Evaluating the reliability of MULTIFAN-CL assessments of the North Pacific swordfish population[1]

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Abstract

In this paper we describe some exploratory testing of the sensitivity of MULTIFAN-CL (MFCL, Fournier et al. 1998) to simulated swordfish data through the use of an operational model. Four simulated swordfish population and fishery scenarios were developed for MFCL analysis. Scenarios differed in spatial stratification and time-series variation in catchability. MFCL fit the simulated length-frequency, catch and effort data with differing structural assumptions for natural mortality and catchability. Results of the simulated "actual" values and estimated MFCL parameter values are summarized for natural mortality (*M*), mean biomass, starting biomass, ending biomass, mean recruitment, mean fishing mortality (*F*) by year, and reference points BF_e/BF_s and BF_e/B_e. Estimated length-at-age and the growth trajectory were in good agreement with actual values. For each scenario, there was a substantial departure in the estimated value of natural mortality as mean values were ~0.6 yr^{-1} compared to simulated values of 0.2 yr^{-1}. Reference point estimates of BF_e/BF_s and BF_e/B_e were better determined if there was no underlying trend in catchability. In general, there was less bias in estimating a trend in catchability when there was no actual trend compared to assuming a lack of a catchability trend when there was an actual trend.

Introduction

The North Pacific swordfish stock was assessed with MULTIFAN-CL (MFCL, Fournier et al. 1998) software at the third meeting of the ISC (Kleiber and Yokawa 2002). The assessment included data from Japanese and Hawaii-based longline fleets with a spatial structure of 4 regions in the North Pacific. The recommendations from ISC3 included an objective to develop, test and apply basin-scale swordfish simulation model to test the sensitivity of the MFCL assessment. The following represents an exploratory analysis with the swordfish simulation to highlight areas where biases may be introduced in MFCL analyzes and evaluate consequences of assumptions typically assumed in stock assessments.

Methods

Simulated swordfish stock and fisheries

An operational model was designed and developed at the Pacific Islands Fisheries Science Center to evaluate the performance of stock assessment methods (Labelle 2002). The model accounts for growth, reproduction, mortality, recruitment and movement of a North Pacific swordfish stock. The current version of the model allows exploitation of multiple stocks by multiple fisheries in 10 regions (Figure 1) and projects trends in abundance, catches, recruitment and spawning biomass and total biomass. Catch and effort statistics used for the various fisheries in the North Pacific reflect the exploitation history. The operational model has a variety of options and criteria such as: 1) catch under-reporting, 2) ageing errors, 3) Ricker or Beverton-Holt stock recruitment function, 4) designation of annual natural mortality, 4) differential natural mortality between males and females, 5) sexually dimorphic growth, 6) Allee effects, 7) variation in catchability (q) and 8) additional realizations of the swordfish population through the use of random number seeds that generate unique estimates of recruitment, fish distribution and error terms.

The model produces a file for MFCL testing which contains estimates of nominal effort, catch (swordfish pieces) and length frequency observations for each fishery for 45 years (1952–1996) at a quarterly resolution. The model produced 31 fisheries which are defined according to gear type and region. Gear types included Japanese, Korean, Taiwanese and US longline, drift gill net and harpoon.

Four simulated scenarios were developed for MFCL analysis. For each scenario, five realizations were simulated to estimate the statistical properties of the MFCL parameter estimates. Scenarios differed in spatial stratification and time-series variation in catchability (q):

- Scenario 1 had 10 regions, 31 fisheries with no time-series variation in catchability
- Scenario 2 had 10 regions, 31 fisheries with time-series variation in catchability for the Japanese longline fleet.
- Scenario 3 aggregated the 10 region and 31 fisheries into 4 regions (Figure 2, northwest, northeast, southwest and southeast) and 6 fisheries (4 longline fisheries plus a gill net fleet and a harpoon fleet) with no time-series in variation catchability.
- Scenario 4 had 4 regions, 6 fisheries with time-series variation in catchability.

Standard deviation in length-at-age is a linear function of the mean length (SD=1+0.053·mean) in all scenarios. There was no sexually dimorphic growth as growth was similar for males and females. Natural mortality rates (M) were set to $0.2 \cdot yr^{-1}$ with no differential mortality between sexes. A Beverton-Holt type stock-recruit function was used to predict recruitment and recruits occurred in regions 5 and 9 in the 10 region model (Figure 1) and region 1 and 2 in the 4 region model (Figure 2). Age-1 individuals were distributed according to region size. Movement was enabled between regions. All individuals were susceptible to harvest by longline fisheries (no gear selectivity) whereas, selectivity increases from 0.4 to 1.0 for ages 1 to 5 in the other fisheries. The catchability coefficient for the Japanese fleet declined by 2% per year as a power function, thus in year 1996 the catchability coefficient was 40% of year 1952. No tag release-recapture data are used in the analysis though these data could be accommodated in the operational model.

Description of MFCL test procedures

The structural assumptions used in the MFCL analyses are summarized in Table 1. In some aspects, MFCL analyses were similarly structured to the simulation conditions: data remained as quarterly observations, no differential growth/mortality, no measurement/observation errors and no age-dependent mortality. Structural assumptions for natural mortality and time-series variation in catchability were altered in the MFCL analyses, thus for each realization there were four (2 *M* x 2 *q* matrix) MFCL tests:

- MFCL test procedure 1 - natural mortality (*M*) fixed at $0.2 \cdot yr^{-1}$ with no time-series variation in catchability
- MFCL test procedure 2 - natural mortality (*M*) fixed at $0.2 \cdot yr^{-1}$ with time-series variation in catchability
- MFCL test procedure 3 - natural mortality (*M*) estimated with no time-series variation in catchability
- MFCL test procedure 4 - natural mortality (*M*) estimated with time-series variation in catchability

MFCL Test Results

There were a total of 80 MFCL analyses (4 scenarios x 5 realizations x 4 MFCL test procedures). Results of the simulated "actual" values and estimated MFCL parameter values are summarized in Table 2 for natural mortality (*M*), mean biomass, starting biomass, ending biomass, mean recruitment, mean fishing mortality (*F*) by year, depletion or the fished biomass at the end of the time-series to the biomass at the beginning of the time-series (BF_e/BF_s) and fished biomass at the end of the time-series to the biomass a the end of the time-series in the absence of fishing (BF_e/B_e). Table 2 also depicts the ratios of the estimated MFCL parameter values to "actual" values. Ratios less than 1.0 indicate that MFCL values were underestimates compared to "actual" value and negatively biased; ratios greater than 1.0 indicate MFCL values were overestimates and positively biased. MFCL generates other parameters of potential interest, such as spawning biomass, movement, catchability, effort deviations and selectivity patterns, but these are not illustrated.

Estimated length-at-age and the growth trajectory were in good agreement with actual values up through age 6 (Figure 3). Asymptotic size (L_∞) differed if natural mortality was $0.2 \cdot yr^{-1}$ or unconstrained. Asymptotic size was similar to simulated values when natural mortality was 0.2, but a larger asymptotic size resulted when natural mortality was unconstrained (Figure 3). This pattern was consistent with all MFCL analyzes.

Figures 4 and 5 illustrate the time-series of biomass for the first realization of the simulation scenarios and the four MFCL test procedures. Scenarios 1 and 3 had a mean population depletion of 8% (BF_e/BF_s=0.92) and a ratio of exploited to unexploited biomass (BF_e/B_e) of 0.44 (Table 2, Figure 4). Scenarios 2 and 4 had a more optimistic trend in population biomass with a mean biomass increase of 26% and less of an impact due to fishing (BF_e/B_e=0.60, Table 2, Figure 5).

For each scenario, there was a substantial departure in the estimated value of natural mortality as mean values were ~0.60 yr^{-1} in MFCL test procedures 3 and 4 (Figures 6–9). Coincident with elevated levels of natural mortality, fishing mortality and recruitment were also positively biased. The high mortality and recruitment in MFCL test procedures 3 and 4 generates a population structured with a larger percentage of juvenile swordfish (Figure 4–5).

Reference point estimates of BF_e/BF_s and BF_e/B_e were better determined for scenarios 1 and 3 with no simulated time-series variation in catchability compared to scenarios 2 and 4 (Table 2, Figures 6 and 8). For scenario 1, the reference point BF_e/BF_s was within 28% of actual values (0.72 and 1.11). Similarly for scenario 3, BF_e/BF_s was within 25% of actual values (0.75 and 1.13) if a time-series of catchability was not estimated.

There was little difference between the full 10 region model with 31 fisheries and the aggregated 4 region model with 6 fisheries if catchability was stationary in the MFCL test procedures (Figures 4 and 5). If catchability was estimated, then biomass trends were negatively biased in the 4 region model compared to the full model. The bias may not relate to a MFCL inability to accurately estimate catchability trends, but perhaps a confounding factor of aggregating the four longline fisheries (Japanese, Korean, Taiwanese and US longline fisheries) into a single fishery. This would be especially problematic in scenario 4 which has a simulated declining trend in catchability for the Japanese longline fishery, but is not simulated for other fisheries.

For the full 10 region model with 31 fisheries, estimating a trend in catchability when there was "no trend in the simulation" was much less biased (scenario 1, MFCL test 2 and 4) compared to assuming no trend in catchability when in fact there were trends in catchability (scenario 2, test 1 and 3).

Conclusion and future required work

This represents an initial attempt in assessing the sensitivity of MFCL using an operational model of a north Pacific swordfish population. MFCL provided unrealistic estimates of natural mortality and future work beyond this exploratory study could place penalties on natural, fishing mortality and/or recruitment to better determine these parameters. The estimation of natural mortality may be improved by the addition of simulated tag-recapture data; however, the operational model was developed to reflect real fishery conditions and tag-recapture data from the north Pacific swordfish population may not be feasible in the near future.

Further work is required to assess the effects of spatial aggregation. A 4 region spatial structure is currently used in the actual MFCL swordfish assessment. If the effects of spatial aggregation are further considered, it would be beneficial to have independent fleets in the 4 region.

Additional work could include:

1. Conduct simulations with sexual dimorphic growth and differential natural mortality, This particular research theme was noted in the ISC3 swordfish

research plan and will be an area of research after placing appropriate penalties on natural mortality, fishing mortality and/or recruitment.

2. Introduce more extensive errors into the simulations such as: catch under-reporting, ageing errors etc.,
3. While the current emphasis is testing the sensitivity of MFCL, simulated data are available for testing of other integrated assessment methods.

References

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Table 1. Main structural assumptions used in MFCL analyzes of simulated North Pacific swordfish populations.

Category	Assumption
Observation model for total catch data	Observation errors small, equivalent to a residual SD on the log scale of 0.07.
Observation model for length-frequency data	Normal probability distribution of frequencies with variance determined by effective sample size and observed frequency.
Recruitment	Occurs as a discrete event in the initial quarter of each year. The spatial distribution of recruitment in each quarter is allowed to vary with a small penalty on deviations from the average spatial distribution. Spatially-aggregated recruitment is weakly related to spawning biomass in the prior quarter via a Beverton-Holt SRR (beta prior for steepness with mode at 0.9 and SD of 0.04) .The spatial distribution of recruitment in each year is constrained to the two southern regions.
Initial population	A function of the equilibrium age structure in each region, which is assumed to arise from the total mortality and movement rates estimated for the initial ten years of the analysis.
Age and growth	20 yearly age-classes, with the last representing a plus group. Juvenile and adult age-class mean lengths constrained by von Bertalanffy growth curve. No differential growth between males and females.
Selectivity	Constant over time. Various smoothing penalties applied. Coefficients for the last 4 age-classes are constrained to be equal. Longline selectivities are non-decreasing with increasing age.
Catchability	Seasonal variation for all fisheries. Catchability constant (constrained) over years and among regions for all fisheries (effort data are scaled to reflect different region sizes) in MFCL test procedures 1 and 3. Time-series variation in catchability for MFCL test 2 and 4 with catchability deviation priors assigned mean 0 and a variance equivalent to a CV of 0.1 on a log scale.
Natural mortality	No age-dependency. Constant over time and among regions. A prior of 0.2 was used for MFCL tests 3 and 4 which estimated natural mortality.

Table 2. Simulated "actual" values and estimated MFCL parameter values for natural mortality (*M*), mean biomass, starting biomass, ending biomass, mean recruitment, mean fishing mortality (*F*) by year, depletion or the fished biomass at the end of the time-series to the biomass at the beginning of the time-series (BF_e/BF_s) and fished biomass at the end of the time-series to the biomass at the end of the time-series in the absence of fishing (BF_e/B_e). Ratios (estimated values/actual) less than 1.0 indicate that MFCL values were underestimates compared to "actual" values and negatively biased; ratios greater than 1.0 indicate MFCL values were overestimates and positively biased.

Scenario 1 - 10 regions, 31 fleets, no catchability assumed, no dimorphic growth									
		MFCL test 1		MFCL test 2		MFCL test 3		MFCL test 4	
Parameter	Acutal	Value	Ratio	Value	Ratio	Value	Ratio	Value	Ratio
Natural mortality	0.20	0.20	1.00	0.20	1.00	0.60	3.00	0.58	2.89
Mean biomass	2.34E+07	2.79E+07	1.19	3.00E+07	1.29	7.45E+07	3.19	6.30E+07	2.69
Mean biomass start	2.95E+07	4.67E+07	1.58	4.80E+07	1.62	8.58E+07	2.90	8.39E+07	2.84
Mean biomass end	2.72E+07	3.10E+07	1.14	4.62E+07	1.70	8.77E+07	3.22	5.72E+07	2.10
Mean recruitment	1.01E+08	1.07E+08	1.06	1.19E+08	1.18	1.02E+09	10.09	8.06E+08	8.01
Overall F by year	0.08	0.10	1.24	0.10	1.16	0.21	2.51	0.24	2.81
BF_e/BF_s	0.92	0.67	0.72	0.96	1.04	1.02	1.11	0.68	0.74
BF_e/B_e	0.44	0.53	1.22	0.63	1.44	0.94	2.13	0.90	2.06

Scenario 2 - 10 regions, 31 fleets, catchability assumed, no dimorphic growth									
		MFCL test 1		MFCL test 2		MFCL test 3		MFCL test 4	
Parameter	Actual	Value	Ratio	Value	Ratio	Value	Ratio	Value	Ratio
Natural mortality	0.20	0.20	1.00	0.20	1.00	0.68	3.42	0.63	3.15
Mean biomass	2.88E+07	2.36E+07	0.82	2.26E+07	0.78	1.75E+08	6.06	9.26E+07	3.21
Mean biomass start	2.95E+07	4.64E+07	1.57	4.28E+07	1.45	2.29E+08	7.75	1.25E+08	4.25
Mean biomass end	3.73E+07	1.66E+07	0.45	2.32E+07	0.62	1.37E+08	3.66	5.54E+07	1.48
Mean recruitment	1.02E+08	7.30E+07	0.72	7.54E+07	0.74	2.66E+09	26.10	1.24E+09	12.19
Overall F by year	0.04	0.10	2.14	0.10	2.18	0.13	3.02	0.18	3.95
BF_e/BF_s	1.26	0.36	0.28	0.54	0.43	0.60	0.47	0.44	0.35
BF_e/B_e	0.60	0.44	0.73	0.53	0.87	0.97	1.62	0.93	1.55

Scenario 3 - 4 regions, 6 fleets, no catchability assumed, no dimorphic growth									
		MFCL test 1		MFCL test 2		MFCL test 3		MFCL test 4	
Parameter	Actual	Value	Ratio	Value	Ratio	Value	Ratio	Value	Ratio
Natural mortality	0.20	0.20	1.00	0.20	1.00	0.57	2.87	0.56	2.80
Mean biomass	2.34E+07	2.87E+07	1.23	2.51E+07	1.07	6.22E+07	2.66	4.85E+07	2.07
Mean biomass start	2.95E+07	4.60E+07	1.56	4.59E+07	1.56	7.02E+07	2.38	6.51E+07	2.20
Mean biomass end	2.72E+07	3.19E+07	1.17	1.53E+07	0.56	7.31E+07	2.69	2.81E+07	1.03
Mean recruitment	1.01E+08	1.11E+08	1.10	9.47E+07	0.94	8.13E+08	8.07	5.98E+08	5.94
Overall F by year	0.08	0.10	1.21	0.13	1.51	0.70	8.35	0.73	8.67
BF_e/BF_s	0.92	0.69	0.75	0.33	0.36	1.04	1.13	0.43	0.47
BF_e/B_e	0.44	0.55	1.26	0.37	0.85	0.92	2.10	0.82	1.86

Table 2 cont.

Scenario 4 - 4 regions, 6 fleets, catchability assumed, no dimorphic growth										
		MFCL test 1		MFCL test 2		MFCL test 3		MFCL test 4	
Parameter	Actual	Value	Ratio	Value	Ratio	Value	Ratio	Value	Ratio
Natural mortality	0.20	0.20	1.00	0.20	1.00	0.56	2.79	0.58	2.91
Mean biomass	2.88E+07	2.62E+07	0.91	2.15E+07	0.75	4.60E+07	1.60	4.50E+07	1.56
Mean biomass start	2.95E+07	4.47E+07	1.51	3.88E+07	1.31	5.85E+07	1.98	6.35E+07	2.15
Mean biomass end	3.73E+07	2.17E+07	0.58	1.15E+07	0.31	3.94E+07	1.06	1.19E+07	0.32
Mean recruitment	1.02E+08	8.59E+07	0.84	7.29E+07	0.72	5.60E+08	5.50	5.59E+08	5.49
Overall F by year	0.04	0.08	1.80	0.10	2.32	0.69	15.47	0.49	10.90
BF_e/BF_s	1.26	0.49	0.38	0.30	0.23	0.67	0.53	0.19	0.15
BF_e/B_e	0.60	0.57	0.95	0.41	0.68	0.91	1.50	0.74	1.23

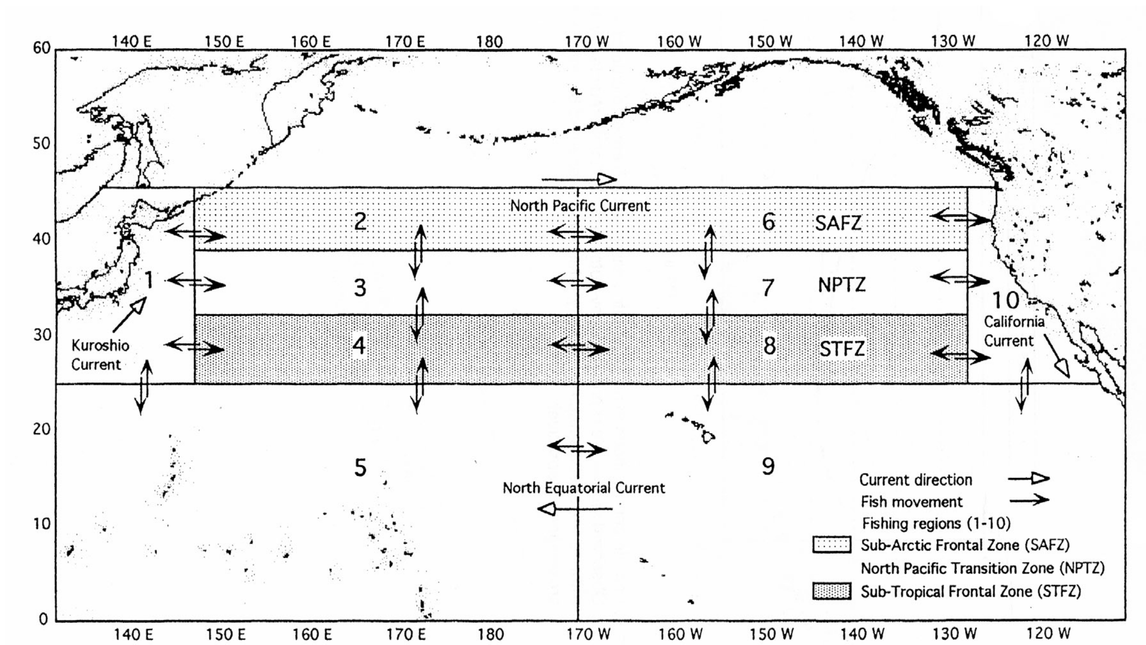


Figure 1. Ten region spatial stratification in an operational model of a North Pacific swordfish population. Ten region stratification used in scenarios 1 and 2.

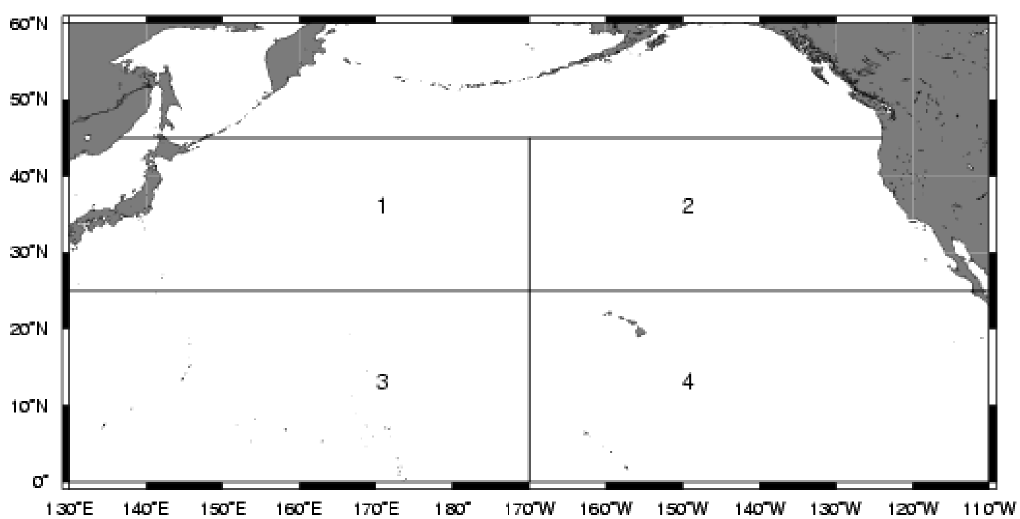
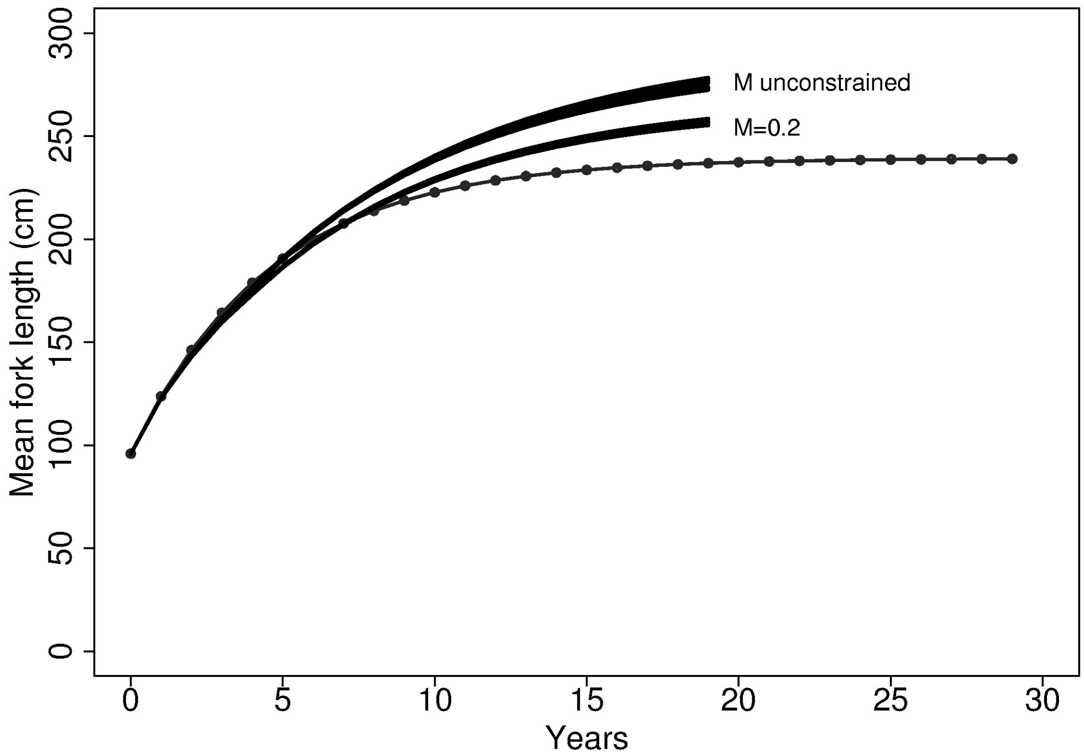
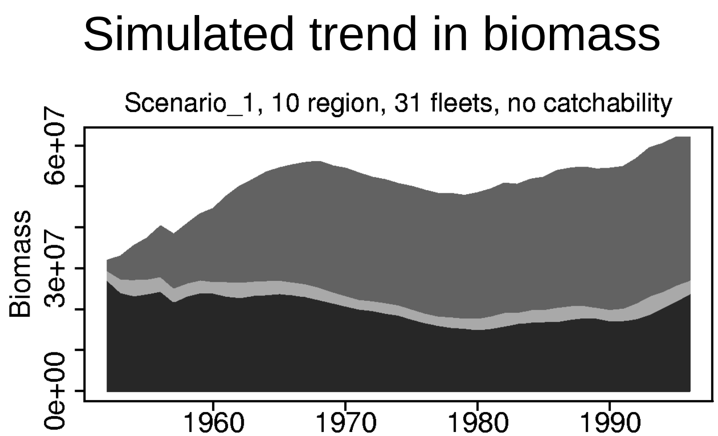


Figure 2. Four region spatial stratification used in scenarios 3 and 4. Stratification based on aggregation of the 10 region model.

Figure 3. Scenario 1, mean lengths-at-age for simulation (line with circles) and five MFCL tests with constrained natural mortality (*M* =0.2) and unconstrained *M*.





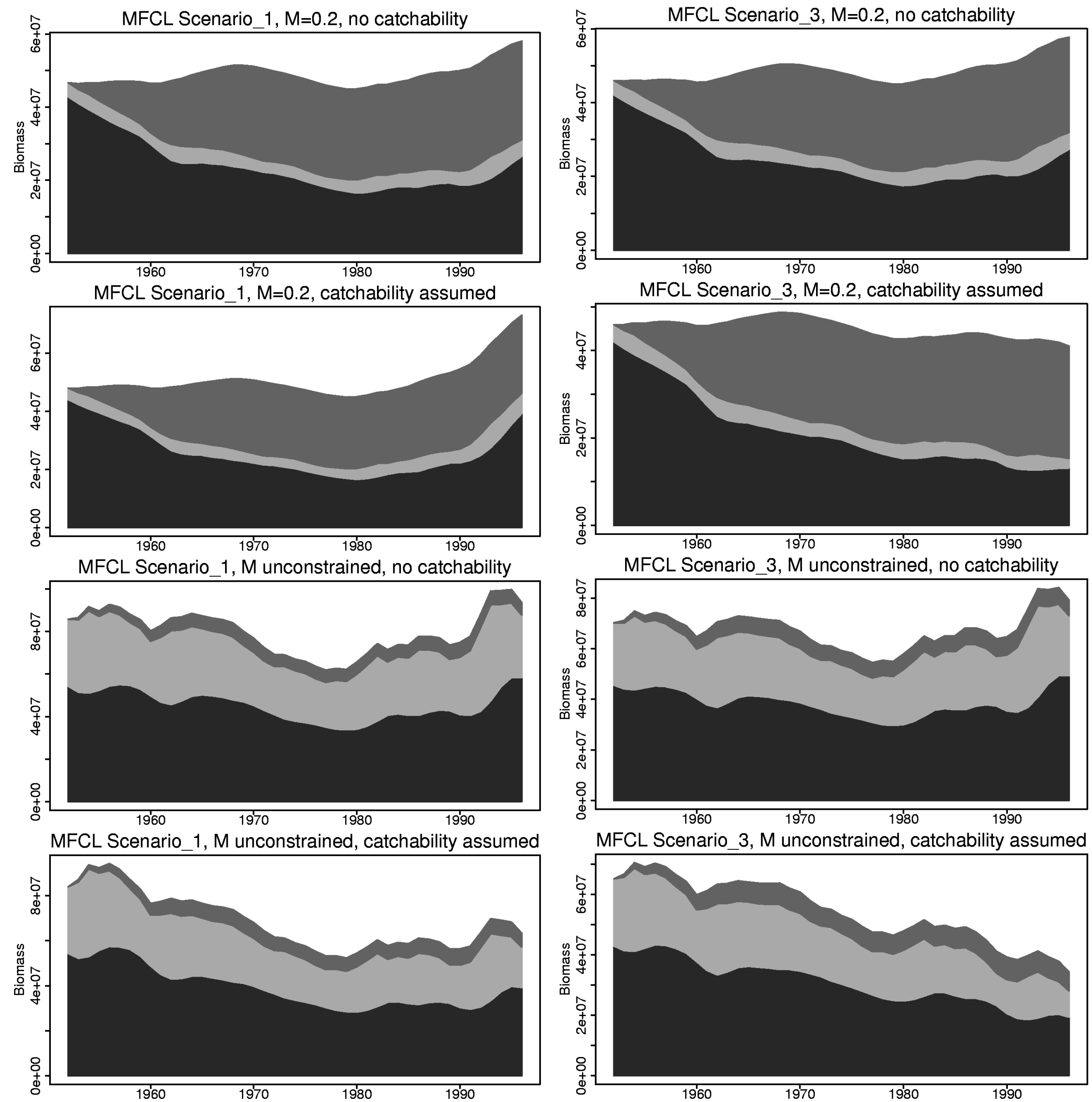
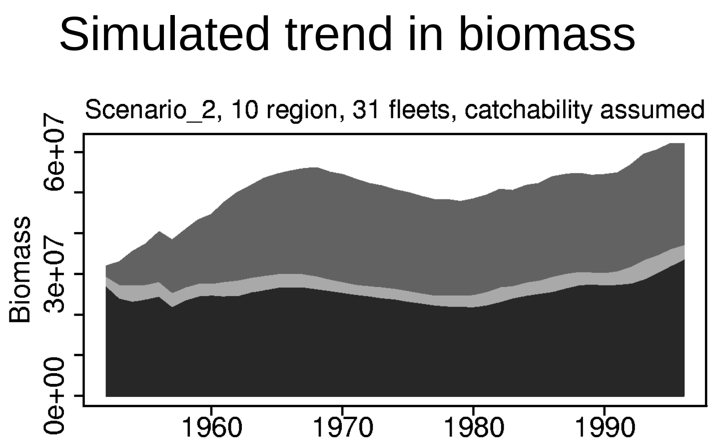


Figure 4. Biomass time-series for Scenario 1, realization 1 (left) and the four MFCL test procedures for a 10 region, 31 fisheries model (middle) and a 4 region, 6 fisheries model (right). Top line is the total biomass in the absence of fishing, middle line is the total biomass with fishing and the bottom line is the adult spawning biomass.



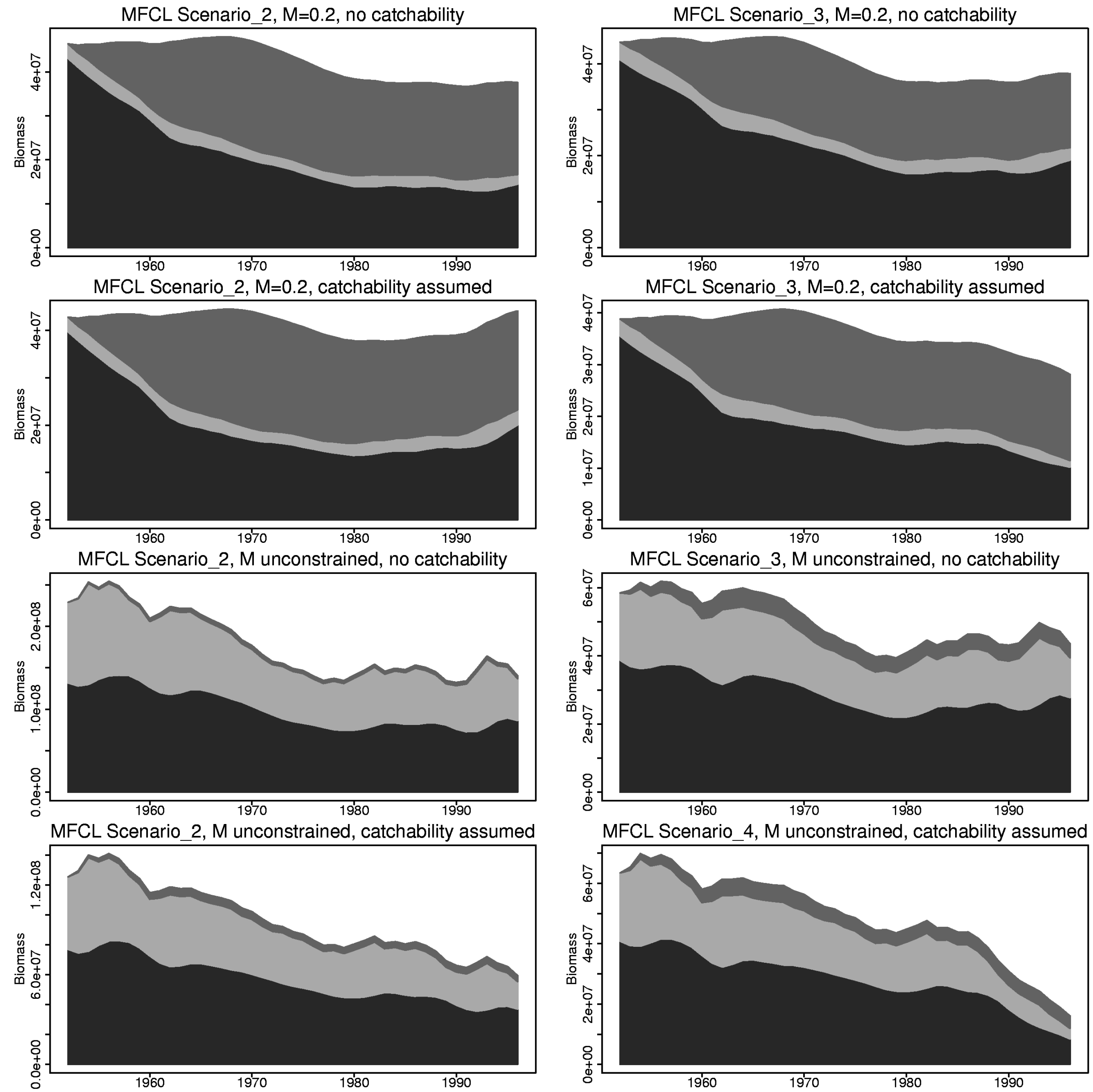


Figure 5. Biomass time-series for Scenario 2, realization 1 (left) and the four MFCL test procedures for a 10 region, 31 fisheries model (middle) and a 4 region, 6 fisheries model (right). Top line is the total biomass in the absence of fishing, middle line is the total biomass with fishing and the bottom line is the adult spawning biomass.

Figure 6. Scenario 1 ratio (MFCL parameter values/actual) results for *M, F,* recruitment, fished biomass at the end of the time-series to the biomass at the beginning of the time-series (BF_e/BF_s) and fished biomass at the end of the time-series to the biomass at the end of the time-series in the absence of fishing (BF_e/B_e). Boxes represent the quartiles estimates of the five realizations, with mid-line representing the median. A ratio of 1 indicates MFCL values are equal to actual simulated values.

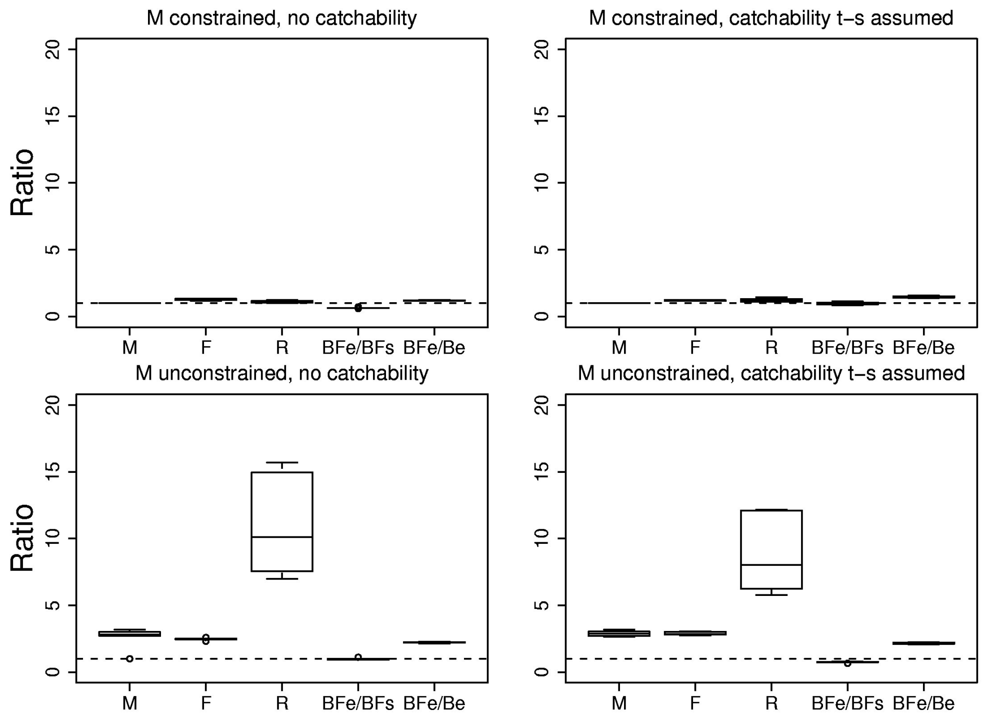


Figure 7. Scenario 2 ratio (MFCL parameter values/actual) results for *M, F,* BF_e/BF_s and BF_e/B_e. See caption of Figure 6 for details.

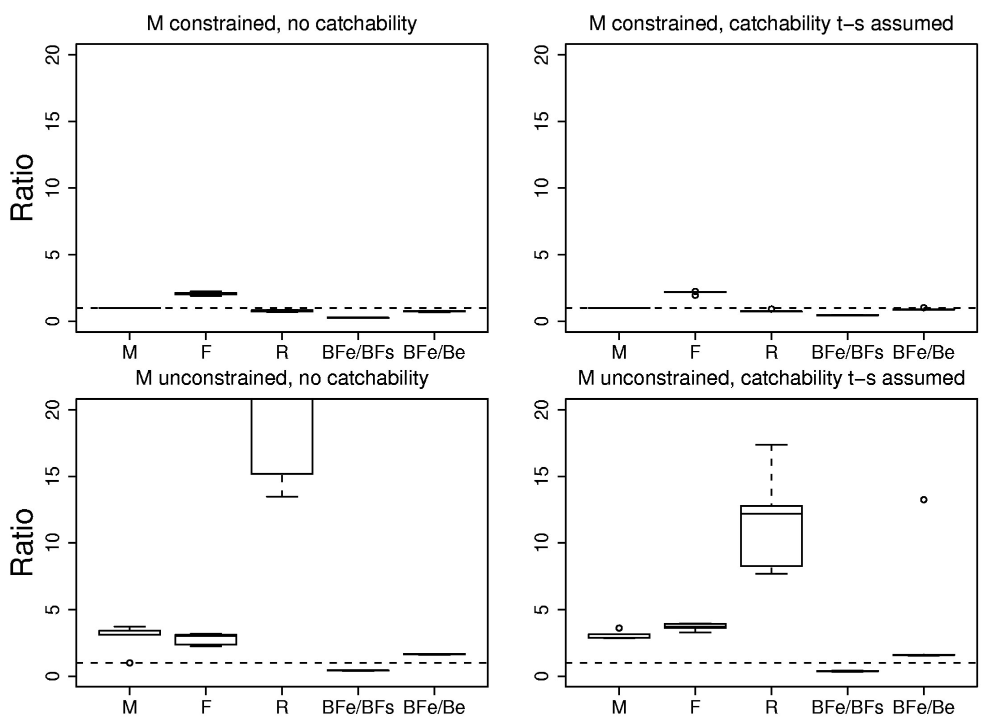


Figure 8. Scenario 3 ratio (MFCL parameter values/actual) results for *M, F,* BF_e/BF_s and BF_e/B_e. See caption of Figure 6 for details.

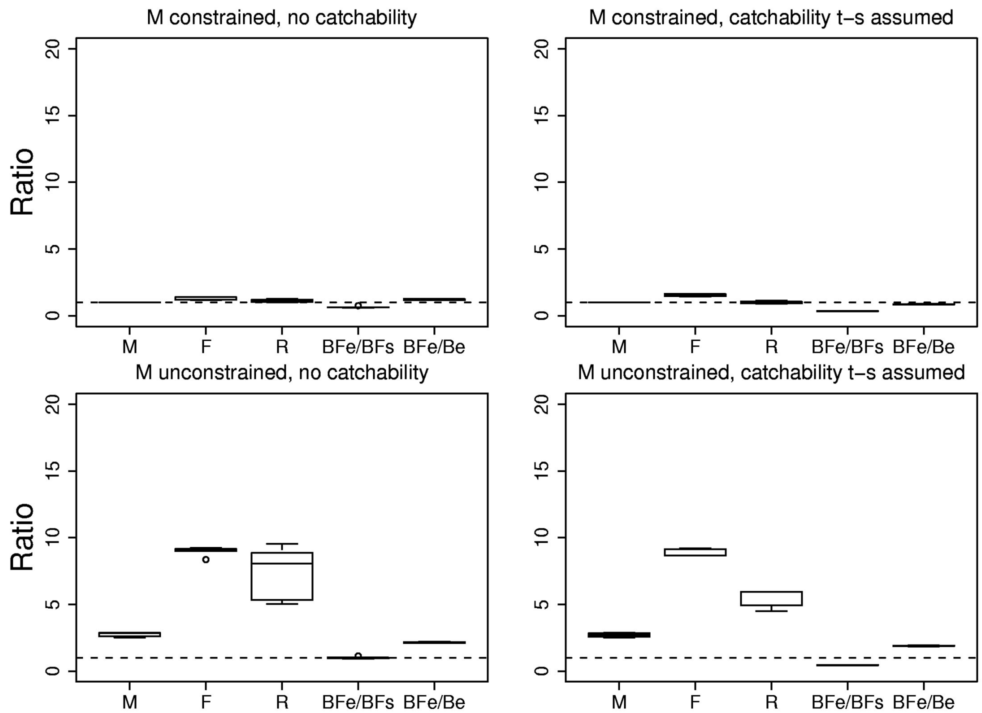


Figure 9. Scenario 4 ratio (MFCL parameter values/actual) results for *M, F,* BF_e/BF_s and BF_e/B_e. See caption of Figure 6 for details.