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Understanding knowledge use for sustainability

James C. Arnott [a,b,*], Maria Carmen Lemos [c]

[a] Aspen Global Change Institute, 104 Midland Avenue, Suite 205, Basalt, CO, 81621, United States
[b] University of Michigan, Graham Sustainability Institute, 625 E Liberty Street, Ann Arbor, MI, 48109, United States
[c] University of Michigan, School for Environment & Sustainability, 440 Church Street, Ann Arbor, MI, 48109, United States

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ABSTRACT

Scientific research is increasingly motivated to produce knowledge for sustainability decision-making and action. This is driving some funders, academic institutions, and researchers to pursue research approaches that are more interactive with potential users of the knowledge created. Yet despite compelling evidence that these more collaborative approaches lead to increased use, it remains unclear what constitutes use and how to evaluate its societal impact. To understand knowledge utilization better, we use data from in-depth interviews of research project team leaders funded through an applied coastal research program in the United States. We show that, empirically, what constitutes 'use' remains elusive: researchers believe that their efforts yield usable knowledge that is impactful but find it difficult to provide clear descriptions about specific uses, user identities, attribution, and evidence of broader outcomes. We argue that rather than an impediment to understanding knowledge utilization, these findings may suggest the inherent messiness of knowledge production and use. These results build on prior findings about the methodological obstacles to studying or explaining knowledge utilization and offer new insight into factors that shape the linking of sustainability knowledge and action.

1. Introduction

Generating actionable scientific knowledge has the potential to transform both science and society towards achieving sustainability goals. Harnessing this transformative potential may require a deeper understanding of what drives knowledge use and how it contributes to sustainability action. Yet what constitutes knowledge use, how to measure it, and its impact is a longstanding research question that has critical practical implications for knowledge funding and making.

The heightened focus on the role of science in informing decision making in the past few decades (Jasanoff and Wynne, 1998; National Research Council Panel on Strategies and Methods for Climate-Related Decision Support (NRC), 2009) has renewed interest in understanding different ways researchers and potential users can work together to produce, or co-produce, actionable knowledge (Meadow et al., 2015; Norström et al., 2020). To realize this goal, funding agencies, universities, and research organizations have increasingly called for the co-production of actionable science. In practice, however, the challenges of assessing knowledge use have meant that when calls for actionable science are answered, outcomes have mostly focused on the process of knowledge production rather than on its impact (Lemos et al., 2018; Mach et al., 2020). While these assessments have yielded many important positive and some negative outcomes (for example in terms of inclusion and diversity of participants and power imbalances between participants, e.g., see Turnhout et al., 2020; Vincent et al., 2020), the impact on action often remains elusive (e.g., Jagannathan et al., 2020). And even though assessing process has value, perhaps the missing link is better understanding the relationship between process and the positive outcomes that funders, researchers, and users seek.

Already, a foundational literature has sought to characterize different forms of knowledge use, diagnose barriers, and consider how various attributes of and approaches to research can overcome them (Caplan, 1979; Landry et al., 2003; Pelz, 1978). In sustainability science, a growing literature has emphasized knowledge co-production, or meaningful collaboration between producers and users of knowledge, as a driver of knowledge use (Clark et al., 2016). Despite increasing scholarly attention to and advocacy for collaborative approaches, less attention has been paid to their impact on sustainability outcomes. As a result, there is still more to learn about how particular processes for the collaborative production of sustainability science can influence uses of that knowledge and society's achievement of sustainability goals.

Ideally, scholarship could overcome this knowledge gap through

* Corresponding author at: Aspen Global Change Institute, 104 Midland Avenue, Suite 205, Basalt, CO, 81621, United States.
E-mail address: jamesa@agci.org (J.C. Arnott).

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more systematic, empirical evaluation of knowledge uses and their drivers. Yet research has long highlighted the methodological challenges of assessing research utilization (Larsen, 1981; Wall et al., 2017; Weiss and Bucuvalas, 1980). Challenges include defining outcome variables, constraining the set of potential independent variables, identifying users, and facilitating user recall of uses (Landry et al., 2003). It is reasonable to speculate that overcoming these challenges could be achieved by just doing things better—from identifying and defining use to applying new methods such as data mining and social experimentation that innovate over current approaches to research evaluation. But it may also be that the very quest to define and identify 'use' narrowly in terms of targeted users would limit the ability to see and explain transformative impacts of knowledge. Indeed, rather than a limitation, embracing the "messiness" of the science-policy interface in terms of how it works to influence the production, use, and outcomes of knowledge may in itself be fundamental to better understanding the drivers of successful sustainability science.

This tension—between the desire to understand use more concretely and the reality of its complex nature—is the focus of this paper. Here, we examine examples of applied research projects where the stated aim is to produce usable scientific knowledge to inform sustainable resource management in coastal areas. In such projects, research investigators are expected, as a condition of their funding, to collaborate with users as they grapple with the challenges of defining, characterizing, and fostering use. Specifically, we ask: to what extent do deliberate approaches to producing usable science yield clearer and more specific description of knowledge use? Do these descriptions and uses meet the expectations of funders and research teams? And if not, what are the implications of this disconnect between expectations and actual outcomes for developing new approaches to understand and inform the generation and use of knowledge for sustainability?

In this article we carry out an in-depth case study of how research grant recipients characterize attributes of knowledge use when reflecting on the process and outcomes resulting from completed projects. We analyze 32 in-depth interviews with recipients of grant awards (hereafter 'grantees') funded from 1998 to 2014 through National Estuarine Reserve Research System (NERRS), a NOAA applied coastal research program. While our findings are limited by the focus on a single program, they are valuable for the deep understanding they provide of how researchers perceive use in response to a funding agency desire to foster the production of actionable knowledge (also see Arnott et al., 2020; Trueblood et al., 2019). As a funding program that increasingly required its grantees to collaborate with resource managers, NERRS serves as testbed for understanding processes and outcomes associated with the deliberate effort to co-produce knowledge. In our analysis we focus on: a) researchers' perspectives on the kinds of use they expect, who the users are, and how use is tracked; b) factors that contribute to use and non-use; and c) what beneficial outcomes result, intended or otherwise.

In the following section, we review relevant literature from studies of sustainability science use, decision-making, policy-making, public administration, and innovation. In Section 3, we describe the setting for the projects and detail our approach for data collection and analysis. We present the results of the analysis in Section 4, followed by discussion in Section 5. In Section 6, we briefly conclude.

2. Unpacking knowledge use

Intuitively, usable knowledge is knowledge that can be used to directly inform a decision or action. However, what makes scientific knowledge usable is a longstanding basic and applied social science question (Lemos et al., 2012; Weiss and Bucuvalas, 1980). When it comes to building fundamental understanding about usable knowledge, scholars of research utilization have been hard pressed to produce an evidence base relevant to researchers, their funders, or potential users. Not unlike other research pursuits that aspire to achieve societal benefits, research into the use of science in decision-making has been rather disconnected from the increasing interest from those investing their money or time into producing knowledge that gets used to inform sustainability. The lack of clear definitions of use and of robust empirical data has long made evaluating particular types of societal impacts from science challenging. For example, in their study of mental health research utilization, Weiss and Bucuvalas (1980) explain how "unclear" and "foggy" definitions of use stymie systematic studies. In efforts to get more concrete, many studies of knowledge use tend to look for 'use' as a discrete part of the decision-making process rather than the product of the relationship between researchers, users, and problems. Disappointment often arises when an intended 'use' cannot be readily identified, even if and when other forms of non-targeted uses emerge (Klenk et al., 2015; Meadow et al., 2015).

Sustainability scientists have long relied on a "knowledge systems" framework to examine the ways in which individual and institutional interactions between knowledge producers and users stimulate higher levels of credibility, relevancy, and legitimacy in the knowledge produced (Cash et al., 2003). It is partly on this foundation that studies on the co-production of knowledge detail how more collaborative research practices such as co-production can increase utilization as well as other societal benefits (Arnott et al., 2020; Dilling and Lemos, 2011; Fujitani et al., 2017; Jagannathan et al., 2020; Lemos et al., 2019). Relatedly, studies of innovations and their diffusion show how innovations more readily emerge through "innovation systems" or "innovation ecosystems," which may include partnerships of universities, industries, and government working in concert with one another to generate new technology (Granstrand and Holgersson, 2020). For example, partnerships between these actors have been observed to support increased opportunities for technology transfer and commercialization (Markman et al., 2005) and to create regional clusters of innovation that accelerate new ideas and applications (Asheim and Gertler, 2009).

But while the outcomes of innovations in some industries may produce discretely observable tools or methods where use can be more readily tracked, the process-driven world of decision-making can make it difficult to discern use as a discrete dimension. While early scholars of innovation and technology adoption defined use as a binary variable of use and non-use (Ryan and Gross, 1943), later scholars focused on research utilization in policy-making distinguished between different ways individuals and organizations incorporate knowledge into decisions or other forms of action. In the late 1970s, DC Pelz (1978) introduced a widely replicated typology that defined use in three main types: a) instrumental use—when knowledge provides direct input to decision-making, b) conceptual use—when knowledge is used more abstractly to inform background understanding of a topic and c) symbolic use—when knowledge is incorporated in more strategic ways to justify already established commitments. Building on this typology, Knott and Wildavsky (1981) described use based on the different stages of the policy process across which knowledge is adopted (see Fig. 1). Not withstanding efforts to delineate different types of use, it can be very difficult to operationalize any of the more nuanced typologies in systematic research. Indeed, application of typologies in the domain of environmental science and policy have been sparse and scattered. For instance, some studies have borrowed approaches from technology adoption to measure knowledge use as a binary variable (i.e. use or non-use) (Arnott et al., 2020; Dilling and Lemos, 2011). Others have measured use through proxies such as comprehension, information retention, or perceived credibility (Fujitani et al., 2017; Lemos et al., 2019).

The apparent difficulty in applying such typologies is less surprising when considering the numerous shortcomings and challenges of empirically assessing knowledge use. For example, Lazarsfeld and Reitz argued that what is fundamentally missing is the "first classification of the ingredients" needed to move from knowledge to action (Lazarsfeld and Reitz, 1975, 37 quoted in Weiss and Bucuvalas, 1980, 25). As Landry et al. (2003) have summarized, some of these persistently missing ingredients include:

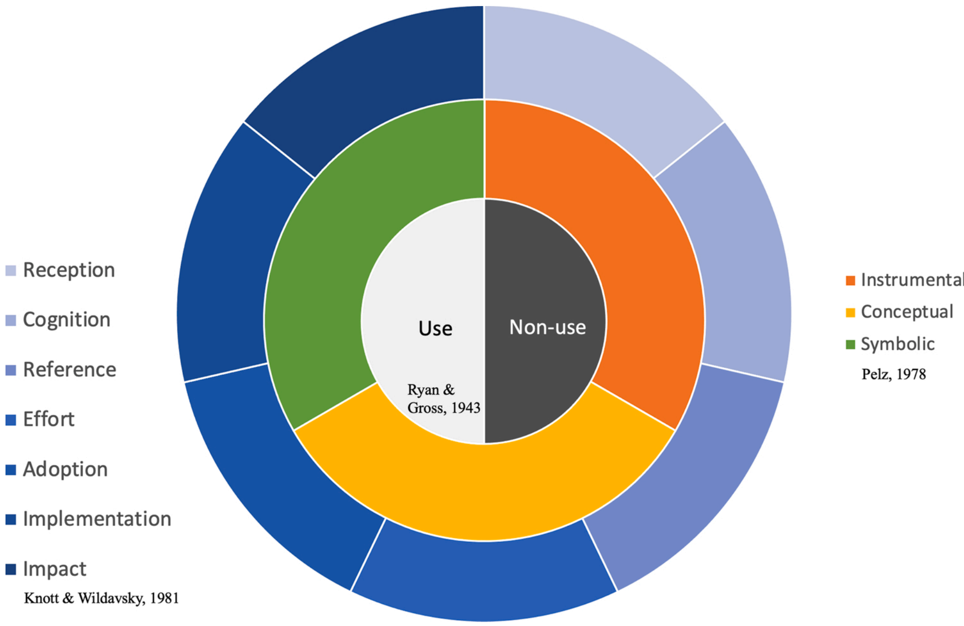

Fig. 1. Three different typologies show a progression toward more multi-faceted conceptualization of use as depicted in this 'kaleidoscope' of use types. Knott and Wildavsky, 1981 outline six types of use: a) Reception: research results were transmitted to the practitioners or professionals contacted; b) Cognition: Research reports/findings were read and understood by the practitioners concerned; c) Reference: Research results were cited as a reference in the reports, studies, and strategies of actions elaborated by practitioners and professionals; d) Effort: Steps were taken to adopt the results by practitioners and professionals; e) Influence: Results influenced choice and decision of practitioners and professionals; f) Application/Impact: Research results gave rise to applications and extension by the practitioners and professionals concerned.

1) identifying the study population (i.e. users)
2) specifying dependent variable(s) (i.e. use)
3) specifying independent variables
4) getting would-be users to recall or attribute use

Because defining and explaining use has been challenging, evaluating the impact of use in the context of individual or organizational decision-making has also been difficult. Efforts to document how potential users perceive knowledge in terms of relevance, timeliness, accessibility, and political acceptance (Dilling and Lemos, 2011; Weiss and Bucuvalas, 1980) have done more to raise questions about our understanding of what constitutes a legitimate use of information. For instance, does utilizing knowledge as a delay tactic or to justify a pre-established position constitute a valid form of use? Even in cases where knowledge may be genuinely sought after to inform a decision, the desired information may only become available when it is already too late to make a decision or may not fit well into pre-established decision-making criteria or calendars (Moss, 2015; Ray and Webb, 2016). Fundamentally, decision contexts are not linear or static, making clean definitions of use and its consequences more challenging. And decision-makers at different moments and across different contexts, may rely upon different "logics" for decision-making: sometimes decisions are taken based on standard procedures (i.e., what is 'appropriate'), other times based on what is estimated to lead to a particular outcome (i.e., what is 'consequential'), and still other times guided by the decision-maker's own efforts to make sense of the world (i.e., what is 'meaningful') (Dewulf et al., 2020).

3. Methods

To understand how assumptions about use emerge out of the effort to produce usable science, we focus on applied science projects funded by the NERRS, a program funded by the U.S. National Oceanic and Atmospheric Administration (NOAA). While much is known about NERRS's nature and culture of collaboration between researchers and coastal managers (Arnott et al., 2020; Matso, 2012a, 2012b; Matso and Becker, 2014, 2013; Riley et al., 2011; Trueblood et al., 2019), less research has focused on how knowledge use is expressed in terms of project outcomes. Although the overall program goal to produce usable science and technology for coastal and estuarine management has stayed constant over the study period between 1998 and 2014, the strategies for meeting this goal changed every 3–5 years, by progressively requiring more interaction between researchers and potential users. Because grantees were increasingly expected not only to interact with but also to identify their 'end' users and propose specific strategies about how they would produce usable research outcomes, this setting provides an ideal context to advance our empirical knowledge of knowledge use.

To study this context, we carried out 32 in-depth interviews with individuals in leadership positions (e.g., PI or co-PI) within the funded projects (n = 32 of 120 invited; average interview length was 41 min, with a range between 13 and 87 min). Individuals were identified by their listing on the front page of project reports and included a combination of researchers and knowledge intermediaries (e.g., extension or collaboration specialists) working for universities, governmental agencies, or individual Estuarine Research Reserves. Because some grantees were funded more than once, these interviewees spoke in detail to 36 distinct projects. Interviews were conducted March-May 2017, meaning that all but nine projects had been completed for at least two years (with those remaining having concluded at least one and a half years by the time of the interview). This interview data complements prior use of the NERRS program database, in which we analyzed research reports of a random sample of 120 projects funded between 1998–2014 (see Arnott et al., 2020). In that process, we divided the sample into four distinctive generations, each progressively more emphatic about the importance of collaboration with users (see Table 1 for breakdown of interviews by generation).

Interviews were conducted using a semi-structured interview protocol (see supplemental materials), audio recorded, and transcribed using a third-party transcription service (rev.com; scribie.com). We asked respondents to characterize whether and how the results from their projects were utilized or had a practical impact. We also invited respondents to reflect about how collaboration within the project shaped the outcomes and uses of the research. Although our key informant responses represent just one perspective in the multi-actor process of co-production, they are important because these individuals are the leading implementers of projects seeking to increase the use of sustainability knowledge.

We coded the interviews based on five themes identified in the literature as obstacles to advancing the study of knowledge use (e.g., Landry et al., 2003; see Fig. 2): how interviewees identified a) uses and b) users; and how they c) tracked, d) attributed, and e) reported outcomes associated with use. We then created a table of anonymized

Table 1
Projects represented by interviewees in each generation.

Generation	Number of Projects	Illustrative topics
I (1998–2001)	5	Eutrophication; wetlands restoration; marshland pollution remediation
II (2001–2005)	7	Nitrogen pollution reduction; non-point source pollution control; eelgrass restoration
III (2006–2009)	8	Low impact development and land use planning; stormwater management; pollution control and removal
IV (2010–2014)	16	Climate resilience; adaptation to sea level rise; green infrastructure

Fig. 2. Guiding questions for analysis of interview transcripts.

descriptions of users and applied taxonomies to each user characterization for both sectoral and geographic placement (Table 2). Finally, we coded for characterization of use, using the three different typologies shown in Fig. 1.

Despite the unique opportunity afforded by this dataset to explore the link between research practice and outcome, there are several limitations. First, the design of the interview protocol and dataset were not intended to be a formal program evaluation. While we included probing questions during our interview, our aim was less about getting to the bottom of what transpired during the project and more about understanding how actors seeking to produce usable knowledge make connections between processes and outcomes. Second, our coding approach relied heavily on high-inference coding that was performed by a single coder, making measurements of intercoder reliability moot. Third, our interview set is relatively small, representing 30 percent of the projects included in the NERRS database. Finally, as suggested by Table 1, the interviews analyzed in this study take place over a broad time period, with different research topics and research styles. We were not able to evenly recruit interviewees across this time period or gain sufficient data from earlier generations, which prevents comparison between funding periods within the larger period of this study design. To the extent that use is a time-dependent component, where knowledge use becomes more apparent or concrete with time, this has been a critical limitation of the study.

4. Results

Our interview data shows that when researchers are funded to produce usable knowledge, they characterize fundamental aspects of knowledge use in wide-ranging, tentative, and often imprecise ways. These perspectives suggest that efforts to incentivize the production of usable knowledge through funding program design do not necessarily yield a well-ordered description of who users are and what kinds of uses occur. Instead, grantee interviews showcase a scattershot approach to describing these elements as well as attribution, tracking, and other outcomes of interaction. These recollections illustrate the highly emergent, unpredictable, and difficult steps that may be needed in order to articulate how deliberate co-production yields usable knowledge.

4.1. Who are the users?

Because NERRS required researchers to develop a close relationship with the estuarine reserves or other coastal partners, a relatively tight-knit community of researchers developed (Trueblood et al., 2019). Notwithstanding, project teams pursued applications with users at varying geographic scales (ranging from a single community or organization, to the entire US) and targeted user groups across multiple sectors and organizational types. Fig. 3 provides a qualitative scatterplot of the different combinations of sectoral and geographic user contexts pursued by project teams based on our coding structure provided in Table 2. Each bubble represents a single project with an index number that corresponds to Table 3. Though the breadth of potential users characterized here is not particularly surprising given the nation-wide scope of the NERRS funding program and the myriad issues arising in coastal sustainability, the depiction nevertheless reveals the great diversity of potential actors and settings in which collaborative research can occur.

We also found the project team members' description of users of their research is generally characterized by uncertainty and improvisation, inclusivity, and fluidity (further described below). Consequently, respondents often had difficulty specifying user groups with confidence or precision. Additionally, who the users were changed over the course of the project and beyond, and we observed an inclination of grantees to incorporate many different types of potential users.

Uncertainty: respondents were uncertain in stating who the actual users of their work might be and at times appeared to improvise about their intended users. For example, a collaboration lead[1] for a project we interviewed quoted a scientist colleague's frustration with identifying users saying, "*You know, I talk about 'managers' all the time when I write my proposals, […] Actually [I] don't know who these people are. Who are they?*" But more frequently, the uncertainty was subtler, expressed in terms of thinking aloud during the context of the interview about who users were versus anonymous stakeholders more generally. For example, when pressed to clarify a point about users during a train of thought listing two different possible user options, one interviewee surmised, "*I don't know, I would say both.*"

Inclusivity: respondents characterized users as any number of people and entities that express an interest in the topical area of research. This observation is typified by the comment, "*I mean when I say end users, I mean they're genuinely interested, and they want to do similar things in their communities.*" Striking an inclusive tone seemed natural in most of the contexts for work described by grantees, particularly given the interconnectedness of the issues they were targeting. In this way, the breadth of selection of actors, as characterized by this grantee, seems wholly

[1] During later years of program design, the funder required a collaboration expert to serve as a Co-I or PI on the grant.

Table 2
Selected coding attributes.

User - Sectoral Specificity	User – Geographic Specificity	Use - Ryan and Gross, 1943	Use – Pelz, 1978	Use - Knott and Wildavsky, 1981
a. General (e.g., public, people)	a. Community	a. Not used	a. Not used	a. Not used
b. Broadly defined stakeholders, resource managers, practitioners, or decision-makers	b. Community - Regional	b. Indeterminate	b. Indeterminate	b. Indeterminate
c. Multiple specific stakeholders, resource managers, practitioners, or decision-makers (3+ specific sectors)	c. Regional	c. Used	c. Conceptual	d. Reception
d. Stakeholders, resource managers, practitioners, or decision-makers (2–3 sectors)	d. Regional - State		d. Instrumental	c. Cognition
e. One specific end-user; one-specified context	e. State		e. Symbolic	e. Reference
	f. State- National			f. Effort
	g. National			g. Adoption
				h. Implementation
				i. Impact

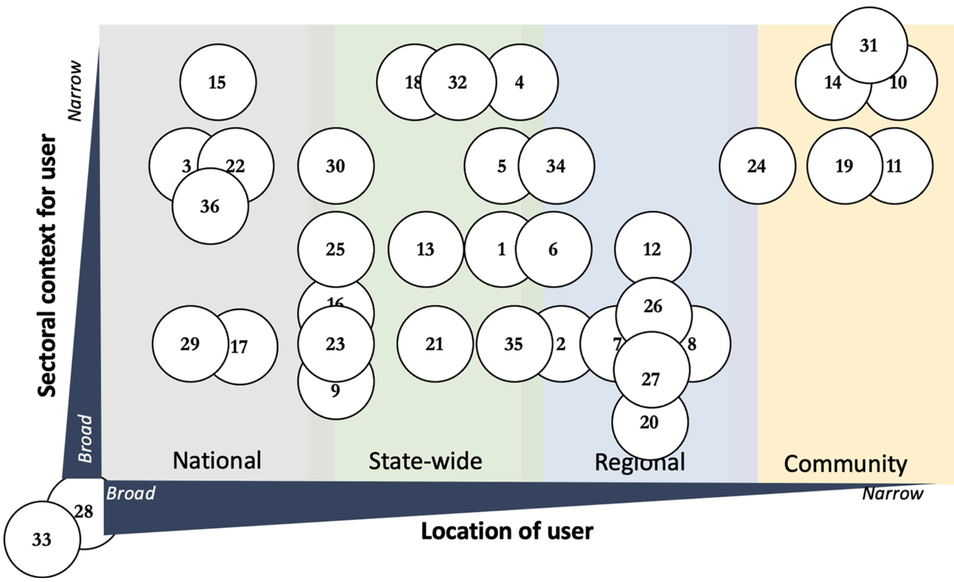

Fig. 3. Qualitative scatter plot of the coding results for users. Circles represents individual projects. Partially overlapping circles indicate user characteristics that were coded to the identical sectoral and/or geographic combination but slightly moved for visibility. Projects 33 and 28 are outliers in the sense that no users (or uses) were identified by interviewees representing those projects.

appropriate:

> We had the research community within remote sensing joining effort with the resource managers who were managing the health of the shellfish, with those resource managers that were managing the health from a public health perspective. And, we had the shellfishermen themselves that were interested in this! So, we were very much a motley crew of folks that were out and about, all engaged in these efforts.

However reasonable and appropriate it may be to cast a wide net, the breadth of actors and different contexts in which they operate further increases the challenge for funders, project teams, or researchers like ourselves to evaluate the various impacts of this work across these contexts.

Fluidity: Painting a clear picture of who the users are is further complicated because often their role changes over the course of the project. New users not initially anticipated come into the scene or intended users drop out or become seen as less relevant. In at least one instance the researchers themselves recast their role to become the user. These changes appear to be driven by a highly fluid style of executing these projects, especially as their participants better understand what uses are possible and in what context. One interviewee put it this way:

> [B]eing new to [this] kind of a Science Collaborative project, I think some of the terminology was new and I mean I knew what an end user was, but I think that there are additional end users that we didn't anticipate or think about. And so, we had our collaborative team, and we had our impact on end users [...] But then I think that list of end users has grown as we've discovered the lasting impact of the project.

In part, the uncertain, fluid, and broad nature of how users are described by interviewees reveals not only how perceptions shift but also how changes in the process of engagement with users shape the aims and practical outcomes of the project. In certain cases, collaboration with one individual, who may be the intended user, can serve to influence other possible users. For example, in several projects that sought to develop guidelines for more sustainable shoreline restoration practices, homeowners were the ultimate users, yet during the project there was also engagement and collaboration with engineers, contractors, and permitting officials, who were considered conduits of information for homeowners. This exemplifies the oftentimes circuitous nature of how knowledge production unfolds and disseminates in the context of grant-funded research. As one respondent put it:

> And so before [homeowners] even find out about ... before they even go to get their permit, they haven't even been exposed to other ideas;

Table 3
Reported end users for each project discussed in interviews.

1	Regional planning commission, local NERR, state environmental quality regulators	19	Local public works and flood management staff, consultant hired by town, local reserve
2	Engineers, landscape architects, state and federal regulators.	20	Homeowners, engineers, business owners, towns/counties, local reserve, and the general public
3	Monitoring equipment company, NERRS	21	State water board and env. quality commissions and associated stakeholder committees
4	State regulators of erosion control structures	22	Federal mission science agencies
5	State Soil & Water Conservation Districts, a county engineer office	23	Federal and state governments devising strategies to make water quality standards; farmers (the regulated community) using technology to meet standards
6	Real estate developers, marine contractors, homeowners, state coastal management, state coastal commission	24	County and municipalities, soil and water conservation
7	Multi-stakeholder conservation groups, local reserve	25	Regional NERR, local fishery managers
8	Engineers, city planners, counties, municipalities and private sector	26	Regional conservation groups, resource management entities
9	Federal regulators, local NERR, local business, State archives	27	Broad regional interests
10	Reserve Coastal Training Program	28	*None mentioned*
11	Watershed protection; Town	29	"Managers, for example"
12	Local watershed association, towns with and without wastewater treatment facilities	30	Federal and private entities responsible for cleanup
13	State natural resource management, soil & water conservation districts, a watershed partnership, local reserve; Reserve Coastal Training Program, engineer consulting firms	31	Local NERR
14	Local coastal park	32	Coastal resource managers that permit shoreline and bulkhead work
15	Federal environmental quality scientist	33	*None mentioned*
16	Coastal communities in the Northeast and elsewhere	34	Resource managers working with shellfish; shellfisherman
17	Federal environmental quality "folks", private sector, consulting companies	35	Restoration practitioner, wetlands manager, state agencies, land management, Reserve
18	The leader of the research project who became a state fisheries manager	36	Licensing agencies, environmental management companies

so we've tried to, with some success—maybe not great success, but with some success—[to] have conversations with engineers and marine contractors about how … they want to make … they want a business model. So, it's both assuring them and the homeowners that these are sustainable.

4.2. What are the uses?

Our data shows that there was no consistent or structured means to articulate the actual uses of project results, which stands in contrast to the funder's primary directive to produce usable knowledge. While some respondents employed very clear and direct language to describe use, the majority of the responses were less straightforward, either because their research was not ready for use due to its preliminary character or because potential forms of use were difficult to identify or characterize. As an example of direct statements of use, one respondent simply stated: *"information was used to create a conservation plan called _* [name omitted] *_, which was presented to the town planning board and then approved…and it became an appendix to the comprehensive plan."* Yet other responses were more vague: *"I don't have any citable evidence of [use] right now. We could probably try to find some."*; or *"[The work] did introduce to the shellfish managers [to] the use […] of some of this emerging technology."* Indeed, while a majority of interviewees were able to share (frequently with great enthusiasm) about some important outcomes of their work, use itself was not a discrete parameter that was easily distinguishable from other outcomes described in the course of the interviews.

In our coding, we systematically analyzed relevant descriptions of use by applying three different typologies of use previously presented in Fig. 1. To each typology we follow Weiss and Bucuvalas findings around "fuzzy and indistinct" uses of knowledge (p. 162) to include an "indeterminate" category to represent cases where use was neither specified, nor explicitly ruled out. Table 4 summarizes the distribution of use types for each typology. We observe no correspondence between how users are construed in terms of their geographic breadth or sectoral specificity and what kind of uses happen. As further elaborated in the discussion section, we wonder whether interviewee statements regarding use could, in the future, be more effectively elicited and articulated if provided the opportunity to articulate use through these or other typologies. The significant share of indeterminate codes—8 or 9 out of 36 projects—further supports this assumption.

4.3. How is use recalled?

Of the 36 projects captured by the interviews, eleven did not cite evidence or even provide anecdotal examples of use. Some were at the time of the interview sufficiently distanced from the context of use and user that they had no readily available data or easy recollection to draw upon: *"No, I never did circle back around and find out what they decided to use."* For others, it became apparent that demonstrable utilization was not feasible for (or the goal of) of their work: *"Well so far, the tools themselves haven't really been utilized because we didn't have any funding to develop them."* Nine interviewees responded to questions about use in a relatively straightforward manner, either with a quickly recalled anecdote or data point: *"The town planner, the one who had come to us about the project, was able to incorporate the ideas into end use planning as he moved forward."*

The remaining 18 projects provide answers that demonstrated the real challenge in recalling use. For some there was hesitation in claiming use because of general uncertainty about the evidence base or methods required to make such assertions. For example, *"we have that kind of qualitative information. But I don't have like, 'Oh, well this regulation was changed.' I don't have more sort of concrete quantitative information."* Or, as another example: *"It's not something I take complete responsibility for. I was one of many researchers who were working in this area. The general idea of adding something that soaks up the chemical of concern, so that's been applied all around the world at this point."* Others responded to the question as an opportunity to reflect about how the project changed them and their understanding of the context and potential for use, for example: *"I basically just became aware of many, many more complexities in terms of seeing this information applied."*

Table 4
Three ways of accounting use of NERRS-funded research.

Ryan & Neale, 1943		Pelz, 1978		Knott and Wildavsky, 1981	
Not used	8	Not used	8	Not used	8
Indeterminate	9	Indeterminate	9	Indeterminate	8
Used	20	Instrumental	15	Reception	2
		Conceptual	5	Cognition	5
		Symbolic	0	Reference	4
				Effort	4
				Adoption	3
				Implementation	3

4.4. How is use attributed?

From our interview set, we obtained responses for 31 projects regarding why researchers believed that their project succeeded, or did not succeed, in achieving use. In analyzing attributions of success across the interviews, we find that projects that fail to meet the underlying aspiration for usable science do so for similar reasons, whereas those that succeed do so for numerous different reasons. Three reasons dominated explanations for relative failure: either there was not enough time or money to achieve something that was usable, there were technological constraints that either rendered the resulting knowledge or tools nonfunctional, or the results were too complex for the intended user audience. In contrast, for those that succeeded, the reasons were manifold. Table 5 lists some of the reasons mentioned in the interviews. Collaboration or outcomes of collaboration were frequently mentioned as influencing success. In a few cases, respondents mentioned a specific policy factor such as a regulatory mandate or some other window of opportunity that made the timing of the research project particularly well suited to a successful outcome.

4.5. What are the outcomes from use?

During many interviews, we elicited responses about outcomes for coastal and estuarine management. These outcomes were conveyed as both "broader" impacts in relation to sustainability, as well as what might be thought of as "narrower" impacts to the participants of the project, such as the personal benefits of their participation. These were sometimes described as discrete from, or even in lieu of, examples of research utilization (see section 4.3 above).

In terms of the broader impacts to sustainability, respondents in multiple instances connected the results of their project to significant efforts in legislation, regulation, or monitoring related to coastal resources. For these cases, interviewees were generally cautious about attributing all the benefit to their project but were nevertheless able to view their work as pushing in the same direction, alongside other efforts, to achieve a result that promoted more sustainable resource management. As one grantee stated:

> I don't know if it's a straight line between a result of this project and that development happening and whatever positive outcomes for the environment that may or may not exist. I don't know how straight that line is because this isn't the only work that's gone on. I'd say with some confidence that it has played a role.

Perhaps because they were closer to home and easier to track, a second set of impacts were narrower in scope but reported with stronger conviction. These often quite heartfelt expressions of satisfaction were attributed to the very nature of collaborative endeavor itself, as in this remark:

> I mean personally […]I really enjoyed working on this project. You know, perhaps more so than other projects that are strictly science focused. I really enjoy working with stakeholders and having that kind of involvement. So, it was fun for me to do for sure.

Table 5
Attribution of use and non-use within grantee interviews.

Reasons for failure	Reasons for success
Technology not functional	Quality and accuracy of information
Technology not in usable form	Functionality of tool
Not enough time or money	Political window of opportunity
	Involvement of students
	Right people in collaborative
	Simplicity of method or tool
	Pre-existing relationships, maturity of project team
	Perceived importance of issue by community
	Communication to decision-makers
	Champion in user community
	Funding for implementation

5. Discussion

Our results show that the effort to (co-)produce research sets in motion a number of different approaches and outcomes that defy a clear or simple assessment. Even though grantees interviewed were funded within the context of a relatively small, targeted program to produce coastal research that could be used in coastal and estuarine management, Tables 3 and 4 illustrate the wide array of users and uses that emerge when participants talk about the projects. The narrative about use was generally unstructured and, in a substantial number of cases, defied our efforts at systematic analysis. Despite these challenges, the interviewees reported on the generation of new ideas, relationships, spin-off collaborations, and follow-on projects, outputs which were oftentimes part of the project in orthogonal and unexpected ways. When considering the full set of experiences and outcomes elicited through these interviews, including unplanned outcomes, it is conceivable that systematic description of knowledge use may not be a necessary precondition for societally impactful sustainability research. Rather our inability to 'nail down' knowledge use in specific terms raises more fundamental questions about the value or desirability of potential structures, such as typologies or guidelines, to assist research-practice partnerships in becoming more explicit and intentional about their collaborations.

Certainly, these projects took place through deliberate and strategic investments—by funders in terms of money, and by grantees in terms of time and relationship-building—to produce usable science. As such, both groups, as well as scholars who study actionable knowledge, might reasonably expect to yield a more definite assessment of project outcomes and their attribution, particularly with respect to utilization. The fact that these expectations were unsupported in terms of our data suggest an intriguing tension at the heart of deliberate efforts to co-produce science in order to solve sustainability problems. Similar to how working to produce knowledge without consideration of use leads to innovations that are difficult to envision at the outset (Flexner, 2017), it also appears producing knowledge *with* deliberate consideration of use does not, on its own, result in a linear conduit to specific use. Nor does co-production appear to neatly fall into a cyclical pathway reminiscent of adaptive management, where iteration and learning occurs through a prescribed rotation of problem defining, information gathering, monitoring, and re-evaluation. Rather, as researchers and users work together to discover needs and approaches, co-production presents itself as a meandering path toward a more emergent set of outcomes that defy the kind of tracking that would support accountability or an inevitable process of learning by doing (Cozzens, 1997; Rowe and Lee, 2012). When guided by societal challenges and driven through interaction with actors across different sectors and institutional settings, the opportunities and pathways to achieve impact are many. Indeed, our data show that the process of knowledge production, whether co-produced or not, can be both catalytic and lead to hard-to-predict outcomes that include, but are not limited to, multiple forms of use.

In this sense, co-production may often be a better fit to the "garbage can" model of organizational choice. As we gleaned from our interviews, knowledges, potential solutions, and problems co-exist and interact as they search out windows of opportunity for alignment. To paraphrase Cohen, March, and Olsen's general appraisal of organizational behavior as "rather anarchic," co-produced science can at times be conceptualized as a collection of choices looking for problems, issues and feelings looking for decision-situations in which their tools and knowledge might be usable, solutions looking for problems to which they might be the answer, and scientists and practitioners looking for work (1972, 2). Adopting this garbage can view of co-production does not negate the possibility, or the value, in more systematically assessing use. Rather, it suggests that strict definitions within narrow bounds do not account for all outcomes and may instead act as a limitation.

Even though funders have since moved to more deliberately encouraging co-production and adopted enhanced approaches to research evaluation, as in the case of NERRS, it is still difficult to describe, or evaluate what kinds of uses are achieved, for what reasons, and to what end. Co-production is invariably productive, but it is still hard to know when intended outcomes are achieved, what broader goals are served, or how results might be expected in a different context if methods are replicated. Although this study further highlights, rather than overcomes, the methodological challenges of studying knowledge use, the results nevertheless advance our understanding of the process of deliberate knowledge co-production in relation to intended outcomes. Even within the case of NERRS, where funders are deliberate and intentional about identifying uses and users, the messy reality of research and co-producing knowledge resists attempts to systematize and typify use neatly into discrete variables. Perhaps it should not be a surprise that the far-from-linear process of collaborative research is hardly more predictable as it gets closer to the realm of policy implementation, which, as Pressman and Wildavsky observed, can dash hopes for a tidy correspondence between aspiration and outcome (1984). Even so, as co-production becomes more institutionalized and widely practiced, there is a growing need to better understand how different modes of science and ways of fostering interaction between science and society will in turn help to understand and expand the systems for knowledge production and innovation required to advance sustainability.

Here funders have a key role to play in this process of discovery and expansion. Drawing on the experience of NERRS as just one case highlights opportunities for other funders, particularly those seeking to fund collaborative research or research targeting more near-term societal benefits, such as sustainability. Firstly, funders can actively collaborate with social scientists as co-investigators working to understand the drivers of knowledge use through the examination of their own experience as well as the experience of peer funders. They can do this while keeping in mind, as the results of this study suggest, that a deeper understanding of co-production outcomes is not likely to be achieved by simply increasing tracking of project outputs and outcomes in a conventional sense. Secondly, funders can be more cognizant of the opportunity to explore their experiences of managing recurring cycles of funding as natural experiments. As the NERRS experience showcases (see also Arnott et al., 2020 for further detail), each periodic iteration in funding program design affords the chance to examine how funding program management approach and other factors influence the process and outcome of research. Finally, funders of research have the opportunity to incorporate this learning into a more adaptive style of program management that intentionally incorporates learning over time into revised approaches. Some funders of collaborative research are already doing this by partnering with each other, and with researchers, to create an evidence-based community of practice (e.g., Transforming Evidence Funders Group). Ultimately, these recommendations may help to situate funders of research as a key component of a knowledge system oriented towards accelerating the innovations required for addressing societal challenges like sustainability.

6. Conclusion

The relationship between scientific knowledge and use is complicated. And not surprisingly, the use of sustainability science in decision-making is difficult to observe, explain, and achieve. Even basic assumptions about what defines scientific knowledge use, or how different forms of use advance sustainability goals, can be challenging to articulate. Despite the promise of strategies such as knowledge co-production to accelerate the production of actionable sustainability science, the complexities and emergent properties arising from the intersection of knowledge production and use are, in the end, likely to be more manageable if embraced and leveraged rather than reduced or ignored.

This article explored the connection between the deliberate effort to produce actionable science with the ability to describe the fundamentals of knowledge use. Prior research has tended to separate consideration of processes for increasing use, such as knowledge co-production, from exploration of the outcome of use itself. This literature also cites persistent methodological problems in the study of research utilization. Our analysis of interviews of research grant recipients who deliberately worked to produce actionable knowledge shows these challenges have yet to be resolved. Although grantees' perceptions typify the potential for how more engaged research approaches can be highly productive and lead to more societally impactful knowledge, their descriptions about the fundamentals of usability – the users, uses, tracking, attribution, and outcomes – were unstructured and in many instances came across as extemporized, speculative, and provisional. Unpacking this further, we see an inherent tension in the effort to co-produce knowledge between structured approaches to understanding and assessing knowledge use and the messy and emergent nature of interactions at the interface of environmental science and policy.

Ultimately, no matter how complex the relationship between knowledge and use may be, understanding more about it is critical to harnessing the power of science to serve society. There are already many well-established reasons for sustainability scientists to pursue collaborative research, but we still need to better understand, across different contexts, the kinds of benefits it can produce, for whom, and how. Creating opportunities for more systematic inquiry into knowledge use, and its outcomes in practice, can serve as a foundation for how to institutionalize better ways for science to serve society. Grant supported research organized to produce usable, actionable knowledge is an ideal context in which these insights may be more readily attained. We foresee future opportunities for collaboration between grantees, funders, evaluators, and scholars of actionable knowledge to co-produce insights and innovation about how to build a more societally beneficial research practice.

Author contributions

JCA and MCL conceived and designed this study. JCA conducted documentary analysis and interviews. All authors contributed to the manuscript.

CRediT authorship contribution statement

James C. Arnott: Conceptualization, Methodology, Investigation, Project administration, Formal analysis, Writing - original draft, Writing - review & editing. **Maria Carmen Lemos:** Conceptualization, Writing - original draft, Writing - review & editing, Funding acquisition.

Declaration of Competing Interest

The authors report no declarations of interest.

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Appendix A. Supplementary data

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