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Overfishing limits (OFLs) for Greater Amberjack from the Stock Synthesis (SS) population model and from several data limited methods with a preliminary review of varying assumptions on natural mortality and current abundance on OFL results

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Introduction

In the US, fishery management of federal resources are carried out under the Fishery Conservation and Management Act of 1976; reauthorized in 1996 as the Magnuson-Stevens Act (MSMA). National Standard 2 of the MSMA states that "conservation and management measures shall be based upon the best scientific information available". However in many regions of the world including the US and in particular the US Caribbean, the required data necessary to conduct sound stock assessments is considered lacking, making it difficult to provide management advice and develop robust harvest strategies that will ensure sustainable resources. The implementation of annual catch limits by the US MSMA in 2006 to prevent overfishing of federal fishery resources makes this situation even more challenging.

Carruthers et al. (2014) described the process under the National Standard 1 (NS1) on settling ACLs in the US as stipulated by the federal fisheries management agency in the US, the "National Marine Fisheries Service's (NMFS) NS1 Guidelines". Briefly, "setting ACLs is a three-step process that begins by identifying an overfishing limit (OFL). The OFL is the annual catch when fishing the stock's current abundance at the maximum sustainable fishing mortality rate (FMSY). In the second step, a harvest control rule is used to determine the acceptable biological catch (ABC). The ABC is a catch level equal to or less than the OFL that accounts for the scientific uncertainty in the estimate of the OFL. Finally, fisheries managers use the ABC to establish an ACL. The ACL is set to a level equal to or below the ABC and accounts for various ecological, social and economic factors in addition to uncertainty in management controls". As noted by Carruthers et al., the basis for OFL determination originates through conducting a stock assessment, the latter required under MSRA (NS2) to be based on the "best scientific data available" as noted above. Such an evaluation typically incorporates information such as: a time series of catch and abundance, observations of abundance from a survey or fishery dock side sampling or logbooks and life history input; however, frequently these statistics do not exist for many fisheries and thus less robust stock evaluation method are sometimes employed to overcome these data limitations.

This work that follows was developed from the intent to explore use of more recently developed data-limited methods for the purpose of deriving OFLs in situations where data are considered insufficient for traditional stock assessment methods. Carruthers et al. (2014) noted the utility of conducting comprehensive management strategy evaluations (MSE) to address this issue. This work should be considered as a preliminary evaluation of impacts from assumptions of several important model inputs regarding current stock status and natural mortality on the OFL calculations. The Gulf of Mexico greater amberjack stock was considered in this evaluation as it provided a basis to address results from application of data limited methods against OFL results from a recent evaluation that employed a data-rich integrated assessment model (Stock Synthesis). The results of the OFL comparisons between models and results of sensitivity analyses are presented with the aim to provide guidance on developing an operating model for this species to consider under a comprehensive management strategy evaluation.

Methods

Species of study- Greater amberjack

Greater amberjack, *Seriola dumerili,* is a subtropical species, associated commonly with rocky reefs, floating debris, and wrecks ranging from 60-240 feet with young individuals observed exhibiting schooling behavior. The greater amberjack is the largest of the jack species and young individuals are easily confused with other members of the jack family (i.e., banded rudder and Almaco) (https://www.flmnh.ufl.edu/fish/Gallery/Descript/GreaterAmberjack/GreaterAmberjack.html). The species is widely distributed from Virginia to Florida on the U.S. Atlantic coast, from Florida through Texas in the Gulf of Mexico, into the Caribbean, and into waters off Central and South America to Brazil. Definitive information on the stock structure is not available (Cummings and McClellan 1997) however the population is managed as two separate stocks (Gulf of Mexico, South Atlantic). Greater amberjack have always been an important by-catch in reef fish fisheries throughout the Gulf of Mexico and south Atlantic and are frequently the primary species targeted by recreational and commercial fishermen along the southeast coasts of the United States (Cummings and McClellan 1997). In the Gulf of Mexico commercial landings of this species rose explosively during the 1980s in response to two main factors: 1) an increase in interest by recreational fishers for this species and 2) increased demand of greater amberjack as a substitute for blackened redfish. Landings in the Gulf of Mexico rose from ~800 mt pounds in the early 1980s to a high of ~ 5,000 mt in 1991 and since then dropped dramatically (SEDAR 2013) (Figure 1). SEDAR 33 provides the management history of the GOM stock and information on historical catches. Strict regulations have been in place since 1998 within the Gulf of Mexico fishery. Recreational fishers are limited to a 1-fish bag limit and a 32" minimum length while commercial fishes are restricted to a minimum size of 36" in length. In addition, seasonal closures were implemented to reduce fishing mortality on the spawning stock. The GOM greater amberjack stock has been considered overfished and undergoing overfishing since ~ 2006, although concerns regarding the stock status were voiced by researchers and stakeholders beginning in the early 1990s.

Data-rich model: Stock Synthesis

The primary assessment model selected for the Gulf of Mexico Greater amberjack stock evaluation assessment was Stock Synthesis (Methot 2010) SS-V3.24S-safe; 07/24/2013 (see http://sedarweb.org/sedar-33-stock-assessment-report-gulf-mexico-greater-amberjack). Stock Synthesis has been widely used and tested for assessment evaluations, particularly in the US west coast NMFS centers (Methot 2009). Descriptions of SS algorithms and options are available in the SS user's manual (Methot and Wetzel 2013) and at the NOAA Fisheries Toolbox website (http://nft.nefsc.noaa.gov/).

Stock Synthesis (SS) is an integrated statistical catch-at-age model widely used for stock assessments in the United States and throughout the world. SS takes relatively unprocessed input data and incorporates many of the important processes (mortality, selectivity, growth, etc.) that operate in conjunction to produce observed catch, size and age composition and CPUE indices. In addition, SS can incorporate time series of environmental data. Because many of these inputs are correlated, the concept behind SS is that they should be modeled together, which helps to ensure that uncertainties in the input data are properly accounted for in the assessment. SS has the ability to incorporate an early, data poor time period for which only catch data are available and a more recent, data-rich time-period for which indices of abundance and length and age-length or age composition observations are available.

As noted by the companion manuscript in this workshop (Sagarese et al. 2015), 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 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 relating to the combined recreational private and charter fleet was selected as this fleet represents the dominant fleet targeting the species and was considered most representative of the fishery geographically. In addition, it was felt that the commercial fleets (i.e., , vertical line, bottom long line) were not the best fleets to infer the population dynamic's as they do not target this species; catches are considered indirect to the primary fishing activities of these fleets. Both length at first capture (LFC) and length at full selection (LFS) were estimated from fleet selectivity curves obtained during the assessment. 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). 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 2015).

Data-limited methods (DLM) Toolkit

As noted in the companion paper of this workshop (Sagarese et. al. 2015), several DLM methods were examined (Table 2) and comprehensive details have been provided elsewhere (Carruthers et al. 2014, Newman et al. 2014, Carruthers et al. in press). As described by Sagarese et al., depletion-based methods (e.g., Depletion-Based Stock Reduction Analysis; Dick & 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 & MacCall 2011, Carruthers et al. 2014). Abundance-based methods (e.g., Beddington & Kirkwood 2005) were tested that rely on current estimates of absolute abundance and F_{MSY} (Carruthers et al. 2014). Simple catch-based methods or catch scalars (e.g., average catch; Newman et al. 2014) were also tested, which rely solely on time series of recent catches. The intent of conducting multiple DLM methods was to examine OFL results in relation to a variety of model input assumptions with the aim to identify patterns between model groups that could aid in 1) evaluating use of the DLM models for greater amberjack in the context of data rich vs data moderate/poor requirements and 2) aid in development of subsequent MSE evaluations for this species.

Model evaluation

Model evaluation was carried out as described in Sagarese et al. 2015 (this workshop). 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 extracted from SS for the three years following the terminal assessment year, due to the fixing of catch and F in the first few years of projections. For greater amberjack, the forecasted retained catch (forecatchret) from SS was considered most representative of the OFL because it inherently takes into account fishery discards which can be substantial.

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 & MacCall 2011) was calculated with the following equation:

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

where $\text{OFL}_{\text{assessment}}$ 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.

Results

Comparison of Greater amberjack OFLs between DLMs and SS estimates of OFLs

The majority of the DLM methods examined for greater amberjack produced relative absolute errors below 1.0; the exception was the Delay Difference methods (Figure 2). The methods examined for greater amberjack were further categorized according to type of DLM based on data inputs (catch-based, index-based, depletion-based, abundance-based, data moderate or age-based). The DLM methods producing the lowest RAEs were generally the index based methods followed by the catch-based, and then the depletion methods. RAEs from the abundance or data moderate DLM were usually ~ two fold higher than other DLM models. RAEs from the abundance DLMs were usually similar on the order of 0.5 or less except for the Catch trend surplus production MSY (SPslope) DLM (Figure 2).

The Index- and Catch-based DLMs produced relatively similar OFL distributions compared to SS (Fig. 3). Depletion, abundance, and age-based DLMs produced OFL distributions generally lower than SS.

Most DLMs produced relatively wide OFL distributions in comparison to the SS OFL distribution. The depletion corrected average catch (DCAC), the slope index harvest control rule (GB_slope), and the yield per recruit (YPR_CC) DLMs all produced RAEs below 0.1 and median quotas within 40% of the SS-derived OFL (Table 2).

Sensitivity of OFL calculations to Natural Mortality and Current Abundance Input

Quota recommendations were frequently sensitive to data inputs across all DLM methods explored (Figures 4 and 5). For almost all applicable DLMs, quota recommendations were particularly sensitive to catches (Cat), natural mortality (Mort), abundance estimates, and depletion estimates, with higher data inputs corresponding to higher quotas. Quota recommendations were occasionally sensitive to life-history parameters relating to growth and maturity including age at maturity (Appendix 1, Supplement).

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The work of all the individuals involved in the data collection informing the SEDAR 33 GOM greater amberjack stock assessment is acknowledged and appreciated. We are grateful for DLM Toolkit being made available to us by the developer for this work. This research was carried out under the NOAA, SEFSC strategic plan and also [in part] under the auspices of the Cooperative Institute for Marine and Atmospheric Studies (CIMAS), a Cooperative Institute of the University of Miami and the National Oceanic and Atmospheric Administration, cooperative agreement #NA17RJ1226.

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Table 1. Summary of data extracted from the Stock Synthesis assessment models for Gulf of Mexico for Greater amberjack input into data-limited methods DLM Toolkit

DLM input[a]	Description/SS output	
General		
Name	Species name	Greater amberjack
Year	Years corresponding to Cat & Ind	1950−2012
t	Length of Year	63 yr
Units catch	–	metric tons (mt)
SigmaL	Sigma length composition	0.3
Life-history		
Mort	Natural mortality	0.28 yr^{-1} (0.3)
AM	Mat 50% Fem	3.0 yr (0.2)
vbt0	Von Bertalanffy t0	−0.95yr (0.02)
vbK	Von Bertalanffy K	-0.20yr(0.01)
vbLinf	L at Amax	143.6 cm (0.02)
wla	Wtlen 1 combined sexes, FL cm	7.05E-05 (0.1)
wlb	Wtlen 2 combined sexes, FL cm	2.63 (0.1)
steep	SR BH steep	0.90 (0.2)
MaxAge	Maximum age	10 yr
Fishery		
Cat	Annual sum of catch (landings + discards)	793 - 4,863 mt (0.5)
AvC	Mean Cat	1718 mt (0.54)
LFC	Length at first capture	10 cm (0.5)
LFS	Smallest length at full selection	35 cm (0.14)

CAA	Catch-at-age from assessment (prop x Nsamp)	24 yr x 10 ages
CAL_bins	Catch-at-length bins	10 - 200 cm, 5-cm Fork Length bins
CAL	Catch-at-length from assessment (prop x Nsamp)	33 yrs x 38 5- cm FL length bins
FMSY_M	Fstd MSY / Mort	0.89 (0.2)
BMSY_B0	SSB MSY / SBzero	0.32 (0.2)
Cref	TotYield MSY	1335 mt (0.07)
Bref	SSB MSY	1398 mt (0.39)
Abundance		
Ind	Index of abundance from MRFSS charter and private combined	Unit of cpue= catch per angler hour
Dt	Depletion over time series from sprseries	0.09 (0.33)
Dep	Current depletion (2012)	0.15(1.0)
Abun	Terminal year abundance	2136.17(171.22)
Reference		
Ref	Median OFL (SD)	1633.11 (428.85) (forecatchret)
Ref_type	Reference document	SEDAR33

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

Table 2. Summary of data-limited methods employed. Additional details on each method available in Newman et al. (2014), Carruthers (2015), 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: λ = 0.4, TAC = 0.8 x $C^{average}$)	Geromont and Butterworth (2014b); Carruthers et al. (in press)
GB_slope	Slope index harvest control rule (TAC adjusted depending upon trend in recent survey index)	(Geromont & Butterworth 2014a); Carruthers et al. (in press)
Depletion-based		
DCAC	Depletion-Corrected Average Catch (DCAC)	MacCall (2009); Carruthers et al. (2014)
DepF	Depletion Corrected Fratio	Carruthers (2015)

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	C. Walters (in Carruthers

	assessment model	et al. 2014)
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 2015)
Fdem_CC	Demographic F_{MSY} method that uses a Catch Curve to estimate recent Z	McAllister et al. (2001)

Table 3. DLM OFL Resulting Metrics for GOM greater amberjack for the minimum, maximum, median and 25 and 75 percentiles. Units are mtons whole weight.

DLM Tool Category	Meths	min	25P	median	75P	max	RAE	% Difference in DLM OFL from SS OFL
Catch	CC1	1033.17	1414.09	1695.46	1971.53	2775.30	0.39	-138.09
Catch	SPMSY	33.06	481.21	819.85	1098.41	1627.63	0.33	-66.26
Index	Islope1	783.52	1198.64	1341.50	1585.85	2158.50	0.10	-109.05
Index	GB_slope	1134.54	1134.54	1202.57	1701.82	1701.82	0.01	-97.65
Depletion	DCAC	22.61	992.31	1267.19	1415.73	1586.62	0.04	-102.96
Depletion	DepF	24.56	172.14	329.40	533.60	1732.69	0.73	-26.02
Depletion	DBSRA	52.52	255.66	555.15	1644.14	5493.25	0.54	-44.54
Depletion	SPSRA	59.67	367.10	1041.57	61534.71	524436.28	0.15	-84.45
Abundance	SPmod	308.69	772.63	979.51	1390.53	2498.57	0.20	-79.36
Abundance	SPslope	0.00	0.00	0.00	0.00	0.00	1.00	1.00
Abundance	Fratio	50.97	271.65	510.93	798.80	2763.41	0.58	-40.91
Abundance	BK	34.08	185.15	269.94	485.10	1892.54	0.78	-21.14
Abundance	Fdem	67.39	382.43	630.62	1092.27	6217.93	0.48	-50.73
Abundance	YPR	72.22	388.12	645.92	1292.42	4493.52	0.47	-51.99
Data Moderate	DD	453.30	1424.36	2849.36	4872.50	19766.26	1.34	-232.75
Age	Fratio_CC	279.37	497.83	820.74	1180.83	2844.89	0.33	-66.33
Age	BK_CC	99.35	315.80	499.33	678.06	1635.69	0.59	-39.96
Age	YPR_CC	245.49	726.63	1159.40	1668.02	4693.88	0.05	-94.11
Age	Fdem_CC	276.28	648.66	1073.17	1575.47	5361.72	0.12	-87.04

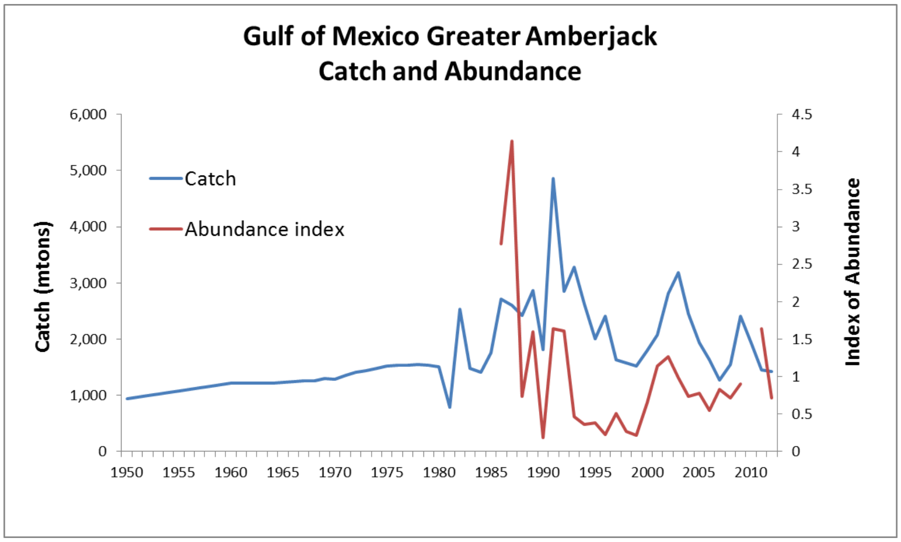

Fig. 1. Time series of catch (landings + discards; solid line) and indices of abundance (dashed line) for Greater amberjack. Indices of abundance are derived from the recreational charter and private angler MRFSS catch per unit of effort index standardizations (reference). Units are mtons whole weight (catch) and standardized catch per angler hour (Index).

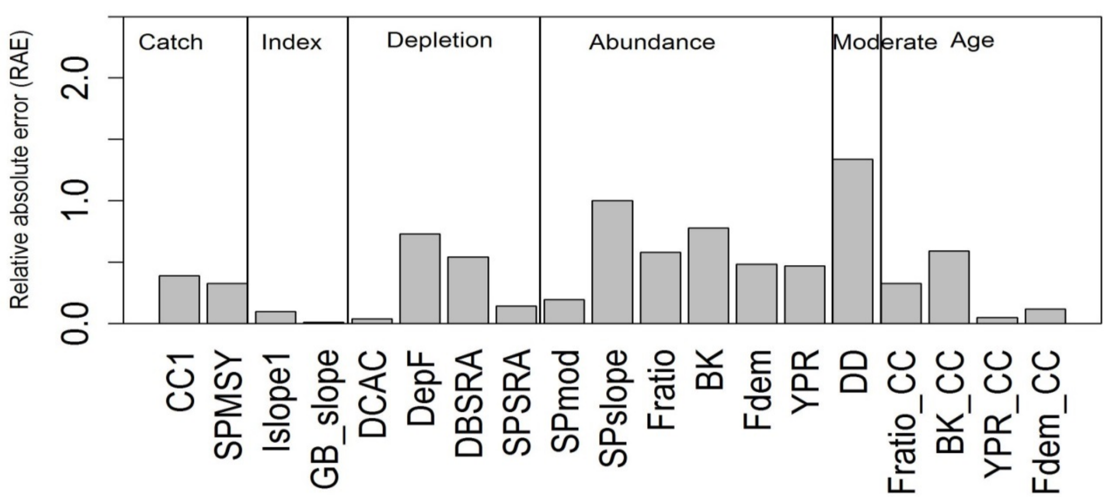

Fig. 2. Comparison of relative absolute errors between Stock Synthesis and data-limited methods for GOM greater amberjack. Note that analysis assumes that the Stock Synthesis OFL is the 'true' value from the MLE estimator.

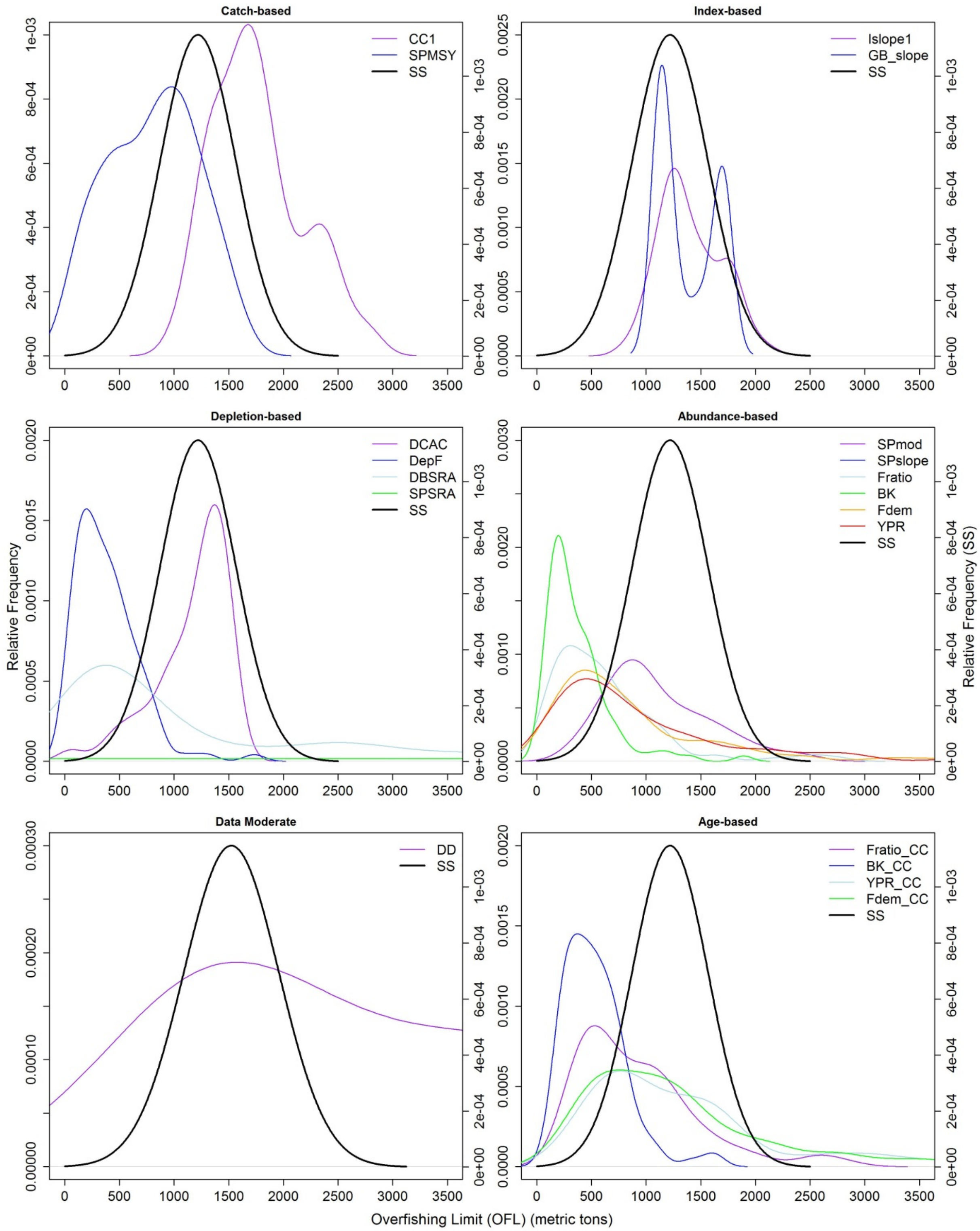

Figure. 3. Comparison of the overfishing limits (OFL) estimated by the data-rich Stock Synthesis model and data-limited methods for Gulf of Mexico Greater amberjack. OFL calculation methods are as defined in Table 2.

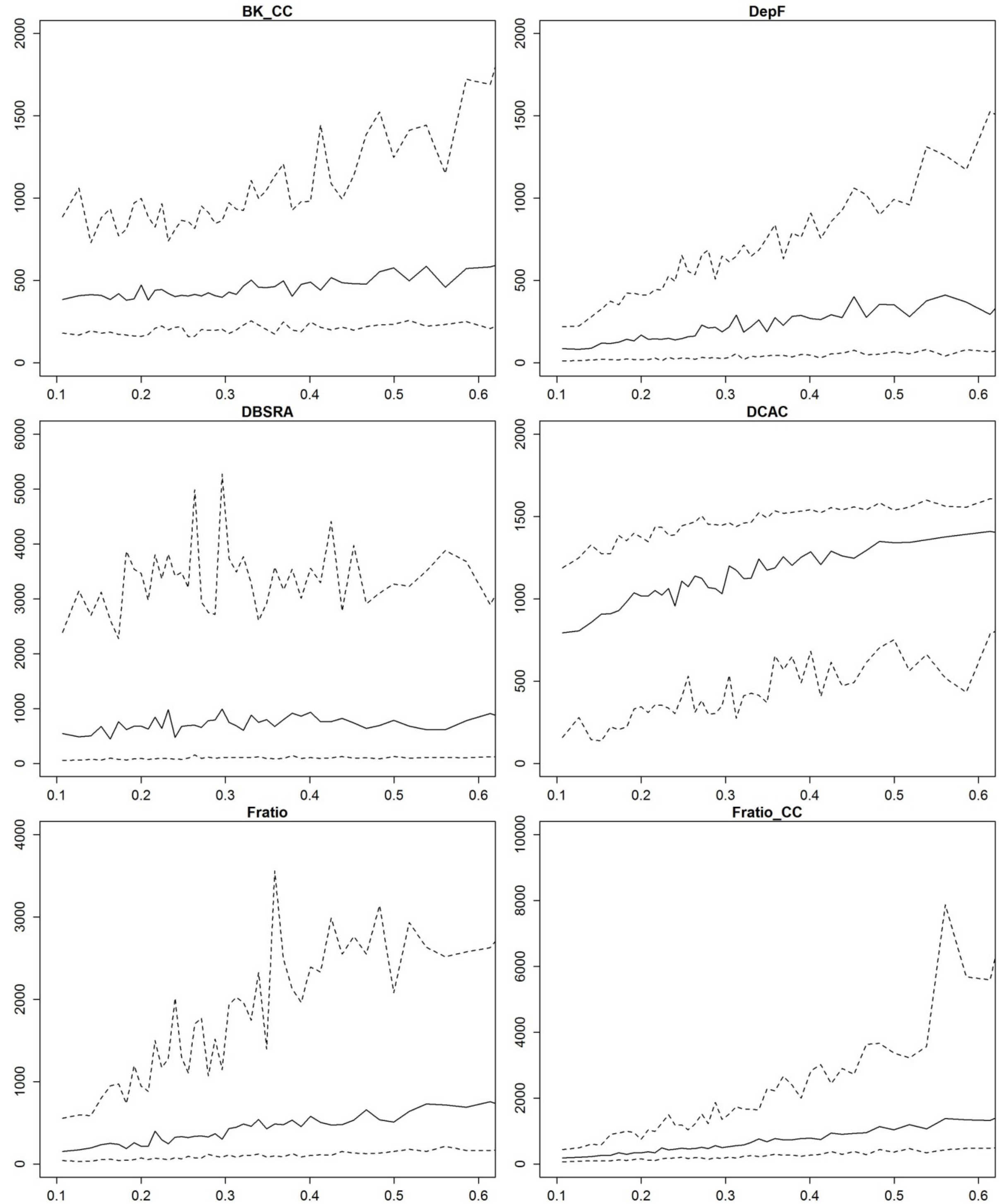

Figure 4a. Results of sensitivity analyses on OFL calculation for natural mortality.

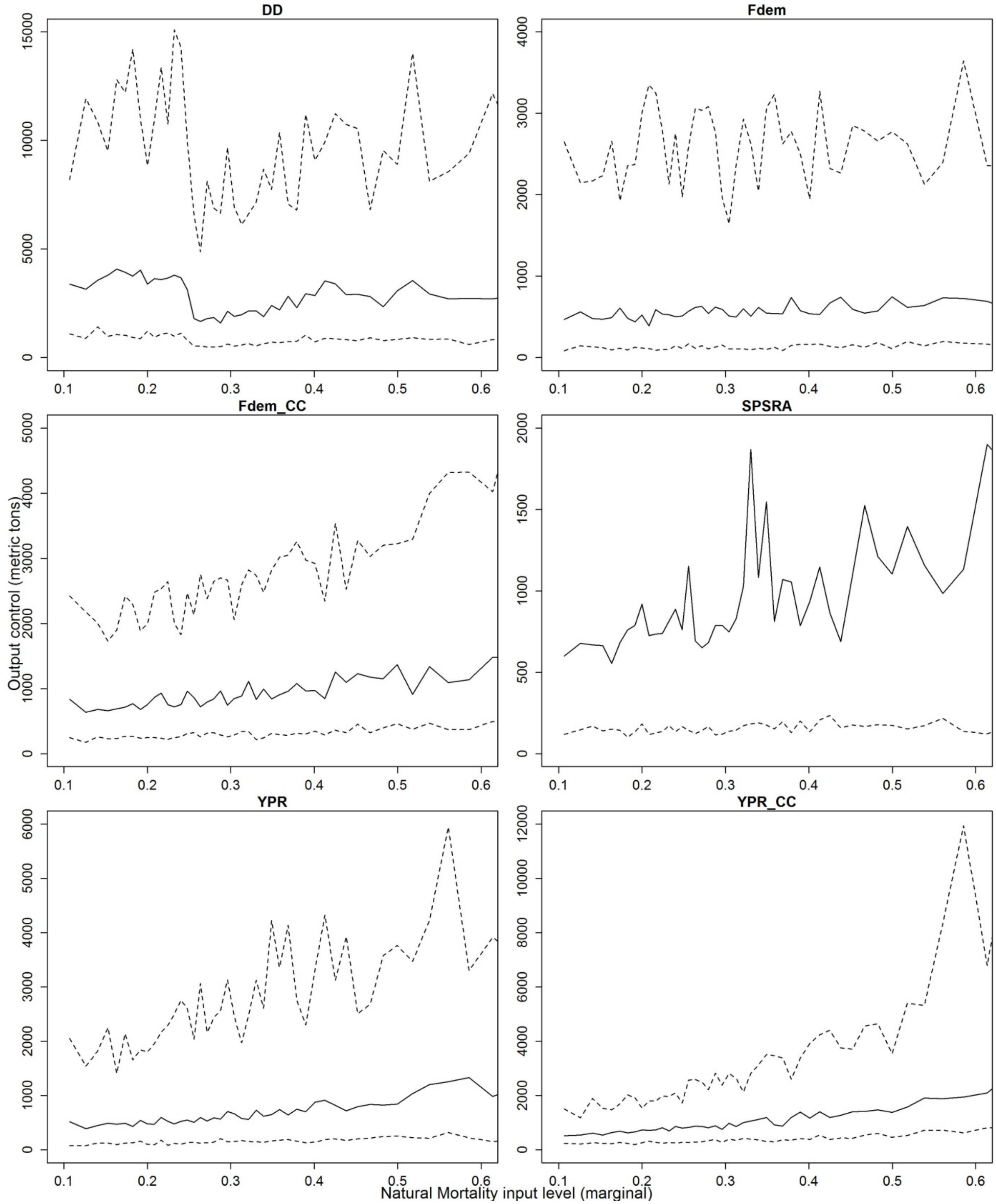

Figure 4b. Results of sensitivity analyses on OFL calculation for natural mortality

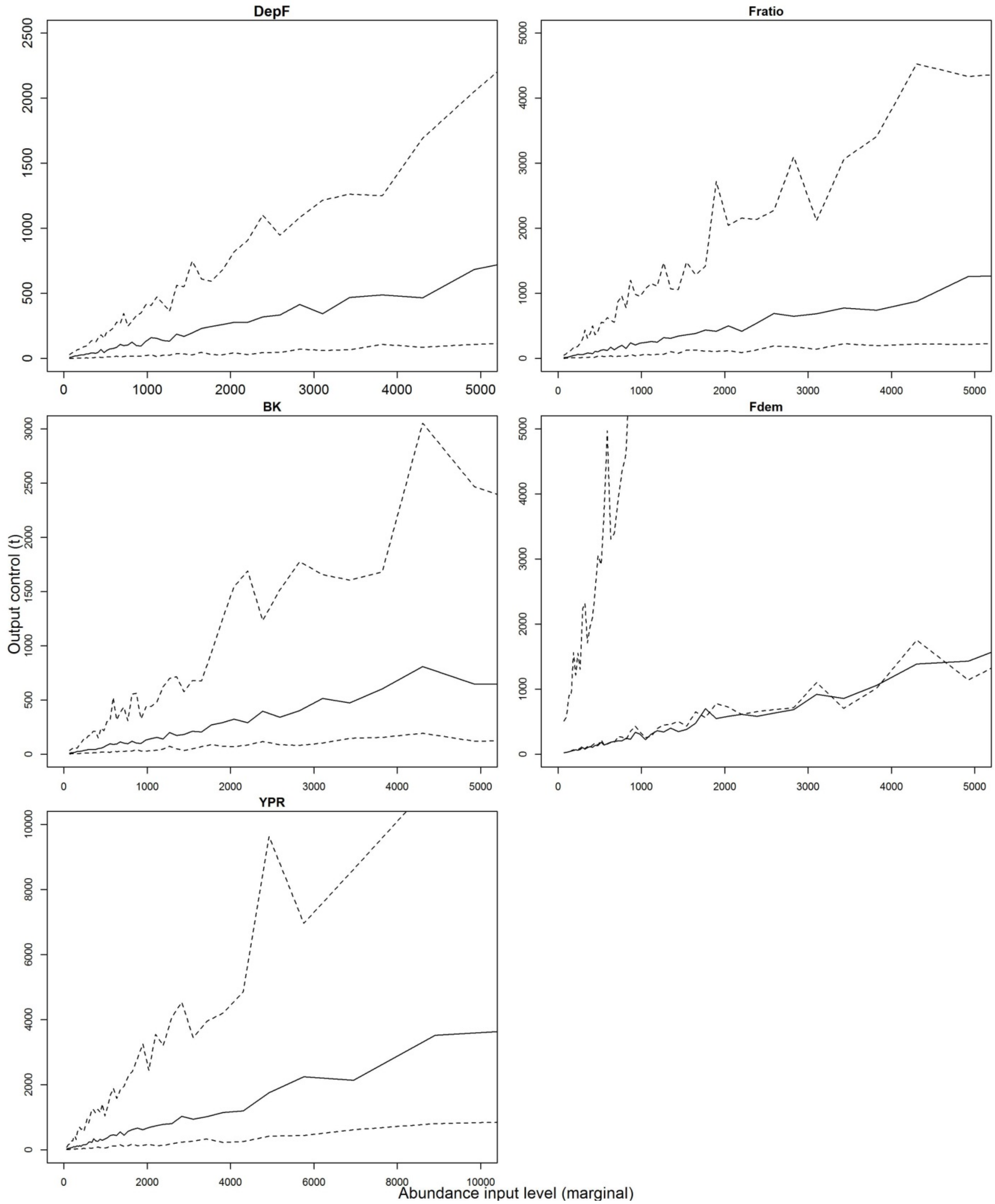

Figure 5. Results of sensitivity analyses on OFL calculation for current abundance.

Appendix 1. DLM Sensitivity analysis results for full suite of DLM models.

See Document Titled SEDAR 46 DLM Sensitivity Analyses for Gulf of Mexico Greater Amberjack Supplement to SEDAR 46 Working Paper Cummings and Sagarese 2015.