A FRAMEWORK FOR ASSESSING HIGHLY MIGRATORY SPECIES USING DATA-LIMITED METHODS

Matthew W. Smith[1*], J. Jeffery Isely[1], Skyler R. Sagarese[1], William J. Harford[2], Shannon L. Cass-Calay[1] and Nancie J. Cummings[1]

SUMMARY

Analyses of fisheries stocks using traditional models employing age and/or length inputs require substantial data and analytical support, and can be challenging where severe data limitations persist. We present multiple approaches that have been used to develop catch recommendations for data-limited species throughout the world. The complexity of data-limited methods ranges from simple empirical approaches, which rely on changes in indicator data, to more traditional approaches such as yield-per-recruit analyses which enable the determination of biological reference points. Data requirements for each model type are discussed and the assumptions of each method presented. In addition, a useful implementation framework that incorporates method feasibility, method selection, and development of catch advice that has recently been applied successfully in the Southeast US is described. The Data-Limited Methods Toolkit (DLMtool) facilitates the evaluation of performance of multiple data-limited assessment models and management procedures in a simulation environment. The DLMtool framework incorporates information content on the stock and fleet dynamics via operating models in addition to information on uncertainty and bias, and relies heavily upon detailed input from stakeholders including managers, fishermen, and scientists.

RÉSUMÉ

Pour mener des analyses de stocks des pêcheries au moyen de modèles traditionnels utilisant des données d'entrées sur l'âge et/ou la taille, une grande quantité de données et un support analytique sont nécessaires et ces analyses peuvent poser des difficultés lorsque de profondes limitations des données persistent. Ce document présente plusieurs approches ayant été utilisées pour élaborer des recommandations sur la prise concernant des espèces pauvres en données dans le monde entier. La complexité des méthodes pauvres en donnée comporte des approches empiriques simples, reposant sur des changements de différents indicateurs à des approches plus traditionnelles telles que des analyses de la production par recrue qui permettent de déterminer des points de référence biologiques. Les exigences en matière de données pour chaque type de modèle sont abordées et les postulats de chaque méthode sont présentés. En outre, un cadre de mise en œuvre utile qui intègre la viabilité de la méthode, la sélection de la méthode et l'élaboration de l'avis relatif à la prise a été récemment appliqué avec succès sur la côte du Sud-Est des États-Unis. La « boîte à outils » de méthodes pauvres en données (DLMtool) facilite l'évaluation des performances de multiples modèles d'évaluation limités en données et de procédures de gestion dans un environnement de simulation. Le cadre DLMtool incorpore des informations sur les dynamiques du stock et des flottilles au moyen de modèles opérationnels, ainsi que des informations sur l'incertitude et le biais, et repose en grande mesure sur des contributions détaillées des parties intéressées des pêcheries dont les gestionnaires, les pêcheurs et les scientifiques.

[1] Southeast Fisheries Science Center, 75 Virginia Beach Drive, Miami, Florida, USA 33149
[2] Cooperative Institute for Marine and Atmospheric Studies, Rosenstiel School of Marine and Atmospheric Science, University of Miami, 4600, Rickenbacker Causeway, Miami, Florida, USA 33149
* Corresponding Author E-mail: matthew.w.smith@noaa.gov

RESUMEN

Los análisis de los stocks de pesquerías que utilizan modelos tradicionales que emplean datos de entrada de talla y/o edad requieren una cantidad importante de datos y trabajo analítico y pueden ser un reto cuando persisten importantes limitaciones en cuanto a datos. Se presentan múltiples enfoques que han sido utilizados para desarrollar recomendaciones de captura para especies con cantidades limitadas de datos en todo el mundo. La complejidad de los métodos con limitaciones de datos oscila entre enfoques empíricos simples que dependen de cambios en los datos sobre indicadores y enfoques más tradicionales como análisis de rendimiento por recluta que permiten la determinación de puntos de referencia biológicos. Se debaten los requisitos de cada tipo de modelo y se presentan los supuestos de cada método. Además, se describe un marco de implementación útil que incorpora la viabilidad del método, la selección del método y el desarrollo de asesoramiento sobre captura que ha sido aplicado recientemente con éxito en la parte sureste de Estados Unidos. El Kit de herramientas de métodos para datos limitados (Data-Limited Methods Toolkit (DLMtool)) facilita la evaluación del desempeño de diferentes modelos de evaluación con datos limitados y los procedimientos de ordenación en un medio de simulación. El marco DLMtool incorpora contenidos de información sobre la dinámica del stock y la flota mediante modelos operativos, además de información sobre incertidumbre y sesgos y depende en gran medida de las aportaciones de datos detallados por parte de los que están implicados en la pesquería, lo que incluye gestores, pescadores y científicos.

KEYWORDS

Management strategy evaluation, Simulation,
Fishery management, Harvest control rule, Data-limited

1 Introduction and Background

The ability to conduct stock assessments and provide harvest advice for small tunas in the ICCAT area has been severely limited by a lack of fisheries statistics (e.g., landings, bycatch, catch per unit of effort) and life history (growth, reproduction) data. The data poor nature of these stocks has prohibited the use of integrated age-structured and yield-per-recruit based methods and in many cases made even the implementation of data-limited methods infeasible.

The ICCAT Small Tunas Year Programme (SMTYP) was endorsed at the 2012 ICCAT Commission meeting. The main objectives of the SMTYP are to improve basic catch (Task I), catch and effort and size information (Task II) and to collect biological data (growth, maturity emphasized) for use in management, prioritization of species within the group for assessment, and identification of approaches appropriate for future assessments.

It is noted that during 2016 the SMTYP continued the recovery of historical fisheries statistics and conducted biological studies on key population parameters for selected small tuna species off the North-eastern coast of Africa. Such activities are essential to conduct small tuna stock assessments in the near future, therefore a new call for tenders was recently launched (ICCAT CIRCULAR # 0706/ 2017).

The ICCAT SMT species group is composed of the following species:

– BLF Blackfin tuna (*Thunnus atlanticus*)
– BLT Bullet tuna (*Auxis rochei*)
– BON Atlantic bonito (*Sarda sarda*)
– BOP Plain bonito (*Orcynopsis unicolor*)
– BRS Serra Spanish mackerel (*Scomberomorus brasiliensis*)
– CER Cero (*Scomberomorus regalis*)
– FRI Frigate tuna (*Auxis thazard*)
– KGM King mackerel (*Scomberomorus cavalla*)
– KGX Scomberomorus unclassified (*Scomberomorus* spp.)
– LTA Little tunny (*Euthynnus alletteratus*)

– MAW West African Spanish mackerel (*Scomberomorus tritor*)
– SSM Atlantic Spanish mackerel (*Scomberomorus maculatus*)
– WAH Wahoo (*Acanthocybium solandri*)
– DOL Dolphinfish (*Coryphaena hippurus*)

This paper addresses the potential for application of data limited models for small tunas in the ICCAT region. Stock assessment analysts of the Sustainable Fisheries Division (National Marine Fisheries Service Southeast Fisheries Science Center) have recently gained extensive experience in the implementation of data-limited assessment methods during benchmark assessments for several species in the Gulf of Mexico and Caribbean. These assessments were conducted using a relatively new software package, the Data-Limited Methods Toolkit ('DLMtool'; Carruthers et al. 2014; Carruthers et al. 2015; Carruthers and Hordyk 2016) in R (R Core Development Team 2016). The DLMtool provides a suite of programs that allows analysts to compare the performace of numerous data limited management procedures in an integrated framework with the ultimate goal of providing catch advice derived from the observed data. The DLMtool package is available freely through the CRAN site (www.cran.org). The DLMtool also facilitates testing of performance across multiple methods according to user specified performance criteria using Management Strategy Evaluation (MSE, Butterworth 1999, Cochrane 1998, Punt *et al.* 2014, cited in Carruthers et al. 2017).

Herein we provide an introduction to the Data-Limited Methods Toolkit with specific regard to the practical application of the toolkit to the SMT data available through the ICCAT data catalogue. In addition, we summarize practical concerns regarding the data available through the ICCAT catalogue for key inputs required for application of the DLMtool (e.g., catch, CPUE, biological information) for the ICCAT SMT species. Finally, we discuss steps towards application of the DLMtool for the SMT group for use in developing potential first time management advice.

2 DLMtool Approach

The Data-Limited Methods Toolkit (DLMtool; Carruthers et al. 2014; Carruthers et al. 2015; Carruthers and Hordyk 2016) is an R package that implements a standardized analytical process for evaluating the performance of multiple data-limited assessment models in a simulation environment using management strategy evaluation (MSE). Once viable methods are identified within the MSE, these methods are then utilized to determine a catch recommendation based on the best available data. In 2014, the DLMtool and its utility were extensively reviewed at a workshop on the "Science and Management of Data-Limited Fisheries" convened by the Natural Resources Defense Council, where widespread support for the DLMtool was garnered by Workshop participants (Newman et al. 2014).

The DLMtool focuses on the development of management advice for data-limited fisheries stocks through the evaluation of data-limited stock assessment models and harvest control rules. This approach, paired with a framework that facilitates simulation and sensitivity examinations, helps to streamline the analytical process to evaluate the status of data-limited stocks (Carruthers et al. 2015). The DLMtool procedure was developed under the R programming language and is freely available for download through the CRAN-R repository at http://cran.rproject.org/web/packages/DLMtool /index.html.

The accessibility and user-friendly design of the DLMtool has introduced some concern regarding potential abuse of its utility, a topic discussed at the 30th Lowell Wakefield Fisheries Symposium on Tools and Strategies for Assessment and Management of Data-Limited Fish Stocks held in May 2015 (Dowling et al. 2015). Rather than apply all possible data-limited methods to available data and select a catch recommendation considered most desirable (e.g. highest catch), a structured procedure is recommended (Carruthers 2015). Further, many methods currently in the DLMtool were designed for specific regional fisheries and may require tuning to more appropriately reflect management objectives in regions under evaluation. To evaluate the potential utility of the DLMtool in providing management advice, a three-step approach should be followed as recommended by the DLMtool developers:

- Determination of feasible methods based on data availability (e.g., landings, CPUE, size composition);
- Simulation testing of feasible methods (through MSE) to eliminate methods which exhibit pathological behavior (e.g. chronic overfishing) and to identify viable methods based on the stock and fleet dynamics as parameterized in the operating model; and
- Application of viable methods for providing management advice.

2.1 Determination of feasible methods based on data availability

The current version of DLMtool (version 3.2.2) includes over 80 data-limited stock assessment methods, harvest control rules, or models (Carruthers and Hordyk 2016). **Table 1** provides a subset of methods included in DLMtool (3.2.2) for developing catch advice. Analyses to develop catch advice for methods in DLMtool rely on various types of data including life history, fishery characteristics, abundance, depletion, composition, and reference parameters (**Table 2**). As expected, data requirements are highly variable across methods and range from simple inputs (e.g., time series of catch for catch-based methods) to more moderate requirements such as an index of abundance (**Table 3**).

2.2 Simulation testing

The use of simulation analysis through MSE is recommended for exploring the relative performance among data-limited methods (Butterworth et al. 2010; Carruthers et al. 2014; Punt et al. 2014). MSE is a scientific approach used to identify the management option(s) that is (are) most robust to assumptions and uncertainties in data inputs, such as whether performance remains consistent across multiple ranges of stock status relative to an unfished state (i.e. the depletion level) as well as robustness to mis-specified model structure (e.g. bias in natural mortality). The use of MSE provides an objective procedure for quantifying tradeoffs between alternative management strategies with particular attention to varying performance interests (e.g. conservation vs harvest) (Punt et al. 2014).

Recently a MSE approach was proposed for Atlantic Bluefin tuna (Anon. 2014) as a suitable framework for providing robust management advice consistent with the precautionary approach (GBYP 2014). A primary component of MSE involves constructing credible inputs on the biology and fishery dynamics within an 'operating model'. Carruthers et al. (2016) suggested a fairly expedient approach for developing operating model inputs using information available freely such as currently collected by ICCAT (i.e., Task I, II, III statistics). Such statistics are available for the ICCAT SMT species and could offer potential use in application of investigating the performance through MSE of one of more data limited methods.

In application, the primary requirements of the MSE approach are: (1) a variety of candidate data-limited stock assessment methods, harvest control rules, or models that are feasible based on available data (data requirements for individual methods are summarized in **Table 3**); (2) an operating model that describes the "true" simulated population; and (3) criteria for evaluating the performance of data-limited methods. The third requirement, performance criteria are usually identified through discussions by managers, stock assessment scientists, and stakeholders.

2.3 Application with the aim of providing management advice

For each DLM, a distribution of recommended catch advice can be developed by stochastically drawing data inputs over a specified number (e.g., 10,000) of times. The sensitivity of catch recommendations to input data can be explored to address how uncertainty in parameter inputs could influence recommended catches. Ultimately, the DLM chosen to provide management advice should take into consideration the quality of input data, method assumptions, sensitivity to input data, and performance in the simulation.

3 Data concerns pertinent to stock assessment and management of ICCAT area Small Tunas

3.1 Biology

Anon. 2017 provided summary information on availability of growth and reproductive information for the SMT species. Although studies have been conducted for some species throughout the region, the WG noted that much of the information was outdated or based only on a single study indicating some level of uncertainty exists on these basic life history parameters. In addition, for many species (SSM, BRS, BLF, KGM, BOP, CERO) there were no studies found in many areas of the ICCAT area. Whether or not the parameters from other regions could be substituted for use in developing relevant stock operating models would require careful deliberations by a group of experts to evaluate the appropriateness of substitutions.

ZONES	NORTHEAST ATLANTIC		SOUTHEAST ATLANTIC		NORTHWEST ATLANTIC		SOUTHWEST ATLANTIC		MEDITERRANEAN	
Species	Growth Parameters	Reproduction parameter	Growth Parameters	Reproduction parameter	Growth Parameters	Reproduction parameter	Growth Parameters	Reproduction parameter	Growth Parameters	Reproduction parameter
LTA										
FRI										
BLT										
SSM										
MAW										
BON										
WAH										
BRS										
BLF										
KGM										
BOP										
CER										
DOL	Not yet reviewed by the WG-SMT									

Data available, several studies and at least one of them was published in the last 10 years
Data available, single study or several older than 10 years
No existing data

3.2 SMT fishery landings data: uncertainty and possible biases and concerns to consider in application of stock assessment analyses

- Catches are highly uncertain due to perception that these species are of low value compared to other (and bigger) tunas thus often not reported in logbooks
- Industrial catches of small tunas often discarded or sold locally along with other mixed species, particularly in Africa
- Difficulty sampling artisanal fleets, which are the primary fleets catching small tunas
- Recently some information being reported from observer samples of purse seine catches
- Misidentification adds to the difficulty in documenting landings by species
- Despite low monitoring, catches of small tunas have high socio and economic importance to artisanal fisheries for most of the coastal countries concerned and for many local communities, particularly in the Mediterranean Sea, in the Caribbean region and in West Africa

3.3 Characterization of primary fisheries harvesting SMT in the ICCAT region and identification of representative fisheries for use in assessment

- Primarily harvested by coastal fisheries and artisanal fisheries
- Bycatch in purse seine and mid-water trawl (West Africa- Mauritania), handline and gillnet
- Increasing importance in FAD fisheries in eastern Caribbean
- Additional harvest by recreational/sport fisheries

3.4 Identification and prioritization of SMT for assessment consideration

- *Species Composition*- Seven species account for ~92% of catch (1950-2014)
    - BON (34%),
    - LTA (14%),
    - FRI (12%),
    - KGM (11%),
    - SSM (11%),
    - BRS (5%) and
    - BLT (5%)

- *Spatial extent of fisheries* ~ 28% of the small tuna catches originates from the Mediterranean and the Black Seas

3.5 Fishery length composition data availability

- Anon. 2017 provides graphical presentations of length composition indicating size composition exists from ~ 1980's for:
    - WAH, BLT, FRI, LTA, BON, BER, KGM, SSM, and CER

- Anon. 2017 presented several reference points for the species above:
- asymptotic length ($L\infty$),
- length at 50% mature ($L50$) and
- two estimates of the size at which a cohort reaches its maximum biomass ($Lopt$) and its proxy ($2/3{\sim}L\infty$).

3.6 Stock Status of ICCAT SMT: As of 2016 ICCAT SCRS Meeting and relevance to prioritization of SMT for assessment consideration

- Information lacking to allow quantitative assessment for most small tuna species
- Few regional assessments have been conducted
- Assessments needed particularly as to the trophic role and importance of the group
- Important to consider ecosystem position and regional context when approaching assessments and when prioritizing species to focus research initiatives on
- Anon. 2017 noted that of the species caught by tuna longline fisheries in the South Atlantic, the following species were considered to be at 'High Risk': WAH , KGM, and LTA
- Anon. 2017 noted that of the species caught by tuna longline fisheries in the North Atlantic, the following species were considered to be at 'High Risk': KGM, SSM, and BLF

4 Discussion and Steps for Application of data limited stock assessment models

Data-limited methods identified as feasible based on data availability and meeting performance criteria in simulation analyses could be selected to provide catch advice (i.e., total allowable catch) for use in management. Such approaches are adaptive in nature and represent clear improvements in terms of monitoring data-limited stocks in comparison to catch-only approaches; however, these data-limited approaches rely on data that are routinely collected and believed to be reliable as well as model assumptions (e.g., asymptotic selectivity). Any catch setting process or framework that is to be considered for implementation should incorporate the following components:

- Consideration of the quality and sufficiency of data inputs as mentioned above relating to biological and fishery statistics, as well as cost considerations for data collection;
- Consideration of key modeling assumptions within the framework and sensitivity of reference points to data inputs to address robustness of DLMs;
- Objectivity and transparency in evaluation (testing) of multiple DLMs through simulation;
- Enable comparisons between multiple DLMs relative to performance criteria developed through a transparent process with all stakeholders (fishers, scientists, managers);
- Identification of acceptable risk levels in terms of tradeoffs identified for performance metrics
    - i.e., if higher long-term yield is desired what level of the probability of not overfishing is acceptable?
- Incorporate considerations of management objectives that evaluate tradeoffs in conservation and economic objectives and integrates feedback control into the decision-making process not presently considered in the TAC (i.e., total allowable catch) setting process; and
- Incorporation of reasonable uncertainty in operational framework including stock and fishery dynamics.

Ultimately, the selection of DLMs to use in establishing TACs for data-limited stocks must consider the following: data sufficiency and quality, model assumptions, model testing framework (i.e., is method simulation tested), incorporation of uncertainty, model performance testing, and exclusion of DLMs yielding unacceptable performance. Further, the scoring of DLMs using simulation analyses and tradeoffs in performance metrics further provides a quantitative approach for stakeholders to evaluate similarities and differences in DLM performance as well as aiding to identify optimal DLMs for species under evaluation. A potential roadmap for guidance in enabling the application of one or more DLM methods is described below:

- A group of experts (e.g., the ICCAT SMT Working Group (SMT WG) would optimally review the available statistics (e.g., catch, CPUE, composition) and identify if sufficient data exists to characterize landings, possibly indices of abundance and catch size composition taking into consideration that the SMWG previously emphasized that data be recovered for these groups:

    - Mediterranean and Black Sea: Bullet tuna, Atlantic bonito, little tunny and frigate tuna;
    - West Africa: Atlantic bonito, little tunny, bullet tuna, West African Spanish mackerel, frigate tuna, wahoo;
    - Caribbean area and south west Atlantic: Blackfin tuna, dolphinfish and king mackerel

- The working group would conduct a thorough review of the available data from the ICCAT catalogue and consider developing a quantitative scoring for:
    - adequacy of temporal coverage,
    - spatial coverage,
    - uncertainty (e.g., discards not reported, etc.),
    - issues with misidentification, biases in composition sampling, etc.,
- In addition, the working group would identify relevant time periods from the available data that represent periods of sustainable harvest/catches,
    - And any other relevant inputs.
- The working group would prioritize one or more species or groups of similar species for which relevant operating stock (biological) and fishery models would be developed through consensus review of the relevant inputs taking into consideration data adequacy, uncertainty and species risk.
- The relevant species/group population and fleet OMs would be made available to data limited stock assessment analysts for possible consideration of application of data limited models. The team of assessment analysts would take into consideration application of models that evaluate one or more indicators such as applied in SCRS 2017 and make use of MSE as recommended in Anon. 2016.

References

Anon. 2012. Report of Biennial Period, 2012-13, Part I (2012) – Vol. 2.

Anon. 2017. Report of Biennial Period, 2016-17, Part I (2016) – Vol. 2.

Beddington, J., and Kirkwood, G. 2005. The estimation of potential yield and stock status using life–history parameters. Philosophical Transactions of the Royal Society B: Biological Sciences **360** (1453):163-170. doi: 10.1098/rstb.2004.1582.

Beverton, R.J.H., and Holt, S.J. 1957. On the dynamics of exploited fish populations. Springer-Science+Business Media, B.V., London, UK.

Butterworth, D.S., Bentley, N., De Oliveira, J.A., Donovan, G.P., Kell, L.T., Parma, A.M., Punt, A.E., Sainsbury, K.J., Smith, A.D., and Stokes, T.K. 2010. Purported flaws in management strategy evaluation: basic problems or misinterpretations? ICES J. Mar. Sci. **67**:567-574. doi: 10.1093/icesjms/fsq009.

Carruthers, T., Powers, J.E., Lauretta, M.V., Di Natale, A., and Kell, L. 2016. A summary of data to inform operating models in management strategy evaluation of Atlantic Bluefin Tuna Collect. Vol. Sci. Pap. ICCAT, 72(7): 1796-1807 (2016).

Carruthers, T., Kell, L., Butterworth, D., Maunder, M., Geromont, H., Walters, C., McAllister, M., Hillary, R., Levontin, P., Kitakado, T., and Davies, C. 2015. Performance review of simple management procedures. ICES J. Mar. Sci. **73** (2):464-482. doi: 10.1093/icesjms/fsv212.

Carruthers, T.R. 2015. DLMtool: Data-Limited Methods Toolkit (v2.0).

Carruthers, T.R., and Hordyk, A. 2016. Package 'DLMtool', version 3.2.2. Available from: http://cran.r-project.org/web/packages/DLMtool/index.html.

Carruthers, T.R., Punt, A.E., Walters, C.J., MacCall, A., McAllister, M.K., Dick, E.J., and Cope, J. 2014. Evaluating methods for setting catch limits in data-limited fisheries. Fish. Res. **153**:48-68. doi: 10.1016/j.fishres.2013.12.014.

CCSBT. 2011. Report of the Sixteenth Meeting of the Scientific Committee. Bali, Indonesia. Commission for the Conservation of Southern Bluefin Tuna. Commission for the Conservation of Southern Bluefin Tuna, Bali, Indonesia.

Dick, E., and MacCall, A.D. 2011. Depletion-based stock reduction analysis: a catch-based method for determining sustainable yields for data-poor fish stocks. Fish. Res. **110** (2):331-341. doi: 10.1016/j.fishres.2011.05.007.

Dowling, N., Butterworth, D., Dichmont, C., and Cadrin, S. 2015. Management panel from tools and strategies for assessment and management of data-limited fish stocks. Alaska Sea Grant, Anchorage, AK. Available from: https://seagrant.uaf.edu/conferences/2015/wakefield-data-limited/panels/Management-Panel.pdf.

Gedamke, T., and Hoenig, J.M. 2006. Estimating mortality from mean length data in nonequilibrium situations, with application to the assessment of goosefish. Trans. Am. Fish. Soc. **135** (2):476-487. doi: 10.1577/T05-153.1.

Geromont, H., and Butterworth, D. 2014. Generic management procedures for data-poor fisheries: forecasting with few data. ICES J. Mar. Sci. **72** (1):251-261. doi: 10.1093/icesjms/fst232.

Gulland, J. 1971. Science and fishery management. Journal du Conseil International pour l'Exploration de la Mer **33** (3):471-477. doi: 10.1093/icesjms/33.3.471.

Hordyk, A., Ono, K., Sainsbury, K., Loneragan, N., and Prince, J. 2015a. Some explorations of the life history ratios to describe length composition, spawning-per-recruit, and the spawning potential ratio. ICES J. Mar. Sci. **72** (1):204-216. doi: 10.1093/icesjms/fst235.

Hordyk, A., Ono, K., Valencia, S., Loneragan, N., and Prince, J. 2015b. A novel length-based empirical estimation method of spawning potential ratio (SPR), and tests of its performance, for small-scale, data-poor fisheries. ICES J. Mar. Sci. **72** (1):217-231. doi: 10.1093/icesjms/fsu004.

ICCAT CIRCULAR # 0706/ 2017. Subject: 2017 Small tunas species group intersessional meeting, 24-27 Miami, FL.

MacCall, A.D. 2009. Depletion-corrected average catch: a simple formula for estimating sustainable yields in data-poor situations. ICES J. Mar. Sci. **66** (10):2267-2271. doi: 10.1093/icesjms/fsp209.

Martell, S., and Froese, R. 2013. A simple method for estimating MSY from catch and resilience. Fish Fish. **14** (4):504-514. doi: 10.1111/j.1467-2979.2012.00485.x.

Newman, D., Carruthers, T.R., MacCall, A., Porch, C., and Suatoni, L. 2014. Improving the science and management of data-limited fisheries: an evaluation of current methods and recommended approaches. NRDC Report R:14-09-B, Natural Resources Defense Council, New York, NY.

Punt, A.E., Butterworth, D.S., Moor, C.L., De Oliveira, J.A., and Haddon, M. 2014. Management strategy evaluation: best practices. Fish Fish. doi: 10.1111/faf.12104.

Table 1. Subset of the categories of data-limited methods available in version 3.2.2 of the Data-Limited Methods Toolkit (DLMtool).

Method	Description	Reference
Catch-based		
CC	Constant catch linked to average catches	Geromont and Butterworth (2014); Carruthers et al. (2015)
Indicator-based (recent index)		
Islope	Incrementally adjusts the TAC to maintain a constant CPUE or relative abundance index	Geromont and Butterworth (2014); Carruthers et al. (2015)
Indicator-based (index target)		
Itarget	Incrementally adjusts the TAC (starting from reference level that is a fraction of mean recent catches) to reach a target CPUE / relative abundance index	Geromont and Butterworth (2014); Carruthers et al. (2015)
Indicator-based (recruitment)		
SBT2	SBT complex, makes incremental adjustments to TAC recommendations based on index levels relative to target levels (BMSY/B0) and catch levels relative to target levels (MSY)	CCSBT (2011); Carruthers et al. (2015)
Indicator-based (length target)		
Ltarget	Incrementally adjusts the TAC to reach a target mean length in catches	Geromont and Butterworth (2014); Carruthers et al. (2015)
Life history-based		
SPMSY	Catch trend Surplus Production MSY, uses Martell and Froese (2012) surplus production model which predicts K, r and depletion and calculates the OFL based on the Schaefer productivity curve	Martell and Froese (2013)
Depletion-based		
DCAC	Depletion-Corrected Average Catch	MacCall (2009); Carruthers et al. (2014)
DBSRA	Depletion-Based Stock Reduction Analysis	Dick and MacCall (2011); Carruthers et al. (2014)
Abundance-based		
Fratio	FMSY/M ratio, Calculates the TAC based on a fixed ratio of FMSY to M multiplied by a current estimate of abundance	Gulland (1971); Martell and Froese (2013); Carruthers et al. (2014); Carruthers et al. (2015)
BK	Beddington and Kirkwood life history method	Beddington and Kirkwood (2005); Carruthers et al. (2014)
YPR	Yield Per Recruit analysis to get FMSY proxy (F0.1)	M. Bryan and T. Carruthers, derived from Beverton and Holt (1957)
Data-moderate		
DD	Delay difference stock assessment with UMSY and MSY leading	C. Walters; Carruthers et al. (2014); Carruthers et al. (2015)
Length-based		
LBSPR	Length-based Spawning Potential Ratio	Hordyk et al. (2015a); Hordyk et al. (2015b)
YPR_ML	YPR paired with a mean length estimate of current stock size	M. Bryan and T. Carruthers; Carruthers and Hordyk (2016); Gedamke and Hoenig (2006)
Age-based	**Age-based**	
YPR_CC	YPR paired to a naive catch curve estimate of recent total mortality	M. Bryan and T. Carruthers; Carruthers and Hordyk (2016)

Table 2. Data inputs required for applications of data-limited methods to develop catch advice. Note that data requirements vary considerably by method type (see Table 3).

Parameter	Abbreviation	Description
General		
Year	Year	A vector of years that correspond to catch and relative abundance data
Duration	t	The number of years corresponding to average catch (AvC) and depletion over time (Dt)
Units	Units	Units of the catch/absolute abundance estimates
Life History		
Natural mortality	Mort	Natural mortality rate
Length at 50% maturity (CV)	L50	Length at 50 percent maturity
Length at 95% maturity (CV)	L95	Length at 95 percent maturity
Von Bertalanffy K (CV)	vbK	The von Bertalanffy growth coefficient
Von Bertalanffy t0 (CV)	vbLinf	Theoretical age at length zero
Von Bertalanffy Linf (CV)	vbt0	Maximum length
Length-weight a (CV)	wla	Weight-Length parameter alpha
Length-weight b (CV)	wlb	Weight-Length parameter beta
Steepness (CV)	steep	Steepness of the Beverton Holt stock-recruitment relationship
Maximum age	Maxage	Maximum age
Fishery		
Catch (CV)	Cat	Total annual catches (commercial and recreational landings + dead discards) in weight
Average catch over time t (CV)	AvC	Average catch over time t
Length at first capture (CV)	LFC	Length at first capture
Length at full selection (CV)	LFS	Smallest length at full selection
Composition		
Catch-at-age	CAA	Catch at Age data matrix (rows=years, columns = ages)
Catch-at-length	CAL	Catch-at-length data matrix (rows=years, columns= length bins)
CAL_bins		The length bins for the catch-at-length data
Mean length	ML	Mean length time series
Abundance		
Abundance index (CV)	Ind	Relative abundance index
Recruitment index (CV)	Rec	Recent recruitment strength
Depletion over time t	Dt	Depletion over time t e.g. Bnow/Bthen
Current stock depletion (CV)	Dep	Stock depletion Bnow/Bunfished
Current stock abundance (CV)	Abun	An estimate of absolute current abundance
Reference		
FMSY/M CV)	FMSY_M	An assumed ratio of FMSY to M
BMSY/B0 (CV)	BMSY_B0	The most productive stock size relative to unfished
Reference Catch (CV)	Cref	Reference or target catch level
Reference index (CV)	Iref	Reference or target relative abundance index level
Reference biomass (CV)	Bref	Reference or target biomass level
Reference OFL	Reference	A reference quota or TAC level
Reference OFL type	Reference	Type of reference provided
MPrec	MPrec	Previous TAC recommendation

Table 3. Subset of data-limited methods with corresponding data requirements (shaded in gray).

Methods	FISHERY				AGE	LENGTH		ABUNDANCE			DEPLETION	
	Cat	AvC	LFC	LFS	CAA	CAL	ML	Ind	Rec	Abun	Dt	Dep
Catch-based												
CC	■											
Indicator-based (recent index)												
Islope	■							■				
Indicator-based (index target)												
Itarget	■							■				
Indicator-based (recruitment)												
SBT2	■								■			
Indicator-based (length target)												
Ltarget	■						■					
Life history-based												
SPMSY	■											
Depletion-based												
DCAC		■									■	
DBSRA	■											■
Abundance-based												
Fratio										■		
BK			■							■		
YPR				■						■		
Data-moderate												
DD	■							■				
Length-based												
LBSPR						■						
YPR_ML	■			■		■						
Age-based												
YPR_CC	■			■	■							

Table 3 continued.

Methods	LIFE HISTORY									REFERENCE		
	Mort	L50	L95	vbt0	vbK	vbLinf	wla	wlb	MaxAge	FMSY_M	BMSY_B0	Cref
Catch-based												
CC												
Indicator-based (recent index)												
Islope												
Indicator-based (index target)												
Itarget												
Indicator-based (recruitment)												
SBT2												
Indicator-based (length target)												
Ltarget												
Life history-based												
SPMSY												
Depletion-based												
DCAC												
DBSRA												
Abundance-based												
Fratio												
BK												
YPR												
Data-moderate												
DD												
Length-based												
LBSPR												
YPR_ML												
Age-based												
YPR_CC												