Exploring the development of scientific research on Marine Protected Areas: from conservation to global ocean sustainability

Picone F.[a,c], Buonocore E.[a,c,*], Chemello R.[b,c], Russo G.F.[a,c], Franzese P.P.[a,c]

[a] UNESCO Chair in "Environment, Resources and Sustainable Development", Department of Science and Technology, Parthenope University of Naples, Centro Direzionale, Isola C4, 80143 Naples, Italy.
[b] Conservation Ecology Lab, Department of Earth and Marine Sciences, University of Palermo, via Archirafi 22, 90123 Palermo, Italy.
[c] CoNISMa, Piazzale Flaminio 9, 00197 Roma, Italy.

Abstract

Marine Protected Areas (MPAs) are playing a central role in the achievement of ocean sustainability and, since 2000, their global coverage has increased over ten times. The success of MPAs, and therefore the delivery of their potential outcomes for human well-being and global sustainability, requires multi-disciplinary, holistic, and comprehensive approaches for its achievement. In this study, the global scientific literature on MPAs was quantitatively reviewed through bibliometrics approaches, investigating patterns and trends in its development over time. In particular, bibliometric network and citation burst analyses of keywords were performed using VOSviewer and CiteSpace software. The bibliographic search on the Scopus and WoS database resulted in a total number of 5908 and 6036 scientific documents published on MPAs. Results showed a multidisciplinary structure of MPA science, in which the ecological, social, and economic domains of research are strongly interconnected. Temporal analyses showed a recent focus on social-ecological systems theory and related fields, suggesting that newer research lines recognize the importance of integrating the human dimension in conservation and sustainability studies. Overall, the results of both the performed bibliometric analyses pointed out the evolution of MPA science from the conventional concept of "marine reserves" to a broader scope integrating ecological, economic, and social aspects. In conclusion, MPA research is timely responding to the identification of MPAs as ocean sustainability tools, opening MPA science to multi-disciplinary research lines by linking the ecological and socio-economic dimensions of sustainability. MPA research is expected to play a crucial role in generating the interdisciplinary scientific knowledge needed to fully contribute to global ocean sustainability and human well-being.

Keywords: Marine Protected Areas, nature conservation, bibliometric analysis, VOSviewer software, CiteSpace software, ocean sustainability.

* Corresponding Author: Elvira Buonocore, E-mail: elvira.buonocore@uniparthenope.it

1. Introduction

Responding to the global need of promoting the sustainable development of human societies, international environmental commitments such as the United Nations Sustainable Development Goals (SDGs) (UN, 2015) and the Aichi Biodiversity Targets of the Convention on Biological Diversity (CBD, 2011) have been made under the Strategic Plan for Biodiversity 2011-2020. Recognizing the fundamental role of marine natural capital for human development and well-being, specific conservation and sustainability objectives were set for the global ocean. In particular, SDG 14 Target 5 and Aichi Biodiversity Target 11 share the objective of conserving at least 10% of coastal and marine areas by 2020 and protecting areas of particular importance for biodiversity and ecosystem services through effectively and equitably managed systems of protected areas (CBD, 2011; UN, 2015).

Marine Protected Areas (MPAs) are among the main solutions identified to achieve these targets, being indeed acknowledged as management tools of the seascape effectively able to protect marine biodiversity and sustainably regulate human activities (Lubchenco and Grorud-Colvert, 2015). MPAs can be defined as "discrete geographic areas of the sea, established by international, national, territorial, tribal, or local laws and designated to enhance the long-term conservation of natural resources therein" (Claudet, 2011). They are established to protect marine biodiversity, natural capital, ecosystem services, and cultural values from the variety of anthropogenic threats on coastal and offshore marine ecosystems (Agardy et al., 2003; Buonocore et al., 2019, 2020a,b; Claudet, 2011; Franzese et al., 2017; Picone et al., 2017). Over the last years, MPAs have been gaining growing interest from scientists, managers, and policy makers and, since 2000, their coverage has increased over ten times reaching the 7.91% of the global ocean, of which more than half established after 2011 (i.e., the starting year of the Strategic Plan for Biodiversity). Such results are due to both an expansion of already existing MPAs and the establishment of new ones (www.protectedplanet.net/marine). This increasing trend worldwide, along with the success of the multi-disciplinary concept of ecosystem services started after the release of the Millennium Ecosystem Assessment's final report in 2005 (MA, 2005; Pauna et al, 2018), has given rise to broader research on MPAs integrating ecological and socio-economic studies through the assessment of the benefits humans receive from the exploitation of natural ecosystems. The intertwined linkages between the sustainable management of natural resources and the social and economic development suggest a driving role of MPAs for the livelihoods of coastal communities

(OECD, 2017). Recent scientific research has been showing how successful MPAs can benefit not only biodiversity but also people through several positive well-being outcomes, potentially leading to win-win situations (Ban et al., 2019; Chaigneau and Brown, 2016). Tourism and fishing sectors in coastal communities are typically favored by the protection of marine natural capital through the establishment of MPAs (Ojea et al., 2017: Pascual et al., 2016). Nonetheless, the contributions of successful MPAs to sustainability are broad and not limited to the economic sector, encompassing also social, health, culture, governance, and environmental domains, indicating therefore the multi-dimensional role of MPAs. Mono-disciplinary approaches are evidently not fully suited for the holistic study of MPAs, missing the comprehensiveness that is required to include all dimensions of sustainability (Christie, 2004; Giakoumi et al., 2018). Indeed, sustainability science underpins the major challenge of integrating ecological, economic, and socio-cultural domains, recognizing their interconnectedness at different scales. The success of MPAs, and therefore the delivery of their potential outcomes for human well-being and global sustainability, requires multi-disciplinary, holistic, and comprehensive approaches for its achievement (Ban et al., 2019; Rasheed, 2020).

Considering the importance of MPAs for the achievement of local and global sustainability goals, it is expected that the scientific literature on this topic will continue increasing over the next years. The integration of social network analysis with bibliometric science has proved to be a useful tool to quantitatively assess trends and patterns in the scientific literature (Buonocore et al., 2018; Cordeiro, 2019; Pauna et al., 2018, 2019; Skaf et al., 2020).

The aim of this study is to explore the global scientific literature on MPAs investigating its development over time. For this goal, a quantitative review of MPA scientific literature was performed by applying bibliometric techniques and social network analysis to identify patterns and trends in past and present MPA science.

2. Materials and Methods

To achieve the objective of the study, a bibliometric analysis of the global scientific literature on MPAs was conducted. Scientific documents were collected on January 15th, 2020 from the Scopus and Web of Science databases. The researches were performed searching for the string “marine protected area*” on documents title, abstract and keywords.

The metadata of the research on Scopus database were exported as ".csv" files after selecting the "Citation information", "Bibliographical information", and "Abstract & keywords" options. Results were then analyzed by means of VOSviewer (version 1.6.13) (van Eck and Waltman, 2019), a software tool designed to create network maps based on bibliographic data. Network maps are generated so that the position of the items displayed (e.g., keywords, authors, countries) is assigned accordingly to the strength of their relatedness. Strongly related items are located close to each other, while weakly related ones are positioned distantly (van Eck and Waltman, 2014). Items are also univocally assigned to clusters, each composed by a set of closely related items (van Eck and Waltman, 2014).

To investigate the trends of the main topics related to MPA research, the co-occurrence map of the authors' keywords was generated. Co-occurrence networks of keywords are based on the number of publications in which two keywords occur together in the title, abstract or keyword list, quantitatively expressing their connection. To visualize the 50 most important keywords, a minimum threshold of 36 occurrences was set. Clustering resolution was lowered from 1 (i.e., default value) to 0.85 to optimize the number of clusters displayed. In addition, the overlay visualization of VOSviewer was applied to allow for the representation of the network items on a time gradient expressing how the co-occurrence of the network items has evolved over time. This visualization feature is based on the average publication year of the documents in which the keywords occurred. Finally, a thesaurus file unifying keywords referring to the same topic was used to avoid repetitions in the generated network map and properly display the results.

The metadata of the research on the Web of Science (WoS) database were exported as "plain text" file and analyzed by means of CiteSpace (version 5.6.R2) (Chen, 2006; Chen, 2017), a software tool designed to perform systematic scientometric reviews. In particular, the "citation burst" analysis was performed to show fast growing topics across the 1990-2019 timespan in the scientific literature on MPAs, selecting those referring directly or indirectly to the human dimension. This analysis allows for the identification of the keywords that experienced an abrupt increase in the number of citations in the investigated literature. A minimum of 1-year burst was set to perform a more detailed analysis.

3. Results and Discussion

The bibliographic search on the Scopus database resulted in 5908 scientific documents published in a timeframe ranging from 1983 to 2020. Of the 10,760 authors' keywords, 50 were displayed according to the occurrences threshold set (Fig. 1, Table 1).

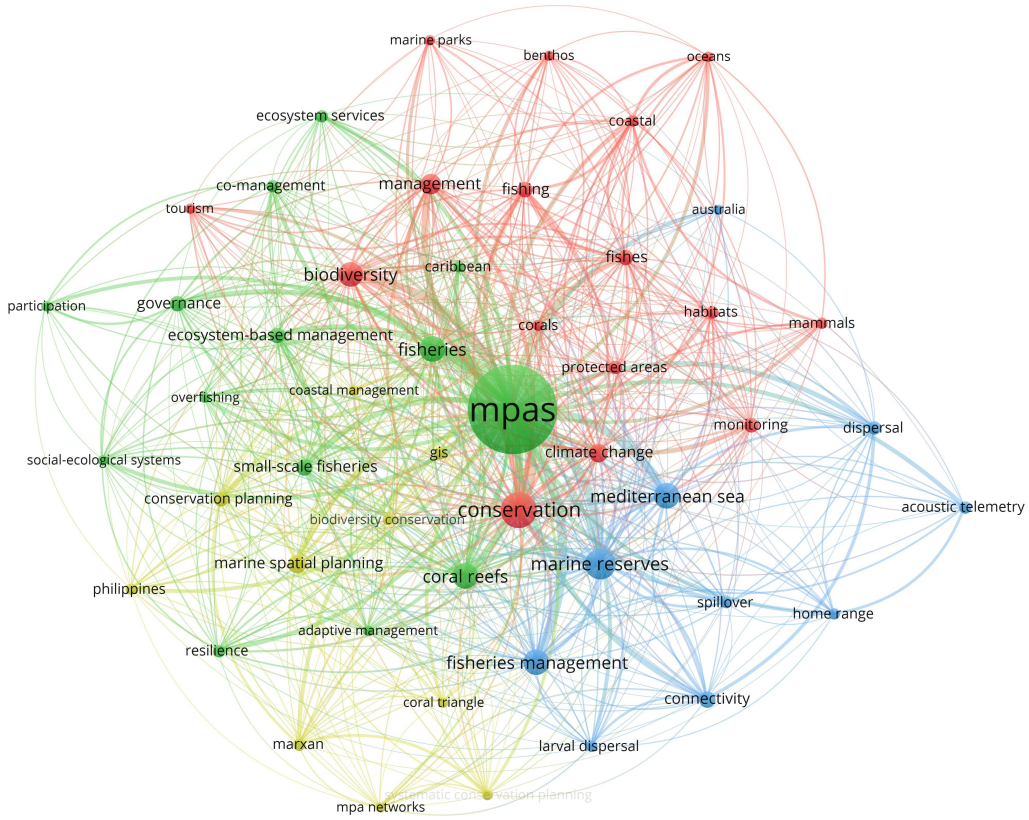

Figure 1. Co-occurrence network map of keywords in the global scientific literature on MPAs. The size of each keyword (node) in the network is directly proportional to its number of occurrences in the documents analyzed. Colors indicate clusters to which keywords are univocally assigned based on their reciprocal relatedness.

Table 1. Clusters and relative keywords resulting from the co-occurrence analysis of keywords.

Cluster	Color	Keywords
1	red	benthos, biodiversity, climate change, coastal, conservation, corals, fishes, fishing, habitats, mammals, management, marine parks, monitoring, oceans, protected areas, tourism
2	green	adaptive management, Caribbean, co-management, coral reefs, ecosystem services, ecosystem-based management, fisheries, governance, MPAs, overfishing, participation, resilience, small-scale fisheries, social-ecological systems
3	blue	acoustic telemetry, Australia, connectivity, dispersal, fisheries management, home range, larval dispersal, marine reserves, Mediterranean Sea, spillover
4	yellow	biodiversity conservation, coastal management, conservation planning, coral triangle, GIS, marine spatial planning, Marxan, MPA networks, Philippines, systematic conservation planning

In the co-occurrence map, the 50 resulting authors' keywords were grouped in 4 different clusters and sized proportionally to their number of occurrences (Fig. 1, Table 1). Cluster 1 broadly focuses on topics linked to biodiversity and conservation, showing keywords referring to ecological features acknowledged as conservation targets such as "corals", "fishes", "mammals", and "habitats", but also to conservation practices like "management", "monitoring", "protected areas", and "marine park". Cluster 2, the one including the central keyword "MPAs", is strongly oriented towards topics that focus on the inclusion of the human component in ecosystems, e.g., "social-ecological systems", "participation", "co-management", and "ecosystem services". Cluster 3 includes the keyword "marine reserves", closely connected to MPAs, and it is mainly focused on spillover-related research, showing keywords such as "dispersal", "larval dispersal", and "home range". Cluster 4, as cluster 1, also includes the topic of biodiversity conservation, but in this case as a single keyword and in relation to conservation planning and spatial design of MPAs, as shown by the presence of "fisheries management", "systematic conservation planning", "GIS", "marine spatial planning", and "Marxan". In addition, the first three clusters have keywords explicitly linked to fishing, highlighting the importance and transdisciplinarity of this topic in the context of MPAs. In fact, the keyword "fisheries" ranked 4th by number of links after "MPAs", "marine reserves", "conservation", and "Mediterranean Sea", showing connections with all 4 clusters of the map. Among its more frequent co-occurrences, meaningful are those with "management" and "governance", pointing out the management of fishing activities as one of the main goals of MPAs. Visually, clusters 1, 2, and 4 show a high degree of overlapping as some keywords are placed in between the network areas of the three clusters. Cluster 2 (in green) partially overlaps with both

clusters 1 (in red) and 4 (in yellow). The intersection area between clusters 2 and 1 is highly interconnected and shows “biodiversity” placed among “co-management”, “ecosystem services”, “management”, “fisheries”, “coastal management”, “ecosystem-based management”, and “governance”, reflecting the role of MPAs in the protection of the marine biodiversity through the regulation of human activities. Clusters 2 and 4 are the most overlapping, with a wide network area that focuses on research topics connected to the social-ecological systems concept. In this section, “small-scale fisheries” is the only stakeholder category explicitly shown in the map. The keyword resulted strongly connected to “fisheries management”, “co-management”, “Mediterranean Sea”, and “conservation”, expressing the importance of implementing co-management strategies for biodiversity conservation in coastal marine ecosystems, especially in environments characterized by high levels of anthropogenic pressure such as the Mediterranean basin.

As regards cluster 3, except from the keyword “Australia”, there is no overlapping with the other clusters, suggesting a lower overall relatedness of its topics to the others found in the map. The high degree of overlapping of clusters 1, 2, and 4, and the thick web of connections of the network map confirm the interconnectedness of MPAs research topics, as well as the interdisciplinary nature and the high relatedness of their keywords. Overall, the whole left part of the network map of Figure 1 shows a strong presence of topics related to social-ecological theory and marine spatial planning in MPA scientific research. Both research areas entail the common element of the inclusion of human component in nature conservation and management of natural resources, representing a key issue in sustainability science.

Figure 2 shows the overlay visualization feature based on the year of documents publication, providing a temporal perspective for the interpretation of the co-occurrence network map of keywords. The distribution of the keywords along a temporal gradient allowed for the understanding of the evolution in MPA scientific research, identifying the most recent topics and research path. The overlay visualization map shows a recent focus on those concepts that include the human dimension such as “ecosystem services”, “marine spatial planning”, “social-ecological systems”, “systematic conservation planning”, and “Marxan” (Fig. 2). Instead, other keywords like “ecosystem-based management”, “adaptive management”, and “conservation” are equally distributed along the publication timeframe, suggesting a homogeneous pace of occurrence in MPA literature.

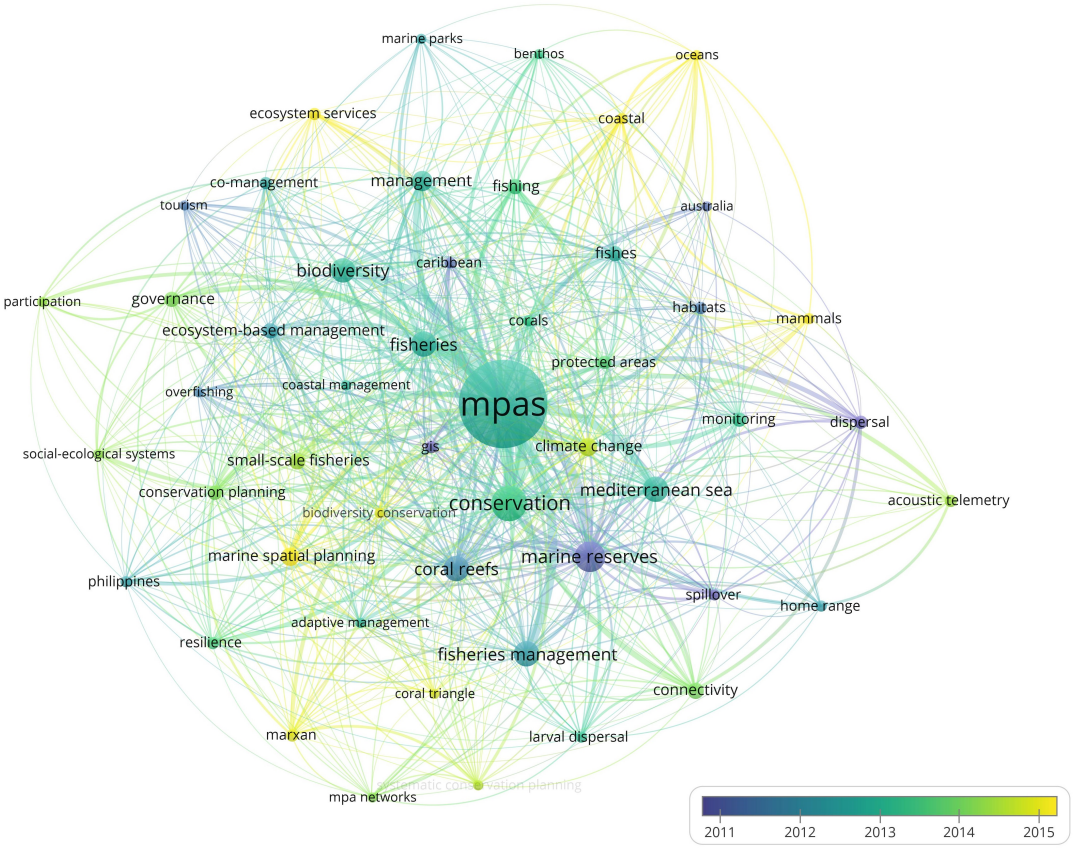

Figure 2. Overlay visualization of the co-occurrence network map of keywords. Keywords are represented based on the average year of publication of documents they occur in, on a color gradient from blue (older publications), to green (publications equally distributed across the timespan), to yellow (more recent publications).

As shown in Figure 1, previously seen, the central keywords “MPAs” and “marine reserves” are strongly related, considering both the closeness of their locations in the network map and the thickness of their connection (high link strength, i.e., high number of co-occurrences). Nonetheless, the overlay map shows a temporal divergence in their co-occurrence (Fig. 2). While “MPAs” is placed in the middle of the temporal spectrum of publication (included in all documents since it corresponds to the search string), the average of occurrences of the keyword “marine reserves” is instead shifted towards the past. The simultaneous presence of the two keywords “MPAs” and “marine reserves” in MPA related scientific literature occurred more before 2011 which, as previously stated, was the starting year of the Strategic Plan for Biodiversity decade. Overall, the left part of the network map in Figure 2 (clusters 2 and 4) included research topics more recently investigated in MPA science, as it is the case of “social-ecological systems”, “ecosystem services”, “systematic conservation planning”, and “marine spatial planning”.

The citation burst analysis (Fig. 3) performed on documents collected from the WoS database showed consistency with the bibliometric network analysis, pointing out a recent focus of scientific research on the integration of the human dimension in conservation. The bibliographic search resulted in 6036 documents, in which 217 keywords experienced a citation burst across the investigated timespan. Among these, a set of 35 keywords involving, directly or indirectly, the human dimension in MPA literature was selected (Fig. 3). Their temporal distribution across the years shows a pattern of increasing interest towards the human dimension of MPA research over time (Fig. 4). The first burst keyword was "human exclusion", which had a burst period of 10 years, from 1996 to 2006. It was followed by "human impact" (2002-2008), "marine reserve" (2003-2007), "fisheries management" (2003-2009), and "closed area" (2004-2005). Even if human related, these keywords focus on the issue of protecting and conserving natural resources from human impacts. Around 2006, when "sustainable development" (2006-2008) appears, the perspective is inverted. Indeed, the burst of keywords such as "systematic conservation planning", "marine spatial planning", "conflict", "stakeholder", "social-ecological systems", "ecosystem services", "human dimension", "small-scale fishery", and "trade-off" points out a different viewpoint on the human component of marine and coastal ecosystems in MPA science. Under this new perspective, local coastal communities are part of the system to be protected and conserved, and uses and biodiversity conservation need to be sustainably balanced. It is worth noting also the presence of the "Aichi Biodiversity Target 11", which proves the relatedness of this sustainability target with MPAs and the attention that the scientific community has been placing upon it.

Figure 3. Citation burst analysis of keywords related to the human dimension in the MPA scientific literature. For each keyword, the burst strength and timespan are shown.

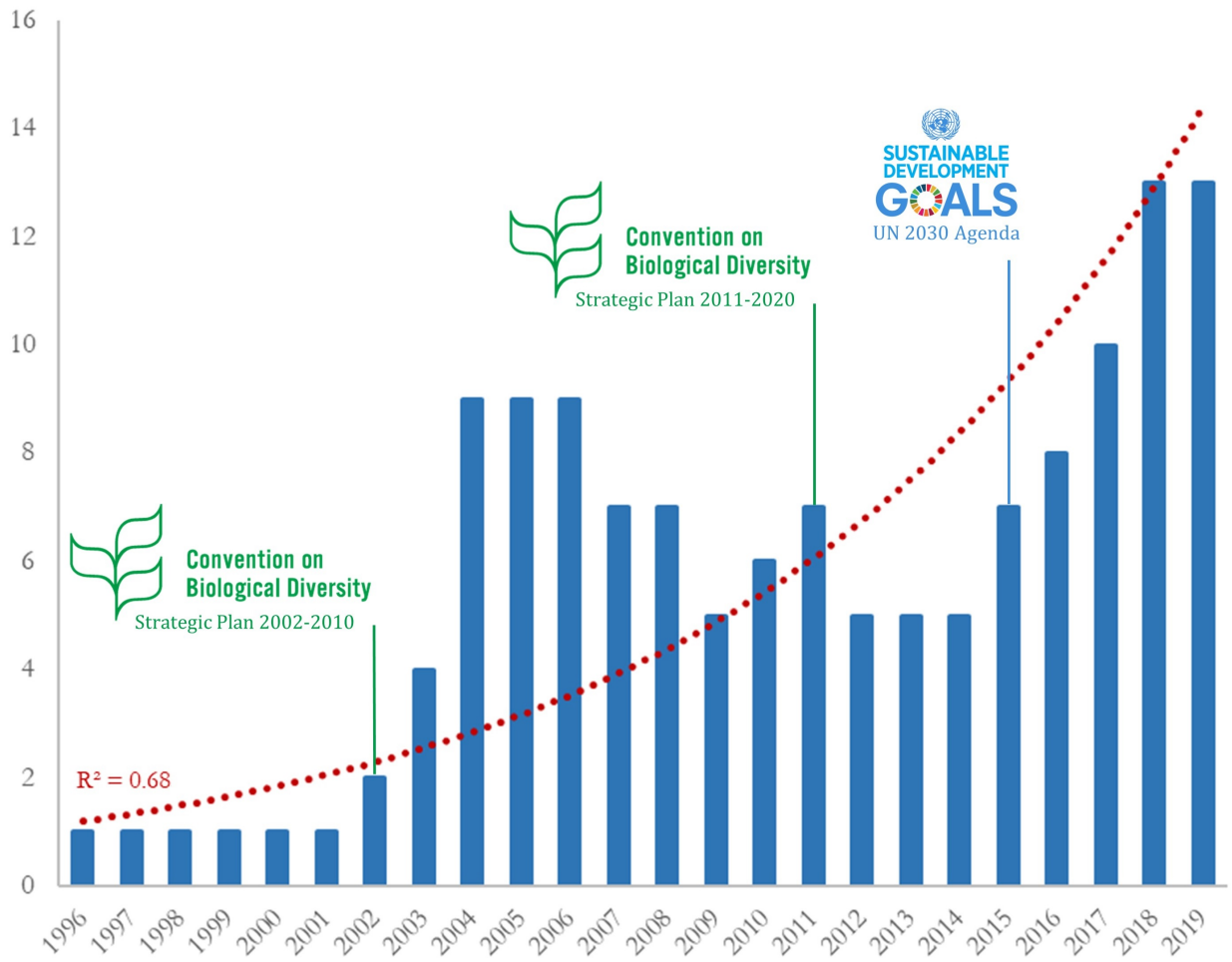

Figure 4. Temporal trend of human related keywords that experienced a citation burst in MPA scientific literature.

Overall, the results of both the performed bibliometric analyses pointed out the evolution of MPA science from the conventional concept of "marine reserves" to a broader scope integrating ecological, economic, and social aspects. These patterns and trends in MPA science are to be framed in the broader context of the evolution of conservation science that, until a few decades ago, used to identify reserves as management tools intended strictly for nature conservation purposes. The exclusion of the human presence was aimed at avoiding anthropogenic impacts on biodiversity and natural resources, thus preserving the natural environment. In recent years, conservation science has been conceiving reserves as management tools aimed at improving the sustainability of human uses by solving trade-offs between conservation goals and use (Claudet, 2011), identifying also in conflict resolution a crucial factor for the success of conservation strategies (Margules and Pressley, 2000). The outcomes of this study confirm this paradigm shift

in conservation theory, entailing a re-thinking of the protection of the marine environment, linking conservation to all dimensions of sustainability. Placing equal importance to the ecological and social domains, social-ecological systems theory (Berkes and Folke, 1998; Ostrom, 2009) provided a strong input to open MPA science to social-ecological research lines and foster MPAs as tools to address ocean and coastal sustainability. Indeed, by recognizing the decisive influence of humans on natural systems and, at the same time, their dependence upon natural resources and processes, social-ecological systems are considered as the analytical unit for the study of sustainability (Folke, 2006; Gallopín, 1991). Marine reserves in which all extractive uses are forbidden (i.e., no-take zones or fully protected areas) are not fully suitable to holistically address sustainability in marine and coastal social-ecological systems. The integration of the human dimension in conservation objectives entailed the development of more complex and multi-use conservation tools characterized by different protection zones where human uses are regulated. The rather recent focus of MPA research on marine spatial planning corroborates this pattern. MPAs are one of the area-based management possibilities of the seascape encompassed by marine spatial planning, a process accounting for both protection and multi-use objectives, aiming at balancing conservation and sustainable use of the ocean by planning and regulating all human activities (Ehler and Douvere, 2011).

Overall, the analysis of the scientific literature on MPA showed a wide variety of topics pertaining to different disciplines as well as a strong connection among them. The temporal analyses pointed out how MPA research is timely responding to the identification of MPAs as ocean sustainability tools by expanding the fields of study in MPA science and opening it to multi-disciplinary research lines, linking and integrating ecological, social, and economic domains.

4. Conclusions

This study explored the variety of topics investigated in the MPA scientific research, providing also a temporal perspective on their evolution over time. The bibliometric analyses allowed for the quantification and visualization of the multi- and trans-disciplinary development of MPA science over time. The study also highlighted that the expansion of research frontiers in MPA science occurred concurrently to international political commitments aimed at fostering the sustainable use of the global ocean. Shifting the focus of marine conservation from ecosystems to social-

ecological systems, the human dimension changed from being excluded to playing an essential role in the development of conservation strategies while the concept of "marine reserves" gave way to the broader concept of MPAs. Acknowledged nowadays as key elements of global ocean sustainability strategies, the political and scientific attention on MPAs worldwide is higher than ever. In the upcoming decade 2021-2030, also called "Ocean Decade" by the United Nations, MPA research is expected to play a crucial role in generating the interdisciplinary scientific knowledge needed to fully contribute to global ocean sustainability and human well-being.

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