FishPath: Tailoring Management to Context in Data-Limited Fisheries

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Executive Summary

Fisheries are increasingly managed with involvement of fishers and other stakeholders. Stakeholders are especially critical where managers lack full knowledge of the system to be managed, resources to gather additional information, and/or resources to monitor and enforce compliance. Such ‘data-limited fisheries’ comprise more than 80% of the total global fish catch and face challenges to maintaining sustainable harvest rates. Sustainable management of data-limited fisheries may be improved by decision support that informs assessment and management choices and that is available to fishers and managers. Here we report results from a field experiment conducted with Australian fisheries stakeholders. The experiment tested FishPath, an interactive decision-support software tool for data-limited fisheries, and its influence on stakeholder buy-in to management. Participants were provided with a hypothetical fishery that mimicked commonly encountered real-world data- and capacity-limitations. In Stage 1, to establish baseline levels of buy-in, we presented participants with a shortlist of management options tailored to the fishery; participants did not interact with FishPath. In Stage 2, to test the effect of FishPath use, participants collectively input the hypothetical fishery into FishPath; the tool then presented the same management options seen in Stage 1. In Stage 3, to assess the effect of expert support, participants were randomly assigned to a control group and a treatment group after a common introduction to FishPath output. The control group explored the output without additional support, while the treatment group explored output with support from a FishPath expert. After each stage, participants were asked to rate: 1) their support for an ongoing process to select management options from the shortlist; 2) how easy or hard they expected management of the fishery to be; and 3) how effective they expected management of the fishery to be. Initial findings indicate that while FishPath use does not significantly increase stakeholder support for management (possibly due to ceiling effects, as support was high in Stage 1), it does significantly increase participants’ perceptions of the ease and effectiveness of management.

Keywords

Fisheries management, data-limited fisheries, stakeholder buy-in, decision support

Introduction

Motivation of the study

Fisheries scholars and agencies have long recognized stakeholders as central to fisheries management (Smith, Sainsbury, and Stevens 1999; Ahmed, Capistrano, and Hossain 1997). Stakeholders are especially critical where managers lack full knowledge of the system to be managed, resources to gather additional information, and/or resources to monitor and enforce compliance (i.e., data-limited fisheries) (Dowling et al. 2015). Data-limited fisheries comprise more than 80% of the total global fish catch (Costello et al. 2012) and their management is rife with uncertainty (Carruthers et al. 2014).
Research suggests that they are increasingly exploited and that current management may fail to address stock declines (Worm and Branch 2012; Costello et al. 2012).

Because of data limitations, gold-standard Western scientific ("formal") fisheries management practices are often impracticable in data-limited fisheries. Moreover, simple, generic, low-cost solutions, such as the broad application of generically parameterized models, should not be indiscriminately applied, or used without care (Dowling et al. 2018). Tailored approaches are required that acknowledge specific species' and fisheries' data and context. This does not, however, preclude any management of such fisheries, particularly as fishery stakeholders themselves have expert knowledge. But engaging stakeholders can be costly, in terms of both time and money, to both coordinating agencies and stakeholder participants.

One possible approach to reducing costs is a standardized method of soliciting stakeholder input. Such an approach may seek to collate existing knowledge about the fishery, identify where additional knowledge may be most fruitfully sought, identify currently feasible management options that are expected to be effective given the fishery context, and increase stakeholder buy-in to management processes and resulting rules. This is the approach taken by FishPath, and to some extent, by other fisheries' management decision support tools (Alagappan and Kumaran 2013). FishPath is a data-limited fisheries management decision-support tool developed by a Science for Nature and People Project (SNAPP) working group (Dowling, Wilson, and Rudd 2016), with a current core team of scientists from The Nature Conservancy, Commonwealth Science and Industry Research Organization (CSIRO) Oceans and Atmosphere, and National Oceanic and Atmospheric Administration (NOAA) Fisheries. This paper seeks to answer the question: How does use of FishPath influence stakeholder buy-in to formal fisheries management, in the presence or absence of in-person expert support?

The report proceeds as follows. We begin with a discussion of why formal management can be challenging in data-limited fisheries, despite ongoing efforts to address these challenges. We then discuss the critical role of stakeholder buy-in to management of fisheries in general, and data-limited fisheries in particular. We include a brief survey of previous efforts towards creating management support tools for fisheries, and provide an overview of FishPath and how it is applied in practice. We then present the design and results of an experiment designed to test whether use of FishPath increases stakeholder buy-in to formal management of a data-limited fishery.

Formal management and data-limited fisheries

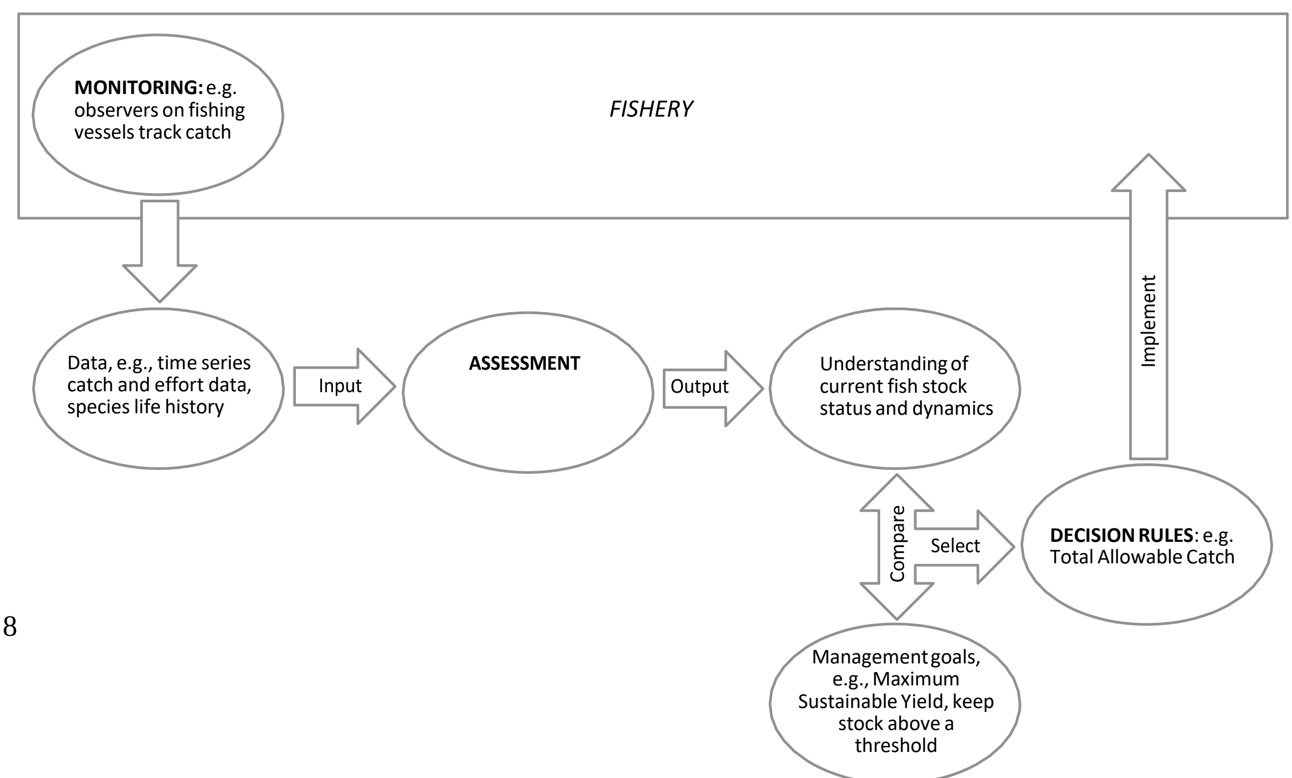
Data-limited fisheries

Data-limited fisheries, which make up more than 80% of global catch (Costello et al. 2012), are those fisheries for which managers lack the information necessary to allow quantitative, model-based assessments of fish stock status. This information deficit challenges managers' ability to track fishery impacts and adapt management (Dowling, Wilson, and Rudd 2016). Data-limited fisheries tend also to be capacity-limited – that is, resource constraints hinder fisheries authorities collect additional data and/or monitor and enforce management (Dowling, Wilson, and Rudd 2016). Here we use "data-limited" to refer to fisheries lacking management data, capacity, or both.

Ideal formal fisheries management

Formal fisheries management, as we use the term here, centers on the development of an implementable, enforceable and effective integrated harvest strategy. Harvest strategies are formal frameworks for managing exploitation of fisheries, usually applied to the species targeted by the fishery (e.g., (Sainsbury, Punt, and Smith 2000; Butterworth and Punt 2003). They comprise a fully specified set of rules for making management decisions, and consisting of three iterative, adaptive components: (1) a species and/or fishery monitoring program (2) indicators of the current status of the fish stocks that will be calculated from the monitoring data (often via a stock assessment), and (3) application of indicators to design or adapt decision rules (e.g., regulations) that effectively meet management goals (goals which may be established by national legislation) (Sainsbury, Punt, and Smith 2000; Butterworth and Punt 2003; Punt, Smith, and Cui 2002). In an ideal, data-rich fishery, for example, comprehensive catch data and species' life history may be collected and used to model the status of the fish stock (i.e., stock assessment), model outcomes may be compared to pre-determined target reference points like Maximum Sustainable Yield, and the results of that assessment may be used to set harvest controls like total allowable catch (Figure 1).

Figure 1. The integrated harvest strategy approach to fishery management.



Within the harvest strategy, monitoring, measurement, assessment, decision rules, and implementation must be specified quantitatively (Sainsbury, Punt, and Smith 2000). Formal management is thus often predicated on extensive data on catch, effort, and trends over time, as well as knowledge of target species' life history and fishery operational characteristics (e.g., types of gear used, vessel size) (Bentley and Stokes 2009; Dichmont et al. 2015). It follows that formal management requires not just data, but also capacity. Capacity may include: people and/or technology to gather/collate knowledge of the targeted species and other species caught inadvertently (bycatch), and to monitor catch and fishery operations; knowledge of, and expertise in applying, assessment methodologies that vary from the straightforward (comparing monitoring data to simple indicators) to the sophisticated (fisheries-specific statistical modeling techniques like stock assessment); the ability to select decision rules that will meet fishery goals, in light of the preceding; the ability to enforce those rules; the ability to track the fishery over time and adapt management approaches as necessary; and funding to finance all of the above.

Data-limited fisheries management

The specifics of what legally constitutes a data-limited fishery differ by jurisdiction, but data-limited fisheries generally exist where species, catch and or effort data are entirely lacking, incomplete, or limited in temporal scope, estimates of total abundance and/or biomass are lacking, or where key reference points like Maximum Sustainable Yield are otherwise incalculable or very uncertain (Dichmont et al. 2015; Dowling et al. 2016). Globally, where central governmental resources are constrained and capacity is limited, fisheries agencies may lack the funding and/or expertise to collect and/or analyze data necessary for adoption of an MSE approach. Subsistence, small-scale, or primarily recreational fisheries may be low commercial value and/or generate minimal income, precluding the imposition of fees sufficient to support MSE management. Data limitations may also be found in fisheries that are new or developing, those that target multiple species either opportunistically or by design, where ports or landing sites are unknown and/or spatially dispersed, etc. Thus, by their very nature, data-limited fisheries are challenging to formally manage.

In some jurisdictions, legislative or managerial subscription to narrowly defined formal management has historically resulted in data-limited fisheries being essentially unmanaged by central authorities even where capacity is relatively high (Bentley and Stokes 2009). More recently, some more developed nations' fisheries management agencies have attempted to bridge the gap between formal management needs and data-limited fishery realities through implementation of tier systems in which data availability and quality, the types of assessments that might be based on existing data, and levels of uncertainty in both data and assessments are used to rank a given fishery into a given tier (Dichmont et al. 2015). Higher-numbered tiers (i.e., data-limited fisheries) are associated with more conservative management as managers build in additional precautionary buffers to address the increased risk of overfishing associated with less refined assessments (Dichmont et al. 2015). Despite such efforts, globally, data-limited fisheries not only constitute a majority of global catch, they appear to be increasingly overfished. FAO data shows that current management is likely ineffective in data-limited contexts, particularly for smaller stocks, with ramifications for long-term sustainability, food security, and ecosystem state (Costello et al. 2012). Analysis that contrasts modeled stock status in data-rich fisheries with global catch trends suggests that data-limited fisheries are increasingly exploited and that current management may fail to mitigate against stock decline (Worm and Branch 2012). New model refinements show that this is most likely where the proportion of the catch that is reported and tracked varies from year to year (Rudd and Branch 2016), as may be the case when management is contested, in flux, or patchily enforced over time.

However, data-limited fisheries management is not impossible. Indeed, the "procedural paradigm" that underlies formal management – that is, iteratively testing a variety of management strategies and selecting the one that best meets management goals – is entirely suitable to data-limited fisheries in theory, although it has until recently been somewhat patchily applied (Bentley and Stokes 2009). Increasingly, assorted empirically verified harvest strategy components are available for data-limited fisheries, although those methods vary in both their effectiveness and associated levels of uncertainty (Kraak et al. 2010; Carruthers et al. 2014; Dowling et al. 2015). Yet, despite scholars' recognition of the need for a way to select appropriate management strategies even when data are limited (Bentley and Stokes 2009), full information on the range of options and their likely feasibility and effectiveness have historically been largely unavailable to data-limited fishery stakeholders (MRAG Ltd. 1991; Dowling et al. 2015).

Stakeholder engagement and buy-in

Stakeholder engagement – the process of involving stakeholders management processes and/or decision-making – can take various forms and serve various ends, from providing information to soliciting information to empowering marginalized voices to enabling stakeholders to manage themselves (Reed 2008). Stakeholder engagement in governance in general, and in natural resource management in particular, has been widely accepted as both pragmatic and normative good practice by scholars, agencies, and decision-makers (Lynam et al. 2007; Reed 2008; Garmendia et al. 2010). Fisheries scholars and agencies have long recognized stakeholders as key players in managing fisheries (Smith, Sainsbury, and Stevens 1999; Ahmed, Capistrano, and Hossain 1997). Fisheries stakeholders may include managers, industry representatives, conservation interests, and scientists (Smith, Sainsbury, and Stevens 1999); they may also include local communities and individual fishers (Allegretti, Vaske, and Cottrell 2012).

Pragmatically, fisheries stakeholder engagement is believed to improve the knowledge base on which management is predicated, allowing for better management decisions (Lane and Stephenson 1998b; Kraak et al. 2010). Consistent with this pragmatic approach, in application, FishPath primarily treats stakeholders as knowledge repositories (Lynam et al. 2007), and seeks to leverage stakeholder expertise to fill in the knowledge gaps that hinder formal management of data-limited fisheries.

Beyond the substantive uses for stakeholders' expert knowledge, there is reason to believe that, as targets of management, some data-limited fishery stakeholders – fishers, in particular – may be key to successful implementation of formal management (Aceves-Bueno et al. 2015). Monitoring methods, especially low-cost ones, often rely on fishers as implementation partners (for example, fishers must be willing to maintain comprehensive, accurate log books where logbooks underpin monitoring efforts). Furthermore, where capacity is severely lacking, enforcement of fishery rules may in practice be reduced to relying on fishers to choose to comply with existing rules in the absence of surveillance and enforcement. Indeed, fishers who are "bought-in" to management may in fact make management self-enforcing both through their own decisions and through the norms they propagate through their networks. This points us to the potential importance of stakeholder buy-in to management of data-limited fisheries.

Here, we define stakeholder buy-in to formal fisheries management as a) stakeholders' beliefs that formal fisheries management is possible and b) that such management would be effective, as well as c) their support for a process designed to move the fishery towards formal management. This definition of buy-in includes efficacy beliefs (self-efficacy, or beliefs about how easy or hard it is for an actor to undertake an action, as well as response efficacy, or beliefs about whether or not the action will have the desired effect (i.e. "outcome expectations") (Bandura 1977)), as well as simple support for management, in order to disaggregate the complex perceptions stakeholders may have about management of a resource. To the extent that stakeholders express support for formal management efforts, and believe that formal management of their fishery is feasible and effective, we should expect that they will be more likely to support and comply with monitoring efforts and decision rules. Efficacy beliefs, in particular, have been found to drive behavior change in the realms of health and climate change mitigation (Bandura 2004; Ortega-Egea, García-de-Frutos, and Antolín-López 2014).

Normatively, stakeholder engagement may let stakeholders know their voices are heard, resulting in reduced conflict, increased trust in decision-making, and improved buy-in to management (Lane and Stephenson 1998a; Reed 2008; Wesselink et al. 2011). Another commonly cited normative benefit of stakeholder engagement is that broadened participation results in increased influence for the traditionally disenfranchised, and more equitable power sharing (Reed 2008; Wesselink et al. 2011). Critics of stakeholder engagement counter that providing equal access and influence to stakeholder groups with different levels of power and voice is deeply challenging, and may in fact backfire in unanticipated ways (including by eroding trust in decisions) (Coglianese 2002; Lynam et al. 2007; Reed 2008; Wesselink et al. 2011). While this critique is salient overall, FishPath does not intrinsically seek to empower stakeholders, merely to pick their brains and convince them that management is feasible, effective, and worth complying with. In particular, FishPath neither engages stakeholders in setting goals or defining management problems (which usually happens at the national, rather than fishery-specific, level), nor seeks consensus solutions to management problems. In terms of rationales for stakeholder engagement (Wesselink et al. 2011), FishPath's aims are simply substantive (improving the substance of decisions) and instrumental (engaging those on whom implementation relies).

A final critique of stakeholder engagement, and specifically of how success is often measured, is that studies too often rely on stakeholders' self-reported perceptions rather than measuring actual outputs, or ideally outcomes, of engagement (Coglianese 2002). We have endeavored to address this issues by including efficacy beliefs, which have been shown to predict behavior change, in our measures of stakeholder buy-in.

Fisheries decision support and FishPath

Fisheries decision support tools

Fisheries management decision-making is complex and multi-faceted, limited by available knowledge, decision-makers' access to knowledge, and their ability to apply that knowledge to meet competing management goals (Alagappan and Kumaran 2013). As a result, previous scholars and practitioners have both noted the theoretical utility of computer-based systems to support management decision-making and made efforts to develop such tools.

Expert systems – computer-based tools that collate the knowledge of multiple human experts in the interests of making that knowledge readily available to non-experts (MRAG Ltd. 1991; Alagappan and Kumaran 2013) – have proliferated in fisheries since the 1990s (Alagappan and Kumaran 2013). However, a recent review reveals that existing expert systems designed to support fisheries management are either narrowly focused, for example on single pre-defined species or hyper-specific management issues (e.g., fish ladder design, invasive species control), or offer

technical solutions that may not be appropriate where data and capacity are limited (Alagappan and Kumaran 2013)..Early tools focused in part on creating a user-friendly interface that made the assessment stage of formal managment more accessible to non-expert decision-makers. However, they also pre-supposed the existence of data-rich inputs and advised users to collect additional data in the face of severe data limitations (MRAG Ltd.
1991) rather than enabling users to work with currently available data. The developers of these early systems explicitly recognized that data limitations would challenge use of the tools they designed, and explored the ramifications of mismatch between data availability and data needs for specific management objectives, but lacked the capacity to include this functionality in the tools they created (MRAG Ltd. 1991). In addition to the limitations discussed above, to our knowledge, none of the existing decision- support approaches are designed with the additional goal of building stakeholder support for management.

FishPath

FishPath was initially developed in 2015, by a Science for Nature and People Partnership (SNAPP) working group, and the tool forms the center of The Nature Conservancy's global fisheries strategy. To date, The Nature Conservancy and FishPath experts have travelled to sites in Australia, the US, Canada, Spain, Peru, Mexico, Kenya, Jamaica, and Indonesia in order to apply FishPath to local fisheries. A FishPath workshop is usually a three-or-so day affair, in which managers, fishers and other stakeholders join forces to work through the tool, and determine a path towards formal management of the fishery in question. FishPath and fisheries management experts provide in-person expert support, helping stakeholders interpret questions and understand output.

FishPath was developed in answer to calls for a way to identify and choose between management approaches in data-limited fisheries. FishPath has multiple aims: to mitigate management paralysis caused by managers restricting themselves to familiar approaches to management; to push existing tools forward and deliver actionable information in data-limited contexts; and to involve stakeholders in management processes, make those processes transparent, and stimulate stakeholder buy-in. FishPath seeks to allow stakeholders in a data- and capacity-limited fishery to interactively assess their fishery via a user-friendly, web-based interface, and identifies a short list of harvest strategy approaches and caveats as to their use based on the input that stakeholders provide.

FishPath distills the current knowledge of best-practice management strategies for data-limited fisheries, the contexts in which given practices are most effective, and the data and capacity requirements of those practices into a series of closed-ended questions presented in a user-friendly computer-based interface (Dowling, Wilson, and Rudd 2016). Questions are designed to canvas stakeholder knowledge on 1) Fisheries data availability; 2) Life histories of target species; 3) Operational characteristics of the fishery; 4) Socio-economic characteristics of the fishery; and 5) Fisheries governance context. The questionnaire is separated into three sections that reflect the components of an integrated harvest strategy (i.e., monitoring, assessment and decision rules); the sections can be run individually or in sequence depending on the needs of users. For each section, the tool compares responses with established data- limited management options, in order to identify feasible and appropriate harvest strategy components and caveats to each strategy's use that are tailored to the specific fishery under consideration (Dowling, Wilson, and Rudd 2016). The ultimate goal of FishPath is to structure stakeholder engagement in order to source knowledge that can be used to move the fishery in question towards formal management.

FishPath output includes information on whether a given management option is considered appropriate to and feasible in the fishery (Figure 1, left margin of Panel A) along with a stoplight-coded system of caveats as to each option's use (Figure 1, left-center of Panel A). The top layer of output also identifies the responses that were most influential in either including or excluding options (Figure 1, bottom of Panel A). Beyond the top layer of output, a number of drop-down and/or click-through options enable users to further investigate the management options and the criteria by which each one was recommended or rejected (Figure 1, Panels B and C). Deeper layers of information that are accessible within FishPath output include 1) explanatory text for each management option, with links to relevant literature (Figure 1, Panel B); and 2) the questionnaire item(s) and associated response(s) that led to that management option being recommended or rejected, with detailed information on the each of the caveats associated with the option and why it applies.

Figure 2. Example FishPath output with informational pop-ups (here monitoring output; some options hidden for ease of presentation). Management options are listed with "stoplight" coded caveats, and flagged as feasible (green check) or infeasible (red circled X) (A). Clicking on an option yields a descriptive pop-up with references (B); from here; clicking on the caveat dropdown yields detailed information on why those caveats apply to the fishery in question (C).

Note that FishPath is "not intended to replace, but rather help guide, hone, and augment, local knowledge or expert judgment" (Dowling, Wilson, and Rudd 2016) (p80). The tool does not provide a single "solution" to the problem of managing the fishery in question, but it does limit the management choice set by identifying possible and appropriate harvest strategy components through a selection process that is transparent to users. The tool also allows users to fully engage with the complexity of their fishery, and to target management more effectively. In particular, where stakeholders hold pre-existing knowledge of or preferences for certain management approaches, FishPath output allows them to ground truth and reconsider those preferences as necessary. For example, users may discover that the tool precludes use of a particular monitoring approach (e.g., satellite vessel tracking) as too costly, but know that local agencies in fact have the resources to institute that approach. The tool's output allows users to identify the questionnaire item and response that led to that approach being rejected, and users may choose to alter their response in order to see how making that change alters the choice set overall.

Alternately, where certain data limitations are flagged in FishPath output as precluding use of a preferred management strategy (e.g., lack of data on ocean conditions at the time of catch precludes calculation of standardized catch-per-unit-effort), existing management or stakeholder capacity may be redirected to gather that data in the future so that the once-rejected approach becomes feasible.

For a thorough overview of FishPath, see Dowling, Wilson et al (2016). The overall approach of FishPath remains unchanged since this study was conducted, although the input and output interfaces and management options continue to evolve.

To date, FishPath has been applied to fisheries in Australia, the US, Canada, Spain, Peru, Mexico, Kenya, Jamaica, Indonesia, and other nations. In practice, stakeholders apply FishPath to their fishery over approximately three days, with in-person support from international fisheries management and FishPath tool experts. Experts help stakeholders navigate and understand the tool and output. They facilitate engagement, answer stakeholder questions, explain technical concepts, and help stakeholders weigh the recommendations FishPath provides both against one another and in the context of stakeholders' nuanced real-world knowledge. Experts also take notes on how the tool can be improved and adapted. However, while there is no cost to local agencies, providing in-person expert support for FishPath use is expensive to the support team, and in some ways limits application of the tool.

Objectives

To sum up the above, data-limited fisheries are common, but difficult to formally manage. Information and other costs are high. Stakeholder buy-in to fisheries management is particularly important to management success in data-limited contexts. FishPath is an approach to data-limited fisheries management that seeks to both reduce the costs of management and increase stakeholder buy-in by allowing fishery stakeholders to cooperatively input fishery and social characteristics, and receive output that consists of a vetted list of management options that are appropriate for their fishery. While FishPath gives data-limited stakeholders access to information that they are unlikely to have had access to previously, its use is still limited by reliance on in-person expert support.

Thus, this report seeks to answer the question: How does engagement of stakeholders via FishPath affect their buy-in to formal management of data-limited fisheries, both in the presence and absence of in-person expert support? We hypothesize that FishPath use alone increases stakeholder buy-in to formal management of a data-limited fishery, and that expert support further increases buy-in.

Objectives of the project – as agreed in the contract – included:

1. To test and inform the utility of FishPath from a stakeholder perspective so that it is end-user friendly and designed to have optimal value as a decision support tool

2. To provide stakeholders with an opportunity to learn about, and influence, the application of a management decision support tool designed to remove uncertainty and improve rigor particularly with regard to small scale fisheries

3. To provide additional extension of project 2015-215 '*Low cost management regimes for sustainable, small low-value fisheries based on coastal inshore species*' and to facilitate stakeholder-based discussions of potential future projects to improve and implement the guidelines for low cost management of small scale fisheries.

Method

Overview

In order to test the influence of FishPath use, both with and without expert support, on fisheries stakeholders' buy-in to formal management, we implemented a field experiment at a specially-designed FishPath workshop held in Darwin, NT in November 2017. The experimental design allows us to make causal inferences about the effects of FishPath use, both with and without expert support, on stakeholder buy-in.

We first provided stakeholders (n=42, 32 of whom completed all experimental stages) with a brief introduction to formal fisheries management, in order to ensure a shared baseline level of knowledge; we then introduced a hypothetical data-limited fishery that we had backwards engineered from the FishPath questionnaire and output. The end result was a fully-specified hypothetical fishery that was associated with a pre-identified set of most feasible and appropriate monitoring, assessment, and decision rule options.

In Stage 1, to establish baseline buy-in measures given shared knowledge of the hypothetical fishery, all participants were presented with a tailored shortlist of management options for the fishery that were selected from the most feasible options identified by FishPath for the hypothetical fishery. Participants did not interact with FishPath in Stage 1. In Stage 2, to determine the effect of tool use on stakeholder buy-in, participants collectively worked through FishPath, inputting the hypothetical fishery information in response to the FishPath questionnaire; the tool then presented output that identified the management options initially seen in Stage 1 as the most feasible of all monitoring, assessment and decision rule options available. In Stage 3, to determine the effect of expert support on stakeholder buy- i n , participants were randomly assigned to one of two groups after a common introduction to FishPath's output. In order to control for the effects of exposure to FishPath over time, Group A (control) was left to explore the output without additional support, while Group B (treatment) explored output with support from a FishPath expert. After each stage, participants were asked to rate: 1) their support for an ongoing process to select management options from the shortlist; 2) how easy or hard they expected management of the fishery to be; and 3) how effective they expected management of the fishery to be. At the end of Stage 1 participants were also asked to complete a demographic questionnaire. The three stages lasted 55, 80, and 55 minutes respectively, including survey administration; participants were given a 15 minute break in the middle of Stage 2. Participants were provided a catered tea during the break, and lunch after completion of Stage 3. Participants were debriefed one-on-one or in small groups after the conclusion of the experiment.

Prior to the Darwin workshop, in order to refine timings and experimental materials, we piloted the full experimental design with a group of graduate students in marine and environmental affairs and fisheries at the University of Washington.

Experimental design and hypothesized effects of treatments are summarized in Table 1.

Table 1. Summary of experimental design and hypothesized treatment effects.

	Stage 1	*Stage 2*		*Stage 3*	
				A (Control)	*B (Treatment)*
Treatment	Fishery information and management shortlist	Stage 1 plus FishPath tool use	*Introduction to FishPath output*	Stage 2 plus unguided time with output	Stage 2 plus expert supported time with output
Test	Pre-test	Post-test 1		Post-test 2	
Hypothesized effect on buy- in	0	+		+	++

Recruitment

A broad range of fisheries stakeholders participated in the workshop. We solicited participants through outreach to Australia's National Seafood Industry Leadership Program alumni, a story/announcement in the Northern Territory Seafood Council newsletter, a release to Northern Territory media outlets, and in some cases through targeted, one-on-one outreach led by workshop organizers. Local expertise was invaluable in identifying and recruiting participants who were expected to vary in their initial attitudes towards formal management.

The Darwin workshop was organized by the Northern Territory Department of Primary Industry and Fisheries and the Northern Territory Seafood Council. In order to ensure broad participation, we scheduled the workshop to take place in conjunction with the Northern Territory Seafood Council's Annual General Meeting; to further encourage participation by a broad range of stakeholders, costs of some participants' workshop attendance were covered by the Fisheries Research and Development Corporation. The Northern Territory is home to a number of data-limited fisheries (primarily due to management capacity limitations), and Northern Territory residents are anecdotally perceived to be resistant to government intervention, including intervention in fisheries.

Hypothetical fishery

We provided participants with the comprehensive information necessary to use FishPath for the hypothetical fishery via a 40-minute narrative presentation followed by a question and answer session, supplemented with a 4-page information sheet (see Appendix 1). The presentation generally followed the order in which items would be encountered when using FishPath, although some pieces of information were combined or taken out of order for coherent narrative structure. The information sheet distilled the critical points from the presentation. For ease of reference, the information sheet used a header-bullet format that was aligned with the general structure of the FishPath questionnaire. We chose to use a hypothetical case-study fishery in which no participant was a stakeholder in order to both remove the influence of vested interests on support for management (thereby allowing for cleaner initial results on the effect of the tool and/or different levels of support for tool use), and so that we could include stakeholders from multiple fisheries and fisheries organizations in our sample.

We designed our hypothetical fishery to be challenging to manage by intentionally manipulating fishery operational and species characteristics, management capacity and jurisdiction, fisher attitudes towards and cooperation with management, and availability of data on species characteristics and fisheries operations.

We set our fictional target species, the “Timor choate”, in the Timor Sea north and west of Darwin, with a range that included both Australian and Timor-Leste waters. We focused workshop application of FishPath on the commercial Timor choate fishery, although the fishery as a whole was designed to be multi-sector (both commercial and recreational, with the sectors fishing with different gears, and at different depths and distances from shore) and multi-species (also catching a closely related species with an overlapping range, with seasonal variation in proportion of species caught). The commercial choate fishery was designed to be both small (55 vessels) and low in commercial value. We had our commercial vessels fish within a limited portion of the choate’s spatial range, and tend to aggregate at sites that varied over time within that area. The commercial fishery was seasonal (limited to non-monsoon conditions); included bycatch issues, in particular bycatch of endangered seabirds; included latent effort in the form of unused permits; was subject to changing operations (hook size and set depth) over time; and showed recent signs of effort creep (catching more weight of fish in the same amount of time). Supply chains were short: catch was primarily sold fresh for local consumption, although a small percentage was flash frozen and exported to markets in Asia.

Management authority and legal mandate was situated with the state: the state-level management agency had jurisdiction over the whole of the Australian commercial fleet, ports, landing sites, and local markets, but did not have jurisdiction over export markets or non-Australian fleets or waters. While the management agency valued data collection, their funding and capacity for regular data collection was limited and their resources stretched across an array of fisheries. Existing commercial choate fishery management was ad hoc rather than based on an integrated MSE-based harvest strategy, and administered through fixed quotas and vessel permits. Choate fishers perceived existing management as ineffective, resulting in low levels of cooperation between fishers and managers; fishers were also concerned that current levels of take might be unsustainable.

In order to simulate a real-world data-limited fishery, we included gaps in our knowledge of Timor choate. Known species characteristics included spawning grounds, juvenile range, poor survivorship after catch-and-release, inability of the species to be live sexed, determinant growth (i.e., known maximum length at maturity), length as a function of age, and the status of the species as a periodic strategist (i.e., slow growing with relatively steady populations and variable recruitment when unfished). Imperfect information was available on overall abundance, length at first capture, the relationships between length and weight and length and fecundity, and variations in recruitment (i.e., the number of young that survive long enough to enter the fishery). Unknowns included spawning season, stock recruitment steepness (i.e., relationships between stock levels and recruitment), growth rate, and carrying capacity.

We also specified which fishery data were currently available and which were not. Our hypothetical fishery managers had access to some time-series data, including twelve years of biennial catch data on total catch, total effort, and length and species composition; the last six of those years also included mean length and length percentile data, allowing managers to estimate gear selectivity (i.e., which sizes of fish the gear in use in the fishery catches). We also specified that, given data collection methodologies and recent changes to the fishery, all available data were uncertain, but that preliminary attempts to assess the fishery indicated that overfishing was likely. Our hypothetical managers had no access to data on total (i.e., fishing plus natural) mortality, maximum sustainable yield, equilibrium exploitation rate, the weight or sex composition of the catch, the effects of fishing on population density, fish abundance in the absence of fishing, catch locations, or oceanographic conditions or phase of the moon at the time of catch.

Management shortlist

After introduction of the hypothetical fishery, we introduced participants to a shortlist of monitoring approaches, assessment techniques, and decision rules (see Appendix 2). We selected the strategies for inclusion in the shortlist by drawing, in each of the three categories, from those options that FishPath identified as most feasible and appropriate given the hypothetical fishery information. Our final management shortlist included the options from each category that FishPath did not specifically recommend against (flag as infeasible) as well as those for which FishPath provided no red caveats (i.e., strong warnings against).

Expert support

Expert support was initially designed to provide specific self- and response-efficacy information for a range of options covered by FishPath output: at least one "recommended" option (a strategy without significant caveats), one "middling" option (a strategy with some caveats, but no red "deal-breaker" caveats), and one "not recommended" option (an option that FishPath specifically recommended against or for which significant red caveats were provided). However, after encountering significant technical difficulties at the end of Stage 2, and simultaneously observing participant fatigue, we made an on-the-fly decision to allow expert support (in the treatment group only) to be guided by participant questions and comments rather than the pre-written script. In this way, implementation of the treatment – while diverging from our original intent – was a much more accurate mirror of the way that FishPath expert support is applied in real-world fisheries than would otherwise have been the case.

Group A (control) directed the facilitator through the exploration of FishPath output (i.e., indicated to facilitators which management options and/or caveats they would like to investigate in more depth). For ease of use, the Group A facilitator navigated through FishPath output based on participants' instructions, However, the Group A facilitator did not provide any additional information or answer any questions. While Group A had access to all the detailed information included in FishPath, they did not have assistance in directing their inquiries or interpreting the output. In essence, Group A explored FishPath use independently, without expert support. Group B (treatment) similarly directed facilitators through the exploration of FishPath outputs, but also engaged with a FishPath and fisheries expert facilitator in an iterative conversation about management options, associated caveats, and why those caveats arose in regards to the hypothetical fishery. That is, Group B received expert support in interpreting FishPath output and in understanding how that output related to the answers they had previously provided.

Measures

At the end of each stage of the experiment, we administered a short survey asking participants to rate their buy-in to formal management of the hypothetical fishery. We assigned anonymous identifiers to allow for frank responses together with tracking of individual change in attitudes over time, with FishPath exposure, and with the experimental treatment. Items asked participants to report how easy or hard they expected formal management of the hypothetical fishery to be (measured on a 7-point Likert scale that ran from 3 ("extremely easy") to -3 ("extremely hard"), centered at 0 ("neither easy nor hard")), how effective they expected formal management of the hypothetical fishery to be in meeting pre-defined management objectives (measured on a 5-point Likert scale that ran from 2 ("successfully attain management objectives") to -2 ("failure to attain management objectives"), centered at 0 (“no effect”)), and their support for an ongoing process to formally manage the hypothetical fishery (measured on a 5- point Likert scale that ran from 2 (“strongly support”) to -2 (“strongly oppose”), centered at 0 (“neither support nor oppose”)). Respondents who selected “slightly oppose” or “strongly oppose” were asked to respond to additional items at the end of Stage 2 and Stage 3, at the request of tool developers. The Stage 3 survey also included an open-ended item soliciting any feedback on FishPath or the workshop that the respondents cared to provide. See Appendix 3 for the survey instrument.

As originally designed, our expert support treatment was intended to manipulate participants’ efficacy beliefs, and questions about the ease and effectiveness of management were designed as a treatment check. However, as noted above, our treatment was not implemented as initially designed. Here we have included our efficacy measures as a component of stakeholder buy-in. We chose to do this in recognition of the fact that stakeholders might, for example, support formal fisheries management as an ideal, but also think it is impossible to do well in their fishery. In this example, we would expect stakeholder buy-in to suffer, regardless of self-reported support. Self-efficacy beliefs influence whether and how people faced with risk change their behavior, and interventions that influence self-efficacy beliefs have been shown to drive behavior change in the realm of health (Bandura 2004); both perceived self- and response efficacy have been found to influence individual behavior in the realm of climate change (Ortega-Egea, García-de-Frutos, and Antolín-López 2014; Doherty 2014). Including efficacy beliefs in a broader definition of stakeholder buy-in thus allows us to both reflect empirical reality derived from other fields, and to extend our study beyond stakeholders’ self-reported support for formal management. The latter may be problematic in our study in particular, given our use of a hypothetical fishery and the possibility of social desirability bias influencing responses to items asking about support.

We collected demographic data after the conclusion of Stage 1, in association with the first survey. Respondents were asked to identify their primary or current, and secondary or past, sector of involvement (response options: industrial (industrial-scale commercial)/commercial (medium- to large- scale commercial)/artisanal (small-scale commercial)/customary or traditional/recreational/other (*please specify*)); their roles in those sectors (response options: resource scientist/resource manager/vessel owner/vessel owner-operator/vessel captain/traditional owner/fisher or recreational angler/processor/other (*please specify*)), their years of experience in those sectors, whether they had previously been involved with a fishery that was formally managed through an integrated harvest strategy (response options: yes/no/don’t know), their primary jurisdiction, and their previous exposure to FishPath (response options: never heard of FishPath before today/heard of FishPath only in the context of today’s workshop/knew of FishPath outside of the context of today’s workshop, but had not used it/had used FishPath previously/other (*please specify*)). The demographic questionnaire is reproduced in Appendix 4.

Analysis

We used two-tailed Welch’s t-tests to test for different levels of perceived ease, effectiveness, and support for management between the treatment and control groups, and one-tailed paired t-tests to test for the effect of 1) initial FishPath use and 2) extended exposure to FishPath, both a) with and b) without expert support, on perceived ease, effectiveness, and support for management. Two-tailed Welch’s t-tests are appropriately used to check for differences between groups as they compare different individuals and do not specify the direction of the difference. Paired t-tests are appropriate for re-tests of the same individuals, and we use one-tailed t-tests to check for treatment effects as our hypotheses specify that FishPath use increases stakeholder buy-in. We used F-tests to check for differences between sample subgroups and tests of association to check for associations between dimensions used to delineate subgroups. We used Fisher’s exact tests to test the demographic balance of the treatment and control groups. Fisher’s exact test is appropriate for testing balance when sample sizes are very small. Fisher’s null hypothesis is that samples are independent of condition; thus, a failure to reject the null is a failure to determine imbalance between control and treatment groups. Data were collated and cleaned in Excel and analyzed in R v3.4.3 (base version).

Results,

Demographics

Forty-one participants attended the Darwin workshop. Of those, 32 completed all three experimental stages and submitted completed surveys. There were 39 full responses in Stage 1, due to one late arrival and one unreadable response, and 38 full responses in Stage 2, due to 3 early departures (including the late arrival)). Based on both our own observations and respondent feedback to open-ended items soliciting feedback on the workshop as a whole, we attribute the large jump in attrition between Stage 2 and 3 to the technical difficulties already referenced, which in turn briefly challenged our ability to show FishPath output and resulted in what one respondent termed "lost momentum." Thirty-six participants submitted readable demographic responses in total; 29 of the 32 participants who completed all three experimental stages also submitted readable demographic questionnaires. Not all respondents answered all demographic items.

For the purposes of the overall results reported here, we report results in two ways. We initially restrict the sample to the 32 full responses. Results are then verified against a dataset that includes partial responses (respondents who participated in Stage 1 and Stage 2, but not Stage 3, or those who participated in Stage 2 and 3 but not 1). Demographic results are reported for the 32 full responses, with NA values assigned where a respondent either skipped an item or did not provide demographic information at all.

Participants represented Commonwealth-wide fishery organizations (n=2) as well as fisheries and fisheries organizations across multiple jurisdictions (n=2) and assorted Australian states, including the Northern Territory (n=14), Queensland (n=1), South Australia (n=1), and Western Australia (n=1). Eight participants who submitted demographic information did not submit jurisdictional information.

Stakeholders identified their current or primary fisheries sectors as industrial (n=1), commercial (n=6), artisanal (n=9), recreational (n=6), customary/traditional (n=3), and other (n=4), the last including research organizations and non-fishing marine stakeholders. Seven respondents indicated involvement with additional sectors, either currently or in the past; secondary sectors mirrored those listed above. Participants' self-reported years of experience in their primary or current sector varied from 1 to 50 years, with a median of 13 and mean of 17.3 years of experience.

Respondents held various positions in their primary sector, including resource scientists (n=2), resource managers (n=8), vessel owner/operators (n=7), recreational fishers/anglers (n=3), and others (n=9) (administrators, industry and policy advisors, licensees, compliance officers, and marketing/promotion). Fifty-two percent of participants who provided a completed demographic questionnaire reported previous experience with formal fisheries management (including one item non- response as a non-report). Six participants had no knowledge of FishPath prior to the workshop, 14 had heard of FishPath only in the context of the workshop, and 6 had previously heard of FishPath outside of the workshop context, but had not used it. No participants reported previous experience using FishPath.

Control vs. treatment group balance

Sixteen participants were randomly assigned to the control group and sixteen to the treatment group. Participants were blind to the treatment and their group assignment. We randomized by having participants draw a strip of numbered stickers from a hat before beginning the experiment;

we assigned participants to the control or treatment group at the beginning of Stage 3, based on a numeric mid-point cut-off. Each participant also attached one of their numbered stickers to their paper survey at the end of each experimental stage as an anonymous identifier.

The groups appear to have been generally well matched on demographic characteristics, assuming non-responses from the control group do not mask major differences (see Table 2). The control group reported their sector variously as commercial (n=5), artisanal (n=4), customary/traditional (n=1), recreational (n=3) and other (n=1), with 2 non-responses. The treatment group included industrial (n=1), commercial (n=1), artisanal (n=5), customary/traditional (n=2), recreational (n=4) and other (n=3) sector representatives. The control group included resource managers (n=3), vessel owner-operators (n=3), fishers/recreational anglers (n=1) and others (n=6), with 3 non-responses. The treatment group included resource scientists (n=2), resource managers (n=5), vessel owner-operators (n=4), fishers/recreational anglers (n=2), and others (n=3). Control group participants identified their primary jurisdiction as Commonwealth (n=1), multiple (n=1), and Northern Territory (n=6), with 8 non-responses; treatment group participants identified their primary jurisdiction as Commonwealth (n=1), multiple (n=1), Northern Territory (n=9), South Australia (n=1) and Western Australia (n=1), with 3 non-responses. Six members of the control group and 9 members of the treatment group indicated previous experience with a formally managed fishery (4 and 0 non-responses, respectively. Four members of the control group had never heard of FishPath prior to the workshop, 6 had heard of FishPath only in the context of the workshop, and 2 had heard of FishPath in other contexts, with 4 non-responses. In the treatment group, 2 participants had never heard of FishPath, 8 had heard of the tool only in the context of the workshop, and 4 had heard of FishPath in another context, with 2 non-responses. Fisher's exact tests show no significant differences between the control and treatment group on any of the above demographic measures (Table 2)

Years of experience also did not differ significantly between the control and treatment group (p=0.59). Control group members averaged 17.27 years in their primary sector (ranging from 2 to 50 years), while treatment group members averaged 16.13 years (ranging from 1 to 50 years).

Table 2. Demographic balance between control (n=16) and treatment group (n=16) showing proportion of respondents in each category. Fisher's exact test used to test for statistically significant differences in category counts between groups.

		Control	Treatment	p-value
Sector	*Industrial*	0.00	0.06	0.66
	Commercial	0.31	0.06	
	Artisanal	0.25	0.31	
	Customary/traditional	0.06	0.13	
	Recreational	0.19	0.25	
	Other	0.06	0.19	
	N/A	0.13	0.00	
Primary position	*Resource scientist*	0.00	0.13	0.57
	Resource manager	0.19	0.31	
	Vessel owner	0.00	0.00	
	Vessel owner-operator	0.19	0.25	
	Vessel captain	0.00	0.00	
	Traditional owner	0.00	0.00	
	Fisher/recreational angler	0.06	0.13	
	Processor	0.00	0.00	
	Other	0.38	0.19	
	N/A	0.19	0.00	
Jurisdiction	*Commonwealth*	0.06	0.06	1
	Multiple	0.06	0.06	
	NT	0.38	0.56	
	SA	0.00	0.06	
	WA	0.00	0.06	
	N/A	0.50	0.19	
Formal management	*Yes*	0.38	0.56	1
	No	0.38	0.44	
	N/A	0.25	0.00	
FP experience	*Never heard of before today*	0.25	0.13	0.66
	Heard of in the context of today	0.38	0.50	
	Heard of in another context	0.13	0.25	
	Used previously	0.00	0.00	
	N/A	0.25	0.125	

No significant differences in perceived ease, effectiveness, and support for management were evident between the treatment and control groups in either Stage 1 or Stage 2 of the experiment (results of Welch's t-tests, control vs. treatment, respectively: means in Stage 1 ease -0.56 vs. -0.63, p=0.86; effectiveness 0.93 vs. 0.56, p=0.32; support 1.00 vs. 1.25, p=0.49; means in Stage 2 ease 0.69 vs. 0.38, p=0.45; effectiveness 1.00 vs. 1.06, p=0.83; support 1.19 vs. 1.31, p=0.68) (Table 2). These results are reported based on the sample that we limited to those participants who responded to surveys for all three stages, but are robust to the inclusion of partial responses.

Table 3 Comparison of mean stakeholder buy-in (two-tailed Welch's t-tests) across measures by control and treatment group. All scales centered at 0; ease and support measured on a 5-point scale running from -2 to 2; effectiveness measured on a 7-point scale running from -3 to 3. Results reported only for complete responses (n=16 each, control and treatment).

		Control	*Treatment*	*T*	*p-value*
Stage 1	*Ease*	-0.56	-0.63	0.18	0.86
	Effectiveness	0.93	0.56	1.10	0.32
	Support	1.00	1.25	-0.70	0.49
Stage 2	*Ease*	0.69	0.38	0.77	0.45
	Effectiveness	1.00	1.25	-0.21	0.83
	Support	1.19	1.31	-0.41	0.68

Effects of initial FishPath use

Initial use of FishPath significantly increased perceived ease of formal management of the hypothetical fishery across the entire sample (one-tailed paired t-test result t=-5.04, p<.0001). Between the end of Stage 1 and the end of Stage 2, mean perceived ease of management increased from a mean of -0.59 to 0.53, or from between "somewhat hard" and "neither easy nor hard" to between "neither easy nor hard" and "somewhat easy." This result is robust to the inclusion of Stage 1/2 partial responses (5 participants who responded to surveys in both Stage 1 and Stage 2, but not in Stage 3).

Initial FishPath use significantly increased perceived effectiveness of formal management of the hypothetical fishery across the entire sample (one-tailed paired t-test result t=-1.96, p=.02). Between the end of Stage 1 and the end of Stage 2, mean perceived effectiveness increased from a mean of 0.75 to a mean of 1.03, or from between "no effect" and "minor success" to "minor success." This result is robust to the inclusion of Stage 1/2 partial responses.

Initial FishPath use did not significantly increase participant support for a process to move the hypothetical fishery towards formal management (paired t-test result t=-0.81, p=0.21). Mean support at the end of Stage 1 was 1.13, or just over "slightly support;" mean support at the end of Stage 2 was 1.25, between "slightly support" and "strongly support" but not significantly higher than at the end of Stage 1. This result is robust to the inclusion of Stage 1/2 partial responses.

The above results are summarized in Table 4.

Table 4. Comparison of mean stakeholder buy-in (one-tailed paired t-tests) at the end of Stage 1 (prior to exposure to FishPath) and at the end of Stage 2 (after initial FishPath exposure). All scales centered at 0; ease and support measured on a 5-point scale running from -2 to 2; effectiveness measured on a 7-point scale running from -3 to 3. Results reported only for complete responses.

	Stage 1 (n=32)	*Stage 2 (n=32)*	*t*	*p-value*
Ease	-0.59	0.53	-5.04	0.00

Effectiveness	0.75	1.03	-1.96	0.03
Support	1.13	1.25	-0.81	0.21

Effect of continued FishPath use, with and without expert support

In the control group (no expert support), continued use of FishPath did not result in any change in perceived ease of formal management of the hypothetical fishery (paired t-test result t=0.00, p=.50). Mean perceived ease of management in the control group was 0.69 or between "neither easy nor hard" and "somewhat easy" at both the end of Stage 2 and the end of Stage 3. In contrast, in the treatment group, continued, expert-supported use of FishPath did result in a significant increase in perceived ease of formal management (paired t-test result t=-2.24, p<.05). Mean perceived ease of management in the treatment group was 0.38 at the end of Stage 2 and 0.89 at the end of Stage 3, increasing from between "neither easy nor hard" to close to "somewhat easy." These results are both robust to inclusion of the Stage 2/3 partial response (1 participant who did not respond to the Stage 1 survey but did respond in Stages 2 and 3).

In the control group, continued use of FishPath resulted in a significant increase in perceived effectiveness of formal management in meeting management objective (paired t-test result t=-1.86, p<.05). Mean perceived effectiveness in the control group was 0.94 or just below "minor success in meeting management objectives" at the end of Stage 2, and 1.19 or slightly above "minor success in meeting management objectives" at the end of Stage 2. The treatment group showed no significant difference in perceived effectiveness of formal management between the end of Stage 2 and the end of their expert-supported Stage 3 (paired t-test result t=-1, p=.17). Mean perceived effectiveness in the treatment group was 1.06, just above "minor success in meeting management objectives," at the end of Stage 2 and 1.13 at the end of Stage 3. These results are generally robust to the inclusion of the Stage 2/3 partial response, although the increase in perceived effectiveness in the treatment group does gain marginal significance (p=.08) when the Stage 2/3 partial response is included.

Additional use of FishPath did not result in a significant change in support for a process to move the hypothetical fishery towards formal management, regardless of the presence or absence of expert support (paired t-test results control t=-1, p=.17, treatment t=-0.37, p=.34). In the control group, mean support was 1.19 or just above "slightly support" at the end of Stage 2 and 1.32, or between "slightly support" and "strongly support" at the end of Phase 3; in the treatment group, mean support was 1.31 or between "slightly" and "strongly support" at the end of Phase 2 and very similar at 1.38 at the end of Stage 3. These results are robust to the inclusion of the Stage 2/3 partial response.

Given the small effect of expert support in Stage 3, we also tested whether further exposure to FishPath affected perceived ease, effectiveness or support for management across the pooled Stage 3 sample (i.e., control and treatment groups combined). With a pooled Stage 3 sample, we find that extended exposure to FishPath caused a significant increase in perceived ease of management (t=1.76, p=.04) from 0.53 to 0.78; significantly increased perceived effectiveness of management (t= 2.10, p<.05) from 1.03 to 1.16, and had no effect on support for management (t=-.90, p=0.19, Stage 2 mean 1.25, Stage 3 mean 1.34). Including the partial response does not substantively change any of these findings.

The above results are summarized in Table 5.

Table 5. Comparison of mean stakeholder buy-in (one-tailed paired t-tests) at the end of Stage 2 (after initial exposure to FishPath) and at the end of Stage 3 (after additional use of FishPath), by Stage 3 control (no expert support) and treatment (expert support) groups and with a pooled sample. All scales centered at 0; ease and support measured on a 5-point scale running from -2 to 2; effectiveness measured on a 7-point scale running from -3 to 3. Results reported only for complete responses.

	Control (n=16)				**Treatment (n=16)**				**Pooled (n=32)**			
	Stage 2	*Stage 3*	*t*	*p-value*	*Stage 2*	*Stage 3*	*t*	*p-value*	*Stage 2*	*Stage 3*	*t*	*p-value*
Ease	0.69	0.69	0.00	0.50	0.38	0.89	2.24	0.02	0.53	0.78	1.76	0.04
Effectivenes	0.94	1.19	1.86	0.04	1.06	1.13	1.00	0.17	1.03	1.16	2.10	0.02
Support	1.19	1.32	-1.0	0.17	1.31	1.38	-0.3	0.34	1.25	1.34	-0.9	0.19

Figure 3 depicts all mean ease, effectiveness and support across all experimental stages, with Stage 3 results included both pooled and separated out by treatment and control groups.

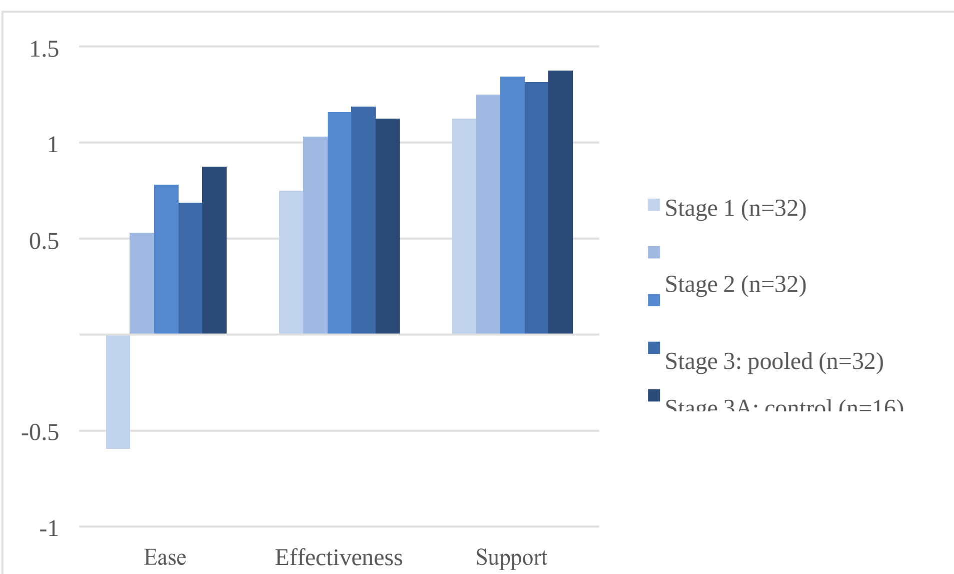


Figure 3. Mean perceived ease, effectiveness, and support for formal fisheries management across experimental stages. Error bars not shown as means represent re-tests of the same individuals (Belia et al 2005).

Subgroup effects

To test for subgroup effects, we first grouped primary sector into manager (resource manager or resource scientist; n=10), user (vessel owner-operator or recreational fisher/angler; n=10), or other (other or NA; n=12), excluding partial responses. No significant differences were found between stakeholder subgroups for perceived ease, perceived effectiveness or support for management.

It is also possible that previous experience with formal management influences the effects of FishPath use. Formal management experience is uncorrelated with stakeholder type (p=.65), so we tested this possibility separately. We found no significant difference in perceptions of ease or effectiveness of management between stakeholders who reported previous experience with formal management and those who reported no such experience (n=15 and n=13 respectively) in any stage of the experiment. We did detect a marginally significant difference in support for a process designed to move the hypothetical fishery towards formal management after Stage 2 (t=-1.89, p=.07), with those without previous formal management experience more supportive. However, this result was not apparent in Stage 1 and disappeared in Stage 3.

Discussion & Conclusion

FishPath is an approach to data-limited fisheries management that seeks to both reduce barriers to formal management and increase stakeholder buy-in. FishPath allows fishery stakeholders to cooperatively input fishery and social characteristics, then receive output consisting of a vetted list of management options that are appropriate for their fishery. While FishPath gives data-limited stakeholders access to information that they are unlikely to have had access to previously, its application to date has been reliant on in-person expert support. Does FishPath increase stakeholder buy-in? Does expert support make a difference to stakeholder buy-in?

FishPath does increase stakeholder buy-in to formal management of a data-limited fishery. We see significant increases in stakeholders' perceptions of the ease and effectiveness of formal management after initial FishPath use, and again after additional time with the tool (when groups are pooled).

Additionally, while we did not find a statistically significant increase in support for formal management, FishPath use was associated with increases in perceptions of ease and effectiveness, as well as increased support, across all stages of the study. The trends were – with only one exception, where we saw no change – uniformly in line with our primary hypothesis.

Our findings on the effect of providing expert support were more mixed. Expert support increased the perceived ease of management but had no statistically significant effect on the perceived effectiveness of management (which did, however, increase significantly in our control group). We believe that, due to the very small sample size when groups were disaggregated, any significant finding here is noteworthy. However, our findings do not allow us to draw any firm conclusions about the influence of expert support on stakeholder buy-in writ large.

It is interesting that FishPath use has no significant effect on self-reports of support for formal management. We attribute this to a combination of ceiling effects and our small sample size. As was the case for both perceived ease and perceived efficacy, support for formal management increased across each stage of the experiment; however, support was initially relatively high (mean 1.13, above “slightly support,” out of a possible maximum of two, “strongly support”). While we targeted recruitment efforts to include participants who we judged likely to be initially suspicious of formal management of data-limited fisheries, our choice to situate our experiment in an Australian context, with Australian fisheries stakeholders, may have challenged our ability to include participants who initially differed on this dimension. Australia’s fishery management structure has emphasized formal management and stakeholder participation since the 1990s (Smith, Sainsbury, and Stevens 1999), so that even participants who had not been involved in a formally-managed fishery were likely to have encountered social norms in favor of formal management more generally. Furthermore, our decision to use a hypothetical fishery meant that our participants had no real stake in management, which may have resulted in participants’ being more influenced by social desirability bias than they might have been in a fishery in which they were personally involved. We chose to use a hypothetical fishery in this study as a relatively clean, proof-of-concept test, but we recognize that this approach is subject to some limitations (discussed in more depth below).

Nonetheless, the increases in perceived ease and effectiveness of management that we find here have significant ramifications for data-limited management success, especially given the breadth of fisheries stakeholders included in our experiment. Formal management of our data-limited fishery was perceived as easier by both fishers and managers after working through FishPath tool. Expert support in navigating FishPath output further increased the perceived ease of management among our stakeholders. Extrapolating from related studies in health and climate change (Bandura 2004; Ortega-Egea, García-de-Frutos, and Antolín-López 2014; Doherty 2014), believing that a management approach is possible in a given context (self-efficacy) is likely to predict managers’ intentions to use the approach and may predict fishers’ intentions to comply with management. Similarly, formal management of our data-limited fishery was perceived as more effective by the range of stakeholders after they used FishPath. Again, perceived effectiveness (response efficacy) has been found to predict behavioral intentions (Ortega-Egea, García-de-Frutos, and Antolín-López 2014; Doherty 2014) and support for policy (Bostrom, Hayes, and Crosman 2018) in other environmental decision-making contexts – it is not too much of a stretch to infer that managers and fishers who believe that formal management will be effective are more likely to, respectively, implement and comply with that management.

Implications & Recommendations

It's worth noting a few limitations to our approach. Firstly, for logistical reasons and in order to present a relatively clean, proof-of-concept test, our study relied on a hypothetical fishery. This decision meant that our participants had no real stake or investment in the management of the fishery we studied, which may have resulted in their being more influenced by social desirability bias than they might have been had the fishery been one in which they were personally involved. This could be especially true for our item measuring support, given the Australian context. Similarly, we might expect to see resistance to formal management most strongly among the targets of regulation (fishers), who might expect that management would result in reductions of catch when compared to the status quo. The fact that we found no sub-group effects when testing a hypothetical fishery should not assure us that no such effects would exist in a real-world application. Finally, the hypothetical fishery, and the modified workshop context in which we explored it, meant that participants were insulated from the costs and benefits of the management process. During debriefs and in written feedback, many respondents indicated that they experienced FishPath as a useful tool, and expressed interest in applying it to their own real-world fisheries. But some participants expressed concern about the opportunity costs of the management process were FishPath to be applied to their own real-world fishery. In short, the use of a hypothetical fishery here clearly challenges the generalizabilty of our findings, and we recommend that a follow-up study be conducted in a real-world context, to see if those findings hold.

In addition, our findings rely on stakeholder self-reports of buy-in (Coglianese 2002). It's difficult to think of a way that we could measure buy-in without relying on self reports, but this does not change the fact that the reason buy-in is interesting is that we expect it to change behavior – in other words, management outputs and outcomes. We believe that including efficacy beliefs, which are known to be associated with behavior change, in our measure of buy-in goes some way to addressing this critique. However, there can be no doubt that all the perceptions we measure here would be likely to change over time in a real-world situation, as the outputs and outcomes of management are felt (Coglianese 2002).

The ecological outcomes of collaborative natural resource management are notoriously difficult to measure on reasonable time scales (Koontz and Thomas 2006). But FishPath presents an opportunity to track both outputs (adoption of formal management strategies) and outcomes (fish stock status and dynamics). If, after use of FishPath, a fishery moves towards formal management, stakeholders are likely to collect time series data and observe changes in fishery indicators over time. This data could be leveraged to get a better sense of how the findings reported here translate into more concrete measures of management success in a real-world fishery.

As noted earlier, FishPath alone does not seek to empower stakeholders to set management goals, define management problems, or seek consensus solutions – all intentions that are often held up as best practice by supporters of stakeholder engagement in general (Lynam et al. 2007; Reed 2008). FishPath also doesn't engage with who should be in the room when the tool is used, or what those choices mean for equity and effectiveness, although there is reason to believe that those choices could be critical for the long-term impacts of management (Lynam et al. 2007; Reed 2008). FishPath can only really be applied in the context of a larger process that addresses these questions.

We recommend that FishPath users be alive to both the importance of process and inclusion in collaboration, and to the hazards of getting those things wrong. Realizing improved compliance and management outcomes will depend as much on the process surrounding FishPath use as on the tool itself. This process should be carefully considered, in order to ensure that all relevant stakeholders are included and that power differentials between different stakeholders are acknowledged and addressed (Reed 2008). Our use of a hypothetical fishery meant that exclusion of stakeholder groups (conservation interests, for example) was not critical; similarly, inter-stakeholder power dynamics were muted in our study. Both of these issues are likely to have significant influence on management in real-world examples. The gains in stakeholder buy-in that we find here could easily be undone by a poorly-designed process that fails to correct for existing power differentials when soliciting participation, or that inequitably distributes the costs and benefits of participation and/or management. Perverse results of a carelessly-designed process could include stakeholders that are disenchanted or actually resistant to formal management strategies, or capture of the process by powerful interests. In both cases we would expect sustainability to suffer. If the tool is embedded in a well-designed and inclusive process, however, FishPath can provide a format for the integration of local and scientific knowledge that is held up as an ideal component of stakeholder participation by some scholars (Reed 2008).

It is worth noting that some participants, especially non-managers, expressed difficulty in understanding some of the terminology included in the tool, and distaste for the highly technical assessment component in particular. This can be seen as an early sign that FishPath creates burdens that are inequitably distributed among different types of respondents. FishPath developers are currently working to address these concerns; however, we note that the challenges inherent to creating a one-size- fits-all interface are likely to be magnified where stakeholders who embody even greater variation in education levels, experience, and ways of knowing are included in the stakeholder pool.

Stakeholders who feel that they have a voice in management are more likely to support management and/or comply (Hatcher et al. 2000; Reed 2008). The extent to which stakeholders perceive use of FishPath as giving them a voice in management, however, will be influenced by both the context and process surrounding tool use. As noted above, when divorced from a larger process, FishPath simply solicits information from stakeholders (e.g., “extractive knowledge use,” (Lynam et al. 2007)). Previous efforts to identify stakeholder participation best practices indicate that stakeholders’ perceptions of their influence on management are greater where they are involved in setting management goals as well as implementing management decisions (Reed 2008). Where management goals are set unilaterally, either by national-level legislation (e.g., the United States, Australia) or by management agencies, stakeholders can expect to have no influence over management goals. A perceived lack of meaningful influence may in fact undermine stakeholders’ willingness to engage over time (Reed 2008). Again, in order to ensure that improved stakeholder buy-in results in improved management outcomes, the processes surrounding the use of FishPath should be carefully designed so that, where possible, stakeholders are meaningfully empowered throughout the management process.

Appendices

Appendix 1. Timor choate fishery information sheet.

Fishery information: General

- The fishery is multi-species, targeting both the Arafura and the Timor choate.
    - The primary species actively targeted is the Timor choate.
    - The Arafura choate is also sometimes caught, especially in the spring when that species is more prevalent in local waters.
- This assessment focuses only on the Timor choate, and does not take an ecosystem or multi- species perspective.
- The Northern Territory choate fishery is managed by Northern Territory Fisheries (the state-level management agency; NT Fisheries).
- The fishery consists of two fleets.
    - The commercial fleet consists of ±55 longliners.
        - The longline fishery is entry-controlled via state-issued permits.
            - Permits are issued to vessels, not co-operatives.
        - 60 permits are owned (not all are owned permits are in current use).
    - The recreational fleet consists of ±100 vessels that fish with rod and reel.

Fishery information: Gears, etc.

- Longliners preferentially target larger fish.
    - In the past five years, longliners have made changes to their gear.
        - Longliners now use larger hooks, and set their hooks deeper, than in previous years.
        - Longline fishers have noticed that the new gears have made them more efficient (they are catching more choate in the same amount of time).
- Longliners do not discard a large proportion of the choate they catch.
- Longlines do result in bycatch, in particular bycatch of seabird species that are listed as vulnerable/endangered.

Fishery information: Markets

- Choate are a muscular, meaty, and mild-flavored fish.
- Both Timor and Arafura choate are sold in the same ways, to the same markets.
    - Most commercial catch is sold locally as “choate” or “sweetfish” to fish markets and restaurants.
        - Local markets are within NT Fisheries’ jurisdiction.
    - A small proportion of commercial catch is flash frozen and exported to Asia.
        - Export markets are not within NT Fisheries’ jurisdiction.

- Markets are generally stable, without much change over time.

Fishery information: Seasonality

- Prime season for choate is May-October.
  - Both the commercial and the recreational fisheries are dependent on non-monsoon conditions.

Fishery information: Geography

- All vessels sail of Darwin or nearby ports.
- All choate catch is landed at known local ports.
- The fished area does not cover the whole of the species range.
  - Fishing locations are limited to a relatively narrow swathe of coastal water.
- Fishing sites vary across fleets and over time.
  - The commercial fleet fishes further away from shore and deeper, while the recreational fleet fishes closer in and shallower.
  - Vessels tend to clump at a small number of locations, though the locations themselves change over time.

Species information: Geography

- Timor Choate occur in the Timor Sea (in Australian, Timor Leste, and Indonesian waters).
- Choate spawn in shallow inshore waters, and remain in the shallows as juveniles.

Species information: Biology

- Choate are free swimming, silver-reddish fish.
- Choate are a slow-growing, long-lived species with variable recruitment.
  - Choate populations remain relatively stable over time, absent fishing pressure.
- Choate do not vary by sex in either their maximum mature size or their growth rate.
  - The sex of choate cannot be determined without killing them.
- Choate may occur in small schools, but do not aggregate in large schools, or to spawn.
  - Spawning season is unknown for choate.
- Choate that are handled live and returned to the water have poor survival.

Fishers: Culture

- Fishers are moderately economically and culturally dependent on the choate fishery.
- Due to ineffective management to date, fishers are mildly suspicious of or resistant to management.
  - Current levels of cooperation between fishers and managers are low.
    - Fishers do not always respect existing regulations.
    - Fishers may be willing to record data about choate catch, but may not always do

so reliably.

  - Fishers would be more likely to help with data collection if they could see an incentive to so (for example, direct benefits from management).
  - Fishers associate via the Northern Territory Choate Fishers Association (NTCFA).
    - NTCFA may provide a starting point for cooperation with management.
- Fishers are concerned that current take of choate may be unsustainable.

Management: Culture

- The broader community supports formal management.
- NT Fisheries provides agency-based leadership for management of the choate fishery.
  - NT Fisheries has a legal mandate to monitor choate populations and fishing activities.
  - NT Fisheries values data collection moderately to highly.
    - Agency resources are limited.

Management: Current approach

- Due to limited resources, current management of the choate fishery is ad hoc rather than through an integrated harvest strategy.
  - The fishery is currently managed through fixed quotas and entry permits.
    - No marine protected areas or other no-take zones are in use.
- NT Fisheries does not suspect high levels of illegal, unregistered or unreported fishing in the choate fishery.

Management: Capacity

- Overall, the choate fishery is considered low commercial value.
  - Funding for management is low to moderate.
    - NT Fisheries has a moderate amount of money to invest in monitoring.
    - NT Fisheries' funding and capacity for research are low to moderate.
- NT Fisheries can collect monitoring data on the choate fishery every two years.
  - Data can be collected in the same places and using the same methods.
  - Data are likely to be spatially biased with respect to the entire population.
  - Data are expected to be representative of the entire Australian choate fleet and fishery.
- Enforcement of choate fishing regulations is by locally-stationed NT Fisheries compliance officers.

Management: Existing knowledge

- Local fishers, scientists and manager have current and complete knowledge on many fishery characteristics, including:
  - Stock status and indicators;
  - Depletion;
  - Fishery/environment interactions;
  - Habitat status;

    - Non-fishing threats;
    - Proxy target and limit reference points.
- Much choate population biology is well-understood, including:
    - Size at maturity;
    - Maximum length;
    - Length as a function of age (von Bertalanffy parameters);
    - Natural mortality.
- However, some choate biology is imperfectly understood, including:
    - Overall abundance;
    - Length at first capture;
    - Length-weight relationships;
    - Length-fecundity relationships;
    - Variations in recruitment.
- Some characteristics of choate are unknown.
    - Stock recruitment steepness is unknown for both the Timor and Arafura choate.
        - Stock recruitment steepness is known for the Coral Sea choate, a related but distinct species.
    - Growth rate and carrying capacity are both unknown for choate.

Management: Existing data

- NT Fisheries has been collecting data on the choate fishery every two years for the last 12 years. Data collected include:
    - Catch;
    - Effort;
    - Catch per unit effort (CPUE);
    - Length composition;
    - Species composition;
- For the last six years, NT Fisheries data collection has also included mean length and length percentiles.
    - Together these data allow estimation of gear selectivity.
- Given data collection methodologies and recent changes to the fishery, all available data are uncertain.
    - However, preliminary attempts to assess the fishery indicate that overfishing is likely.
        - Note that, given recent changes to the fishery, any assessment that assumes a certain mathematical form of selectivity should be applied with care to ensure that model assumptions accurately reflect real-world conditions.
    - Preliminary assessments do not suggest a particular form of decision rule.
- No data exists on:
    - Total mortality;
    - Maximum sustainable yield;
    - Equilibrium exploitation rate;
    - Weight composition;
    - Sex composition;
    - Fishery-dependent density;
    - Fishery-independent abundance;
    - Specific fishing locations;
    - Oceanographic conditions at time of catch;
    - Phase of the moon at time of catch.

Appendix 2. Timor choate management shortlist: Recommended formal management options by category.

Monitoring approaches:
Port/landing site monitoring Snapshot data gathering Interviews

Processor monitoring Fish market surveys Independent surveys Voluntary logbooks Legally required logbooks Catch disposal records

Assessments:

Expert judgment

Risk analysis/Vulnerability Empirical reference point Multiple empirical indicators Catch only models

Decision rules:

Spatial restrictions

Levies or taxes that incentivize fishers to avoid areas Temporal restrictions

Apply additional precautionary buffers to existing management Gear restrictions

Additional data collection

Overrides in case of exceptional circumstances

Appendix 3. Survey completed by participants at the end of each experimental stage.

Reminder: Formal management is designed to achieve agreed-upon objectives, in this case maximising catch while maintaining fishery sustainability. Formal management centers on an integrated harvest strategy that includes three linked parts:

1. Monitoring of the fishery (collecting data on fishing activities);
2. Assessment of the fishery (using monitoring data to estimate fish populations and trends over time);
3. Decision rules (using assessment outcomes to select fishery rules and regulations).

1. How easy or hard would it be to *formally manage* this fishery? (*Please circle one*)

Extremely easy	Very easy	Somewhat easy	Neither easy nor hard	Somewhat hard	Very hard	Extremel hard

2. What effect would formal management have on *attaining management objectives* (maximising catch while maintaining fishery sustainability) in this fishery? (*Please circle one*)

Successfully attain management objectives	Minor success in attaining management objectives	No effect	Minor failure to attain management objectives	Failure to attain management objectives

3. Please review the formal management options presented in the attached list. Based on these options, how much do you support or oppose formal management of this fishery? (*Please circle one*)

Strongly support	Slightly support	Neither support nor oppose	Slightly oppose	Strongly oppose

3a. Please answer only if you selected “Slightly oppose” or “Strongly oppose” in response to Question 3.
Would adding specific *monitoring, assessment, and/or decision rule options* to this list lead you to support formal management of this fishery? (*Please circle one. If you select “Yes”, please specify below*)

Yes No

Specific monitoring option(s):

Specific assessment option(s):

Specific decision rule option(s):

4. If you listed other options in your response to Question 3a, briefly, why would the approaches you listed work for this fishery?*

5. If the input you provided in your response to Question 4 was included in the caveats FishPath provides when recommending and/or eliminating strategies, would that change your level of support for formal management of this fishery? (*Please circle one*)*

Yes, completely Yes, a lot Yes, a little No

6. Is there any other feedback you would like to provide on FishPath or this session?*

**Items 4, 5 and 6 were included only in the Stage 3 questionnaire*

Appendix 4. Demographic questionnaire.

Fisheries sector (current or primary sector): (*Please check one*)

❑ Industrial (industrial-scale commercial)
I Commercial (medium- to large-scale commercial)
I Artisanal (small-scale commercial)
I Subsistence I
Recreational
I Other: *(Please specify)*____________________

Primary role in this sector: (*Please check one*)

I Resource scientist
I Resource manager
I Vessel owner
I Vessel owner/operator
I Vessel captain
I Fisher
I Processor
I Other: *(Please specify)*____

Years of experience in this sector:__________

Alternate fisheries sector, if applicable (past or secondary sector): (*Please check one*)

I Industrial (industrial-scale commercial)
I Commercial (medium- to large-scale commercial)
I Artisanal (small-scale commercial)
I Subsistence I
Recreational
I Other: *(Please specify)*____________________

Primary role in this sector: (*Please check one*)

I Resource scientist
I Resource manager
I Vessel owner
I Vessel owner/operator
I Vessel captain
I Fisher
I Processor
I Other: *(Please specify)*____

Years of experience in this sector:__________

Have you ever been involved with a fishery that is formally managed through an integrated harvest strategy?

I Yes I
No
I Don't know

Jurisdiction of primary residence:____

Before today, how familiar were you with FishPath? (*Please check one*)

I Never heard of FishPath before today
I Heard of FishPath only in the context of today's workshop
I Knew of FishPath outside of the context of today's workshop, but had not used
it I Had used FishPath previously
I Other (*Please specify*) ____

References

Aceves-Bueno, Eréndira, Adeyemi S Adeleye, Darcy Bradley, W Tyler Brandt, Patrick Callery, Marina Feraud, Kendra L Garner, et al. 2015. "Citizen Science as an Approach for Overcoming Insufficient Monitoring and Inadequate Stakeholder Buy-in in Adaptive Management: Criteria and Evidence." *Ecosystems* 18 (3): 493–506. doi:10.1007/s10021-015-9842-4.

Ahmed, M, A D Capistrano, and M Hossain. 1997. "Experience of Partnership Models for the Co-Management of Bangladesh Fisheries." *Fisheries Management and Ecology* 4. Blackwell Science Ltd: 233–48. doi:10.1046/j.1365-2400.1997.00115.x.

Alagappan, M, and M Kumaran. 2013. "Application of Expert Systems in Fisheries Sector – a Review." *Research Journal of Animal, Vetrinary and Fishery Sciences* 1 (8): 19–30.

Allegretti, Arren Mendezona, Jerry J Vaske, and Stuart Cottrell. 2012. "Predicting Stakeholder Support for Fishery Policies." *Coastal Management* 40 (1): 20–32. doi:10.1080/08920753.2011.637484.

Bandura, A. 2004. "Health Promotion by Social Cognitive Means." *Health Education & Behavior* 31 (2): 143–64. doi:10.1177/1090198104263660.

Bandura, Albert. 1977. "Self-Efficacy: Toward a Unifying Theory of Behavioral Change." *Psychological Review* 84 (2): 191–215.

Bentley, Nokome, and Kevin Stokes. 2009. "Contrasting Paradigms for Fisheries Management Decision Making: How Well Do They Serve Data-Poor Fisheries?." *Marine and Coastal Fisheries* 1 (1): 391– 401. doi:10.1577/C08-044.1.

Bostrom, A, A L Hayes, and K M Crosman. 2018. "Efficacy, Action, and Support for Reducing Climate Change Risks." *Risk Analysis*.

Butterworth, D S, and A E Punt. 2003. "The Role of Harvest Control Laws, Risk and Uncertainty and the Precautionary Approach in Ecosystem-Based Management." In *Responsible Fisheries in the Marine Ecosystem*, edited by Michael Sinclair and Grimur Valdimarsson, 311–19. Cambridge, MA, Rome: CABI Publishing, FAO.

Carruthers, Thomas R, André E Punt, Carl J Walters, Alec MacCall, Murdoch K McAllister, Edward J. Dick, and Jason Cope. 2014. "Evaluating Methods for Setting Catch Limits in Data-Limited Fisheries." *Fisheries Research* 153 (May): 48–68. doi:10.1016/j.fishres.2013.12.014.

Coglianese, Cary. 2002. "Is Satisfaction Success? Evaluating Public Participation in Regulatory Policymaking." John F. Kennedy School of Government Harvard University Faculty Research Working Papers Series.

Costello, Christopher, Daniel Ovando, Ray Hilborn, Steven D Gaines, Olivier Deschenes, and Sarah E Lester. 2012. "Status and Solutions for the World's Unassessed Fisheries." *Science* 338 (6106). American Association for the Advancement of Science: 517–20. doi:10.1126/science.1223389.

Dichmont, Catherine M, André E Punt, Natalie Dowling, José A A De Oliveira, Lorne R Little, Miriana Sporcic, Elizabeth Fulton, et al. 2015. "Is Risk Consistent Across Tier-Based Harvest Control Rule Management Systems? a Comparison of Four Case-Studies." *Fish and Fisheries* 17 (3): 731–47. doi:10.1111/faf.12142.

Doherty, Kathryn Laing. 2014. "From Alarm to Action: Closing the Gap Between Belief and Behavior in Response to Climate Change." Edited by Thomas Webler.

Dowling, N A, C M Dichmont, M Haddon, D C Smith, A D M Smith, and K Sainsbury. 2015. "Empirical Harvest Strategies for Data-Poor Fisheries: a Review of the Literature." *Fisheries Research* 171 (November): 141–53. doi:10.1016/j.fishres.2014.11.005.

Dowling, N A, J R Wilson, and M B Rudd. 2016. "FishPath: a Decision Support System for Assessing and Managing Data-and Capacity-Limited Fisheries." *Tools and Strategies …*.

Dowling, Natalie A, André E Punt, L Richard Little, Catherine M Dichmont, David C Smith, Malcolm Haddon, Miriana Sporcic, Elizabeth A Fulton, and Rebecca J Gorton. 2016. "Assessing a Multilevel Tier System: the Role and Implications of Data Quality and Availability." *Fisheries Research* 183 (November). Elsevier B.V.: 588–93. doi:10.1016/j.fishres.2016.05.001.

Dowling, Natalie A, Anthony D M Smith, David C Smith, Ana M Parma, Catherine M Dichmont, Keith Sainsbury, Jono R Wilson, Dawn T Dougherty, and Jason M Cope. 2018. "Generic Solutions for Data-Limited Fishery Assessments Are Not So Simple." *Fish and Fisheries* 171 (2). Wiley/Blackwell (10.1111): 732. doi:10.1111/faf.12329.

Garmendia, Eneko, Gonzalo Gamboa, Javier Franco, Joxe Mikel Garmendia, Pedro Liria, and Marta Olazabal. 2010. "Social Multi-Criteria Evaluation as a Decision Support Tool for Integrated Coastal Zone Management." *Ocean & Coastal Management* 53 (7): 385–403. doi:10.1016/j.ocecoaman.2010.05.001.

Hatcher, Aaron, Shabbar Jaffry, Olivier Thebaud, and Elizabeth Bennet. 2000. "Normative and Social Influences Affecting Compliance with Fishery Regulations." *Land Economics* 76 (3): 448–61.

Koontz, Tomas M, and Craig W Thomas. 2006. "What Do We Know and Need to Know About the

Environmental Outcomes of Collaborative Management?.” *Public Administration Review* 66 (December). American Society for Public Administration: 111–21.

Kraak, Sarah B M, Ciaran J Kelly, Edward A Codling, and Emer Rogan. 2010. “On Scientists’ Discomfort in Fisheries Advisory Science: the Example of Simulation-Based Fisheries Management- Strategy Evaluations.” *Fish and Fisheries* 11 (2): 119–32. doi:10.1111/j.1467-2979.2009.00352.x.

Lane, D E, and R L Stephenson. 1998a. “Fisheries Co-Management: Organization & Process & and Decision Support.” *Journal of Northwest Atlantic Fishery Sciences* 23: 251–265].

Lane, D E, and R L Stephenson. 1998b. “Fisheries Co-Management: Organization & Process & and Decision Support.” *Journal of Norwest Atlantic Fishery Science* 23 (December): 251–65.

Lynam, Timothy, Wil de Jong, Douglas Sheil, Trikurnianti Kusumanto, and Kirsten Evans. 2007. “A Review of Tools for Incorporating Community Knowledge, Preferences, and Values Into Decision Making in Natural Resources Management.” *Ecology and Society* 12 (1): 1–15.

MRAG Ltd. 1991. “Fisheries Management Expert Systems: Theoretical Consideration and Production of ProTuna and ProFish.” Fish Management Science Program.

Ortega-Egea, José Manuel, Nieves García-de-Frutos, and Raquel Antolín-López. 2014. “Why Do Some People Do ‘More’ to Mitigate Climate Change Than Others? Exploring Heterogeneity in Psycho- Social Associations.” Edited by Bayden D Russell. *PLoS ONE* 9 (9): e106645–18. doi:10.1371/journal.pone.0106645.

Punt, André E, Anthony D M Smith, and Gurong Cui. 2002. “ Evaluation of Management Tools for Australia's South East Fishery.3. Towards Selecting Appropriate Harvest Strategies.” *Marine and Freshwater Research* 53 (3). CSIRO PUBLISHING: 645–60. doi:10.1071/mf01009.

Reed, Mark S. 2008. “Stakeholder Participation for Environmental Management: a Literature Review.” *Biological Conservation* 141 (10): 2417–31. doi:10.1016/j.biocon.2008.07.014.

Rudd, Merrill, and Trevor Branch. 2016. “Does Unreported Catch Lead to Overfishing?.” *Fish and Fisheries*.

Sainsbury, Keith J, André E Punt, and Anthony D M Smith. 2000. “Design of Operational Management Strategies for Achieving Fishery Ecosystem Objectives.” *ICES Journal of Marine Science* 57 (3). Oxford University Press: 731–41. doi:10.1006/jmsc.2000.0737.

Smith, A D M, K J Sainsbury, and R A Stevens. 1999. “Implementing Effective Fisheries-Management Systems – Management Strategy Evaluation and the Australian Partnership Approach.” *ICES Journal of Marine Science* 56 (6). Oxford University Press: 967–79. doi:10.1006/jmsc.1999.0540.

Wesselink, Anna, Jouni Paavola, Oliver Fritsch, and Ortwin Renn. 2011. “Rationales for Public Participation in Environmental Policy and Governance: Practitioners' Perspectives.” *Environment and Planning A* 43 (11): 2688–2704. doi:10.1068/a44161.

Worm, Boris, and Trevor A Branch. 2012. “The Future of Fish.” *Trends in Ecology & Evolution* 27 (11): 594–99. doi:10.1016/j.tree.2012.07.005.