A Multi-indicator Framework for Adaptive Management of Data-limited Fisheries with a Case Study from Belize

Un Marco de Indicadores Múltiples para el Manejo Adaptativo Pesquerías con Datos Limitados: Estudio de Caso en Belice

Approche Multi-indicateurs pour la Gestion Adaptative des Données Limitées de Pêcherie: Une Étude du Cas de Belize

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ABSTRACT

Management decisions in data-limited fisheries regarding how to adjust fishing pressure, and by how much, can be the most difficult decisions managers must make. Too often, these fisheries are not managed at all or are managed based on standard practices without an adequate scientific basis; this creates a high risk of overfishing and potential loss of economic and social benefits from fisheries.

Here, we describe a multi-indicator framework for making fisheries management decisions in data-limited fisheries. The framework is adaptive so that managers can respond to changing environmental, socioeconomic, and fishing conditions. Using stakeholder-defined goals as a foundation, fishery performance indicators are chosen that can be evaluated easily using available data. Reference points are set for each indicator based on fishery goals. Multiple performance indicators from multiple data streams are used to gain a more complete understanding of the fishery and to reduce the implications of uncertainty; corroboration between indicators can allow for a confident interpretation of fishery performance. Data-limited methods can be used to evaluate performance indicators within this framework in lieu of conventional stock assessments. Each year, managers and stakeholders evaluate each performance indicator against the associated reference points, interpret the results using scientific and local knowledge, and adjust management accordingly using pre-defined harvest control rules. A case study is presented that describes the application of this framework to the management of conch and lobster fisheries of Belize.

KEY WORDS: Data limited fisheries; adaptive fisheries management; management under uncertainty

INTRODUCTION

Effective management of marine capture fisheries promotes social and economic returns to fishery stakeholders while maintaining a portfolio of ecosystem benefits that society values. For some fisheries, management decisions are made on the basis of quantitative statistical stock assessments that estimate the status of the resource relative to predefined target or limit reference points (Mace 1994). Status indicators and reference points are often calculated in terms of biomass of the stock relative to the biomass that achieves maximum sustainable yield (Walters and Martell 2002). However, more than 80% of the global catch occurs in fisheries that lack the necessary data, resources, infrastructure, and expertise to use conventional statistical stock assessment models to quantify biomass levels and estimate maximum sustainable yield (Costello et al. 2012). Instead, these fisheries, which are often small-scale in nature, go unmanaged or are managed with little scientific input, resulting in suboptimal harvest rates, ineffective regulations, and poor social and economic outcomes for those dependent on fishing (Costello et al. 2012).

Data limited analytical methods that use proxies for biomass or that focus on the estimation of fishing mortality-based metrics offer significant promise for assessing and managing data limited fisheries. There has been a renewed interest in using these types of methods to inform an adaptive approach to fisheries management for fisheries with limited data (*e.g.*, the 2013 World Conference on Stock Assessment Methods in Boston included a day-long symposium on data-limited approaches). Data-limited methods have been developed that rely on age and length data (Ault et al. 2005, Gedamke and Hoenig 2006, Wayte and Klaer 2010, Hordyk et al. 2014a, Hordyk et al. 2014b), the density and size of fish inside and outside of no-take zones (Wilson et al. 2010, Babcock and MacCall 2011, McGilliard et al. 2011), and catch-per-unit-effort (CPUE) (Little et al. 2010). Data limited methods can be used to estimate metrics such as Spawning Potential Ratio (SPR), Yield-per-Recruit (YPR), density ratio inside and outside of no-take marine reserves (DR), and fishing mortality (F) that are related to stock and fishery performance. These metrics can be used to guide management decisions when compared against reference points in the same currency. For example, practical experience with many fisheries has shown that maintaining SPR levels above 30 - 40% (depending on species) (Mace and Sissenwine 1993, Ralston 2002) and keeping F levels at or below natural mortality (M) often result in long-term sustainable yields (Zhou et al. 2012).

Data-limited methods can be effective for certain fisheries, but a wholesale reliance on such methods is cause for concern when known assumptions are violated (Wilson et al. 2014). Many data limited approaches have been shown to be effective at meeting target objectives for simulated fisheries with certain characteristics, but perform poorly when assumptions of equilibrium are violated (Carruthers et al. 2014). To overcome problems resulting from violation of model assumptions, fishery metrics can be treated as indicators. If data from multiple (preferably independent) sources are available, several performance indicators can be integrated into an adaptive decision-making framework to mitigate the uncertainty associated with any one indicator. A multi-indicator framework for adaptive management of data-limited fisheries provides managers with the flexibility and guidance to achieve fishery objectives for fisheries management without the need to estimate stock biomass.

In addition to being useful in data-limited situations, adaptive and flexible approaches are important in fisheries management generally due to the dynamic nature of fisheries which can experience fluctuating environmental conditions, variable fishing behaviors, spatial and temporal changes in the productivity of the resource, and dynamic market and economic conditions. Development of a robust adaptive management framework therefore provides managers with the means to re-evaluate and adjust decisions periodically based on observations about fishery conditions and from learning from the outcomes of previous management decisions. Adaptive learning and management are essential in moving towards successful management in communities with limited data and resources.

Here, we describe a framework for adaptive decision-making in data limited fisheries that draws on decades of research in conventional and alternative assessment models as well as indicator-based approaches to guiding management decisions. The approach starts by defining stakeholder-oriented goals and key target species to be managed. Based on these goals and species, appropriate performance indicators and reference points are chosen that can be easily quantified using the available data. Finally, a process to guide decisions is elucidated in which pre-defined harvest control rules based on interpretations of different scenarios increases management discipline and reduces the risk of ad-hoc decision making in response to crises.

A 9-step Multi-indicator Framework for Adaptive Management of Data-limited Fisheries

The following section describes a 9-step framework for adaptively assessing and managing a data-limited fishery over time. It is important that the entire adaptive management process be participatory in order to:

i) Draw on the knowledge of scientists, resource users, government agencies, and others,
ii) Create common goals and a common understanding of the fishery, and
iii) Create a context for learning together and working cooperatively.

This reduces uncertainty and conflict while increasing the likelihood of compliance with regulations generated by the adaptive management process. Many fishery performance indicators are strongly affected by attributes of the fishery such as price or weather fluctuations that are better understood by fishermen than by scientists or managers, putting a premium on local knowledge for interpreting indicators. The steps for using the adaptive management framework are shown in Figure 1 and are outlined as follows:

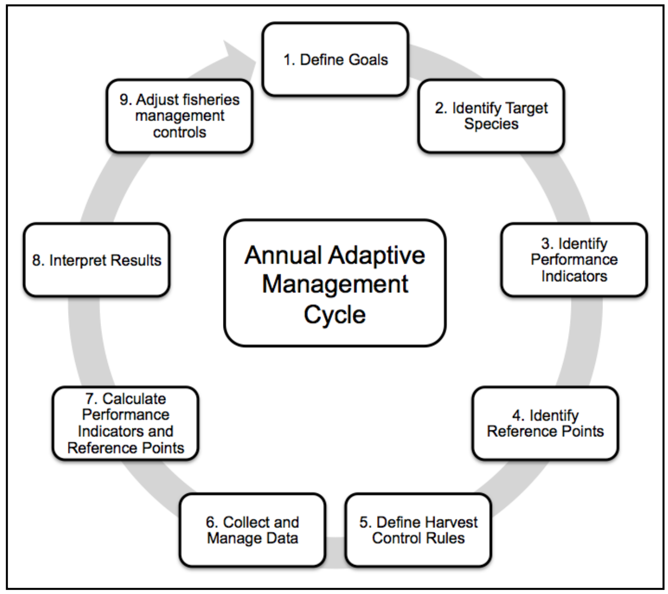

Figure 1. A 9-step multi-indicator framework for adaptive management of data-limited fisheries

Step 1 - Define social, ecological, and economic goals

Careful articulation of fishery goals will inform the rest of the design process. For example, a community whose goal is to maximize fisheries harvest every year will set very different reference points than a community interested in generating fishery yields while also increasing fish biomass in the water to support tourism. The goals that are collectively decided upon can be used to determine the most appropriate performance indicators, reference points, and harvest control rules.

Step 2 - Identify key target species for management

These species may have economic importance (high value or high volume species), special cultural or ecological value (such as endangered or keystone species), or may be particularly vulnerable or resilient. Tools such as the Productivity and Susceptibility Analysis (PSA) can be used to determine the vulnerability of species (Patrick et al. 2010). It is important to consider not only the species that are currently generating the most yield or revenue, but also species that may once have been important fisheries targets but are now depleted. Other species may also be included in the suite of managed species because of their importance in ecological structure or function.

Step 3 - Identify performance indicators

Based on the goals and target species, identify appropriate performance indicators for each species. Performance indicators are data streams or model outputs that provide information about the current performance or trends of the stock or fishery - they indicate how the fishery is doing. For example, examining trends over time in the ratio of observed fish density outside to inside a well-functioning no-take zone marine reserve can provide insight into whether a stock is locally overfished and the general health of the ecosystem (Karr et al. in revision, McClanahan et al. 2011). Other performance indicators include fish density (Karr et al. in revision, McClanahan et al. 2011), CPUE (Little et al. 2010), fishing mortality (*F*) (Ault et al. 2005), Spawning Potential Ratio (SPR) (Hordyk et al. 2014a, Hordyk et al. 2014b), percentage of catch in particular life stages (Froese 2004), local ecological knowledge, and many others (see Table 1 for several examples). In order to calculate certain indicators, data limited methods are often employed. Additionally, some indicators are appropriate for single species management, while some are appropriate for multi-species or ecosystem-based management. An online tool is available (Framework for Integrated Stock and Habitat Evaluation, or FISHE) that offers guidance for selecting appropriate data limited methods and using outputs to assess and manage ecosystem risk, prioritize stocks, evaluate performance indicators, and develop management measures (Environmental Defense Fund 2013).

Multiple performance indicators that are related to fishery goals should be selected, ideally from independent data streams, in order to gain a more complete understanding of the fishery and reduce potential uncertainty associated with any single model or data type. The indicators that are chosen will depend on what analytical methods work well for a particular species, resources available for data collection, and technical capacity for analyzing data. The necessary technical capacity will depend on the indicator - analysis may range from a simple calculation of fished to unfished fish density to more complex model-based calculations of SPR. Managers should also understand that each type of indicator will be accompanied by assumptions and caveats that should be carefully considered when using results to inform management decisions.

Additionally, ecosystem-level indicators should be included in the suite of indicators if the sustainable provision of non-fishery ecosystem services is a management goal (Karr et al. in revision, McClanahan et al. 2011).

Step 4 - Set reference points for each indicator

For each indicator, set target and/or limit reference points. A target reference point (TRP) is a numerical value (or range of values) that indicates that the performance of the fishery is at a desirable level; often management is geared towards achieving or maintaining this target. A limit reference point (LRP) is a numerical value that indicates that the performance of the fishery is unacceptable (*e.g.*, severely overfished), and that management action should be taken to improve fishery performance or population levels. Additionally, target or limit reference points can be defined as trends in a particular indicator (*e.g.,* CPUE is increasing relative to a running average of CPUE) (Caddy and McGarvey 1996). While studies in the literature have identified appropriate reference points for certain species, regions, and circumstances (*e.g.,* SPR = 30 - 40% for particular species), setting these points for a particular fishery will depend on social, ecological, and economic goals as well as the goal of maintaining stock productivity at levels high enough to sustain desired yields. Example reference points are given in Table 1.

Step 5 - Define harvest control rules

Using the suite of species and ecosystem indicators identified, define harvest controls rules that adjust harvest regulations annually based the values performance indicators relative to their reference points. A harvest control rule prescribes the translation of the interpretation of fishery performance into adjustments in fisheries management controls. The rule may specify some combination of adjustments in effort, gear restrictions, size and sex-specific regulations, spatial or seasonal closures, and total annual catch (TAC) limits that is expected to cause the performance indicator to move away from limit reference points and toward target reference points. The appropriate fisheries management control, and how much it should be adjusted

Table 1. Common performance indicators, data requirements, management type applicability (single-species, multi-species, or ecosystem-based) and example target and limit reference points. Many methods will require life history information (LHI).

Performance Indicator	Data requirements	Single-Species/Multi-Species/Ecosystem Management	Example Target Reference Point (TRP)	Example Limit Reference Point (LRP)
Previous Season's Total Landings	Catch data	Single/Multi/Ecosystem	Previous Season's Total Landings stable or decreasing from running average (without knowledge of effort)	Previous Season's Total Landings increasing rapidly increasing from running average (without knowledge of effort)
Spawning Potential Ratio (SPR)	Fishery-dependent length data, LHI	Single	SPR_{Tar}=40%	SPR_{Lim}=20%
Fishing Mortality (F)	Fishery-dependent length data, LHI	Single	F_{Tar}=0.75M	F_{Lim}=2M
Catch-per-unit-effort (CPUE)	Catch and effort data	Single/Multi	CPUE increasing from running average	CPUE decreasing rapidly from running average
Density	Fishery-independent surveys	Single/Multi/Ecosystem	D_{Tar}=800kg/Ha	D_{Lim}=500kg/HA
Outside/Inside MPA Density Ratio (DR)	Fishery-independent surveys	Single/Multi/Ecosystem	DR_{Tar}=0.4	DR_{Lim}=0.2 (single stocks) DR_{Lim}=0.3 (ecosystems)
Fraction Mature (Lmat)	Fishery-dependent length data, LHI	Single	$Lmat_{Tar}$=100%	$Lmat_{Lim}$=80%
Fraction Megaspawner (Lmega)	Fishery-dependent length data, LHI	Single	$Lmega_{Tar}$=20%	$Lmega_{Lim}$=30%
Fraction Optimal (Lopt)	Fishery-dependent length data, LHI	Single	$Lopt_{Tar}$=90%	$Lopt_{Lim}$=50%

in different situations, will depend on the target species, likelihood of compliance, social and political feasibility, capacity for enforcement, and data availability. It is important for stakeholders and managers to agree on harvest control rules before any new management decisions need to be made. This can help improve compliance by ensuring management responses are objective, consistent, transparent, and appropriate.

In a simple single-indicator framework, the interpretation can begin as simply as first determining if the performance indicator is above, at, or below the TRP and LRP. If the performance indicator is at or above the TRP, no obvious management response is necessary although managers may still decide to implement a response based on other data. If the performance indicator falls below the TRP, a management response may be warranted after interpreting other available information (see Step 8). If the performance indicator falls below the LRP, an immediate management response and a reduction in catch is warranted. It can be helpful to outline all possible scenarios, interpretations, and harvest control rules in a table when completing Step 5. An example of this table for a single-indicator adaptive management framework is shown in Table 2.

Matters become more complicated when multiple indicators are used; however, this reduces uncertainty and increases confidence relative to single indicator approaches. In developing the harvest control rules, it is important for managers and stakeholders to think through every foreseeable scenario of performance indicator and reference point outcomes (*e.g.*, SPR is above, at, or below the TRP and LRP) and describe the management response that should occur under each scenario. For example, if three performance indicators are used, a table similar to Table 2 should be developed that describes all possible scenarios, interpretations, and harvest control rules that may be able to help alleviate problems. If interpreting performance indicators relative to their respective TRPs and LRPs leads managers to believe the fishery is stable or moving in a desirable direction, either no management response is necessary or management restrictions could even be relaxed. On the other end of the spectrum, if interpreting the performance indicators relative to their TRPs or LRPs leads managers to believe the fishery is moving in an undesirable direction, it is likely that a management response is necessary. However, if the indicators are conflicting in their messages (for example, one indicates the fishery is going in a desirable direction and one indicates it is going in an undesirable direction), careful interpretation is required to determine the likely performance of the fishery and if a management response is necessary. In many cases, interpretations may include such causes as changes in spatial or temporal fishing patterns, changes in gear types, environmental stochasticity, recruitment failures or pulses, hyperstability, risk tolerance, etc. Under any scenario that suggests that the fishery is in decline or not reaching management objectives, it is critical that before harvest control rules are triggered, calculations are verified, any other available data are checked, and local resource users and stakeholders are consulted to better understand what is happening in the fishery. Similarly, scenarios that suggest the fishery is performing well should be carefully scrutinized before allowing fishing mortality to increase in order to reduce the risk of overfishing. This verification process should take place during Step 8, which is aimed at interpreting results. In cases of conflicting outcomes, it may be advisable to exercise precautionary management actions and to increase monitoring of the resource.

It should be noted that interpreting indicators and defining harvest control rules is a technical process and should include formal Management Strategy Evaluation (MSE) and consultation with fisheries scientists if possible. Management strategy evaluation simulates a fish population, a fishery, a monitoring program, and a management decision-making process to explore probable outcomes from applying a specific set of monitoring and management actions over time (Butterworth et al. 1999). Many data-limited assessment approaches have shown to be effective in these simulation models and result in meeting target objectives for the hypothetical fishery.

Step 6 - Collect and manage data necessary to inform performance indicators and reference points

Calculating indicators and reference points will require certain data. Example data requirements for several indicators are given in Table 1. Standardized data collection protocols should be developed for each indicator such that sampling strategies are fully understood and accounted for and such that an appropriate level of statistical confidence

Table 2. Example interpretation and harvest control rule table for a single-indicator adaptive management framework.

Scenario	Performance Indicator (PI) and Reference Point (RP) Comparison	Interpretation	Harvest Control Rule
1	PI > TRP	Stock productivity and fishery performance increasing or above desired state	Once interpretation has been verified in Step 8, adjust fisheries management control to be more relaxed (*e.g.*, increase the Total Allowable Catch)
2	PI = TRP	Stock productivity and fishery performance stable and at desired state	Once interpretation has been verified in Step 8, make no changes to fisheries management controls
3	PI < TRP	Stock productivity and fishery performance decreasing or below desired state	Once interpretation has been verified in Step 8, adjust fisheries management control to be more restrictive (*e.g.*, lower the Total Allowable Catch)
4	PI < LRP	Stock productivity and fishery performance below a critically undesirable state	Once interpretation has been verified in Step 8, close the fishery

can be associated with each indicator. Sampling methods should be designed to cover the range of the target species and stratification of the fishery (including biological, spatial, and temporal stratification and stratification across gear type). Often, the data collection process will be collaborative and require fisher participation, so appropriate stakeholder engagement is critical. Additionally, many methods will require life history information (LHI) that can either be obtained from new species- and location-specific life history studies or from the literature. When borrowing life history information from the literature, care should be taken to understand the study and possible differences in LHI between the species and locations studied and the species and locations being managed. Since LHI values have strong effects on all fishery models, including data limited models, it is advisable to conduct local field studies to determine LHI values when feasible. All data should be managed in a robust and secure manner, and ideally stored in a centralized and secure relational database.

Step 7 - Calculate performance indicators and reference points

During this step, available data are used to calculate performance indicators and reference points. Data-limited methods may be required to calculate certain indicators such as fishing mortality or SPR.

Step 8 - Interpret results

During this step, stakeholders, scientists, and managers collaboratively determine the likely performance of the fishery based on the calculated performance indicators and a comparison with their respective reference points. As a starting point, stakeholders can consult the interpretation and harvest control rule tables generated during Step 5 (an example is shown in Table 2).

In all cases, several specific steps should be taken to verify the interpretation before either maintaining the *status quo* or triggering a harvest control rule and implementing a management response. These include:

i) Verify data and calculations,
ii) Review sampling protocols,
iii) If data are available, assess size structure of the population,
iv) If using fishery independent surveys, ensure they overlap with known or assumed distribution (depth and space) of population and fishing effort,
v) If data are available, assess estimates of CPUE, effort metrics, spatial distribution of effort, and previous year's catch,
vi) Double check assumptions and reference points,
vii) Consult with local experts, resource users, and scientists, and
viii) If trends persist, adjust fisheries management controls in Step 9 and develop a recovery plan if necessary.

Step 9 - Adjust fisheries management controls if necessary

Using the pre-defined harvest control rules and interpretation results, adjust fisheries management controls as necessary. Figure 2 depicts a stylized fishery in which a single performance indicator responds to adjustments in management controls made in years 1, 2, 3, and 4 that are triggered by the agreed upon harvest control rules. As time goes on and the framework improves, subsequent management actions are able to bring the performance indicator closer to the TRP.

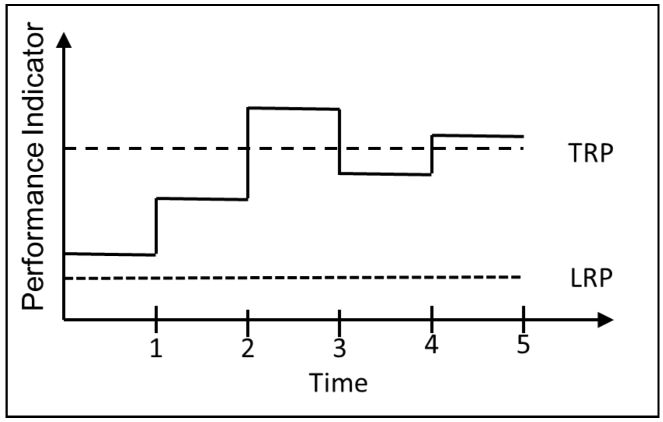

Figure 2. Performance indicator response over time in a stylized fishery. Management responses occur in years 1, 2, 3, and 4. Target Reference Point (TRP) and Limit Reference Point (LRP) are shown as dashed lines.

Adaptive Management: A case study from Belize

Belize has been a global leader in marine conservation, widely recognized for innovative and effective ecosystem-based management. The Belize Fishery Department (BFD) is committed to using the best available science for the management of important fishery resources. To support the management of these resources, the Department is developing national Fishery Management Plans for conch and lobster using the adaptive management framework described above. At the same time, BFD is improving data collection activities to facilitate future analyses in support of ecosystem-based fishery management.

BFD oversees the Belize Fisheries Science Team (Science Team), formed to provide technical support for the adaptive management of the nation's lobster and conch fisheries, as well as for priority finfish stocks in designated territorial user rights fisheries (TURFs) called Managed Access sites in Belize. These Managed Access sites, in which fishing access is strictly controlled and in which fishing activity is carefully monitored, were established to test the efficacy of limiting access to achieve fishery management goals (Foley 2012). The Science Team is made up of managers and scientists from BFD, Environmental Defense Fund (EDF), Sustainable Fisheries Group at University of California Santa Barbara (SFG), RARE, The Nature Conservancy (TNC), Wildlife Conservation Society (WCS), Toledo Institute for Development and Environment (TIDE), and Healthy Reefs for Healthy People. The Team gathers and evaluates data, conducts stock analyses, and provides advice on the adaptive management of fisheries to the Department. It is important to note that Belize Fisheries Department has the final say over the recommendations given by the Science Team. This allows for decisions to be made simultaneously with policies and management plans of the government.

Both the spiny lobster (*Panulirus argus*) and queen conch (*Strombus gigas*) are critical fishery resources in Belize. They are the two most economically important wild capture fisheries in the country, with lobster exports being valued at $7.4 million in 2006 and conch exports being valued at $3.4 million US in 2006 (Epstein 2008). Additionally, over 3,000 full- and part-time fishers are currently registered in Belize, of which over 90% participate in the lobster and conch fisheries (Carcamo 2003). In order to continue to generate these benefits and increase them over time, the Science Team has recommended limiting access to the fishery and controlling harvest based on adaptive scientific surveys and analysis. Managed Access is one of several tools in Belize for limiting access, including other limited access programs on certain species such as sharks and sea cucumbers. Adaptive management is the new strategy developed by the Belize Science Team for controlling harvest.

Together, Managed Access and adaptive management promote and are consistent with the Ecosystem Based Management (EBM) system that Belize is employing. EBM calls for the management of people and ecosystem services, not just fish or invertebrates. Harvest controls implemented under the adaptive management framework, applied to Managed Access areas, will ensure that the Belize Barrier Reef Complex will continue to produce good yields, one of the most important services generated by this ecosystem, and help to build and sustain ecosystem health and resilience.

The first steps in developing a national framework were to define goals and key target species for management (Steps 1 and 2 in the adaptive management framework). Lobster and conch were chosen as the initial focus of adaptive management because of their economic, ecological, and cultural value. Belize Fisheries Department has outlined several goals for the lobster and conch fisheries, including prevention of fisheries decline, increased abundance to protect the health of the Belize Barrier Reef Complex, improved livelihoods and industry, increased collaboration between diverse stakeholders, and improved fisheries management and compliance with international commitments. Once Fishery Management Plans for conch and lobster have been established, the adaptive management framework will be expanded to include key target finfish species as well.

The next steps in developing the adaptive management frameworks for these species were to identify performance indicators and reference points (Steps 3 and 4 in the framework). To facilitate this process, the Science Team conducted three in-person adaptive management workshops to choose and evaluate performance indicators and reference points for the nation's lobster and conch fisheries tied to national fishery goals (Table 3 and Table 4). Participants of the workshops chose performance indicators from several different data streams that are currently being collected on a national scale. Each indicator and data stream provides complimentary evidence on the performance of the fishery. The indicators are also relatively simple, are straightforward to explain to stakeholders, and have well understood assumptions and limitations. Target and Limit Reference Points were also identified for all indicators. All Target Reference Points are set at the average of that indicator over the last 10 years. This represents a relatively stable and desirable level of fishery performance that the Department wishes to maintain. Additionally, a Limit Reference Point of 88 adult individuals/ha was set for conch patch density using local knowledge of critical habitat and the results of a study done in the Bahamas that found a minimum viable threshold of 56 adult individuals/ha (Stoner et al. 2012) as well as the CITES recommended minimum threshold of 100 adult individuals/ha (CITES Report 2012).

With the identified performance indicators and reference points, workshop participants worked through all foreseeable scenarios of indicator values relative to reference points, and thought through appropriate harvest control rules for each one (Step 5). Through this process, the group developed a comprehensive table that can be used annually to interpret results and adjust management regulations accordingly (similar in concept to Table 2). These harvest control rules will be used to adjust the Total Allowable Catch of each species on an annual basis. Additionally, minimum size limits, closed seasons, and gear restrictions also apply for both species. Minimum size limits are currently 7-inch shell length or 3-ounce market clean weight for conch and 3-inch carapace length or 4-ounce tail weight for lobster. Conch season is currently open from October 1 through June 30 (or until the TAC is reached) and lobster season is currently open from June 15 through February 14 (or until the TAC is reached). Finally, lobster fishing is restricted to free-diving, traps, and shades while conch fishing is restricted to just free-diving. Performance Indicators, reference points, and harvest control rules have been agreed upon by diverse stakeholders and will be incorporated into national Fishery Management Plans for lobster and conch. By developing these plans in advance of upcoming conch and lobster season openers, the subjectivity in possible management responses has been reduced.

To support the calculation of performance indicators on an annual basis, data collection protocols at the national and Managed Access scales are being modified to improve data quality (Step 6 of the framework). Additionally, a new national database, data entry, and data retrieval system is being developed to facilitate data analysis and management. Data will be collected throughout the coming conch and lobster seasons and database analysis will allow for real-time calculation of performance indicators (Step 7). Looking ahead, the Belize Fisheries Department plans to interpret performance indicators during upcoming seasons with new data (Step 8), and adjust management measures accordingly using the pre-determined harvest control rules (Step 9). Looking forward, the adaptive nature of this framework will allow the Belize Fisheries Department to constantly improve management based on new data streams, more sophisticated analysis, and changing conditions on the water.

The BFD is also engaged in the process of designing adaptive management frameworks at the smaller spatial scale of prospective Managed Access sites. While the current adaptive management framework focuses on managing national Total Allowable Catch of both conch and lobster, similar adaptive frameworks at the Managed Access scale will be used to develop management guidance based on data collected at this smaller spatial scale. This will become increasingly important as Belize implements a national policy to establish Managed Access Areas that will extend over most of the nation's territorial waters. At a workshop hosted by BFD, six sites (Caye Caulker, Lighthouse Reef, Sapodilla Cayes, South Water Caye, Bacalar Chico Reserve, and Turneffe Atoll) identified potential performance indicators, data streams with which to evaluate lobster and conch, potential reference values for management, and data gaps. Preliminary performance indicators at the Managed Access scale are well-aligned with indicators at the national scale. Eventually, performance indicators at Managed Access sites will be evaluated and compared to reference values to assess fishery performance and drive adaptive management recommendations at this spatial scale. The Science Team has already made significant progress in developing data collection methodologies, analyses of available data, and adaptive management frameworks for finfish, lobster, and conch at the two pilot Managed Access sites as well, Port Honduras Marine Reserve and Glover's Reef Marine Reserve (Foley 2012).

CONCLUSIONS

The use of data-limited methods can reduce the costs of scientific fisheries management and expand the range of fisheries that can be scientifically managed, reducing the risk of overfishing and other adverse fishery outcomes. An adaptive fisheries management framework is proposed here which uses multiple fishery performance indicators that can be evaluated using data-limited methods and interpreted together in order to reduce uncertainty and increase confidence in scientific guidance for management. Belize has developed such an adaptive fisheries management framework for its lobster and conch fisheries, and is planning on using this framework as the basis for national Fishery Management Plans. Belize also plans to develop similar frameworks for a system of Managed Access sites that will be established over the next few years.

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Table 3. Indicators, metrics, reference points, and data streams for the national-scale conch adaptive management framework. These are currently recommendations only.

Performance Indicator	Reference Point	Data Stream
Pre-season adult and sub-adult patch density	**Target** - Average over last 10 years **Limit** – 88 individuals/Ha	National fishery independent conch survey
Previous season's total catch	Average over last 10 years	Export data
Pre-season average shell length	Average over last 10 years	National fishery independent conch survey
Early and late season CPUE	Average over last 10 years	National co-op data

Table 4. Indicators, metrics, reference points, and data streams.

Performance Indicator	Reference Point	Data Stream
Early and late season CPUE	Average over last 10 years	National co-op data
Previous season's total catch	Average over last 10 years	Export data
Previous season's average tail weight	Average over last 10 years	National co-op data

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