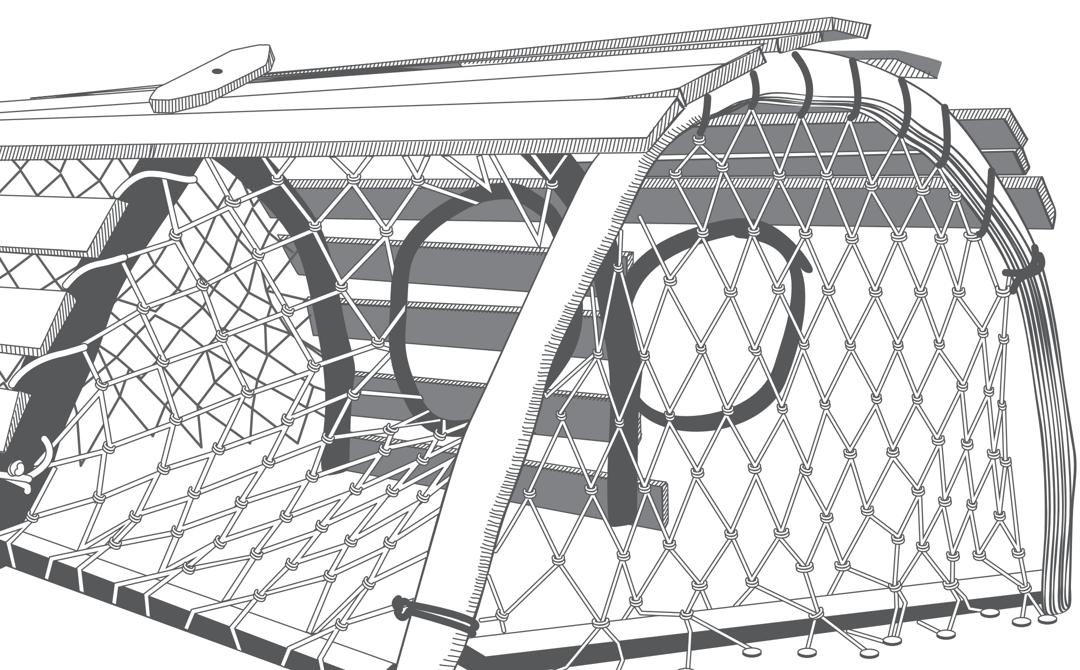
Science-Based Management of Data-Limited Fisheries

A SUPPLEMENT TO THE

CATCH SHARE DESIGN MANUAL

Ashley M. Apel, Rod Fujita and Kendra Karr



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Any views expressed in the Design Manual are those of the authors and do not necessarily represent those of the contributors or their organizations. Any errors are those of the authors.

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Introduction

Fisheries around the world are in need of biological assessment. Global statistics on the status of fisheries indicate that 30% are depleted or being overfished, 57% are at maximum sustainable yield (MSY) and 13% are underexploited (FAO, 2012). However, these statistics are based on the small fraction of fish stocks in the world that have been scientifically assessed; the vast majority have not. As many as 10,000 stocks may be subject to fishing globally, and many of those may lack catch data or management of any kind. A recent study suggests that most unassessed small-scale fisheries may be overfished (Costello et al., 2012). While this analysis provides a more complete picture of global fish stock status, it is limited by the dearth of catch data and hence, includes only a small portion of the world's fisheries (Costello et al., 2012).

Most assessed fish stocks are managed by industrialized nations and produce large volumes of catch and/or generate high revenues, justifying the significant costs of scientific monitoring and assessment. Many unassessed stocks are being fished in developing countries that have limited resources to conduct monitoring or assessments. It is important to note, however, that many stocks remain unassessed even in industrialized countries: for example, fewer than half of all federally managed stocks in the United States have been assessed (NMFS, 2012).

Failure to assess the status and productivity of fish stocks can increase the risk of stock collapse and lead to loss of social and economic benefits associated with sustainable yield. One obstacle to increasing the number of stocks that are assessed is cost: in many cases, the costs of data collection and stock assessments may be near to, or even exceed, revenues generated by the fishery. Another obstacle is often the need for historically rich data records.

In order to overcome these obstacles, fishery scientists have developed a suite of new assessment methods—"data-limited methods"—that do not require historical data records and can be done rapidly and cheaply. The field of data-limited assessment is growing rapidly, and new methods appear regularly in the literature (Prince et al., 2011; Cope, 2012; Martell and Froese, 2012). Honey et al. (2010) and the California Sea Grant College Program (2008) provide a summary of some data-limited methods. Comparisons of the results from data-limited methods and complex stock assessment models using the same data show that three peer-reviewed, data-limited methods[1] yield reliable fishery management guidance (e.g., overfishing limits and sustainable yield levels) under certain conditions (Honey et al., in prep). 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. (J. DeVore, personal communication, 2012). Due to the data-limited nature of these methods, multiple models are often used to corroborate results.

While data-limited methods tend to produce results that call for precautionary management decisions (Honey et al., in prep), and many do not generate conventional reference points such as maximum sustainable yield, arguably the risks and consequences of fishery collapse are great enough to justify using these methods in unassessed and/or unmanaged fisheries. Data collection and analytical costs are much lower using data-limited assessment methods than using data-rich methods. Data-limited assessment techniques are also available to qualitatively determine the status of ecosystems that support fisheries and ecological risks posed by fishing (Hobday et al., 2011; McClanahan et al., 2011).

Due to the complexity of data-limited stock assessments, we have developed a six-step framework that produces rapid, adaptive and precautionary management guidance to help make use of the growing number of assessment methods. Data-limited methods require different types of data than the more heavily used data-rich methods and generate different types of management guidance. This framework is designed to help ease the intricate assessment process by combining multiple methods (and their various data requirements) into a structured step-by-step process. The information produced via the assessment models found in this integrated framework can serve as the scientific basis for managing data-limited fisheries. While the framework does not provide an instruction manual on each data-limited assessment method, a more thorough discussion can be found in the primary literature referenced throughout.

SIX-STEP INTEGRATED FRAMEWORK

Data-limited methods that are currently available can be used to estimate risks to marine ecosystems, determine the vulnerability of a stock to fishing pressure, calculate the level of biomass depletion, assess the sustainability of the fishery and establish sustainable fishing targets and other management reference points. These methods are combined in the step-by-step integrated framework laid out in Figure 1, generating guidance for data-limited fisheries and taking advantage of improved data over time.

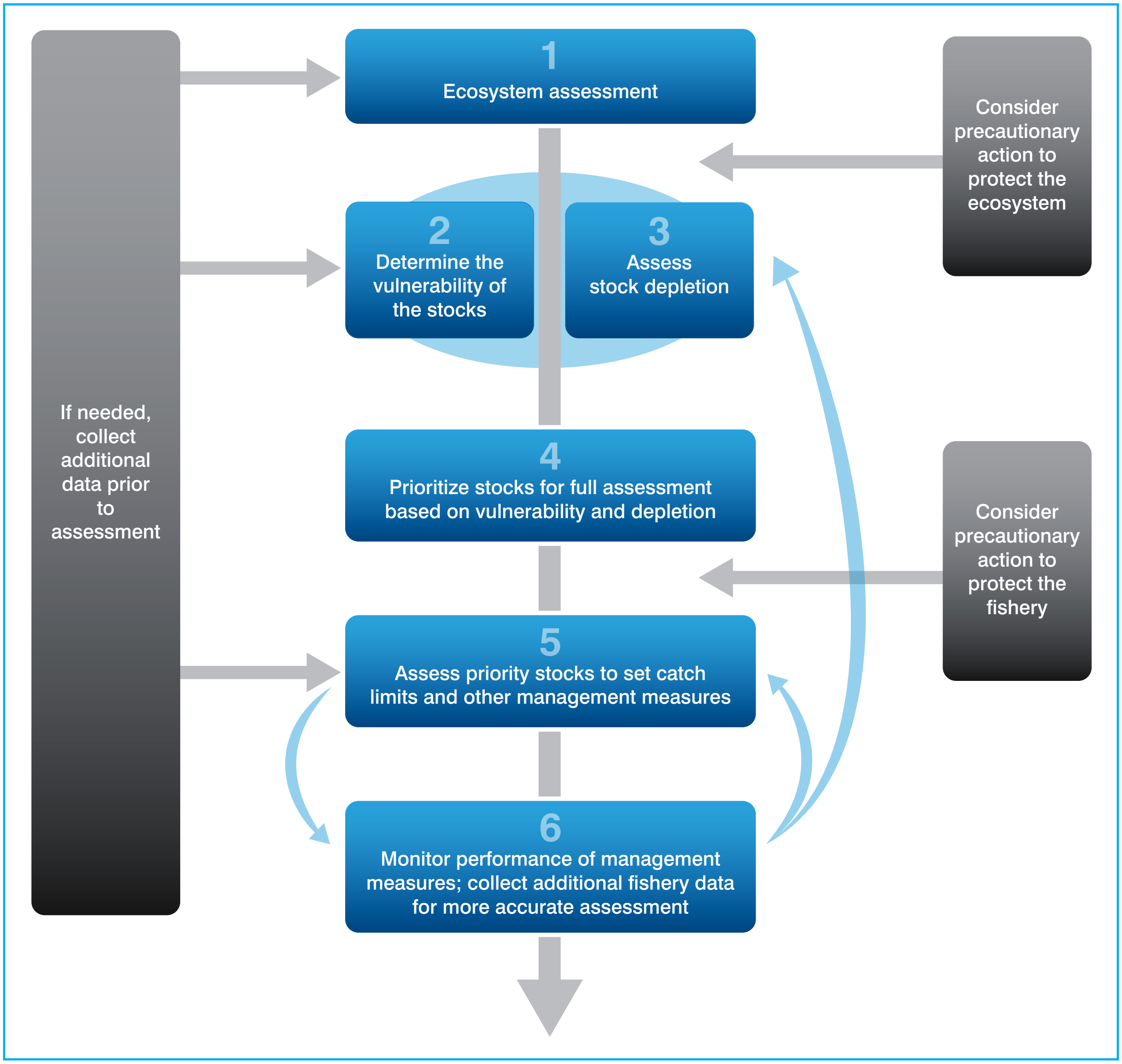
STEP 1: Assess the ecosystem status and impacts of fishing

The first step of the integrated framework is to qualitatively assess the status of the marine ecosystem and the associated impacts of fishing. This can be done using local and/or expert knowledge of the area, or through simple-to-gather measurements such as fish density. Ecosystem assessment models help prioritize management decisions by determining which species or habitat may be most at risk.

The Ecological Risk Assessment method was developed to characterize the risks to marine ecosystems associated with fishing (Smith et al., 2007). For some ecosystems, including coral reefs, recent studies show the existence of quantitative thresholds associated with fish densities (measured in kg/ha). Below these thresholds, ecosystems change from desirable (e.g., high coral cover) to less desirable states (e.g., dominated by algae) (McClanahan et al., 2011). The result is less resilient, more vulnerable systems with fewer ecosystem services. Fisheries in ecosystems with documented fishing thresholds can be managed to remain above these limits, reducing the risk of system collapse. Fish densities can be measured with fishing or visual surveys and then compared to the threshold limits. Management implications for coral reef thresholds in the Indian Ocean and Caribbean Sea are shown in Tables 1 and 2,

1 The stock assessment methods compared are Depletion-Corrected Average Catch, Depletion-Based Stock Reduction Analysis and Length-Based Reference Point.

FIGURE 1 | *Integrated Framework for Data-Limited Stock Assessments*



respectively. Because threshold analyses are relatively new, only a few locations have been studied. Thus far, however, it appears that coral reef thresholds for the Indian Ocean and Caribbean Sea are consistent with other locations, such as Indonesia, providing a larger context for applicability (Karr et al., in prep(b)).

When system thresholds or other quantitative data relating fishing intensity to ecosystem conditions are not available, an Ecological Risk Assessment for the Effects of Fishing (ERAEF) can be conducted in data-limited locations and can assimilate more data as they become available (Hobday et al., 2011). In an ERAEF, information from the literature, surveys and stakeholder interviews is used to generate a

TABLE 1 | THRESHOLDS FOR CORAL REEFS IN THE INDIAN OCEAN (McClanahan et al., 2011), with management implications added

FISH DENSITY RATIO (FISHED AREA/ UNFISHED AREA)	FISH DENSITY THRESHOLD (KG/HA)	INDICATOR	MANAGEMENT IMPLICATIONS
	1200 (unfished) to 1130	Healthy ecosystem	Maintain status quo; address non-fishing threats to the ecosystem
> 0.50	< 1130	Increased variance in macroalgal abundance	Early warning sign; monitor the ecosystem
	850	Increased variance in ratio of coral to macroalgal abundance	Warning sign of impending state change
~ 0.50	640	Reduced predation rates on urchins	Indicator of impending ecosystem state change
< 0.50	500	Shift to macroalgal dominance (> 30% cover)	Ecosystem recovery potentially possible; reduce fishing pressure
< 0.25	300	Changes in species richness, fish population structure, urchin biomass, calcifying algae and coral cover	Ecosystem state change; recovery potentially difficult

TABLE 2 | POTENTIAL ECOSYSTEM THRESHOLDS FOR CARIBBEAN CORAL REEFS (Karr et al., in prep(b))

FISH DENSITY RATIO (FISHED AREA/ UNFISHED AREA)	FISH DENSITY THRESHOLD (KG/HA)	INDICATOR	MANAGEMENT IMPLICATIONS
	~ 1300 (unfished) to 1146	Healthy ecosystem	Maintain status quo; address non-fishing threats to the ecosystem
> 0.50	< 1146	Increased macroalgal cover, increase in proportion of invertivore fishes	Early warning signs; monitor the ecosystem
< 0.50	610	Decreased fish richness	Warning sign of impending state change; reduce fishing pressure
< 0.40	470	Increased urchin densities, increased ratio of coral to macroalgal abundance	State change to one dominated by macroalgal cover (> 30%); reduce fishing pressure
< 0.30	410	Decreased proportion of herbivorous fish	Ecosystem recovery potentially possible; reduce fishing pressure
< 0.25	360	Decreased coral cover	Ecosystem state change; recovery potentially difficult

risk assessment that identifies the most vulnerable parts of the system (i.e., target species, bycatch species, threatened species, habitats, ecological communities). This analysis is used to detect high-risk activities that require immediate management attention and to screen out low-risk activities from further analysis.

STEP 2: Assess the vulnerability of stocks to fishing pressure

The second step of the framework is to assess the vulnerability of target stocks to fishing pressure using basic biological and fishery information. This is most often done using the Productivity and Susceptibility Analysis (PSA) model (Patrick et al., 2009). Even if fishery data such as landings, effort or length frequency of the catch are not available, a PSA can inform management decisions by indicating which stocks should be prioritized for further assessment and precautionary management.

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. This information is used to estimate the biological productivity of the stock. These parameters can typically be obtained from the literature or online databases, but when possible, information from local studies and stakeholder/expert interviews should be used. Qualitative information may be used if specific measurements are lacking. All values should be vetted with local biologists and fishermen to increase reliability.

Information on the nature of the fishery, including the geographic overlap of the fishery and fish stocks, current management practices, value of the fishery and impacts on habitat is needed to estimate the susceptibility of the stock to overfishing. Again, much of this information can be qualitative and gleaned from interviews with fishermen and managers. Software for conducting a PSA is available free of charge 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.

STEP 3: Estimate the level of stock depletion

After conducting a PSA on target species, the next step is to determine whether target stocks are overfished and if so, by how much. Several data-limited methods can be used to estimate the degree of stock depletion relative to unfished levels. If catch records are not available, if records do not include catches early in the history of the fishery or if important changes in management and fishing effort have occurred (thus confounding the relationship between catch and stock size), depletion status can be estimated using three sources: fish density data from inside and outside well-enforced references areas, catch-based length information and/or visual survey data (see Table 3).

No-take marine protected areas (MPAs) and other well-enforced reference areas provide excellent baselines against which to compare fished stocks—better in many respects than even the longest of catch histories. This is because they provide empirical information on the unfished density and length structure of the stock, rather than estimates. Fish densities (measured in kg/ha) inside and outside the MPA can be estimated from the results of fishing or visual surveys. The MPA Density Ratio (fished/unfished fish density) can then be calculated to serve as an indicator of stock status (Babcock and MacCall, 2011). Effort-based harvest control rules can be generated directly (Babcock and MacCall, 2011), or the results of the analysis can be used in conjunction with PSA results to prioritize stocks for further assessment in order to set catch limits and other management measures.

Length-based methods can also be used to estimate degree of stock depletion. Sustainable fishing practices generally require fishermen to leave large proportions of juveniles in the water so they can spawn at least once to avoid growth overfishing. Large, highly fecund adults should also remain in the water to reduce the risk of recruitment overfishing. Because of this, the length frequency of fish in the catch can be used to calculate indicators of whether or not fishing is sustainable (Froese, 2004). A recent improvement on this method accounts for differences in the selectivity of the fishery (Cope and Punt, 2009).

TABLE 3 | DATA-LIMITED ASSESSMENT METHODS TO DETERMINE DEPLETION OF TARGET STOCKS

METHOD	REQUIRED DATA	OUTPUT	CAVEATS	RESOURCES NEEDED
MPA Density Ratio[1]	• Fish density inside and outside effectively managed MPAs • Life history parameters	Stock status; indicates whether fishing effort is sustainable	Assumes reserves are well-enforced and conditions inside represent an unfished population	$ ◷ ▤
Length-Based Reference Point[2]	• Length data for at least one year (catch data are not needed) • Life history parameters	Fishery status relative to management reference points; indicates whether catches are sustainable	Does not estimate optimal harvest levels and assumes length data from the catch are representative of the stock	$ ◷◷ ▤▤
Spawning Potential Ratio-Based Decision Tree[3]	• Length data from catch • Catch-per-unit-effort (CPUE) • Life history parameters, including fecundity	Recommended biological catch	CPUE may not accurately reflect stock abundance	$ ◷◷ ▤▤
Reserve-Based Spawning Potential Ratio[4]	• Length or age data inside and outside MPAs • Life history parameters, including fecundity	Estimates of sustainable yield; indicates whether catches are sustainable	Assumes reserves are well-enforced and conditions inside represent an unfished population	$ ◷◷ ▤▤▤
Visual Survey Spatial Assessment[5]	• Fishery independent length frequency and habitat data	Predicts fish density by life stage through species-habitat associations; products include designation of rebuilding areas	Assumes species-habitat associations are a good indicator of species presence	$ $ ◷◷◷ ▤▤▤

Resources Needed:

$ Funding ◷ Time ▤ Data

References:

(1) Babcock and MacCall, 2011; (2) Cope and Punt, 2009; (3) Prince et al., 2011; (4) Honey and He, in prep; (5) Karr et al., in prep(a)

Length-based assessment methods may be difficult to use with some fish species, including those whose growth patterns 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 butterflyfish. Length-based assessment is also difficult for species that show little difference in size between length classes (Cope and Punt, 2009), or suffer low rates of natural mortality (e.g., some shark species, for which it may be more appropriate to protect older juveniles than young juveniles) (B. Hueter, personal communication, 2012). In some cases, the spawning potential ratio (SPR, or average fecundity of a recruit over its lifetime) of the stock can be estimated from length frequency data if the relationship between length and weight and/or age is known (Prince et al., 2011). If a well-enforced MPA is available, SPR analysis can be improved since length frequency information from the MPA (obtained with fishing surveys) provides a baseline (unfished SPR) to which SPR of the fished population can be compared (Honey and He, in prep).

In fisheries that lack catch data, fishery-independent visual survey data can be used to assess stock status, using estimates of fish density by life stage in each habitat type. Density estimates allow managers to create regulations that limit fishing mortality in specific locations to rebuild depleted fish stocks. These rebuilding areas are designed to protect appropriate densities of each life stage and may shrink as rebuilding proceeds (Karr et al., in prep (a)).

The results of stock depletion analyses can be grouped into low, medium and high depletion categories so they can be integrated with the results of other analyses.

STEP 4. Prioritize stocks for further assessment and precautionary management

After vulnerability and depletion levels have been determined, the fourth step combines these data into a useful context for management. For each combination of vulnerability and depletion categories, different precautionary management advice can be developed. An example of this approach is given in Table 4. 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. Assess priority stocks

Once priorities for assessment are identified and precautionary measures are taken, data should be carefully evaluated and matched to appropriate data-limited assessment methods in order to set catch limits or other fishing mortality controls for high priority stocks. The available data will dictate the type of assessment methods that can be used. Data-limited assessment methods are relatively simple to use but require a great deal of care in interpreting the results to generate useful management guidance. Multiple analyses are recommended to increase the dependability of the results. Table 5 outlines commonly used data-limited methods; however, new models are continuously being developed, tested and peer-reviewed for use in the field.

TABLE 4 | PRIORITIZATION MATRIX

	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

TABLE 5 | DATA-LIMITED ASSESSMENT METHODS TO SET MANAGEMENT TARGETS

METHOD	REQUIRED DATA	OUTPUT	CAVEATS	RESOURCES NEEDED
Depletion-Corrected Average Catch (DCAC)[1]	• Catch records >10 years • Estimated initial catch • Life history parameters	Estimates of sustainable yield; indicates whether catches are sustainable	Requires reliable catch data (landings plus bycatch); does not work well for highly depleted stocks	$ ◷ ▤▤
Depletion-Based Stock Reduction Analysis (DB-SRA)[2]	• Catch records >10 years • Estimated initial catch • Life history parameters	Estimates of sustainable yield; indicates whether catches are sustainable	Requires reliable catch data (landings plus bycatch); does not work well for highly depleted stocks	$ ◷ ▤▤
Fractional Change in Lifetime Egg Production (FLEP)[3]	• Length data from the fishery and an unfished population • Length-egg production relationship • Life history parameters	Biological reference point for stock persistence (lifetime egg production)	Does not estimate optimal harvest levels	$ ◷◷ ▤▤
MPA-Based Decision Tree[4]	• Catch-per-unit-effort (CPUE), fish density surveys, or visual census data • Age-length data inside and outside MPAs • Life history parameters	Catch limit	Assumes reserves are well-enforced, conditions inside represent an unfished population and CPUE surveys are unbiased by targeting or aggregation behavior	$ $ ◷◷ ▤▤▤
Catch-MSY[5]	• Catch records • Estimated ranges of stock size in the first and final years of the catch data • Life history parameters	Maximum sustainable yield	Assumes population growth rate and carrying capacity do not change over time	$ ◷◷◷ ▤▤▤

Resources Needed:

$ Funding ◷ Time ▤ Data

References:

(1) MacCall, 2009; (2) Dick and MacCall, 2011; (3) O'Farrell and Botsford, 2005; (4) Wilson et al., 2010; (5) Martell and Froese, 2012

STEP 6. Collect more data for future stock assessments

As sufficient resources become available, additional fisheries data can be collected and used to drive more sophisticated stock assessments that determine reference points for maximum sustainable yield, maximum economic yield or other management goals. Additional data will need to be gathered in some cases in order to estimate stock depletion levels (**Step 3**); in others, this may need to occur before stocks can be further assessed (**Step 5**).

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. It is important to carefully design data collection systems to match assessment methods and management needs. Many data collection systems have required much effort and cost but have not yet resulted in useful data.

Well-designed collection programs should include data on the biological, social and economic aspects of the fishery. While biological data have 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 can be highly informative and useful for determining the economic and social health of fishing communities. Poor economic health may be an indicator of declining fish populations. Information on fishing costs and revenue is also necessary to estimate maximum economic yield.

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

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 can help reduce data collection costs (Danielsen et al., 2008), and the community-based approach may help increase the likelihood of successful management outcomes (Pomeroy, 1995; Defeo and Castilla, 2005).

CONCLUSION

Thousands of commercial and recreational fisheries exist worldwide, but the status of most stocks is unknown, increasing the risk of stock collapse and the loss of the social, ecological and economic benefits associated with sustainable fisheries. Fishery managers often have very little, if any, data concerning the health of the marine ecosystem and/or target fish stocks, leading to uninformed management decisions that allow fisheries to approach and surpass sustainable levels of fishing. Data-limited stock assessment methods provide managers with the tools they need to take appropriate management actions in order to maintain sustainable yields over time. This six-step framework provides guidance for how and when to use specific data-limited methods. As the global needs for food security and healthy ocean ecosystems increase, understanding the status of fish populations will become ever more important. The use of data-limited analytical methods can help keep fisheries ecologically sustainable and economically profitable.

References

References

Babcock, E. A. and MacCall, A. D. (2011). How useful is the ratio of fish density outside versus inside no-take marine reserves as a metric for fishery management control rules? *Canadian Journal of Fisheries and Aquatic Sciences*, 68, 343-359.

Blackhart, K. Stanton, D. and Shimada A. (2006). *NOAA Fisheries Glossary*. NOAA Technical Memorandum NMFS-F/SPO-69. National Oceanic and Atmospheric Administration. Silver Spring, Maryland. Retrieved from http://www.st.nmfs.noaa.gov/st4/documents/FishGlossary.pdf

California Sea Grant College Program (2008). *Managing Data-Poor Fisheries: Case Studies, Models & Solutions*. Managing Data-Poor Fisheries Workshop, December 1-4, 2008, Berkeley, CA.

Cope, J. M. (2012). Implementing a statistical catch-at-age model (Stock Synthesis) as a tool for deriving overfishing limits in data-limited situations. *Fisheries Research*, in press.

Cope, J. M. and Punt, A. E. (2009). Length-based reference points for data-limited situations: applications and restrictions. *Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science*, 1, 169-186.

Costello, C., Ovando, D., Hilborn, R., Gaines, S. D., Deschenes, O. and Lester, S. E. (2012). Status and solutions for the world's unassessed fisheries. *Science Express Reports*, September 27, 1-4.

Danielsen, F., Burgess, N. D., Balmford, A., Donald, P. F., Funder, M., Jones, J. P. G., Alviola, P., Balete, D. S., Blomley, T., Brashares, J., Child, B., Enghoff, M., Fjeldså, J., Holt, S., Hübertz, H., Jensen, A. E., Jensen, P. M., Massao, J., Mendoza, M. M., Ngaga, Y., Poulsen, M. K., Rueda, R., Sam, M., Skielboe, T., Stuart-Hill, G., Topp-Jørgensen, E. and Yonten, D. (2008). Local participation in natural resource monitoring: a characterization of approaches. *Conservation Biology*, 23(1), 31-42.

Defeo, O. and Castilla, J. (2005). More than one bag for the world's fishery crisis and keys for co-management successes in select artisanal Latin American shellfisheries. *Fish Biology and Fisheries*, 14, 265-283.

Dick, E. J. and MacCall, A. D. (2011). Depletion-based stock reduction analysis: a catch-based method for determining sustainable yields for data-poor fish stocks. *Fisheries Research*, 110, 331-341.

Food and Agriculture Organization of the United Nations (FAO) (n.d.). *Fisheries Glossary*. Food and Agriculture Organization of the United Nations. Retrieved from http://www.fao.org/fi/glossary/default.asp

Food and Agriculture Organization of the United Nations (FAO) (2012). *The state of world fisheries and aquaculture*. Fisheries and Aquaculture Department, Food and Agriculture Organization of the United Nations. Rome. Retrieved from http://www.fao.org/docrep/016/i2727e/i2727e00.htm

Froese, R. (2004). Keep it simple: three indicators to deal with overfishing. *Fish and Fisheries*, 5, 86-91.

Hobday, A. J., Smith, A. D. M., Stobutzki, I. C., Bulman, C., Daley, R., Dambacher, J. M., Deng, R. A., Dowdney, J., Fuller, M., Furlani, D., Griffiths, S. P., Johnson, D., Kenyon, R., Knuckey, I. A., Ling, S. D., Pitcher, R., Sainsbury, K. J., Sporcic, M., Smith, T., Turnbull, C., Walker, T. I., Wayte, S. E., Webb, H., Williams, A., Wise, B. S. and Zhou, S. (2011). Ecological risk assessment for the effects of fishing. *Fisheries Research*, 108, 372-384.

Honey, K., Apel, A. M., Cope, J., Dick, E. J., MacCall, A. and Fujita, R. In prep. Rags to fishes II: quantitative comparison of data-poor methods for fisheries management.

Honey, K. T., Moxley, J. H. and Fujita, R. M. (2010). From rags to fishes: data-poor methods for fishery managers. In *Managing Data-Poor Fisheries: Case Studies, Models and Solutions* (pp. 159-184). California Sea Grant College Program.

Honey, K. T. and He, X. In prep. Application of dynamic SPR and mean weight from marine reserves for information-limited fisheries management.

Karr, K., Fujita, R., Kritzer, J. and Babcock, B. In prep(a). Using visual survey data to assess and manage nearshore data-poor coral reef fisheries.

Karr, K., Halpern, B., Kappel, C., Crowder, L., Samhouri, J., Selkoe. K. and Fujita, R. In prep(b). Coral reef assessment and management using generic ecosystem thresholds as reference points for phase shifts in the Caribbean Sea.

MacCall, A. D. (2009). Depletion-corrected average catch: a simple formula for estimating sustainable yields in data-poor situations. *ICES Journal of Marine Science*, 66, 2267-2271.

Martell, S. and Froese, R. (2012). A simple method for estimating MSY from catch and resilience. *Fish and Fisheries*, in press.

McClanahan, T. R., Graham, N. A. J., MacNeil, M. A., Muthiga, N. A., Cinner, J. E., Bruggemann, J. H. and Wilson, S. K. (2011). Critical thresholds and tangible targets for ecosystem-based management of coral reef fisheries. *Proceedings of the National Academy of Sciences of the United States of America*, 108(41), 17230-17233.

National Marine Fisheries Service (NMFS) (2012). *Status of stocks: report on the status of U.S. fisheries for 2011*. National Oceanic and Atmospheric Administration. Retrieved from http://www.nmfs.noaa.gov/sfa/statusoffisheries/SOSmain.htm

National Research Council (NRC) (1999). *Sharing the Fish: Toward a National Policy of Individual Fishing Quotas*. The National Academies Press. Washington, D.C.

Ocean Studies Board (2000). *Improving the Collection, Management, and Use of Marine Fisheries Data*. National Research Council. The National Academies Press. Washington, D.C.

O'Farrell, M. R. and Botsford, L. W. (2005). Estimation of change in lifetime egg production from length frequency data. *Canadian Journal of Fisheries and Aquatic Sciences*, 62(7), 1626-1639.

Patrick, W. S., Spencer, P., Ormseth, O., Cope, J., Field, J., Kobayashi, D., Gedamke, T., Cortés, E., Bigelow, K., Overholtz, W., Link, J. and Lawson, P. (2009). *Use of productivity and susceptibility indices to determine stock vulnerability, with example applications to six U.S. fisheries*. U.S. Department of Commerce. NOAA Technical Memo. NMFS-F/SPO-101. 90 pp. Retrieved from http://www.pifsc.noaa.gov/library/pubs/NOAA_TM_NMFS_F-SPO_101.pdf

Pomeroy, R. S. (1995). Community-based and co-management institutions for sustainable coastal fisheries management in Southeast Asia. *Ocean & Coastal Management*, 27(3), 143-162.

Prince, J. D., Dowling, N. A., Davies, C. R., Campbell, R. A. and Kolody, D. S. (2011). A simple cost-effective and scale-less empirical approach to harvest strategies. *ICES Journal of Marine Science*, 68(5), 947-960.

Smith, A. D. M., Fulton, E. J., Hobday, A. J., Smith, D. C. and Shoulder, P. (2007). Scientific tools to support the practical implementation of ecosystem-based fisheries management. *ICES Journal of Marine Science*, 64, 633-639.

Sparre, P. J. (2000). *Manual on sample-based data collection for fisheries assessment: examples from Viet Nam*. FAO Fisheries Technical Paper. No. 398. Rome. 171 pp. Retrieved from http://www.fao.org/docrep/005/x8923e/x8923e00.HTM

Wilson, J. R., Prince, J. D. and Lenihan, H. S. (2010). A management strategy for sedentary nearshore species that uses marine protected areas as a reference. *Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science*, 2, 14-27.

Glossary

Glossary

Age-length data – Data comparing the length of an individual fish with its age.

Breeding strategy – Provides an indication of the level of natural mortality that may be expected for offspring in the first stages of life. Includes placement of larvae, level of parental protection and length of gestational period (Patrick et al., 2009).

Bycatch (*syns*.: Incidental catch, Non-target catch/species) – Fish other than the primary target species that are caught incidental to the harvest of those species. Bycatch may be retained or discarded. Discards may occur for regulatory or economic reasons (NRC, 1999).

Carrying capacity – The maximum population of a species that an area or specific ecosystem can support indefinitely without deterioration of the character and quality of the resource (Blackhart et al., 2006).

Catch (*syn*.: Harvest) – The total number (or weight) of fish caught by fishing operations. Catch includes all fish killed by the act of fishing, not just those landed (FAO, n.d.).

Catchability (*syn*.: Vulnerability) – 1. The extent to which a stock is susceptible to fishing. Catchability changes depending upon fish behavior and abundance and the type and deployment of fishing gear (Blackhart et al., 2006). 2. The fraction of a fish stock which is caught by a defined unit of the fishing effort (FAO, n.d.).

Catch limit (*syn*.: Total allowable catch) – The scientifically determined, acceptable level of fishing mortality.

Catch-per-unit-effort (CPUE) - The weight or number of fish caught with a specific unit of fishing effort (e.g., time and/or gear used).

Ecosystem services – The benefits people obtain from ecosystems. These include provisioning services, such as food and water; regulating services, such as flood and disease control; cultural services, such as spiritual and cultural benefits; and supporting services, such as nutrient cycling, that maintain the conditions for life on Earth (FAO, n.d.).

Fecundity – The potential reproductive capacity of a fish species, usually represented by the number of eggs produced in a reproductive cycle. Fecundity often increases with age and size (Blackhart et al., 2006).

Fishing mortality (*syn.:* Mortality) – A measurement of the rate of fish removal from a population by fishing. Fishing mortality can be reported as either annual or instantaneous. Annual mortality is the percentage of fish dying in one year. Instantaneous mortality is the percentage of fish dying at any given point in time (Blackhart et al., 2006).

Growth overfishing – Occurs when juvenile fish are harvested before their growth potential is fully reached. Restricts fisheries from producing their maximum poundage (Blackhart et al., 2006).

Length at maturity – *See:* Size at maturity.

Length-based data – Data based on the length of fish (e.g., length at maturity and maximum length).

Life-history parameters – Basic biological information such as size and age at maturity, natural mortality and fecundity for a specific species.

Macroalgae – Large, multi-celled, photosynthetic algae. Commonly called seaweed.

Marine reserve (*syn*.: Marine protected area) – A geographically defined space in the marine environment where special restrictions are applied to protect some aspect of the marine ecosystem including plants, animals and natural habitats (Blackhart et al., 2006). No-take reserves are a type of marine reserve.

Maximum Economic Yield (MEY) – The catch level that corresponds to the highest amount of profit that could be earned from a fishery (Blackhart et al., 2006).

Maximum length – The biggest fish, length-wise, in a sample or catch, or the biggest fish recorded for a specific species.

Maximum Sustainable Yield (MSY) – The largest average catch that can be taken continuously (sustained) from a stock under average environmental conditions. This is often used as a management goal (Blackhart et al., 2006).

Megaspawner – A highly fecund, older female fish (Froese, 2004).

Mortality – A measurement of the rate of death of fish, resulting from several factors but mainly predation and fishing.

No-take reserve (*syn.*: No-take zone) – A defined marine area in which fishing and other extractive activities are prohibited.

Recruit – An individual fish entering the fishable stage of its life cycle.

Recruitment – The number of fish added to a fishable stock each year due to growth and/or migration into the stock.

Recruitment overfishing – When high rates of fishing mortality result in low annual recruitment, a reduced spawning stock and decreased proportion of older fish in the catch. May result in stock collapse (Blackhart et al., 2006).

Size at maturity – The weight or length at which 50% of fish of a given sex reach reproductive maturity.

Spawning potential ratio – The number of eggs that could be produced by an average recruit in a fished stock divided by the number of eggs that could be produced by an average recruit in an unfished stock (Blackhart et al., 2006).

Vulnerability (*syn.*: Catchability) – Equivalent to catchability, but usually applied to a specific part of the fish stock, such as individuals of a specific size or length (Blackhart et al., 2006).

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