Knowledge Co-production in Recreational Fisheries Science and Management

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Abstract Recreational fisheries need flexible approaches to knowledge production and decision support that involve interaction with stakeholders of civil society (e.g., recreational fishers, guides, conservationists), governments, and other organised and non-organised actors. Co-production of knowledge grounds research in relevant societal challenges and yields outputs that can have a transformative impact on practice, management, and governance. The term co-production is variously defined and used in the literature. We consider co-production as a process where research questions are informed by practical problems or co-developed, studies are implemented, and findings are interpreted jointly by scientists and other actors in problem-oriented ways that meet their collective interests and needs, while bridging

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different knowledge domains and ways of knowing. The concept shares overlap with co-design, co-creation, mode-2 science, transdisciplinary science, action research, citizen and community science, co-learning, co-assessment, and other related "co-terms," but is not equivalent. In this chapter, we introduce and define co-production and place it in the context of research and management (and contrast it with co-management) related to recreational fisheries, laying out the aspirations, benefits, and challenges. A short narrative review of co-production work in recreational fisheries is provided. We write from a Western academic perspective on the key steps of co-production: identifying which stakeholders to include, exploring how to co-design research, determining data needs and roles, and suggesting one procedural approach. We also refer to leading methodological guidelines. We discuss the challenges and give guidance on weaving diverse visions, world views, and types and sources of knowledge and the importance of being aware of power asymmetries, roles, and (often hidden) norms and values in co-producing knowledge. The chapter concludes with three co-production case studies from recreational fisheries as examples.

Keywords Citizen science · Co-design · Rights holders · Stakeholders · Transdisciplinary

> Co-production is better for society. It also leads to better research — both technically, because it accounts for more factors, and ethically, because it's more equitable…what emerges will be more suitable for take-up Nature (2018)

1 Introduction

Managing recreational fisheries is a complex challenge at the interface between social, environmental, and cultural interactions (Arlinghaus et al. 2017). Recreational-fisheries management has added layers to consider beyond primarily valuing catch as with commercial fisheries. Instead, recreational fishers value the multifaceted fishing experience (Holland and Ditton 1992; Fedler and Ditton 1994; Hunt et al. 2019; Birdsong et al. 2021). Different recreational fishers value distinct aspects of the fishing experience including some that are completely independent of catching fish (e.g., the social or experiential aspect of the fishing trip). Individual recreational fishers are heterogeneous not only in their skill and their priorities, but also in how they behave and respond to changes in policy or the social-ecological environment (Murray-Jones and Steffe 2000; Lynch 2006; McCluskey and Lewison 2008; Johnston et al. 2010; Hunt et al. 2025). Recreational fishers come from diverse socio-cultural and demographic backgrounds, and the recreationally fished waters are often shared in use with other members of the public, as well as other fishery sectors, such as commercial or Indigenous fisheries. In some areas of the world, recreational fishing communities, through their organisations, are not only natural resource users, but they can have management rights and responsibilities for the waters they fish that are legally binding and secured (e.g., in German inland fisheries; Daedlow et al. 2011). The same holds for Indigenous communities who are rights holders about fisheries. Almost certainly, all recreational fishers have some level of personal interest or stakes in management issues. Conventional approaches to management decision-making and underlying knowledge generation to inform decisions tend to exclude diverse stakeholders. Also, the convention is that scientists should primarily define research questions, conduct research, and interpret findings that are then used, alongside other information sources in management decision-making. Such approaches fail to create pathways for engagement of scientists or managers with different stakeholders, and in doing so can lead to science-based knowledge that is less relevant and less likely to be embraced by decision makers, fishers, other participants, and stakeholders (Hakkarainen et al. 2022). Co-production of knowledge is an increasingly common approach of engaging in joint inquiry towards informing the best, scientifically sound management decisions; it is the topic of this chapter and one way to bridge, synthesise, and work together across historically separated dimensions (e.g., science and society).

Given the multi-faceted nature of recreational fisheries and the millions of people being affected by management decisions, pursuing triple-bottom-line sustainability, an ideal where ecological, social, and economic sustainability are jointly achieved at some compromise (Dichmont et al. 2021), requires agility. Management challenges in recreational fisheries can be considered in the context of complex adaptive systems (Arlinghaus et al. 2017) whereby the problems are often "wicked" (Rittel and Webber 1973). Addressing such problems requires diverse inputs from various actors, including individual stakeholders and organised interest groups as well as rights holders, to recognise and effectively consider the complexity of the system (Bammer 2019). One way by which stakeholder values and knowledge outside academia can be considered is by bringing interested people into dialogue and synthesising what they have to say and believe in a transparent and productive way. Co-production goes beyond the "simple" inclusion or consideration of stakeholders, participants, and other actors, by emphasising the joint production of new knowledge that is in turn used to address pertinent management problems (Hakkarainen et al. 2022). In this chapter, we present broad and flexible roadmaps to knowledge co-production that can fit the needs of a particular case in recreational fisheries. This chapter will acquaint readers with the state of co-production and provide guidelines for embracing a co-production approach in recreational fisheries. Whereas no general recipe for co-production exists, there are elements that will nearly always be important. We provide insights about those elements and conclude with case studies illustrating various approaches to co-production in recreational fisheries.

2 Defining Co-production of Knowledge for Sustainability of Natural Resource Use

Knowledge co-production is a loosely defined, constantly evolving term for a specific form of knowledge generation that goes beyond academia (i.e. beyond the domain of scientists and researchers). It can be associated with an overlapping series of related concepts that emphasise some form of collaboration among science and society, such as transdisciplinarity (Hirsch Hadorn et al. 2006), integrative research, (adaptive) co-management, co-creation, co-assessment, co-learning, action research, mode-2 science, or co-design (Hakkarainen et al. 2022). The differentiation among these concepts is not obvious (Norström et al. 2020), but we direct the reader to Hakkarainen et al. (2022) who does an excellent job in clarifying the various co-concepts and their relations (summarised in Fig. 1, see also Glossary).

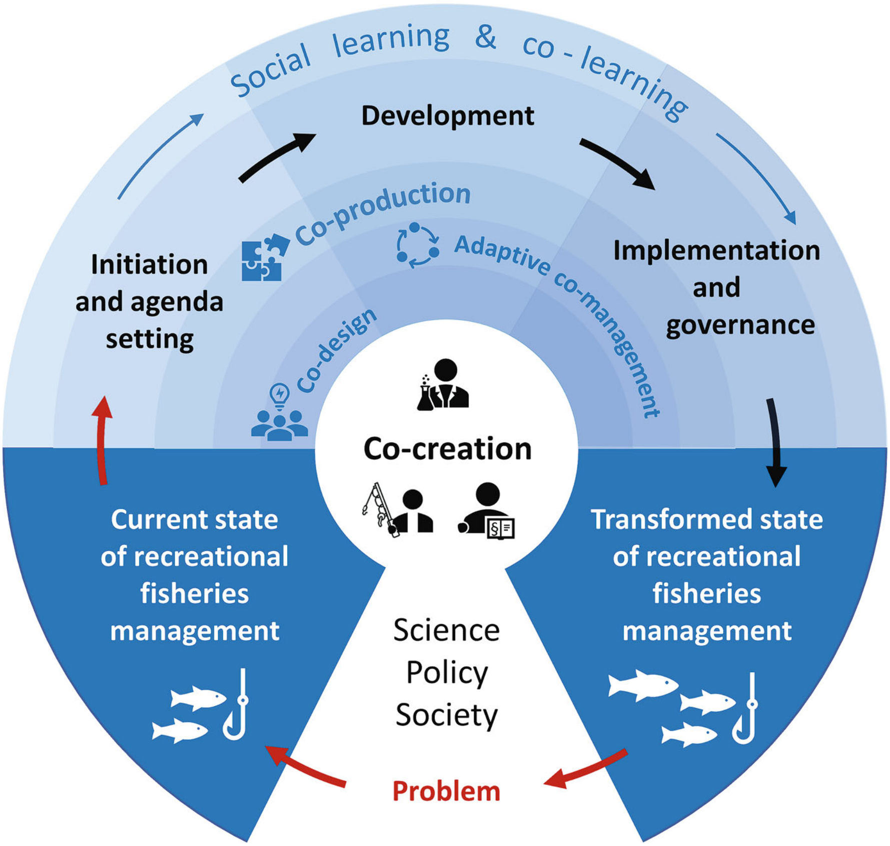

Fig. 1 An overview of the various co-concepts aimed at supporting collaboration among scientists, recreational fishers, and other actors, interest groups, and stakeholders. (Modified from Hakkarainen et al. 2022)

The roots of knowledge co-production are related to Latour (1988), who considered knowledge and action as reciprocal. Miller and Wydorn (2018) trace co-production to three main academic fields: public administration, science and technology studies, and sustainability science, which involves fisheries science. Within the latter tradition, Norström et al. (2020) defined co-production as "iterative and collaborative processes involving diverse types of expertise, knowledge, and actors to produce context-specific knowledge." Cooke et al. (2021) defined knowledge co-production specifically for fisheries as "the contribution of different knowledge sources, ways of knowing, and perspectives from different user groups with the goal of co-creating knowledge and information to inform fisheries management and conservation." A third definition that follows the first two but provides additional key areas of focus describes co-production as a "processes that iteratively unite ways of knowing and acting leading to mutual reinforcement and reciprocal transformation of societal outcomes" (Wyborn et al. 2019). This aspect of co-production is further elaborated by Moser (2016) in that a co-production process itself can be an instrument of transformation, changing not only the research projects envisioned but the people involved (Fujitani et al. 2017), while inviting critical reflection of the role of science in society, norms, and power asymmetries.

Though definitions vary and co-concepts overlap (Fig. 1), key to all definitions of co-production mentioned above is that both scientists and practitioners, stakeholders, and rights holders are involved in the knowledge generation and that four key procedural principles are met (Norström et al. 2020): (i) context-based, (ii) pluralistic, (iii) goal-oriented, and (iv) interactive (see Fig. 2 for details). If all four principles are met, the process will lead to co-production of knowledge among scientists and practitioners working towards solving a concrete problem in recreational fisheries (e.g., whether fish stocking produces positive outcomes or how to design best-practices in catch-and-release to limit impacts on a key species).

Hakkarainen et al. (2022) reviewed the aspiration of co-production in the context of natural resources management more generally, concluding that co-production projects exist in four variants with different outputs intended (Table 1): (i) outcome oriented, (ii) practical and pragmatic, (iii) empowering, and

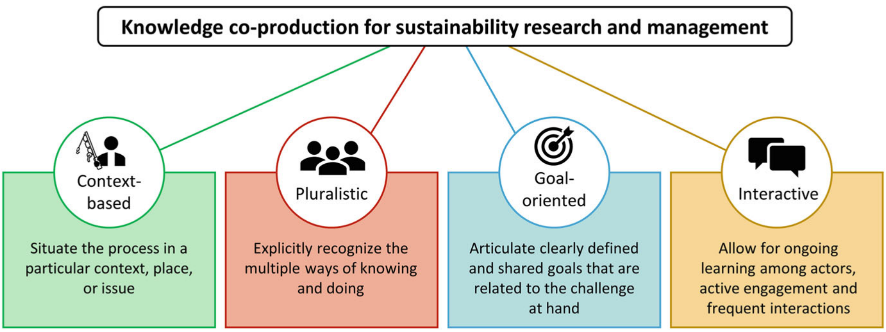

Fig. 2 Principles for knowledge co-production in sustainability sciences and specifically fisheries. (Modified from Norström et al. 2020)

Table 1 Variants of co-production of knowledge in natural resource management contexts

Variants	Outcomes oriented	Practical and pragmatic	Empowering	Transformative
Promises	Better understanding of data and monitoring	Increased relevance, scope, and usability of science, building of adaptive capacity	Creating partnerships that lead to better fisheries management	Better understanding and democratising management of fisheries by developing synergies across knowledge systems
Role of actors outside academia	Informants	Stakeholders	Partners	Co-researchers (often Indigenous or local people with rights on resources)
What kind of co-production?	From knowledge transfer to co-sharing. Actors are valued more as implementers of research outcomes (not necessarily because of their knowledge)	Co-production as a skill-dependent activity that enhances co-ownership of knowledge and builds capacity and stewardship	All are involved as equal partners and co-producers of knowledge. The process is more bound in time and scope than transformation	Appreciating different knowledge systems and embracing epistemological differences. Linking co-production with political issues (e.g., human rights, Indigenous rights)
Example from recreational fisheries	Recreational fishers sharing catch data in an online application that is then used in science for assessment	Conducting stocking experiments in collaboration with recreational fisher communities where the general design is developed by scientist without involvement of recreational fishers (see second case study in later section)	Working on improving catch-and-release practices in joint partnership of scientists and recreational fishers, where the goal is to identify best-practices that are encoded in local regulations or codes of conduct (see first case study in later section)	Co-development of visions, objectives, research approaches and data interpretation, with the goal to solve conflicts in co-exploited situations (see third case study in later section)

From Hakkarainen et al. (2022)

(iv) transformative. The promise of outcome-orientation is a better understanding of data and improved monitoring. Stakeholders can have distinct roles in this process, from merely becoming informants about fishery developments to becoming partners in the research process. If people outside academia stay as mere informants, these actors may be valued more as implementers of research outcomes than as knowledge holders. Practical and pragmatic approaches have the aspiration to increase the relevance, scope, and usability of science and to build adaptive capacity for management. Stakeholders involved become "knowledge stakeholders," and the co-production process is meant to lead to co-ownership of knowledge. The promise over empowerment is to create partnerships among scientists and non-scientists that lead to better fisheries management where all involved are co-producers and equal partners. Finally, the aspiration of transformative approaches is that actors outside academia become co-researchers to better understand and more democratically manage natural resource systems, where different knowledge sources are appreciated and embraced, and co-production of knowledge is linked with political dimensions of change and transformation.

3 Benefits of Co-production

Co-production can help to solve key scientific or practical issues in recreational fisheries as in other natural resource contexts. These solutions and issues range from questions stemming from a single scientific discipline (e.g., what is the impact of fisheries harvest on a local fish biomass and size structure), to basic research questions enmeshed in the complex social-ecological systems of a fishery (e.g., what are the principles of information spread in recreational fisher networks), to applied knowledge intended to directly inform management actions and policies (e.g., what are the social or economic factors determining the outcomes of a new harvest regulation).

The following recommendations are written from a Western perspective, envisioning someone with a science or resource management background in the primary role of designer or instigator of the process, with a normative approach of co-producing knowledge to achieve a shared goal with others (e.g., stakeholders, participants in the fishery, managers, rights holders). However, the frameworks discussed here are applicable in other situations. Our focus on knowledge produced rather than the policy outcomes as well as the explicit participation of people with stakes, rights, or influence, separates it from co-management, though the concepts may overlap (Fig. 1).

Knowledge co-production brings together different perspectives, ways of knowing and sensing, and epistemologies, and thus, draws on deliberately diverse sources of knowledge. It can thus provide a more complete, holistic, and importantly inclusive picture about a problem of relevance to recreational fisheries locally or regionally. In co-production, the lines of inquiry are typically developed collaboratively (Table 1 and Fig. 1), leading to research questions that may spin off in new directions, linking societal concern and political systems, fitting the local context, and responding to real needs of people "on the ground" (Reed et al. 2014; Meadow et al. 2015; Lemos et al. 2018). Co-production calls into question traditional roles of knowledge producers and consumers, "forcing" scientists, managers, rights holders, and all stakeholders to confront their own biases and consider other perspectives and ways of knowing. This aims to increase equity, buy in, and acceptance of the research process and results, which shall strengthen local ownership and build local management and evaluative capacity. In most co-production processes, local stakeholders and rights holders are constantly involved and informed throughout a transparent process that tends to build trust among all involved, which can be key to having new knowledge accepted and used by practitioners (Nguyen et al. 2019a, b). Collaboration in a knowledge-generating process with management implications will often also lead to a sense of ownership of and foster local stewardship of natural resources, and support for co-produced management outcomes. Co-production thus aims to bridge science-society-policy gaps, bridge the knowledge-action divide (Fazey et al. 2014; Cvitanovic et al. 2015, 2016; Metz et al. 2019), and facilitate transformative change through the interactions inherent in the co-creative research process to address specific sustainability issues in fisheries and beyond (Boaz et al. 2018; Bammer 2019). In summary, the key benefits of co-production to recreational fisheries are (adapted from Cooke et al. 2021):

- Integrating the diverse ecological and social knowledge held by people on a given problem.
- Increasing the acceptability and applicability of research results to solve sustainability issues.
- Increasing the relevance of science for social benefit.
- Increasing the uptake of research results to inform management and bridge the knowledge-action gap.
- Enhancing the human capacity to deal with problems in the future.
- Increasing interpersonal trust and building relationships among stakeholders, rights holders, and other actors and among science and society.
- Strengthening the research process in terms of relevance, credibility, saliency, and legitimacy.
- Confronting and mitigating biases of those involved in the process, including scientists.

4 Limitations and Challenges of Co-production

Achieving co-production is extremely challenging as working across scientific disciplines, regions, and societal groups requires new methods and concepts regarding communication and a willingness of all parties to engage and stay involved over time. Collaborative research often relies explicitly on "boundary objects" (Star and Griesemer 1989; Nel et al. 2016), which include conflicting narratives about an ongoing management problem and tools emerging from the realm of scientific investigation, such as data tables, logbooks, models, or maps, that can structure and share data between different user groups. These objects used for creating, storing, and sharing knowledge are understood and used differently by distinct groups, which cannot be taken for granted if they are to function well in co-producing knowledge. Researchers and non-research stakeholders need to reflect throughout the process. This is cognitively challenging, resource intensive, and very often time-consuming.

Co-production processes generally require skills that are outside the standard research toolkit of most fisheries biologists, including identifying, motivating, and involving relevant stakeholders, considering equity issues, addressing communication and language obstacles, and conflict resolution. Unfortunately, few formal opportunities exist for learning the suite of skills needed for co-production processes in fisheries science more generally (Cooke et al. 2021), and the idiosyncratic nature of each co-production relationship means that even with a strong background, one is always learning anew. Each co-production relationship fundamentally requires trust and relationship building, which necessitates large investments in face-to-face time and willingness of all people to understand and respect each other (Brinkerhoff 2002; Austin 2004).

Whereas one can design co-production very purposefully (examples later in this chapter), it can also develop more informally as relationships among science and society evolve and opportunities emerge. At times, it may involve just a few participants whereas in other instances co-produced projects become massive undertakings with hundreds of people directly or indirectly involved. Here, the timelines of researchers, management, and other stakeholders may not align with the speed and nature of research and outputs. Such issues are often the case for research or government institutional arrangements, considering constraints set by funding and associated budget and project timelines. Other limitations and challenges to co-production involve psychological, scientific, procedural, and financial aspects.

From a psychological perspective, delegating scientific inquiry into a co-design process risks losing scientific autonomy and having the research affected, if not driven and motivated by various norms and expectations of involved people outside academia. Whereas this is mainly an issue for scientists (Young et al. 2016), it may also lead to stakeholders and right holders avoiding engaging for assorted reasons including blue fear (i.e., the fear that outcomes of the research may have negative consequences such as motivating stricter regulatory control in the future). Stakeholders and other actors may also fear inferiority and the outcomes of research results affecting future decisions on which their own well-being is based. In particular, the results of co-production processes may find their way into management, which can be perceived as threatening to stakeholders and rights holders, or research results may disclose sensitive information (e.g., locations of fishing grounds) that people do not want to be revealed. It is extremely important to be open and transparent about how research results will be used, who owns them and what can or cannot follow for stakeholders and scientists to buy in. The necessary transparency can lead to processes breaking down in terms of functionality if the fear of consequences reduces the continuous willingness to engage.

A primary driver for some forms of co-production is the expectation, by researchers, managers, or funders, that it will increase the likelihood that the research output will influence policy and management (Table 1). However, this expectation itself, and the expectations of involved stakeholders, are just one of many challenges that must be navigated and managed through the process. One way these expectations may collide is when researchers are confronted by changes in the original research question and study design, especially when co-production is practised from the problem identification stage and stakeholders are involved in co-developing the research questions and approaches. These changes may bring the co-production process outside of the researchers' area of expertise, comfort zone or interest. Flexibility and constant modifications are part of the iterative and collaborative process, but the reality may be jarring for some. Thus, one must be realistic in the scientific team about how much room is available to change the research focus and whether and to what degree one is willing to engage in novel problem framing after engaging with stakeholders. If co-production begins in the problem framing phase, there must be room, in terms of capacity and flexibility, from oversight boards or funding institutions, to allow for stakeholder input to increase the relevance and applicability of the production process. Bringing stakeholders into a research program that is already predefined is co-production in a very contrived sense, and maybe better described as classical citizen science, where stakeholders are often mere informants in an already structured process. It is also possible to engage stakeholders after research findings are in hand to interpret and think about the application of knowledge, which is termed co-assessment (Sutherland et al. 2017). Researchers may engage in co-assessment but mistakenly consider it to be co-production (see glossary and Fig. 1).

From a scientific perspective, the risks include, especially if research questions are co-developed with stakeholders and data streams depend on stakeholder collaboration, that certain stakeholder norms and expectations can lead to strategic behaviour that undermines the research process in terms of data quality. For example, as mentioned before stakeholders may fear that the information they provide may later be used for more regulations, which can result in data (including verbal communication of observations) being withheld or shared in a misguided way. Seeking compromises in the research design phase may then not result asking the difficult, controversial questions, meaning those that instil high conflict potentials, which in turn can lead to projects that do not tackle the challenging issues. Also, some of the most controversial questions may simply not be answerable given the available resources and sites (e.g., due to lack of replication), which may create disappointment on the side of stakeholders and limit participation in future processes.

Procedurally, co-production entails a great ability of the leading team and all contributing people to compromise and to have the time and resources to engage. This particularly holds for people who invest free time into the process. During the process, interests, norms, and expectations may be strategically used, causing role conflicts on the side of scientists or managers. It is difficult for anyone in the process, including scientists, to escape normative expectations of stakeholders, which may perceive the scientist or other partners in the process to be biased. Situations like this can delay or break the process, leading to conflicts or even active resentment of the process itself due to non-compliance and other types of strategic behaviour to ensure one's own preferences are met. Effective co-production also requires a high level of skills, including facilitation and moderation, from those running the projects, which take time to develop and if poorly designed can quickly degrade a process. Scientists are usually working in project cycles with deadlines, which can be incompatible with a process that usually takes time to unfold positive relationships with a given stakeholder community (Cooke et al. 2021).

Perceived power imbalances can also occur in co-production processes. Typically, scientists with a high degree of formal training engage with stakeholders who often lack this training, which gives scientists an advantage in interpreting and understanding complex data. Scientists are also the people that typically guide publications and reports in writing, which means they have interpretational power about outcomes. When managers are involved and decision-makers do not delegate at least some responsibility for the ultimate decisions to be made for management away to the participating stakeholder group, the process might be perceived as fruitless as the ultimate power to install decisions out of the process may still rest with those that are not at the table.

One key aim of co-production is to bring together diverse perspectives, and though this diversity is often a strength, it can also be a source of conflict. Diversity in perspectives can mean diverging interests and values, disciplinary or cultural differences, and incompatible mental models. For this reason, finding a shared vision (Thoms 1997) in a co-production project is crucial, and this vision must be developed early in the process so that all follow a common framework and are felt as being heard.

Expectations must be carefully managed in any co-production relationship. There may be political or institutional barriers, as well as (hidden) power imbalances that need to be addressed for partnerships. Co-producing knowledge successfully depends on clear roles and responsibilities for all scientists and other people involved. This extends to transparency and early negotiation of which stakeholders are included at what stages of the process.

Finally, co-production demands time and money investments, resources that may not always be available. Successful co-production initiatives can easily take years to occur and must be built on trust, which again is time-consuming to develop. Relationship building is often disregarded by academics concerned solely on publication outputs. Developing relationships is ultimately about sharing time and own values, meeting face-to-face, having meals together and thereby building trust. Repeated interactions between groups are often necessary. In this context, formal workshops often need to be professionally moderated. If the resources are not available, the process can quickly break down and be disappointing to all. Then, instead of co-production, co-assessment of current knowledge bases (or new knowledge that has been generated) offers a suitable alternative and first step (Sutherland et al. 2017). In summary, co-designed research with an aspiration leading to co-production will always be more time and resource intensive and may be more unpredictable than “business as usual” science. Such research may be entirely incompatible with disciplinary expectations of many graduate programs.

Special considerations are needed when considering engaging in co-production with Indigenous communities and other rights holders. Indigenous community members are not stakeholders, but rights holders. The same may apply, for example, to angler communities in central Europe who are rights holders in local fisheries. In such a context, co-production involves a particularly salient ethical issue of who has the right to use the new knowledge and how it can be disseminated. Clearly, all research practices in co-production must obtain consent of those that retain the fishing rights, but even if consent is provided, a researcher can still violate morals and negatively affect local communities if, for example, a research paper is written that discloses specific fishing grounds or make statements about future management recommendations that could conflict with local norms. Tackling this issue well is difficult and necessitates a high degree of ethical standards in data use and reporting and continuous discussions with leaders of communities about research results and its use. The OCAP (Ownership, Control, Agency, and Possession) principles must be adhered to when engaging with Indigenous knowledge systems specifically (Schnarch 2004).

5 Types of Stakeholder Engagement in Co-production

There are several types of knowledge co-production, and various levels of involvement and intensity by stakeholders or Indigenous communities and other rights holders. There is no one right answer to the proper level of this involvement, as this is dictated by goals, needs, and resources of the project. However, wrong answers exist. Furthermore, the scientific or management stakeholders may not be the only ones who can dictate the needs and feasibility of a co-production process. All participants, including those initiating and guiding the co-production process, need to be willing to step out of their comfort zone, be challenged, and be open to changing their minds and deviating from their original ideas and biases.

That said, co-production should be seen as a spectrum, not a ladder where “more” is better, but a wheel (as in participation, Davidson 1998, Fig. 3) where the appropriate level for a given case is selected. Regardless of the level of involvement, the co-production process must be respectful and transparent about the aims and level of involvement sought and always be based on full consent by the affected parties and those involved in the process. A summary of different typologies and levels of stakeholder engagement is provided (Table 2) to show the diversity of stakeholder relationships possible. Many of them can be effective vehicles for co-production. Employing co-production need not be dogmatic as the needs of a particular case will dictate the specificities. However, most of the guidance in this

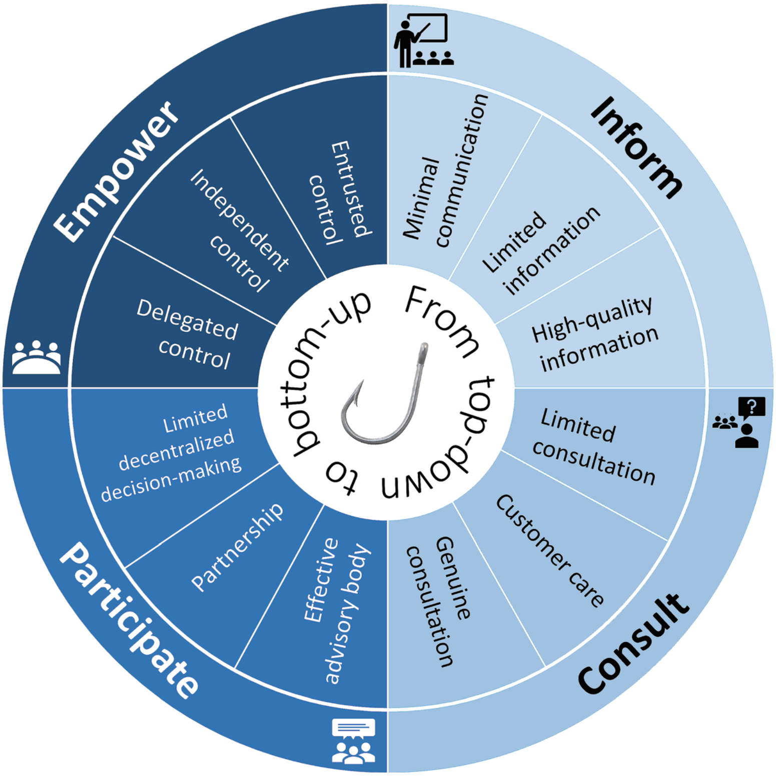

Fig. 3 The wheel of participation with stakeholders. (Modified from Dooris and Heritage 2011, after Davidson 1998)

chapter focuses on "collaborative" co-production (Table 2) as this yields the most benefits, including empowerment. Whereas this kind of co-production is time and resource-intensive, it is the most rewarding and shows the most promise to close the knowledge-action gap for using research results (Fujitani et al. 2017; Cooke et al. 2021).

6 Frameworks for Co-production Processes

A first step for researchers to begin an engaging co-production is co-production within the academic disciplines. This can be challenging enough, to move beyond the concepts of multidisciplinarity (scientists from multiple disciplines working alongside each other on the same question or facets of the same question, but remaining within their respective disciplines in terms of methods, theories and

Table 2 Typologies and levels of stakeholder engagement in natural resource management (the grey section is most closely aligned with this chapter's definition of co-production, allowing for a flexible continuum of science stakeholder interactions across a given project with respectful, inclusive, and early consultations of stakeholders outside academia)

Modes of stakeholder engagement (Biggs 1989)	Description	Relationship	International Association for Public Participation (IAP2) spectrum of public participation in decision making	Description	Relationship
Contractual	Test application of modern technology or knowledge	Flow of information from researchers to stakeholders	Inform	Provide objective and balanced information	Flow of information from researchers to stakeholders
Consultative	Use research to solve real-world problems	Researchers consult with stakeholders for problem definition, research design, and diffusion of findings	Consult	Obtain public feedback on analysis and decisions	Listen to concerns, provide feedback on public input influenced decisions
Collaborative	Learn from stakeholders to guide research	Partnerships with joint diagnosis of problem and ongoing collaboration	Involve	Work directly with public so that concerns reflected	Ensure input is considered in each step, providing feedback
			Collaborate	Partner with public in all aspects of the process	Work together to formulate solutions
Collegial	Strengthen local research capacity	Researchers encourage local research	Empower	Place decision in hands of the public	Implement what the public decides

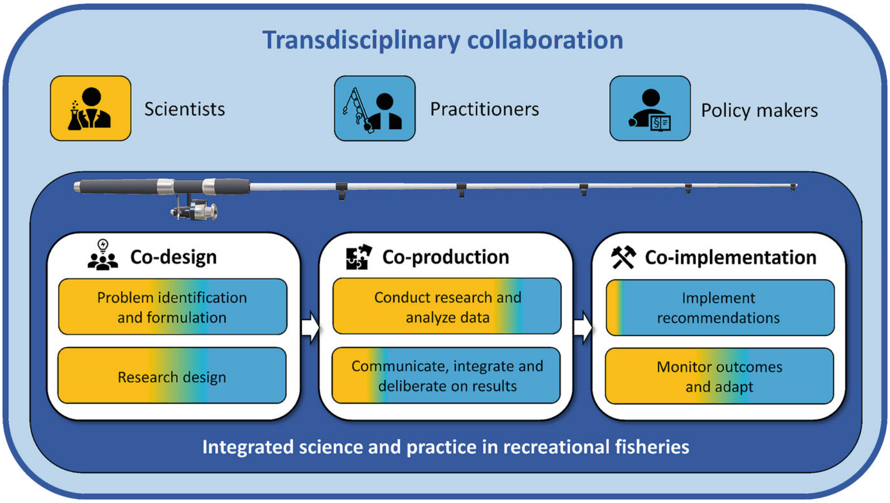

Fig. 4 Transdisciplinary science in recreational fisheries, including a co-production step. (Modified from Bennett et al. 2017)

knowledge production) to interdisciplinarity (topics, methods and concepts cross disciplinary boundaries and are jointly developed, knowledge is co-produced across disciplines) towards transdisciplinarity (crossing of disciplinary and academic boundaries, bridging science and society through integration of actors from multiple disciplines and beyond academia, joint goal-setting and development of integrated knowledge and theory). We draw from the literature on interdisciplinary and transdisciplinary knowledge integration to provide insights into knowledge co-production. The framework of Bennett et al. (2017) provides a useful and succinct roadmap for transdisciplinary conservation teams (Fig. 4). Note that in this framework, co-production is highlighted in the area about research and results, whereas in our definition, we include co-design and co-implementation as areas that may be flexibly part of the co-production process (see also Fig. 1).

The framework by Bennett et al. (2017) emphasises the circular approach to co-production, which runs through to the implementation phase of results and the monitoring of outcomes. This is closely related to what is known in environmental sciences as adaptive management with structured decision-making and stakeholder involvement (Fig. 5, see Robinson et al. 2026). Stakeholder involvement here, crucially, also means that ecological knowledge and perceptions of stakeholders are used to design objectives, synthesise what we know about system behaviour and the unknowns, and all further steps to fill the knowledge gaps and inform decisions to solve the fishery sustainability problem. The difference is that the adaptive management framework with stakeholder involvement emphasises strongly the testing of management options (e.g., does a harvest regulation work?), given what

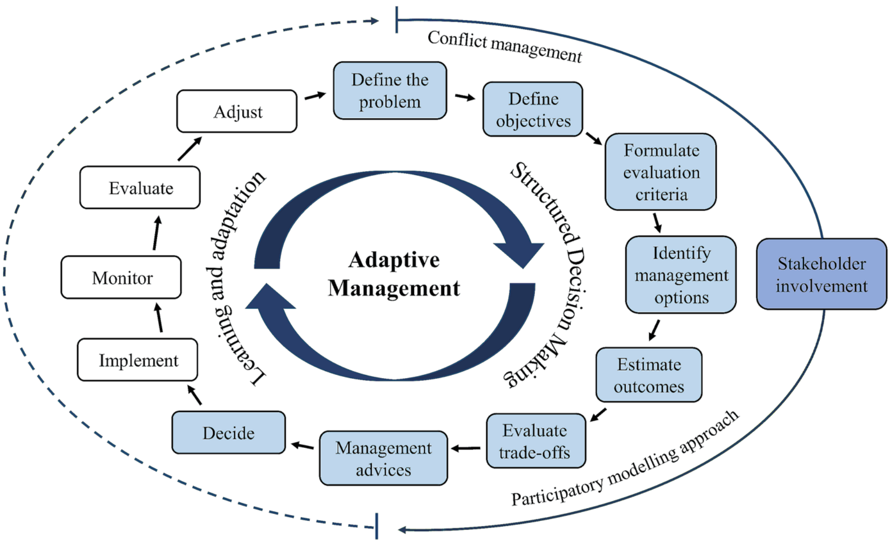

Fig. 5 Examples of adaptive management with structured decision making involving stakeholders. (From Ehrlich et al. 2023a)

is currently known or co-produced in the process, though other forms of co-production of knowledge unrelated to management are obviously possible and not part of the adaptive management process (e.g., what causes stakeholder conflicts?).

Both frameworks just mentioned share commonalities in terms of the key steps to collaboration of science and society within a co-production system. In the most basic case, the process consists of seven steps (see Box 1). They include identifying the issue and of stakeholders along with building relationships and trust. Often, the issues are brought to the researchers by the stakeholders. This is followed by generating a shared understanding about the issue at stake and clarifying the roles, power structure, and responsibilities of each partner in the process. This is further followed by the actual research process, ending with making the research available to others and applying the results. Later in this chapter, we propose a concrete four-step procedural approach that builds on these principles for effective co-production processes.

Box 1: Key Points to Consider in Knowledge Co-production Processes and Key References

Steps and recommendations	Key resources and references
Background reading on co-production	https://i2s.anu.edu.au/resources https://naturalsciences.ch/co-producing-knowledge-explained/methods/td-net_toolbox http://i2Insights.org https://www.futureearthcoasts.org/our-coastal-futures/ Reed and Abernathy (2018), Hickley et al. (2018), Bergman et al. (2012)
1. Identify the scope of the issue and relevant stakeholders, potential partners, and assess the state of existing knowledge	Reed et al. (2009), Beier et al. (2017), Lyon et al. (2020)
2. Build relationships and trust, reflect on hierarchies, power imbalances, establish conflict resolution mechanisms	Wilson (2008), Kovach (2010), Balser and McClusky (2005), Ostrom (2005), Chapman and Schott (2020)
3. Clarify roles, responsibilities, and expectations, develop an understanding of the critical unknowns and how to manage them	Hickley et al. (2018), Breckwoldt et al. (2021)
4. Generate a shared understanding, aim, scope, and vision of the goals of the collaboration as well as a model against which to judge each knowledge contribution	Mach et al. (2020), Cvitanovic et al. (2021), Thoms (1997), Baumgärtner et al. (2008)
5. Plan and implement the research, generate new knowledge, weave it with existing knowledge	Bammer (2013)
6. Make research available, transmitting and transferring the knowledge	Cooke et al. (2017a), Beck et al. (2020), Sopinka et al. (2020)
7. Apply knowledge, looking towards continuation in the medium and long-term, if applicable	Cooke et al. (2021)
Throughout: Adapt and learn from the process	Walters (1986), Fujitani et al. (2017), Ehrlich et al. (2023b)

Central to successful co-production is identifying, accounting for, and weaving diverse visions and worldviews, given power asymmetries and positionality in co-producing knowledge. Careful attention is therefore paid to potential disparities throughout all phases of a research project, from design to implementation, to foster strong working relationships and a partnership of equals. However, the specifics of each partnership and context are so diverse that no one-size-fits-all recommendation can be provided (Bammer 2013). One popular framework to find a workable consensus based on interests instead of personal positions and relationships is principled negotiation (Fisher et al. 2011). This is a structured and rational approach that is well-suited to some applications, but it is Western-centric and may not be effective in other cultural contexts. A more general recommendation is to smooth power asymmetries and flatten hierarchies, but this is also a Western academic perspective and it would be dishonest to think some entrenched imbalances can easily be smoothed. Even so, all involved in designing or running processes should be aware of hierarchies and power structures, how they impact relationships and information sharing, and how to handle them in a situationally appropriate way. A neutral facilitator can play a decisive role here, especially if conflicting situations are debated (e.g., impacts of fish-eating birds, recreational and commercial fisher conflicts).

An emerging paradigm is that of co-productive agility. This concept refers to the willingness and ability of diverse actors to iteratively engage in reflexive dialogues to grow shared ideas and actions that would not have been possible from the outset (Chambers et al. 2022). Co-productive agility will not emerge in all cases and presumably requires time to evolve. However, when it does, the potential for transformative change is strong (Chambers et al. 2022).

Transdisciplinary research with stakeholders usually aims at generating three types of knowledge related to: objectives and goals, how the system functions, and how to steer the systems in more desired directions (Hirsch Hadorn et al. 2006). Co-production can generate the same knowledge types. Methods must be devised on how to synthesise diverse knowledge sources (e.g., through modelling, environmental synthesis, Cooke et al. 2026, or causal mapping, van Maurik et al. 2023). Beyond a Western-centric approach, Indigenous frameworks exist that are wary of knowledge integration as assimilation, with a preference for terms such as “weaving” or “braiding” or “bridging” (Reid et al. 2019). Methods that bring together diverse ontologies and epistemological backgrounds can serve as further roadmaps to knowledge co-production that seeks to eliminate hierarchies and instead consider knowledge in parallel, such as the “Two-Eyed Seeing” in Canada (Reid et al. 2020; Bartlett et al. 2012) and the “Two-Ways” management in Australia (Hoffmann et al. 2012; Muller 2012).

7 Co-production in Recreational Fisheries and What It Is Not

Works on the co-production of knowledge in a fisheries context are increasing in number, including some applications within recreational fisheries. For example, Piczak et al. (2022) presented recommendations for Canada’s fisheries to further highlight knowledge co-production, Gervasi et al. (2022) showed how angling guides can co-produce testable hypotheses in the crevalle jack (*Caranx hippos*) fishery in the Florida Keys, and Fujitani et al. (2017) presented quantitative data on how co-producing knowledge about fish stocking changes mental models, attitudes, and norms of the involved anglers and managers in Germany. Cooke et al. (2021) provided general guidelines for co-production in fisheries management, whereas Mills et al. (2022) described a global United Nations Ocean Decade programme to co-produce knowledge for climate-resilient fisheries. Studies of co-production with Indigenous and local knowledge are particularly rich in the literature on small-scale fisheries (Silvano et al. 2023). However, there are few works solely focusing on knowledge co-production and recreational fisheries (Cooke et al. 2021), although there are a few that have used participatory modelling of stakeholders and scientist to co-design management regulations that are accepted by all and where the computer model was the knowledge integrator (Wilberg et al. 2026). Later, we provide three case studies that followed co-production processes as idealised in this chapter, and more examples exist (summarised in Cooke et al. 2021).

One paper explicitly focusing on recreational fisheries and knowledge co-production highlighted the fact that in these arrangements, recreational fishers create data about themselves, but they also may have incentives for a fishery to be managed a certain way (Eden 2012). Eden's (2012) discussion of co-production reflects on a theme found in fisheries knowledge co-production research, that recreational fishers as a source of data are seen as collaborators in co-production. This is a narrow definition of citizen science, where fishers merely inform the process by generating information and data. Recreational fisher knowledge may be laid out to fill gaps, particularly in data-poor fisheries to run parallel to observed data and fill gaps in our scientific knowledge (Bevilacqua et al. 2016). They may contribute participatory maps, locate and report invasive species, and help tag and report marked fish or co-design testable hypotheses (Granek et al. 2008; Gervasi et al. 2022). Often, this knowledge is incorporated into existing fisheries models (Bentley et al. 2019; Ainsworth and Pitcher 2005; Bevilacqua et al. 2016). However, this contrived role in the research process is not what we emphasise as core to the co-production. In these situations, research stakeholders should be careful to differentiate recreational fishers as units of research observation (informational role), from fishers as consultants, and fishers as collaborators (Fig. 3). Though it was emphasised earlier that knowledge co-production can be a spectrum, fishers as study objects and token consultation of fishers do not fall within our scope of co-production. Researchers should also be aware of the implicit or explicit hierarchy that merely informational creates, with the Western scientific tradition producing knowledge that other ways of knowing are "validated" against or used as supplements due to data paucity. Model-based syntheses, though promising to integrate several types of knowledge, are nonetheless a managerial-technological process (that) automatically subjugates and silences forms of knowledge that it does not know how to validate, translate, and analyse (Said and Trouillet 2020). A solution might be to engage in participatory modelling, but here the recreational fishers are part of the model-building process (e.g., help building a model of cause-and-effect), which in turn is used to outline novel scenarios (Irwin et al. 2011; Ehrlich et al. 2023a). This is a vastly different role than "just" being informants to scientists. We urge readers not to confuse co-production with a simple observational role that is common in many citizen science applications in recreational fisheries.

Research on knowledge co-production in fisheries supports broader themes found in the co-production literature, with specifics for the fishery context. Young et al. (2016) described co-management of Pacific salmon fisheries in Canada's Fraser River and assessed how different stakeholders use knowledge. Stakeholders and participants (e.g., active recreational fishers) often draw on tacit, informal, and experiential knowledge above scientific knowledge (which can in fact, when diversity is accounted for, mirror scientific knowledge, Aminpour et al. 2020). Specifically, government employees were found to focus on the immediate applications of research to known problems, whereas other non-research and non-government stakeholders were interested in the political and direct implications (Young et al. 2016). Thus, communication must be tailored to the priorities of different stakeholder groups. Olson and Pinto de Silva (2019) catalogued the shift from basic and disciplinary research to applied, policy-driven, and participatory knowledge production through ninety oral histories of fisheries science practitioners. They found that this shift is expected, and even desired, and yet scientists struggle with the multiple new roles they must play as well as with the politicisation of their research. Other ways of engagement have rendered recreational fishers and managers of angling clubs as co-designers of the research and interpretation process (Fujitani et al. 2017; Ehrlich et al. 2023a, b) or as generators of testable hypotheses about fishery developments (Gervasi et al. 2022, see also the case studies below in this chapter) .

8 Ways of Doing Co-production in Recreational Fisheries

Co-production in recreational fisheries can come in four forms: (i) revealing and synthesising existing knowledge, (ii) generating new data and observations, (iii) identifying and shaping new research questions, and (iv) developing partnerships across the entire research process. We describe briefly what these areas are and suggest tools that have worked for us in our own co-production projects.

Synthesising knowledge occurs when scientific and other types of knowledge are brought together to understand the state of the art. Knowledge bases that are held outside academics are variously described as practitioner knowledge, traditional (ecological and social) knowledge, or "lay" ecologies. The word "lay" is meant to describe knowledge by non-scientists, and clearly, stakeholders can and do hold immense knowledge that is not codified in the literature. Whereas such knowledge bases often remain hidden to scientists, when properly collected and integrated, they can mirror the best scientific knowledge about fisheries and their dynamics (Aminpour et al. 2020). It is important to represent the full diversity of stakeholders and rights-based holder knowledge if one is to approach the best understanding, as Aminpour et al. (2020) showed in their study on ecological and social factors impacting northern pike (*Esox lucius*) ecology and exploitation. Diversity here means not only diverse people, but also people with diverse roles (e.g., recreational fishers, managers) because within any group (including scientists) there is a tendency to seek confirmatory knowledge and for biases to affect knowledge generation.

The wisdom of the crowd idea, where the diversity of individual knowledge well approximates truth, crucially depends on the principle of hearing diverse voices and considering the knowledge at the individual level and assessing it without the influence of others (Arlinghaus and Krause 2013). Examples of including non-academic knowledge bases revolve around identifying ecological and social phenomena (e.g., spawning sites or migratory routes of exploited fishes or the attitudes, mental models, and behaviours of recreational fishers). Focus groups are a standard means by which researchers capture the knowledge of users when designing research; capturing traditional knowledge can go far beyond this. For example, Roser et al. (2023) used traditional knowledge about past spawning places held by anglers, guides, fishers, water managers, residents, and farmers to reconstruct the level of anadromy exhibited by northern pike in a coastal fishery in Germany. Methods to synthesise existing knowledge range from mapping techniques (e.g., assessment of mental models (Gray et al. 2015) or participatory mapping by stakeholders (Schmitz Nunez et al. 2021)), verbal and digital reports of observations (e.g., capture locations of invasive species through digital apps (Venturelli et al. 2017)), to participatory synthesis exercises through verbal reports in association with peer-reviewed and other literature (e.g., systematic reviews (Cooke et al. 2026)). Synthesis is also possible through the building of participatory models that are used to examine the likely outcomes of different management regulations, as shown in several case studies involving anglers (Irwin et al. 2011; Ehrlich et al. 2023a).

Generating new data and observations are perhaps the most obvious way of co-production. Such approaches can generate a wealth of data that would otherwise not be available to researchers. The key challenge is to develop and maintain a two-way interaction among the research team and the individual stakeholders such that data generated and conclusions drawn are fed back from scientists to stakeholders. Digital applications (apps) are gaining momentum and can serve this role (Venturelli et al. 2026). In the case study presented later, the research team sent digital maps of recapture locations of marked fishes back to reporting anglers. Therefore, their knowledge was put into context, and they could learn from the movement distances of the fishes they reported. In workshop settings, data can be gathered through maps or mind maps (e.g., when identifying areas that are hotspots of the phenomenon of interest).

The most advanced process of knowledge co-production involves joint identification of issues, shaping and development of research questions, and co-design of research projects, with subsequent involvement of actors outside academia in data collection and analysis. This process is a typical situation when a management agency or a fishing club with its own fishing rights teams up with a research team to find answers to a question of common interest. One formalised approach to achieve outcomes is the four-step approach outlined below in paired workshop-field settings, where repeated workshops are used to: identify the problem to be solved, frame it, decide on a research path and data to be collected, distribute roles, and allow repeated interactions to discuss intermediate research outcomes and results. Although the formal analysis step of the raw data is typically delegated to the research team, stakeholders can still be involved in onsite data generation and should ideally always form part of result interpretation. One of the case studies shown below is an example of this approach, although many other examples exist with less formalised, yet still active involvement of recreational fishers in research design and interpretation (summarised in Cooke et al. 2021; see also Danylchuk et al. 2011; Griffin et al. 2023).

To maximise the benefit of workshop settings where co-production is developed, it is critical to develop trust beforehand, and one might need to engage a trained facilitator of the workshop. Multiple facilitation techniques exist to raise knowledge and break people's aversion to speaking up and engage, such as silent discussions or the use of the five-times-why question approach to unleash in-depth argumentative structures. Note that it is critical to carefully reflect on who owns the final research results, how to get written and moral consent on how to use the research results, and how to formally document each session and exchange mutually agreed protocols among all participants. All participants and perhaps even others should scrutinise sensitive research results before release, and researchers must pay attention to the possible misuse and misinterpretation of research findings (Cooke et al. 2017b). All results, even those that seem uncontroversial at first, may interfere with the morals, norms, and expectations of stakeholders. In co-production scenarios, paying due diligence to stakeholders is key throughout the entire process and in the aftermath, which is resource-intensive and demands critical people skills of all that are involved. Although one can never please all people, getting the process wrong will typically result in damage that will not be easily repaired and may completely break down relationships and potential future opportunities.

9 A Suggested Four-Step Approach to Co-production Processes in Recreational Fisheries

One way to think about co-production is a so-called four-step approach (Bath 2010). Although other approaches exist (see case studies) and many will not be as formalised, the four-step approach has worked for the authors in multiple cases, specifically in those conditions where conflicts are to be solved through collaboration. It starts with effectively listening to diverse groups, beginning with one-on-one interviews to identify the common issues and construct a common ground matrix. Next, a balancing of individual views and understanding the amount of consensus within each interest group is accomplished, possibly assisted through quantitative research of members of the group or the use of secondary data about the views held in the community. The third step involves the implementation of an applied, often facilitated workshop series whereby repeated interactions occur. Fourth, effective content evaluation of the process is undertaken that moves beyond the traditional objective and goal-oriented evaluations. This four-step approach has been used effectively in a variety of wildlife issues and parts of it within recreational fisheries issues (Ehrlich et al. 2023b). A brief description of the key steps of this process follows.

9.1 Step 1: Build Relationships with Diverse Actors

The first step for a researcher to design a co-production process is to thoroughly listen to the perspectives of different interest groups and individual people, often referred to as stakeholders but can also include rights holders, and to build trusted relationships. This typically involves face-to-face interviews or discussions with individual people that are relevant in each fisheries context. Whereas one could formally call this step a stakeholder analysis, it is, importantly, meant to develop an understanding of the issues and arguments present in the system and to build trust and relations. One-on-one meetings and discussions are key, which also serve the task of identifying key individuals and the issue at hand. The result of the first step of the process could be developing a common ground matrix that identifies, for each stakeholder group, areas where there is mutual understanding, worldviews, and values, and others where there is disagreement. The former serves for trust building and engagement further in the process (by focusing on those areas that are shared), whereas the latter serves to identify the new knowledge that is to be gathered or synthesised through the process or where mediation may be needed, which can be assisted by new knowledge jointly produced.

9.2 Step 2: Understanding the Amount of Consensus and Disagreement Present in a System

Many co-production processes involve some form of continued formal workshops or more informal conversations in which stakeholders and rights holders, scientists, and managers unite to develop a shared understanding, integrate knowledge, plan new knowledge generation, and discuss and evaluate results (see next step). The level of engagement and the need for formal synthesis of a given situation depend on the issue at hand, the scale of the issue, and the level of conflict present. If no conflict is present and the spatial scale of the issue is small, formal workshops may be unnecessary, and consensus can be reached merely through informal conversations of a few key people involved. If conflicts are present or the size of the community is large (e.g., thousands of users), formalised workshop settings with representatives of the various groups will be superior as beginning departure points for in-depth discussions.

Addressing conflicting situations in large populations of users (e.g., recreational fishers in conflict with commercial fishers, or fisheries with conservation) benefits from the availability of either secondary human-dimensions data or survey information that can tell the smaller workshop group about how prevalent certain views are in the wider community of users. This step will not be needed in a conflict-free situation where a small team of scientists and managers, and stakeholders unite to seek answers to a communal problem. However, objective human dimensions data on values, beliefs, and attitudes will help find compromises in more conflicting situations and for large populations. It is next necessary to choose the workshop team wisely (e.g., involve people that represent an underlying interest group and make these people accountable for informing their reference groups about ongoing processes and results). Subsequently, if resources are available and following step 1, quantitative surveys of stakeholders and rights holders (e.g., local recreational and other fisher populations) are useful to assess the current level of consensus on a given topic that is to be solved through co-production and to moderate workshop discussions. Alternatively, the team might have access to secondary data from already completed assessments about how the local stakeholders perceive a given problem. These data can be used to quantify the beliefs, values, norms, and attitudes of a large sample of users that are not in the room, assess the degree of polarisation on contentious topics (e.g., which management regulations to follow, the perceived underlying reasons for a fish population decline). Statistical tools (Vaske et al. 2010) might be applied to survey questions to be able to show in the subsequent workshops and meetings what the perception of the public and of key subgroups is on a given topic. Such data are relevant to moderate processes during workshop settings and to guide discussions. For example, vocal people in workshops may voice opinions that recreational fishers in the region have a certain attitude on a given topic. The perception may represent 1% or 90% of the fisher population or some value in between, but it cannot be validated without further data. Quantitative data following the principles outlined elsewhere in the book can provide such data, if they are currently not available, and thereby guide discussions.

9.3 Step 3: Create Pathways for Collaboration and Engagement, e.g., Through Moderated Human Dimension Workshops

The process continues by establishing a group of key stakeholders that are critical for understanding and solving the issue under investigation and by inviting the people to a series of workshops with a goal to synthesise knowledge and to reach consensus on the topic, and to document any other issues that do not reach consensus. Other collaboration formats are possible, but workshops seem like the most straightforward approach in large-scale conflicting situations. The number of workshops needed depends on the issue and the available information base and the level of disagreement, but the key is to invite key stakeholders and all rights holders, including those representing a larger group of stakeholders, whose task is to reveal what they know and do not know about a given topic, develop visions and objectives, and then engage in a continued process of issue identification and knowledge synthesis, revealing what is known from various perspectives, the open question to be solved, and favoured solutions (Ehrlich et al. 2023b).

The open questions typically identified in a series of workshops scattered throughout the project lifetime can then serve to nail down research questions and the process of co-generation of answers through novel research or clever weaving of existing knowledge bases. Roles and expectations about who is involved in the knowledge generation and how the knowledge is synthesised must be clearly clarified, and rules of efficient but equal communication must be agreed upon by all. Practitioners should ideally be involved as partners in the research that is then developed outside of the workshop settings by the research-practitioner team (e.g., joint marking and recapturing of fish, surveying people, collecting field observations, or implementing novel management interventions). The ongoing results are then repeatedly and iteratively brought back to the workshop settings, where they are jointly interpreted and evaluated, and next steps identified. It is in this step that co-production of new knowledge happens. If conflicts are severe, it is crucially important that the process is moderated by neutral people outside the core project team who are skilled at using moderation and facilitation techniques. The moderator should be broadly knowledgeable about the issues. In less conflicting situations, the communication pathway can be organised separately by those involved without external help.

9.4 Step 4: Documenting Results and Evaluation of Procedural Outcomes

The last step is a thorough reporting of outcomes and recommendations and evaluation of procedural outcomes (Table 1), which will typically generate results far beyond the solving of concrete fisheries management problems (e.g., new networks and new relationships or innovative approaches to management). The process shall evaluate all key principles of effective knowledge co-production that Norström et al. (2020) identifies: assessing the context-based principle (does the outcome produce results relevant to the context at stake?), assessing the pluralistic principle (have all voices been heard and included?), assessing the goal-oriented principle (did the process enable articulation, revision and achievement of desired goals, including reflexivity?) and assessing the interactive principle (what was the nature, frequency and quality of interactions among participants?).

Ideally, the outcome of joint knowledge production will result in a significant advance in the current understanding of the issue. The outcomes may also directly feed into management processes—an aspect that typically demands managers and policy makers to be part of the process, or the latter delegating responsibility for identification of future pathways to be delegated to the group at the onset of the process (see the case studies for examples). Of course, other formats of co-production of knowledge are possible (e.g., see Cooke et al. 2021).

10 Transitioning from Co-developed Knowledge to Co-implementation and Dissemination

The next phase after the co-producing knowledge on a given issue can be the design of co-implementation and dissemination processes (Fig. 1). Ideally, decision-makers are either part of the process of knowledge co-production or delegated responsibility for action away to the group. Then, the implementation of research results would be straightforward as long as legally and financially possible. Otherwise, the project team must identify leverage and entry points or wait for windows of opportunity to implement the research results. Some results may have implications for personal behaviours of actors (e.g., best practice of catch-and-release) in which case implementation is closely related to dissemination to the wider community so that a wide array of users is exposed to the novel findings. Influencers and other role models are key partners in this regard. Dissemination is often an integral component of co-production and can take many forms from multiplicative effects through stakeholder networks, capacity building to structured activities such as offering seminars, models, brochures and policy briefs, social media activity and podcasts, video or other movie formats, and presentations and publications, typically written in local non-scientific languages to facilitate knowledge uptake. Abundant resources and trained personnel (and other resources) are needed for effective science communication, but the benefits can be high. As a rule, a peer-reviewed publication will only reach scientists and some managers, whereas practitioners, most managers, and other stakeholders and rights holders need tailored approaches to dissemination via alternative channels.

11 Case Studies of Co-production in Recreational Fisheries

We finally present several case studies intended to demonstrate the diverse ways in which co-production can occur. It is important to note that although each case study followed the same general four-step process, there was significant variation in how the steps were implemented. This helps to emphasise that the steps can be scaled to a specific issue and modified to suit a given context, which is consistent with the advice from Djenontin and Meadow (2018). In some cases, where there is rapid and easy development of trusting relationships and agreement around issues of mutual interest, there may be less need for formal processes. Again, the larger the number of actors involved and the greater the conflict or lack of consensus, the greater the need for more formal, data-informed approaches such as social science surveys and structured facilitation that were previously discussed in the section above.

11.1 Co-Production Case Study: Muskellunge Science and Management

Muskellunge (*Esox masquinongy*), or musky, is an enigmatic freshwater fish species in the Midwest of North America. They grow to attain large sizes (over 1.3 m in length and 30 kg in mass) and are considered elusive, low-abundance, and difficult-to-catch fish for recreational anglers and spearers. In fact, they have been referred to as the "fish of 10,000 casts." Recreational anglers who target muskellunge tend to be highly specialised and are not motivated to harvest this species as release rates are >90% today (e.g., Fayram 2003). Specialised muskellunge anglers are often associated with fishing clubs (such as Muskies Canada or Muskies, Inc. in the United States of America) that bring together like-minded individuals interested in musky fishing and conservation.

Beginning in 2006, the Fish Ecology and Conservation Physiology Laboratory at Carleton University began to engage with the local chapter (Ottawa, Canada) of Muskies Canada. Initially, this involved providing a seminar and attending chapter meetings to develop relationships and understand the respective needs and abilities of the academic and Muskies Canada team (step 1 above). It soon became clear that there were mutual interests and strong consensus around several topics, including restoration and the associated habitat science (thus, allowing us to forgo step 2 in a formal way). That led to an interest in putting radio tags into muskellunge in Dow's Lake—a water body on the edge of Carleton's campus (Gillis et al. 2010). Muskies Canada representatives were concerned about the effects of water reductions during the fall as well as various development activities on muskellunge. Muskies Canada provided funding for the transmitters as well as several volunteer anglers to assist with fish capture. There were many opportunities for students to interact directly with the anglers, which created mutual learning opportunities (step 3—but doing so also connected back to step 1). As the relationship developed further, it became evident that there were concerns about the fate of muskellunge that were caught and released. A potential graduate student who was an avid muskellunge angler became engaged and eventually led to a graduate-level project on catch-and-release (Landsman et al. 2011) that involved working together with Muskies Canada to assist with tagging and tracking fish. Importantly, Muskies Canada assisted with sharing findings within and beyond their community through the development of educational materials. Besides doing science, the team from Carleton and Muskies Canada organised a symposium that brought together additional actors from across the Midwest, culminating in a conference report (Midwood et al. 2015). The relationship between the Carleton team and Muskies Canada now extends over

18 years and many other projects beyond the ones described here. Step 4 was never formally conducted, although both the academic team and Muskies Canada re-evaluated the relationship and project process along the way. The fact that the team is still co-producing knowledge almost two decades after when it began is telling.

There are a few lessons that arose from this work that contributed to the success. First and foremost, there was a sense of mutual respect where it was clear that Muskies Canada members were holders of a rich knowledge base on musky biology. This made it easy to embed Muskies Canada anglers in academic research and to embed students within the Muskies Canada organisation. Likewise, Muskies Canada was keen to work closely with academics and to bring science to the table. Second, through spending time together and developing strong personal relationships, it was easy to identify priority topics that were of mutual interest to the academics and Muskies Canada. Never has the academic team proposed a project for funding or partnership without those ideas emerging from discussions with Muskies Canada members and leadership. Third, there has been an opportunity to acknowledge the work that Muskies Canada has done in enabling co-production. For example, the academic team nominated Muskies Canada and Muskies, Inc. for a conservation award from the American Fisheries Society (which they won), and several Muskies Canada members are co-authors on peer-reviewed publications based on this work that further reflect their level of engagement.

11.2 Examining Fish Stocking Outcomes in Collaboration with Local Angling Clubs in Germany

"Hand in hand for sustainable stocking" was the subtitle of the Besatzfisch (German: stocked fish) project that ran from 2010 to 2016 in north-western Germany (Arlinghaus et al. 2015, 2022). Fish stocking plays a vital role in freshwater recreational fisheries management in Germany and elsewhere. Though the literature suggests that stocking can potentially have serious economic and ecological consequences if not conducted in a thoughtful way (e.g., Cowx et al. 2010; Laikre et al. 2010; Lorenzen et al. 2012; Johnston et al. 2018), understanding how stocking is practised in German recreational fisheries and identifying recommendations to move forward would be best achieved through knowledge co-production of anglers, angling clubs, and scientists. To that end, the Besatzfisch project team at Leibniz Institute of Freshwater Ecology and Inland Fisheries in Berlin Germany, designed a participatory active adaptive experiment in fish stocking in the locally managed water bodies that included volunteer angling clubs as fishing rights holders and partners in a co-production framework (summarised in Arlinghaus et al. 2015; Fujitani et al. 2017). Whereas subsequent projects focused on habitat enhancement in lakes (Radinger et al. 2023; Arlinghaus et al. 2023a), we discuss the key co-production principles based on the fish stocking project.

In the project Besatzfish, scientists and anglers in 17 angling clubs investigated together the ecological, economic, and social aspects of stocking and jointly conducted release experiments with marked model species (northern pike as a model of a recruiting and carp (*Cyprinus carpio*) as a model of a non-recruiting species) to co-produce knowledge about when stocking adds to the stock and when it fails. The research design was both interdisciplinary and transdisciplinary, with strong co-design aspects. In each angling club, representative groups of 10–30 club members were formed, which included the managers of the clubs and water bailiffs. Using collaborative and moderated workshops, they designed, conducted, and evaluated experiments to test stocking in their own club waters. Other clubs were passively involved (i.e., only received seminars about stocking) or served as placebo controls who were not exposed to training about stocking or the joint execution of release experiments, but where also seminars for joint knowledge exchange on other topics than stocking were held (Fujitani et al. 2017). During the process, which followed the four-step approach mentioned above (including an initial "listening phase" by the research team to understand key issues and standardised surveys, Arlinghaus et al. 2014), stakeholders were exposed to scientific knowledge about stocking through seminars and some clubs were additionally involved in designing and interpreting the outcome of the fish stocking experiments. Ordinary club members who were not part of the workshop settings were constantly informed about the project results through the club leadership, lectures, and a website, and all were invited to take part in regular fish assessment and participated in filling out logbooks, electrofishing, and tagging and releasing fish to both learn about the process and contribute own data. Besides the scientific outputs from the project, which showed conditions where stocking did and did not work to increase fisheries above natural recruitment (Arlinghaus et al. 2015; Johnston et al. 2018; Hühn et al. 2023), the project also demonstrated the impact of the participatory active adaptive management and knowledge co-production on learning, retention, and behavioural intentions of the involved anglers (Fujitani et al. 2017). The knowledge, attitudes, norms, and behavioural intentions of involved managers and anglers strongly changed as a result of the co-creation of stocking results, and the acceptability of stocking as a management tool strongly declined in response (Fujitani et al. 2017). To also disseminate the project results beyond the core participating angling club, the research team developed a nationwide seminar series and a handbook on sustainable fish stocking (Arlinghaus et al. 2015) as well as a fisheries management textbook in German (Arlinghaus et al. 2017), several brochures, comics, calendars, videos, podcasts, and a 60-minute documentary that was viewed by over 160,000 people in Germany alone (https://www.youtube.com/watch?v=27Ar-A5PLA0). As a result, stocking practices are beginning to change all over Germany. In 2014, the German UNESCO Commission honoured Besatzfisch for its education concept.

11.3 Co-designing Knowledge and Management Recommendation for Coastal Northern Pike Co-exploited by Anglers and Commercial Fishers

The northern pike stock in the brackish lagoons of the Baltic Sea in northeastern Germany, an area of large conservation interest, is under government-regulated open-access and co-exploited by commercial and recreational fishers (Arlinghaus et al. 2021; Koemle et al. 2021, 2022a, b, van Gemert et al. 2022; Arlinghaus et al. 2023b, c). Like muskie in the USA, pike is a popular angling fish that becomes exceptionally large in these brackish lagoons due to suitable food conditions and attracts not only local but also many tourist anglers (Arlinghaus et al. 2021; Koemle et al. 2021, 2022b). Whereas pike is a relevant economic factor for the region (Strehlow et al. 2025), catch rates have decreased in recent years. The pike stock is also targeted by a small-scale commercial fishery, and yields have also fallen over time (van Gemert et al. 2022; Olsson et al. 2023). In recent years, natural predators like cormorants (*Phalacrocorax carbo sinensis*) and grey seals (*Halichoerus grypus*) have risen and contribute to pre-recruit and recruited pike mortality (Arlinghaus et al. 2021). A recent study using catch-only stock assessment models documented that the pike stock is slightly growth- and certainly size-overfished (van Gemert et al. 2022). These results were supported by length-based assessments (Fitzgerald et al. 2023) and mirror stakeholder perspectives (van Gemert et al. 2022).

A collaborative BODDENHECHT (lagoon pike) project started in 2019 and had the overall goal to develop a management plan for Baltic pike that is widely accepted by all interest groups. It was funded by the Ministry for Agriculture, Environment and Fisheries at Mecklenburg-Western Pomerania (MWP) and EU funds tailored for structural aid to the fishery. The transdisciplinary project was designed in closely collaboration with angling guides, fishers, and other interested groups. It was coordinated by a scientist team at Leibniz Institute of Freshwater Ecology and Inland Fisheries in Berlin, Germany, that performed studies on important biological (e.g., spawning areas, migratory behaviour, meta-population structure, growth, and mortality) and socio-economic factors (e.g., economic importance and angler and fisher attitudes to management) being relevant for the understanding and predicting dynamics of the pike stock and its fishery. The entire project was done in collaboration with other academic and non-academic partners and strongly involved fishers, anglers, and guides (e.g., in mark-and-recapture experiments, social surveys, joint workshop for management plan development). The research was intended to provide the body of knowledge needed for effective management decisions. The project followed exactly the four-step approach introduced in this chapter because it was critical to include stakeholder knowledge and bring all actors together that were currently mired in conflict (Arlinghaus et al. 2022). A neutral facilitator was hired who managed the 11 workshop settings that were needed to reach consensus on 35 of 54 management options (Ehrlich et al. 2023a, b).

After an initial phase of stakeholder analysis and abundant face-to-face interactions for problem identification and trust building (step 1), step 2 generated abundant quantitative information on the attitudes and preferences of fishers (Koemle et al. 2022a) and anglers (Koemle et al. 2022b; Slaton et al. 2023). A stakeholder group with representatives from all interest groups was formed, which started in late 2019 and was facilitated by the scientist team and external neutral facilitators. The group engaged in a repeated workshop series (step 3) with 11 workshops being conducted over 3 years and a total of 60 hours in attendance. The Ministry for Agriculture, Environment and Fisheries (Ministerium für Klimaschutz, Landwirtschaft, Ländliche Räume und Umwelt in MWP) delegated responsibility to the stakeholder group to develop agreed-upon management recommendations that the ministry would then examine for implementation. This empowerment gave the stakeholder group a mandate and strong incentive to work cooperatively.

Over the course of the workshops, the stakeholders developed a shared vision, mutually agreed, quantifiable objectives, and identified and discussed the trade-offs involved in the management options. During the process, ecological and social knowledge was synthesised, and research gaps were identified, which the research team addressed throughout the process in close collaboration with recreational anglers, guides, and commercial fishers (e.g., assessing fishing mortality by sector and understanding movement ecology of the pike, inter lagoon exchange rates, genetic structure of the stock, and stakeholder views on management options). Quantitative social science data generated in step 2 were used in various workshops to outline representative views by fishers and anglers towards the acceptability of certain management tools that were being considered. Participatory models were designed and implemented during some of the workshops, based on cognitive maps about cause-and-effect expressed by the stakeholders, which served as a key knowledge integration mechanism (Ehrlich et al. 2023a). The cognitive maps were translated by the scientist team into mathematical models, which were used in further workshop rounds to assess the possible effectiveness of tools such as harvest limits, stocking, habitat improvement, and cormorant predation control. The models were all informed by ongoing research completed outside the workshop setting that was communicated to the stakeholders through further meetings. The stakeholder group thereby defined the scientific inputs they wanted and needed throughout the process, which involved repeated interactions with the team scientists to clarify important intermediate results that were stepping stones to evaluate management options considering new knowledge.

The results in step 4 were crafted into a management plan that was agreed and endorsed by the stakeholder group (Ehrlich et al. 2023b). This product was handed over to the ministry of fisheries in a public meeting that included a symposium, with a strong recommendation to implement the actions. Besides this output, the project generated new networks, trust, and understanding and resolved conflicts among the stakeholders, although contentious issues remained where interest groups clashed in perspectives (e.g., on the question of whether commercial fishing should be regulated by quotas in the future). The minister for fisheries repeatedly stressed that they intend to implement the recommendations (Backhaus 2021). At the time this book was printed, the first management measures were implemented, and more will likely follow through the renewal of the coastal fishery bylaws in 2026. The overall process was thoroughly evaluated, and research results were documented in an extensive 800-page German monograph and associated video material (Arlinghaus et al. 2023c). In a follow-up phase, the team engaged in various other forms of knowledge dissemination, which has generated abundant public attention. The project received an award for excellence in transdisciplinary research.

12 Conclusions

Co-production of knowledge among recreational fisheries scientists and various actors in the recreational fishing realm (e.g., recreational fishers, guides, outfitters, fisheries managers) is crucial to solve concrete problems locally, especially those where academic knowledge is insufficient and issues to be solved are uncertain or polarised. Co-production of new knowledge in recreational fisheries can generate important solutions, help overcome local issues and build bridges among conflicting parties that otherwise may not have been developed. The process, however, is often time and resource intensive, demands skilled staff and resources, and is replete with challenges of expectations, norms, and strategic behaviour that need to be navigated. This chapter suggests a four-step approach to effective knowledge co-production that has delivered positive results in multiple cases and is thus recommended as a roadmap for future application. The approach can be scaled to a given issue and can range from a very formal process (e.g., the Besatzfisch and Boddenhecht projects above) to one that is much more informal (muskellunge example above). Scientists are advised to pay particular attention to ensure they are an honest knowledge broker and if necessary to involve trained facilitators in the process, especially if the issue at hand is contentious. When done correctly, the benefits of co-production to science and management of recreational fisheries can be extensive.

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