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Monitoring marine environments with Autonomous Underwater Vehicles: A bibliometric analysis

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ABSTRACT

A sustainable and effective monitoring of the environment is necessary to assess its current status. In particular, marine ecosystems are more and more subjected to external inputs and pollutants in general, which may considerably affect their biodiversity and the regularity of their processes, with consequences on the global system. Autonomous Underwater Vehicles are frequently used to perform research and monitoring operations, being usually more cost-effective and less time-consuming than the traditional methods. In this study, the global scientific literature on the employment of AUVs for the environment is explored. The bibliometric analysis on the networks between authors, countries, journals and keywords related to the topic allowed to verify the major research interests and assess the current weaknesses on which researcher are currently focused. This approach proved to be a promising way for exploring the scientific literature by applying systems thinking in bibliometric science.

1. Introduction

The sustainability and management of natural resources is regularly cited as the biggest problem of our generation [1], since the importance of their preservation is increasing everyday more. In particular, the sustained and cost-effective monitoring of the marine environment is becoming one of the main goals of researchers. Sea and land waters provide energy and resources to humans, as they are used for agricultural activities or for raw materials extraction [2]. Examples include aquacultures fish farming and offshore oil production [3]. Furthermore, the ocean plays a crucial role as an indicator for climate change [3], other than being home of a wide variety of animals and florae species which have to be preserved. As a fundamental component of the global ecosystem, it is thus important to assess the health status of the marine environment, with the aim of detecting and understanding reasons and consequences of both natural- and anthropogenic-induced changes [4]. In the past, marine pollution and its related issues have been analysed through the study of the environment composition. Nowadays, these techniques have been improved thanks to the recent advances in technology: in this sense, the combinations of appropriate sets of chemical and biological data efficiently monitor the environment [4], outlining the impact of hazardous substances on marine processes and organisms [5]. On this basis it is then possible to reduce pollutants inputs into waters (especially from maritime and industrial activities) [6] and to develop methods to avoid waste production [7]. As a natural consequence, the need to provide regulatory actions and remedial responses is gaining the priority among the agencies worldwide. The European Environment Agency (EEA), for example, gives independent information on the environment to support sustainable development [8], aiming at significantly improving European environmental status. In partnership with EEA, the Water Information System for Europe (WISE) specifically focuses on water quality assessment reports, which can only be obtained through the continuous analysis of data collected at sea [9]. To these days, sea surveys have generally been conducted onboard research vessels, thus requiring high resources management and costs other than long preparation periods [3]. Recent developments in the robotic field made marine drones an efficient alternative to the traditional approaches. In particular, Autonomous Underwater Vehicles (AUVs) provided scientists with a powerful tool for oceanographic research, changing the way ocean science is conducted [1]. In the last years, in fact, AUVs have been largely employed in various fields. Some of the main examples include military and surveillance tasks, forest fire observation, aerial surveys and of course environmental monitoring. Among their useful characteristics, the AUVs ability to follow and control their trajectory together with the possibility to provide the platform with a wide variety of instrumentation and sensors make them well suited to collect different typologies of data

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[10]. In spite of the exceptional results obtained by the researchers, the optimization of AUVs performances at sea still remains a challenging task, and the potential for further innovation is still wide-ranging [11]. To assess the current AUVs employment in environmental monitoring operations and to investigate any possible future working areas, this paper presents the results of a bibliometric analysis made on this topic. In the last years, this kind of approach has given remarkable performances in trends analysis of large amounts of data [12]. The statistical techniques employed in bibliometrics to assess research quality and developments are combined with the social network analysis (SNA), which allows to investigate social structures and relations [13]. In the case of academic literature, this methodology provides a quantitative analysis of a topic of interest. The outcome of the bibliometric analysis is in fact an evaluation of the existing networks among researchers, countries, organizations or keywords dealing with the specific field of science [14,15]. In this study, the results of the bibliometric analysis of the global scientific literature on AUVs and environmental monitoring is presented.

Table 1
VOSviewer terminology [16].

Term	Description
Items	Chosen object (e.g. publications, researchers, organizations, keywords).
Link	Relation between two items (e.g. co-occurrence of keywords).
Link strength	Positive numerical value defining the attribute of each link. In the case of co-occurrence of keywords links, higher value means high number of publications reporting the keywords.
Network	Set of items connected by their links.
Cluster	Sets of items of the map. An item can be part of only one cluster.
Number of links	Number of links between two items.
Total link strength	The total links strength of a single items with the others.

Table 2
VOSviewer performed analysis [16].

Analysis type	Description
Co-authorship	The connection between researchers or countries is made through the number of jointly authored publications.
Co-occurrence	The number of co-occurrences is defined on the basis of the number of publications in which both the keywords occur together in the title, abstract or keyword list.
Citation	Two items are linked if at least one cites the other.

2. Methodology

2.1. Bibliometric analysis

The bibliometric network analysis was performed using VOSviewer software (version 1.6.13). This tool elaborates the bibliometric network data to obtain clusters-based maps which allows an easy classification of the outputs. Once the topic of interest is identified, different target can be investigated. Table 1 shows the main technical terms of the software. The clusters-structured resulting maps are sized basing on the total link strength; the thickness of the lines connecting the nodes is determined by the link strength. To modify the level of detail of the results, and then the number of displayed clusters, the resolution parameter value can be set basing on the needs: high value means high resolution and then high number of clusters. The analysis of this work is based on the co-authorship, co-occurrence and citation analyses to provide the networks of: (1) the co-occurrence of keywords, (2) the co-authorship among researchers and countries and (3) cited scientific journals (Table 2). The resolution applied in this study is set as 1, as default of VOSviewer.

2.2. Bibliographic data acquisition

The data used in this research were collected on the Scopus web search engine on January 16th, 2020. The search string was composed by the terms Autonomous Underwater Vehicle* OR AUV* AND environment**. The * symbol is intended to substitute an eventual letter and comprehend both the AUV and AUVs terms. The results were exported as. csv files after selecting Citation information, Bibliographical information, Abstract & keywords, and Include references.

3. Results and discussion

3.1. Temporal trend analysis

In addition to the bibliometric network analysis, the temporal trend of publications related to AUVs used for environmental tasks has been investigated. Fig. 1 shows the number of papers per year. Being still in progress, the year 2020 was not considered.

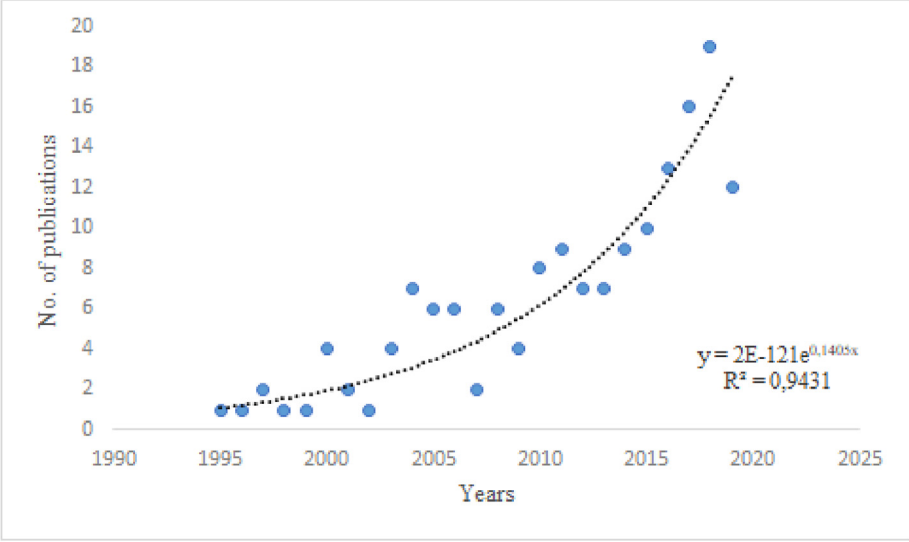


Fig. 1. Temporal trend of scientific articles published on “AUV” and “Environment”.

3.2. Bibliometric network analysis

This section contains the analysis of the five maps generated through bibliometric network analysis. Tables 3–7 show items classification according to different weight attributes (number of documents, citations, and total link strength).

Co-occurrence analysis of keywords The analysis of the co-occurrence of keywords produced 2183 results. Applying a threshold of 5 occurrences, 64 keywords were selected and grouped into 4 clusters (Fig. 2). The first 15 keywords by total link strength are listed in Table 3. Keywords ranking higher by total link strength reflect the topics most related to the deployment of AUVs for environmental monitoring tasks. As confirmed by the results in Table 3, AUVs and ROVs (Remoted Operated Vehicles) are widely used for the monitoring of the environment, especially for oceanography- and biology-related research (see the words oceanography, animals, nonhuman, water pollution"). Being specific for each typology of study, the underwater equipment mounted on board has a great interest among researchers, as it strictly affects the vehicle efficiency. Moreover, it has to be noticed the link strength of the words "underwater acoustics": in fact, this method stands at the basis of many underwater localization techniques, together with those based on inertial and visual data [17]. Despite the exceptional progresses made in this area, however, navigation and positioning of underwater vehicle still remains a challenging task for researchers [18].

Citation analysis of documents The 10 most cited documents dealing with the topic of AUV used for environmental-related tasks are listed in Table 4. The paper Remote environmental monitoring units: An autonomous vehicle for characterizing coastal environments published in Journal of Atmospheric and Oceanic Technology by Moline M. A. et al. (2005) is the most cited. The paper with the highest number of links (3) is instead Integration of scientific echo sounders with an adaptable autonomous vehicle to extend our understanding of animals from the surface to the bathypelagic published in Journal of Atmospheric and Oceanic Technology by Moline M. A. et al. (2015). Fig. 3 shows the largest set of connected documents (only 8).

Co-authorship analysis of authors The co-authorship analysis of authors produced 611 results. Among them, 24 authors met the threshold of a minimum of 3 published documents, while documents with a number of co-authors greater than 25 were excluded. The largest set of connected authors is composed by 7 authors, divided into 4 clusters and shown in the network map (Fig. 4a). The top 10 authors are reported in Table 5 ranked by number of citations.

Co-authorship analysis of countries The co-authorship analysis of countries revealed that 14 out of 36 countries published at least 3 articles

Table 3
First 15 results of the co-occurrence analysis of keywords, ordered by total link strength.

Keyword	Total Link Strength	Occurrence
Environmental monitoring	518	115
AUV	442	118
Article	143	19
Oceanography	120	23
ROV	112	21
France	100	16
Controlled study	93	10
Underwater acoustics	93	18
Underwater equipment	89	17
Animals	83	11
Procedures	82	9
Nonhuman	81	8
Water pollution	80	9
Monitoring	79	16
Auvergne-Rhone-Alpes	76	9

Table 4
Most cited documents on the topic of AUV and "Environmental monitoring".

Document	Citations	Links
Moline M. A. (2005)	80	2
Dunbabin M. (2005)	78	0
Robbins I. C. (2006)	60	1
Prestero T. (2001)	57	0
Stokey Roger (1997)	51	0
Marthiniussen R. (2004)	48	0
Short R. T. (1999)	45	0
Huavenne V. A. I. (2016)	41	1
Harvey J. B. J. (2012)	39	1
Marco D. B. (1996)	31	0

Table 5
First 10 items of the co-authorship analysis of authors ordered by number of citations.

Authors	Citations	Documents	Total Link Strength
Moline M. A.	181	4	6
Bett B. J.	51	3	4
Huvenne V. A. I.	51	3	4
Ura T.	33	3	0
Maehle E.	31	6	0
Bose N.	30	4	1
Campos R.	26	3	0
Amory A.	22	4	0
Gasparoni F.	21	8	0
Jaramillo S.	19	3	3

Table 6
First 10 items of the co-authorship analysis of countries ordered by number of citations.

Countries	Citations	Documents	Total Link Strength
United Kingdom	113	12	8
United States	648	51	8
Australia	123	7	5
Canada	64	10	5
Portugal	58	9	2
Germany	36	9	1
Spain	54	5	1
China	60	14	0
France	113	18	0
Italy	59	15	0

Table 7
First 10 items of the co-authorship analysis of authors ordered by number of citations.

Source	Documents	Citations	Total Link Strength
Sea technology	7	7	0
Oceans Conference Record (IEEE)	6	137	0
Science of the total environment	5	44	0
Marine Pollution Bulletin	4	16	0
Journal of atmospheric and oceanic technology	3	101	0
MTS/IEEE Oceans 2015	3	8	0
MTS/IEEE Oceans 2012	3	19	0
Plos one	3	24	0
Proceedings of the 2000 international symposium on underwater technology	3	24	0
Proceedings on the international offshore and polar engineering conference	3	18	0

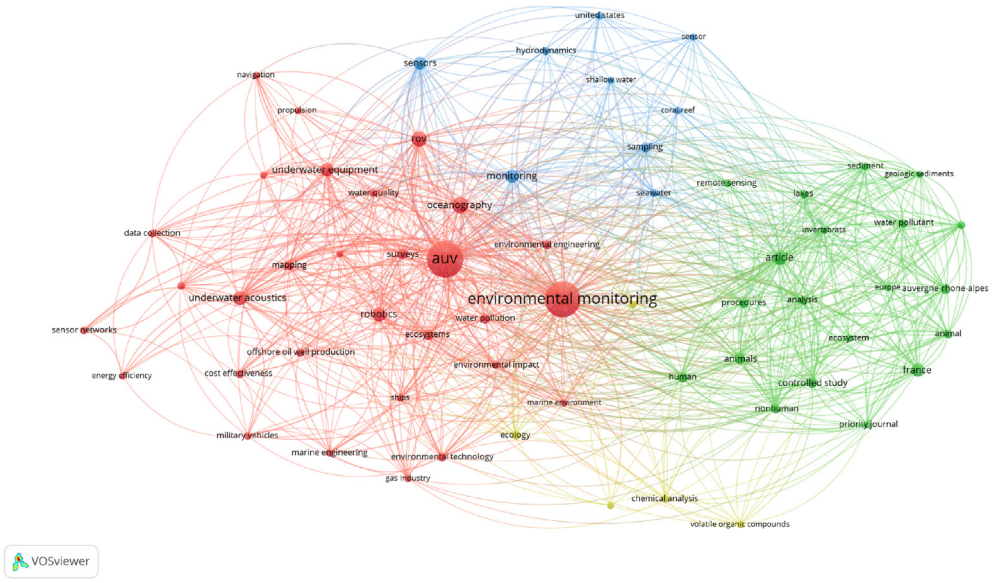


Fig. 2. Keywords network.

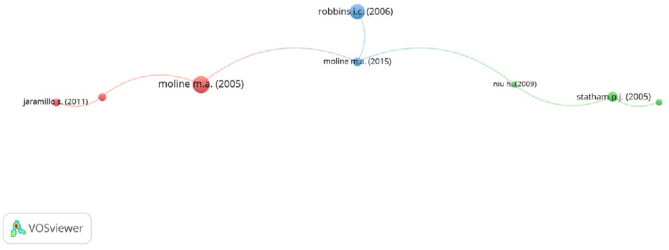


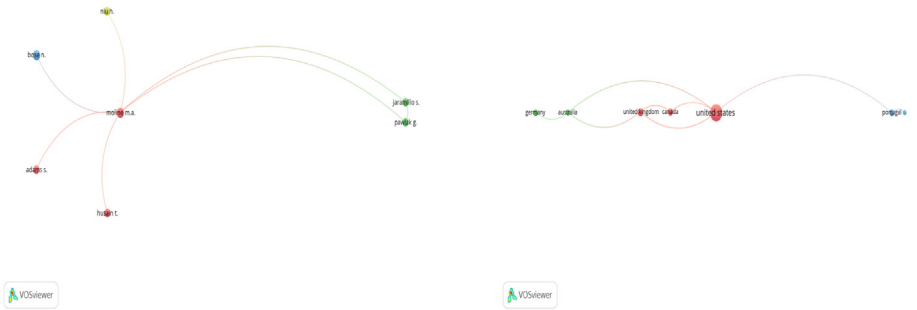
Fig. 3. Most cited documents on the topic of AUV and "Environmental monitoring".

on environmental monitoring exploited by AUVs. The network map shows that only 7 of the 14 elements are linked and divided into 3 clusters: Fig. 4b only reports the clusters. Table 6 shows the first 10 countries ordered by total link strength. The results highlight the leading role of United Kingdom and United States as they are much more connected to other countries than the others. China, France and Italy, even if not in the network, published more documents than the UK, collecting a high number of citations.

Citation analysis of journals The citation analysis of journals resulted in an overall number of 118 journals, among which 11 met the minimum threshold of 3 published articles. The first 10 journals ranked by number of produced documents are shown in Table 7: none of them results to be linked, reason why no figure is here provided.

4. Conclusions

This study presents the results of a bibliometric analysis made to assess the current global scientific literature on the topic of AUVs deployed for environmental monitoring. The software "VOSviewer" has been used to elaborate the data acquired from the Scopus web search engine to obtain clusters-based maps representing the existing network among researchers, countries, organizations and keywords dealing with the topic. This allows a quantitative analysis of the results, which can help to identify possible developments and further works of interest for the scientific community. In this case, the evaluation of the networks confirmed that there is a strong connection between the AUVs and the environmental monitoring, being them widely used for most of the related task. However, the shortage of links between countries and journals, other than the publication year of the articles, suggests that much more work could be done to improve the results achieved in the field, especially when it comes to collaborations among different institutions. Moreover, the optimization of underwater systems concerning both the equipment of the vehicle and its positioning represents an important issue, being the efficiency of the AUV and the consequent success of the mission strictly related to it.



(a) Co-authorship analysis of the authors. (b) Co-authorship analysis of the countries.

Fig. 4. Network analysis of Authors and Countries.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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