nessa investigação, e evidenciou que ainda há poucos estudos na área, todavia com abordagens distintas. Assim, sugere-se mais pesquisas que tratem do aprimoramento das técnicas de aproveitamento destes resíduos, e mais incentivo político-econômico à utilização dos mesmos.

**PALAVRAS-CHAVE:** concha de marisco, cálcio, indústria, bibliometria, PRISMA.

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## 1 INTRODUCTION

Until the early 1970's, man developed his economic activities aiming only at profit, leaving aside essential topics such as those concerning environmental issues (Pott & Estrela, 2017). Due to the considerable increase in the degradation of the natural environment, one of the issues much discussed in national and international plans and policies concerns solid waste (Crociata, Agovino & Sacco, 2015; Deus, Battistelle & Silva, 2015). The mismanagement of these materials negatively impacts both human health, the environment and the economy, in terms of the spread of diseases, environmental degradation and the costs of their remediation (Gworek et al., 2016; Ziraba, Haregu & Mberu, 2016; Medus, Escudero & Cifuentes, 2019).

The industrial production and artisanal extraction of shellfish (shellfishing) are economic activities that have drawn the attention of various sectors around the world, because, among other aspects, they generate a waste that is commonly discarded without any use: the shell of the shellfish (Oliveira, Castilho & El-Deir, 2016; Yao et al., 2014). If in some artificial cultures these wastes are sent to landfills or incinerators, in most artisanal extractions, these wastes are discarded in natural environments, causing the degradation of these sites (Pereira & Saraiva, 2019; R. G. Souza, Sant'Anna, Fredel & Alarcon, 2014). Therefore, in either of the two situations, shellfish shells are being treated purely as waste, a fact that opens relevant discussions in the technical-scientific environment about the possibilities of use that these materials may have, essentially due to the large content of calcium carbonate in its composition (Hamestera, Balzer & Becker, 2012).

Besides the importance that recycling these wastes has for natural environments, such practice can economically favor the industrial and craft generators of these materials, since it also becomes a source of extra income, as discussed by Caldas (2018) and Lima and Lopes (2016). Such fact gains even more relevance when considering the social conditions in which many families of shellfish shellers find themselves; often in a precarious situation, without access to health and education, for example, as addressed by Campos et al. (2018) and Nuraini (2016). In short, the use of shellfish shells allows these wastes to be included in the production chain of several industries, instead of simply being excluded from it. Thus, the construction, glass, paint, animal feed, and soil improvement industries, among others, can use this waste as a raw material in their processes (HeriyantoPahlevani & Sahajwalla , 2018; Perea, Kelly & Hangun-Balkir, 2016; C.-H. Wang, Doan, Nguyen, Nguyen & Wang, 2019; S.-L. Wang, Tseng & Liang, 2011).

Given the above, this study aimed to investigate the worldwide technical-scientific production, indexed in the Scopus database, on the use of shellfish waste and mariculture. Conducting a systematic review with meta-analysis contributes to bringing the research closer to the object of study, because it uses a methodology that eliminates the emergence of biases (W. Liu, Wang, Li, Chen & Sun, 2019; Bastos, Almeida Pinto, Fiúza & Barros, 2017). Thus, this type of literature review allows the construction of a broad and consistent overview of the state of the art, managing to locate the gaps and trends of scientific productions in the area studied (Pantaleão & Veiga, 2019; Ferigollo & Busato, 2018; Ellegaard & Wallin, 2015).

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## 2 METHODOLOGY

According to Pluye and Hong (2014), the systematic review should be based on a mixed methodology that combines quantitative and qualitative techniques for the literature review and for the bibliometric analysis, in order to validate the study. Thus, for the delimitation of the present research, a systematic method was employed from a set of phases and steps, seeking to investigate the panorama, the applications and the results of the works published on the theme seafood waste.

The work was divided into three phases: (1) database search, (2) meta-analysis, and (3) quantitative and qualitative data analysis (Figure 1).

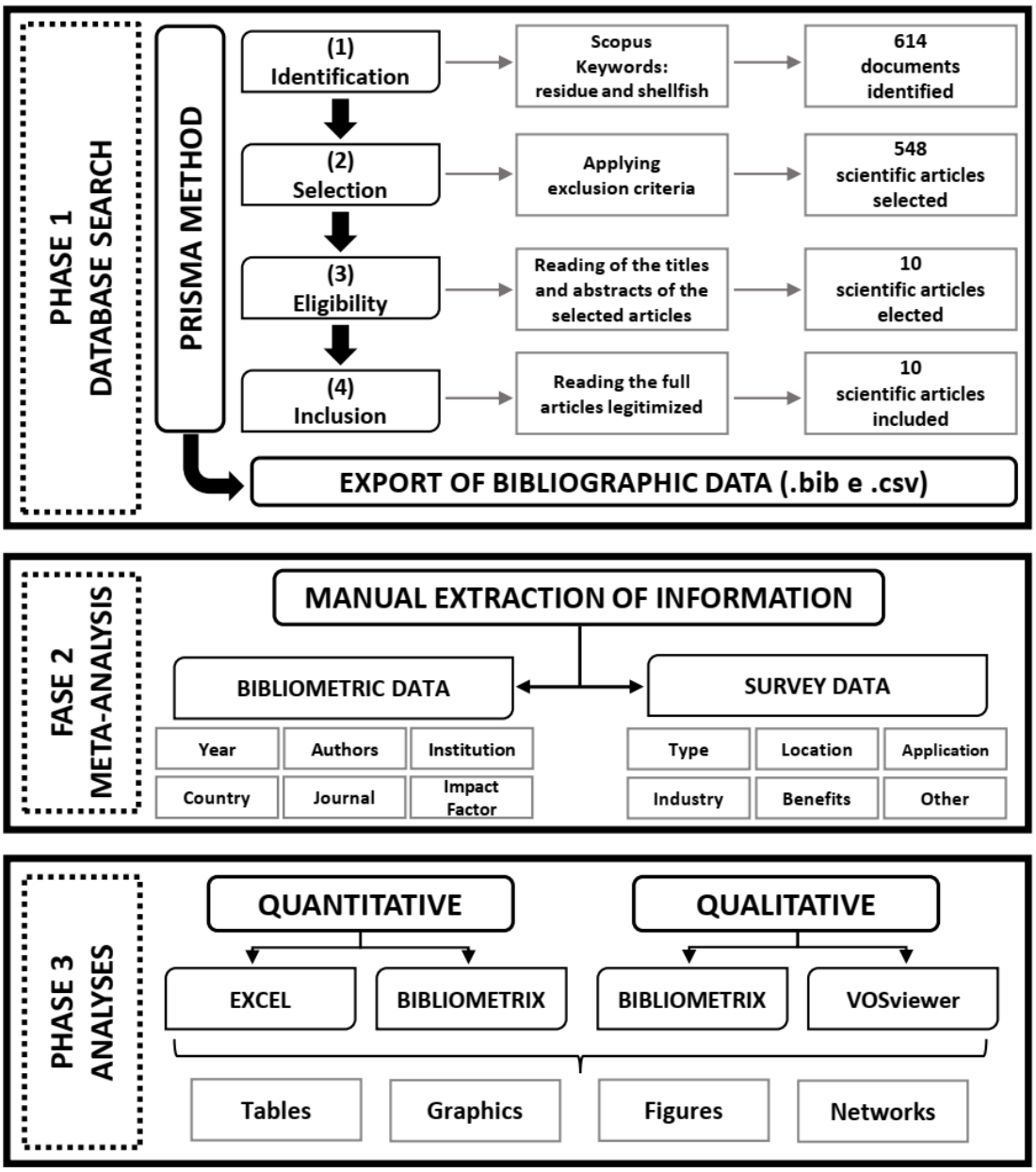


**Figure 1: Systematic flowchart of the research.**

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## 2.1 Phase 1: Search for articles in the database

To select the articles that fit the context of this research, the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) methodology was applied, which is divided into four steps: (1) Identification, (2) Selection, (3) Eligibility, and (4) Inclusion (Moher, Liberati, Tetzlaff & Altman, 2010).

In the Identification stage, through the Periodical Portal of the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), the Scopus database was used, where the search was conducted in April 2020. For this, the search applied the keywords residue and shellfish, which should appear in the title or abstract or in the keywords of each scientific writing. In this stage 614 documents were located.

In the second stage, Selection, the papers resulting from the search went through exclusion criteria, through the following filters:

- Year – articles published in 2020;
- Document type – book, book chapter, event document and review, and research abstract;
- Publication phase – articles that have not yet been published in their final version;
- Source type – book and event proceedings.

At the end of the selection stage, 548 scientific articles that met all the parameters specified below remained:

- Articles published through 2019;
- Articles in the format of research or literature review papers;
- Articles already published in periodicals (scientific journals);
- Articles from anywhere in the world;
- Articles in any language.

In the third stage, Eligibility, we proceeded with the reading of the titles and abstracts of the articles to select the works that were part of the central thematic axis analyzed (utilization of shellfish waste and mariculture), in order to make the sample more precise. Seeking to coherently cover the works related to the theme and to eliminate possible errors, the selection was made through a double reading, carried out independently by the present authors. Thus, after reading the titles and abstracts, 10 articles were unanimously selected.

In the fourth stage, Inclusion, the 10 articles were read in full to confirm the definitive insertion of the works in the next stages: Meta-analysis and Quantitative and Qualitative Data Analysis. Finally, the information from the articles was exported from Scopus in .bib and .csv formats, so that it could be read by the following bibliometry software: R Studio (Bibliometrix package) and VOSviewer.

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## 2.2 Phase 2: Meta-analysis

The extraction of the information was also performed in a double manner by independent reviewers, aiming for greater accuracy of the data. Initially, the meta-analysis was based on a table manually created in Microsoft Office Excel software containing the data from the articles. These data were separated into two types: bibliometric data of the publication and information regarding the research.

As bibliometric data of the publication, the items listed below were understood:

- Year of publication of the study;
- Authors and authors' institution and country of origin;
- Periodical;
- Journal Qualis and impact metrics.

As for the information referring to the research, it concerns the following data, linked to the object of the articles:

- Type of seafood;
- Place of origin of the waste;
- Application of the residue;
- Industrial sector of application of the processed residue;
- Benefits of residue utilization.

Later, tables, graphs, figures, and networks were created from the collected data and the information exported from Scopus.

## 2.3 Phase 3: Quantitative and qualitative data analysis

The quantitative analysis was done using Microsoft Office Excel and R Studio (Bibliometrix package) software, using descriptive statistics to make tables, graphs, and figures to illustrate the organized and exported information.

The R Studio software (Bibliometrix package) was also used to group the words according to repetition. Thus, the frequency of the words was determined through the cloud elaborated in the textual analysis (qualitative) of a group of texts, which corresponded to the titles, the abstracts and the keywords of the authors and the database of each investigated article.

Also used for the qualitative analysis was the VOSviewer software, which allows the construction and visualization of bibliometric networks. These networks can be built based on citation, on co-citation, on bibliographic coupling (the relationship between two articles, based on the number of references in common cited by those articles) or on coauthorship relationships.

It is worth noting that since these tools are only for processing the acquired data, the interpretation and analysis of the articles were performed by the researchers themselves.

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## 3 RESULTS AND DISCUSSIONS

The 10 selected papers were published between the years 2006 and 2019, with one paper written in portuguese and nine in english. The number of authors per paper ranged from two to six, in H.-Y. Liu and Chen (2017) and Fulgencio et al. (2018), respectively, totaling 41 authors. It was noticed that no researcher was an author or co-author in more than one article (Table 1).

**Table 1: General data of the selected articles on waste from shellfish harvesting and mariculture activities. (continued)**

| Title | Authors | Institution | Country | Periodical | Year |
|---|---|---|---|---|---|
| Building a low-cost domestic wastewater reclamation system using local agricultural waste in Kinmen islands, Taiwan | Liu, H.-Y. | Quemoy National University | Taiwan | Paddy and Water Environment | 2017 |
| | Chen, S. | Chung Yuan Christian University | | | |
| Calcium diglyceroxide as a catalyst for biodiesel production | Catarino, M. | University of Lisbon | Portugal | Journal of Environmental Chemical Engineering | 2019 |
| | Martins, S. | | | | |
| | Dias, A. P. S. | | | | |
| | Pereira, M. F. C. | | | | |
| | Gomes, J. | University of Lisbon | | | |
| | | Polytechnic Institute of Lisbon | | | |
| Combining sewage sludge and clam shell waste to prepare adsorbents for efficient phosphorous removal | Souza, T. A. | State University of Feira de Santana | Brazil | Water, Air and Soil Pollution | 2018 |
| | Mascarenhas, A. J. S. | Federal University of Bahia | | | |
| | Andrade, H. M. C. | | | | |
| | Santos, T. S. M. | State University of Feira de Santana | | | |
| Effects of mussel shell addition on the chemical and biological properties of a cambisol | Paz-Ferreiro, J. | Mabegondo Agricultural Research Center | Spain | Chemosphere | 2012 |
| | | Polytechnic University of Madrid | | | |
| | Baez-Bernal, D. | Mabegondo Agricultural Research Center | | | |
| | Insúa, J. C. | | | | |
| | García Pomar, M. I. | | | | |

**Table 1: General data of the selected articles on waste from shellfish harvesting and mariculture activities. (continued)**

| Title | Authors | Institution | Country | Periodical | Year |
|---|---|---|---|---|---|
| Study of the incorporation of seashell powder in porcelain tile paste | Fulgencio, E. B. G. A. | Federal University of Paraíba | Brazil | Ceramics | 2018 |
| | Medeiros, F. K. | | | | |
| | Cartaxo, J. M. | Federal University of Campina Grande | | | |
| | Dutra, R. P. S. | Federal University of Paraíba | | | |
| | Macedo, D. A. | | | | |
| | Campos, L. F. A. | | | | |
| Pyrolytic oil production by catalytic pyrolysis of refuse-derived fuels: Investigation of low cost catalysts | Whyte, H. E. | Nantes School of Mines | France | Fuel Processing Technology | 2015 |
| | Loubar, K. | | | | |
| | Awad, S. | | | | |
| | Tazerout, M. | | | | |
| Recycling of shell wastes into nanosized calcium carbonate powders with different phase compositions | Lu, J. | Nanchang Hangkong University | China | Journal of Cleaner Production | 2015 |
| | Lu, Z. | | | | |
| | Li, X. | | | | |
| | Xu, H. | | | | |
| | Li, X. | | | | |
| Recycling waste seashells to produce calcitic lime: characterization and wet slaking reactivity | Ferraz, E. | Polytechnic Institute of Tomar | Portugal | Waste and Biomass Valorization | 2018 |
| | Gamelas, J. A. F. | University of Coimbra | | | |
| | Coroado, J. | Polytechnic Institute of Tomar | | | |
| | Monteiro, C. | Conservation of Artistic Heritage | | | |
| | Rocha, F. | Aveiro University | | | |
| Seashells: detoxifying agents for metal-contaminated waters | Tudor, H. E. A. | Columbia University | United States | Water, Air and Soil Pollution | 2006 |
| | Gryte, C. C. | | | | |
| | Harris, C. C. | | | | |
| The use of solid residues derived from different industrial activities to obtain calcium silicates for use as insulating construction materials | Felipe-Sesé, M. | University of Jaén | Spain | Ceramics International | 2011 |
| | Eliche-Quesada, D. | | | | |
| | Corpas-Iglesias, F. A. | | | | |

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All institutions had only one publication in the applied search. Also, no interactions were found between institutions from different countries, i.e., in cases where the authors of the same article were linked to different institutions, these belonged to the same country, as was the case of the works of H.-Y. Liu and Chen (2017), Catarino, Martins, Dias, Pereira and Gomes (2019), T. A. Souza, Mascarenhas, Andrade and Santos (2018), Paz-Ferreiro, Baez-Bernal, Castro Insúa and García Pomar (2012), Fulgencio et al. (2018) and Ferraz, Gamelas, Coroado, Monteiro and Rocha (2018). Given this, it is understood that there was no scientific collaboration between research groups from different countries, regarding the theme addressed. It is also possible to state that there is low cooperation between members of different groups from the same country. These verifications draw attention, as they meet some of the purposes that guide the essence of a research group: support and sharing of experiences among members and search for partnerships between groups from other institutions (Katz & Martins, 1997; Newman, 2004), in order to generate a network of relationships that adds to the advancement of technical and scientific knowledge and the welfare of society, consolidating the academic tripod (teaching, research and extension).

The annual number of publications ranged from one to two. The years 2015, 2018, and 2019 had two publications, and the others, only one. Since the first manuscript dates from the year 2006, there is an indication that the subject analyzed has been studied for a short time (Figure 2).

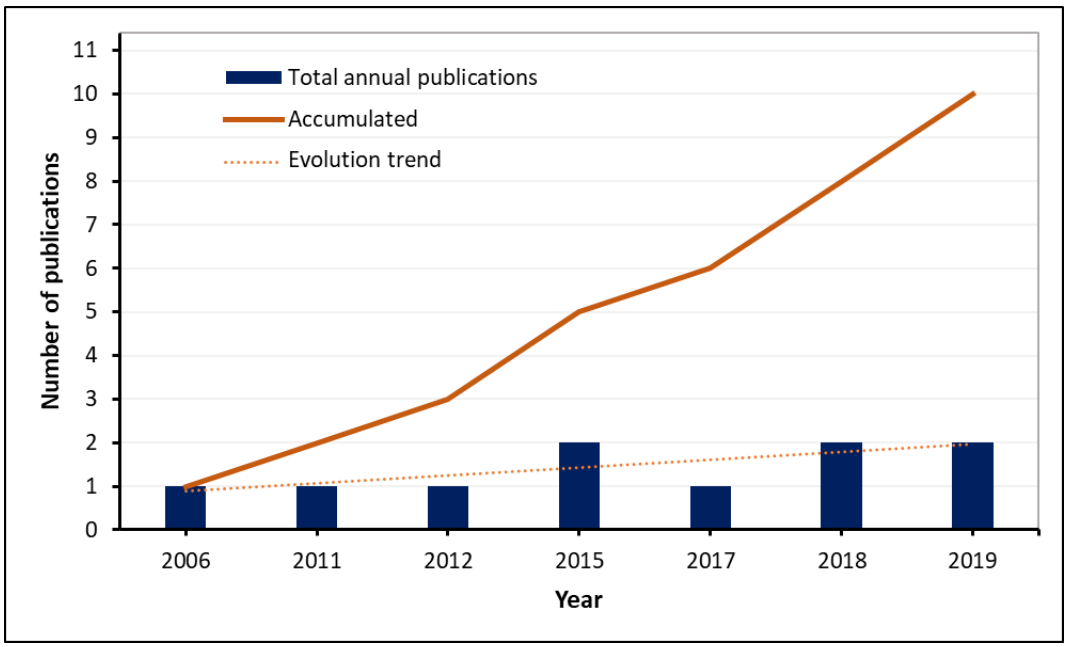


**Figure 2: Number of articles on waste from shellfish and mariculture activities by year from 2006 to 2019.**

It was observed that there were temporal gaps between some publications, the largest being between 2006 and 2011 (five years). From 2011 to 2019 a rise in the frequency of publications could be seen, and from 2017 to 2019, there was no time gap. Even though the number of publications per year is low, the graph shows a slight growth trend, which, together with the absence of time gaps between the last three years, indicates an increase in the frequency of publications. Thus, a discontinuity of publications and a low scientific production on the theme is noted, which highlights opportunities for researchers and the possibility of new scientific discoveries.

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As can also be noted, the publications came from seven different countries, with Brazil, Spain, and Portugal having two publications each, and China, the United States, France, and Taiwan having one publication each. Thus, the European continent had the largest number of publications (five), followed by the American continent, with three publications, and lastly, the Asian continent, with two. In other words, 80% of the analyzed works were concentrated in the West (Figure 3).

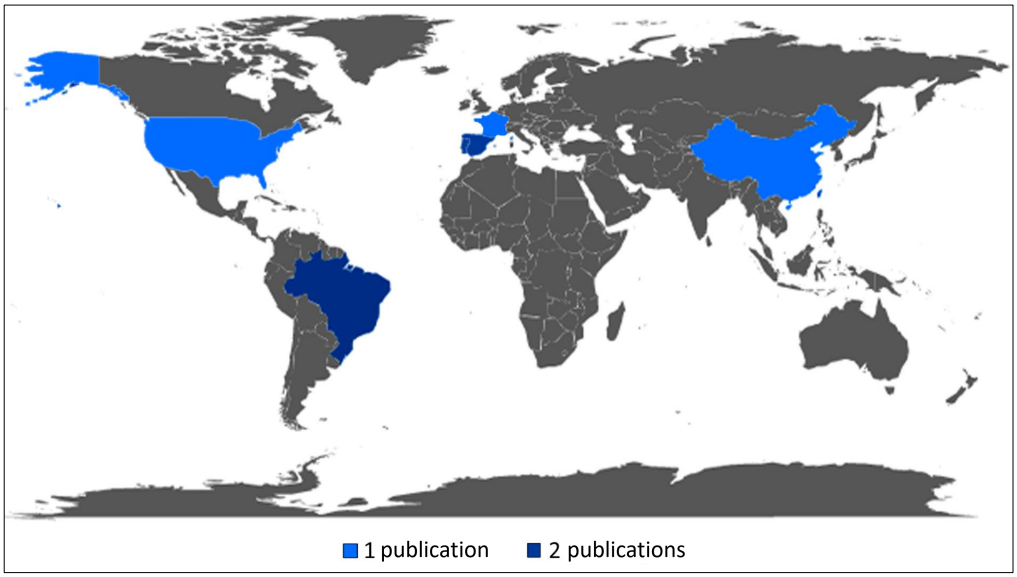


**Figure 3: Worldwide distribution of articles on waste from shellfish and mariculture activities.**

According to the Science and Engineering Indicators 2020, from the National Science Foundation of the United States (2020), China and the United States, in that order, produce the most scientific papers worldwide. However, the United States and the European Union countries produce the most impactful publications. Coincidentally, or not, although the United States was not the country with the most publications in this study, the one publication from that country had the highest number of citations. Thus, the paper by Tudor, Gryte, and Harris (2006) was the most cited in the Scopus database, with a total of 39 citations, and the papers by Fulgencio et al. (2018), H.-Y. Liu and Chen (2017), and T. A. Souza, Mascarenhas, Andrade, and Santos (2018) were the three least cited, i.e., with only one citation (Figure 4).

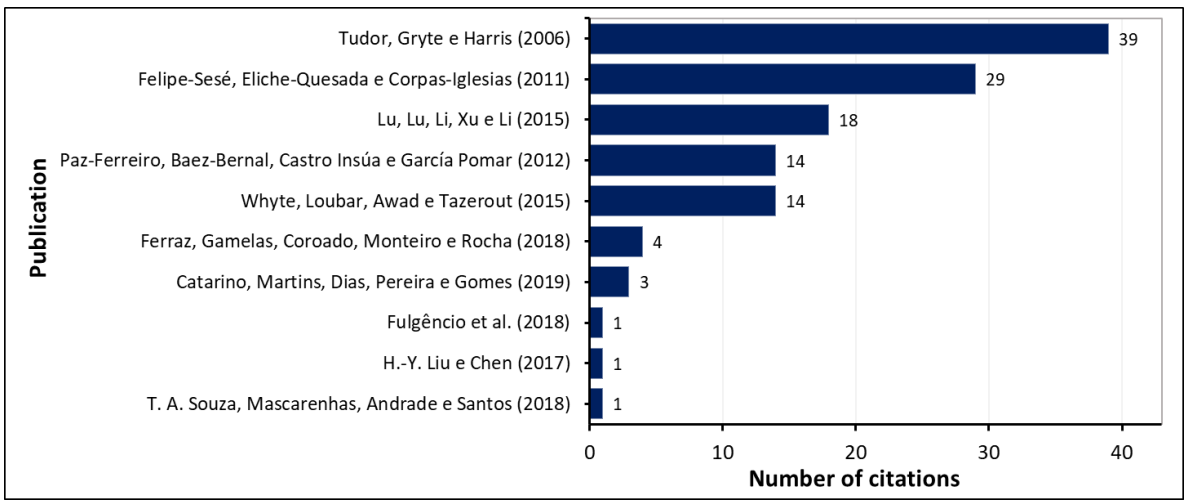


**Figure 4: Number of citations per publication on waste from shellfish harvesting and mariculture activities.**

It is important to mention that the number of citations is linked to several factors, among them the interest of the technical-scientific community in the topic, the quality of the writing, the relevance of the contributions of the work, the journal where the article was published, the form of indexing of the journal and the time of publication of the manuscript (USP Agency for Academic Information Management [AGUIA], 2016). Although the number of citations indicates a probable influence of the article in the scientific environment, it is no guarantee that the research is relevant to the area of knowledge analyzed.

Through Figure 4, it could be confirmed some aspects that interfere with the number of citations, such as the publication time of the manuscript, since the articles by H.-Y. Liu and Chen (2017), Ferraz, Gamelas, Coroado, Monteiro and Rocha (2018), Fulgencio et al. (2018), T. A. Souza, Mascarenhas, Andrade and Santos (2018) and Catarino, Martins, Dias, Pereira and Gomes (2019), published in the last three years, had few citations, well below the average of the 10 articles analyzed. In addition, the oldest publication, Tudor, Gryte, and Harris (2006), has the highest number of citations. Another circumstance that may interfere is the language in which the article was written, as papers in English tend to have a wider reach. Thus, this is a hypothesis for the fact that the article by Fulgencio et al. (2018), published in Portuguese, had only one citation.

Figure 5 presents the bibliographic coupling network of the articles. This analysis checks the relationship of the citations present in the papers, that is, it assumes that the more two papers cite the same papers the more similar they will be. In other words, the occurrence of the same citations in distinct articles converges to a greater relationship between these articles (Eck & Waltman, 2018). In view of this, it is attested that three papers have a relationship with two other papers: Lu, Lu, Li, Li, Xu, and Li (2015) with Tudor, Gryte, and Harris (2006) and Paz-Ferreiro, Baez-Bernal, Castro Insúa, and García Pomar (2012); Paz-Ferreiro, Baez-Bernal, Castro Insúa and García Pomar (2012) with Lu, Lu, Li, Xu and Li (2015) and Ferraz, Gamelas, Coroado, Monteiro and Rocha (2018); and Ferraz, Gamelas, Coroado, Monteiro and Rocha (2018) with Paz-Ferreiro, Baez-Bernal, Castro Insúa and García Pomar (2012) and T. A. Souza, Mascarenhas, Andrade, and Santos (2018).

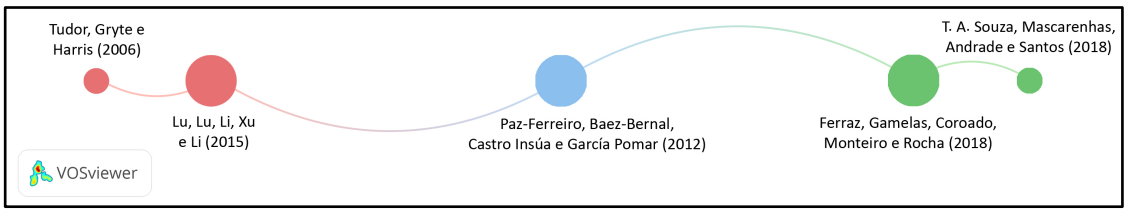


**Figure 5: Bibliographic linkage analysis of articles about residues from shellfish harvesting and mariculture activities.**

Figure 6 illustrates the most frequent terms in the titles, abstracts, authors' keywords, and database keywords, i.e., the greater the frequency of appearance of the term in the mentioned topics, the larger the size of its illustration in the figure. As more than 90% of the papers were published in English, the R Studio software (Bibliometrix package) identified few terms in Portuguese from the article by Fulgencio et al. (2018).

The words that appeared most in the titles were shell (shell), calcium (calcium), and waste (waste or residue). It was also observed terms in Portuguese from the article by Fulgencio et al. (2018), but unlike the words in English, the R Studio software (Bibliometrix package) ends up

showing words without meaning when analyzed in isolation, as in the case of the prepositions "de", "da" and "em" (Figure 6a). In the abstracts of the articles, the most prominent expressions are: shell (shell), calcium (calcium), materials (materials), catalyst (catalyst), shells (shells) and soil (Figure 6b).

For the word cloud elaborated with the authors' keywords (Figure 6c), the terms oyster shell and residues stand out. It was observed that although it is common for scientific articles to have three to five key words from the authors, this number in the articles analyzed ranged from four to 22, the highest number found in the article by Tudor, Gryte and Harris (2006). The most frequent words in the keywords entered by the database were shellfish, molluscs, article, bivalvia, calcium, nonhuman, scanning electron microscopy, shell, and wastewater treatment (Figure 6d).

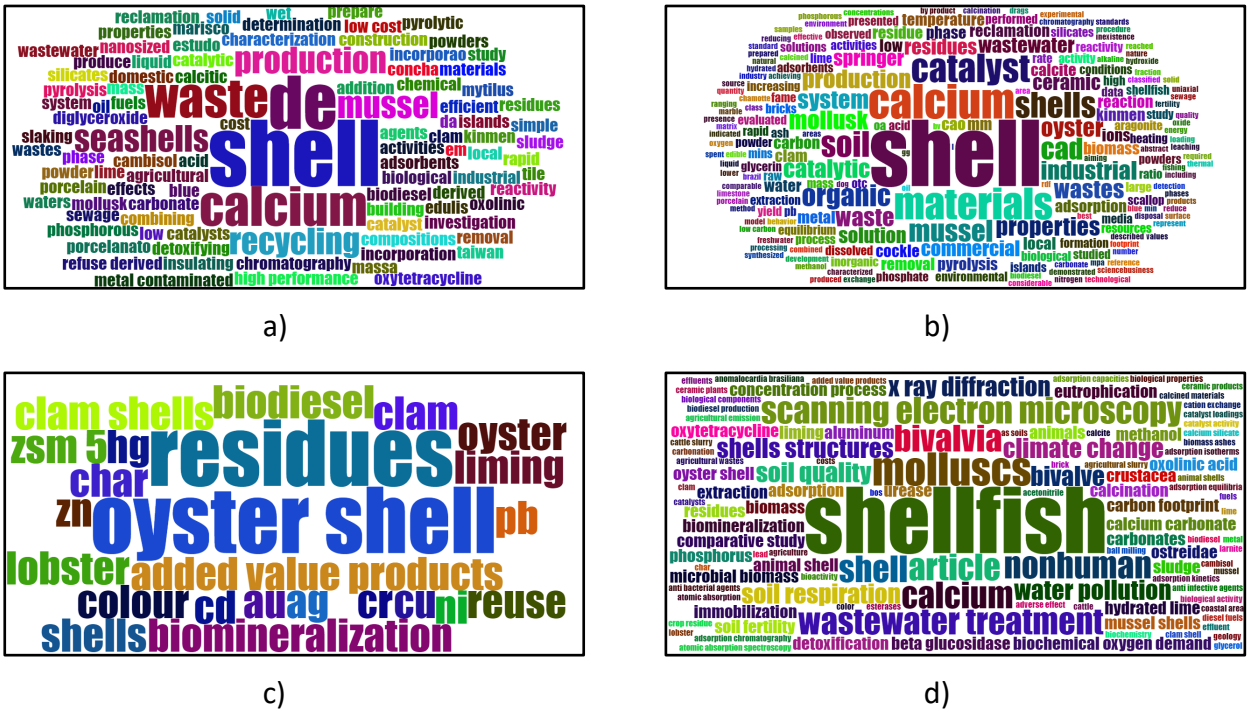


**Figure 6: Word cloud formed from - a) the titles; b) the abstracts; c) the authors' keywords; d) the database keywords, about waste from shellfish harvesting and mariculture activities.**

Thus, when analyzing the four word clouds, it can be seen that the most relevant terms for the 10 articles were shell, shellfish, oyster shell, molluscs, residues, materials, and calcium, which corroborates the choice of the keywords, residue and shellfish, in the first stage of the first phase, Identification, also confirming that the chosen terms are associated with the central axis of the research.

Table 2 illustrates the identification (according to Table 3), the place of acquisition, the application and the industrial sector investigated in each article. In total, 17 different identifications were found for the shellfish used in the analyzed papers. However, 13 shellfish were identified at the species level, and four were designated using common terms, such as shellfish, mussel, oyster, and scallop. Table 3 details the 17 identifications of the shellfish investigated in the studies, given by the species name and the common name(s) of each animal.

**Table 2: Methodological details of the selected articles.**

| Article | Seafood used | | Application | Industrial Sector |
|---|---|---|---|---|
| | Code (see Table 3) | Source | | |
| H.-Y. Liu and Chen (2017) | 12 | Kinmen Archipelago, China | Wastewater Treatment | Water and sewage |
| Catarino, Martins, Dias, Pereira, and Gomes (2019). | 17 | Food waste | Catalyst for biodiesel production | Energy |
| T. A. Souza, Mascarenhas, Andrade, and Santos (2018). | 1 e 15 | Artisanal Fishing (Bahia, Brazil) | Production of adsorbents for wastewater treatment | Water and sewage |
| Paz-Ferreiro, Baez-Bernal, Castro Insúa and García Pomar (2012) | 10 | Calizas Marinas S. A. (Boiro, Spain) | Soil improvement | Agriculture |
| Fulgencio et al. (2018) | 8 | Paraíba, Brazil | Porcelain tile production | Construction |
| Whyte, Loubar, Awad, and Tazerout (2015) | 12 | Unidentified | Catalyst for pyrolytic oil production | Energy |
| Lu, Lu, Li, Xu and Li (2015) | 16 | Freshwater Seafood Market | Calcium Carbonate Powder Production | Not specified |
| Ferraz, Gamelas, Coroado, Monteiro, and Rocha (2018). | 2, 3, 5, 6, 7, 11, 13 e 14 | Unidentified | Production of limestone | Not specified |
| Tudor, Gryte and Harris (2006) | 9 e 4 | Suppliers of seafood and restaurant food waste | Treatment of water contaminated by metals | Water and sewage |
| Felipe-Sesé, Eliche-Quesada and Corpas-Iglesias (2011) | 10 | Canneries (Galicia, Spain) | Production of calcium silicate for the manufacture of ceramic materials | Construction |

**Table 3: Breakdown of shellfish species used in the selected articles.**

| Code | Shellfish identification | |
|---|---|---|
| | Species | Common Name |
| 1 | *Anomalocardia brasiliana* (Gmelin, 1791) | Cockle, sponge, chum or sernambi |
| 2 | *Cerastoderma edule* (Linnaeus, 1758) | Cockle |
| 3 | *Crassostrea gigas* (Thunberg, 1793) | Pacific oyster |
| 4 | *Crassostrea virginica* (Gmelin, 1791) | American Oyster |
| 5 | *Donax vittatus* (Da Costa, 1778) | Puppy or Conchilla |
| 6 | *Ensis siliqua* (Linnaeus, 1758) | Longboat or razor |
| 7 | *Glycymeris glycymeris* (Linnaeus, 1758) | Castanhola |
| 8 | - | Seafood |
| 9 | *Mercenaria mercenaria* (Linnaeus, 1758) | Quahog clam or mercenary clam |
| 10 | - | Mussel |
| 11 | *Mytilus galloprovincialis* (Lamarck, 1819) | Mediterranean Mussel |
| 12 | - | Oyster |
| 13 | *Pecten maximus* (Linnaetus, 1758) | Vieira |
| 14 | *Spisula solida* (Linnaeus, 1758) | Kidney bean |
| 15 | *Tagelus plebeius* (Lightfoot, 1786) | Old claw or beach knife |
| 16 | *Tapes japonica* (Deshayes, 1854) | Manila clam or Japanese clam |
| 17 | - | Vieira |

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It was observed that the shellfish shell waste investigated in the studies had three distinct types of origin: (1) when the shellfish shells used came directly from nature, (2) when the shellfish shells were purchased from commercial outlets such as seafood stores and restaurants, and (3) when the shellfish shells were purchased from seafood processing industries. Two groups of authors did not specify the origin of the waste used in their studies.

Shellfish shell waste was investigated regarding its application in six distinct processes: wastewater treatment, biodiesel production, soil improvement for agricultural purposes, manufacture of ceramic materials, and production of calcium carbonate and lime. Thus, the articles analyzed focused on the use of shellfish shell waste in the water and sewage, energy, agriculture, and construction sectors, with water and sewage being the sector with the highest number of occurrences in the studies analyzed: three in total. The industrial sector was not identified or did not apply to the investigations in two of the 10 articles reviewed. The following are the authors' main comments regarding the results of the application of seafood waste.

According to the analysis of H.-Y. Liu and Chen (2017), the developed domestic wastewater recovery system, having shellfish shell waste as a filtering agent, presented a good performance, having a low energy consumption. Because it is compact, the authors say that it can be implemented at the wastewater generation site itself, besides having a low installation and maintenance cost, being a good option for places whose population has few financial resources, such as shellfish shell communities. Due to these characteristics, the treatment is an alternative to more conventional forms of water recovery, which besides spending more energy, generate residues from the filtering material.

Also according to H.-Y. Liu and Chen (2017), the wastewater treated in this system reached the quality required for the recharge of natural water courses and reservoirs. However, the authors emphasize the importance of optimizing the operating parameters of the system in order to maintain the quality of the recovered water. T. A. Souza, Mascarenhas, Andrade, and Santos (2018) also obtained positive results in their experiment using *Anomalocardia brasiliana* and *Tagelus plebeius* shell waste to remove phosphate from wastewater.

Furthermore, shellfish shell waste also has the potential to even reduce the load of heavy metals in the aquatic environment. In their paper, Tudor, Gryte, and Harris (2006) showed that shell waste from *Mercenaria mercenaria* reduced an initial lead concentration from 10,000 $mg.L^{-1}$ to 0.5 $mg.L^{-1}$ in less than five minutes. At higher initial concentrations of the metal, the performance of the experiment was better when *M. mercenaria* and *Crassostrea virginica shell waste* were used together. In the first hour of contact, these wastes were more effective at retaining lead than geological materials such as calcite, aragonite, and chitosan. However, after this period, calcite and aragonite became more effective in removing lead, while chitosan was not.

Besides the two mollusk species, Tudor, Gryte, and Harris (2006) also did tests with shell waste from *Homarus americanus* (H. Milne Edwards, 1837), the American lobster, but it has about 60% of the calcium carbonate content of the mollusks. As with shellfish shell waste, investigations into the use of shellfish shell waste may also suggest positive environmental and economic impacts, since shellfish are highly prized in cuisines around the world.

In the analysis of Whyte, Loubar, Awad and Tazerout (2015), oyster shell waste proved to be good catalysts for the pyrolysis process (high temperature transformation) of waste-derived fuel to produce oil. According to the authors, there was a reduction in the amount of tar produced, an unwanted byproduct in the process, and there was a greater generation of organic liquid in the transformation. After catalytic pyrolysis, it was identified that the physical properties of the oil were similar to those of conventional diesel fuel. In addition, the final composition of the oil contained chemical elements that made it a source of valuable chemicals. The process produces a gas with a high heating value that can also be used for power generation, although it contains high concentrations of carbon dioxide gas, which from an environmental point of view was not so beneficial. To the same end, the work of Catarino, Martins, Dias, Pereira, and Gomes (2019) produced a catalyst from calcium oxide from seashell waste, achieving similar results.

When applying mussel shell waste for soil correction, Paz-Ferreiro, Baez-Bernal, Castro Insúa, and García Pomar (2012) observed that the material, together with doses of residual sludge, can be used in soil liming. As results, the authors obtained improvements in soil pH and reduced aluminum concentrations. As discussed by the researchers, under very favorable conditions, in the medium term there can be an increase in soil microbial activity, which contributes greatly to its degree of fertility.

Fulgencio et al. (2018) proposed different formulations for the inclusion of calcium carbonate from seashell waste in the manufacture of porcelain tiles. According to the authors, the product met the determination of NBR 13818/1997 - Ceramic tiles for coverings: specifications and methods (Brazilian Association of Technical Standards [ABNT], 1997), when it had in its formulation up to 7% of the product from shellfish shells. In the study, experiments showed that calcium carbonate from shellfish shell waste has a regulating function, which prevents cracks in the final product. In addition, it was also observed that this application decreased the temperature of one of the process stages, leading to higher processing speed and reductions in energy consumption. Thus, the authors speak that shellfish shell waste is a promising raw material for this type of industry, i.e., this material has the potential to replace commercial calcium carbonate.

The brick produced with this waste by Felipe-Sesé, Eliche-Quesada and Corpas-Iglesias (2011) also showed a good structural quality, having as its main characteristic the capacity of thermal insulation, which leads to energy savings in buildings where they are used. Even differing in some aspects from conventional bricks, the bricks made with shellfish shell waste met the standards of the local regulatory agency.

Although they have not developed their study focusing on any specific industry, Lu, Lu, Li, Li, Xu and Li (2015) corroborate the results of the other articles analyzed in this study: shellfish shell waste has great potential to be incorporated into the production processes of various industries, making them cleaner. Moreover, Ferraz, Gamelas, Coroado, Monteiro, and Rocha (2018) share the same idea and also address the importance of recycling seashells, in terms of the absence of environmental impacts typical of limestone extraction in quarries and the reduction of energy costs. Furthermore, the lime obtained by them through the use of this waste presented a white color tone superior to that of conventional whales.

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Table 4 details the forms of shellfish shell waste treatment employed in the research.

**Table 4: Details of the treatment of shellfish shell waste used in each article.**

| Article | Treatment of shellfish shell waste |
|---|---|
| H.-Y. Liu and Chen (2017) | Burning. However, there were no details of the other procedures adopted. |
| Catarino, Martins, Dias, Pereira, and Gomes (2019). | Lime is obtained by calcination at 900 °C for 3 h. |
| T. A. Souza, Mascarenhas, Andrade, and Santos (2018). | Washed with distilled water and dried at 105 °C for 24 h. Subsequent grinding and sieving (200-325 mesh). |
| Paz-Ferreiro, Baez-Bernal, Castro Insúa and García Pomar (2012) | Washing with ordinary water, heating to 500 °C to remove organic matter and further grinding. The yield of the process was between 70 and 80 % and the final product had 90 % calcium carbonate. |
| Fulgencio et al. (2018) | Dry grinding of the shells in a disc mill to obtain a fine powder, which is then sieved to obtain particles with diameter less than or equal to 74 µm (#200). |
| Whyte, Loubar, Awad, and Tazerout (2015) | Grinding of the shells, resulting in particles of approximately 1 mm. |
| Lu, Lu, Li, Xu and Li (2015) | Washing with household detergent and hand grinding with mortar and grit hand, followed by sieving through a 180 mm sieve. The coarse powder was immersed in a 5 % aqueous sodium hydroxide solution and mechanically stirred at 85 °C for 4 h to remove the periostraco. The light yellow powder was filtered, washed with distilled water and dried overnight. |
| Ferraz, Gamelas, Coroado, Monteiro, and Rocha (2018). | Drying of the shells at 105 ± 5 °C, coarse crushing and grinding in a tungsten grinder for 3 min and sieving with 38 µm mesh. |
| Tudor, Gryte and Harris (2006) | Cleaning of the shells to remove protein residues, washing with water and drying in an oven at 50-60 °C. Subsequent grinding until particles of 125 to 250 µm are obtained. Immediate use, to avoid possible contamination. |
| Felipe-Sesé, Eliche-Quesada and Corpas-Iglesias (2011) | Grinding in a hammer mill and then a ball mill to obtain 100 mm particles. Mixing of the lime with silicon dioxide, in a molar ratio of 1: 1. Subsequent removal of moisture by heating the mixture at 110 °C for 24 h. Finally, it was placed in a laboratory oven at 1100 °C for 24 h with a heating ramp of 20 °C/min to obtain calcium silicates through a solid state reaction. |

From Table 4, it could be noted that, in general, the forms of treatment of shellfish shell waste used by the researchers of the analyzed studies consist basically in washing, drying, crushing (or grinding), and sieving. However, it could also be observed that in some articles there was the addition of some treatments, such as immersion in aqueous solution with sodium hydroxide or mixing with silicon dioxide, as happened in the works of Lu, Lu, Li, Li, Xu and Li (2015) and Felipe-Sesé, Eliche-Quesada and Corpas-Iglesias (2011), respectively. This analysis makes it evident that most of the treatments necessary for the use of this type of waste are cheap and accessible to industries and research institutions, especially.

Finally, a total of nine different journals were identified where the analyzed articles were published. With the exception of Water, Air and Soil Pollution, which had two publications, all other journals had only one publication. Regarding the Qualis/CAPES classification for the 2013-2016 quadrennium, of the nine journals that included the selected publications, only the Paddy and Water

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Environment did not have an evaluation for the areas considered in this study (Environmental Sciences and Engineering I). Six journals, on the other hand, have the 2018 CiteScore impact metric, which ranged from 3.50 (Ceramics International) to 7.32 (Journal of Cleaner Production). Nine journals were found possessing the Impact Factor 2018 metric, whose index ranged from 0.039 (Ceramics) to 6.395 (Journal of Cleaner Production) (Table 5).

**Table 5: Breakdown of journals by total articles, Qualis/CAPES ranking (2013-2016) and impact metrics.**

| Periodical | Total articles | Qualis/CAPES Classification (2013-2016 quadrennium) | | Impact Metrics | |
|---|---|---|---|---|---|
| | | Environmental Sciences | Engineering I | CiteScore 2018 | Impact Factor 2018 |
| Ceramics | 1 | B1 | B2 | - | 0.039 |
| Ceramics International | 1 | A2 | A1 | 3.50 | 3.450 |
| Chemosphere | 1 | A1 | A1 | 5.34 | 5.108 |
| Fuel Processing Technology | 1 | A1 | A2 | 4.72 | 4.507 |
| Journal of Cleaner Production | 1 | A1 | A1 | 7.32 | 6.395 |
| Journal of Environmental Chemical Engineering | 1 | A1 | B1 | 4.09 | - |
| Paddy and Water Environment | 1 | - | - | - | 1.264 |
| Waste and Biomass Valorization | 1 | B1 | A2 | - | 2.358 |
| Water, Air and Soil Pollution | 2 | A2 | A1 | - | 1.774 |

For the evaluation area Environmental Sciences of the Qualis/CAPES classification, the concept that presented the highest number of publications was A1, with a total of four papers, and the concept with fewer publications was B1, with two papers. The Engineering I assessment area, on the other hand, had four papers classified as A1 (the concept with the highest occurrence in this area) and one paper classified as B1 and B2 (two concepts with the lowest occurrence) (Figure 7). It is worth noting that the two evaluation areas of Qualis/CAPES analyzed in this study are outside the scope of the journal Paddy and Water Environment and, therefore, it did not present a concept for any of the two areas.

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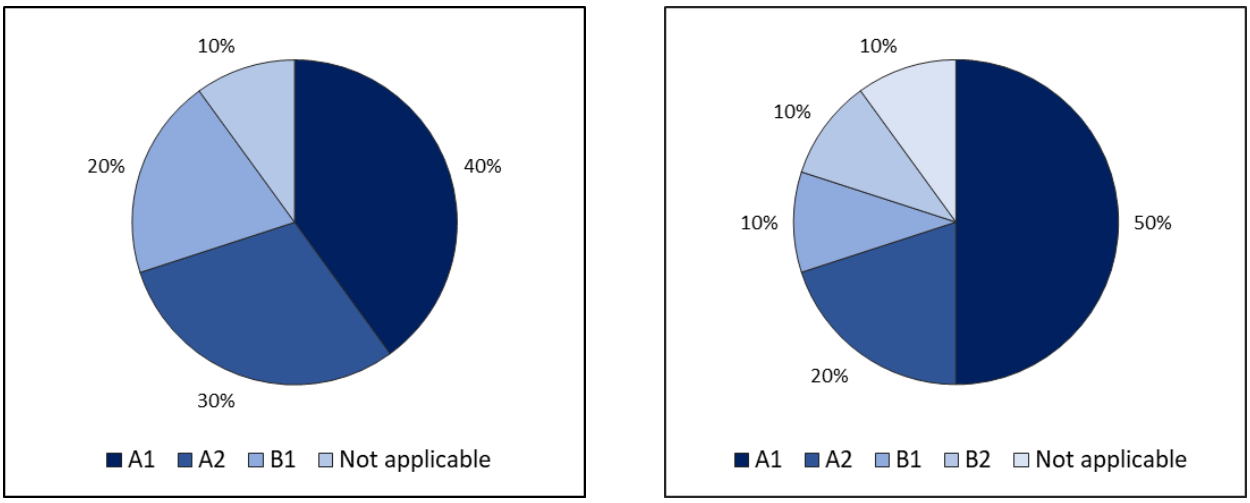


a) b)

**Figure 7: Distribution of Qualis/CAPES concept by evaluation area - a) Environmental Sciences; b) Engineering I.**

Figure 7 illustrates that, for both assessment areas, 70% of the journals where the analyzed articles were published have excellent concepts (A1 and A2) in the Qualis/CAPES classification for the 2013-2016 quadrennium, showing that the research conducted has a good quality and met rigorous assessment criteria.

## 4 CONCLUSION

The systematic review with meta-analysis proved to be an effective method for understanding the global technical and scientific panorama of the use of waste from shellfish farming and mariculture, as well as for guiding future research that seeks new scientific discoveries on the subject, since it was proven that there were few publications until the completion of this article.

The main points discussed by the authors regarding the use of shellfish shell waste are: the benefits of energy savings in various industrial processes, the abundance of this type of waste, and the reduction of environmental impacts in terms of inadequate disposal sites and the extraction of new raw materials in nature. In view of these aspects, it is of great relevance the development of norms and policies aimed at the use of these materials, especially in places where there is a large generation of this waste, but its utilization does not occur.

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