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Is this what success looks like? Mismatches between the aims, claims, and evidence used to demonstrate impact from knowledge exchange processes at the interface of environmental science and policy

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ABSTRACT

As anthropogenic pressures on the environment grow, science-policy interaction is increasingly needed to support evidence-informed decision-making. However, there are many barriers to knowledge exchange (KE) at the science-policy interface, including difficulties evaluating its outcomes. The aims of this study are to synthesize the literature to elucidate the a) *intended* and b) *claimed* outcomes of KE processes at the interface of environmental science and policy, as well as the c) *evidence* used to evaluate them and d) methods used for collecting evaluation data. Results from systematically identifying and analyzing 397 articles show that co-production, knowledge brokerage, boundary organizations, and social connections were the most common strategies for KE. KE processes commonly aimed, claimed and referred to evidence regarding the usability of knowledge (e.g. credibility, salience, legitimacy) and social outcomes (e.g. networking, awareness, learning, trust-building). They also aimed for deeper policy/economic/societal impacts and actual use of scientific knowledge within decision-making. These additional goals, however, were seldom claimed to have been achieved, although products (e.g. maps/tools) and process attributes (e.g. equity, power-relations, transparency) were commonly used for evidencing impact. Hence, this study found that success from KE at the interface of environmental science and policy comes in diverse forms and showed a divergence between what studies aim for (ambitious) and what they evidence or claim as an achievement (more modest). This may represent failures of KE processes to reach intended goals, shortcomings in evaluation literature/approaches, or mismatches between timescales of evaluation and impact. Overall, this suggests a need to better align goals with evaluation measures to plan, facilitate, and appreciate the diverse impacts of KE processes.

1. Introduction

Anthropogenic pressures are continuing to cause global losses of habitats, biodiversity and ecosystem goods and services (Brondizio et al., 2019), pushing the Earth's safe operating space for humanity closer to and beyond its planetary boundaries with subsequent impacts on human well-being and prosperity (Rockström et al., 2009; Nash et al., 2017). An important factor for successfully navigating these impacts, and the complex, interacting and dynamic challenges they pose, is the implementation of evidence-informed environmental policy. Indeed, within the arena of environmental management, the need for evidence-informed practices is widely demanded (Sutherland et al., 2004; Adams and Sandbrook, 2013; Pressey et al., 2017; Rose et al., 2019). Hence, calls for improved knowledge exchange at the interface of environmental science (meaning knowledge generated in the research sector) and policy to facilitate evidence-informed decision making processes are countless (e.g. Cornell et al., 2013; Bainbridge, 2014; Cvitanovic et al., 2015a; Thorp, 2020).

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In the literature, knowledge exchange (KE) is conceptualized in various ways and the diversity of terms used to describe it illustrates varying definitions and assumptions (Fazey et al., 2013, 2014). For example, knowledge transfer generally (but not always) refers to linear and one-way knowledge flow (i.e. from science to policy); knowledge exchange refers to multiple paths and mutual benefits for both science and policy (Fazey et al., 2013); and knowledge co-production is an early-stage interactive knowledge generation process (Fazey et al., 2013; Norström et al., 2020). Thereby, the latter two are more prevalent in environmental management given the interdependencies within complex socio-ecological systems (Fazey et al., 2014). While we acknowledge the diversity of terms and definitions used to describe KE, in this paper we define KE as the interchange of knowledge between "scientific" producers and research users, encompassing all activities and facets of knowledge production, sharing, storage, mobilization, translation and use (following e.g. Cvitanovic et al., 2015a).

Similarly, while definitions of KE vary, so do the range of options that have been identified for improving KE at the interface of environmental science and policy (reviewed by Fazey et al., 2013; Cvitanovic et al., 2015a). They comprise concepts such as 'embedding' scientists within decision-making agencies, knowledge brokering and boundary spanning (Sheate and Partidário, 2010; Driscoll et al., 2011; Partidario and Sheate, 2013; Fazey et al., 2013; Cook et al., 2013; Cvitanovic et al., 2015a, 2017; Hering, 2016; Bednarek et al., 2018; Maag et al., 2018; Posner and Cvitanovic, 2019). At the same time as these strategies to improve KE have emerged, there has also been an increased recent focus on developing improved approaches to training and capacity development to equip scientists with the skills and attributes needed to operate effectively at the science-policy interface - skills that are not commonly taught as part of scientific training programs (Evans and Cvitanovic, 2018). Research has also begun to identify the critical principles that underpin the practice of KE, such as joint and early inclusion of stakeholders in research design processes, the identification and systematic representation of the diversity, needs and perspectives of stakeholders involved, the delivery of tangible outcomes as soon as possible in the process, as well as general long-term dialog, patience, empathy and trust (Reed et al., 2014; Brugger et al., 2016; Lacey et al., 2018; Cvitanovic and Hobday, 2018; Rose et al., 2020).

Despite these advances, however, to date researchers' ambitions to impact policy-making – for example to "influence the way policy is designed, implemented and followed-up" (Neicu et al., 2020, p.154) – often remain far below their potential (e.g. Cvitanovic et al., 2015b). Despite substantial efforts and ongoing research, many challenges remain in science-policy KE (Cortner, 2000; Choi, 2005; Briggs, 2006; Roux et al., 2006; Cvitanovic et al., 2015a, 2015b). Alongside exogenous challenges, such as funding for KE within projects and a lack of political will to utilize scientific knowledge, a range of endogenous barriers have also been identified. Persistent endogenous barriers include cultural differences between science and policy, institutional barriers and dis-incentives, science inaccessibility, and personal worldviews (Cvitanovic et al., 2014; Rose et al., 2018; Walsh et al., 2019). For example, in a survey of 78 marine scientists around Australia, while most scientists had the personal goal of achieving impacts on policy and practice, very few could report cases where they had successfully achieved this, with instead most study participants reporting a lack of knowledge and skills for policy engagement (Cvitanovic et al., 2015b). Thus, there remains much to be learned about how to improve KE at the environmental science-policy interface and the best approaches for connecting science to policy across contexts (McNie, 2007; Cvitanovic et al., 2015a, 2016).

One promising avenue for advancing our understanding of how to improve KE at the environmental science and policy interface may be through the study of 'bright-spots' – situations whereby environmental science has successfully influenced policy and/or practice (following Cvitanovic and Hobday, 2018). However, the meaning of 'success' in relation to KE at the interface of environmental science and policy remains unclear (Cooke et al., 2020). Recent studies have started to answer this question, for example trough a synthesis of expert experiences (Cooke et al., 2020). This, however, does not systematically assess the full suite of KE strategies or the outcomes and impacts that are aimed for, claimed and evidenced. Having a better understanding of what constitutes success at the interface of science and policy can inform how we plan/evaluate KE and research impact, and is hence crucially needed (Meagher et al., 2008; Fazey et al., 2013; van Kerkhoff and Lebel, 2015; Reed et al., 2021).

Thus, the objective of this study is to address this knowledge gap to help environmental researchers and their institutions plan for and attain research impact at the interface of environmental science and policy. The overarching question for this systematic scoping review is: How does academic literature frame the meaning of 'success' in science-policy interactions around environmental management? This is addressed by the following research questions:

a) What goals, desired outcomes and statements of intended success are articulated for KE processes?
b) What positive outcomes are claimed as (achieved) success?
c) What types of evidence are used to decide if KE was successful?
d) Which practical methods are used for these evaluations?

The review presented here goes beyond comparable studies (Fazey et al., 2014; Cvitanovic et al., 2015a; Wall et al., 2017) by focussing on environmental management, the full spectrum of science to policy connections, as well as the desired and achieved outcomes. In contrast to studies on the usability (e.g. Dilling and Lemos, 2011) or the pure impact of science on policy (Boaz et al., 2009; Neicu et al., 2020; Reed et al., 2021), we specifically focus on the KE interactions at this interface. Thereby, we aim to elucidate and articulate the science perspective on the intentions and measures of KE.

2. Methods

2.1. Scoping reviews

A range of approaches for reviewing the scientific literature are available – the most common of which include narrative reviews, systematic reviews, systematic maps, and scoping reviews (e.g. Moher et al., 2015; Munn et al., 2018; Snyder, 2019). Here, a scoping review was identified as the most appropriate method for this study. Belonging to the family of systematic reviews (Moher et al., 2015), scoping reviews require systematic, rigorous and transparent methods (in contrast to most traditional narrative reviews). While systematic reviews require a very specific question (Arksey and O'Malley, 2005; Collaboration for Environmental Evidence, 2018; Munn et al., 2018), scoping reviews are used to clarify the characteristics of research and concepts in a certain field, particularly working definitions in the literature, and unravel potential knowledge gaps (Arksey and O'Malley, 2005; Colquhoun et al., 2014; Peters et al., 2015; Munn et al., 2018). While our research questions are specific, they cover an array of terms and environmental fields without homogenous definitions (e.g. of success) or terms to analyze. The scoping review implemented here allowed for a systematic exploratory investigation of a large, complex, and heterogeneous body of literature. A rigorous scoping review as undertaken here, draws from best-practice guidelines for systematic reviews (e.g. Collaboration for Environmental Evidence, 2018) regarding steps in the literature search and study selection.

2.2. Steps and protocol

For the scoping review, the protocols by Arksey and O'Malley (2005) and Peters et al. (2015) were utilized and additions to that methodology were considered (Levac et al., 2010; Tricco et al., 2016). The following sections provide an overview of the steps of the scoping review, starting with the definition of inclusion criteria, and followed by literature

search, study selection, and data acquisition and analysis.

2.3. Inclusion criteria for the scoping review

The scope of this review comprises literature in the English language. Case studies, theoretical frameworks/opinion pieces and reviews were included as authors often add their own interpretation of goals and success. Book chapters were only considered if they were available online or in the university library (Australian National University) and likewise any study was only included if available as full text. As the inclusion of grey literature is crucial for scoping reviews (cf. Peters et al., 2015) because it helps reduce publication bias (Haddaway and Bayliss, 2015), it was included in this review. For this study, grey literature was defined as articles that were not formally published by commercial academic publishers (following Haddaway et al., 2015; Haddaway and Bayliss, 2015). We included only academic grey literature such as theses or conference papers. This helped maintain a clear and transparent focus on the academic framing of science-policy interactions.

In addition to the above-mentioned bibliographic scope, content related criteria for inclusion were: a) substantial focus on KE activities (including brokers, boundary organizations and co-production), b) topics related to environmental management and/or conservation, and c) science-policy interactions. Thereby, the focus was on research-based knowledge (as used in e.g. Van Kerkhoff and Lebel, 2006) reaching public policy (meaning an authoritative statement by a government or other public authority, see Bridgman and Davis (2000), and including both policy-makers and decision-makers). We acknowledge that such distinctions can be difficult, for example around land or protected area management or where several stakeholder groups are included. Additional and more detailed justification for exclusions can be found in the Supplementary List 1.

2.4. Search string development

The search string was developed systematically. Following Badullovich et al. (2020) and Althor and Witt (2020), at first, triangulation studies were systematically identified through searches in Web of Science (WoS) and SCOPUS (see Supplementary Table 1) and complemented with 3 relevant recently published studies (that the authoring team had identified from familiarity with the field) to total 9 triangulation studies (namely, Pullin et al., 2009; Sheate and Partidário, 2010; Fazey et al., 2013, 2014; Reed et al., 2014; Cvitanovic et al., 2015a; Wall et al., 2017; Maag et al., 2018; Posner and Cvitanovic, 2019). It is important to note that the selection of these papers does not indicate the authors' interpretation of the quality of the papers, but rather, the relevance of articles to develop the search string.

The starting point for the development of the search string was an initial test string originating from these triangulation studies (see Supplementary Table 2). From there, several iterating steps were undertaken to find a search string that a) gives comprehensive results b) does not carry unimportant/misleading components and c) includes identified triangulation studies (Supplementary Table 3). The identified best-available search comprised the topic, topic qualifiers and outcome (see Fig. 1) and included a range of terms with varying implications used in the knowledge exchange arena (Fazey et al., 2013).

2.5. Literature search

The systematic literature search was conducted using the generated search string. Based on suggestions from the methodological literature, the applied search comprised various distinct blocks of sources: databases, web searches, bibliographic searches and organizations/experts (Arksey and O'Malley, 2005; Althor et al., 2016; Collaboration for Environmental Evidence, 2018). SCOPUS and WoS were the databases searched in April 2020, using advanced search and the developed search string (Boolean operators were adjusted if unavailable in search options). Web searches were conducted using, among others, Google Scholar, Open Access Theses and Dissertations, DART-Europe, DiVA, NARCIS, BASE and Open Grey (Supplementary Table 3). For Google Scholar, which plays an important role in the acquisition of grey literature, particularly when using title searches (Haddaway et al., 2015), the first 400 results were screened, to serve as a sufficient addition (Haddaway et al., 2015). The bibliographic search (or 'citation search': identification of studies via the reference lists of important articles) was conducted on the previously identified triangulation studies. Finally, organizations, governmental projects and conference pools were searched (see Supplementary Table 4, following Althor et al., 2016 and McKinnon et al., 2016). All search results combined accounted for 5634 entries.

2.6. Study selection

The study selection process (Fig. 1) followed the various guides on systematic reviews (Collaboration for Environmental Evidence, 2018) as well as examples from systematic maps (McKinnon et al., 2016; Badullovich et al., 2020) which have been adjusted to scoping studies (Davis et al., 2014; Peters et al., 2015; Tricco et al., 2016).

To assure consistency of the main reviewer and the precision of applied exclusion criteria, sub-samples of firstly 100, secondly 50, random studies (from database search) were generated and screened in two iterations at title/abstract level by four authors (DBK, CC, RMC, IvP) individually (see, e.g., Althor et al., 2016; Badullovich et al., 2020). The decision-making was compared between DBK and the three other authors using the kappa statistic (Cohen, 1960) as a coefficient of agreement resulting in relative mutual agreement between 82% and 90%.

The studies that remained relevant after title/abstract screening were subsequently acquired in full text and checked for inclusion parameters. For edited books, only the relevant chapters were considered. Where conference papers or thesis chapters were also published in a journal, only the journal publication was considered (even if the latter was not originally among the search results, see Supplementary List 2). Documents that were not relevant at full text stage were given a reason for exclusion (Supplementary List 3). Ultimately, 397 articles were identified to be relevant for this scoping review (Supplementary List 4).

2.7. Data extraction

Once the body of literature was narrowed down to articles that were relevant to this study, a combined thematic and content analysis was conducted. The collection of bibliographic and geographic data was conducted in Microsoft Excel.

In addition, a range of other information was extracted for each study through inductive coding (Table 1), for which the software package Nvivo 12 was used (as in, e.g., Tricco et al., 2016, Fogarty et al., 2019). Following e.g. Reed et al. (2021), portraying desired and achieved impacts/outcomes, we only focus on positive outcomes and benefits. The thematic analysis followed Braun and Clarke (2006). Case studies were coded per example and if there were several distinguishable and distinct case examples that showed different approaches, goals or methods, content coding for each case was conducted in a separate file. For coding, we used a combination of broad pre-determined topics (Table 1) based on the research questions together with an inductive approach as for example in Fogarty et al. (2019).

Categorization within these topics was initially kept broad, iterating content and themes using inductive qualitative coding (e.g., for the KE process). Starting from the research questions and respective data topics (Table 1), initial individual codes were generated. Data codes within the topics of interest were grouped into themes, which were revisited when more studies were coded, providing constant comparative reevaluation of themes (Braun and Clarke, 2006). The coding and grouping of themes and categories were independent from the exact wording and intended to merge codes of comparable meaning together (not looking for

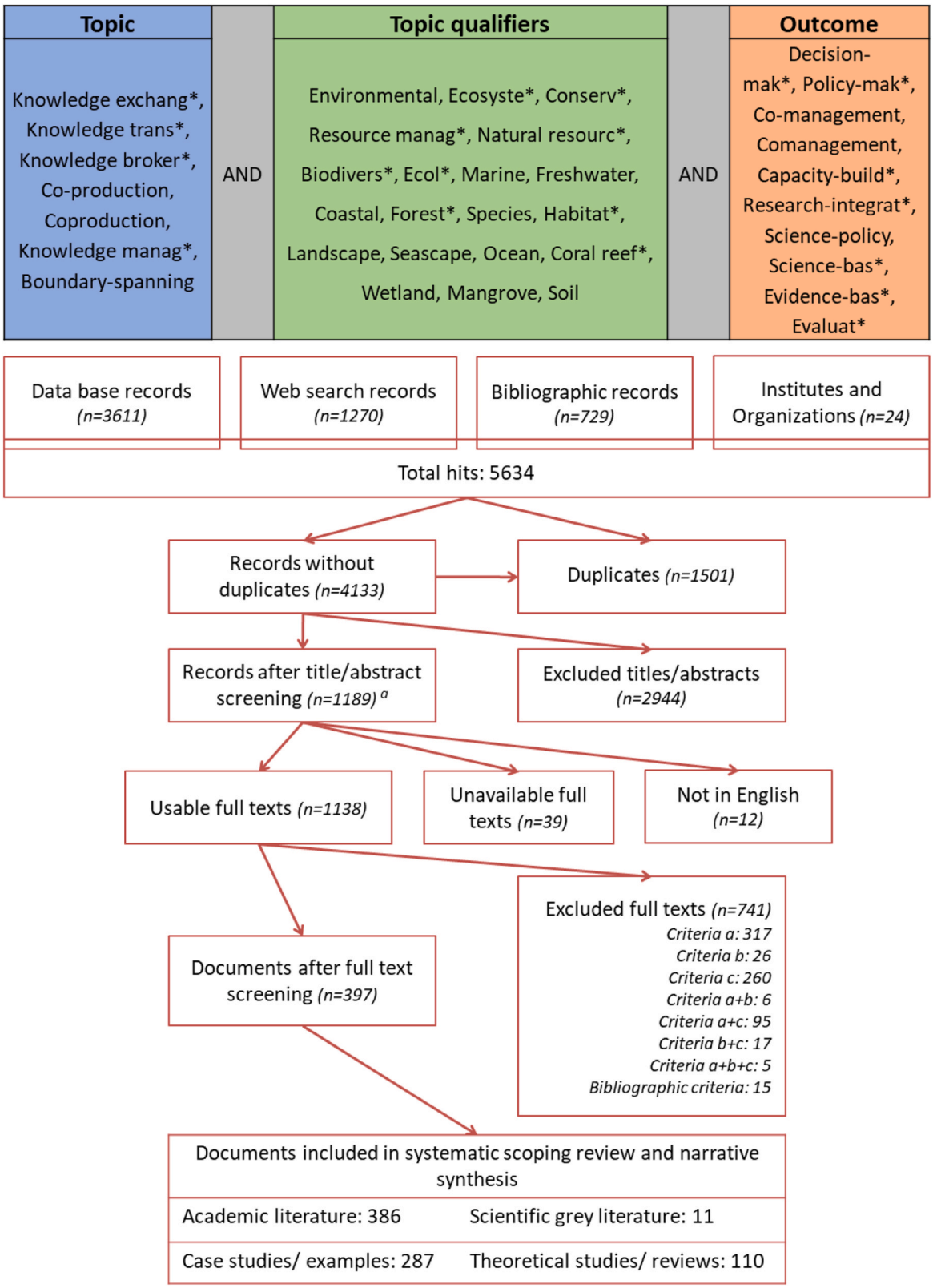

Fig. 1. Topics (blue), topic qualifiers (green) and outcomes (orange) used in the systematically developed search string. Below these are the diversity of data sources used, and the subsequent study selection process (following e.g. Davis et al. (2014), Peters et al. (2015), Tricco et al. (2016)); [a] the exact entries vary slightly because a few entries (i.e. theses or books) were replaced by their relevant published chapters (see Supplementary List 2).

Table 1
Types of data collected during coding. Data collected in NVivo12 and coded inductively (a) for more than one affiliation only the first one was considered, (b) implicit goals can for example be extrapolated from more ambiguous statements, negative outcomes or barriers, (c) negative outcomes were not included (only to implicitly understand which outcomes would have been desired). Italics indicate data collected in an Excel file. For more information see Supplementary Material 1.

Context	Data collected
Bibliographic	*Author(s), year, title, study type (case study/example, opinion/ theory/perspective/framework, review)*
Geographic	*Country of first author*[a]
Environmental context	Topic/ecosystem type
KE process	Strategies used to achieve outcomes/impacts (e.g. co-production, knowledge broker, etc.)
	Other actors involved (additional to science and policy)
	Goals/desired outcomes
	Explicit or implicit[b] *goals for the process*
	Achieved outcomes[c]
	Evidence for successful KE (outcomes/impacts) and indicators used to measure/monitor success
	Explicit or implicit measures
	Methods used to evaluate KE process (interviews, surveys, etc.)

pre-defined key words). This allowed the themes and ultimately categories to emerge naturally from the data. Contents were coded only once per study. Hence, where the number of references for a category is higher than the number of studies coded, this indicates a merging of themes into a category.

The responses to the research questions in this review were ultimately synthesized from the final set of categories. The content analysis was performed on a quantification of categories, e.g. comparing prevalence of categories within the total body of analyzed literature. In this scoping review we extracted both explicit and implicit goals and indicators of success. Explicit were those which were stated by authors in the texts. Implicit, however, were those that were not stated explicitly, but were inferred from the text (e.g. what the authors chose to measure).

Given that desired, achieved and evidenced outcomes are often interwoven or overlap (e.g. a claimed outcome implicitly shows how success was evidenced), the body of literature was analyzed across three artefacts of data.

1. 'articles' - to characterize the body of literature, all relevant articles including theoretical studies, reviews, opinion pieces and case studies were considered (397 articles) (green color in the figures of the *Results*).
2. 'studies' - much of the content coded for (goals, strategies, measures, etc.) was specific to case examples rather than the 'article'. Several 'case study' articles comprised more than one explicit, detailed and distinguishable example. Therefore 'studies' were considered separately to 'articles', and with the total literature body added up to 478 studies (red color in the figures of the *Results*).
3. 'explicit case studies' - to focus more specifically on the evidence gathered from case studies, and particularly those with explicit statements relevant to our research questions, the third data characteristic comprised the case study examples and, for the respective research questions, particularly those that stated explicit goals and ways to evidence them (gray color in the figures of the *Results*).

2.8. Study limitations

The chosen methodology comes with some limitations, for example that the search string cannot include all possible terms and, for example, the terms 'climate change' and 'sustainability' were not included. Furthermore, sorting and coding of articles includes a human factor, but the error was reduced by following the outlined systematic steps and including the kappa comparison among four co-authors. Coding decisions can be difficult even for seemingly clear aspects (such as deciding on whether goals are explicit or implicit) but our coding was not intended to provide causality between the research questions (i.e. a strategy and an outcome, or a type of evidence and the method to acquire data). A final limitation is that for us the scoping review served to create an overview addressing many broad questions, rather than analyzing one specific question in-depth (see section *Scoping reviews*). Hence, we did not collate or question articles' definitions of terms that might be interpreted in different ways (e.g. 'stakeholder', 'social learning', 'legitimacy').

3. Results

3.1. Broad overview of the literature body that formed the basis of this review

Among the 397 articles that comprised this scoping review, the vast majority were published by first authors who had a European (46%) or North American (31%) affiliation. At the country level, the USA had the largest number of publications (25%), followed by Australia (14%), Netherlands (10%) and the UK (10%) (Fig. 2). More than half the literature (51%) was published in the past five years (Fig. 2B). Of the 478 individual studies and case examples (see *Methods* section), 28% were focused on environment broadly (e.g. environmental management/governance, conservation as well as combinations of topics, e.g. forest, soil, agriculture, climate change), whilst 14% focused on marine/coastal settings, 10% on freshwater/wetland systems, and 10% on urban settings.

3.2. Strategies used in science policy interactions

The most common KE strategies described or applied within the body of literature that formed the basis for data analysis were co-production (n = 216 studies), knowledge brokerage (n = 118 studies) and the use of boundary organizations (n = 102 studies). The merged category *social connections* (meaning semi-organized/institutionalized groups, networks, partnerships, fora, platforms, and communities of practice) also comprised a large fraction (97 references / n = 84 studies, Table 2). Those were followed by co-design (n = 72 studies) and merged category of other forms of participatory action research (58 references / 53 studies). The KE strategies often occurred in combination. For example, boundary organizations were described as partnerships performing knowledge brokerage, and participatory research, co-designing studies and co-producing knowledge were also used together. For a detailed list of KE strategies as well as their definitions generated from literature, please refer to Table 2.

3.3. Actors included in knowledge exchange

Besides research and policy/management actors (which was a precondition for inclusion in our review), additional actors identified through data analysis included those from non-governmental organizations (n = 132 studies), business and industry (n = 87), local or Indigenous communities (n = 57), and small-scale resource users/owners (n = 52). Respective details can be found in Table 2, as well.

3.4. Goals of KE associated with science-policy interactions

3.4.1. Overall 'studies'

Among all studies, the category usability of knowledge was the most stated goal (458 references from 230 studies, Fig. 3). Usability was most commonly described through attributes such as relevance/salience/applicability (140 references), credibility (73 references) and legitimacy (70 references), and also timing (25 references), accessibility (25 references) and comprehensiveness (17 references). The second most

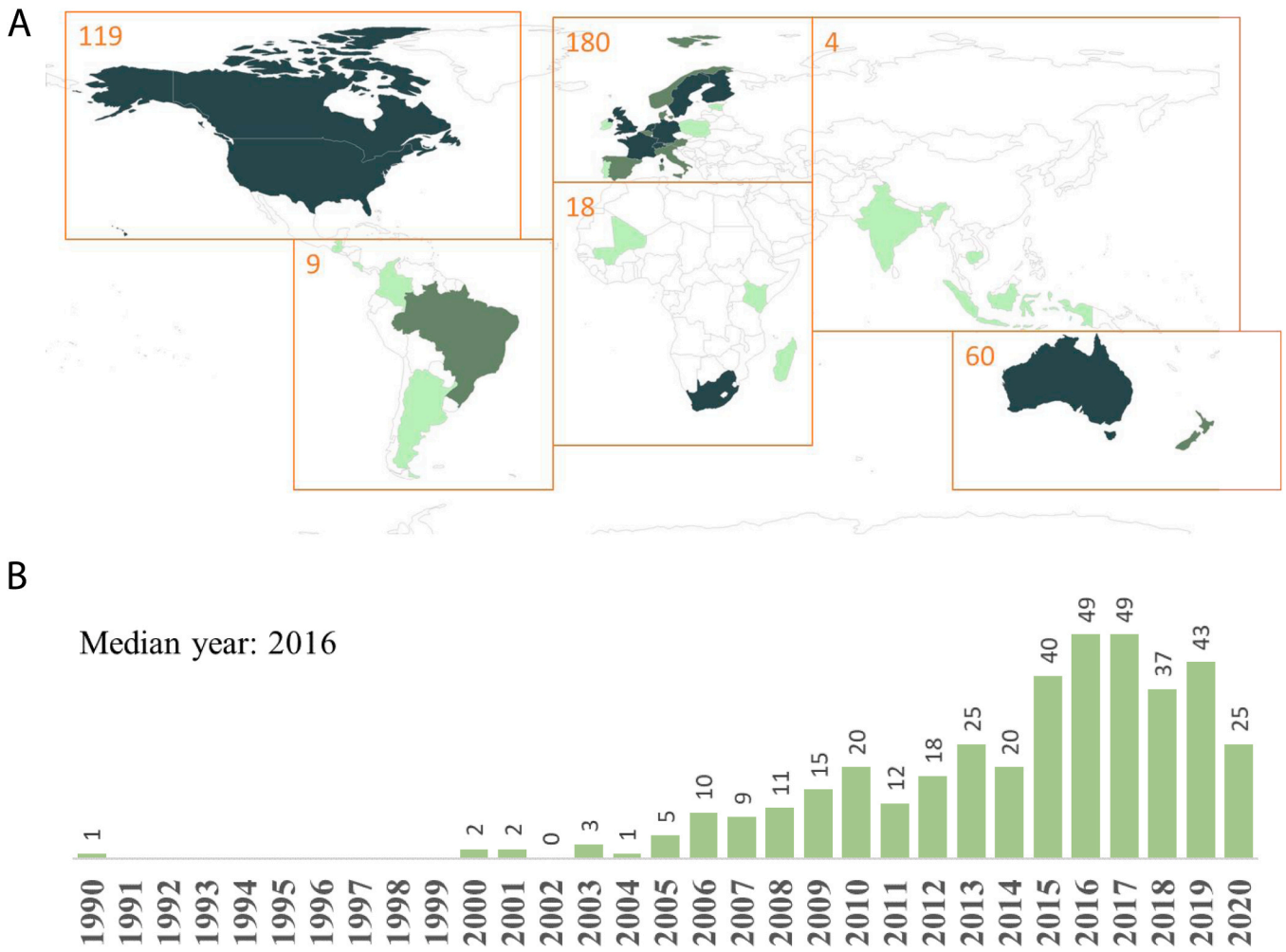

Fig. 2. Characterization of the body of literature. A: Countries and continents of first authors' primary affiliation; mapping conducted with the 'rwoldmap' package in R following South (2011), n = 390 articles (7 not available); 1–2 articles: mint green, 3–7 articles: green, 8–96: dark green. B: Year of publication of the literature (n = 397 articles).

stated goal related to the category of social outcomes (e.g. behavior change, creating networks, learning/awareness/communication, minimizing conflicts, shared or mutual understanding, social learning, trust building) (226 references from 155 studies). This was followed by the actual use (i.e. implementation) of knowledge (215 references from 204 studies) in policy/management, or in political or scientific debate, and more profound/ambitious policy/societal impact (186 references from 164 studies). Other reoccurring themes were present but appeared less frequently, such as a (good) process (e.g. the co-production/KE itself, recognition of different perspectives/knowledge, fairness/empowerment, flexibility/adaptability), quality/outlook (e.g. better/richer knowledge, follow up projects, innovation), products (i.e. scientific or boundary products), public– (i.e. justification, attention, reputation) and personal outcomes (i.e. buy-in/ownership, satisfaction/motivation). A more detailed composition of sub-themes within these categories is provided in Supplementary Table 6.

3.4.2. Focus on 'explicit case studies'

Focusing on the characteristics of explicit case studies (here: case studies and examples that mentioned goals for KE explicitly, see *Methods* section), a comparable distribution occurred (Fig. 3). However, the relative dominance of desired usability was lower there, and the relative share of social/learning goals higher.

3.5. Claimed (i.e. achieved) outcomes of KE interactions

3.5.1. Overall 'studies'

Social outcomes were the most numerous and common claimed outcomes of KE processes (220 references from 138 studies), which were dominated by awareness/learning/ communication, networks, relationship/interaction and trust building. The second most referenced category was usability (164 references from 86 studies), followed by boundary or scientific products (92 references from 78 studies) Table 3.

3.5.2. Focus on 'case studies'

The distribution of referenced categories was similar to that in the overall 'studies'. Social outcomes and products were referenced slightly more frequently in case study claims compared to overall 'studies' (and also compared to case study goals).

3.6. Evidence used to evaluate KE and its success

3.6.1. Overall 'studies'

The usability of knowledge and outputs of science-policy interactions was the most numerous category (250 references from 105 studies) for evaluating the success of KE activities within the papers analyzed in this study. This was followed by social outcomes (226 references from 115 studies, e.g. awareness/learning/capacity, communication/ distribution, interaction/engagement, network/relations, shared

Table 2
Strategies, practical components, and additional actors (besides research and policy actors) given as number of studies as well as number of references ('ref') if different from number of studies. Contents are coded only once per study (n = 478) and hence differences between both numbers only occur where codes were grouped or collected as (remaining) 'other'. Definitions/interpretations may vary in the studies' self-identification. *Listed here only when self-identified as such, no emphasis added.

Strategies, theories	Studies	Description
Co-production	216	An iterative and collaborative process integrating diverse types of expertize, knowledge and actors in the creation of context-specific and goal-oriented knowledge through mutual learning (Armitage et al., 2011; Chambers et al., 2021; Fazey et al., 2013; Norström et al., 2020).
Knowledge Brokerage	118	The full suite of activities required to non-linearly link decision-makers with researchers, facilitating or mediating their interaction so that they are better able to understand each other's goals and professional cultures, exchange complex knowledge, influence each other, create partnerships and promote evidence-informed decisions (Canadian Health Services Research Foundation, 2003; Lomas, 2007; Partidario and Sheate, 2013; Fazey et al., 2013; Cvitanovic et al., 2017).
Training	1	
Boundary Organisations	102	Organizations that are placed between science and policy, linking research to decision-making on multiple levels, involving actors from both sides of the boundary (Cash, 2001; Guston, 2001). These organisations more broadly represent expertise and management of science-policy interfaces (Gustafsson and Lidskog, 2018). Boundary spanning by boundary organisations refers to work enabling exchange between production and use of knowledge to support evidence-informed decision-making in a specific context (Bednarek et al., 2018).
Social connections	84 (97 ref)	Less institutionalized connections of people, groups or organizations of different backgrounds performing such boundary work often with specific focus topics. Their functions include "knowledge creation and sharing with diverse audiences, as well as the provision of training to their members on knowledge generation, synthesis and dissemination" (Kelemen et al., 2021, p.94).
Network	40	
Group, partnership	35	
Forum, platform	13	
Community of Practice	9	
Co-design	72	Inclusion of various non-academic actors in the early stages of (e.g. participatory) research (design, methods, questions) to jointly frame a challenge/project to be tackled to meet collective needs (Mauser et al., 2013; Moser, 2016).
Other forms of participatory action research	53	A societal problem-oriented and hence policy-relevant, stakeholder driven, reflexive process that aims to integrate multidisciplinary scientific and non-scientific actors and knowledge in the planning and research process, hoping to improve the quality of decisions through broader representation of knowledges and mutual learning (Salter et al., 2010; Jahn et al., 2012; Meadow et al., 2015).
Participatory Research	28	
Transdisciplinary Science	25	
Translational Ecology	3	
Sustainability Science	2	
Knowledge transfer	37	One-way process where knowledge is portable in a linear direction (Fazey et al., 2013).
Advisory body, consultants	34	Institutions or individuals that are directly mandated to gather and provide scientific knowledge/advice to organizations or governments, often implying one-way processes.
Descriptive boundary strategies	26 (28 ref)	Focus on practical components of brokerage and boundary organizations (without clear connection to either of the two) often referring to matchmaking, engaging, mediating, designing, translating, communicating and integrating (Feldman and Ingram, 2009; Michaels, 2009; Turnhout et al., 2013; Vignola et al., 2013).
Environmental/Impact assessment	20	Knowledge generation, structuring, provision and debate to integrate environmental concerns into strategic decision-making aiming for better and more sustainable decisions, not indicating the exact mode of collaboration and knowledge interaction (i.e. one- or two-way) (Deelstra et al., 2003; Hugé et al., 2011; Kuldna et al., 2015).
Co-management or co-governance	18	A knowledge partnership including distributed management rights and responsibilities with regard to a specific natural resource (Berkes, 2009).
Non-broker boundary individuals	9 (10 ref)	Collective of the group of boundary workers that were described in literature as distinct from knowledge brokers and vary in their relation to the decision-making process (e.g. only focusing on knowledge-independent networking/ match-making, or bearing personal interest and stake in the outcomes). They were classified, e.g. by Gould and Fernandez (1989) and Pielke and Roger (2007).
Intermediary	3	
Networker	2	
Bridging agents	1	
Entrepreneurial researcher	1	
Facilitator	1	
Liasons	1	
Science arbiter	1	
Other	9 (10 ref)	Specific approaches that were not grouped together or to any of the other strategies (e.g. co-delivery, rapid assessment, joint ventures).
Researcher in management	8	Positions that embed individual researchers in management organizations to provide in-house expertise on high-priority knowledge gaps (Cook et al., 2013).
Social Learning	7	Wider "change in understanding that goes beyond the individual to become situated within wider social units or communities of practice through social interactions between actors within social networks" (Reed et al., 2010, p.6)* .
Funders	6	An active role (e.g. supporting KE or making it a funding requirement) of research funders in research and science-policy activities*.
Formal links	3	Formal arrangements between institutions or resource management agencies and (not fully embedded) scientists or scientific institutions (Cook et al., 2013).
Mainstreaming	3	Making an (environmental) issue publically aware and understood to integrate it into decision-making processes, policies, strategies and practices of public and private actors (e.g. institutions, policy, education, technologies) (Akhtar-Schuster et al., 2011; Huntley and Redford, 2014).
Knowledge Management	3	Processes of "generating, storing and circulating new knowledge and identifying, bringing together and applying existing knowledge to achieve

(continued on next page)

Table 2 (*continued*)

Strategies, theories	Studies	Description
		specific objectives" (following Reed et al., 2013, p.311) covering the range that others refer to knowledge sharing, transfer and exchange (Zheng et al., 2019).
Movement, public pressure	2	Indirect method to generate public or policy impact via public social attention.
Methods/Material		
Events	194	Events used for KE interactions (e.g. conferences, excursions, etc).
Boundary Material	149	Objects used to carry and exchange knowledge and that are adaptable to local needs, intersect social worlds and metaphorically sit "in the middle of a group of actors with divergent viewpoints" (Star, 1989, p.46). For example, reports, products, maps, etc. that were used as a strategy and not only as an output.
Interviews	5	Oriented towards knowledge generation and exchange via often once-only knowledge interaction.
Other	4 (5 ref)	Remaining methods not easily grouped (e.g. role-playing exercise, etc.).
Third places	2	Safe space for academics and non-academics to meet, share experiences with equal voice and learn from each other (Roux et al., 2017)*.
Additional actors		
Interest and non-governmental groups	132	NGOs and groups of like-minded individuals who have a shared interest (e.g. associations).
Business and Industry	87	Stakeholders with business and economic interest.
Local or Indigenous communities	57	Acknowledging the difficulties around the 'community' term, this comprises spatially distinct groups of people (e.g. fishing village) implying spatial and maybe cultural ties within (compared to e.g. 'stakeholders' or vague 'citizens').
Small-scale resource users or owners	52	Farmers, fishers, forest owners, etc.
Consultants	37	Mandated individuals to provide advice, independent from the knowledge interaction strategy.
Stakeholders	33	Broad group of people having an interest on the matter*.
Funding agencies	28	Funders mentioned as additional (side) actors however not directly/strategically involved.
Other	28 (29 ref)	Other additional actors ranging from churches and schools, to volunteers and freelancers or analysts and lawyers.
Citizens	27	Named as such in the studies, i.e. vaguely defined members of society.
Practitioners	14	Non-policy conservation individuals, park rangers, etc* .
Media, Communication	13	Newspapers, communication agents and outreach specialists.
Experts locally or from other sectors	10	Expertizes in other fields (e.g. architecture) or specific to certain spaces.
Civil society groups or organisations	9	Groups often voluntarily working in and organizing community life*.
Tourism	5	Tourism managers and operators.

understanding, trust) and the evaluation of the process and its conditions (162 references from 65 studies, e.g. fairness/respect/equity, power relations/leadership/roles, process preconditions/input, recognition of perspectives, rewards/incentives, transparency). In addition to the reoccurring categories, comparison and reflection emerged as an additional category in our coding (29 references from 24 studies, e.g. achieving goals, external backgrounds to compare, organized reflection).

3.6.2. Focus on 'explicit case studies'

Explicit case studies generally showed the same distribution and relative importance of themes, but the focus on usability was again much smaller than in the overall body of literature, making it the third most referenced category within the case studies that gave explicit measures.

3.7. Methods of evidencing success

The analysis of all studies (n = 478) uncovered a range of different methods for evidencing success in science-policy KE (Fig. 4). The most abundant method was interviews with 79 references (from 79 studies). Studies conducted an average of 25 interviews. The second most commonly used method were surveys/questionnaires with 49 references (from 49 studies) with an average of 88 survey respondants per study. Other commonly used methods were document analysis (42 references) and workshops/focus groups (22 references). While our study did not intend to establish causality between categories of evidence used to evaluate success (i.e. evidence used) and the methods used to generate the data for evidencing success, simple co-occurrences can be seen. For example, 'explicit case studies' that applied some form of network analysis, survey or focus group/workshop to generate data for evaluation were more likely to co-occur with *social outcomes* used for evidencing than other methods (Supplementary Figure 1). Likewise, 'explicit case studies' that conducted network analysis or surveys appeared to put less emphasis on evidencing *usability* than studies that used other methods. Those using documents and scientific citations as a method for evaluation were more likely to evidence *use* of knowledge.

4. Discussion

This systematic scoping review of science-policy interactions and KE processes around environmental management included a large, diverse and relatively recent body of literature. The review identified commonly used KE strategies, as well as the desired and claimed outcomes of interactions, the evidence used to evaluate outcomes and specific methods of evaluation. Our review highlights that success comes in diverse forms. It also shows a critical divergence between what studies aim for in KE and what they claim to have achieved by KE. We found that *usability*, *social outcomes* and the actual *use* of knowledge are the main goals of KE, followed by KE leading to *policy or societal impact*. However, when it comes to the claimed outcomes of KE they were more frequently related to *social outcomes*, *process components* and the creation of (boundary or scientific) *products*. This section serves to synthesize these findings and suggest some implications, considering other studies in the field. In this section, we first discuss the dominating theme of *usability* and then shift towards the role of *social outcomes* and *process components*. Subsequently, we discuss the practical methods used in evaluations. For generalization and comparison, we then gather other approaches to categorize success/impact in literature and briefly look beyond the environmental sector. Finally, we indicate remaining questions and reflect on the included body of literature before concluding.

First and foremost, the focus on the *usability* of knowledge, particularly by the attributes of credibility, legitimacy and salience (Supplementary Table 6), was apparent in the aims, claimed outcomes and evidence used for the evaluation of KE (as described by Cash et al., 2003). This dominance of Cash's model is underlined by the fact that more than half of the articles analyzed here referred to this body of KE work. While Cash's seminal work is relatively older than the remainder of the analyzed literature, other early articles also referred to attributes like credibility and relevance (Sabatier, 1978 cited in Cullen, 1990). From our review we cannot untangle what the reason is for the dominance of Cash's model in the broader literature. However, it could be speculated that Cash's became a key model because it was among the first works specific to the environment (compared to e.g. Jasanoff, 1987, 2004) strategically moving past the linear and 'loading-dock' approach

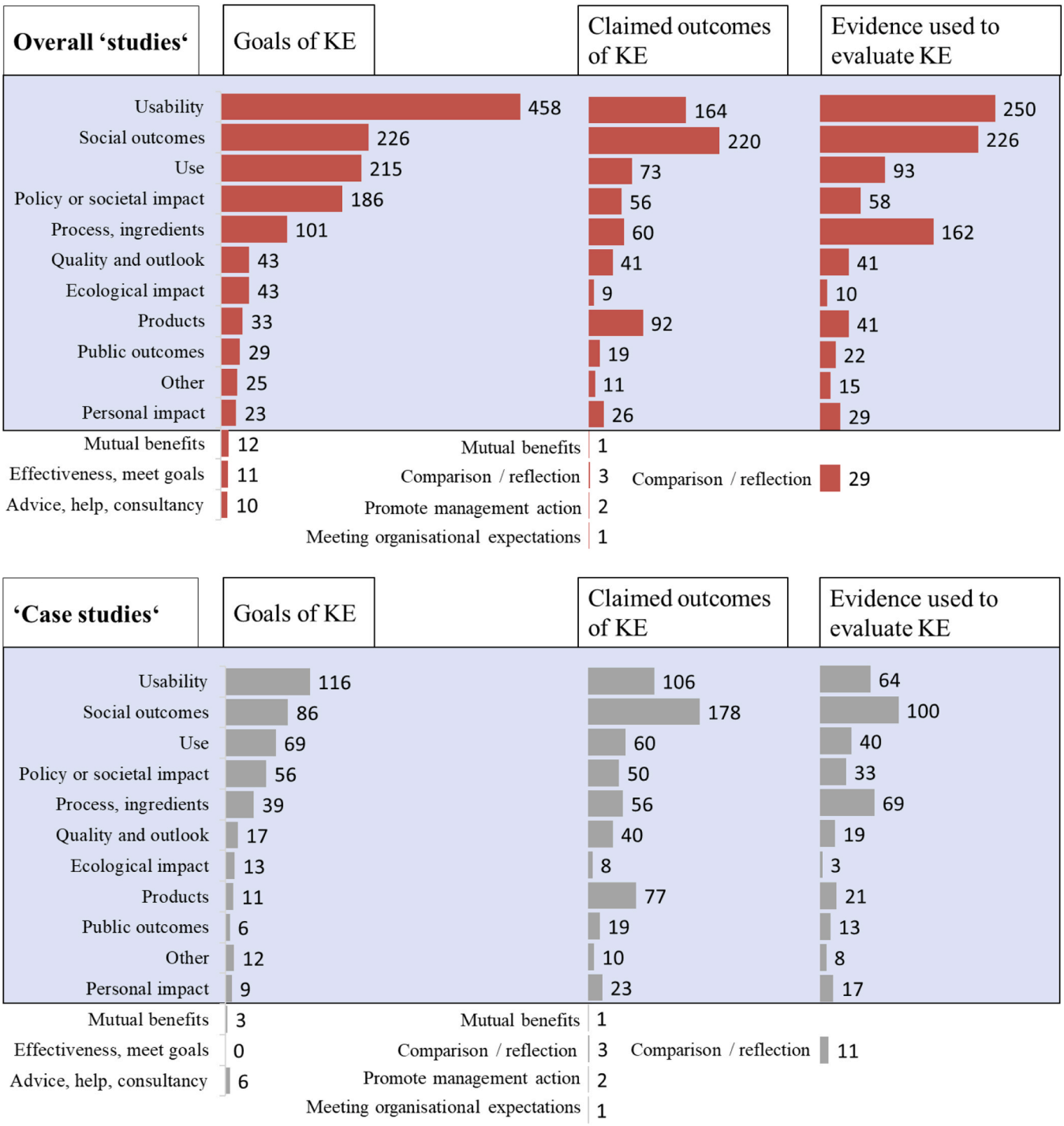

Fig. 3. Number of references coded for goals, claimed outcomes and evidence used to evaluate KE of all studies (n = 478) in red and of explicit case studies (n_{goals}=136, $n_{claimed}$=338, $n_{evidenced}$=103) in gray. Blue boxes indicate reoccurring categories among all three columns with axis labels valid for all three columns. The exact scale between figures varies slightly. A detailed code book with all themes and sub-themes is provided as Supplementary Table 6, as well as a brief explanation of their meaning (Table 3).

of knowledge transfer and to suggest co-production and boundary work (Cash et al., 2006). Accordingly, articulations of success in the KE literature are widely based on those three attributes (Kowalczewska and Turnhout, 2012; Hegger and Dieperink, 2014; Schuttenberg and Guth, 2015; Leitch et al., 2019). However, while these are certainly important aspects, there are other important preconditions for increasing social learning, knowledge use, trust, and achieving impact. Others are pertinence (research targets issues that public decision-makers can influence), quality (e.g. trustworthiness of research), and timeliness (Ford et al., 2013). Comprehensiveness, accessibility and solution orientation have also been identified as important characteristics of the usability of knowledge for policy makers (Dunn and Laing, 2017), but these aspects are rarely found in project planning.

Second, explicit case studies focused more on the *process* and related *social outcomes* of KE such as learning and networking- particularly for claimed outcomes and their evidencing (cf. Fig. 3). The achievement of social and process-related outcomes could be interpreted as contributing indirectly towards environmental outcomes, based on the widely

Table 3
Brief characterization of reoccurring categories (blue part in Fig. 3) for the claimed outcomes of KE by their coding themes and some references from the analyzed body of literature.

Category	Coding theme	Examples from the body of literature
Usability		
This category comprises attributes related to the outcomes of interactions and related knowledge, collaborations, or products. It does not mean aspects that are related to the actual use but only leading to their use/application (i.e. being ready-to-use).	Accessibility	(Naylor et al., 2012; McGonigle et al., 2014; O'Connor et al., 2019)
	Comprehensive, understandable	(Gooch et al., 2010; Steingrover et al., 2010)
	Credibility	(Cash et al., 2006; Tuinstra, 2007; Hegger and Dieperink, 2014)
	Legitimacy	(Tuinstra, 2007; Hegger et al., 2014; Tambe et al., 2019; Leitch et al., 2019)
	Prioritization	(Bielak et al., 2008; Munoz-Erickson et al., 2010)
	Relevant, salient	(Tuinstra, 2007; Gooch et al., 2010; Hegger and Dieperink, 2014; Galafassi et al., 2017)
	Timeliness	(Cash et al., 2006; Slob et al., 2017)
	Useful information, usable, actionable	(McGee et al., 2016; Colavito, 2017; Shrestha et al., 2018; Sanders et al., 2020)
Social outcomes		
Outcomes at the level of social interactions and behavior.	Awareness, learning, communication	(McKenzie et al., 2014; Knapp et al., 2017; Dunn et al., 2017)
	Behavior change	(O'Connor et al., 2019; Kankeu et al., 2020)
	Changes in organizational or institutional culture	(Cvitanovic et al., 2018; O'Connor et al., 2019)
	Consensus, conflict resolution	(Deelstra et al., 2003; Cobb and Thompson, 2012)
	Empowerment	(McKenzie et al., 2014; Queste and Wassenaar, 2019)
	Network	(Cvitanovic et al., 2017; Watkins et al., 2018; O'Connor et al., 2019)
	Relationship, interaction	(Cummins and McKenna, 2010; Galafassi et al., 2017; Colavito et al., 2019)
	Shared understanding, joint definition	(Kuldna et al., 2015; Siew et al., 2016)
	Social learning	(Ungar and Strand, 2012; Xavier et al., 2018; White et al., 2019)
	Start discourse, discussion, questioning	(Kemp and Rotmans, 2009; Frantzeskaki and Kabisch, 2015)
	Support to participants during process	(Mitchell et al., 2017)
	Trust	(Frantzeskaki and Kabisch, 2015; Clark et al., 2016; Murti et al., 2020)
Use		
The intermediary outcome between usability (theoretically ready to be used) and impact (changes in practice). *Use* includes evidence-informed actions, applying knowledge or other components of KE	For training	(Driscoll et al., 2012; Lawson et al., 2017)
	In scientific discussions	(Kankeu et al., 2020)
	Informed management or decisions, use, inclusion in policy	(Bielak et al., 2008; Driscoll et al., 2012; McKenzie et al., 2014; Kirchhoff et al., 2015; Nel et al., 2016; Holness et al., 2018) (Do et al., 2018)
	Selective use by policy makers	
	Utilization of (boundary) products	(Macleod et al., 2008; Driscoll et al., 2012; Palutikof et al., 2019)
Policy or societal impact		
A longer-term broad impact on policy, influence on policy making, or a policy change following a knowledge interaction. It can also include the societal impact of interventions as for example impacts on democracy, economy or the overall development and well-being of society.	Science-based decisions, impact, policy change	(Cummins and McKenna, 2010; Kaiser-Bunbury et al., 2015; Leimona et al., 2015; Bednarek et al., 2016; Buizer et al., 2016; Do Thi et al., 2017)
	Societal outcomes	(Lopez-Rodriguez et al., 2019; Kankeu et al., 2020)
Process, ingredients		
Components and attributes relating to the KE process such as accountability, facilitation quality, fairness/ respect/ equity, inclusion of students/ training, power relations/ leadership/ roles. See Supplementary Table 5 for more attributes in this category.	Continuity	(Duncan et al., 2019)
	Coverage of actors and perspectives	(Slob et al., 2017; Queste and Wassenaar, 2019)
	Efficiency, cost-effective, resource sharing	(Munoz-Erickson et al., 2010; Perez-Soba et al., 2018; Richards, 2019)
	Event	(Gooch et al., 2010)
	Exchange of knowledge	(Grizzetti et al., 2010; Posner et al., 2020)
	Flexibility, adaptability	(Summerell et al., 2015)
	Process, collaboration	(Sitas et al., 2016; Sessa, 2016; Swartling et al., 2019)
	Safe or third places	(Leith et al., 2016; Swartling et al., 2019)
	Transparency	(Tuinstra, 2007; Turnhout et al., 2014)
Quality and outlook		
Outlooks as well as built-in comparison with a project's goal were very specific to the project. This category also captured the implications of KE for the future (e.g. creating something).	Anticipating outcomes and trade-offs	(Galafassi et al., 2017)
	Created group, platform, or institution	(Jensen-Ryan, 2017; Kankeu et al., 2020)
	Future projects, needs, funding	(Hegger and Dieperink, 2015; Wall et al., 2017; Laursen et al., 2018)
	Innovation	(Dunn et al., 2017)
	Navigating unforeseen events, responsive	(Summerell et al., 2015; Cvitanovic and Hobday, 2018)
	Research quality	(Hegger et al., 2014; Kankeu et al., 2020)
	Willingness to continue	(Lopez-Rodriguez et al., 2019)
Ecological impact		
The ecological impact of science-policy work that can be seen in the field (including environmental protection of a status-quo).	Ecological benefits	(Smith, 2009; Fischer and Paige Fischer, 2015; Ratajczyk et al., 2017; Cvitanovic and Hobday, 2018; Goggin et al., 2019)
Products		
Distinguishing outcomes (not strategies) by boundary products/ reports and scientific products/publications.	Boundary objects, reports	(Naylor et al., 2012; Frantzeskaki and Kabisch, 2015; Cvitanovic et al., 2016; Knapp et al., 2017; Roux et al., 2017; Halimanjaya et al., 2018; Daly and Dilling, 2019)
	Scientific publications and their metrics	(Driscoll et al., 2012; Hegger and Dieperink, 2014)

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Table 3 (*continued*)

Category	Coding theme	Examples from the body of literature
Public outcomes All references to public opinion and media (i.e. beyond project actors).	Change in narrative	(O'Connor et al., 2019)
	Public acceptance, policy justification, socially robust	(Kouplevatskaya, 2007; Seijger et al., 2016)
	Public attention, media	(Macleod et al., 2008; Driscoll et al., 2011, 2012)
	Reputation	(Hegger and Dieperink, 2015)
Personal impact Personal level achievements, or references to individual characteristics of participants, that knowledge interactions and the participation in such endeavors came with.	Satisfaction, motivation	(Hegger and Dieperink, 2015; Cvitanovic et al., 2018)
	Scientific or professional merit	(Cummins and McKenna, 2010; Ugolini et al., 2015)
	Sense of ownership, pride	(Leith et al., 2016; Vargas-Nguyen et al., 2020)
	Willingness to use	(Kocher et al., 2012)
	Other benefits	(Ungar and Strand, 2012; Rubenstein et al., 2016; Taylor et al., 2016)
Other This category gathered all remaining codes that could not be grouped after inductive coding. They tended to be either very broad or very specific.		

accepted role of social and other learning processes in environmental governance (Reed et al., 2010; Newig et al., 2018; Ernst, 2019) or positive relationships between satisfactory participatory processes, learning and implementation (de Vente et al., 2016; Schmid et al., 2016; Reed et al., 2018). Although, whether learning, indeed, plays a direct or immediate role facilitating environmental outcomes has recently been questioned (Newig et al., 2019). Social outcomes may be less important to funders, who typically prioritize more instrumental outcomes (Reed et al., 2021). But if social outcomes are planned for, they can help justify projects, lead to more diverse impacts, and foster deeper and more enduring collaboration between those involved in the project (Reed and Fazey, 2021). Our study supports the suggestion that such "non-linear, less visible changes in problem framing, mindsets, and relationships" (Louder et al., 2021, p.264) should be captured more in planning and evaluation. Particularly so given that social outcomes were generally overlooked when stating research aims, but were claimed as outcomes. Together with procedural impacts (as Gow and Redwood, 2020 termed them) (e.g. fairness, recognition of other perspectives, etc.) social outcomes are likely to be particularly important in the context of boundary organizations where building and maintaining trust is essential but can be difficult (Cvitanovic et al., 2018, 2021). As such, the evaluation of social outcomes can provide formative feedback to help guide and enhance subsequent KE, which may in turn increase the likelihood of achieving longer-term impacts (Reed et al., 2021).

At this point, it is also worth noting that both overall 'studies' (all articles plus case examples) and 'explicit case studies' (see *Methods*) show a similar pattern/relative distribution of codes to key categories. The only striking difference lies in the focus on *usability* among the goals of KE and the evidence used to evaluate it, which is much more dominant in overall 'studies' than in 'explicit case studies'. This may indicate two things. Firstly, that *usability* (*c.f.* Cash's model) often comes with three or more attributes (e.g. credibility, legitimacy, relevance). There were more overall 'studies' than 'explicit case studies'. The effect of sample size on *usability* codes might therefore be tripled by *usability* coming in triplets of attributes. Compared to categories which may correspond to sample sizes in a more linear fashion, here this would for the difference of sample sizes result in threefold more codes per overall 'study'. Indeed, overall 'studies' in average of those mentioning *usability* referred to more than two attributes of it. However, 'explicit case studies' did not (on average only 1.2–1.4 references per study naming *usability*). To fully explain this difference, a second explanation may apply. That is, that *usability* may be a more dominant KE goal in theoretical works, and 'explicit case studies' may depend less on such overarching themes, as they are likely to be more specific. That being said, both overall 'studies' and 'explicit case studies', mainly aimed to provide *usable* knowledge for its *use* and deeper *impact* (be it political, societal or ecological) but did not tend to claim or evidence these outcomes. For the overall 'studies' this could be explained by the fact that they included reviews and theoretical work which tend to be less applied in nature, and so are less likely to report actual use or impact arising from usable knowledge. More generally, reasons for aiming for rather than actually achieving/evidencing *use* and (policy, ecological or societal) *impact* might be that it: a) is more ambitious to generate funding; b) is more difficult to achieve; and/or c) requires much longer time spans to become evident (and evidencable) than for example learning or the creation of boundary products (e.g. Cooke et al., 2020). For example, Gow and Redwood (2020) found that over 90% of the most highly rated impacts submitted to the UK's Research Excellence Framework

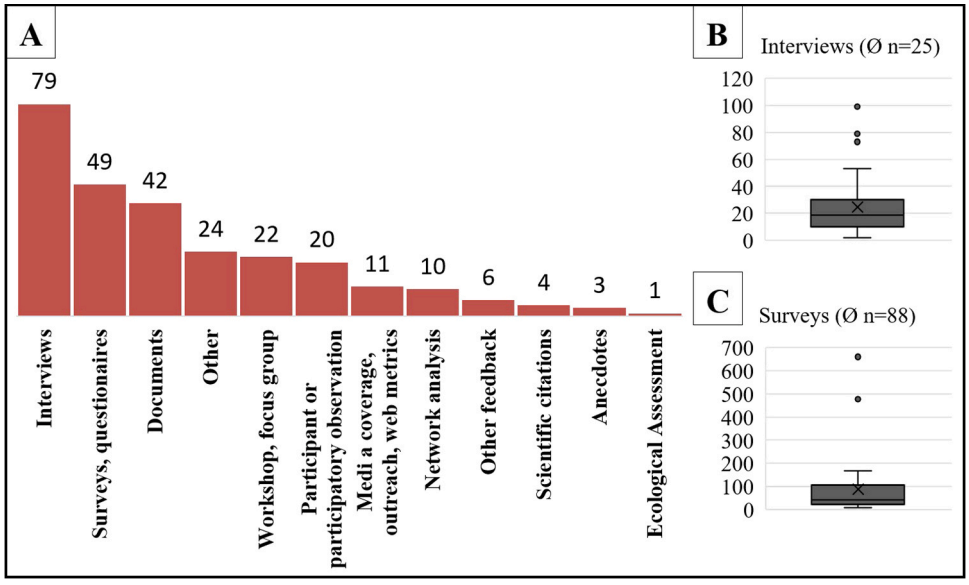

Fig. 4. A: Number of references coded for different methods of evidencing success (n = 478 studies). Box plots indicate the sample sizes for the evidencing methods interviews (B; sample sizes drawn from 72 studies) and surveys (C; sample sizes drawn from 32 studies).

(REF2014) were based on research that started in the 1990s. Furthermore, goals may vary among knowledge interaction strategies and according to the type/structure of the problem (Turnhout et al., 2007; Slob and Duijn, 2014). Being unique, every project requires unique criteria to assess success (Cooke et al., 2020).

Endeavors to evaluate KE and its impacts are both recent and rare (Wall et al., 2017; Cvitanovic et al., 2018; Maag et al., 2018; Posner and Cvitanovic, 2019; Edwards and Meagher, 2020). Thereby, measures for success and evaluation can be explicit but still vague (e.g. Maag et al., 2018). We identified measures and indicators (including more abstract intermediary measures) that were used to evidence the success of KE initiatives, but even examples with seemingly positive outcomes often lacked clear or explicit success measures. In the 'explicit case studies', we found more codes for claimed outcomes than explicit measures to evidence those outcomes. That is, while publications discussed their achievements in terms of KE, they did not explicitly articulate how that achievement was measured or evidenced. Besides other possible explanations (e.g. implicitly described evidencing or different number of studies for claims and evidences), this suggests that studies may highlight outcomes that are not explicitly included in their evaluation process. This may be because claimed outputs were described in more detail than the measures used to evaluate them, or because unintended outcomes were being reported, which had not been formally evaluated (Hakkarainen et al., 2020; Reed et al., 2021).

Our results show that the evaluation of outcomes resulting from KE at the interface of environmental science and policy has been mainly done via interviews, surveys, and document (content) analysis. This corroborates the methods described by others for the purpose of evaluating research impact and KE (Fazey et al., 2014; Gruzd et al., 2016; Posner and Cvitanovic, 2019; Reed et al., 2021). The strong reliance on interviews might be explained by the complexity of science-policy interactions, requiring discussion and probing to make implicit insights explicit (Posner and Cvitanovic, 2019). One complexity around these methods, including interviews, is that they are often conducted as a follow-up to participation in the KE processes. This highlights the difficulty of choosing a time frame for evaluation (e.g. Walter et al., 2007), as impressions and experiences might be more vivid shortly after participation, while impacts may only become apparent over time. While interviews and surveys are specifically useful in evaluating outcomes of research referring to personal, subjective perceptions (Maag et al., 2018), Reed et al. (2021) found a wider range of impact evaluation methods in their review, including experimental and statistical methods, systems analysis methods, arts-based methods and evidence synthesis approaches. Although a wide range of methods for evaluating outcomes were identified in the review, there were important nuances in their application, given the subjective nature of success and what might be defined as beneficial.

Reed et al. (2021) argue, contrary to traditional definitions of impact as "demonstrable" change or benefits to society, that perception matters and the evaluation of any impact as beneficial or desirable must take into account the perceptions of the intended beneficiaries, as well as other groups who might be disadvantaged or harmed (both winners and losers). This is particularly important for the evaluation of credibility, legitimacy and salience, the perceptions and interpretations of which (as well as perspectives and hidden assumptions more broadly) are likely to differ significantly between researchers and stakeholders (Cash et al., 2003; Hegger and Dieperink, 2014; Colvin et al., 2020), as well as across the authors of the literature we analyzed. The same can be said for learning – is it *perceived* learning or *evidence of* durable learning outcomes and knowledge that has been gained (and by which actor group)? It is clear therefore, that perceived outcomes are specific to, and can highly vary between, the parties involved (i.e. researchers and policy-makers) which should be considered in evaluation (Jacobs et al., 2005; Parker and Crona, 2012). And in such evaluation, future research should also better differentiate between internal and external evaluations, adding to the complexity of perspectives. To understand such different perspectives more deeply is likely to require insights from the social sciences, arts and humanities, which should be considered in the planning phase and resource allocation in transdisciplinary research.

Our inductively coded outcome categories appear at first glance to contrast with some of those identified by others. For example, other studies have focused on individual and organizational outcomes (Knapp et al., 2017), research, integration, utilization (Böcher and Krott, 2014; Do Thi et al., 2017), or instrumental impacts, conceptual impacts, capacity, enduring connectivity, culture/attitudes towards KE (Edwards and Meagher, 2020). Others classify interaction successes according to inputs, process/activities, outputs, outcomes, impacts and external factors (Wall et al., 2017; Colavito et al., 2019; Euskirchen et al., 2020; Koontz et al., 2020). Recently, efforts also focus on impacts on policy and decision-making, personal impacts and institutional impacts (Cvitanovic et al., 2018). Consequently, it seems there is a 'blurry line' between outcomes and impacts in KE. More precisely, the achievement of project goals is seen as an outcome indicator, but better understanding a problem and using information (e.g. for policy decisions) are identified as impact indicators (Wall et al., 2017). However, there is considerable overlap between our inductively coded reoccurring categories and these types of outcome or impact. Our research therefore aligns with other studies giving a broader definition of impacts as "changes in awareness, knowledge and understanding, ideas, attitudes and perceptions, and policy and practice" (Morton, 2015, p.36) and hence with regard "to individuals, groups, organizations and society" (Reed et al., 2021, p.3).

Looking beyond the environmental literature, it is possible to consider our findings in the context of studies on research impact and knowledge mobilization. In those fields, achieving impacts from research also requires complex, dynamic, and collaborative processes with respective stakeholders, publics, patients or participants (Abma et al., 2017). Knowledge mobilization has been used as an umbrella under which KE, coproduction, producer-push and user-pull (knowledge transfer) are gathered and which spans a continuum of research use from more conceptual uses (awareness, understanding) to more instrumental uses (attitudes, policy change) (Nutley et al., 2007; Phipps and Shapson, 2009). Knowledge mobilization literature regularly use measures/evidence for evaluation that are comparable to the ones presented here. For example it groups them into measures of inputs, outputs, outcomes and impacts, process measures, technology system measures, and sustainability measures (Bennet et al., 2007), as well as experimental and statistical methods, textual, oral and arts-based methods, systems analysis methods, indicator-based approaches and evidence synthesis approaches for evaluating impact (Reed et al., 2021). Others categorize benefits from research as dissemination, uptake, implementation, and impact from co-produced pathways to knowledge mobilization (Phipps et al., 2016). While many risks and challenges exist around the assessment of overall research impact (Penfield et al., 2014), the importance of structured impact studies as a means to evaluate knowledge mobilization and KE can be highlighted (Grant et al., 2015). Overall, this body of literature agrees with us on the need to build institutional capacity and funders' support for capacity building beyond technology transfer (Phipps and Shapson, 2009), and suggests that in doing so, it may be possible to shape and evaluate impact cultures that emerge from shared purpose, lived through interactions of academic and non-academic communities, supported by appropriate institutional capacities (Reed and Fazey, 2021).

Finally, it is important to note the often-described publication bias among the analyzed body of literature with most first authors affiliated with institutions in Europe and North America. For this study, we were interested in the meaning of success as portrayed by scholarly research and were thus unable to overcome this bias. To overcome the bias toward western and northern hemisphere countries in the short-term, including more (non-scientific) grey literature if accessible (Corlett, 2011; Haddaway and Bayliss, 2015) and reaching out (e.g. via snowballing) to researchers working in rarely covered parts of the world may help. The body of KE literature consisted of many recent studies (last 5

years), suggesting increasing coverage of the topic, perhaps due to increased focus on the impact agenda, but also the novelty of the terms and processes included therein. The search string we used also included rather recent terms, and it is not surprising that mainly those more recent, interactive two-way knowledge exchanges were captured (rather than older, one-dimensional frameworks). Despite KE, co-management and knowledge transfer being among the search terms, mainly co-production, boundary work and knowledge brokerage dominated the literature. It would be interesting, via future research, to trace more direct links between certain boundary strategies used and the quality and quantity of diverse successes, particularly in cases of surprisingly positive outcomes (e.g. 'bright spots', Cvitanovic and Hobday, 2018).

In conclusion, this systematic scoping review found a large and recent body of literature on science-policy interactions around environmental management. Drawing on this literature we are now able to better understand what success looks like at the interface of environmental science and policy. Success has been defined as "respectfully conducted, partner-relevant research that is accessible, understandable, and shared, with the potential to contribute to change" (Cooke et al., 2020, p.361). While our review found that the goals or implicit definitions of success for KE interactions were dominated by their *usability*, *use*, *policy or societal impact* and *social outcomes*, the reviewed studies' attempts to claim and evidence successes were also based on *usability* and *social outcomes*, and on the production of (boundary or scientific) *products* and evaluation of the *process* itself. Hence, our review revealed a divergence between which KE outcomes studies aim for and what they actually claim or evidence. In line with Fazey et al. (2014), who suggested that such evaluations "need to consider a diversity of outcomes" (p.217), our review suggests that in environmental KE literature, success is even more diverse than in the definition by Cooke et al. (2020), which addressed mainly our study's categories of *usability* and *process ingredients*. We would suggest Cooke 's et al. (2020) definition could be expanded to (additions italicized):

> "respectfully conducted, partner-relevant research that is accessible, understandable, shared, *and used, enabled by good knowledge exchange products, - processes, and social outcomes (*e.g. *creating networks, mutual understanding, social learning, and trust building),* with the potential to contribute to change*s in policy and demonstrable societal impact*".

Our findings indicate the need to appreciate the diverse impacts of knowledge exchange activities (i.e. social outcomes, products and process components), and likewise put even more focus on the use of qualitative research methods to evaluate those successes. Therefore, we encourage researchers and boundary practitioners to not only include social, personal and process factors in the evidencing of success (as e.g. in Cooke et al., 2020; Cvitanovic et al. 2021) but also directly in their planning to better align goals and evidence.

CRediT authorship contribution statement

DBK: Conceptualization, Methodology, Investigation, Formal analysis, Writing – Original Draft, Writing – Review & Editing, Visualization. **CC:** Conceptualization, Methodology, Investigation, Writing – Original Draft, Writing – Review & Editing, Resources. **RMC:** Methodology, Investigation, Writing – Review & Editing. **IEvP:** Methodology, Investigation, Writing – Review & Editing. **MSR:** Formal analysis, Writing – Review & Editing, Visualization.

Declaration of Competing Interest

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

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.envsci.2021.08.012.

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