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A will-o'-the wisp? On the utility of voluntary contributions of data and knowledge from the fishing industry to marine science

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For future sustainable management of fisheries, we anticipate deeper and more diverse information will be needed. Future needs include not only biological data, but also information that can only come from fishers, such as real-time 'early warning' indicators of changes at sea, socio-economic data and fishing strategies. The fishing industry, in our experience, shows clear willingness to voluntarily contribute data and experiential knowledge, but there is little evidence that current institutional frameworks for science and management are receptive and equipped to accommodate such contributions. Current approaches to producing knowledge in support of fisheries management need critical re-evaluation, including the contributions that industry can make. Using examples from well-developed advisory systems in Europe, United States, Canada, Australia and New Zealand, we investigate evidence for three interrelated issues inhibiting systematic integration of voluntary industry contributions to science: (1) concerns about data quality; (2) beliefs about limitations in useability of unique fishers' knowledge; and (3) perceptions about the impact of industry contributions on the integrity of science. We show that whilst these issues are real, they can be addressed. Entrenching effective science-industry research collaboration (SIRC) calls for action in three specific areas; (i) a move towards alternative modes of knowledge production; (ii) establishing appropriate quality assurance frameworks; and (iii) transitioning to facilitating governance structures. Attention must also be paid to the science-policy-stakeholder interface. Better definition of industry's role in contributing to science will improve credibility and legitimacy of the scientific process, and of resulting management.

KEYWORDS

collaborative research, fishers' knowledge research, experiential knowledge, stakeholder engagement, fisheries science, trust, co-production of knowledge, science-industry research collaboration

Introduction

Science-industry research collaboration (SIRC) in fisheries is at a crossroads. SIRC, in our experience, is driven by a clear willingness on the part of the fishing industry to voluntarily collect and provide information to science in support of management, and by a growing interest within the scientific community to collaborate with fishers and their associated organizations ('the fishing industry') (Holm et al., 2020a; Steins et al., 2020a; Mackinson, 2022). For many, SIRC is seen as the way forward for cost-effective, improved data collection (Johnson and Van Densen, 2007; Wendt and Starr, 2009; Kraan et al., 2013; Stephenson et al., 2016; Mangi et al., 2018; Thompson et al., 2019). Experience shows that SIRC done well, can also increase transparency and communication, build capacity amongst fishers and scientists, improve societal relevance of research, and build a collaborative rationale for durable solutions (Karp et al., 2001; Johnson and Van Densen, 2007; Johnson, 2009; Innes and Booher, 2010; Doerner et al., 2015; Mackinson and Middleton, 2018; Mangi et al., 2018; Thompson et al., 2019; Holm et al., 2020a; Steins et al., 2020a; Mackinson, 2022).

In the field of gear technology, SIRC goes back many years (Feekings et al., 2019). However, in fish stock assessment and ecosystem science, input to science from the fishing industry has generally taken the form of recording and submitting a narrow range of fisheries-dependent types of data, such as statutory data on landings and fleet effort generated by industry, and data from sampling on board of fishing vessels by scientific observers. Since the turn of the 21st century some individual scientists and research projects have been more receptive to the benefits of direct participation of industry in gathering scientific data and exchanging knowledge (Stanley and Rice, 2007; Hind, 2015). Furthermore, openness to Indigenous knowledge became required in some regions of the world. Also, the need for active stakeholder involvement is now explicitly acknowledged in international policy frameworks such as the United Nations' Sustainable Development Goals (UN, 2015), and its guidelines for small-scale fisheries (FAO, 2015). As part of its criteria for research grants, Europe's Responsible Research and Innovation policy and actions (Owen et al., 2012) demands partnerships with industry and delivery of outcomes that address societal issues. These criteria encourage researchers to gather and access data through engagement with the fishing industry (Johnson and Van Densen, 2007; Doerner et al., 2015; Hind, 2015; Dubois et al., 2016; Stephenson et al., 2016; Mackinson and Middleton, 2018; Nursey-Bray et al., 2018; Baker et al., 2019; Bentley et al., 2019; Thompson et al., 2019; Holm et al., 2020a; Raicevich et al., 2020; Steins et al., 2020a).

In addition to the ability to collect and share quantitative data, the fishing industry also possesses important *"experiential knowledge"* (Stephenson et al., 2016) that can give context, and help with the interpretation of quantitative scientific and industry data and findings. Nevertheless, experiential knowledge routinely gets little consideration, often being qualified as biased or 'anecdotal' (Johannes and Neis, 2007) and thus not fit for purpose in science for management advice. Both quantitative and experiential information sources can be unique in the evidence and insight they offer and are relevant for enhancing scientific understanding of the marine environment (Neis et al., 1999; Bentley et al., 2019). They can inform the development of responsive management systems, as fishers are often the first to notice changes at sea. They can also contribute to the inclusion of social and economic considerations in fisheries management frameworks (Stephenson et al., 2018; Foley et al., 2020; Stephenson et al., 2021), hypothesis testing (Stanley and Rice, 2007) and coping with uncertainty (Dankel et al., 2012).

Despite a rich global literature on different forms of SIRC, there are only a few peer-reviewed publications where SIRC projects made a difference in scientific assessments as part of advisory processes (Melvin et al., 2002; Röckmann et al., 2015; Hesp et al., 2017; Duplisea, 2018; Bentley et al., 2019; Chagaris et al., 2020; Clegg et al., 2021; Howell et al., 2021). This indicates that while the value of using industry data and knowledge contributions and SIRC partnerships is increasingly recognized, there are still challenges about how to engage in

SIRC in a way that delivers good quality information considered trustworthy within the constraints of established, evidence-based decision-making processes. These challenges relate to both the mechanics of the scientific advisory system and opinions on how to govern its integrity (Linke et al., 2020).

This paper addresses questions about the utility of *voluntary* data and knowledge contributions from the fishing industry to enhance the evidence base used to inform fisheries science and ultimately, management. We combine insights from a literature review, our own experiences, and findings from structured expert discussions in regional workshops in Australia/New Zealand, the Americas and Europe, to investigate and characterize the conditions that determine whether voluntary data and knowledge contributions from the fishing industry are, should, or could be considered useful; or not. Our objective is to disentangle challenging, intertwined issues related to personal and institutional perceptions and practices around using industry information in assembling 'the best available information' for science.

We focus on 'voluntary contributions' – as opposed to 'statutory requirements' – including situations where the fishing industry by its own initiative or choice engages in SIRC as active contributors of their data and knowledge. Voluntary contributions may include situations that are more transactional in nature, but still characterized by deliberate choices over the extent to which fishers contribute. This would include, for example, the chartering of commercial vessels by scientific institutes to undertake fish stock surveys and responding to questionnaires and researcher requests for interviews. In this paper, the term 'fishing industry' encompasses both *fishers*, i.e., those who fish – whether it be small-scale, large-scale, independent, contractual, and irrespective of their gender, and *fishing organizations*, i.e., those higher-level entities such as alliances, associations, companies, cooperatives and unions, that represent fishers, fleets, or sectors. Fishers and fishing organizations are present in many science and management forums, making it hard to separate their voluntary contributions. That said, we recognize that they may encompass groups with different value systems, including around how they share their knowledge and with whom, and that the fishing industry is extremely heterogeneous around the world depending on the types of fisheries and even within the same métiers (Schadeberg et al., 2021), governance systems and cultures. Where separation of contributions by fishers and fishing organizations is important to the discussion, we make that distinction. The same thinking applies to the words 'scientists' and 'science' and the groups and phenomena they describe. Our focus on voluntary industry contributions is explicitly directed at regions with well-developed scientific advisory systems because this is where issues about the transition in governance and participatory approaches in fisheries are matters of debate rather than necessity (Stilgoe et al., 2013; García et al., 2016; Holm et al., 2020b; Linke et al., 2020; Macher et al., 2021).

In the next section, we outline our approach to identifying three key issues inhibiting systematic integration of voluntary industry contributions to science: (1) concerns about data quality; (2) beliefs about limitations in useability of unique fishers' knowledge; and (3) perceptions about the impact of industry contributions on the integrity of science. We will then review these issues. In particular, we focus on understanding the utility of voluntary contributions in specific applications and how they might affect confidence in the integrity of information, processes and science organizations. In summing up, we expose the dilemmas associated with using voluntary industry contributions and what it means for how the future of fisheries science is best conducted in the emerging frameworks for responsible research and innovation.

Method

Investigative critique

This research triangulates findings from a literature review, causal explanation (Nachmias and Frankfort-Nachmias, 1976), and expert judgement. The first five authors (Steins, Mackinson, Stephenson, Mangi, and Pastoors) originally set out to develop a comparative analysis of international experiences of SIRC projects using a review of the literature to arrive at tangible recommendations for sustained integration of knowledge generated through co-creation between fishers and scientists within the institutional frameworks for science and management. While conducting the review, these authors found few published examples where SIRC projects had made a difference in science or management, prompting them to confront their beliefs and wonder whether they were perhaps being led astray by a will-o'-the wisp[1]. This resulted in a new approach towards developing an investigative critique of the evidence around SIRC, formulating explanations in the form of the most vexatious and thorny questions related to involvement of fishers and the fishing industry in the provision of data and knowledge for science. A deliberately provocative approach was adopted, rooted in experiential observations of implicit bias against voluntary contributions. This enabled us, as confessed proponents of SIRC, to confront ourselves and the readers with the difficult questions that we might otherwise be expected to avoid.

1 *Will-o'-the-wisp is an atmospheric ghost light seen by travelers at night, especially over bogs, swamps or marshes, and is said to mislead travelers by resembling a flickering lamp or lantern. In literature, will-o'-the-wisp metaphorically refers to a hope or goal that leads one on but is impossible to reach, or something one finds sinister and confounding.* https://en.wikipedia.org/wiki/Will-o%27-the-wisp *and* https://historydaily.org/will-o-the-wisp-deadly-fairy-lights.

The original authors drew on their own knowledge of the literature and experience in SIRC or scientific advisory settings to identify five key elements associated with resistance to the use of voluntary knowledge contributions in scientific evidence to support management: (i) threats to quality; (ii) lack of reliability; (iii) threats to the integrity of science; (iv) concerns about the uniqueness or lack of added- value in SIRC; and (v) inconsistent availability. We then articulated potential explanations for these elements in five provocative statements intended to expose 'the elephant in the room[2]. We then carried out a literature review to assess the evidence to support or refute these statements (see Supplementary Materials). We focused on voluntary data and knowledge contributions, rather than statutory requirements, because they demonstrate an appeal from the fishing industry for engagement with science beyond that which is mandatory. Furthermore, it is here where questions about conflict of interest, trustworthiness and reliability make some scientists and receivers of scientific advice start to feel concerned. However, we did not neglect the importance of contributions linked to statutory reporting in the critique. In some contexts contributions linked to statutory reporting are also subject to the same issues of trust or conflict of interest and reliability as such data is also the industry's responsibility The evidence was drawn from referenced case studies from regions with well-developed fisheries assessment and scientific advisory processes.

Regional workshops

Having collated our evidence, the original team then identified a group of scientific experts with backgrounds in natural and social sciences and in fisheries research, advice and management, SIRC, and science-policy interfaces and invited them to participate in expert panels. Twenty-eight international colleagues agreed to meet to discuss whether arguments for and against the five provocative statements were justified. The meetings took the form of three online workshops for the following regions: Europe, Australia/New Zealand and the Americas. Each workshop was facilitated by a chair recruited from outside the original author group (authors Ballesteros, Brooks, and McIsaac). Chairs also prepared the resulting meeting reports (see Supplementary Materials). Participants received an evidence document ahead of the meeting and were asked to fill out a short assessment report and point to additional references or observed evidence relevant to the discussion. During the workshops, the original five authors introduced each of the 5 elements with a provocative statement to prompt discussion (see Supplementary Materials). They subsequently participated as observers as participants discussed each statement. Following the regional workshops, participants who could commit to an active role in the writing process joined the author group. All authors were involved in analyzing emerging themes from each workshop, as well as the separate evidence supplied by individual participants. Analysis took place *via* two online author meetings, joint working documents and by email correspondence, resulting in a rich and substantial volume of documented information (see Supplementary Materials).

Workshop discussions resulted in the merger of the original five key elements into three main issues relating to (1) the quality of voluntary contributions by the fishing industry; (2) the uniqueness of fishers' knowledge; and (3) the integrity of science (Figure 1; definitions in Table 1). Using this refined 'lens' for our approach, in the remainder of this paper, we look to identify with confidence, what, where and when there is utility in including the data and knowledge products of SIRC as evidence in assessment and scientific advisory processes, and the utility of the SIRC process itself in achieving this. We use 'quality' and 'uniqueness' as the key metrics of utility. We also explore important issues about notions of 'integrity' because they are linked with perceptions about utility.

Definitions

Beyond the clarification already made in the introduction regarding definitions for 'voluntary' and 'fishing industry', during discussions and subsequent analysis, it became clear that a common vocabulary was needed. For example, participating social scientists used the term 'data' to refer to all information and knowledge, whereas natural scientists generally referred to data as quantified information and were inclined to link experiential knowledge to 'anecdotal' information. For this reason, we developed a number of operational definitions for the main terminology used in this paper (Table 1).

Findings: Utility of fishing industry contributions to science

Compared to statutory fisheries data, there is limited evidence that either voluntary data from the fishing industry or experiential knowledge are systematically used in well-developed systems for fisheries assessment and management advice. This observation is in contrast to the keenness routinely expressed by industry in various fora to get involved in supporting the provision of scientific evidence (Graham et al., 2011; Doerner et al., 2015; ICES, 2019d), and with the growing interest by the scientific community to collaborate to improve the knowledge base for fisheries management (Holm et al., 2020a; Steins et al., 2020a; Mackinson, 2022). This lack of use

2 *The elephant in the room' is a metaphor to refer to an obvious major problem of issue that people avoid discussing or acknowledging because it makes at least some of them uncomfortable or is personally, socially, or politically embarrassing, controversial, inflammatory, or dangerous.* https://en.wikipedia.org/wiki/Elephant_in_the_room.

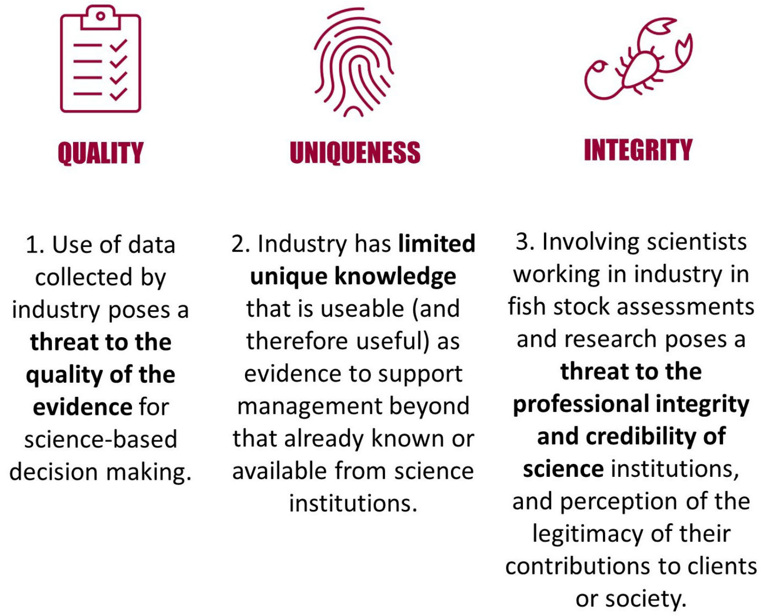

FIGURE 1
Analytical framework: Three key issues and associated provocative statements.

of voluntary data persists despite clear drivers in policy frameworks and funding mechanisms to facilitate stakeholder contributions to science [e.g., (Bradley et al., 2019; ICES, 2021c; ICES, 2021b)]. Our analysis suggests this is rooted in perceptions about the quality of voluntary industry contributions, uniqueness of fishers' knowledge and integrity of science (Figure 1).

Issue 1: Quality of voluntary industry contributions

Provocative debate prompt: Use of data collected by industry poses a threat to the quality of the evidence for science-based decision-making (Figure 1).

This statement is rooted in beliefs that voluntary contributions from industry cannot live up to the quality standards and consistent availability that should be expected of scientific data; additionally, that voluntary contributions are driven by opportunistic motives implying bias, or that information provided is 'anecdotal' and therefore not suitable. Evidence shows that concerns about quality issues related to industry data are indeed legitimate. Work on observer programs has shown disparity between data collected by fishers and observers, where the former are keen to record data on species they exploit or are more familiar with, while ignoring other species in the catch (Mangi et al., 2016). Similarly, positive bias has been observed in fishers' sampling data versus scientists' in stock surveys where both were using the same methodology (Mayfield et al., 2011). In this regard, fishers may not be equipped with the necessary professional education, skills and understanding of sampling design to collect data that meet scientific standards (Calderwood et al., 2021a), or have received instructions from scientists that were unclear or open to interpretation (Kraan et al., 2013; Stenevik et al., 2020). Also, self-sampling schemes may suffer from low sampling rates thereby increasing uncertainty in results (Starr, 2010; Clegg et al., 2022). Another quality concern is that the process of engaging in SIRC is associated with bias in relation to who participates and thus, where and which data are collected, as voluntary data collection often involves the same group of selected or motivated fishers (Kraan et al., 2013; Raicevich et al., 2020; Steins et al., 2020a).

Quality may also be affected when industry is constrained from engaging in SIRC due to limited finances or available time. They may underestimate the extent of the commitment and continuity of resources required for sustained research (Starr, 2010), making it difficult to ensure that data provision persists (Lordan et al., 2011; Mangi et al., 2015; Mangi et al., 2018; Raicevich et al., 2020; Steins et al., 2020a; Van Helmond et al., 2020). Continuity may also be affected when committed fishers leave the fishery (Jones et al., 2022) or when there are trust issues, for instance, when participating fishers or their peers fear the information they provide will be used against them, serving only to punish efforts of collaboration (Carruthers and Neis, 2011; Kraan et al., 2013; Mangi et al., 2015; Röckmann et al.,

TABLE 1 Operational definitions of terminology (in alphabetical order).

Term	Definition
Best available (scientific) information	Refers to not only the data, information, knowledge used for assessment and decision-making, but also the framework and processes that ensure this information is solicited, reviewed and evaluated, including objective-setting. The information may include environmental, biological, technical, economic and/or social data. The process should be iterative and targeted to address specific needs and aims and must be transparent, open, inclusive and objective. It should include independent review, validation, and be central to and embedded within management mechanisms (Lynch et al., 2018; ICES, 2019a; Su et al., 2021).
Co-production of data, information and knowledge AKA Mode 2 science	Scientific knowledge that is co-produced with stakeholders in academic-industry/stakeholder interactions. Compared to Mode 1 science, Mode science 2 is characterized by: (1) a context of application; (2) transdisciplinarity; (3) heterogeneity in terms of organizations involved; (4) reflexivity, in that is a dialogic process that incorporates multiple perspectives; (5) a novel quality control approach, where traditional peer-review is supplemented by additional criteria (socio-economic, cultural, political) (Hessels and van Lente, 2008)..
Data	Individual facts, figures, signals and measurements that are products of observation. Data represent the properties of objects, events and their environments but lack meaning or value as data are without context (Ackoff, 1989; Rowley, 2007).
Fishers' Experiential Knowledge	Contextual knowledge and sensitivity about the social-ecological system as a result of fishers' or fishing communities' experiences from working in that system and its associated socio-economic, cultural, technological, physical or other changes, often over many generations (Johannes, 1981; Neis and Felt, 2000; Perry and Ommer, 2003; Haggan et al., 2007; St. Martin et al., 2007; Hind, 2015; Stephenson et al., 2016). Experiential knowledge includes Traditional Ecological Knowledge with a focus on Indigenous peoples (Johannes, 1981) and Local Ecological Knowledge with a focus on fishers rooted in communities with a long history of engaging in particular subsistence, commercial or recreational fisheries (Neis and Felt, 2000).
Fishers' Knowledge Research	A body of research that does not regard science and fishers' knowledge as two separate entities but suggests that data from measured observations and experiential knowledge of fishers should be included in scientific assessments in support of management. Fisher's Knowledge Research covers a broad spectrum, from providing observational-based data or experiential information to scientists to full participation and acceptance of experiential knowledge as part of using the best available information (Stephenson et al., 2016).
Fishing industry	Generic catch-all term representing both fishers, i.e., those who fish whether it be small-scale, large-scale, independent, contractual, and irrespective of their gender, and the fishing organizations, i.e. those higher-level entities such alliances, associations, companies, cooperatives and unions, that represent fishers, fleets or sectors.
Information	Extracted from data, through processing, analysis and organization, to add value to the understanding of a subject [broadly based on (Ackoff, 1989; Rowley, 2007)].
Integrity of science	Defined as research that is: (1) reliable – as it ensures research quality; (2) honest – by being transparent, fair, full and unbiased; (3) respectful – for participants, stakeholders and the social, cultural and natural environment; (4) accountable – for its design, organization and wider impacts (ALLEA, 2017).
Knowledge	Facts, information, and skills acquired through experience or education, resulting in theoretical or practical understanding of a subject (Jenkins, 2004).
Knowledge – fishers' knowledge	Both a body of knowledge held by individuals or groups of fishers or fishing communities and a process of producing and assembling that knowledge through observations, trial and error, contextual experiences and research.
Knowledge – scientific knowledge AKA Mode 1 science	Both a body of knowledge and a process of producing knowledge in which that knowledge is produced and organized in systematic ways and according to general principles. Processes of observation and experimentation are typically used to produce empirical scientific knowledge and support scientific theory building. This traditional interpretation of scientific knowledge is also referred to as Mode 1 science (Hessels and van Lente, 2008).
Mode 1 science	See Knowledge – Scientific knowledge above.
Mode 2 science	See Co-production of data, information and knowledge AKA Mode 2 science above.
Quality of research	Narrow definitions of quality used in disciplinary research focus on scientific excellence and relevance, with established disciplinary criteria and processes for evaluating research quality (Belcher et al., 2016). We define Quality from a Mode 2 science perspective. Good quality 'transdisciplinary research' (Tress et al., 2005) meets 4 principles: (1) relevance – the importance, significance, and usefulness of objectives, process and findings to problem context and society; (2) credibility – robustness and trustworthiness of knowledge produced; (3) legitimacy – research is perceived as fair and ethical by end-users; (4) effectiveness – research contributes to positive change in the social, economic and/or environmental problem context (Belcher et al., 2016).
Statutory data	Fisheries-dependent quantified data that fishers or the fishing industry must provide to national authorities and science organizations as part of legal obligations. Examples of statutory data include landings and effort data, discards data from observer schemes, biological data on species, results of gear selectivity trials, data on the frequency of interactions with vulnerable species, economic performance data and social metrics.
Uniqueness of knowledge	Knowledge that is the result of fishers' experience and observations, which cannot be derived from other sources.

(Continued)

TABLE 1 Continued

Term	Definition
available from fishers	
Voluntary contributions	Data, information and knowledge actively contributed to science by industry's own initiative or willingness to engage in SIRC. Examples of voluntary contributions can be similar as those mentioned under statutory data; they may also be transactional in nature such as chartering their vessels for research surveys. Voluntary contributions are always by the fisher's own choice.

2015; Barz et al., 2020; Wätjen and Ramírez-Monsalve, 2020; Calderwood et al., 2021b; Cvitanovic et al., 2021; Ford and Stewart, 2021). Finally, data may be withdrawn because of opportunistic motives, as was the case for a stock assessment by the International Council for the Exploration of the Sea (ICES), where *"a fishing industry offered survey data they had funded but withdrew the information when the inclusion resulted in a lower Total Allowable Catch [advice]"* (ICES, 2014).

Evidence also shows, however, that concerns about the quality of industry data can and have been successfully addressed through a variety of methods including training, development of sampling standards, interviewing, and systems of verification and validation (Neis et al., 1999; Stephenson et al., 1999; Johannes et al., 2000; MinPI, 2011; Kraan et al., 2013; Mion et al., 2015; Fry et al., 2018; Mangi et al., 2018; ICES, 2019d; Keane et al., 2019; Thompson et al., 2019; Flores Martin, 2020; Raicevich et al., 2020; Stenevik et al., 2020; Suuronen and Gilman, 2020; Van Helmond et al., 2020). Further, concerns about data quality are not unique to industry but also apply to science (Liggins et al., 1997; Benoit and Allard, 2009; Cartwright, 2019; Gismondi et al., 2020; Fernandes et al., 2021).

Using fishers to collect data allows for dealing with time, cost and spatial and temporal restrictions associated with scientific catch sampling programs (Poos et al., 2013; Jones et al., 2022). When many vessels of a fleet are involved in sampling, geographical coverage can be extensive and fully representative of the area fished by this fleet. The number of trips sampled can outweigh limitations of small sample sizes from each vessel (Bjørkan, 2011; Pennington and Helle, 2011; Kraan et al., 2013; Gawarkiewicz and Malek Mercer, 2019; Jones et al., 2022). Voluntary fishing industry data, including from fish processors, may exceed that collected by government or third-party sampling schemes in amount and distribution (Mackinson et al., under review; Power et al., 2007; Rochette et al., 2018; Dunn, 2020; Kenyon et al., 2022). Such sampling can go beyond providing data on catches, and can contribute to surveying parts of the stock not targeted in the same way that fisheries-independent scientific surveys do (Gerlotto et al., 2012; Schram et al., 2021). In addition to fish stock assessments, industry data have also contributed to an improved knowledge base or validation of by-catch data regarding seabirds, marine mammals and Endangered, Threatened and Protected species (Bjørkan, 2011; Fangel et al., 2015; Fry et al., 2018; Moan et al., 2020). Such voluntary industry contributions, provided they are done well, all contribute to improving quality of data collected by science institutions.

To overcome concerns about consistent, long-term availability of voluntary industry data, most long-term SIRC initiatives rely on an assortment of remuneration options, such as remuneration for haul specific logbook data or discard samples (Kraan et al., 2013; Jones et al., 2022); payment of net income differences with comparable vessels not involved in research (Schram et al., 2021); additional quota allocations (Kindt-Larsen et al., 2011; Van Helmond et al., 2016); or payment for ship and crew hire (Ressler et al., 2009; Gallaudet, 2021; Hoff et al., 2021). In this context, it is important to note that concerns about long-term availability of data and information are not exclusive to industry contributions. There is a perception that fisheries-independent data collection has a high level of funding security, because it is usually embedded in (inter)national agreements. But this is not a guarantee that such scientific sampling schemes will continue. For example, the ICES stock assessment for North East Atlantic mackerel was impacted by Norway's decision to step out of the egg survey to pursue a swept-area survey (Spijkers and Boonstra, 2017). In Canada, the 4WX larval herring survey was eliminated after 22 years (Stephenson et al., 2015) during a time of fiscal restraint within government. Also in New Zealand, statutory data systems have suffered from continuity of quality (Langley, 2014; Middleton, 2021). Equally, major changes in commercial fisheries due to policy decisions, such as fishery closures, can result in the termination of long-term Catch per Unit of Effort (CPUE) series used in assessments. Finally, there are continuity issues in scientific data collection in relation to a changing world. For example, in the context of climate change, scientific surveys that are standardized to allow for time-series development of relative changes in fish stock populations may miss important changes in stock dynamics (Karp et al., 2022). Here, fishers' knowledge contributions can assist evaluation of the need for potential changes in survey design.

In considering the quality of voluntary industry contributions, concerns about the trustworthiness and reliability of such data, as well as conflict of interest (see issue 3), make some scientists and receivers of scientific advice worry. However, issues with data quality and reliability are not unique to industry. In this context, it is worth reflecting on experiences with existing statutory data collection, which share related concerns about reliability. For instance, catch misreporting or aggregation of species into generic groups may lead to incorrect interpretations of fishing pressure on stocks and affect the quality of assessments and the advice upon which they are based (Patterson, 1998; Bradley et al., 2019). Despite these concerns, statutory catch data collection schemes remain a cornerstone of information for assessments. Another example is observer bias, a known issue, even when highly trained scientific observers collect data (Liggins et al., 1997; Benoit and Allard, 2009; Kraan et al., 2013; Suuronen and Gilman, 2020). Observer bias is accepted implicitly, whereas information provided by industry is more heavily scrutinized (Kraan et al., 2013; Berg et al., 2022; Clegg et al., 2022).

When specific concerns about the quality of data contributions from industry have been addressed, as is best practice for any source of data, there is no reason why such information should not be used in scientific research. Indeed, fisheries-dependent data are often the only available source for assessments of commercially important fish stocks when there are financial, spatial or temporal limitations to fisheries-independent data collection. This is the case for Alaska, Australia, Canada and New Zealand. Potential shortcomings of voluntary industry contributions can be mitigated by co-design of sampling schemes and putting in place necessary quality control measures in the same way as implemented by most scientific institutes or science organizations. But the presence of such quality control systems does not mean that issues and concerns regarding quality can always be fully eliminated. There are numerous examples in well-developed scientific advisory systems where data and methodological errors were detected after scientific advice was given (Hilborn and Peterman, 1996; Spijkers and Boonstra, 2017; ICES, 2019c; SWFPA and SFA, 2021; ICES, 2022). Mostly, the evidence trail for these is transparent, but not always. For example, in the ICES assessment for blue whiting, the 2010 survey estimate was initially included in the assessment (ICES, 2010) and later withdrawn because it was considered to be an outlier, i.e., quality issue, without a clear explanation (ICES, 2012).

There is evidence that fishers' motives for data collection can be short-term and motivated by a combination of objectives such as deriving immediate financial gain, improving fishing opportunities, and providing evidence to impact decision-making (Woo et al., 2013; Dubois et al., 2016). This will also influence their decisions to be involved in long-term data collection. While scientists' objectives for data collection are unlikely to be driven by opportunities for personal financial gain, scientists do have interests to consider, such as research grants, project objectives and publication track records. Scientists also often share fishers' motivations to influence others' views. This is a reality of the competition for scientific knowledge and differences in opinion that exists in science; even if the 'scientific approach' seeks to be neutral, treating different viewpoints as testable hypotheses, without a stake in any particular result. However, SIRC experiences also show that it is wrong to assume that by default the industry has only short-term, opportunistic motivations with regards to voluntary data collection. The industry also recognizes the importance of long-term data collection, including funding these schemes (Starr, 2010; Mackinson and Middleton, 2018; Pastoors, 2021). The motivations for SIRC projects are often founded upon a desire to contribute knowledge and data to a continuous improvement process for stock assessment and advice, and also to provide internal business intelligence information relevant to skippers and owners. Examples are European pelagic industries that work on the development of standardized commercial CPUE series for data-limited stocks (Pastoors and Hintzen, 2020; Quirijns and Pastoors, 2020). They have also implemented self-sampling data collection schemes to clarify biological questions on the duration of the spawning period of mackerel and the linkage between populations in the western area and the North Sea (Pastoors, 2021; Kenyon et al., 2022; Mackinson, 2022). The Dutch demersal industry initiated a dedicated survey for North Sea turbot and brill in response to ICES advice that highlights the need for such a survey (ICES, 2019b; Schram et al., 2021). Other motivations for funding voluntary data collection include, for example, requirements to provide evidence in support of sustainability certification schemes or providing information for developing fisheries management plans, including harvest control rules and protection of spawning and nursery areas (Steenbergen et al., 2017; Holm et al., 2020a).

Increasing recognition and experience of the benefits of industry participation in catch sampling and surveys (Poos et al., 2013; Doerner et al., 2015; Mangi et al., 2018; Gawarkiewicz and Malek Mercer, 2019; Holm et al., 2020a; Steins et al., 2020a; De Boois et al., 2021; Jones et al., 2022; Mackinson, 2022), combined with government budget declines, and increasing data and information demands to service ecosystem-based advice and management (Ballesteros et al., 2018; Bradley et al., 2019), have led to increased delegation of responsibilities and costs of sampling from government to industry. Such delegation can also contribute to the development of trust relations. It is widely recognized that SIRC can contribute to developing mutual trust (e.g., St. Martin et al., 2007; Holm et al., 2020a; Steins et al., 2020a; Ford and Stewart, 2021; Macher et al., 2021; Köpsel, 2022) and to industry's perceptions about the legitimacy of science (Murray et al., 2008b; Johnson and McCay, 2012; Röckmann et al., 2015;

Stephenson et al., 2016; De Boois et al., 2021; Su et al., 2021). Once trust has been established the degree of integration of industry data (Stephenson et al., 2016; Cvitanovic et al., 2021) and unique experiential knowledge (Steins et al., 2020a) may evolve. However, in our experience, acceptance of this experiential knowledge in well-developed scientific advisory systems for fisheries and ecosystem management tends to be problematic.

Issue 2: Uniqueness of fishers' knowledge

Provocative debate prompt: Industry has limited unique knowledge that is usable (and therefore useful) as evidence to support management beyond that already known or available from science institutions (Figure 1).

Most SIRC projects have focused narrowly on working with fishers on gear and selectivity research, using fishers to help collect basic biological and catch information or using industry vessels for science-directed survey observation platforms. Whereas engagement with measurable industry data is growing, experiential knowledge seems to be overlooked. Globally, fisheries scientists struggle to include information that is not quantitative or is considered to be 'anecdotal' (Johannes and Neis, 2007) and, while potentially beneficial to providing important context, is not regarded as fit-for-purpose in quantitative science or usable in receiving systems that prefer fisheries-independent information and independent sampling. Using experiential knowledge also suffers from even more pronounced suspicions than measurable industry data regarding opportunistic motives and efforts to frame alternative explanations to scientific findings (Issue 1, previous section). These perceptions persist despite the existence of policy frameworks in regions with well-developed scientific advisory systems that prescribe or include binding requests to use the best available information, including fishers' knowledge (MinPI, 2011; Owen et al., 2012; Lynch et al., 2018; ICES, 2020a). In these contexts, the question is whether and under what conditions experiential knowledge, due to its unique nature, can be used and is therefore useful as evidence to inform management beyond that already known or available from science institutions.

Some experiential observations are perceived as relevant and fit readily into assessment-related evaluation, e.g. the impact of tide conditions on catchability. But often experiential information does not fit easily into the established assessment structure and therefore is perceived as unsubstantiated evidence used in an attempt to influence management. One example is where fishers' knowledge of fish distribution and how it changes leads them to question the utility of random sampling as a scientific research design (De Boois et al., 2021). This is one of the contexts where experiential knowledge is overlooked or often dismissed as being 'anecdotal', even when the collective experience of individual fishers or fishing communities point to changes in a stock that may affect the appropriateness of a particular survey design. What makes 'anecdotal' information considered to be less true useful for monitoring change is not necessarily that it is less true, but that it is regarded as not 'systematic' (Wilson, 2009). For example, stock assessment science tends to be based on large spatial scale units, discrete sampling techniques, and standardized sampling protocols, whereas experiential knowledge is often more localized and is based on different and often variable temporal scales and continuous sampling practices and technologies (Perry and Ommer, 2003; Wilson, 2009; Karp et al., 2022). These are some of the reasons why experiential knowledge is often considered unusable in fish stock or ecological assessment models; particularly those that are already data-rich (Mackinson and Nøttestad, 1998). Most stock assessment protocols lack the flexibility to incorporate experiential knowledge in a meaningful way.

Dismissing fishers' experiential knowledge as 'anecdotal' and thus not useable may have serious unintended consequences. Several examples illustrate that dismissing information from fishers came at a high price. These include the cod stock collapse in Canada (Finlayson, 1994; Neis et al., 1999; Rose and Kulka, 1999) and the ICES Northeast Atlantic mackerel assessment (Spijkers and Boonstra, 2017; ICES, 2019c). Indeed, where scientists have made efforts to include experiential knowledge in quantitative fisheries science, it can make significant contributions. In Canada, systematically collected information from experiential knowledge furthered understanding of relevant variables in the northern cod assessments such as stock structure, identification of spawning areas, technological creep and spatial dynamics (Neis, 1992; Neis et al., 1999; Murray et al., 2008a; Murray et al., 2008b; Johnsen et al., 2009). Within ICES, fishers' experiential knowledge was successfully used to improve the Irish Sea ecosystem model for informing the fisheries stock assessment process (ICES, 2020b). The model that included experiential information performed the best overall statistical fit, capturing the biomass trends of commercial stocks. It also replicated the increase in landings of benthos and epifauna, which were poorly simulated in the model that only used scientific data (Bentley et al., 2019). These examples also highlight that, like fishers, scientists also make assumptions about how fisheries and ecosystem dynamics work.

While scientists' assumptions may be rooted in existing science findings, their assumptions are also based on their own experiences or perceptions, and therefore it must be noted that scientists' assumptions may be flawed, just like fishers' assumptions can be. For example, fishers' knowledge successfully challenged scientists' assumptions about past landings by providing insights on discards and high-grading (Palmer and Sinclair, 1997; Duplisea, 2018). In Alaska, scientists' assumptions for a 'safe counting protocol' for bowhead whale migration led to meaningless scientific estimates. Eventually, after 14 years, a revised and more satisfactory monitoring program based on Inuit fishers' knowledge was adopted (Johannes et al., 2000).

It is true that experiential knowledge may not always be available in a form that is fit for quantitative assessmentsor evaluating the options among alternative management approaches, but there are also alternative ways of incorporating it into science and management. The private Marine Stewardship Council certification program developed a qualitative, risked-based assessment methodology for the evaluation of data-limited fisheries against its standard for sustainable fisheries (MSC, 2022). This precautionary methodology for stock and ecosystem assessment relies heavily on qualitative appraisal of fishers' experiential knowledge. Also, science organizations have been known to use experiential information from fishers in validating or cross-checking scientific findings. For example, between 2002 and 2014, the international Fishers' North Sea Stock Survey (FNSS) provided a qualitative assessment of fishers' perceptions on relative changes in abundance, fish size, discards and recruitment of eight species compared to the previous year (Napier, 2014). Although the relevant ICES stock assessment group could not use the FNSS results in their quantitative models and the survey was considered to be *"non-quantitative and subjective [in] nature"* (Napier, 2014; Stange, 2017), the group responsible for drafting ICES advice occasionally used the results of the FNSS qualitatively for sense-checking of stock assessment results. The survey was discontinued due to declining fishers' participation, possibly caused by frustration about lack of uptake by ICES (Stange, 2017). In Australia and New Zealand, fishers' experiential knowledge has also proven to be useful in understanding changes in CPUE trends, particularly when no or limited fisheries-independent data are available. After all, CPUE deviations do not necessarily have to be related to changes in stock abundance but can be related to technological changes, changes in fisher behavior resulting from market/economic drivers or regulatory changes (Johnsen et al., 2009), or changes in fish behavior (Fernö et al., 2011).

Experiential knowledge from fishers is also useful for guiding assumptions and interpreting results from Management Strategy Evaluations (MSEs). Most MSEs are largely based on relatively complex simulation tools that have a very simplistic representation of fishers' decision-making and behavior. The same applies to mixed fisheries models and displacement models (Nielsen et al., 2018; Wijermans et al., 2020). Information from the fishing industry can be used to test assumptions and generate more realistic expectations on the type of changes that may be assumed when management measures change, thus making fisheries and ecosystem models and MSEs more informative for management (Steenbergen et al., 2015; Pope et al., 2019; Wijermans et al., 2020; Schadeberg et al., 2021). One example is the development of a harvest strategy for the Australian Southern and Eastern Scale Fish and Shark Fishery. Separate quantitative and qualitative stakeholder information-based MSEs were done, including projecting the same set of indicators under the same set of alternative harvest strategies. Both showed very similar results. The qualitative MSE was, however, *"instrumental in helping industry confront a range of systemic problems and issues in the fishery, and was used in part as the basis for a successful call for assistance in restructuring the fishery to achieve the changes that were identified as needed"* (Smith et al., 2007). Information on fishing strategies, including economic and social aspects is also key in evaluation of 'full spectrum sustainability' (Foley et al., 2020), which extends the traditional focus of MSEs on ecological and economic to include social, cultural and institutional considerations (Stephenson et al., 2018). As attention to these 'human dimensions' of fisheries management increases, the need for, and role of, fishers' experiential knowledge will also increase (Stephenson et al., 2021).

Scientists also have used experiential knowledge to find alternative explanations for scientific observations. For example, in the case of a camera monitoring scheme as part of North Sea cod management, the apparent behavior of the fleet did not follow scientific predictions, which were based on incorrect assumptions. Subsequent interviews with fishers resulted in a logical, but unconsidered, explanation for these changes (Van Helmond et al., 2016). Engaging with fishers in research and, by extension, with their experiences does not always result in changes to science but can add to the sum total of knowledge on both sides, as with the collaboration between commercial fishers and government scientists related to Pacific rockfish off British Columbia that ranged from hypothesis formulation through data analysis (Stanley and Rice, 2007).

Other areas of fisheries science where fishers' experiential knowledge has been used is in the documentation of new or invasive species (Azzurro et al., 2019), reporting of ecological change (Keane et al., 2019), enhancing the underpinning of the science base for protecting vulnerable species and habitats (Gass and Willison, 2005; Colpron et al., 2010; Bjørkan, 2011; Kraan, 2015), establishing the relationship between vessel size, gear size and catching capacity (Reid et al., 2011), and in survey gear technology (Cotter, 2004; Reid et al., 2007; DeCelles et al., 2012; Johnson and McCay, 2012; De Boois et al., 2021; Jones et al., 2021).

Even where fishers' experiential knowledge is very relevant, linking it to phenomena at a broader spatial and temporal scale such as those used to study stock dynamics, requires that it is systematically collected, structured and made available. This is often not the case when changes are being observed in real-time and require management action (Wilson, 2009). The unique nature of experiential knowledge means that 'interdisciplinary expertise' (Tress et al., 2005) is needed to make experiential knowledge systematically accessible in forms that are useable to aid in knowledge transfer to bridge gaps between fishers and natural scientists. Gathering experiential data and information through interviews, for example, not only requires skills in interview techniques but also scientific rigor around sampling to help ensure those sampled are considered by their peers to be most knowledgeable (Davis and Wagner, 2003). Since fishers' experiential knowledge is socially distributed and shared by actors involved, also crew, shore-based personnel and processors need to be included, depending on the research question at hand (Palsson, 2000). Using this knowledge also requires consideration of variability in experiential knowledge related to ecological patchiness and change over time. This is crucial to research that seeks to use experiential information for historical reconstruction of fisheries and changing fish ecology, for understanding shifting effort, for documenting migration patterns, stock structure, spawning areas including those now extinct, the location of deep-water corals, endangered species abundance, and changing fishing strategies and dynamics (Neis et al., 1999; Murray et al., 2008a; Colpron et al., 2010; Dawe and Neis, 2012; Paterson et al., 2018; Bentley et al., 2019). Furthermore, researchers have to be aware that information providers, for all kinds of reasons, may deliberately provide erroneous information, may suffer from *"personal or generational amnesia"* (Papworth et al., 2009), or experiential bias (Shackeroff and Campell, 2007; Raicevich et al., 2009; Slooten et al., 2017).

Attention to both ecological and social variability in fishers' experiential knowledge is critical in research design, including ensuring participants' information collectively captures the full temporal, spatial and technological scale of relevant fisheries, to ensure appropriate contextualization. This concern bridges both interview-based research and participatory or collaborative research design. However, most marine institutes and science organizations do not have sufficient social science capacity, and marine social scientists often reside in academia instead of applied science organizations. Moreover, the institutions involved in science for advice tend to get by on fisheries-independent and fisheries-dependent statutory data. Where attempts are being or have been made to incorporate contributions from industry, receiving science systems focus on basic biological data provided by industry and are slow in expanding research design and science capacity. They tend to lack capacity to deal with data and information beyond the natural sciences, even when it concerns quantifiable socio-economic data. Incorporation of experiential knowledge requires involvement of social scientists and substantial financial resources; fisheries scientists would have to be trained in social science epistemology and methods to foster interdisciplinary approaches and social scientists would have to be structurally included in fisheries research frameworks including funding (DePiper et al., 2017; Macher et al., 2021; Moon et al., 2021). Too often, fishers' experiential knowledge is considered to be 'nice-to-know', something to be documented in academia so that it does not get lost to mankind (Johannes, 1981), instead of as an important source of information that can be applied to further understanding of fisheries and marine ecosystem dynamics, due to the costs and governance changes needed to incorporate it.

Issue 3: Integrity of science

Provocative debate prompt: Involving fishers, representatives, or industry-scientists in fish stock assessments and research poses a threat to the professional integrity and credibility of science institutions, and perception of the legitimacy of their contributions to clients or society (Figure 1).

This statement seems paradoxical in view of global efforts by science-policy systems to make the required adaptations to accommodate industry information as part of using 'best available information' policies. But nonetheless the point of view is still prevalent. Examples of science institutions where the goal of industry participation is operationalized are the New Zealand system with its Research Science and Information Standard (MinPI, 2011; Mackinson and Middleton, 2018), NOAA fisheries science (Lynch et al., 2018; Link et al., 2021), the Canadian science advisory peer review process (CSAS, 2021) and various stakeholder engagement initiatives within ICES (Dickey-Collas and Ballesteros, 2019; ICES, 2019c; ICES, 2021c). Such efforts have a strong focus on quality assurance including Conflict of Interest (COI) and Code of Conduct policies. Preconceptions remain however that opportunistic motives may lead to 'tainted' data contributions from industry (Issue 1 section) and that fishers' knowledge, as well as input from industry-employed scientists, should not be trusted because of a perceived threat to the integrity of the science profession and the credibility and even legitimacy of science in support of management. These claims might sound overly dramatic, but such lines of thought pervade scientific and management arenas, even if rarely explicitly articulated.

For example, such thinking may have informed the narrative directing to events in New Zealand that led to the dissolution of Trident Systems, an industry-led, not-for-profit organization established as a research provider in 2012 (Middleton, 2018). Trident was founded with the support of the Ministry of Primary Industries and worked collaboratively with government research providers and industry. In debates associated with the New Zealand fisheries management system (Melnychuk et al., 2017; Slooten et al., 2017), there appears to be some lack of understanding that 'data provided by the industry' are diverse. For example, catch, effort and landings data are provided by industry but as part of statutory obligations and are subject to verification by government. However, other data are voluntarily provided by the industry. Trident was considered to be an example of how use of both statutory data and industry contributions to science in support of management could be organized (Mackinson and Middleton, 2018). Nevertheless, Trident's integrity was publicly questioned. This appeared to be triggered when Trident became engaged in the development of video monitoring for fisheries observation, which in an NGO press release was confused with the government's responsibility of fisheries compliance (Greenpeace-NZ, 2017; Johnston, 2017; Middleton and Guard, 2021). Subsequently, the New Zealand fisheries research system was subjected to a COI review (Jenkins and Wallace, 2019). Trident decided in 2019 *"that it was not possible to meet their objectives of improving the efficiency of fisheries data collection and extracting greater value from fisheries data in an environment in which Trident's industry ownership had become a barrier to its participation in Government funded or supported research"* (Middleton and Guard, 2021). It took several years to establish a role for an industry-led research provider, but little time to have its foundations pulled away.

Other examples are found in the US and the ICES context. In the US, legal mandates in relation to 'best available scientific knowledge' constrained use of proven experiential knowledge (Lynch et al., 2018; Link et al., 2021). In the case of Atlantic bluefish, use of fishers' experiential knowledge was blocked by preventing the scientists from using what they felt was their best scientific judgement (Wilson and Degnbol, 2002). Events around the US Trawl Survey Advisory Panel, set up to integrate scientists' and fishers' expertise in developing a new and improved survey trawl net and gear, show how notions about 'objectivity' resulted in the demise of the panel (Johnson and McCay, 2012). Established to increase the credibility and legitimacy of science, industry members left the panel when the Science Centre unilaterally decided to order trawl doors, as in relation to *"something as important as a resource survey [they could not] allow themselves to be seen as fully cooperative with the industry"* (Johnson and McCay, 2012). Such thinking was also exposed in high level discussions in the ICES council and, to a lesser extent, in the advisory committee, where not all members agreed on the merits of opening up science work to be more inclusive of contributions from industry or other stakeholders. Some perceive this as not appropriate, despite many good governance measures ICES has put in place to maintain the professional integrity and credibility of its expert groups (Dickey-Collas and Ballesteros, 2021) and workshops that have sought to foster dialogue about transparency and objectivity on the quality of science (Doerner et al., 2015; ICES, 2019c; ICES, 2019d; ICES, 2021c).

Preconceptions about industry involvement in generating scientific evidence or about the personal integrity of industry-employed scientists may encourage beliefs that such involvement potentially jeopardizes the credibility of the science organizations involved in the advisory process. This is a particular concern in cases where industry disagrees with specific management actions, does not have confidence in their scientific basis, or mistrusts the science or management institutions or processes (cf. (Dubois et al., 2016). Whilst there are only a few documented cases where scientists and scientific consultants employed by the fishing industry or other stakeholders have 'bent' scientific evidence in favor of the industry or conservation purposes, or have contested the scientific process (Starr et al., 1998; Loring, 2017; Moore et al., 2018; Le Manach et al., 2019; Kraan et al., 2020; O'Brien, 2022), such cases have contributed to the perception that stakeholder-employed scientists should be regarded with suspicion. However, there are also cases where scientists from marine institutes or academia, using their institutional credentials in the name of the scientific advice committee they are a member of, have acted as advocacy scientists in support of stakeholder views (Rice, 2011; Steins et al., 2020b; Mossler, 2021; Harris, 2022; Hutchings, 2022) or have selectively used information in science communications as a commodity seeking to polarize views to highlight debate and garner readership, instead of promoting understanding (for example, Pauly et al., 2013; Harris, 2022). Finally, there are also (mostly un-documented) examples from Europe and Canada where government, not industry or conservation stakeholders, has put pressure on scientists to advocate specific positions (e.g., Hutchings, 2022). Related to this, in most scientific advisory systems there tends to be a rather close link between government-employed scientists and the clients of advice: policy makers (e.g., Wilson, 2009; Dankel et al., 2016). This close science-policy relation, while it also pertains to issues of integrity and independence, is usually taken for granted. Inclusion of industry contributions in the scientific process in and of itself does not necessarily compromise credibility. Institutional credibility is based on the capability to create authoritative, replicable, and trusted information (Cash et al., 2002). As long as data and information used meet scientific quality standards and process, origin does not matter.

In ICES, discussion about industry participation in expert groups started when it was decided to include all names of expert group and workshop participants as authors in reports. For a number of years, ICES assessment groups had already included scientists employed by industry (Dickey-Collas and Ballesteros, 2021). Despite initial reservations, the data and information industry-employed scientists bring to the table is considered useful, and in many cases innovative (Mackinson, 2022). There have been no signals from these groups to the advisory committee or the council that this led to bias in assessment results. However, when it comes to participating in post-assessment stages, there are different procedures for stakeholder-employed scientists compared to scientists from marine institutes or academia. This is due to concerns about how clients and stakeholders will perceive the independence of the advice. This is also why in ICES, engagement with stakeholder interest groups is limited to workshops and advice drafting groups (Dickey-Collas and Ballesteros, 2019).

In Canada, diverse members of the fishing industry have been participating more actively in the provision of information and for some time in the assessment peer reviews of the Canadian Science Advisory Secretariat (Stephenson et al., 1999; Winter and Hutchings, 2020; CSAS, 2021). In cases where scientific consultants or industry-employed scientists critically reviewed or even contested government stock assessments, this brought benefits including intensive peer-review, the ability to bring data from all parties to the process, and improved understanding and trust. It has been shown that this contributed to substantially improved assessments (Starr et al., 1998) and therefore to scientific credibility. Also, in New Zealand, the assessment system reinforces healthy scrutiny of data and assessments (Mackinson and Middleton, 2018).

The credibility of science is closely linked to its legitimacy (Röckmann et al., 2015; Su et al., 2021). It is widely acknowledged that industry-employed scientists, can contribute to increasing the legitimacy of science within industry in their role as 'boundary spanners' who recognize the value of fishers' knowledge and are able to communicate on both sides of the boundary between scientific and fishers' knowledge (Johnson, 2011). Where industry and the scientific community consider the integration of industry contributions to be a way forward to increasing legitimacy of science, other stakeholders may perceive this differently. The earlier example of Trident Systems, where NGOs have successfully questioned the legitimacy of science from industry-management partnerships, is a case in point. Equity and fairness principles are obvious issues of concern that call for reflection on more inclusive participatory approaches to evidence-building based on stakeholders' capability and availability. Obviously, the fishing industry is linked with vessels out at sea with the possibility of making and contributing observations, and many industry organizations and fishers are also acutely aware that fisheries-dependent and fisheries-independent data are required for stock assessments as a basis for management. But experience-based knowledge comes from diverse sources, and the scientific process needs to be open to accepting and using industry observations as part of 'best available information'. For example, in Australia, Resource Assessment Groups provide peer-review of scientific data and information and advice on stock status, economic status of the fishery and ecosystem impact. They include members from science, industry and, where relevant, members from conservation interests and recreational and Indigenous fisheries (AFMA, 2021). In Canada, assessments and peer review under the Canadian Science Advisory Secretariat process increasingly include NGOs (CSAS, 2021). In ICES, NGO representatives can be invited as workshop member or obtain observer status for advice drafting groups (Dickey-Collas and Ballesteros, 2019). It is also conceivable that like industry-employed scientists, scientists employed by NGOs will become involved in assessment working groups. The ICES national delegates have the discretionary power to nominate experts on the basis of their reputation and scientific credibility, not on behalf of a specific employer. However, adding scientists employed by stakeholders to scientific expert groups in itself is unlikely to solve potential legitimacy challenges of scientific advice, as perceived credibility of science is also part of the equation (Röckmann et al., 2015). Quality assurance, transparency and accountability are key aspects of the integrity of the processes and procedures governing the production of scientific advice. In this context, stakeholder engagement throughout the scientific advisory process contributes to dialogue and improved understanding, and hence to perceptions about its credibility and saliency. However, as is shown in a comparison of Canadian and EU scientific advisory processes, it is important to clearly distinguish between the science, irrespective of the source, and 'interest driven' input and be transparent about this (Winter and Hutchings, 2020).

Discussion

Is sea-change upon us?

Despite the normative calls for participatory research and consistent evidence of SIRC benefits in the literature, fisheries science in regions with well-developed scientific advisory systems remains firmly rooted in traditional 'Mode 1' knowledge production (Hessels and van Lente, 2008) and associated approaches and beliefs (cf. (Su et al., 2021). In our evidence, we recognize important contributions of SIRC, but we do not yet see overwhelming evidence of a sea-change towards the systematic integration of industry contributions and more transdisciplinary fisheries science as part of 'Mode 2' (Hessels and van Lente, 2008) approaches.

Any such sea-change is hindered by three interrelated issues that are embedded in traditional Mode 1 ways of thinking about science: (1) concerns about the quality of industry contributions; (2) beliefs about limitations in the useability of unique fishers' knowledge; and (3) perceptions about the impact of industry contributions on the integrity of science. Our assessment of each of these issues suggests that the first and second can easily be addressed through a combination of mechanisms. The third issue, which entails perceptions from a variety of stakeholders with different belief systems, is more difficult to tackle. It is an important inhibiting factor for 'mainstreaming' knowledge co-production in fisheries science, even when the first and second concerns have been successfully addressed. We will discuss ways forward following a brief summary assessment of each of the three concerns.

Summary assessment of the three statements

The first issue, that use of industry data and information poses a threat to the evidence for science-based decision-making, can be addressed through recognizing that such contributions do not pose a threat, but rather raise challenges and have limitations related to the conditions of their application. Concerns about industry's independence and conformity with the same procedural standards of collecting data, formatting, verification and submitting information as other data sources are certainly legitimate. Quality concerns and underlying beliefs about opportunistic motives that result in bias and lack of consistent availability are not exclusive to industry or other non-scientific stakeholders, but equally apply to all participants, including scientists. Voluntary industry contributions are most often made on the basis of good will and, when this is done in collaboration with scientists, usually adhere to basic agreed data collection standards. We need to appreciate that industry data have their limitations, and that industry is not monolithic, with significant variability in types of fisheries, vulnerability to overfishing, resources to apply to contributing to science and influencing management, and often competitive interests within and across fleet sectors. This has implications for data collection, its use, and for motivations to participate in SIRC or full industry-driven research programs. The same applies to science, and this also affects if and how SIRC are set up, including consideration of power and how data and information are used.

The second issue, that industry has limited unique knowledge that is useable (and therefore useful) as evidence to support management beyond that already known or available from science institutions, is flawed. Doubt has been cast on fishers' experiential knowledge because of mis-perceptions that it is inherently decontextualized and local, hence 'anecdotal', or pressing a particular agenda, but these characteristics are variable. It is undeniable that experiential knowledge can be valuable and when drawn systematically from a range of fishers with careful attention to sampling, can be structured and applied quantitatively and qualitatively. Qualifying experiential knowledge as unusable entails an inherent risk that management will not be based on the best available information, particularly when fishers see in real time what is happening on the grounds and scientific assessments (forecasts) show a delay in appreciating the actual situation. The paradigm in well-developed scientific advisory systems that an assessment is only a 'good' assessment if it is fully quantitative, is thus not only problematic but results in limited input to management decisions. Moreover, it is associated with social justice issues: from this perspective fishers, fisheries or nations having limited access to quantitative data and assessment models would never be able to evaluate the status of their fisheries resource and the effectiveness of management measures. Our evidence shows that, where interdisciplinary efforts were made to systematically make experiential knowledge available in regions with well-developed science systems, this contributed to improving the scientific knowledge base and understanding of variability in stock and ecosystem dynamics and impacts of these on fisheries.

For both the first and second issues, it is important to acknowledge that not all data and information are the same and these should be used in a way appropriate to the source and the intrinsic limitations therein. While some voluntary industry contributions may be suitable for use in traditional stock assessments or as structured evidence to support management decisions, others may be more useful in interpreting and validating model outcomes or (re)setting model parameters, or for full spectrum sustainability evaluations (see Supplementary Materials for an overview of applications for industry contributions in fisheries and marine ecosystem science). In cases where information from the fishing industry has been sought for inclusion in scientific analysis, we found it has also served as a mechanism to open dialogue, benefiting both fishers and scientists. This is particularly important considering prevailing trust issues, which relate, for both sides, to the trustworthiness of the data and the scientific process, as well as to trust by fishers that their contributions are not being used against them in the translation from scientific advice to management measures.

Trust is also an underlying theme in the third issue identified: the concern that involving the fishing industry in science poses a threat to the professional integrity and independence of the scientific institutions and, hence, perceptions of the legitimacy and credibility of their advice. We found some evidence for these concerns, but even more examples were identified where industry involvement benefited the scientific process. There may be some documentation bias here, as published evidence for misbehavior is difficult to find; perhaps this is also illustrative of the discomfort of addressing this issue. Where industry or other stakeholders criticize scientific work, this should be embraced rather than merely dismissed as being politically motivated; all scientists should welcome critical review of their work, including when it is not from their disciplinary peers. Furthermore, there is an irony in 'condemning' the situation where the industry, by being actively involved in the scientific process, becomes more 'literate' and subsequently uses the knowledge they obtained to criticize the scientific advice or influence management discussions. Advocacy by stakeholders is inextricably bound to the governance domain. This does not mean that these stakeholders cannot be part of producing credible, quality assured science. Indeed, there is ample evidence that credible science contributes to increasing the legitimacy of science.

Collaborative research has had an impact in terms of building trust between fishers and scientists in improving research findings, in creating a situation where fishers are more willing to cooperate, and in capacity building for fishers and scientists. But much of this impact is limited to the domain of dedicated research projects, many of which are useful for science and policy but are not really being structurally integrated into routine scientific processes. Hence, SIRC tends to remain limited to successes at local or regional levels. It has proven difficult to change science and management systems that are based on routines. Examples where SIRC really made an impact on the science that informs fisheries management are either largely invisible or scarce, but the opportunities have been equally scarce. Without a doubt, *"it is easier to organize collaborative research than to make it count"* (Holm et al., 2020a). This is problematic, because many projects that use fishers' knowledge are aimed at making an impact on the science that informs management. There are, of course, various reasons for this. ICES, for example, has only recently started to think about how to integrate industry data, while at the same time there are still many problems with the data from scientific institutes which need to be sorted out (ICES, 2019d; ICES, 2021b; ICES, 2021c). The bottom line is that if findings from fishers' knowledge projects aimed at improving the knowledge base for management are not used, research collaborations will be eroded along with carefully built trust (Johnson and McCay, 2012; Steins et al., 2020a). This, in turn, will impact trust in management.

Ways forward

The scope of fisheries evaluation in the modern context of sustainability is becoming more comprehensive (Foley et al., 2020; Stephenson et al., 2021) making explicit the limitations of conventional research. There is increasing need to integrate ecological with economic and social factors. Further, addressing the increased uncertainties associated with climate change and other factors, as well as the potential of introducing additional uncertainty to assessments, means that the traditional systems of data gathering and assessment will need to be adapted for this purpose. Current assessment and management structures will no longer be able to get by with the statutory and fisheries-independent data that has been available from within government departments or science institutions. Information on fishing strategies, economic and social aspects in fishery evaluation is key information, most of which has not traditionally been collected by government and scientific institutions. Industry is better able to contribute such information. In addition to bridging social, economic, and fishing behavioral knowledge gaps, industry contributions of quantitative data and experiential knowledge are relevant for a broad spectrum of fisheries science applications (see Table in Supplementary Materials). For responsive management *"we must tap from a diversity of sources and we must find ways to use this knowledge to build a complete picture"* (Wilson, 2009). We anticipate that the future of fisheries evidence will be based on much the same principles as held now, but with a broader range of data, information and knowledge providers, and more transparent agreed processes. Its credibility and legitimacy rely upon (a) respecting and making the most of different sources of knowledge to learn as much as we can, and (b) the need to verify the knowledge through evidence or reasoned argument and carefully balancing and assessing the strengths and weaknesses of different types of knowledge, as we have undertaken to do here.

We aimed to identify with confidence, what, where and when there is utility in including the data, information and knowledge contributions of science-industry research collaboration as evidence in regions with well-developed scientific advisory systems, and the utility of the SIRC process itself in achieving this. The answer is not breaking news: SIRC is context-dependent and shaped by the institutional framework within which it takes place, so the utility 'depends' on the case. In addressing these questions, we provide systematic and robust evidence for: a) practitioners to assess the suitability of SIRC on a case-by-case basis; b) researchers to explore the implications for theoretical developments in knowledge production; c) policymakers to gain a better understanding of what SIRC entails for scientific support and management performance.

The evidence shows SIRC's potential contributions, limitations and constraints. The analysis details associated challenges and reviews the methods to cope with them, illustrated with examples. While no panaceas apply, entrenching SIRC calls for action in three specific areas:

i. Knowledge production has to advance towards alternative science modes that ensure effective SIRC, fostering accountability of both scientists and industry in the process.
ii. Quality Assurance frameworks, including COI provisions, need to become part of the institutional context to tackle objective and perceived pitfalls, generating credibility and transparency.
iii. Governance structures should facilitate the move towards alternative science modes that rely on plural sources of information, by providing arenas for continuous dialogue, building trust to manage real and perceived threats to the integrity and independence of scientific advice, and financial support.

Move towards alternative modes of knowledge production

The integration of fishers' knowledge requires current scientific assessment and advisory systems to actively embrace and facilitate transdisciplinary modes of knowledge production (Tress et al., 2005; Hessels and van Lente, 2008; Stephenson et al., 2016). Consequently, besides industry expertise, expertise from a broader range of scientific disciplines must be mobilized. Many scientific advisory systems do not yet include expertise from the social sciences to assist in making fishers' experiential knowledge systematically accessible and available. This is not necessarily because they are unwilling to do so, but may be because their clients, including governments, do not ask for 'full spectrum advice' (Foley et al., 2020; Stephenson et al., 2021). A way forward is to demonstrate to recipients of advice what full spectrum advice could look like, as ICES has recently done in its Aquaculture Overview for the Norwegian Sea Ecoregion (ICES, 2021a) or NOAA Fisheries in the context of integrated ecosystem assessments for marine regions in the USA (Levin et al., 2016). Operational advances towards alternative modes of knowledge production requires: (a) funding for full spectrum advice; (b) effective learning across disciplines (epistemology, developing joint methodology, training and developing interdisciplinary trust (DePiper et al., 2017; Thompson et al., 2019; Macher et al., 2021; Moon et al., 2021); and (c) addressing potential ethical issues (Carruthers and Neis, 2011), power imbalances and related threats to social justice that could be affected by uneven SIRC initiatives.

Appropriate quality assurance frameworks

Moving towards alternative modes of knowledge production will require agreement on appropriate processes for validation and quality control. Acknowledging the challenges to credibility, integrity and independence posed by the use of measurable industry data and experiential knowledge, we argue that there is a suite of methods and processes able to cope with them. Formalized and transparent quality assurance systems for all data contributions, irrespective of their source, will be needed to ensure rigor in design and quality of data collection and verification and in its use for analysis. These should include: (a) documented sampling designs, methods and quality controls applied through the data chain; (b) documentation of the source(s) of data and information, by whom it was collected and when and where; (c) documentation of any assumptions, hypotheses and data inconsistencies, as part of a risk assessment with regards to data quality; (d) development of data sharing agreements that define rationale for sharing these data and information and constraints on their use; (e) transparent, documented coding systems for data; (f) independent validation and peer-review. We refer to the report of the ICES Workshop on Standards and Guidelines for Fisheries-dependent Data for a comprehensive overview of international examples of quality assurance processes (ICES, 2021c). A particular challenge here is that meeting the same standards could be difficult when fish and fisheries straddle multiple jurisdictions.

Agreed processes for quality assurance should, as much as possible, be in place before data are collected and delivered[3]. Many scientific organizations already have some form of quality assurance in place. Adapting these to be applicable and receptive for contributions by the fishing industry and other non-scientific actors will therefore be a gradual, iterative process. It is important that all non-scientific actors who may be contributing data and information are informed with the appropriate data collection processes (ICES, 2021c). Training and communication are key here, as well as having 'boundary spanners' (Johnson, 2011). Scientists employed by stakeholder groups and who work closely with colleagues in science organizations should be well-equipped for this role (Mackinson, 2022). In this context, concerns about professional integrity can be a sensitive topic, but one that is nonetheless important to address. Joint reflection on *"whose hat [scientists] are wearing"* (Dankel et al., 2016) is likely to be more effective in overcoming such concerns.

Conflict of Interest protocols are a formal way of organizing transparency about who participates in scientific processes. Conflicts of interest related to data collection and knowledge contributions are different from other situations where COI may occur, such as scientific meetings and review panels. In the latter case, COI may be handled by balancing representation of participants and adoption of well-established review protocols (e.g., ICES, 2020a; CSAS, 2021; NPRB, 2021). While standards for managing COI in scientific meetings are not directly applicable to data and knowledge contributions, the underlying principles are relevant, and have a direct relation to quality assurance. Standards for COI management should be extended to include managing perceived or actual COI in the collection and application of data for use by scientific advisory systems. The purpose should be to protect the legitimacy of advice when data-collectors with potential conflicts of interest are involved (ICES, 2021c). In this context, we note that the European fishing industry has voluntarily established a Code of Conduct for industry observers attending ICES meetings (NPWG, 2016b) and for industry-affiliated scientists (NPWG, 2016a) to allay potential COI concerns, which seems testament to their willingness to engage in SIRC. Development of implementable standards for managing COI should not only address the additional legitimacy-risks introduced by third-party participation in data collection, but also manage the risks that may already be associated with the data collection performed by scientific institutions. A standard for managing conflicts of interest in data collection should therefore clearly address requirements for transparency and documentation.

3 We note challenges associated with unplanned or rare events on the water (e.g., superpod convergence). Information on such events is imperative in understanding ecosystem function, yet it would be difficult for fishers to guarantee quality assurance before collecting data on these occurrences.

Facilitating governance structures for alternative modes of knowledge production

Guidelines for SIRC stress the importance of communication (Johnson and Van Densen, 2007; Mackinson et al., 2017; Mangi et al., 2018; Steins et al., 2020a; De Boois et al., 2021; Jones et al., 2022). This includes communicating about the purpose of data collection, why it is done in a certain way and its limitations. It also includes communicating about preliminary and final results and how these have been used. Expectations management is key here, particularly when fishers are contributing towards development of time-series or when use of fishers' experiential knowledge is not yet part of established routines. Communicating about things that went wrong is also essential. Both expectations management and being open about mistakes are closely linked to building trust relations (Mangi et al., 2018; Cvitanovic et al., 2021). Communication should not be limited to those directly involved in collaborative research, but also to a wider stakeholder audience. After all, once the collaborative science gets into the policy and societal domain, trust in its quality and integrity is key. Trust is *"a critical precondition underpinning successful knowledge exchange [and] evidence-informed decision-making"* (Cvitanovic et al., 2021). Trust issues do not resolve themselves by merely setting up appropriate scientific quality assurance systems. These also require continuous dialogue between all parties involved to manage real and perceived threats to integrity and independence of scientific advice, though this is by no means a panacea (e.g., Delaney et al., 2022). Extensive stakeholder-oriented communication does not necessarily come naturally to many scientists and science organizations and is often at the bottom of research budgets or not seen as a priority task. Fundamental change is needed, for example by allocating specific roles and budgets to boundary spanners in transdisciplinary science. Trust-building strategies are a crucial part of ways forward in integrating industry contributions in science; proposals on how to do so have been made in a recent publication by Cvitanovic and colleagues (Cvitanovic et al., 2021).

Enabling scientific advisory systems to move towards collaborative approaches also requires financial support. This includes facilitation of balanced voluntary industry contributions to science. It would be naive to think that an industry-led data collection program can run indefinitely on the good will of fishers, particularly when science-led programs are government-funded. Direct funding is an obvious route, but financial support can also take indirect forms, such as additional quota allocations. In areas where responsibilities for data collection are increasingly delegated to industry, we also see that costs are downloaded to industry with potential negative impacts on younger, less established fishing enterprises and on opportunities to expand the research disciplinary focus to include social science. Expecting industry to fully pay for data collection also brings along equity issues, as not all industries have sufficient financial means and human capital to organize data collection. The impacts of this became clear in Australia, where cost recovery policies for fishery-independent data collection have been introduced in some jurisdictions and vary considerably in what costs are attributed to industry and to public good (Cox, 2001). For smaller-scale, lower value fisheries cost of these programs are more burdensome given they do not gain the advantages of efficiencies of scale (MFA, 2020). The implication is that the evidence-base for management of these latter fisheries has to rely on less fishery-independent data and therefore higher uncertainty and more precautionary harvest settings as a result. In cases where profitability of fisheries declines due to decreasing fishing opportunities or increasing costs, the result may be that the industry has a perverse incentive to cease or narrow the scope of data collection. Thus, while one could argue that acceptance and use of voluntary industry contributions is likely to be the greatest reward to fishers for engaging in science support, there are limits to what can be expected on the basis of fisheries' scale and profitability. These must be well-considered. As part of ways forward, we recommend a review of current funding and alternative support mechanisms for fisheries data collection involving the industry and the development of best support practices.

In our search for explanations for why fisheries advisory systems in well-developed regions only make limited use of observational and experiential data, information and knowledge from SIRC and our exploration of ways forward, we found the exchange of experiences between different regions in our regional workshops to be incredibly insightful. Some regions had already developed solutions for challenges experienced in others or were experiencing positive or negative impacts from changes. A problem or solution in one region does not of course have to play out similarly in other regions in view of contextual, cultural and institutional differences. But looking at issues from different angles is very helpful. As part of ways forward in integrating voluntary industry contributions in regional scientific advisory systems, we therefore recommend organizing regional exchanges of experiences.

Final reflections and perspectives

We believe the growing momentum for using voluntary industry contributions in science is linked to a generational change where scientists who embrace more inclusive and transdisciplinary ways of thinking about science are now at the point in their careers where they can make a difference. Well-meaning efforts to enable the use of 'best available information' are, however, confronted with legitimate concerns regarding perceived and real risks that it might be detrimental to the credibility of scientific advice – particularly when science evidence becomes an object of negotiation in management decisions (Winter and Hutchings, 2020). Safeguarding against this requires transparent quality assurances systems for the processes intended to deliver 'best available information', as well as objective evaluation of the performance of the information for its intended purpose. To differing degrees across the world, achieving this will involve adaptations to current fisheries governance frameworks toward new cultures of cooperation. Proposals for possible avenues have been suggested in a number of recent publications (Gómez and Köpsel 2023; Bradley et al., 2019; Holm et al., 2020a; Fulton, 2021; Hart, 2021; Macher et al., 2021; Stephenson et al., 2021; Su et al., 2021; Strand et al., 2022). Better definition of industry's role in contributing to science will improve credibility and legitimacy of the scientific process, and of resulting management. As part of progressing towards integration of voluntary industry contributions into science for advice, further analysis of the receiving systems that have been more receptive of fishers' and other sources of knowledge is needed. Carrying out a performance evaluation of fisheries managed on the basis of fisheries-dependent data or voluntary industry contributions versus fisheries managed (mostly) on the basis of fisheries-independent data, may help rationalize the debate about the utility of voluntary industry contributions. The best evidence for utility of industry data, after all, lies in its performance.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material. Further inquiries can be directed to the corresponding author.

Ethics statement

Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

NAS, SM, SCM, MP and RLS conceived of the idea for this manuscript, collated the initial evidence document and prepared the regional workshops. MB, KB and JAM chaired the regional workshops and prepared their reports. All authors participated in the regional workshops and subsequent analysis. NAS prepared the manuscript with significant contributions from all other authors. Authorship is in alphabetical order after considering the aforementioned types of contributions. All authors contributed to the article and approved the submitted version.

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Conflict of interest

Author SCM is employed by MRAG Ltd. All authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2022.954959/full#supplementary-material

References

Ackoff, R. L. (1989). From data to wisdom. *J. Appl. Syst. Anal.* 16, 3–9.

AFMA (2021). *Fisheries administration paper No.12 - resource assessment groups* (Canberra: Australian government: Australian Fisheries Management Authority). Available at: https://www.afma.gov.au/sites/default/files/fisheries_administration_paper_12_-_final_draft.pdf.

ALLEA (2017). *The European code of conduct for research integrity. revised ed* (Berlin: All European Academies). Available at: www.allea.org.

Azzurro, E., Sbragaglia, V., Cerri, J., Bariche, M., Bolognini, L., Ben Souissi, J., et al. (2019). Climate change, biological invasions, and the shifting distribution of Mediterranean fishes: A large-scale survey based on local ecological knowledge. *Glob. Change Biol.* 25, 2779–2792. doi: 10.1111/gcb.14670

Baker, M., Brandon, H., Eckert, G., Gauvin, J., Harris, B., Criddle, K., et al (Eds.) (2019). "Strategies for integrating industry perspectives and insights in fisheries science," in *Lowell Wakefield Fisheries symposium 2019*, vol. 34 (Alaska SeaGrant: Anchorage, AK). Available at: https://alaskaseagrant.org/wp-content/uploads/2019/05/Abstract-Book-Wakefield-Symposium-2019.pdf.

Ballesteros, M., Chapela, R., Ramírez-Monsalve, P., Raakjaer, J., Hegland, T. J., Nielsen, K. N., et al. (2018). Do not shoot the messenger: ICES advice for an ecosystem approach to fisheries management in the European union. *ICES J. Mar. Sci.* 75, 519–530. doi: 10.1093/icesjms/fsx181

Barz, F., Eckardt, J., Meyer, S., Kraak, S. B. M., and Strehlow, H. V. (2020). `Boats don't fish, people do′ - how fishers′ agency can inform fisheries-management on bycatch mitigation of marine mammals and sea birds. *Mar. Policy* 122, 12. doi: 10.1016/j.marpol.2020.104268

Belcher, B. M., Rasmussen, K. E., Kemshaw, M. R., and Zornes, D. A. (2016). Defining and assessing research quality in a transdisciplinary context. *Res. Eval.* 25, 1–17. doi: 10.1093/reseval/rvv025

Benoit, H. P., and Allard, J. (2009). Can the data from at-sea observer surveys be used to make general inferences about catch composition and discards? *Can. J. Fish. Aquat. Sci.* 66, 2025–39. doi: 10.1139/F09-116

Bentley, J. W., Serpetti, N., Fox, C., Heymans, J. J., and Reid, D. G. (2019). Fishers' knowledge improves the accuracy of food web model predictions. *ICES J. Mar. Sci.* 76, 897–912. doi: 10.1093/icesjms/fsz003

Berg, H. S. F., Clegg, T. L., Blom, G., Kolding, J., Ono, K., and Nedreaas, K. (2022). Discards of cod (Gadus morhua) in the Norwegian coastal fisheries: Improving past and future estimates. *ICES J. Mar. Sci.* 79, 1548–1560. doi: 10.1093/icesjms/fsac081

Bjørkan, M. (2011). *Fishing for advice: The case of the Norwegian reference fleet (PhD dissertation)* (Tromsø: UiT The Arctic University of Norway). Available at: https://munin.uit.no/handle/10037/3770.

Bradley, D., Merrifield, M., Miller, K. M., Lomonico, S., Wilson, J. R., and Gleason, M. G. (2019).). opportunities to improve fisheries management through innovative technology and advanced data systems. *Fish Fish.* 20, 564–583. doi: 10.1111/faf.12361

Calderwood, J., Bal, G., and Reid, D. G. (2021a). Trial and error: Tactical changes in fishing behaviour can help reduce discards and exposure to chokes, but scientific trials can fail to spot this. *Mar. Policy* 124, 11. doi: 10.1016/j.marpol.2020.104365

Calderwood, J., Pedreschi, D., and Reid, D. G. (2021b). Technical and tactical measures to reduce unwanted catches in mixed fisheries: Do the opinions of Irish fishers align with management advice? *Mar. Policy* 123, 11. doi: 10.1016/j.marpol.2020.104290

Carruthers, E. H., and Neis, B. (2011). Bycatch mitigation in context: Using qualitative interview data to improve assessment and mitigation in a data-rich fishery. *Biol. Conserv.* 144, 2289–2299. doi: 10.1016/j.biocon.2011.06.007

Cartwright, I. (2019). Abalone assessment and management: What have we learned, what are the gaps and where can we do better? *Workshop summary report, Melbourne*, 1–23.

Cash, D., Clark, W. C., Alcock, F., Dickson, N., Eckley, N., and Jäger, J. (2002). *Salience, credibility, legitimacy and boundaries: Linking research, assessment and decision making.* Harvard University, John F. Kennedy School of Government, Faculty Research Working Paper Series RWP02-046. doi: 10.2139/ssrn.372280

Chagaris, D., Drew, K., Schueller, A., Cieri, M., Brito, J., and Buchheister, A. (2020). Ecological reference points for Atlantic menhaden established using an ecosystem model of intermediate complexity. *Front. Mar. Sci.* 7. doi: 10.3389/fmars.2020.606417

Clegg, T. L., Fuglebakk, E., Ono, K., Vølstad, J. H., and Nedreaas, K. (2022). A simulation approach to assessing bias in a fisheries self-sampling programme. *ICES J. Mar. Sci.* 79, 76–87. doi: 10.1093/icesjms/fsab242

Clegg, T. L., Kennelly, S. J., Blom, G., and Nedreaas, K. (2021). Applying global best practices for estimating unreported catches in Norwegian fisheries under a discard ban. *Rev. Fish Biol. Fish.* 31, 1–23. doi: 10.1007/s11160-020-09624-w

Colpron, E., Edinger, E., and Neis, B. (2010). Mapping the distribution of deep-sea corals in the northern gulf of st. Lawrence using both scientific and local ecological knowledge. *DFO Can. Sci. Advis. Sec. Res. Doc.* 2010, 047.

Cotter, J. (2004). "Can fishers teach scientists how to improve fish surveys? selected results from spatially intense, commercial FV surveys of nine English fisheries in 2003-4," in *Report of the working group on survey design and analysis (WKSAD), Aberdeen, 21–25 June 2004. ICES CM 2004/B:07.* Ed. D. G. Ref. (Copenhagen: International Council for the Exploration of the Sea).

Cox, A. (2001). "Cost recovery in fisheries management: The Australian experience," in *Microbehavior and macroresults: Proceedings of the tenth biennial conference of the International Institute of Fisheries Economics and Trade*, Corvallis, Oregon, USA, July 10-14, 2000, Vol. 9.

CSAS (2021) *Policy on participation in science peer review meetings*. Available at: https://www.dfo-mpo.gc.ca/csas-sccs/process-processus/peer-participation-pairs-eng.html (Accessed November 29, 2021).

Cvitanovic, C., Shellock, R. J., Mackay, M., van Putten, E. I., Karcher, D. B., Dickey-Collas, M., et al. (2021). Strategies for building and managing 'trust' to enable knowledge exchange at the interface of environmental science and policy. *Environ. Sci. Policy* 123, 179–189. doi: 10.1016/j.envsci.2021.05.020

Dankel, D. J., Aps, R., Padda, G., Röckmann, C., van der Sluijs, J. P., Wilson, D. C., et al. (2012). Advice under uncertainty in the marine system. *ICES J. Mar. Sci.* 69, 3–7. doi: 10.1093/icesjms/fsr179

Dankel, D. J., Stange, K., and Nielsen, K. N. (2016). What hat are you wearing? on the multiple roles of fishery scientists in the ICES community. *ICES J. Mar. Sci.* 73, 209–216. doi: 10.1093/icesjms/fsv199

Davis, A., and Wagner, J. R. (2003). Who knows? on the importance of identifying "experts" when researching local ecological knowledge. *Hum. Ecol.* 31, 463–489.

Dawe, J. L., and Neis, B. (2012). Species at risk in Canada: Lessons learned from the listing of three species of wolfish. *Mar. Policy* 36, 405–413. doi: 10.1016/j.marpol.2011.06.010

De Boois, I. J., Steins, N. A., Quirijns, F. J., and Kraan, M. (2021). The compatibility of fishers and scientific surveys: Increasing legitimacy without jeopardizing credibility. *ICES J. Mar. Sci.* 78, 1769–1780. doi: 10.1093/icesjms/fsab079

DeCelles, G., Roman, S., Barkley, A., and Cadrin, S. (2012). "Forming collaborative partnerships to improve fisheries research surveys," in *ICES International Science Conference*, Bergen, Norway, 17-21 September 2012. (Copenhagen: International Council for the Exploration of the Sea).

Delaney, A. E., Reid, D. G., Zimmermann, C., Kraan, M., Steins, N. A., and Kaiser, M. J. (2022). Socio-technical approaches are needed for innovation in fisheries. *Rev. Fish. Sci. Aquac.* 1–19. doi: 10.1080/23308249.2022.2047886

DePiper, G. S., Gaichas, S. K., Lucey, S. M., Da Silva, P. P., Anderson, M. R., Breeze, H., et al. (2017). Operationalizing integrated ecosystem assessments within a multidisciplinary team: Lessons learned from a worked example. *ICES J. Mar. Sci.* 74, 2076–2086. doi: 10.1093/icesjms/fsx038

Dickey-Collas, M., and Ballesteros, M. (2019). "Swinging back? science ethos and stakeholders' engagement in ICES advisory processes," in *ICES news artic* (Copenhagen: International Council for the Exploration of the Seas). Available at: http://ices.dk/news-and-events/Documents/News articles/2019 09 Opinion_piece_Fishing_industry_as_authors_of_ICES_expert_groups.pdf.

Dickey-Collas, M., and Ballesteros, M. (2021). *The process in ICES of opening up to increased stakeholder engagement, (1980– 2020)* Vol. Vol.353 (Copenhagen: ICES Cooperative research report). doi: 10.17895/ices.pub.8516

Doerner, H., Graham, N., Bianchi, G., Karp, W. A., Kennelly, S. J., Martinsohn, J. T., et al. (2015). From cooperative data collection to full collaboration and co-management: A synthesis of the 2014 ICES symposium on fishery-dependent information. *ICES J. Mar. Sci.* 72, 1133–1139. doi: 10.1093/icesjms/fsu222

Dubois, M., Hadjimichael, M., and Raakjær, J. (2016). The rise of the scientific fisherman: Mobilising knowledge and negotiating user rights in the Devon inshore brown crab fishery. *UK. Mar. P* 65, 48–55. doi: 10.1016/j.marpol.2015.12.013

Dunn, M. R. (2020). *Developing a stock assessment for new Zealand bluenose* (Wellington: Ministry for Primary Industries). Available at: https://www.mpi.govt.nz/dmsdocument/42715-FAR-202034-Developing-a-stock-assessment-for-New-Zealand-bluenose.

Duplisea, D. E. (2018). Fishermen's historical knowledge leads to a re-evaluation of redfish catch. *Mar. Coast. Fish.* 10, 3–11. doi: 10.1002/mcf2.10006

Fangel, K., Aas, Ø., Vølstad, J. H., Bærum, K. M., Christensen-Dalsgaard, S., Nedreaas, K., et al. (2015). Assessing incidental bycatch of seabirds in Norwegian coastal commercial fisheries: Empirical and methodological lessons. *Glob. Ecol. Conserv.* 4, 127–136. doi: 10.1016/j.gecco.2015.06.001

FAO (2015). *Voluntary guidelines for securing sustainable small-scale fisheries in the context of food security and poverty eradication* (Rome: Food and Agricultural Organisation of the United Nations). Available at: https://www.fao.org/3/i4356en/i4356en.pdf.

Feekings, J., O'Neill, F. G., Krag, L., Ulrich, C., and Veiga Malta, T. (2019). An evaluation of European initiatives established to encourage industry-led development of selective fishing gears. *Fish. Manage. Ecol.* 26, 650–660. doi: 10.1111/fme.12379

Fernandes, A. C., Oroszlányová, M., Silva, C., Azevedo, M., and Coelho, R. (2021). Investigating the representativeness of onboard sampling trips and estimation of discards based on clustering. *Fish. Res.* 234, 13. doi: 10.1016/j.fishres.2020.105778

Fernö, A., Huse, G., Jakobsen, P. J., Kristiansen, T. S., and Nilsson, J. (2011). "Fish behaviour, learning, aquaculture and fisheries," in *Fish cognition and behavior*. Eds. C. Brown, K. Laland and J. Krause (Oxford: Blackwell Publishing Ltd), 359–404. doi: 10.1002/9781444342536.ch16

Finlayson, A. C. (1994). *Fishing for truth: A sociological analysis of northern cod stock assessments from 1977-1990* (St. John's (NL, CA: ISER Books).

Flores Martin, N. (2020). "Taking the initiative on Maltese trawl industry management: Industry and science collaboration on identifying nursery and spawning areas for trawl fisheries target species," in *Collaborative research in fisheries: Co-creating knowledge for fisheries knowledge in Europe*, vol. vol 22 . Eds. P. Holm, M. Hadjimichael, S. Linke and Mack, (Cham: Springer), 249–262. doi: 10.1007/978-3-030-26784-1_15

Foley, P., Pinkerton, E., Wiber, M. G., and Stephenson, R. L. (2020). Full-spectrum sustainability: An alternative to fisheries management panaceas. *Ecol. Soc* 25, 1–9. doi: 10.5751/ES-11509-250201

Ford, E., and Stewart, B. D. (2021). Searching for a bridge over troubled waters: An exploratory analysis of trust in united kingdom fisheries management. *Mar. Policy* 132, 104686. doi: 10.1016/j.marpol.2021.104686

Fry, G., Laird, A., Lawrence, E., and Tonks, M. (2018). Monitoring interactions with bycatch species using crew-member observer data collected in the northern prawn fishery: 2014-2016. *Final Rep. to AFMA* R2015, 0812.

Fulton, E. A. (2021). Opportunities to improve ecosystem-based fisheries management by recognizing and overcoming path dependency and cognitive bias. *Fish Fish.* 22, 428–448. doi: 10.1111/faf.12537

Gallaudet, R. A., De Robertis, A., Foy, R., Sims, J., Fandel, C., and Casanova, H. L. (2021). Application of emerging science and technologies to advance NOAA missions in the Arctic. *Coast Guard Journal of Safety & Security at Sea, Proceedings of the Marine Safety & Security Council* 78, 87–92.

García, D., Zuazua, E., Perat, B., and López, I. (2016). "A practical guide to responsible research and innovation," in *Key lessons from RRI tools* (Barcelona: la Caixa Foundation). Available at: https://www.rri-tools.eu/documents/10184/16301/RRI+Tools.+A+practical+guide+to+Responsible+Research+and+Innovation.+Key+Lessons+from+RRI+Tools.

Gass, S. E., and Willison, J. H. M. (2005). "An assessment of the distribution of deep-sea corals in Atlantic Canada by using both scientific and local forms of knowledge," in *Cold-water corals and ecosystems*. Eds. A. Freiwald and J. M. Roberts (Berlin, Heidelberg: Springer-Verlag), 223–245.

Gawarkiewicz, G., and Malek Mercer, A. (2019). Partnering with fishing fleets to monitor ocean conditions. *Ann. Rev. Mar. Sci.* 11, 391–411. doi: 10.1146/annurev-marine-010318-095201

Gerlotto, F., Gutiérrez, M., and Bertrand, A. (2012). Insight on population structure of the Chilean jack mackerel (Trachurus murphyi). *Aquat. Living Resour.* 25, 341–355. doi: 10.1051/alr/2012036

Gismondi, R., Labanchi, L., Marzocchi, B. M., and Sermoneta, C. (2020). "Statistiche sulla pesca in italia, uso integrato di indagini campionarie e dati amministrativi," in *ISTAT working paper*, vol. 4. (Rome: Istituto nazionale di statistica), 2020. Available at: https://www.istat.it/it/files/2021/01/IWP_8-2020.pdf.

Gómez, S., and Köpsel, V. (2023). *Transdisciplinary marine research: bridging science and society.* (Abingdon-on-Thames: Routledge).

Graham, N., Grainger, R., Karp, W. A., MacLennan, D. N., MacMullen, P., and Nedreaas, K. (2011). An introduction to the proceedings and a synthesis of the 2010 ICES symposium on fishery-dependent information. *ICES J. Mar. Sci.* 68, 1593–1597. doi: 10.1093/icesjms/fsr136

Greenpeace-NZ (2017) *Broadcasting standards authority confirms accuracy of Greenpeace criticism of fishing industry* (New Zeal: Greenpeace). Available at: https://www.greenpeace.org/aotearoa/press-release/broadcasting-standards-authority-confirms-accuracy-of-greenpeace-criticism-of-fishing-industry/ (Accessed December 29, 2021).

Haggan, N., Neis, B., and Baird, I. G. (2007). *Fishers' knowledge in fisheries science and management* (Paris: UNESCO Publishing).

Harris, H. E. (2022). Science vs. sensationalism: Lessons for science communication in fisheries from netflix's seaspiracy. *Fisheries* 47, 154–56. doi: 10.1002/fsh.10727

Hart, P. J. B. (2021). Stewards of the sea. giving power to fishers. *Mar. Policy* 126, 1–9. doi: 10.1016/j.marpol.2021.104421

Hesp, S., Caputi, N., Penn, J., Kangas, M., Sporer, E., Hogan, B., et al. (2017). Improving fleet efficiency to maximise economic yield in a Western Australian prawn fishery. *Mar. Policy* 86, 82–93. doi: 10.1016/j.marpol.2017.09.006

Hessels, L. K., and van Lente, H. (2008). Re-thinking new knowledge production: A literature review and a research agenda. *Res. Policy* 37, 740–760. doi: 10.1016/j.respol.2008.01.008

Hilborn, R., and Peterman, R. M. (1996). "The development of scientific advice with incomplete information in the context of the precautionary approach," in *Precautionary approach to fisheries. part 2: Scientific papers. prepared for the technical consultation on the precautionary approach to capture fisheries (including species introductions). lysekil, Sweden, 6–13 June 1995. (A scientific meeting organized*, vol. 210. (Rome: Food and Agricultural Organization). Available at: https://www.fao.org/3/w1238e/W1238E04.htm#ch2.

Hind, E. J. (2015). Knowledge research: A challenge to established fisheries science. *ICES J. Mar. Sci.* 72, 341–358. doi: 10.1093/icesjms/fsu169

Hoff, G. R., Malecha, P. W., Rooper, C. N., Olson, J. V., Costa, B. M., Adams, C. M., et al. (2021). *Science plan for the Alaska deep-Sea coral and sponge initiative (AKCSI): 2020-2023 AFSC "Processed Rep. 2021-01"* (Seattle: National Oceanic and Atmospheric Administration). Available at: https://repository.library.noaa.gov/view/noaa/28910.

Holm, P., Hadjimichael, M., Linke, S., and Mackinson, S. (2020a). *Collaborative research in fisheries: Co-creating knowledge for fisheries governance in Europe* Vol. vol 22 (Cham: Springer). doi: 10.1007/978-3-030-26784-1

Holm, P., Hadjimichael, M., Mackinson, S., and Linke, S. (2020b). "Bridging gaps, reforming fisheries," in *Collaborative research in fisheries: Co-creating knowledge for fisheries knowledge in Europe*, vol. vol 22 . Eds. P. Holm, M. Hadjimichael, S. Linke and S. Mackinson (Chams: Springer), 205–314. doi: 10.1007/978-3-030-26784-1_17

Howell, D., Schueller, A. M., Bentley, J. W., Buchheister, A., Chagaris, D., Cieri, M., et al. (2021). Combining ecosystem and single-species modeling to provide ecosystem-based fisheries management advice within current management systems. *Front. Mar. Sci.* 7. doi: 10.3389/fmars.2020.607831

Hutchings, J. A. (2022). Tensions in the communication of science advice on fish and fisheries: Northern cod, species at risk, sustainable seafood. *ICES J. Mar. Sci.* 79, 308–318. doi: 10.1093/icesjms/fsab271

ICES (2010). *Report of the working group on widely distributed stocks (WGWIDE), 28 august - 3 September 2010, vigo, spain. ICES C.M. 2010/ACOM:15* (Copenhagen: International Council for the Exploration of the Sea).

ICES (2012). *Report of the working group on widely distributed stocks (WGWIDE), 21 - 27 august 2012, lowestoft, united kingdom. ICES C.M. 2012/ACOM:15* (Copenhagen: International Council for the Exploration of the Sea).

ICES (2014). "Annual science conference advisory committee consultations 2013," in *Report of ICES advisory committee. ICESCM2013/ACOM:01* (Copenhagen: International Council for the Exploration of the Sea), 23–41. Available at: https://www.ices.dk/sites/pub/PublicationReports/Forms/DispForm.aspx?ID=28583.

ICES (2019a). *Advisory plan 2019* (Copenhagen: International Council for the Exploration of the Sea). doi: 10.17895/ices.pub.5468

ICES (2019b). *ICES advice on fishing opportunities, catch, and effort celtic seas and greater north Sea ecoregions: Brill (Scophthalmus rhombus) in subarea 4 and divisions 3.a and 7.d–e (North Sea, skagerrak and kattegat, English channel* (Copenhagen: International Council for the Exploration of the Sea). doi: 10.17895/ices.advice.4858

ICES (2019c). "Workshop on a research roadmap for mackerel (WKRRMAC)," in *ICES scientific reports*, vol. 1. (Copenhagen: International Council for the Exploration of the Sea), 48. doi: 10.17895/ices.pub.5541

ICES (2019d). "Workshop on science with industry initiatives (WKSCINDI)," in *ICES scientific reports* (Copenhagen: International Council for the Exploration of the Sea), vol. 1. , 68. doi: 10.17895/ices.pub.5610

ICES (2020a). "Guide to ICES advice and principles," in *ICES advice* (Copenhagen: International Council for the Exploration of the Sea), 1–8. doi: 10.17895/ices.advice.7648

ICES (2020b). "Workshop on an ecosystem based approach to fishery management for the Irish Sea (WKIrish6; outputs from 2019 meeting)," in *ICES* *scientific reports*, vol. 2. (Copenhagen: International Council for the Exploration of the Sea), 4. doi: 10.17895/ices.pub.5551

ICES (2021a). "Norwegian Sea Ecoregion – aquaculture overview," in *ICES advice*, vol. 15. (Copenhagen: International Council for the Exploration of the Sea). doi: 10.17895/ices.advice.9585

ICES (2021b). "Workshop on stakeholder engagement strategy (WKSHOES)," in *ICES scientific reports*, vol. Vol.3. (Copenhagen: International Council for the Exploration of the Sea). doi: 10.17895/ices.pub.8233

ICES (2021c). "Workshop on standards and guidelines for fisheries dependent data (WKDSG; outputs from 2020 meeting)," in *ICES scientific reports*, vol. 3. (Copenhagen: International Council for the Exploration of the Sea), 38. doi: 10.17895/ices.pub.8038

ICES (2022). "Report of the annual meeting between ICES and requesters of ICES advice (MIRIA), 2022," in *ICES business reports*, vol. 1. (Copenhagen: International Council for the Exploration of the Sea), 12. doi: 10.17895/ices.pub.21324261

Innes, J. E., and Booher, D. E. (2010). *Planning with complexity: An introduction to collaborative rationality for public policy. 1st ed* (New York: Routledge).

Jenkins, A. (2004). "Why define? the case for definitions of knowledge," in *Proceedings of the tenth Americas conference on information systems*, New York; New York, Association for Information Systems, Atlanta August 2004. (Atlanta: Association for Information Systems), 4165–4173. Available at: http://aisel.aisnet.org/amcis2004/520.

Jenkins, K., and Wallace, N. (2019). "Fisheries research: Managing conflicts of interest," in *Report for fisheries New Zealand* (Wellington: Martin, Jenkins & Associates Limited).

Johannes, R. E. (1981). *Words of the lagoon: Fishing and marine lore in the Palau district of Micronesia* (Berkeley: University of California Press).

Johannes, R. E., Freeman, M. M. R., and Hamilton, R. J. (2000). Ignore fishers ' knowledge and miss the boat. *Fish and Fisheries* 1, 257–271.

Johannes, R. E., and Neis, B. (2007). "The value of anecdote," in *Fishers' knowledge in fisheries science and management*. Eds. N. Haggan, B. Neis and I. G. Baird (Paris: UNESCO Publishing).

Johnsen, J. P., Murray, G. D., and Neis, B. (2009). North Atlantic fisheries in change: From organic associations to cybernetic organizations. *Marit. Stud.* 7, 55–82.

Johnson, T. R. (2009). Cooperative research and knowledge flow in the marine commons: Lessons from the northeast united states. *Int. J. Commons* 4, 251. doi: 10.18352/ijc.110

Johnson, T. R. (2011). Fishermen, scientists, and boundary spanners: Cooperative research in the U.S. illex squid fishery. *Soc Nat. Resour.* 24, 242–255. doi: 10.1080/08941920802545800

Johnson, T. R., and McCay, B. J. (2012). Trading expertise: The rise and demise of an industry/government committee on survey trawl design. *Marit. Stud.* 11, 1–24. doi: 10.1186/2212-9790-11-14

Johnson, T. R., and Van Densen, W. L. T. (2007). Benefits and organization of cooperative research for fisheries management. *ICES J. Mar. Sci.* 64, 834–840. doi: 10.1093/icesjms/fsm014

Johnston, K. (2017) *Fishing industry monitor is wholly owned by seafood new Zealand, investigation reveals* (New Zeel. Her. Available at). Available at: https://www.nzherald.co.nz/nz/fishing-industry-monitor-is-wholly-owned-by-seafood-new-zealand-investigation-reveals/S5O7YQR2C43CSYJOGXCSVFTBIM/ (Accessed December 7, 2020).

Jones, A. W., Burchard, K. A., Mercer, A. M., Hoey, J. J., Morin, M. D., Gianesin, G. L., et al. (2022). Learning from the study fleet: Maintenance of a large-scale reference fleet for northeast U.S. fisheries. *Front. Mar. Sci* 9, 1–14. doi: 10.3389/fmars.2022.869560

Jones, A. W., Miller, T. J., Politis, P. J., Richardson, D. E., Mercer, A. M., Pol, M. V., et al. (2021). Experimental assessment of the effect of net wing spread on relative catch efficiency of four flatfishes by a four seam bottom trawl. *Fish. Res.* 244, 106106. doi: 10.1016/j.fishres.2021.106106

Karp, M. A., Brodie, S., Smith, J. A., Richerson, K., Selden, R. L., Liu, O. R., et al. (2022). Projecting species distributions using fishery-dependent data. *Fish Fish*, 1–22. doi: 10.1111/faf.12711

Karp, W. A., Rose, C., JR, G., SK, G., MW, D., and GD, S. (2001). Government-industry cooperative fisheries research in the north pacific under the MSFCMA. *Mar. Fish. Rev.* 63, 40–46.

Keane, J., Mundy, C., Porteus, M., and Johnson, O. (2019). *Can commercial harvest of long-spined sea urchins reduce the impact of urchin grazing on abalone and lobster fisheries* (IMAS-FA: University of Tasmania).

Kenyon, S., Pastoors, M., Mackinson, S., Cornulier, T., and Marshall, C. T. (2022). Intra- and inter-annual variability in the fat content of Atlantic herring (Clupea harengus) as revealed by routine industry monitoring. *ICES J. Mar. Sci.* 79, 88–99. doi: 10.1093/icesjms/fsab244

Kindt-Larsen, L., Kirkegaard, E., and Dalskov, J. (2011). Fully documented fishery: A tool to support a catch quota management system. *ICES J. Mar. Sci.* 68, 1606–1610. doi: 10.1093/icesjms/fsr065

Köpsel, V. (2022). A social scientific self-reflection of co-developing an acoustic stock sampling method in the bay of Biscay. *ICES J. Mar. Sci.*, 1–12. doi: 10.1093/icesjms/fsac129

Kraan, M. (2015). *Visserijvrije zone binnen centrale oestergronden en friese front: evaluatie voorstel visserijsector* (IJmuiden: IMARES Notitie 15.IMA0384-MK-lcs).

Kraan, M., Groeneveld, R., Pauwelussen, A., Haasnoot, T., and Bush, S. R. (2020). Science, subsidies and the politics of the pulse trawl ban in the European union. *Mar. Policy* 118, 1–8. doi: 10.1016/j.marpol.2020.103975

Kraan, M., Uhlmann, S., Steenbergen, J., Van Helmond, A. T. M., and Van Hoof, L. (2013). The optimal process of self-sampling in fisheries: Lessons learned in the Netherlands. *J. Fish Biol.* 83, 963–973. doi: 10.1111/jfb.12192

Langley, A. D. (2014). "Updated CPUE analyses for selected south island inshore finfish stocks. Wellington: Fisheries new Zealand," in *New Zealand fisheries assessment report* (Wellington: Fisheries New Zealand, New Zealand Fisheries Assessment Report 2014/40), vol. 2014, 40. Available at: https://fs.fish.govt.nz/Doc/23673/FAR_2014_40_2781_UpdatedCPUEanalysesforselectedSouthIslandinshorefinfishstocks.pdf.ashx.

Le Manach, F., Bisiaux, L., Villasante, S., and Nouvian, C. (2019). Public subsidies have supported the development of electric trawling in Europe. *Mar. Policy* 104, 225–231. doi: 10.1016/j.marpol.2019.03.003

Levin, P. S., Breslow, S. J., Harvey, C. J., Norman, K. C., Poe, M. R., Williams, G. D., et al. (2016). Conceptualization of social-ecological systems of the California current: An examination of interdisciplinary science supporting ecosystem-based management. *Coast. Manage.* 44, 397–408. doi: 10.1080/08920753.2016.1208036

Liggins, G. W., Bradley, M. J., and Kennelly, S. J. (1997). Detection of bias in observer-based estimates of retained discarded catches from a multi species trawl fishery. *Fish. Res.* 32, 147.

Linke, S., Hadjimichael, M., Mackinson, S., and Holm, P. (2020). "Knowledge for fisheries governance: Participation, integration and institutional reform," in *Collaborative research in fisheries: Co-creating knowledge for fisheries governance in Europe*, vol. vol 22 . Eds. P. Holm, M. Hadjimichael, S. Linke and S. Mackinson (Cham: Springer), 7–26. doi: 10.1007/978-3-030-26784-1_2

Link, J. S., Werner, F. E., Werner, K., Walter, J., Strom, M., Seki, M. P., et al. (2021). A NOAA fisheries science perspective on the conditions during and after covid-19: Challenges, observations, and some possible solutions, or why the future is upon us. *Can. J. Fish. Aquat. Sci.* 78, 1–12. doi: 10.1139/cjfas-2020-0346

Lordan, C., Cuaig, M.Ó., Graham, N., and Rihan, D. (2011). The ups and downs of working with industry to collect fishery-dependent data: The Irish experience. *ICES J. Mar. Sci.* 68, 1670–1678. doi: 10.1093/icesjms/fsr115

Loring, P. A. (2017). The political ecology of gear bans in two fisheries: Florida's net ban and alaska's salmon wars. *Fish Fish.* 18, 94–104. doi: 10.1111/faf.12169

Lynch, P. D., Methot, R. D., and Link, J. S. (2018). Implementing a next generation stock assessment enterprise: An update to the NOAA fisheries stock assessment improvement plan. NOAA technical memorandum NMFS-F/SPO-183. U.S. dep. commer. *NOAA Tech. Memo. NMFS-F/SPO-183*, 127. doi: 10.7755/TMSPO.183

Macher, C., Steins, N. A., Ballesteros, M., Kraan, M., Frangoudes, K., Bailly, D., et al. (2021). Towards transdisciplinary decision-support processes in fisheries. experiences and recommendations from a multidisciplinary collective of researchers. *Aquat. Living Resour.* 34, 21. doi: 10.1051/alr/2021010

Mackinson, S. (2022). The fall and rise of industry participation in fisheries science - a European story. *ICES J. Mar. Sci.*, 1–10. doi: 10.1093/icesjms/fsac041

Mackinson, S., Brigden, K., Clarke, L., Craig, J., Angus, C., Pert, C., et al (under review). *The road to incorporating Scottish pelagic industry data in science for stock assessments. Frontiers in Marine Science* . (Brixham: Fishing into the Future).

Mackinson, S., Mangi, S., Hetherington, S., Catchpole, T., and Masters, J. (2017). "Guidelines for industry-science data collection: Step-by-step guidance to gathering useful and useable scientific information," in *Fishing into the future report to seafish*. Available at: https://www.fishingintothefuture.co.uk/wp-content/uploads/2017/07/Data-Protocols-Guidance_FINAL-CLEAN.pdf.

Mackinson, S., and Middleton, D. A. J. (2018). Evolving the ecosystem approach in European fisheries: Transferable lessons from new zealand's experience in strengthening stakeholder involvement. *Mar. Policy* 90, 194–202. doi: 10.1016/j.marpol.2017.12.001

Mackinson, S., and Nøttestad, L. (1998). Combining local and scientific knowledge. *Rev. Fish Biol. Fish.* 8, 481–490. doi: 10.1023/A:100884710698

Mangi, S. C., Dolder, P. J., Catchpole, T. L., Rodmell, D., and de Rozarieux, N. (2015). Approaches to fully documented fisheries: Practical issues and stakeholder perceptions. *Fish Fish.* 16, 426–452. doi: 10.1111/faf.12065

Mangi, S. C., Kupschus, S., Mackinson, S., Rodmell, D., Lee, A., Bourke, E., et al. (2018). Progress in designing and delivering effective fishing industry–science data collection in the UK. *Fish Fish.* 19, 622–642. doi: 10.1111/faf.12279

Mangi, S. C., Smith, S., and Catchpole, T. L. (2016). Assessing the capability and willingness of skippers towards fishing industry-led data collection. *Ocean Coast. Manage.* 134, 11–19. doi: 10.1016/j.ocecoaman.2016.09.027

Mayfield, S., McGarvey, R., Gorfine, H. K., Peeters, H., Burch, P., and Sharma, S. (2011). Survey estimates of fishable biomass following a mass mortality in an Australian molluscan fishery. *J. Fish Dis.* 34, 287–302. doi: 10.1111/j.1365-2761.2011.01241.x

Melnychuk, M. C., Hilborn, R., Elliott, M., Peterson, E., Hurst, R. J., Mace, P. M., et al. (2017). Viewing fisheries management challenges in a global context. *Proc. Natl. Acad. Sci. U. S. A.* 114, E4903–E4904. doi: 10.1073/pnas.1706654114

Melvin, G., Li, Y., Mayer, L., and Clay, A. (2002). Commercial fishing vessels, automatic acoustic logging systems and 3D data visualization. *ICES J. Mar. Sci.* 59, 179–189. doi: 10.1006/jmsc.2001.1124

MFA (2020). *South Australian productivity commission, research and development inquiry* (Port Adelaide: Submission by the Marine Fishers Association). Available at: https://www.sapc.sa.gov.au/:data/assets/pdf_file/0007/218635/Marine-Fishers-Association.pdf.

Middleton, D. (2018). *The rationale for trident systems: A seafood industry research provider* (Wellington: Trident Systems).

Middleton, D. A. J. (2021). "Comparing paper and electronic reporting: A parallel reporting trial," in *New Zealand fisheries assessment report*, vol. 2021. (Wellington: Fisheries New Zealand), 65. Available at: https://www.mpi.govt.nz/dmsdocument/48190-FAR-202165-Comparing-paper-and-electronic-reporting-a-parallel-reporting-trial.

Middleton, D. A. J., and Guard, D. (2021). "Summary and evaluation of the electronic monitoring programmes in the SNA 1 trawl and bottom longline," in *New Zealand fisheries assessment report*, vol. 2021. (Wellington: Fisheries New Zealand), 37.

MinPI (2011). *Research and information standard for new Zealand fisheries* (Wellington: Ministry for Primary Industries). Available at: https://fs.fish.govt.nz/NR/rdonlyres/D1158D67-505F-4B9D-9A87-13E5DE0A3ABC/0/ResearchandScienceInformationStandard2011.pdf.

Mion, M., Piras, C., Fortibuoni, T., Celić, I., Franceschini, G., Giovanardi, O., et al. (2015). Collection and validation of self-sampled e-logbook data in a Mediterranean demersal trawl fishery. *Reg. Stud. Mar. Sci.* 2, 76–86. doi: 10.1016/J.RSMA.2015.08.009

Moan, A., Skern-Mauritzen, M., Vølstad, J. H., and Bjørge, A. (2020). Assessing the impact of fisheries-related mortality of harbour porpoise (Phocoena phocoena) caused by incidental bycatch in the dynamic Norwegian gillnet fisheries. *ICES J. Mar. Sci.* 77, 3039–3049. doi: 10.1093/icesjms/fsaa186

Moon, K., Cvitanovic, C., Blackman, D. A., Scales, I. R., and Browne, N. K. (2021). Five questions to understand epistemology and its influence on integrative marine research. *Front. Mar. Sci.* 8. doi: 10.3389/fmars.2021.574158

Moore, J. W., Nowlan, L., Olszynski, M., Jacob, A. L., Favaro, B., Collins, L., et al. (2018). Towards linking environmental law and science. *Facets* 3, 375–391. doi: 10.1139/facets-2017-0106

Mossler, M. (2021)Retraction of flawed MPA study implicates larger problems in MPA science. In: *Sustain. fish. - sci. sustain. seaf. explain*. Available at: https://sustainablefisheries-uw.org/flawed-mpa-science-retracted/ (Accessed December 29, 2021).

MSC (2022). *Marine stewardship council fisheries standard, version 3.0 (26 October 2022)* (London: Marine Stewardship Council). Available at: https://www.msc.org/docs/default-source/default-document-library/for-business/program-documents/fisheries-program-documents/msc-fisheries-standard-v3-0.pdf?sfvrsn=53623a3_21.

Murray, G., Neis, B., Palmer, C. T., and Schneider, D. C. (2008a). Mapping cod: Fisheries science, fish harvesters' ecological knowledge and cod migrations in the northern gulf of st. Lawrence. *Hum. Ecol.* 36, 581–598. doi: 10.1007/s10745-008-9178-1

Murray, G., Neis, B., Schneider, D. C., Ings, D., Gosse, K., Whalen, J., et al. (2008b). "Opening the black box: Methods, procedures and challenges in the historical reconstruction of marine socio-ecological systems," in *Making and moving knowledge*. Eds. J. S. Lutz and B. Neis (Montreal & Kingston: McGill-Queen's University Press), 100–120.

Nachmias, D., and Frankfort-Nachmias, C. (1976). *Research methods in the social sciences* (New York: St. Martin's Press).

Napier, I. R. (2014). *Fishers' north Sea stock survey 2014* (NAFC Marine Centre: University of the Highlands and Islands).

Neis, B. (1992). Fishers' ecological knowledge and stock assessment in Newfoundland. *Newfoundl. Stud* 8, 155–178. Available at: https://journals.lib.unb.ca/index.php/nflds/article/view/926/1279.

Neis, B., and Felt, L. (2000). *Finding our sea legs: Linking fishery people and their knowledge with science and management* (St. John's, Newfoundland: ISER Books).

Neis, B., Schneider, D. C., Felt, L., Haedrich, R. L., Fischer, J., and Hutchings, J. A. (1999). Fisheries assessment: What can be learned from interviewing resource users? *Can. J. Fish. Aquat. Sci.* 56, 1949–1963. doi: 10.1139/f99-115

Nielsen, J. R., Thunberg, E., Holland, D. S., Schmidt, J. O., Fulton, E. A., Bastardie, F., et al. (2018). Integrated ecological–economic fisheries models–evaluation, review and challenges for implementation. *Fish Fish* 19, 1–29. doi: 10.1111/faf.12232

NPRB (2021). *Conflict of interest policy north pacific research board* (Anchorage, AK: North Pacific Research Board). Available at: https://www.nprb.org/assets/uploads/files/General_NPRB/NPRB_coi_policy_final.pdf.

NPWG (2016a). *Code of conduct for industry affiliated scientists attending ICES expertgroups, benchmarks and workshops (1 august 2016)* (Brussels: Northern Pelagic Working Group). Available at: https://scottishpelagic.co.uk/wp-content/uploads/2021/06/Code-of-Conduct-for-Industry-Affiliated-Scientists.pdf.

NPWG (2016b). *Code of conduct for industry observers attending benchmarks, data compilation workshops, review and advice drafting groups plus ACOM meetings (1 august 2016)* (Brussels: Northern Pelagic Working Group). Available at: https://scottishpelagic.co.uk/wp-content/uploads/2021/06/Code-of-Conduct-for-Industry-Observers.pdf.

Nursey-Bray, M., Fidelman, P., and Owusu, M. (2018). Does co-management facilitate adaptive capacity in times of environmental change? insights from fisheries in Australia. *Mar. Policy* 96, 72–80. doi: 10.1016/j.marpol.2018.07.016

O'Brien, T. (2022). *DFO scientists' union says members' work in N.L. undermined by industry and political interference* (Toronto: CBC News). Available at: https://www.cbc.ca/news/canada/newfoundland-labrador/dfo-scientists-union-1.6322758.

Owen, R., Macnaghten, P., and Stilgoe, J. (2012). Responsible research and innovation: From science in society to science for society, with society. *Sci. Public Policy* 39, 751–760. doi: 10.1093/scipol/scs093

Palmer, C. T., and Sinclair, P. R. (1997). *When the fish are gone: Ecological collapse and the social organization of fishing in Northwest newfoundland 1982-1995* (Blackpoint (Nova Scotia): Fernwood Publishing).

Palsson, G. (2000). "Finding one's sea legs: Learning, the process of enskilment, and integrating fishers and their knowledge into fisheries science and management," in *Finding our sea legs: Linking fishery people and their knowledge with science and management*. Eds. B. Neis and L. Felt (St. John's (NL, CA: ISER Books), 26–40.

Papworth, S. K., Rist, J., Coad, L., and Milner-Gulland, E. J. (2009). Evidence for shifting baseline syndrome in conservation. *Conserv. Lett.* 2, 93–100. doi: 10.1111/J.1755-263X.2009.00049.X

Pastoors, M. A. (2021). *Report on 2020 scientific research projects* (Zoetermeer: Pelagic Freezer-trawler Association). Available at: https://pelagicfish.eu/media/pdf/PFA 2021_01reporton2020scientificresearchprojects.pdf.

Pastoors, M. A., and Hintzen, N. (2020). CPUE standardization for the offshore fleet fishing for jack mackerel in the SPRFMO area. *SPRFMO SC8-JM02*, 43.

Paterson, B., Neis, B., and Stephenson, R. L. (2018). A social-ecological study of stock structure and fleet dynamics in the Newfoundland herring fishery. *ICES J. Mar. Sci.* 75, 257–269. doi: 10.1093/icesjms/fsx097

Patterson, K. R. (1998). Assessing fish stocks when catches are misreported: Model, simulation tests, and application to cod, haddock, and whiting in the ICES area. *ICES J. Mar. Sci.* 55, 878–891. doi: 10.1006/jmsc.1998.0351

Pauly, D. W., Hilborn, R., and Branch, T. A. (2013). Fisheries: Does catch reflect abundance? *Nature* 494, 303–306.

Pennington, M., and Helle, K. (2011). Evaluation of the design and efficiency of the Norwegian self-sampling purse-seine reference fleet. *ICES J. Mar. Sci.* 68, 1764–1768. doi: 10.1093/icesjms/fsr018

Perry, R. I., and Ommer, R. E. (2003). Scale issues in marine ecosystems and human interactions. *Fish. Oceanogr.* 12, 513–522. doi: 10.1046/j.1365-2419.2003.00254.x

Poos, J. J., Aarts, G., Vandemaele, S., Willems, W., Bolle, L. J., and van Helmond, A. T. M. (2013). Estimating spatial and temporal variability of juvenile north Sea plaice from opportunistic data. *J. Sea Res.* 75, 118–128. doi: 10.1016/j.seares.2012.05.014

Pope, J. G., Hegland, T. J., Ballesteros, M., Nielsen, K. N., and Rahikainen, M. (2019). Steps to unlocking ecosystem based fisheries management: Towards displaying the n dimensional potato. *Fish. Res.* 209, 117–128. doi: 10.1016/j.fishres.2018.07.023

Power, M. J., Clark, K. J., Fife, F. J., Knox, D., Melvin, G. D., and Stephenson, R. L. (2007). *2007 evaluation of 4VWX herring. CSAS research document 2007/040* (New Brunswick: Canadian Science Advisory Scretariat).

Quirijns, F. J., and Pastoors, M. A. (2020). CPUE standardization for greater silversmelt in 5b6a. WD03 for ICES WKGSS benchmark workshop on greater silver smelt. In *Benchmark workshop of greater silversmelt (WKGSS; outputs from 2020 meeting). ICES scientific reports* (Copenhagen: International Council for the Exploration of the Sea) 3 (5), 192–209.

Raicevich, S., Dubois, M., Bullo, M., Franceschini, G., Mion, M., Nalon, M., et al. (2020). "The Italian job: Navigating the (im)perfect storm of participatory fisheries research in the northern Adriatic Sea," in *Collaborative research in fisheries: Co-creating knowledge for fisheries knowledge in Europe*, vol. vol 22 . Eds. P. Holm, M. Hadjimichael, S. Linke and S. Mackinson (Cham: Springer), 121–140. doi: 10.1007/978-3-030-26784-1_8

Raicevich, S., Fortibuoni, T., Franceschini, G., Celic, I., and Giovanardi, O. (2009). *The use of local ecological knowledge to reconstruct the history of marine animal populations: Potential and limitations. in when humanities meet ecology. historic changes in Mediterranean and black Sea marine biodiversity and ecosystems since the Roman period until nowadays. languages, methodologies and perspectives. proceedings of the international HMAP Mediterranean and bl.* Eds. R. Gertwagen, T. Fortibuoni, O. Giovanard, S. Libralato, C. Solidoro and S. Raicevich (Rome: ISPRA), 81–94.

Reid, D. G., Allen, V. J., Bova, D. J., Jones, E. G., Kynoch, R. J., Peach, K. J., et al. (2007). Anglerfish catchability for swept-area abundance estimates in a new survey trawl. *ICES J. Mar. Sci.* 64, 1503–1511. doi: 10.1093/icesjms/fsm106

Reid, D. G., Graham, N., Rihan, D. J., Kelly, E., Gatt, I. R., Griffin, F., et al. (2011). Do big boats tow big nets? *ICES J. Mar. Sci.* 68, 1663–1669. doi: 10.1093/icesjms/fsr130

Ressler, P. H., G.W., F., Wespestad, V. G., and Harms, J. (2009). Developing a commercial-vessel-based stock assessment survey methodology for monitoring the U.S. west coast widow rockfish (Sebastes entomelas) stock. *Fish. Res.* 99, 63–73. doi: 10.1016/j.fishres.2009.04.008

Rice, J. C. (2011). Advocacy science and fisheries decision-making. *ICES J. Mar. Sci.* 68, 2007–2012. doi: 10.1093/icesjms/fsr154

Rochette, R., Sainte-Marie, B., Allain, M., Baker, J., Bernatchez, L., Boudreau, V., et al. (2018). The lobster node of the CFRN: Co-constructed and collaborative research on productivity, stock structure, and connectivity in the American lobster (Homarus americanus). *Can. J. Fish. Aquat. Sci.* 75, 813–824. doi: 10.1139/cjfas-2016-0426

Röckmann, C., van Leeuwen, J., Goldsborough, D., Kraan, M., and Piet, G. (2015). The interaction triangle as a tool for understanding stakeholder interactions in marine ecosystem based management. *Mar. Policy* 52, 155–162. doi: 10.1016/j.marpol.2014.10.019

Rose, G. A., and Kulka, D. W. (1999). Hyperaggregation of fish and fisheries: How catch-per-unit-effort increased as the northern cod (Gadus morhua) declined. *Can. J. Fish. Aquat. Sci.* 56, 118–127.

Rowley, J. (2007). The wisdom hierarchy: Representations of the DIKW hierarchy. *J. Inf. Sci.* 33, 163–180. doi: 10.1177/0165551506070706

Schadeberg, A., Kraan, M., and Hamon, K. (2021). Beyond métiers: Social factors influencing fisher behaviour. *ICES J. Mar. Sci* 78, 1530–41. doi: 10.1093/icesjms/fsab050

Schram, E., Hintzen, N., Batsleer, J., Wilkes, T., Bleeker, K., Amelot, M., et al. (2021). *Industry survey turbot and brill in the north Sea: Set up and results of a fisheries-independent survey using commercial fishing vessels 2018-2020* Vol. C037 (IJmuiden: Wageningen Marine Research report), 21. doi: 10.18174/544588

Shackeroff, J. M., and Campell, L. M. (2007). Traditional ecological knowledge in conservation research: Problems and prospects for their constructive engagement. *Conserv. Soc* 5, 343–360.

Slooten, E., Simmons, G., Dawson, S. M., Bremner, G., Thrush, S. F., Whittaker, H., et al. (2017). Evidence of bias in assessment of fisheries management impacts. *Proc. Natl. Acad. Sci. U. S. A.* 114, E4901–E4902. doi: 10.1073/pnas.1706544114

Smith, A. D. M., Fulton, E. J., Hobday, A. J., Smith, D. C., and Shoulder, P. (2007). Scientific tools to support the practical implementation of ecosystem-based fisheries management. *ICES J. Mar. Sci.* 64, 633–639. doi: 10.1093/icesjms/fsm041

Spijkers, J., and Boonstra, W. J. (2017). Environmental change and social conflict: the northeast Atlantic mackerel dispute. *Reg. Environ. Change* 17, 1835–1851. doi: 10.1007/s10113-017-1150-4

Stange, K. (2017). *Knowledge production at boundaries: an inquiry into collaborations to make management plans for European fisheries (PhD dissertation)* (Wageningen: Wageningen University and Research). doi: 10.18174/402072

Stanley, R. D., and Rice, J. C. (2007). "Fishers' knowledge? why not add their scientific skills while you are at it?," in *Fishers' knowledge in fisheries science and management*. Eds. N. Haggan, B. Neis and I. G. Baird (Paris: UNESCO Publishing), 401–420.

Starr, P. (2010). Fisher-Collected sampling data: Lessons from the new Zealand experience. *Mar. Coast. Fish.* 2, 47–59. doi: 10.1577/c08-030.1

Starr, P., Annala, J. H., and Hilborn, R. (1998). Contested stock assessment: Two case studies. *Can. J. Fish. Aquat. Sci.* 55, 529–537. doi: 10.1139/f97-230

Steenbergen, J., Trapman, B. K., Steins, N. A., and Poos, J. J. (2017). The commons tragedy in the north Sea brown shrimp fishery: How horizontal institutional interactions inhibit a self-governance structure. *ICES J. Mar. Sci.* 74, 2004–2011. doi: 10.1093/icesjms/fsx053

Steenbergen, J., Van Kooten, T., Van de Wolfshaar, K. E., Trapman, B. K., and Kraan, M. (2015). *Management options for brown shrimp (Crangon crangon) fisheries in the north Sea* Vol. C181 (IJmuiden: IMARES WageningenUR Rapport), 15. Available at: https://edepot.wur.nl/366175.

Steins, N. A., Kraan, M., van der Reijden, K. J., Quirijns, F. J., van Broekhoven, W., and Poos, J. J. (2020a). Integrating collaborative research in marine science: Recommendations from an evaluation of evolving science-industry partnerships in Dutch demersal fisheries. *Fish Fish.* 21, 146–161. doi: 10.1111/faf.12423

Steins, N. A., Toonen, H. M., and Delaney, A. E. (2020b). Commentary 1 to the manifesto for the marine social sciences: fisheries. *Marit. Stud* 19, 125–127. doi: 10.1007/s40152-020-00181-3

Stenevik, E. K., Høines, Å., Kvamme, C., Otterå, H., Salthaug, A., and Svendsen, B. V. (2020). "Fangstprøvelotteriet 2019," in *Rapport fra havforskningen 2020-17* (Bergen: Havforskningsinstituttet). Available at: https://www.hi.no/hi/nettrapporter/rapport-fra-havforskningen-2020-17.

Stephenson, R. L., Hobday, A. J., Allison, E. H., Armitage, D., Brooks, K., Bundy, A., et al. (2021). The quilt of sustainable ocean governance: Patterns for practitioners. *Front. Mar. Sci.* 8. doi: 10.3389/fmars.2021.630547

Stephenson, R. L., Paul, S., Pastoors, M. A., Kraan, M., Holm, P., Wiber, M., et al. (2016). Integrating fishers' knowledge research in science and management. *ICES J. Mar. Sci* 73, 1459–65. doi: 10.1093/icesjms/fsw025

Stephenson, R. L., Paul, S., Wiber, M., Angel, E., Benson, A. J., Charles, A., et al. (2018). Evaluating and implementing social–ecological systems: A comprehensive approach to sustainable fisheries. *Fish Fish.* 19, 853–873. doi: 10.1111/faf.12296

Stephenson, R. L., Power, M. J., Laffan, S. W., and Suthers, I. M. (2015). Tests of larval retention in a tidally energetic environment reveal the complexity of the spatial structure in herring populations. *Fish. Oceanogr.* 24, 553–570. doi: 10.1111/fog.12129

Stephenson, R. L., Rodman, K., Aldous, D. G., and Lane, D. E. (1999). An in-season approach to management under uncertainty: The case of the SW Nova Scotia herring fishery. *ICES J. Mar. Sci.* 56, 1005–1013. doi: 10.1006/jmsc.1999.0555

Stilgoe, J., Owen, R., and Macnaghten, P. (2013). Developing a framework for responsible innovation. *Res. Policy* 42, 1568–1580. doi: 10.1016/j.respol.2013.05.008

St. Martin, K., McCay, B. J., Murray, G. D., Johnson, T. R., and Oles, B. (2007). Communities, knowledge and fisheries of the future. *Int. J. Glob. Environ. Issues* 7, 221–239. doi: 10.1504/IJGENVI.2007.013575

Strand, M., Ortega-Cisneros, K., Niner, H. J., Wahome, M., Bell, J., Currie, J. C., et al. (2022). Transdisciplinarity in transformative ocean governance research–reflections of early career researchers. *ICES J. Mar. Sci.* 79, 2163–2177. doi: 10.1093/icesjms/fsac165

Su, S., Tang, Y., Chen, J., Chang, B., and Chen, Y. (2021). A comprehensive framework for operating science-based fisheries management: A checklist for using the best available science. *Fish Fish.* 22, 798–811. doi: 10.1111/faf.12551

Suuronen, P., and Gilman, E. (2020). Monitoring and managing fisheries discards: New technologies and approaches. *Mar. Policy* 116, 103554. doi: 10.1016/j.marpol.2019.103554

SWFPA, and SFA (2021). "ICES-plus: Scientific advice in fisheries management," in *Policy paper* (Fraserburgh: Scottish White Fish Producers Association Ltd & Shetland Fishermen's Association), vol. 4. Available at: https://www.shetlandfishermen.com/site/assets/files/1918/sfa_p4-_ices-plus.pdf.

Thompson, S. A., Stephenson, R. L., Rose, G. A., and Paul, S. D. (2019). Collaborative fisheries research: The Canadian fisheries research network experience. *Can. J. Fish. Aquat. Sci.* 76, 671–681. doi: 10.1139/cjfas-2018-0450

Tress, G., Tress, B., and Fry, G. (2005). Clarifying integrative research concepts in landscape ecology. *Landsc. Ecol.* 20, 479–493. doi: 10.1007/s10980-004-3290-4

UN (2015). *Transforming our world: The 2030 agenda for sustainable development (A/RES/70/1)* (New York: United Nations). Available at: https://www.un.org/ga/search/view_doc.asp?symbol=A/RES/70/1&Lang=E.

Van Helmond, A. T. M., Chen, C., Trapman, B. K., Kraan, M., and Poos, J. J. (2016). Changes in fishing behaviour of two fleets under fully documented catch quota management: Same rules, different outcomes. *Mar. Policy* 67, 118–129. doi: 10.1016/j.marpol.2016.01.029

Van Helmond, A. T. M., Mortensen, L. O., Plet-Hansen, K. S., Ulrich, C., Needle, C. L., Oesterwind, D., et al. (2020). Electronic monitoring in fisheries: Lessons from global experiences and future opportunities. *Fish Fish.* 21, 162–189. doi: 10.1111/faf.12425

Wätjen, K., and Ramírez-Monsalve, P. (2020). "Aiming for by-catch: Collaborative monitoring of rare and migratory species in the wadden Sea," in

Collaborative research in fisheries: Co-creating knowledge for fisheries knowledge in Europe, vol. vol 22. (Cham: Springer), 105–120. doi: 10.1007/978-3-030-26784-1_7

Wendt, D. E., and Starr, R. M. (2009). Collaborative research: An effective way to collect data for stock assessments and evaluate marine protected areas in California. *Mar. Coast. Fish.* 1, 315–324. doi: 10.1577/c08-054.1

Wijermans, N., Boonstra, W. J., Orach, K., Hentati-Sundberg, J., and Schlüter, M. (2020). Behavioural diversity in fishing: Towards a next generation of fishery models. *Fish Fish.* 21, 872–890. doi: 10.1111/faf.12466

Wilson, D. C. (2009). *The paradoxes of transparency: Science and the ecosystem approach to fisheries management in Europe* Vol. vol 5 (Amsterdam: Amsterdam University Press).

Wilson, D. C., and Degnbol, P. (2002). The effects of legal mandates on fisheries science deliberations: The case of Atlantic bluefish in the united states. *Fish. Res.* 58, 1–14. doi: 10.1016/S0165-7836(01)00366-6

Winter, A. M., and Hutchings, J. A. (2020). Impediments to fisheries recovery in Canada: Policy and institutional constraints on developing management practices compliant with the precautionary approach. *Mar. Policy* 121, 104161. doi: 10.1016/j.marpol.2020.104161

Woo, J., Rossiter, T., and Woolmer, A. (2013). *Lyme Bay fully documented fisheries trial* (London: Blue Marine Foundation). Available at: https://www.lymebayreserve.co.uk/download-centre/files/Lyme_Bay_Fully_Documented_Fisheries_Trial_Final_Report.pdf.