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CONTRIBUTED PAPERS

Five approaches to producing actionable science in conservation

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Abstract

The knowledge produced by conservation scientists must be actionable in order to address urgent conservation challenges. To understand the process of creating actionable science, we interviewed 71 conservation scientists who had participated in 1 of 3 fellowship programs focused on training scientists to become agents of change. Using a grounded theory approach, we identified 16 activities that these researchers employed to make their scientific products more actionable. Some activities were more common than others and, arguably, more foundational. We organized these activities into 3 nested categories (motivations, strategies, and tactics). Using a co-occurrence matrix, we found that most activities were positively correlated. These correlations allowed us to identify 5 approaches, framed as profiles, to actionable science: the discloser, focused on open access; the educator, focused on science communication; the networker, focused on user needs and building relationships; the collaborator, focused on boundary spanning; and the pluralist, focused on knowledge coproduction resulting in valuable outcomes for all parties. These profiles build on one another in a hierarchy determined by their complexity and level of engagement, their potential to support actionable science, and their proximity to ideal coproduction with knowledge users. Our results provide clear guidance for conservation scientists to generate actionable science to address the global biodiversity conservation challenge.

KEYWORDS

actionable science, boundary spanning, boundary work, conservation science, coproduction, engaged scholarship, knowledge to action, science communication

Cinco estrategias para producir ciencia práctica en la conservación

Resumen: El conocimiento producido por los científicos de la conservación debe ser práctico para poder abordar los obstáculos urgentes que enfrenta la conservación. Entrevistamos a 71 científicos de la conservación que participaron en uno de los tres programas de becas enfocados en la formación de científicos como agentes de cambio para entender el proceso de creación de la ciencia práctica. Usamos una estrategia de teoría fundamentada para identificar 16 actividades empleadas por estos investigadores para hacer más prácticos sus productos científicos. Algunas actividades fueron más comunes que otras y, probablemente, más fundamentales. Organizamos estas actividades en tres categorías anidadas: motivaciones, estrategias y tácticas. Con una matriz de co-ocurrencia, encontramos que la mayoría de las actividades estaban correlacionadas positivamente. Estas correlaciones nos permitieron identificar cinco estrategias, encuadradas como perfiles, para la ciencia práctica: la reveladora, enfocada en el acceso abierto; la educativa, enfocada en la comunicación de la ciencia; la interconectora, enfocada en las necesidades del usuario y en construir relaciones; la colaborativa, enfocada en la expansión de las fronteras; y la pluralista, enfocada en la coproducción del conocimiento como el origen de resultados valiosos para todas las partes. Estas estrategias se apoyan entre sí en una jerarquía determinada por su complejidad y el nivel de compromiso, su potencial para apoyar la ciencia práctica y su proximidad a la coproducción ideal con los usuarios del conocimiento. Nuestros resultados proporcionan directrices claras para que los científicos de la conservación generen ciencia práctica para abordar los retos de conservación que enfrenta la biodiversidad mundial.

PALABRAS CLAVE

becas comprometidas, ciencias de la conservación, ciencia práctica, comunicación de la ciencia, del conocimiento a la acción, coproducción, expansión de fronteras, trabajo fronterizo

【摘要】

保护科学家必须产出可操作的知识,才能应对紧迫的保护挑战。为了解创造可操作科学的过程,我们采访了71位保护科学家,他们参与了培养科学家成为变革者的三项奖金项目中的一项。基于扎根理论方法,我们确定了这些研究者为创造可操作的科学产出而开展的16项活动。有些活动比其他活动更为常见,并且可以说是更为基础。我们将这些活动分为三个嵌套的类别(动机、策略和战术)。利用共生矩阵,我们发现大多数活动是正相关的,且基于这些相关性可以确定出五种方法,作为可操作科学的框架:专注于开放存取的公开者;专注于科学交流的教育者;专注于使用者需求和建立关系的网络者;专注于跨越边界的合作者;以及专注于知识协同生产、为各方带来有价值结果的多元主义者。这些特征相互建立在一个层级结构上,而这个层级结构由其复杂性和参与度、支持可操作科学的潜力,以及与知识使用者理想的协同生产的接近度决定。本研究的结果为保护科学家产出可操作科学以应对全球生物多样性保护挑战提供了明确的指导。**【胡怡思;审校:聂永刚】**

INTRODUCTION

The urgent challenges facing the field of biodiversity conservation demand that the science produced by researchers be actionable. Actionable science—also sometimes called usable knowledge (Cash, Borck, et al., 2006; Clark et al., 2016; Dilling & Lemos, 2011; Fabian et al., 2019)—is fundamental to the discipline of conservation, which aims "to provide principles and tools for preserving biological diversity" (Soulé, 1985, p. 727). What makes conservation science actionable is the ease with which it is incorporated into decision-making and used to inform conservation efforts on the ground. Actionable science is defined as "data, analyses, projections, or tools that can support decisions in natural resource management; it includes not only information, but also guidance on the appropriate use of that information" (Beier et al., 2017, p. 289).

Actionable science aims to amend the traditional model of connecting academic research to impact, in which research findings are put out on the metaphorical loading dock for others to pick up, placing the onus of interpretation and application of research on the users rather than the knowledge producers (Barge & Shockley-Zalabak, 2008). The production and use of knowledge in this model is linear—a 1-way pipeline from scientists to the public (Feldman & Ingram, 2009). This "science push" model, in which scientists pursue knowledge for its own sake, contrasts with the "demand pull" model, where information is sought by those who wish to use it in pursuit of a solution to a problem (Dilling & Lemos, 2011; Sarewitz & Pielke, 2007).

Challenges associated with the linkage of knowledge and action include the lack of engagement between scientists and decision makers, lack of institutional support for knowledge transfer, applicability and availability of scientific knowledge, and use of different logics (Barton et al., 2021; Fazey et al., 2013; McNie et al., 2016; Rose et al., 2018; Schwartz et al., 2019). Overcoming these challenges is not trivial, and the challenges are not limited to conservation.

Numerous models for making science more actionable have been developed and described by scientists in recent decades, including (but not limited to) knowledge exchange, boundary spanning, boundary organizations, coproduction, engaged scholarship, action research, participatory research, and translational ecology (Cash et al., 2003; Cook et al., 2021; Enquist et al., 2017; Feldman & Ingram, 2009; Friere, 1970; Goodrich et al., 2020; Guston, 2001; Hacker, 2013; Lemos & Morehouse, 2005; Lewin, 1946; Miller & Wyborn, 2020).

However, many models of actionable science still see knowledge transfer as unidirectional and embody the "knowledge deficit model," which is based on the assumption that knowledge will be used if it is made available. These approaches are therefore focused on improving the production of knowledge and its transfer to practitioners (Cook et al., 2013; Simis et al., 2016; Stocklmayer & Bryant, 2012). However, evidence suggests that knowledge is not a thing to be transferred, but rather the result of a dynamic, multidirectional, and iterative process of relating that involves negotiation of meaning (Roux et al., 2006; Toomey et al., 2017).

More recent approaches to actionable science consider the importance of social capital between knowledge producers and users (Bednarek et al., 2018; Beier et al., 2017; Mach et al., 2020; Meadow et al., 2015; Miller & Wyborn, 2020). This model, sometimes identified as postpositivist (Buschke et al., 2019; Enquist et al., 2017; Fazey et al., 2014), purposely moves past the language of a knowledge–action gap, to focus instead on the interconnectedness of stakeholder groups and their ability to collaboratively produce knowledge (Beier et al., 2017; Toomey et al., 2017; Van Kerkhoff & Lebel, 2015). These approaches focus on building strong relationships between stakeholders, which ultimately leads to better conservation outcomes (Bednarek et al., 2016; Reed et al., 2014; Toomey et al., 2017).

Those who use knowledge are generally not passive consumers. They are often interested in shaping the science produced and may even adopt tools and methods being used to generate their own knowledge (Vogel et al., 2016). Indeed, the subject of study and the assumed audience for the knowledge produced may be one and the same. Yet under the linear model, knowledge users are excluded from the research process (Cash, Borck, et al., 2006).

Therefore, an important variable influencing the actionability of science and its use in decision-making is whether key decisions about the research design are made by the producers (science push), the users (demand pull), or a collaborative combination of push and pull in which knowledge is coproduced (Cash, Borck, et al., 2006; Dilling & Lemos, 2011). Coproduction allows for the incorporation of multiple forms of knowledge as well as bidirectional (or multidirectional) flows of knowledge (Roux et al., 2006). Coproduction is often seen as an ideal model for linking science and action (Bednarek et al., 2018; Jagannathan et al., 2020; Lemos et al., 2018; Mach et al., 2020; Posner & Cvitanovic, 2019).

We considered the question: What do conservation researchers do to create actionable science? Using a descriptive approach, we aimed to understand how the constellation of actionable science models relate to one another in practice. We interviewed conservation scientists to identify the activities they engage in to make their science more actionable and determined which activities were used in conjunction with each other. Meadow et al. (2015) and Brugger et al. (2016) conducted similar work, although ours is broader because we considered all kinds of conservation science (not limited to, but including climate work) and took a wider perspective on actionable science (not limited to coproduction activities).

METHODS

Population sampling

We employed a purposive sampling strategy in selecting our sample population. Purposive samples are designed to select study subjects based on specified attributes and are commonly used in qualitative research studies on hard-to-find populations or intensive case studies (Bernard et al., 2016). This selection strategy allowed us to target individuals with both experience in conducting conservation science and an explicit interest in ensuring its actionability.

Our sample was drawn from the alumni rosters of 3 conservation fellowship programs that train scholars in the production of actionable science—the Wilburforce Fellowship, the Leopold Fellowships, and the Pew Fellows in Marine Conservation. Our objective was not to build a representative sample of conservation scientists, nor was it to study these specific fellowship programs. Instead, our goal was to sample individuals who self-selected into groups that prioritize the translation of scientific knowledge about conservation into effective conservation practice. Although we cannot generalize our results to the broader population of conservation scientists or to the population of those who are interested in producing actionable science, our selection of interview respondents from the ranks of specialized, selective fellowship programs provides confidence that our subjects have experience with and a commitment to producing actionable science.

We invited 443 individuals to participate in our study. Of these, 85 expressed interest in participating and 71 were successfully interviewed. On average, respondents had 24 years of professional experience (SD 12) (measured as years since completion of terminal degree). Respondents had primarily PhD degrees (82%) in a variety of disciplines; the majority were in biological sciences. At the time of our interviews, respondents were employed in several types of institutions, including nongovernmental organizations (NGOs) and government agencies; the majority (73%) were at universities. The majority of respondents were male (64%). Thirty-six respondents participated in the Leopold fellowship, 16 in Wilburforce, and 20 in Pew. One respondent participated in Leopold and Pew. Respondents were mostly based in North America, but the sample also included researchers at institutions in Latin America, Asia, the Pacific islands, and Europe.

Interview protocol

We developed an interview protocol utilizing a semistructured interviewing approach, which is often used to encourage interviewees to share their expertise beyond the narrow framing of questions (Leech, 2002). Interviews were conducted via teleconference between January and June 2018 and were recorded with the respondents' consent. All interview questions and methods were approved by the Institutional Review Board at Arizona State University. Interview questions are in Appendix S1.

Coding of interview data

All interview recordings were transcribed and systematically analyzed using a grounded theory approach. We began with in-vivo open coding of interview selections for key actions and activities in vivo, meaning that emphasis was placed on the spoken words and intent of the respondents (Manning, 2017). This was followed by focused coding for the categories established in the open coding process. Later, the transcripts were re-coded, building on the first codes derived early in the coding process, which revealed new codes, all of which emerged from the data. This iterative process was repeated until all transcripts had been reviewed for all codes. Samples of coded data are in Appendix S2. We could not provide all data due to our data privacy protocol regarding human subjects.

Grounded theory is an approach for generating theory entirely grounded in data, rather than from existing theories or literature. It does not necessarily involve interaction with the literature (Bernard et al., 2016). However, in our experience, it is most effective when approached as an iterative process of inductive coding through interpretation of the data combined with examination and exposition of the literature (Strauss & Corbin, 1998). We aimed to discover relationships among the concepts being coded for by engaging in comparison among codes in various interview transcripts and by informing these with insights from the literature, also known as axial coding (Bernard et al., 2016; Corbin & Strauss, 2014). The results are informed by, but not necessarily reflective of, ideas present in the literature.

Coding was an iterative, multistage process in which codes were discovered in the data through multiple passes made until no new codes were added and all interview transcripts had been reviewed for all codes. All the coding was carried out by the same investigator, and the team met periodically to discuss the results of coding.

Correlation analyses

To discover which coded activities co-occurred with other activities, and how often, we organized the data into an occurrence table (Appendix S3) that captured whether each of the 71 informants engaged in each of the 16 actionable science activities identified. This is similar to the methods used by Scharp (2021). We reported engagement in each activity with a dichotomous measure: 1, informant reported a particular actionable science activity, or 0, informant did not report a particular actionable science activity. The interviews with the greatest number of codes were largely those that contained data that had been coded as coproduction. This was logical, because coproduction is an involved and multilayered process that involves many of the other activities we coded for. This discovery led us to explore patterns regarding which activities generally co-occurred with others through a co-occurrence matrix (matrix available from https://osf.io/gtvfa/?view_only=fabf6be5d01b427da05117b2510d696c).

To investigate relationships and patterns occurring between the identified actionable science activities, we analyzed this data set with correlation analyses, calculated with Stata 15.1. Phi and tetrachoric correlation measures, which are suited for calculating correlations between dichotomous variables (Chen et al., 2002). The selection between these methods is dictated by a variety of considerations, including assumptions of the variable dichotomization and data set size. Phi correlation is appropriate for naturally dichotomized variables (such as land or ocean), whereas tetrachoric correlation is appropriate for artificially dichotomized variables (such as pass or fail grades that correspond to underlying ratio or interval scale data) (Demirtas, 2016). Qualitative interview data have attributes of both natural and artificial dichotomization. Thus, we selected the method based on data set size: mean estimate of correlation given by tetrachoric correlation is biased when cell frequencies in the contingency tables are <5 (Brown & Benedetti, 1977). Given the small size of the data set and expectation that many of the bivariate contingency tables would have values of <5 and even 0 in the cells, we used phi to calculate correlations between the 16 codes.

The phi correlation value for a pair of dichotomous variables is calculated using a 2×2 contingency table. Phi ranges from -1 to 1. A phi value near 1 indicates a positive relationship between the dichotomous variables; thus, (0, 0) and (1, 1) cells have high frequencies and the 2 dichotomous variables occur frequently or are both absent frequently. A phi value near 0 indicates little to no relationship between the variables, such as when the frequencies of all 4 cells of the contingency table are nearly equal. A phi value near -1 indicates a strong negative correlation between the variables, which occurs when 1 variable is often not present when the other variable is present and vice versa.

The co-occurrence matrix revealed clusters of activities that often occurred together. By revisiting the occurrence matrix, the co-occurrence matrix, and the coded data, we were able to discern and describe common groups of activities, which ultimately led us to describe 5 approaches to creating actionable science.

RESULTS

Activities producing actionable science

We identified 16 activities that were important in the creation of actionable science. Table 1 lists these and has a description of each and the proportion of respondents who mentioned each of them. Detailed examples and quotes from interviews for each of the 16 activities are presented in Appendix S1.

Below, we explain each of the activities in decreasing order of frequency (how many interviews were coded with this activity). There was necessarily some amount of similarity among the themes because they describe what 71 scientists said about their work producing actionable science. Despite the fact that some of these codes might intuitively be assumed to overlap or imply each other, our findings indicated they were distinct and existed in the data independent of one another (i.e., the presence of 1 code did not necessarily imply the presence of any other).

Focus on real-world impacts

Ninety percent of respondents described a focus on real-world impacts, which reflects their intention that their research be designed to answer questions that will be of direct use to conservation professionals and practitioners. Respondents described not only their desire to see the tangible impacts of their work in the world around them, but also the actions they took to realize this goal and the evidence they saw of real impacts.

Science communication

Eighty-six percent of respondents described science communication to the public, to policy makers, or to other scientists. They described framing and tailoring scientific findings to reach

TABLE 1 Activities producing actionable science, as the results of axial coding of data from interview selections answering the question "What types of actions do you take to make your research actionable?"

Codes	Description of activities	Frequency (%)*
Focus on real-world impacts	Research designed to answer a known unknown and to have direct impacts in the world of practice; policy and conservation outcomes more important than contribution to theoretical or scientific knowledge	90
Science communication (3 kinds) to the public, to policy makers, and to other scientists (potentially in another sector or discipline)	Translate science into formats intended for various audiences; reduce jargon; media outreach or readiness; public speaking engagements for key audiences; communications plans; participation in meetings; awareness campaigns; and so forth	86
Building agency, capacity, and knowledge	Provide tools, training, or both; empower decision makers and communities of practice with knowledge or scientific resources	79
Focus on user needs (use-inspired research)	Listening to and striving for better understanding of user needs and tailoring scientific approach to answer those needs (does not necessarily imply the intended users are involved in research design or process in all cases); sometimes focus on user needs does not mean user needs are well understood; sometimes scientists assume they know what user needs are	65
Networking and building relationships	Outreach to key groups and communities of interest; connect actors; create and improve lines of communication; build trust and respect among stakeholders	65
Boundary spanning	Bridge and translate across the space, linking multiple stakeholder groups; understand perspectives on all sides; navigate incentives and information needs of various organizations	58
Create long-standing partnerships (with managers)	Based on mutual trust and respect; this is beyond relationship building or networking stages in terms of time, understanding, and personal chemistry; partners learn to work as a team and produce useful science	48
Collaborative (interdisciplinary or transdisciplinary) research	Working with scientists from other disciplines (interdisciplinary) and in practicing in the public, private, and NGO sectors (transdisciplinary)	45
Involving intended users in design of research & questions	Early engagement and actively bringing managers into the process of deciding what questions to address, how to address them, and what products to create	42
Involvement in management, policy, or action forum	Working within (or have been a part of in the past) a management or policy forum involved in real-world action and implementation	42
Strategic planning	Focus on ultimate impact of research products; long-term planning from the start, before outreach, or beginning research plans; consider stakeholders to be included	42
Deep listening and understanding	Listen deeply and gain a deep understanding of context in which the policy partners are working; effective boundary spanners consider perspectives, power differentials, and so forth	39
Early engagement of stakeholders and end users of knowledge	Outreach (prior to development of grant proposals, research questions, or designs) to engage communities that are the intended target audience and stakeholders affected by the science they aim to produce	35
Coproduction of questions, process, and results of research to create results relevant to science and policy or management	Iterative and collaborative process involving stakeholders and intended users of end products in the (collaborative) production of scientific knowledge and policy or applied management outcomes or public goods	31
Face-to-face interaction	Actually see the scientists, or meet people in the field—decision makers and community	17
Open access and open source	Make information, data, and insights available widely to users without restrictions on access or usage	13

*Proportions of interviews coded with the corresponding activity.

specific audiences, eliminating jargon from reports, training scientists how to speak to the media and do press releases, holding public talks and press conferences, participating in meetings and planning awareness campaigns, and so forth. Some of the researchers interviewed utilized the expertise of communications staff at their universities, but quite often they did this work on their own or with partner organizations.

A common topic was finding ways to communicate scientific findings other than through academic publications. Respondents highlighted the importance of communicating through other formats, such as policy briefs, reports, maps, summaries, posters, presentations, press releases, or blogs. According to the respondents, these work products had real effects because they were designed to clearly communicate the science to those who could use it. Often our informants reported creating these products in addition to publishing journal articles and noted that this work was not likely to help their careers. They did it because they believed it would help make a difference.

We identified at least 3 different kinds of science communication, differentiated by the intended audience: the public or mainstream media, policy or decision makers, and other scientists. Because effective communication involves understanding the needs and constraints of the audience; communicating science to one group is likely to require a different approach than communicating science to another. Communicating science to other scientists sometimes required its own strategies because scientists may have very different disciplinary backgrounds or use terminology differently in different discipline-specific jargon.

Building agency, capacity, and knowledge

Seventy-nine percent of respondents engaged in building agency, capacity, or knowledge within partner organizations. Various practices were described, including providing tools, training, or data to empower communities of practice, managers, or decision makers to act on specific challenges they face. This activity went a step further than science communication by providing resources that fit a specific context. For example, a partner organization might have specific needs with regard to a conservation action, and a conservation scientist could provide tools and knowledge tailored to meet these needs.

Focus on user needs

Sixty-five percent of respondents reported the importance of considering the needs of knowledge users. This often—but not always—included consulting with the end users of the scientific research. This could be called use-inspired research because a focus on user needs does not necessarily mean that user needs were actually well understood. Sometimes scientists assumed they knew what knowledge users needed without confirming with the users themselves.

Networking and building relationships

Sixty-five percent of respondents reported networking and relationship-building activities. Respondents often found partners via outreach to key groups or through events of common interest. Respondents reported that networking was helpful because it built trust and understanding, allowed them to learn more about the context in which the knowledge they produce would be used, helped them understand the kinds of information needed and desired by stakeholders, and helped them identify what questions stakeholders had.

Boundary spanning

Fifty-eight percent of respondents described using boundary-spanning activities. This involves bridging and translating across a space between multiple stakeholder groups to help all parties understand each another's perspectives in an inclusive knowledge exchange process to support evidence-informed decision-making (Bednarek et al., 2018; Cash, Adger, et al., 2006). Boundary spanning was often described as an iterative process involving a series of regular meetings with a set group of stakeholders. The process was often collaborative, with input and suggestions going in both directions.

Create long-standing partnerships

Forty-eight percent of respondents reported creating long-standing partnerships with practitioners. These are relationships based on mutual respect and trust. It potentially leads to a virtuous cycle of more capacity building, and a greater understanding on the part of the researchers about the needs of knowledge users. When synergies occur, partners may choose to continue working together over a long term, or on new projects.

Collaborative research

Forty-five percent of respondents reported engaging in collaborative, interdisciplinary (working with scientists from other disciplines), or transdisciplinary (working with scientists in the public, private, or NGO sector) research. For the purpose of this research, we used the term *collaborative research* to refer to interdisciplinary and transdisciplinary research in which the collaboration is among scientists from different fields, sectors, or disciplines. We used other terminology, such as *boundary spanning* and *coproduction*, to indicate collaborating with practitioners.

Involving intended users in design of research and questions

Forty-two percent of respondents emphasized the importance of involving the intended users of knowledge in the research

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design process and actively brought users into the process of deciding what questions to address, how to address them, and what products to create. This activity was similar to early engagement of stakeholders, but went beyond engagement and was close to boundary spanning but put the users front and center in the research process. Engaging users is often difficult to do in the traditional linear flow of academic research, in which work must be proposed (including a research question) before funding is granted. It therefore may be somewhat risky to engage a community in advance of identifying the research questions. Some informants discussed how they strategically established fundamental science research questions to begin with and then later developed more applied questions and products designed to deliver real-world results, once they had the funding.

Involvement in management, policy, or action fora

Forty-two percent of respondents reported working within (or having been a part of) some sort of management or policy forum involved in real-world action utilizing conservation science. These included conservation organizations, government agencies, and intergovernmental organizations. In some cases, involvement in the forum sparked the researcher's commitment to actionable science.

Strategic planning

Forty-two percent of respondents described a high degree of forethought regarding their desired outcomes from the research, including consideration of politics, culture, personalities, economics, and other factors. If the research goals were policy oriented, a deep understanding of the political context was needed. This included discovering who has the ability to make the relevant decision and who would be the best person (or group) to communicate or receive the findings. Many observed the importance of having clear goals from the outset when working toward actionable research, especially when working in concert with stakeholders.

Deep listening and understanding

Thirty-nine percent of respondents explained the need to listen deeply and gain a deep understanding of the context in which their science would be used.

Early engagement of stakeholders and end users of knowledge and science

Thirty-five percent of respondents discussed the importance of early engagement with stakeholders who have an interest in the science they aim to produce. This includes outreach by scientists to the intended users of their research (government agencies, NGOs, communities, etc.). This activity was one of the most consistent in terms of phrasing, including "early involvement of stakeholders" and "starting out" with talking to practitioners "from the beginning" or "right at the beginning" and "from the ground up." It was also characterized as "a bottom-up approach."

Coproduction of research questions, processes, and results of value to science and policy

Thirty-one percent of respondents described coproduction as a key activity for making their research more actionable. We reserved the term *coproduction* for iterative and collaborative boundary spanning that included all stakeholders in all stages of the research and cocreated products of value to both science and society (Jasanoff, 2004; Lemos & Morehouse, 2005; Miller & Wyborn, 2020; Norström et al., 2020).

Face-to-face interaction

Seventeen percent of respondents indicated that seeing people face-to-face on a regular basis was an important part of working with a community or a research group. Several respondents described regular meetings in which people from diverse backgrounds could come together to find common ground and a shared vision for conservation.

Making data or findings open access

Thirteen percent of respondents mentioned the importance of making published findings and raw data available widely to users without restrictions on access or usage. Few informants cited this directly as a strategy for generating actionable science.

Activities with the least and most co-occurrence

Figure 1 presents a matrix of the phi correlation coefficients between all 16 codes. Visual inspection of the matrix provided insights into the relationships in and between these 16 activities.

The majority of the correlation coefficients in the matrix were positive, indicating that informants who engaged in any given actionable science activity also tended to engage in other actionable science activities. Yet, these correlations provided evidence that the 16 codes were conceptually distinct and captured nuances in the ways individuals engaged in actionable science. The highest observed correlation between any 2 codes was 0.7326. Thus, even for the most correlated actionable science activities, some individuals in the sample only engaged in 1 of those 2 practices. Therefore, the derived actionable science practices were related, but distinct.

Open access and science communication had either low or negative correlations with all other actionable science activities. Thus, respondents engaging in open access or science

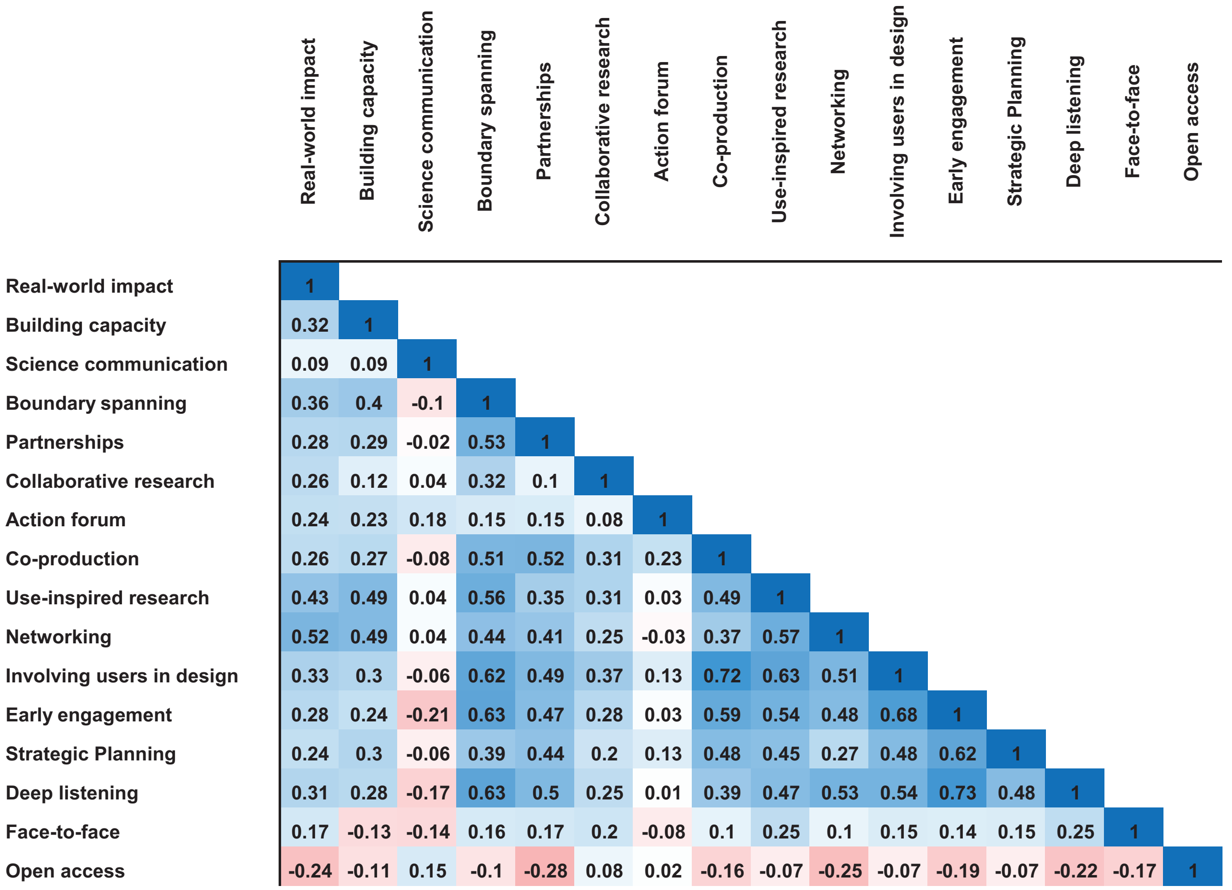

FIGURE 1 Correlation matrix of actionable science activities coded from interviews of 71 scientists in the field of conservation (blue, positive correlation; red, negative correlation)

communication practices were not likely to engage in other actionable science practices. Collaborative research had positive but relatively low correlations with other actionable science activities.

There were several highly positive correlations between actionable science activities. The strongest positive correlations were between early engagement and deep listening; coproduction and involving intended users; and early engagement and involving intended users in design. Use-inspired research was strongly correlated with several other codes, including networking, involving users in design, early engagement, and boundary spanning. Four highly correlated activities—early engagement, deep listening, boundary spanning, and coproduction—focused on the process of linking the needs of knowledge users and the needs of knowledge producers.

Networking was most strongly correlated with deep listening. Boundary spanning was also highly correlated with deep listening, as was early engagement, involving users in design, use-inspired research, partnerships, and coproduction. Similarly, these activities were all involved in coproduction.

Creating long-standing partnerships was most strongly correlated with boundary spanning and coproduction because coproduction requires cross-boundary partnerships. Deep listening was strongly correlated with early engagement, networking, boundary spanning, and partnerships. Early engagement and coproduction were both strongly correlated with involving users in design.

DISCUSSION

Emerging approaches for the production of actionable science

We categorized the 16 activities into 3 nested levels (Table 2). Some are specific tactics, others are broader strategies, and a few are motivations or intended outcomes. Motivations give rise to strategies, which are implemented as tactics. Another way to think of these categories is as answers to the questions why scientists go about making science actionable (motivations), what they do (strategies), and how they do it (tactics). These nested categories, along with the co-occurrence data, can be used to explore emerging groupings of activities, which we call approaches.

TABLE 2 Nested levels of activities used to produce actionable science reported in interviews with conservation scientists, from overarching intent through specific activities

Scale of activities	Activities
Why respondents pursued actionable science (motivations, values, overall intended outcomes, goals of research activity)	Focus on real-world impacts; building agency, capacity, and knowledge
How respondents pursued actionable science (strategies)	Science communication; boundary spanning; creating long-standing partnerships with managers; collaborative inter- and transdisciplinary research; involvement in management, policy, and action forums coproduction
What respondents did to pursue actionable science (tactics and specific activities and skills)	Focus on user needs; networking and building relationships; involving intended users in design of research; early engagement of stakeholders; strategic planning; deep listening and understanding; face-to-face interaction; open access and open-source data or findings

Five levels of engagement of researchers producing actionable science

Many of the 16 activities for generating actionable science reinforce and build on each other. Although each is a distinct action that conservation scientists believe contributes to actionable science, different arrangements of these create unique mosaics of engaged scholarship. The results of the correlation matrix (Figure 1) imply groupings of activities, or approaches, that scientists engage in to make their science more actionable. For example, open access and science communication do not co-occur with the other activities. These clearly represent a discrete approach to the creation of actionable science. We identified 5 such approaches (Table 3). While some activities build on others, they certainly do not coincide in all cases and are not they causally linked.

We conceptualized these 5 approaches as building on one another in a hierarchy of levels of engagement determined by their complexity, their potential to support actionable science, and their proximity to ideal coproduction. We assigned each approach a moniker, based on the identity or profile a researcher using the approach might assume, that incorporates the motivations, strategies, and tactics listed in Table 2. Each level builds on the previous level; therefore, the pluralist incorporates features from all previous approaches and adds new features.

The discloser is concerned mainly with making publications and data open access or open source. This is the most basic activity, mentioned by only 13% of respondents. It is not correlated with any other codes, meaning this was usually the only activity employed by those respondents who emphasized this activity. Although open access is crucial to the democratization of science, it is also a relatively passive approach to sharing information (Roche et al., 2022), and outreach is likely still necessary to engage the right audiences in actually using the science in conservation practice. Managers are unlikely to stumble on this

TABLE 3 Five approaches to the production of actionable science, framed as a typology of identities based on the strategies and 16 activities identified through interpretation of the correlation matrix, based on interviews with 71 conservation scientists*

Profile (approach)	Motivation	Strategy	Tactic	Characteristic
Discloser			Open access, open-source data or findings	Does not necessarily involve direct, active engagement
Educator		Science communication		1-way information flow
Networker	Building agency, capacity, knowledge		Focus on user needs; networking and building relationships	2-way information flow; specific user groups
Collaborator	Focus on real-world impacts	Boundary spanning; creating long-term partnerships; focus on user needs	Deep listening and understanding; early engagement of stakeholders and end users of knowledge; strategic planning	Engage in long-term, boundary-spanning knowledge partnerships
Pluralist		Coproduction	Involving intended users in design of research; strategic planning; early engagement of stakeholders	Coproduction requires that value be produced for, and by, both knowledge users (practitioners) and knowledge producers (researchers)

*The least and most correlated activities reveal different approaches to actionable science. The proximity to ideal coproduction increases from top to bottom.

information themselves—even if it is open access (Fabian et al., 2019). Some of the other activities promoting actionable science will also be needed to successfully address conservation problems because the linear model of knowledge production—which the discloser embodies—does not generate successful or sustained conservation outcomes (Beier et al., 2017; Nguyen et al., 2017; Reed et al., 2014; Shackleton, et al., 2009; Toomey et al., 2017).

The educator adds a strategic component to disclosure by engaging in science communication. This code captures a variety of activities and includes communicating to the public, policy makers, and in some cases, other scientists, but is often a 1-way flow of information from the scientist to the second party (Dietz, 2013). Most science communication involves framing and tailoring scientific findings to fit communication methods, formats, and sources that are most likely to effectively reach desired audiences (Rainie et al., 2015). Science communication was a commonly mentioned activity, but it is not correlated with any of the other activities. This indicates that it is a strategy unto itself. Indeed, for several of our respondents all the activities they described could be considered science communication, implying that it is understood to be a comprehensive approach to the creation of actionable science.

The networker brings a specific motivation to their work: the desire to build agency and capacity in others. These researchers begin to engage in use-inspired and stakeholder-engaged research. Starting at this level, information is more likely to be flowing in both directions between knowledge producers and knowledge users. One key way in which this approach is different from the educator's approach is that these researchers ask questions about who will be using their research and attempt to reach out to these groups. Building relationships between scientists and practitioners by focusing on user needs can lead to new ideas, research partnerships, and alignment with other actors (Meadow et al., 2015) and advances conservation outcomes (Carrera et al., 2019; Suryanarayanan & Kleinman, 2013).

The collaborator goes a step beyond the networker by focusing on real-world impacts as well as capacity building. Collaborators aim to connect with knowledge users, identify their needs, and produce knowledge that meets these needs. These researchers engage in long-term, boundary-spanning knowledge partnerships, which involve deepening the activities of the networker. Involving knowledge users in the design of research is a hallmark of engaged scholarship and demand-driven production of knowledge for the benefit of science and society (Meadow et al., 2015). Relationships become partnerships for collaborators as more formal ties begin to create bridges spanning the boundaries between sectors, organizations, and conservation issues. Far more than simply bridging a gap, boundary spanning is a more dynamic, interactive, cyclical, and iterative process than linear models suggest (Feldman and Ingram, 2009; Toomey et al., 2017).

Boundary spanning is an intense activity that requires specific skill sets, including deep listening; an understanding of the science thorough enough to guide intelligent discussions of it; the ability to recognize and control for power differentials among all parties involved; and skill in navigating the incentives and information needs of various stakeholders and stakeholder groups (Goodrich et al., 2020; Karlin et al., 2016). It involves empathy and a willingness to learn by interacting with stakeholders and through personal reflection (Gerber et al., 2020; McNie et al., 2016; Reed et al., 2014). The best way to understand the context and its needs is often taking the time to listen deeply to these communities and consider their perspectives and the challenges they face (Brugger et al., 2016). The collaborator engages relevant stakeholders throughout the research process, which often results in their use of research outcomes (Dilling & Lemos, 2011).

At the highest level of engagement, the pluralist takes boundary spanning to an even higher level by engaging in coproduction. This strategy requires that value be produced for—and by—knowledge users (practitioners) and knowledge producers (researchers). When users are engaged (ideally early in the research design process), results of the research are more likely to be utilized (Dilling & Lemos, 2011). This strategy may produce a common boundary object (Star & Griesemer, 1989) or separate products that are coproduced by way of long-term collaboration between the researchers and practitioners. At this level, importance is placed on transparency regarding what is being produced for whom and why, and it is no longer simply assumed that the resulting science will be valued by all stakeholders.

Hallmarks of coproduction include early engagement of stakeholders and the involvement of the intended users in the design of research projects, including the formulation of the research question and interpretation of the end products. These processes are dynamic and information flows are multidirectional. All of this requires strategic planning, as well as patience and persistence, to set common agendas and collective goals (Cheruvelil et al., 2014). Some of the key components of coproduction, according to Djenontin and Meadow (2018), are communication, deep engagement, and codefining research questions or project coleadership. Many of the activities we identified are components of coproduction that may also be practiced on their own without necessarily being a part of a coproduction process—it is the combination of them that amounts to knowledge coproduction.

The basis of coproduction is boundary spanning, but the key difference is that coproduction focuses explicitly on the simultaneous cocreation of products that are useful from a scientific and a societal perspective. Coproduction produces real-world outcomes as well as scientific knowledge (Miller & Wyborn, 2020). Additionally, coproduction requires that the entire research process, including the research design, be conducted collaboratively with all relevant stakeholders (Lemos & Morehouse, 2005). If it is truly an iterative process of boundary spanning in which the questions, processes, and results are determined in collaboration with the entire group and the outputs are valuable to science and society, it can rightly be called coproduction. See Wall et al. (2017) for a list of indicators for identifying coproduction.

These approaches can be characterized as a continuum from those who see the process of moving knowledge to action as linear and unidirectional (the discloser and the educator), to those who see it as cyclical and interactive (the networker and the collaborator), and finally to those who understand it as the dynamic, multidirectional process of coproduction (the collaborator and the pluralist).

We identified and described 16 distinct activities that scientists do to make their science more actionable. The 5 distinct approaches to actionable science we identified build on one another in a hierarchy determined by their complexity and level of engagement, their potential to support actionable science, and their proximity to ideal coproduction with knowledge users. These approaches and their constituent activities represent opportunities for addressing the increasingly pressing challenges in biodiversity conservation and environmental management.

One limitation of our study is that we sampled a relatively small subset of conservation scientists; so, it remains to be seen how much our results can be generalized. Future research could investigate which approaches and which activities produce the most impact in terms of conservation outcomes. While it is intuitive to assume that coproduced actionable science has greater impact on real-world conservation outcomes than less engaged forms of knowledge production, our work represents an important step in assessing this assumption. Future research should investigate the demand side of conservation knowledge to understand knowledge needs for conservation practitioners and how these are or could be best met.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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