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SOUTHWEST PACIFIC SWORDFISH STOCK PROJECTIONS

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Southwest Pacific swordfish stock projections

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Summary

This paper describes the results of stochastic stock projections for southwest Pacific Ocean swordfish, using the 2021 stock assessment (Ducharme Barth et al. 2021). The projections explore the outcomes of 8 different future fishing (catch- or effort-based) scenarios according to requests from WCPFC16 and SC17. The scenarios included in the paper are as follows:

- **"Status quo (SQ) catches":** this projection assumes recent (average 2016-2018) levels of fishing (catch) both north and south of 20°S.
- **+/- "SQ catches":** an additional limited number of projections which assume future catch scenarios across the region that are a fixed percentage above and below "status quo" and that result in a range of upward and downward long-term biomass trends. For this request we provide projections with a 20% decrease and increase on the status quo catch.
- **"SQ effort":** this projection assumes recent (average 2016-2018) levels of fishing effort both north and south of 20°S.
- **+/- "SQ effort":** for this request we provide projections under a 20% decrease and increase on the status quo effort.
- **"Fully caught limits":** this projection assumes recent (average 2016-2018) levels of fishing (catches) north of 20°S and CCM-nominated maximum total catch levels (para 4 CMM 2009-13) of fishing south of 20°S.
- **"Maximum catch":** this projection assumes peak (2011-2013) levels of fishing (catches) north of 20°S and CCM nominated maximum total catch levels (para 4 CMM 2009-13) for fishing south of 20°S.

Note: *supplementary projection results for catch and effort scenarios of +/- 10 and 30% of SQ levels are included in appendices.*

The results of the projections are presented in terms of the standard performance indicators and reference points used for tuna species by the WCPFC, i.e., spawning potential depletion ($SB/SB_{F=0}$), fishing mortality relative to the fishing mortality expected to achieve maximum sustainable yield (F/F_{MSY}), and spawning potential relative to spawning potential at maximum sustainable yield (SB/SB_{MSY}). Risk is presented as the percentage of models that breached reference points used for tuna species by the WCPFC, i.e., $SB/SB_{F=0}<0.2$, $F/F_{MSY}>1$, $SB/SB_{MSY}<1$. Note, however, there are no formally agreed reference points for this swordfish stock.

The results of the 30-year projections showed that of the 8 scenarios, the "Maximum catch" and "Fully caught" scenarios, which involved considerably higher catches than observed over the history of the fishery, often crashed the stock, and led to a high number of projections (54-69%) declining to <20% $SB_{F=0}$ by the terminal year. The other catch and effort-based projections had lower impacts. The status quo scenarios maintained the stock at a similar, albeit slightly less depleted status, than at the beginning of the projection period, with low numbers of models (<10%) breaching the standard overfishing and overfished benchmarks for tuna species. The 20% increase and decrease in status quo catches and effort had a moderate impact on terminal stock status compared to status quo. The 20% increases led to a slightly more depleted stock status than the 2019 starting level, with 8-22% of models breaching the benchmarks for overfishing or overfished status applied to tuna by the WCPFC.

Summary table of projection outcomes at the end of 10 years and 30 years, in terms of median depletion ($SB/SB_{F=0}$) and risk relative to the tuna LRP), and median MSY-related metrics and associated risks under each scenario examined. The first row is the outcome for the 26 models from the 2021 assessment (last year 2019) using the model uncertainty only and the length-weight bias correction. Note risk level values from the assessment are not directly comparable to those from the projection period.

Scenario No.	Scenario	10-year outcome						30-year outcome					
		$SB/SB_{F=0}$		F/F_{MSY}		SB/SB_{MSY}		$SB/SB_{F=0}$		F/F_{MSY}		SB/SB_{MSY}	
		Median value	Risk < 0.2	Median value	Risk > F_{MSY}	Median value	Risk < SB_{MSY}	Median value	Risk < 0.2	Median value	Risk > F_{MSY}	Median value	Risk < SB_{MSY}
Projection start values	Assessment values	0.39	*4%*	0.53	*15%*	3.70	*4%*	0.39	*4%*	0.53	*15%*	3.70	*4%*
1	SQ catch -20%	0.49	6%	0.34	8%	3.24	4%	0.54	1%	0.24	1%	3.62	1%
2	SQ catch	0.41	12%	0.38	11%	3.19	4%	0.44	9%	0.32	9%	3.04	7%
3	SQ catch +20%	0.35	22%	0.46	15%	3.15	4%	0.36	22%	0.43	21%	2.52	17%
4	Fully caught limits	0.21	46%	0.51	23%	3.03	5%	0.18	54%	0.80	43%	1.45	40%
5	Max catch	0.16	59%	0.31	24%	2.98	6%	0.10	69%	1.21	56%	0.95	51%
6	SQ effort -20%	0.47	5%	0.34	8%	3.25	4%	0.48	4%	0.27	4%	3.39	2%
7	SQ effort	0.41	11%	0.36	8%	3.20	4%	0.42	9%	0.33	8%	2.98	5%
8	SQ effort +20%	0.36	18%	0.31	12%	3.16	4%	0.36	17%	0.40	15%	2.66	8%

Introduction

In 2021, a new stock assessment was completed for southwest Pacific Ocean (SWPO) swordfish (Ducharme-Barth et al. 2021). While there are no formally agreed reference points for SWPO swordfish, the assessment indicated that the stock was not currently overfished or undergoing overfishing according to the relevant benchmarks established by the WCPFC for tuna species. The ensemble of models used to provide management advice indicated that the spawning potential depletion ($SB/SB_{F=0}$) in the terminal year (2019) had a median value of 0.39 (0.18 - 0.79, 10^{th} and 90^{th} percentiles) with 13% of models suggesting it was below the tuna limit reference point of 20% $SB_{F=0}$. The assessment showed trends of increasing depletion and declining spawning potential since the 1960s, with an increased rate of stock decline from the late 1990s until the late 2000s. From the late 2000s the stock appeared to have increased for several years, before showing a declining trend over the last few years of the assessment period.

Concerns over the implications of recent levels of swordfish catch for the long-term stock trajectory have led to renewed interest in conducting stochastic stock projections based on the 2021 stock assessment (Ducharme-Barth et al. 2021) (Fig. 1). The projections can be used to evaluate potential future stock status and risk levels under recent (e.g., 2016 to 2018) and alternative future catch and effort levels, as well as under levels of future catch permitted under CMM 2009-03. WCPFC16 and SC17 have requested that a series of projections be conducted based on the 2021 stock assessment model grid. This paper describes the outcomes of this new series of stock projections.

Methods

Model ensemble

The projections are based on the 2021 south west Pacific Ocean swordfish assessment (Ducharme-Barth et al. 2021) that applied an enhanced approach to capturing uncertainty in management advice (see Appendix - Note 1). Following advice from SC17 to conduct a bias correction on the length-weight conversions applied in the assessment, the model ensemble procedure from the assessment was rerun with this correction, which produced minor differences in management quantities, and a final ensemble of 26 models. Technically the bias correction is appropriate, so for this projection study we have used these 26 models that employed the length-weight bias correction. The results for these 26 models for the terminal year of the assessment period are very similar to the original assessment (see Appendix – Table A1) and are used in this paper as the starting values for the stock projections.

Finally, the stock assessment results included parameter estimation uncertainty as well as the typically included model or structural uncertainty (Appendix - Note 1). It was not technically possible within the time frame to add this additional estimation uncertainty into the stock projections. Therefore, the projections in this paper are restricted to the model (structural) uncertainty only. This means that, compared to the results of the stock assessment, the projections will have a reduced range of uncertainty as can be seen in the Appendix, Table A1.

Stochastic stock projections

The potential stock consequences of alternative future fishing scenarios that were requested by the WCPFC16, and several additional requested by SC17 (described below, Table 1), were evaluated using

stochastic stock projections for 30 years. The 30-year projection period (2020-2049) is deemed sufficient to evaluate the equilibrium stock status under the alternative fishing scenarios. However, we also include results for a 10-year projection period to explore shorter term outcomes. Each of the scenarios was interpreted in terms of a scalar on the status quo (average 2016—2018) catch or effort. The 26 models from the 2021 assessment following the length-weight bias correction were used. For each model and scenario, we conducted 100 projections with future recruitments defined by the estimated stock recruitment relationship, with variability around it sampled randomly from historical recruitment deviates estimated by the stock assessment across the period 1995-2018. This period was less than the full assessment period because the assessment lacked information to estimate recruitment deviations prior to 1995 (Ducharme Barth et al. 2021). Details of the 13 fisheries and spatial assessment structure can be found in Table 3 and the Appendix (Fig. A1). For the effort projections, catchability (which can have a trend in the historical component of the model) was assumed to remain constant in the projection period at the average level estimated for 2016-2018.

Table 1. Scenario descriptions and associated scalar values.

Scenario			
No.	**Name**	**Catch scalar**	**Effort scalar**
1	SQ catch -20%	0.8	NA
2	SQ catch	1.0	NA
3	SQ catch +20%	1.2	NA
4	Fully caught limits	Varies by fishery (Table 3)	NA
5	Max catch	Varies by fishery (Table 3)	NA
6	SQ effort -20%		0.8
7	SQ effort		1.0
8	SQ effort +20%		1.2

The outputs of the projections are presented for the terminal year of the projection period when the stock is expected to have reached equilibrium under the specific fishing scenarios, as well as for the shorter projection period of 10 years. Results are presented for spawning potential depletion ($SB/SB_{F=0}$), fishing mortality relative to the fishing mortality expected to achieve maximum sustainable yield (F/F_{MSY}) and spawning potential relative to spawning potential at maximum sustainable yield (SB/SB_{MSY}). Risk is presented as the percentage of models that breached reference points used for tuna species by the WCPFC, i.e., $SB/SB_{F=0}<0.2$, $F/F_{MSY}>1$, $SB/SB_{MSY}<1$.

A description of the future fishing scenarios is provided below:

- **"Status quo (SQ) catches":** this projection assumes recent (average 2016-2018) levels of fishing (catch) both north and south of 20°S.
- **+/- "SQ catches":** an additional limited number of projections which assume future catch scenarios across the region that are a fixed percentage above and below "status quo" and that result in a range of upward and downward long-term biomass trends. For this request we provide projections with a 20% decrease and increase on the status quo catch.
- **"SQ effort":** this projection assumes recent (average 2016-2018) levels of fishing effort both north and south of 20°S.

- **+/- "SQ effort":** for this request we provide projections under a 20% decrease and increase on the status quo effort.
- **"Fully caught limits":** this projection assumes recent (average 2016-2018) levels of fishing (catches) north of 20°S and CCM-nominated maximum total catch levels (para 4 CMM 2009-13) of fishing south of 20°S. The nominated catch levels, reproduced from CMM 2009-13, are listed in Table 2.
- **"Maximum catch":** this projection assumes peak (2011-2013) levels of fishing (catches) north of 20°S and CCM nominated maximum total catch levels (para 4 CMM 2009-13) for fishing south of 20°S.

Table 2. CCM-nominated maximum total catch of swordfish in the area south of 20°S.

CCM	CATCH (MT)
Australia	2,126
EU	3,170.36
Japan	588.00
Korea	42.25
New Zealand	1,027.00
Chinese Taipei	466.00
USA	74 vessels (Samoa)

Defining catch scenarios

The 2021 stock assessment has two main regions that are each stratified into three fishery areas, resulting in six fishery areas (Appendix, Fig. A1). Thirteen extraction fisheries were defined in the assessment (Table 3), with some spanning entire model regions (e.g., AU_1) but others having separate fisheries allocated to the different fishery areas (i.e., DW_1N, DW_1C, DW-1S). We note there were also three index fisheries in the stock assessment, but these index fisheries play no role in the projections. To determine the scalars for the catch projection scenarios, we used a combination of 5° x 5° logbook data and the annual catch estimates (ACE). The ACE catch data is deemed to be the most accurate data on the total catches by specific flags, but lacks the spatial resolution required to determine the area/fleet specific scalars for projections with spatial components. The estimated catches in metric tonnes for each flag (CCM) from the 5° x 5° logbook data were raised proportionally such that the sum was equal to the ACE. Resulting historical catch levels are illustrated in Figure 1.

Status quo

The status quo catch scenario is straight forward for determining the scalar as there is no spatial component to the scalar – every fishery is scaled the same based on the aggregate average catches for the 2016-2018 period. The +/- 20% scenarios simply scaled the catch by fishery accordingly.

Fully caught limits scalars

Using the raised catch data as described above, the 2016-2018 average catches within each of the six fishery areas were computed for each flag. For the flags with nominated limits under CMM 2009-13 (i.e., south of 20°S), the projected catch was distributed among the six fishery areas in proportion to the average distribution of 2016-2018 catch. Within each of the 13 fisheries in Table 3, the individual flag catch levels – either the 2016-2018 average or the nominated limits – were then summed. The fishery-

specific scalar was then computed as the ratio of the fully-caught scenario catch levels to the sum of the 2016-2018 average catch for all the flags (Table 3).

Max catch scalars
This is the same as for 'Fully caught' scalars, except for the treatment of projected catch in Regions 1N and 2N (i.e., north of 20°S). For each relevant flag, the maximum annual catch from 2011-2013 in regions 1N and 2N was determined. For a number of flags, this value was less than their 2016-2018 average, so in line with the intent of this evaluation, we used the maximum of the two values when computing the scalar for the various fisheries (Table 3).

Catch projections
The projections based on catch scalars carry the following caveat. 11 of the 13 fisheries in the assessment are projected on number of fish in the catch, while 2 (the EU fisheries) are projected on weight. For the fisheries projected on number, it is not possible to project based on a fixed catch in weight due to the model configuration. For these projections, we therefore compute the scalars based on catch weights (Table 3) and these scalars are applied to the average numbers of fish caught during 2016-2018. As such, future catches during the projection period can vary in weight even though numbers of fish caught is projected as a constant. This occurs because the size distribution of the fish in the catch will vary annually due to variable recruitment and the influx of large or small year classes into the catch. Over the course of 100 simulations the median catch approaches a roughly constant level.

With constant catch-based projections, some combinations of recruitment and fishing mortality led to projections resulting in stock crashes (i.e., population going to zero). Most of these crashes occurred after more than 10 years of projection. For the projections that crashed the stock, a value of 0 was used for terminal depletion ($SB/SB_{F=0}$) and SB/SB_{MSY}. For F/F_{MSY}, projections that crashed the stock were given a terminal value of 3. For some projections, the stock reached very low levels, and extremely large values of F/F_{MSY} were sometimes estimated. In these instances, values larger than 3 were also set to a value of 3. Median terminal-year values will be accurate for all three metrics, as will distributions for $SB/SB_{F=0}$ and SB/SB_{MSY}, however the distribution of F/F_{MSY} was truncated to a range of 0 to 3. Values are also provided for these metrics after the first 10 years of the projection period.

Additionally, projections in which the stock crashes currently result in output time series that are unreliable and cannot be included in time-series plots showing the 30-year projection period. We therefore provide the depletion trajectories across the 8 scenarios for the 10-year projections only as these trajectories are little affected by crashed runs.

Defining effort scenarios

For projections based on effort, the status quo scenario applied the average effort and catchability by each fishery for the 2016-2018 baseline period. The +/- 20% scenarios simply scaled the effort accordingly while applying the same catchability.

Table. 3 Fishery definitions from the 2021 southwest Pacific swordfish assessment with catch values (metric tonnes) for the status quo (SQ), Fully Caught limits (FCL) and Maximum catch (MAX) scenarios and their associated fishery specific scalars. The numbers associated with the fishery names, i.e., 1, 2, 1N, 2C etc. refer to the model regions and fishery areas (Appendix, Fig. A1). Flag/fleets: AU = Australia; DWFN = Distant Water Fishing Nations; EU = European Union; NZ = New Zealand; PICT = Pacific Islands Countries and Territories and other small miscellaneous contributors.

Fishery	Name	Fleet	Catch (mt)			Scalar	
			SQ (2016-18)	FCL	MAX	FCL	MAX
1	DW_1N	DWFN	129.7	129.7	577.0	1.00	4.45
2	DW_1C	DWFN	147.8	337.7	337.7	2.28	2.28
3	DW_1S	DWFN	97.0	473.8	473.8	4.88	4.88
4	AU_1	AU	968.5	2165.1	2196.5	2.24	2.27
5	EU_1	EU	56.5	138.6	138.6	2.46	2.46
6	Other_1	PICT	44.7	44.7	199.1	1.00	4.46
7	DW_2N	DWFN	3566.7	3566.7	4843.0	1.00	1.36
8	DW_2C	DWFN	274.1	360.1	360.1	1.31	1.31
9	DW_2S	DWFN	0.0	0.0	0.0	1.00	1.00
10	NZ_2	NZ	574.0	1027.0	1027.0	1.79	1.79
11	EU_2	EU	1234.9	3031.7	3031.7	2.46	2.46
12	Other_2N	PICT	299.3	299.3	472.3	1.00	1.58
13	Other_2C	PICT	164.6	164.6	164.6	1.00	1.00
		Total	7557.7	11738.9	13821.4		

Results

Table 4 provides a summary of the number and percentages of models that, over the 10 and 30-year projection time periods, had at least one run that crashed the stock, and the total number and percentages of projections that crashed the stock for each of the scenarios. Stock crashes were most common for the “Fully caught limits” (25% of projections) and “Maximum Catch” (36% of projections) scenarios. All catch projections except for the 20% catch reduction scenario had at least one projection that crashed the stock. In comparison, none of the effort-based projection scenarios resulted in population crash.

The results for the terminal year for the key management metrics are provided in Tables 5-7, and Figures 2-5 (results for supplementary scalars on catch and effort +/- 10% and +/- 30% are in the Appendix, Tables A2-A7, Figures A2-A4). The percentile values of 10, 50, and 90 are provided. The value of the 90th percentile indicates that 90% of the model projections terminated below this value, the 50th percentile is the median across all the projections and the 10th percentile indicates that 10% of the model projections terminated below this value. Table 8 provides the risk summary.

Table 4. Summary of the numbers and percentages of models and individual projections with stock crashes.

Scenario		10-year projections				30-year projections			
		Models with ≥ 1 stock crash projection (out of 26)		Projections with stock crashes (out of 2600)		Models with ≥ 1 stock crash projection (out of 26)		Projections with stock crashes (out of 2600)	
No.	Name	No.	%	No.	%	No.	%	No.	%
1	SQ catch -20%	0	0.0	0	0.0	0	0.0	0	0.0
2	SQ catch	0	0.0	0	0.0	2	7.7	29	1.1
3	SQ catch +20%	0	0.0	0	0.0	4	15.4	163	6.3
4	Fully caught limits	1	3.8	2	0.1	11	42.3	653	25.1
5	Max catch	2	7.7	11	0.4	14	53.8	936	36.0
6	SQ effort -20%	0	0.0	0	0.0	0	0.0	0	0.0
7	SQ effort	0	0.0	0	0.0	0	0.0	0	0.0
8	SQ effort +20%	0	0.0	0	0.0	0	0.0	0	0.0

Depletion ($SB/SB_{F=0}$)

The terminal (equilibrium) median $SB/SB_{F=0}$ levels for the 'Fully caught limits' and 'Maximum catch' scenarios were both well below the 2019 starting value of 0.39 and below the limit refence point (20% $SB_{F=0}$) applied to tuna species, being 0.18 and 0.10 $SB/SB_{F=0}$ respectively. For the status quo catch scenario, the terminal median $SB/SB_{F=0}$ = 0.44, slightly less depleted status than the 2019 starting value, and ranged from 0.54 – 0.36 for the -20% and +20% scenarios, respectively (Table 5). For the 'Fully caught limits' and 'Maximum catch' scenarios 54% and 69% of projections, respectively had terminal $SB/SB_{F=0}$ <0.2. For the status quo catch scenario and the reduced catch scenarios, less than 10% of projections had terminal $SB/SB_{F=0}$ <0.2, however for the 20% catch increase 22% of projections had terminal $SB/SB_{F=0}$ <0.2 (Table 8, Fig. 3).

For the effort-based projections, the status quo scenario had terminal median $SB/SB_{F=0}$ = 0.42 and ranged from 0.48 – 0.36 for the -20% and +20% scenarios, respectively (Table 5). While the effort-based projections had slightly more depleted terminal status than the status quo catch-based projections, they had lower risk of $SB/SB_{F=0}$ <0.2 for the +20% scenarios (Table 8, Fig. 3).

For the 10-year projections, $SB/SB_{F=0}$ was slightly lower (more depleted) than for the 30-year terminal point across all scenarios except for the 'Fully caught limits' and 'Maximum catch' scenarios that were slightly less depleted (Table 5, Figs. 2, 3). Consistent with these patterns, the percentage of models below 20% $SB_{F=0}$ was slightly higher for the 10-year projection point across all scenarios except for the 'Fully caught limits' and 'Maximum catch' scenarios for which slightly fewer models were below 20% $SB_{F=0}$ (Table 8).

F/F_{MSY}

The terminal median F/F_{MSY} levels for the 'Fully caught limits' and 'Maximum catch' scenarios were 0.8 and 1.21 respectively, both well above the 2019 median starting value of 0.53, indicating increased fishing pressure (and in the maximum catch scenario, fishing above F_{MSY} levels). For the status quo catch scenario the terminal median F/F_{MSY} = 0.32, below the 2019 median starting value, and ranged from 0.24– 0.43 for

-20% and +20% scenarios (Table 6). For the 'Fully caught limits' and 'Maximum catch' scenarios, 43% and 56% of projections respectively had terminal F/F_{MSY} >1. For the status quo catch scenario and the reduced catch scenarios less than 10% of projections had terminal F/F_{MSY} >1, however, for the 20% catch increases 21% of projections had terminal F/F_{MSY} >1 (Table 8, Fig. 4).

For the effort-based projections, the status quo scenario had terminal median F/F_{MSY} = 0.33 and ranged from 0.27 – 0.40 for the -20% and +20% scenarios, respectively; all were below the 2019 median value (Table 6). In terms of F/F_{MSY} the effort-based projections performed similarly to the overall catch-based projections, but with slightly lower risk of F/F_{MSY} >1 for the +20% scenarios (Table 8, Fig. 3).

For the 10-year projections, F/F_{MSY} was generally similar or slightly higher than for the 30-year terminal point, except for the 'Fully caught limits' and 'Maximum catch' scenarios, for which it was lower (Table 6). Notably fewer projections had F/F_{MSY}>1 for the 'Fully caught limits' and 'Maximum catch' scenarios in the 10-year projections than the full 30-year projections (Table 8).

SB/SB_{MSY}

The terminal median SB/SB_{MSY} levels for the 'Fully caught limits' and 'Maximum catch' scenarios were 1.45 and 0.95, respectively, both well below the 2019 median starting value of 3.70 and indicative of a declining stock. For the status quo catch scenario the terminal median SB/SB_{MSY} = 3.04 and ranged from 3.62 – 2.52 for -20% and +20% scenarios, all were below the 2019 median starting value (Table 7, Fig. 4). For the 'Fully caught limits' and 'Maximum catch' scenarios, 40% and 51% of projections respectively had terminal SB/SB_{MSY} <1. For the status quo catch scenario and the reduced catch scenario less than 10% of projections had terminal SB/SB_{MSY} <1, however for the 20% catch increase 17% of projections had terminal SB/SB_{MSY} <1 (Table 8, Fig. 4).

For the effort-based projections, the status quo scenario had terminal median SB/SB_{MSY} = 2.98 and ranged from 3.39 – 2.66 for the -20% and +20% scenarios, respectively (Table 7). In terms of SB/SB_{MSY} the effort-based projections performed similarly to the overall catch-based projections, but with slightly lower risk of SB/SB_{MSY} <1 for the status quo and +20% scenarios (Table 8, Fig. 3).

For the increased and status quo catch and effort scenarios the 10-year projections of SB/SB_{MSY} were higher than for the 30-year terminal point, and for the reductions in catch or effort they were lower (Table 7). For the 10-year projections, very few projections (≤ 7%) for any scenario had SB/SB_{MSY} <1 (Table 8).

Table 5. Values for the 10th, 50th and 90th percentiles of the terminal (equilibrium) $SB/SB_{F=0}$ for the 100 stochastic projections for each future catch and effort scenario. The first row is the outcome for the 26 models from the 2021 assessment (last year 2019) using the model uncertainty only and the length-weight bias correction.

Scenario No.	Scenario	Percentiles for 10-year projections			Percentiles for 30-year projections		
		10	(median) 50	90	10	(median) 50	90
Projection start value	2019 model uncertainty only	0.24	0.39	0.53	0.24	0.39	0.53
1	SQ catch -20%	0.25	0.49	0.66	0.35	0.54	0.69
2	SQ catch	0.18	0.41	0.60	0.22	0.44	0.62
3	SQ catch +20%	0.12	0.35	0.54	0.07	0.36	0.54
4	Fully caught limits	0.03	0.21	0.41	0.00	0.18	0.39
5	Max catch	0.00	0.16	0.36	0.00	0.10	0.32
6	SQ effort -20%	0.24	0.47	0.63	0.27	0.48	0.65
7	SQ effort	0.20	0.41	0.57	0.21	0.42	0.58
8	SQ effort +20%	0.16	0.36	0.53	0.16	0.36	0.53

Table 6. Values for the 10th, 50th and 90th percentiles of the terminal (equilibrium) F/F_{MSY} for the 100 stochastic projections for each future catch and effort scenario. The first row is the outcome for the 26 models from the 2021 assessment (last year 2019) using the model uncertainty only and the length-weight bias correction.

Scenario No.	Scenario	Percentiles for 10-year projections			Percentiles for 30-year projections		
		10	(median) 50	90	10	(median) 50	90
Projection start value	2019 model uncertainty only	0.38	0.53	1.07	0.38	0.53	1.07
1	SQ catch -20%	0.17	0.34	1.02	0.12	0.24	0.62
2	SQ catch	0.19	0.38	1.15	0.16	0.32	0.95
3	SQ catch +20%	0.22	0.46	1.73	0.20	0.43	1.67
4	Fully caught limits	0.25	0.51	3.00	0.32	0.80	3.00
5	Max catch	0.16	0.31	0.91	0.42	1.21	3.00
6	SQ effort -20%	0.17	0.34	0.98	0.14	0.27	0.79
7	SQ effort	0.18	0.36	1.04	0.17	0.33	0.96
8	SQ effort +20%	0.16	0.31	0.92	0.20	0.40	1.14

Table 7. Values for the 10th, 50th and 90th percentiles of the terminal (equilibrium) SB/SB_{MSY} for the 100 stochastic projections for each future catch and effort scenario. The first row is the outcome for the 26 models from the 2021 assessment (last year 2019) using the model uncertainty only and the length-weight bias correction.

Scenario No.	Scenario	Percentiles for 10-year projections			Percentiles for 30-year projections		
		10	(median) 50	90	10	(median) 50	90
Projection start value	2019 'model uncertainty' only	1.74	3.70	5.54	1.74	3.70	5.54
1	SQ catch -20%	1.52	3.24	5.07	1.91	3.62	5.83
2	SQ catch	1.47	3.19	4.96	1.28	3.04	5.16
3	SQ catch +20%	1.43	3.15	4.86	0.66	2.52	4.56
4	Fully caught limits	1.34	3.03	4.67	0.00	1.45	3.40
5	Max catch	1.35	2.98	4.60	0.00	0.95	2.86
6	SQ effort -20%	1.52	3.25	5.09	1.68	3.39	5.50
7	SQ effort	1.49	3.20	5.00	1.33	2.98	4.98
8	SQ effort +20%	1.46	3.16	4.92	1.06	2.66	4.55

Table 8. Percentage of projections that breached standard WCPFC reference points for tuna species. These values are commonly termed 'risk' when referring to breaching of reference points. Note risk levels from the assessment (2019 'model uncertainty' only levels) are not directly comparable to those from the projection period.

		Percentages for 10-year projections			Percentages for 30-year projections		
No.	Scenario	$(SB/SB_{F=0})$ < 0.2	(F/F_{MSY}) > 1.0	(SB/SB_{MSY}) < 1.0	$(SB/SB_{F=0})$ < 0.2	(F/F_{MSY}) > 1.0	(SB/SB_{MSY}) < 1.0
Projection start value	2019 'model uncertainty' only	*4*	*15*	*4*	*4*	*15*	*4*
1	SQ catch -20%	6	8	4	1	1	1
2	SQ catch	12	11	4	9	9	7
3	SQ catch +20%	22	15	4	22	21	17
4	Fully caught limits	46	23	5	54	43	40
5	Max catch	59	24	6	69	56	51
5	SQ effort -20%	5	8	4	4	4	2
7	SQ effort	11	8	4	9	8	5
8	SQ effort +20%	18	12	4	17	15	8

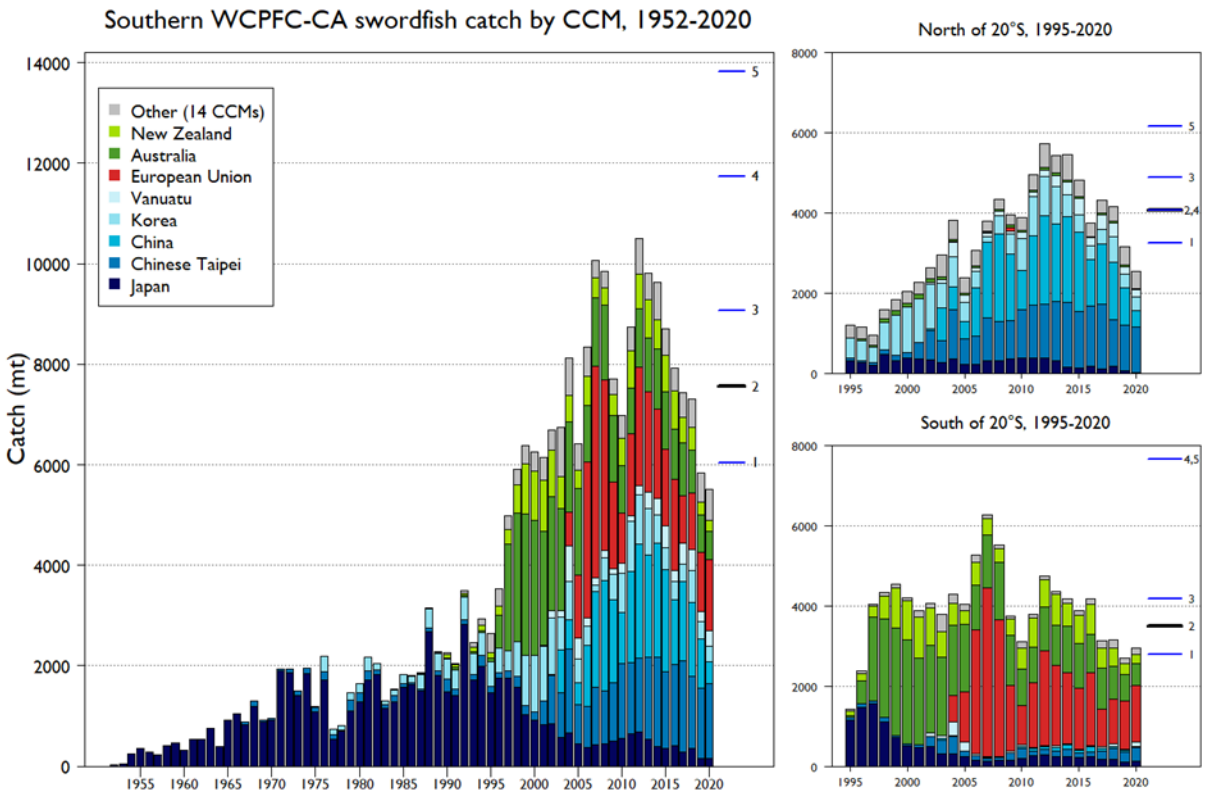

Figure 1. Catch of southwest Pacific Ocean swordfish over the period 1952-2020, taken south of the equator in the WCPFC-CA. Top contributors are identified individually; the European Union includes catch by Spain and Portugal. The 14 CCMs combined in the 'Other' category are mostly Pacific Island Countries and Territories, but also include occasional participants from outside the region. Total catch is shown in the left side plot, while the catch north and south of 20°S is shown in the two right-side plots. The horizontal, numbered lines, in each plot are the constant catch levels projected under the five catch projection scenarios (Table 1). Catch resulting under the effort-based projection scenarios is not shown as this varies over the projection period.

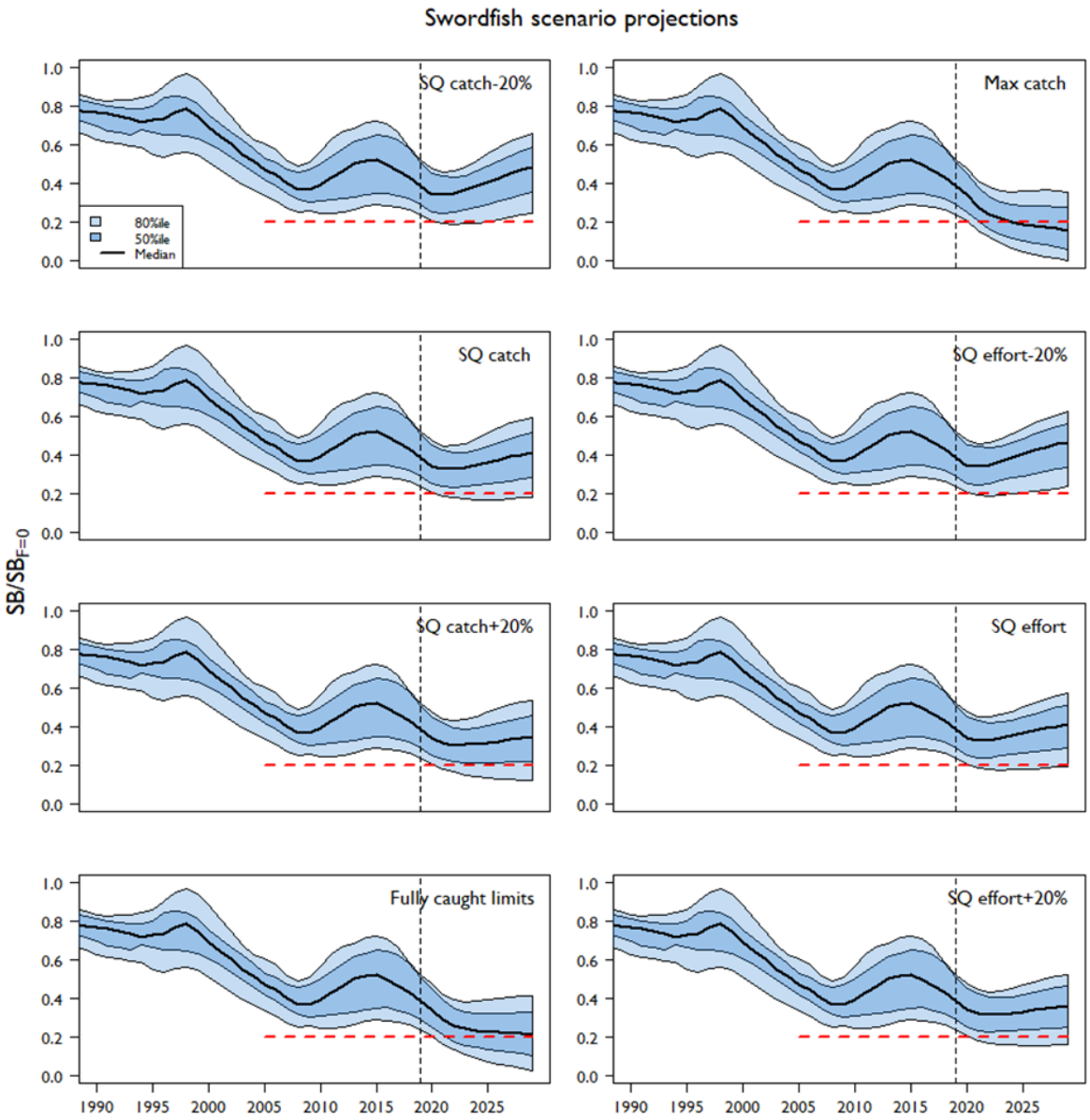

Figure 2. Time series of southwest Pacific Ocean swordfish spawning biomass depletion ($SB/SB_{F=0}$) from the uncertainty grid of assessment model runs for the period 1990 to 2019 (the vertical dashed line at 2019 represents the last year of the assessment), and stochastic projection results for the period 2020 to 2029 for each of the 8 scenarios of projected catch and effort. During the projection period (2020-2029) levels of recruitment variability are related to those over the time period used to estimate the stock-recruitment relationship (1995-2018). The red horizontal dashed line represents the agreed WCPFC limit reference point for tuna species.

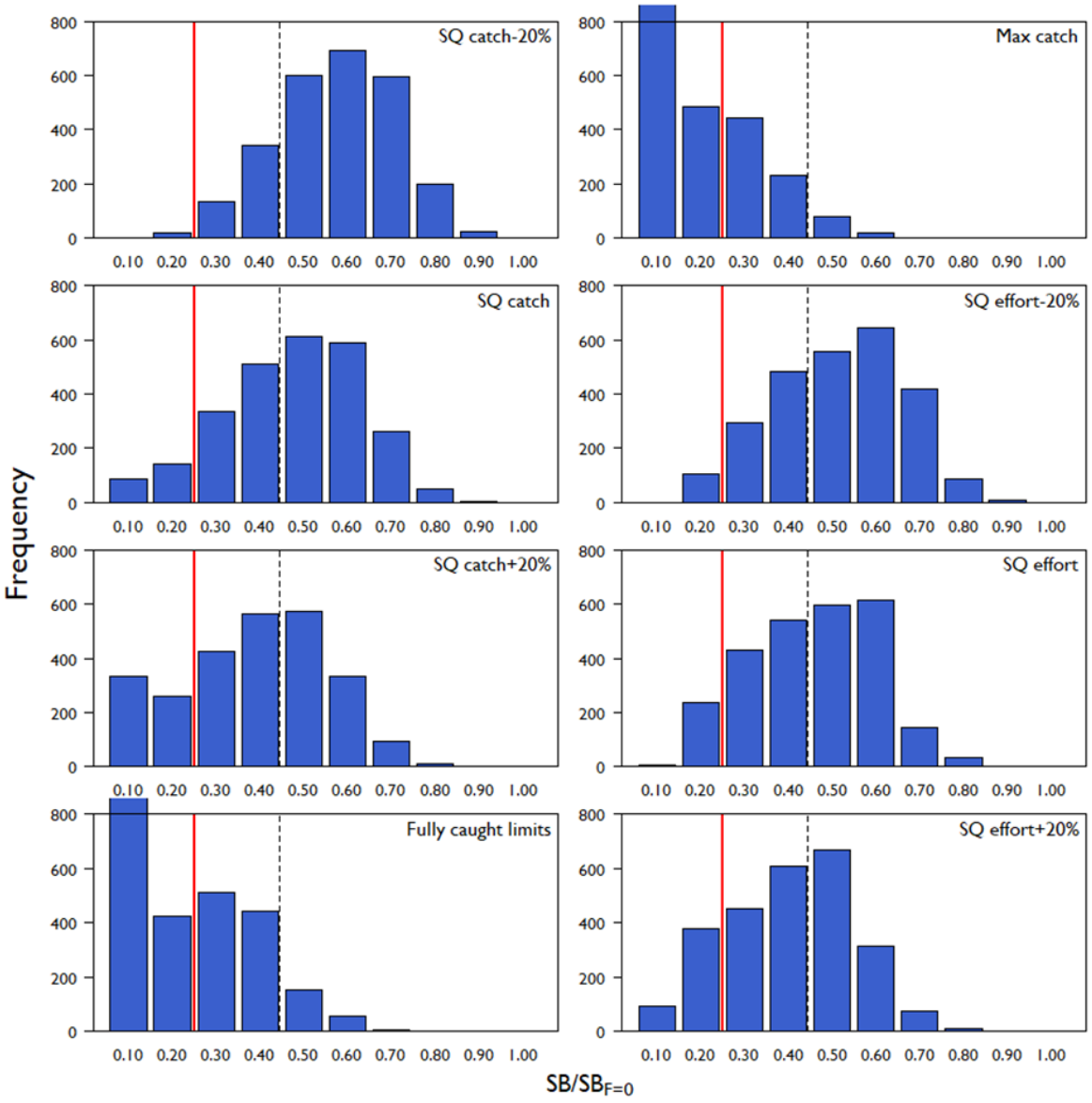

Figure 3. Histograms of the distributions of **terminal** $SB/SB_{F=0}$ for the 8 projection scenarios. Red line indicates the WCPFC limit reference point for tuna species, and the dashed line is the median value (0.39) for the 26 models at the start of the projection (2019).

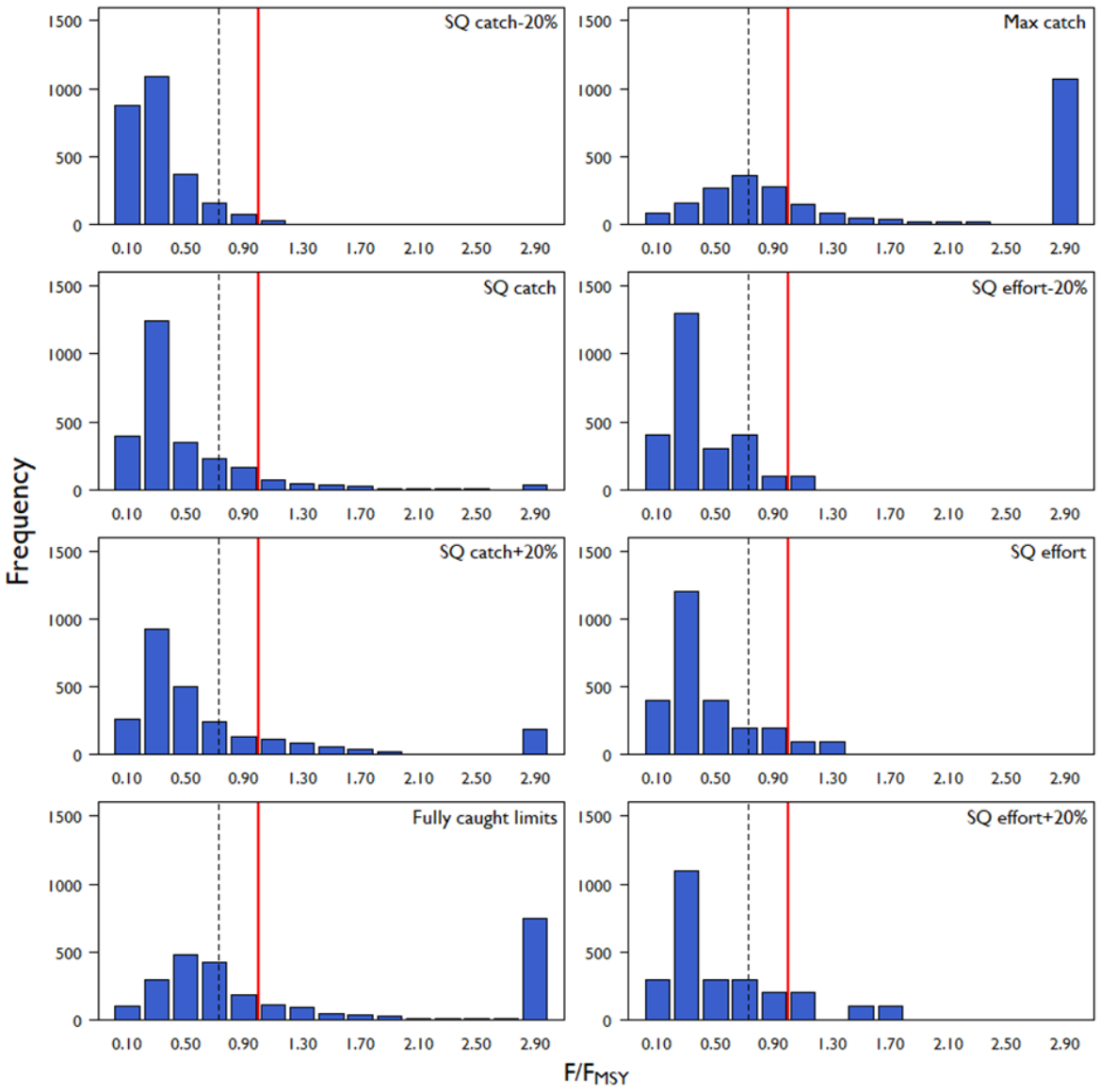

Figure 4. Histograms of the distributions of **terminal** F/F_{MSY} for the 8 projection scenarios. Red line indicates limit reference points applied to tuna, and dashed line indicate the median value (0.53) for the 26 models at the start of the projection (2019).

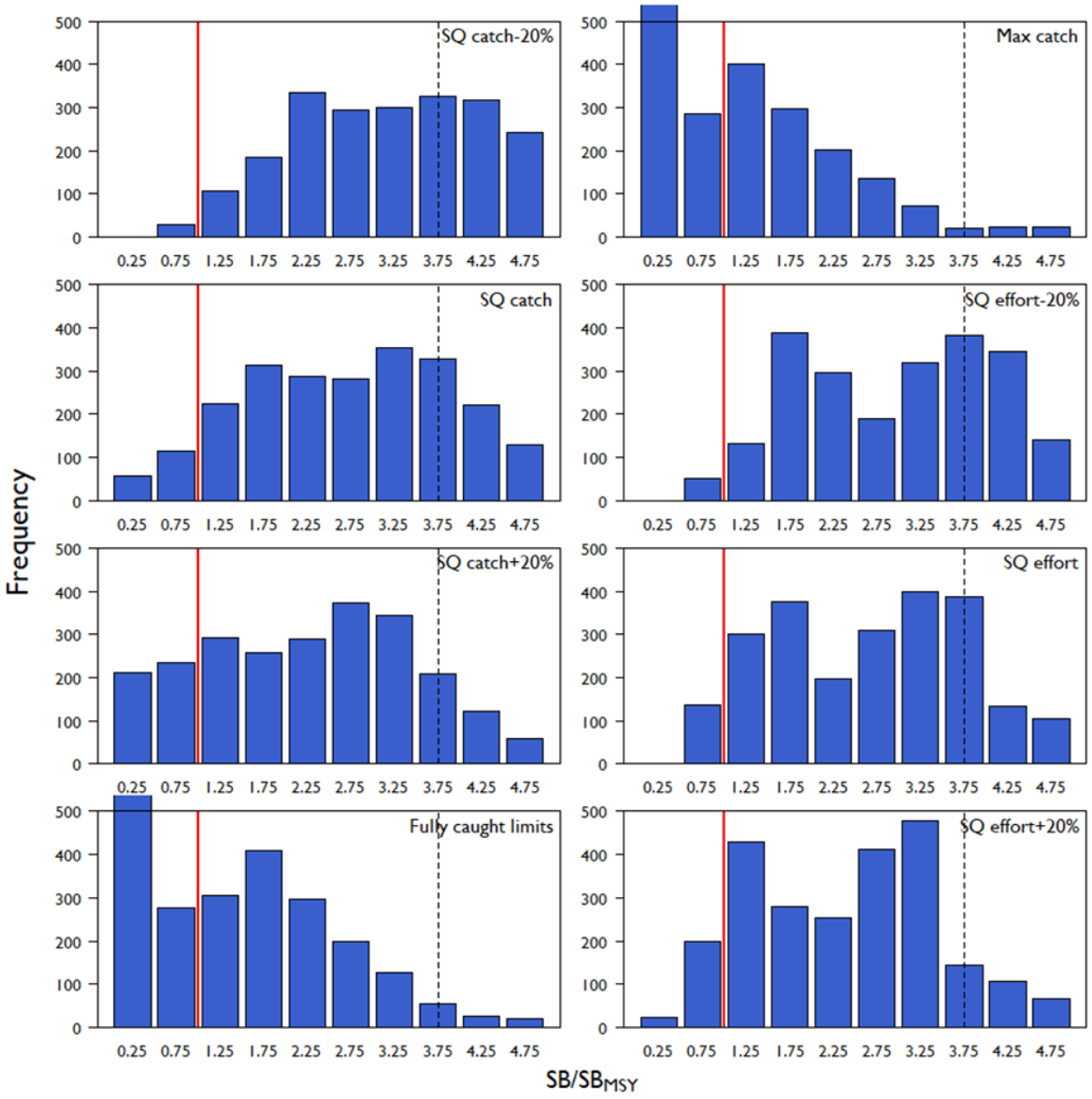

Figure 5. Histograms of the distributions of **terminal** SB/SB_{MSY} for the 8 projection scenarios. Red line indicates limit reference points applied to tuna, and dashed line indicate the median value (3.70) for the 26 models at the start of the projection (2019).

Discussion

Of the 8 future catch scenarios evaluated, the 'Fully caught limits' and the 'Maximum catch' scenarios produced the worst outcomes for stock status. These scenarios both led to the stock becoming considerably more depleted than at the start of the projection period, with relatively high numbers of projections indicating the stock crashed after 10 years into the projection period. Over half the projections in these two scenarios (54% and 69% for the 'Fully caught' and 'Maximum catch' scenarios, respectively) led to a terminal stock status <20% $SB_{F=0}$ at the end of the 30-year projection period. These scenarios, not surprisingly, also led to poor outcomes for the F/F_{MSY} and SB/SB_{MSY} performance measures. The 'Maximum catch' scenario was clearly the highest scalar with an average catch scalar across flags of 2.4, and the 'Fully caught limits' had an average scalar across flags of 1.8, compared to the highest status quo-related catch scalar of 1.2.

For the status quo +/- catch-based scenarios, projections that maintained the status quo catch levels tended to result in the stock being maintained at similar to, or slightly less, depleted levels than at the starting year of 2019, both at the 10 year and terminal year stage of the projections. The status quo scenario also had low associated risk of breaching the standard WCPFC tuna benchmarks for indicating overfishing and overfished status. Compared to the status quo catch scenario, the 20% catch increase scenario had a more notable impact, with ca. 20% of projections breaching the standard benchmarks for overfishing and overfished status applied to tuna species by the WCPFC. The 20% catch reduction scenario led to a substantially less depleted stock than the 2019 starting year, with only one projection that declined to <20% $SB_{F=0}$. It is worth noting that in recent years catches have decreased compared to the 2016-2018 baseline period, with average catches in 2019-2020 being approximately 75% of the 2016-2018 average.

Effort-based projections general performed similar to the catch-based scenarios across the status quo and +/- 20% scenarios. However, while the median values for the stock performance measure were similar between the catch or effort-based projections, there was a trend for reduced risk of models breaching the standard benchmarks for overfishing and overfished status for higher effort scalars compared to the higher catch scalars. This became more obvious when the effort and catch were increased by 30% (appendix Table A7).

References

Ducharme-Barth, N., Castillo-Jordan, C., Hampton, J., Williams, P., Pilling, G. and Hamer, P. 2021. Stock assessment of southwest Pacific swordfish. WCPFC-SC17-2021/SA-WP-04.

Ducharme-Barth, N. and Vincent, M. (2021). Focusing on the front end: A framework for incorporating uncertainty in biological parameters in model ensembles of integrated stock assessments. WCPFC-SC17-2021/SA-WP-05.

Appendix

Note 1: 2021 assessment approach for characterizing uncertainty in management quantities

The 2021 stock assessment developed a new model ensemble approach for characterizing uncertainty in management quantities that included both model (structural) and estimation (statistical) uncertainty (Ducharme-Barth et el. 2021; Ducharme-Barth and Vincent 2021). This provided a more complete representation of uncertainty than previous assessments that considered only the model uncertainty. The new approach used a combination of a factorial grid of discrete factors, overlaid on correlated parameter sets drawn from a joint prior to generate a set of models that best represented the uncertainty in biological parameters and data inputs. The approach also applied a post-hoc filtering process to remove models that produced implausible results and/or poor model fits, ultimately resulting in 25 models being used for generating management advice. For each of these 25 models, estimation uncertainty was included using a parametric bootstrap. The addition of the estimation uncertainty broadens the range of uncertainty for the management quantities, which has implications for the calculation or risk levels, as can been seen in table A1 (i.e., higher risk levels for the assessment ensemble that included estimation uncertainty).

Table A1. Comparisons of management advice quantities at the end (i.e. 2019) of the assessment period for the model ensembles used in the projection study (length-weight bias correction and model uncertainty only) and the 2021 assessment (no length-weight bias correction, with inclusion of model and estimation uncertainty).

Model ensemble	$SB/SB_{F=0}$, median (10^{th} and 90^{th} percentiles)	Risk % models $SB/SB_{F=0}$ <0.2	F/F_{MSY}, median (10^{th} and 90^{th} percentiles)	Risk % models F/F_{MSY} >1	SB/SB_{MSY}, median (10^{th} and 90^{th} percentiles)	Risk % models SB/SB_{MSY} <1
2021 assessment	0.39 (0.18, 0.79)	13%	0.47 (0.25, 1.29)	20%	2.95 (0.99, 6.78)	10%
Projections	0.39 (0.24, 0.53)	4%	0.53 (0.38, 1.07)	15%	3.70 (1.74, 5.54)	4%

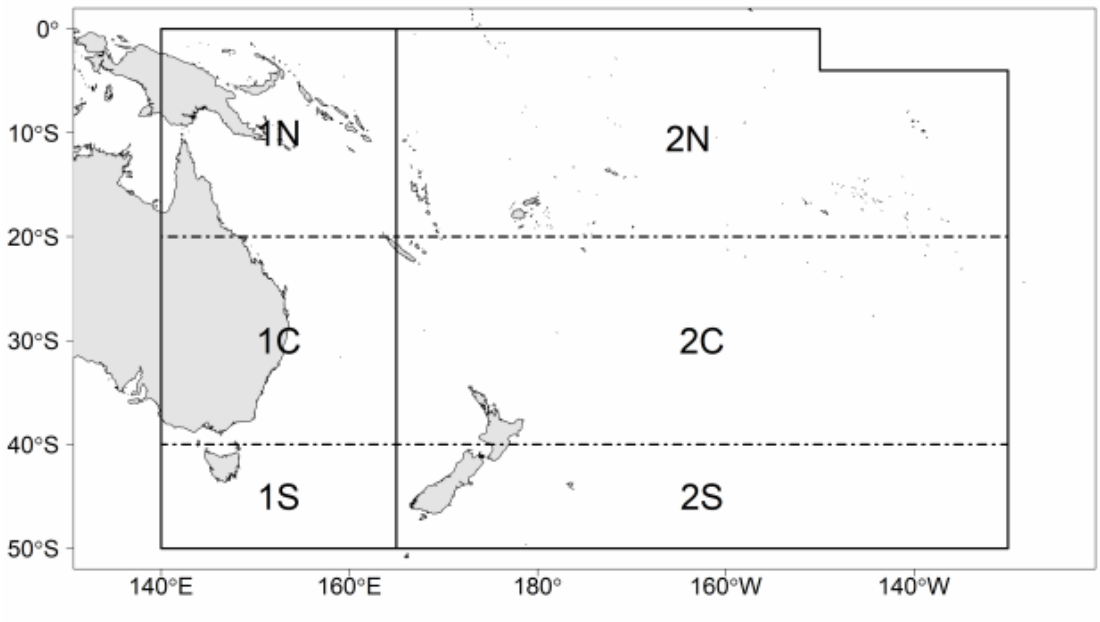

Figure A1. Spatial structure for the 2021 southwest Pacific swordfish stock assessment. Sub-regions used to differentiate fisheries are shown with the dotted lines.

Results for supplementary catch and effort scenarios

Table A2. Supplementary scenarios. Descriptions and associated scalar values.

Scenario			
No.	Name	Catch scalar	Effort scalar
1	SQ catch -30%	0.7	NA
2	SQ catch -10%	0.9	NA
3	SQ catch +10%	1.1	NA
4	SQ catch +30%	1.3	NA
5	SQ effort -30%	NA	0.7
6	SQ effort -10%	NA	0.9
7	SQ effort +10%	NA	1.1
8	SQ effort +30%	NA	1.3

Table A3. Supplementary scenarios. Summary of the numbers and percentages of models and individual projections with stock crashes for the supplementary scenarios.

Scenario		10-year projections				30-year projections			
		Models with ≥ 1 stock crash projection (out of 26)		Projections with stock crashes (out of 2600)		Models with ≥ 1 stock crash projection (out of 26)		Projections with stock crashes (out of 2600)	
No.	Name	No.	%	No.	%	No.	%	No.	%
1	SQ catch -30%	0	0.0	0	0.0	0	0.0	0	0.0
2	SQ catch -10%	0	0.0	0	0.0	1	3.8	2	0.1
3	SQ catch +10%	0	0.0	0	0.0	4	15.4	90	3.5
4	SQ catch +30%	0	0.0	0	0.0	6	23.1	235	9.0
5	SQ effort -30%	0	0.0	0	0.0	0	0.0	0	0.0
6	SQ effort -10%	0	0.0	0	0.0	0	0.0	0	0.0
7	SQ effort +10%	0	0.0	0	0.0	0	0.0	0	0.0
8	SQ effort +30%	0	0.0	0	0.0	0	0.0	0	0.0

Table A4. Supplementary scenarios. Values for the 10th, 50th and 90th percentiles of the terminal (equilibrium) $SB/SB_{F=0}$ for the 100 stochastic projections for the supplementary future catch and effort scenarios. The first row is the outcome for the 26 models from the 2021 assessment (last year 2019) using the model uncertainty only and the length-weight bias correction.

Scenario No.	Scenario	Percentiles for 10-year projections			Percentiles for 30-year projections		
		10	(median) 50	90	10	(median) 50	90
Projection start value	2019 model uncertainty only	0.24	0.39	0.53	0.24	0.39	0.53
1	SQ catch -30%	0.28	0.53	0.69	0.42	0.59	0.74
2	SQ catch -10%	0.22	0.45	0.63	0.29	0.49	0.66
3	SQ catch +10%	0.15	0.38	0.57	0.15	0.40	0.58
4	SQ catch +30%	0.10	0.32	0.51	0.00	0.31	0.51
5	SQ effort -30%	0.26	0.50	0.66	0.31	0.52	0.68
6	SQ effort -10%	0.22	0.44	0.60	0.24	0.45	0.61
7	SQ effort +10%	0.18	0.39	0.55	0.18	0.39	0.55
8	SQ effort +30%	0.15	0.34	0.50	0.14	0.34	0.50

Table A5. Supplementary scenarios. Values for the 10th, 50th and 90th percentiles of the terminal (equilibrium) F/F_{MSY} for the 100 stochastic projections for the supplementary future catch and effort scenarios. The first row is the outcome for the 26 models from the 2021 assessment (last year 2019) using the model uncertainty only and the length-weight bias correction.

Scenario No.	Scenario	Percentiles for 10-year projections			Percentiles for 30-year projections		
		10	(median) 50	90	10	(median) 50	90
Projection start value	2019 model uncertainty only	0.38	0.53	1.07	0.38	0.53	1.07
1	SQ catch -30%	0.15	0.30	0.87	0.14	0.28	0.76
2	SQ catch -10%	0.16	0.33	0.97	0.18	0.38	1.22
3	SQ catch +10%	0.18	0.36	1.08	0.23	0.49	3.00
4	SQ catch +30%	0.20	0.40	1.23	0.12	0.23	0.70
5	SQ effort -30%	0.15	0.30	0.87	0.15	0.30	0.88
6	SQ effort -10%	0.16	0.33	0.94	0.19	0.36	1.05
7	SQ effort +10%	0.18	0.35	1.01	0.22	0.43	1.22
8	SQ effort +30%	0.19	0.37	1.08	0.10	0.20	0.49

Table A6. Supplementary scenarios. Values for the 10th, 50th and 90th percentiles of the terminal (equilibrium) SB/SB_{MSY} for the 100 stochastic projections for the supplementary catch and effort scenarios. The first row is the outcome for the 26 models from the 2021 assessment (last year 2019) using the model uncertainty only and the length-weight bias correction.

Scenario No.	Scenario	Percentiles for 10-year projections			Percentiles for 30-year projections		
		10	(median) 50	90	10	(median) 50	90
Projection start value	2019 'model uncertainty' only	1.74	3.70	5.54	1.74	3.70	5.54
1	SQ catch -30%	1.54	3.27	5.12	2.22	3.90	6.20
2	SQ catch -10%	1.50	3.22	5.01	1.59	3.31	5.48
3	SQ catch +10%	1.45	3.17	4.91	0.96	2.77	4.85
4	SQ catch +30%	1.41	3.13	4.82	0.34	2.28	4.28
5	SQ effort -30%	1.54	3.27	5.13	1.89	3.62	5.79
6	SQ effort -10%	1.50	3.23	5.04	1.49	3.17	5.23
7	SQ effort +10%	1.47	3.18	4.96	1.19	2.81	4.76
8	SQ effort +30%	1.44	3.15	4.88	0.95	2.52	4.37

Table A7. Supplementary scenarios. Percentage of supplementary scenario projections that breached standard WCPFC reference points for tuna species.

		Percentages for 10-year projections			Percentages for 30-year projections		
No.	Scenario	$(SB/SB_{F=0})$ < 0.2	(F/F_{MSY}) > 1.0	(SB/SB_{MSY}) < 1.0	$(SB/SB_{F=0})$ < 0.2	(F/F_{MSY}) > 1.0	(SB/SB_{MSY}) < 1.0
Projection start value	2019 'model uncertainty' only	4	15	4	4	15	4
1	SQ catch -30%	3	8	4	0	0	0
2	SQ catch -10%	8	9	4	4	5	4
3	SQ catch +10%	17	13	4	16	15	11
4	SQ catch +30%	26	17	4	30	26	23
5	SQ effort -30%	4	8	4	1	0	0
5	SQ effort -10%	8	8	4	5	8	4
7	SQ effort +10%	14	12	4	13	12	7
8	SQ effort +30%	22	15	4	22	23	12

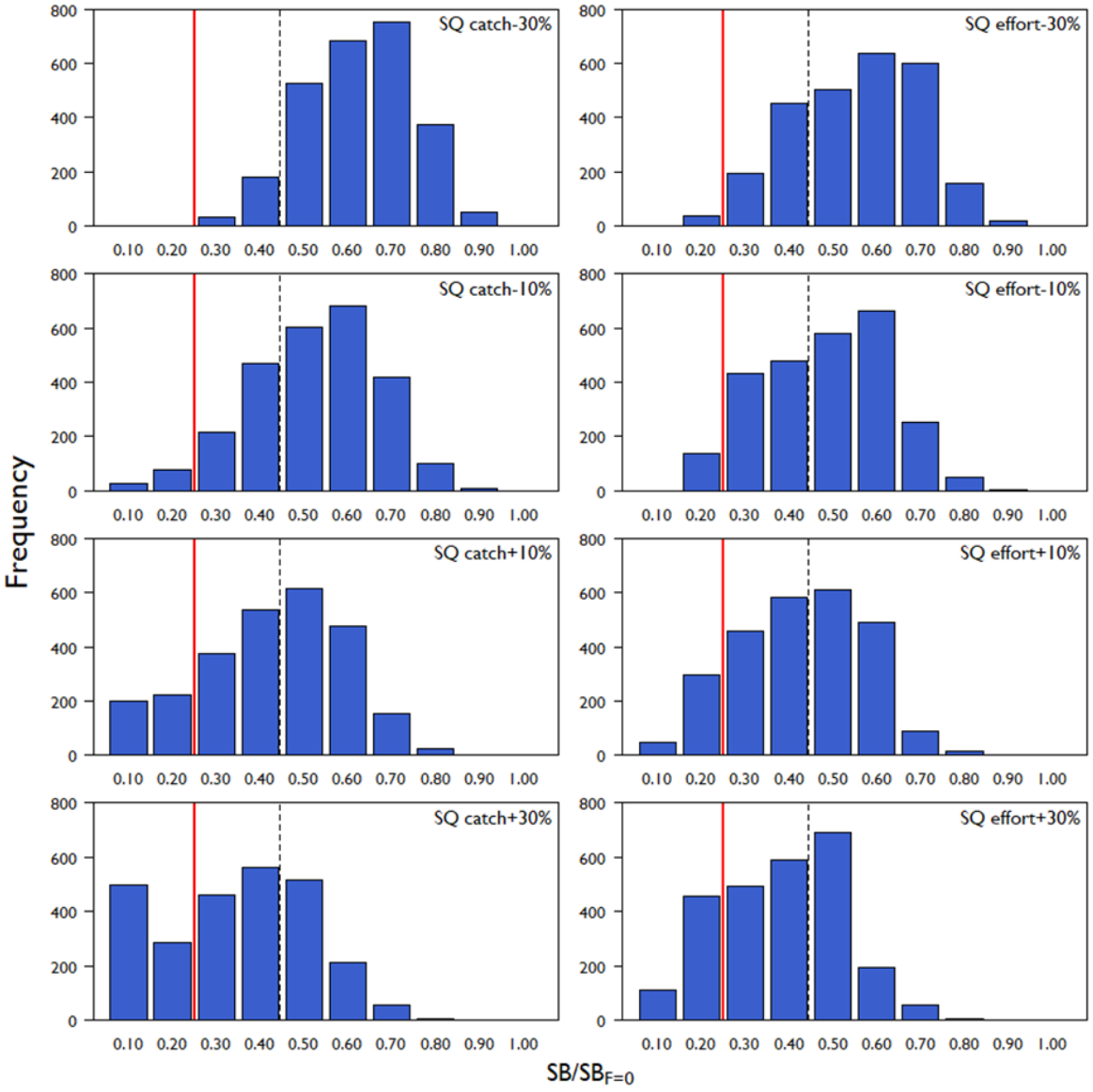

Figure A2. Supplementary scenarios. Distribution of terminal depletion ($SB/SB_{F=0}$) values for the 100 stochastic projections across 8 supplementary future catch and effort scenarios. Red line is 20% $SB_{F=0}$, dashed line is median value in the 2019 starting year.

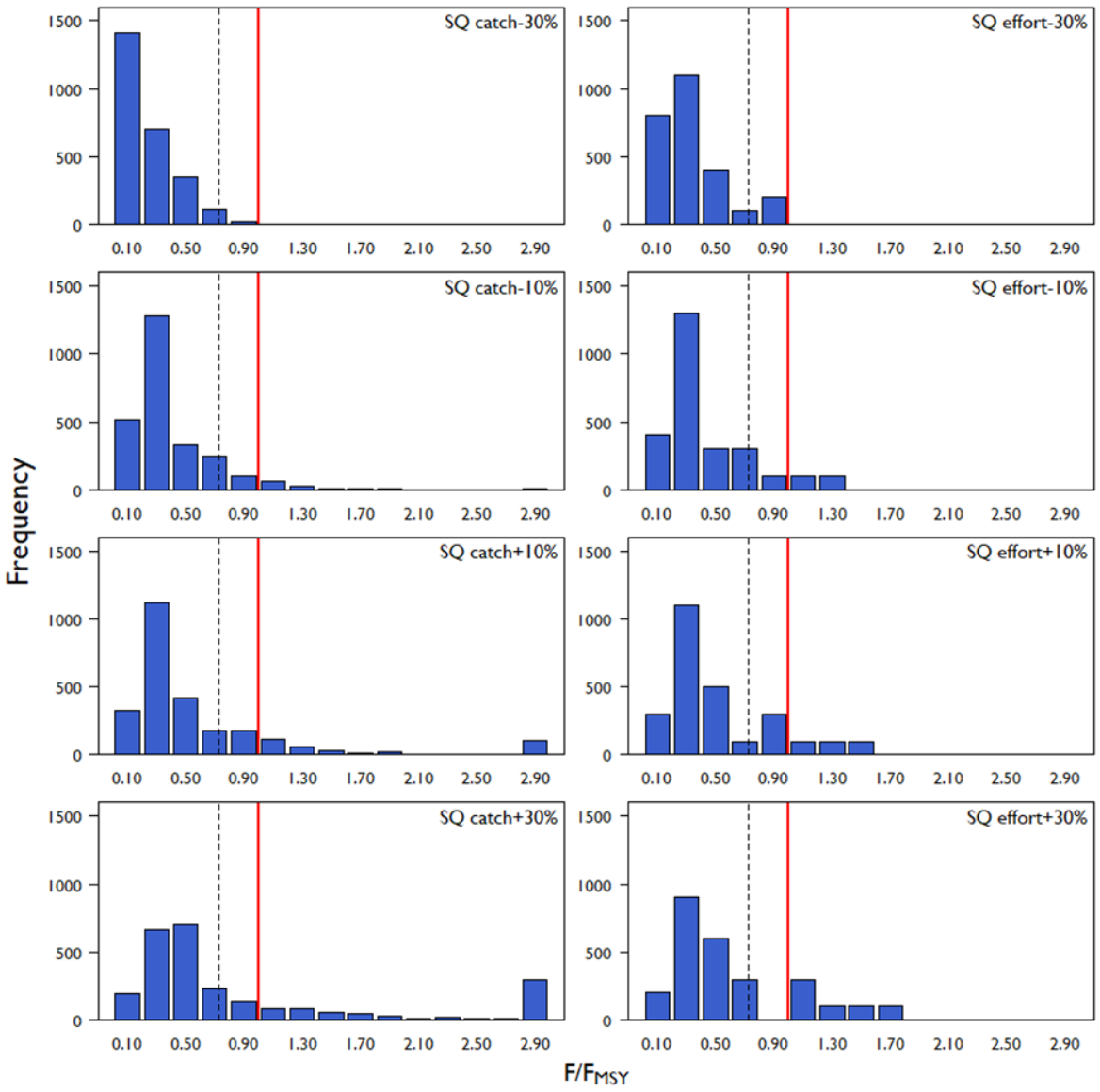

Figure A3. Supplementary scenarios. Distribution of terminal F/F_{MSY} values for the 100 stochastic projections across 8 supplementary future catch or effort scenarios. Red line is the reference point value of 1, dashed line in median value in 2019 starting year.

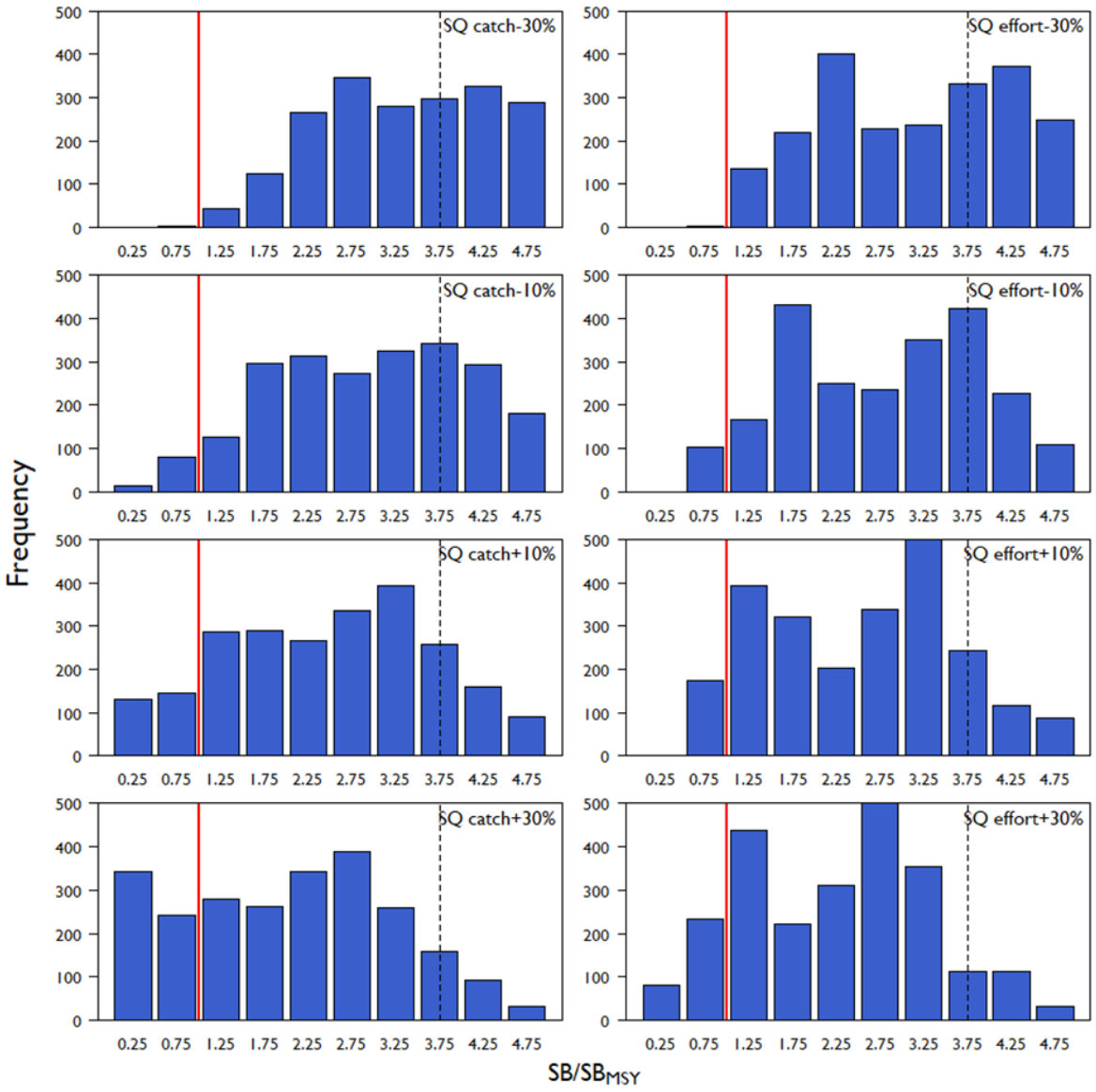

Figure A4. **Supplementary scenarios.** Distribution of terminal SB/SB_{MSY} values for the 100 stochastic projections across the 8 supplementary future catch scenarios. Red line is the reference point value of 1, dashed line in median value in 2019 starting year.