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Southwest Pacific striped marlin stock projections to evaluate CMM 2006-04

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Executive Summary

This analysis was conducted to support discussions on potential management of striped marlin in the Southwest Pacific Ocean. In particular, it explored the potential outcomes for the striped marlin stock under CMM 2006-04, which proposed that "*Commission Members, Cooperating Non-Members, and participating Territories (CCMs) shall limit the number of their fishing vessels fishing for striped marlin in the Convention Area south of 15°S, to the number in any one year between the period 2000 – 2004".* SC15 [paragraph 115] recommended the use of stochastic stock projections, examining the expansion of the geographic scope of CMM2006-04 by assuming average fishing effort during 2000-2004 by CCMs and zero fishing mortality in assessment Region 1 (0°-15°S, 140°E-130°W), to evaluate the potential long-term performance of the CMM.

The following scenarios were therefore examined:

- 'Status quo': all fisheries projected on average effort over 2015-2017;
- CMM 2006-04: longline effort in model Regions 2-4 (south of 15°S) projected at 2000-2004 levels, all other fisheries at 2015-2017 average effort;
- CMM 2006-04 expansion: longline effort in all model regions projected at 2000-2004 levels, recreational fisheries at 2015-2017 average effort;
- Region 1 closure: longline effort in model Regions 2-4 projected at 2000-2004 levels, longline effort in Region 1 set to zero, recreational fisheries at 2015-2017 average effort.

All scenarios led to median stock depletion levels similar to, or less depleted than, the recently assessed stock condition. However, projections of striped marlin stock biomass under the CMM 2006-04 scenario, or the scenario expanding the Measure into Region 1, were less effective in terms of the risks of biomass declining below SB_{MSY} or fishing mortality exceeding F_{MSY}, than maintaining the recent average fishing pattern from 2015-2017 across all regions. The most effective scenario tested was to apply the Measure across Regions 2-4 and close longline fishing for striped marlin in Region 1. Only in this last scenario did the risk of the stock being below SB_{MSY} and fishing mortality being above F_{MSY} fall below 20%; for all other scenarios those risks ranged between 33 and 44%.

The outcomes of this projection study initially appear counter intuitive but can be explained by differences in the patterns of fishing effort by particular fisheries over time and space. This study illustrated the value of model-based projections in exploring the likely outcomes and relative performance of fixed management changes aimed at reducing or restricting effort as they integrate the impacts of the measure across the fisheries, each of which can vary due to different historical effort profiles, efficiency, selectivity and regions of operation.

We invite WCPFC-SC16 to:

- Consider the outcomes of these projections, in particular, the performance of the scenarios requested by SC15.

- Note that all the scenarios tested, including those projecting 2000-2004 effort levels, led to median stock depletion levels similar to, or less depleted than, the recently assessed stock condition.

Introduction

The most recent stock assessment for Southwest Pacific Ocean (SWPO) striped marlin was conducted in 2019, using data inputs up until 2017 (Ducharme-Barth *et al.*, 2019). The assessment indicated long term declining trends in biomass (though an upturn in the last year or two) and that levels of depletion and indicators of fishing mortality were in the vicinity of limit reference points (LRPs) applied to the key tuna stocks in the WCPO.

While uncertainty in the assessment outcomes was noted due to uncertainty in key biological parameters; 69% of the model runs in the uncertainty grid estimated recent spawning biomass to be less than the spawning biomass that supports MSY. Furthermore, 50% of models indicated that recent spawning biomass was at less than 20% of the unfished level of spawning biomass ($SB_{recent}/SB_{F=0}$). With respect to fishing mortality, 44% of model runs estimated recent levels of fishing mortality exceeded fishing mortality that would result in MSY. While there are currently no established LRPs for billfish in the WCPO, these results suggest that SWPO striped marlin are likely overfished based on reference points used for tuna species.

Based on the recent assessment outcomes, SC15 recommended SC16 *to "use stochastic stock projections of the Southwest Pacific striped marlin stock, including the expansion of the geographic scope of CMM 2006-04 by assuming average fishing effort during 2000-2004 by CCMs and zero fishing mortality in assessment Region 1, to evaluate the potential long-term performance of the CMM".* (Para 341, SC15 Report).

This paper therefore presents a series of stochastic stock projections for SWPO striped marlin to address the above recommendation from SC15 to further evaluate the potential implications of CMM 2006-04. Figure 1 shows the SWPO striped marlin assessment region and the four sub-regions used in the recent assessment and that apply in this study. Table 1 shows the fisheries recognized in the recent 2019 assessment and applied in this study.

Methods

The stock projections in this study used the most recent MULTIFAN-CL assessment model developed for SWPO striped marlin (Ducharme-Barth *et al.,* 2019). Stock assessments of pelagic species in the WCPO assess the structural uncertainty in the assessment model by running an "uncertainty grid" of models to explore all the interactions among selected "axes" of uncertainty. The structural uncertainty grid for the 2019 SWPO striped marlin assessment used for these projections included 300 models and is detailed in Ducharme-Barth *et al.* (2019). Briefly the grid was constructed from 6 axes: growth, natural mortality, steepness, CPUE indices, size frequency weighting and the CV on the recruitment penalty.

To evaluate the long-term performance of CMM 2004-06 and possible modifications, we devised four scenarios (see below) and used stochastic stock projections (*e.g.* Pilling *et al.*, 2016) to estimate their impact on the SWPO striped marlin stock over a 30-year time horizon.

Key features of the projections for each scenario were:

- Stochastic projections for a 30 year time period were run for each scenario, from the last year of the stock assessment in 2017;
- Projections were run across the grid of 300 models used to capture uncertainty in our knowledge of SWPO striped marlin;
- For each scenario, 100 projections were run from each of the 300 models (30,000 projections in total);
- Future recruitment in each projection was determined by randomly sampling from the recruitment deviates from the stock recruitment relationship estimated in each model, from the period 1952-2017;
- Catches were based on projected effort for all 30 years, including the years of 2018 and 2019 for which reliable catch estimates were not available
- Catchability (which can have a trend in the historical component of the model) was assumed to remain constant in the projection period at the level estimated in the terminal year of the assessment model, *i.e.*, no effort creep or hyperstability is assumed to occur.

A set of figures and summary statistics was produced for each scenario. The depletion ($SB/SB_{F=0}$[2]) trajectories were summarized and plotted as a median trajectory with 60th and 95th percentiles. Additionally, the median depletion value at three time periods, 2025, 2035 and 2047 (the terminal projection year) was computed.

The distributions of the 30,000 terminal values of SB_{2047}/SB_{MSY} and $F_{2043\text{-}2046}/F_{MSY}$ for comparison across the scenarios were plotted as box and whisker plots[3]. Finally, we computed the median terminal values of SB_{2047}/SB_{MSY} and $F_{2043\text{-}2046}/F_{MSY}$ and also determined the probability of $SB_{2047}/SB_{MSY} < 1.0$ and $F_{2043\text{-}2046}/F_{MSY} > 1.0$. Additional information on regional and fishery catch and effort histories, and projected catches for each fishery and aggregated across fisheries, are presented to assist with interpretation of the projection results.

Definition of fishery scenarios for the evaluation

Paragraph 1 in CMM 2006-04 states that *"Commission Members, Cooperating Non-Members, and participating Territories (CCMs) shall limit the number of their fishing vessels fishing for striped marlin in the Convention Area south of 15°S, to the number in any one year between the period 2000 – 2004"*.

To perform the projections, we relate future effort levels to a status quo period, specifically the average effort over 2015-2017 (the final years of the 2019 stock assessment model). Within the assessment, effort in longline fisheries is defined using raised logbook records of number of hooks deployed for the commercial longline fisheries or days fished for recreational fisheries. To reflect the CMM, we therefore assume that the number of hooks and number of longline vessels are directly related over time. Effort estimates used in the assessment, and for these projections, for the two recreational fisheries are in terms of angler days.

[2] Note results of the $SB_{'latest'}/SB_{F=0}$ are presented here. Equivalent median $SB_{2017}/SB_{F=0}$ from the 2019 stock assessment was 0.238.

[3] Only terminal MSY-related quantities are available from the projections.

Under the intent of the Measure, we use the average effort levels for the 2015-2017 period as a baseline status quo effort against which to assess long-term performance of the stock under the CMM or alternative effort levels for selected periods and sub-regions, through the following four scenarios:

Scenario 1 – Status quo. Longline effort in all four regions is projected using average effort of the recent period 2015-2017; the two recreational fisheries, both located in Region 3, are also projected using average 2015-2017 effort. In this scenario therefore all scalars = 1.

Scenario 2 – CMM 2006-04. Longline effort in Regions 2-4 is projected using the 2000-2004 average (scalar = avg. 2000-2004 / avg. 2015-2017, see Table 2 last column), longline effort in Region 1 is projected using the recent 2015-2017 average (scalar = 1); recreational effort is also projected under the 2015-2017 average (scalar = 1).

Scenario 3 – CMM 2006-04 expansion. Longline effort in all four regions is projected on the basis of 2000-2004 averages (scalar = avg. 2000-2004 / avg. 2015-2017, Table 2 last column); recreational effort is projected under the 2015-2017 average (scalar = 1).

Scenario 4 – Region 1 closure. Longline effort in Regions 2-4 is projected using the 2000-2004 average (scalar = avg. 2000-2004 / avg. 2015-2017, Table 2 last column), longline effort in Region 1 is set to zero (scalar = 0); recreational catch is projected under the 2015-2017 average (scalar = 1).

Results

Fishery catch and effort trends

Table 2 provides a summary of the effort and catch ratios (scalars) for the 2015-2017 (status quo) period relative to the historical period of 2000-2004 referenced in CMM 2006-04. The scalar values show that effort and catch was higher in 2000-2004 compared to 2015-2017 (i.e. scalar > 1) for Fisheries 1—9, but for Fisheries 10—14, which includes the Distant Water Fishing Nation/Pacific Island Countries and Territories (DWFN/PICT) longline fisheries, and the NZ recreational fishery, effort was lower in 2000—2004 compared to 2015—2017, although catches were higher for DWFN/PICT longline Fisheries 11 and 12. These scalars suggest that the implications of applying the CMM 2006-04 will depend on the fisheries and the regions they fish. Importantly, the model projections integrate the effects of changes to all fisheries and so capture the consequences of the variation in the scalars across fisheries and how these impact fishing mortality and hence overall catch. Figures 2 and 3 display the catch and effort trends across the four fishery regions from 1990 to 2017.

Projections

Common to all projections is the use of effort-based scalars to project effort for all 30 years. Actual catch and effort estimates are not available for 2018 and 2019, thus values used in those projection years are based on averages from the relevant time periods. The use of effort scalars, in addition to an increase in biomass late in the actual assessment, contributes to the relatively high catches obtained in the scenarios for 2018 and 2019, which may have differed considerably from the projected values.

Scenario 1[4] **– <u>Status quo</u>** <u>(Fig. 4):</u> projections based on the 2015-2017 status-quo effort predict that the median $SB/SB_{F=0}$ will remain > 0.2 (the tuna LRP) for the entire projection period with a terminal value in 2047 of 0.28 (Table 3). The uncertainty around the median estimate was wide reflecting the range of uncertainties captured in the model grid. This applies to all scenarios. In terms of risk across all the model projections, assuming equal weighting of all models, this scenario showed a 34% risk of the terminal spawning biomass being below SB_{MSY} (i.e. $SB_{2047}<SB_{MSY}$), and 33% risk of the terminal fishing mortality being above F_{MSY} (i.e. $F_{2043\text{-}2046}>F_{MSY}$) (Table 3).

Scenario 2 – <u>CMM 2006-04</u> <u>(Fig. 5):</u> projections based on the 2000-2004 effort in Regions 2—4, and status-quo for both Region 1 longline and Region 3 recreational fisheries predict that the median $SB/SB_{F=0}$ will remain > 0.2 for the entire projection period with a terminal value in 2047 of 0.24 (Table 3). In terms of risk across all the model projections, assuming equal weighting of all models, this scenario showed a 44% risk of the terminal spawning biomass being below SB_{MSY} (i.e. $SB_{2047}<SB_{MSY}$), and a 43% risk of the terminal fishing mortality being above F_{MSY} (i.e. $F_{2043\text{-}2046}>F_{MSY}$) (Table 3).

Scenario 3 – <u>CMM 2006-04 expansion</u> <u>(Fig. 6):</u> projections assuming 2000-2004 longline effort in all regions and status-quo for recreational fisheries predict that the median $SB/SB_{F=0}$ will remain > 0.2 for the entire projection period with a terminal value in 2047 of 0.26 (Table 3). In terms of risk across all the model projections, assuming equal weighting of all models, this scenario showed a 38% risk of the terminal spawning biomass being below SB_{MSY} (i.e. $SB_{2047}<SB_{MSY}$), and 37% risk of the terminal fishing mortality being above F_{MSY} (i.e. $F_{2043\text{-}2046}>F_{MSY}$) (Table 3).

Scenario 4 – <u>CMM 2006-04 Region 1 closure</u> <u>(Fig. 7):</u> projections based on the 2000-2004 effort for Regions 2-4, no longline striped marlin fishing in Region 1 and status-quo for recreational fisheries predict that the median $SB/SB_{F=0}$ will remain > 0.2 for the entire projection period with a terminal value in 2047 of 0.36 (Table 3). In terms of risk across all the model projections assuming equal weighting of all models, this scenario showed a 16% risk of the terminal spawning biomass being below SB_{MSY} (i.e. $SB_{2047}<SB_{MSY}$), and 14% risk of the terminal fishing mortality being above F_{MSY} (i.e. $F_{2043\text{-}2046}>F_{MSY}$) (Table 3).

All scenarios led to a decrease in fishing mortality and increase in biomass relative to recently assessed conditions. Scenario 4 was the most effective in maintaining spawning biomass above B_{MSY} and fishing mortality below F_{MSY} and involved closure of Region 1 to longline fishing for striped marlin. Risk was similar across the other three scenarios, with slightly higher risk indicated for scenario 2, i.e. CMM 2006-04, with 2000-2004 effort in Regions 2-4. and status-quo for Region 1 fisheries and the recreational fisheries. The distributions of SB/SB_{MSY} and F/F_{MSY} for the terminal years in all 30,000 projections and all four scenarios are summarized in Figure 8 as box and whisker plots.

[4] In the projection scenarios, it is possible for values of $SB/SB_{F=0}$ to exceed a value of 1.0. This derives from the manner in which the two values are calculated. The denominator, $SB_{F=0}$, is based on a moving 10 year window, lagging SB_{latest} which is the numerator of the depletion calculation ($SB_t/SB_{F=0,t\text{-}1 \text{ to } t\text{-}10}$). Given variability and potential trends in the $SB_{F=0}$ moving average, particularly early in the projection period, SB_{latest} can exceed average $SB_{F=0}$. See Berger et al. (2013) for greater detail.

Discussion

This analysis was conducted to support discussions on potential management of striped marlin in the Southwest Pacific Ocean. In particular, it explored the potential outcomes of various scenarios of effort management in relation to CMM 2006-04, which proposed that "*Commission Members, Cooperating Non-Members, and participating Territories (CCMs) shall limit the number of their fishing vessels fishing for striped marlin in the Convention Area south of 15°S, to the number in any one year between the period 2000 – 2004".* In our projections, we treat our effort scalars as equivalent to vessel scalars, even though the scalars are based on hooks, which is the truest measure of longline fishing effort. Generally speaking, a reduction or increase in fishing effort will involve a roughly proportion change in both vessels and hooks fished.

All four of the projections show an increase in spawning biomass (i.e. less depletion) over the first few years; this occurs as a number of relatively strong year classes estimated in the last few years of the assessment enter the adult population. Over the longer term, all scenarios led to median stock depletion levels similar to or less depleted than the recently assessed stock condition. However, their performance in terms of the risk of the stock falling below 20% $SB_{F=0}$ or SB_{MSY}, and fishing mortality exceeding F_{MSY}, differed.

Projections of striped marlin stock biomass under the CMM 2006-04 scenario performed no better in terms of the risks of biomass declining below B_{MSY} or fishing mortality exceeding F_{MSY} than maintaining the recent average fishing pattern from 2015-2017, or expanding the measure into Region 1 (i.e. north of 15°S). The most effective scenario tested was to apply the measure across Regions 2-4 and close longline fishing for striped marlin in Region 1. Realistically, this scenario is equivalent to complete non-targeting of SWPO striped marlin and release of those taken as bycatch.

The outcomes of this projection study initially appear counter intuitive but can be explained by differences in the patterns of fishing effort by particular fisheries over time and space. The low impact of the CMM 2006-04 on biomass depletion levels and fishing mortality compared to maintaining the recent fishing effort profile appeared due to fishery specific differences in the changes in effort between the recent period and the 2000-2004 period proposed under the Measure. In particular, several fisheries (i.e. longline Fisheries 2, 3, 6, 7, 8) operating primarily in Regions 2 and 3 had substantial higher effort in 2000-2004 compared to 2015-2017. Applying the 2000-2004 effort levels in the projections meant that these fisheries were projected with higher effort and therefore notably higher catches than if they were projected based on 2015-2017 effort (see Fig. 9). The increased catches by these fisheries exceeded reductions to the other fisheries operating in Regions 2 and 3 (i.e. fisheries 10, 12, 13), resulting in the higher projected median depletion, and higher risk of breaching the MSY-based reference points than maintaining the status quo effort profile.

Overall given the recent declines in effort in several of the longline fisheries, applying 2000-2004 effort profiles does not result in any notable reductions in overall fishing effort and therefore fishing mortality compared to maintaining the status quo. The decrease in overall striped marlin fishing mortality is illustrated in the recent stock assessment (Ducharme-Barth et al. 2019, Figure 31). Thus, if the 2000-2004 fishery effort profiles were re-established in the immediate future, the risks to stock biomass would be marginally higher than maintaining the status quo. However, acknowledging the wide uncertainty in the projections due to uncertainty in key biological parameters, none of the

projection scenarios lead to more depleted spawning biomass levels than were indicated at the end of the most recent assessment period.

Improvements in understanding of biological parameters, in particular growth, will be important in reducing uncertainty in future stock assessment and projection studies for SWPO striped marlin (Ducharme-Barth *et al.*, 2019). Further, developing management strategies and testing their relative performance will require decisions on limit reference points, and targets, if stock rebuilding is a management objective. We note SC15 has proposed work to develop options for limit reference points for SWPO striped marlin, and the reference points applied in the current study are those applied to tuna species by the WCPFC. This study illustrated the value of model based projections in exploring the likely outcomes and relative performance of fixed management changes aimed at reducing or restricting effort as they integrate the impacts of the measure across the fisheries, each of which can vary due to different historical effort profiles, efficiency, selectivity and regions of operation.

We invite WCPFC-SC16 to:

- Consider the outcomes of these projections, in particular the performance of the scenarios requested by SC15.

- Note that all the scenarios tested, including the 2000-2004 effort levels, led to median stock depletion levels similar to, or less depleted than, the recently assessed stock condition.

References

Berger, A., Pilling, G., Kirchner, C., and Harley, S. (2013). Determination of appropriate time windows for calculation of depletion-based limit reference points. Technical Report WCPFCSC9-2013/MI-WP-02, Pohnpei, Federated States of Micronesia.

Ducharme-Barth, N., Pilling, G. and Hampton, J. (2019). Stock assessment of SW Pacific striped marlin in the WCPO. WCPFC-SC15-2019/SA-WP-07.

Pilling, G., Scott, R. and Hampton, J. (2016). Biologically reasonable rebuilding timeframes for bigeye tuna. WCPFC-SC12-2016/MI-WP-02.

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Tables

Table 1. Definition of fisheries for the 2019 Southwest Pacific Ocean (SWPO) striped marlin stock assessment (from Ducharme-Barth *et al.,* 2019).

Fishery	Nationality	Gear	Sub.region
1: JP 1 LL	JP	Longline	1
2: JP 2 LL	JP	Longline	2
3: JP 3 LL	JP	Longline	3
4: JP 4 LL	JP	Longline	4
5: TW 4 LL	TW	Longline	4
6: AU 2 LL	AU	Longline	2
7: AU 3 LL	AU	Longline	3
8: NZ 3 LL	NZ	Longline	3
9: AU 3 REC	AU	Recreational	3
10: NZ 3 REC	NZ	Recreational	3
11: OTHER 1 LL	DWFN/PICT	Longline	1
12: OTHER 2 LL	DWFN/PICT	Longline	2
13: OTHER 3 LL	DWFN/PICT	Longline	3
14: OTHER 4 LL	DWFN/PICT	Longline	4

Table 2. Average catch, average effort and resultant scalars for the striped marlin fishery comparing the 2000-2004 and 2015-2017 time periods for the 14 defined striped marlin fisheries. The scalars are computed as a ratio of the earlier (baseline) period average to the recent (2015-2017) period average; therefore a value > 1.0 indicates a decrease over time. LL = Longline fishery – effort in hook numbers/year, REC = recreational fishery – effort in days/year).

			Catch (no. fish)			Effort (million hooks or days)		
Fishery	Region	Type	2000 -2004	2015 - 2017	scalar	2000 -2004	2015 -2017	scalar
1	1	LL	1228	332	3.70	22.7	9.5	2.38
2	2	LL	1549	298	5.20	3.2	1.1	3.05
3	3	LL	1213	355	3.42	8.7	2.2	3.99
4	4	LL	18	2	11.78	0.1	0.0	11.31
5	4	LL	2024	414	4.88	17.3	4.2	4.10
6	2	LL	6257	2433	2.57	8.6	6.0	1.43
7	3	LL	3036	900	3.37	3.9	2.1	1.89
8	3	LL	627	489	1.28	9.1	1.9	4.90
9	3	REC	89	NA	NA	78.3	48.4	1.62
10	3	REC	467	713	0.66	426.1	1063.1	0.40
11	1	LL	11172	8298	1.35	200.6	290.0	0.69
12	2	LL	5541	2644	2.10	68.2	75.8	0.90
13	3	LL	226	247	0.91	3.3	6.6	0.49
14	4	LL	1362	2345	0.58	14.5	41.5	0.35

Table 3. Summary of key stock status indicators for the four different scenarios, which are titled as follows in the text: Scenario 1 = Status quo; Scenario 2 = CMM 2006-04; Scenario 3 = CMM 2006-04 expansion; Scenario 4 = Region 1 closure. Risk indicates the percentage of model runs under each scenario. Final row summarises the status from the 2019 stock assessment.

	Median depletion ($SB/SB_{F=0}$)			Median	Risk (%)	Median	Risk (%)
Scenario	2025	2035	2047	SB_{2047}/SB_{MSY}	$SB_{2047}<SB_{MSY}$	$F_{2043\text{-}2046}/F_{MSY}$	$F_{2043\text{-}2046}>F_{MSY}$
1	0.31	0.29	0.28	1.30	34	0.75	33
2	0.26	0.24	0.24	1.11	44	0.88	43
3	0.29	0.27	0.26	1.23	38	0.79	37
4	0.38	0.37	0.36	1.75	16	0.53	14
2019	2017 median depletion			2017 values		2017 values	
assessment	0.24			0.90	61	0.91	44

Figures

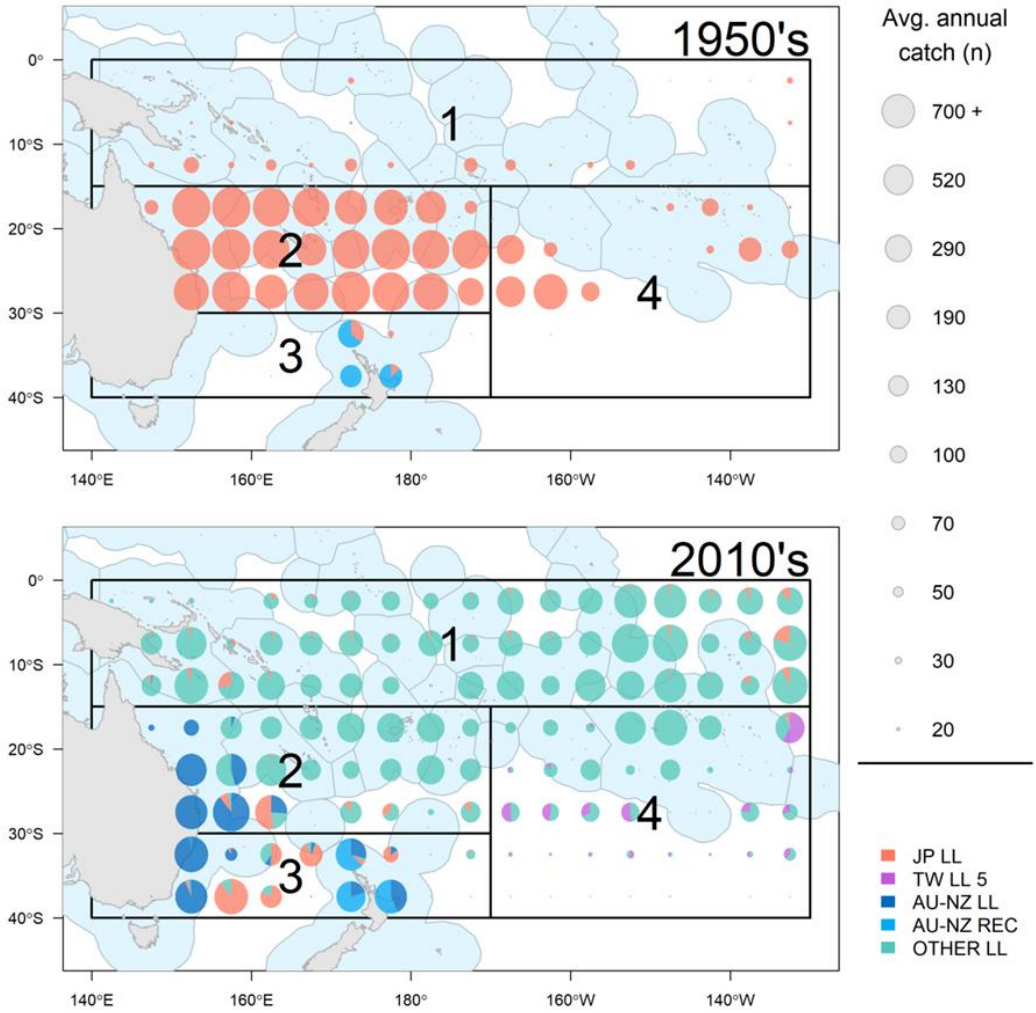

Figure 1. Average annual catches of striped marlin in the SWPO by 5˚×5˚ cell, during the 1950s (top panel) and the 2010s (bottom panel) indicating the large shift in fisheries composition over time. The black lines represent the boundaries of the assessment Region (outer lines) for striped marlin in the SWPO and the four sub-regions used to define the fisheries (from Ducharme-Barth *et al.,* 2019).

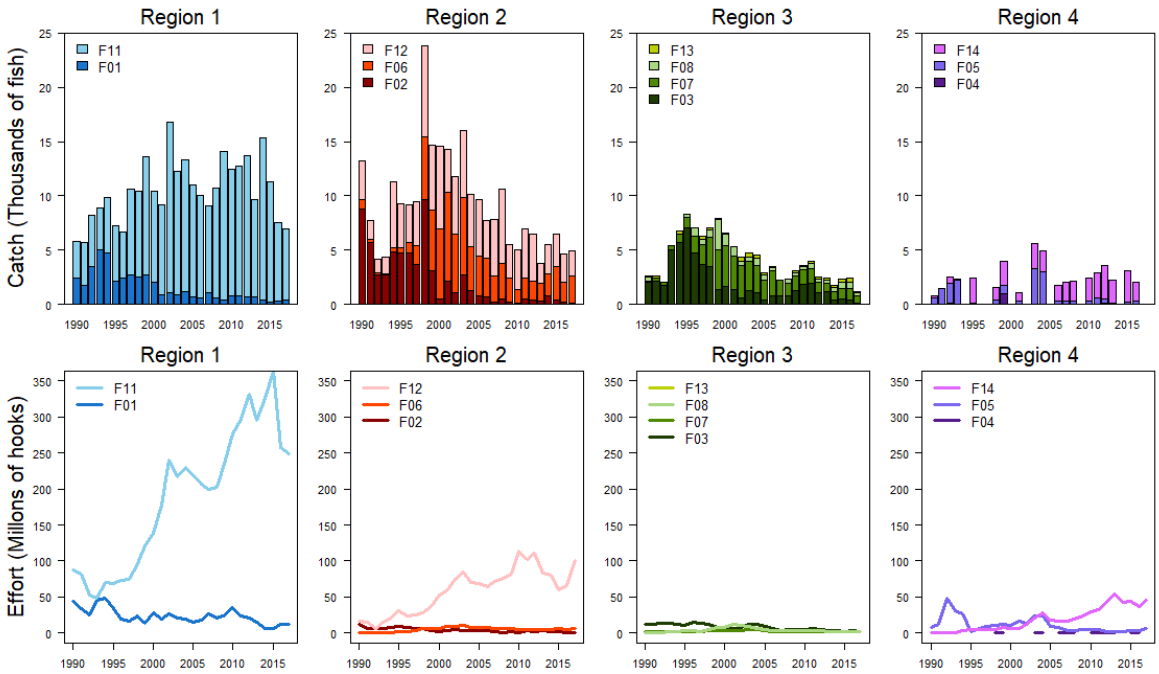

Figure 2 Catch (top) and effort (bottom) by Region for the 11 longline fisheries. The fisheries are identified in the legend as they are numbered in the stock assessment and are grouped here by stock assessment Region.

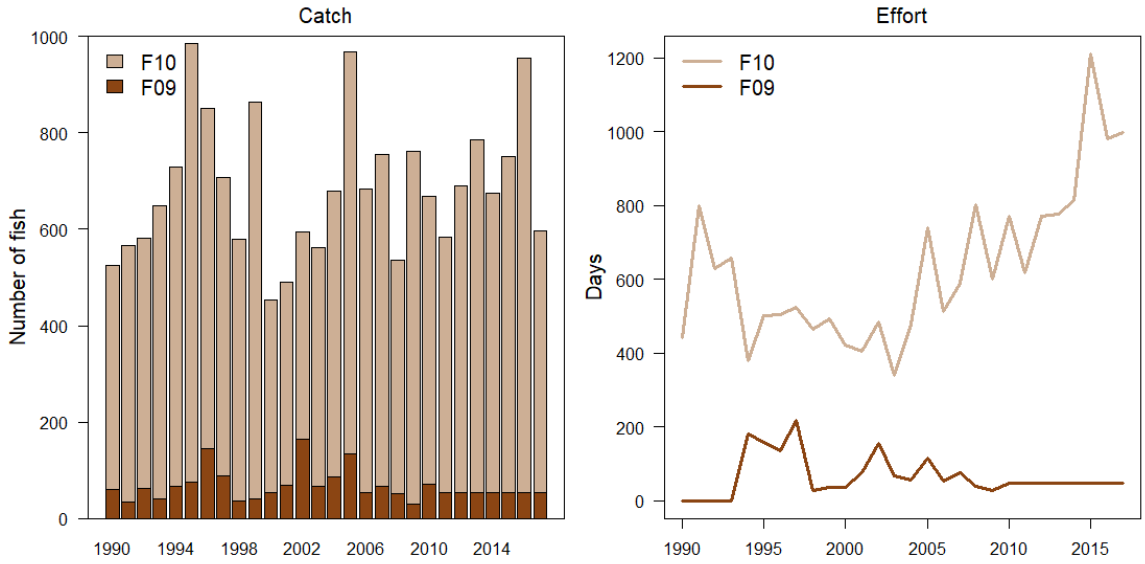

Figure 3. Catch (left) and effort (right) for the two recreational fisheries. The fisheries are identified in the legend as they are numbered in the stock assessment, and both occur in Region 3. Note that catch estimates are missing for the last six years (2011-2017) for Fishery 9, the values shown here are the average catches over the preceding five years.

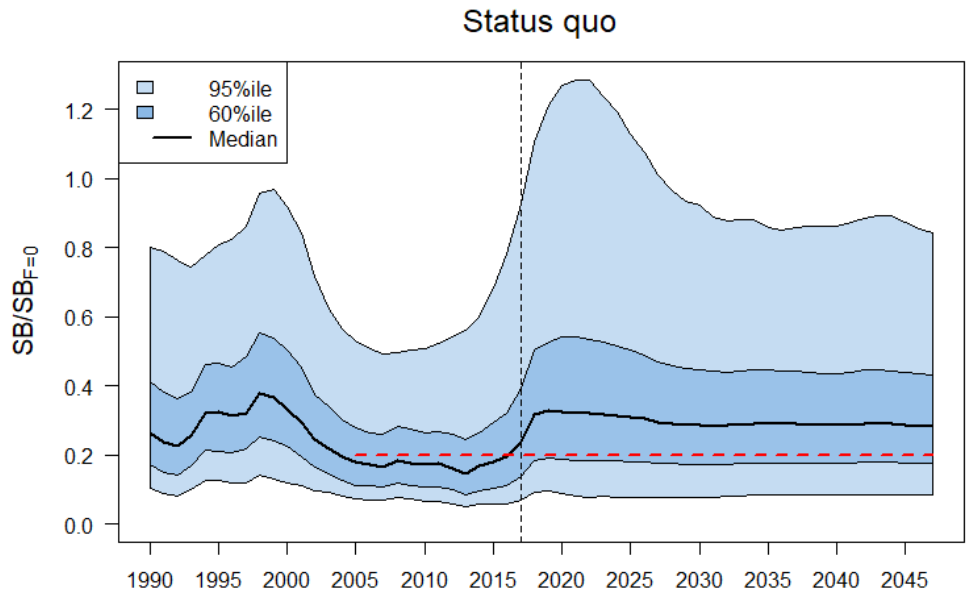

Figure 4. Scenario 1 – Status quo projection results. The plot shows the depletion trajectory over time. The striped marlin assessment model estimates depletion through to 2017 (the vertical line), stochastic projections are shown for the 300 models x 100 simulations each in the assessment grid for 2018-2047. The projections assume the same level of recruitment variability used to estimate the stock-recruitment relationship in the assessment. See text for scenario projection details.

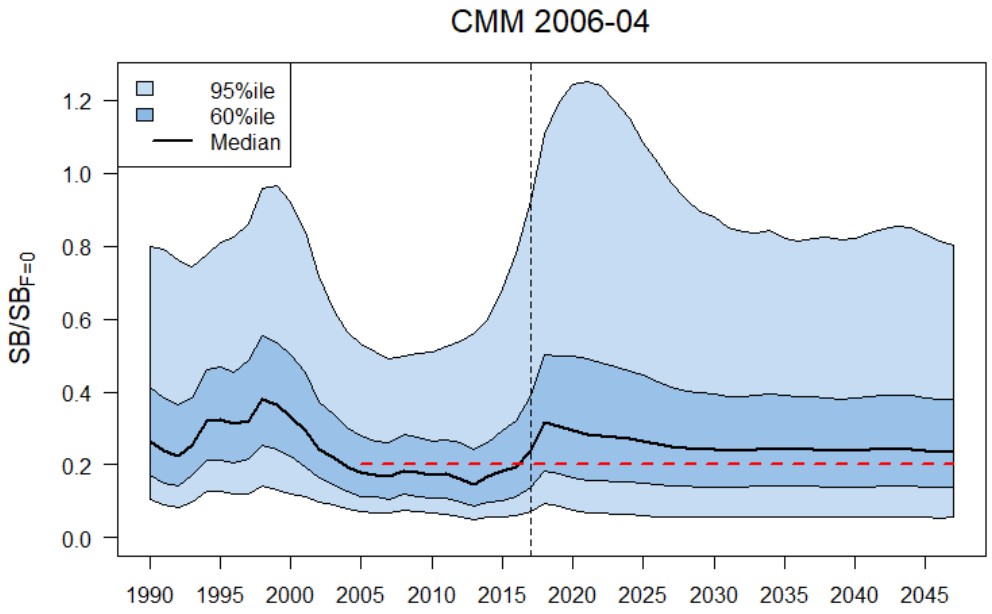

Figure 5. Scenario 2 – CMM 2006-04 projection results. The plot shows the depletion trajectory over time. See figure 4 for further details and main text for scenario projection details.

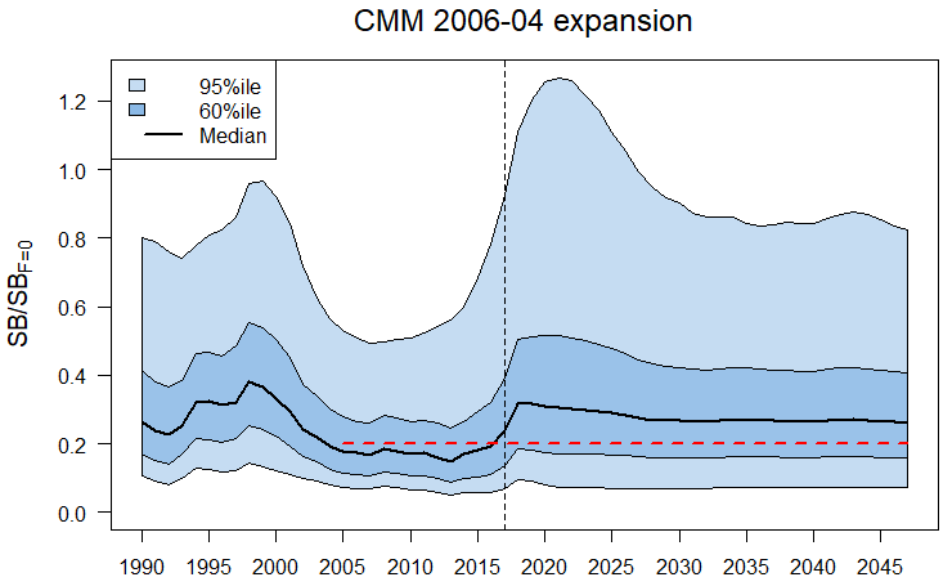

Figure 6. Scenario 3 - CMM 2006-04 expansion projection results. The plot shows the depletion trajectory over time. See figure 4 for further details and main text for scenario projection details.

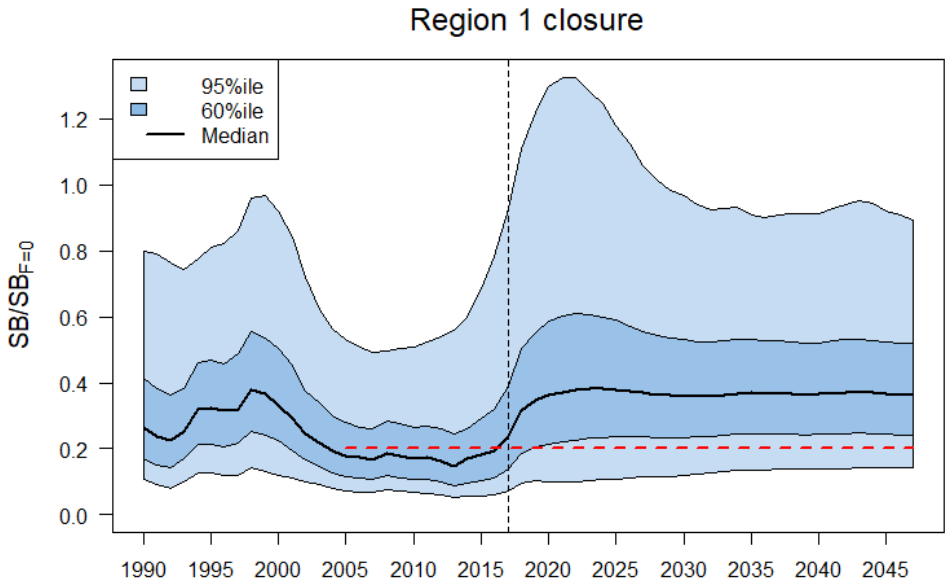

Figure 7. Scenario 4 - Region 1 closure projection results. The plot shows the depletion trajectory over time. See figure 4 for further details and main text for scenario projection details

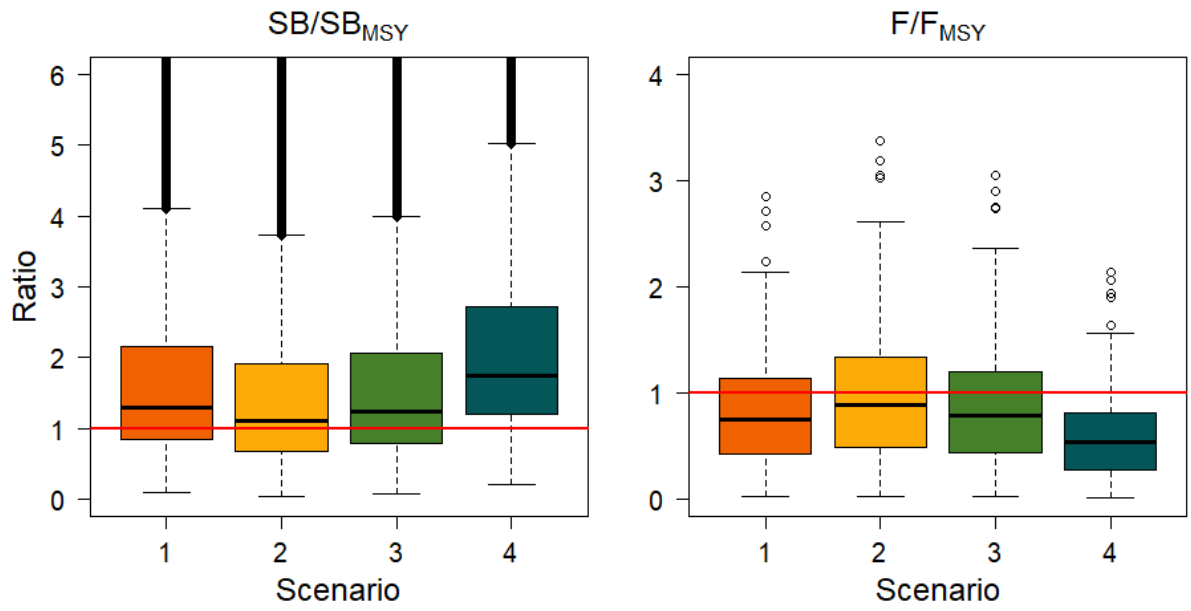

Figure 8. Box plots comparing the distributions of terminal depletion (left) and fishing mortality (F) (right) values estimated across the 300 models x 100 simulations. Values above the horizontal red line for SB/SB_{MSY} indicated acceptable depletion levels, values below the horizontal red line for F/F_{MSY} indicated acceptable fishing mortality levels. The boxes show the median (black line), lower 25th and upper 75th percentile values of the distributions, the whiskers indicate the range in which most of the values fall and the open/black dots indicate outliers.

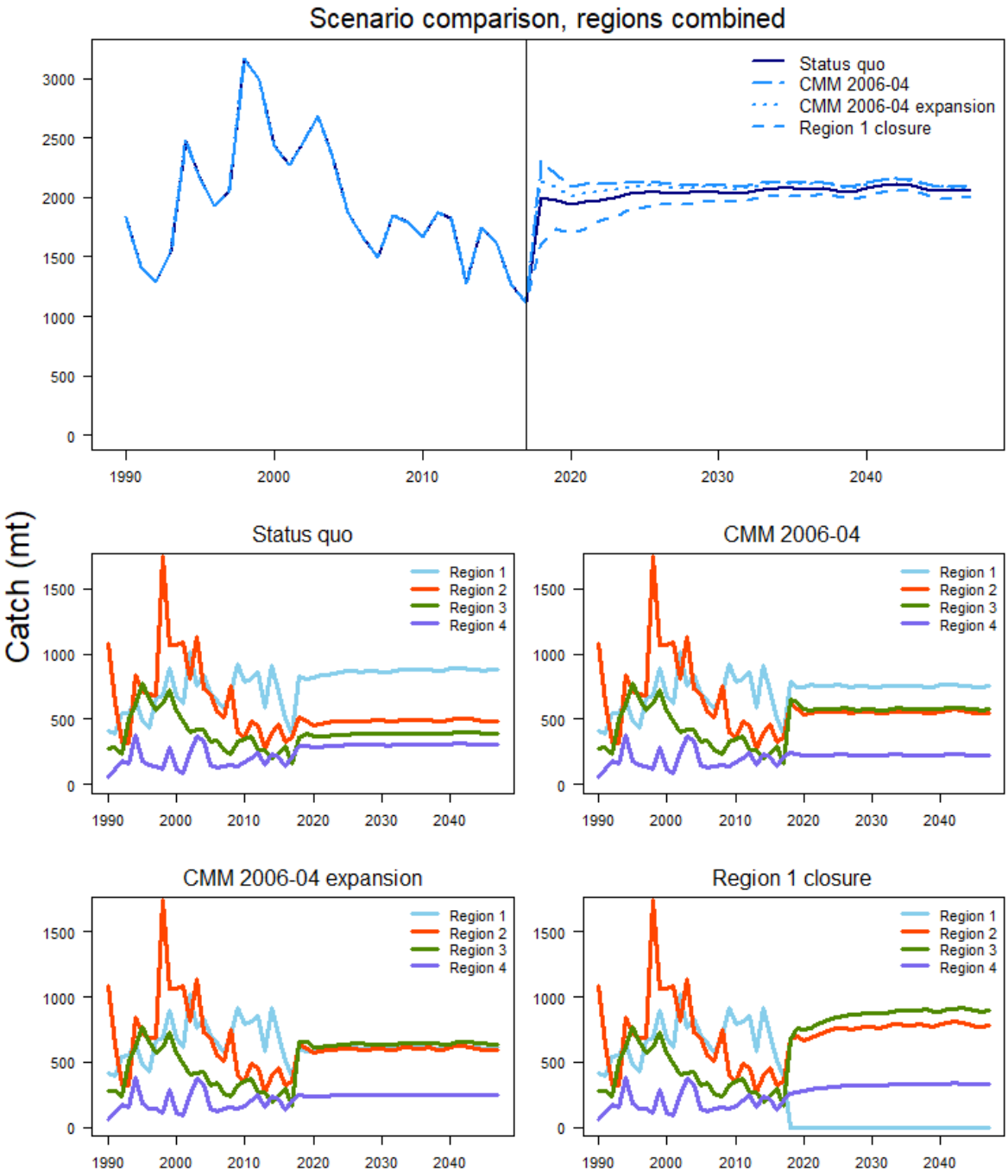

Figure 9. Graphs of median catch trajectories under each of the four striped marlin projection scenarios. The top figure shows total estimated catch trajectories, which start in 2017 (marked by a vertical line). The bottom four figures show the regional estimated catch trajectories for each of the scenarios. All trajectories represent median values from the 100 stochastic projections made from each of the 300 stock assessment grid models. Historical catches from 1990-2017 are shown for perspective.