TRANSDISCIPLINARY MARINE RESEARCH

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Introduction

Marine Oceans and coastal waters are usually shared by heterogeneous groups, such as commercial fisheries (e.g. exploitation of fisheries resources), tourism (e.g. holiday and recreation), or industry (e.g. generation of renewable energy). The resulting diverse requirements for space and resources often cause problems and conflicts between user and interest groups, so-called stakeholders.[1] Different stakeholders hold diverging perceptions of the systems they are a part of, their interactions and dynamics (Gray et al., 2012; Stier et al., 2015; Aminpour et al., 2020), and the knowledge associated with it (Schwermer et al., 2021a, 2021b). They face different economic interdependencies (Lopes et al., 2017; Schupp et al., 2021; Stelzenmüller et al., 2022) and have different cultural identities (Sterling et al., 2017). Oceans and coastal waters consequently transform into very complex systems. The implementation of "right" management measures that are aligned with the many requirements and desires of stakeholders becomes a difficult task. In such a situation, the implementation of sustainability goals is limited (Burns and Stöhr, 2011; Adams et al., 2003).

These multi-layered, complex, and interlocked problems, also known as "wicked problems", pose increasing challenges to management, society and science (Jentoft and Chuenpagdee, 2009; DeFries and Nagendra, 2017; Jones and Seara, 2020; Hare, 2020). As first described by Rittel and Webber (1973), wicked problems describe a complex and tricky problem that is both symptom and cause of other problems. It is difficult to capture and tackle the problem in its entirety, partly because of the many stakeholders involved and their varying perceptions, knowledge, and interests (Rittel and Webber, 1973; Jentoft and Chuenpagdee, 2009; Hare, 2020). This complexity is further enlarged by the fact that climate change poses additional challenges to oceans and coastal seas (Möllmann et al., 2021;

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IPCC, 2022). To find a way forward that not only promotes the health of marine ecosystems but also secures the livelihoods of coastal communities, transdisciplinary approaches are a possible solution.

The Swiss psychologist Jean Piaget is considered responsible for coining the term "transdisciplinarity" in the 1970s. He defines it as a higher level of interdisciplinary relations, placing them in a more complex system. To date, transdisciplinarity research is a growing field in academia, but there is still no uniform definition. It is often contrasted to disciplinary, multi- and inter-disciplinary research: while disciplinary research involves only one discipline, multi- and inter-disciplinary research includes several disciplines (see Figure 1.1). However, the difference of interdisciplinary research is the collaboration of all disciplines to achieve the goals set within a given project. Furthermore, transdisciplinary research involves stakeholder groups from various backgrounds.

We aim to better understand the research landscape in marine research related to "transdisciplinarity". Particularly, we examine whether and how publications in marine research can be clustered and how these groups can be set in relation to one another. The resulting picture should help to better understand how "transdisciplinarity" is used in the context of marine research. To do so, we performed a systematic literature review to identify publications on marine topics using the term "transdisciplinarity". We conducted a cluster analysis and interpreted the detected clusters based on the significant words as well as their spatial positioning in the overall cluster.

We identified 9,228 publications using the term "transdisciplinarity". Among them, 388 include terms from the marine realm and 211 of them could be identified as relevant. Based on a detrended correspondence analysis and an agglomerative hierarchical cluster analysis (programme R), six research clusters could be detected: (i) "Scientific methodology", (ii) "Governance", (iii) "Ecosystem Services", (iv) "Fisheries and Management", (v) "Hazards and Resilience" and (vi) "Geosciences". We display the research clusters in a two-dimensional space (see Figure 1.3 later in the chapter), that is, the *y*-axis shows the application of the concepts of disciplinary, interdisciplinary, and transdisciplinary approaches, while the *x*-axis refers to the topics examined relating to biotic and abiotic factors (e.g. fishery vs. hazards). "Scientific methodology" shows that many publications deal with transdisciplinary methodology: who is involved in research, how is research conducted, and how are the results managed. "Ecosystem services", "Hazards and Resilience" and "Fisheries and Management" indicate the strong relation between humans and nature, while "Governance" focuses on regulating the interaction of humans and nature. Especially the first three clusters range across the inter- to the trans-disciplinary realm while "Governance" stretches more towards the disciplinary realm. The cluster "Geosciences" was particularly surprising. It turned out that transdisciplinarity and interdisciplinarity are used synonymously, such that this cluster contrasts with the other five clusters in terms of the conceptualization and application of the term transdisciplinary. This is a clear indication of the different uses of this concept, requiring a close examination of its origin and the need to clarify concepts when working in teams with different (disciplinary) backgrounds.

Our cluster analysis reveals different traditions in the fields related to the emphasis put on disciplinary, multi-, inter- and trans-disciplinary elements within transdisciplinary approaches.

Literature review: transdisciplinarity – a paradigm shift in science

Etymologically, transdisciplinarity means "beyond disciplines", which can be understood in two ways: either as positioning beyond single scientific disciplines or as motion, with knowledge production moving away from the traditional academic way of disciplinary working (Vilsmaier, 2021). These possible translations reflect two different understandings of transdisciplinarity – one focusing on the relation between traditional scientific disciplines, and the other on epistemology and the question of how knowledge is created. Nicolescu (2010) even called this a "war of definitions". Having a closer look at this academic debate and the origin of the various schools (e.g. Nicolescuian School), it becomes obvious that despite all differences there is one common issue: the discussion about the self-perception of scientists and scientific methodology as part of society. This discussion inevitably leads to the question of which role science plays in solving problems in general and "wicked problems" in specific (Rittel and Webber, 1973; Hare, 2020).

Within the academic discourse, the term transdisciplinarity first came up in the 1970s when the Swiss psychologist Jean Piaget asked for improving the cooperation between different scientific disciplines (Lawrence et al., 2022) (Figure 1.1). Like Piaget in the 1970s, Mittelstraß (2007) suggested broadening the concept of interdisciplinarity to enable science to tackle problems. The intention was not to replace disciplines, rather to have them cooperate to overcome traditional thinking (Figure 1.1). The topic received increased interest with the "First World Congress of Transdisciplinarity" in 1994, followed by the "Manifesto of Transdisciplinarity" (Nicolescu, 2002, 2010). Lawrence et al. (2022) analysed the immense amount of literature published since then and conclude that many publications belong to a "Nicolescuian School". It is characterized by their demand for a "Unity of Knowledge": instead of separating science into hundreds of new disciplines, we should return to an understanding of science as one principle. The "Charter of Transdisciplinarity", adopted by the first "World Congress of Transdisciplinarity" in 1994, even asked for a dialogue between different knowledge cultures, academic and nonacademic disciplines (Nicolescu, 2002).

Another way of understanding transdisciplinarity is summarized by Lawrence et al. (2022) as "Social Engagement Transdisciplinarity" (the Zurich School). In this context, Gibbons et al. (1994) introduced the "Mode 2 Knowledge Production". While "Mode 1" refers to the traditional occidental science and scientific discovery, "Mode 2" is defined as a paradigm shift towards user-oriented research relating to societal needs. This debate about the relation between science and society grew in a context of intense public and political discussion about environmental

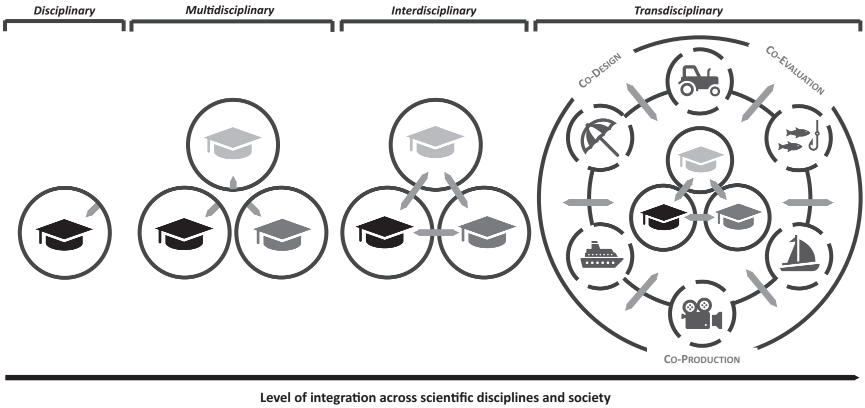

FIGURE 1.1 Conceptual distinction between disciplinary, multidisciplinary, interdisciplinary, and transdisciplinary research related to actors involved. While disciplinary research involves only one discipline, multi- and inter-disciplinary research includes several disciplines. However, the difference of interdisciplinary research is the collaboration of all disciplines (displayed as bi-directional arrows) to achieve the goals set within a given project. Transdisciplinary research further involves stakeholder groups from various backgrounds, for example, tourism, agriculture, or fisheries. In this regard, co-design, co-evaluation, and co-production are key aspects.

problems and social challenges as wicked problems (Gibbons et al., 1994). Central questions emerged regarding the shaping of a sustainable future and that of a society with a focus on bridging the gap between science and society, making knowledge available for necessary decision-making in society, and supporting participatory decision-making (Pohl and Hirsch Hadorn, 2006). With this understanding, science is not isolated from societal issues but is part of its learning process.

Today, almost 50 years after the first mention of the term "transdisciplinarity", there is still no unified concept. However, Lawrence et al. (2022) identify seven key elements: (i) focus on the theoretical unit of knowledge, (ii) inclusion of multi- and inter-disciplinarity, (iii) involvement of societal actors, (iv) focus on real-world problems, (v) working in a transformative manner, (vi) orientation towards a common good, and (vii) reflexivity.

Even if the Nicolescuian and the Zurich School seem to differ in some way, there is a huge overlap. The understanding of transdisciplinarity can even be simplified to three characteristics (WBGU, 2011; Defila and Di Giulio, 2018; Pohl et al., 2017): (i) the goal of transdisciplinarity is to create new knowledge by integrating existing knowledge from various sources (e.g. experience, observation, trainee), perspectives, and cultures. (ii) This knowledge, known as transformative knowledge, supports society to transform towards a more sustainable future. (iii) Science combines abstract knowledge with case specific knowledge and thus becomes part of a social learning process.

From the classical academic point of view, scientists working in research institutions are interacting with stakeholders outside academia (Wagner-Ahlfs et al., 2021) – there is a "we" (academia) and "they" (society). The democratization of knowledge creates a need for a new self-reflection: who is taking which role in a transdisciplinary research process? In this regard, various existing concepts reflect on the different levels of participation (Arnstein, 1969; Stauffacher et al., 2008; Shirk et al., 2012). Arnstein (1969), in his reflections on citizen participation as key element of democracy, draws a "ladder of citizen participation" ranging from manipulation (= no citizen power at all) to informing and partnership to citizen control (= maximum citizen power). Stauffacher et al. (2008) focus on societal decision processes and name different intensities of involvement: information, consultation, cooperation, collaboration and empowerment. Shirk et al. (2012) give three simplified levels how societal actors can be involved in the creation of academic knowledge from a scientific perspective: "Contribution" is a low level of interaction because the project is planned, run and evaluated by scientists, whereby stakeholders only contribute data or information. "Collaboration" is a higher level of interaction, as the stakeholders are involved in planning and analysis. "Co-creation" can be considered the gold standard of transdisciplinary research as stakeholders are involved from the beginning, designing the project as well as formulating the research questions. Thus, stakeholder involvement in scientific projects not only helps to make research more socially relevant and robust but also ensures that it is more easily understood and accepted by a wide range of stakeholders, strengthening the relation between science and society (Köpsel et al., 2021).[2]

Material and methods

To explore the concept of transdisciplinarity in the marine realm,[3] we conducted a systematic literature review adopted after the approach of Abson et al. (2014) and Drupp et al. (2020), that is, a quantitative full-text analysis of scientific publications using a cluster analysis. We used a four-step procedure to identify and analyse relevant publications: (i) data searching, (ii) data screening, (iii) data download, and (iv) data analysis, consisting of three different sub-steps (i.e. conceptual vocabulary, detrended correspondence analysis, and cluster analysis) (Figure 1.2A).

In a first step, we derived relevant publications from the scientific database *Web of Science* (WoS, *www.webofscience.com*) using the search string displayed in Table 1.1 (Figure 1.2A, *data searching*):

The keywords that compose search "Term 1" relate to the marine realm and were discussed in several rounds between all authors, that is, the search string was iteratively developed. As our aim is to better understand how the term "transdisciplinarity" is used in publications related to marine topics, our search "Term 2" included the keyword "transdisciplinarity" and known misspellings of this keyword. To assess whether the search string was well-developed, we first compiled a list of publications that are relevant to the study field according to the authors' knowledge and thus should appear in the WoS hit list. Second, we took a sample of

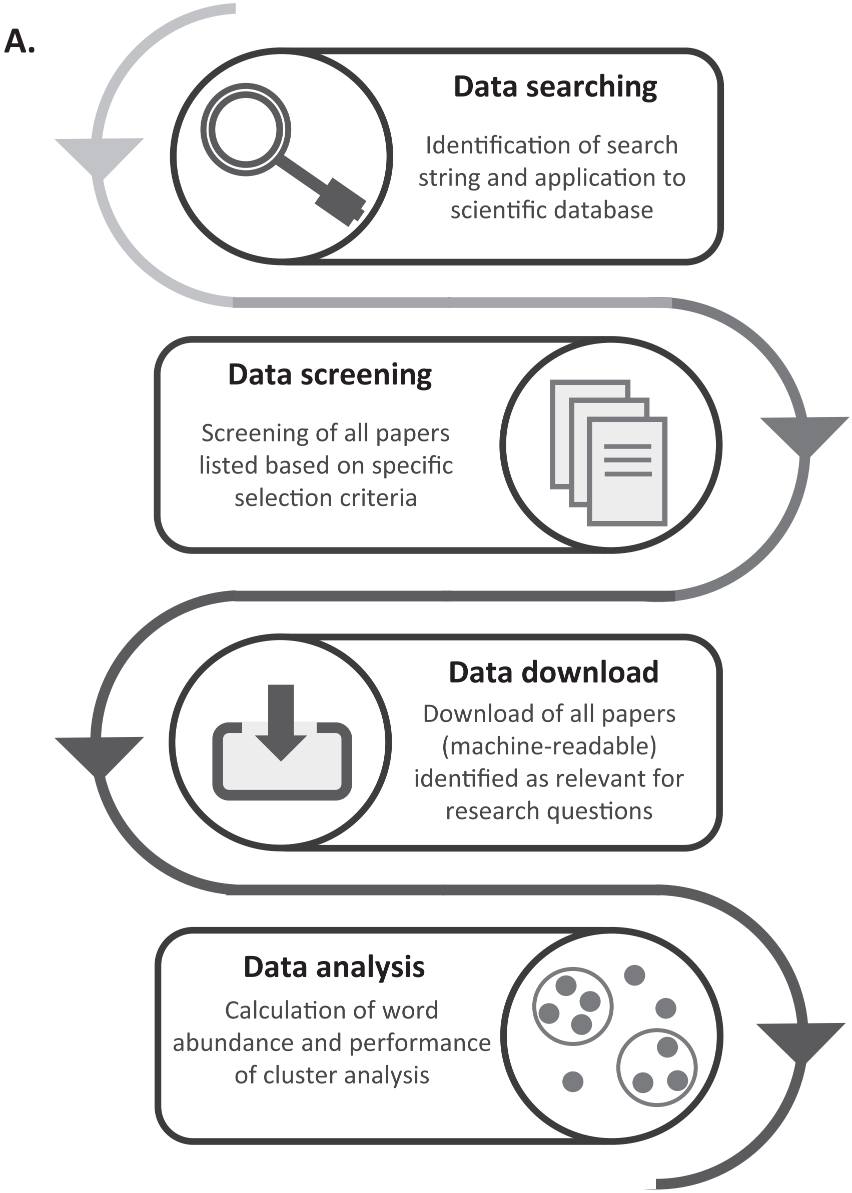

FIGURE 1.2 (A) Four-step methodological approach and stepwise selection of relevant papers (data searching and data screening). Literature was filtered by a predefined search string (*data searching*) and checked for relevance based on five different categories (*data screening*). Relevant papers have been downloaded (*data download*) and further analysed (*data analysis*). (B) A systematic literature review has been conducted focusing on the conceptualization of "transdisciplinarity" in the marine realm. A keyword-based identification strategy has been applied to Web of Science (*data searching, data screening*).

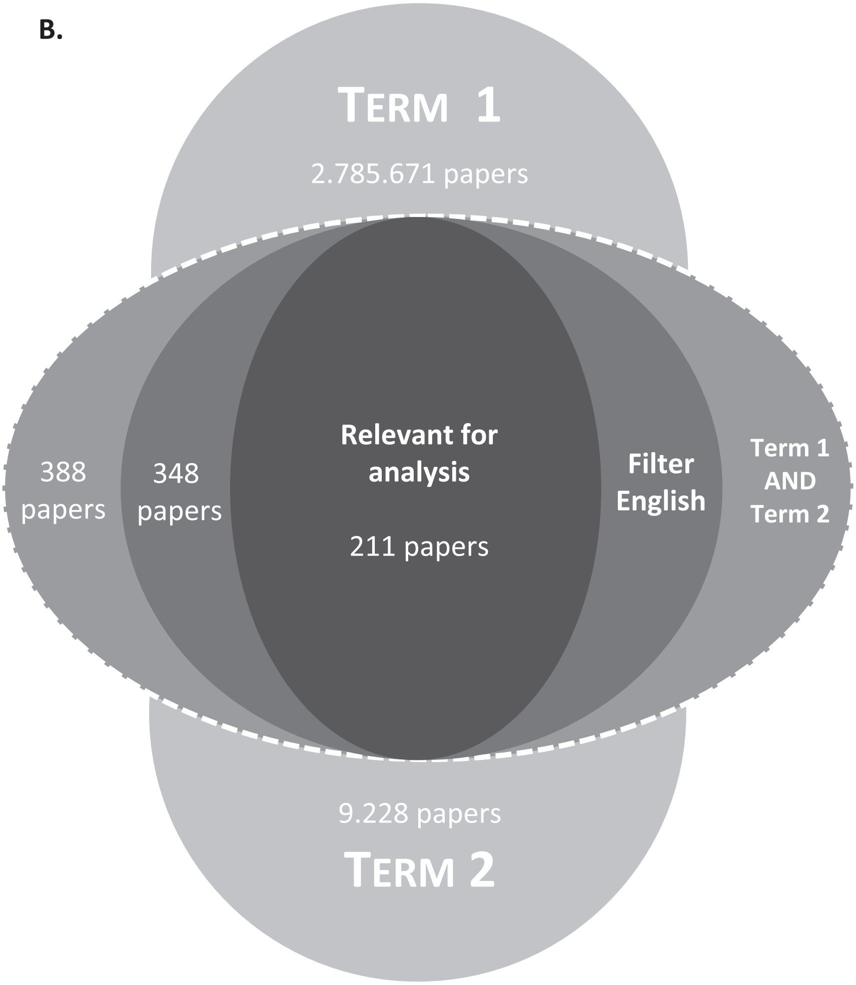

FIGURE 1.2 (Continued)

10% of the publications identified by our search string and checked their relevance to our topic by reviewing title, abstract and keywords. After minor adjustments, we arrived at our final search string identified in Table 1.1, resulting in a total of 388 papers (Figure 1.2B). Applying a language filter focusing only on English publications reduced the number of publications to 348 (Figure 1.2B).

In the second step, all identified publications were divided among the authors of this paper and reviewed in terms of their relevance (Figure 1.2A, *data screening*). For this, a deductive approach was applied, using the following five criteria: (i) marine focus, (ii) transdisciplinarity, (iii) English language, (iv) availability, and (v) quality (Appendix A.1). If a paper was not clearly identified as relevant by the reviewing author, we conducted a group discussion among all authors.

TABLE 1.1 Identified search string

Term 1	*Term 2*
marine OR maritime OR ocean OR oceanic OR oceanograph* OR seabed OR sea OR seawater OR seaside OR seafloor OR seacoast OR seashore OR seafront OR coast OR coastal OR coastline OR coastland OR shore OR shoreline OR shoreside OR shorefront OR bay OR saltwater OR "salt water" OR pelagic OR "high seas" OR demersal OR fish* OR aquaculture OR angling OR "offshore wind*" OR "offshore drilling*" OR shipping OR "blue sector" OR "blue growth" OR mariculture OR "EU water framework directive" OR beach	transdi$ciplinary OR transdi$ciplinarity OR transdi$cipline

Note: An advanced keyword search has been applied to publications title, abstract and authors keywords using all databases of *Web of Science* for the most comprehensive results.

In this context, we included 211 papers that were published between 1974 and 2022 (Appendix A.2) (Figure 1.2B). Third, all relevant publications were downloaded in a machine-readable format as pdf-files for further analysis of full-texts (Figure 1.2A, *data download*).

Fourth, we evaluated how the term "transdisciplinarity" is used within the marine realm. Doing so, relevant publications were analysed on the basis of their full-texts employing a detrended correspondence analysis. This method is usually applied to ecological community data but has been widely tested to identify principle gradients in research landscapes of review papers before (e.g. Abson et al., 2014; Drupp et al., 2020). The data analysis consisted of three sub-steps: (i) selection of conceptual vocabulary from relevant full-texts as the basis for the analysis; (ii) identification of principle gradients in the research landscape using a detrended correspondence analysis; (iii) performance of an agglomerative hierarchical cluster analysis (Figure 1.2A, *data analysis*).

To obtain the conceptual vocabulary, we applied automated and manual filters. At least two authors needed to agree to keep or remove words for further analysis. Using the software R, we then performed a cluster analysis on the basis of the conceptual vocabulary (for details, see Appendix – Additional information to Material and Methods).

Overall, a total of 556 significant words were found within the transdisciplinary marine research environment (Appendix A.7). For each cluster, we selected 15 significant words that we consider to be most representative (see the list of significant word in Table 1.2), based on which the gradients of the research landscape – represented by the axes – have been determined.

TABLE 1.2 Six research clusters in the transdisciplinary, marine landscape

Cluster	*# of papers*	*Significant conceptual words*
Scientific Methodology	22	perspectives, communication, collaboration, engagement, experiences, transdisciplinarity, expectations*, non-academic, interdisciplinarity, stakeholders, academic, participants, societal, recommendations*, guide
Governance	30	marine, biodiversity*, monitoring, sciences, network, science-policy, exchange, ecosystem-based, international, cross-disciplinary, experts, implementing, ecosystems, action, governance
Ecosystem Services	77	ecosystem, habitat, services, conservation, conceptual*, modelling, process, ecological, indicators, consultation, reserve*, quality, recreation, agricultural, trade-offs
Fisheries and Management	22	economic, fisheries, small-scale, fishers, poverty, cooperative, compliance, artisanal, by-catch, management, co-management, policies, socioeconomic, quotas, interviewed
Hazards & Resilience	24	change, climate, planning, public, coast, risk, protection, adaptation, vulnerability, hazards, damage, citizens, resilience*, exposure*, decision-makers
Geosciences	36	morphology, volcanic, isotope, deposition, composition, periods, plate, shoreline, dune, hydrodynamic, satellite, formation, sedimentary, geology, jurassic

Note: For each cluster, the number of relevant publications and the most representative[4] significant conceptual words (N=15) are listed (words marked with "*" have not been plotted in order to improve the readability of Figure 1.3).

Cluster names are chosen manually on the basis of significant words or even consist of them. On top of the cluster analysis, we further checked for connectivity among the research clusters by spanning ellipses around the plotted words of each cluster.

Results

Based on the detrended correspondence analysis of 211 relevant publications, six research clusters could be identified within marine science using the term transdisciplinary. The respective clusters are visualized by means of an ordination plot (Figure 1.3), with axes scaled by DCA units.[5]

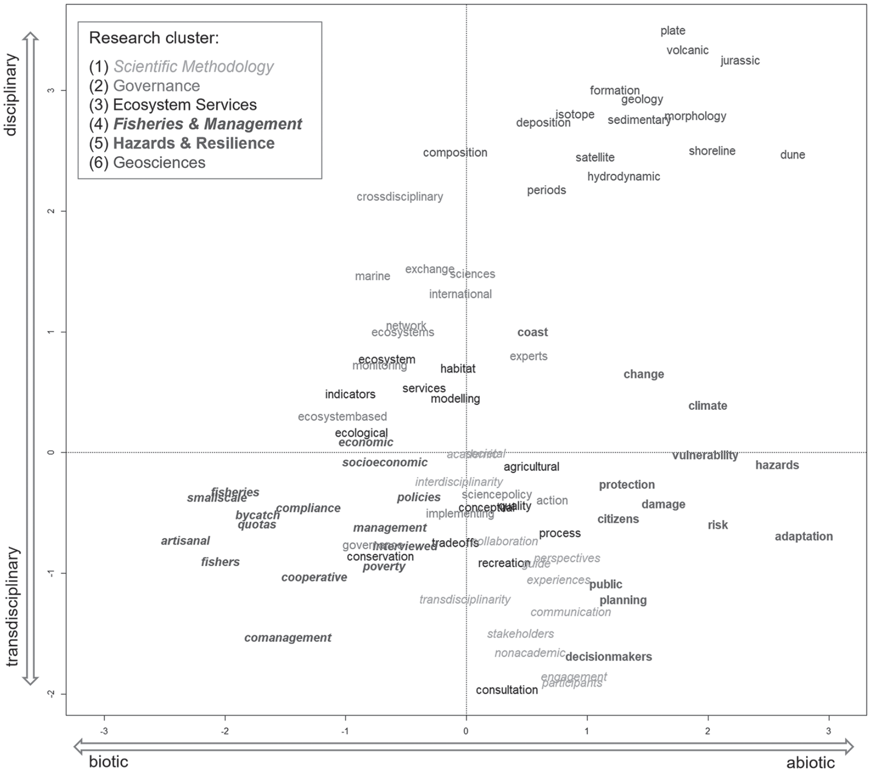

FIGURE 1.3 The multifaceted picture of transdisciplinarity in the marine realm. Six research clusters could be identified on the basis of a full-text analysis of 211 relevant publications. For each cluster, the most significant words are displayed (see Table 1.2 for a list of plotted words).

The ordination plot (Figure 1.3) shows the multifaceted picture of transdisciplinarity in marine-related research, ranging over six DCA units from −3 to +3. We interpret the horizontal axis as the research environments that deal with either biotic or abiotic factors (from left to right). The vertical axis displays the level of integration across scientific disciplines and societies, similar to Figure 1.1. Starting at the top (+3.5), research focuses strongly on its own discipline. Along the axis, the degree of knowledge integration increases continuously, as indicated by the terms "crossdisciplinary" (+2) and "interdisciplinarity" (−0.25), with the highest degree "transdisciplinarity" at the lower end (−2). Thus, we interpret this gradient as the level of knowledge integration, ranging from specific disciplinary academic knowledge to the integration and active involvement of non-academic knowledge. Both gradients allow us to classify and analyse relevant publications into clusters based on their significant conceptual words. Each cluster represents publications sharing similar conceptual vocabulary, whereas dissimilar vocabulary, and thus clusters, is placed far apart. However, the identified research clusters may overlap in the conceptual vocabulary of the respective publications.

Next, we provide detailed thematic descriptions of the six research clusters including their spatial arrangements along the gradients, placing them in a larger context. Further, we analyse how the research clusters are (dis-)connected in terms of their conceptual vocabulary.

Methodological approaches applied in transdisciplinary research

The significant conceptual vocabulary of cluster 1 "Scientific Methodology" can be derived from the area of methodology: (i) who is involved in the research, (ii) how is the research conducted, and (iii) how are the results managed? "Transdisciplinarity" is identified as one of the most significant words, indicating that the methodological approaches are primarily used in a transdisciplinary context. Interestingly, the term "interdisciplinarity" is identified as significant as well, defining the scope of application range.

One thematic area of this cluster focuses on the level of "stakeholder" involvement in transdisciplinary research. The term "society" in connection with the word pair "non-academic" versus "academic" hints to the idea of exchange between different groups, and between science and society. Along those lines, stakeholders outside of academia may act as "participants", exchanging "expectations" and "experiences". Generally, active "communication" is a key element of transdisciplinarity, although it is important to specify what kind of communication is considered: (i) one-way communication or (ii) bi-directional communication. The different kinds of communication become even clearer by considering another significant term: "collaboration". Thus, stakeholders can be actively involved in the research, not only by contributing some information but also by having a more intense communication, either by co-designing the research questions or by co-analysing and co-interpreting the results.

Another research theme focuses on the development of "recommendations" for society or political decisions. While the concept of objective knowledge generation dominates in the classical understanding of science, interaction with society plays an essential role in transdisciplinary research according to our understanding. There is "engagement" and the aim to include different "perspectives", possibly to "guide" policy-makers. Overall, we note that scientific methodology of transdisciplinarity is applied when different research areas overlap as the cluster's location at the intersection of biotic and abiotic environments reveals.

Goals, measures, and stakeholder involvement in ocean governance

The "Governance" cluster is captured as ocean governance addressing the following key questions: (i) where does ocean governance take place, (ii) what are the goals behind ocean governance, (iii) who is involved in the conceptualization and implementation of ocean governance, and (iv) which measures are needed to achieve these defined goals?

In general, "ocean" "governance" is about managing the use of the oceans "worldwide" such that an "international" approach seems to matter. One focus is on "marine" "ecosystems", for example, preserving and enhancing their "diversity" (i.e. "biodiversity"). Central to this is "ecosystem-based" management, often in a "spatial" context. To ensure a successful implementation of the goals set, it is necessary to involve different "sciences" (also called "crossdisciplinary"), as well as other "experts". With regard to the "science-policy" interface, the key role of ocean governance is on the "exchanges" of experiences and good practices and thus the joint creation of knowledge with the aim of informing decision-making. In this regard, various "actions" and "initiatives" can be defined and implemented to achieve these goals. These include, for example, "forums" or "platform" that contribute to strengthening knowledge about the ocean system and associated marine ecosystems but can also support the development of a common "vision". Here, "monitoring" and "observation" are central in order to accompany the implementation of measures aiming for clean, healthy and productive oceans.

Orienting along the vertical gradient in Figure 1.3, the cluster "Governance" mainly covers the area from cross-disciplinary to interdisciplinary research. The clusters thematic focus (horizontal axis) is mainly on biotic ecosystems of the ocean.

Trade-offs in managing ecosystems

The cluster "Ecosystem Services" encompasses mainly literature from a broad field of ecology. It deals with (i) different marine ecosystems and methodological approaches to asses them, (ii) its use values, (iii) nature conservation, and (iv) its inherent close connectivity to other disciplines and society.

The location of the cluster in the ordination plot (Figure 1.3) reveals the complexity of ecological research due to a large shared vocabulary with other clusters. It focuses on "ecosystems" and "habitats" having direct implications on society. To assess the state of an ecosystem, ecological "indicators" are commonly used to identify drivers of change or the habitat structure. Above, dynamic behaviours of a complex, adaptive system can be investigated by "conceptual" or quantitative "modelling". Explaining conditions within landscape units, conceptual models illustrate the connections of environmental stressors, management actions and resulting effects on ecology and society, involving transdisciplinary research (Fiksel et al., 2014). In addition, further insights into the system can be provided due to "consultation" between stakeholders and scientists.

The interaction between humans and nature is demonstrated by values that ecosystems provide in form of ecosystem "services". Significant words such as "recreation" and "quality" refer to cultural services, indicating the relevance of social aspects in transdisciplinary research. As this cluster overlaps with the governance cluster, the quantification of ecosystem services seems to play a crucial role in the conservation and management of nature in the long run, benefiting both nature and humans. In the marine context, conservation issues are directly related to management approaches and can range, for instance, from marine protected areas to tidal river management. Thereby, this thematic area of environmental protection ("conservation", "reserve") is strongly linked to human well-being.

The complexity of ecological systems and their use leads to "trade-offs" and synergies between different sectors. Another research focus is on "agricultural" activities, being of particular interest in landscape ecology. Generally, the "ecosystem services" cluster is an important research area dealing with spill-overs of different biotic and abiotic systems. Nonetheless, the clusters' wide expansion along the vertical axis, including inter-, and trans-disciplinary research (Figure 1.3), suggests that publications within the group might have a different understanding of the involvement of participants outside academia.

Bycatch and overexploitation as key problems in fisheries management

Another cluster can be summarized as "Fisheries & Management". As the title implies, this research landscape deals with "fisheries" and encompasses the following thematic fields: (i) disciplines that study fishery-related issues, (ii) stakeholders, (iii) methodological approaches, and (iv) governance. Figure 1.3 shows that the cluster deals exclusively with biotic factors as marine resources such as fish reflect the basis of this research area. The methodological scope along the vertical gradient is mostly bounded to transdisciplinary approaches, but also extends into interdisciplinary research. Reasoning is the collaboration between economists and ecologists, who make use of ecological-"economic" models to analyse fish stocks and their development under certain management schemes.

Significant terms such as "bycatch" and "poverty" reduction mirror active research fields of the past years. The complete list of significant words allows for detailed insights into the research area (see Appendix A.7). Accordingly, "overfishing", "overexploitation", "illegal", and "collapse" are still challenging issues, being opposed to term "sustainability". In this context, "socioeconomic" considerations are necessary to show the resulting consequences on society, for example, people whose livelihoods depend on fishing. Different stakeholders such as "artisanal" and "small-scale" "fishermen" could be identified. The involvement of these actors in transdisciplinary fisheries research includes methodological concepts from interviews (i.e. actors are "interviewed") to "co-management". Co-management, that is, the inclusion of non-scientific actors in management decisions, can take several forms and is an official goal of the European Common Fisheries Policy. Another thematic focus within the "Fisheries and Management" cluster is related to governance issues or "management" regulations such as "quotas". Transdisciplinary research addresses "policy" questions, a topic of special interest to non-scientific actors, including "compliance" as one important component which requires actors' acceptance for a successful and sustainable management. In this way, the management aims to create a fair balance between the interests of various actors involved.

Risk = hazard × exposure × vulnerability

The cluster "Hazards and Resilience" focuses in the context of transdisciplinary research on the following sub-fields: (i) the relationship of risk in a changing system, (ii) the effects of hazards on the society, (iii) the reaction of nature and society to hazards, and lastly (iv) regional aspects. The cluster covers a large part of the fourth quadrant of the ordination plot, slightly merging with the first one (Figure 1.3). Thus, publications of this cluster focus on abiotic environments like climate. Interdisciplinary approaches form the basis of this cluster, being extended by methodological concepts from transdisciplinary research.

The "Hazards and Resilience" cluster can be described by the so-called risk equation whose components correspond to significant conceptual words, namely: "risk" = "hazard" × "exposure" × "vulnerability". These terms are essential and often used in hazard and resilience studies. Especially the term "risk", being the product of the other factors, plays an important role as transdisciplinary research in this field often aims to reduce it. Another theme within this research cluster seems to relate to the effects on and from society to hazards and potential damage. Here, the most significant terms are concentrating around "citizens", "planning", "public" and "resilience". Transdisciplinarity is paramount for many planning studies on resilience, which includes citizens, academia and public authorities. In this domain, especially in the decision-making process, transdisciplinarity is already a standing term and an applied approach.

Further typical characteristics of this cluster are reactions of nature and society to external forcing, putting the cluster in a larger framework. The term "change" is of great importance as it might relate to climate change and a "warming" climate. Over the past decades, the field of climate change has become a major research area itself. This is in contrast to concepts such as "adaptation" and "protection", which represent the response of societies to changes in the Earth's system. Overall, all societies that are affected by marine hazards are located at the "coast". Hence, a strong connection of marine transdisciplinary research is expected to target both, the coastal area as a research focus and its interaction with "citizens".

Ocean and marine systems from a morphological perspective

The cluster "Geosciences" investigates (i) the structure and age of the Earth in general and rocks of the solid Earth in particular, as well as (ii) the processes of their formation and dynamics within Earth's system. The transdisciplinary research within this area is focusing on "geology", for example, "morphology" or "volcanic", encompassing the "formation" and "composition" of a geological system.

The "Geosciences" cluster is limited to the upper part of the first quadrant, describing a very disciplinary space that focuses on abiotic factors and coastal landscape formations. In contrast to the other five clusters, this cluster does not appear to include non-academic stakeholders when considering significant words in addition to scientific disciplines (e.g. "sedimentary"). Furthermore, Figure 1.3 shows that this cluster has a particular vocabulary, being very distinct from the other clusters and showing no overlap. Even though the term "transdisciplinarity" is used by publications belonging to this cluster, no methodological approaches relating to the transdisciplinary realm (see "Scientific Methodology") are applied.

Connectivity among research clusters

The (dis-)connectivity of the six research clusters in terms of conceptual vocabulary is displayed in Figure 1.4. Based on the cluster analysis given earlier, we found that one cluster focuses on methodological approaches in transdisciplinary research, while the remaining five clusters correspond to research fields of a variety

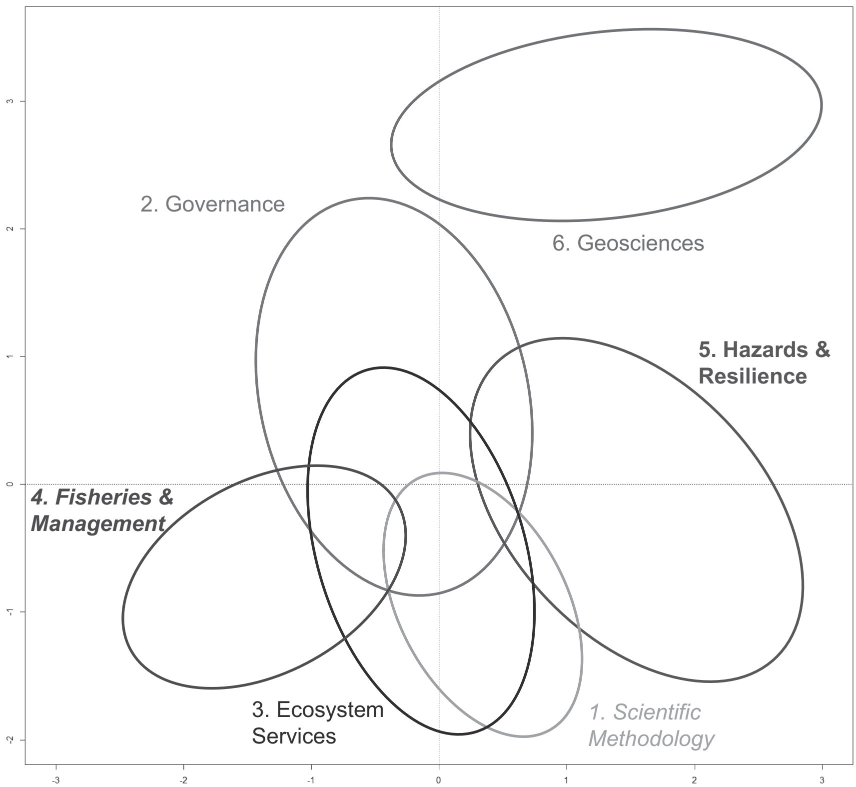

FIGURE 1.4 Connectivity between the six research clusters of transdisciplinarity in the marine realm. Ellipses are drawn around the significant words of the respective cluster (same scale as in Figure 1.3) to display the connectivity among research fields.

of disciplines which conduct transdisciplinary research, according to their understanding of the term.

We observe that "Geosciences" is very disconnected from the other research clusters. Although all publications deal with transdisciplinary approaches, the clusters "Geosciences" and "Scientific Methodology" do not overlap in terms of similar vocabulary. In comparison, the remaining research clusters are more closely linked to each other, whereby the "Governance" cluster plays a very central thematic role (large shared vocabulary with other clusters) across the marine research landscape. To be highlighted, "Fisheries and Management", "Governance", and "Hazard and Resilience" overlap with (i.e. are connected to) "Scientific Methodology", indicating that research in the marine field is subject to different transdisciplinary approaches.

Discussion

Our results demonstrate that there is neither a common understanding nor application of transdisciplinarity in marine research across and within disciplines. One of the underlying reasons is shown in the different terminology of "stakeholders" as they are assigned different expectations and tasks in the transdisciplinary landscape. Various underlying components are discussed next, helping to create an aligned understanding of transdisciplinarity.

The performed analysis showed that "Geoscienes" does not overlap with the other research cluster in terms of vocabulary. The disconnection of the "Geosciences" from the "Scientific Methodology" cluster reveals the fact of divergent understandings of transdisciplinarity. Among all significant words within the "Geosciences" cluster (Appendix A.7), none of them deal with the definition or application of transdisciplinary research according to our understanding (Figure 1.1). The reason for this gets obvious by taking a closer look at publications representing this cluster. For instance, Regier et al. (1974) argue that transdisciplinary researchers can address their research issues independently of stakeholders from different fields. This understanding is in line with several studies from the early 2000s, conceptualizing transdisciplinarity as the intersection of different disciplines (e.g. Karl, 2002; Becker and Grupe, 2012; Seabloom et al., 2012), contrasting our understanding of the concept (Figure 1.1). Even though the perception of transdisciplinary has evolved over time in this research cluster, some geoscientists still understand this concept in a manner of interdisciplinary cooperation or the use of different methods to collect data (e.g. Aucelli et al., 2021). We note that most researchers have had, and some still have, different understandings of transdisciplinarity. This emphasizes the necessity to consciously address one's own understanding of this concept to develop a common terminology for the collaboration between science and society. In turn, this can promote the exchange and success of transdisciplinary projects.

The evolution of the changing conceptual use of transdisciplinarity is also emerging in the literature of the "Ecosystem Services" cluster. While Paterson et al. (2010) observed the interchangeability of the terms "multi-, inter-, trans-disciplinarity", some more recent publications focus on the perception of knowledge integration in transdisciplinary research. Similar to Shirk et al. (2012) describing collaboration, co-creation and co-design as different levels of participation, Mobjörk (2010) uses a slightly different terminology with "consultative" or "participatory" transdisciplinarity. The former describes an approach in which non-academic stakeholders merely gather and collect data for scientists or respond to their research, while society is not directly involved in knowledge production (e.g. Torell et al., 2012). The latter approach values societal and scientific knowledge equally, considering a collective knowledge production process (e.g. Berninsone et al., 2018; Gurney et al., 2019). The publications cited earlier indicate that both concepts of communication exchange are used in recent literature and are thus implemented in practice. A changing use of the term "transdisciplinarity" is discernible, but does not apply to all publications. Accordingly, the term evolves independently of temporal changes.

In the context of sustainability research, even an understanding of transdisciplinary research as "transformation research" arose where science takes an active role in society with the aim of developing society further (Lawrence et al., 2022). However, this transformative level of transdisciplinarity is not found across all research clusters. Only in the area of "Fisheries & Management" a focus on "sustainability" research is indicated as significant (Appendix A.7). This evolved role of transdisciplinarity is not surprising as fisheries-related research already has a very strong understanding of transdisciplinarity in terms of active stakeholder engagement, for example, co-management (e.g. Esther et al., 2021).

Conceptualization and involvement of relevant actors

Stakeholders (in the broad conceptualization) are a central pillar of transdisciplinary research. However, the conceptualization of the term in general and in particular of the actors involved in each specific case sometimes reveals major variations. These differences are evident in the general inclusion of stakeholders but also in the definition of the stakeholder itself, ranging from very broad terms like expert (e.g. Johnson, 2021) to the specific identification of relevant stakeholders like fishers (e.g. Esther et al., 2021). On this basis, the question of who is named as a stakeholder in the various clusters and included in the field of transdisciplinary research will be explored in more detail further.

While from the "Geosciences" cluster, stakeholders or stakeholder groups are not among the significant conceptual words, "Ecosystem Services" focuses at least on one methodological approach (i.e. "consultation"), indicating the engagement or participation of stakeholders (e.g. Celliers et al., 2021). However, a more detailed investigation of the clusters "Scientific Methodology", "Governance", and "Fisheries and Management" reveals a distinctly different picture. In fact, this includes scientists from different disciplines, including several concepts such as "disciplinary," "cross-disciplinary," or "interdisciplinary," as well as stakeholders outside of science who are involved or affected in the different areas (e.g. "fisheries"). This very broad picture is closely related to Freeman's (2010) definition of stakeholder, according to which stakeholders are described as any group or individual who, for example, can influence or is affected by the achievement of a defined goals. While Tiller et al. (2015) are criticizing this concept as too broad, this reflects the situation given in transdisciplinary research. To further illuminate Freeman's (2010) definition and the diversity we have identified in the marine transdisciplinary context, we will exemplify the conceptualization of the term stakeholder in relation to the "Governance" and "Fisheries and Management" clusters.

Based on the results of the cluster analysis, it can be seen that in the context of governance as a research field, "experts" are considered to be the key stakeholders, in addition to "science". In this regard, a precise conceptual distinction needs to be made in the use of the term "expert". On the one hand, this term is used exclusively in a scientific context, namely "expert from science" (Hoerterer et al., 2020). However, according to Rudd et al. (2018), experts are a group of actors across sectors and disciplines, which places the definitions of expert in a broader context including stakeholders outside academia. In contrast, Johnson (2021) and Levesque et al. (2021) use the term "technical expert" to explicitly refer to the function of an "expert", namely consultation with stakeholders, such as decision-makers or community stakeholders regarding for example, the display and interpretation of data. Schmidt et al. (2014) take a completely different approach and use the term in a geographical sense (i.e. "regional experts"). Even if by definition an expert is the one we make it in the individual case (this includes the different disciplines inside and outside academia). This digression shows the diverse uses and frames the diversity of the term applied in marine transdisciplinary research.

In the context of fisheries, stakeholders are conceptualized as actors outside academia like "fishers", equivalently "fisher-men" (-"women"). In the underlying publications of the cluster "Fisheries and Management", the term "fishers" refers to either fishers represented by fishing cooperatives (Bojórquez-Tapia et al., 2021) or fishers themselves (Esther et al., 2021). Transdisciplinary research focuses on stakeholders from small-scale or artisanal fisheries. In addition, recreational fishers such as anglers, subsistence, and indigenous fisher are considered as well. Probably, successful transdisciplinary research requires close contact and the building of trust which might be less complicated in small-scale/artisanal fleets with their connection to the local socio-economic network than in larger companies.

Through our methodological approach,[6] we have demonstrated the existence of different understandings of transdisciplinary concepts. Although we can observe a gradient from disciplinary to transdisciplinary research along the vertical scale, it is interesting to note that many words explaining methodological transdisciplinary approaches are located close to the field of interdisciplinary research. Reasoning might be that interdisciplinarity is a part of the transdisciplinarity definition as shown in Figure 1.1. Nonetheless, no strong gradation of the transdisciplinary knowledge integration level is apparent in the ordination plot. For example, "consultation" is allocated at the lowest intercept of the y-axis. According to our understanding, consultation represents a lower degree of knowledge integration and thus should be located further.

Conclusion

We quantitatively examined the usage of the concept "transdisciplinarity" in the marine realm on the basis of relevant identified papers published between 1974 and beginning of 2022. Our cluster analysis revealed six larger research fields using the terminology transdisciplinarity. We found that across and even within research clusters, no common understanding of the concept exists. Especially geosciences seem to often consider transdisciplinarity synonymously to interdisciplinarity. In addition, the degree of knowledge integration of non-academic stakeholders plays a decisive role in whether and to what extent research is understood as transdisciplinary.

Through our conceptual distinction of multi-, inter- and trans-disciplinarity, we have created awareness for the various existing concepts. Especially our reflection on the use of transdisciplinarity in the (marine) scientific community contributes to a better understanding of how differently the term has been used so far. In this context, it is necessary to further sharpen the understanding of transdisciplinary methods. Here, a conscious examination of one's own understanding of transdisciplinarity is the first step and can thus promote cooperation between science and society due to the exchange of various conceptualizations in a second step.

Data availability statement

The data presented in this study are available on request from the corresponding author. The data are not publicly available due to restrictions, that is, privacy and ethics.

Appendix

For the traceability and reproducibility of our data, all information regarding the step data screening and data analysis are presented in detail in the appendix. In addition, this comprehensive document contains a list of all publications considered relevant for the cluster analysis: http://ssrn.com/abstract=4132482

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Notes

1 We use the term stakeholder for user groups outside the university system. But – as discussed in the chapter "Conceptualization and involvement of relevant actors" – the use of term stakeholder varies greatly in the reviewed literature.
2 Additional information to the literature review can be found in the appendix.
3 Our definition of the marine realm encompasses the marine system itself and sectors that are directly linked to it. Zones from the open ocean to the continental shelf, including adjacent coastal areas, form the framework. Thus, research studies that deal directly with these systems as well as sectors that make use of them are considered, for example, fisheries, offshore wind and shipping. Studies that address the interaction of terrestrial and marine systems, for example, via inputs of nutrients or sewage are included. Publications dealing exclusively with water systems such as freshwater or inland waters are excluded.
4 According to our understanding of representative words, we chose significant words that reflect the different facets of the respective research field and those that are connected to transdisciplinarity. If similar terms such as "fishing", "fisheries" and "fish" were among the significant words, only one of them was depicted. Same holds true for redundant words, for example, we selected the word "hazards" but ignored terms such as "storms", "flooding" and "erosion".
5 Ordination describes a multivariate technique where a multidimensional dataset (here significant words by publications) is projected onto a lower dimensional space to understand the intrinsic pattern of the underlying data (Pielou, 1984). In ecology, ordination is used on community data to describe the relation between species composition and environmental gradients. Hence, similar species are plotted close to each other, whereas dissimilar species are plotted further apart. A difference of three to four DCA units already indicate a complete turnover in species composition. Figuratively speaking in ecological terms, this corresponds to the transition of a forest to an adjacent meadow.
6 The discussion of our applied method can be found in the appendix.

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