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A 2019 stock assessment of ORH 7A including Westpac Bank

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Table of Contents

EXECUTIVE SUMMARY

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***New Zealand Fisheries Assessment Report 2019/33*. 45 p.**

Orange roughy on the southwest Challenger Plateau (ORH 7A, including Westpac Bank) are regarded as a single stock. Annual catches peaked in 1987–88 at about 12 000 t (the level of the TACC) before it was known for certain that orange roughy were very long-lived. TACCs and catches were rapidly reduced but in 2000–01 the fishery was essentially closed when the TACC was reduced to 1 t.

The results of a combined acoustic and trawl survey in 2009 were used in a 2010 stock assessment which saw the fishery reopened in 2010–11 with a TACC of 500 t and an allowance for incidental mortality of 25 t (5% of the TACC). The TACC was further increased to 1600 t following a stock assessment in 2014. The New Zealand fishery on this stock also received Marine Stewardship Council (MSC) certification in 2016 and is managed under a Harvest Control Rule (HCR) with a target biomass range of 30–50% B_0. However, as a straddling stock, the South Pacific Regional Fisheries Management Organisation also has some management responsibility and they have set a catch limit on Westpac Bank of 200 t for the calendar year 2019.

The 2019 assessment used very similar methods to those used in the four orange roughy stock assessments in 2014. However, it made greater use of acoustic survey spawning biomass estimates from the time series of trawl and acoustic surveys that occurred within the period from 2005 to 2018. In particular, the survey estimates of spawning biomass on Volcano (an Underwater Topographical Feature on Westpac Bank) were used for the first time. The assessment was conducted using NIWA's Bayesian stock assessment package CASAL.

In the 2019 assessment, current stock status (B_{2019}) is estimated to be near the top of the target biomass range (47% B_0 with a 95% CI: 39–55% B_0). The results are most sensitive to changes in the value of natural mortality (M) and the means of the informed priors on the proportionality constants for biomass indices. However, even in the "worst case" scenario (LowMHighq), which has a 20% shift in those parameters, current stock status is estimated to be within the target biomass range (37% B_0 with a 95% CI: 30–45% B_0).

Five year projections with annual catches of 1600 t show that under the "worst case" scenario (LowMHighq) stock status is expected to stay within the target biomass range. However, the stock is managed under a Harvest Control Rule (HCR) which when applied to the base model gives a TACC of 2448 t. Also, there is an assessment scheduled for 2023 at which time the TACC is likely to change again. Assuming that the HCR is applied in 2019 and again in 2023, a projection for the base model shows projected stock status staying within the target biomass range through to 2027 (median: 38% B_0 with a 93% probability of being above 30% B_0). For the same TACCs, applied to the LowMHighq model, stock status is expected to stay well above the soft limit through to 2027 (median: 28% B_0 with a 7% probability of being below 20% B_0).

1. INTRODUCTION

Orange roughy on the southwest Challenger Plateau (ORH 7A, including Westpac Bank) are regarded as a single stock. Historically, the fishery mainly occurred in the south-western region of the Challenger Plateau, both inside and outside the EEZ. Fish were caught throughout the year, with most effort in winter during the orange roughy spawning season. Annual catches peaked in 1987–88 at about 12 000 t (the level of the TACC) before it was known for certain that orange roughy were very long-lived. TACCs and catches were rapidly reduced but in 2000–01 the fishery was essentially closed when the TACC was reduced to 1 t.

The results of a combined acoustic and trawl survey in 2009 were used in a 2010 stock assessment (Cordue 2010a) which saw the fishery reopened in 2010–11 with a TACC of 500 t and an allowance for incidental mortality of 25 t (5% of the TACC). The TACC was further increased following a stock assessment in 2014 (Cordue 2014a). The New Zealand fishery on this stock also received Marine Stewardship Council (MSC) certification in 2016 and is managed under a Harvest Control Rule (HCR) (Cordue 2014b). However, as a straddling stock, the South Pacific Regional Fisheries Management Organisation (SPRFMO) also has some management responsibility and they have set a catch limit on Westpac Bank of 200 t for the calendar year 2019, with 190 t allocated to New Zealand and 10 t to Australia (SPRFMO 2019).

The 2019 assessment used very similar methods to those used in the four orange roughy stock assessments in 2014 (Cordue 2014a). However, this assessment made greater use of acoustic survey spawning biomass estimates from the time series of trawl and acoustic surveys that occurred within the period from 2005 to 2018. In particular, the survey estimates of spawning biomass on Volcano (an Underwater Topographical Feature (UTF) on Westpac Bank) were used for the first time. The assessment was conducted using NIWA’s Bayesian stock assessment package CASAL (Bull et al. 2012).

2. METHODS

From 2010 to 2013, assessments of ORH 7A were conducted using an ad hoc approach which combined the virgin biomass estimate from the 2000 assessment (Annala et al. 2000, Field & Francis 2001) and current biomass estimates from annual combined acoustic and trawl surveys (see Doonan et al. 2009, Doonan et al. 2010, Hampton et al. 2013, Hampton et al. 2014, Cordue 2010a, 2012, 2013). A model-based Bayesian stock assessment was carried out for this stock in 2014 (Cordue 2014a).

The 2014 assessment for this stock was one of four orange roughy assessments carried out in 2014 which all used similar methods. The same approach was continued in 2019 although there was a review of previous data inputs and substantial amounts of new data were available. Two fisheries were modelled, one for the EEZ and another for Westpac Bank (which is outside the EEZ). An age-structured population model was fitted to acoustic and trawl-survey estimates of spawning biomass and six age frequencies.

2.1 Catch history

The catch history was taken from earlier Plenary reports where it was already split into EEZ and Westpac Bank catch up to 1996–97 (e.g., see the 2018 Plenary report). For 2010–11 onwards the proportions by area from estimated catches were used to split the reported total catch (Table 1). This left the three fishing years 1997–98 to 1999–2000 for which the proportion of catch by area had not been estimated. For 1997–98 and 1998–99 the catch was split using the percentage of tows reported in each area from Field & Francis (2001); for Westpac, 12% in 1997–98 and 19% in 1998–99. In 1999–2000 it was assumed that 15% of the catch was from Westpac Bank (15% being the average of 12% and 19%).

The catch taken during the trawl and acoustic surveys in the period 2005 to 2018 was also included in the catch history by area (Table 1). Finally, the over-run percentages that have been used in previous assessments were applied (1980–81 to 1987–88, 30%; 1988–89, 25%; 1989–90, 20%; 1990–91, 15%; 1991–92 to 1992–93, 10%; 1993–94 onwards, 5%) to obtain the catches for use in the stock assessment models (Figure 1). For 2018–19 the assumed catches before over-runs were 1400 t and 200 t for the EEZ and Westpac Bank respectively.

Table 1: Reported catches (t) and TACCs (t) from 1980–81 to present for ORH 7A. QMS data from 1986–present. The last two columns are for research surveys on commercial vessels and give the research catch that was not recorded against ACE (WP = Westpac Bank) and need to be added to the total catch.

Fishing year	EEZ	Outside EEZ	Total catch	TACC	EEZ extra	WP extra
1980–81†	1	32	33	-	0	0
1981–82†	3 539	709	4 248	-	0	0
1982–83†	4 535	7 304	11 839	-	0	0
1983–84†	6 332	3 195	9 527	-	0	0
1984–85†	5 043	74	5 117	-	0	0
1985–86†	7 711	42	7 753	-	0	0
1986–87†	10 555	937	11 492	10 000	0	0
1987–88	10 086	2 095	12 181	12 000	0	0
1988–89	6 791	3 450	10 241	12 000	0	0
1989–90	3 709	600	*4 309	2 500	0	0
1990–91	1 340	17	1 357	1 900	0	0
1991–92	1 894	17	1 911	1 900	0	0
1992–93	1 412	675	2 087	1 900	0	0
1993–94	1 594	138	1 732	1 900	0	0
1994–95	1 554	82	1 636	1 900	0	0
1995–96	1 206	463	1 669	1 900	0	0
1996–97	1 055	253	1 308	1 900	0	0
1997–98	+	+	1 502	1 900	0	0
1998–99	+	+	1 249	1 425	0	0
1999–00	+	+	629	1 425	0	0
2000–01	+	+	0.2	1	0	0
2001–02	+	+	0.1	1	0	0
2002–03	+	+	4	1	0	0
2003–04	+	+	< 0.1	1	0	0
2004–05	+	+	< 1	1	141	17
2005–06	+	+	< 1	1	196	22
2006–07	+	+	< 0.1	1	0	0
2007–08	+	+	< 0.1	1	0	0
2008–09	+	+	0.12	1	218	22
2009–10	+	+	< 0.1	1	339	5
2010–11	476	0	476	500	0	5
2011–12	504	7	511	500	0	0
2012–13	513	0	513	500	259	4
2013–14	484	13	497	500	0	50
2014–15	1 594	0	1 594	1 600	0	0
2015–16	1 248	320	1 568	1 600	0	0
2016–17	1 595	28	1 623	1 600	0	0
2017–18	1 026	575	1 601	1 600	126	53

†FSU data
*This is a minimum value, because of unreported catches by foreign vessels fishing outside the EEZ.
+Unknown distribution of catch between inside and outside the EEZ

The large majority of the catch was taken within the EEZ although there were some substantial catches on Westpac Bank prior to 1990 (Table 1, Figure 1). Most of the catch was taken prior to 1990 (Table 1, Figure 1).

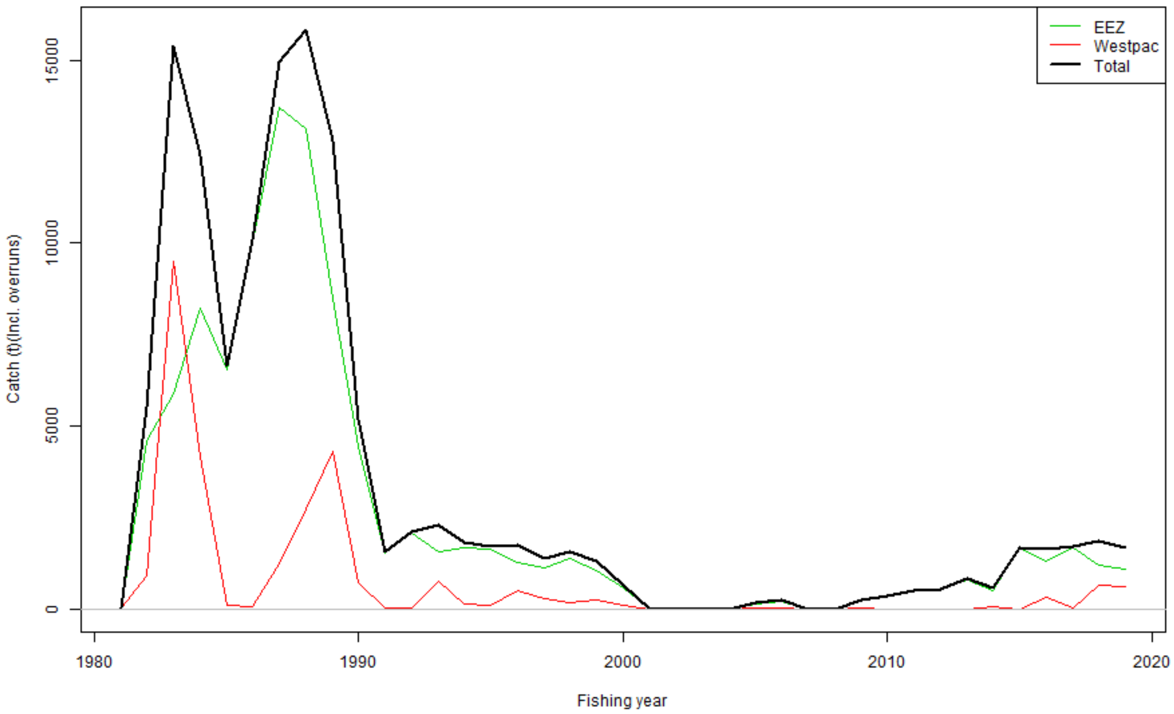

Figure 1: The catch history for the ORH 7A fishery split into EEZ and Westpac Bank (outside the EEZ). The catches include orange roughy caught during the combined trawl and acoustic surveys during the period 2005 to 2018 and also have the over-run percentages applied (see the text).

2.2 Data quality, input data, and statistical assumptions

As in the 2014 stock assessment, a high quality threshold was imposed on data before they were allowed to be used in the assessment.

There were three main data sources for observations fitted in the assessment: spawning biomass estimates from acoustic and trawl surveys (2005, 2006, 2009–2014, 2018); an early trawl survey time series of relative spawning biomass (1987–1989); four age frequencies from trawl surveys (1987, 2006, 2009, and 2018); and two age frequencies from acoustic surveys on Volcano (2014 and 2018).

2.2.1 Research surveys

Trawl surveys of orange roughy on the Challenger Plateau were conducted regularly from 1983 to 1990. However, a variety of vessels and survey strata were used which makes comparisons problematic (Dunn et al. 2010). Wingtip biomass estimates in 1983–1986 ranged from 100 000–185 000 t but the 1989 and 1990 survey estimates were much lower at approximately 10 000 t. From these early trawl surveys a “comparable area” time series, defined by Clark & Tracey (1994) and covering the period 1987–89, was selected for use in the assessment to provide some information on the early rate of spawning biomass decline (see the *Amaltal Explorer* time series in Table 3).

In 2005, a new series of combined trawl and acoustic surveys was begun using the FV *Thomas Harrison* with a survey area comparable to that used from 1987–1990 (Clark et al. 2005). The survey was repeated in 2006 (with an enlarged survey area) and was then conducted annually from 2009–2013 (Clark et al. 2006, Doonan et al. 2009, Doonan et al. 2010, Hampton et al. 2013, Hampton et al. 2014, Boyer et al. 2014) with another survey in 2018 (Ryan et al. 2019). It was apparent from the later surveys that the 2005 survey did not cover an appropriate area as the spawning biomass distribution had shifted in the intervening years. The surveys from 2006 onwards appear to have covered the bulk of the spawning biomass. Also, in 2014 an acoustic survey of Volcano was conducted using an Acoustic Optical System (AOS) (Ryan et al. 2015) in addition to a hull-mounted transducer. The data from all of the surveys since 2005 have been analysed to produce acoustic and trawl survey indices of spawning biomass.

Acoustic survey indices

For the 2014 assessment, the method of Cordue (2010a, 2012) was used to produce combined acoustic and trawl survey indices for 2010 and 2013. This method used an estimate of orange roughy trawl vulnerability to allow the trawl survey estimates to be combined with the acoustic estimates (trawl estimates were essentially scaled down by a vulnerability distribution with a mean of 1.66). This assumed that the scalar (1.66) had been reliably estimated. To avoid this assumption in the 2019 assessment the acoustic data and trawl data were used separately.

The acoustic biomass estimates from 2005 to 2018 were reviewed and a number of adjustments were required to ensure that the time series of estimates were consistent (see Appendix 2). Acoustic estimates of spawning aggregations on Volcano and in the west and east of the flats within the EEZ were used in three separate time series (Table 2). Estimates from the hull-mounted transducer were adjusted as necessary so that they all used the latest length to target strength relationship, the Doonan et al. (2003) absorption coefficient (see Appendix 4), and a combined motion and bubble layer correction (1.33) borrowed from work done on the Chatham Rise (Cordue 2010b, Doonan et al. 2012). The estimates from the AOS (2014 and 2018) were adjusted to use the Doonan et al. (2003) absorption coefficient (see Appendix 4). In 2005, 2011, and 2013, the motion corrections applied to the snapshots were not documented and a factor of 1.06 (the mean for snapshots in 2006 and 2009) was used in the adjustment calculations. In those years the acoustic indices were assigned an additional 20% of process error to account for the approximate adjustment.

The acoustic biomass estimate for each aggregation in each year is an average of a number of “snapshots” (individual surveys/estimates) of the aggregation in that year. Some of the snapshots in some years were not used in the average because they appeared to have been taken before the aggregation was fully formed (judged on the basis of female gonad stages from trawl catches at the time of the snapshot). Some snapshots in the eastern area (in 2010 and 2011) were not used, as an examination of the distribution of backscatter on the transects showed that a genuine spawning aggregation was not surveyed (e.g., just a single transect on which positive backscatter was recorded). See Appendix 2 for details of each snapshot.

In 2018 there were a number of snapshots of Volcano which showed substantial biomass (about 4000 t) but it was unclear from the gonad staging whether spawning was underway. These snapshots were not used in the assessment (and therefore there is no estimate for Volcano in 2018). In 2009, there was a single snapshot on Volcano which satisfied the timing criteria but it was a very low estimate (671 t) compared to all of the other years. It was considered that, while possible (especially given the high acoustic/trawl estimates within the EEZ in 2009), this estimate was unlikely to be representative of the spawning biomass on Volcano in 2009. It was not used in the base model but was used in a sensitivity run.

Table 2: Acoustic biomass estimates of spawning aggregations surveyed on Volcano, and the West and the East within the EEZ. The model CV is the observation error CV with an additional 20% of process error in the years when the vessel motion correction was unknown (2005, 2011, and 2013).

	West		East		Volcano	
Year	Biomass (t)	Model CV (%)	Biomass (t)	Model CV (%)	Biomass (t)	Model CV (%)
2005	4 210	53			2 682	39
2006	4 383	59			6 329	39
2009	13 555	22	8 471	61		
2010	8 114	14	1 707	34		
2011	13 340	33				
2013	10 183	22	5 365	26	4 559	34
2014					3 954	29
2018	9 966	9				

Informed priors on the proportionality constants (*q*) were used for the acoustic time series. The means of the priors were derived from the 2013 proportions across aggregations and the assumption that all three aggregations combined represented “most” of the spawning biomass (80%). The prior used in this case for orange roughy assessments (since 2014) is LN(mean=0.8, CV=19%) (Cordue 2014a). Splitting this prior into three components, each with the same CV, gave priors for the West, East, and Volcano *q*s respectively: LN(0.41, 30%), LN(0.22, 30%), LN(0.18, 30%).

Trawl survey indices

The spawning biomass estimates from the *Thomas Harrison* trawl surveys (Table 3) were used as relative biomass with an informed prior. They excluded the rough terrain strata 9–11 and the mean of the informed prior was: 0.9 × 0.85 × 1.25 = 0.95 (allowing for total-survey availability (0.9), exclusion of strata 9–11 (0.85) and trawl vulnerability, the adjusted mean of estimated vulnerability distribution = 1.25). Given the problematic nature of these trawl surveys (fish pluming and moving within the area), a process error CV of 20% was added to the estimated CVs (Table 3).

Table 3: Biomass indices from trawl surveys used in the stock assessment. The model CV is the observation error CV with an additional 20% of process error.

Vessel	Year	Biomass (t)	Model CV (%)
Amaltal Explorer	1987	75 040	33
	1988	28 954	34
	1989	11 062	23
Thomas Harrison	2006	13 987	34
	2009	34 864	31
	2011	18 425	33
	2012	22 451	27
	2013	18 993	55
	2018	48 038	55

Age frequencies

Age frequencies were available from four of the trawl surveys for use in the assessment. A previous analysis produced age frequencies for the 1987 *Amaltal Explorer* survey and the 2009 *Thomas Harrison* survey (Doonan et al. 2013). Although that study was based on a relatively small number of otoliths, it showed that the 2009 age frequency had much younger fish than the 1987 age frequency. For the 2014 stock assessment, the existing age frequencies were augmented with an increased number of otoliths (for a total of about 300 for each survey) and a new age frequency (from about 300 otoliths) was produced for the 2006 *Thomas Harrison* survey. For the 2019 assessment the age data from the 2018 survey were used to produce an age frequency for the west aggregation (300 otoliths, 3 trawls), the EEZ (750 otoliths, 47 trawls but dominated by 3 trawls) and Volcano (150 otoliths, 1 trawl). An age frequency was also produced from the 2014 survey of Volcano (470 otoliths, 5 trawls) (Doonan et al. 2015).

The age frequencies were assumed to be multinomial and were mainly assigned effective sample sizes of 300/5 = 60 (with the sample size reflecting the number of trawl survey stations rather than the number of otoliths). However, the 2018 age frequency from Volcano was obtained from only one targeted trawl and this was given a much lower effective sample size of 30 (to reflect that it may not have been representative of the spawning plume). No reweighting was attempted because of the short time series.

There are no age frequencies from the commercial fishery.

2.3 Model structure

The model was single-area, single-sex and age-structured (1–100 years with a plus group), with maturity also tracked (i.e., fish were classified by age and as mature or immature). Two time steps were used: a full year of natural mortality followed by an instantaneous spawning season and fisheries on the spawning fish. Two fisheries were modelled, one within the EEZ and one on Westpac Bank (which is outside of the EEZ). The fishery selectivity for the EEZ was uniform across ages (for spawning fish) while a logistic selectivity (on spawning fish) was used for Westpac Bank where slightly older fish are caught. 100% of mature fish were assumed to spawn each year.

Natural mortality was fixed and the stock-recruitment relationship was assumed to follow a Beverton-Holt function.

The fixed biological parameters were:

Natural mortality:	0.045
Beverton-Holt steepness:	0.75
Length-weight (a, b):	9.21e–5, 2.71 (cm to kg)
von Bertalanffy (L_∞, k, t_0):	34.2 cm, 0.065, –0.5 years

2.4 Estimation methods and model runs

The estimation methods were almost identical to those used in the 2014 orange roughy assessments (Cordue 2014a). The stock assessments were done using the general Bayesian estimation package CASAL (Bull et al. 2012). The CASAL input files for the base model are given in Appendix 3. The final assessments were based on the marginal posterior distributions of parameters and derived parameters of interest (e.g., virgin biomass (B_0), current biomass (B_{2019}), and current stock status (B_{2019}/B_0)). The marginal posterior distributions were produced using Markov chain Monte Carlo methods (hence termed "MCMC" runs). Preliminary analysis and many sensitivity runs were performed using just the Mode of the Posterior Distribution (MPD) which can be obtained much more quickly than the full posterior distribution (hence "MPD" runs). An MPD estimate is associated with the "best fit" that can be obtained – it is useful to check that the "best fit" is not too bad otherwise there would be concerns about the appropriateness of the model.

In the base model, the informed priors were used, as described above, and natural mortality (M) was fixed at 0.045. There were numerous MPD and MCMC sensitivity runs but four main sensitivity runs are presented in this report: "All trend" (informed priors removed), estimate M, and the LowMHighq and HighMLowq runs (LowMHighq has M fixed and reduced by 20% and simultaneously has the mean of the informed q priors increased by 20% - both changes are expected to reduce estimated stock status; similarly the HighMLowq run has changes of 20% in the opposite directions which are expected to increase estimated stock status). There were also a number of additional sensitivity runs, for example: putting high weight on the Amaltal Explorer trawl time series, including the very low 2009 acoustic estimate of Volcano, adjusting the motion and bubble layer correction in response to reported weather conditions during the acoustic surveys.

In the base model the main parameters estimated were: virgin biomass (B_0), the maturity ogive, the selectivity for Westpac Bank and year class strengths (YCS) from 1925 to 1995 (with the Haist parameterisation and "nearly uniform" priors on the free parameters). There were also the five qs for the two trawl and three acoustic survey time series.

The general approach taken to data weighting within the stock assessment was to down-weight age frequency data relative to biomass indices to allow any scale and trend information in the biomass indices to drive the assessment results. This is very much in the spirit of Francis (2011) who argued that composition data were generally given far too much weight in stock assessment models and were often allowed to dominate the signals from biomass indices.

MCMC chain diagnostics

Mathematical theory proves that MCMC chains will eventually converge to provide the joint posterior distribution. However, one can never be certain that a chain, or multiple chains, have been run long enough to achieve "sufficient" convergence. There is never proof that a chain has converged but there may be evidence that a chain has not yet converged. Many diagnostics exist to help determine whether a chain has achieved sufficient convergence.

In New Zealand, a common approach to judge convergence is to use multiple chains (each with a different random number seed) and to compare the marginal posterior distributions for the (derived) parameters of interest. The idea is that the chains are sufficiently converged when all of the chains give the "same" answer. For this assessment, three chains of 5 million were used. One in every one thousand samples were retained and the first one thousand retained samples were discarded as a "burn-in" (which allows the chain to move away from the MPD starting value). The three posterior distributions were judged primarily on the basis of their median values as to whether they were sufficiently similar that the chains were long enough. “Near identical” median values were required (e.g., two out of three chains being the same to two significant figures with the third almost the same; e.g., stock status medians across the three chains of 48, 49, and 49 %B_0 were considered close enough). Estimates use all three chains combined after the burn-in (and so are based on 12 000 samples).

Fishing intensity

Fishing intensity was estimated in each year as the total exploitation rate (total catch over beginning of fishing season spawning biomass) for each MCMC sample to produce a posterior distribution for fishing intensity by year.

The exploitation rate associated with the fishing intensity reference points $U_{30\%B0}$ and $U_{50\%B0}$ were determined for the catch split assumed in 2018–19 (1400 t and 200 t in the EEZ and Westpac Bank respectively, noting that the Westpac Bank fishery operates in the winter and the 200 t limit for this area for the calendar year 2019 would all be expected to be taken during the 2018–19 fishing year). Note, in general, the fishing intensity that forces the stock to deterministic equilibrium at x% B_0 is denoted as $U_{x\%B0}$.

Projections

At the request of Fisheries New Zealand, projections were done over a 5-year time period for the current TACC of 1600 t (plus 5% incidental mortality). The random YCS were brought in immediately after the last estimated YCS and were resampled from the last 10 years of estimates (this is done because YCS are possibly correlated rather than being independent from year to year). Projections were done for the base model and the LowMHighq model (the most pessimistic run).

3. RESULTS

3.1 Model diagnostics

The MCMC (and MPD) fits to the data in the base model were very good except in two cases.

The *Amaltal Explorer* time series shows a very steep decline over only three years in the late 1980s (Figure 2). The steep decline cannot be fitted by the model unless a very high weight is placed on the time series and all other data are down-weighted. In this case the estimate of the minimum stock status is reduced to about 5% B_0 (compared to 15% B_0 for the base case) but the estimate of current stock status is unchanged from the base model. It is likely that the *Amaltal Explorer* indices do not reflect true stock abundance in those years.

There are good fits to the main biomass indices, the West aggregation (Figure 3) and the *Thomas Harrison* trawl indices (Figure 4). Both sets of indices and the fits show an increase from 2005/2006 through to 2018.

The second poor fit is for the 2018 Volcano age frequency (Figure 5). This age frequency was obtained from a single large catch on Volcano and only 150 otoliths. It has much older fish than the age frequency from Volcano in 2014 which was obtained from samples from five trawl catches on Volcano. It is possible that the 2018 age frequency is not representative of the age distribution of the spawning aggregation on Volcano in 2018. Compared to 2018, the fit and associated residuals for the 2014 age frequency are excellent (Figure 6).

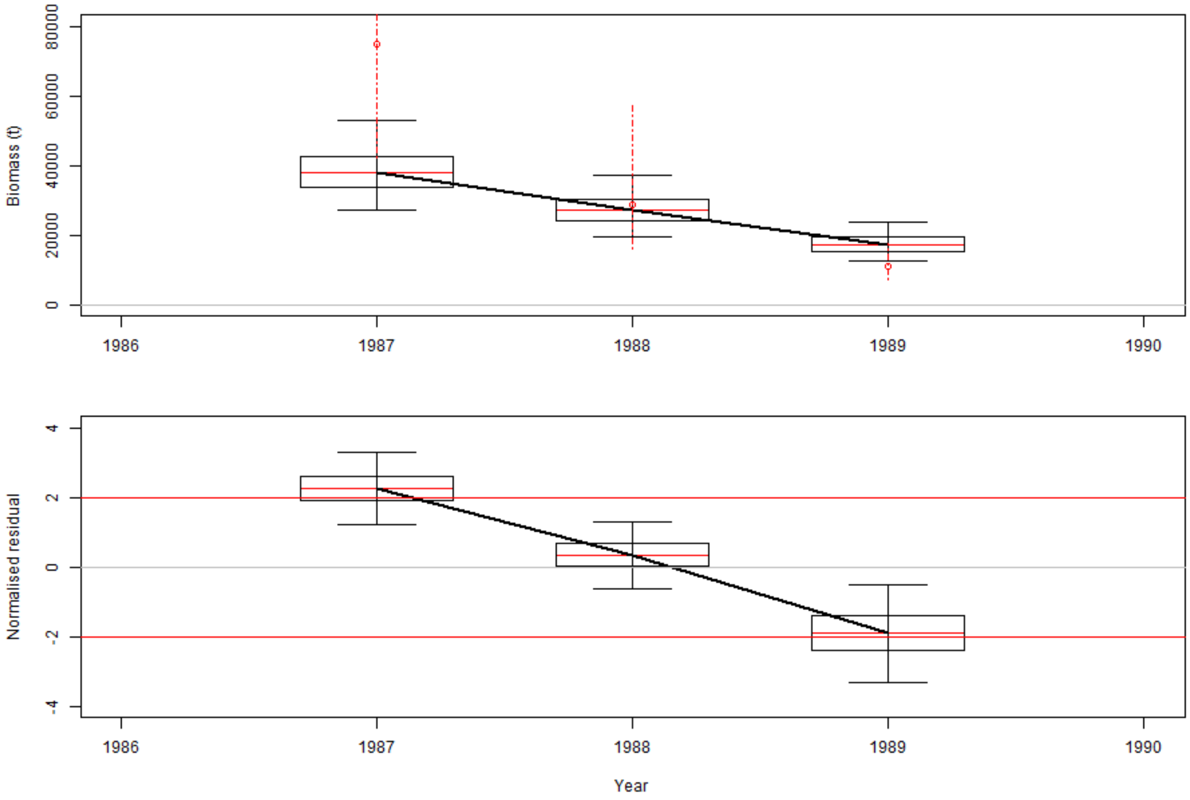

Figure 2: Base, MCMC: fit to the *Amaltal Explorer* trawl indices (top panel) and the associated normalised residuals (bottom panel). Each box covers the middle 50% of the distribution and the whiskers extend to 95% CIs. The indices are plotted in the top panel (open circles) with 95% CIs (dashed red lines).

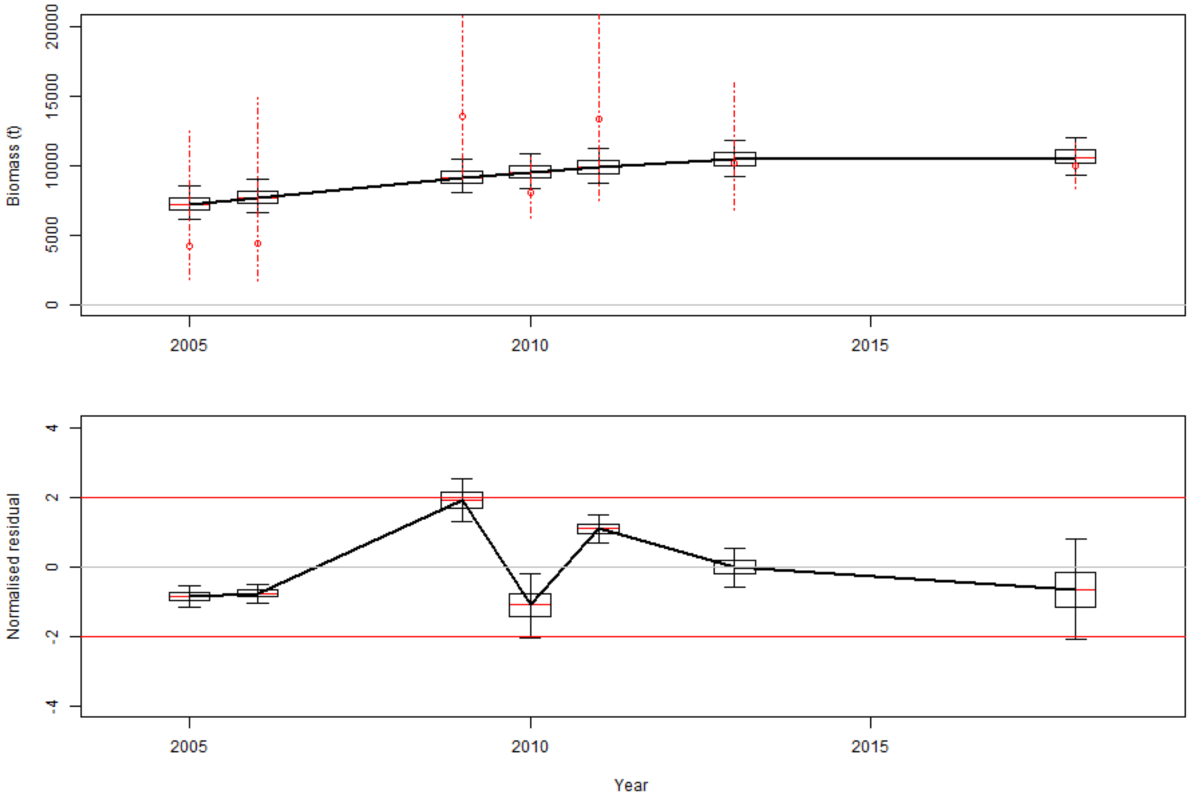

Figure 3: Base, MCMC: fit to the West spawning aggregation (top panel) and the associated normalised residuals (bottom panel). Each box covers the middle 50% of the distribution and the whiskers extend to 95% CIs. The indices are plotted in the top panel (open circles) with 95% CIs (dashed red lines).

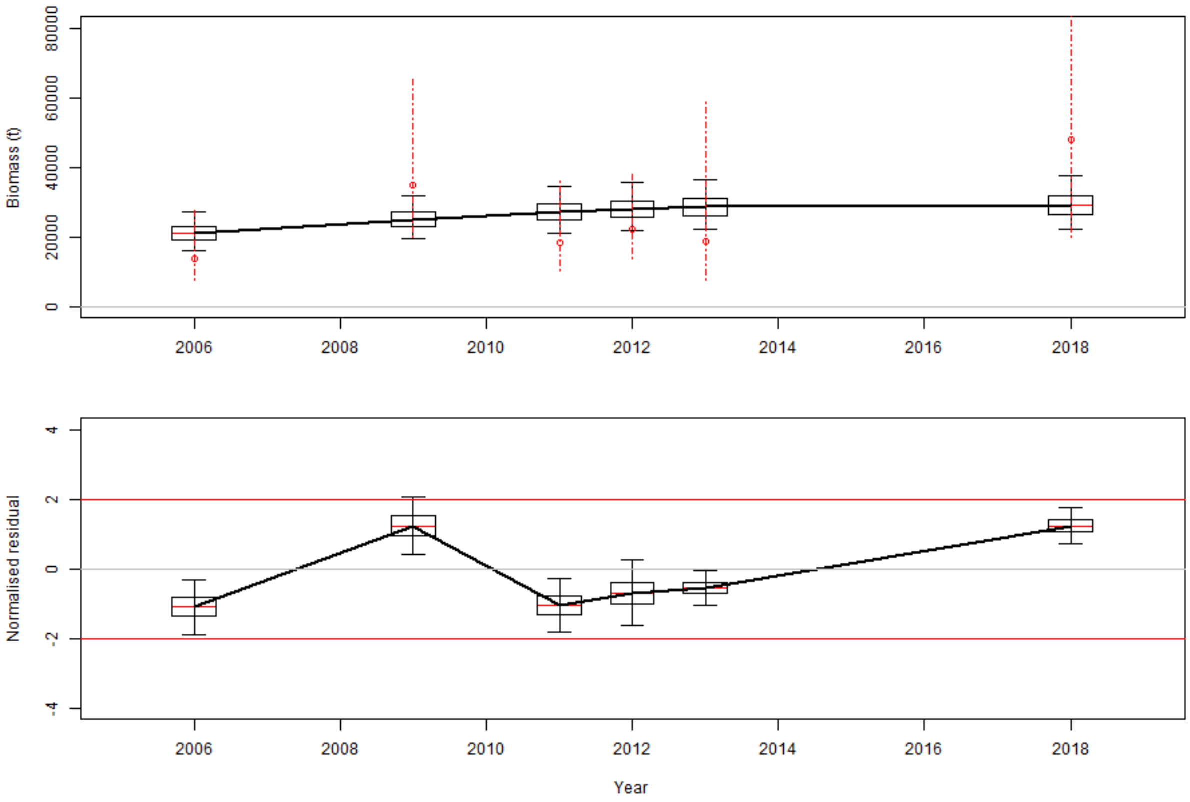

Figure 4: Base, MCMC: fit to the *Thomas Harrison* trawl indices (top panel) and the associated normalised residuals (bottom panel). Each box covers the middle 50% of the distribution and the whiskers extend to 95% CIs. The indices are plotted in the top panel (open circles) with 95% CIs (dashed red lines).

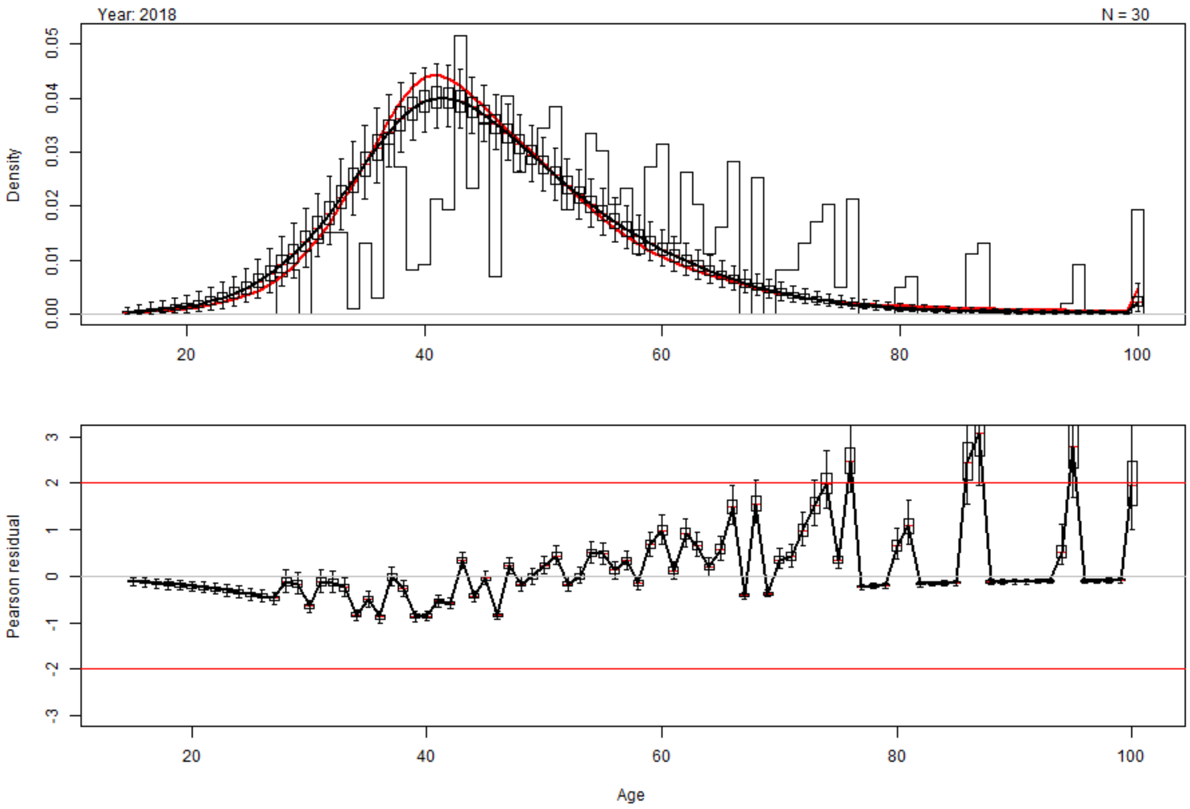

Figure 5: Base, MCMC: fit to the 2018 Volcano age frequency (top panel) and the associated Pearson residuals (bottom panel). Each box covers the middle 50% of the distribution and the whiskers extend to 95% CIs. The indices are plotted in the top panel (open circles) with 95% CIs (dashed red lines). The MPD fit is shown in red (top panel).

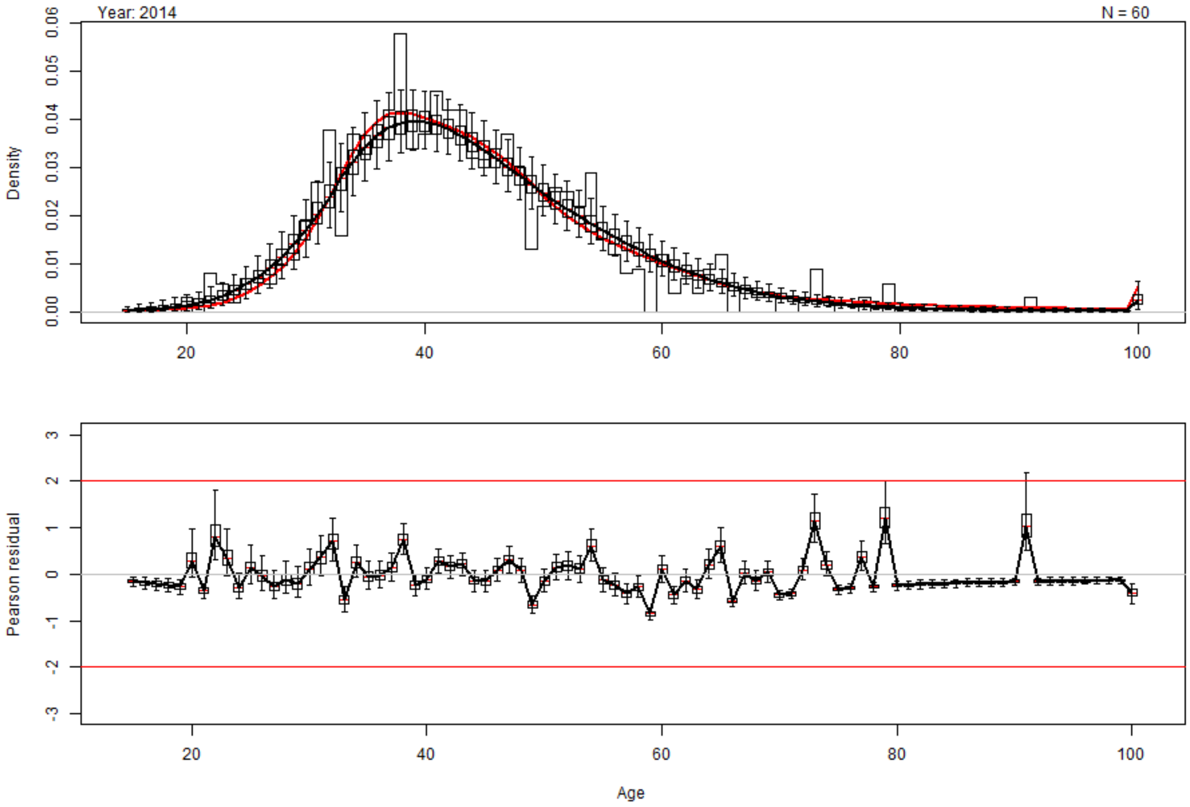

Figure 6: Base, MCMC: fit to the 2014 Volcano age frequency (top panel) and the associated Pearson residuals (bottom panel). Each box covers the middle 50% of the distribution and the whiskers extend to 95% CIs. The indices are plotted in the top panel (open circles) with 95% CIs (dashed red lines). The MPD fit is shown in red (top panel).

The posterior distributions of the *q*s, which had informed priors, show movement to lower values of *q* for *Thomas Harrison*, the West, and the East aggregations, with a shift to higher values for Volcano (Figure 7). Although there is a substantial move to the left (for West and East), the posterior distributions are still within the range of the prior distributions and so the estimates of *q* are credible. For Volcano, the move to higher values probably reflects the nature of the associated selectivity which is to the right of maturity (which is the selectivity for the West and East aggregations) (see Figures 8 and 9).

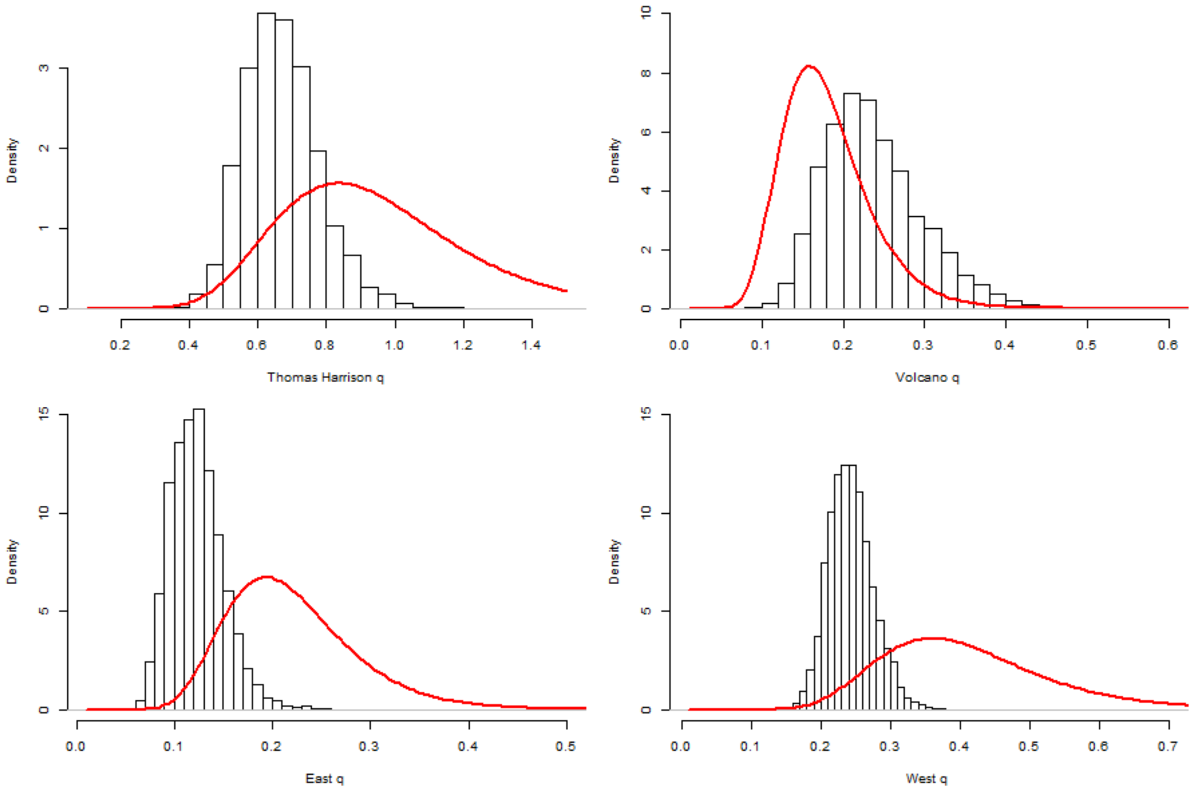

Figure 7: Base, MCMC: Prior distributions (solid red lines) and marginal posterior distributions (histograms) for the *Thomas Harrison* and acoustic *q*s.

3.2 MCMC results

For the base model, and the sensitivity runs, MCMC convergence diagnostics were excellent (see Appendix 1). Virgin biomass (B_0) was estimated to be about 95 000 t for all runs except when the informed priors on the qs were removed (Table 4). When the informed priors were removed, virgin biomass was estimated to be higher than in the base model (Table 4). This indicates that the trend in the biomass indices, and to some extent the age frequencies, support a higher virgin biomass than was implied by information on the scale of the stock from the informed priors. The base model estimates are to be preferred as the informed priors contain information on orange roughy target strength and spawning biomass areal availability that is not otherwise available to the model. For all runs, current stock status was estimated to be within or above the target biomass range of 30–50% B_0 (Table 4).

Table 4: MCMC estimates of virgin biomass (B_0) and stock status (B_{2019} as %B_0) for the base model and four sensitivity runs.

	M	**B_0 (000 t)**	**95% CI**	**B_{2019} (%B_0)**	**95% CI**
Base	0.045	94	86–104	47	39–55
All trend	0.045	107	94–126	57	46–67
Estimate M	0.037	97	89–106	40	31–51
LowM-Highq	0.036	95	88–103	37	30–45
HighM-Lowq	0.054	94	85–106	56	48–65

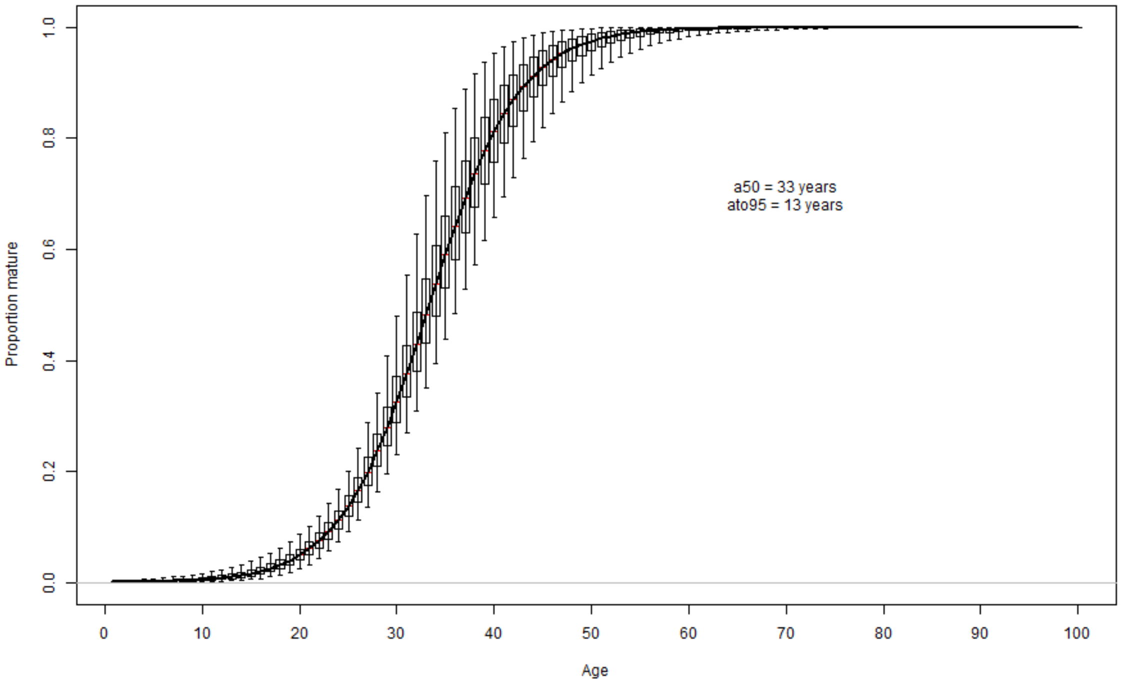

Figure 8: Base, MCMC estimated proportion mature at age in the virgin population. The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution. The median estimates of the two parameters of the logistic curve are also given.

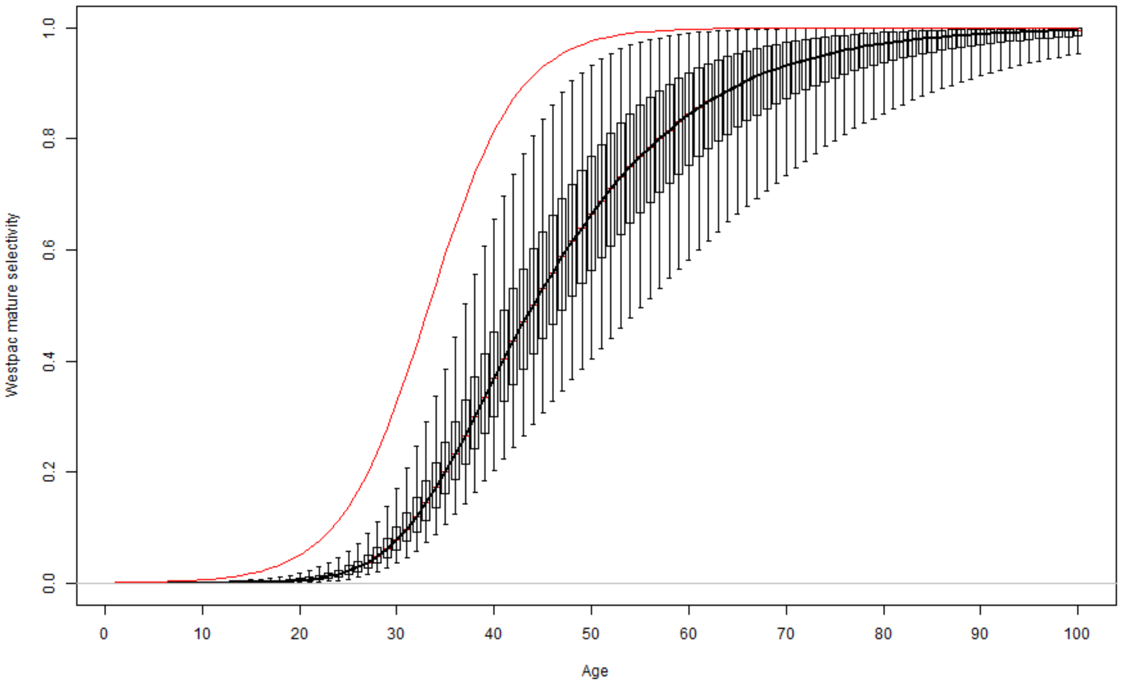

Figure 9: Base, MCMC estimated proportion at age for selected biomass in the Westpac Bank fishery (for the virgin population). The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution. The red line is the median proportion mature at age in the virgin population.

Maturity was in the model partition and was estimated as a logistic producing curve (a constant proportion maturing at age). This means that in the virgin population (when the model is at an age-structured equilibrium) that the proportion mature at age follows a logistic curve (Figure 8). The median estimate of 50% mature (a_{50}) was 33 years, with 2.5% mature at 20 years (median a_{to95} = 13 years) and 97.5% mature at 46 years (Figure 8).

The selectivity for the Westpac Bank fishery was specified to be logistic for mature fish. The maturity and selectivity estimates were combined to produce the estimated proportion at age in the selected virgin biomass for the Westpac Bank fishery (Figure 9). The proportion at age in the Westpac Bank selected biomass is well to the right of the median proportion mature at age (about 10 years at the age of 50% selection) (Figure 9).

The estimated YCS show little variation across cohorts but exhibit a long-term trend (Figure 10). The cohorts from 1989–1995 were spawned when SSB was estimated to be at about 20% B_0 (Figure 11). It is encouraging that the mean YCS estimate for these cohorts is about average (Figure 10). This suggests that steepness in the assumed Beverton-Holt stock recruitment relationship for this stock is not particularly low.

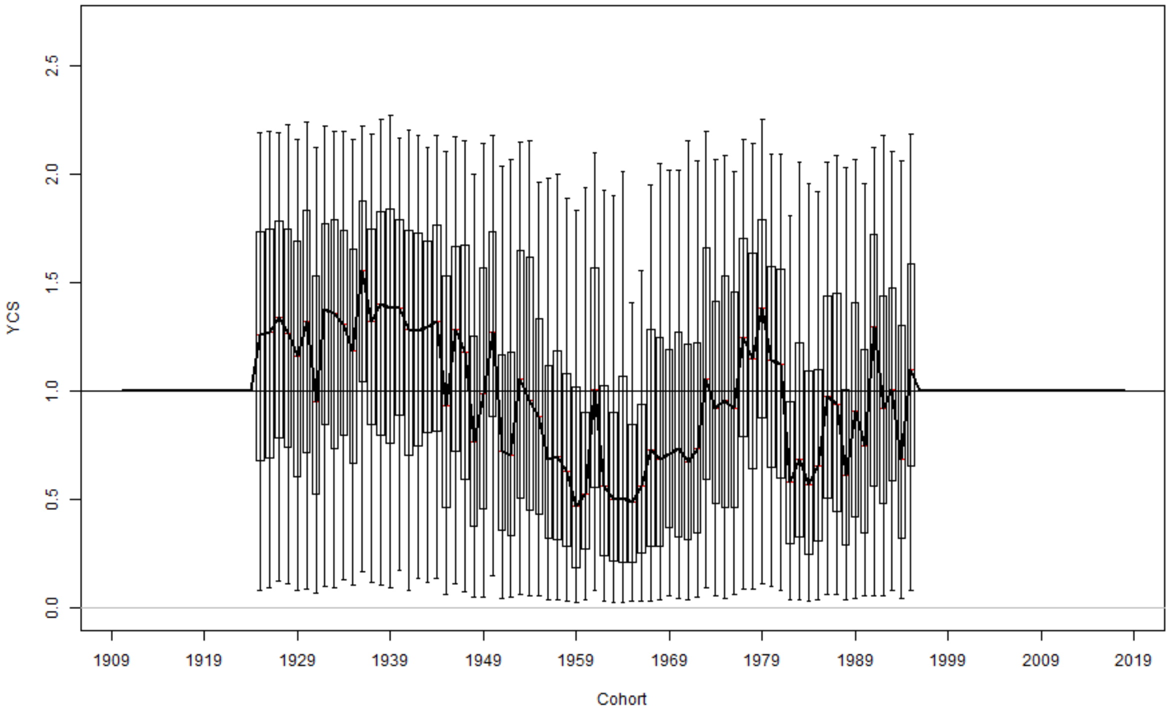

Figure 10: Base, MCMC estimated YCS. The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution.

The stock status trajectory shows a steep decline to about 15% B_0 in 1990, reflecting the large removals during the initial fish-down phase of this stock (Figure 11). From 1990, stock status remains at about 15% B_0 until an upturn in the late 1990s (Figure 11). Biomass is estimated to have peaked in 2015, near the top of the target biomass range, before the increased catches (enabled by a TACC increase) caused a levelling out of the biomass trajectory (Figure 11)

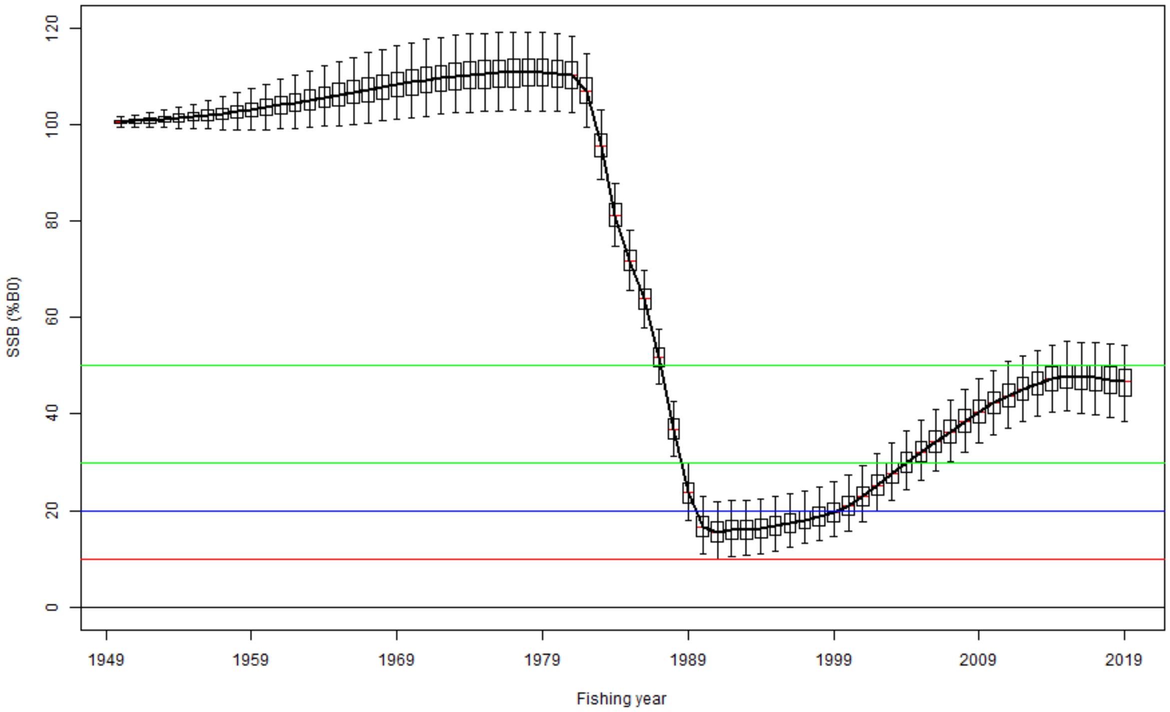

Figure 11: Base, MCMC estimated spawning-stock biomass trajectory. The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution. The hard limit 10% B_0 (red), soft limit 20% B_0 (blue), and biomass target range 30–50% B_0 (green) are marked by horizontal lines.

Fishing intensity was estimated in each year as the total exploitation rate (total catch over beginning of fishing season spawning biomass) for each MCMC sample to produce a posterior distribution for fishing intensity by year. The fishing intensity reference points $U_{30\%B0}$ and $U_{50\%B0}$ were also calculated in terms of exploitation rate (for the catch split assumed in the 2018–19 fishing year).

Estimated fishing intensity was generally well above the target range ($U_{30\%B0}$–$U_{50\%B0}$) up until the closure of the fishery in 2001. Subsequently, it was well below the target range until 2014 and since 2015 it has been at the lower end of the range (Figure 12).

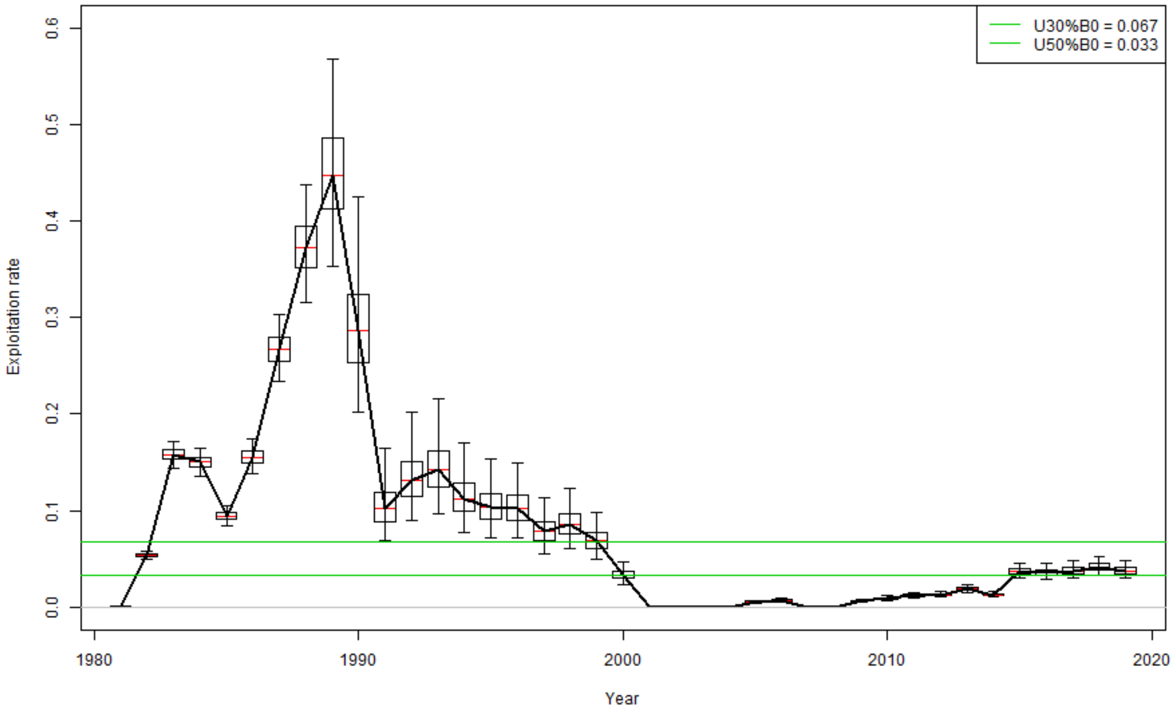

Figure 12: Base, MCMC estimated fishing-intensity trajectory. The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution. The fishing-intensity range associated with the biomass target of 30–50% B_0 is marked by horizontal lines.

3.4 Projections

Five-year projections were conducted (with resampling from the last 10 estimated YCS, 1986–1995) for a constant catch of 1600 t (the current TACC). A 5% catch over-run was assumed. Projections were done for the base model and for the LowMHighq sensitivity model (as a “worst case” scenario).

At the current TACC (1600 t), SSB is predicted to decrease slowly over the next five years for both models, while staying within the target biomass range (Figure 13). For both models the estimated probability of SSB going below either the soft limit (20% B_0) or the hard limit (10% B_0) is zero. For the base model projection at the current TACC, exploitation rates are predicted to slowly increase but still be at the lower end of the fishing intensity target range in 2024 (95% CI 0.030–0.054 compared to the target range of 0.033–0.067).

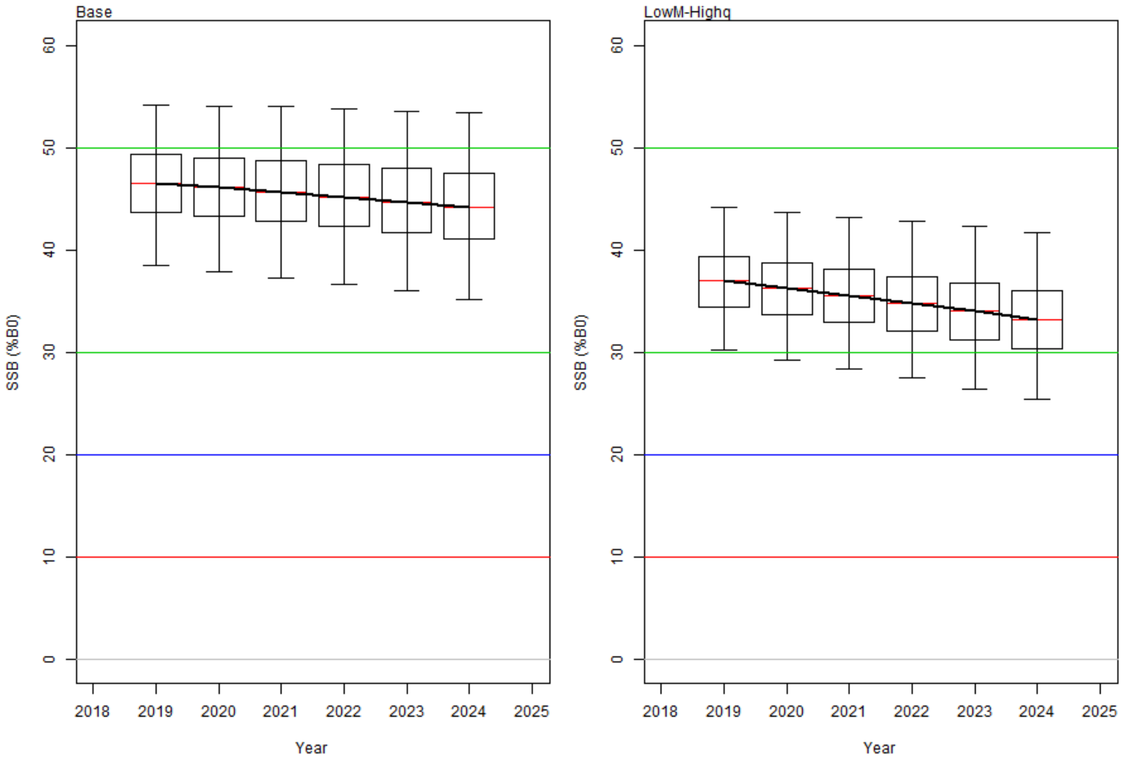

Figure 13: MCMC projections for a constant catch of 1600 t (plus a 5% allowance for incidental catch) for the base model and the LowMHighq model. The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution. The target biomass range (30–50% B$_0$) is indicated by horizontal green lines, the hard limit (10% B$_0$) by a red line and the soft limit (20% B$_0$) by a blue line.

4. DISCUSSION AND CONCLUSIONS

Although the estimation methods used in the 2014 and 2019 stock assessments were almost identical the data inputs were very different because of the extensive review in 2019 of the acoustic survey results. The methods used to produce the acoustic estimates varied from year to year and it was necessary to make several adjustments to the estimates from the source documents to ensure that they were comparable between years and within years (see Appendix 2).

The removal of the motion correction from many of the original estimates was necessary so that an adjustment could be made for motion *and* bubble layer absorption. The application of a single motion and bubble layer correction of 1.33 for each snapshot is a “blunt instrument”. It is clear that it will be too high if the weather was very good and bubble layers were not present. Equally, it could be too low if the weather was at the top end of the worst conditions under which acoustic surveying was possible. Early model runs did investigate the effect of varying the motion and bubble layer correction according to reported weather conditions in each annual survey (with a maximum correction for bad weather equal to the highest annual estimate (1.42) from Doonan et al. 2012). This made no difference to the stock assessment results.

The inclusion of the very low acoustic estimate from Volcano in 2009 also made no difference to the overall stock assessment results. The outcome was simply a drop in the average spawning biomass associated with Westpac Bank with no change in estimated stock status.

An “audit trail” from the 2014 assessment to the 2019 assessment was uneventful in that the addition and removal of single data sets produced no surprising results. There were only small changes in the estimates of virgin and current biomass as small changes were made in the input data set. The previous assessment estimated stock status in 2013–14 at 42% B$_0$ (95% CI: 35–49% B$_0$; Cordue 2014a). The 2019 assessment has higher estimated stock status in that year of 47% B$_0$ (95% CI: 40–55% B$_0$) which substantially overlaps with the previous estimate, and is almost identical to the estimated stock status in 2018–19 (Figure 11).

The 2019 assessment estimates current stock status is near the top of the target biomass range (47% B_0 with a 95% CI: 39–55% B_0). The results are most sensitive to changes in the value of *M* and the means of the informed q priors. However, even the “worst case” scenario (LowMHighq), which has a 20% shift in those parameters, still estimates current stock status to be within the target biomass range (37% B_0 with a 95% CI: 30–45% B_0).

The five year projections at annual catches of 1600 t (plus 5% incidental mortality) show that even under the “worst case” scenario (LowMHighq) stock status is expected to stay within the target biomass range (see Figure 13). However, the stock is managed under a HCR which, when applied to the base model, gives a TACC of 2448 t (Annex 1). Also, there is an assessment scheduled for 2023 at which time the TACC is likely to change again. Projections were also done at annual catches of 2448 t (plus 5% incidental mortality) for 8 years and the TACC in 2023 was updated by applying the HCR to the median projected beginning of year vulnerable biomass in that year (the new TACC was 1940 t, see Annex 1). The projection for the base model showed projected stock status staying within the target biomass range through to 2027 (median: 38% B_0 with a 93% probability of being above 30% B_0, Figure 14). For the LowMHighq model, stock status was expected to stay well above the soft limit even in 2027 (median: 28% B_0 with a 7% probability of being below 20% B_0, Figure 15).

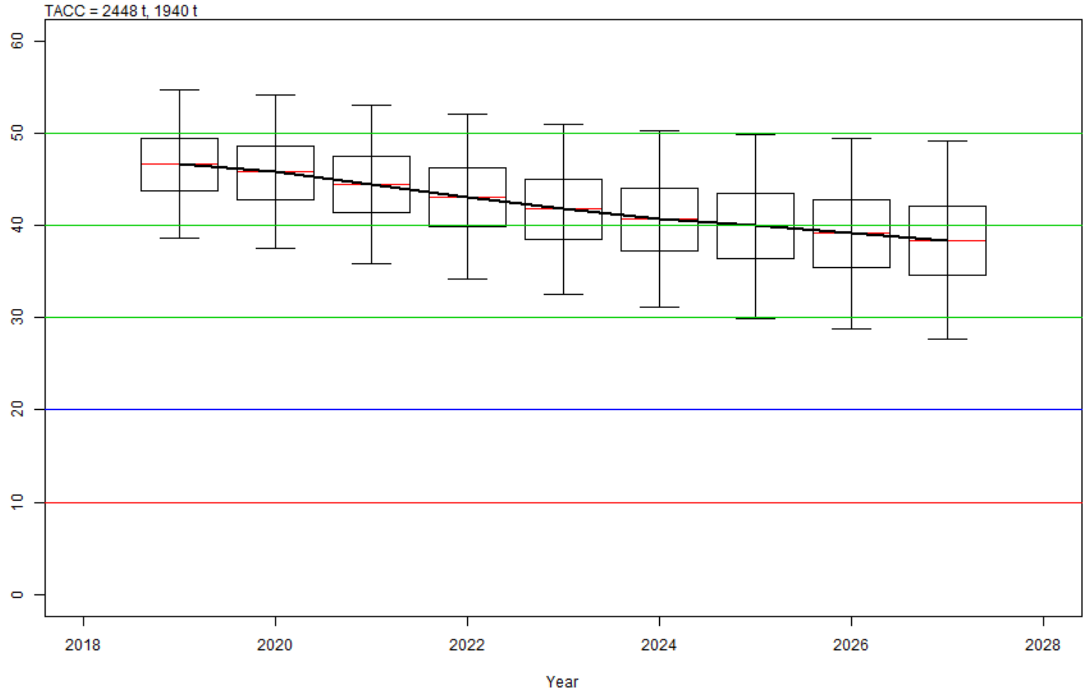

Figure 14: Projection results for the base model under the HCR TACCs (updated in 2023). Each box covers the middle 50% of the distribution and the whiskers extend to 95%. The medians of the distribution in each year are joined by lines. The target biomass range is 30–50% B_0 (upper and lower green lines). The soft limit is 20% B_0 (blue line) and hard limit 10% B_0 (red line).

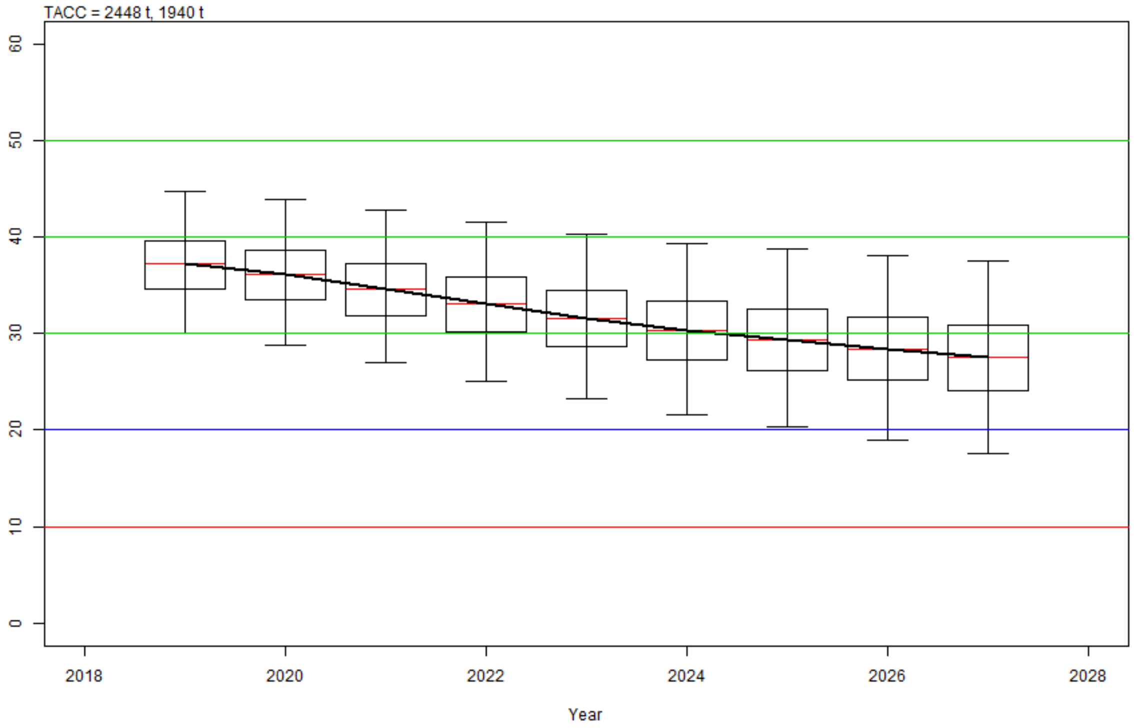

Figure 15: Projection results for the LowMHighq model under the HCR TACCs (updated in 2023). Each box covers the middle 50% of the distribution and the whiskers extend to 95%. The medians of the distribution in each year are joined by lines. The target biomass range is 30–50% B_0 (upper and lower green lines). The soft limit is 20% B_0 (blue line) and hard limit 10% B_0 (red line).

5. ACKNOWLEDGEMENTS

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APPENDIX 1: MCMC chain diagnostics for the base model

The chains for the objective function show the need for a burn-in as the chains move away from the MPD estimate (Figure A1). The objective function values appear to mix well – they are not getting stuck at high or low values for an extended period (Figure A1.). The same is true for the B_0 chains (Figure A2). The three chains gave almost identical median estimates of B_0 and current stock status (Figures A3, A4).

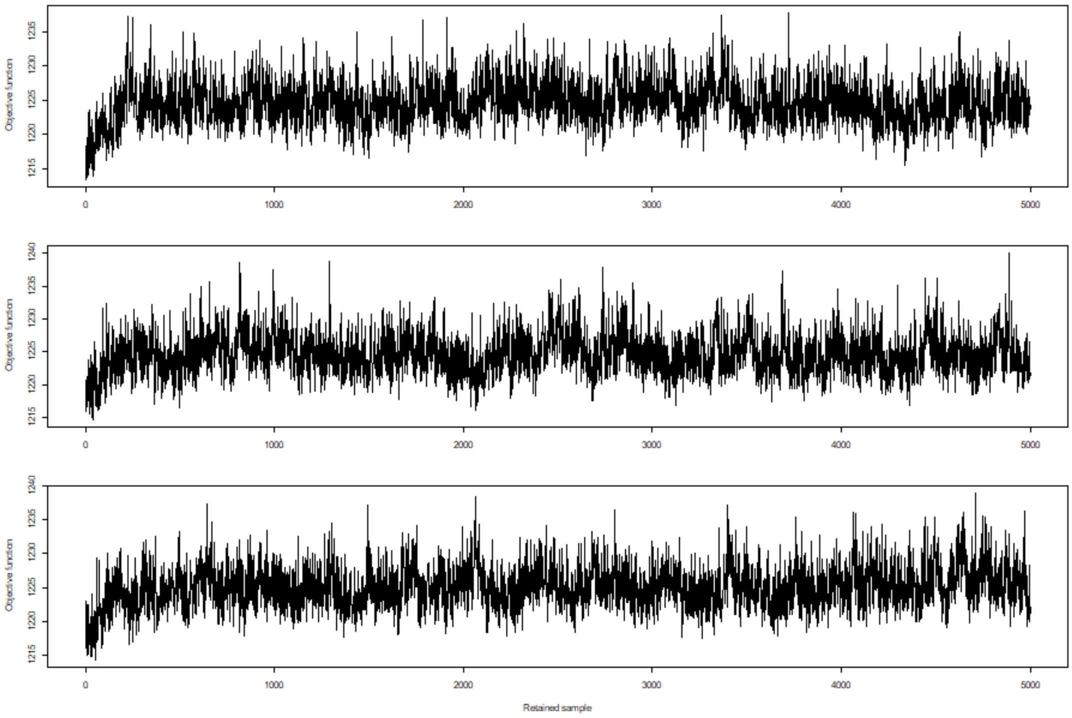

Figure A1: MCMC base model: objective function values for the retained samples for each of the three chains including the burn-in (the first 1000 retained samples).

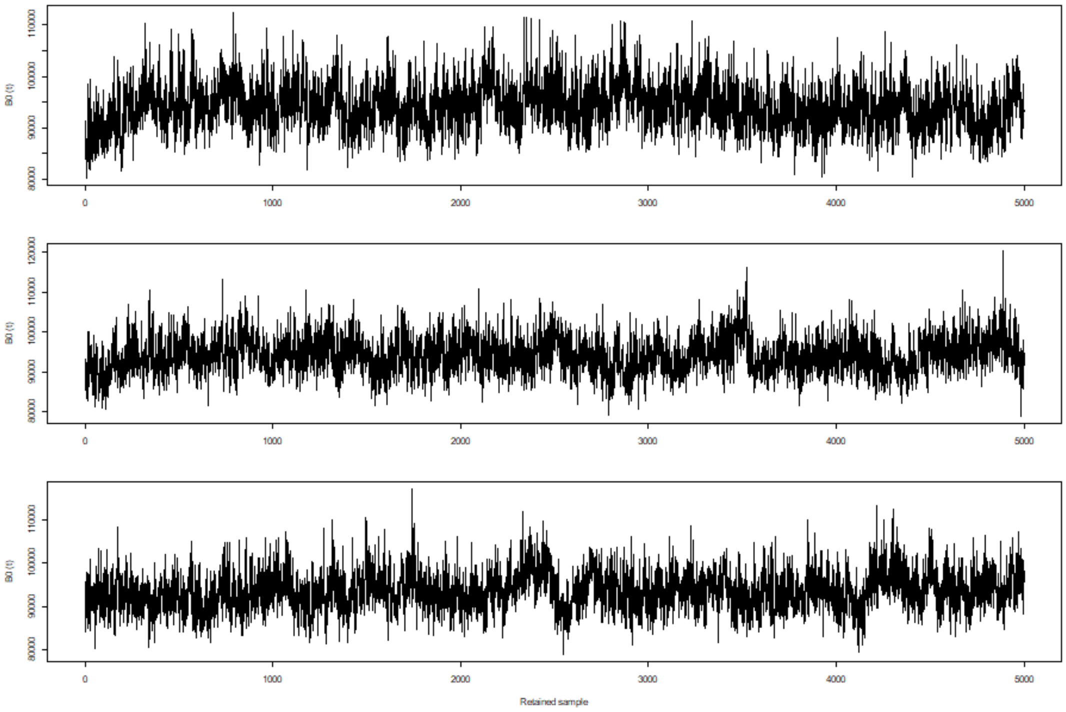

Figure A2: MCMC base model: B_0 estimates for the retained samples for each of the three chains including the burn-in (the first 1000 retained samples).

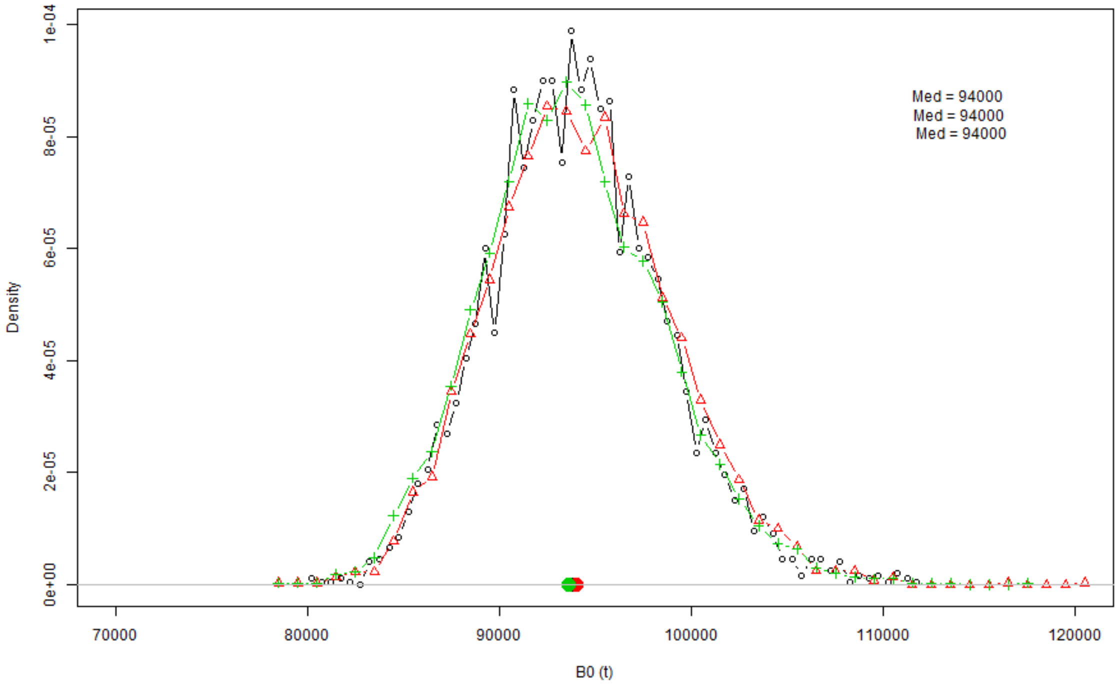

Figure A3: MCMC base model: histograms of the B_0 estimates for the retained samples for each of the three chains excluding the burn-in (the first 1000 retained samples). The B_0 medians (“Med”) for the three chains are also given.

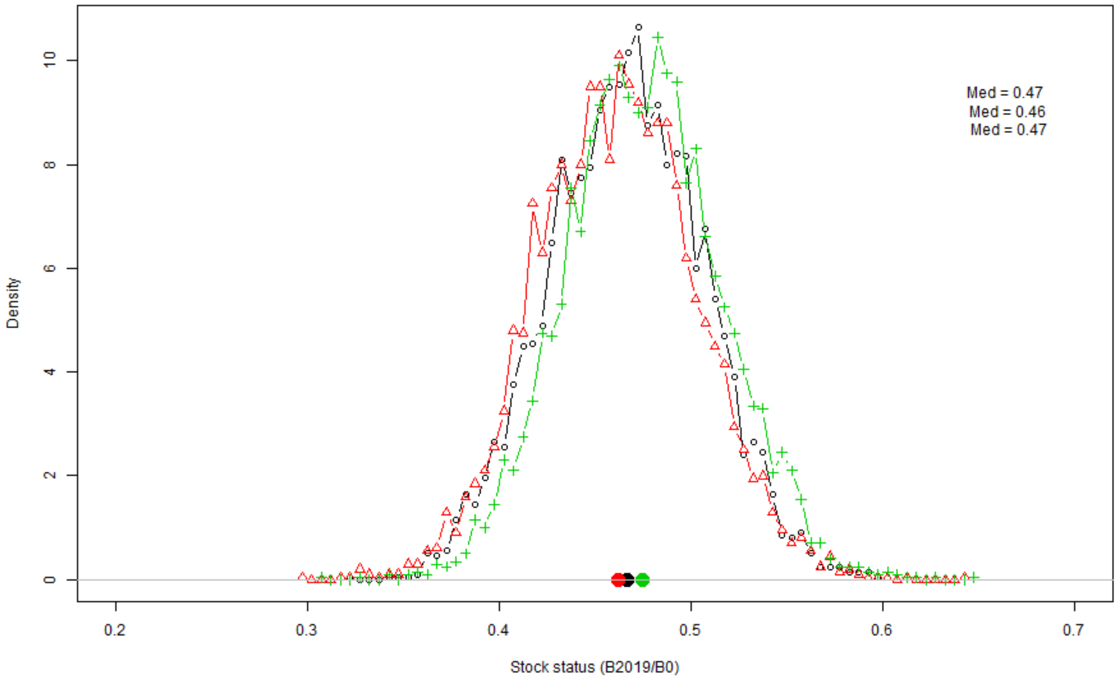

Figure A4: MCMC base model: histograms of the current stock status estimates for the retained samples for each of the three chains excluding the burn-in (the first 1000 retained samples). The current stock status medians (“Med”) for the three chains are also given.

APPENDIX 2: Adjustments to original acoustic estimates for ORH 7A and Volcano

This appendix gives the details of how the acoustic snapshot estimates in the source documents were made consistent across years and within years (when there were AOS and hull-mounted estimates). Decisions were made on which snapshots would be used and a number of adjustments needed to be made to the original estimates.

A snapshot was used in a stock assessment run only if it was a snapshot of a spawning aggregation (vertical extent and areal extent – not just a school or two) and the timing was "good" or "3 days" according to the following definitions (based on location specific female gonad stages):

Good:	at least 30% of females more advanced than "maturing"
3 days:	does not satisfy "good" on the day of the snapshot but the snapshot occurred within 3 days of a day when timing was "good"
Early:	satisfies neither "good" nor "3 days"
Unk.:	unknown, i.e. no gonad samples available on which to base a decision

The source documents are given in the main references:

Survey year	Document from which the estimates were sourced	Notes
2005	Clark et al. 2005	Old target strength
2006	Clark et al. 2006	Old target strength
2009	Hampton 2010	A revision of the estimates in the 2009 report
2010	Doonan et al. 2010	
2011	Hampton et al. 2013	
2012	Hampton et al. 2014	
2013	Boyer et al. 2014	
2014	Ryan et al. 2015	
2018	Ryan et al. 2019	

It is important to note that the estimates for Volcano in the source documents for the 2009 to 2013 surveys inclusive are incorrect. The estimates for star pattern snapshots were incorrect because of a spreadsheet error. The corrected estimates are given in Hampton (2015a, 2015b).

In the tables below the given CVs are CV1 when there are fewer than five snapshots and CV2 when there are five or more snapshots. CV1 is derived from the measured observation error. CV2 is derived from the between snapshot variation. In some tables, some of the columns are not completed for snapshots that were not used in an assessment run. Bolded entries in the tables were used in the assessment as estimates of spawning biomass for the given aggregation and year.

Table B1: Acoustic biomass estimates for Volcano and the western aggregation in 2005. The first column of biomass estimates (Old TS) is from the source document before partitioning of backscatter; the second column is corrected for the new TS relationship (2.47 dB difference or a factor of 1.77); the last column contains the fully adjusted estimates (removed original motion correction (1.06 assumed) and applied combined motion and bubble layer correction factor of 1.33).

		Biomass estimate (t)				
Aggregation	**Date**	**Old TS**	**New TS**	**Adjusted**	**CV (%)**	**Timing**
Volcano	28 Jun 2005	1 462	2 588	3 247	44	3 days
	1 Jul 2005	953	1 687	2 116	52	Good
Mean		1 208	2 137	**2 682**	**34**	
West	5 Jul 2005	1 772	3 136	3 935	67	Good
	5 Jul 2005	2 019	3 574	4 484	71	Good
Mean		1 896	3 355	**4 210**	**49**	

Table B2: Acoustic biomass estimates for Volcano and the western aggregation in 2006. The first column of biomass estimates (Old TS) is from the source document before partitioning of backscatter; the second column is corrected for the new TS relationship (2.47 dB difference or a factor of 1.77); the last column contains the fully adjusted estimates (removed original motion correction and applied combined motion and bubble layer correction factor of 1.33).

		Original	Biomass estimate (t)				
Agg.	**Date**	**motion factor**	**Old TS**	**New TS**	**Adjusted**	**CV (%)**	**Timing**
Volcano	25 Jun 2006	1.020	97			137	Early
	29 Jun 2006	1.083	3 640	6 443	7 912	37	3 days
	3 Jul 2006	1.079	2 175	3 850	4 745	84	Good
Mean			2 908	5 146	**6 329**	**39**	
West	25 Jun 2006	1.026	0				Good
	29 Jun 2006	1.033	2 119	3 751	4 829	71	Good
	2-3 Jul 2006	1.059	1 771	3 135	3 937	98	Good
Mean			1 945	3 443	**4 383**	**59**	

Table B3: Acoustic biomass estimates for the three aggregations in 2009. The first column of biomass estimates is from the source document, the second column has removed the partition factor, and the last column is the fully adjusted estimates (removed partition factor and original motion correction and applied combined motion and bubble layer correction factor of 1.33).

			Original	Biomass estimate (t)				
Agg.	**Date**	**Partition factor**	**motion factor**	**Source**	**No partition**	**Adj.**	**CV (%)**	**Timing**
Volcano	29 Jun 2009	0.80		0				Early
	29 Jun 2009		1.08	759	949	1 168	36	Early
	5 Jul 2009		1.10	444	555	**671**	**21**	Good
Mean				602	752	920	24	
East	5 Jul 2009	0.908	1.09	6 304	6 943	**8 471**	**61**	Good
West	27-28 Jun 2009	0.936	1.03	7 447	7 956	10 274	67	Good
	28 Jun 2009		1.02	8 968	9 581	12 493	26	Good
	1 Jul 2009		1.10	4 518	4 827	5 836	90	Good
	2 Jul 2009		1.02	5 836	6 235	8 130	36	Good
	4 Jul 2009		1.07	18 024	19 256	23 936	37	Good
	5 Jul 2009		1.07	15 557	16 621	20 659	37	Good
Mean	First 4			6 692	7 150	9 183	26	
	All			10 058	10 746	**13 555**	**22**	
	Last 2			16 791	17 939	22 297	26	

Table B4: Acoustic biomass estimates for the three aggregations in 2010. The first column of biomass estimates is from the source document, the second column has removed the partition factor, and the last column is the fully adjusted estimates (removed partition factor and original motion correction and applied combined motion and bubble layer correction factor of 1.33). In the east, only the last snapshot could be considered a survey of a spawning aggregation based on the occurrence of marks seen on the transects.

				Biomass estimate (t)				
Agg.	**Date**	**Partition factor**	**Original motion factor**	**Source**	**No Partition**	**Adjusted**	**CV (%)**	**Timing**
Volcano	1 Jul 2010	0.608	1.06	622		1 281	12	Early
	1 Jul 2010			140		288	45	Early
	2 Jul 2010			459		946	28	Early
	6 Jul 2010			938		1 932	22	Early
	6 Jul 2010			588		1 211	67	Early
Mean				549		1 132	24	
East	29 Jun 2010	0.865	1.06	603	697	875	67	Good
	29 Jun 2010			0				Good
	3 Jul 2010			411	475	596	50	Good
	3 Jul 2010			164	190	238	100	Good
	3 Jul 2010			**1 177**	**1 361**	**1 707**	**34**	Good
Mean				589	681	854	27	
West	29 Jun 2010	0.935	1.06	5 327	5 697	7 149	29	Good
	29 Jun 2010			2 550	2 727	3 422	17	Good
	2 Jul 2010			6 161	6 589	8 268	21	Good
	4 Jul 2010			8 044	8 603	10 795	11	Good
	7 Jul 2010			6 345	6 786	8 515	39	Good
	8 Jul 2010			7 852	8 398	10 537	18	Good
Mean				6 047	6 467	**8 114**	**14**	

Table B5: Acoustic biomass estimates for Volcano and the western aggregation in 2011. The first column of biomass estimates is from the source document, the second column has removed the partition factor, and the last column is the fully adjusted estimates (removed partition factor and original motion correction (assumed 1.06) and applied combined motion and bubble layer correction factor of 1.33).

				Biomass estimate (t)				
Agg.	**Date**	**Partition factor**	**Original motion factor**	**Source**	**No Partition**	**Adjusted**	**CV (%)**	**Timing**
Volcano	5 Jul 2011	0.26	1.06	46		222	63	Unk.
	5 Jul 2011			25		121	48	Unk.
Mean				36		171	44	
East	3 Jul 2011	1.00	1.06	108	108	136	56	Good
West	1 Jul 2011	1.00	1.06	11 723	11 723	14 709	61	Good
	4 Jul 2011			9 554	9 554	11 988	28	Good
	5 Jul 2011			10 618	10 618	13 323	31	Good
Mean				10 632	10 632	**13 340**	**26**	

Table B6: Acoustic biomass estimates for the three aggregations in 2013. The first column of biomass estimates is from the source document, the second column has removed the partition factor, and the last column is the fully adjusted estimates (removed partition factor and original motion correction (assumed 1.06) and applied combined motion and bubble layer correction factor of 1.33).

				Biomass estimate (t)				
Agg.	**Date**	**Partition factor**	**Original motion factor**	**Source**	**No Partition**	**Adjusted**	**CV (%)**	**Timing**
Volcano	8 Jul 2013	0.9	1.06	1 512	1 680	2 108	33	Good
	9 Jul 2013			2 851	3 168	3 975	65	Good
	9 Jul 2013			5 448	6 053	7 595	37	Good
Mean				3 270	3 633	**4 559**	**28**	
East	1 Jul 2013	1.00	1.06	2 811	2 811	3 527	24	Good
	1 Jul 2013			5 627	5 627	7 060	17	Good
	2 Jul 2013			5 971	5 971	7 492	14	Good
	5 Jul 2013			4 694	4 694	5 890	21	Good
	6 Jul 2013			2 276	2 276	2 856	12	Good
Mean				4 276	4 276	**5 365**	**17**	
West	29 Jun 2013	1.00	1.06	5 729	5 729	7 188	30	Good
	30 Jun 2013			4 230	4 230	5 307	32	Good
	30 Jun 2013			9 151	9 151	11 482	39	Good
	1 Jul 2013			7 129	7 129	8 945	12	Good
	1 Jul 2013			11 794	11 794	14 798	24	Good
	2 Jul 2013			7 032	7 032	8 823	19	Good
	4 Jul 2013			9 553	9 553	11 986	56	Good
	5 Jul 2013			7 222	7 222	9 062	35	Good
	5 Jul 2013			12 783	12 783	16 039	38	Good
	12 Jul 2013			8 427	8 427	10 574	31	Good
	12 Jul 2013			6 223	6 223	7 808	23	Good
Mean				8 116	8 116	**10 183**	**10**	

Table B7: Acoustic biomass estimates for Volcano in 2014. The first column of biomass estimates is from the source document, the second column has had the adjustment for absorption, and the final column is the fully adjusted estimates (AOS: 10% correction for Francois & Garrison; Vessel: 25% correction for Francois & Garrison, removed original motion correction and applied combined motion and bubble layer correction factor of 1.33).

			Biomass estimate (t)				
Platform	**Date**	**Original Motion factor**	**Source**	**Absorp. adjust**	**Fully adjusted**	**CV (%)**	**Timing**
AOS	1 Jul 2014		1 658	1 492	1 492	22	Early
	2 Jul 2014		925	833	833	26	Early
	4 Jul 2014		2 291	2 062	2 062	15	3 days
	5 Jul 2014		5 802	5 222	5 222	17	Good
Vessel	1 Jul 2014	1.17	1 951	1 463	1 663	17	Early
	2 Jul 2014	1.17	1 545	1 159	1 317	19	Early
	4 Jul 2014	1.20	2 158	1 618	1 794	18	3 days
	5 Jul 2014	1.11	3 205	2 404	2 880	20	Good
	5 Jul 2014	1.20	9 395	7 046	7 810	18	Good
Mean	1–2 July		1 520		1 326	10	
Mean	**4–5 July**		4 570		**3 954**	**29**	

Table B8: Acoustic biomass estimates for Volcano and the western aggregation in 2018. The first column of biomass estimates is from the source document and the second column is the fully adjusted estimates (AOS: 10% correction for Francois & Garrison; Vessel: no correction as Doonan et al. and the combined bubble and motion correction have already been applied).

			Biomass estimate (t)			
Platform	**Date**	**Aggregation**	**Source**	**Adjusted**	**CV (%)**	**Timing**
AOS	4 Jul 2018	Volcano	4 449	4 004	18	Early
	8 Jul 2018		4 072	3 665	27	Unk.
Mean			4 261	3 834	16	
Vessel	29 Jun 2018	West	6 557	6 557	27	3 days
	29 Jun 2018		7 548	7 548	18	3 days
	2 Jul 2018		11 865	11 865	29	Good
	3 Jul 2018		11 165	11 165	24	Good
	7 Jul 2018		9 876	9 876	12	Good
AOS	29 Jun 2018	West	10 758	9 682	19	3 days
	1 Jul 2018		11 497	10 347	39	Good
	2 Jul 2018		14 098	12 688	23	Good
Mean			10 421	**9 966**	**9**	

Table B9: Fully adjusted annual acoustic biomass estimates for the spawning aggregations surveyed in the west, east, and on Volcano. In 2005, 2011, and 2013, the CVs have been inflated by adding a 20% process error to account for the assumption of a motion correction of 1.06 (the values were not provided in the source documents in those years; 1.06 is the average motion correction for 2006 and 2009). These estimates are derived from Tables 1–8 using the mean of the fully adjusted snapshot estimates that surveyed aggregations and had acceptable timing in each area and year.

	West		East		Volcano	
Year	**Biomass (t)**	**CV (%)**	**Biomass (t)**	**CV (%)**	**Biomass (t)**	**CV (%)**
2005	4 210	53			2 682	39
2006	4 383	59			6 329	39
2009	13 555	22	8 471	61		
2010	8 114	14	1 707	34		
2011	13 340	33				
2013	10 183	22	5 365	26	4 559	34
2014					3 954	29
2018	9 966	9				

APPENDIX 3: CASAL input files for the base model

The population and estimation files used in the MCMC base model are given below.

population.csl

```
# ORH7A: 2019 base model with two fisheries Westpac and EEZ
# Separate acoustic time series for each of three areas: west, east, volcano

# PARTITION
@size_based False
@min_age 1
@max_age 100
@plus_group True
@sex_partition False
@mature_partition True
@n_areas 1

# TIME SEQUENCE
@initial 1911
@current 2019
@final 2024
@annual_cycle
time_steps 2

# recruitment
recruitment_time 1

# spawning
spawning_time 2
spawning_part_mort 0.5
spawning_p 1

# growth and mortality
aging_time 1
M_props 1 0
baranov False

# maturation
n_maturations 1
maturation_times 1

# fishery
fishery_names EEZ Westpac
fishery_times    2    2


# RECRUITMENT
@y_enter 1
@standardise_YCS True
@recruitment
YCS_years    1910 1911 1912 1913 1914 1915 1916 1917 1918 1919 1920 1921 1922 1923 1924 1925
1926 1927 1928 1929 1930 1931 1932 1933 1934 1935 1936 1937 1938 1939 1940 1941 1942 1943
1944 1945 1946 1947 1948 1949 1950 1951 1952 1953 1954 1955 1956 1957 1958 1959 1960 1961
1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979
1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997
```

```
1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015
2016 2017 2018
YCS   1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2 1 2 1 2 1 2 1 1 1 .4 1 .3
1 2 1 .6 1 .8 1 2 .2 1 .5 1 2 1 2 1 .5 1 .5 1 .5 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1

SR  BH
steepness 0.75
sigma_r  1.1
first_free 1925
last_free 1995

# recruitment variability
@randomisation_method lognormal

@fishery EEZ
years           1981 1982 1983          1984    1985    1986    1987    1988    1989    1990
        1991    1992    1993    1994    1995    1996    1997    1998    1999    2000            2001
        2002    2003    2004    2005    2006    2007    2008    2009    2010    2011    2012    2013
2014 2015 2016 2017 2018 2019
catches          1  4601  5896  8232  6556 10024 13722 13112  8489  4451  1541  2083  1553  1674
1632  1266  1108  1388  1062   561     0     0     4     0   148   206     0     0   229   356   500   529   811
508  1674  1310  1675  1210  1470
selectivity SELspawn
U_max 0.8
future_constant_catches 1470

@fishery Westpac
years           1981 1982 1983          1984    1985    1986    1987    1988    1989    1990
        1991    1992    1993    1994    1995    1996    1997    1998    1999    2000            2001
        2002    2003    2004    2005    2006    2007    2008    2009    2010    2011    2012    2013
2014 2015 2016 2017 2018 2019
catches         42  922 9495 4154   96   55 1218 2724 4312  720   20   19  743  145   86  486  266  189
249   99    0    0    1    0   18   23    0    0   23    5    5    7    4   66    0  336   29  659  210
selectivity SELvolcano
U_max 0.8
future_constant_catches 210

# MATURITY
@maturation
rates_all logistic_producing 15 50 30 3

# SELECTIVITIES
@selectivity_names SELspawn SELvolcano

@selectivity SELspawn
mature constant 1
immature constant 0

@selectivity SELvolcano
mature logistic 30 3
immature constant 0

# NATURAL MORTALITY
@natural_mortality
all    0.045
```

```
# SIZE AT AGE
@size_at_age_type von_Bert
@size_at_age_dist normal
@size_at_age
k 0.065
t0 -0.5
Linf 34.2
cv1 0.10
cv2 0.05
by_length True
@size_weight
a 9.21e-8
b 2.71


# INITIALISATION
@initialization
B0 130000
```

estimation.csl

```
# ESTIMATION
@estimator Bayes
@max_iters 1000
@max_evals 3000
@grad_tol 0.0001


# MCMC
@MCMC
start 0
length 5000000
keep 1000
stepsize 0.06
burn_in 1000


####
#### 1987 Amaltal Explorer and
#### 2006, 2009, 2018 Thomas Harrison age freqs
####
#### Also Volcano AFs 2014, 2018
####

@proportions_at AFreq
years 1987 2006 2009 2018
step 2
proportion_mortality 0.5
sexed F
sum_to_one True
at_size False
plus_group True
ogive SELspawn
min_class 15
max_class 100
```

```
ageing_error True
1987 0 0 0 0 0 0 0 0 0 0 0.00656168 0.003937008 0.01706037 0.01312336 0.01312336 0.01049869
0.03674541 0.01574803 0.0144357 0.01181102 0.0183727 0.02230971 0.01049869 0.02493438
0.0183727 0.02230971 0.0183727 0.03018373 0.03149606 0.01968504 0.04724409 0.01968504
0.02493438 0.02493438 0.04199475 0.01574803 0.03805774 0.02493438 0.009186352 0.02362205
0.02624672 0.01968504 0.01312336 0.01706037 0.01574803 0.02099738 0.02887139 0.00656168
0.01181102 0.01312336 0.002624672 0.01312336 0.01968504 0.007874016 0.009186352
0.002624672 0.001312336 0.01049869 0.00656168 0.00656168 0.009186352 0 0.01181102 0
0.005249344 0.009186352 0.005249344 0 0.00656168 0.01049869 0 0.001312336 0.00656168
0.003937008 0.002624672 0 0.005249344 0 0 0.003937008 0.007874016 0.001312336 0 0.00656168
0 0.01968504
2006 0 0 0.0008532423 0.002559727 0.001706485 0.001706485 0.004266212 0.005119454
0.005119454 0.01706485 0.03754266 0.0665529 0.04522184 0.06484642 0.05887372 0.02645051
0.04095563 0.04692833 0.008532423 0.03242321 0.08532423 0.02986348 0.03924915 0.0162116
0.0443686 0.03156997 0.03583618 0.01535836 0.01279863 0.05119454 0.02389078 0.01194539
0.01706485 0.006825939 0.004266212 0.003412969 0.006825939 0.01962457 0.004266212
0.001706485 0.01279863 0.01279863 0.001706485 0.005972696 0.002559727 0.005119454 0 0
0.002559727 0.003412969 0 0 0 0 0 0.006825939 0 0 0.001706485 0.01109215 0 0 0 0 0.001706485
0 0 0 0.001706485 0 0 0 0 0 0.0008532423 0 0 0 0 0 0 0 0
2009 0 0 0.001703578 0 0.001703578 0.003407155 0.0306644 0.02896082 0.01873935 0.02725724
0.02725724 0.04770017 0.03236797 0.02214651 0.07325383 0.03577513 0.07495741 0.03407155
0.04770017 0.04599659 0.03918228 0.04940375 0.02896082 0.03918228 0.04088586 0.02385009
0.03407155 0.02896082 0.02725724 0.005110733 0.0306644 0.005110733 0 0.005110733 0.00681431
0.005110733 0.001703578 0.008517888 0 0.005110733 0.003407155 0.008517888 0.008517888
0.003407155 0 0 0.003407155 0 0 0.003407155 0.00681431 0.001703578 0.005110733 0 0 0 0 0 0
0.005110733 0 0 0 0 0 0 0.001703578 0 0 0 0 0 0 0.01022147 0 0 0 0 0 0 0 0 0 0
2018 0 0 0 0 0.005060266 0 0.006761356 0.01002867 0.01268612 0.0146093 0.01844751 0.02278862
0.01672607 0.01019668 0.01251519 0.008008393 0.01998815 0.02982031 0.04219187 0.01733302
0.03176847 0.02335195 0.03298992 0.04931774 0.02693554 0.03646654 0.02449202 0.03340329
0.03163068 0.05372512 0.04284767 0.03743045 0.02181655 0.0348701 0.04319939 0.02246943
0.0179859 0.02329616 0.01198962 0.0125024 0.02281883 0.008449655 0.009778681 0.009010675
0.009834479 0.004297498 0.002530133 0.004963169 0.004455632 0.002292933 0.008403726
0.003914957 0.001997012 0.006246265 0.002372 0.003083599 0.006552056 0 0 7.906665e-05
0.00312429 0.003552761 0.001265066 0.004448078 0.002570824 0.004264361 0 0.003795199
0.0008569413 0.0001581333 0 0 0 0 0 0 0.0003953333 0 0 0 0 0.0005534666 0 0 0 0.004284706
dist multinomial
r 0.00001
N_1987 60
N_2006 60
N_2009 60
N_2018 60

@proportions_at AFreqVol
years 2014 2018
step 2
proportion_mortality 0.5
sexed F
sum_to_one True
at_size False
plus_group True
ogive SELvolcano
min_class 15
max_class 100
ageing_error True
2014 0 0 0 0 0 0.003 0 0.008 0.006 0.002 0.007 0.007 0.006 0.01 0.011 0.019 0.027 0.038 0.016 0.037
0.033 0.036 0.042 0.058 0.034 0.037 0.046 0.042 0.042 0.032 0.03 0.034 0.037 0.03 0.013 0.022 0.026
0.025 0.022 0.029 0.015 0.012 0.008 0.009 0 0.012 0.004 0.007 0.004 0.009 0.012 0 0.005 0.003 0.004
```

```
0 0 0.003 0.009 0.003 0 0 0.003 0 0.006 0 0 0 0 0 0 0 0 0 0 0 0.003 0 0 0 0 0 0 0 0 0
2018 0 0 0 0 0 0 0 0 0 0 0 0 0 0.00708502 0.008097166 0 0.01315789 0.01518219 0.01518219
0.001012146 0.01315789 0.003036437 0.03340081 0.02732794 0.008097166 0.009109312
0.02125506 0.01923077 0.05161943 0.02327935 0.0354251 0.00708502 0.04048583 0.02631579
0.02935223 0.03441296 0.03846154 0.01923077 0.02226721 0.03340081 0.03036437 0.02024291
0.02327935 0.0111336 0.02732794 0.03137652 0.01315789 0.02631579 0.02024291 0.0111336
0.01619433 0.02834008 0 0.02530364 0 0.008097166 0.008097166 0.01315789 0.01720648
0.02024291 0.005060729 0.02125506 0 0 0 0.005060729 0.00708502 0 0 0 0 0.0111336 0.01315789 0
0 0 0 0 0 0.002024291 0.009109312 0 0 0 0 0.01923077
dist multinomial
r 0.00001
N_2014 60
N_2018 30

@ageing_error
type normal
c 0.1



#
# Amaltal Explorer trawl indices
# Clark's reduced area comparable indices
#

@relative_abundance Amaltal
step 2
biomass True
ogive SELspawn
proportion_mortality 0.5
dist lognormal
q Amaltalq
years 1987 1988 1989
1987    75040
1988    28954
1989    11062
cv_1987 0.33
cv_1988 0.34
cv_1989 0.23

@estimate
parameter q[Amaltalq].q
lower_bound 0.10
upper_bound 2.00
prior uniform-log

#
# Thomas Harrison trawl indices
# Using short-tow adjusted, excl. strata 9-11
# Have had 20% process error added
#

@relative_abundance Thomas
step 2
biomass True
ogive SELspawn
proportion_mortality 0.5
```

```
dist lognormal
q Thomasq
years 2006 2009 2011 2012 2013 2018
2006 13987
2009 34864
2011 18425
2012 22451
2013 18993
2018 48038
cv_2006 0.34
cv_2009 0.31
cv_2011 0.33
cv_2012 0.27
cv_2013 0.55
cv_2018 0.55

@estimate
parameter q[Thomasq].q
lower_bound 0.1
upper_bound 2.5
prior lognormal
mu 0.95
cv 0.30


# Volcano only estimates
# 20% process error added for years where motion correction not known

@relative_abundance acoVol
step 2
biomass True
ogive SELvolcano
proportion_mortality 0.5
dist lognormal
q acoVolq
years 2005 2006 2014
2005 2682
2006 6329
#2013 4559
2014 3954
cv_2005 0.39
cv_2006 0.39
#cv_2013 0.34
cv_2014 0.29

@estimate
parameter q[acoVolq].q
lower_bound 0.01
upper_bound 1.5
prior lognormal
mu 0.18
cv 0.30

# East only estimates
# 20% process error added for years where motion correction not known

@relative_abundance acoEast
```

```
step 2
biomass True
ogive SELspawn
proportion_mortality 0.5
dist lognormal
q acoEastq
years 2009 2010 #2013
2009 8471
2010 1707
#2013 5365
cv_2009 0.61
cv_2010 0.34
#cv_2013 0.26

@estimate
parameter q[acoEastq].q
lower_bound 0.01
upper_bound 1.5
prior lognormal
mu 0.22
cv 0.30

# West only estimates
# 20% process error added for years where motion correction not known

@relative_abundance acoWest
step 2
biomass True
ogive SELspawn
proportion_mortality 0.5
dist lognormal
q acoWestq
years 2005 2006 2009 2010 2011 2013 2018
2005 4210
2006 4383
2009 13555
2010 8114
2011 13340
2013 10183
2018 9966
cv_2005 0.53
cv_2006 0.59
cv_2009 0.22
cv_2010 0.14
cv_2011 0.33
cv_2013 0.22
cv_2018 0.09

@estimate
parameter q[acoWestq].q
lower_bound 0.01
upper_bound 1.5
prior lognormal
mu 0.41
cv 0.30

# Q METHOD
```

```
@q_method free

@q Amaltalq
q .2
@q Thomasq
q .7
@q acoVolq
q 0.3
@q acoWestq
q 0.5
@q acoEastq
q 0.5


#@q_method nuisance

# ESTIMATION BLOCKS

@estimate
parameter selectivity[SELvolcano].mature
lower_bound 10 1
upper_bound 60 50
prior uniform

@estimate
parameter maturation[1].rates_all
lower_bound     10        1
upper_bound     100       100
prior uniform

# B0
@estimate
parameter initialization.B0
lower_bound 30000
upper_bound 200000
prior uniform-log

@profile
parameter initialization.B0
n 14
l 50e3
u 160e3

# YCS
@estimate
parameter recruitment.YCS
lower_bound 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01
0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01
0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01
0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 .01 .01 .01 .01 .01 .01 .01 .01 .01 .01 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1
upper_bound 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
#prior uniform
prior lognormal
```

```
mu 26489122130 26489122130 26489122130 26489122130 26489122130 26489122130
26489122130 26489122130 26489122130 26489122130 26489122130 26489122130 26489122130
26489122130 26489122130 26489122130 26489122130 26489122130 26489122130 26489122130
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# CATCH PENALTIES

@catch_limit_penalty
label CatchPenaltyEEZ
fishery EEZ
multiplier 200
log_scale True

@catch_limit_penalty
label CatchPenaltyWestpac
fishery Westpac
multiplier 200
log_scale True
```

APPENDIX 4: Correct formula for Doonan et al. (2003) absorption coefficient

Doonan et al. (2003) has incorrect equations for f_2 and P_2 which means that their predictive equation for the absorption coefficient gives results that were not intended. The correct equations were kindly supplied by Ian Doonan (pers. comm.) and they were incorporated into an R function which is given below.

```
function(temp,depth,sal,fq=38){

# Absorption coefficient following Doonan et al. (2003)

a2 <- 22.19 * sal * (1 + 0.017* temp)
f2 <- 1.8 * 10^(7 - 1518/(temp + 273.1))
p2 <- exp(-1.76 * 10^-4 * depth)
a3 <- 4.937 * 10^-4 - 2.59*10^-5 * temp + 9.11*10^-7 * temp^2 - 1.5*10^-8 * temp^3
p3 <- 1 - 3.83*10^-5 * depth + 4.9*10^-10 * depth^2
cc <- 1412 + 3.21*temp + 1.19*sal + 0.0167*depth

alpha <- (1/cc) * ((a2 * p2 * f2 * fq^2) / (f2^2 + fq^2))+ a3*p3*fq^2

return(list(c=cc, alpha=alpha))
}
```

Where,

Temp = temperature (degrees Celsius)
depth = depth (metres)
sal = salinity (ppt)
fq = frequency (kHz)
cc = speed of sound in water (m/s)
alpha = absorption coefficient (dB per km)

ANNEX 1: Application of the HCR and associated projections

Stock assessment of ORH7A (including Westpac Bank): Application of the Harvest Control Rule and associated projections

P.L. Cordue, ISL
23 July 2019

ISL Client Report to DWG

Executive summary

In 2019 a stock assessment of ORH 7A (including Westpac Bank) was conducted by Innovative Solutions Ltd (ISL) under contract to Deepwater Group Ltd (DWG). The assessment was presented to Plenary in May 2019 and was accepted to be used for management purposes. In the base model, 2018-19 stock status was estimated at 47% B_0 (95% CI: 39–55% B_0). This is near the top of the target biomass range of 30–50% B_0.

ORH 7A is one of three orange roughy stocks in New Zealand that have Marine Stewardship Council (MSC) certification. There is an accepted Harvest Control Rule (HCR) for these orange roughy stocks. The HCR uses the base model point estimate of current stock status (2018–19) to calculate a TACC for the next fishing year (2019–20). This TACC remains in place until the next assessment (scheduled for 2023). There are no sustainability concerns with a TACC derived from the HCR as the HCR has been thoroughly simulation tested. However, under the HCR there is the potential for a large increase in TACC in 2019–20 that will direct the stock status to lower levels within the management target range, possibly to be followed by a substantial decrease at the next assessment in 4 years.

Projections were performed for the base model and also for the standard orange roughy sensitivity which is designed as a “worst case” scenario (the “LowMhighq” model). It is possible that the LowMhighq model represents the true state of the stock but it is an unlikely scenario. It has the lowest estimated 2018–19 stock status of the models considered in 2019 (37% B_0). The purpose of doing projections from this model is to check that TACCs derived from the base model will, even in the “worst case” scenario, do little harm to the stock. This was found to be true for the HCR TACC and the other projections considered. All TACCs are for catches from the whole stock and thus include any catches from, or allocations for, Westpac Bank.

Model projections for the next 8 years (i.e., for two assessment cycles) were performed for the base model and the LowMhighq model for a range of potential catch values derived from the HCR, current TACC and zero catch:

1. TACC = 0 t for all years (comparative purposes only)
2. TACC = 1600 t for all years (current TACC)
3. TACC = 2060 t for all years
4. TACC = 2448 t for 4 years, followed by 1940 t for another 4 years
5. TACC = 2200 t for 4 years, followed by 2037 t for 4 years

At a TACC of 2060 t for the next 4 years it happens that the expected HCR TACC at the stock assessment in 2023 is also 2060 t (Projection 3). **Application of the HCR to the 2019 base model gives a TACC = 2448 t**. The projection on the base model then gives a HCR TACC of 1940 t at the 2023 assessment (Projection 4). Projection 5 starts with a TACC approximately equal to the average annual yield over the 8 years from Projection 4.

The choice of 2019–20 TACC depends on how much catch decision makers are willing to forgo in order to create more TACC stability and have an expectation of a smaller decrease in TACC following the 2023 assessment:

2019–20 TACC (t)	**Increase from 2018–19 TACC (t)**	**Projected decrease for 2023–24 TACC (t)**	**Average annual yield (t)**	**Projected 2023 stock status (%B_0)**	**Projected 2027 stock status (%B_0)**	**P(B_{27} > 30% B_0)**
2 060	460	0	2 060	43	40	0.96
2 200	600	163	2 119	43	39	0.95
2 448	848	508	2 194	42	38	0.93

Introduction

In 2019 a stock assessment of ORH 7A (including Westpac Bank) was conducted by Innovative Solutions Ltd (ISL) under contract to Deepwater Group Ltd (DWG). The assessment was peer reviewed in the Deepwater Fisheries Assessment Working Group and presented to Plenary in May 2019 and was accepted to be used for management purposes.

ORH 7A is one of three orange roughy stocks in New Zealand that have Marine Stewardship Council (MSC) certification. There is an accepted Harvest Control Rule (HCR) for these orange roughy stocks that can be used to set the TACC for the next fishing year (2019–20) and subsequent years until the next assessment (scheduled for 2023 in this case).

This document describes the application of the HCR to the 2019 stock assessment for ORH 7A together with projections aimed at checking the expected consequences of the HCR TACC and some more precautionary lower alternative TACCs. The HCR has been thoroughly simulation tested (Cordue 2014) so there should be no sustainability concerns with the HCR-derived TACC. However, there is the potential for the TACC to increase substantially under the HCR only to be followed by a substantial decrease at a subsequent assessment.

The HCR TACC is determined from the 2019 base model. Projections are done for the base model and also for the LowMhighq model which is the sensitivity that has the lowest estimated current stock status of the models considered in 2019. The purpose of doing projections from the LowMhighq model is to check that TACCs derived from the base model will not cause poor sustainability outcomes for the stock should the pessimistic LowMhighq model represent the true state of the stock (i.e., a check on what happens if the base model is wrong).

Methods

For both models for which projections were performed, three MCMC chains of length 5 million were available (1 in every 1000 samples retained with the first 1000 retained samples discarded as a burn in). As for the stock assessment results, all three chains combined were used to calculate projected values.

Stochastic recruitment

Year class strengths (YCS) from 1996 onwards were resampled from the last 10 estimated YCS (1986–1995). These YCS are about average (90% of the long-term average) but as fish are 50% recruited at about 33 years these cohorts have little effect on short-term projection results considered here.

Application of the HCR

The HCR uses the point estimate of current stock status to calculate an exploitation rate to be applied to the next year's beginning-of-year vulnerable biomass to determine the catch limit. For ORH 7A, the vulnerable biomass is the spawning stock biomass (SSB).

For estimates of stock status within the target biomass range of 30–50% B_0, the exploitation rate is simply stock status multiplied by 0.1125 (see Cordue 2014, there is a linear relationship between stock status and the exploitation rate, and when stock status is estimated at 40% B_0 the exploitation rate is 0.045 which is the value of natural mortality, M, used for orange roughy in the assessment).

Projection runs

Five projection runs, each for 8 years, were performed for the base model and the LowMhighq model. All TACCs are for catches from the whole stock and thus include any catches from, or allocations for, Westpac Bank:

1. TACC = 0 t for all years
2. TACC = 1600 t for all years
3. TACC = 2060 t for all years
4. TACC = 2448 t for 4 years, followed by 1940 t for another 4 years
5. TACC = 2200 t for 4 years, followed by 2037 t for 4 years

Projection 1 is simply for comparative purposes to see how much the stock status will increase in the absence of catch. The current TACC is 1600 t (Projection 2).

At a TACC of 2060 t for the next 4 years it happens that the expected HCR-derived TACC at the assessment in 2023 is also 2060 t (Projection 3). Application of the HCR to the base model gives a TACC = 2448 t (see Results). The projection on the base model then gives a HCR-derived TACC of 1940 t at the 2023 assessment (Projection 4). Projection 5 starts with a TACC approximately equal to the average annual yield from Projection 4.

Projection 3, which uses a TACC = 2060 t, gives very similar results to a projection using a catch that is the average of the HCR TACC (2448 t) and the current TACC (1600 t) (that average being 2024 t).

Catches were split between the EEZ and Westpac Bank assuming the full 200 t catch limit was taken for the Westpac each year: EEZ = 1400/1600 = 88%, Westpac Bank = 200/1600 = 12%.

An additional incidental mortality of 5% of the TACC was applied in each year.

Results

Application of the HCR

For the current assessment, the base model estimate of stock status is 47% B_0 and the estimated beginning-of-year SSB in 2019–20 was 46 296 t. This gives a TACC:

HCR TACC = 46296 × 0.1125 × 0.47 = 2448 t.

Similar calculations gave the expected TACCs in 2023–24 for Projections 3–5 (see Projection runs).

Projection results

For the base model projections, the median stock status (B_i/B_0) and the probability of being above the lower bound of the target biomass range (P[B_i > 30% B_0]) were tabulated. It is useful to check that potential TACCs are expected to maintain the SSB within or above the target biomass range. This is the case for all projections with a greater than 90% probability of SSB being above 30% B_0 in all years (Table 1). Under all projections, stock status is predicted to change no more than about 1% B_0 from year to year (even when there is no catch) (Table 1).

Table 1: Projection results for the base model. TACC (t) defines the projection (see Projection runs); ss = stock status (%B_0); Prob = P(B_i > 30% B_0).

	Projection 1			Projection 2			Projection 3			Projection 4			Projection 5		
	TACC	ss	Prob	TACC	ss	Prob	TACC	ss	Prob	TACC	ss	Prob	TACC	ss	Prob
2019	1 600	47	1.00	1 600	47	1.00	1 600	47	1.00	1 600	47	1.00	1 600	47	1.00
2020	0	47	1.00	1 600	46	1.00	2 060	46	1.00	2 448	46	1.00	2 200	46	1.00
2021	0	48	1.00	1 600	46	1.00	2 060	45	1.00	2 448	44	1.00	2 200	45	1.00
2022	0	50	1.00	1 600	45	1.00	2 060	44	1.00	2 448	43	1.00	2 200	44	1.00
2023	0	51	1.00	1 600	45	1.00	2 060	43	1.00	2 448	42	0.99	2 200	43	1.00
2024	0	52	1.00	1 600	44	1.00	2 060	42	0.99	1 940	41	0.99	2 037	42	0.99
2025	0	53	1.00	1 600	44	1.00	2 060	41	0.99	1 940	40	0.97	2 037	41	0.98
2026	0	54	1.00	1 600	43	0.99	2 060	40	0.98	1 940	39	0.96	2 037	40	0.97
2027	0	55	1.00	1 600	43	0.99	2 060	40	0.96	1 940	38	0.93	2 037	39	0.95

To the eye there is little difference between the SSB trajectories for Projections 3–5 which decrease at only a slightly higher rate than Projection 2 (current TACC) (Figure 1). The SSB is almost wholly within or above the target biomass range in every year for all projections including the HCR TACC (Projection 4) (Figure 1, Table 1).

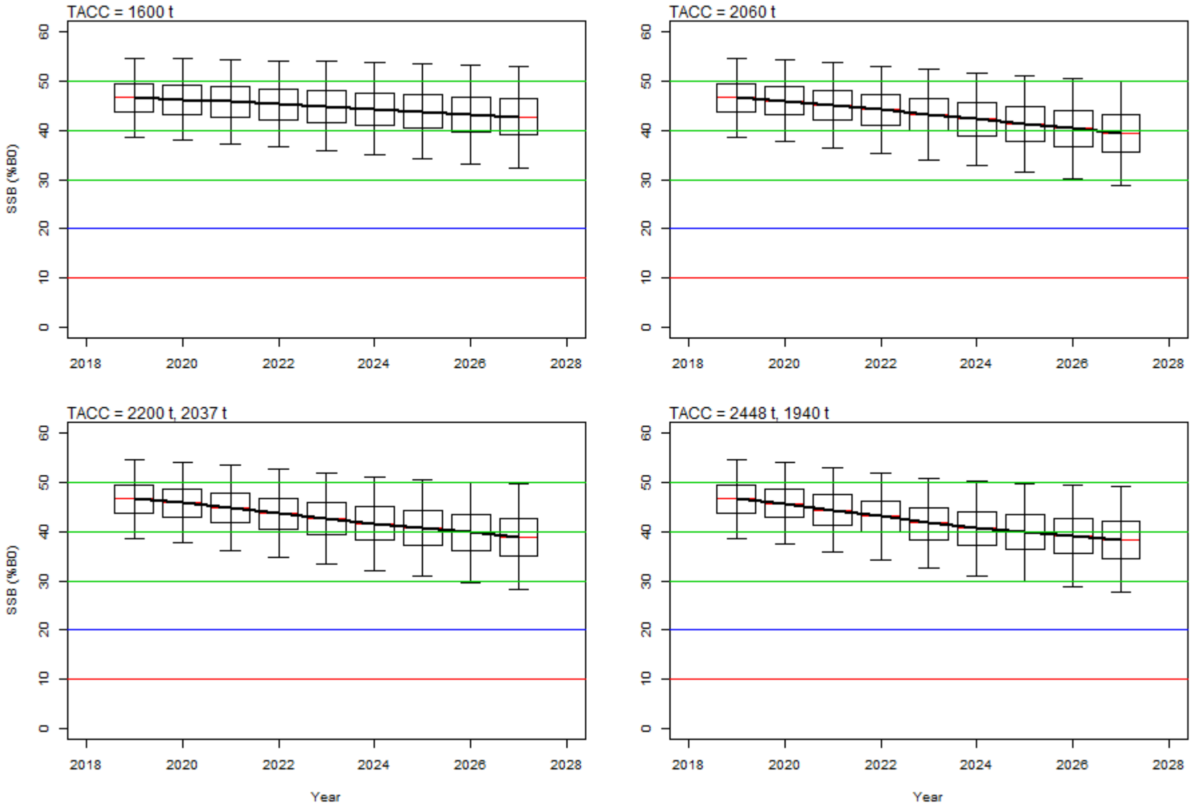

Figure 1: Projection results for the base model showing a box and whiskers plot for each projection with non-zero catch (Projections 2–5). Each box covers the middle 50% of the distribution and the whiskers extend to 95%. The medians of the distribution in each year are joined by lines. The green lines show the upper, midpoint and lower bounds of the management target range; the blue line is the soft limit, 20% B_0 (=limit reference point); and the red line is the hard limit, 10% B_0.

For the LowMhighq model projections, the median stock status (B_i/B_0) and the probability of being below the soft limit (P[$B_i < 20\% B_0$]) were tabulated. For this pessimistic model, it is important to check that potential TACCs (derived from the base model) are **not** expected to cause a dramatic decline in SSB. This is the case for all projections, with less than a 10% probability of SSB being below 20% B_0 in all years (Table 2).

Table 2: Projection results for the LowMhighq model. TACC (t) defines the projection (see Projection runs); ss = stock status (%B_0); Prob = P($B_i < 20\% B_0$).

	Projection 1			Projection 2			Projection 3			Projection 4			Projection 5		
	TACC	ss	Prob	TACC	ss	Prob	TACC	ss	Prob	TACC	ss	Prob	TACC	ss	Prob
2019	1 600	37	0.00	1 600	37	0.00	1 600	37	0.00	1 600	37	0.00	1 600	37	0.00
2020	0	37	0.00	1 600	37	0.00	2 060	36	0.00	2 448	36	0.00	2 200	36	0.00
2021	0	39	0.00	1 600	36	0.00	2 060	35	0.00	2 448	35	0.00	2 200	35	0.00
2022	0	40	0.00	1 600	35	0.00	2 060	34	0.00	2 448	33	0.00	2 200	34	0.00
2023	0	41	0.00	1 600	35	0.00	2 060	33	0.00	2 448	32	0.00	2 200	32	0.00
2024	0	42	0.00	1 600	34	0.00	2 060	32	0.00	1 940	30	0.01	2 037	31	0.01
2025	0	42	0.00	1 600	33	0.00	2 060	31	0.01	1 940	29	0.02	2 037	30	0.01
2026	0	43	0.00	1 600	33	0.00	2 060	30	0.02	1 940	28	0.04	2 037	29	0.03
2027	0	44	0.00	1 600	32	0.01	2 060	28	0.04	1 940	28	0.07	2 037	28	0.05

As for the base model, to the eye there is little difference between the SSB trajectories for Projections 3–5 for the LowMhighq model (Figure 2). They decrease at only a slightly higher rate than Projection 2 (current TACC) (Figure 2). The SSB is almost wholly above the soft limit in every year for all projections including the HCR TACC (Projection 4) (Figure 2, Table 2).

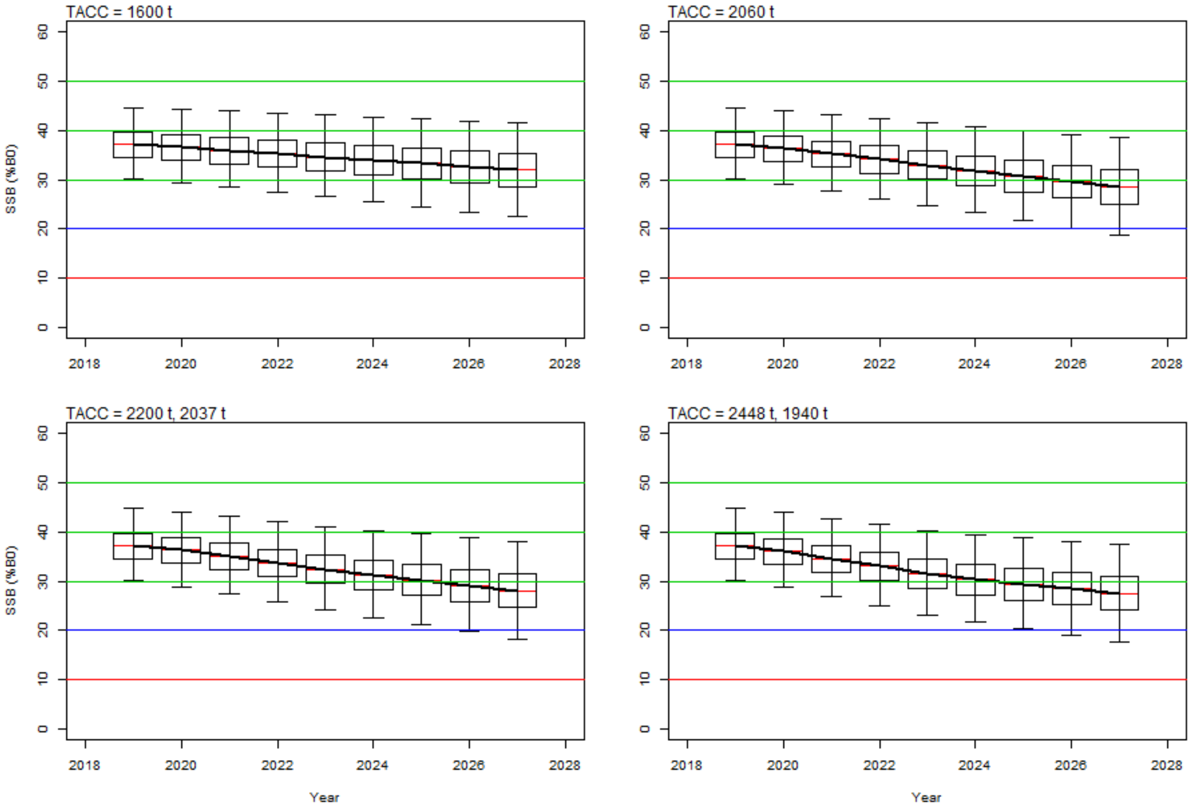

Figure 2: Projection results for the LowMhighq model showing a box and whiskers plot for each projection with non-zero catch (Projections 2-5). Each box covers the middle 50% of the distribution and the whiskers extend to 95%. The medians of the distribution in each year are joined by lines. The green lines show the upper, midpoint and lower bounds of the management target range; the blue line is the soft limit, 20% *B₀* (=limit reference point); and the red line is the hard limit, 10% *B₀*.

Discussion

It is crucial to understand that the results of the projections from the base model and the LowMhighq model should be held to very different standards. The base model represents our best estimation of biological parameters and the current status of the stock (47% B_0). Any proposed TACCs must be such that SSB is expected to stay within or above the target biomass range and the projection results should be judged on this basis.

However, the LowMhighq model has been constructed to represent a pessimistic representation of biological parameters (a low M) and to deliver a lower stock status (37% B_0) than the base model. It is a possible model rather than a probable model. It is used to judge how bad the situation could be rather than as a likely estimate of the true status of the stock. In projections, it should be used to ask whether a proposed TACC would result in a poor sustainability outcome for the stock (i.e., SSB going so low that recruitment could be impaired). This is why the LowMhighq results are judged by the probability of going below the soft limit (20% B_0) rather than the probability of being above the lower bound of the target biomass range (30% B_0). It is not of concern if the projected biomass for this pessimistic scenario is below the target biomass range; it is only of concern if the projected biomass has a high probability of being below the soft limit.

Projection 4 which uses the HCR TACCs is the most aggressive TACC option but it creates no sustainability concern. In 2026–27, for the base model, it has a 97% chance of being above the lower bound of the target biomass range and for the LowMhighq model only a 7% chance of being below the soft limit. The other projections have lower average annual TACCs and all represent lower risk.

Therefore, a 2019–20 TACC of up to the HCR TACC of 2448 t presents almost no risk in the short term (given there is a scheduled assessment in 4 years and a potential adjustment to the TACC). However, if the HCR TACC was implemented there is the expectation of a substantial decrease in TACC at the next assessment. This may be considered undesirable by the fishing industry or by the Minister. It may be disruptive in terms of the logistics of catching the TACC. There is a trade-off between annual average yield and the expected decrease in TACC in the 2023 assessment (Table 3). (It is a coincidence that the last two columns of Table 3 sum to 1 for each row.)

Table 3: Summary statistics for the three projections with an increased TACC in 2019–20. Each column, except for the last, is derived from base model projections. The last column represents a risk of the stock status falling below the soft limit given the 2019–20 TACC if the base model is wrong (and the real situation is represented by the LowMhighq model).

2019–20 TACC (t)	TACC increase from 2018–19 (t)	Projected TACC decrease 2023–24 (t)	Average annual yield (t)	Projected 2023 SSB ($\%B_0$)	Projected 2027 SSB ($\%B_0$)	P(B_{27} > 30% B_0) base model	P(B_{27} < 20% B_0) LowMhighq
2060	460	0	2060	43	40	0.96	0.04
2200	600	163	2119	43	39	0.95	0.05
2448	848	508	2194	42	38	0.93	0.07

The trade-off between catch and TACC stability can be easily quantified. For example, a 2019–20 TACC of 2060 t gives an expectation of no change to the TACC in 2023 but it has an annual average cost of 134 t of catch for the next 8 years when compared to a 2019–20 TACC of 2448 t (Table 3).

It should be noted that these are projections. The 2023 assessment results will depend on the new data that enter the model and whatever changes are made to model structure (if any). If the 2019–20 TACC is set at 2060 t then with certainty 388 t of catching opportunity will be lost in each of the next 4 years compared to the HCR TACC of 2448 t. But if the HCR TACC was adopted, there is no certainty that the TACC resulting from the HCR in 2023 will have to drop by 508 t. This is just an expectation and if the 2023 assessment is more optimistic than the current assessment then there may not have to be a decrease. Of course, if the 2023 assessment is more pessimistic than the current assessment then there may have to be an even larger decrease than currently projected.

References

Cordue, P.L. 2014. A management strategy evaluation for orange roughy. ISL Client Report for Deepwater Group Ltd. 42 p.