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Two decades of research on ocean multi-use: achievements, challenges and the need for transdisciplinarity

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This paper offers a comprehensive, analytical, and critically informed overview of the current state of ocean multi-use research. It delves into the origins, trajectory, and driving forces behind this emerging research field, all within the broader context of investigations addressing the management of increasingly diverse and intensifying activities at sea. The Bibliometrix R package is employed to analyze the social, geographical, and conceptual dimensions of multi-use scientific production. The results obtained are then compared to a larger corpus of publications focusing on both multiple-use Marine Protected Areas (MPAs) and Marine Spatial Planning (MSP). Finally, the paper addresses research gaps, with a particular emphasis on the transdisciplinary challenges associated with translating this new marine policy concept into practical implementation and extending its application beyond European seas.

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INTRODUCTION

In 2004, a group of German scholars published two papers that asserted offshore wind development in the North Sea presented opportunities for expanding offshore aquaculture[1,2]. Over the ensuing years, this research group continued its investigation into open-ocean aquaculture techniques[3–5] and the integration of seafood production with wind farms[6–9]. It argued that the concept of "multi-use" could effectively address the quest for spatial efficiency[10].

In the early 2010s, the European Commission embraced this idea and provided funding for applied research programs with the aim of identifying and promoting synergies among maritime industries. As a result, it formally recognized multi-use (MU) as a legitimate field of study and integrated it into its political agenda, primarily through the European Union Blue Growth Strategy[11]. Since then, MU has evolved into a trendy marine policy concept. Scholars and practitioners alike believe that it has the potential to create new economic opportunities and achieve economies of scale[9,12–16]. Beyond fostering growth, the combination of human activities at sea is also intended to mitigate conflicts over space and resources[17–22], as well as alleviate human pressures on marine ecosystems[18,19,23,24].

The keen interest in MU has resulted in broadening its original formulation. This concept has been theoretically applied to a multitude of combinations, ranging from the integration of wind and wave energy technologies to the repurposing of decommissioned oil and gas platforms or the development of fishing-based tourism (commonly known as pescatourism). Today, MU encompasses a broad spectrum of functional, spatial, and temporal interactions, making it challenging to define and comprehend, especially for those new to the concept. Its meaning has become increasingly blurred, further exacerbated by the frequent use of related or similar-sounding terms, such as "multiple uses", "multifunctional use", or "co-use"[16,24,25]. In the scientific literature, MU is formally defined as the co-location of complementary activities at sea[25,26], their clustering[16], or their combination[13,21,27]. Some authors emphasize distinctions, such as "multi-use platforms" (MUP) versus "multi-use of space" (MUS)[13,14,28]. Others differentiate between "hard" and "soft" multi-use, with a focus on the presence or absence of infrastructures[18–20,24,29]. Only one definition explicitly emphasizes synergies[27], when they appear to distinguish MU from other approaches to managing maritime spaces. A recent paper introduced a functional typology defining four MU levels, ranging from repurposing to full integration[21]. While this classification aids in characterizing MU in its various forms, it considers space and time as default dimensions, which complicates the inclusion of local historical, geographical, and socio-political processes underlying the development of multi-use systems.

Defining MU has become even more challenging due to the difficulties encountered in its on-the-ground implementation. In fact, there have been few operational "win-win" combinations of marine uses. The gap between theory and practice can be attributed to several factors. Marine users are not always aware of MU concept, nor interested or willing to share maritime spaces and cooperate with each other[7,13,24,30]. MU experiments often face hurdles in the form of unsuitable regulatory frameworks and challenges in obtaining the necessary operating permits and licenses[12,17,19,24]. Potential economic benefits are weighed against the backdrop of immature technologies and business models, particularly in the case of "hard" multi-use[9,13,31,32]. Lastly, there exists a limited understanding of how combined uses might impact marine ecosystems[17,24,33], particularly regarding their potential cumulative effects[20,32]. Although scholars and practitioners have identified potential solutions to tackle these challenges, the results have thus far been rather limited. This, in turn, has dampened enthusiasm and slowed down innovation,

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investments, stakeholder engagement, and regulatory adaptations[32].

Difficulties in translating MU into practice emphasize, without prejudice to possible future developments, that it largely remains a theoretical construct. Recognizing this, we can define and approach MU primarily as a narrative regarding why and how marine users can and should cooperate with each other. This prompts a consideration of crucial questions that have been insufficiently explored by scholars advocating for MU, such as:

1. Why and how MU became a popular marine policy concept?
2. What are the primary similarities and distinctions between MU and other existing approaches to managing maritime spaces and resources?
3. How MU can be transposed outside the European seas?
4. In what ways can scientific disciplines, research, policy, and society be better integrated within the field of MU studies?

This paper endeavors to address these questions through a bibliometric analysis of the scientific literature on MU. Firstly, it traces the origins and historical development of MU research within the broader context of investigations dealing with the management of increasing and diversifying activities at sea. Secondly, the Bibliometrix R package is used to scrutinize the social, geographical, and conceptual structures characterizing multi-use scientific production. The findings are compared to a more extensive collection of journal articles concentrating on multiple-use Marine Protected Areas (MPAs) and Marine Spatial Planning (MSP). Lastly, the paper delves into research gaps, with particular attention to the transdisciplinary challenges entailed in translating this innovative marine policy concept into reality, including its applicability beyond the European seas.

TWO DECADES OF OCEAN MULTI-USE RESEARCH: A REVIEW

Several publications already traced the history of ocean multi-use[20–22] or provided a panorama of investigations dealing with particular marine uses combinations such as those based on marine aquaculture[34], multi-purpose offshore platforms[35] and pescatourism[36]. Apart from the paper written by Kyvelou and Ierapetritis discussing MU in the light of maritime cohesion[22], these synthesis have three important limitations. First, they essentially rely on a descriptive approach consisting in presenting key milestones underpinning the development of MU research, policies and experiments. Second, they rely on an applied-science perspective that promotes MU but often lacks a balanced reflection on the territorial context, political motivations, and potential social and spatial implications of multi-use. Third, they frequently overlook previous and related academic work focusing on coexisting marine uses, thereby making it less evident to identify similarities and differences between MU and other approaches to managing maritime spaces. All the more a majority of the 311 scientific publications identified on Scopus related to multi-use and its synonyms revolve around MPAs and MSP. In fact, only 63 articles concentrate on combined marine uses. In the following discussion, the entire corpus is referred to as the “large collection", while the selection of documents addressing multi-use in the context of European understanding is termed the “short collection. The structure of this corpus reveals that multi-use is not a new concept, and its usage extends beyond Europe. Consequently, it is pertinent to juxtapose its European significance with what multi-use predominantly refers to: MPAs and MSP.

A brief history of multi-use studies

Investigations related to MU have a relatively long history when viewed in the broader context of this concept (i.e. interacting marine uses). They appear considerably more recent when the focus narrows to its specific sense (i.e. synergistic marine uses combinations) (Fig. 1).

The earliest papers of the large collection date back to the 1970s. The scientific production has steadily grown since the 1980s and has experienced significant acceleration in the past decade. The dynamics of the short collection mirror this pattern, albeit with a time lag: pioneering papers emerged in the early 2000s, followed by a rapid increase in publications from 2015 onwards. The term “multiple uses” predates “multi-use” and is largely recorded in the large collection. These differences suggest that both sets of publications refer to two different, yet complementary, fields of study.

After delving into the origins of multiple uses, the fact remains that this concept was coined in the early 1940s by American conservationists involved in forestry management. It was institutionalized in 1960 when the Multiple Use Sustained Yield Act was enacted[37]. The purpose of this law was to promote a more coordinated, rationale and sustainable management of forest areas and their resources. From the 1970s onwards, this approach was transposed to the marine realm and embraced by Western scientists reflecting on the diversification of marine uses. The earliest papers in the large collection, dating back to this period, examined how this transformation was generating conflicts[38–41], impacting natural resources[42,43], and emphasizing the necessity

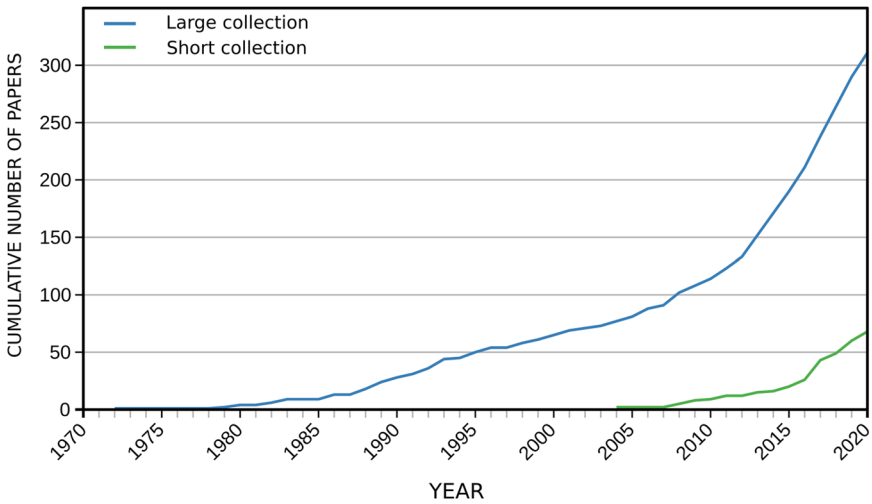

Fig. 1 Multi-use scientific production over time. This graph represents the cumulative number of publications from each of the two corpora (*y*-axis) over the period 1970–2020 (*x*-axis).

for new management models[44,45] and planning policies[46,47]. The concept of multiple uses shed light on the reality that oceans were becoming increasingly crowded, contested, and fragile spaces. Consequently, it underscored the importance of regulating and planning their occupation, appropriation, and exploitation. It took on a new dimension when it was adopted by the architects of the new zonation of the Great Barrier Reef Marine Park[48,49]. The Australian experience boosted marine conservation globally and gave rise to a new research field focusing on the integration of human activities within MPAs. These reflections were extended with the emergence of MSP, which explains the increase of the large collection's scientific production observed since 2010. MSP can be understood as the (re)transposition of marine conservation's principles, tools and researches from marine conservation into broader maritime spaces[50].

Investigations related to the European interpretation of MU are notably more recent and, despite their rapid growth, they remain a scientific niche. The first publications of the short collection were authored by the German research group studying how to integrate aquaculture into wind energy projects in the North Sea[1,2,4]. While taking advantage of offshore wind farms posed technical and economic challenges, it was also considered as a means to overcome limitations hindering the development of aquaculture in coastal areas, including lack of space, user conflicts, and pollution. Beyond the specific case of aquaculture and wind energy, MU - alternatively referred to as "multifunctional use"[2] or "multiple use"[10] - was conceived as a heuristic concept which could be applied to other marine uses combinations. Several years later, another form of multi-use also emerged in Portugal where it refers to multipurpose artificial reefs[51–54]. Originally designed to protect vulnerable coastal areas, these underwater structures are intended for additional purposes, such as recreational activities (surfing, fishing, etc.) and biodiversity enhancement. Although these two distinct interpretations of MU evolved independently, they share a common objective of exploring complementarities among marine uses and functions.

The rise of MU occurred at the intersection of science and policy, with the European Commission playing a pivotal role in legitimizing this concept through its political agenda and successive innovation and research programs. It was integrated into the Blue Growth Strategy, in line with the objective of creating synergies between industries of the maritime economy[13,20,29]. The preparatory report called "Blue Growth: Scenarios and drivers for Sustainable Growth from the Oceans, Seas and Coasts" already claimed that "synergies are [...] not a luxury but a pre-condition for future growth and development"[[55], p. 19], arguing that "several maritime economies activities combined are likely to produce more growth and jobs than the sum of their parts"[[55], p. 115]. The Blue Growth Strategy took this notion a step further by placing the two main multi-use drivers (i.e. marine renewable energies and aquaculture) at the top of the five Blue Growth Focus Areas, and by encouraging stakeholders from the aquaculture industry to "meet the concerns of other users of coastal or sea space - for example, by building cages along with offshore wind farms or by integrated multi-trophic aquaculture"[[11], p. 9]. This push for a more rationale approach to maritime spaces management was also echoing the principles of integrated marine policies, especially the Directive 2014/89/EU on Maritime Spatial Planning. Although the directive did not explicitly mention MU, it defined MSP as a means of "identifying and encouraging multi-purpose uses, in accordance with the relevant national policies and legislation" (Article 19 of Directive 2014/89/EU of the European parliament and of the council of 23 July 2014 establishing a framework for maritime spatial planning.). The European Commission continued to advocate for MU within the framework of marine renewable energies development[56] and Blue Growth greening[57].

Beyond policymaking, the European Commission has played an active and influential role in promoting MU through the FP7 and the Horizon 2020 innovation and research frameworks, as well as the Interreg development program. It co-financed several large-scale applied science projects with the objective of identifying and assessing the most promising combinations of marine uses. These projects had a dual focus: one on developing innovative multi-purpose offshore platform concepts and the other on exploring synergies among co-located activities at sea, outlining two different, yet complementary, approaches to MU[13,14,28]. MUSES evaluated 17 different combinations, including pescatourism - a practice and research field that had evolved independently from MU. It also introduced a foundational definition adopted by Schupp et al. characterizing this concept as "the intentional joint use of resources in close geographic proximity by either a single user or multiple users"[[21], p. 4].

In essence, multi-use is a scientific construct that has been intricately shaped within the framework of the European Union's political and economic agenda. This development was based on a dual process. On the one hand, MU emerged without direct reference to, and in some cases even in disregard of, prior work that focused on multiple-use territories, particularly MPAs. On the other hand, it garnered the attention of an expanding community of scientists, marine planners, and policymakers who sought to expand its original formulation (i.e. aquaculture within offshore wind farms) in order to promote Blue Growth and foster synergies between maritime industries.

Dynamics and structures of multi-use research

MU research is driven by extensive and dense research groups, and this trend is particularly pronounced within the short collection. Notably, a striking 96% of the papers pertaining to the latter have been authored by at least two researchers, and the average number of co-authors per document stands at 5.2. In contrast, these figures are 76% and 3.8, respectively, within the large collection (Table 1). This result likely arises from the fact that the short collection, being more recent (as indicated in Fig. 1), aligns more closely with the prevailing trend of increased collaboration within the scientific community. But it also probably reflects the continental scale of MU research projects.

In both collections, scientific collaborations are propelled by highly productive researchers whose contributions exert a substantial impact on their respective communities (Fig. 2). Among the top 20 authors in the larger collection, several are distinguished specialists of multiple uses MPAs, which seems logical considering that most of the papers are dealing with this field of study. But the list also includes 11 scientists investigating synergies between human activities, with prominent positions held by researchers who coined the concept of MU.

Co-authorship networks (Fig. 3) unveil topical and geographical boundaries dividing the large and the short collections' communities, but also, yet to a lesser extent, distinction among researchers focused on different approaches to multi-use. In this visualization, the size of the boxes corresponds to the number of articles authored by the mentioned authors, while the thickness of the links between them indicates the frequency of their co-authorship. Eight distinct social clusters can be identified, evenly

Table 1. Authorship indicators

	Large collection	Short collection
Total number of authors	978	250
Multi-authored publications	76%	96%
Average number of co-authors per publication	3.8	5.2

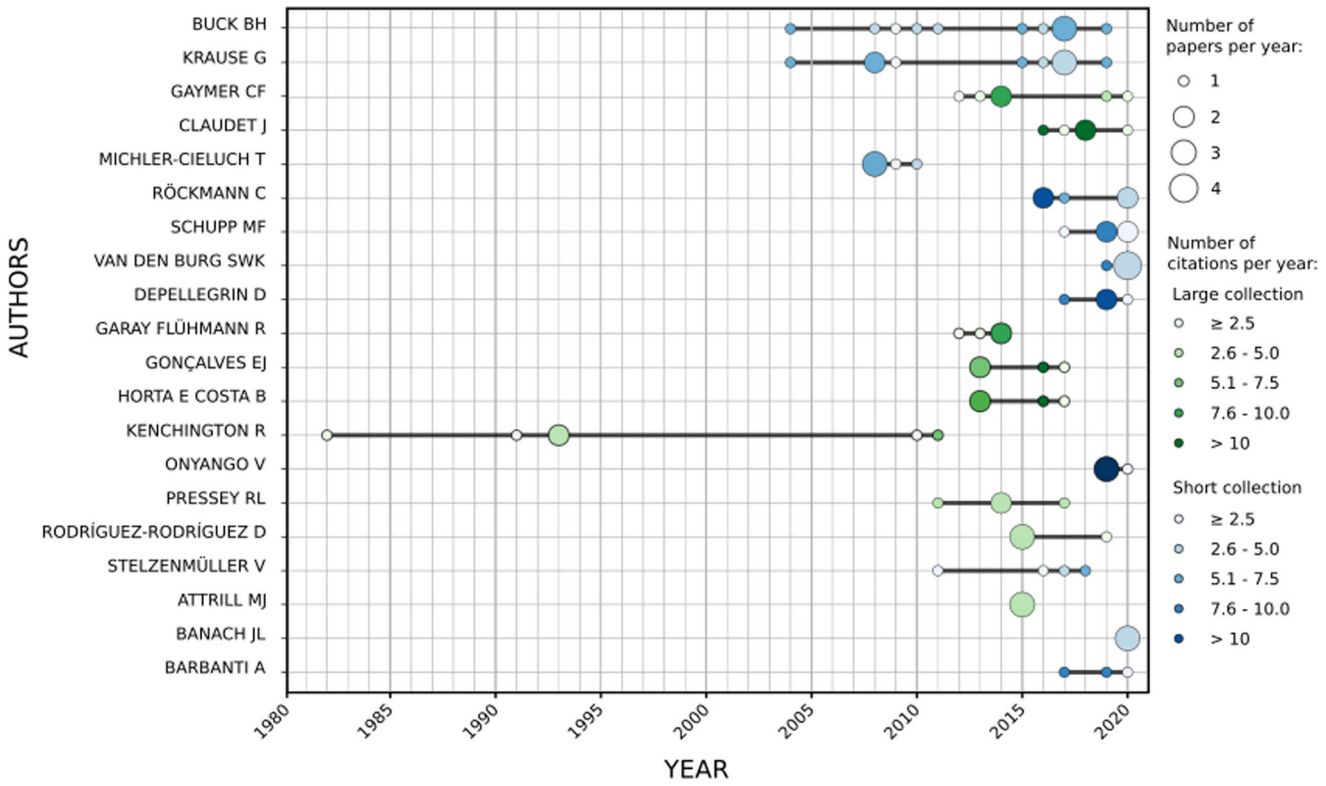

Fig. 2 Large collection top 20 leading authors production over time. This graph represents, for each of the top 20 most productive authors and over the period 1980-2020, the total number of articles they co-authored per year (proportional circles), as well as the number of times they have been cited (intensity of blue for the large collection and green for the short collection).

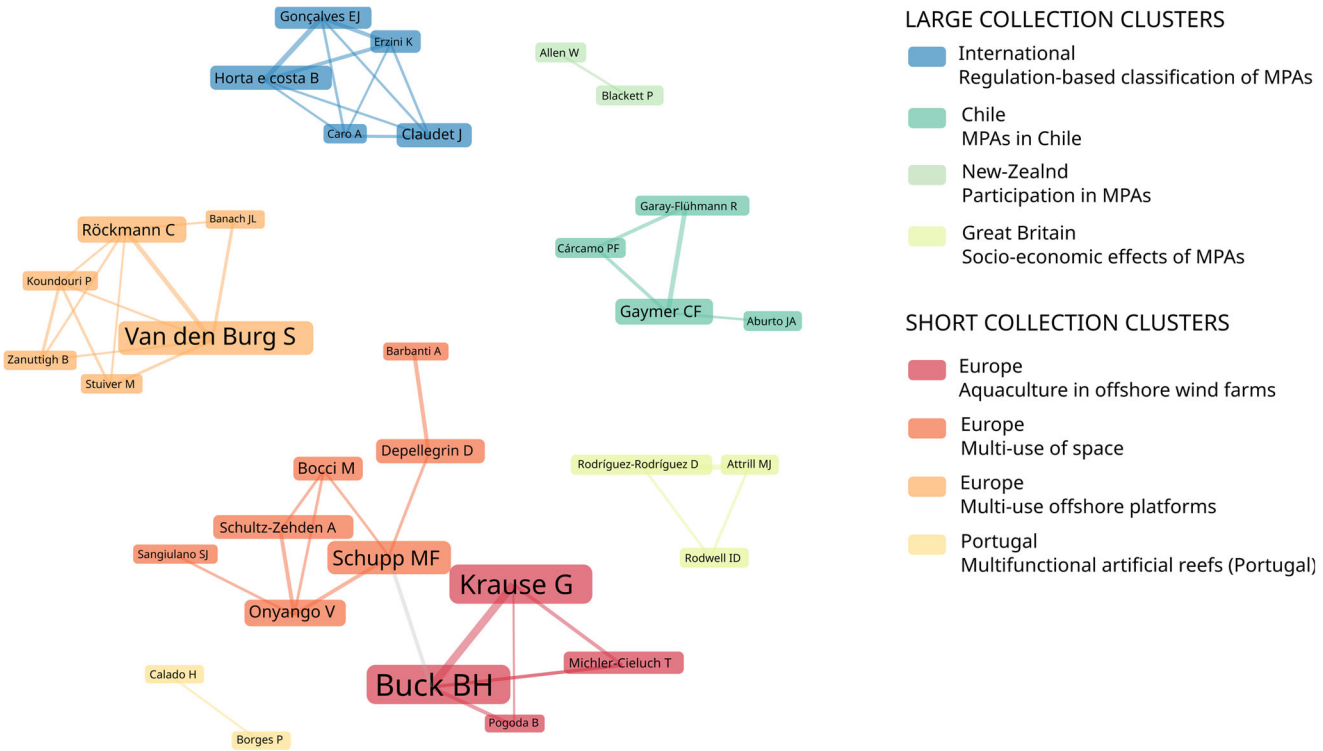

Fig. 3 Large collection co-authorship networks. The network produced with Biblioshiny using the following parameters: normalization = association, layout = Fruchterman Reingold, clustering algorithm = Louvain, number of nodes = 50 isolated nodes, minimum number of edges = 2, removed and repulsion forces = 0.

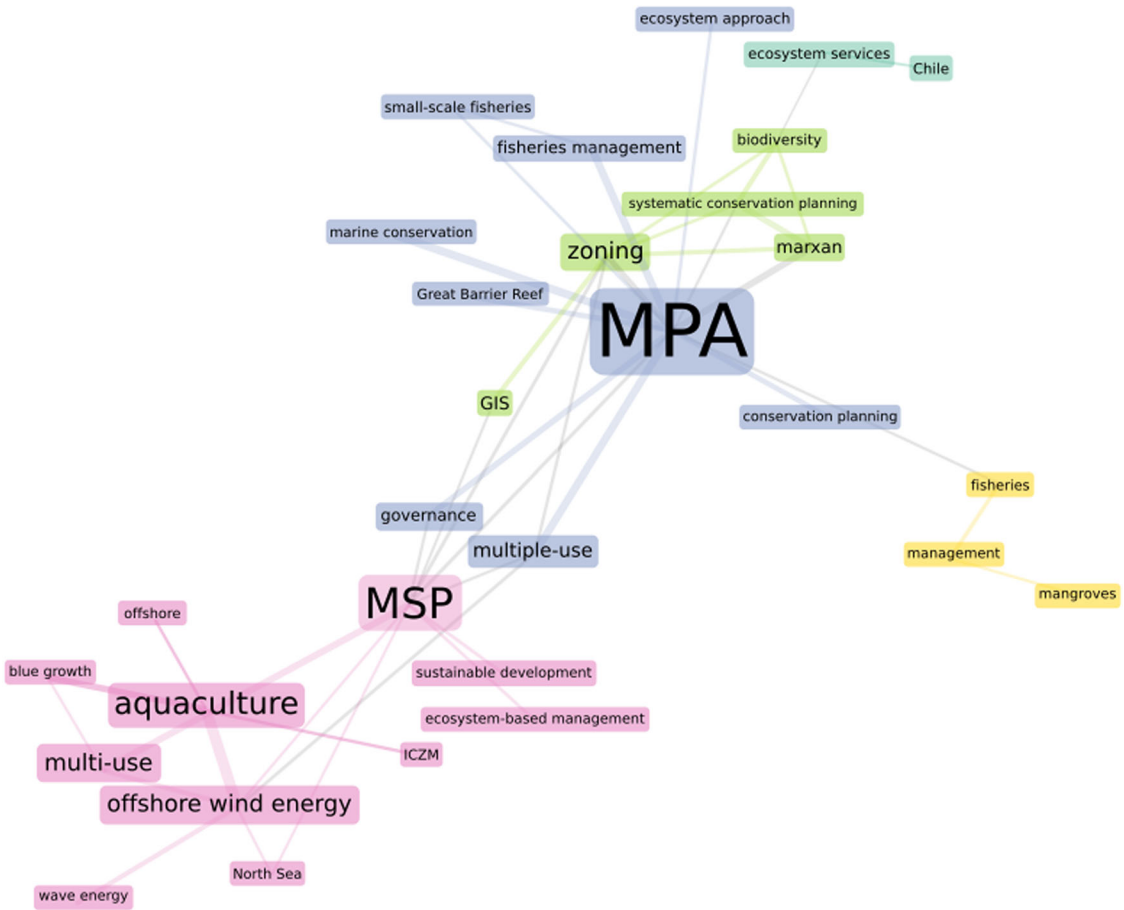

Fig. 4 item Large collections authors keyword co-occurrence networks. Network produced with Biblioshiny using the following parameters: normalization = association, layout = Fruchterman Reingold, culstering algorithm = Louvain, number of nodes = 50, minimum number of edges = 2, removed and repulsion forces = 0.

split between multiple uses MPAs and MU in its narrower sense. Marine conservation scientists are distributed among four independent, moderately-sized groups, which reflect the specialization and fragmentation within this research domain. At the top of the figure, the dark blue cluster stands out as the only one predominantly built on international collaborations, bringing together advocates of MPA classification. Conversely, the other three groups situated at the top and right of the figure primarily represent national communities focused on specific aspects related to integrating activities within protected areas. These include socio-political issues (dark green cluster), socio-economic effects (yellow cluster), and participation processes (light green cluster). These approaches exhibit slight differences from the naturalistic perspective dominating the scientific literature concerning marine conservation, reflecting the manner in which these territories are approached within the large collection: the integration of traditional marine uses into marine ecosystems preservation. In contrast, the four clusters centered on marine use combinations and located at the bottom and right of the figure are significantly larger and denser than their counterparts. The red and dark orange groups, interconnected, encompass scientists who introduced the idea of combining different activities at sea and those who actively explored its potential. The light-orange cluster unites specialists in offshore multi-purpose platforms and its different variations. These three scientific communities correspond to continental networks originated by research programs and projects funded by the European Union. Lastly, the small light-yellow group consists of the principal researchers dedicated to multipurpose artificial reefs in Portugal.

The co-occurrence networks of author keywords within the large collection (Fig. 4) offer a comprehensive insight into how MU is approached conceptually. The size of the boxes corresponds to the frequency of each keyword's appearance in titles, abstracts, or keywords, while the thickness of the links between keywords indicates the frequency of their co-occurrence. A prominent central cluster in blue serves as the nucleus, with four minor subclusters distributed around it. The central blue cluster revolves around the keyword "MPA", its size and centrality emphasizing its significance. This cluster encapsulates the essence of multiple uses Marine Protected Areas, reflecting how they are conceptualized, managed, and studied. In addition to their core objective of "marine conservation", several keywords relate to "fisheries", particularly "small-scale fisheries". Fishing stands as the most prevalent and archetypal traditional activity integrated within marine protected areas. Terms such as "governance", "fisheries management", and "conservation planning" underscore that the regulation of multiple uses predominantly relies on comprehensive management strategies. The light green cluster within the network centers on "zonation" and its associated tools, such as "GIS" and "marxan". In contrast, the dark green and yellow groups represent sub-research domains that link specific topics and locations. These encompass discussions on ecosystem services offered by MPAs in Chile and fisheries management within mangrove areas, respectively. The pink cluster, positioned adjacent to "MSP", forms its own structure. It encompasses the two primary activities that serve as the foundation for MU: "aquaculture" and "marine renewable energies". Foremost among these is "offshore wind energy". "Multi-use" maintains a direct

connection to “Blue Growth", reflecting the economic perspective underlying marine use combinations, as opposed to the environmental objectives typically associated with MPAs.

MU scientific production appears dynamic, even when compared to established academic works dealing with MPAs and MSP. This is probably due to the novelty of MU concept as well as the political and financial support of the European Union. This notwithstanding, only a few authors are at the forefront of large European consortia dedicated to exploring and promoting synergies between maritime industries. It is striking that these groups have not collaborated yet with global scientific communities investigating MPAs. This explains why MU specialists do not refer to studies that examine the integration of traditional marine uses into protected areas. While MU, in both its theoretical and practical aspects, addresses the coexistence of marine uses, fostering collaboration and knowledge exchange with complementary research endeavors could prove instrumental in bridging existing research gaps.

DISCUSSION

Ocean multi-use research should be viewed within the context of a rich, extensive, and global scientific tradition centered on the management of maritime spaces. This perspective becomes even more crucial as the investigation, promotion, and implementation of multi-use practices resonate with transdisciplinary challenges already faced in and partly addressed by MPAs and MSP investigations. Studying complex systems combining different activities at sea requires crossing scientific disciplines and fields of study. A comprehensive understanding of how these systems interact with both social and natural environments involves transcending the traditional division between Nature and Culture. Translating this European marine policy concept into reality raises important questions concerning the political and societal role of researchers. It seems of interest to analyze how MU investigations fit into dynamics initiated by MPAs and MSP, which strive for transdisciplinarity in its broadest sense - that is, the breaking down of boundaries between science, policy, and society. Fig. 5 portrays archetypal scenarios along a continuum that spans from division to complete integration. While this representation may seem simplistic given the diverse range of attitudes and approaches in marine sciences, it serves to formalize the challenges that lie ahead in ocean multi-use research.

The first dimension of integration is related to the topics of study, particularly the relationships among various uses of the sea and its resources. Four theoretical configurations were identified: co-existence, interactions, cooperation and integration. The concept of MU corresponds to the two higher levels while MPAs and MSP cover a larger, but lower, spectrum ranging from co-existence to cooperation. The primary goal of MU is to foster synergies between human activities at sea, although this is not always explicitly stated in the scientific literature. In contrast, MPAs and MSP often focus on regulating, rather than combining, multiple marine uses to achieve sustainability[50,58,59]. It should be noted however that MPAs only allow, within their designated boundaries, those human activities which align with conservation goals such as sustainable forms of small-scale fishing or tourism. Additionally, many marine protected territories are home to active cooperation between stakeholders when they are not directly co-managed by their users[60–62]. It is also worth emphasizing that MSP is increasingly concentrating on identifying and promoting synergies between existing or planned activities[25,63]. But whatever the objectives are, MPAs and MSP always rely on on spatial processes, involving the delineation of perimeters of action and often of zones allocated to specific activities or combinations of activities[50,64–66]. Conversely, MU is grounded in technical, design, and management solutions aimed at achieving functional integration of marine uses. This is why combined marine uses are frequently referred to as “multi-use at sea"[15,67] whereas MPAs and MSP are often described as means to achieve “multiple uses of the sea”. Examples of new uses of the sea resulting from the full integration of diverse activities remain rare. Furthermore, the idea that MU “represents a radical change from the concept of exclusive resource rights to the inclusive sharing of resources and space”[21, p. 4][12,18,24,68] is open to debate and even specious. On the one hand, many traditional or long-standing marine activities (i.e. fishing, shipping, military operations) are inherently mobile, temporary, and coexist with each other, allowing for maritime spaces’ co-use. On the other hand, MU arose together with the emergence of exclusive, or at least fixed, uses such as marine renewable energies and offshore aquaculture promoting carrying ideas of spatial sobriety and functional synergy. In this respect, the industrial model that underpins this concept aligns fits to the

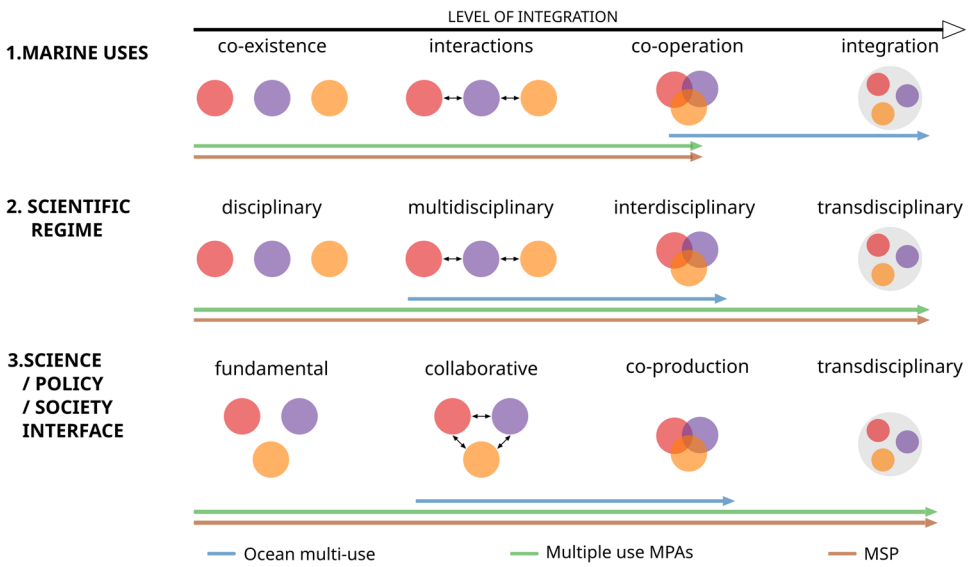

Fig. 5 Integration levels of multi-use, MPAs and MSP research. This figure schematically represents the degree of integration within these three research fields. Integration is delineated in three dimensions: the relationships between uses (object of study), the scientific regime (relationships between disciplines), and transdisciplinarity (relationships between science, society, and politics).

ongoing dynamics of ocean grabbing, which was so far driven by MPAs[69] and MSP[70]. In general terms, this aligns with the overarching logic of division versus integration that underlies the appropriation of maritime spaces[71]. Therefore, it is crucial to remain vigilant to ensure that MU does not devolve into a narrative that merely serves to legitimize contested activities and new enclosures.

The second dimension of integration involves the disciplinary framework and the Nature-Culture duality. Most typologies commonly distinguish between disciplinary, multidisciplinary, interdisciplinary and transdisciplinary approaches[72,73] where scientific disciplines are respectively divided, collaborating, grouped and transcended. The division between scientific disciplines is partly framed by the opposition between natural and social sciences[74,75]. In theory, MU should be approached through transdisciplinary approaches since it is defined by relationships between combined activities, functioning as a system that cannot be reduced to the sum of its parts[18]. Moreover, the short collection reveals the existence of cross-cutting issues such as risks[28,32,67] or governance[17,21,32,76]. MU research should also align with sustainability sciences, given that combinations of activities may generate specific positive or negative impacts on social and natural spheres compared to single marine uses. However, the level of integration between scientific disciplines and specialities is still limited, especially when compared to MPAs and MSP studies. Even though MU research was initiated by multidisciplinary projects, most of the scientists involved have backgrounds in natural or engineering sciences and specialize in activities directly related to the industrial archetype. In fact, among the 11 most productive authors of the short collection (see Fig. 2) 8 have been working, at least occasionally, on offshore aquaculture or marine renewable energies. Moreover, social sciences have often been relegated to investigation techniques and tools, such as surveys and interviews. A few studies have focused on how MU development and related challenges are perceived by marine users and planners[6,7,18,77] or have discussed this concept from a conceptual standpoint[21,22,25]. But in general terms, marine uses combinations are primarily conceived as technical and management solutions to socio-political problems. Paradoxically, environmental issues such as cumulative impacts remain minor subjects as reflected by the conceptual structure of the short collection. In summary, there is a discrepancy between the true nature of MU and the disciplinary framework used to investigate it. Similar research gaps also exist in studies on MPAs and MSP[78,79], but they are not as pronounced. Although the scientific literature on marine conservation was historically dominated by naturalists, social scientists are playing an increasingly important role in shedding light on the human dimensions of environmental protection and driving this research field towards sustainability sciences[80]. This shift is reflected in the significance of topics such as participation[81–84] and ecosystem services[85–90] in the large collection. A similar dynamic is observed in MSP studies, even though it may not be as evident in the bibliographic database due to the lower number of publications.

The third and final dimension of integration extends beyond strict scientific considerations; it pertains to the role of science in policy and society.The relationships among these three domains are very diverse and complex, as reflected by the literature dedicated to the subject[91–93]. However, following the same logic as mentioned above, these relationships can span from fundamental research to transdisciplinarity in its broadest sense. This broadly corresponds to the historical evolution of the science-policy-society interface and its theorization[94]. MU research occupies an intermediary position in this spectrum, while studies on MPAs and MSP cover the entire range. Although the idea of combining activities at sea was initially proposed by scientists, it gained momentum through the support of European institutions that funded large-scale research projects aimed at identifying synergies to drive Blue Growth. In return, these projects yielded practical knowledge on how to integrate different activities at sea, as well as insights into the opportunities and challenges of MU. In this respect, MU research tends to rely on a post-science approach, where expertise takes precedence over pure scientific inquiry. Simultaneously, it often embraces a post-political perspective that prioritizes solutions over addressing the root causes of the problems it seeks to solve, keeping political and social implications of MU at a distance. Scientists advocating for MU have effectively taken on political roles, as this concept lacks a legal basis compared to environmental protection or MSP. It should be noted however that pescatourism is officially recognized and promoted in Italy and Greece[36], and the Netherlands has passed a law requiring offshore wind developers to consider potential combinations with other marine uses[95]. However, in general terms, researchers tend to take on a leading role in issues related to politics, in the original sense of the term (i.e. the life of the city), without engaging in critical thinking about the MU concept and its broader implications for society. Beyond technical feasibility, security concerns, and regulatory obstacles, many critical questions remain unanswered, such as those related to power dynamics, sharing of space and resources, and impacts on marine environments. This situation is further compounded by the fact that researchers often implement stakeholder engagement as a strategy to promote, design, and experiment with MU. Participation is often applied through a top-down approach, where the concept and its rationale are imposed on stakeholders, rather than building on their own vocabulary, representations, and aspirations. This is one reason why MU development has been slow and limited to conceptual cases. Most studies on MPAs and MSP primarily also rely on a positivist applied-science approach or even a post-science perspective[96–98], which align with dominant interests[99]. Nevertheless, since their inception, some scholars have distanced themselves from policy-making to address fundamental research questions and explore the social and political dimensions of marine conservation and sea-use planning[100–103]. Drawing on this expanding body of literature could help MU advocates better articulate issues of normativity and objectivity, as well as the interplay between knowledge and action.

CONCLUSION

Over the past decade, ocean multi-use has gained momentum and garnered enthusiasm among European marine scientists and planners. While it may seem innovative, this concept is a direct continuation of previous academic efforts aimed at managing the intensification and diversification of human activities at sea, particularly within MPAs and MSP studies. However, MU stands out due to its clear emphasis on economic growth and its intention to foster synergistic relationships among maritime industries. In this regard, it represents a shift from mere co-existence to full integration and from spatial considerations to a more functional approach. Yet, translating the concept of MU into practical reality has proven to be challenging, highlighting that it still largely remains a theoretical construct, especially when compared to the concrete implementations of MPAs and MSP. Nevertheless, this hasn't prevented the dissemination of this concept both within and beyond Europe, coinciding with the growth of marine renewable energies and offshore aquaculture. As a result, MU has reshaped scientific and political discourse surrounding how to think, manage and govern the Blue realm. While this presents promising opportunities, it also raises critical questions that could be addressed through a more open approach to MU research.

Multi-use is propelling integration dynamics within studies on cohabiting marine uses. First, the exploration of marine use combinations necessitates the construction of bridges across scientific disciplines and beyond specialized knowledge domains.

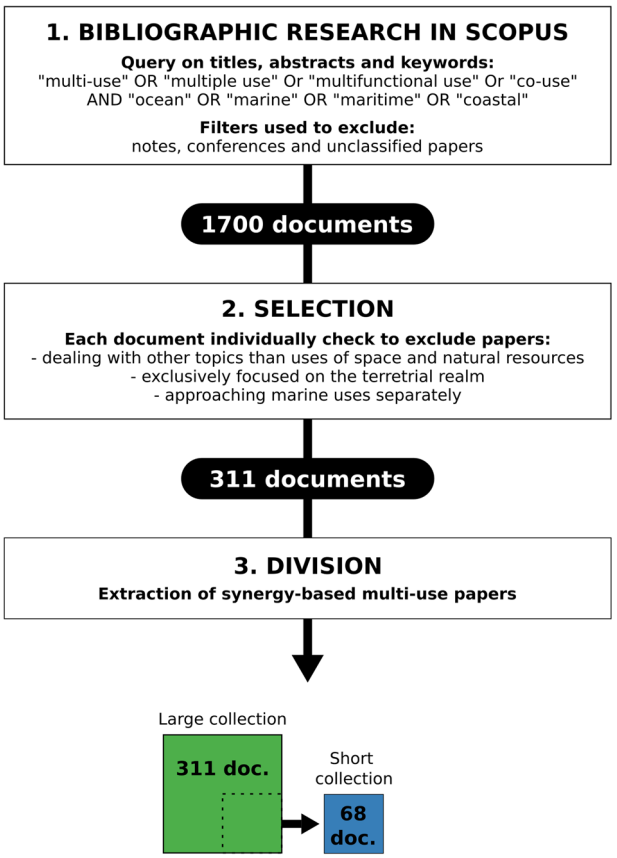

Fig. 6 Constitution of ocean multi-use scientific corpus. This figure represents the major stages and choices that led to the constitution of the two scientific corpora.

Given that MU endeavors to address political issues within the marine domain, it cannot be limited to engineering and management solutions alone. In this regard, social sciences can play a more substantial role by delving into subjects such as participation, power dynamics, cultural values, and more. At the same time, natural sciences could help to fill in the main research gap: the sustainability of MU systems, especially cumulative impacts on marine ecosystems. Besides, applied-science investigations that advocate for MU should be complemented with reflexive approaches. Challenging the concept itself, its underlying rationale, relevance, and potential implications provides a means to better align objectivity and normativity, as well as science and action.

METHODOLOGY: A BIBLIOMETRIC ASSESSMENT OF MULTI-USE SCIENTIFIC PRODUCTION

The literature review was based on a bibliometric approach, involving the analysis of metadata from scientific publications related to MU (Fig. 6). Scopus was chosen as the primary database for creating the corpus due to its accessibility. While it may be less selective than the Web of Science, Scopus offers more reliable results than Google Scholar[104]. It is important to note that Scopus tends to underrepresent papers published before 2000, those adopting a social sciences perspective, and non-anglophone journals compared to Web of Science. However, these potential biases are less applicable to multi-use research, which is a relatively recent research field primarily involving natural and engineering scientists, with most papers being published in English. The bibliographic search was performed on the titles, abstracts, and keywords of publications using the following keywords: “multi-use" OR “multiple uses" OR “multifunctional use" OR “co-use" AND “ocean" OR “sea" OR “marine" OR “maritime" OR “coastal". Filters were applied to exclude conference papers, notes, and unclassified publications. This query yielded 1,700 distinct documents published between 1970 and 2020. After a

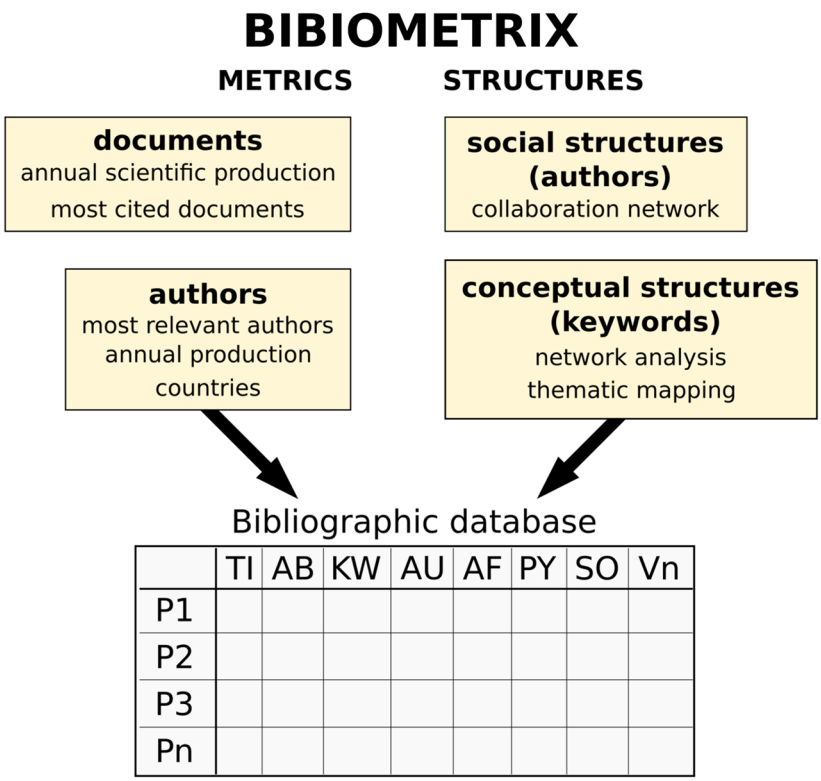

Fig. 7 Bibliometric indicators used to analyze the large and the short collections. This figure represents the structure of the two bibliographic databases and the main variables analyzed by Bibliometrix software.

comprehensive individual review, 1,389 publications were removed from the corpus as they exclusively focused on terrestrial topics, covered subjects unrelated to human activities at sea, or approached marine uses in isolation.

The analysis and comparison of the large and short collections were conducted using the Bibliometrix R package and Biblioshiny, its graphical web interface. These free and open-source softwares provide a range of statistical methods and visual representations for mapping research trends and structures[105]. The analysis was based on various indicators that provide insights into the dynamics of scientific production, including publication year, authorship, countries, etc. Additionally, graphical representations were utilized to depict the social and conceptual structures of this research domain, focusing on collaboration among authors and networks of keywords (Fig. 7). This comprehensive and quantitative comparison of both collections was complemented by a qualitative examination of the most influential papers, particularly those from the short collection. This qualitative approach aimed to gain a deeper understanding of which authors, methodologies, and geographical regions have made significant contributions to the field of multi-use studies. Ultimately, these findings were contextualized within the historical framework, considering potential implications and the narratives that have shaped the emergence of this new research field.

DATA AVAILABILITY

The data used in this study to describe and analyze multi-use scientific production is available to the public under a Creative Commons license at https://doi.org/10.5281/zenodo.7875438.

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AUTHOR CONTRIBUTIONS

J.G.T. and B.T. contributed to the conception of this research. J.G.T. proceeded to data collection and analysis and led the writing of the manuscript. B.T. contributed to the writing and provided insight and context to support the interpretation of results. All authors contributed to the edition of the manuscript and have approved the final manuscript.

COMPETING INTERESTS

The authors declare no competing interests.

ADDITIONAL INFORMATION

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