A Framework for Developing Scientific Management Guidance for Data-Limited Fisheries

Un Marco para el Desarrollo de la Dirección Gerencia Científica para la Pesca de Datos Limitados

Un Cadre pour L'élaboration de Principes de Gestion Scientifique des Pêches de Données Limitées

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ABSTRACT

Many data-limited stock evaluation methods are now available, but they typically do not estimate current stock abundance or biomass associated with the production of maximum sustainable yield. Instead, they provide a variety of fishery performance indicators that can be used together to estimate stock status and the sustainability of current levels of fishing. I will present a framework for using data-limited methods to assess the status of coral reef ecosystems with respect to fishing, characterize stock vulnerability to fishing, estimate stock status, and evaluate the sustainability of fishing in order to develop management guidance. I will also present a case study from Belize of how this framework can be used to inform adaptive management through a transparent and participatory process.

KEY WORDS: Data limited, assessment, adaptive management

INTRODUCTION

The status of the world's fisheries is uncertain, but only about 400 stocks are scientifically assessed (FAO 2012), probably a small fraction of the total number of exploited stocks in the world which may exceed 10,000 (Costello et al. 2012). An unknown but very large number of fish stocks are exploited in nearshore tropical ocean ecosystems such as coral reefs and estuaries, in jurisdictions that often have limited technical and financial resources to devote to fisheries management. As a result, these fisheries are often not assessed; more than 80% of global fisheries catch may come from fisheries that lack the necessary data, resources, infrastructure, and expertise to use conventional stock assessment models to support sustainable management (Costello et al. 2012, FAO 2011, Richard et al. 2011).

Failure to assess the status and productivity of fish stocks is likely to increase the risk of stock collapse and the loss of social and economic benefits associated with sustainable yield. Because many of these fisheries occur in countries that rely heavily on fish products for food security, development, and overall well-being of local communities (Allison and Ellis 2001, Salas et al. 2007), the stakes are very high. One obstacle to increasing the number of stocks that are assessed has been the cost of data collection and developing stock assessments, especially for subsistence fisheries that do not generate much revenue. Other obstacles include the need for high levels of technical expertise to develop and run complex assessment models, and the need for long and rich data records to support conventional assessments.

These obstacles can be overcome to some extent by using analytical methods that do not require long data records and can be done rapidly and cheaply ("data-limited" assessment methods). Some were developed decades ago, while others are relatively new (California Sea Grant College Program 2008, Honey et al. 2010).

While data-limited methods tend to be precautionary (because they do not estimate Maximum Sustainable Yield reference points), arguably the risks and consequences of fishery collapse in unassessed fisheries are great enough to justify the use of these methods, especially since data collection and analytical costs are much lower in comparison to data-rich assessment methods. Assessment techniques are also available to estimate the overall status of ecosystems that support fisheries, and the ecological risks posed by fishing (Hobday et al. 2011, DFO 2012, Battista et al., In preparation) -- important steps toward ecosystem-based fisheries management. Where fishery management is non-existent, it may in fact be easier to implement ecosystem based management, as there may be fewer institutional barriers blocking implementation of fishery management aimed at both producing good yields and conserving a variety of other ecosystem services.

Some data limited methods have been used for many years; others have been applied more recently. For example, overfishing thresholds generated from two data-limited methods (Depletion-Corrected Average Catch and Depletion-Based Stock Reduction Analysis) are now being used to manage 48 stocks off the West Coast of the U.S., and a few others elsewhere. While in some cases it will prove desirable to create rich streams of fishery data, in other cases data-limited methods and associated data streams may prove to be sufficient.

In some ways, data-limited methods may yield improved management guidance compared with conventional data-rich stock assessments. For example, the simple comparisons of fish density to coral reef ecosystem thresholds described below can indicate the risk of driving the ecosystem into a less desirable state if the fish densities associated with the thresholds are known (e.g., McClanahan et al. 2011, Karr et al., In review) – providing a stepping stone to ecosystem based fishery management which is missing from conventional assessments. Similarly, comparison of fish density in fishing grounds with fish density in well enforced no-take marine reserves may provide estimates of relative depletion that are superior to estimates derived from long-term catch records used to extrapolate unfished biomass levels, as they are not confounded by factors that skew the relationship of catch to abundance, or by changes in other variables over time. Simulation studies indicate that harvest control rules based on the ratio of fish biomass inside and outside of no-take reserves could produce 75 - 90% of the yield produced by more conventional control rules (Babcock and MacCall 2011, McGilliard et al. 2011).

Data-limited methods require different kinds of data and generate different kinds of outputs than conventional assessment methods. We provide a framework aimed at guiding users through several types of data-limited analyses and then interpreting the outputs in order to generate adaptive management guidance.

6-STEP FRAMEWORK FOR THE ASSESSMENT AND MANAGEMENT OF DATA-LIMITED FISHERIES

The following 6-step framework (Figure 1) provides a sequence of analyses that can be combined to generate management guidance for data-limited fisheries. A case study describing the application of this framework to a multispecies coral reef fishery is provided by Fujita et al. (2013).

i) *Ecosystem assessment* — Qualitatively and quantitatively assess the status of the ecosystem and impacts of fishing using local and expert knowledge.
ii) *Vulnerability analysis* — Assess the vulnerability of stocks to overfishing using basic biological and fishery information.
iii) *Estimate status* — Estimate level of biomass depletion or intensity of fishing mortality.
iv) Prioritize stocks with respect to their vulnerability and status levels.
v) Assess priority stocks to evaluate performance indicators and to set catch limits and other adaptive management measures, and
vi) Evaluate performance indicators against reference values and modify management measures as needed.

Step 1: Ecosystem Assessment

Because all fisheries are supported by marine ecosystems, it is important to understand the status of these ecosystems, and the risks to their capacity to maintain fisheries and other ecosystem services. Several data-limited methods for assessing ecosystem status and risks are available. In some cases (e.g., coral reefs in the Indian Ocean and the Caribbean), recent studies show the existence of quantitative thresholds associated with fish biomass (McClanahan et al. 2011, Karr et al., in review). Beyond these thresholds, ecosystems change from desirable (e.g., high coral cover) to less desirable states (e.g., dominated by algae), resulting in less resilient, more vulnerable systems with fewer ecosystem services (e.g., fisheries). Fish biomass within fishing grounds can be compared to fish biomass measured within no-take reserves; this ratio can then be compared to threshold values to estimate ecosystem status (Figure 2) .

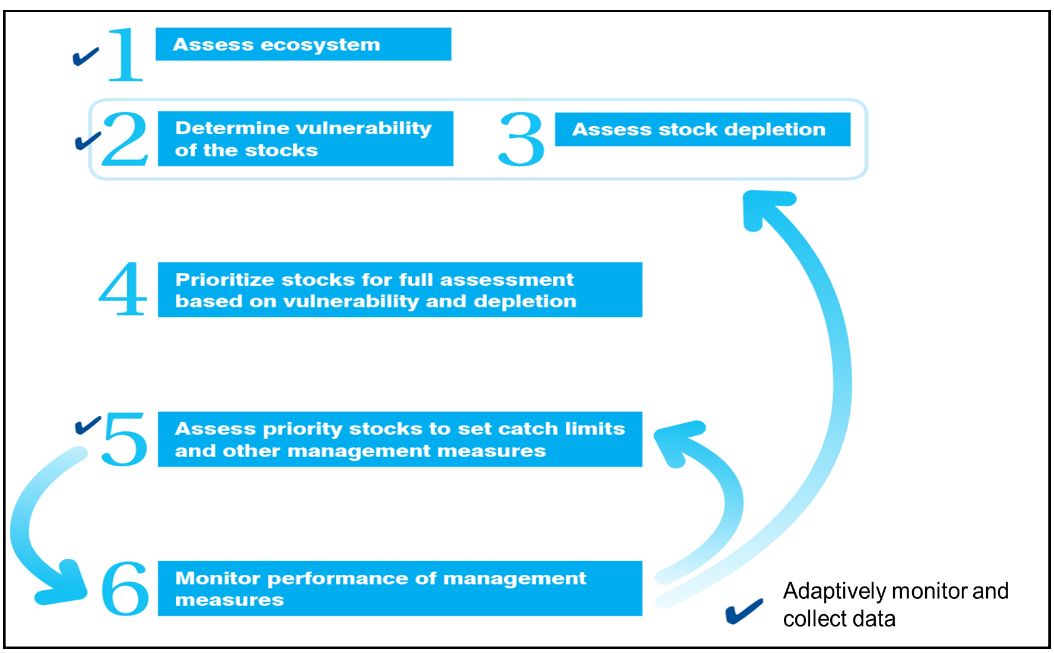

Figure 1. The 6-Step Framework for integrating data-limited analyses to generate scientific fishery management guidance.

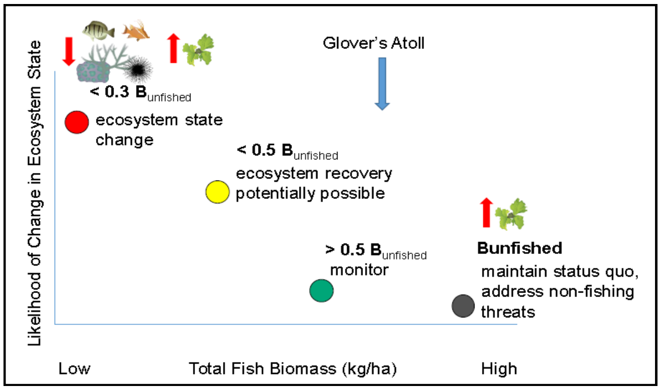

Figure 2. Concept for assessing status of coral reef ecosystems when thresholds for state change are known.

Where specific data on ecosystem state metrics are not available, methods that rely on available data and expert judgement can be applied (Hobday et al. 2011, Battista et al., in prep). Aggregate catch limits or other regulations designed to achieve total fish biomass goals to maintain ecosystem status can then be put in place. However, because aggregate limits can result in the sequential overfishing of vulnerable stocks, it is important to assess stock vulnerability and develop assessments and management measures that are stock-specific (Fujita et al. 2013).

Step 2: Assess the Vulnerability of Stocks to Fishing Pressure

Even if fishery data such as landings, effort, or length frequency of the catch are not available, a Productivity and Susceptibility Analysis (PSA) can be used to inform management decisions by indicating which stocks should be prioritized for further assessment and precautionary management (Patrick et al. 2009, Cope et al. 2011).

The PSA requires information on the life history of a species, including the length at first maturity, maximum length, fecundity, breeding strategy, growth rate, and natural mortality (Patrick et al. 2009). All of these parameters can be obtained from the literature or online databases, but when possible, information from local studies and stakeholder/expert interviews should be used. All values should be vetted with local biologists and fishermen to increase reliability. This information, some of which may be qualitative if specific measurements are lacking, is used to score the biological productivity of the stock. Information on the nature of the fishery, including the geographic overlap of the fishery and fish stocks, current management practices, the value of fishery, and impacts on habitat, is used to score the relative susceptibility of the stock. Again, much of this information can be qualitative and gleaned from interviews with fishermen and managers. Software for conducting a PSA is freely available from the NOAA Fisheries Toolbox (http://nft.nefsc.noaa.gov/). Scores from the PSA can be grouped into low, medium, and high vulnerability categories to facilitate integration with other analyses (Figure 3).

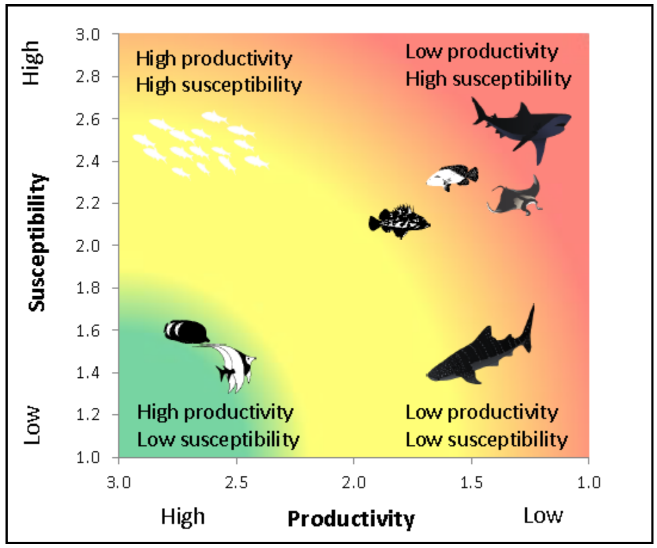

Figure 3. Assessing stock vulnerability to fishing using Productivity Susceptibility Analysis. After vulnerability scores are computed by scoring productivity attributes related to the biology of the species and susceptibility attributes related to fishing gear, practices, and management, the vulnerability scores are plotted and categorized. The most vulnerable stocks (which have low productivity and are highly susceptibility to the fishery) are located in the solid red region; stocks that are the least vulnerable are located in the solid green region. Stocks with intermediate levels of vulnerability are located in the yellow region.

Step 3: Estimate Stock Status

Several data-limited methods can be used to estimate stock status relative to unfished levels or the intensity of fishing mortality. If no catch records are available, if records do not include catches early in the history of the fishery, or if important changes in management and fishing effort have not occurred (thus confounding the relationship between catch and stock size), length data can be used to estimate status (i.e., current length composition is compared with theoretical length composition to estimate fishing mortality relative to an appropriate reference value such as natural mortality).

Several length-based assessment methods are currently in use, some of which have been used for decades. Because sustainable fishing generally requires fishermen to leave large proportions of juveniles in the water so they can spawn at least once (avoiding growth overfishing) and leave large, highly fecund adults in the water (to reduce the risk of recruitment overfishing), the length frequency of fish in the catch can be used to calculate indicators of whether or not fishing is sustainable (Froese 2004) if the data accurately reflect the actual length composition of the catch, and if catch is a good proxy for fishing mortality (i.e., if discard mortality is high, and discards are not recorded, the catch composition does not accurately reflect the mortality of different size classes of fish). A recent improvement on this method takes differences in the selectivity of the fishery into account (Cope and Punt 2009). Methods based on average length (Ault et al. 2005, Gedamke and Hoenig 2006) and entire length compositions (linearized catch-curve analysis; Sparre and Venema 1998, Wayte and Klaer 2010) can be used to estimate fishing mortality and spawning potential ratio (SPR). Comparisons of these outputs to widely used reference values (e.g., natural mortality as a proxy for Fmsy and SPR = 40%) can be used to estimate stock status.

Most of the length-based methods rely on the assumptions that the stocks exhibit equilibrium dynamics, recruitment is relatively stable and that fishing pressure has not changed dramatically. They are sensitive to life history parameters such as length at maturity and growth rate, as well as to sampling errors that result in length composition data that are not representative of the catch.

Some fisheries may violate the basic assumptions underlying the use of length-based assessment methods. For example, some species may have growth patterns which do not allow easy categorization of length classes into juvenile, adult, and highly fecund megaspawners; this is fairly typical in coral reef fishes such as butterfly fish. Sequential hermaphroditism in some species also complicates the interpretation of length composition data. Length-based assessment methods may also be difficult to use with species that show little difference in size between length classes (Cope and Punt 2009) or with species that suffer low rates of natural mortality (e.g., some sharks, in which it may be more appropriate to protect older juveniles than young juveniles). In many cases, SPR of the stock can be estimated from length frequency data if the relationship between length and weight and/or age is known (Hordyk et al. 2014) even in the face of considerable but predictable natural variation in life history parameters (Prince et al. 2014).

Reference areas such as no-take marine reserves can provide excellent baselines against which to compare fished stocks -- better in many respects than even the longest of catch histories -- if they are large enough, long-standing, and well enforced. Comparisons of length compositions inside and outside no-take reserves may reduce the number of assumptions required to estimate fishing mortality as well. This is because they provide empirical information on the unfished density and length structure of the stock instead of an estimate based on growth rate and demographic changes. Such comparisons also reduce bias in estimates of unfished biomass and length composition because they are not confounded by changes in ocean productivity or other factors, as catch histories are. Fish densities (kg/ha) inside and outside the MPA can be estimated from the results of fishing or visual surveys. The MPA Density Ratio (fished/unfished density) can then be calculated to serve as an indicator of stock status (Babcock and MacCall 2011). Effort-based harvest control rules such as season length can be generated directly (Babcock and MacCall 2011) (Figure 4), or the results of the analysis can be used in combination with PSA results to prioritize stocks for assessment and management (Figure 5).

If a well-enforced no-take reserve containing habitat similar to fished habitat is available, SPR analysis can also be improved since length frequency information from the reserve (obtained with independent monitoring, i.e., scientific fishing surveys) provides a baseline (unfished SPR) to which SPR of the fished population can be compared (Honey 2012, Wilson et al. 2013).

The results of these types of status estimates can be grouped into low, medium, and high depletion categories that can be integrated with the results of other analyses.

Step 4. Prioritize Stocks for Assessment and Management

For each combination of vulnerability and depletion categories (derived in Steps 2 and 3, respectively), different precautionary management advice can be developed, and priorities can be assigned to each stock under analysis. An example of this approach is given in Figure 5. Management guidance will vary depending on the value of the stock for fishing and for other uses (e.g., tourism, recreational fishing, or ecological role), risk tolerance, and special status (i.e., threatened or endangered species).

Step 5. Assessment of Priority Stocks

Once priorities for assessment are identified, data should be carefully evaluated and matched to appropriate data limited assessment methods for more fully assessing the status of fishery stocks and providing more detailed information to guide management. Data-limited assessment methods are relatively simple to use but require a great deal of care in the interpretation of the results to generate useful management guidance. Multiple analyses are recommended to increase the dependability of the results.

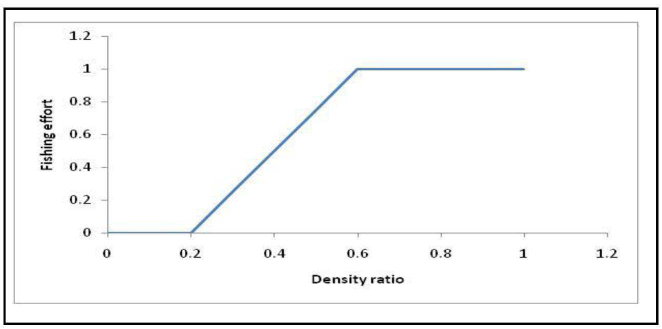

Figure 4. Concept for using estimates of biomass depletion due to fishing based on the MPA Density Ratio Method to manage a fishery. When the Density Ratio is above the limit, recent catch and effort levels are maintained; when the Density Ratio is reduced to levels below the limit, allowable catch or effort is reduced to levels aimed at achieving the target Density Ratio.

	Low Vulnerability	Medium Vulnerability	High Vulnerability
Low Depletion	**Low Priority** Potential for increased harvest	**Medium Priority** Potential for increased harvest; monitor the stock	**Medium Priority** Use precaution; assess if targeted for expanded fishing effort or if bycatch rates are high
Medium Depletion	**High Priority** Potential for relatively high sustainable yield; assess and set management measures	**High Priority** Potential for relatively high sustainable yield; assess and set management measures	**High Priority** Potential for low or moderate sustainable yield; assess and set management measures
High Depletion	**High Priority** Reduce fishing; anticipate rapid rebuilding	**High Priority** Reduce fishing; anticipate slower rebuilding	**High Priority** Ban fishing; anticipate slow rebuilding

Figure 5. Prioritizing stocks for research and management based on stock vulnerability and biomass depletion. Based on the results of data limited analyses, stocks are categorized with respect to their vulnerability scores and estimated levels of depletion or fishing pressure; management guidance is developed for stocks in each category.

The field of data-limited assessment is growing rapidly, and new methods appear regularly in the literature (Cope 2012, Martell and Froese 2012, Hordyk et al. 2014, Prince et al. 2014). Honey et al. (2010) and CA Sea Grant College Program (2008) provide summaries of some data-limited assessment methods.

The available data will dictate the type of assessment methods that can be used (Table 1) and the potential outcomes. Adaptive management that will reduce the risk of overfishing while continuing to improve over time is carried out by using data-limited methods to evaluate fishery performance indicators such as fishing mortality rate, spawning potential ratio, MPA density ratio, or CPUE trend and comparing the outputs to predefined targets or “reference points.” These results are then interpreted using detailed knowledge of the fishery and supporting ecosystem, and used to develop management measures designed to bring the performance indicators into alignment with the reference values (Figure 6).

Results from most data limited assessments are more uncertain or biased than conventional statistical stock assessments models (Carruthers et al. 2014). Recognizing and considering uncertainty and bias in assessment outputs is critical to making informed management decisions. Accounting for uncertainty and bias becomes even more important when attempting to manage multi-species and multi-gear fisheries, when borrowing information from similar species or nearby geographies, when data do not accurately represent a random sample of the population, or when equilibrium assumptions are violated, among others. Adaptive management that is based on several performance indicators that are evaluated using independent data streams can be used to hedge against uncertainty and improve management over time.

Step 6. Collect more Data for Future Stock Assessments

For some fisheries, stakeholders and managers may determine that higher investment in data collection and assessment is necessary to enhance fishery outcomes. For other fisheries, data-limited assessment and adaptive management may suffice.

Data collection systems should be designed to continuously improve the quality and quantity of data available for assessment and management, within the cost and capacity constraints of the fishery. Careful design of data collection systems to match assessment methods and management needs is important; many data collection systems have required much effort and cost but have not resulted in useful data. Closely tying data collection investments to improvements in outputs will also enhance fishermen’s and managers’ confidence in the process.

Well-designed collection programs should include data on the biological, social, and economic aspects of the fishery. While biological data has long been considered necessary to determine the status of the fishery, social and economic data have not routinely been a part of data collection programs. Information such as market prices, fishing costs and revenues, and employment characteristics however, can be highly informative and used to determine the economic and social health of coastal communities as well as to aid in the process of setting fishery management goals. For some fisheries, it may be desirable to keep fish biomass levels relatively high by reducing fishing pressure below levels consistent with maximum sustainable yield in order to maintain other ecosystem services that are valued locally. Examples include sportfishing, where high biomass levels can result in higher encounter rates and larger trophy fish, dive tourism, or fisheries in which it is desirable to increase profits by reducing search time and

Table 1. Matching data availability with assessment methods

Method	Required Data	Output	Caveats
MPA Density Ratio[3]	Fish density inside and outside MPAs Life history parameters	Stock status; indicates whether or not fishing effort is sustainable	Assumes reserves are well-enforced and conditions inside represent an unfished
Length-Based Reference Point[4]	Length data for at least 1 year (catch data are not needed) Life history parameters	Fishery status relative to management reference points; indicates whether or not catches are sustainable	Does not estimate optimal harvest levels Assumes length data from the catch is representative of
Mean Length (LBAR)[5]	Length data from the catch and independent monitoring Life history parameters	calculate Calculates fishing pressure (F/Fmsy), adjusts fishing pressure according to the dis-	Assumes that Fmsy equals natural mortality and equilibrium dynamics
Spawning Potential Ratio-Based Decision Tree[6-8]	Length data from catch Catch per Unit Effort	Recommended biological catch	Catch per Unit Effort may not accurately reflect stock abun-
Reserve-Based Spawning Potential Ratio[9]	Length or age data inside and outside MPAs Life history parameters, including	Estimates of sustainable yield; indicates whether or not catches are sustainable	Assumes reserves are well-enforced and conditions inside represent an unfished
Depletion-Corrected Average Catch (DCAC)[10]	Catch records > 10 years Estimated initial catch Life history parameters	Estimates of sustainable yield; indicates whether or not catches are sustainable	Requires reliable catch data (landings plus bycatch/ discard mortality)
Depletion-Based Stock Reduction Analysis (DB-SRA)[11]	Catch records > 10 years Estimated initial catch Life history parameters	Estimates of sustainable yield; indicates whether or not catches are sustainable	Requires reliable catch data (landings plus bycatch/ discard mortality)
Catch-MSY[12]	Catch records Estimated ranges of stock size in the first and final years of the catch	Maximum sustainable yield	Assumes population growth rate and carrying capacity do not change over time
Fractional Change in Lifetime Egg Production (FLEP)[13]	Length data from the fishery and an unfished population	Management reference points	Does not estimate optimal harvest levels
MPA-Based Decision Tree[14]	Catch per Unit Effort (CPUE) or fish density surveys Age-length data inside and outside	Catch limit	Assumes reserves are well-enforced and conditions inside represent an unfished

(1) McClanahan et al. 2011; (2) Patrick et al. 2009; (3) McGuillard et al. 2011; (4) Ault et al. 2005; (5) Cope and Punt 2009; (6) Wilson et al. 2013; (7) Prince et al. 2011 (8) Hordyk et al. 2014; (9) Honey and He *in prep*; (10) MacCall 2009; (11) Dick

Scenario	Reference Point			Interpretation / possible causes	Suggested management response sequence
	Length LIMIT	F LIMIT	SPR ($F_{20\%}$)		
1	↑	↑	↑	○ Stock productivity and fishery performance stable and/or increasing	*No response required, but optionally:* 1) Monitor reference point (RP) trends a) Make no change (if RP trends are stable or just above limits) b) Ease harvest rate regulation (if RP trends high/increasing)
2	↓	↑	↑	○ Fishery lightly harvested (i.e., fishing effort and harvest rates are low)	*No response required, but optionally:* 1) Monitor reference F and SPR trends and recruitment, gear and behavior patterns a) Make no change (if F/SPR trends stable/just above limits) b) Ease harvest rate regulation (if F/SPR trends increasing)
3	↑	↓	↑	○ Increased pressure or new gear ○ Low sample sizes of old fish ○ Large recruitment pulse	*No response required, but optionally:* 1) Confirm/monitor SPR values with multiple models/approaches a) No change (if SPR trends are stable/near limit) b) Harvest rate reduction or gear restriction c) No change (if sample sizes are small)

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Figure 6. Adaptive fisheries management. Using a participatory process, several fishery performance indicators are chosen based on relevance to fishery goals and availability of data. Reference values that reflect fishery goals are also chosen. The indicators are then evaluated using data limited methods, ideally using independent data streams (e.g., some indicators are based on length composition data from the catch, while others are based on fishery independent data) and compared to the reference values. Results are interpreted and management guidance based on these interpretations is developed in a participatory process.

associated costs (i.e., increasing catch per unit effort).

Biological data should encompass both fishery dependent and independent data to fully assess the status of fish stocks (Ocean Studies Board 2000, Sparre 2000). Fishery dependent data including total catch, landings, and fishing effort can be gathered through the use of logbooks and representative dockside samples of length and weight. Underwater visual surveys of fish species, density, and individual fish lengths, along with habitat types in both fished and unfished areas are important fishery independent records that are underutilized in fisheries assessment and management. Additional biological data, such as size at maturity, fecundity, and sex ratio, are also highly useful, and can often be collected using relatively simple sampling protocols.

In many locations, fishermen and local community members help design and carry out data collection and sampling programs. Incorporating the knowledge and manpower of local fishermen and their families often cuts sampling costs and may help increase community acceptance of management decisions.

CONCLUSION

Tens of thousands of commercial and recreational fisheries exist worldwide, and the population status of most is unknown. Often, fishery managers have very few, if any, data concerning the status of target fish stocks and/or the ecosystems that support these fisheries, increasing risk for poor fishery outcomes or even complete fishery collapse. Data-limited stock assessment methods do not generate MSY reference points or biomass estimates, but instead produce other types of useful indicators of stock status. Because it is preferable to use multiple data-limited methods, and interpret them together as a hedge against the uncertainty inherent in analyzing data-limited fisheries, we provide a six-step framework for how to apply data-limited methods and use their outputs to guide fisheries management. As the global need for food security and healthy ocean ecosystems increases, understanding the status of fish populations will become ever more important, and the integrated use of stock assessments for data-limited fisheries can help keep fisheries ecologically sustainable and economically profitable.

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