A comparison of data-rich versus data-limited methods in estimating overfishing limits

Skyler R. Sagarese, John F. Walter, J. Jeffery Isely, Meaghan D. Bryan, Nancie Cummings

SEDAR46-DW-01

19 October 2015

Please cite this document as:

Sagarese, S.R., J.F. Walter, J. J. Isely, M.D. Bryan, N. Cummings. 2015. A comparison of data-rich versus data-limited methods in estimating overfishing limits. SEDAR46-DW-01. SEDAR, North Charleston, SC. 28 pp.

A comparison of data-rich versus data-limited methods in estimating overfishing limits

Skyler R. Sagarese[1], John F. Walter[2], J. Jeffery Isely[2], Meaghan D. Bryan[2], Nancie Cummings[2]

[1]Cooperative Institute for Marine and Atmospheric Studies, Rosenstiel School of Marine and Atmospheric Science, University of Miami, 4600 Rickenbacker Causeway, Miami, Florida, USA 33149

[2]Southeast Fisheries Science Center, 75 Virginia Beach Drive, Miami, Florida, USA 33149

Introduction

A recent mandate to halt overfishing and enhance management efficacy implemented the setting of annual catch limits for all federally-managed stocks (MSFCMA 2007; Methot 2009; Newman et al. 2015). Fishery stock assessments are the preferred approach in estimating the overfishing limit, or the annual catch when fishing the stock's current abundance at F_{MSY}, which is required to prescribe an ACL (Newman et al. 2015). Age or length structured assessment models such as Stock Synthesis (SS) are commonly employed because they integrate multiple data sources, simultaneously model various processes and are flexible in terms of model configuration (Cope 2013; Methot and Wetzel 2013). However, these types of model applications demand substantial data and analytical support and are particularly challenging in the southeast and Caribbean U.S. where severe data limitations persist such as short time-series and uncertain catch histories.

Annual catch limits in the U.S. Caribbean have been set in the past by the Caribbean Fishery Management Council using catch-only methods (Berkson and Thorson 2015; Newman et al. 2015). Over the last decade, various data-limited assessment methods (DLMs) have been developed and tested (Carruthers et al. 2014; Newman et al. 2014; Newman et al. 2015). Combined with the development of the 'DLMtool' package in R (Carruthers 2015b), which has consolidated these methods and enabled simultaneous analysis, these efforts have greatly enhanced the efficiency of data-limited assessment (Carruthers et al. 2014; Newman et al. 2014; Newman et al. 2015). In this paper we apply a suite of DLMs using the 'DLMtool' package version 2.0 (Carruthers 2015b; Carruthers 2015a) in R (R Development Core Team 2013) to multiple species reflecting different life histories in the southeast U.S. We compare the results obtained with DLMs to those obtained with SS to address whether a similar assessment result could be achieved with less data or with computationally less-intensive methods on aggregated data, a key issue discussed at the 2014 Gulf and Caribbean Fisheries Institute Data-limited Assessment Workshop (Cummings et al. 2014).

Methods

Species of interest

Cobia (*Rachycentron canadum*) is a pelagic species that occurs worldwide and often associates with coral reefs, rocky substrates, and estuaries (McEachran and Fechhelm 2006). Adults are targeted primarily by recreational (charterboat, private, shore, headboat) fisheries, with some effort directed by the commercial handline and longline fisheries (SEDAR 2013). All fishing fleets exhibit asymptotic selectivity (SEDAR 2013). As juveniles, cobia are vulnerable to the shrimp trawl fishery and are frequently caught as bycatch (SEDAR 2013). Relative abundance inferred from shrimp bycatch per unit effort was consistently high between the late 1970s and early 2000s (Fig. 1). Total catch increased from the 1950s to peak levels during the mid-1990s and declined thereafter (Fig. 1). Management regulations for this species have included the implementation of a size limit in 1985 and a possession limit in 1990 for both commercial and recreational fisheries (SEDAR 2013).

Gray triggerfish (*Balistes capriscus*) occurs throughout the Atlantic, Gulf of Mexico, and Caribbean and associates with coral reefs, grassy and sandy bottoms (McEachran and Fechhelm 2006). Triggerfish are targeted primarily by recreational (headboat and other) fisheries but also captured by commercial (handline, longline, trap) fisheries (SEDAR 2015), all of which exhibit dome-shaped selectivity. Age-0 triggerfish are also discarded by the shrimp trawl fishery (SEDAR 2015). As observed for cobia, relative abundance of gray triggerfish inferred from shrimp trawl bycatch per unit effort increased to relatively consistent levels between the late 1970s and mid 2000s and has since declined (Fig. 1). Total catch increased to peak values in the early 1990s and has since declined (Fig. 1). Various management regulations have been implemented for both commercial and recreational fisheries such as quotas, seasonal closures, trip or bag limits, and size limits (SEDAR 2015).

Golden tilefish (*Lopholatilus chamaeleonticeps*) associates with mud and sand bottoms and are found between 81 and 540 m throughout the western Atlantic and Gulf of Mexico (McEachran and Fechhelm 2006). Adults are targeted primarily by commercial fisheries (handline and longline) but are also captured sporadically by recreational fisheries (SEDAR 2011a). Fishery selectivity is assumed to be asymptotic for all fleets (SEDAR 2011a). Relative abundance as inferred by the commercial longline index has generally increased over time although substantial inter-annual variability is evident within the time series (Fig. 1). Since 1980, with the exception of the late 1980s, total catches have remained relatively consistent between 100 and 250 metric tons (mt) (Fig. 1). Management regulations have been widespread throughout the time series and have included closures and trip limits for the commercial fisheries and bag limits for the recreational fisheries (SEDAR 2011a).

Data-rich model: Stock Synthesis

Stock Synthesis (Methot 2012) is a biological and statistical framework and has been used in more than 60 fishery stock assessments worldwide (Methot and Wetzel 2013). The SS modeling framework consists of 3 sub-models: (1) a population sub-model that mirrors a traditional statistical catch-at-age model; (2) an observational sub-model that incorporates various data sources and calibrates predictions against observations; and (3) a statistical sub-model which quantifies the goodness of fit statistic by comparing values expected (i.e., from population and observation models) with those observed (i.e., from data) (Methot and Wetzel 2013). Specific improvements in characterizing stock dynamics with SS include its ability to incorporate multiple fisheries and surveys with diverse characteristics such as selectivity and retention patterns, its flexibility in parameters to set controls and allow prior constraints, the option for time-varying processes such as mortality, and its ability to scale down data limitations (Methot 2009; Cope 2013).

Data

Data inputs (Table 1) were extracted directly from the SS report file for each species using the r4SS package (Taylor et al. 2014) and code written in R to synthesize DLM inputs. Since DLMs currently only accommodate one index of abundance, the index displaying the lowest RMSE among all indices was selected, under the assumption that this was the best fitting index of abundance according to SS. Both length at first capture (LFC) and length at full selection (LFS) were estimated from fleet selectivity curves obtained from the assessment reports. Catch-at-age and catch-at-length data were extracted from the SS data input file and converted from proportions into numbers using the corresponding sample size (Nsamp). All remaining parameters (see Table 1) were extracted from the SS report files with the exception of t_0 which was obtained from each species-specific SEDAR Data Workshop report. Where possible, coefficients of variation were estimated using SD and values reported in the SS report files. For derived quantities such as F_{MSY}/M and B_{MSY}/B_0, the CVs were set based on estimates within Carruthers et al. (2014) or example data files for similar species (e.g., red snapper *Lutjanus campechanus*) within the ‘DLMtool’ package (Carruthers 2015b).

Data-limited Methods Toolkit

Various DLMs were examined (Table 2) and are detailed elsewhere (Carruthers et al. 2014; Newman et al. 2014; Carruthers et al. in press). Depletion-based methods (e.g., Depletion-Based Stock Reduction Analysis; Dick and MacCall 2011) were tested that adjust historical catches using assumptions about life history characteristics and rely on estimates of depletion relative to unfished populations (Dick and MacCall 2011; Carruthers et al. 2014). Abundance-based methods (e.g., Beddington and Kirkwood 2005) were tested that rely on current estimates of absolute abundance and F_{MSY} (Carruthers et al. 2014). Simple catch-based methods (e.g., constant catch linked to average catch, CC1; Geromont and Butterworth 2014b) were also tested, which rely solely on time series of recent catches.

Management Strategy Evaluation

To explore the relative performance among potentially applicable DLMs for each life-history stage examined, we performed a simple management strategy evaluation (Carruthers et al. 2014; Carruthers 2015a) on three species: (1) cobia, (2) gray triggerfish, and (3) golden tilefish. For each species, we customized the generic snapper stock operating model within the 'DLMtool' package to mimic the life history of the species of interest using data inputs from their respective SEDAR Data workshop reports (Table 3). For this analysis, we ran 400 simulations with 200 repetitions (samples per method) on applicable DLMs for 30 years every 5 years, the assumed interval between assessments. Within the MSE, we accounted for imprecise and potentially biased data inputs and considered a generic fishing fleet with either dome-shaped selectivity (gray triggerfish) or asymptotic selectivity (cobia, golden tilefish). To assess DLM performance, we compared the trade-offs between the probability of overfishing, relative long-term yield, and the probability of the biomass dropping below B_{MSY}.

Model evaluation

The OFL distributions produced by each DLM were compared to the SS-derived OFL distribution to assess agreement between methods for each species. The OFL distribution from SS was assumed normal and was obtained using the Hessian-based parametric approach. The OFL was extraction from SS three years following the terminal assessment year due to the fixing of catch and F in the first few years of projections. For both cobia and gray triggerfish, the forecasted retained catch (forecatchret) from SS was considered most representative of the OFL because it inherently takes into account fishery discards. In contrast, forecasted catch was used to reflect the OFL for golden tilefish.

To quantitatively compare outputs from each DLM to the data-rich SS model for each species, the relative absolute error (RAE) for the OFL (Dick and MacCall 2011) was calculated with the following equation:

$$RAE = \frac{|median(OFL) - OFL_{assessment}|}{OFL_{assessment}}$$

where $OFL_{\text{assessment}}$ was extracted from projections using the base SS assessment model as discussed above. Larger RAE values indicate greater divergence in OFL distributions between methods (i.e., DLM versus SS) whereas smaller RAE values suggest similar OFL distributions between methods. Inherently we assume that derived products and parameters from SS reflect "known truth" for the purpose of addressing whether simpler models can produce similar results, an assumption which may not be accurate.

Sensitivity to data inputs

A sensitivity analysis was undertaken for each species and all DLMs to reveal which data inputs most strongly affected quota recommendations (Carruthers 2015a). Sensitivity was defined by any parameter that revealed a significant ($\alpha = 0.05$) linear relationship between simulated data input values and the OFL quota recommendation. A significant result would suggest that changes in the data input value would result in different quota recommendations. This analysis was used to infer the importance of data inputs in evaluating all DLMs. One thousand sensitivities were run for all methods.

Results

Management Strategy Evaluation

Cobia: All DLMs tested in the MSE displayed low probabilities of the biomass dropping below B_{MSY} (<10%) but low to high probabilities of overfishing (5 – 70%) (Fig. 2). Some methods such as SPmod, CC1 and DD resulted in relatively high yields but at the expense of moderate probabilities of overfishing (~50%) (Fig. 2). Methods such as SPslope and DCAC produced relatively moderate yields at lower probabilities of overfishing.

Gray triggerfish: Compared to the other species examined, gray triggerfish exhibited higher probabilities of the biomass dropping below B_{MSY} (Fig. 2). Of the DLMs tested in the MSE, most resulted in moderate yields (40 – 80 mt), low to moderate probabilities of overfishing (15 – 50%), and moderate probabilities of the biomass dropping below B_{MSY} (40 – 60%) (Fig. 2).

Methods such as DCAC and Islope1 produced relatively high yields with low probabilities of overfishing (<30%) but moderate probabilities of the biomass dropping below B_{MSY} (Fig. 2).

Golden tilefish: Most DLMs in the MSE resulted in relatively large yields (>100 mt), low to moderate probabilities of overfishing (10 – 50%), and low probabilities of the biomass dropping below B_{MSY} (5 – 25%) (Fig. 2). A wide array of DLMs such as DD, DepF and Fratio produced relatively high yields at a low cost in terms of overfishing and dropping below B_{MSY}.

Comparison of OFLs between DLMs and SS

Cobia: Abundance-based and index-based DLMs tended to produce RAEs below 1 (Fig. 3) and relatively similar OFL distributions compared to SS (724 mt) (Fig. 4). The majority of DLMs tested resulted in higher OFL distributions (median range: 392 mt [BK] – 15642 mt [SPSRA]) compared to SS (Fig. 4). Most DLMs produced relatively wide OFL distributions in comparison to the SS OFL distribution. Both BK_CC and DepF produced RAEs below 0.1, median quotas within 30% of the SS-derived OFL, and OFL distributions that peaked near the SS OFL distribution. When combined with the MSE results, and with acceptable tradeoffs identified by moderate yield and low probabilities of overfishing (<30%) and of the biomass dropping below B_{MSY} (<10%), SPslope, Islope1 and DCAC could be viable methods for cobia.

Gray triggerfish: Age-based and index-based DLMs tended to produce RAEs below 1 (Fig. 3) and relatively similar OFL distributions when compared to SS (350 mt) (Fig. 5). As observed for cobia, the majority of DLMs analyzed resulted in wider and larger OFL distributions (range: 383 mt [Fdem_CC] – 16782 mt [DD]) compared to SS (Fig 5). Only Fdem_CC produced a RAE below 0.1, a median quota within 10% of the SS-derived OFL, and an OFL distribution that peaked near the SS OFL distribution. When combined with the MSE results, Islope1 and DepF could be viable methods for triggerfish.

Tilefish: The majority of DLMs tested with the exception of DBSRA and DD resulted in RAEs below 1 (Fig. 3). However, most resulted in lower OFL distributions (range: 57 mt [YPR] – 1644 mt [DD]) compared to SS (224 mt) (Fig. 6). Only Fdem produced a RAE below 0.1, a median quota within 10% of the SS-derived OFL, and an OFL distribution that peaked near the SS OFL distribution. When combined with the MSE results, DepF and Fratio could be viable options because these methods produced relatively high yields at a relatively low probability of overfishing (< 30%).

Sensitivity

Quota recommendations for each species were frequently sensitive to data inputs across methods (Tables 4-6). For almost all applicable DLMs, quota recommendations were particularly sensitive to catches (Cat), natural mortality (Mort), abundance estimates (Abun), and depletion estimates (Dep) with higher data inputs corresponding to higher quotas. Quota recommendations were occasionally sensitive to life-history parameters relating to growth and maturity such as age at maturity.

Discussion

The purpose of this study was to investigate whether similar assessment results could be achieved with data-limited methods as opposed to more complex conventional stock assessment methods for different life histories. Index-based DLMs tended to produce similar results across life history stages. Other viable methods included abundance-based and age-based DLMs for both gray triggerfish and golden tilefish and depletion-based DLMs for cobia and golden tilefish. This analysis highlights the wide range of data-limited methods available to date; yet, this analysis also cautions their misuse in a real world setting. While multiple methods were feasible for each species based on available data inputs as estimated by SS, the resulting OFL distributions are not necessarily accurate or robust to uncertainty. Many OFL distributions were extremely wide for DLMs, suggesting a substantial amount of uncertainty. Even further, quota recommendations were highly sensitive to data inputs such as natural mortality, catch history, abundance estimates, and depletion estimates where required.

This analysis is dependent upon the assumption that SS output reflected ‘true’ values (Dick and MacCall 2011) and does not necessarily imply that *any* of the models are correct. Any application of an assessment model may also be biased by failure to meet assumptions (e.g., constant fishing efficiency) or other model misspecifications (Carruthers et al. 2014). While more complex models are often ranked as higher tiered models for advice in the practice of setting harvest recommendations (Carmichael and Fenske 2011), these models are not applicable within the U.S. Caribbean at present due to severe data limitations.

Data-limited methods are not designed to account for fishery complexities such as dome-shaped selectivity (Carruthers 2015b). A similar analysis undertaken for gag grouper revealed a tendency to provide lower OFL estimates derived from DLMs when compared to SS output. It was hypothesized that this was the result of DLMs expecting higher F because these methods do not allow for cryptic biomass. In contrast, the opposite result was observed for gray triggerfish in that DLMs estimated higher OFLs compared to SS. Additional analysis on other species exhibiting dome-shaped selectivity may help elucidate whether there is a pattern to the distribution of OFLs in DLMs. Either way, if a pattern exists and there is a bias in the OFL distributions derived from DLMs as a function of the selectivity pattern, appropriate adjustments may be required.

For data-poor species, the lack of consistent and long-term fishery-independent surveys exacerbates uncertainty in assessing stock dynamics (Cummings et al. 2014; Suprenand et al. 2015). Simple management procedures based on an index of abundance are gaining momentum in recent years (Geromont and Butterworth 2014b; Geromont and Butterworth 2014a). The MSEs conducted for cobia and gray triggerfish identified such simplistic management procedures as viable options based on tradeoffs examined, warranting additional efforts to quantify relative abundance. Additional data sources such as the REEF Fish Survey (www.reef.org) may provide interim estimates of relative abundance for many species considered data-poor in the absence of long-term fishery independent surveys (e.g., Thorson et al. 2014). This citizen science fish count survey, which employs a roving diver transect, was used to inform goliath abundance for the 2011 goliath grouper stock assessment (SEDAR 2011b).

Acknowledgements

We are grateful to all the researchers for their contributions to the SEDAR 22 Gulf of Mexico golden tilefish, SEDAR 28 Gulf of Mexico cobia, and SEDAR 43 Gulf of Mexico gray triggerfish stock assessments.

References

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

Berkson, J., and Thorson, J. T. 2015. The determination of data-poor catch limits in the United States: is there a better way? ICES Journal of Marine Science 72(1):237-242. doi: 10.1093/icesjms/fsu085

Beverton, R. J. H., and Holt, S. J. 1957. On the Dynamics of Exploited Fish Populations, London, UK.

Carmichael, J., and Fenske, K. 2011. Third National Meeting of the Regional Fisheries Management Councils' Scientific and Statistical Committees. South Atlantic Fishery Management Council, Report of a National SSC Workshop on ABC Control Rule Implementation and Peer Review Procedures, Charleston, SC, October 19-21, 2010

Carruthers, T., Kell, L., Butterworth, D., Maunder, M., Geromont, H., Walters, C., McAllister, M., Hillary, R., Kitakado, T., and Davies, C. in press. Performance review of simple management procedures. ICES Journal of Marine Science.

Carruthers, T. R. 2015a. DLMtool: Data-Limited Methods Toolkit (v2.0). Available from: https://cran.r-project.org/web/packages/DLMtool/vignettes/DLMtool.pdf

Carruthers, T. R. 2015b. Package 'DLMtool'. 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. Fisheries Research 153:48-68. doi: 10.1016/j.fishres.2013.12.014

Cope, J. M. 2013. Implementing a statistical catch-at-age model (Stock Synthesis) as a tool for deriving overfishing limits in data-limited situations. Fisheries Research 142:3-14. doi: 10.1016/j.fishres.2012.03.006

Cummings, N. J., Karnauskas, M., Michaels, W. L., and Acosta, A. 2014. Report of a GCFI Workshop: Evaluation of Current Status and Application of Data-limited Stock Assessment Methods in the Larger Caribbean Region, NOAA Technical Memorandum NMFS-SEFSC-661

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. Fisheries Research 110(2):331-341. doi: 10.1016/j.fishres.2011.05.007

Geromont, H., and Butterworth, D. 2014a. Complex assessments or simple management procedures for efficient fisheries management: a comparative study. ICES Journal of Marine Science 72(1):262-274. doi: 10.1093/icesjms/fsu017

Geromont, H., and Butterworth, D. 2014b. Generic management procedures for data-poor fisheries: forecasting with few data. ICES Journal of Marine Science 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.

MacCall, A. D. 2009. Depletion-corrected average catch: a simple formula for estimating sustainable yields in data-poor situations. ICES Journal of Marine Science 66(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 and Fisheries 14(4):504-514. doi: 10.1111/j.1467-2979.2012.00485.x

Maunder, M. 2014. Management strategy evaluation (MSE) implementation in Stock Synthesis: application to Pacific bluefin tuna. Inter-American Tropical Tuna Commission, Document SAC-05-10b

McAllister, M., Pikitch, E. K., and Babcock, E. 2001. Using demographic methods to construct Bayesian priors for the intrinsic rate of increase in the Schaefer model and implications for stock rebuilding. Canadian Journal of Fisheries and Aquatic Sciences 58(9):1871-1890. doi: 10.1139/f01-114

McEachran, J. D., and Fechhelm, J. D. 2006. Fishes of the Gulf of Mexico: Scorpaeniformes to Tetraodontiformes, volume 2. University of Texas Press.

Methot, R. 2012. User manual for stock synthesis: Model Version 3.24f. NOAA Fisheries, Seattle, WA. Available from: http://nft.nefsc.noaa.gov/Stock_Synthesis_3.htm

Methot, R. D. 2009. Stock assessment: operational models in support of fisheries management. Pages 137-165 *in* R. J. Beamish, and B. J. Rothschild, editors. Future of Fishery Science – Proceedings of the 50th Anniversary Symposium of the American Institute of Fishery Research Biologista. Springer, Seattle, WA.

Methot, R. D., and Wetzel, C. R. 2013. Stock synthesis: A biological and statistical framework for fish stock assessment and fishery management. Fisheries Research 142:86-99. doi: 10.1016/j.fishres.2012.10.012

MSFCMA. 2007. Magnuson-Stevens Fishery Conservation and Management Act. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service

Newman, D., Berkson, J., and Suatoni, L. 2015. Current methods for setting catch limits for data-limited fish stocks in the United States. Fisheries Research 164:86-93. doi: 10.1016/j.fishres.2014.10.018

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. Natural Resources Defense Council, NRDC Report R:14-09-B, New York, NY

SEDAR (Southeast Data Assessment and Review). 2011a. SEDAR 22: Gulf of Mexico Tilefish Stock Assessment Report. SEDAR, North Charleston, SC

SEDAR (Southeast Data Assessment and Review). 2011b. SEDAR 23: South Atlantic and Gulf of Mexico Goliath Grouper Stock Assessment Report. SEDAR, North Charleston, South Carolina

SEDAR (Southeast Data Assessment and Review). 2013. SEDAR 28: Gulf of Mexico Cobia Stock Assessment Report. SEDAR, North Charleston, SC

SEDAR (Southeast Data Assessment and Review). 2015. SEDAR 43: Gulf of Mexico Gray Triggerfish Stock Assessment Report. SEDAR, North Charleston, SC

Suprenand, P. M., Drexler, M., Jones, D. L., and Ainsworth, C. H. 2015. Strategic assessment of fisheries independent monitoring programs in the Gulf of Mexico. PLoS ONE 10(4):e0120929. doi: 10.1371/journal.pone.0120929

Thorson, J. T., Scheuerell, M. D., Semmens, B. X., and Pattengill-Semmens, C. V. 2014. Demographic modeling of citizen science data informs habitat preferences and population dynamics of recovering fishes. Ecology 95(12):3251-3258. doi: 10.1890/13-2223.1

Walters, C., and Martell, S. J. 2002. Stock assessment needs for sustainable fisheries management. Bulletin of Marine Science 70(2):629-638.

Table 1. Summary of data extracted from the Stock Synthesis assessment models for Gulf of Mexico cobia (SEDAR 28), golden tilefish (SEDAR 22), and gray triggerfish (SEDAR 43) for input into data-limited methods.[a]

DLM input[a]	Description/SS output	Data Input Value (CV)		
General				
Name	Species name	Cobia	Golden tilefish	Gray triggerfish
Year	Years corresponding to Cat & Ind	1945−2011	1992−2008	1945−2013
t	Length of Year	67 yr	17 yr	69 yr
Units	–	metric tons (mt)	metric tons (mt)	metric tons (mt)
SigmaL	Sigma length composition	0.2	0.2	0.2
Life-history				
Mort	Natural mortality	0.48 yr^{-1} (0.5)	0.07 yr^{-1} (0.5)	0.40 yr^{-1} (0.5)
AM	Mat 50% Fem	2.0 yr (0.2)	2.0 yr (0.2)	1.5 yr (0.2)
vbt0	Von Bertalanffy t0	−0.53 yr (0.02)	−2.86 yr (0.2)	−1.66 yr (0.5)
vbK	Von Bertalanffy K	0.21 (0.18)	0.12 (0.2)	0.14 (0.2)
vbLinf	L at Amax	133.3 cm (0.07)	78.3 cm (0.2)	59.0 cm (0.2)
wla	Wtlen 1 Fem	9.64E-06 (0.1)	7.53E-06 (0.1)	2.16E-05 (0.1)
wlb	Wtlen 2 Fem	3.03 (0.1)	3.08 (0.1)	3.01 (0.1)
steep	SR BH steep	0.92 (0.14)	0.94 (0.1)	0.46 (0.12)
MaxAge	Maximum age	11 yr	40 yr	15 yr
Fishery				
Cat	Annual sum of catch (landings + discards)	0.4−2296 mt (0.5)	0−431 mt (0.5)	8−4521 mt (0.5)
AvC	Mean Cat	953 mt (0.54)	175 mt (0.28)	1758 mt (0.59)
LFC	Length at first capture	10 cm (0.5)	30 cm (0.5)	5 cm (0.5)
LFS	Smallest length at full selection	35 cm (0.8)	52 cm (1.1)	19 cm (0.2)
CAA	Catch-at-age from assessment (prop x Nsamp)	23 yr x 11 ages	12 yr x 29 ages	33 yr x 11 ages
CAL_bins	Catch-at-length bins	6−165 cm, 3−cm bins	20−114 cm, 2−cm bins	-

CAL	Catch-at-length from assessment (prop x Nsamp)	33 yr x 54 length bins	25 yr x 48 length bins	-
FMSY_M	Fstd MSY / Mort	1.07 (0.2)	1.59 (0.2)	0.39 (0.2)
BMSY_B0	SSB MSY / SBzero	0.39 (0.2)	0.25 (0.2)	0.69 (0.2)
Cref	TotYield MSY	1335 mt (0.07)	57 mt (0.10)	1942 mt (0.10)
Bref	SSB MSY	1398 mt (0.39)	5913 mt (0.10)	1.2E+10 eggs (0.19)
Abundance				
Ind	Index of abundance from fleet with lowest RMSE	Shrimp trawl: 0.001 - 2.156 bycatch per unit effort (0.59)	Commercial longline: 0.362 - 2.065 weight per hook fished (0.46)	Shrimp trawl: 0.001 - 1.623 bycatch per unit effort (0.57)
Dt	Depletion from sprseries	0.27 (0.26)	0.66 (0.14)	0.31 (0.22)
Dep	Current depletion	0.28 (1.0)	0.61 (1.0)	0.26 (1.0)
Abun	Terminal year abundance	3030 mt (1.0)	894 mt (1.0)	8842 mt (1.0)
Reference				
Ref	Median OFL (SD)	724 mt (112) in 2014 (forecatchret)	224 mt (0.1) in 2011 (forecatch)	350 mt (49) in 2016 (forecatchret)
Ref_type	Reference document	SEDAR28	SEDAR22	SEDAR43

[a]Further details regarding DLM inputs are provided within Newman et al. (2014) and Carruthers (2015b).

Table 2. Summary of data-limited methods employed. Additional details on each method available in Newman et al. (2014), Carruthers (2015b), and Carruthers et al. (in press).

Method	Description	Reference
Catch-based		
CC1	Constant catch linked to average catches (TAC = $C_{average}$)	Geromont and Butterworth (2014b); Carruthers et al. (in press)
SPMSY	Surplus production MSY	Martell and Froese (2013)
Index-based		
Islope1	CPUE slope (maintain constant CPUE: $\lambda = 0.4$, TAC = 0.8 x $C^{average}$)	Geromont and Butterworth (2014b); Carruthers et al. (in press)
Itarget1	CPUE target (TAC adjusted to achieve a target CPUE: I_{target}=1.5 $I^{average}$, TAC = $C^{average}$)	Geromont and Butterworth (2014b); Carruthers et al. (in press)
Age-based		
Fratio_CC	F_{MSY}/M ratio MP that uses a Catch Curve to estimate current abundance based on catches and recent F	Gulland (1971); Walters and Martell (2002); Martell and Froese (2013)
BK_CC	Beddington and Kirkwood life history method that uses Catch Curve to estimate current abundance based on catches and recent F	Beddington and Kirkwood (2005)
YPR_CC	Yield per recruit analysis that uses a Catch Curve to estimate recent abundance	M. Bryan (in Carruthers 2015b)
Fdem_CC	Demographic F_{MSY} method that uses a Catch Curve to estimate recent Z	McAllister et al. (2001)
Depletion-based		
DCAC	Depletion-Corrected Average Catch (DCAC)	MacCall (2009); Carruthers et al. (2014)
DepF	Depletion Corrected Fratio	Carruthers (2015b)
DBSRA	Depletion-Based Stock Reduction Analysis (DBSRA)	Dick and MacCall (2011); Carruthers et al. (2014)
SPSRA	Surplus Production Stock Reduction Analysis	McAllister et al. (2001)
Abundance-based		
SPmod	Surplus production based catch-limit modifier	Carruthers et al. (in press); Maunder (2014)
SPslope	Catch trend surplus production MSY	Carruthers et al. (in press); Maunder (2014)
Fratio	F_{MSY}/M ratio MP	Gulland (1971); Walters and Martell (2002); Martell and Froese (2013)

BK	Beddington and Kirkwood life history method	Beddington and Kirkwood (2005); Carruthers et al. (2014)
Fdem	Demographic F_{MSY} method	McAllister et al. (2001)
YPR	Yield-per-recruit analysis	Beverton and Holt (1957)
Data-moderate		
DD	Delay-difference stock assessment model	C. Walters (in Carruthers et al. 2014)

Table 3. Parameter estimates or range of values for operating model inputs for Gulf of Mexico cobia, golden tilefish, and gray triggerfish for management strategy evaluation.

OM input	Description	Data Input Value or Range		
General				
Name	Species name	Cobia	Golden tilefish	Gray triggerfish
nyears	Years for historical simulation	50	50	50
Source	Source of information	SEDAR28	SEDAR22	SEDAR43
Life-history				
MaxAge	Maximum age	11 yr	40 yr	15 yr
R0	Magnitude of unfished recruitment	1033	87	18120
Mort	Natural mortality rate	c(0.26, 1.7)	c(0.05, 0.25)	c(0.26, 0.80)
steep	Recruitment compensation (steepness)	c(0.70, 0.99)	c(0.75, 0.95)	c(0.35, 0.80)
SRrel	Type of stock-recruitment relationship	Beverton-Holt	Beverton-Holt	Beverton-Holt
vbLinf	Maximum length	c(124, 142)	c(56, 83)	c(50, 90)
vbK	Maximum growth rate	c(0.17, 0.25)	c(0.13, 0.28)	c(0.07, 0.15)
vbt0	Theoretical length at age 0	c(-0.6, -0.4)	c(-6, -1)	c(-2.10, 0.05)
wla	Length-weight parameter a	9.64E-06	7.53E-06	2.16E-05
wlb	Length-weight parameter b	3.030	3.082	3.007
ageM	Age-at-maturity	c(2, 3)	c(2, 3)	c(1, 2)
Fishery				
D	Current level of stock depletion	c(0.05, 0.60)	c(0.05, 0.65)	c(0.05, 0.60)
Size_area_1	Relative size of area 1	c(0.1, 0.1)	c(0.1, 0.1)	c(0.1,0.1)
Frac_area_1	Fraction of unfished biomass in area 1	c(0.05, 0.2)	c(0.05, 0.2)	c(0.05, 0.2)
Prob_staying	Probability that individuals in area 1 stay there	c(0.90, 0.99)	c(0.90, 0.99)	c(0.90, 0.99)
AFS	Youngest age class fully vulnerable to fishing	c(2, 2.5)	c(4, 5)	c(1, 1.5)
age05	Youngest age class at 5% vulnerability	c(1, 1.5)	c(1, 1.5)	c(0.5, 1.0)
Vmaxage	Vulnerability of oldest age class (controls extent of dome-shaped selectivity)	c(0.9, 1.0)	c(0.9, 1.0)	c(0.1, 0.5)
Fsd	Interannual variability in historical F	c(0.1, 0.4)	c(0.1, 0.2)	c(0.1, 0.4)

Table 4. Sensitivity (X) of data inputs needed (shaded cell indicates required input) for data-limited methods and management procedures for Gulf of Mexico cobia. Data inputs and methods are as defined in Tables 1 and 2, respectively.

	Data Inputs																				
Method	Mort	AM	vbt0	vbK	vbLinf	wla	wlb	steep	MaxAge	Cat	LFC	LFS	CAA	CAL	FMSY_M	BMSY_B0	Cref	Ind	Dt	Dep	Abun
CC1										X											
SPMSY										X											
Islope1										X								X			
Itarget1										X											
YPR_CC	X		X	X	X		X			X		X									
DepF	X														X					X	X
SPSRA	X	X		X				X		X										X	
SPmod										X											X
SPslope										X											
Fratio	X														X						X
BK				X	X						X										X
Fdem	X	X		X			X	X													X
YPR	X			X	X		X					X									X
DD	X	X		X			X			X								X			

Table 5. Sensitivity (X) of data inputs needed (shaded cell indicates required input) for data-limited methods and management procedures for Gulf of Mexico gray triggerfish. Data inputs and methods are as defined in Tables 1 and 2, respectively.

	Data Inputs																				
Method	Mort	AM	vbt0	vbK	vbLinf	wla	wlb	steep	MaxAge	Cat	LFC	LFS	CAA	CAL	FMSY_M	BMSY_B0	Cref	Ind	Dt	Dep	Abun
CC1										X											
SPMSY										X											
Islope1										X								X			
Itarget1										X											
YPR_CC	X		X	X	X		X			X		X									
DepF	X														X					X	X
SPSRA	X	X	X	X				X		X										X	
SPmod										X											X
SPslope										X											
Fratio	X														X						X
BK				X	X						X										X
Fdem	X	X	X	X			X	X													X
YPR	X		X	X	X		X					X									X
DD	X	X	X	X						X											

Table 6. Sensitivity (X) of data inputs needed (shaded cell indicates required input) for data-limited methods and management procedures for Gulf of Mexico golden tilefish. Data inputs and methods are as defined in Tables 1 and 2, respectively.

	Data Inputs																					
Method	Mort	AM	vbt0	vbK	vbLinf	wla	wlb	steep	MaxAge	Cat	AvC	LFC	LFS	CAA	CAL	FMSY_M	BMSY_B0	Cref	Ind	Dt	Dep	Abun
CC1										X												
SPMSY										X												
Islope1										X									X			
Fratio_CC	X									X												
YPR_CC	X		X	X	X		X			X			X									
Fdem_CC	X	X	X	X			X	X		X												
DCAC	X										X					X	X			X		
DepF	X															X					X	X
DBSRA	X									X						X	X				X	
SPSRA	X		X	X				X		X											X	
Fratio	X															X						X
Fdem	X	X	X	X			X	X														X
YPR	X		X	X	X		X						X									X
DD	X									X												

Fig. 1. Time series of catch (landings + discards; solid line) and indices of abundance (dashed line) for cobia, gray triggerfish, and golden tilefish. Indices of abundance are derived from the shrimp trawl for cobia and gray triggerfish (units = bycatch per unit effort) and the commercial longline for golden tilefish.

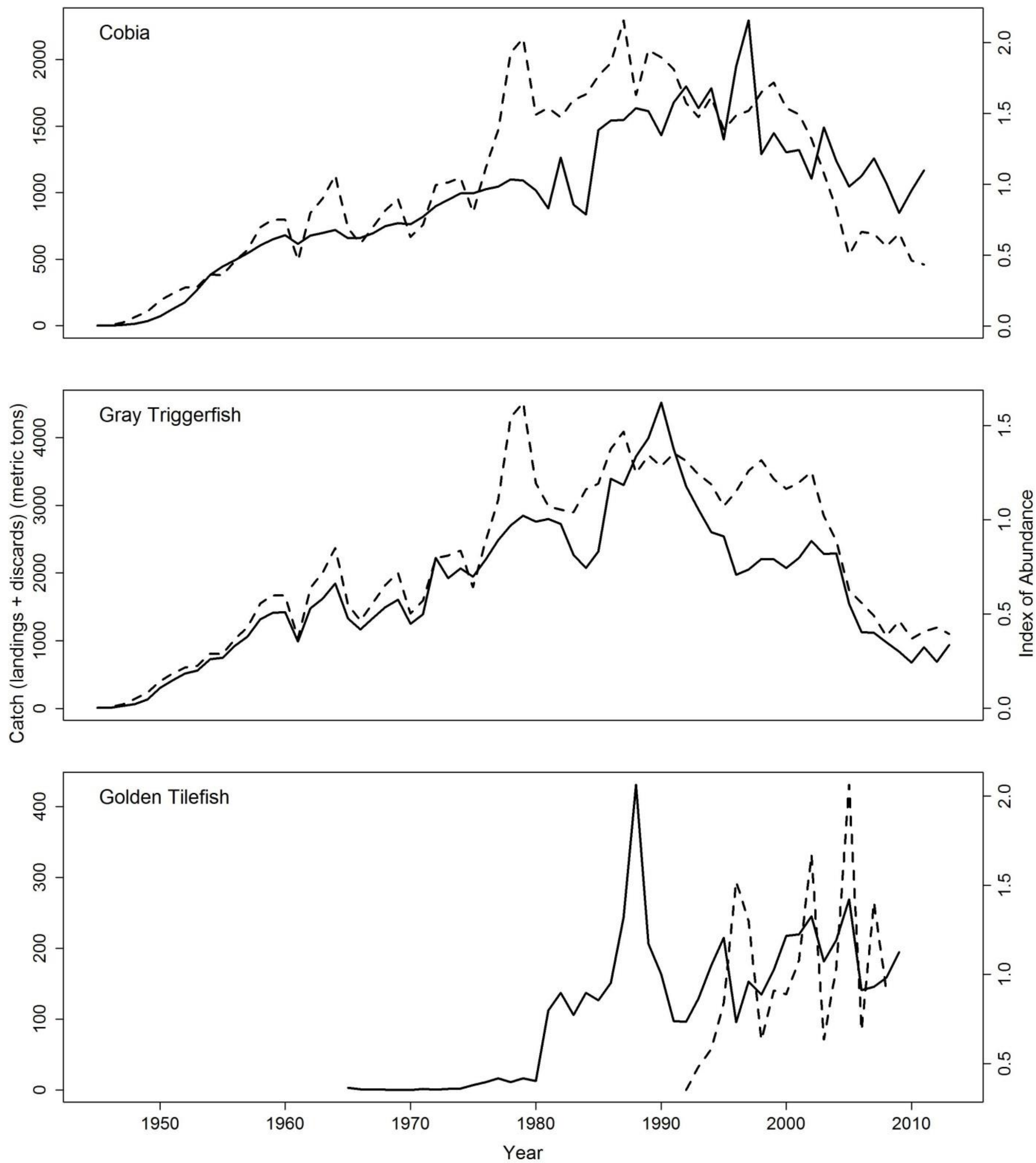

Fig. 2. MSE-based tradeoffs of applicable data-limited methods for Gulf of Mexico cobia, gray triggerfish, and golden tilefish in terms of the probability of overfishing, relative long-term yield, and the probability of the stock biomass dropping below B_{MSY}.

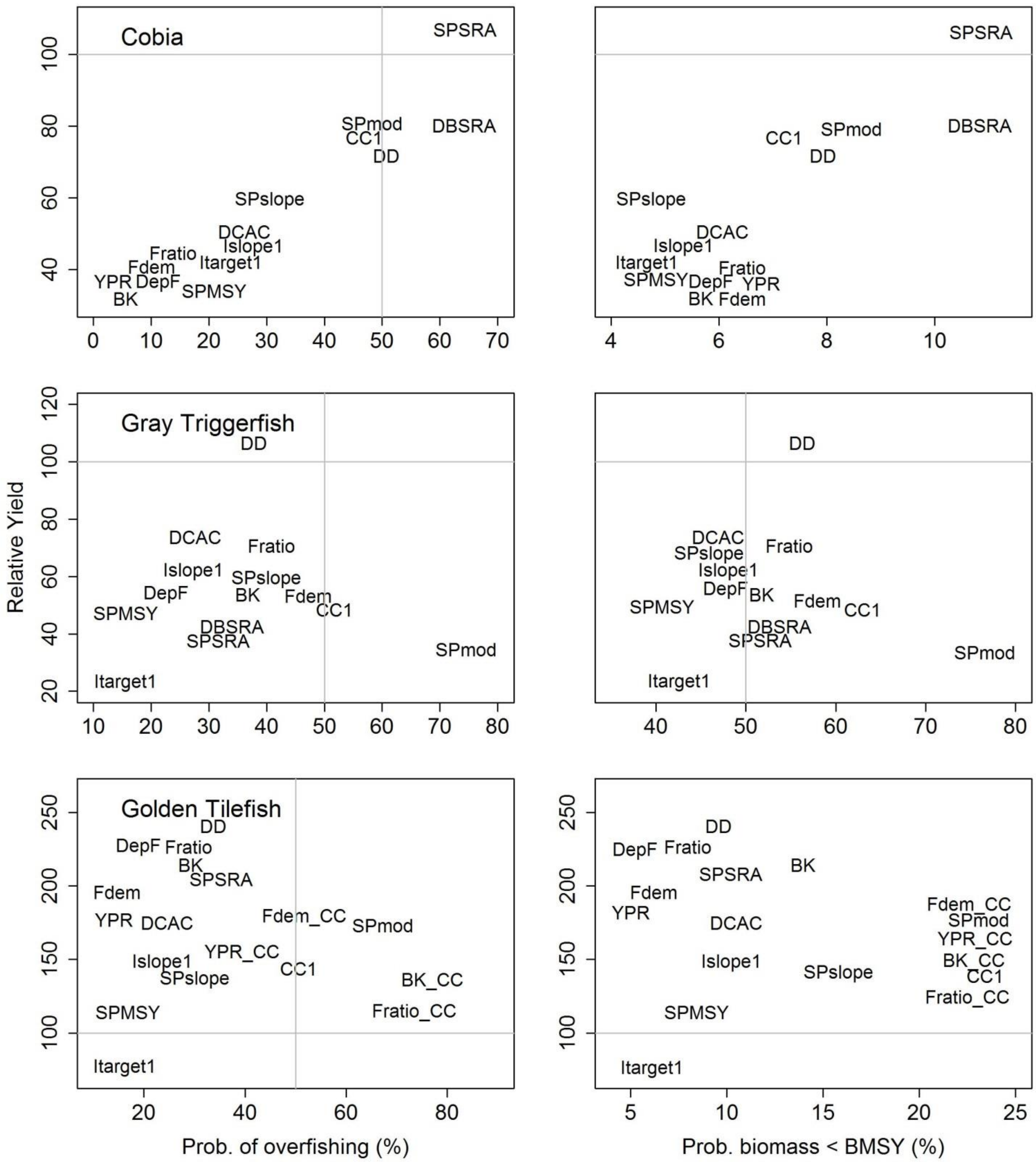

Fig. 3. Comparison of relative absolute errors between Stock Synthesis and data-limited methods for cobia, gray triggerfish, and golden tilefish. Note that analysis assumes that the Stock Synthesis OFL is the ‘true’ value and *y*-axes have been clipped at 5.

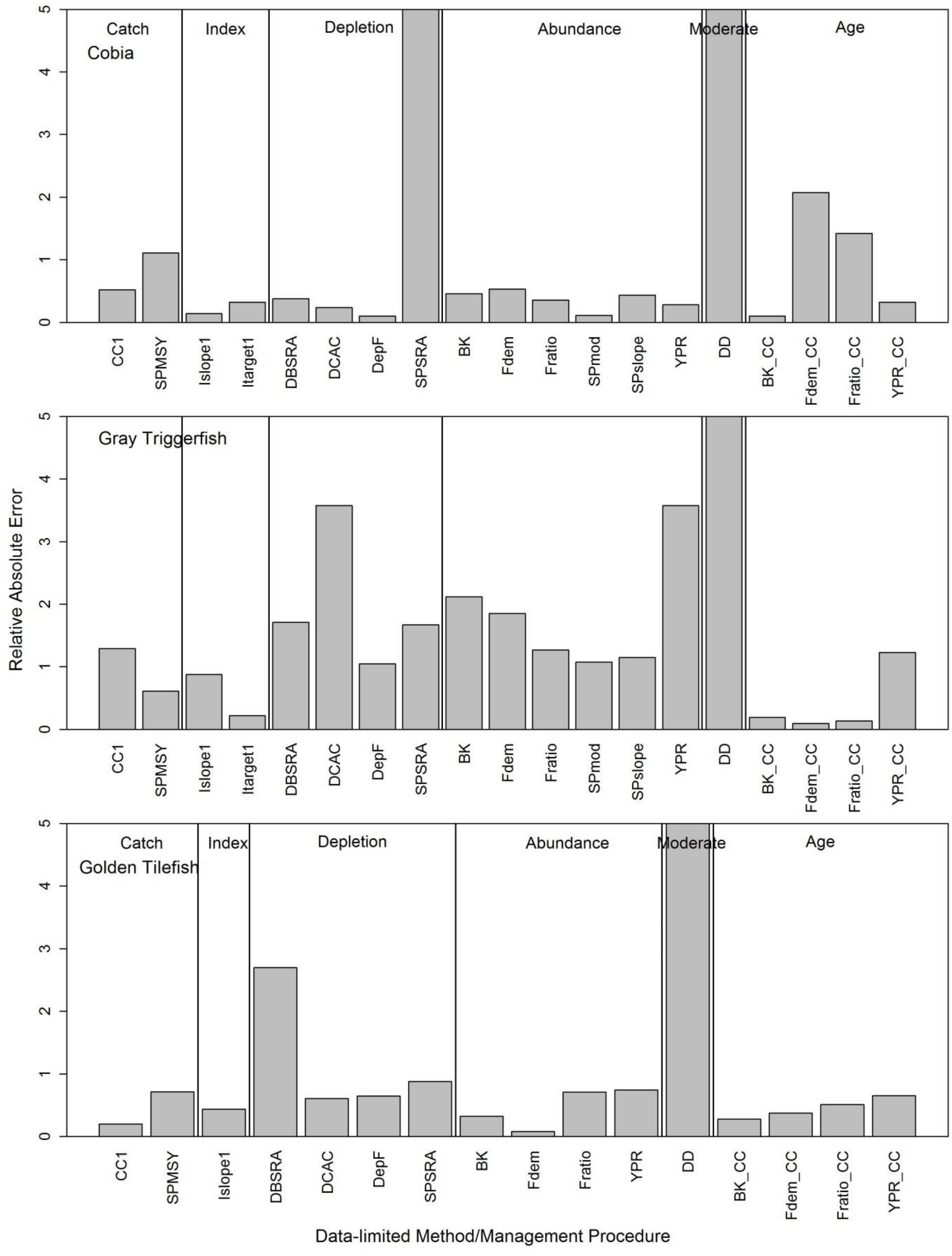

Fig. 4. Comparison of the overfishing limits (OFL) estimated by the data-rich Stock Synthesis model and data-limited methods for Gulf of Mexico cobia. Methods are as defined in Table 2. Note that primary and secondary *y*-axes display data-limited and data-rich SS methods, respectively, and that axes differ between panels.

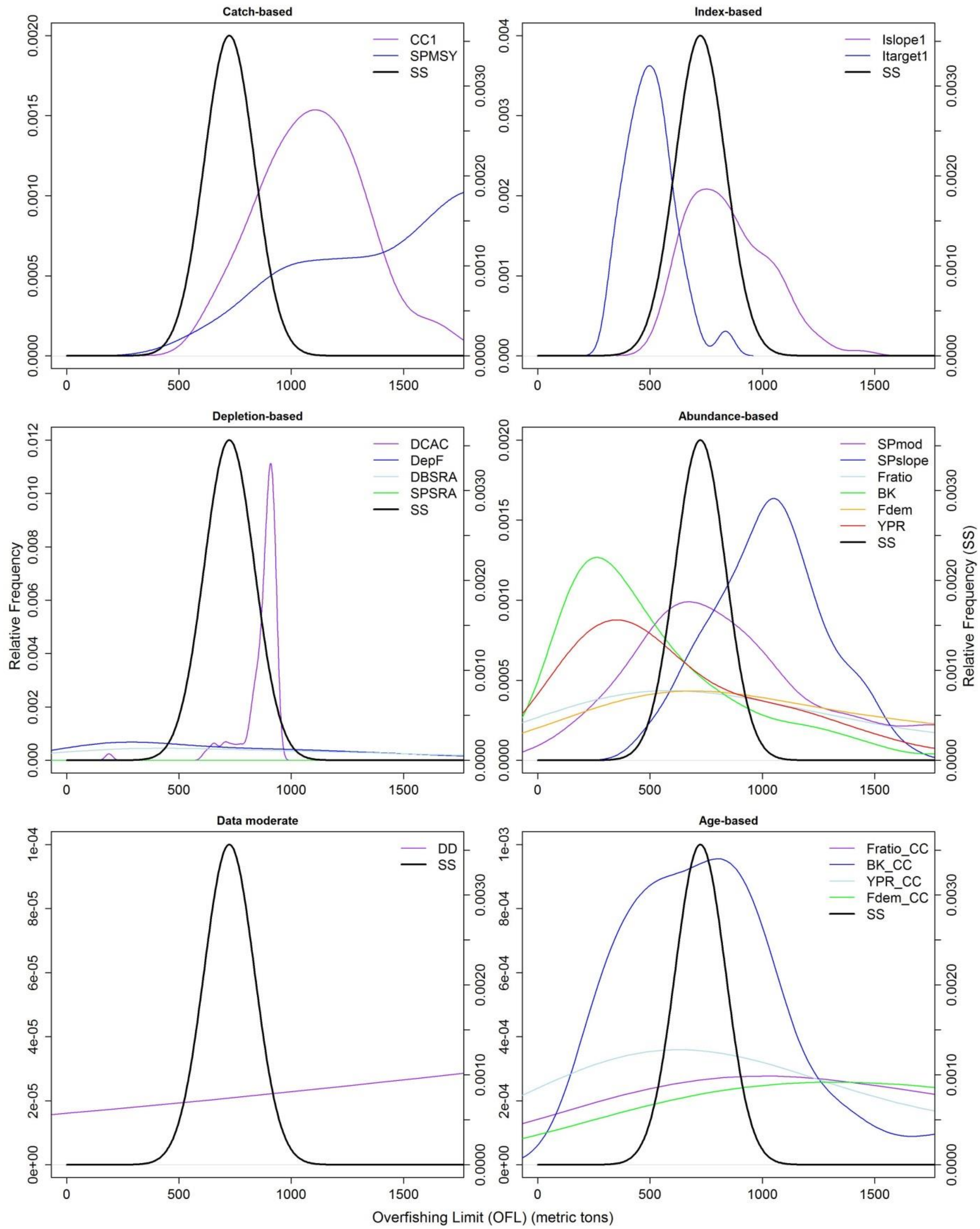

Fig. 5. Comparison of the overfishing limits (OFL) estimated by the data-rich Stock Synthesis model and data-limited methods for Gulf of Mexico gray triggerfish. Methods are as defined in Table 2. Note that primary and secondary *y*-axes display data-limited and data-rich SS methods, respectively, and that axes differ between panels.

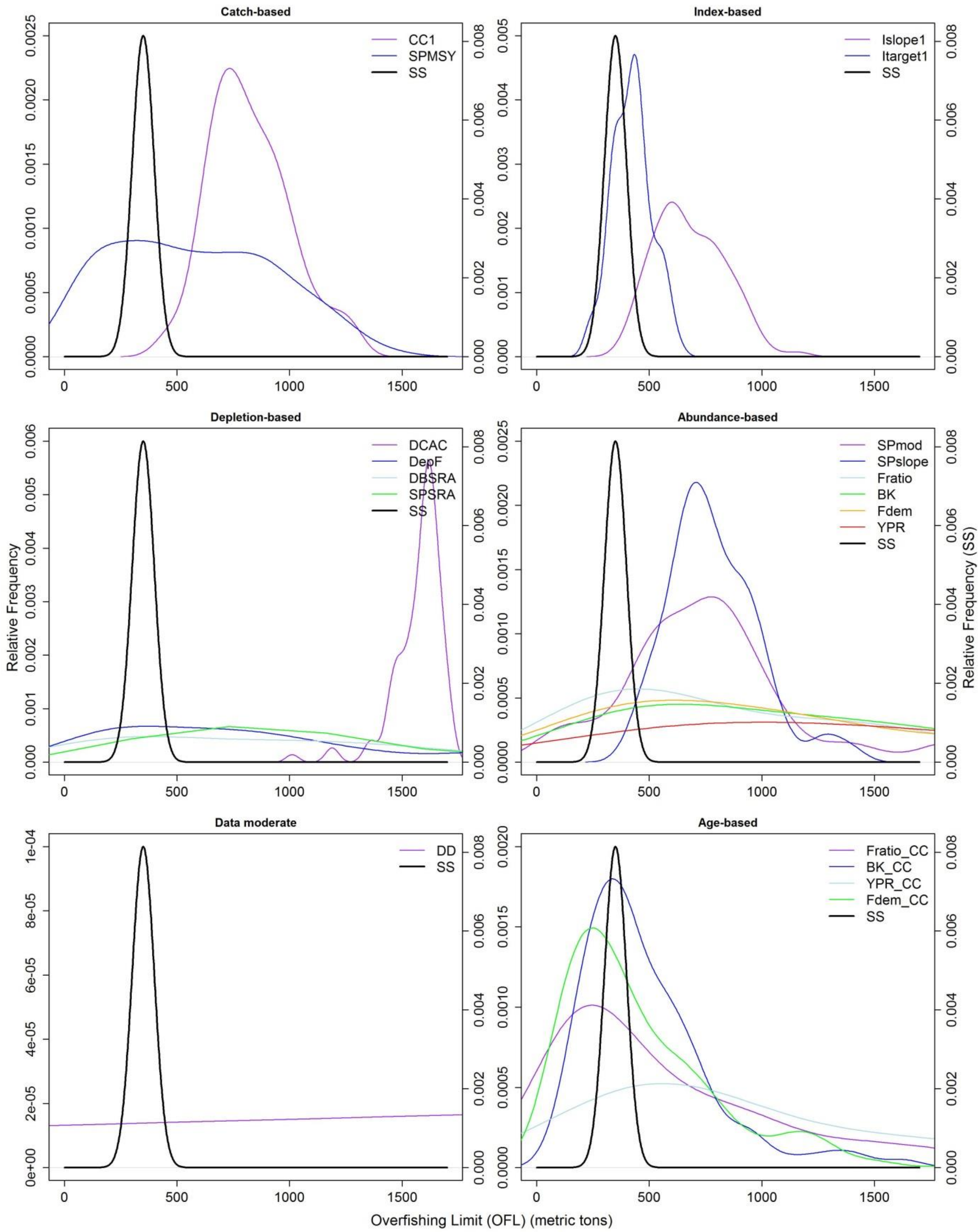

Fig. 6. Comparison of the overfishing limits (OFL) estimated by the data-rich Stock Synthesis model and data-limited methods for Gulf of Mexico golden tilefish. Methods are as defined in Table 2. Note that primary and secondary *y*-axes display data-limited and data-rich SS methods, respectively, and that axes differ between panels.