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Knowledge production at the science–policy interface: Lessons from fisheries scientists

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Abstract

While fisheries science in the USA has in the past been dominated by mode 1 knowledge production that is discipline-specific and focused on basic research, it has increasingly opened up to concerns with relevance, participation, and interdisciplinary inquiry. We consider how this transition has been experienced through the analysis of oral histories conducted with marine scientists, looking at the changes they have seen to their role as scientists and to the practice of doing science at the interface of knowledge production and policy. In particular, we examine scientists' ideas about and experiences of collaboration, public responsibility, freedom and politics in science, diversity and outreach, involvement, and relevance to society. In so doing, we explore the implications of the co-production of science and policy as traditional domain boundaries are increasingly problematized.

Key words: co-production; collaboration; interdisciplinary science; mode 2 science; participation; science–policy interface; sustainability science

1. Introduction

Fisheries management straddles the worlds of science and policy. It does so in a context where the traditional Mertonian version of science—as objective, disinterested, done in good faith but removed from society—has been challenged by changes in scientific practice, characterized variously as mode 2 science (Gibbons et al. 1994), post-normal science (Funtowicz and Ravetz 1993), regulatory science (Jasanoff 1990) to the triple helix (Etzkowitz and Leydesdorff 2000). Though critics have debated to what extent these are truly well-grounded and novel changes (see reviews in Hessels and van Lente 2008, Shinn 2002), the practices they have highlighted are also especially critical in the sustainability sciences that require moving 'knowledge into societal action' (Kates 2011). These include looser boundaries between science and society, participatory involvement at different levels of research, interdisciplinarity, and the importance of relevance and applicability. As Cornell et al. (2013: 61) write, tackling problems marked by complex social–ecological interactions requires knowledge system open up and address the 'interface between science and policy, communication and outreach'. This implies finding ways to collectively and transparently determine, frame, and review research agendas and processes in a way 'that accommodates a diversity of values, and effective processes for stakeholder and dialog participation' (Cornell et al. 2013: 63). Such expanded involvement can enhance knowledge of community concerns, widen enquiry to causes and consequences of environmental problems, and 'enable a more multifaceted knowledge base' (Berg and Lidskog 2018: 8).

The scholarly work addressing this science–policy interface has relied on the concept of boundary work, first discussed by Gieryn (1983) as a means to illuminate the ideological work involved in distinguishing 'science' from 'non-science'. While science studies have long noted how scientific work is 'thoroughly social' (Sismondo 2004), this implies not the collapse of the distinction between science and politics but rather recognition of 'how problematic this distinction is. The social relations that science involves necessarily influence both the character of scientific understandings upstream and the particular political outcomes that may result from them downstream in legislation' (Demeritt 2001: 309). Thus, in seeking to understand how to reconcile different views emerging at the science–policy interface, many scholars have noted the importance—and the tricky balancing act entailed—of actively managing the boundaries between science and policy. As Cash et al. (2003: 8089) write, successful efforts devote time and attention not just to knowledge production but also to 'communication, translation, and or mediation' in order to negotiate the inevitable trade-offs between 'salience, credibility, and legitimacy'. Clark et al. (2016) explain how too rigid boundaries impede 'meaningful communication' such that research might not address decision-maker needs, while too porous boundaries risk both politicizing science to 'support decisions . . .already made and scientizing politics by hiding value-laden decisions behind technical pronouncements' (Clark et al. 2016: 4617). They too write that key to successful boundary management is genuine involvement and accountability in setting research agendas and systems of governance, as well as finding concrete boundary objects such as reports and maps around which collaboration can be structured (Clark et al. 2016: 4615).

In this regard, fisheries are especially instructive. Fisheries science and policy across the globe are dominated by institutions where knowledge production involves actors from within and between different organizations—both public and private, management involves varying degrees of involvement of scientists, regulators, and fishermen, and interest in community-based forms of management and fishermen's knowledge has a long scholarly history (Hind 2015; Sen and Nielsen 1996). Nonetheless, as Holm (2003: 6) has argued, the positivist ideals of Mertonian or mode 1 science have still been important sources of legitimization for fisheries science precisely because of uncertain and contested boundaries between science and policy, and nature and society, so typical of regulatory sciences (Jasanoff 1990). When boundaries are tightly maintained, different role identities between scientists and managers that variously stress 'credibility' or 'applicability' can strain 'communication and co-operation' (Delaney and Hastie 2007). Legitimacy can be undermined without transparency about the multiplicity of roles engaged in (Dankel et al. 2016), while different ways of evaluating the validity of knowledge claims are further impacted by legal and institutional constraints on what evidence can even be brought to the table (Wilson 2003). Moreover, the confrontational debates that often mark fisheries can lead to drawing ever harder and more defensive boundaries between what is viewed as the objectivity of science and subjectivity of policy. The effect, as Demeritt (2001) has written in the context of climate research, is to undermine more 'reflexive engagement', both because the uncertainties inherent to scientific advice may not be fully appreciated by downstream policy users (Demeritt 2001: 327), and because of a tendency to rely on 'narrowly technical problem formulations' that 'offer the seductive promise of unimpeachably scientific solutions to contentious political problems' (Demeritt 2001: 328).

We consider these issues using oral histories of a cadre of marine scientists, the majority at or nearing retirement age, who experienced the transition of government-sponsored marine research from basic and exploratory science to directly applied and policy-relevant assessments. Oral histories, given the dialogic and conversational nature of their creation, are particularly valuable for eliciting meanings of the past and their impact on community identities, including communities of scientists. They also provide unique insight into 'traditionally invisible members of scientific communities' such as women and other underrepresented groups, insight into 'largely unexplored dimensions of scientific activity' such as life outside the laboratory, 'the role of tacit knowledge', that is, commonly held ways of understanding and doing that are usually not explicitly verbalized, 'community traditions and communication patterns', and the 'dynamics of research institutions' (Doel 2003: 359–62). Using oral histories of marine scientists at National Oceanic and Atmospheric Administration (NOAA) Fisheries, the governmental agency responsible for management of marine resources in US federal waters,[1] this article explores how these scientists have understood their role in, the changes they have seen to, and what it means to do science at the interface of knowledge production and policy. The interviews illustrate the struggle to negotiate moving boundaries and changing concerns that have arisen over the history of the agency as it or the problems it addresses have evolved, involving boundaries-in-motion between science and policy (particularly the change from a top-down technocratic style to one with varying degrees of user input), between scientific disciplines (as fisheries management has moved from primarily fisheries biology to, with varying degrees, more interdisciplinary analyses), and between scientific and folk knowledge (where boundaries center on issues of theoretical and practical expertise). In particular, we examine how scientists' self-understandings and world-views, particularly the ethical commitments they bring to their work, imbue the visions they have of the role of science today, and consider how these understandings might inform building up the institutions, practices, and relations necessary for sustainable futures.

2. Methods

This study is based on ninety semi-structured, oral history interviews that were conducted during the summer of 2016 with predominantly natural scientists employed or previously employed primarily at NOAA's regional Fishery Science Centers. The initial project was exploratory with the objective to capture institutional knowledge and insight into changes in the practice of science, documenting such perspectives as archival sources of information. Interviews were sought with scientists who helped advance the scientific or institutional development of the agency, as determined by a team of social scientists and key informants across the National Marine Fisheries Service (NMFS). Seventy of the interviewees were male and twenty were female; interviews were sought with early female scientists in the agency, but the predominance of white, male interviewees reflects the demographics of the retiring cohort. Age was given in just over half of the interviews, with age at the time of interview ranging from forty-nine to ninety-three. Thirty gave a birthdate in the 1940s or earlier, thirteen in the 1950s, and three in the 1960s. Using other information given, another thirty-one interviewees were still working in their 1950s and 1960s, and the remaining thirteen were retired or of retirement age. The majority of interviewees (seventy-five) were natural scientists, with seven social scientists, three engineers, and five working in administrative and legal posts also interviewed. Given that retiring scientists were targeted, their perspectives on institutional transformations in the agency were especially sought. Thus questions concerned the scientists' scholarly output, context of work, changes in the marine sciences, as well as questions into the broader context of their lives. Interviews were semi-structured and questions were open-ended, following the interests of the interviewee and the dialogue created with the interviewer.

Interviews were conducted by a team of social scientists and then recorded, transcribed, and made publicly available via the Voices from the Fisheries oral history database (www.voices.nmfs.noaa.gov), with written permission from interviewees. (Although none of the histories in this project are anonymous, we have followed common practice in qualitative social analysis by identifying interviewees not by name but rather with the transcriptions' numbering system, using page number to identify excerpt location.) The transcriptions were subsequently coded and analyzed for this study using MAXQDA, software designed for qualitative and mixed methods analysis of textual data, to identify, organize, and analyze prominent themes. Such coding necessarily involves the judgment of the analyst, but in this case preliminary coding was also informed by emerging themes discussed in team meetings of oral historians involved in the project.

In addition to charting historical changes in the agency and the sciences, important themes to emerge during analysis of the oral histories include collaboration, responsibility, politics in science, diversity, outreach, involvement, and relevance to society. In a previous paper, we have detailed these historical changes, discussing the influence of institutional changes and regional differences on scientific work, the increasing use of mathematical modelling, and new changes incorporating ecosystems and human communities (Olson and Pinto da Silva 2019). Here, we would like to focus on what interviewees identified or talked about as emerging trends in fisheries science and policy, trends that many viewed with hopefulness in the face of threatened environments and skeptical publics. We begin, however, in the next section by setting the stage for these new openings by describing the shift that occurred in NOAA Fisheries when legislative changes moved the agency from a focus on basic scientific research to a more regulatory stance. These changes would come to have a profound impact on scientific practices in the agency, resulting 'in a nationalization of resources that changed the political nexus from Cold War to domestic politics, and a shift in emphasis from more basic or exploratory science to stock assessment efforts that directly interfaced with management needs' (Olson and Pinto da Silva 2019: 373).

3. Discussion

3.1 From disconnect to deliberation

The most significant transformations that occurred during the careers of most of the scientists interviewed occurred in the late 1970s, with the creation of NOAA, NMFS, and the passage of the Fishery Conservation and Management Act (later known as the Magnuson-Stevens Act), which extended the EEZ to 200 miles and enacted the regional council system that would govern these waters. As described earlier, in this system federal fisheries are collaboratively managed by eight regional fisheries management councils made up of appointees from the fishing industry and other interested parties such as environmental groups, as well as government officials. These councils rely on biological, social, economic, and other scientific advice provided by NOAA's regional fisheries science centers. While the close connection between councils and users was described by one scientist as a 'pioneering experiment in self-governance or co-management' (6489: 13), its early days were viewed critically by many of the participating scientists. While the pre-Magnuson era also saw conflict over scientific advice (e.g. 5854: 24–25; 6493: 10), many scientists in New England especially felt that 'there was not too much interest in really regulating ... they really weren't interested in our assessments because they figured they weren't needed' (5854: 27). As another recalled, 'Their attitude at the time was catch as many fish as possible or we'll all go out of business .... We had no clout to do anything' (6839: 12–13). Early conflict between scientists and industry over local or foreign contributions to overfishing (6489: 8) continued in the 1980s and 1990s with reviews and court actions: 'there was conflict between NOAA Fisheries and the fishermen and the council in terms of how we would rebuild the stocks. That went on for years .... I think there was always a conflict between the science and the council and the industry about how much we needed to do' (6451: 9; see also 6031: 8).[2]

The transition to NFMS and the council system thus instigated a very different relationship with the fishing industry, as many found their scientific work newly scrutinized by a skeptical public. Yet the effects from the Magnuson transition were regionally and temporally uneven. Scientists in the Pacific region, for example, continued to focus on fisheries development and exploration long after those in the Northeast turned to population dynamics, stock assessments, and increased regulation. Meanwhile, many satellite labs that had previously focused on ecological or aquaculture concerns found budgets squeezed with an increasing imperative to link research endeavors more tightly with perceived management needs (see Olson and Pinto da Silva (2019: 375–7) for a fuller discussion of regional differences). In the midst of these differential engagements, those in less politicized contexts tended to interpret engagement—even difficult encounters—as being more democratic than partisan, suggesting the importance of 'local social orders' in shaping the science–policy interface (Meehan et al. 2018). In terms of the changes experienced with the new council system, a biologist in the Southeast recalled how '[Magnuson] brought the understanding of what was going on more down to ... people who were actually doing the fishing ... rather than being remotely handled in Washington ... it made it more of a democratic system. But I think to this day it seems to be working quite well. And you get, you know, people that don't, you know, win the arguments, they're always unhappy, but from a basic research point of view, at least our opinions as researchers were heard by those people. They didn't get shuffled off into Neverland' (6477: 7–8). In Hawaii, a social scientist agreed that 'it was really good the Magnuson Act was set up that way, to have stakeholders involved. I don't like the way that agencies that can hide behind formal processes do it. I like the contention of the fishery management council' (6465: 20). A national level science advisor concurred: 'If you're interested in conservation, there's probably no better place to be .... It takes a long time to do anything [in the councils], there's a lot of yelling, there's a lot of pain, but that's what democracy is' (5956: 29).

In the face of such competing perspectives, many scientists felt their role was to provide limits rather than specific mandates. One scientist recalled his realization that 'science really didn't do anything effective in the management arena ... unless it was applied and directed to that .... So I've spent most of my career sitting at that interface of science and policy ... not as an advocate, but as an analyst presenting a balanced picture of proposed management actions ... I did not come into it saying, you can't, you can't catch that many fish, look how bad it'll be. I just said, well, if you catch this many fish this'll happen, if you catch fewer fish, this'll happen. You make your decision' (5936: 7; see also 5930: 15; 6031: 13–14; 6429: 12). This traditional notion of neutrality relies on clear communications with competing audiences, as one scientist explained: 'at a scientific level, you want to be able to defend yourself scientifically. At the lay level you're trying to ... explain it in a broad sense, and ... at the management level you're trying to cover your ass ... answer the questions they ask you but also answer the questions they should've asked you because most, I mean like any political body, most questions they ask you are loaded' (6016: 15; see also 6839: 22; 5933: 6; 6034: 13–14). As Dankel et al. (2016) write, these traditional notions rely on 'increased formalization' of roles rather than 'enhanced reflective capacity' on the multiple demands placed on regulatory scientists, or as one scientist described : 'trying to be a neutral body and kind of just present the facts as much as possible and give multiple options ... the fisheries have a pretty solid culture of emphasizing science and a really strong division between science and policy which I think kind of protects the science from too much policy influence' (6413: 9; see also 6016: 17; 6039: 11–12).

Such notions of neutrality also result in strong boundary maintenance between science and management, in which science is only about facts and policy is only about values. But as Demeritt (2001: 308) has noted, 'One consequence of this rather conventional view of science as hermetically sealed off from politics is that very little attention has been paid to the cultural politics of scientific practice and its consequential role in framing' environmental problems. The import of such inherent problem-framing is seen with particular clarity in the face of multiple competing perspectives, for as one scientist recalled, 'I don't know that scientists have the same respect … they had in the past. It used to be that if you brought a scientist in and they gave you the information that, that would be the state of knowledge. But that's not necessarily the case anymore and so we have lots of scientists from different groups putting together what I will say are cases for, or arguments for any particular action [… and managers are] supposed to figure that out' (6453: 32). As Myanna Lahsen (2005: 142) has written, 'the liberating potential of exposure to a plurality of scientific pronouncements' has a limited impact on broadening participation in environmental decision-making or breaking down technocratic approaches if different perspectives are presented simply as facts needing no discussion. Instead, she writes that 'Purported scientific claims, as well as claims to expertise, need to be critically examined, not passively accepted; the contingent, negotiated character of both need to be recognized, leaving room for critical discussion. Such discussion will necessarily have to involve deliberation on better and worse sources of knowledge … As responsible citizens, we must learn how to recognize the difference and to define the general good by means of truly participatory processes' (Lahsen 2005: 161).

Movement toward these more deliberative and participatory processes has begun to emerge in approaches that grapple with ecosystem-based management, where knowledge that is more about possibility rather than direct control is co-evolving and co-produced at the science–policy interface (van den Hove 2007), a point to which we return later in this article. As one scientist involved with ecosystem-based modelling explained, scientific uncertainty inherent in such multifaceted modelling leads to a more fluid science–policy interface:

> here's the range of what's impossible, can't ecologically get there. Here's the range of scenarios or alternatives that would be really bad, would make you violate the law. And here's a range of scenarios that are okay, pick amongst those. That kind of it's not as precise as we might be used to, but that kind of broader level bounding the problem, scoping it out, is where we're headed … that, to me, is almost more important, to make sure we're not being very precise but inaccurate and missing a major driver just because we're not thinking about modeling it. (6432: 11–12; see also 5863: 9; 5944: 13)

As Kovacic (2018) suggests, following Mol (2008), such presentation of uncertainty can become a form of reflexivity that practices 'logics of care' that 'acknowledge the need for continuous engagement between a multiplicity of actors, with purposes that may go beyond decision-making and include social learning' (2018: 1058) rather than one-off provision of facts that stabilize conventional relations of power.

Yet for most scientists, one fundamental obstacle to that kind of engagement is, among other things, the intense pressure to provide a constant stream of management and legislatively-driven analyses (see also Delaney and Hastie 2007). As one said, 'what most stock assessment scientists would say is that the real challenge is that they don't have enough time for anything else but to turn the crank' (6448: 15; see also 5939: 7; 5961: 12; 6016: 28; 6122: 30; 6451: 7; 6489: 28). Such pressures, while ostensibly in the public interest and policy relevant, as mode 2 science would predict, were seen to preclude more thoughtful analysis. As one scientist explained, 'all the people are measuring is noise, because they're doing things … too quickly on the same thing [… with] too little information to try to do re-analyses, but they're demanded by the council. And more recently the law forces them to take it so they flip flop over things. You have big changes from one time to the next that probably aren't real' (5871: 8). Another described how: 'the real lifeblood for a research scientist is to do research, and do new things, not do the old things … so with more and more of these requirements and demands for doing this and doing that and somebody else thinking you should look at this and look at that, you have less and less time to do your own research' (6475: 21; see also 6453: 25). Before Magnuson, as one scientist recalled, 'we weren't driven by the needs of the management councils cause the management councils were just getting started, and it was really, I would say, a much more enjoyable time, because you'd just do good science? We looked at fish food habits because, well, we ought to do that. It wasn't because the management council wanted to know something' (6884: 5). He continued that 'We should be doing the science that's going to give them the answers five years from now … so we can come up with reasonable management decisions that actually sustain fisheries, rather than be reactive. For the whole of my career, and even to this day, I dare say that our management has been more reactive than proactive' (6884: 18).

3.2 Interdisciplinarity, collaboration, and the broadening of value

Many scientists expressed a desire to have relevance, impact policy, and serve the public good (5863: 24; 5880: 24; 5906: 5; 5922: 5; 5939: 14; 5947: 13–14; 5961: 5; 6029: 16; 6039: 12; 6416: 5; 6425: 13; 6428: 16; 6432: 6; 6473: 4; 6500: 9; 6784: 24). As one explained, 'to be a successful scientist and to have many dozens of published papers and all … that would not be enough. The real desire was to be able to have some impact on leaving the planet in a little bit better place' (6420: 16). This was motivated by a sense of urgency in the face of balancing conservation with utilization. One scientist explained, 'it was kind of cool to just think about basic ecology and what drives fish to do what they do, the real world was changing and changing really quickly so I then started doing more applied work' (5942: 4). Another noted the 'satisfaction from doing something that we know is contributing to not just the continued flourishing of these species but also deriving benefits from them. We're not creating preservation parks where no harvest is allowed' (5930: 14; see also 6125: 16). This meant 'you're trying to understand and make the best use of publicly owned resources. And so that's a pretty idealistic position to be in. It's a lot better than selling things on the street' (6034: 15).

The complexity this entailed, coupled with often far-ranging policy implications, was commonly seen to demand an increasingly collaborative and interdisciplinary approach, which has challenged both the production of knowledge and its supporting organizational apparatus. One scientist stressed 'that collaboration, partnerships are essential for us to carry out our mission. I think for many years, the culture within the federal government … was, we felt like we had to do the work, right? All of the work … we weren't really reaching out as effectively to partners, to [stakeholders], to other organizations that are equally invested in the mission …That's something where I think there's been a really cultural change in the way we look at things' (6497: 22). She reflected on the work needed during negotiations to reduce ship strikes on marine mammals, where they relied on 'a diversity of expertise at the table. We could not have made it happen without the science. We could not have made it happen without a lawyer' (6497: 20). Similarly in efforts to reduce marine mammal takes in commercial fisheries, 'Data and information, trying to understand the other organization, agency, industry … we've got people with very different agendas …. Having them come together and try to work through these issues is challenging, but I think for the most part has been quite successful' (6497: 29). Such collaboration intimately involved not only working 'more cooperatively with other parts of the organization' but also engaging with how the public used and shaped science (6497: 30).

The practical difficulties encountered in this crossing of multiple domains and expertise also emerge in other 'wicked problems' marked by complex science, such as climate research. As one science director noted, 'The climate change issue has really brought a lot of people together because it's pushing us much harder to come up with new science' (5956: 21). As a scientist involved in coordinating climate change policies described, such changes imply the need for multidisciplinary scenario planning that concerns 'climate and physics and oceanography through to fishery biology, fishery management, and then out the other end to community well-being and social and economic science. That takes teams of people working across those disciplines and it takes a science enterprise that puts a premium on that kind of product' (6420: 14; see also 5898: 20; 6432: 10; 6489: 33), from directing budget and resources to an issue as well as bringing together otherwise piecemeal efforts. Concerted attention to the impacts from sediment and pollution run-off on coral reefs, for example, led to collaboration with other federal and state agencies and international experts, which 'empowered a network … that resulted in kind of collaborative efforts to identify the major threats to reefs in each of our jurisdictions …. We were able to do it and institutionalize that' (6420: 18–19).

Ecosystem-based work has also demanded collaborative and interdisciplinary efforts. Some of the scientists involved in early modeling efforts recalled the wide-ranging nature of those collaborations. In the Northeast, early efforts to compile the status of regional ecosystems were 'the first time we got the entire center involved in a project of that scale' (6451: 10). In Hawaii, a scientist explained how the development of the widely used Ecopath model evolved from its initial impetus to integrate disparate topics: 'we chose the island of French Frigate Shoals where people were studying 20 different compartments of the ecosystem. And so this model was a way to really do a budget to see … If that all made sense or if there were some gaps in the energy flow we were missing' (6457: 4). He continued that his own training as an ecosystem scientist evolved through working with these other scientists, where he 'gained an appreciation of a way of thinking about the ecosystem that I hadn't really had because I came from a statistical background and a modeling background' (6457: 5). Such learning across boundaries was echoed by another scientist involved in ecosystem management in the Pacific: 'we started learning from people, experts around the globe, who are facing the same challenges of overfishing, destructive fishing, land-based source of pollution, climate change … my team was there primarily to provide technical assistance and help build their capacity …. But I'd be the first to admit I think [I] learned more in that entire process' (5866: 15). For him, such work was not only collaborative but necessarily straddled science with public involvement: 'ecosystem-based management at the end of the day is really trying to achieve a balance between human wellbeing, the societal uses of these marine systems, and ecological wellbeing … good governance we believe needs to be based on sound science, of both the people side, and the ecological side' (5866: 11–12). As a microbiologist explained, 'we can't sit around in our own little disciplines anymore [you] have to talk to other people and learn how to communicate with them in order for your work to have value in a different field, you have to be able to talk to the people' (6473: 5).

But various constraints have structured the demands for and the nature of collaborations.[3] An oceanographer described how 'there's a lot more effort and interest in working across disciplines and working across organizations than there used to be … it's forced by budget … but I also think that many of the questions that we're struggling with truly are interdisciplinary. And so you have to work across to answer the question that you want to address' (5928: 7). He cited the need to understand the multiple factors affecting fisheries abundance to regain an ecosystemic perspective and 'develop long-term sustainable fisheries in the face of fishing, climate change, species interactions, and changes in habitat' (5928: 8). A microbiologist concurred that relevance demanded interdisciplinarity: 'One of the thing that has happened over the past five years or so is everybody's resources are getting reduced and … people are more willing to collaborate … to answer the bigger questions rather than everybody working in their own little areas or their own little niche' (6011: 9). She cited work to help shellfish growers that involved stakeholders as well as other government agencies 'to see what tools are needed by the growers to be able to do these forecasts [about bacteria …] we cannot all be modelers and forecasters or researchers … So that's kind of very encouraging to know that all the research we are doing is actually moving forward in an area that would be of benefit to the industry' (6011: 6). The temporal and spatial scale of these interdisciplinary questions demand 'a good teamwork environment … no one or even a small group of people could do it' (7130: 10; see also 5880: 24; 6019: 25–26). As another scientist explained, there is a lot of: 'basically deadly dull work in science … breakthroughs and so forth are usually the product of lots and lots of people doing relatively mundane kinds of things' (6471: 15).

While many wished to include more diverse backgrounds and work with 'people with different perspectives … most everything you see has five authors because that's how you build really exciting things' (6416: 17; see also 5922: 6; 5942: 7; 6014: 6; 6024: 10; 6411: 11; 6448: 4; 6500: 16; 6505: 10), underrepresented scientists, particularly in the social sciences, recounted their battles to also be included. An early anthropologist in the agency recalled: 'There was still, especially among the natural scientists, a little bit of concern that, you know, what do you really do, is this really science—I mean, the economists, they have models and equations, but are you just like, collecting anecdotes, or what are you doing? How is this science?' (5880: 5; see also 6407: 31; 6425: 18–19; 6784: 7). She continued that

> more and more in recent years—especially as Magnuson Act has added more and more pieces about ecosystem-based management—we've started to try to figure out how we can do joint work with the biologists and the oceanographers … I mean, initially we had to fight all the social scientists including the economists to be on say, the plan development teams so that we could input ideas early in the planning process rather than just being approached at the end …. Now, they've gotten kind of the idea

> that actually, if you're going to write something up we need to be there at the beginning and all work together to figure out how it works. (5880: 11–12; see also 6465: 14; 7130: 14)

Nonetheless, as a former policy director explained,

> NMFS and NOAA, their strengths are in the natural sciences. So, their ability to understand and relate to the constituents and the affected public, I think, is limited by sort of their disciplinary blinders ... we pay very little attention to some of those basic premises of social science and the importance of fisheries to communities and small businesses and aboriginal or customary uses. We're all about the stock assessments and we're all about the natural science of oceanography and understanding the fish, and very much less about the impacts and the consequences. (6425: 18-19)

3.3 Transparency, trust, and involvement

Despite the long history of research into the ecological knowledge of fishermen, it has seldom directly informed management. Hind (2015) argues that mainstream fisheries science must better integrate such different 'knowledge cultures' in order to address shortcomings and more fully inform new approaches to sustainable futures. Bailey et al. (2017) found that significant exchange of information and learning does occur in often informal settings, but 'genuinely integrated research is difficult and rare ... lay people most frequently participate in such projects as data collectors but fairly rarely in the formulation of research questions or the research design' (2017: 601; see also Hartley and Robertson 2008). Yet despite these longstanding boundaries, numerous interviewed scientists praised the unique knowledge fishermen gained from their constant presence in the water. As one scientist explained, 'I really like working with the fishermen because they're real; they're out there, they see. I come from a natural history field biologist background. So the closer I am to ... the fishermen, the more grounded I feel .... Otherwise you'll sit at your computer and apply your Leslie Matrices and have no idea whether you're really accomplishing anything' (5936: 8). Another described how 'you actually can't ask the right questions in the first place unless you have a real intuition for what's going on, right. And one way to get that intuition at the scale of the ecosystem is to work with fishermen and actually talk to them' (5947: 9; see also 5942: 12).

The history of more informal cooperation between the 19th century founders of marine biology and local fishermen was recalled as a rationale for modern cooperative research, 'to try to be a little bit more transparent with our work and involve the fishermen, and get a little more of a personal rapport between fishing community and the research scientists so that we understand each other's views more than we have in the recent past. I think if you go back early when Spencer Baird and the boys were there, back in the beginning of the Fish Commission and stuff, there was a better, more open relationship with the fishing community because we did rely on them to get information' (6884: 16–17; see also 5928: 10; 6031: 7; 6036: 11; 6475: 17; 6493: 21). In the applied aquaculture programs, scientists described how by working in close proximity with actual practitioners: 'we really get to know each other. We get to know what they're doing, and all the conversation that happens includes transferring scientific knowledge. And also getting questions back' (6500: 9; see also 5857: 8; 5860: 7). As another described methods learned by fishermen through trial and error (6887: 9), what emerged was a description of learning from fishermen's observations through respectful listening: 'I asked a lot of questions of the local people ... I listen to what they say, and I don't buy everything, but it's, I listen, I hear it, and do I hear it again? How about my own observations, does that jive with what I saw' (6887: 14)? Similarly, another biologist learned that by aggregating his data that he had mistakenly discounted fishermen's observations about different spawning seasons, a lesson that taught him 'the value of fishermen's knowledge', finding he could discuss different hypotheses in an 'exchanging and engaging kind of relationship that was, was wonderful' (6441: 11–12; see also 6451: 12; 6468: 12).

The exchange of information was also viewed as a responsibility to the public, as impacted fishermen have 'a lot of legitimate questions as well as a right to challenge these types of conclusions. So you do have a responsibility as a scientist to sort of take the time to work with them in a variety of ways' and to recognize that 'there are different ways of interpreting or trying to understand the data' that have social consequences (6471: 27). As a biologist who spent time working with native tribes noted, 'in many cases our western ideas of conservation, by western I mean white, rich, are just another form of colonialism. We are imposing our values and culture on another community and in doing so sometimes you have the opposite effect that you would want ... it launched me into doing a lot more social science myself or at least with others in close collaboration' (5942: 10–11; see also 6416: 7–8; 6438: 5). Such understandings of mutuality have also evolved as different groups have sought access to decision-making. One scientist recalled how past environmental groups 'created a lot of animosity' by suing instead of participating in the council process, but when they began to participate, 'The number of lawsuits dropped, the number of council actions that actually did what they wanted to do increased [... fishermen are also] concerned about having a fishery for their kids' future. So, they are often willing to listen to the same kind of arguments that motivates the environmental community if you don't demonize them' (6019: 19; see also 5930: 10; 6016: 29; 6443: 6). A scientist involved in the development of Large Marine Ecosystems (LMEs) expressed his optimism that efforts were succeeding precisely because they were 'a bottom up approach rather than top down' (6929: 14; see also 6471: 19). In addition to interdisciplinary involvement (6929: 12), international collaboration (6929: 12), and transparent indicators spanning natural, social, and governance domains (6929: 14), he noted the importance of 'persistent champions' and public support: 'now people talk about ecosystems and they talk about model projections and climate change on an everyday basis. So the public is tuned in and so are most politicians' (6929: 16).

Others saw it as incumbent among researchers to try to break down barriers with fishermen and the 'perception slash maybe misperception that the more science we do, the more uncertainty we uncover and then more restrictions they are going to be hit with' (6448: 23; though cf. 6909: 8–9 and 6471: 26–27 on disincentives for accurate data reporting). A scientist in the Northeast, where industry relations have often been strained, explained how controversy over the net configuration of a research vessel led to engaging 'in some very meaningful conversations with commercial fishery stakeholders that resulted in the establishment of a trawl survey advisory process' (5874: 12). He described how a fisherman designed a dredge that allowed scientists to capture differentially sized clams as 'a really beautiful thing. And to be honest with you, the industry paid to build it because they were interested in the science ... you start out with an industry that is at loggerheads with the government ... coming around to a situation where we're working very closely together, where they're asking, they're asking very legitimate questions . . . not just criticizing, you know, sort of standing shoulder to shoulder and saying, okay, we're going to help you find a solution to this' (5874: 17).

Using this particular event as a case study, Johnson and McCay (2012) discuss how the fragility of these collaborative processes stem in part from fundamentally different expectations about the nature of involvement and the degree of transparency that effective involvement requires. The scientist involved felt a keen desire to make the stock assessment process more 'inclusive', but also noted that 'it just takes longer . . . so we're constantly sort of working through that trade-off of saying, okay, do you want a lot of stock assessments, do you want more involved stock assessments, do you want more, uh, meaningful, you know, meaningful interaction with our stakeholders' (5874: 17–18). But as Johnson and McCay (2012) write, when communication was perceived to become 'one-way' and fishermen no longer felt involved in decisions or that their expertise was valued, collaboration broke down. Institutional constraints on allowable expertise and power differences in decision-making also served to maintain long-standing boundaries between science and non-science, to the detriment of collaboration (see also Clark et al. 2016; Wilson 2003).

Nonetheless, many scientists expressed awareness of the increasing need for participation, collaboration, and interdisciplinary perspectives to effectively manage today's highly-complex social–ecological systems. As one ecosystem scientist explained, 'We've moved from experts . . . to a community approach . . . it used to be, you'd get your Ph.D. and you were kind of a world authority in something. That's, that's not so much the case anymore. It really is kind of turning into a, to a community. This idea of citizen science, right?' (6453: 29).[4] He continued that science

> can't be just about understanding. It's moving to recovery, okay, you've got to have action . . . And recovering that population may have more to do with dealing with the people than dealing with the animals . . . . Prior, it was all science in the sense that, that it was about the animals, what they're eating, where they're going, and then what the population level was. So it's a different type of science . . . it's more than just the outreach, it's basically trying to understand, you know, why people are actually thinking the way they do. (6453: 30)

This need to understand and involve people, traditionally the domain of the social sciences, finds expression particularly among ecosystem scientists struggling to understand in a holistic fashion multiple factors that cross social and natural domains. For example, a scientist involved in the modelling of ecosystem processes described how the application of his work in an integrated ecosystem assessment involved listening to the issues and concerns of locals in an area with 'a diverse, very passionate community of users. We hold science symposiums over there and we get tremendous turnout from NGOs [non-governmental organizations], from federal and state agencies, but also . . . a lot of residents there that want to know about . . . uses of that ecosystem from tourism, fishing, cage culture, energy' (6457: 12). Another scientist expressed frustration that other scientists did not want to 'get their hands dirty by working with people in the industry' (5947: 15). Rather, he explained that

> you have to understand not just the effects of the ocean on the distribution of the animals and the dynamics of the fleet, but you have to understand the effects of global economics on fish prices and the incentive to fish in the first place. So, it gets very complicated and it's a wicked problem. It's not a deterministic system that you can come out with one solution and that's it. It's a process of sort of mining what's happening right now and coming up with the best solution in an environment where there's very little trust. But if you can find a few collaborators and develop very good relationships with them . . . you can go a long way . . . . Economics and ecology are not separate field, in the end. They're the same. That's the problem that we are walking into now, is that ecosystem science is all of it together and they're not independent. (5947: 9–10)

4. Conclusion

The implementation of the Magnuson-Stevens Act, with its collaborative structure of fisheries management, changed the nature of fisheries science and presented new challenges and opportunities for scientists to study, understand, and engage in the conservation of fisheries resources. The ninety oral histories reviewed for this study document how science practitioners have sought to understand complex and highly-dynamic social–ecological systems in a context marked by contested and politicized interpretations and values, in which they themselves are participants. In such a context, scholars have noted the importance of 'moving beyond panaceas' (Ostrom 2007) and avoiding the 'tunnel vision' of adhering too rigidly to any particular discipline (Degnbol et al. 2006). Fisheries problems are 'wicked problems' that 'have no technical solution, it is not clear when they are solved, and they have no right or wrong solution that can be determined scientifically. Instead . . . governance must rely on the collective judgment of stakeholders involved in a process that is experiential, interactive and deliberative' (Jentoft and Chuenpagdee 2009: 553).

Echoing changes that scholars of science have characterized as mode 2 science, fisheries scientists have increasingly engaged in multidisciplinary, applied, policy-driven, collaborative, and participatory knowledge production, crossing organizational, disciplinary, and national boundaries in efforts to address problems that are too big and complex for any single approach. But the history shared by these scientists also paints a picture of adaptation through compromise as they learn a different way of doing science and being a scientist. Scientists have had to learn how to adjust to, participate, and communicate in a co-managed council management system, but many have struggled with the politicization of their contributions, effective understanding of the diverse needs of stakeholders, and polarization over expertise, particularly in regions marked by a history of mistrust. Regulatory needs have had an increasing influence on the very science produced, bringing the potential for better matching research with decision-maker needs and incorporating diverse perspectives in the research framing process. Yet scientists also underlined clear disadvantages from policy-driven research that becomes reactive rather than proactive, and pulled by different and sometimes contradictory priorities. Legislative constraints that structure participation, as well as the different needs, values, and understandings that stakeholders bring to the table, have compounded the challenges to enacting participatory processes and highlighted the difficulty of boundary work at the science–policy interface.

But scientists interviewed articulated increasing awareness of the need for participation, collaboration, and interdisciplinary perspectives in the context of the wicked problems that dominate the sustainable management of social–ecological systems. Although the legacy of mistrust remains in many quarters, new modes of outreach, increased incorporation of diverse knowledge, and new involvement of the public mark different approaches to the science–

policy interface. Though further study is warranted on the public experience of these attempts, these oral histories offer particular insight and reflection on the changing nature of knowledge production in a rapidly-changing socio-environmental context as seen from the eyes of the scientists themselves, where the next generation of sustainability science will need to be less a solo act than an improvised synergy created with others. Their experiences and reflections point to the need to further foster diversity, communication, transparency, and the better integration of people, their values and their interpretations, into the full spectrum of knowledge production.

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Notes

1. NOAA Fisheries, also known as the National Marine Fisheries Service, is a US federal agency (part of the National Oceanic and Atmospheric Administration in the Department of Commerce) that is responsible for managing ocean resources and habitat in the US 200-mile Exclusive Economic Zone (EEZ). NOAA Fisheries comprises five regional offices that handle rule-making, permitting, and data management, six regional science centers that provide scientific advice through assessments and research, and numerous field stations and laboratories. Fisheries management is a key responsibility, but other responsibilities include conservation of protected resources such as marine mammals, safety inspection of seafood, and protection of critical habitat. These different responsibilities are governed by different legislation and thus involve differing regulatory processes. Protected species management, for example, is governed by the Endangered Species Act (ESA) and the Marine Mammal Protection Act (MMPA), and tends to involve 'consultations' between NOAA and other federal agencies. Fisheries management, on the other hand, involves partnership between NOAA Fisheries and regional Fishery Management Councils to develop regulatory measures. Councils include a variety of officials from different levels of government as well as local stakeholders with knowledge and interest in managed species. The regulatory process is governed by the Magnuson-Stevens Fishery Conservation and Management Act (MSA) as well as the National Environmental Policy Act (NEPA) and includes requirements to conduct public meetings, assess impacts from regulations, and conform to various standards such as reducing bycatch and considering impacts to communities.
2. Similarly, scientists spoke of congressional interference in management plans (6451: 19–20; 6489: 19); how research priorities, funding, and support could shift quickly after a change in leadership (6021: 14; 6471: 8; 6477: 14; 6500: 10–11; 6503: 19; 6884: 15); politically-driven influences on budgets (6475: 19; 6489: 37; 6884: 11), reviews (6016: 19–20), executive orders (6125: 16–17; 6465: 11), international agreements (6495: 13–14), legislative interpretation (6497: 13), and research framing (6122: 14; 6455: 8).
3. Budget constraints were frequently mentioned. Strategies pursued to cope with such constraints included cooperative research, outside funding, and research with external partners (6448: 16; 6453: 16–17; 6455: 9; 6465: 6; 6468: 5; 6493; 6884: 14–15). Many were also concerned that government scientists were increasingly subject to grant chasing and decreasing control over research budgets (5952: 7; 6429: 10; 6477: 17; 6884: 6). As one scientist explained, 'there's really problems with how science is funded in the U.S. and there's so much pressure to get another grant that I feel like that's the goal ... that doesn't necessarily produce the best science or the most quick science for use in application' (6475: 13; see also 6031: 5).
4. Burgeoning interest in citizen science reflects not only its long history in scientific enquiry (Silvertown 2009) but also such expected benefits from enhanced awareness to capacity building to site management (Cigliano et al. 2015). As one scientist explained, 'People learn more and care more about whatever they're working on' (6473: 15). Another called attention to the negative effects from restrictions on volunteers, since 'Citizen science ... actually increased our capabilities in places [when] we've been able to partner with volunteer groups' (6416: 8; also 6128: 16; 6497: 18). A scientist interested in culvert removal to increase salmon habitat explained 'why it's important to have local groups that are interested ... there is no giant federal group that is going to come in and restore 10,000 culverts across the West Coast ... that requires again broad based public support and interest ... the little things collectively and the big things can be important' (6039: 10). Others described making the public aware of their impact on sustainable fisheries through better communicating scientific knowledge (6473: 8), education and outreach to involve people in mitigating impacts on their own lives from changing environments (6420: 24), and crowdsourcing knowledge and insight through new technological capabilities (5947: 8; 6495: 19; see also Cornell et al. 2013: 69).

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