

Review

Knowledge exchange at the interface of marine science and policy: A review of progress and research needs

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ABSTRACT

The management of oceans and coasts needs to be informed by the best available knowledge. One way to support that is through interactive knowledge exchange (KE). Over the last decade, KE strategies have been shared with the marine research community, however, it is unclear whether this has led to recent (i.e., since 2015) progress. Through a systematic review of 60 recent academic articles applying or evaluating marine science-policy KE we synthesize trends in strategies, reasons for using a specific strategy, enablers, achievements, and evaluation. Most articles located were from North America, routinely included local actors or organizations, and spanned different governance levels. In addition to knowledge co-production and boundary organizations as well-established strategies, research networks and engaged funders coordinating and supporting science-policy KE played an increasing role. However, studies rarely provided reasons for why they adopted a specific KE approach within their given context. Achievements of KE are becoming more broadly understood and, among others, included the generation of new knowledge and impact on management or individuals. Factors that enable such achievements are a key area of progress in the literature. Individual case studies referred to the process level (e.g., practical collaboration, inclusive participation and equity, clear goals, continuity), interpersonal level (e.g., trust building, relationships, regular face-to-face contact), and individual level (e.g., skillsets, understanding, champions, facilitators). The measures to evaluate the effectiveness of KE were predominantly qualitative (e.g., relevance of knowledge, use of knowledge in management, individual conceptual impacts, and level of engagement). It is increasingly understood what diversity of impacts to look for and unfold ways for more purposeful evaluation. In conclusion, much progress has been made in recent years, and we identify ten further research needs around the inclusivity, institutionalization, strategy selection, and efficiency of KE approaches to support evidence-informed ocean and coastal management.

1. Introduction

In unprecedented times of increasing human impacts on oceans and coasts (Crain et al., 2009; He and Silliman 2019), the management of these environments and the human activities within them needs to be informed by the best available knowledge. To enable more effective and holistic management of social-ecological systems that emphasizes knowledge use and learning, a range of governance approaches have emerged (Berkes et al., 1998; Cvitanovic et al., 2018a), among them are adaptive governance (Österblom and Folke 2013) and its conceptualizations considering different types of knowledge (Wyborn 2015).

One of the knowledge sources that can, and should be, considered within governance processes and structures is research-based

knowledge¹ (cf. Van Kerkhoff and Lebel 2006). In recent years, studies have shown the importance for interactive ‘knowledge exchange’ (KE) as one of the approaches for achieving evidence-informed decision-making in ocean and coastal governance (Clarke et al., 2013; Cvitanovic et al., 2015; Nguyen et al., 2019). KE embraces the interdependencies and differences between actors from research and management (e.g., Contandriopoulos et al., 2010), and in doing so moves beyond traditional and linear models of knowledge transfer (e.g. the ‘loading dock’ approach, Cash et al., 2006). Approaches to interactive KE (e.g. knowledge co-production, *sensu* Norström et al., 2020; Chambers et al., 2021) intend to be more inclusive and account for all interactions between knowledge ‘producers’ and ‘users’ throughout processes of knowledge generation, sharing, mobilization, translation, management,

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¹ For the purpose of this paper, we have opted to use the language of ‘research-based knowledge’, opposed to ‘scientific knowledge’. We do so following van Kerkhoff and Lebel (2006, p.447) who use this term to explicitly include “all areas of systematic inquiry that are justified by their adherence to a research process as defined by peers” (e.g., social science, history, philosophy).

and use (e.g., [Best and Holmes 2010](#)). In doing so, KE aims for knowledge to become “*accessible, understandable, shared, and used, enabled by good knowledge exchange products, - processes, and social outcomes [...] with the potential to contribute to changes in policy and demonstrable societal impact*” ([Karcher et al., 2021](#), p.214). Thereby, effective KE can support ocean and coastal governance – which has struggled ([Haas et al., 2022](#)) – and help enable evidence-informed decisions that benefit people and biodiversity. Therefore, KE in the marine space is directly aligned with the ongoing UN Decade of Ocean Science for Sustainable Development which aims for science-informed policy responses through stronger science-policy connections and participatory, communicative, two-way engagement mechanisms at the science-policy interface ([UNESCO 2017, 2018, 2020](#)).

In recognition of the need for effective KE to support ocean and coastal governance, a comprehensive literature review was undertaken by [Cvitanovic et al. \(2015\)](#). Drawing on a narrative approach to reviews (e.g., [Pautasso 2019](#)), they synthesized the literature to identify and describe four key strategies for improving KE at the interface of marine science and policy, namely co-production, knowledge brokers, embedding, and boundary organizations. Building on their review, [Cvitanovic et al. \(2015\)](#) outlined the need for institutional innovations needed, including the ways in which we incentivize and reward broader research impacts. In addition, the review also revealed a number of research gaps that, if answered, would provide the necessary knowledge base to improve the implementation of KE strategies to increase the likelihood that they will support evidence-informed decision-making. Among them is the need to better understand enabling factors to effective KE (beyond just the barriers, which had been the focus of most research until that point), and improved approaches to evaluating KE and its impacts.

Drawing from the research gaps identified by [Cvitanovic et al. \(2015\)](#), through this paper we consider the extent to which these critical research gaps have been addressed in the past 8 years. We posit that such an update is timely given that a recent review of the KE literature (broadly across the environmental sciences and not just marine) found that literature on KE peaked in be 2016, meaning that half the relevant studies were published then or later ([Karcher et al., 2021](#)). Specifically, we aim to build on [Cvitanovic et al. \(2015\)](#) and provide an update on how KE operates between marine research and management. We do so via a systematic analysis of the recent literature on marine science-policy KE. By focusing on literature case studies (both applying and evaluating KE), we aim to capture:

- i. What strategies are applied and emerging for improving KE at the interface of marine science and management?
- ii. What are the reasons/rationales for using a specific KE strategy, within a specific context?
- iii. What enabled the KE to be effective within the context it was applied?
- iv. What was achieved through KE (i.e., what are the positive outcomes and impacts associated with the implementation of KE)?
- v. What were the measures used to evaluate KE?

Doing so will identify areas of progress in relation to our knowledge of KE at the interface of marine science and management and allow for the identification of the remaining research needs that remain to be addressed to help progress the field.

2. Methods

As outlined above, the aim of this paper is to build on [Cvitanovic et al. \(2015\)](#), and thus we only searched and analyzed marine science-policy studies that were published since this time. Specifically, to compile the literature body for the present study, we conducted a literature search targeting articles from 2015 to 2022 through systematic search string development, search, and screening. This process and search string was based on [Karcher et al. \(2021\)](#) and common protocols

for systematic reviews and systematic maps ([Collaboration for Environmental Evidence, 2013](#)).

2.1. Literature search

The search string used in this study has been systematically developed in [Karcher et al. \(2021\)](#). This process included drawing relevant search terms from a range of triangulation studies ([Pullin et al., 2009](#); [Sheate and Partidário 2010](#); [Fazey et al., 2013, 2014](#); [Reed et al., 2014](#); [Cvitanovic et al., 2015](#); [Wall et al., 2017](#); [Maag et al., 2018](#); [Posner and Cvitanovic 2019](#)) and ensuring that those triangulation papers re-appear in preliminary searches. The final search string covered three layers targeting the environmental component (conserve*, ecol*, marine, coastal, ocean, etc.), the knowledge exchange component (knowledge exchange*, knowledge trans*, knowledge brok*, boundary-spanning, co-production, etc.) and the science-policy component (decision-mak*, policy-mak*, science-policy, evidence-bas*). Searches were conducted in the literature bases Scopus and Web of Science, and diverse online sources including Google scholar, Open Access Theses and Dissertations, DiVA, BASE. Searches took place in June 2022 and were retrieved July 29, 2022. More detail can be found in the [Supplementary Material](#).

2.2. Study selection process and criteria

The search results were collated, and duplicates removed. To be included in our analysis, articles had to fulfill certain criteria (i.e., following protocol requirements a set of inclusion criteria was established). Regarding article types, we only included academic literature in English language due to resource constraints and acknowledge the associated limitations. To align with the expertise of the author group, our review is centred on marine science-policy KE. Across the author group, we have experience as researchers, research managers, research funders, and government decision-makers. Our background and work experience lies mainly in the English speaking ‘global North’. We acknowledge that KE and associated strategies are Westernised concepts that may not be applicable in other contexts (e.g., cultural, institutional) and geographies. Content-wise, the articles had to:

- a) have a focus on KE activities (in any form, including for example, brokers, boundary organizations, co-production, participatory tool design, etc.),
- b) cover topics related to marine/ocean/coastal management and/or conservation,
- c) include KE between *science* and *policy* (meaning at least including research-based knowledge and public policy/marine management), and
- d) present at least one case study/setting/example of KE that is either empirically analyzed or includes practical (i.e., applied) strategies of KE (i.e., include primary and novel data).

According to these criteria, the search results were first screened on title and abstract level. For those articles that fulfilled the inclusion criteria based on title and abstract screening, full-texts were acquired and screened in full. This selection process resulted in a combined data set of 60 articles on KE activities between research and management in the marine realm in the time period covered in this paper.

2.3. Coding and data analysis

There were several topics that formed the core interest to our analysis ([Table 1](#)). We inductively coded information regarding the above-described research foci in the Software NVivo12. Through *in vivo* coding the emerging codes directly reflected the language used in the articles. This step of coding was piloted and differences discussed among three of the authors to account for interpersonal coding reliability. In a second round of coding, a thematic analysis was conducted through

Table 1
Research foci of this systematic review under which data driven codes were compiled.

Section	Coding question
Setting	Where (in which country) is the KE taking place? Governance level addressed by KE (e.g., local, state/province, national, regional, global)
Strategies	Are there non-science non-policy actors involved in KE (which)?
Rationale	What KE strategies are applied? Contextualisation & rationale for KE strategy (including pre-story and explicit reasons for a specific KE strategy)
Enablers	What enabled the KE (and how it was supported)?
Successes	What was achieved/what is the success (including outputs, outcomes, impacts etc.)?
Measures	How was KE evaluated and what are measures of success (both methods and indicators)?

which the numerous evolving codes within each research focus were grouped into themes based on their content (Saldaña 2015; Blythe and Cvitanovic 2020). Final categorization and grouping of themes was implemented based on discussions among three of the authors. The coding was conducted on the level of individual case studies (following Karcher et al., 2021). This means that where a study included several individual, separate case studies, they were included as individual entries.

3. Results and discussion

The presented body of literature comprised 60 articles that altogether represented 74 individual case studies. The themes that emerged from thematic analysis are presented on a basis of those individual case studies and shown as the number of sources (n = number of case studies), as well as the total number of references made (i.e., how often a certain theme came up). From the case study settings onwards, themes mentioned by less than three case studies are not presented in the results. Here, we present the results from the systematic literature review along with a discussion reflecting developments and progress in KE strategies, achievements, and measures in the last few years.

3.1. Case study setting

3.1.1. Findings

The majority of case studies took place in North America and Europe, together accounting for 60% of all individual case studies (Fig. 1). In 19 out of 74 case studies, the governance level of KE (i.e., the involvement of decision-makers) covered more than one level (e.g., policy actors from more both federal and state levels were involved). Most commonly, marine KE case studies focused at local (n = 14) or national (n = 10) governance levels, followed by regional (n = 5) and global (n = 2) levels. We furthermore found that a high number of case studies engaged additional actors in KE (beyond actors from science and policy/decision-making, which was a prerequisite to be included in this study). Most commonly these included actors from other organizational types (mostly NGOs; n = 28), local people (i.e., local communities; n = 16), stakeholders (n = 10), and economic actors (mainly from industry and business; n = 15).

3.1.2. Discussion

In this study, we purposefully focused on science-policy KE. However, it was evident that KE case studies engaged a wide range of additional actors. KE is to be inclusive beyond only actors from research and management. A more holistic knowledge-governance interface was proposed (Turnhout et al., 2021). Meaningful inclusivity is an oft-reported enabler of KE and can increase the legitimacy of provided knowledge (e.g., Deelstra et al., 2003; Wyborn et al., 2019; Latulippe and Klenk 2020; Chambers et al., 2022). The consideration and meaningful inclusion of multiple lines of evidence including local,

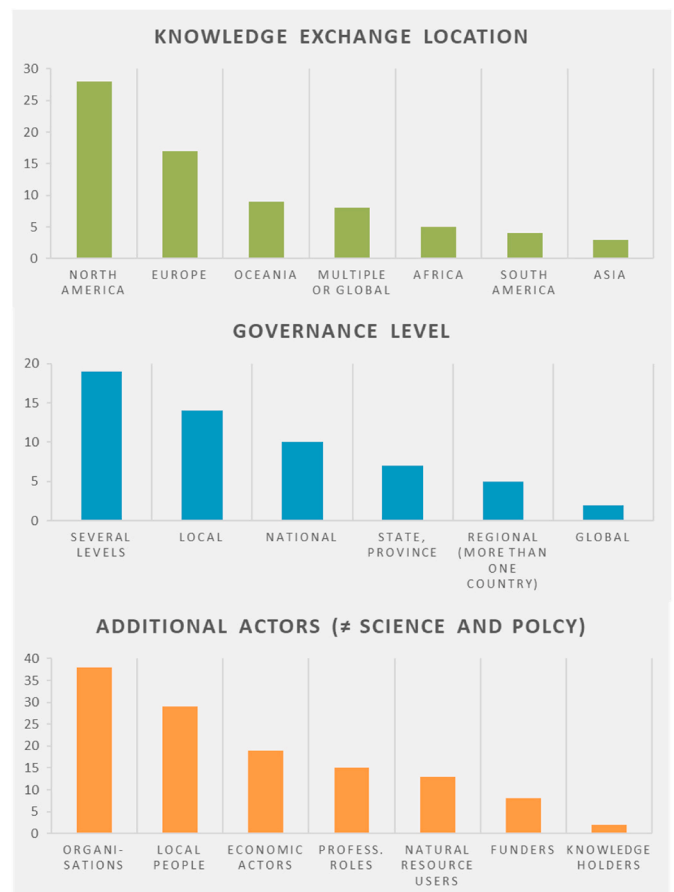


Fig. 1. Knowledge exchange location, governance level, and additional actors beyond science and policy of the 74 analyzed case studies.

experience-based, and Traditional Knowledges is important for environmental management (Raymond et al., 2010; Cook et al., 2012; Stephenson et al., 2016; Bentley et al., 2019; Dawson et al., 2021). If engaged but not effectively integrated or considered, the respective knowledge holders lose trust in the process and outcome (Florido-del-Corral & Abbot-Jiménez 2022).

The outnumbering of KE articles from the 'global north' could be either due to publication bias or a nuanced terminology of similar approaches in different parts of the world. While a mix of both is likely to be present, the latter suggests that KE and its core strategies are mostly terminologies in the English speaking 'global North' epistemic communities. For instance, KE may be termed 'participatory research', 'community-engaged research', 'community-based research', 'participatory action research'. We acknowledge limitations spanning associated terms and hence the geographies those are used more commonly in, or where informal transdisciplinary processes may occur without explicit labelling (see e.g., Kitolelei et al., 2022). This points to a need for the science-policy KE field to provide a more holistic account for such strategies.

3.2. Strategies (i.e., concepts and practical activities) for achieving knowledge exchange at the interface of marine science and policy

3.2.1. Findings

Analysis of the literature that was identified as meeting our inclusion criteria revealed that case studies applied a wide range of strategies for improving KE, which included higher-level conceptual frames and the plethora of practical activities and tasks sitting under such conceptual frameworks. Our review identified the most described concepts (Fig. 2) to be knowledge co-production (including 'co-development'; n = 32)

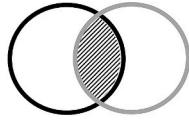
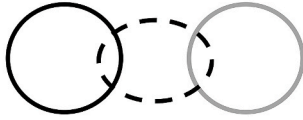
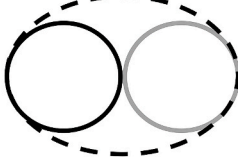
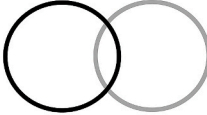
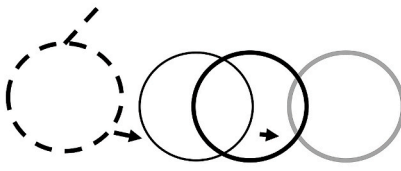
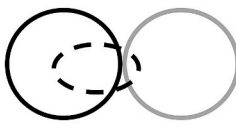
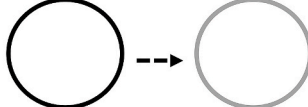

<p>Researchers (black circle) and decision-makers (gray circle) closely engaging in collaborative space (shaded)</p>	<p>i) Co-production</p> 	<p>ii) Boundary spanning</p> 	<p>Independent organisation or system (dotted oval) bridging research (black circle) and decision-making (gray circle)</p>
<p>Overarching forum (dotted oval) for researchers (black circle) and decision-makers (gray circle) to exchange</p>	<p>iii) Network</p> 	<p>iv) Co-design</p> 	<p>Joint and early planning of research between researchers (black circle) and decision-makers (gray circle)</p>
<p>Funder (dotted circle) pushing (arrows) researchers (black circle) to engage decision-makers (gray circle)</p>	<p>v) Active funder</p> 	<p>vi) Knowledge brokering</p> 	<p>Individual (dotted oval) bridging research (black circle) and decision-making (gray circle) & facilitating exchange</p>
<p>Linear transfer (dotted arrow) of information from research (black circle) to decision-makers (gray circle)</p>	<p>vii) Knowledge transfer</p> 	<p>viii) Advisory body</p> 	<p>Formal committee (dotted oval) that engages researchers (black circle) in advice to decision-makers (gray circle)</p>

Fig. 2. The most applied concepts of KE in the 74 individual case studies of KE between marine research and management. It is important to note that these are not necessarily clear-cut and not mutually exclusive.

and boundary spanning (including boundary organizations and other boundary spanning systems; n = 21). Other commonly used conceptual strategies include networks (n = 8), co-design (n = 8), active funders (n = 8), knowledge brokers or brokering (n = 7), knowledge transfer (n = 4), and advisory bodies (n = 4). It is important to note that in real-world examples, these are neither so distinct from one another, nor mutually exclusive. This means there can be overlap among concepts and strategies and the case studies in our review often applied more than one concept at once. For example, Lopez-Rodriguez et al. (2019) used co-production workshops together with designated knowledge brokers to navigate KE engagement.

With regard to the practical activities of KE (i.e., specific activities or actions used to facilitate KE among actors within the case study), our analysis revealed the importance of direct regular contact among KE actors. This was described most commonly through a multitude of - often overlapping/additive - events and meetings (n = 49), other communication pathways and products (n = 30), iterative collaboration (n = 29), compiling and synthesizing of information (n = 14), and connecting people and organizations (n = 5).

3.2.2. Discussion

Our systematic analysis of recent literature revealed a variety of commonly used strategies. Reflecting on other findings, knowledge co-production and boundary spanning are the most applied concepts not only in the marine arena but in the broader environmental field (Karcher et al., 2021). Despite not being the focus of our literature search, also linear modes of knowledge transfer continue to be present. While criticized for shortcomings in legitimacy and relevance (e.g., Cash et al., 2006; Roux et al., 2006), linear pathways (e.g., knowledge transfer,

advice bodies) continue to be found valid in specific contexts and particularly where initially demanded by the policy side (Steger et al., 2021; Karcher et al., 2022a; Maas et al., 2022). Compared to the previous review (i.e., Cvitanovic et al. 2015), an update and extension of applied concepts can be observed. It appears that in recent years research networks and engaged funders (e.g., coordinating KE) have become more important. Some years back, literature had discussed the role of funding and funders as enabling factors supportive to KE and important pieces to a functioning KE framework (Shanley and López 2009; Roux et al., 2010; Cvitanovic et al., 2015, 2016), but the more active function as a KE approach and its empirical analysis is a more recent development (Arnott et al., 2020; Arnott 2021; Cvitanovic et al., 2021c; Tseng et al., 2022; Karcher et al., 2023). Drawing from this emerging body of research, more impact-oriented funding modes (e.g., requiring for co-production) may help to support KE practice (Arnott et al., 2020). There, the roles of funders towards research impact can be facilitating connections, creating capacities, and incentivising impact and best practice (Knetsch and Tuckerman 2022). Cvitanovic et al. (2021c) suggest funders to, among other things, fund teams with diverse and complimentary skill sets, fund and facilitate full participation of management partners, schedule regular communication, ensure flexibility in funding and structure, and invest beyond the research project.

3.3. Rationale for using specific approaches to KE in any given context

3.3.1. Findings

Despite our best efforts to identify the explicit or implicit reasons why included case studies performed a specific KE approach within their given context, more than two thirds of the case studies did not make

reference to this. The 24 case studies that did make such reference were vague and tended to mix a justification for a specific strategy with a general rationale for KE engagement. Some recurring themes in why KE was performed in a certain way included that the funder required engagement (n = 6). For example, the National Estuarine Research Reserve System (USA) “increased requirements for collaboration between researchers and coastal managers” over the years (Arnott et al., 2020, p.2) and the Oregon Sea Grant clearly states what engagement they are looking for and provides guidance on how to plan for that (Jones et al., 2021). Additional rationales were that the wicked problem at hand required the involvement of many actors (n = 6), the benefit of boundary products was highlighted (n = 5) and the need to create a space to tackle shared problems across individuals and countries (n = 3).

3.3.2. Discussion

One of the critical research needs relating to KE at the interface of marine science and policy identified by Cvitanovic et al. (2015) was information to match KE strategy to context. This remains a critical gap in our understanding of KE, as illustrated above (Section 3.2.1). However, recent advances by Karcher et al. (2022b) offer some progress in this regard, embedding the planning of KE into broader considerations of scales (e.g., complexity, trade-offs, conflicts), context (e.g., socio-political, available/needed knowledge, legitimacy, actor/stakeholder mapping), timeframes (e.g., time for expectations and trust, timeframe of impact, priorities and evaluation, continuity), and efficiency ((e.g., direct/indirect costs, cost vs benefit, risks; Karcher et al., 2022b). Other studies raise as guidance the type of question and available resources (Meadow et al., 2015), as well as the size and diversity of the actor community, governance structure and required legitimacy, clarity of needs, leadership and institutional support, and also the problem complexity, justice and cultural aspects, resources, and time-sensitivity (Bamzai-Dodson et al., 2021). For the case of more individualistic efforts at the science-policy interface, such as knowledge brokers or transformative change agents, more such guidance exists (Michaels 2009; Westley et al., 2013). Irrespective of this progress, this clearly remains a critical gap in our knowledge regarding the comparative effectiveness of the full suite of available concepts, strategies, and activities that should be addressed for progressing the field of KE in relation to coastal and ocean governance.

3.4. Enablers of successful KE between marine research and management

3.4.1. Findings

The enablers of KE at the interface of marine science and policy that

were identified through our systematic review (see Fig. 3) were grouped into ten themes being related to i) process (n = 38), ii) interpersonal (n = 24), iii) individual (n = 19), iv) financial (n = 16), v) group/team (n = 16), vi) resources and information (accessible, relevant, credible, n = 12), vii) institutional (recognition, KE architecture, co-location/embedding, n = 11), viii) focus (n = 7), ix) timing (n = 7), x) public opinion or pressure (n = 3).

The process related enablers referred to, for example, practical collaboration and coproduction, inclusive participation and equity, clear goals and strategies, continuity of engagement, and iteration, feedback, and improvement over time. An example for some of those factors is shown by (Celliers et al., 2021): “The members were also requested to comply with the “rules of engagement”, which included a philosophy of democratic participation and equal right to speak. [...] There was an agreement and assumption that all knowledge was equal.” (p.3). Interpersonal factors included trust and trust building, relationships, and regular face-to-face contact. On an individual level, the individual skillsets and understanding was described, but also having open and committed champions, facilitators, and effective leaders. Financial enablers referred to an engaged funder, flexibility in funding and project plans, and long-term funding. Group characteristics spanned diverse actors, a transdisciplinary team and the right people with a shared vision.

3.4.2. Discussion

Compared to previous works (e.g., Cvitanovic et al., 2016), the interpersonal and procedural enablers of KE have gained particularly increasing attention over the last years. That work has revealed the inherent challenges with decoupling the overall impacts of KE from the enablers such that our discussion considers both in aggregate. KE approaches consider not only knowledge but also behaviors, attitudes, and skills crucial to effectively guide decisions toward sustainability goals. Our findings resonate with studies which describe process-based factors like the maturity of relationships, the context knowledge, and the intensity of engagement as key contributors to KE success (Ferguson et al., 2022). Process expertise includes knowing how to design collaborative arrangements, facilitating those and “generating a weakly institutionalized ‘in-between space’, in which researchers and policymakers interact to find more inclusive ways of tackling complex challenges” (Molinengo et al., 2021, p.1). Process design like the collaborative nature of continuous engagement with clear goals and iterative steps was found to be one of the success factors that can be planned for with co-productive capacity developing over time through reflection and improvement (Sarkki et al., 2015; Verwoerd et al., 2023; Karcher et al., 2023).

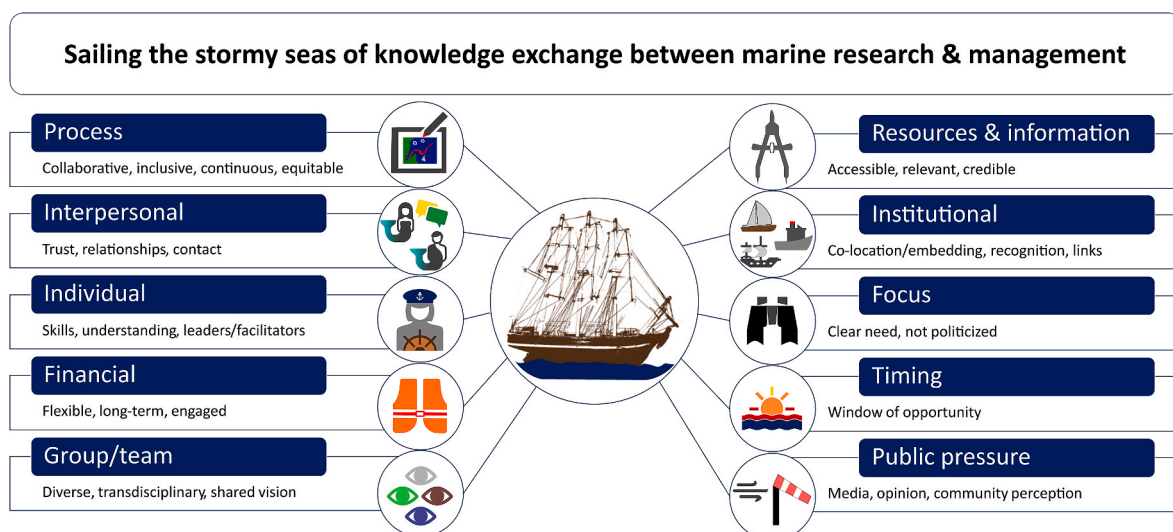


Fig. 3. Enablers of knowledge exchange between marine research and management as identified through systematic review of recent literature.

The importance of trust and interpersonal relationships for KE has become increasingly understood and focused on in the last few years (Berkes 2009; Paterson et al., 2010; Rathwell et al., 2015; Tinch et al., 2018; Newig et al., 2019). Effective KE often requires active and deliberate nurturing of relationships, particularly given the highly dynamic and fragile nature of trust (Meadow et al., 2015; Lacey et al., 2018). As such, within the context of KE trust cannot be taken for granted and requires immense investment of time, resources, and emotional effort (Karcher et al., 2022b) – often beyond what can be achieved in a project timeline and with resources provided by funders. However, recent advances related to understanding how to build and maintain trust through KE at the interface of marine science and policy have been made. For example, drawing on the International Council for the Exploration of the Sea as a case study, Cvitanovic et al. (2021b) outline strategies for building and managing trust like ensuring transparency, independence, expertise, and regular contact for feedback and focus.

3.5. Successes and achievements through recent marine science-policy KE

3.5.1. Findings

Our analysis identified five main types of successes that recent marine science-policy case studies reported and which we will consider in this section. They related to i) outputs and the generation of new knowledge (n = 26), ii) impact on management or policy (n = 26), iii) impact on individuals (n = 25), iv) achievements beyond project context (n = 22), and v) interpersonal impacts (n = 20). Other themes of achievements were good processes (n = 11), capacity building (n = 8), and organisational impacts (n = 6).

Successes related to outputs and knowledge referred to, on the one hand, the characteristics of information being usable, relevant, credible, and accessible. On the other hand, it referred to the produced materials themselves, for example academic publications, new tools, or reports. Impacts on management or policy mainly referred to the use of information in policy or management, meaning informed decision-making, and influencing management or policies, meaning to have an impact on the content of policies or decisions. For example, in a study of the university-based boundary organisation of the Baltic Eye project (Sweden), study participants identified how their engagement was taken up in high-level speeches, documents, and informed the focus areas of government priority funding (Cvitanovic et al., 2018b).

Impacts on individuals included a diversity of actors being impacted – researchers, decision-makers, and additional actors like natural resource users. The type of achievements referred to having gained a better understanding of something (e.g., a deeper understanding of the new knowledge that had been developed). For example, having a better understanding multiple actors that were relevant to a given context, having a better understanding of the social-ecological system in which the KE activities were embedded, or of the importance of early, regular, and open communication between researchers and decision-makers. Associated with that was also increased awareness of science among decision-makers, increased awareness of decision-maker and actor needs among researchers and increased interest in engagement and communication. Ultimately, also enhanced skill sets and individual recognition or invitations to speak at policy events were named as achievements within the reviewed literature.

Successes beyond the direct project context included new projects, initiatives, or funding but also the societal uptake of knowledge, models, or tools for example by fishers or local communities. Public attention through media was also named as an achievement from KE work. Interpersonal impacts were achieved, for example, where new relationships and networks were created. Another strong theme in the interpersonal achievements was trust among the KE actors. Additional successes were reported in the engagement space covering more contact between actors and the built capacity for collaboration.

3.5.2. Discussion

Despite the wide range of barriers and challenges that are associated with KE at the science-policy interface (Cvitanovic et al., 2016; Rose et al., 2018; Walsh et al., 2019), impacts from KE were actually occurring and reported. This reflects our findings that beyond the generation of relevant knowledge and its use in decision-making a wide range of other impacts from individuals to society exist. This diversity in impact dimensions has also been reviewed by Wyborn et al. (2019) who, among other outcomes of co-production in this case, list redistributed power, creativity in generating new ideas, improved individual well-being, and changed knowledge systems (e.g., policy, institutional). Ultimately, our findings and the broader recent literature point to more appreciation, particularly from a decision-maker perspective, of not only instrumental but also conceptual impacts (i.e., change of thinking, understanding, or behaviour; Edler et al., 2022; Reid and Chaytor 2022; Karcher et al., 2023).

3.6. Measures to evaluate marine science-policy knowledge exchange

3.6.1. Findings

Our analysis revealed that the metrics used to measure and evaluate the effectiveness of KE were predominately qualitative (n = 24). Only two studies formulated numeric measures for evaluation, which were, for example, number of participants, quantity of external funding, number of returning advice requestors, number of new advice requestors. Qualitative indicators for success in KE were associated with i) knowledge (n = 14), ii) impact on policy or management (n = 11), iii) individual factors (n = 8), iv) level of engagement (n = 7), v) societal impact (n = 4), and vi) engagement in the future (n = 3).

Knowledge-based indicators included the relevance of information for respective users. It also more specifically related to the credibility, saliency, and legitimacy framework. Related to credibility, research conduct or quality was named as a factor. Ultimately, also data access and sharing belonged to the knowledge-based factors for assessment. The second theme (impacts on policy and management) outlined any evidence of use or uptake of shared knowledge in decision-making and management practice. The third theme (individual factors) measured a change of knowledge or understanding. Related to that is evaluating the change in assumptions or perspectives including actors' attitude towards other actors, the policy process or science in general. An additional indicator was individual experience and satisfaction of KE actors with the process of engagement. The level of engagement (theme 4) on the one hand referred to participation, for example, by asking how actors were involved. It also refers to the specification of who was engaged, for example considering academic diversity, gender equity, and the inclusion of government scientists. Ultimately, it also included how actors are engaging, for example, end-users asking detailed questions. Societal impact (theme 5) included any contributions to democracy or good governance, as well as social well-being. Future engagement measures (theme 6) captured, for example, management users coming back for future engagement, the upscaling and follow-up projects building on KE and the sustainability of the KE process.

3.6.2. Discussion

The need to establish metrics and indicators for measuring and evaluating KE at the interface of marine science and policy was also identified as a critical research need in Cvitanovic et al. (2015). Our results show that since this time progress has been made, particularly in terms of identifying qualitative measures of KE impact. The nuance associated with KE (Reed et al., 2018; Norström et al., 2020; Karcher et al., 2022a) may simply demand and be better served by qualitative measures. These findings also speak to the fact that KE is done for different reasons and the specific context may matter in terms of what is deemed a success.

It may be unlikely it would be easy or even possible to devise a standard set of indicators that works across KE modalities and contexts.

As such, Mach et al. (2020, p.35) suggest a principles-based evaluation targeting principles like substantive interactions between actors, equitable relationships, usable knowledge through questions like “*Are these principles meaningful to the participants? Did the participants adhere to the principles throughout the process? Did the process lead to desired results?*”. Through time, we have undoubtedly gotten better at evaluation (e.g., Cooke et al., 2020; Reed et al., 2021), but lack homogenous measurable indicators across different timeframes of impact. In many instances the number of actors involved may also be small (e.g., a handful of practitioners working on a given topic) such that it would be difficult to generate sufficient replicates to have statistical rigour with quantitative metrics. This again points to the value of more qualitative approaches and metrics underlining the need for KE individuals and organizations apply and appreciate more qualitative metrics for assessing the full scope of impact from KE work (Cvitanovic et al., 2021a; Kapoor et al., 2023). For example, specific KE strategies such as knowledge brokering have developed indicators that can be process related (e.g., number of meetings), output related (e.g., created opportunities), or outcome related (e.g., changes in understanding) (Maag et al., 2018; Scarlett et al., 2020).

Challenges remain with operationalizing assessments, matching expectations and outcomes (e.g., Jagannathan et al., 2020; Karcher et al., 2021), and generating reliable metrics. This can be approached by asking questions such as “*Did the policy discussions include consideration of the research results?*” (Bednarek et al., 2016, p.293). There has also been much interest of late in determining how to better characterize impacts of science on policy and practice as well as societal impacts of science beyond simply asking respondents about whether they felt that such impacts were observed. It is now possible to assess policy documents (e.g., Bornmann et al., 2016) and generate altmetric scores (e.g., Holmberg et al., 2019) to assess impact. However, that still lacks the necessary nuance assuming one wants to move beyond just the binary options of “yes” or “no” in terms of impact. Such challenges also apply in well-established evaluation frameworks that unfold detailed qualitative indicators often as presence/absence evaluative questions (e.g., Luederitz et al., 2017; Wall et al., 2017) while their content is often intangible, complex, and hard to measure (e.g. trust, integrity, use) while not being attributable to a specific value addition through KE. As we continue to move towards more openness and transparency around decision-making at least in some governments and contexts (Ball 2009; Moore 2018), this also creates opportunities to be able to better assess if and how different evidence was considered and ultimately influenced resultant decisions without having to rely on interviews and surveys. The fact that many of the examples we found were focused on learning/understanding as being a key achievement of KE is perhaps symptomatic of the inherent difficulties of incorporating new knowledge (evidence) into workflows and operationalizing it in decisions. To that end, Dotti and Walczyk (2022, p.1) find a “*shift from ‘attribution’, i.e., looking for causal relationships between research and societal changes, to ‘contribution’*” which perhaps mirrors the need to include conceptual impacts much more in KE evaluation (Meagher et al., 2008; Doyle 2018; Edler et al., 2022; Reid and Chaytor 2022).

Another way to view KE assessment would be through the lens of theory of change models (see Greggor et al., 2021). For example, in the context of conservation consider an example where there is a highly imperiled species. There is a pathway from issue identification to KE among relevant actors, to generating empirical, co-produced knowledge, to changes in management (e.g., removal of threat), to potential recovery of a given population as indicated by abundance. Rarely would a study of KE extend all the way to abundance of the imperiled species even if that was the ultimate goal. Rather, at best there would be extension to the management action itself. Although important to try and measure the ultimate goal, a change model approach where one looks at sequential steps (i.e., a so-called results chain; Margoluis et al., 2013) may be more attainable. Related questions for evaluation may be detailing “*What changed?...Who changed?...How did changes occur?*”

(Edwards and Meagher 2020, p.3). We also acknowledge that science and engagement with diverse actors and end-users may often be much less linear than implied by a change model such that impacts are more indirect and thus more difficult to quantify.

4. Ten research needs to improve future marine science-policy knowledge exchange

Despite significant progress, a range of challenges and research needs remain, some long known, some becoming clear just now. For example, we need more emphasis on the KE terminology, practice, and contexts in the ‘global South’ where our KE-focused search terms did not pick up a lot of case studies and practical work on the ground. Local and Indigenous communities play an increasing yet still too small role in the KE literature and practice. Improving this will require more dedicated boundary spanning between and co-evolution of mainstream Western science and Indigenous knowledges and deeper engagement with different types of knowledge in KE (Chapman and Schott 2020; Hatch et al., 2023; Muhl et al., 2023). Ways forward have been described through, for example, a multiple evidence approach with two-eyed seeing, knowledge-weaving processes, or an ethic of equivocation (Tengö et al., 2014; Reid et al., 2021; Korhonen-Kurki et al., 2022; Root-Bernstein et al., 2023). Thus there remains a critical need to improve engagement with Indigenous knowledge systems in an ethical manner to achieve more equitable and impactful collaborations through Indigenous research leadership (Latulippe and Klenk 2020; Mahajan et al., 2023). To that end, not only the sensitivity of contexts but also the power of voice is critical – who is included and how are different voices heard to prevent only engaging the ‘usual’ (Colvin et al., 2016; Reed and Rudman 2023). Participatory science-policy engagement can contribute by empowering local, post-colonial decision-making, reorganizing governance structures, and contributing to societal transition (Wyborn et al., 2019; Hill et al., 2020).

We agree with Jagannathan et al. (2023, p.174) who, for the broader environmental field, identify the needed research agenda to focus “*on how to define success, support intermediaries, build trust, and evaluate the importance of consensus and its alternatives – all in the diverse contexts of science-society-decision-making interactions*”. Beyond those and building on our systematic review, we raise ten critical research needs that if addressed could help improve KE between marine research and management.

1. Evidence on which strategy to use in which context is still very scarce. We have attempted to further our understanding of this through the research focus on KE context and the rationale for specific KE strategies applied in the analyzed case studies. Based on the small number of studies providing insights on this question, we can summarize that there is still a scarcity of such guidance in the marine science-policy literature. This may be achieved, for example, by broadening out the scope of KE research across multiple locations within a single study. This would contrast current trends in research, whereby KE strategies are applied in a single location and/or context.
2. Progress in theory and practice in marine science-policy KE would benefit from engaging more with other fields that contribute to KE theory. For example, learning from scholarship in health, business and social innovation through transformative agency (see Westley et al., 2013) would be fruitful ways forward.
3. Drawing from individual case studies provides a breadth of experiences to learn from. However, academic KE literature as a result most often takes its learnings from singular projects or programs of small temporal and topical scope and scientific perspective. We suggest more comparative insights and a spotlight on science-policy practitioners in boundary organizations, government agencies, learned communities, and formal advice bodies to better understand their needs through more formalized

- mechanisms. Such efforts to uncover what practitioners and end-users require and contribute to engaging effectively could also benefit from the progress in global ocean sustainability knowledge networks interfacing with decision-making, under initiatives like Future Earth and the UN Ocean Decade.
4. Better and more adaptive processes are needed to monitor KE over time (e.g., co-production) to be able to pick-up issues that might become apparent along the way (e.g., coalitions of power). Constant reflection on the processes and actor group (Chapman and Schott 2020; Cooke et al., 2021; Steger et al., 2021), as well as the iterative nature and flexibility to adjust (Sarkki et al., 2015; Verwoerd et al., 2023; Karcher et al., 2023) are common recommendations, but the monitoring structures to effectively pick up and action on changes is an area of improvement. Here, a more formalized monitoring of KE can ensure regular engagement and the achievement of possibly changing goals (Karcher et al., 2023).
 5. The evaluation of KE has seen a lot of progress over the last years. Remaining gaps in understanding remain regarding direct metrics for the value addition of KE to real-world outcomes. This aspect also requires better insights into the direct links of existing evaluation frameworks with the exact outcome/achievement they measure.
 6. Global sustainability and ocean governance spans extensive efforts including for example the International Science Council's "Mission Science" model, the collaborative endeavors of the International Panel for Ocean Sustainability, the enhanced framework anticipated for the III World Ocean Assessment, and the initiatives under the UN Ocean Decade (Claudet et al., 2020; Gerhardinger et al., 2023). Related to that, more research is needed on how to better institutionalize KE strategies in the agendas of research institutions and government agencies (Wyborn et al., 2019; Dinesh et al., 2021; Karcher et al., 2022a; Pearman and Cravens 2022). How can valuable long-term engagement efforts be un-linked from a specific research activity and project timeline, but become central and recognized parts of bigger institutions? Moving forward could also cover research how to better recognize and reward what people working in this space invest that is not covered by publication metrics. We suggest going beyond giving recommendations and empirically identify what can change individual, organizational, and structural pathways to KE and such recognition.
 7. With KE often depending on individual skills and experiences, there is a need to re-imagine how we train ECRs to have the skills to be effective scientists and effective KE practitioners. Particularly Early Career Researchers face challenges with engaging in KE (Rölfer et al., 2022). Over the past years, a range of required skills have been identified (Pietri et al., 2013; Bednarek et al., 2018; Evans and Cvitanovic 2018). Training collaboration, internships, supervision, and mentorship all hold valid contributions to nurturing those skills (Duchelle et al., 2009; Lyall and Meagher 2012; Rozance et al., 2020). Yet, the opportunities require a more structural approach for those interested to train and practice KE.
 8. The increasing role of research funders actively demanding or facilitating KE between researchers and research 'users' is a growing factor in KE. Recommendations for funders aiming to support research impact through KE have been described in the literature (Cvitanovic et al., 2021c; Tseng et al., 2022). Many of those relate to the formal requirements that researchers have to fulfil (Arnott et al., 2020). The more actively engaging roles of research funders and managers (e.g., through the use of knowledge brokers) are just starting to be described with more procedural lessons to learn (Karcher et al., 2023; Tuohy et al., 2023).
 9. The emerging role of AI in the field of science-policy engagement should be explored in more detail. How can AI be used

purposefully to help generate and synthesize credible, legitimate, and salient information (cf. Cash et al., 2003) to support KE? Besides that, vast amounts of marine data exists beyond published research (e.g., unpublished data, satellite images, ship sensors, photos on social media) for which transparent and rewarded data sharing and the use of AI could be beneficial (Pendleton et al., 2019). Recent findings furthermore suggest that AI can play an active role as a 'collaborator' in systematic literature reviews, even where qualitative questions and analysis are pursued (Thomas et al., 2017; Haddaway et al., 2020; Spillias et al., 2023). However, such progress also comes with barriers and challenges, for example limited interoperability, nuance of implied meaning, and lack of trust in machine produced/supported research outputs (O'Connor et al., 2019; Haddaway et al., 2020).

- 10 It is slowly becoming common sense that interactive KE engagement requires a lot of time and effort (including emotional), but is often not sufficiently planned and budgeted for (Karcher et al., 2022b). Considering that research resources (including time, scope, energy) are limited, we urgently need more conceptual understanding of best possible returns on KE investment (Kaufman and Boxshall 2023) and practical guidance on what to consider regarding the cost-efficiency of KE in different contexts. Such research should also be nuanced to know how to balance cost and potential return on investment across the different models of KE identified here.

5. Conclusion

From our systematic review of recent developments in KE between marine research and management, it is apparent that there is progress being made since Cvitanovic et al. (2015). For example, while we found that the most common KE strategies were co-production and boundary spanning (including boundary organizations), which were identified in Cvitanovic et al. (2015), a range of new and more nuanced approaches have also been used and empirically tested. The recent literature has provided a better understanding of what makes KE work at the marine science-policy interface and has unfolded ways for more purposeful evaluation of such approaches. Our review shows lots of progress has been made, but we need to keep moving forward with inclusivity, institutionalization, training, strategy selection, and efficiency of future KE to support ocean and coastal governance.

CRedit authorship contribution statement

Denis B. Karcher: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Software, Visualization, Writing – original draft, Writing – review & editing. **Paris Tuohy:** Data curation, Formal analysis, Investigation, Methodology, Validation, Writing – review & editing. **Steven J. Cooke:** Validation, Writing – original draft, Writing – review & editing. **Christopher Cvitanovic:** Conceptualization, Formal analysis, Methodology, Supervision, Validation, Visualization, Writing – review & editing.

Declaration of competing interest

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

Data availability

Data will be made available on request.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.ocecoaman.2024.107137>.

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