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FishPath: A Decision Support System for Assessing and Managing Data- and Capacity-Limited Fisheries

Natalie A. Dowling
CSIRO Oceans and Atmosphere, Hobart, Tasmania, Australia

Jono R. Wilson
The Nature Conservancy, University of California Santa Barbara, Santa Barbara, California, USA

Merrill B. Rudd
University of Washington, School of Aquatic and Fishery Sciences, Seattle, Washington, USA

Elizabeth A. Babcock
University of Miami, RSMAS, Miami, Florida, USA

Matias Caillaux
The Nature Conservancy, Lima, Peru

Jason Cope
NOAA Fisheries, Northwest Fisheries Science Center, Seattle, Washington, USA

Dawn Dougherty
National Center for Ecological Analysis and Synthesis, University of California Santa Barbara, California, USA

Rod Fujita
Environmental Defense Fund, San Francisco, California, USA

Todd Gedamke
MER Consultants, Stuart, Florida, USA

Mary Gleason
The Nature Conservancy, Monterey, California, USA

Nicolas Gutierrez
Food and Agriculture Organization of the United Nations, Rome, Italy

Adrian Hordyk
Murdoch University, Centre for Fish and Fisheries Research, Western Australia, Australia

George W. Maina
The Nature Conservancy, Africa Regional Office, Nairobi, Kenya

Peter J. Mous
The Nature Conservancy, Indonesia

Dan Ovando
University of California Santa Barbara, Bren School, Santa Barbara, California, USA

Ana M. Parma
Centro Nacional Patagónico, Argentina

Jeremy Prince
Biospherics Pty Ltd, South Fremantle, Western Australia, Australia

Carmen Revenga and Jeremy Rude
The Nature Conservancy, Arlington, Virginia, USA

Cody Szuwalski and Sarah Valencia
University of California Santa Barbara, Bren School, Santa Barbara, California, USA

Steven Victor
The Nature Conservancy Micronesia Program, Palau Field Office, Koror, Palau, Micronesia

Abstract
A majority of fisheries across the globe are data- and/or capacity-limited, in that they lack data and/or resources to generate statistical estimates of stock status, often leading to ineffective or nonexistent management. Improving management actions and outcomes could be accomplished by using analytical methods and management measures

that are effective even when data and capacity are limited, positively impacting the livelihoods of millions of people and generating significant conservation benefits. Cost-effective methods for analyzing and managing data-limited fisheries exist, but they are challenging to navigate due to the myriad options, different data requirements, unique outputs, and a lack of understanding of the relative costs and advantages of each approach. There is also an increasing body of general guidance for the process of developing management strategies, i.e., the pre-agreed system of monitoring, assessment, and decision rules used to achieve management objectives for data-limited fisheries. However, this body of guidance has yet to be organized in a way that allows fishery management practitioners to apply it easily. Thus, there remains a disconnect between the development of assessment approaches and decision rule options, and their on-the-ground implementation in a management context. To fill this gap, we have developed FishPath: a decision support system that allows users to characterize their fishery with respect to (i) available data; (ii) biological/life history attributes of relevant species; (iii) fishery operational characteristics; (iv) socioeconomic characteristics; and (v) governance context. FishPath allows users to identify a subset of management strategy options appropriate for the fishery based on this characterization. We are currently applying FishPath to a range of data-limited fisheries globally to evaluate its efficacy. FishPath is the first ever comprehensive and standardized approach to guiding the selection of monitoring, assessment, and decision rule options for data-limited fisheries. If widely applied, FishPath will help ensure that more data-limited, capacity-limited fisheries, particularly those in developing countries, become assessed and managed, leading to improved conservation and fishery outcomes.

Introduction

Most of the theory and practice of fishery stock assessment and management has been built around data-rich stocks, where dynamic population models fitted to long time series of catch, effort, size, and age data combined with fishery independent data are used to assess stock status and guide management. However, more than 90% of global fisheries, representing more than half the global catch, lack adequate data to be managed with statistical estimates of stock status (Costello et al. 2012). Such data-limited fisheries are generally further hindered by limited institutional capacity, infrastructure, personnel, expertise, and/or resources (Orensanz et al. 2005) to perform quantitative stock assessments and implement robust management actions (Dowling et al. 2014a,b); that is, they are also “capacity-limited.” Furthermore, management paralysis in response to data poverty is a problem that contributes to overfishing risk. However, data poverty and capacity limitations should not be used as an excuse to forgo development of a management strategy (that is, the monitoring approaches, assessment methods, and decision rules used to manage a fishery). Indeed, it can be argued that data-limited fisheries are performing far worse than data rich fisheries (Costello et al. 2012) and are most in need of proactive management strategies (Worm and Branch 2012, Sloan et al. 2014, Dowling et al. 2014b, Smith et al. 2014).

Many options now exist for the assessment and management of data-limited fisheries; Dowling et al. (2014a) provide a recent review. Unquestionably, the heaviest emphasis has been on the assessment component, be this fully quantitative (model-based) or empirical (e.g., Kruse et al. 2005, Dick and MacCall 2010). Yet, fisheries management strategies (aka "harvest strategies") extend beyond the estimation of stock status and include considerations regarding the monitoring and the decision rule(s) required to effectively meet objectives. Decision rules comprise the management measure(s) (e.g., catch limits, seasons, or spatial closures) and their associated harvest control rule(s) (e.g., "adjust catch by x%") and explicitly link the outcomes of monitoring and assessment with a management response (Sainsbury et al. 2000, Punt et al. 2002, Butterworth and Punt 2003). Monitoring and decision rule options exist that can be effective even in the context of data and capacity limitation (Dowling et al. 2014a, Berkson and Thorson 2015). Advice provided via decision rules, however, has been strongly focused on setting catch limits (e.g., ICES 2012). Other options (e.g., spatial management or size limits) have not received equal consideration in the data-limited context, largely because these are more difficult to model than catch limits.

The selection and implementation of an appropriate management strategy is dependent upon several factors, including the objectives of stakeholders, the population biology and life history characteristics of the species, the available data, the operational characteristics of the fishery, the socioeconomic context, and the governance and institutional structure. While there has been general guidance to managers of data-limited fisheries when undertaking assessments and developing management strategies (Dowling 2014b, Fujita et al. 2014), this has typically lacked an explicit acknowledgment of the socioeconomic and governance context (Hilborn et al. 2005, Cinner and McClanahan 2006). Omission of such key considerations in fishery management can lead to ineffective implementation of management strategies, erosion of support and buy-in for policies and regulations from stakeholders, and weak conservation and social outcomes. Few process-oriented, context specific approaches to developing a management strategy in the data-limited context currently exist. In contrast with approaches that provide top-down prescriptions and pre-suppose successful implementation, a process-oriented approach allows practitioners to work with local constituents to develop tailored options leading to equitable outcomes.

Context-appropriate management strategies must reflect an understanding of available assessment techniques, the quality and quantity of data required to use a particular technique, the types of decision rules that can achieve desired fishery objectives, as well as an understanding of the trade-offs between the costs and benefits of a particular approach. Moreover, a clearly documented and streamlined tool would facilitate the analysis and management of fisheries where technical expertise is lacking, and provide clear guidelines. A process-oriented approach should allow for customization to address the needs and objectives of fishery managers and practitioners on the ground, while noting that goals and objectives are likely to depend on the context.

In order to bridge these critical gaps, we have developed FishPath: a generalized, process-based decision support system for assessing and managing data-limited fisheries. FishPath is an interactive software system that guides decision-making with the aid of data, models, and user knowledge. In this paper, we provide a broad overview of FishPath, consider its perceived efficacy, and present the strengths and limitations of the approach.

FishPath description

FishPath is an interactive, process-oriented software tool that guides users through the selection of appropriate techniques and tools for assessing and managing data- and capacity-limited fisheries. It provides context-specific advice by identifying appropriate monitoring, assessment and decision rules (collectively, management strategies) for a specific fishery. FishPath is designed for fisheries that lack the data, resources, and/or institutional capacity to perform more formal (model-based) quantitative stock assessment and management. Information about the fishery is elicited through a diagnostic interface and from a "cost of management" relational database.

FishPath explicitly considers five key categories of information (Table 1):

- Available fishery dependent and independent data (quantitative or qualitative)
- Biological/life history attributes of relevant species
- Fishery operational characteristics
- Socioeconomic indicators and characteristics
- Governance context

Table 1. Summary of the questionnaire component of the diagnostic tool. Column headers represent the five main information categories, while the rows describe the general scope of questions under each category.

Available data from monitoring programs	Population/life history data	Fishery operational characteristics	Socio-economics	Governance
Currently collected? (e.g species composition, length composition, age composition, mean length, mean weight, fishing location, catch, effort, CPUE, sex composition, fishery dependent density, fishery independent abundance, inside/outside MPA length and density)	Current state of knowledge?	(e.g.) type of gear, number of operators, fishing location/season, species targeted, possible latent effort, discarding practices...	Social structure within the fishery or the community or the region of interest?	Current institutional structure?
Possible to collect?	How obtained?	How do the fishermen and markets respond to environmental, management, economic and social changes at play in the fishery?	How are peer to peer interactions structured?	Strong top down or bottom up processes?
What types of information could be used as performance indicators and reference points?	Is information specific to the local fishery, specific to the species in general, or borrowed from related species?		Current relationship between different user-groups (fishermen, processors, managers, NGOs, etc.).	How is enforcement carried out?
Spatial/temporal consistency?			What is the current economic status of the fishery (prices, costs, volume, etc.)?	Concerns related to IUU fishing?
Data quality			Fishery subsistence or commercial?	Types of access rights?
Data quantity			Level of cooperation with managers? Extent of familiarity with formal management?	Strong legal or customary policies?
What is realistic given the current research capacity ?			Level of resource dependency?	

(Note that the latter two have traditionally received less attention in a management strategy selection context.)

Within FishPath, a management strategy selection process considers the information from the above five categories and identifies a suite of possible management strategy options, that are tailored to the specifics of the fishery of interest (Fig. 1).

Fishery diagnostic tool

The fishery diagnostic tool is designed to help fishery managers, practitioners, nonprofit organizations, and stakeholder working groups focus attention on understanding the five key information categories defined above. The diagnostic may also be of use in scoping fishery and management objectives, if these have not previously been elicited. Objectives may include aspects related to fish catch, jobs and livelihoods, resource access, cultural considerations, short- and long-term profitability, habitat considerations, threatened and endangered species protections, and other ecosystem considerations. However, management objectives are often conflicting and stakeholders need to decide how to trade off the competing objectives (Punt 2015).

By definition, information availability and/or technical capacity are typically low for data-limited fisheries (with technical capacity issues being typically more pronounced in developing nations), increasing the importance of eliciting data, knowledge, and information from stakeholders and local experts. The diagnostic tool is designed for use in a participatory setting, and has two stages. The first is a general scoping of the target fishery to identify key attributes of the fishery relating to the key information categories (per Table 1) and to provide the context for developing a subsequent refined subset of more direct or detailed questions. The second stage is designed to elicit more detailed information on available data, life history/population dynamics, and fishery operational characteristics, given the responses from the first stage. For example, if stage 1 reveals that there is no size-based information available in the fishery, stage 2 cannot elicit more detailed information on length-at-first-capture, mean size of the catch, or temporal changes in fish size.

A copy of the diagnostic tool is available as supplementary online material (Appendix 1).

Cost of management database

The cost database allows FishPath users to compare the relative costs of alternative management systems. Management costs are dependent on several fishery characteristics and socioeconomic factors. However, a few simple indicators can be used to estimate the relative magnitudes of these expenses. Indicators include labor days, wages, boat days, fuel costs, fishery area, number of ports, and fleet size, defined in the

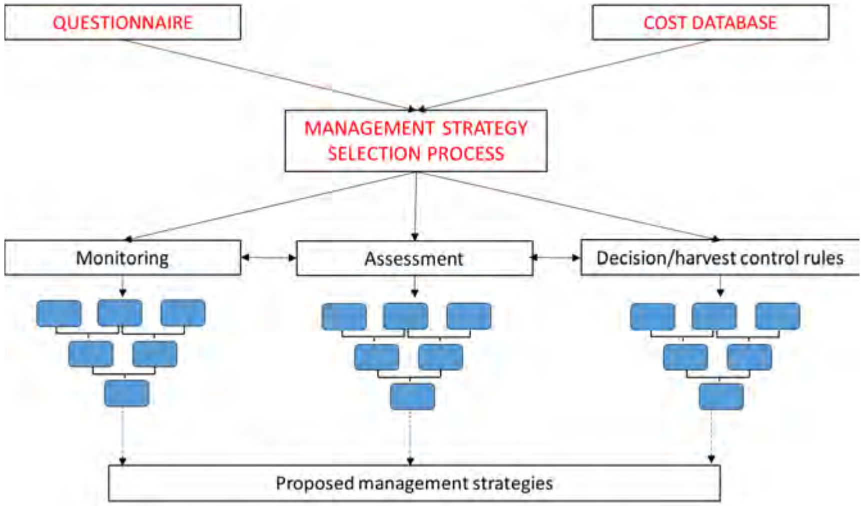

Figure 1. Schematic of FishPath. The Management Strategy Selection Process (MSSP) is informed via the diagnostic tool, here indicated as "Questionnaire," and via the cost database. Confronted with this information, the MSSP, via a series of caveats and criteria, presents the user with a subset of monitoring, assessment, and decision rule options. Collectively, these form potential management strategies.

context of three main management cost categories: monitoring, assessment, and enforcement. These can be ascertained either during the diagnostic process, from fishery managers, or from agency records. The cost database does not produce absolute values related to the costs of management, but rather provides relative values according to the scale of the fishery, man hours required to perform the task, the relative labor costs of the geographic region, and other pertinent factors. The costs of management are used to refine the possible suite of management strategies provided in the management strategy selection process (described below) whereby the costs are weighed against the fishery characteristics (described above) to generate a set of possible management strategies that may be appropriate for the context of the fishery.

Management strategy selection process

The diagnostic tool and cost database underpin a management strategy selection process, which is a user-friendly guide to selecting the monitoring approach, assessment methods, and types of decision rules. It can be applied to single-species or multispecies fisheries. The selection process takes information gleaned from the fishery diagnostic process and the cost database, to select all possible options for monitoring, assessment models, and decision rules that are appropriate for the fishery given the biology, fishery characteristics, socioeconomic indicators, available data, governance context, and costs of management.

The first phase of the management strategy selection process is to identify possible options for future monitoring. These can either corroborate or point out deficiencies with existing monitoring programs, and can highlight approaches that could augment or supplant existing protocols. The fishery of interest is confronted with a range of criteria and caveats (Fig. 2) to identify monitoring options, of which more than one may be applicable (Fig. 3). A set of five criteria form an initial filter, via which monitoring options are eliminated if the fishery is below the minimum requirement associated with each criterion. A subsequent suite of caveats, where applicable to the fishery, may also result in the monitoring option being eliminated, or they may carry a warning, or recommendation, that the option is less, or more, desirable given the fishery's circumstances.

Second, the management strategy selection process identifies a suite of possible and appropriate assessment options. We have identified 39 possible assessment options from the published literature that are appropriate for data-limited fisheries lacking the data and/or capacity for formal model-based stock assessment to inform a model-based assessment (Dowling et al. 2014a) (Table 2). Each assessment option is associated with a vector of scores corresponding to the minimum life history/biological attributes, quality of available indices, and the extent of available expert judgment necessary to undertake the assessment (Fig. 4). A corresponding vector of scores for the fishery of interest is determined directly from the outcomes of the fishery diagnostic process. The extent of matching between the assessment option and the vector of scores for the fishery of interest is used to identify possible assessment options (Fig. 5). This approach can also identify areas where, if the quality of information were improved, a more robust assessment could be undertaken.

The assessment options are then further refined via a set of caveats and criteria that largely pertain to assumptions associated with the assessments (e.g., that the fleet is engaging in active targeting, that data are assumed to be spatially/temporally/fleet representative, that selectivity is constant).

The families of assessments under consideration for use include the following (see Table 2):

- Those without reference points, such as expert judgment-based approaches (e.g., Productivity Susceptibility Analyses, Ecological Risk Assessment for the Effects of Fishing, and changes to species composition, gear deployment, and spatial distributions of effort and landings.

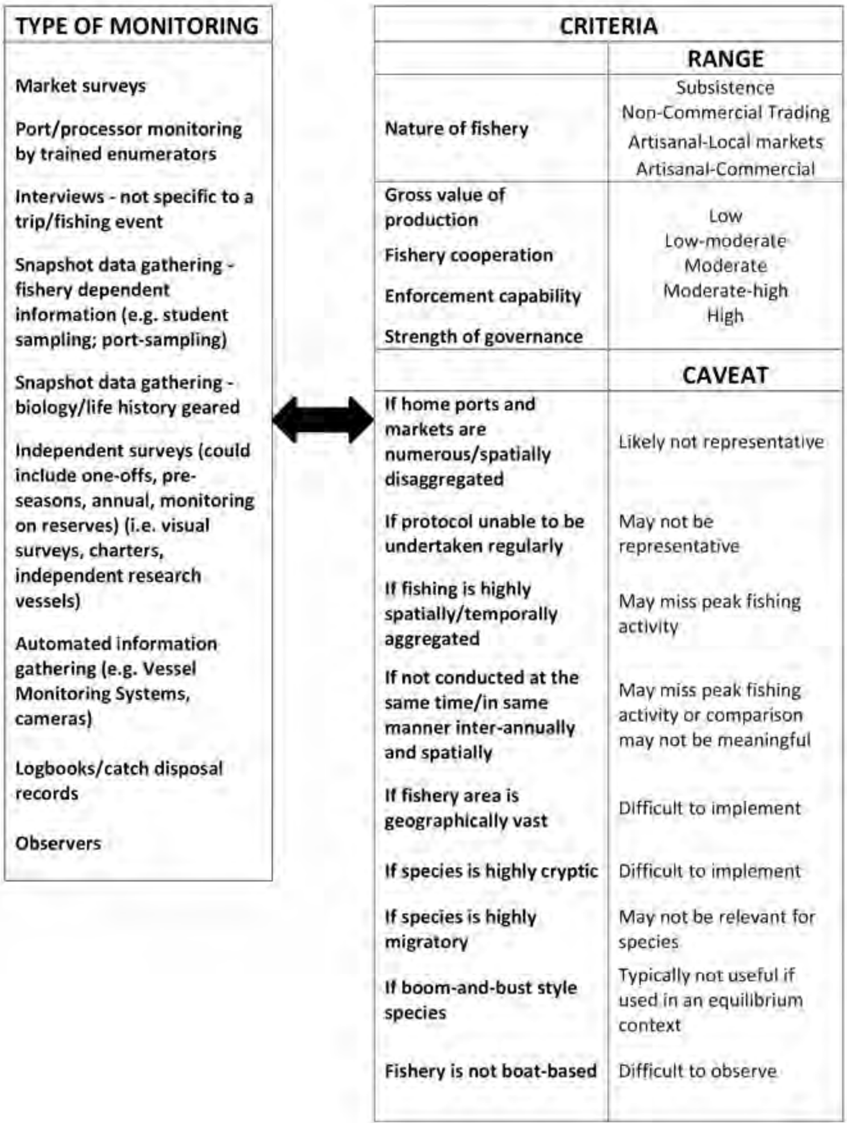

Figure 2. Monitoring options together with an example subset of the criteria and caveats against which each option is considered. Criteria are associated with ranges of values, for which each monitoring option has a minimum requirement. These criteria are the initial filter via which monitoring options are eliminated if the fishery is below the minimum required level. Caveats applicable to the fishery may also result in the monitoring option being eliminated, or they may carry a warning that renders the option less desirable given the fishery's circumstances.

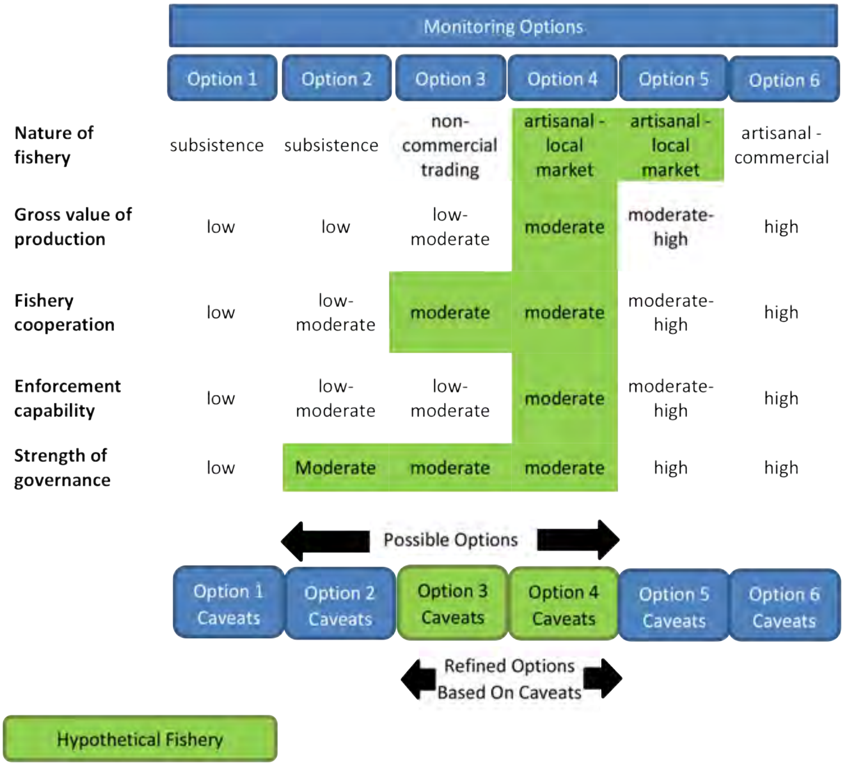

Figure 3. Schematic of how monitoring options are narrowed down to a feasible short list for a hypothetical fishery. Criteria are listed vertically, with the minimum required levels for each monitoring option in the body of the table. The characteristics of the hypothetical fishery are highlighted in green, yielding a subset of possible monitoring options (options 2-4) from the criteria. These options are then refined (to options 3-4) according to caveats associated with each monitoring option (per Fig. 2).

Table 2. List of the 39 forms of data-limited assessments, with citations, as used in FishPath. Assessments are grouped according to the extent of available reference points, and what is estimable.

NO REFERENCE POINTS	
Initial formal investigation	
None -> direct to management (control rules)	Dowling et al. 2014a
Exploratory analysis (e.g. corral data)	Dowling et al. 2008
Expert judgement	Dowling et al. 2008
Harm/no harm	
Ecological risk analysis (ERA)	Smith et al. 2007
Comprehensive assessment of risk to ecosystems (CARE)	Fujita et al. 2014
Ecosystem threshold analysis	Fujita et al. 2014
Productivity-susceptibility analysis (PSA) to estimate the risk of overfishing	Patrick et al. 2010
Sustainability indicators	Cope and Punt 2009, Froese 2004
Sustainability assessment for fishing effects (SAFE)	Zhou and Griffiths 2008, Zhou et al. 2009
Changes worthy of some management response	
Changes in dominant species	Dowling et al. 2008
Changes in species composition ratios	Dowling et al. 2008
Changes in spatial distribution of catch or effort	Dowling et al. 2008
Changes in gear type or manner of deployment	Dowling et al. 2008
PROXY REFERENCE POINTS	
Time series-based ideally with reference point (e.g., slope-to-target)	
Standardized CPUE as a proxy abundance index	Dowling et al. 2014a
Catch, CPUE by size indicators	Froese 2004
Changes in mean length/weight/size percentiles	Dowling et al. 2014a
Linear regression on CPUE time series	Dichmont and Brown 2010, Haddon 2010, O'Neill et al. 2010
Depletion analysis (CPUE versus cumulative catch)	Hilborn and Walters 1992
Size relative to size-at-maturity	Basson and Dowling 2008, Punt et al. 2001
Ratio of density inside to outside MPAs	Babcock and MacCall 2011, McGilliard et al. 2011
Use biomass surveys to inform spatial management (e.g., areas suitable to open/close under rotational spatial management)	Dowling et al. 2008
Size-specific catch rate indicators for fish sampled inside and outside of MPAs, and per-recruit	Wilson et al. 2010
STOCK-STATUS-BASED REFERENCE POINTS	
Estimating life history attributes	
Modal analysis to estimate growth rates	MacDonald and Pitcher 1979
Estimating fishing mortality, F	Fournier and Breen 1983, Haddon 2011
Length-based spawner-biomass-per-recruit (SPR)	Hordyk et al. 2014, 2015; Prince et al. 2014
Estimating lifetime egg production	O'Farrell and Botsford 2006
Estimating sustainable yield	
Zhou's catch-only approach	Zhou pers comm.
Only Reliable Catch Series (ORCS)	Berkson et al. 2011
Depletion-corrected Average Catch (DCAC)	MacCall 2009
Depletion-based Stock Reduction Analysis (DB-SRA)	Dick and MacCall 2011
Production model	Hilborn and Walters 1992
"FRAMEWORK"-BASED ASSESSMENT TYPES	
CUSUM	Scandol 2003, 2005
Traffic lights	Caddy 2004, 2009; Caddy et al. 2005; Halliday et al. 2001
RAPFISH (multidimensional scaling, MDS)	Pitcher et al. 2013, Pitcher and Preikshot 2001
Hierarchical decision trees - may or may not have reference points	Prince et al. 2011
Size-based sequential trigger system	Dowling et al. 2008
Catch or effort based sequential trigger systems	Dowling et al. 2008
Sequential trigger framework involving catch and/or effort, CPUE, size, sex ratio etc.	Dowling et al. 2008
Decision tree for defining indicator values of stock status	Cope and Punt 2009

- Those with proxy reference points such as length-based indicators, regression analyses, marine reserve–based density ratios, or those based on standardized catch per unit effort (CPUE).
- Those with stock status–based reference points such as estimation of fishing mortality (*F*), and spawning potential ratio (SPR) approaches (noting that a production model is the most "data-rich" assessment considered).

Indices

INFORMATION TYPE	SCORING	SCORE DEFINITION
Species composition Length composition Age composition Mean length Mean weight Catch Effort Catch-Per-Unit-Effort Sex composition Fishery dependent density Fishery independent abundance Inside:outside No-Take Zones/Marine Protected Areas	blank or 0 1 2 3 4	absent snapshots/intermittent/<5years 5-10 regular years (i.e. not necessarily every year) 10+ regular years (i.e. not necessarily every year) regularly since inception

Biology/Life History

INFORMATION TYPE	SCORING	SCORE DEFINITION
General population biology Life-history ratios M/K (can be borrowed) Natural Mortality Maturity ogive/ size at maturity Von Bertalanffy parameters	blank or 0 1 2 3	absent borrowed in situ but poor in situ but reliable

Expert judgement

INFORMATION TYPE	SCORING	SCORE DEFINITION
Expert judgement/common knowledge of stock status/depletion Expert judgement re: fishery operations and interaction with broader environment Expert judgement re: non-fishing threats, ecosystem services, threat interactions Expert judgement re: Marine Protected Areas and habitat status	blank or 0 1 2	absent borrowed - outside expert in situ - local expert

Figure 4. List of the information types, used in determining feasible assessment options, grouped by "indices," "biology/life history," and "expert judgement." The right-hand boxes describe the corresponding scoring system used to identify the availability and quality of each data type.

- "Frameworks" such as decision trees, traffic light systems, cumulative sum control charts (CUSUM), RAPFISH, or sequential trigger systems. These use a range of indicator values and/or indicator types, and may also incorporate some of the "stand-alone" assessment approaches. For example, combinations of indicator values lead to specific branches of a decision tree, which in turn may lead to specific types of assessments.

	Assessment method 1	Assessment method 2	Assessment method 3	Assessment method 4	Assessment method 5	FISHERY
Biology/life history attributes						
a	0	1	2	3	3	2
b	1	1	1	2	1	1
c	2	1	2	2	2	1
Indices						
a	0	1	1	2	3	1
b	1	1	2	2	2	1
Types of expert judgement						
a	1	1	2	1	2	2
b	1	1	1	2	2	1

Figure 5. Schematic diagram illustrating the extent of matching between scoring vectors (equating to the presence and quality of indices, biology/life history information, and available expert judgment—per Fig. 4) for each assessment approach, and the vector for the fishery of interest. The scores in the body of the table correspond to the minimum levels of availability and/or quality of information required to undertake the assessment. In the right hand box are the scores that correspond to the information available for the hypothetical fishery. For this example, the vector corresponding to the available information for the hypothetical fishery most closely approximates the vector equating to the minimum information requirements to undertake Assessment method 2. It can also be seen that, with some improvement in the quality of information under "Biology/life history attribute (c)" and "Indices (b)" the fishery stock status could alternatively be assessed using Assessment method 3.

Finally, the management strategy selection process identifies options for types of decision rules (management measures and harvest control rules), via the consideration of a range of criteria against the five key information categories. Thirteen broad "families" of management measures (input and output controls) have been identified (Table 3), and these are evaluated against approximately 40 criteria pertaining to available data, biological/life history attributes, fishery operational characteristics, socioeconomics, and governance attributes.

Many decision rules can be used with any assessment, but some are more or less appropriate under certain circumstances, and the selection process attempts to explicitly acknowledge this. Additionally, in many

Table 3. List of decision rule "families" and descriptions of the nature of each.

	Harvest control rule "families"
1	**Catch limits (daily, seasonal, annual)**
a.	adjust by fixed proportions up or down
b.	adjust in proportion to distance from a (possibly proxy) reference point - requires said reference points
c.	according to assessment outcomes (e.g. depletion analysis, CPUE regression, 40/10 rules)
d.	from monitoring closed areas or marine protected areas (e.g. Babcock and MacCall (2011); McGilliard et al. (2011) ; Wilson et al. (2010))
2	**Effort limits (daily, seasonal, annual)**
	Effort limits includes # days fishing/# hooks/# fishing hours/# lines set/net setting time/trip limits/
a.	adjust by fixed proportions up or down
b.	adjust in proportion to distance from a (possibly proxy) reference point - requires said reference points
c.	according to assessment outcomes (e.g. depletion analysis, CPUE regression, 40/10 rules)
d.	from monitoring closed areas or marine protected areas (e.g. Babcock and MacCall (2011); McGilliard et al. (2011) ; Wilson et al. (2010))
3	**Gear restrictions: managing by selectivity (i.e. can manage towards targets, and can avoid effort creep issues)**
	NB subject to effort creep - need to define "effort", but don't necessarily manipulate effort directly as part of rule
	e.g. mesh/hook sizes; trap escape rings; use of light sticks, cod ends, escape hatches, size limits etc.
4	**Other gear controls not related to selectivity**
	These are focussed on avoiding limits rather than on achieving targets
	May be related to avoiding capture of vulnerable/at risk bycatch species, or related to selectivity (e.g. avoid catching juveniles)
	e.g. removal of seines, dredges, destrcutive gears (remove non-selective techniques)
5	**Spatial restrictions**
	Can be invoked or modified by harvest control rules
	Closures: permanent/Marine Protected Area
	Closures: rotational/seasonal/in response to trigger being reached/stock status indicating overfished
	"move-on" provisions
	Territorial User Rights Fisheries
6	**Temporal restrictions**
	Can be invoked or modified by harvest control rules
	Adjust time of day allowed to fish (e.g. no day setting of longlines to avoid capturing seabirds)
	Adjust season duration (e.g. for highly productive, short-lived species subject to management by a fishing season of fixed duration, real-time within-season management may be applied to adjust season duration)
	Seasonal closure
	Closure in response to trigger being reached/stock status indicating overfished
7	**Size limits**
	pertaining to controlling selectivity (e.g. protecting juveniles, or oldest (largest) fish that have highest reproductive contribution)
	May be indirectly achieved via gear/spatial/temporal restrictions
8	**Sex regulations**
9	**Invoke data collection**
	This does not confer the necessity to immediately analyse the collected data. Data may be archived against a time when required and/or the GVP/capability exists to analyse it.
10	**Apply additional (precautionary) buffers/adjustments to catch or effort**
	e.g. if high discarding or illegal/unregulated/unreported activity known or suspected
	May be useful if uncertainty is high, or an assessment (such as a decision tree) suggests that overfishing is more probable.
	May be useful if latent effort may be activated
	May be used to avoid volatility in interannual changes in allowable catch or effort
11	**Overrides in case of exceptional circumstances**
	(could argue that these should be included in all harvest strategies, on the proviso they are scientifically defensible)
	May be useful if latent effort may be activated
12	**Retain status quo**
	"watch and wait", particularly if minimal current funds and capacity and no immediate concerns re: stock status
	Often goes together with commitment to invoke data collection
13	**Levies, taxes (e.g. as incentives to avoid areas)**
	Other incentives as proxy enforcement - i.e. rewarded for doing right thing (e.g. some kind of accreditation)

instances multiple decision rules could (and often, should) be applied. For example, decision rules pertaining to gear or effort may be the main management lever, but these may be augmented by spatial closures to protect an incidentally caught, highly vulnerable, or threatened species (e.g., Dowling et al. 2008). The selection of appropriate decision rule options focuses on those that should be eliminated, or those that are particularly recommended, for given circumstances. Management measures and harvest control rules will still need to be considered in the context of the management objectives for the fishery. This is not currently an explicit component of FishPath, but may be achieved by accompanying management strategy evaluation to examine the trade-offs between alternative forms of monitoring, assessment, and decision rules.

Case study example

FishPath is being tested for a range of case studies globally, that embrace a broad cross-section of data-limited fisheries (in terms of the five key information categories, Table 1). Here we provide a case study to illustrate how FishPath can be applied to generate management guidance, for the Lorna Drum (*Sciaena deliciosa*) finfish species in Peru. This is a low-value demersal finfish species that is landed at more than 23 sites throughout the country using multiple gear types. Relatively good data exist covering the last 10 years and the fishery is currently managed under a size limit and a mesh size limit (for gill nets and purse seines), but weak regional governance capacity prevents the enforcement of policies and management regulations. In collaboration with the Instituto del Mar del Peru (IMARPE), the fisheries science and monitoring agency of Peru, we applied FishPath to the Lorna Drum fishery during a workshop in Lima, Peru, in June 2015. The diagnostic tool and cost database were completed in a group session by managers and scientists highly familiar with the fishery.

Against the "monitoring" criteria, the gross value of production and the strength of governance were both classed as "moderate," which limited monitoring options to market surveys, port/processor monitoring, interviews, snapshot data gathering (biological or fishery-dependent information), and independent surveys. Monitoring options based on automated information gathering, logbook/catch disposal (sales docket) records, and observer programs were excluded. Additional information from the diagnostic process invoked caveats that further refined the recommendations to market surveys or port/processor monitoring, and interviews. (Port monitoring is currently being undertaken as the main monitoring method, so it was encouraging validation of FishPath that the recommended options embraced the existing approach). Snapshot data gathering was precluded because fishing is highly spatially aggregated, and because it is not likely that data could be collected at the same time and/or in the same manner interannually and spatially. The geographic vastness of the fishery mitigated against the use of fishery independent surveys.

In terms of assessment options, the existing data for Lorna Drum are comprehensive (the fishery is more "capacity-limited" than "data-limited" due to its operational characteristics (e.g., it is open access, and has a high level of illegal and unregulated fishing) and its low strength of governance (although its research capacity is high). As such, the vector matching exercise excluded only seven of the 39 assessment options. However, the subsequent assessment criteria and caveats cautioned against 14 more, mostly on the basis of assessments assuming active targeting (Lorna Drum are not actively targeted) and having sensitivity to selectivity (the selectivity pattern for Lorna Drum is not clearly understood). This yielded nine options under the "no reference points" family of assessments, two under the "proxy reference points" family, six empirical indicator-based frameworks, and three stock-status based reference point assessments. Given the high research capacity within Peru, the latter options were recommended because they are presumably more robust (in terms of data richness and certainty in a management strategy evaluation context).

Factors that limited the options for decision rules were the open access, opportunistic, multi-fleet and multispecies characteristics of the fishery, the lack of enforcement capability, and the suspected illegal/unregulated/unreported catch. Specifically, lack of enforcement and low fisher/community cooperation, together with the open access nature of the fishery, precluded catch or effort limits. Spatial and temporal restrictions were associated with cautions give the open access nature of the fishery and the aforementioned issues. (That said, options can easily be re-evaluated assuming limited access could be achieved—currently this is not realistic given socioeconomic and governance constraints). Gear restrictions to manage via selectivity, precautionary buffers, and levies/taxes were the options with the least associated limiting caveats. Size limits, while unable to be formally enforced, are also possible, and are likely to be more successful where these are underpinned, for example, by incentives from buyers purchasing only fish above the minimum length.

Overall, the management strategy options for the Lorna Drum fishery were limited not by data availability or research capacity, both of which were relatively high, but by the open access, opportunistic nature of the fishery, and particularly by the low strength of governance and enforcement capability. It was an encouraging validation of the tool that the identified management strategy options embraced those currently in place for the fishery, while also suggesting possible alternatives that had not previously been considered. Most importantly, managers were enthusiastic about being presented with new, plausible alternatives. FishPath is also being applied within Peru to Chita (*Anisotremus scapularis*), a finfish species for which data availability is far more limited. This will provide a useful contrast to the Lorna Drum example, given the same governance issues apply.

Importantly, once the diagnostic process and cost databases had been completed (which took approximately three hours with experts present), the process of identifying management strategy options was completed in under an hour. This was the first major case study application of FishPath, and was undertaken manually, with the monitoring, assessment, and decision rule components in spreadsheet form. Embedding the content in a formal software interface would have reduced the task to seconds, although such software would have to maintain transparency—and certainly there was benefit in a more manual process in that it engendered constructive dialogue. In the previous experience of the first author (largely within the Australian Commonwealth data-limited fisheries), the identification of possible management strategy options in the absence of a process-based tool such as FishPath has typically taken days, and usually multiple meetings of stakeholders and experts.

The strength of FishPath was in its transparency, its unbiased, comprehensive inventory of available options, and its acknowledgment of socioeconomic and governance aspects in addition to those of data, life-history/biology, and fishery operational characteristics. Moreover, by highlighting the specific criteria by which monitoring, assessment, and harvest control rule options are rejected, FishPath identifies clear pathways to the potential improvement of fishery management. It not only shows what is currently possible, but what may be possible in the future, if stakeholders and managers can overcome the limiting aspects of their fishery's characteristics, as identified by FishPath.

FishPath is also in the process of being applied to the following case study fisheries:

The spiny lobster (Panulirus spp.) and multispecies finfish fisheries in Kenya. The former is a high-value export fishery that is harvested mainly by free-diving fishers using scoop nets. The latter targets dozens of coastal species with various gear types including gillnets, hook and line, traps, and seines. Recent monitoring projects have collected data on size/catch/effort, but management and enforcement institutions remain capacity-limited. There is support from the government to pursue certification of the shallow water spiny lobster fishery under the Marine Stewardship Council (MSC). Primarily, the greatest barrier toward MSC certification is not lack of infrastructure but issues associated with data leakages, limited information on stock status, and lack of a well-defined management strategy.

The coral reef finfish fishery of the Northern Reefs in Palau is a culturally significant tourism and artisanal market-driven fishery of over 50 species, which are harvested by spearfishing and line fishing. There have been local landing surveys to collect some size-based data. Traditional rights-based fishing has been eroded by a modern open access philosophy, and only a few legislated management controls are currently in place, but there is little institutional capacity to control fishing capacity and catch levels.

The rock crab (Cancer spp.) fishery in California is characterized by three short-lived, fast-growing crab species that are harvested by commercial and recreational fishers using mainly traps. The government has a well-managed permit system and size limit in place; however, there is very little monitoring data available and no information on stock status.

In the context of these case studies we aim to refine our approach, reform fisheries on the ground in these locations, and create a scalable model for global use. This work represents progress toward the vision of a universal practical decision-support system for the management of data- and capacity-limited fisheries.

Discussion

Strengths of the FishPath approach

FishPath is a process-oriented software tool that translates user information and knowledge into the selection of a fishery-specific management strategy including (a) monitoring, (b) assessment, and (c) decision rules. FishPath is unique in that it is the only known framework for identifying assessment and management options for data-limited fisheries that incorporates socioeconomic and governance characteristics in addition to biology and fishery characteristics. FishPath considers all three management strategy components, i.e., monitoring and decision rules as well as (empirical and model-based) assessments, and it is not limited to catch quota-based management measures (i.e., many other types of decision rules are included). We consider nine categories of approaches to collecting data, embracing more than 20 types of fishery dependent and independent data that can be used to assess stock status. The management strategy selection process includes 39 possible data-limited assessment options (not including variants of each option), and 13 possible “families” of decision rules for consideration. Moreover, it is simple to extend the process to include additional monitoring, assessment, and decision rule options.

FishPath is structured to generate viable management strategies that can be employed in the near-term so as to ensure against managerial paralysis. The process can easily be repeated over time as more information becomes available. Importantly, by pinpointing the criteria and caveats that preclude the use of specific monitoring, assessment, and decision rule options, FishPath includes explicit guidance for continuing or improving monitoring systems to address existing shortfalls. It also includes among its decision rule options a commitment to data collection, as per the "data archiving" recommendation of Dowling et al. (2008). By making the commitment to collect and archive additional data an explicit decision rule option, such data collection becomes a formal component of the management strategy. This commitment to data collection is a decision rule that may be imposed regardless of perceived stock status. Collecting data may not have a short-term payoff, nor indeed may the economic or research capacity exist to immediately analyze such data. In the long-term, however, a time series may offer valuable insights and may be necessary for improving the level of certainty regarding stock status (Dowling et al. 2008).

Moreover, many of the empirical assessment approaches (such as indicator-based trigger systems), are inherently adaptive. The response to a trigger point, for example, may demand a more defensible assessment before the fishery can expand further. Such an assessment is likely to require a time series of data. If this has been retrospectively established, delays to the fishery's assessment, and hence to ongoing operations, are minimized. At the same time, it is acknowledged that the economic value of some data-limited fisheries is so low that it may not make economic sense to invest in moving the fishery to a more data-rich state (while also noting that [i] even fisheries that remain data-poor need to collect some data over time, to demonstrate sustainability and/or because of the need to adapt to changing ecological and fishery conditions; [ii] governments and development agencies will often look beyond the exclusive economic value of the fishery and emphasize food security and livelihood, and acknowledge the importance of data collection for these reasons; and [iii] if a fishery is worth managing, it is worth collecting data against this). More generally, the benefits of strategic investments in alternative arenas (such as addressing bycatch) to achieve specific goals, may outweigh that of investing in broader-based data collection.

Learnings and current issues

The FishPath management strategy selection process is intended to be an automated and efficient tool, and thus may give the impression that it provides a "silver bullet" for fixing fisheries. While FishPath can make the selection of management strategies much simpler for data-limited fisheries, it is not a panacea and requires a substantial amount of interpretation and thought to use. Many important considerations are made transparent to the user to acknowledge this complexity and facilitate careful interpretation. These include the criteria on which management strategy options have been included or rejected for their fishery and other caveats that are critical for users to understand prior to implementing a particular management strategy. To complement the interpretation of FishPath recommendations, an adaptive "how-to" guide with detailed explanations of each management strategy option (i.e., all monitoring, assessment and decision rule options), together with the cautions and caveats associated with each, will be provided to the user.

Empirical "assessments" (especially those with no reference points), and the families of decision rules where the management measure is not directly quantitative (e.g., gear or spatial controls, as opposed to catch limits), pose a particular challenge for implementing and evaluating data-limited management strategy options. While conceptually simple, to explicitly interpret these requires significant judgment in the face of ambiguity. Issues include but are not limited to, lack of precedent, definition of reference points, quantifying management measures, implementation, interpretation of outcomes, and legislative (more detail is provided as supplementary online material, Appendix 2). Addressing these problems is certainly feasible and is ongoing within our development process, but we mention them here to emphasize that the implementation of supposedly simple data-limited approaches is not a trivial exercise.

The largest outstanding issue in the context of our work to date is how and indeed whether we consider how much to restrict catch or access, within the context of the advice provided. Currently, FishPath generates recommended management strategies but does not consider the degree to which they should be implemented, given the stock status from an assessment. For example, FishPath does not prescribe detailed (equation-based) catch harvest control rules according to some level of certainty (e.g., as per ICES 2012). It also embraces more empirical harvest control rules, such as gear and spatial restrictions, for which it is important to understand the context of the data, environment and assessment outcomes before fully prescribing the strength at which a management measure should be adjusted up or down. Work is ongoing to develop generic guidance for the design of quantitative adjustments to management measures within harvest control rule options, while noting that this also involves objectives and trade-offs that are highly fishery specific. The question is whether we can provide a process through which managers and stakeholders in specific fisheries can arrive at a rational magnitude of harvest control. The development of a database of case studies, as well as the outputs of management strategy evaluation (MSE), will be informative to this process. Recent work by Carruthers et al. (2014) has generated a standardized approach to MSE through the DLMTool (https://cran.r-project.org/web/packages/DLMtool/DLMtool.pdf). Updates to the tool and ongoing efforts to integrate the outputs of FishPath with the DLMTool show exciting promise toward this goal.

While clearly articulated within the diagnostic tool, the socioeconomic and governance information categories currently require more careful consideration within the management strategy selection process. Socioeconomics and governance considerations are often under-represented in fisheries management, yet can render an otherwise applicable management strategy approach infeasible. While it is easy to acknowledge socioeconomics and governance as important, actually using such data and information is a significant and ongoing challenge.

Reviewing management strategy options in the context of fishery objectives

FishPath does not prescribe a single "best" management solution, but rather provides a decision-making process via which a suite of potential options may be identified. These options should be explored in collaboration with stakeholders and in the context of a clear delineation of management objectives. The use of FishPath will be most successful if the process is inherently adaptive (Smith et al. 1999, Dowling et al. 2008). To this end, an ongoing collaborative approach should be maintained to maximize the potential for ensuring ongoing buy-in, stakeholder confidence, and support for management (Dowling et al. 2008).

Like any decision support tool, FishPath carries with it the risk that managers or practitioners will conclude that its use will require less interpretation on their behalf, especially for fisheries with low research capacity and governance. We emphasize that FishPath is not intended to replace, but rather help guide, hone, and augment, local knowledge or expert judgment. Managers and practitioners must trust in their own expert knowledge and the concerns of other stakeholders, and have confidence to consider the subset of identified management options in context of their fishery's objectives.

Broader application

FishPath is intended to be applicable for data- and/or capacity-limited fisheries globally. However, there are undoubtedly circumstances in which its application would be difficult. Some fisheries may have data and/or management issues that are yet to be addressed within FishPath (such as stocking with fish from hatcheries, whose population dynamics vary from those of wild stocks). Other issues with lack of fit for FishPath may well emerge as the case studies progress.

Nonetheless, in the context of requirements for data-limited fishery management, FishPath can provide pragmatic guidance for the assessment and management of a majority of global fisheries. This capability is urgently needed given recent recognition that unassessed and/or unmanaged fisheries perform poorly (Costello et al. 2012) and the growing effort to improve conservation and economic outcomes for the thousands of fisheries and millions of fishermen worldwide that rely on such fisheries (HLPE 2014).

There is indisputable demand for a tool such as FishPath. The majority of the world's fisheries are unassessed and essentially unmanaged, and most of these appear to be overfished and/or experiencing overfishing (Costello et al. 2012), and presumably producing far less food and revenue than they could be as a result. Economists estimate more than $200 billion is required to reform fisheries management to maximize long-term yields (Sumaila et al. 2012). But money alone won't solve this problem; investment decisions need structured guidance, such as that generated by FishPath, to achieve success. One example of the potential use of FishPath to facilitate sustainable fishing is through fishery improvement projects (FIPs), many of which may not yet be achieving desired outcomes (Sampson et al. 2015). FIPs provide expanded options for fisheries to meet sustainable seafood certification criteria, but have struggled to choose effective assessment and management measures in key fisheries, which are obviously required for success. While acknowledging Sampson et al.'s (2015) point that the major problem with FIPs is early market access, which reduces incentives to apply management measures, widespread use of FishPath in FIP development and tracking may be one way to improve FIP performance and assure that more fisheries meet certification (e.g., MSC) criteria.

FishPath is a decision support tool for fisheries management that incorporates fishery information across five data categories, to provide guidance for the selection of assessment methods and management strategies tailored to fit individual fisheries. Although this guidance is critical, a remaining step (and one that is currently under way) is to provide sufficient technical support (e.g., through user-friendly interphases and capacity building) to implement those more sophisticated, model-based assessments in fisheries with limited technical capacity. Nonetheless, FishPath represents a valuable step forward in improving the management of data-limited fisheries globally.

Dedication

We respectfully dedicate this paper to the life, work, and memory of Jose Maria (Lobo) Orensanz, who did so much to raise awareness of the issue and needs of small-scale, spatially complex and data-poor fisheries. The world of fisheries is a sadder place without him.

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Appendix 1: Diagnostic Tool

Diagnostic tool: Phase one

The goal of the questions that may be asked under phase 1 is to encourage stakeholders to describe the fishery, so that a general sense of its context and characteristics may be obtained. Subsequent questions under phase two may then be honed so that they are relevant to the fishery context.

Phase 1 questions should guide the user as appropriate, and stakeholders should be encouraged to speak freely.

OPERATIONAL CHARACTERISTICS

Harvested species

1. Approximately how many species are currently landed?
2. Can you describe the target / most frequently caught / most vulnerable / byproduct / bycatch species in this fishery?
3. What are the top species by landings?
4. What are the top species by value ($/kg)?
5. What are the top species by cultural value? What is the cultural importance?
6. Are there vulnerable or threatened species captured (either targeted or incidentally) that may have the potential to limit the fishery due to environmental concern?
7. Using questions above as a guide, what are the “key” species? May include those most frequently caught / those targeted / most vulnerable / most valued economically / culturally.

Fishing activity

8. What are the main fishing gears used? Is there a mix of fishing techniques?
9. What is the total number of current participants or vessels in the fishery?
10. Is the fishery exploited by more than one fleet? *A fleet is defined in the following way:*
    1) A fleet is a group or boats or fishers that use the same gear type.
    2) A fleet has a similar average fishing capacity (distance, duration, size)

11. Are the fleets actively targeting species or is it more passive / opportunistic?

12. What is the average catch per fishing event / trip?

13. What is the distribution of the catch over time? Are there seasons or months where the catch is concentrated?

Spatial extent of fishing

14. What is the maximum spatial extent of the fishery (km^2)?

15. How many "home ports" are there? Where are they located?

16. How many other landing sites are there? Where are they located?

17. Where are the main fishing grounds located?

DATA

18. Who collects the data (e.g., government agencies, fisher cooperatives, fish processors)?

19. What **forms** of data are currently available? May include:

    Logbooks
    Port monitoring
    Observers
    Surveys
    Snapshots

20. Is the data readily accessible (e.g., are there potential legal/bureaucratic hurdles)?

21. How is the information collected and stored (e.g., paper, electronic database)?

Fishery dependent data

22. For each form of fishery dependent data collection, what **types** of data are available? May include:

    Catch (total landings)
    Effort / CPUE
    Discarded catch
    Size / weight
    Size distribution
    Sex composition
    Smallest/average/largest size (or other percentiles related to reference point proxies) of fish in catch

Approximate relative proportions of size of fish in catch (small, medium, large)

Multispecies fisheries
a. For each "key" species, what data is available?
b. Is species composition or ratios of species composition informative?

Fishery Independent data

23. If fishery independent surveys are available, what **types** of data are available? May include:

    Total biomass thresholds
    Size data from survey—mean, maximum (or other percentiles related to reference point proxies)
    Habitat mapping

General

24. If there are no-take zones, are there:

    Inside/outside density ratios?
    Inside/outside size structures/age structures?

25. For each form of data currently available, how regularly is data collected?

BIOLOGY/LIFE HISTORY

Biological

26. Can you anecdotally describe the species? Is it slow/fast growing? What is the estimated time before spawning? High/low fecundity? High/low sensitivity to fishing pressure?

Life history

27. Can you describe the population dynamics of the species? Does it resemble a steady state population? Is it cyclical or irregular? Are there periods of boom and bust?

28. What is the life cycle of the species like? Are there migration periods? Is there a cryptic phase? Are there important nursery grounds?

29. Is there a clear spawning season? Are there spatial aggregations?

Ecological

30. What is the trophic level of the species?

31. What are the habitat associations of the species throughout its life cycle?

SOCIOECONOMICS

General

32. Is this a value-based fishery or volume-based fishery?

33. Does the price for these species fluctuate? Why?

34. Have household surveys been undertaken?

35. Are fishers receiving subsidies?

Supply Chain

36. What are the main markets for this fishery (subsistence, local, domestic commercial, export)?

37. Where is the catch going and how is it getting there?

GOVERNANCE

General

38. What are the jurisdictional boundaries of management? Do these boundaries cover the spatial extent of the stock? Do management units coordinate well?

39. What kind of governance exists at community, regional, state, and national levels?

    Do local government officials hold power over fishing regu lations? Are regulations enforced?
    Is there strong leadership in place?

40. Are there existing management tools in place? Are they formal or informal? May include:

    Temporal closures (Season length, days of the week, temporary/permanent)
    Spatial closures (Closed areas, rotating closures, move-on provisions, temporary/permanent)
    Size limits
    Catch limits (Bans, TAC, tradeable quota)
    Effort limits (TAE, Limited entry, Licenses)
    Gear controls (Bans, mesh size, escape ports on traps, hook size or type, number of hooks, light sticks,)
    Others

41. What are the penalties for violating a regulation?

Access/tenures

42. Who has access to the fishery? It is open access or limited entry? Is it regulated / enforced?

Monitoring and research capacity

43. What kind of institutions are in place that could help with monitoring and research? (e.g., Government, universities, fishery cooperatives, NGOs)

Cooperative behavior:

44. Is there cooperative behavior among fishermen, processors, buyers, and distributors?
45. Are there fishing associations or cooperatives? What do they do, and what is their role (consultative or decision-making)?
46. How culturally ingrained is cooperation in relation to management?
47. Are fishermen incentivized to be involved in management?
48. Do village chiefs/community leaders hold power over fishing regulations?

Enforcement

49. Who is responsible for enforcement?
50. What types of enforcement systems exist? May include:

    Patrol boats
    Officers (local, regional, state, national)
    What other tools are used? May include:
        Radios
        Dockside monitors
        Cameras
        Vessel monitoring systems (VMS)
        Observers

Diagnostic tool: Phase two

These questions directly map to the criteria and caveats within FishPath for each of the three management strategy components (i.e., monitoring, assessment, decision rules).

Given the responses under Phase 1, certain questions under Phase 2 may not be applicable, and, as such, should be disregarded.

Questions/considerations (= criteria/caveat against management strategy component)	Management strategy component(s)		
Data availability			
Species composition		Assessment	
Length composition		Assessment	
Age composition		Assessment	
Mean length or length percentiles		Assessment	
Mean weight or weight percentiles		Assessment	
If only size data and/or species composition data are available			Decision Rule
Catch		Assessment	
Effort		Assessment	
If only effort data are available			Decision Rule
Is effort data available by location?		Assessment	
Is catch data available by location?		Assessment	
Catch-Per-Unit-Effort		Assessment	
Sex composition		Assessment	
Fishery dependent density		Assessment	
Fishery independent abundance		Assessment	
Is there some estimate of assumed depletion?		Assessment	
Is there some estimate of assumed abundance?		Assessment	
Inside:outside No-Take Zones/MPA		Assessment	
Expert judgement/common knowledge of stock status/depletion		Assessment	
Expert judgement re: fishery operations and interaction with broader environment		Assessment	
Is there local knowledge of suitable targets for indicators? E.g. historically, this level of catch corresponded to a "good" stock status		Assessment	
?? Expert judgement re: non-fishing threats, ecosystem services, threat interactions		Assessment	
?? Expert judgement re: MPA and habitat status		Assessment	
Selectivity ogive (0= unknown; 1= able to be inferred; 2 = known)		Assessment	
Has the selectivity pattern changed over time?		Assessment	
If there are multiple fleets, are the selectivity ogives different for each?		Assessment	
Does the assessment approach assume equilibrium dynamics?		Assessment	
Does the assessment type have the ability to explicitly consider uncertainty?		Assessment	
If there is <100% spatial coverage, is the existing coverage representative of the entire fleet/geographic range of fishery? If "no": (M) / Is the data representative of the fleet as a whole? (Y = this is required) (A)	Monitoring	Assessment	
Is the data representative of the spatial extent of the fishing? (Y = this is required)		Assessment	
Are there additional variables that may be used to standardise CPUE?		Assessment	
Is there a time series of data? (NB refers to specific assessment requirements)		Assessment	
Attributes of assessments ("attributes")		Assessment	
NOT A QUESTION - Assessment-specific additional requirements (that ARE limiters)		Assessment	
Does a target reference point, or proxy, exist?			Decision Rule
High level of uncertainty?			Decision Rule
No knowledge			Decision Rule
No immediate concerns re: stock status			Decision Rule
Does assessment suggest overfishing is probable?			Decision Rule
Does assessment suggest a certain form of decision rule?			Decision Rule

Diagnostic tool: Phase two continued

Questions/considerations (= criteria/caveat against management strategy component)	Management strategy component(s)		
Biology/life history			
Is the species highly cryptic?	Monitoring		
Is the species highly migratory?	Monitoring		Decision Rule
Does the species follow a boom-and-bust cycle? Highly productive, short-lived ("boom and bust") species?	Monitoring		Decision Rule
General population biology		Assessment	
Life-history ratios M/K (can be borrowed)		Assessment	
Natural Mortality		Assessment	
Maturity ogive/ size at maturity		Assessment	
Relationship between length and fecundity		Assessment	
Von Bertalanffy parameters		Assessment	
Is the species largely sedentary/sessile?			Decision Rule
Determinate growth?			Decision Rule
"Periodic strategist" species? (slow-growing, long-lived, steady state population, but with variable recruitment)			Decision Rule
Sexually dimorphic growth?			Decision Rule
Survivorship on release?			Decision Rule
Biomass-based reference points meaningful?			Decision Rule
Nursery grounds vulnerable to gear?			Decision Rule
Nursery grounds in distinct area?			Decision Rule
Spawning grounds, aggregations?			Decision Rule
Spawning seasons?			Decision Rule
Operational characteristics			
If home ports/landing sites and markets are numerous/spatially disaggregated	Monitoring		
Is fishing highly spatially or temporally aggregated? (M) Spatial concentrations of effort? (DR)	Monitoring		Decision Rule
Is fishing highly spatially or temporally aggregated? (M) Seasonal concentrations of effort? (DR)	Monitoring		Decision Rule
Is the fishery area is geographically vast relative to entire coastlineo or EEZ? (>X km2)	Monitoring		
Do fishing activities (irrespective of management) correspond with the spatial extent of the stock?	Monitoring		
Is the species highly migratory, and the fishery does not embrace spatial extent of the stock? (here, "N" = assessment method unable to be applied)		Assessment	
Are gears and deployment manners known?		Assessment	
Are there multiple gears used?	Monitoring		
Are there gear considerations that would preclude the use of the assessment? (e.g. per purse seine)		Assessment	
Multispecies fishery?			Decision Rule
Are there multiple species targeted, or no fixed target species? (M) / Is the species being actively targeted? (Y = this is required) (A)/ Fishing opportunistic/no fixed target species? (DR)	Monitoring	Assessment	Decision Rule
Is the number of participants low?		Assessment	
Multiple fleets?			Decision Rule
Latent effort?			Decision Rule
Effort creep likely?			Decision Rule
Is the nature of the fishery changing rapidly?	Monitoring		
IF TEMPORAL CHANGES HAVE OCCURRED (i.e. is what happened x years ago relevant to today's landscape?) If historical or recent changes have occurred in how the fishery is operating, apply caution to assessment approaches requiring time series or temporally representative data (here, "N" = assessment method unable to be applied)		Assessment	
(Not a question): Given that there exist conditions (e.g. environmental, oceanographic, weather temperature) that affect either FISH AVAILABILITY or ABILITY TO FISH, consider the following (i.e. within-cell) caveats (re: assumptions around catchability):		Assessment	
Are there conditions (e.g. environmental, oceanographic, weather temperature) that affect either fish availability or ability to fish?			Decision Rule
Have there been operational changes in the fishery? (A) / Is the nature of fishing operations (e.g. target species, gear types, fishing locations, markets) changing? (DR)		Assessment	Decision Rule
Do landing sites account for all fishing activity?	Monitoring		
Are ports and/or markets matched to managed area?	Monitoring		
Is there illegal, unregulated, or unreported fishing?	Monitoring		
Are the fishing locations (if not boat-based) and ports variable?	Monitoring		
Threatened or vulnerable species/habitat locations?			Decision Rule
Additional species/habitat threatened by gear?			Decision Rule
High discarding or illegal/unregulated/unreported activity known or suspected?			Decision Rule

Diagnostic tool: Phase two continued

Questions/considerations (= criteria/caveat against management strategy component)	Management strategy component(s)		
Socio-economic			
Gross value of production (range); current budget for monitoring: COMPARE/RECONCILE WITH COST DATABASE (and/or use cost database to inform categories?) Options: low, low-moderate, moderate, moderate-high, high	Monitoring		Decision Rule
What is the cost of the assessment? - along with rules of thumb - e.g. if >10% of GVP, think twice.		Assessment	
Nature of fishery (range): Options: Subsistence; Artisinal - subsistance and local markets only; Artisinal -commerical (large range of boats - may sell locally and/or for export); Large-scale commercial/industrial	Monitoring		Decision Rule
Fishery cooperation (wrt HS approach): How culturally ingrained is cooperation to management? Categories 1) unwilling to share and unwilling to record, 2) willing to share info but unwilling to record info, 3) willing to share and record but may not do so reliably, 4) willing and reliable sharing and recording	Monitoring		Decision Rule
Level of community cooperation			Decision Rule
Are fishers incentivised/motivated/willing to be involved?	Monitoring		
Is there strong spatial bias in the extent of data coverage and/or fisher cooperation?	Monitoring		
Resource dependency (low to high)			Decision Rule
Governance			
Research capacity/ institution capability. Options: low, low-moderate, moderate, moderate-high, high	Monitoring		
What is the research capacity required? (to undertake the assessment)		Assessment	
Willingess to invest in data gathering. Options: low, low-moderate, moderate, moderate-high, high	Monitoring		
Are regulations enforced?	Monitoring		
Are the jurisdiction boundaries matched to the spatial extent of the stock?	Monitoring		
Open access governance, to limited entry. (e.g.in an open access governance system the efficacy of tools like size , fishing season, or effort limits is often reduced by effort creep, but when access is limited this seems to be less of a problem and so the same tool would look more attractive) (DR) / Is the fishery open access? (as opposed to limited entry) (M)	Monitoring		Decision Rule
What is the dominant system of governance? (Community level, Regional, State, National)	Monitoring		
Are there existing cooperatives or associations that could provide a starting point?	Monitoring		
Do local government officials hold power over fishing regulations?	Monitoring		
Is there strong governance leadership in place to support/faciliate monitoring?	Monitoring		
Are permits community based? (as opposed to individual-based)	Monitoring		
What management controls are familiar and can easily align with community management practices and processes?			Decision Rule
Number of levels of buying/distribution (re: markets)	Monitoring		
Is monitoring protocol undertaken regularly?	Monitoring		
Is monitoring difficult?			Decision Rule
Can monitoring be conducted at the same time and in the same manner interannually and spatially?	Monitoring		
Is/are there an MPA/s, and if so, are these well enforced and do they represent unfished size and density dynamics?		Assessment	

Appendix 2: Challenges in implementing and evaluating empirical assessments, and decision rules, where the management measures are not directly quantitative

Empirical "assessments" (especially those with no reference points), and the families of decision rules where the management measure is not directly quantitative (e.g., gear or spatial controls, as opposed to catch limits), pose a particular challenge for implementing and evaluating data-limited management strategy options. While conceptually simple, to explicitly interpret these requires significant judgment in the face of ambiguity. Issues include, but are not limited to, issues of precedent, definition of reference points, quantifying management measures, implementation, interpretation of outcomes, and legislative:

General:

- Little precedent in the international fishery science community (e.g., FAO) (an exception is Pauly and David's (1981) length-based model-free assessment method)
- Defining proxy reference points for "assessments" for which these are lacking
- Quantifying management measures where these are not immediately explicit (e.g., "improved data collection"—How much more data? What type of data? Over what time frame? Or, "overrides under exceptional circumstances"—What circumstances? How large an override? Of what nature?)

Implementation:

- How to implement assessments and decision rules across the fishery—e.g., for an empirical assessment of catch triggers, should these be applied by spatial zone, or across the fishery as a whole? How should the magnitude of the adjustments be determined? (For multispecies fisheries) by which species? How many trigger levels (proxy reference points) should there be?
- Uncertainty buffers—should harvest control rules apply a discount factor (Punt et al. 2012) or uncertainty buffer to be additionally precautionary, when assessment outcomes are considered to be less robust or defensible? If so, how large?

Interpretation of outcomes:

- Ambiguity in interpretation of outcomes of empirical assessments (e.g., what do unusually high catch levels mean? CPUE trends? What if the outcomes of several assessments appear to conflict with each other? What is the most plausible interpretation of the outcomes, accounting for all relevant factors (e.g., price and weather fluctuations, changes in stock abundance, etc.)?
- Unforeseen consequences of supposedly simple strategies. These may be (i) operational—e.g., trophic interactions, vessel relocations; and, ii) implementation-based—e.g., a system of catch triggers may cause the fishery to undesirably oscillate biennially between a trigger level at which the fishery is closed, and one where the fishery is open (e.g., Dowling 2011).

Legislative:

- How to ensure the management strategy is defensible in context of national/international legislative requirements (while the "governance" criteria should explicitly account for this to some extent, the fact remains that where the existing data are limited, assessments and the form of decision rules may not be directly consistent with legislative mandates [e.g., that where reference points are based on maximum sustainable yield]).

Addressing the above problems is certainly feasible and is ongoing within our development process, but we mention them here to emphasize that the implementation of supposedly simple data-limited approaches is not a trivial exercise.