# An alternative approach to setting annual catch limits for data-limited fisheries: Use of the DLMtool and mean length estimator for six US Caribbean stocks

Nanice Cummings, Skyler Sagarese, and Quang C. Huynh

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**An alternative approach to setting annual catch limits for data-limited fisheries: Use of the DLMtool and mean length estimator for six US Caribbean stocks**

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Nancie Cummings[1], Skyler Sagarese[1] and Quang C. Huynh[2]

[1] NOAA Fisheries, Southeast Fisheries Science Center
Sustainable Fisheries Division
75 Virginia Beach Drive
Miami, FL 33149

[2] Virginia Institute of Marine Science,
P.O. Box 1346, Gloucester Point, VA 23062

## Background and Need

Recent legislation in the United States for scientifically-derived annual catch limits (ACLs) has particularly challenged the stock assessment process in regions such as the Southeast US (Berkson and Thorson 2015, Newman et al. 2015), where species biodiversity exceeds that of other marine ecosystems (e.g., Northeast US; Fautin et al. 2010). The ability to set ACLs differs among species primarily due to the quantity and quality of data. When basic information on catch, relative abundance and/or biology exist, conventional fisheries stock assessments can be conducted on these "data rich" or "data-moderate" stocks (Carruthers et al. 2014, Newman et al. 2015). Within the US Caribbean, 100% of stocks are managed as "data-poor", meaning there is insufficient data to conduct a statistical assessment that yields meaningful information on reference points or stock status relative to such meaningful reference points (Geromont and Butterworth 2014, Edwards 2015). Nationally, nearly 60% of stocks are considered data-poor (Newman et al. 2015). As noted by Edwards (2015), "shortcomings in data provide an incentive for the development of assessment methods that have lower data requirements than those currently in use".

The setting of ACLs generally amounts to a four step process (Figure 1): (i) identify the annual catch when fishing the stock's current abundance at an estimate of the annual fishing mortality that corresponds to maximum sustainable yield (Overfishing limit, OFL; Carruthers et al. 2014, Punt et al. 2014); (ii) determine the catch level below the OFL that accounts for scientific uncertainty using a buffer against overfishing as prescribed by the most recent stock assessment (Acceptable Biological Catch, ABC; Carruthers et al. 2014, Newman et al. 2015); (iii) establish the catch level below the ABC (i.e., establish a buffer) which accounts for various ecological, social, and economic factors and triggers accountability measures (Annual Catch Limit, ACL; Methot 2009, Carruthers et al. 2014, Newman et al. 2015); and (iv) set an Annual Catch Target (ACT) below the ACL which accounts for management uncertainty. A tiered approach has been used by some US Fishery Management Councils (to select an appropriate buffer, by scaling the OFL by varying degrees to produce an ABC according to the degree of uncertainty associated with that tier or category (Fisheries Leadership and Sustainability Forum 2010), in a manner similar to that applied in Australia (Smith et al. 2009).

**Concerns with the current catch setting method used in the US Caribbean (average catch)**

Currently, OFLs/ABCs in the US Caribbean are computed using methods reliant upon catch scalars and average catch for stock complexes, which are comprised of multiple stocks assumed to exhibit similar life history and exploitation levels (e.g., shallow-water groupers) (Newman et al. 2015). Although the adoption of average catch for setting ACLs has been widespread throughout the US Caribbean, this data-limited technique has not received the level of scrutiny required to determine the potential long-term risks of applying these methods on Caribbean stocks. The evaluation of potential management strategies should precede implementation in the real world because these methods may not be robust to a wide range of uncertainties. Although not identical to the procedure followed by the Caribbean Fishery Management Council (CFMC), simulation testing of catch-based data-poor techniques (e.g., third highest catch, median catch) often reveals poor performance such as lower yields and greater probabilities of overfishing across a wide range of stock types (Carruthers et al. 2014).

A key limitation of using average catch in setting harvest controls includes the lack of feedback between stock status and the catch recommendation (see Geromont and Butterworth 2014). Further, this method assumes that catches are known without error (i.e., low uncertainty) and are reported accurately (i.e., unbiased). In addition, the use of constant catch ('CC') control rules may not ultimately lead to maximum sustainable yields (ICES 2012, Carruthers et al. 2014, Geromont and Butterworth 2014).

**An alternative catch estimation approach applied in SEDAR 46: DLMtool**

The SEDAR 46 stock evaluations explored the use of a relatively new fisheries software package that implements a fairly standard analytical process, the Data-Limited Methods Toolkit ("DLMtool", Carruthers et al. 2014) in conjunction with application of the Gedamke-Hoenig (2006) mean length estimator approach previously applied in the US Caribbean. The SEDAR 46 stock evaluation was treated as a "proof of concept" of implementing multiple modeling approaches in a data-limited context to demonstrate the utility of the DLMtool package in R. The DLM toolkit offers a suite of R functions that provides access to a variety of assessment procedures (Carruthers 2015). This toolkit can be used to evaluate the performance of multiple data-limited assessment models and management procedures in a simulation environment using management strategy evaluation. Traditionally the terminology management procedure (MP) refers to a collection of specifications, methods, analyses and rules which maps the pathway from fisheries data to fisheries management actions in response to changes in fishery indicators (Bentley and Stokes 2009). However, within the context of the DLMtool which is applied during SEDAR 46, the term MP refers to a wide range of data-limited procedures including stock assessments and harvest control rules (Carruthers 2015a). The management strategy evaluation approach incorporates a transparent and objective framework which included stakeholders (fishers, scientist, and managers) in the process. Figures 2 through 7 provide assessment summaries for multiple data-limited approaches for the six species-island units evaluated under SEDAR 46: Puerto Rico hogfish and yellowtail snapper, St. Thomas queen triggerfish and spiny lobster, and St. Croix spiny lobster and stoplight parrotfish.

The MP approach for setting harvest control rules has been used to provide scientific recommendation for some of the high-value stocks in the southern hemisphere including sardine, anchovy, and lobster (see Geromont and Butterworth 2014 for discussion). Some of the benefits of this approach used during SEDAR 46 include:

- Involvement of stakeholders (fishers, scientists, managers) in the process;
- Evaluation of management advice in terms of trade-offs between critical resource sustainability concerns and long term economic benefits (i.e., maximizing catch versus achieving sustainability);
- Incorporation of uncertainty in the modeling framework (i.e., through operating model specifications) thus implicitly addressing the need to evaluate risks and uncertainties with alternative management options for improved decision making; and
- Implementation of a simulation framework to evaluate performance between MPs (excluding the mean length estimator approach) for use in setting harvest recommendations.

The chief aims of the SEDAR 46 stock evaluations and the focus of this report are to: (1) provide managers with an alternative approach to setting ACLs for data-limited stocks (i.e., the DLMtool and the mean length estimator), (2) to identify important concerns that should be taken into account when evaluating performance of multiple MPs; and 3) to outline possible options for selecting between MPs for management decisions.

A brief description of the DLMtool follows as well as advantages of the DLMtool process and concerns and issues identified by users of the tool. A detailed description of the DLMtool approach is provided in Carruthers et al. (2015) and Newman et al. (2014). The Gedamke-Hoenig (2006) mean length estimator has been previously described.

*DLMtool background*

The DLMtool provides a framework that can aid in streamlining the assessment process and enhance the capacity of scientists and managers through simulation capabilities and sensitivity examinations (Carruthers et al. 2015). Application of the DLMtool was a focus of the 2014 Workshop convened by the Natural Resources Defense Council (NRDC) Workshop on the "Science and Management of Data-Limited fisheries" (Newman et al. 2014). The DLMtool procedure is developed under the R programming language and is freely available for download through the CRAN-R repository archived at http://cran.rproject.org/web/packages/DLMtool/index.html.

*DLMtool approach: Advantages:*

As noted by Newman et al. (2014), the DLMtool exhibits a number of beneficial properties, including:

- Application of a set of peer reviewed MPs which could greatly enhance the efficacy and throughput of data-limited assessments;
- Powerful diagnostic tools for testing methods;
- Facilitated simulation testing and direct comparison of methods (as recommended by Geromont and Butterworth 2014, Edwards 2015);
- Incorporation of a closed-loop management strategy evaluation that allows for testing of the performance of any method with side-by-side comparisons of performance metrics;
- Sensitivity testing to capture uncertainty and identify the impact of certain data inputs on the accuracy and precision of method outputs;
- "Off the shelf" output products which provide guidance on prioritizing data collection and assessment methods in a cost-effective manner;
- Pre-tested and freely available computer code; and

- An open architecture, simple data input form, and user-friendly graphical outputs which promote transparency, credibility, and increased buy in from stakeholders (fishers, scientists, managers).

At the time of the SEDAR 46 evaluation, 61 data-limited methods were available in DLMtool Version. 2.1.2 (release November 2015) (Carruthers 2015b).

<u>*DLMtool approach: Disadvantages and concerns:*</u>

- Limitations of the current version (2.1.2) include:
    - Exclusion of length-based estimators within the management strategy evaluation due to computational constraints in current version;
    - Incomplete accounting for the range of hypotheses regarding population structure and cannot realize the full complexity of the biology such as:
        1. Time- and age-varying natural mortality
        2. Hermaphroditism
        3. Ontogenetic migrations
    - Incomplete realization of the full complexity of the fishery such as:
        1. Multiple fleets or gear types
        2. Changes in fishing operations
        3. Regulations
        4. Real world application of data-limited methods assumes knife-edge selectivity
    - Lack of implementation error of the harvest control rule within the management strategy evaluation
- While the DLMtool is relatively easy to implement, interpretation of results and potential recommendations requires investigation of the caveats associated with different methods and the quality of data inputs;
- Public availability introduces the potential for abuse of applying the DLMtool;
- Method-specific assumptions accompanying each method (which are detailed in the Assessment Report, Appendix 4.4)
- Need for a framework for taking DLMtool output and packaging it as a product for use by managers, as in the case with the US Caribbean data-limited stocks. For SEDAR 46, the framework adopted for the application included:
    - Management strategy evaluation to compare performance between MPs according to performance criteria defined from consensus of stakeholders (fishers, scientists, managers) and analysts (e.g., high probabilities of not overfishing, high probabilities of the biomass being above half BMSY; average annual variability in long term yield being within 15%)
        - Considered uncertainty within stock and fleet dynamics to ensure results were robust to varying assumptions
    - Calculations of catch for each applicable method based on available real world data compiled during the SEDAR 46 Data Triage
        - Conducted sensitivity analyses on data inputs to see how catch recommendations varied with input parameters
    - Reported a guidance table, which provided the performance metrics for each applicable method along with key assumptions and caveats regarding data inputs to assist in MP selection

*Applications of the DLMtool and use in management situations*

*1. Mid-Atlantic black sea bass DLMtool application*

Black sea bass are classified as a Tier 4 data poor stock by the Mid-Atlantic Fishery Management Council (MAFMC) Scientific and Statistical Committee (SSC). Under Tier 4, the SSC uses a pre-defined method of setting a constant catch value. The constant catch that is defined is taken from the catch achieved during a period of time where the SSC believes the stock was rebuilding and is therefore believed to be a safe harvest level (Carmichael and Fenske 2011). McNamee et al. (2015) applied the DLMtool to evaluate the performance of multiple MPs and to provide an alternative to the current 'constant catch' ACL setting method. In addition, McNamee suggested that application of the DLMtool may provide a framework for ACL specification in the interim until an approved analytical assessment can be conducted. In their application, 47 different MPs were examined using DLMtool (version 1.35).

The MAFMC SSC concluded that three MPs used to estimate reference points provided a reasonable foundation for providing an ABC for black sea bass. The three MPs are dynamic, catch-based procedures that combine an estimate of recent catch and a weighted estimate of the slope of the fishery-independent survey indices over the recent period. These approaches were selected because they are adaptive and rely on data that are routinely estimated and believed to be reliable. While the SSC did have additional suggestions for improvement to the approach (including ensemble approach to method selection, addition of catch-curve method examination, improved index), it was noted that the "subcommittee agrees that the analysis as presented is acceptable for management use." According to the MAFMC SSC, the approach of McNamee et al. (2015) using DLMtool was preferred to the current SSC constant catch-based approach because their approach "allows the performance of alternative MPs to be evaluated relative to each other, whereas *the performance of the current SSC constant-catch approach remains unknown*".

*Strengths of the DLMtool application for black sea bass:*

- The "CC1" MP procedure, which uses a constant catch from a set number of years, was considered a reasonable proxy for comparison and treated as the procedure in the DLMtool package closest to the ACL setting procedure currently used by the SSC.
- Application of a single MP to estimate reference points and set ACLs may be less reliable than an approach that incorporates an ensemble of methods. The MAFMC SSC noted that a simple average or weighted average (i.e., weighted by the number of "states of nature" tables) across MPs could be considered.
- Ability to incorporate uncertainty around numerous parameters through simulation allows for evaluating model performance, leading to robust testing across a broad range of realities. Parameters addressed were: M, steepness, depletion, selectivity of oldest age classes, growth (L infinity, K), and age at first capture.

*Weaknesses of the DLMtool:*

- Currently, the DLMtool can only accommodate 1 index of abundance. The MAFMC SSC noted the need to combine additional sources of survey information (e.g., hierarchical modeling; Conn 2010) or weigh each index by its areal extent to construct a more representative and robust fishery independent index of abundance for the black sea bass stock. Ideally, this index would be less subjected to uncertainties in interannual trends.

- Concerns were raised over the limited realism in black sea bass' unusual life history (i.e., protogynous hermaphroditism) incorporated into the management strategy evaluation. Further the MAFMC SSC noted:

  > "Because of the broad spectrum of dynamics considered by the operating model, and because Black Sea Bass is a data poor, level IV species, it was unrealistic to require the operating model to explicitly include all features of the biology and exploitation of the species being assessed. But, as a consequence, the subcommittee also recognized that the limited realism that can be demanded of the operating model also means that managers should not expect extreme precision from reference points developed by the DLMtool box. Accordingly, managers should exercise caution in applying estimates that are "aggressive" or high when compared among ABC based reference points."

- The MAFMC SSC noted in its review the importance of maintaining clear distinction in methods leading to OFL-based advice and those leading to ABC-based advice (Boreman 2015). They further noted:

  > "OFL-based reference points should all provide estimates of the same quantity from different approaches, and therefore should be of similar magnitude. Thus, ensemble based approaches could be used to provide a more reliable estimate of OFL. ABC-based reference points are all trying to estimate a sustainable catch level, but there is less reason to expect that individual estimates should be similar to each other. Whether ensemble-based approaches to estimating ABC reference points are appropriate has not been evaluated. An additional advantage of maintaining the distinction between OFL and ABC-based reference points is that the two categories of reference points may provide an additional empirical check on the reliability of each because OFL estimates should be greater than the ABC estimates."

*2. Additional applications of the DLMtool for setting catch limits*

For Atlantic mackerel, Wiedenmann (2015) compared the results of calculating catch limits from 22 MPs using the DLMtool, from a simulation model, and from catch curve analyses with the aim of providing options for setting ABCs using different approaches. Additional work using the DLMtool is currently underway by the Marine Stewardship Council (H. Geromont, pers. comm). These applications have not undergone formal review yet.

**Current road-blocks with using DLMtool to set catch limits in the US Caribbean**

The need exists for an objective and transparent framework for setting ACLs for data-limited stocks (CFM - SSC 2015). Any catch setting process or framework that is to be considered for implementation should incorporate the following components:

- Objectivity and transparency in evaluation (testing) of multiple MPs through simulation;
- Incorporation of reasonable uncertainty in operational framework including stock and fishery dynamics;
- Consideration of key modeling assumptions within the framework and sensitivity of reference points to data inputs to address robustness of MPs;
- Enable comparisons between multiple MPs relative to performance criteria developed through a transparent process with all stakeholders (fishers, scientists, managers);

- 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 US Caribbean ACL setting process;
- Consideration of the quality and sufficiency of data inputs as well as cost considerations for data collection; and
- 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?

**A proposed roadmap for using DLMtool to set ACLs for US Caribbean stocks**

Borrowing from the Mid-Atlantic black sea bass evaluation, MPs identified as feasible in the SEDAR 46 DLMtool application and also meeting the performance criteria specified by the DW/AW Panel could be selected for use in management if they are adaptive and also rely on data that are routinely collected and believed to be reliable. The scoring of MPs using the performance metrics further provides a quantitative approach for stakeholders to evaluate similarities and differences in MP performance across all six species-island units as well as aiding to identify optimal MPs by individual species-island units. Comparison of tradeoffs in performance across both conservation and economic management objectives can be evaluated from Table 2 and Figures 2-7, providing an additional aid in MP selection and stimulation of additional discussion. Finally, important considerations noted on reliability of data, model assumptions, and performance allows for semi-quantitative comparison of method inputs (Tables 3, 4). Selection of MPs to use in establishing ACLs for data-limited stocks in the US Caribbean must include considerations of all of these factors: data sufficiency and quality, model assumptions, model testing framework (i.e., is method simulation tested), incorporation of uncertainty, model performance testing, and identification of MPs yielding unacceptable performance.

The SEDAR 46 stock evaluation results for the DLMtool applications and the mean length estimator provide options for setting catch limits for data-limited species in the US Caribbean that reflect improved procedures from the current constant catch setting methods. The SEDAR 46 evaluations build on objective and transparent analytical procedures for comparing multiple methods (i.e., simulation/management strategy evaluation), incorporate feedback into the analyses, and employ performance metrics developed through consensus to quantitatively compare multiple methods, thus eliminating subjective selection of methods.

Table 3 provides recommendations for MPs that should be excluded from further use in setting ACLs at this time in the US Caribbean until pertinent data and modeling issues are resolved. Relevant concerns are provided in addition to recommendations for improvements needed to minimize existing gaps or deficiencies. Table 4 provides recommended MPs to consider for further use in setting ACLs in the interim. For cases where multiple MPs are recommended, options include combining recommendations across methods (e.g., averaging using appropriate weighting factors as done for MAFMC black seabass).

While the recommended DLMtool and mean length estimator methods could be employed in the interim, the following guidance further outlines areas where application of the DLM tool and the mean length estimator could be improved on in the long term:

1. *Data sufficiency and integrity (life history, catch, abundance time series, fishery dynamics, depletion, abundance):*

- Convene a workshop of regional experts in the wider Caribbean to review important life history demographic data for key commercially and recreationally important species
- Convene an expert team to review and develop reasonable estimates of important data-limited model parameters (e.g., depletion estimates) and explore the use of Productivity-Susceptibility Analysis for informing depletion.

2. *Assessment method modeling of processes*

- Convene a workshop of experts trained in application of data-limited models to review available methods for determining harvest levels (e.g., NMFS 2011) and address the following topics at a minimum:
    - Data requirements of the method?
    - Model assumptions
    - Robustness of models to departures (biases)
    - Model uncertainty framework to evaluate models
    - Identification of scenarios where models fail or are inappropriate or not applicable
    - Identify process to evaluate model results that incorporates objectivity, transparency (i.e., simulation/ management strategy evaluation)
    - Consideration of the frequency of assessment
    - Consideration of implementation of management considerations on the choice of method used to set ACLs

An interim framework for setting ACLs using the SEDAR 46 DLMtool and mean length estimator results should be established considering that the work of SEDAR 46 incorporated the following guiding principles:

- Use of objective and transparent methods that allow comparison of results across methods
- Identification of performance metrics through stakeholder consensus that allow quantitative comparison of results across methods addressing management conservation and economic objectives
- Use of simulation/management strategy evaluation taking into considerations reasonable characterizations of uncertainty in the main fishery and life history components
- Incorporating considerations as to how well the data and model assumptions are met (e.g., as in Figures 2-7 and Table 3)
- Rejection of methods that clearly result in unacceptable performance (e.g. in terms of LTYs as identified in Table 3)
- Incorporation of first principles in selection between multiple methods or combining results from an ensemble approach
- Incorporation of buffer to address scientific uncertainty and management uncertainty

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Table 1. Summary of data-limited methods or management procedures applied during the SEDAR46 stock evaluations using the DLMtool.

| MP | Description | Reference |
|---|---|---|
| **Catch-based** | | |
| CC4 | Constant Catch linked to 70% average catches | Geromont and Butterworth (2014); Carruthers et al. (2015) |
| SPMSY | Surplus Production MSY | Martell and Froese (2013) |
| **Index-based** | | |
| Islope1 | CPUE slope (maintain constant CPUE) | Geromont and Butterworth (2014); Carruthers et al. (2015) |
| Islope4 | CPUE slope (maintain constant CPUE); more precautionary | Geromont and Butterworth (2014); Carruthers et al. (2015) |
| Itarget1 | CPUE target (TAC adjusted to achieve a target CPUE) | Geromont and Butterworth (2014); Carruthers et al. (2015) |
| Itarget4 | CPUE target (TAC adjusted to achieve a target CPUE); more precautionary | Geromont and Butterworth (2014); Carruthers et al. (2015) |
| IT5 | Index Target 5 | Carruthers (2015b) |
| IT10 | Index Target 10 | Carruthers (2015b) |
| ITM | Index Target with M | Carruthers (2015b) |
| **Depletion-based** | | |
| DCAC | Depletion-Corrected Average Catch (DCAC) | MacCall (2009); Carruthers et al. (2014) |
| DCAC_40 | DCAC assuming stock depletion is 40% of unfished levels | MacCall (2009); Carruthers et al. (2014) |
| CAC4010 | DCAC with a 40:10 harvest control rule | MacCall (2009) |
| EDCAC | Extra Depletion-Corrected Average Catch | Carruthers (2015b); Harford and Carruthers (in prep) |
| MCD | Mean Catch Depletion | Carruthers (2015b) |
| **Abundance-based** | | |
| Fratio | FMSY to M ratio | Gulland (1971); Walters and Martell (2002); Martell and Froese (2013); Carruthers et al. (2014) |
| BK | Beddington and Kirkwood life history method | Beddington and Kirkwood (2005); Carruthers et al. (2014) |
| YPR | Yield-Per-Recruit analysis | Beverton and Holt (1957) |
| **Data-moderate** | | |
| DD | Delay-Difference stock assessment model | C. Walters; Carruthers et al. (2014) |
| DD4010 | Delay-Difference stock assessment model with a 40:10 harvest control rule | C. Walters; Carruthers (2015b) |
| **Length-based** | | |
| LstepCC1 | Mean length (Mean length relative to historical levels used to alter TAC) | Geromont and Butterworth (2014); Carruthers et al. (2015) |
| LstepCC4 | Mean length (Mean length relative to lower initial historical catch levels used to alter TAC); more precautionary | Geromont and Butterworth (2014); Carruthers et al. (2015) |
| Ltarget4 | Length target (TAC adjusted to reach a target mean length) | Geromont and Butterworth (2014); Carruthers et al. (2015) |
| YPR_ML | Mean length estimator and Yield-per-recruit analysis | Bryan et al (in progress); Gedamke and Hoenig (2006) |

Table 2a. Summary of management strategy evaluation results for the probability of not overfishing and the probability of the biomass being above or equal to 0.5 BMSY for all feasible MPs satisfying the SEDAR 46 DW/AW Panel performance criteria. Results are presented across species-island units including: Puerto Rico hogfish (PR_Hog) and yellowtail snapper (PR_YT), St. Thomas queen triggerfish (STT_QT) and spiny lobster (STT_SL), and St. Croix spiny lobster (STX_SL) and stoplight parrotfish (STX_Stop). Traffic light scheme coding (i.e., shadings of green, yellow, and red) is used to denote high, medium, and low performance respectively. – denotes MPs which did not fall within acceptable performance criteria. Note that FMSYref represents the "true" FMSY reference level using perfect information about FMSY within management strategy evaluation.

| Category | MP | Prob. of not overfishing | | | | | | Prob. of B being above or equal to 0.5 BMSY | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | PR_Hog | PR_YT | STT_QT | STT_SL | STX_SL | STX_Stop | PR_Hog | PR_YT | STT_QT | STT_SL | STX_SL | STX_Stop |
| Reference | FMSYref | 95.2 | 88.9 | 93.9 | 70.5 | 71.8 | 87.5 | 98.6 | 99.1 | 98.4 | 93.3 | 91.0 | 95.0 |
| Catch-based | CC4 | 73.9 | 77.6 | 58.4 | 53.9 | - | - | 92.0 | 89.6 | 84.9 | 82.1 | - | - |
| | SPMSY | 80.5 | 72.6 | 79.4 | 68.1 | 63.3 | 81.0 | 92.1 | 85.0 | 90.4 | 85.5 | 83.0 | 86.1 |
| Index-based | Islope1 | 55.6 | 60.9 | 59.5 | 63.3 | 60.8 | 59.8 | 82.2 | 82.6 | 86.2 | 87.8 | 84.8 | 77.7 |
| | Islope4 | 57.3 | 61.1 | 61.7 | 64.0 | 61.8 | 64.2 | 82.1 | 82.2 | 86.2 | 87.6 | 84.7 | 78.4 |
| | Itarget1 | 78.4 | 87.3 | 53.1 | 59.5 | 51.8 | - | 94.9 | 94.8 | 87.5 | 88.8 | 85.3 | - |
| | Itarget4 | - | - | - | 99.1 | 98.7 | 97.9 | - | - | - | 97.9 | 96.1 | 95.3 |
| | IT5 | 67.0 | 63.4 | 72.5 | 71.0 | 70.8 | 76.9 | 88.5 | 86.2 | 91.4 | 91.2 | 88.7 | 85.4 |
| | IT10 | 69.1 | 56.3 | 73.0 | 69.4 | 71.6 | 77.4 | 91.5 | 84.9 | 93.5 | 92.3 | 90.9 | 87.1 |
| | ITM | 68.8 | 55.8 | 72.7 | 68.2 | 71.5 | 76.1 | 91.0 | 85.2 | 93.6 | 93.3 | 91.5 | 87.6 |
| Depletion | DCAC | - | 62.0 | - | - | - | - | - | 84.7 | - | - | - | - |
| | DCAC_40 | - | 61.5 | - | - | - | - | - | 82.9 | - | - | - | - |
| | DCAC4010 | 92.0 | 93.7 | 94.9 | 82.4 | 83.6 | 96.7 | 98.6 | 99.2 | 98.5 | 97.8 | 96.4 | 96.3 |
| | EDCAC | 57.9 | - | 54.4 | 52.8 | 54.8 | 61.5 | 96.9 | - | 97.0 | 96.0 | 93.8 | 92.6 |
| | MCD | 79.0 | 71.6 | 78.8 | 64.3 | 66.4 | 82.2 | 98.2 | 98.4 | 98.2 | 96.4 | 94.1 | 95.3 |
| Abundance | Fratio | 61.8 | 59.5 | 58.1 | - | 60.0 | 57.8 | 94.9 | 91.7 | 93.5 | - | 86.5 | 84.2 |
| | BK | 79.0 | - | - | - | - | - | 95.1 | - | - | - | - | - |
| | YPR | - | - | - | - | - | - | - | - | - | - | - | - |
| Data-moderate | DD | 76.8 | 55.7 | 81.7 | 67.3 | 71.7 | 88.9 | 97.4 | 92.7 | 96.9 | 92.1 | 91.7 | 93.5 |
| | DD4010 | 93.2 | 75.3 | 95.0 | 77.9 | 83.9 | 96.7 | 98.7 | 97.7 | 98.6 | 95.3 | 95.6 | 96.0 |
| Length-based | LstepCC1 | 59.4 | 63.5 | 63.8 | 65.6 | 63.0 | 66.4 | 83.3 | 83.6 | 87.2 | 88.1 | 84.8 | 79.2 |
| | LstepCC4 | 59.1 | 63.3 | 63.9 | 65.7 | 63.0 | 66.3 | 83.2 | 83.5 | 87.2 | 88.1 | 84.9 | 79.3 |
| | Ltarget4 | 92.6 | 96.7 | 91.0 | 88.0 | 83.7 | 85.9 | 97.5 | 98.7 | 96.6 | 95.9 | 92.8 | 90.5 |
| Mean Length | YPR_ML | 70.0 | 54.0 | 68.0 | - | - | 52.0 | 84.0 | 73.0 | 83.0 | - | - | 72.0 |

Table 2b. Summary of management strategy evaluation results for all feasible MPs satisfying the SEDAR 46 DW/AW Panel performance criteria. Metrics shown include the relative long-term yield (fraction of simulations achieving > 50% FMSY yield over final 10 projection years) and the probability of the average annual variability in yield remaining within 15%. Results are presented across species-island units including: Puerto Rico hogfish (PR_Hog) and yellowtail snapper (PR_YT), St. Thomas queen triggerfish (STT_QT) and spiny lobster (STT_SL), and St. Croix spiny lobster (STX_SL) and stoplight parrotfish (STX_Stop). Traffic light scheme coding (i.e., shadings of green, yellow, and red) is used to denote high, medium, and low performance respectively. – denotes MPs which did not fall within acceptable performance criteria. Note that FMSYref represents the "true" FMSY reference level using perfect information about FMSY within management strategy evaluation.

| Category | MP | Relative long-term yield | | | | | | Prob. of Average Annual Variability in Yield within 15% | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | PR_Hog | PR_YT | STT_QT | STT_SL | STX_SL | STX_Stop | PR_Hog | PR_YT | STT_QT | STT_SL | STX_SL | STX_Stop |
| Reference | FMSYref | 100.0 | 100.0 | 96.2 | 84.6 | 81.3 | 99.3 | 100.0 | 99.8 | 100.0 | 99.2 | 99.0 | 100.0 |
| Catch-based | CC4 | 30.4 | 32.2 | 52.2 | 43.6 | - | - | 100.0 | 100.0 | 99.8 | 95.0 | - | - |
| | SPMSY | 63.8 | 60.8 | 47.3 | 39.1 | 40.7 | 34.5 | 98.2 | 98.4 | 99.4 | 93.0 | 94.2 | 99.6 |
| Index-based | Islope1 | 83.0 | 81.3 | 78.0 | 53.3 | 50.8 | 73.7 | 96.2 | 98.6 | 99.6 | 95.8 | 97.2 | 99.8 |
| | Islope4 | 80.2 | 79.0 | 71.2 | 52.2 | 46.6 | 63.0 | 96.2 | 98.4 | 99.6 | 95.8 | 96.8 | 99.8 |
| | Itarget1 | 26.3 | 22.2 | 60.6 | 47.5 | 47.8 | - | 100.0 | 100.0 | 100.0 | 99.8 | 99.4 | - |
| | Itarget4 | - | - | - | 0.0 | 0.0 | 0.0 | - | - | - | 64.4 | 71.6 | 64.6 |
| | IT5 | 77.4 | 86.5 | 66.3 | 47.8 | 40.2 | 44.2 | 97.0 | 99.2 | 99.6 | 97.4 | 98.2 | 99.8 |
| | IT10 | 79.8 | 86.5 | 73.0 | 46.3 | 43.4 | 57.6 | 98.8 | 99.4 | 100.0 | 98.6 | 98.8 | 99.8 |
| | ITM | 78.3 | 86.4 | 74.3 | 48.5 | 43.4 | 61.8 | 98.8 | 99.4 | 100.0 | 99.2 | 99.2 | 99.8 |
| Depletion | DCAC | - | 86.8 | - | - | - | - | - | 97.4 | - | - | - | - |
| | DCAC_40 | - | 83.0 | - | - | - | - | - | 96.8 | - | - | - | - |
| | DCAC4010 | 91.5 | 90.4 | 76.3 | 62.2 | 56.6 | 63.6 | 68.4 | 79.4 | 73.6 | 66.8 | 60.2 | 72.6 |
| | EDCAC | 97.4 | - | 89.3 | 72.5 | 73.3 | 87.0 | 58.4 | - | 64.0 | 64.4 | 69.0 | 55.8 |
| | MCD | 96.6 | 94.3 | 85.0 | 71.7 | 70.7 | 81.5 | 75.8 | 65.6 | 66.0 | 71.4 | 72.8 | 70.0 |
| Abundance | Fratio | 96.0 | 94.1 | 84.4 | - | 64.0 | 81.5 | 52.0 | 51.0 | 50.8 | - | 52.2 | 54.2 |
| | BK | 93.5 | - | - | - | - | - | 59.2 | - | - | - | - | - |
| | YPR | - | - | - | - | - | - | - | - | - | - | - | - |
| Data-moderate | DD | 98.9 | 96.0 | 90.9 | 68.6 | 69.6 | 87.5 | 100.0 | 100.0 | 99.6 | 98.4 | 99.0 | 97.4 |
| | DD4010 | 99.0 | 97.2 | 86.6 | 66.7 | 66.6 | 79.6 | 98.4 | 95.6 | 82.8 | 76.2 | 75.0 | 55.6 |
| Length-based | LstepCC1 | 74.2 | 77.9 | 64.2 | 48.5 | 44.0 | 49.4 | 96.2 | 98.8 | 99.6 | 96.2 | 97.4 | 99.8 |
| | LstepCC4 | 74.1 | 78.6 | 64.4 | 48.6 | 44.0 | 50.6 | 96.2 | 98.8 | 99.6 | 96.2 | 97.4 | 99.8 |
| | Ltarget4 | 2.4 | 1.2 | 9.1 | 12.2 | 16.6 | 13.3 | 99.8 | 100.0 | 100.0 | 99.6 | 99.8 | 99.8 |
| Mean Length | YPR_ML | 77.0 | 69.0 | 70.0 | - | - | 75.0 | 78.0 | 95.0 | 92.0 | - | - | 96.0 |

Table 3. Identification and relevant support for exclusion of MPs for further use in recommending catch levels. Strikethrough indicates exclusion of method.

| Acceptance Issue | PR_Hog | PR_YT | STT_QT | STT_SL | STX_SL | STX_Stop | Research Recommendations |
|---|---|---|---|---|---|---|---|
| **Data quality** | | | | | | | |
| Depletion uncertain | ~~MCD~~ | ~~MCD~~ | ~~MCD~~ | ~~MCD~~ | ~~MCD~~ | ~~MCD~~ | Convene expert team to develop estimates of depletion, explore Productivity-Susceptibility Analysis |
| Current Abundance uncertain | ~~Fratio, BK~~ | ~~Fratio~~ | ~~Fratio~~ | | ~~Fratio~~ | ~~Fratio~~ | Convene expert team to develop estimates of current abundance using better estimates of F (e.g., from mean length approaches) |
| Life history | | | | | | | Convene workshop to characterize LH demographics and uncertainty estimates |
| Uncertain maximum Age and/or Mort | | | ~~DD, DD4010, SPMSY~~ | ~~DD, DD4010, SPMSY~~ | ~~DD, DD4010, SPMSY~~ | | |
| Protogyny | ~~SPMSY, DD, DD4010~~ | | | | | | |
| Uncertain growth parameters | | | | | | ~~DD, DD4010, SPMSY~~, ~~YPR_ML~~ | |
| Index of abundance restricted | | | | | | ~~Islope1, Islope4~~ | Develop statistically robust fishery-independent surveys |
| **Unrealistic results** | | | | | | | |
| Catch recommendations exceeding or near largest observed catches | ~~DD, DD4010~~ | ~~DD, DD4010~~ | ~~DD, DD4010~~ | ~~DD, DD4010~~ | ~~DD, DD4010~~ | | Further investigation into discard estimates, catch reporting and verification |
| **Unacceptable performance in MSE** | | | | | | | |
| Long-term yield < 50% relative to FMSYref | ~~Itarget1, CC4~~ | ~~Itarget1, CC4~~ | ~~SPMSY~~ | ~~CC4, SPMSY, Itarget1, Itarget4~~ | ~~Islope4, Itarget1, Itarget4, SPMSY~~ | ~~SPMSY~~ | Convene methods workshop to develop framework for harvest control rule approaches for data limited stocks (e.g., NMFS 2011) |

Table 4. Potential methods for setting catch recommendations based on sufficient and quality of data, model assumptions, and performance metrics. - Indicates no recommendations made.

| **Recommended methods** | **PR_Hog** | **PR_YT** | **STT_QT** | **STT_SL** | **STX_SL** | **STX_Stop** |
|---|---|---|---|---|---|---|
| Index-based | Islope1, Islope4 | Islope1, Islope4 | Islope1, Islope4, Itarget1 | Islope1, Islope4 | Islope1 | - |
| Catch-based | - | SPMSY | CC4 | - | - | - |
| Length-based | Mean Length Estimator (YPR_ML) | Mean Length Estimator (YPR_ML) | Mean Length Estimator (YPR_ML) | - | - | - |

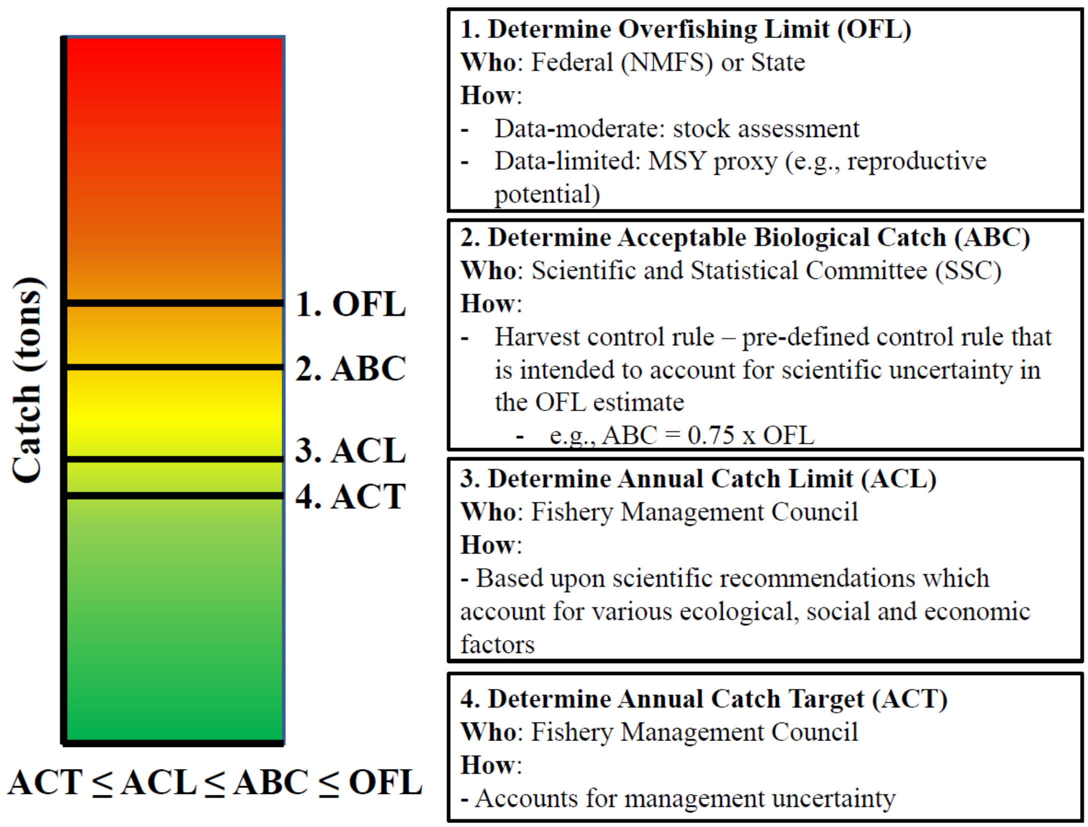
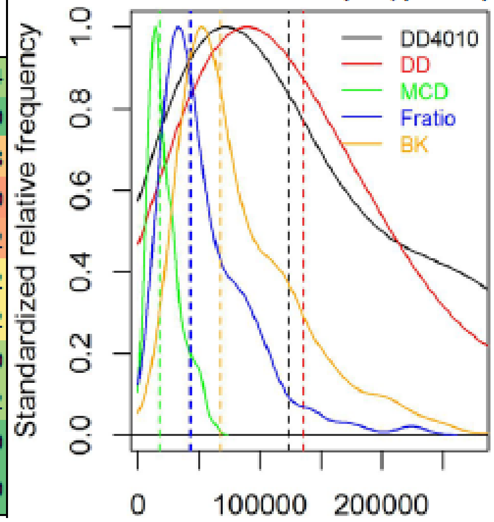



Figure 1. Procedure for setting annual catch limits and catch targets, adapted from the US Magnuson Stevens Fishery Conservation and Management Act National Standard 1 Guidelines.

## Hogfish (*Lachnolaimus maximus* ) Puerto Rico Diving

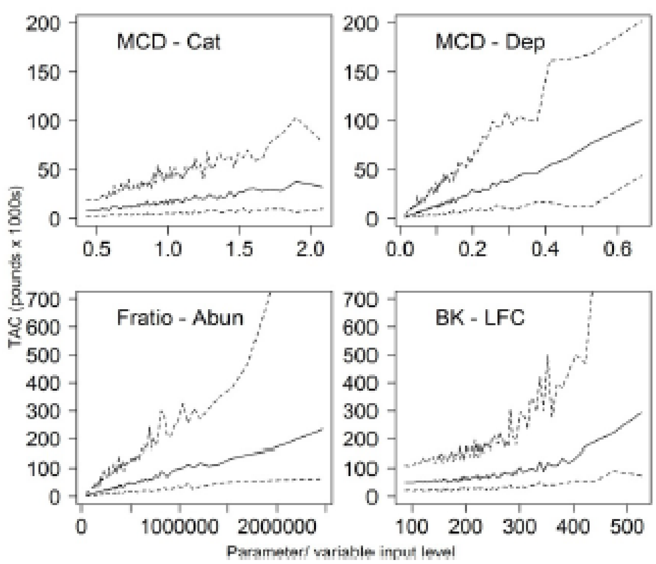
| Management Evaluation Performance Results | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Ordered by PNOF | | | | | Ordered by LTY | | | | |
| No | MP | PNOF | B50 | | No | MP | LTY | AAVY | |
| 1 | DD4010 | 93.2 | 98.7 | | 1 | DD4010 | 99.0 | 98.4 | |
| 2 | SPMSY | 80.5 | 92.1 | | 2 | DD | 98.9 | 100.0 | |
| 3 | BK | 79.0 | 95.1 | | 3 | MCD | 96.6 | 75.8 | |
| 4 | MCD | 79.0 | 98.2 | | 4 | Fratio | 96.0 | 52.0 | |
| 5 | Itarget1 | 78.4 | 94.9 | | 5 | BK | 93.5 | 59.2 | |
| 6 | DD | 76.8 | 97.4 | | 6 | Islope1 | 83.0 | 96.2 | |
| 7 | CC4 | 73.9 | 92.0 | | 7 | Islope4 | 80.2 | 96.2 | |
| 8 | YPR_ML | 70.0 | 84.0 | | 8 | YPR_ML | 77.0 | 78.0 | |
| 9 | Fratio | 61.8 | 94.9 | | 9 | SPMSY | 63.8 | 98.2 | |
| 10 | Islope4 | 57.3 | 82.1 | | 10 | CC4 | 30.4 | 100.0 | |
| 11 | Islope1 | 55.6 | 82.2 | | 11 | Itarget1 | 26.3 | 100.0 | |

**Distributions and Medians (dashed) for DLMtool Total Allowable Catch (TAC; pounds)**




**PNOF** = Prob. of not overfishing (%); **B50** = Prob. of B being above 0.5 BMSY (%); **LTY** = Relative long-term yield (fraction of simulations achieving > 50% FMSY yield over final 10 projection years); **AAVY** = fraction of simulations where average annual variability in yield < 15%

**Subset of Catch Statistics Sensitivities:**




| DLMtool Catch Statistics (lbs) | | | |
|---|---|---|---|
| **MP** | **Min** | **Median** | **Max** |
| **Highest long-term yields in MSE** | | | |
| DD4010 | 3,637 | 123,440 | 2,948,048 |
| DD | 11,387 | 173,400 | 2,333,902 |
| Fratio | 6,936 | 44,959 | 245,645 |
| MCD | 1,652 | 17,283 | 63,112 |
| BK | 17,760 | 75,670 | 250,913 |
| **Other MPs that meet AP criteria** | | | |
| Islope1 | 33,629 | 49,368 | 77,728 |
| Islope4 | 23,369 | 37,415 | 53,197 |
| SPMSY | 1,880 | 34,898 | 74,192 |
| CC4 | 27,654 | 41,262 | 66,965 |
| Itarget1 | 30,163 | 41,765 | 59,958 |

| Mean length estimator (Huynh) | |
|---|---|
| YPR_ML (F0.1) | 45,791 |

| Catch Statistics (lbs) | | | |
|---|---|---|---|
| Catch | 35,297 | 65,754 | 131,073 |
| 2014 Catch | | | 58,569 |
| 2012–2014 Average Catch | | | 59,946 |
| 1983-2014 Average Catch | | | 70,634 |

**Concerns and Caveats:**

- **Method-specific assumptions** (e.g., constant M)
- **Sensitivity to data inputs**: life history parameters, depletion, and abundance
- **Data quality**: **life history parameters** derived from South Atlantic; hermaphroditic; underreporting of **catch**; Appropriateness of fishery-dependent **index of abundance**, estimates of **stock depletion** and **current abundance**, appropriateness of TIP data in quantifying **length at first capture**

**Considerations:**

- Exclude MPs with catch recommendations near or exceeding maximum observed catches (DD/DD4010)
- Weigh trade-offs in metrics and data quality

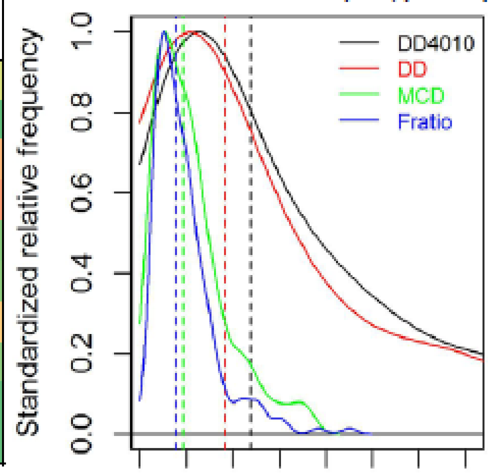
Figure 2. Summary of SEDAR 46 assessment results for Puerto Rico hogfish.

## Yellowtail snapper (*Ocyurus chrysurus* ) Puerto Rico Handline

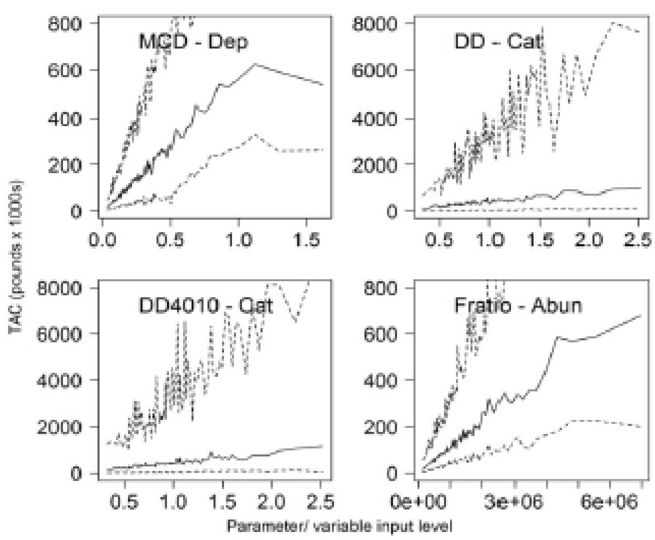
| Management Evaluation Performance Results | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Ordered by PNOF | | | | | Ordered by LTY | | | | |
| No | MP | PNOF | B50 | | No | MP | LTY | AAVY |
| 1 | Itarget1 | 87.3 | 94.8 | | 1 | DD4010 | 97.2 | 95.6 |
| 2 | CC4 | 77.6 | 89.6 | | 2 | DD | 96.0 | 100.0 |
| 3 | DD4010 | 75.3 | 97.7 | | 3 | MCD | 94.3 | 65.6 |
| 4 | SPMSY | 72.6 | 85.0 | | 4 | Fratio | 94.1 | 51.0 |
| 5 | MCD | 71.6 | 98.4 | | 5 | Islope1 | 81.3 | 98.6 |
| 6 | Islope4 | 61.1 | 82.2 | | 6 | Islope4 | 79.0 | 98.4 |
| 7 | Islope1 | 60.9 | 82.6 | | 7 | YPR_ML | 77.0 | 78.0 |
| 8 | Fratio | 59.5 | 91.7 | | 8 | SPMSY | 60.8 | 98.4 |
| 9 | DD | 55.7 | 92.7 | | 9 | CC4 | 32.2 | 100.0 |
| 10 | YPR_ML | 54.0 | 73.0 | | 10 | Itarget1 | 22.2 | 100.0 |

**PNOF** = Prob. of not overfishing (%); **B50** = Prob. of B being above 0.5 BMSY (%); **LTY** = Relative long-term yield (fraction of simulations achieving > 50% FMSY yield over final 10 projection years); **AAVY** = fraction of simulations where average annual variability in yield < 15%

**Distributions and Medians (dashed) for DLMtool Total Allowable Catch (TAC; pounds)**




**Subset of Catch Statistics Sensitivities:**




| DLMtool Catch Statistics (lbs) | | | |
|---|---|---|---|
| **MP** | **Min** | **Median** | **Max** |
| **Highest long-term yields in MSE** | | | |
| DD4010 | 27,628 | 450,093 | 5,924,792 |
| DD | 11,424 | 368,194 | 7,153,145 |
| MCD | 8,006 | 189,991 | 759,445 |
| Fratio | 32,926 | 156,541 | 732,805 |
| **Other MPs that meet AP criteria** | | | |
| Islope1 | 78,516 | 157,096 | 247,785 |
| Itarget1 | 68,293 | 132,242 | 229,522 |
| CC4 | 72,870 | 129,130 | 265,171 |
| SPMSY | 4,232 | 125,071 | 255,162 |
| Islope4 | 69,387 | 112,336 | 185,335 |

| Mean length estimator (Huynh) | |
|---|---|
| YPR_ML (F0.1) | 201,354 |

| Catch Statistics (lbs) | | | |
|---|---|---|---|
| Catch | 122,999 | 277,810 | 688,908 |
| 2014 Catch | | | 200,667 |
| 2012–2014 Average Catch | | | 186,790 |
| 1983-2014 Average Catch | | | 297,299 |

**Concerns and Caveats:**

- **Method-specific assumptions** (e.g., constant M)
- **Sensitivity to data inputs**: life history parameters, depletion, and abundance
- **Data quality**: **life history parameters** derived from Brazil; underreporting of **catch** and inconsistency in recording snappers in data files; Appropriateness of fishery-dependent **index of abundance**, estimates of **stock depletion** and **current abundance**, appropriateness of TIP data in quantifying **length at first capture**

**Considerations:**

- Exclude MPs with catch recommendations near or exceeding maximum observed catches (DD4010)
- Consider methods with high PNOF and LTY and weigh trade-offs in metrics

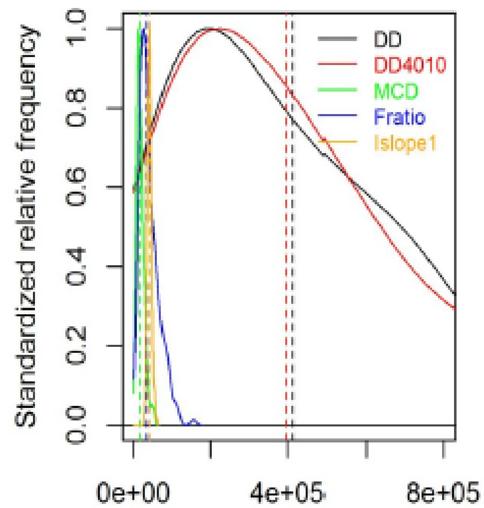
Figure 3. Summary of SEDAR 46 assessment results for Puerto Rico yellowtail snapper.

## Queen triggerfish (*Balistes vetula* ) St. Thomas traps and pots

| Management Evaluation Performance Results | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Ordered by PNOF | | | | | Ordered by LTY | | | | |
| No | MP | PNOF | B50 | | No | MP | LTY | AAVY | |
| 1 | DD4010 | 95.0 | 98.6 | | 1 | DD | 90.9 | 99.6 | |
| 2 | DD | 81.7 | 96.9 | | 2 | DD4010 | 86.6 | 82.8 | |
| 3 | SPMSY | 79.4 | 90.4 | | 3 | MCD | 85.0 | 66.0 | |
| 4 | MCD | 78.8 | 98.2 | | 4 | Fratio | 84.4 | 50.8 | |
| 5 | YPR_ML | 65.0 | 78.0 | | 5 | Islope1 | 78.0 | 99.6 | |
| 6 | Islope4 | 61.7 | 86.2 | | 6 | Islope4 | 71.2 | 99.6 | |
| 7 | Islope1 | 59.5 | 86.2 | | 7 | YPR_ML | 63.0 | 93.0 | |
| 8 | CC4 | 58.4 | 84.9 | | 8 | Itarget1 | 60.6 | 100.0 | |
| 9 | Fratio | 58.1 | 93.5 | | 9 | CC4 | 52.2 | 99.8 | |
| 10 | Itarget1 | 53.1 | 87.5 | | 10 | SPMSY | 47.3 | 99.4 | |

**PNOF** = Prob. of not overfishing (%); **B50** = Prob. of B being above 0.5 BMSY (%); **LTY** = Relative long-term yield (fraction of simulations achieving > 50% FMSY yield over final 10 projection years); **AAVY** = fraction of simulations where average annual variability in yield < 15%

**Distributions and Medians (dashed) for DLMtool Total Allowable Catch (TAC; pounds)**

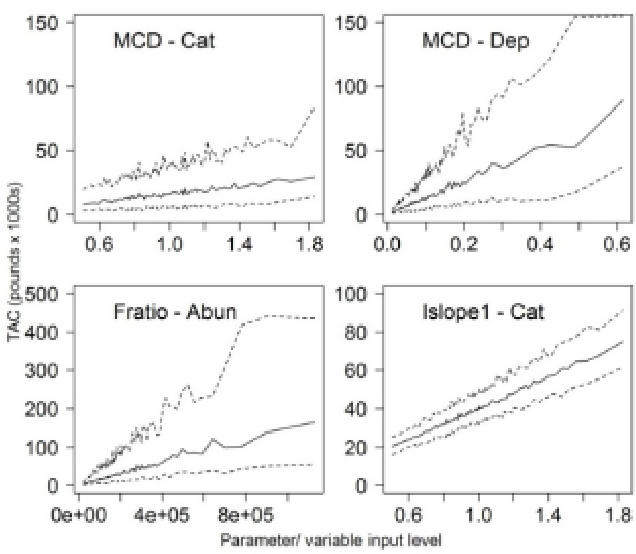



| DLMtool Catch Statistics (lbs) | | | |
|---|---|---|---|
| **MP** | **Min** | **Median** | **Max** |
| **Highest long-term yields in MSE** | | | |
| DD | 22,311 | 580,772 | 9,990,730 |
| DD4010 | 15,025 | 444,872 | 6,774,825 |
| Islope1 | 28,381 | 40,033 | 53,618 |
| Fratio | 7,648 | 33,454 | 167,219 |
| MCD | 3,403 | 16,844 | 64,207 |
| **Other MPs that meet AP criteria** | | | |
| CC4 | 26,371 | 36,986 | 50,565 |
| Itarget1 | 23,978 | 33,912 | 46,302 |
| Islope4 | 20,571 | 30,520 | 39,667 |
| SPMSY | 1,196 | 23,927 | 56,094 |

| Mean length estimator (Huynh) | |
|---|---|
| YPR_ML (F0.1) | 26,406 |

| Catch Statistics (lbs) | | | |
|---|---|---|---|
| Catch | 43,762 | 70,499 | 98,528 |
| 2014 Catch | | | 44,107 |
| 2012–2014 Average Catch | | | 44,235 |
| 1998-2014 Average Catch | | | 63,367 |

**Subset of Catch Statistics Sensitivities:**




**Concerns and Caveats:**

- **Method-specific assumptions** (e.g., constant M)
- **Sensitivity to data inputs**: life history parameters, depletion, and abundance
- **Data quality**: **life history parameters** derived from multiple regions outside Caribbean; underreporting of catch and inconsistency in recording triggerfish in data files; Appropriateness of fishery-dependent **index of abundance**, estimates of **stock depletion** and **current abundance**, appropriateness of TIP data in quantifying **length at first capture**

**Considerations:**

- Exclude MPs with catch recommendations near or exceeding maximum observed catches (DD/DD4010)
- Consider methods with high PNOF and LTY and weigh trade-offs in metrics

Figure 4. Summary of SEDAR 46 assessment results for St. Thomas queen triggerfish.

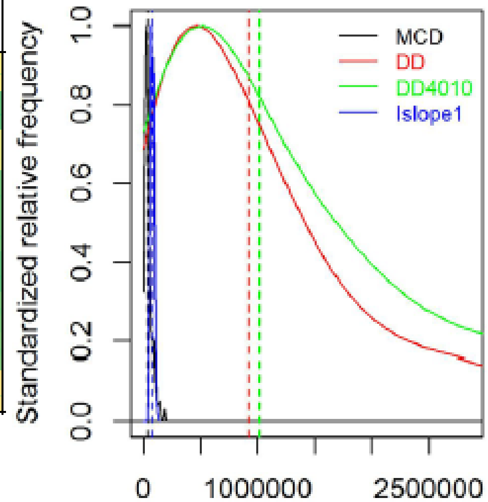
## Spiny lobster (*Panulirus argus*) St. Thomas traps and pots

**Management Evaluation Performance Results**

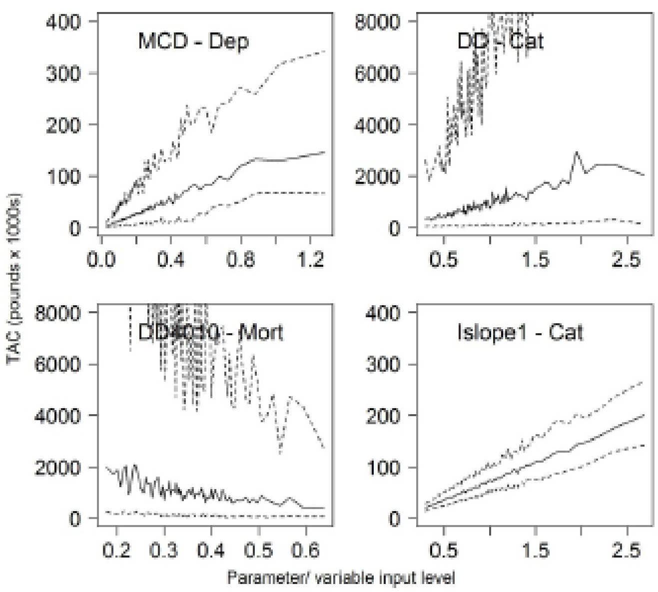
| Ordered by PNOF | | | | Ordered by LTY | | | |
|---|---|---|---|---|---|---|---|
| No | MP | PNOF | B50 | No | MP | LTY | AAVY |
| 1 | Itarget4 | 99.1 | 97.9 | 1 | MCD | 71.7 | 71.4 |
| 2 | DD4010 | 77.9 | 95.3 | 2 | DD | 68.6 | 98.4 |
| 3 | SPMSY | 68.1 | 85.5 | 3 | DD4010 | 66.7 | 76.2 |
| 4 | DD | 67.3 | 92.1 | 4 | Islope1 | 53.3 | 95.8 |
| 5 | MCD | 64.3 | 96.4 | 5 | Islope4 | 52.2 | 95.8 |
| 6 | Islope4 | 64.0 | 87.6 | 6 | Itarget1 | 47.5 | 99.8 |
| 7 | Islope1 | 63.3 | 87.8 | 7 | CC4 | 43.6 | 95.0 |
| 8 | Itarget1 | 59.5 | 88.8 | 8 | SPMSY | 39.1 | 93.0 |
| 9 | CC4 | 53.9 | 82.1 | 9 | Itarget4 | 0.0 | 64.4 |

**PNOF** = Prob. of not overfishing (%); **B50** = Prob. of B being above 0.5 BMSY (%); **LTY** = Relative long-term yield (fraction of simulations achieving > 50% FMSY yield over final 10 projection years); **AAVY** = fraction of simulations where average annual variability in yield < 15%

**Distributions and Medians (dashed) for DLMtool Total Allowable Catch (TAC; pounds)**




**Subset of Catch Statistics Sensitivities:**




**DLMtool Catch Statistics (lbs)**

| MP | Min | Median | Max |
|---|---|---|---|
| **Highest long-term yields in MSE** | | | |
| DD4010 | 57,788 | 975,309 | 14,037,830 |
| DD | 42,888 | 869,317 | 18,334,000 |
| Islope1 | 34,146 | 74,327 | 137,648 |
| MCD | 4,271 | 37,994 | 163,253 |
| **Other MPs that meet AP criteria** | | | |
| SPMSY | 34,351 | 96,269 | 150,547 |
| CC4 | 24,725 | 60,922 | 115,889 |
| Itarget1 | 34,357 | 59,332 | 104,463 |
| Islope4 | 30,786 | 52,064 | 89,433 |
| Itarget4 | 17,124 | 35,017 | 63,534 |

| **Mean length estimator (Huynh)** |
|---|
| none meet performance criteria |

**Catch Statistics (lbs)**

| | | | |
|---|---|---|---|
| Catch | 6,742 | 75,991 | 136,027 |
| 2014 Catch | | | 89,092 |
| 2012–2014 Average Catch | | | 85,494 |
| 1975-2014 Average Catch | | | 72,232 |

**Concerns and Caveats:**

- **Method-specific assumptions** (e.g., constant M)
- **Sensitivity to data inputs**: life history parameters, depletion, and abundance
- **Data quality**: uncertainty in **MaxAge and Mort**; **underreporting of catch** ; Appropriateness of fishery-dependent **index of abundance**, estimates of **stock depletion**, and appropriateness of TIP data in quantifying length at first capture

**Considerations:**

- Exclude MPs with catch recommendations near or exceeding maximum observed catches (DD/DD4010)
- Consider methods with high PNOF and LTY and weigh trade-offs in metrics

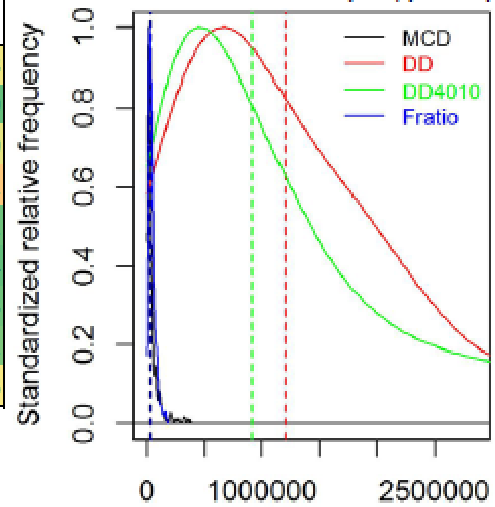
Figure 5. Summary of SEDAR 46 assessment results for St. Thomas spiny lobster.

## Spiny lobster (*Panulirus argus*) St. Croix diving

| Management Evaluation Performance Results | | | | | | | |
|---|---|---|---|---|---|---|---|
| Ordered by PNOF | | | | Ordered by LTY | | | |
| No | MP | PNOF | B50 | No | MP | LTY | AAVY |
| 1 | Itarget4 | 98.7 | 96.1 | 1 | MCD | 70.7 | 72.8 |
| 2 | DD4010 | 83.9 | 95.6 | 2 | DD | 69.6 | 99.0 |
| 3 | DD | 71.7 | 91.7 | 3 | DD4010 | 66.6 | 75.0 |
| 4 | MCD | 66.4 | 94.1 | 4 | Fratio | 64.0 | 52.2 |
| 5 | SPMSY | 63.3 | 83.0 | 5 | Islope1 | 50.8 | 97.2 |
| 6 | Islope4 | 61.8 | 84.7 | 6 | Itarget1 | 47.8 | 99.4 |
| 7 | Islope1 | 60.8 | 84.8 | 7 | Islope4 | 46.6 | 96.8 |
| 8 | Fratio | 60.0 | 86.5 | 8 | SPMSY | 40.7 | 94.2 |
| 9 | Itarget1 | 51.8 | 85.3 | 9 | Itarget4 | 0.0 | 71.6 |

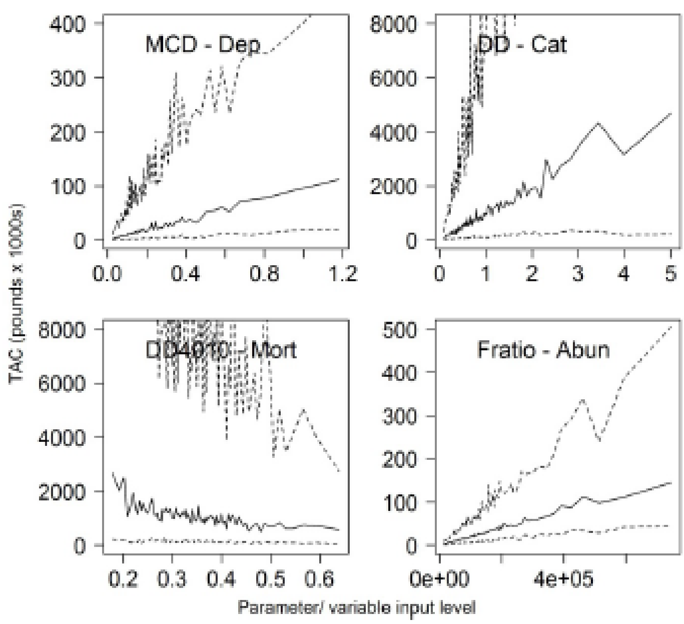
**PNOF** = Prob. of not overfishing (%); **B50** = Prob. of B being above 0.5 BMSY (%); **LTY** = Relative long-term yield (fraction of simulations achieving > 50% FMSY yield over final 10 projection years); **AAVY** = fraction of simulations where average annual variability in yield < 15%

**Distributions and Medians (dashed) for DLMtool Total Allowable Catch (TAC; pounds)**




| DLMtool Catch Statistics (lbs) | | | |
|---|---|---|---|
| **MP** | **Min** | **Median** | **Max** |
| **Highest long-term yields in MSE** | | | |
| DD | 38,692 | 1,047,478 | 17,270,400 |
| DD4010 | 24,497 | 894,563 | 23,764,310 |
| Fratio | 4,637 | 29,015 | 144,193 |
| MCD | 1,242 | 21,247 | 247,998 |
| **Other MPs that meet AP criteria** | | | |
| Islope1 | 15,102 | 55,563 | 178,913 |
| Itarget1 | 13,800 | 50,164 | 162,328 |
| Islope4 | 11,589 | 47,936 | 146,667 |
| SPMSY | 1,356 | 39,761 | 80,001 |
| Itarget4 | 10,098 | 30,551 | 107,502 |

**Subset of Catch Statistics Sensitivities:**




| Mean length estimator (Huynh) |
|---|
| none meet performance criteria |

| Catch Statistics (lbs) | | | |
|---|---|---|---|
| Catch | 1,288 | 32,870 | 168,005 |
| 2014 Catch | | | 39,681 |
| 2012–2014 Average Catch | | | 62,025 |
| 1975-2014 Average Catch | | | 53,134 |

**Concerns and Caveats:**

- **Method-specific assumptions** (e.g., constant M)
- **Sensitivity to data inputs**: life history parameters, depletion, and abundance
- **Data quality**: uncertainty in **MaxAge and Mort**; **underreporting of catch** ; Appropriateness of fishery-dependent **index of abundance**, estimates of **stock depletion** and **current abundance**, and appropriateness of TIP data in quantifying **length at first capture**

**Considerations:**

- Exclude MPs with catch recommendations near or exceeding maximum observed catches (DD/DD4010)
- Consider methods with high PNOF and LTY and weigh trade-offs in metrics

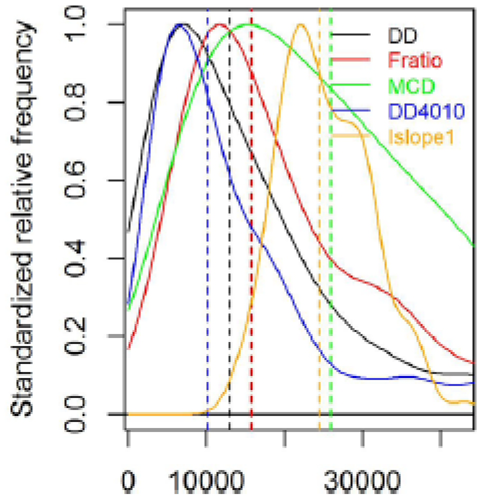
Figure 6. Summary of SEDAR 46 assessment results for St. Croix spiny lobster.

## Stoplight parrotfish (*Sparisoma viride* ) St. Croix diving

| Management Evaluation Performance Results | | | | | | | |
|---|---|---|---|---|---|---|---|
| Ordered by PNOF | | | | Ordered by LTY | | | |
| No | MP | PNOF | B50 | No | MP | LTY | AAVY |
| 1 | DD4010 | 96.7 | 96.0 | 1 | DD | 87.5 | 97.4 |
| 2 | DD | 88.9 | 93.5 | 2 | MCD | 81.5 | 70.0 |
| 3 | MCD | 82.2 | 95.3 | 3 | Fratio | 81.5 | 54.2 |
| 4 | SPMSY | 81.0 | 86.1 | 4 | DD4010 | 79.6 | 55.6 |
| 5 | Islope4 | 64.2 | 78.4 | 5 | YPR_ML | 75.0 | 96.0 |
| 6 | Islope1 | 59.8 | 77.7 | 6 | Islope1 | 73.7 | 99.8 |
| 7 | Fratio | 57.8 | 84.2 | 7 | Islope4 | 63.0 | 99.8 |
| 8 | YPR_ML | 52.0 | 72.0 | 8 | SPMSY | 34.5 | 99.6 |

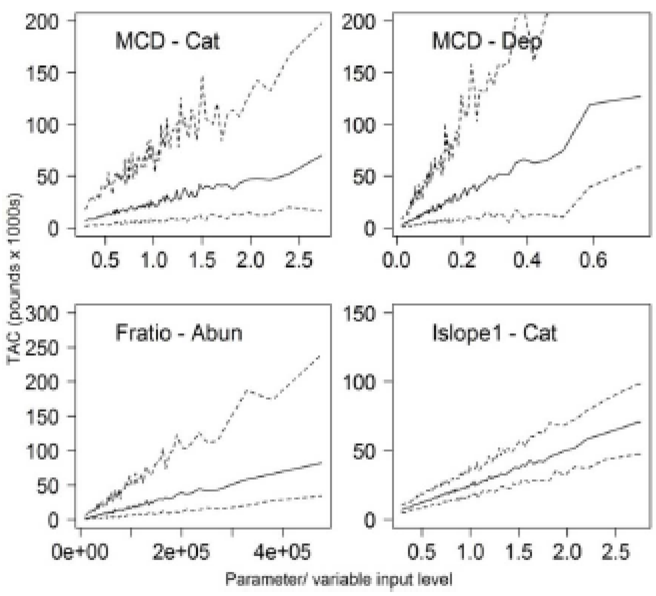
**PNOF** = Prob. of not overfishing (%); **B50** = Prob. of B being above 0.5 BMSY (%); **LTY** = Relative long-term yield (fraction of simulations achieving > 50% FMSY yield over final 10 projection years); **AAVY** = fraction of simulations where average annual variability in yield < 15%

**Distributions and Medians (dashed) for DLMtool Total Allowable Catch (TAC; pounds)**




| DLMtool Catch Statistics (lbs) | | | |
|---|---|---|---|
| **MP** | **Min** | **Median** | **Max** |
| **Highest long-term yields in MSE** | | | |
| Islope1 | 11,089 | 25,620 | 47,084 |
| MCD | 2,355 | 23,067 | 156,974 |
| Fratio | 1,391 | 15,415 | 107,133 |
| DD4010 | 489 | 10,253 | 78,481 |
| DD | 757 | 9,749 | 90,988 |
| **Other MPs that meet AP criteria** | | | |
| SPMSY | 973 | 31,043 | 76,106 |
| Islope4 | 11,312 | 19,912 | 34,876 |

**Subset of Catch Statistics Sensitivities:**




| Mean length estimator (Huynh) | |
|---|---|
| YPR_ML (F0.1) | 21,374 |

| Catch Statistics (lbs) | | | |
|---|---|---|---|
| Catch | 20,152 | 98,980 | 164,576 |
| 2014 Catch | | | 21,750 |
| 2012–2014 Average Catch | | | 32,464 |
| 1996-2014 Average Catch | | | 90,089 |

Concerns and Caveats:

- **Method-specific assumptions** (e.g., constant M)
- **Sensitivity to data inputs**: life history parameters, depletion, and abundance
- **Data quality**: uncertainty in **growth parameters**; underreporting of catch and inconsistency in recording parrotfish in data files; Appropriateness of fishery-dependent **index of abundance** to characterize trends in fishery resource, estimates of **stock depletion** and **current abundance**, and appropriateness of TIP data for diving fishery in quantifying **length at first capture**

Considerations:

- Consider methods with high PNOF and LTY and weigh trade-offs in metrics

Figure 7. Summary of SEDAR 46 assessment results for St. Croix stoplight parrotfish.