ISBN: 978-628-95207-8-1. ISSN: 2414-6390. Digital Object Identifier: 10.18687/LACCEI2024.1.1.962

Antifouling Paint Particles: Bibliometric Analysis and Brief Review of Studies in Latin America and the Caribbean

Lorgio Valdiviezo-Gonzales, Doctor[1], Nereida Llerena Valdivia, Doctor[2], Fernando García -Ávila, PhD[3], Gabriel Enrique De-la-Torre, Bachiller[4]
[1,2]Universidad Tecnológica del Perú, Perú, lvaldiviez@utp.edu, nllerena@utp.edu.pe
[3]Universidad de Cuenca, Facultad de Ciencias Químicas, Carrera de Ingeniería Ambiental, Cuenca, Ecuador,
[3]Departamento de Química Aplicada y Sistemas de Producción, Grupo de evaluación de riesgos ambientales en sistemas de producción y servicios (RISKEN), Universidad de Cuenca, Ecuador, fernando.garcia@ucuenca.edu.ec
[4]Universidad San Ignacio de Loyola, Perú, gabriel.delatorre@usil.pe

Abstract- ***Antifouling paint particles (APP) are considered highly toxic pollutants, whose presence has been reported in areas close to port activities, vessels, fishing, and maintenance. The present study aims to conduct a bibliometric study of the APP evaluation of Latin American and Caribbean research (original articles, conference papers, and reviews), published between 2011-2023, in two of the most important global academic databases, Web of Science (WoS) and Scopus. The search chain and selection of documents identified 28 articles in WoS and 21 in Scopus. Brazil is the leading country in terms of publications on this topic. The articles report values as high as 40,300 µg/g of APP in sediments, containing metals such as Cu, Zn Si, Fe, Cr, and Pb among others. Butyltin diuron, Irgarol, 4,5-dichloro-2-octyl-1,2-thiazol-3(2H)-one (DCOIT), and other biocides are also reported. Further studies are expected on toxicity and proper management of these wastes in estuaries and port areas in Latin America and the Caribbean.***

Keywords: antifouling paints, biocides, heavy metals, marine environment.

I. Introduction

Antifouling paints are used as inhibitors of biofouling that tend to adhere to boats or other structures in contact with the marine environment [1]. Inconveniences caused by biofouling on vessels include structural damage, loss of speed, and increased fuel consumption [2].

To fulfill this function, contemporary biofouling paint contains biocides based on inorganic compounds such as copper and zinc [3] among others, reinforced with organic compounds such as irgarol and diuron [4], in addition to solvents, binders, fillers, and additives, which means that it is considered a complex compound, toxic to the ecosystem and difficult to characterize.

Antifouling paint particles (APP) originate from the cleaning and maintenance of boats [5], as well as the erosion of abandoned vessels [6]. Although there is a concern about antifouling paints and their impact on the ecosystem [7], there is a paucity of studies on the abundance, distribution, and ecotoxicity of these paints in particulate form [8].

Latin America has 10 of the 66 large marine ecosystems, unfortunately, these large ecosystems are threatened by several factors, such as coastal population growth and pollution [9].

Important original articles have been reported on the identification and characterization of APP in this region. Likewise, some reviews have identified the focus of the study being biocides. Among these reviews, we have the survey elaborated by [10], including publications in Springer, Web of Science, and Science Direct on booster biocides in Latin America and the Caribbean during the last two decades. In addition, a review by [11] includes a brief history of three generations of antifouling paints and highlights the need for further studies in South America.

Therefore, there is a lack of reviews that address methodologies for identifying and characterizing APP in Latin American and Caribbean ecosystems. Because of the above, the present study aims to conduct a review with bibliometric analysis of scientific publications that include the identification, characterization, and toxicity of APP in marine ecosystems of Latin America and the Caribbean.

II. Materials and Methods

A. Search strategy

The search for indexed scientific documents was conducted in two of the main global academic databases, Scopus and Web of Science [12]. The search string included the terms (antifouling) AND (paint* OR coating) AND (particle), considering articles, reviews, and conference papers published in Latin America and the Caribbean. The publication date considered was from 2011 to November 2023. This allowed obtaining 21 documents in Scopus and 28 in WoS.

Bibliometric analysis is used to identify the annual number of publications, citations, authors with the highest

Digital Object Identifier: (only for full papers, inserted by LACCEI).
ISSN, ISBN: (to be inserted by LACCEI).
DO NOT REMOVE

number of publications and citations, institutions, and countries with the highest number of publications; more importantly, it allows stakeholders to discover emerging trends in a specific research area. Reference [13] indicated that bibliometric analysis allows us to unravel the evolutionary nuances of a specific field, as well as to identify emerging areas in that field.

C. *Information analysis*

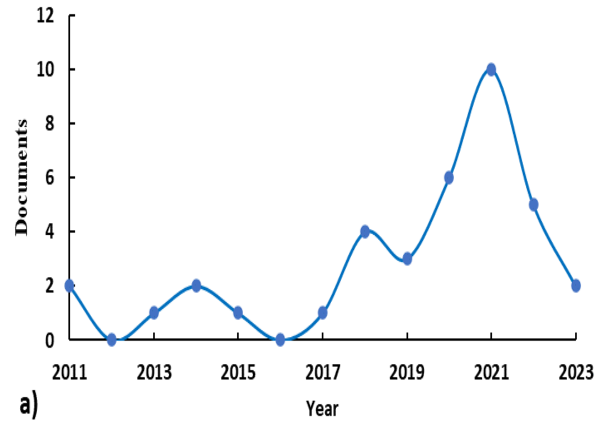
The bibliometric analysis was performed with the support of an open-source tool RStudio-Biblioshiny package version 4.1.2 software. Rstudio has been used for its relative ease of integrating documents from both academic databases and presenting tables and/or figures considering the information from both databases [14]–[16].

The present review includes the analysis of 15 original articles published in both academic databases (excluding duplicates and articles not related to the topic). The topics addressed are: Sample collection and treatment, APP characterization methodology, and reported results.

III. Result and Discussion

A. *Production of documents* and *Overlapping*

Fig. 1a shows the scientific production from 2011 to November 2023, in both academic databases, we can observe that there is increasing production of scientific papers, reaching a maximum production of 10 papers in 2021. In this regard, at a global level, an increase in publications related to marine pollution has been reported in [17], therefore, a similar impact is expected in Latin America and the Caribbean in the coming years. Fig. 1b shows the scientific papers identified in both academic databases. It is observed 12 papers published in both academic databases (duplicates). The strong overlap of scientific papers in WoS and Scopus has been reported in other engineering studies [18], [19]. In the present study, 24.5% of the documents were published in both academic databases. This indicates that many journals that publish in this field have double indexing.



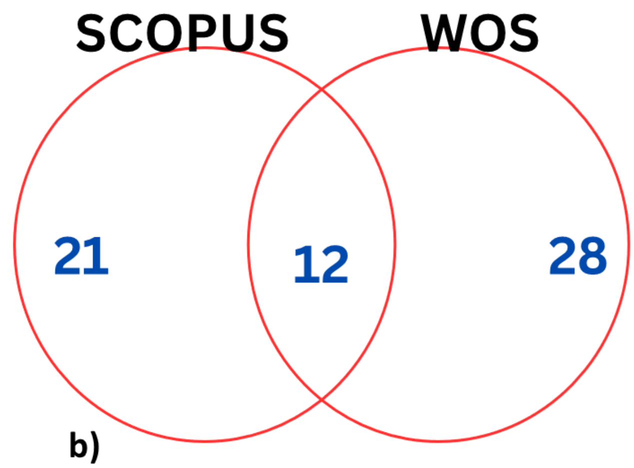


Figure 1. Scientific document productions a) Overlapping a) and b) productions by academic's base

B. *Most cited documents*

Table 1 presents the most cited papers, global citations and DOI. This information is relevant for those researchers who require an initial overview of the scientific studies with the greatest impact carried out in the region in this field of study. It also allows linking the researchers responsible for these publications and the journals that published these studies. Among the authors, Batista-Andrade J [20], who is the first author of the most cited article (90 citations at the time of writing of this study), stands out. Also, Soroldoni S, who is the author of 4 of the 10 most cited articles in this field [21]–[24].

TABLE I

MOST CITED DOCUMENTS IN WOS AND SCOPUS

Author	Global citations	DOI
[20]	90	10.1016/j.envpol.2017.11.063
[22]	70	10.1016/j.jhazmat.2017.02.001
[25]	70	10.1016/j.marpolbul.2020.111847
[26]	58	10.1016/j.jhazmat.2020.122937
[21]	53	10.1016/j.watres.2018.02.064
[27]	31	10.1016/j.ecolind.2015.05.030
[23]	31	10.1016/j.ecoenv.2017.10.060
[24]	26	10.1016/j.chemosphere.2019.124610
[28]	17	10.1016/j.marpolbul.2021.112255
[29]	17	10.1016/j.scitotenv.2019.136216

C. Journal, authors, institutions, countries with most publications, and most used keywords

Fig. 2a shows the journals with the most publications in this field. Marine Pollution Bulletin, Science of the Total Environment, and Journal of Hazardous Materials are the 3 main journals that publish studies related to APP, all of them indexed in Scopus and WoS.

Meanwhile, the three authors with the highest number of publications (Fig. 2b) are: Castro I, Fillmann G, and Soroldoni S, however, the articles produced by these authors are not necessarily the most cited (see Table 1) except for Soroldoni S, as previously mentioned.

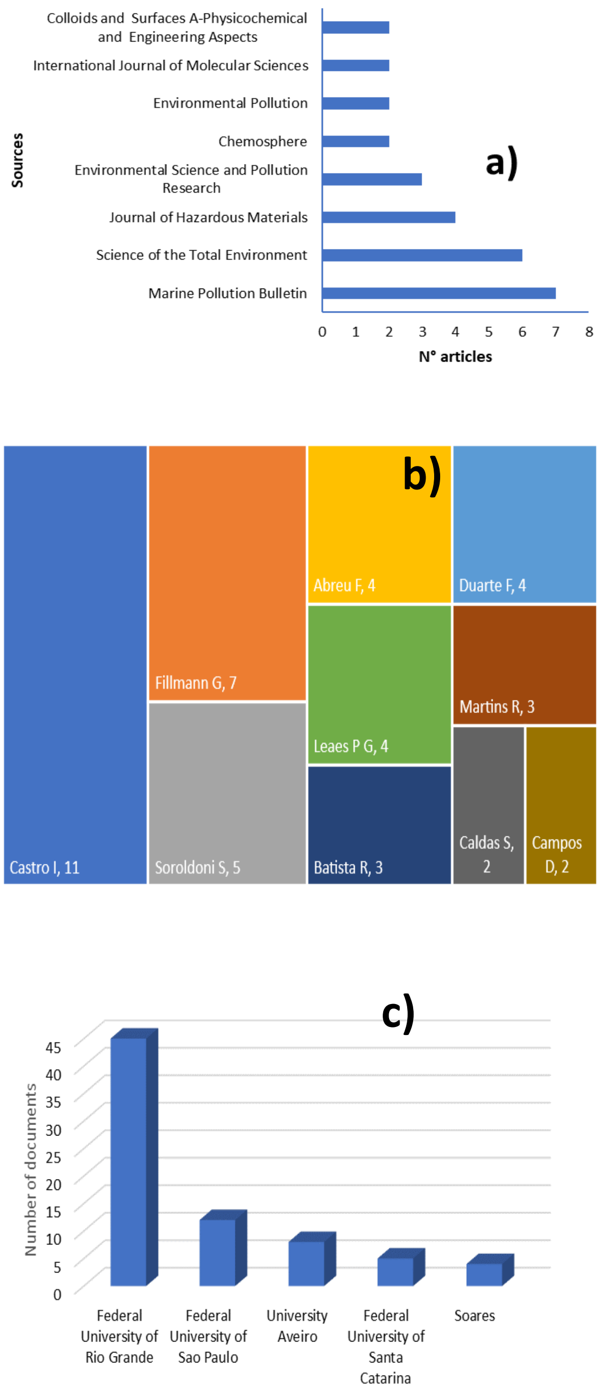
Publications with more citations may, on average, have more scientific impact, but this is not always the case [30].

Fig. 2c. shows the main institutions related to publications in the region. The federal universities of Brazil (public) stand out, among them the Federal University of Rio Grande. In Brazil, public universities are responsible for 95% of research and publish the highest quality research [31].

Fig. 2d also shows the keywords commonly used to identify published scientific papers. These include antifouling paint particles, booster biocide, and sediments. This indicates that most studies focus on the characterization of APP and the identification of biocides present in marine sediments.

Likewise, the countries with the highest number of publications are Brazil (88%), Mexico (5%), Argentina (4%) and Peru (3%) (Fig. 2e). This can be explained by the greater diversity of ecosystems and financial resources in Brazil compared to other countries in the region. According to [32], Brazil leads the region in R&D investments and scientific publications.

The bibliometric indicators presented above are especially relevant for new researchers as they provide an overview of current and future research related to this field of study. This information facilitates a quick immersion in the subject, identifying the authors and articles with the highest impact, the leading institutions concerning research on APP, and the most important research institutions in the region.



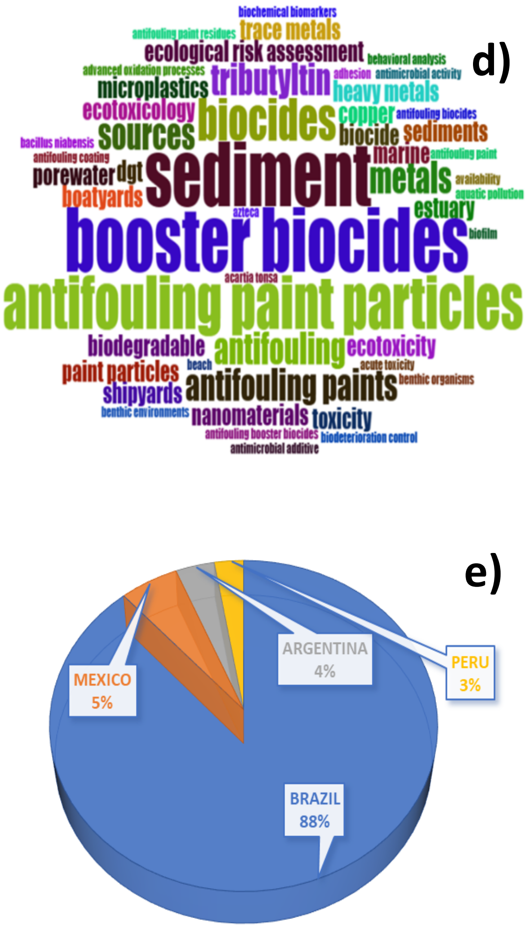


Fig. 2 Main bibliometric indicators (a) scientific journals with the highest production b) authors with the highest number of publications; c) main institutions with the highest production d) keywords commonly used e) countries with more publications

D. APP sample collection and processing

In the assessment of APPs, some studies have opted for the collection of marine sediment samples close to activities such as fishing, shipyards, and marine vessels [20], [26], [28]; while others opt for the direct collection of APP in maintenance activities or direct scraping of marine vessels [21], [22], [24], [33]. However, all these studies determine the concentration of heavy metals, due to their toxicity to the ecosystem.

Regarding the treatment of the sample, most studies follow the methodology proposed by [34], which is summarized by sieving (>500 µm) an aliquot of 100 grams of wet sediment, dried at 40°C and observed under a stereo microscope (5X), the possible APPs are weighed (>500 µm) [26] and determination of color and shape. This methodology does not allow identifying the presence of APP in particles smaller than 500 µm, underestimating the presence of these particles in the analyzed samples [26].

The determination of heavy metals present are determined by Inductively Coupled Plasma Optical Spectroscopy, ICP-OES [21], [33], Atomic Absorption Spectroscopy, AA [21] (quantitative) or X-Ray Spectroscopy, EDX (qualitative) [20], [21]. The determination of the metal and the concentration in the APPs allows the identification of the type of paint and its potential toxicity in the ecosystem.

Table 2 shows the concentrations of APPs obtained in various studies, as well as the presence of heavy metals and some associated biocides.

D. Determination of butyltin compounds and booster biocides

Determination of butyltin compounds such as tributyltin (TBT) and its degradation products: dibutyltin (DBT) and monobutyltin (MBT) have been investigated in addition to the characterization of the APP [20], [26], [28], [35]. This is explained by the high toxicity of TBT in marine ecosystems. According to [36], TBT is considered the most toxic substance intentionally introduced into the aquatic environment.

Because of this, most European countries banned the use of TBT in antifouling paints in the late 1980s and early 1990s. The International Maritime Organization banned it between 2003-2008[37]. However, due to its persistence, its presence has been identified in many parts of the world particularly in the study region.

As an alternative to TBT-based antifouling paints, copper-based antifouling compounds were proposed together with biocide enhancers such as dichlofluanid, diuron, irgarol, sea-nine and tolifluanid, among others.

Numerous studies in Latin America and the Caribbean report the presence of APPs (color, form and mass) along with the identification of booster biocides [20], [22], [26], [28], [35]. Also, noteworthy is the work carried out by [27] who evaluated the toxicity of Irgarol 1051 and Diuron, individually, on meiofauna, with emphasis on the dominant nematode assemblages: they also evaluated the toxicity of Irgarol 1051 and Diuron, individually, on meiofauna, with emphasis on the dominant nematode assemblages. Reference [38] developed an analytical method employing vortex-assisted matrix solid-phase dispersion (MSPD) for the extraction of diuron, Irgarol 1051, (TCMTB) 2-thiocyanomethylthiobenzothiazole and 4,5-dichloro-2-n-octylene from sediment samples (DCOIT). Table 2 reports the findings reported by various studies on biocidal boosters.

Likewise, Table 2 shows the potential sources of APP, especially maintenance activities, ports, shipyards, fishing vessels, etc. However, due to the fragility and low density of these wastes, transportation to nearby areas should not be ruled out.

.

TABLE II

MAIN RESEARCH RESULTS ON THE CHARACTERIZATION OF APP, BUTYLIN AND BOOSTER BIOCIDAL

Study area	Potential sources of contamination	APP, BT and booster biocides	Author(s)
Patos Lagoon Estuary, Brazil	Shipyard, maintenance activities, fishing port.	High levels of Cu (234,247 ± 268 g-1), Zn (112.404 ± 845 g-1) and DCOIT (0,13 g-1). Also identified Zn, Pb, Ni, Cr and Mn.	[22]
Patos Lagoon Estuary, Brazil	Shipyard, maintenance activities, fishing port was shown as the main source of APP.	130 -40,300 µg/g APP in sediments. Ti, Al, S, Cu y Zn in all APPs, Si and Fe were predominant. Low Cu and Zn content in the sediment APPs.	[21]
Rio Grande, Brazil	boat maintenance	Higher Zn release at low salinities and more Cu at high salinities. Mortality of 100% of *Acartia tonsa* in all salinities.	[23]
Pacific and Caribbean coasts in Panama	marinas and fishing and commercial vessels	Irgarol 1051 and Diuron. Levels > environmental limits	[20]
Estuarino de Santos and São Vicente-Brazil	Shipyards, recreational boats, marinas, fishing.	APP between 4.8-5248 µg/g, the highest concentration in areas near the shipyards (> 1500 µg/g). Presence of diuron, Irgarol, DCOIT and dichlofluanid) and BT	[26]
Patos Lagoon Estuary, Brazil	Shipyard, maintenance activities, fishing ports	Presence of high levels of Cu y Zn. *M. schubarti* was more sensitive than *H. azteca*.	[24]
Bahia Guanavara, RJ, río Itajaí-Açu SC and Patos Lagoon Estuary, Brazil	The number of shipyard areas, which vary depending on the period and the intensity of the ships' activity.	The highest concentrations of labile metals were found in the shipyards with the longest operating histories.	[29]
Estuarino de Vitoria, sureste de Brazil	Shipyard, marina and fishing port	APP <0.01 and 5,969 µg/g. The biocides found were DCOIT, diuron, dichlofluanid, Irgarol and chlorothalonil (> LD) in 64%, 36%, 29%, 29% and 14%, respectively.	[28]
Yucatan Peninsula, Mexico	Fishing and boat maintenance activities	Imposex in caenogasteropods, high concentrations of BT. APP at 15/19 sites studied (> 1600 µg g-1).	[35]
Belém, Pará (PA), north of Brazil.	ship abandonment is a major source of pollution in shipyard areas.	29,588 mg kg-1 of Ba, 9,350 mg kg-1 of Zn, 1,097 mg kg-1 of Pb and 548 mg kg-1 of Cr	[33]

IV. CONCLUSIONS

The presence of highly toxic components linked to antifouling paints such as heavy metals, butyltin and booster biocides have aroused the interest of researchers in Latin American and Caribbean countries, as evidenced by the increase in publications in recent years. Brazil presents the country with the highest number of research, with an important contribution of researchers from the Federal University of Rio Grande. Marine Pollution Bulletin presents the largest number of publications on this subject.

The studies relate the evaluation of antifouling paints, identification of metals, butyltin compounds and booster biocides, as evidenced by the keywords most frequently found in the publications, demonstrating a close relationship between these terms.

Concentrations of up to 40,300 µg/g APPs in marine sediments have been reported, as well as the presence of metals such as Cu, Ni, Fe, Cr, Al, S, Ni, Mg, Pb and butyltin compounds. While the booster biocidal includes diuron, Irgarol, DCOIT and dichlofluanid. In addition, studies have shown the toxicity of these biocides. Therefore, APPs prove to be a constant source of contamination to the marine ecosystem and should be further characterized.

Further studies are expected in Latin America and the Caribbean given the relevance of the subject and the growing concern of scientists about these particles and their toxicity.

ACKNOWLEDGMENT

The authors express their deep gratitude to the Universidad Tecnológica del Perú for the financial support that allowed the execution of this research

REFERENCES

[1] F. J. Kroon *et al.*, "Sources, presence and potential effects of contaminants of emerging concern in the marine environments of the Great Barrier Reef and Torres Strait, Australia," *Sci. Total Environ.*, vol. 719, p. 135140, 2020, doi: https://doi.org/10.1016/j.scitotenv.2019.135140.

[2] A. Kotrikla, "Environmental management aspects for TBT antifouling wastes from the shipyards," *J. Environ. Manage.*, vol. 90, pp. S77–S85, 2009, doi: https://doi.org/10.1016/j.jenvman.2008.07.017.

[3] H. Okamura and H. Mieno, "Present Status of Antifouling Systems in Japan: Tributyltin Substitutesin Japan BT - Antifouling Paint Biocides," I. K. Konstantinou, Ed. Berlin, Heidelberg: Springer Berlin Heidelberg, 2006, pp. 201–212.

[4] L. D. Chambers, K. R. Stokes, F. C. Walsh, and R. J. K. Wood, "Modern approaches to marine antifouling coatings," *Surf. Coatings Technol.*, vol. 201, no. 6, pp. 3642–3652, 2006, doi: https://doi.org/10.1016/j.surfcoat.2006.08.129.

[5] A. Turner, "Marine pollution from antifouling paint particles," *Mar. Pollut. Bull.*, vol. 60, no. 2, pp. 159–171, Feb. 2010, doi: 10.1016/J.MARPOLBUL.2009.12.004.

[6] A. B. Rees, A. Turner, and S. Comber, "Metal contamination of sediment by paint peeling from abandoned boats, with particular reference to lead," *Sci. Total Environ.*, vol. 494–495, pp. 313–319, 2014, doi: https://doi.org/10.1016/j.scitotenv.2014.06.064.

[7] M. Lagerström, M. Norling, and B. Eklund, "Metal contamination at recreational boatyards linked to the use of antifouling paints—investigation of soil and sediment with a field portable XRF," *Environ. Sci. Pollut. Res.*, vol. 23, no. 10, pp. 10146–10157, 2016, doi: 10.1007/s11356-016-6241-0.

[8] F. G. Torres and G. E. De-la-Torre, "Environmental pollution with antifouling paint particles: Distribution, ecotoxicology, and sustainable alternatives," *Mar. Pollut. Bull.*, vol. 169, p. 112529, 2021, doi: https://doi.org/10.1016/j.marpolbul.2021.112529.

[9] N. P. Muñoz Sevilla and M. Le Bail, "Latin American and Caribbean regional perspective on Ecosystem Based Management (EBM) of Large Marine Ecosystems goods and services," *Environ. Dev.*, vol. 22, pp. 9–17, 2017, doi: https://doi.org/10.1016/j.envdev.2017.01.006.

[10] J. C. Almeida, Í. B. Castro, B. Z. Nunes, and E. Zanardi-Lamardo, "Antifouling booster biocides in Latin America and the Caribbean: A 20-year review," *Mar. Pollut. Bull.*, vol. 189, p. 114718, Apr. 2023, doi: 10.1016/J.MARPOLBUL.2023.114718.

[11] Í. B. Castro, E. Westphal, and G. Fillmann, "Tintas anti-incrustantes de terceira geração: novos biocidas no ambiente aquático," *Quim. Nova*, vol. 34, no. 6, pp. 1021–1031, 2011, doi: 10.1590/S0100-40422011000600020.

[12] J. Zhu and W. Liu, "A tale of two databases: the use of Web of Science and Scopus in academic papers," *Scientometrics*, vol. 123, no. 1, pp. 321–335, 2020, doi: 10.1007/s11192-020-03387-8.

[13] N. Donthu, S. Kumar, D. Mukherjee, N. Pandey, and W. M. Lim, "How to conduct a bibliometric analysis: An overview and guidelines," *J. Bus. Res.*, vol. 133, pp. 285–296, 2021, doi: https://doi.org/10.1016/j.jbusres.2021.04.070.

[14] A. Caputo and M. Kargina, "A user-friendly method to merge Scopus and Web of Science data during bibliometric analysis," *J. Mark. Anal.*, vol. 10, no. 1, pp. 82–88, 2022, doi: 10.1057/s41270-021-00142-7.

[15] H. Kasaraneni and S. Rosaline, "Automatic Merging of Scopus and Web of Science Data for Simplified and Effective Bibliometric Analysis," *Ann. Data Sci.*, 2022, doi: 10.1007/s40745-022-00438-0.

[16] S. Echchakoui, "Why and how to merge Scopus and Web of Science during bibliometric analysis: the case of sales force literature from 1912 to 2019," *J. Mark. Anal.*, vol. 8, no. 3, pp. 165–184, 2020, doi: 10.1057/s41270-020-00081-9.

[17] S. Thanuskodi, "Authorship Pattern and Degree of Collaboration in Marine Pollution Research," in *Challenges and Opportunities of Open Educational Resources Management,* 2020, pp. 162–183.

[18] L. G. Valdiviezo Gonzales, F. F. García Ávila, R. J. Cabello Torres, C. A. Castañeda Olivera, and E. A. Alfaro Paredes, "Scientometric study of drinking water treatments technologies: Present and future challenges," *Cogent Eng.*, vol. 8, no. 1, p. 1929046, Jan. 2021, doi: 10.1080/23311916.2021.1929046.

[19] L. G. Valdiviezo Gonzales, C. A. Castañeda-Olivera, R. J. Cabello-Torres, F. F. García Ávila, R. V. Munive Cerrón, and E. A. Alfaro Paredes, "Scientometric study of treatment technologies of soil pollution: Present and future challenges," *Appl. Soil Ecol.*, vol. 182, p. 104695, 2023, doi: https://doi.org/10.1016/j.apsoil.2022.104695.

[20] J. A. Batista-Andrade, S. S. Caldas, R. M. Batista, I. B. Castro, G. Fillmann, and E. G. Primel, "From TBT to booster biocides: Levels and impacts of antifouling along coastal areas of Panama," *Environ. Pollut.*, vol. 234, no. September 2008, pp. 243–252, 2018, doi: 10.1016/j.envpol.2017.11.063.

[21] S. Soroldoni *et al.*, "Antifouling paint particles: Sources, occurrence, composition and dynamics," *Water Res.*, vol. 137, pp. 47–56, 2018, doi: 10.1016/j.watres.2018.02.064.

[22] S. Soroldoni, F. Abreu, Í. B. Castro, F. A. Duarte, and G. L. L. Pinho, "Are antifouling paint particles a continuous source of toxic

chemicals to the marine environment?," *J. Hazard. Mater.*, vol. 330, pp. 76–82, 2017, doi: 10.1016/j.jhazmat.2017.02.001.
[23] S. Soroldoni, S. E. Martins, I. B. Castro, and G. L. L. Pinho, "Potential ecotoxicity of metals leached from antifouling paint particles under different salinities," *Ecotoxicol. Environ. Saf.*, vol. 148, no. November 2017, pp. 447–452, 2018, doi: 10.1016/j.ecoenv.2017.10.060.
[24] S. Soroldoni, S. Vieira da Silva, Í. B. Castro, C. de Martinez Gaspar Martins, and G. L. Leães Pinho, "Antifouling paint particles cause toxicity to benthic organisms: Effects on two species with different feeding modes," *Chemosphere*, vol. 238, pp. 1–9, 2020, doi: 10.1016/j.chemosphere.2019.124610.
[25] C. C. Gaylarde, J. A. B. Neto, and E. M. da Fonseca, "Paint fragments as polluting microplastics: A brief review," *Mar. Pollut. Bull.*, vol. 162, p. 111847, Jan. 2021, doi: 10.1016/J.MARPOLBUL.2020.111847.
[26] F. E. L. Abreu, J. N. Lima da Silva, Í. B. Castro, and G. Fillmann, "Are antifouling residues a matter of concern in the largest South American port?," *J. Hazard. Mater.*, vol. 398, no. January, p. 122937, 2020, doi: 10.1016/j.jhazmat.2020.122937.
[27] F. Gallucci, I. B. De Castro, F. C. Perina, D. M. De Souza Abessa, and A. De Paula Teixeira, "Ecological effects of Irgarol 1051 and Diuron on a coastal meiobenthic community: A laboratory microcosm experiment," *Ecol. Indic.*, vol. 58, pp. 21–31, 2015, doi: 10.1016/j.ecolind.2015.05.030.
[28] F. E. L. Abreu, R. M. Batista, Í. B. Castro, and G. Fillmann, "Legacy and emerging antifouling biocide residues in a tropical estuarine system (Vitória state, SE, Brazil)," *Mar. Pollut. Bull.*, vol. 166, no. December 2020, 2021, doi: 10.1016/j.marpolbul.2021.112255.
[29] A. Valero *et al.*, "Potential availability of trace metals in sediments in southeastern and southern Brazilian shipyard areas using the DGT technique and chemical extraction methods," *Sci. Total Environ.*, vol. 710, p. 136216, 2020, doi: 10.1016/j.scitotenv.2019.136216.
[30] L. Waltman, N. J. van Eck, and P. Wouters, "Counting publications and citations: Is more always better?," *J. Informetr.*, vol. 7, no. 3, pp. 635–641, 2013, doi: https://doi.org/10.1016/j.joi.2013.04.001.
[31] M. Lloyd, "Las Políticas de Fomento a la Ciencia y Tecnología en México y Brasil: Un Estudio de Caso de la Universidad Autónoma Nacional de México y la Universidad de Saõ Paulo [Science and Technology Policies in Mexico and Brazil: A Case Study of the National Auton," Universidad Nacional Autónoma de México., 2013.
[32] S. Olavarrieta and M. G. Villena, "Innovation and business research in Latin America: An overview," *J. Bus. Res.*, vol. 67, no. 4, pp. 489–497, 2014, doi: 10.1016/j.jbusres.2013.11.005.
[33] R. H. E. Guimarães, M. Wallner-Kersanach, and J. A. M. Correa, "Assessment of anthropogenic metals in shipyard sediment in the Amazon delta estuary in northern Brazil," *Environ. Sci. Pollut. Res.*, vol. 29, no. 51, pp. 77007–77025, 2022, doi: 10.1007/s11356-022-20960-1.
[34] C. K. Takahashi, A. Turner, G. E. Millward, and G. A. Glegg, "Persistence and metallic composition of paint particles in sediments from a tidal inlet," *Mar. Pollut. Bull.*, vol. 64, no. 1, pp. 133–137, 2012, doi: https://doi.org/10.1016/j.marpolbul.2011.10.010.
[35] R. G. Uc-Peraza, V. H. Delgado-Blas, J. Rendón-von Osten, Í. B. Castro, M. C. Proietti, and G. Fillmann, "Mexican paradise under threat: The impact of antifouling biocides along the Yucatán Peninsula," *J. Hazard. Mater.*, vol. 427, no. December 2021, 2022, doi: 10.1016/j.jhazmat.2021.128162.
[36] E. D. Goldberg, "TBT: An Environmental Dilemma," *Environ. Sci. Policy Sustain. Dev.*, vol. 28, no. 8, pp. 17–44, Oct. 1986, doi: 10.1080/00139157.1986.9928814.
[37] M. A. Champ, "A review of organotin regulatory strategies, pending actions, related costs and benefits," *Sci. Total Environ.*, vol. 258, no. 1, pp. 21–71, 2000, doi: https://doi.org/10.1016/S0048-9697(00)00506-4.
[38] S. S. Caldas, B. M. Soares, F. Abreu, Í. B. Castro, G. Fillmann, and E. G. Primel, "Antifouling booster biocide extraction from marine sediments: a fast and simple method based on vortex-assisted matrix solid-phase extraction," *Environ. Sci. Pollut. Res.*, vol. 25, no. 8, pp. 7553–7565, 2018, doi: 10.1007/s11356-017-0942-x.