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# Tier 5 analyses for seamount Blue-Eye Trevalla in 2021

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**Robin Thomson and Malcolm Haddon**

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# Contents

# 1 Executive Summary

Blue-eye Trevalla in the SESSF are assessed as two separate stocks, with a Tier 4 applied to the Slope stock and Tier 5 to the seamount stock. Recent catches on the seamounts have been relatively low (even including those in nearby international waters: 39t, 37t, 11t in 2018, 2019, 2020 respectively). The relatively sedentary nature of adult Blue-Eye Trevalla likely allows localised depletion to take place, so that it would be best to ensure that catches are spread across seamounts rather than allowing all catches to take place in a limited area.

The first data-limited (Tier 5) investigation of Blue-Eye Trevalla caught in the SESSF fishery's eastern seamount stock was performed by Haddon & Sporcic (2018) using two data-limited methods (Catch-MSY and an age structured Stock Reduction Analysis). We repeat their work, making some additional or alternative assumptions, and use a Tier 1-like Harvest Control Rule for the age structured Stock Reduction Analysis model. We considered three alternative stock definitions: Tasmantid (eastern) seamounts only (essentially the definition used by Haddon and Sporcic, 2018), Tasmantid seamounts plus Lord Howe Rise, and Tasmantid plus Lord Howe Rise plus Gascoyne seamount. Williams et al (2017) indicated that the Gascoyne seems to be a separate stock from the Tasmantids but that evidence for separation of Lord Howe Rise from the Tasmantids is present but weak. We present results for the scenario that includes the Gascoyne for interest only, but do not recommend using those for management of the seamount stock as Gascoyne is likely to be a separate stock and is also outside of the Australian EEZ. This collection of potential stock structures was used because, while juvenile fish are relatively mobile, once adult Blue-Eye Trevalla settle on a seamount they are generally assumed to remain on that seamount. Such sessile behaviour means that delineating stock structure becomes difficult because functionally separate populations with different dynamics and productivity may still have genetic similarities.

The C-MSY model aims to generate an approximate estimate of MSY (productivity) but does not provide a valid estimate of current depletion or of the sustainable catch at the current stock status. The method provides a range of possible levels of current stock status that are not inconsistent with the catch data, rather than an estimate of current stock status. Linking the output (an estimate of MSW) to a useful harvest control rule to produce a current sustainable catch level is therefore difficult. The range of values of current depletion that result from the method can be somewhat informative, depending on the nature of the catch time series, and the upper *K* value that corresponds with the lowest *r* in the chosen range. This is not the case for seamount Blue-Eye Trevalla, where the results reflect the full range of allowed depletion levels i.e. almost zero to almost 1.

It is important to note that, in the case of the C-MSY analysis, updating the analysis using the same catch series plus recent managed catches, would not be a valid application of the method as it would operate either to ratchet the catches down or up depending on whether the original catch levels were biased low or high relative to the actual productivity and unknown current status. If catch-MSY (or any catch-only method) is all that can be used, then an RBC could be set once but should remain fixed into the future because updating the analysis when one only has new catch data is invalid.

We present results using data to 2018, as well as updated catch time series resulting from alternative choices regarding stock definition. The geometric mean values of MSY range from 96t to 105t (if Gascoyne is not considered, as we recommend). Note that MSY would be a sustainable level of catch only if the stock remained at, or above, 50% of its unfished level.

The age-structured SRA model is very sensitive to the form of the selectivity function that is chosen, and to the upper limit for the harvest rate imposed. Across the range of values for natural mortality, steepness, upper harvest rate and stock definition (catch time series) RBCs range from 0t to 176t. All scenarios examined resulted in some combinations of parameter values that lead to a zero RBC. Scenarios that allow the fishery to take younger fish result in many more combinations that lead to zero RBCs as well as lower maximum RBC values.

Interpretation of the RBC values presented here must be done in the context of the stock definition used. For example, when using Tasmantid seamount and Lord Howe Rise catches in a model, the modelled RBCs relate to catches, some of which are not under quota, so that the TAC resulting from this RBC needs to be reduced by the proportion of catches that are under quota. When using only Tasmantid seamount catches, the RBC applies to a population a little smaller than that which is fished, because this assumes that the catches on the Lord Howe Rise are taken from a separate stock.

Data-limited methods such as those presented here are used in situations where there is no reliable index of abundance to give an indication of the response of a stock to fishing, as is the case for seamount Blue-Eye Trevalla. As such, current stock status is unknown and estimates of sustainable catches are very broad. Stock Reduction Analyses, which are not fitted to data, provide a range of plausible states of nature that are consistent with the catches that were taken. It is therefore invalid to use statistics such as the median, average, or mode to characterise the results. The extremes are as likely to be ‘true’ as the central value. For the C-MSY model, the geometric mean of the MSY values is used because that model makes use of the negative correlation between the *r* and *K* parameters, which results in the range of derived MSY values being tighter than the ranges of the separate r and K parameters. Nevertheless, it would be invalid to treat the set of biomass trajectories in the same fashion e.g., by reporting mean stock status in 2020.

As Haddon & Sporcic (2018a, b) clearly stated, it is essential to collect future data to allow the estimation of the impact of fishing on this stock because these data-limited methods cannot provide that evidence. The alternative is to treat this seamount fishery as a form of exploratory fishery, set a cautious TAC, encourage that the catches taken are spread over a large area, and monitor the fishery for any changes in either the spatial extent or intensity of the fishery through time.

Ignoring models that include catches from the Gascoyne, an annual catch in the range of 30-40t (which includes the 36t per annum currently allowed) appears likely to be sustainable, even somewhat conservative, for the majority of models considered. The collection of data that can serve as an index of abundance is strongly encouraged, although the difficulties involved in doing so for Blue-Eye Trevalla are acknowledged.

# 2 Acknowledgements

Natalie Dowling and Geoff Tuck (CSIRO) are thanked for useful comments on an earlier draft of this manuscript and for several informative conversations during the development of the Tier 5 approach this year. Dan Corrie, Sally Weekes and Lou Cathro (AFMA) provided insights in the data, fishery, and management of this stock as well as helping to make sense of the results from the data-limited methods. Members of SESSFRAG and SERAG provided input into the 2018 Tier 5 assessment process, much of which was repeated here.

# 3 Introduction

Blue-Eye Trevalla are a high value species caught in the Southern and Eastern Scalefish and Shark Fishery (SESSF). Until recently, a single stock has been assumed and assessment has been conducted using the ‘Tier 4’ empirical method, which uses the ratio of recent to past catch rate (CPUE) to adjust catches. An investigation into Trevalla stock structure using a range of methods including spatial analysis of age and growth, otolith microchemistry, and ecological dispersal modelling, indicated clear stock separation between Trevalla on the seamounts and those on the continental slope (Williams et al 2017). Stock delineation amongst fish on the continental slope was less clear and AFMA’s SESSF RAG ‘RAG Chairs’ meeting chose to assess Blue-Eye Trevalla as two separate stocks: slope and seamount (AFMA 2018). The slope stock is assessed using Tier 4 but fishing on the seamounts has been sporadic and is complicated by the potential for localised depletion, so that Tier 4 is not an appropriate method.

The SESSF fishery has been managed using Tier 1 (full age-structure assessment models), Tier 3 (Catch Curves used to calculate current fishing mortality rates, coupled with Yield-per-Recruit models to establish F-based target and limit reference points), and Tier 4 (an empirical Harvest Control Rule that uses catches and standardised CPUE). However, Tier 3 was shown by simulation testing to be an unreliable method (Fay et al 2011, Fulton pers comm) and it became apparent that CPUE based on reported landed catches was not a reliable index of abundance for some stocks, particularly those that have high discard rates (not the case for Blue-Eye Trevalla), are no longer targeted, or that are only sporadically fished. As a method of last resort, ‘Tier 5’ is intended to draw on the burgeoning field of data-limited or data-poor methods (Haddon et al 2015).

Haddon et al (2015) used Management Strategy Evaluation to test the efficacy of seven candidate data-limited methods by applying those to two data rich SESSF species that have very different life histories: Tiger Flathead and School Whiting. These seven methods were the median, average, and third highest catch estimates (for stocks for which catch is the only data available), and model assisted catch-only methods that included the Depletion-Corrected Average Catch, the Depletion-Adjusted Catch Scalar, and the Depletion-Based Stock Reduction Analysis (which are aimed at species for which some biological information are available in addition to catch data).

Haddon & Sporcic (2018a, b) applied two data-limited methods (Catch-MSY and an Age Structured Stock Reduction Model) to seamount Blue-Eye Trevalla. This is currently the only Tier 5 assessment that has been used to set a TAC in the SESSF. The array of data-limited methods tested by Haddon et al (2015) were applied to the data-limited stock, Smooth Oreo, as part of exploratory work but were not used as an accepted Tier 5 analysis because the assumptions of the methods were not met by that stock (Haddon et al 2015).

Note the clear advice given by Haddon & Sporcic (repeated in both 2018a and 2018b): “Fisheries that only have such catch data but that also require management advice are only marginally served by such ‘assessment’ methods. Such data-poor assessments are not usefully updated by including future catch levels if those catch levels came from the predictions of such an assessment. Rather, the application of such methods is effectively an admission that such a fishery should be classed exploratory. This implies that evidence needs to be gathered concerning any impact the exploratory fishing has upon the stock being fished.” In other words, application of data-limited methods should only ever be considered a stop-gap measure pending collection and analysis of meaningful data to inform fishery dynamics.

The Tier 5 Harvest Control Rule Working Group (AFMA 2021) noted (at its March 2020 meeting) the importance of identifying a pathway out of Tier 5 assessments to allow species to be assessed at a higher Tier level, including data collection (i.e., age and length sampling, better estimates of CPUE) and monitoring. A subsequent meeting of that group (February 2021, AFMA 2021) emphasized the need to approach each new Tier 5 assessment by thoroughly exploring the data that are available, the potential for improving data collection, to identify data-limited methods that can appropriately be applied, and to consider appropriate harvest control rules perhaps with trigger limits. A decision support tool, such as FishPath, can help to identify the range of methods that can be used, and to easily access critical information on the assumptions, strengths, and limitations of each method. CSIRO’s advice, ratified by the Working Group, is to apply, if at all possible, a range of methods, ideally using independent data sets and differing assumptions, to determine whether outcomes corroborate or contradict one another (AFMA 2021).

The outcomes of a FishPath evaluation of the seamount stock of Blue-Eye Trevalla have yet to be considered. This stock, along with the Slope stock, are the subject of a close kin mark recapture (CKMR) scoping study that might lead to a full CKMR assessment. Pending that work, we have repeated the Catch-MSY and age structured stock reduction analyses (SRA) of Haddon & Sporcic (2018a, b). We have used an alternative catch time series, one that considers catches from the Gascoyne seamount, which lies outside of the Australian EEZ. High seas catches are not routinely included in AFMA stock assessments but could be important in considering the biological stock as a whole. Additionally, for the age structured SRA, we have used an alternative growth curve and we explore an alternative selectivity curve. Our growth curve attempts to overcome the bias that results from recruitment to the fishery being a function of size instead of age.

# 4 Data

The data-limited methods used here rely heavily, or entirely, on the catches removed from the stock and should therefore consider all catches likely to have been taken from the biological stock. The purpose of this work is to provide advice to fisheries managers on the TAC for catches taken in regions, and by gears, for which Blue-Eye Trevalla are under quota. The biological stock, and the quota region, do not necessarily match. For example, in the East Coast Deep Water (ECDW) region of the SESSF, trawl catch are under quota but non-trawl catches are not. For the purpose of the work presented here, all catches that are taken from the biological stock under investigation must be included, but an adjustment might need to be made later to account for the component of the stock that is not under TAC. For example, if 80% of the catches were under TAC but the RBC applies to the whole stock, then only 80% of the RBC should be considered for TAC purposes.

## 4.1 Catches

The Tasmantid seamounts are a chain of extinct undersea volcanoes that parallel the continental shelf off Queensland and NSW (Figure 1). The southernmost seamount in this chain, Gascoyne seamount, is somewhat isolated towards the southern end of the chain and is the only Tasmantid seamount that falls outside of the Australian EEZ. For clarity of presentation, throughout this report we somewhat incorrectly use the term ‘Tasmantid seamounts’ to refer to the Tasmantid chain excluding Gascoyne seamount. Blue-Eye Trevalla catches are also made on other seamounts and undersea structures to the west of the Tasmantid chain, most notably the South Lord Howe Rise (Figure 1). Logbook reported catches are shown in (Figure 2).

Williams et al (2017) found clear stock separation between Blue-Eye Trevalla on the Tasmantid seamounts and the continental slope. They write that the “southernmost Gascoyne Seamount appears different to the remainder of the Tasmantid seamounts but is outside the Australian EZ.” The implication being that because Gascoyne is outside the EEZ, catches from this region will not be considered by management. We include a scenario that includes Gascoyne catches, as an interesting illustration of the impact on model results of the relatively large catches that were taken from the Gascoyne during the early 2000s (Figure 3). However, we advise against using these results for management purposes because Gascoyne seems not to be part of the Tasmantid seamount stock.

Regarding the Lord Howe Rise, Williams et al (2017) write that “Growth of Blue-Eye Trevalla is significantly different on the Lord Howe Rise compared to all other areas, including seamounts … and there is limited connection with the seamounts … A boundary between the seamounts and Lord Howe is not suggested because ‘stock’ differences are not strong, and catches are small.” The Lord Howe Rise falls partly within and partly outside the EEZ (Figure 1).

The data-limited methods presented here rely on catches alone to make inference about stock status, therefore the inclusion or exclusion of catches from the Gascoyne and Lord Howe Rise greatly impacts results. The decision to exclude catches from the Gascoyne is a relatively easy one given Williams et al (2017)’s conclusion that that seamount population seems different from the rest, and that being outside the EEZ, that region is not part of the SESSF TAC decision. Alternatively, the Lord Howe Rise falls partly within the EEZ and partly outside, and although there is some evidence of stock separation between it and the Tasmantid seamount chain, that evidence is weak. We therefore consider two catch scenarios: (i) seamounts with Lord Howe Rise, (ii) seamounts and without Lord Howe Rise.

Historical catches prior to the start of the AFMA logbook time series were provided by Rowling (2006). These are almost identical to the historical catches used by Haddon & Sporcic (2018a, b) which were taken from Tilzey (1997); see Figure 3 for catches prior to 1998. Catches from 1998 onwards were taken from the AFMA logbook database. Haddon & Sporcic (2018a, b) defined the ‘seamount’ region as being north of latitude 28.2S (the ‘Barrenjoey line’ or northern limit of SET zone 10) thereby excluding catches from the Gascoyne seamount (Haddon & Sporcic 2018a, b) and likely including some of the Lord Howe Rise catches.

In this report, we use longitude 153°E as the delineator between the ‘shelf’ and ‘seamount’ stocks of Blue-Eye Trevalla (Figure 2); longitude 160 °E to separate Lord Howe Rise from Tasmantid seamounts, and Latitude 35°S to distinguish Gascoyne seamount from the remainder of the Tasmantid seamounts. We do not distinguish between catches made under quota and those not under quota, i.e., non-trawl catches from the ECDW sector are included in our catch time series.

To account for the known downward bias in logbook reported catches, we applied a multiplier of 1.1 to these catches, reflecting the average ratio between CDR and associated logbook catches for this species (Althaus et al 2021). Post-1997 catches used in the present study are therefore slightly larger than those used by Haddon & Sporcic (2018a, b) (Figure 3). Discard rates for Blue-Eye Trevalla are typically below 1% (Althaus et al 2021) and were therefore ignored.

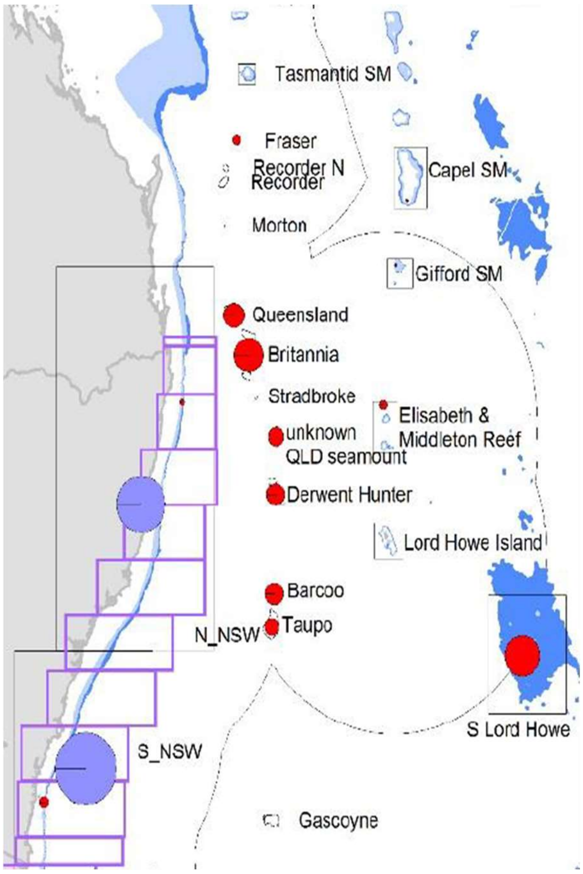

**Figure 1 Location of Blue-Eye Trevalla fishing off eastern Australia, showing the Tasmantid seamount chain as well as other features to the west. Depth contours 200-700 m (light) and 700-1100 m (dark) are coloured in two shades of blue. Figure taken from Williams et al 2017.**

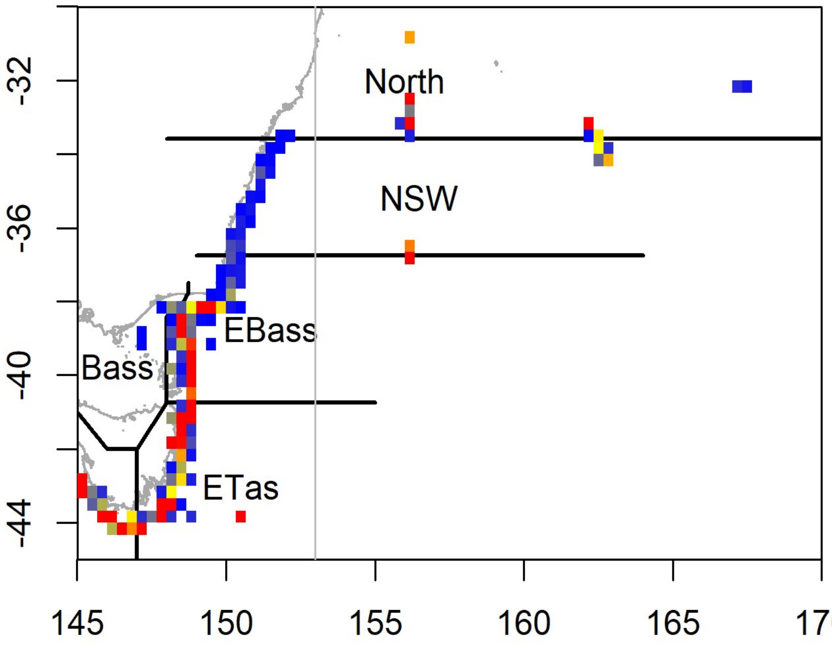

Figure 2 Location of logbook reported catches of Blue-Eye Trevalla, in third of a degree blocks. Blocks from which fewer than 5 vessels reported catches are not shown, resulting in the masking of blocks that together represent 13% of the total catch. Catches have been summed over all years; red represents highest, yellow intermediate, and blue lowest catches.

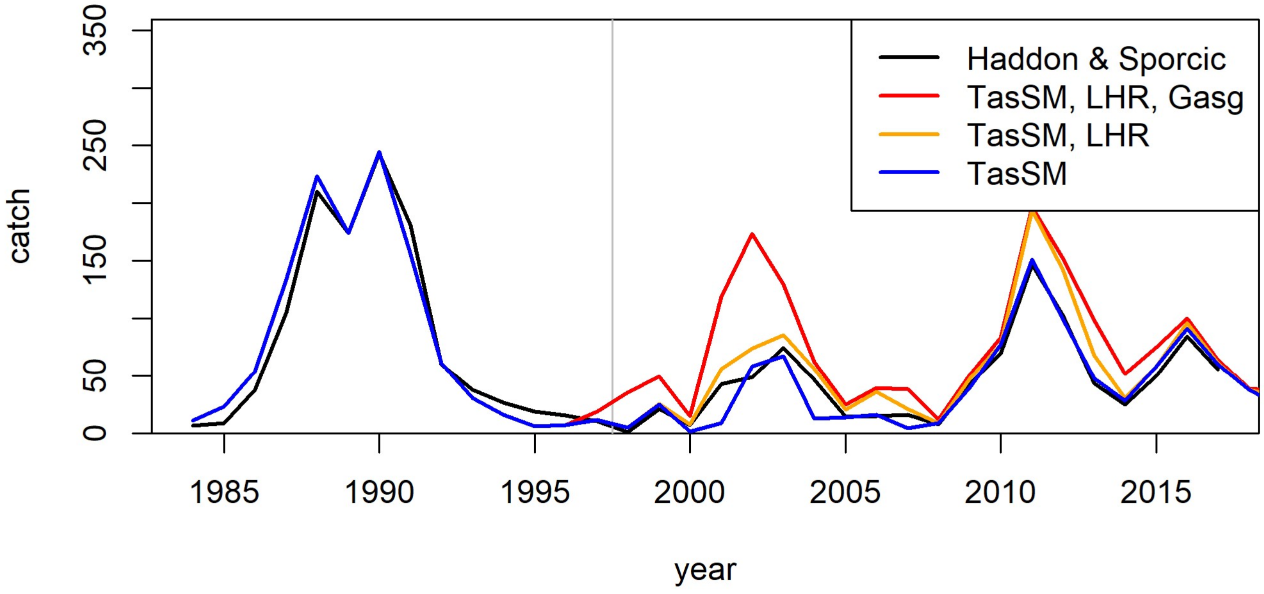

Figure 3 Blue-Eye Trevalla annual seamount catches used by Haddon & Sporcic (2018a, b) and by this report. A vertical grey line at 1997.5 demarcates the historical from the AFMA time series.

## 4.2 Growth

Young Blue-Eye Trevalla show considerable variation in growth rates during their early years. They settle into a benthic habitat (where they become vulnerable to fishing) at a relatively precise size of approximately 45cm rather than as a function of age. This is evident from a histogram of the lengths of all samples held in the Fish Ageing Services (FAS) database (Figure 4). Consequently, growth curves calculated from samples collected from the fishery are strongly biased by the absence of the slower growing fish that have not yet reached 45cm and the presence of the fastest growing fish that reached that size at a younger age (Thomson & Baelde 2002, Horn 2010). Horn used measurements of otolith radii to back-calculate the length at pre-capture ages of older fish and in so doing calculated growth curves for New Zealand caught Trevalla that showed much smaller median length-at-age for younger fish than those calculated in the conventional manner.

Not having access to otolith radius measurements, we were unable to apply Horn (2010)'s back-calculation method to our sample. We attempted to produce unbiased (or at least less biased) growth curves by (1) fixing the von Bertalanffy $t_0$ parameter at the value calculated by Horn (2010), $t_0$=-0.0627; and (b) restricting the sample used for the von Bertalanffy estimation to just those over the age of 5, which appears from Horn's work to be an age by which most fish have recruited to the fishery.

There are sex differences in growth of Blue-Eye Trevalla, with females attaining somewhat greater length than males, but the difference is small enough to ignore for a data-limited assessment where other uncertainties are much greater. We also ignore the considerable variability in growth rates amongst seamounts demonstrated by Williams et al (2017).

We therefore calculate a single growth curve for both sexes and all areas combined using data from the FAS database, this does not include data collected by Williams et al (2017). We used data for all 11,261 Blue-Eye Trevalla stored in the Fish Ageing Services (FAS) database, only one of which was recorded as having been collected in the ECDW fishery, the remainder being drawn from SESSF and GAB zones. Future work could include re-estimating the growth curve using data from the seamounts.

Growth curves that estimate $t_0$, whether applied to all samples or only to those over 5 years, are much flatter than those that fix $t_0$ at Horn's value (Figure 5). The curve that fixes $t_0$ but uses all samples provides a poor fit to older animals. The curve that fixes $t_0$ and uses only individuals over 5 years of age appears to be the most realistic, although it seems to under-estimate the size at age for the oldest animals. A Richard's growth curve might provide an improved fit overall, but would redefine the meaning of the $t_0$ parameter, making the use of Horn's value invalid. Ideally, Horn's back-calculation method would be applied to samples collected from Australian seamounts and von Bertalanffy and Richard's growth curves applied to those data.

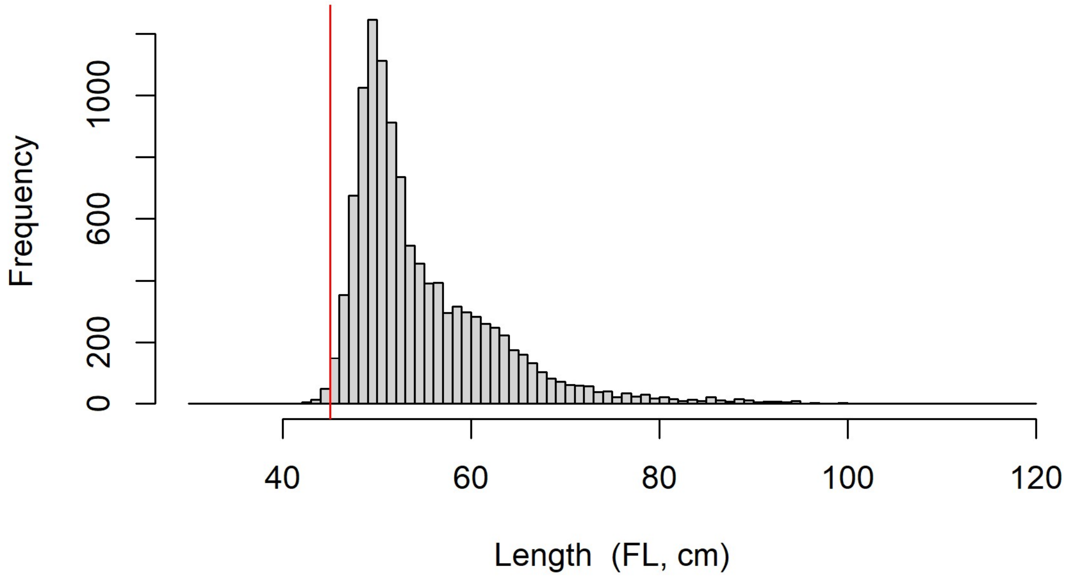

Figure 4 Histogram of lengths of all samples held in the Fish Ageing Services database. A red vertical line indicates 45cm.

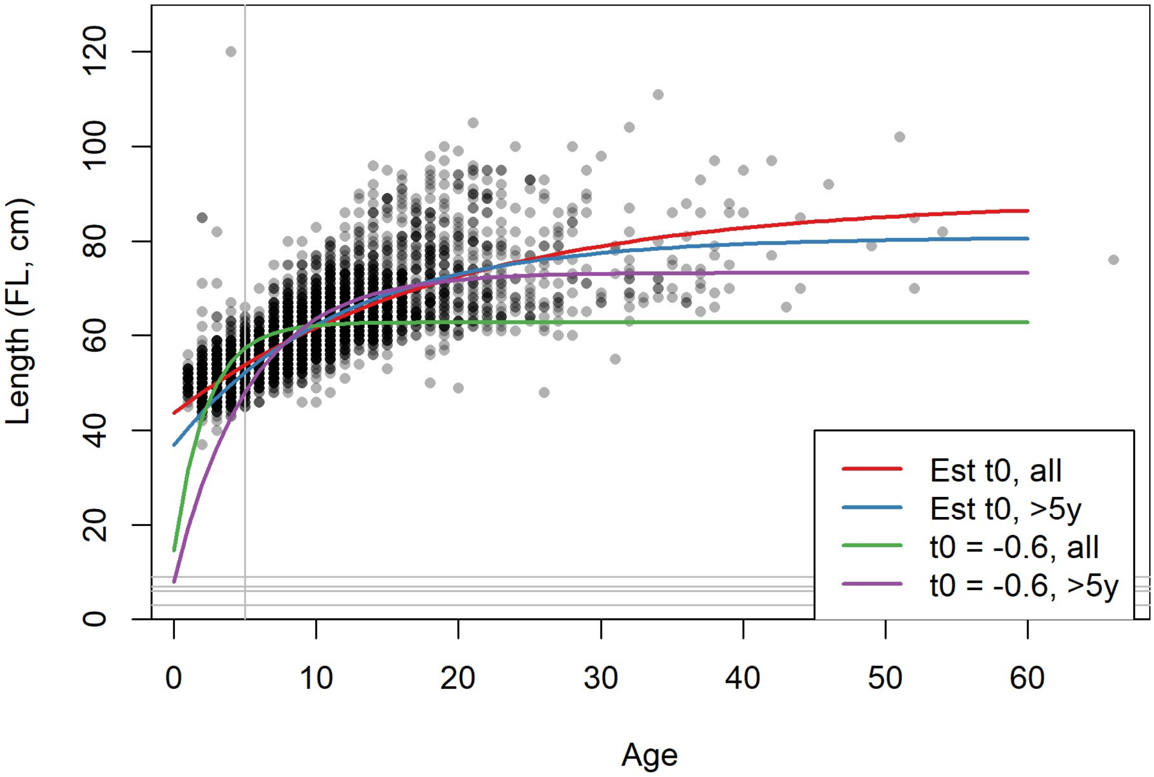

Figure 5 Age and length data for Blue-Eye Trevalla from the Fish Ageing Service database. Growth curves were fitted to all data *all* or just those over 5 years *> 5y* either estimating the $t_0$ parameter *Est* $t_0$ or fixing it $t_0 = -0.6$. Horizontal grey lines show the sizes of the smallest Blue-Eye ever collected.

## 4.3 Selectivity and biological parameters

Haddon & Sporcic (2018a)'s fishing selectivity function (which reflects both gear selectivity and availability) was chosen by examining the available data and choosing a relationship that seemed consistent with those data. The age at 50% selectivity is 10y, which corresponds with a mean length of 64cm (Figure 5). This age might seem high in light of the FAS length samples (Figure 4) but might be reasonable given that seamount Blue-Eye are likely to be typically larger than the shelf Blue-Eye in the FAS database. However, the sampled lengths rise rapidly from a little over 45cm to a peak at 50cm (Figure 4) and the mean length at age 8y is close to 50cm.

Klaer & Thomson (2005) assumed logistic, length-based selectivy for Trevalla, with 25% selectivity at 48cm and 50% selectivity at 50cm which implies 50% selectivity at age 5.4y given the growth curve presented in this report. However they do not discuss the origin of those figures and given the lengths and ages considered here, a higher age at 50% selectivity seems more feasable.

We therefore consider two alternative selectivity functions, that chosen by Haddon & Sporcic (2018a) that has an age at 50% selectivity of 10y, and another that uses 8y. We did not alter the selectivity parameter that defines how steeply selectivity increases with age. Note that spatial information is not considered here but that seamount fish were not included in the length-age dataset.

We use the parameter ranges chosen by Haddon & Sporcic (2018a) for natural mortality (*M*), steepness (*h*), and unfished recruitment (*R0*) as well as the fixed parameter values they used for the age of the plus group, and the length-weight and maturity relationships (fecundity is defined as weight multiplied by maturity). These parameter values, along with the new growth parameters, are shown in Table 1. The length-based biological relationships specified by these parameters are shown in Figure 6.

## 4.4 Harvest rates

To reduce the range of results from the models presented here, an upper limit is placed on the harvest rate (i.e. proportion of the stock that is available to the fishing gear that is removed) in any year. A range of upper harvest rate limits, from 0.25 to 0.5, was assumed. An upper limit of 0.5 is relatively large, suggesting that a fishing vessel might remove 50% of all available fish in a single year. The reason for using such a large value is the argument (Pascale Baelde, pers comm) that when resident fish are removed, younger fish that have not yet found suitable habitat in which to settle, will fill those spaces and hence higher harvest rates could be maintained for long periods. In the absence of further information on which to base this decision, a relatively large upper limit is a conservative assumption, at least for the age-structured SRA model.

Table 1 Parameter values, ranges, and increments used in the analyses presented here.

| PARAMETER | VALUE | MIN | MAX | INC | EXPLANATION |
|---|---|---|---|---|---|
| **Linf** | 73.175 | | | | Growth parameter |
| **K** | 0.191 | | | | Growth parameter |
| **$t_0$** | -0.600 | | | | Growth parameter |
| **a** | 0.018 | | | | Length-weight parameter |
| **b** | 3.016 | | | | Length-weight parameter |
| **M50** | 11.000 | | | | Age-Maturity parameter |
| **dM** | 1.000 | | | | Age-Maturity parameter |
| **S50** | | 8.00 | 10.00 | | Age-selectivity parameter |
| **dS** | 1.500 | | | | Age-selectivity parameter |
| **aplus** | 56.000 | | | | Age of plus group |
| **M** | | 0.08 | 0.12 | 0.01 | Natural mortality |
| **h** | | 0.60 | 0.80 | 0.10 | Steepness |
| **ln(R0)** | | 9.50 | 12.50 | 0.01 | Log unfished recruitment |
| **maxH** | | 0.25 | 0.50 | 0.25 | Maximum allowed annual harvest rate |

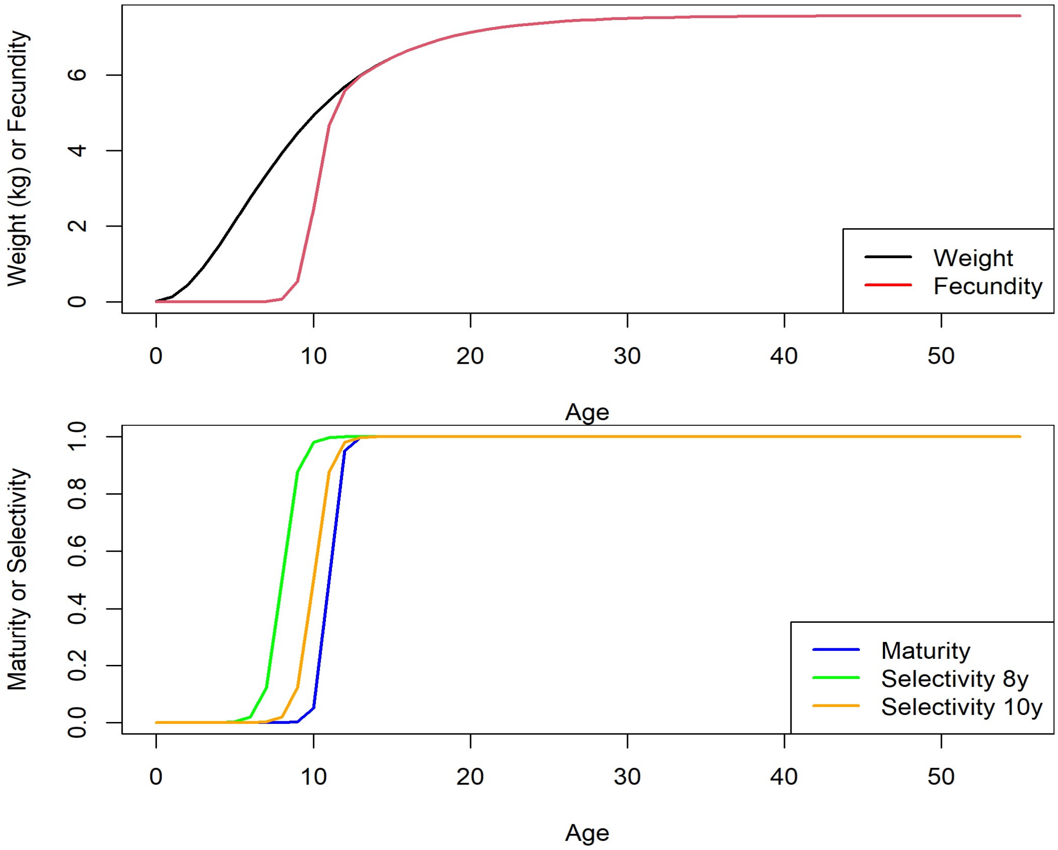

Figure 6 Biological and fishing relationships used in this analysis. The selectivity relationship reaches 0.5 at either age 8y or age 10y.

# 5 Methods

We repeat the work of Haddon & Sporcic (2018a, b) in applying two data-limited methods: Catch-MSY (C-MSY) and age structured Stock Reduction Analysis. When implementing a Stock Reduction Analysis (SRA), known catches are sequentially removed from a stock, typically assuming that the stock was pristine at the start of the catch time series. The model that is used can be an aggregated biomass model (such as a Schaefer production model), a full age-structured model, or anything in between. The defining feature of an SRA is that no index of abundance is available to tune the model.

See Martell & Froese (2013) and Haddon & Sporcic (2018b) for details on the catch-MSY and age-structured models used here.

## 5.1 Catch-MSY (C-MSY)

C-MSY, although not normally described as an SRA in the literature, involves no parameter estimation, only the removal of catches from a modelled population (Martell & Froese 2013). The model used is a Schaefer Surplus Production model. Plausible ranges are chosen for the parameters of that model: the intrinsic growth rate *r*, and unfished biomass *K*. Combinations of *r* and *K* that cannot support the catches that are known to have been taken, or that lead to biomass values above *K*, are trimmed from the parameter set, leaving a reduced set of possible pairings of *r* and *K*. The method cleverly exploits the intrinsic correlation between *r* and *K* in a Schaefer Surplus Production model in that the range of MSY values resulting from the trimmed set of *r*-*K* pairs is narrow relative to the range in each of the *r* and *K* sets. Martell & Froese (2013) recommend using the geometric mean of the resulting MSY values as an estimate of MSY for the stock. Note that MSY is an indication of the level of catch that would be expected to be sustainable only if the population is at or above B_{MSY}, which for a Schaefer model is 50% of the unfished biomass (*K*). If the stock is below that level, then catches must be below MSY to allow recovery to $B_{MSY}$. Martell & Froese (2013) suggest that stock status can be assessed using indicators (if available) such as changes in survey biomass, CPUE, changes in lengths over time, and whether past catches have exceeded MSY.

## 5.2 Age-structured SRA

The model that is used to remove catches from a stock that begins in an unfished state need not be a Production Model. If biological parameters (length-at-age, length-weight relationship, maturity-at-age) are available, and a guess can be made regarding the fishing selectivity-at-age, then a full age-structured model can be used instead. As Haddon & Sporcic (2018b) point out, the assumptions of a Production Model might not be adequately met for a long-lived species such as Trevalla, which can live to over 50 years. Like C-MSY, the application of an age-structured SRA involves choosing plausible ranges for parameters, removing known catches from a stock that is considered to be in an unfished equilibrium at the start of fishing (or making a guess at its stock status in that year), and trimming parameter combinations that lead to implausible or impossible biomass trajectories.

The most notable difference between the results of SRA and conventional stock assessment models is that SRA does not involve conditioning model parameters using an index of abundance i.e. there is no model fitting. Instead, there are pre-selected ranges of plausible parameter values that are trimmed by removing combinations of values that are not consistent with available information. The range of plausible trajectories (and the parameter combinations that gave rise to these) from an SRA can be further reduced based on external evidence of changes in abundance. This might include survey or CPUE data points for particular years, if any are available.

When the parameters of a model are tuned to available data, there will be a set of point estimates that are best supported by the data. The mode or median of a distribution of parameter estimates, and the stock status given by these, will be the 'best-fit' point. By contrast, the range of parameter values resulting from an SRA, and their associated biomass trajectories and stock status, are all equally probable - none have greater weight of evidence. It is therefore best to choose values that give conservative results, rather than values near the center of the range.

## 5.3 Harvest Control Rule

To convert the results of the age-structured SRA model to future catches, we use a Tier 1-like Harvest Control Rule (HCR) defined in terms of harvest rates instead of fishing mortality rates. The recommended harvest rate lies between zero and the harvest rate that would take a previously unexploited population to 48% stock status (H48). For each biomass trajectory calculated as part of the SRA modelling we calculate a harvest rate (Hnext) for the following year, based on the HCR and the stock status (depletion) in the most recent year (Dnow):

$$Hnext = 0 \qquad Dnow < 0.2$$

$$Hnext = H48 * (Dnow - 0.2)/(0.35 - 0.2) \qquad 0.2 < Dnow < 0.35$$

$$Hnext = H48 \qquad Dnow > 0.35$$

We apply the resulting harvest rate (Hnext) to the population calculated by the SRA (for the given set of assumed parameter values) to give a catch figure for the next year. Blue-Eye are a long-lived species that recruit to the fishery between 2 and 6 years old so expected changes in stock status over a three year period as a result of one year's altered catch is likely to be small in comparison to the much greater variation in model results from alternative values of natural mortality, steepness, and selectivity. For that reason, and to reduce complexity of presentation, we did not calculate longer time series of future catches from the HCR but only a single year.

# 6 Results

The inclusion of catches from Gascoyne seamount greatly increase the 'peak' in catches that occurred around 2001-2004. To a lesser extent, inclusion of Lord Howe Rise catches slightly inflate the 2011-2013 'peak.' SRA methods are most optimistic if high catches occurred early in the time series, followed by a relatively long period of low catches that allow time for the stock to build up a large biomass. Age structured SRA model results that use catches from the Gascoyne and Lord Howe Rise are therefore more pessimistic than those that, like Haddon & Sporcic (2018a), use catches from Tasmantid seamounts only.

## 6.1 Catch MSY

Haddon & Sporcic (2018b) accepted many of the default settings used by their implementation of the catch-MSY model. These include:

- an initial upper limit for *K* of 60 times the maximum catch in any year of the available catch time series, which is later reduced to the smallest *K* that provides an acceptable trajectory when assuming the lowest value of *r* (as recommended by Martell & Froese 2013),
- a stock status range in the first year for which catches are available, of 0.5 to 0.975 (provided catch in the very first year is less than a quarter of the maximum catch, which it is for all catch time series considered here),
- a stock status range in the final year for which catches are available, of 0.05 to 0.5 (provided catch in the very last year is less than half of the maximum catch, which it is for all catch time series considered here).

The behaviour of the C-MSY model implemented here can be seen by comparing the results from using the TLG (Tasmantid plus Lord Howe Rise plus Gascoyne) catches to the Tasmantid only catches (HS2018 and T series) (Figure 7). For the Tasmantid-only models, the lowest value of *r*, coupled with relatively low values of *K* (see the first bullet point above), can sustain the catches that were observed. However, to sustain larger catches after 1998, the lower *K* values are now rejected. This results, somewhat counterintuitively, in a higher geometric mean MSY value for the TLG model (69t) than any of the other models (50t - 58t).

Another reason for the rejection of higher *K* values from the T and TL models is the limit on stock status in the final year, which causes rejection of combinations of *r* and *K* values that lead to a very productive stock. However, the TLG catch time series, having larger catches in more recent years produces a more depleted stock in the final year (Figure 7) and therefore allows larger *r* and *K* values compared with the other models (Figure 8). The distribution of resulting MSY values is quite similar for all catch time series, although that for TLG is shifted slightly to the right (Figure 8).

The current status of Blue-Eye Trevalla on the eastern seamounts is unknown, given the absence of an index of abundance. It could perhaps be argued that the pseudo-rational harvesting across the array of seamounts should avoid the lower levels of depletion. To be conservative, we chose to allow the full possible range of depletion levels, from zero to 1. The stock status of Blue-Eye Trevalla on the eastern seamounts is unknown but is likely to have been close to unfished prior to the start of known fishing in the early 1980s. For these reasons, we changed the default stock status ranges

- from 0.5-0.975 to 0.8-1 in the initial year, and
- from 0.05-0.5 to 0.05-1 in the final year.

The tighter stock status range in the initial year does not offset the effect of the much wider range in the final year, so that the resulting range of acceptable *r* and *K* values is much broader (Figure 9 and Figure 10). The resulting geometric mean MSY estimates are consequently larger: 97t - 115t, Figure 10).

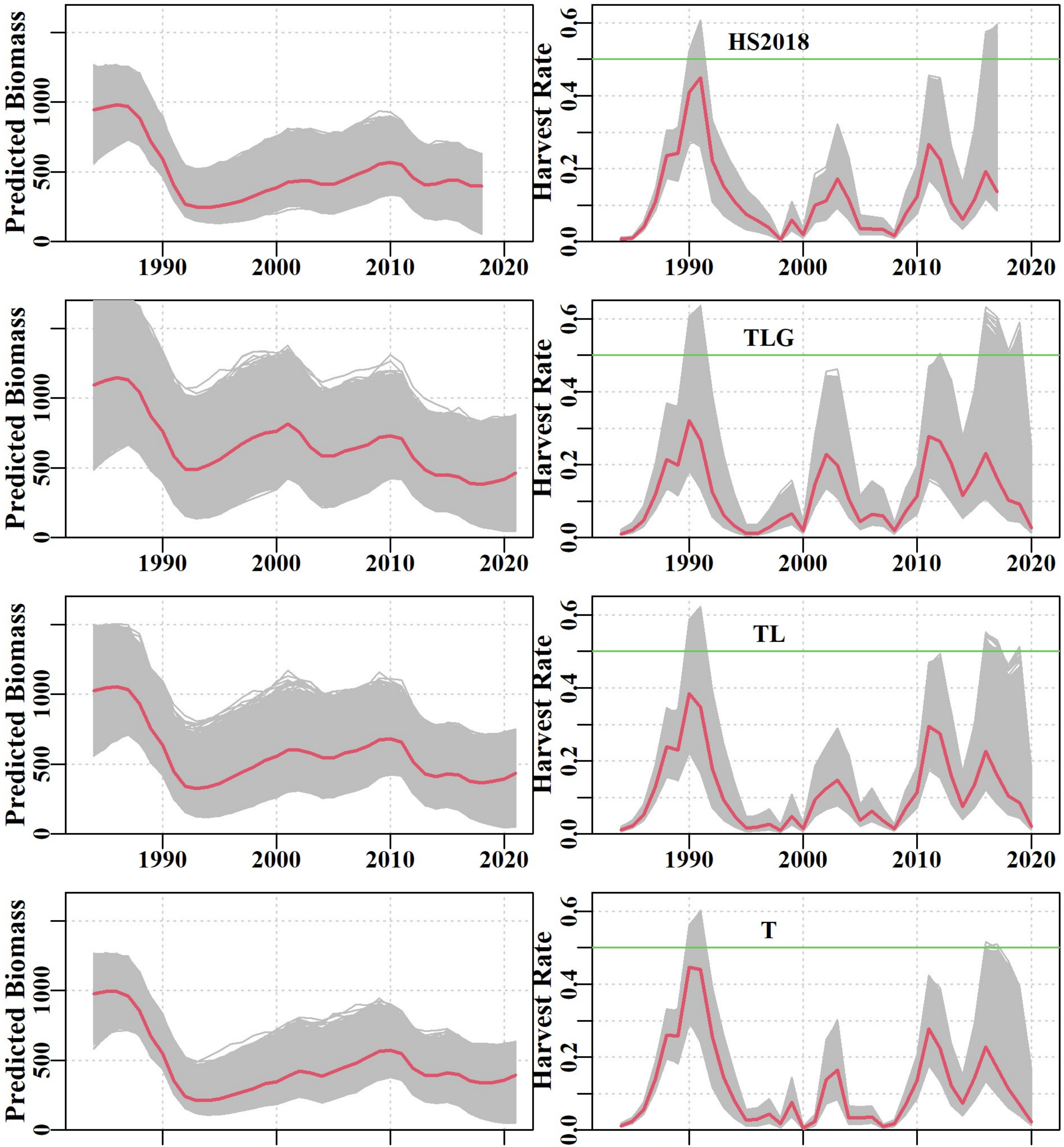

Figure 7 Stock biomass and implied harvest rates for C-MSY using Haddon & Sporcic (2018)'s catches (first row), new catches for all regions TLG (second row), without Gascoyne TL (third row) and Tasmantids only T (fourth row). Red lines join mean values from each year. Default stock status ranges were used for the initial and final years.

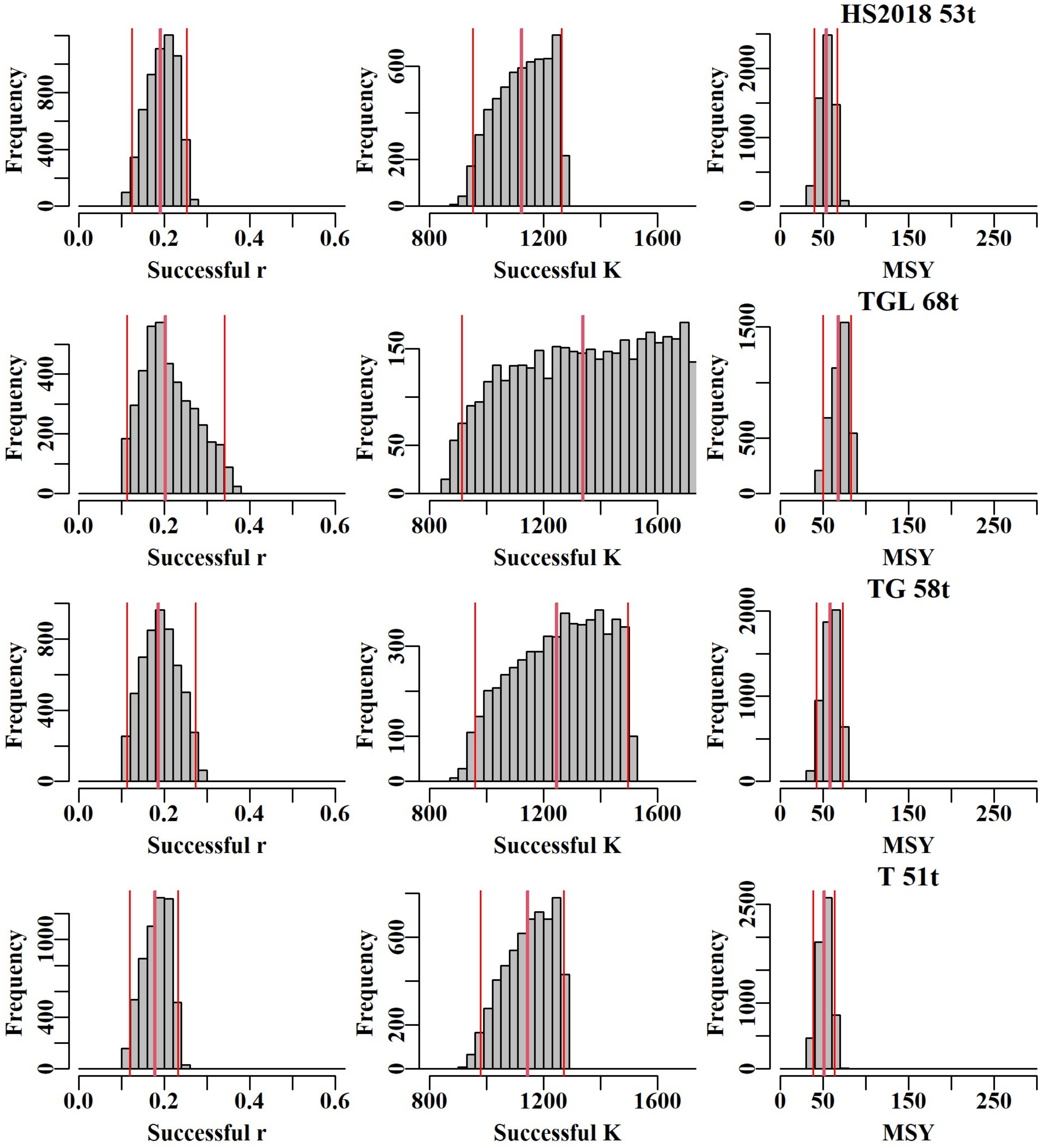

Figure 8 Histograms of accepted r, K, and resulting MSY values using Haddon & Sporcic's catches (first row), new catches for all regions TLG (second row), without Gascoyne TL (third row) and Tasmantids only T (fourth row). Default stock status ranges were used for the initial and final years. Geometric mean MSY rounded to the nearest tonne is shown.

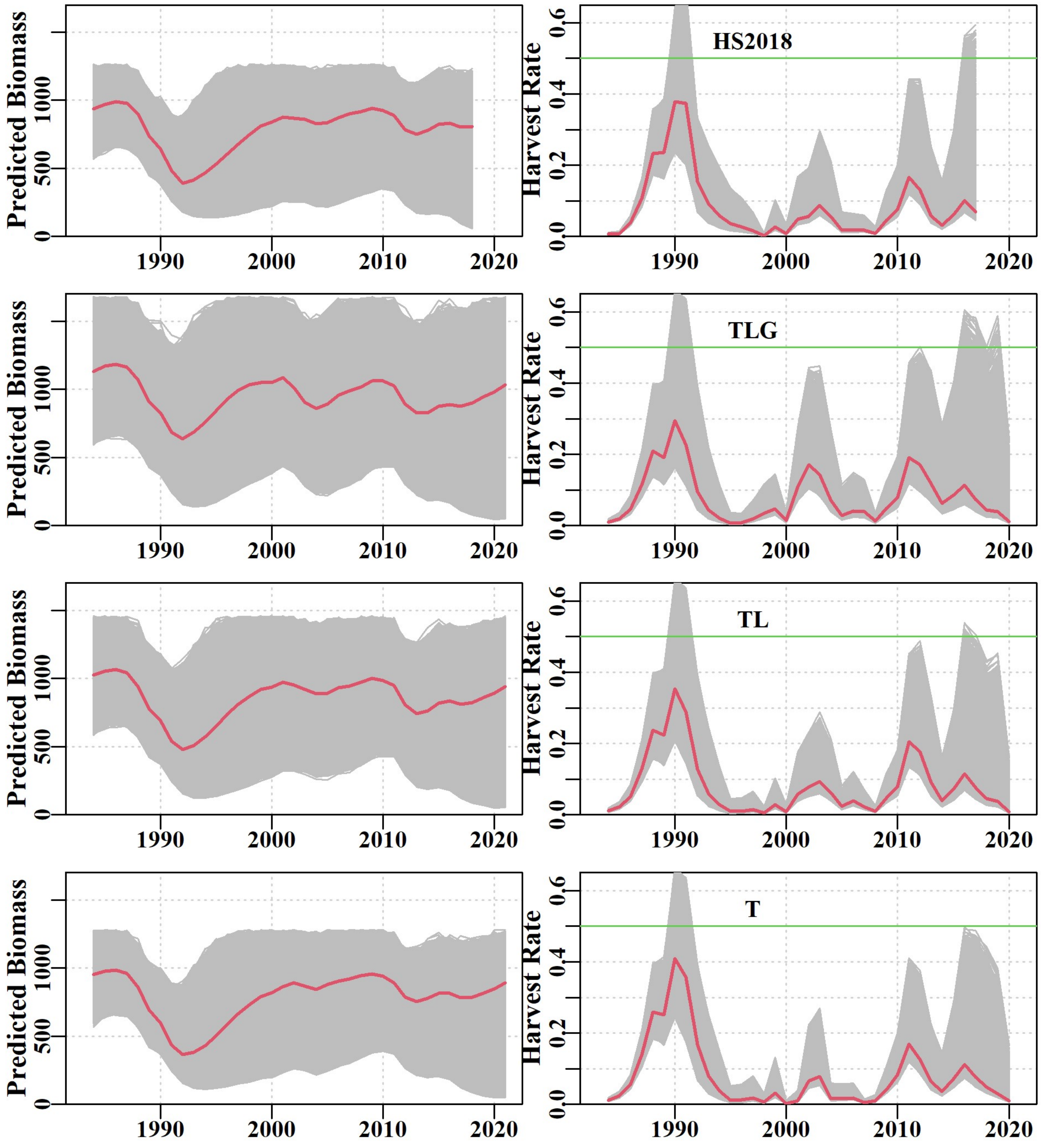

Figure 9 Stock biomass and implied harvest rates for C-MSY using Haddon & Sporcic (2018)'s catches (first row), new catches for all regions TLG (second row), without Gascoyne TL (third row) and Tasmantids only T (fourth row). Red lines join mean values from each year. Default stock status ranges were *not* used for the initial and final years.

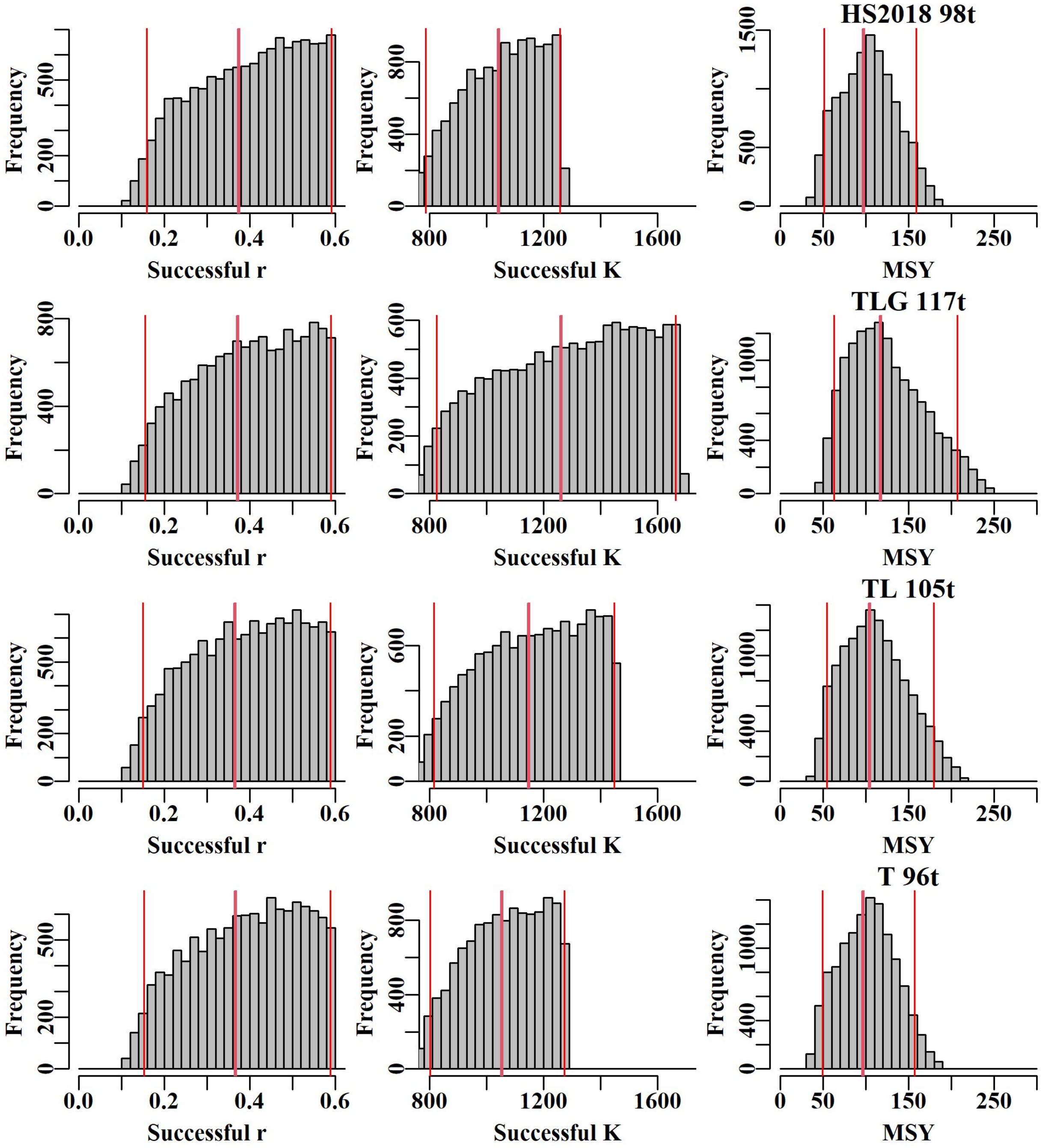

Figure 10 Histograms of accepted r, K, and resulting MSY values using Haddon & Sporcic (2018)'s catches (first row), new catches for all regions TLG (second row), without Gascoyne TL (third row) and Tasmantids only T (fourth row). Default stock status ranges were *not* used for the initial and final years. Geometric mean MSY rounded to the nearest tonne is shown.

## 6.2 Age-structured SRA

To examine the effect of each of the changes (new growth curve, altered catch time series, and alternative selectivity function) we introduced each change sequentially. Altering the growth curve has little influence because it primarily affects younger fish that have yet to recruit to the fishery (Figure 11). Allowing the Gascoyne and Lord Howe catches in addition to those from the Tasmantid seamount chain results in greater depletion in recent years primarily due to the large catches on the Gascoyne during the early 2000s which slow recovery from the catches during the 1980s and 1990s. Results that include catches on Lord Howe are similar, but a little more depleted, than those that consider only the Tasmantid seamount chain (Figure 11). Allowing the fishery to catch younger fish (i.e. changing the age at 50%-selectivity from 10y to 8y) results in much lower stock status in the most recent years (Figure 12).

## 6.3 Varying parameter values

Thus far, results have been shown for a single value of natural mortality and steepness in order to more easily age-structured SRA compare models that use alternative catch time series, growth curves, and selectivity curves. Now we investigate the effect of alternative values of natural mortality and steepness. Results are shown in terms of the estimated depletion in the most recent year, as was shown by Haddon & Sporcic (2018a), and also in terms of future catch from application of the HCR.

Stock status (Figure 13) and catch (Figure 14) results are shown for all natural mortality and steepness values, and both assumed selectivity curves for the lowest and highest extremes of the accepted set of ln(R0) values. Models that resulted in stock status below 0.2 (see horizontal red dotted line in Figure 13) result in zero RBC in Figure 14. The model that allows Trevalla to be selected at younger ages results in non-zero catches for only the highest R0 values with maximum exploitation rate of a relatively low 0.25.

Histograms of the RBC values resulting from each parameter combination of steepness, natural mortality, R0 and upper harvest rates are shown in Figure 15 for each model scenario (i.e., catch time series and selectivity curve).

# 7 Discussion and Conclusions

We have discussed the model results within the Results section; our conclusions and recommendations are captured in the Executive Summary and are not repeated here. Consideration of Future Work follows the figures below.

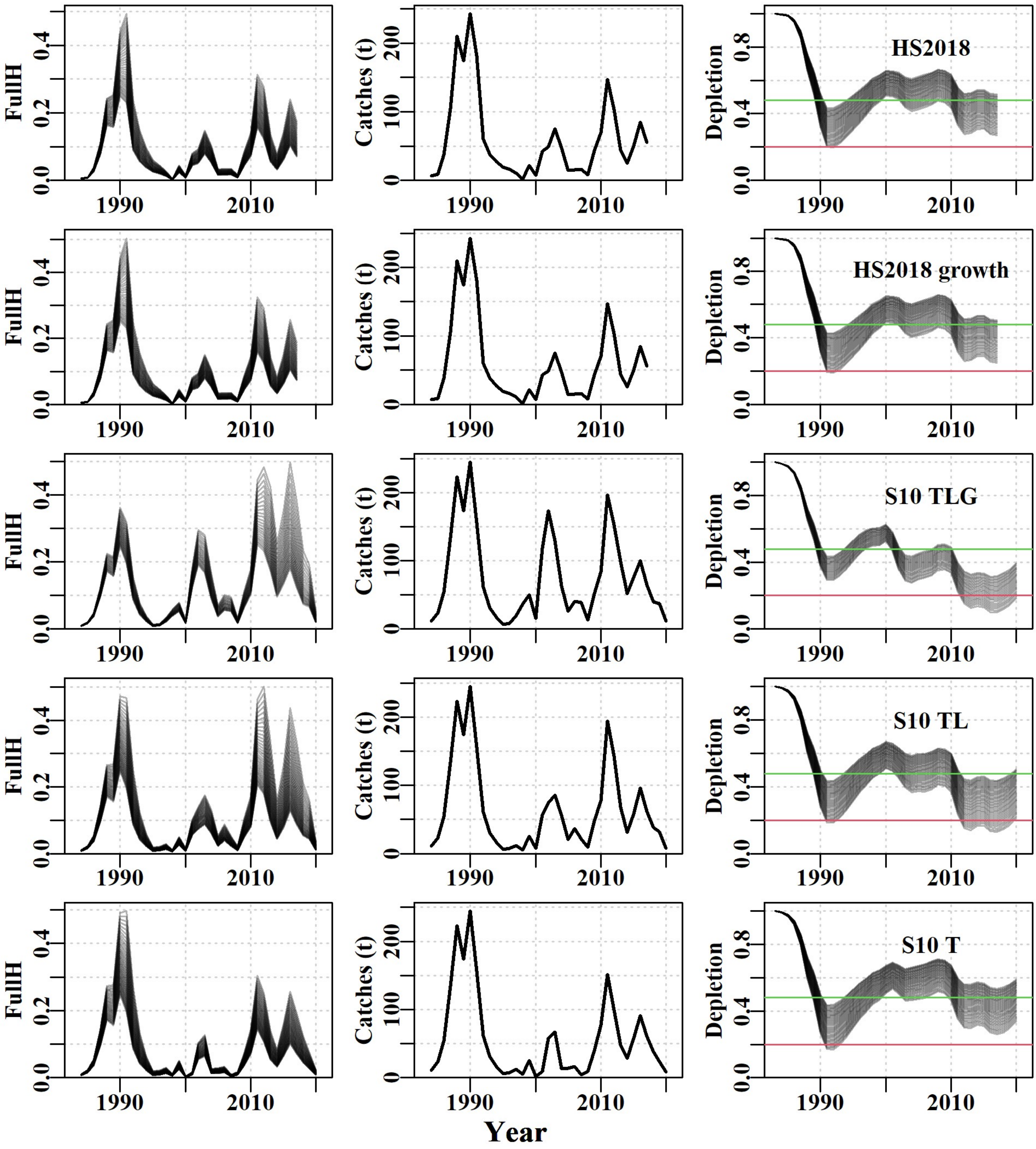

Figure 11 Harvest rate (left), annual catches (centre), and stock status (right) for the dataset used by Haddon & Sporcic (2018a) (first row), new growth curve (second row), Haddon & Sporcic's catches (first row), new growth curve 2018_growth (second row), new catches for all regions TLG (third row), without Gascoyne TL (fourth row) and without Lord Howe Rise T (fifth row). Results are shown for all parameter combinations that supported known catches. Values of *M*=0.1, and *h*=0.7 were used and all other parameter values or ranges are shown in Table 1.

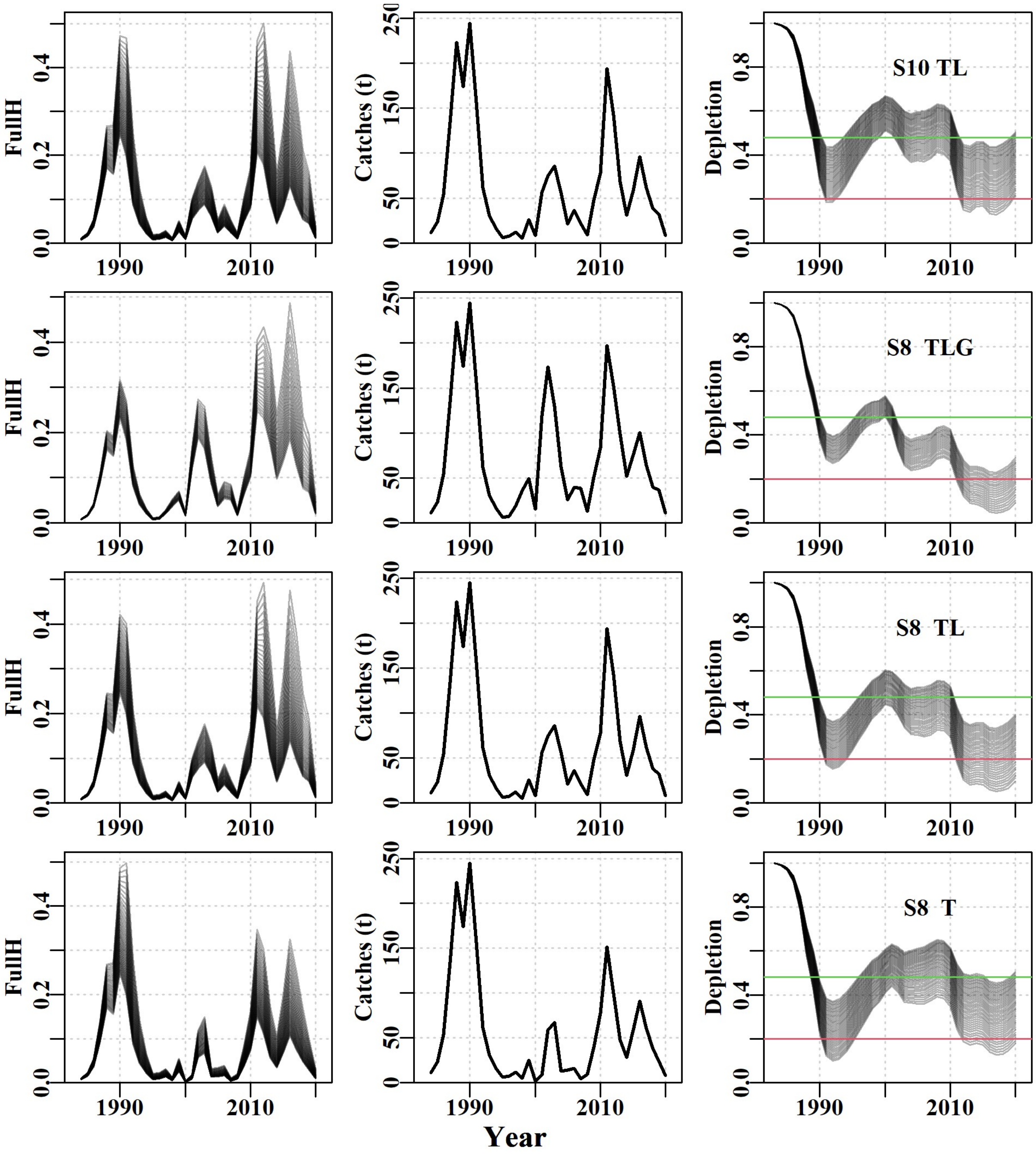

Figure 12 Harvest rate (left), annual catches (centre), and stock status (right) using 50% selectivity at 10y (first row), or 50% selectivity at 8y for all regions TLG (second row), without Gascoyne TL (third row) and without Lord Howe Rise T (fourth row). Values of *M*=0.1, and *h*=0.7 were used and all other parameter values or ranges are shown in Table 1.

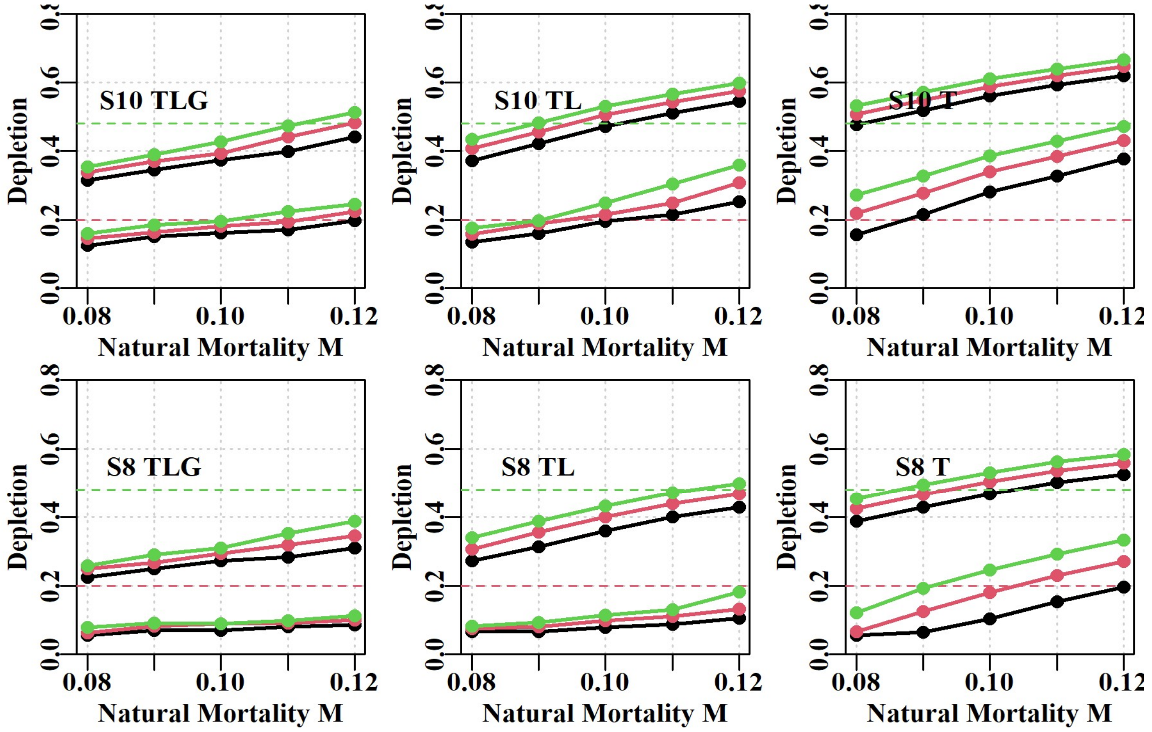

Figure 13 The stock depletion levels predicted at the lower and upper maximum harvest rates (H=0.25 - upper set, and H=0.5 - lower set). Results are shown for selectivity curves S50=10, S50=8 and implied stock structure TLG (Tasmantid plus Lord Howe Rise plus Gascoyne), then TL and T. The steepness values are 0.6 (black line), 0.7 (red line) and 0.8 (green line).

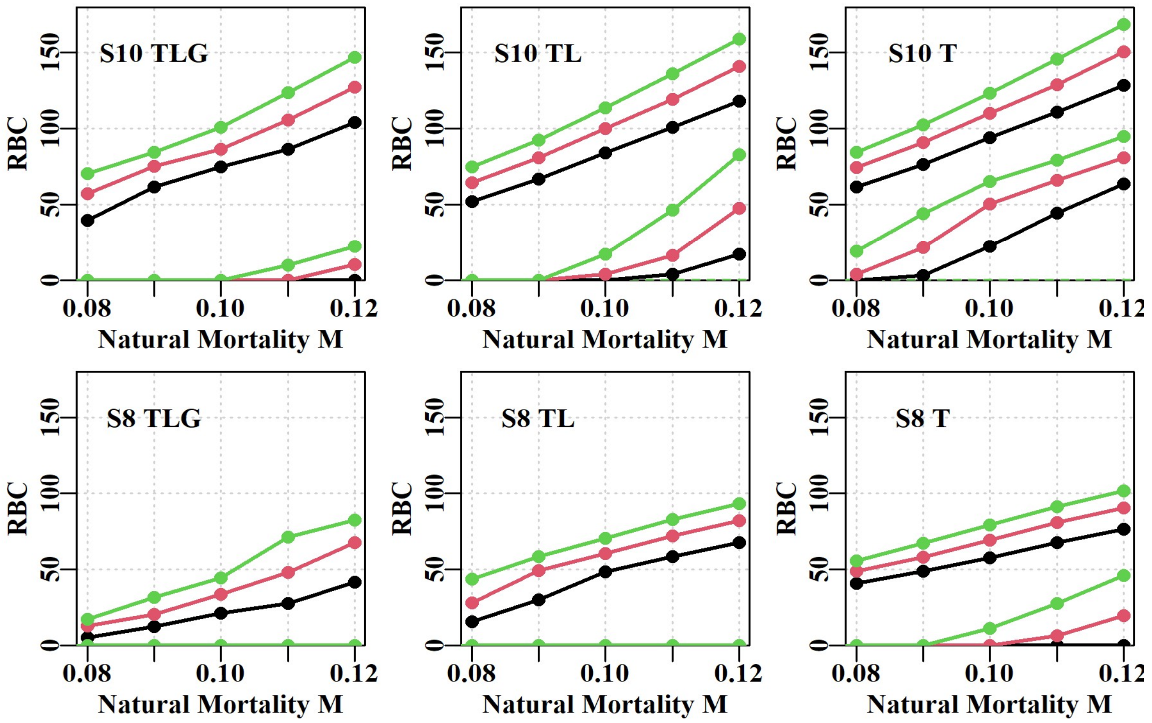

Figure 14 RBCs calculated from the Tier 1-like HCR at the lower and upper maximum harvest rates (H=0.25 - upper set, and H=0.5 - lower set). Results are shown for selectivity curves S50=10, S50=8 and implied stock structure TLG (Tasmantid plus Lord Howe Rise plus Gascoyne), then TL and T. The steepness values are 0.6 (black line), 0.7 (red line) and 0.8 (green line).

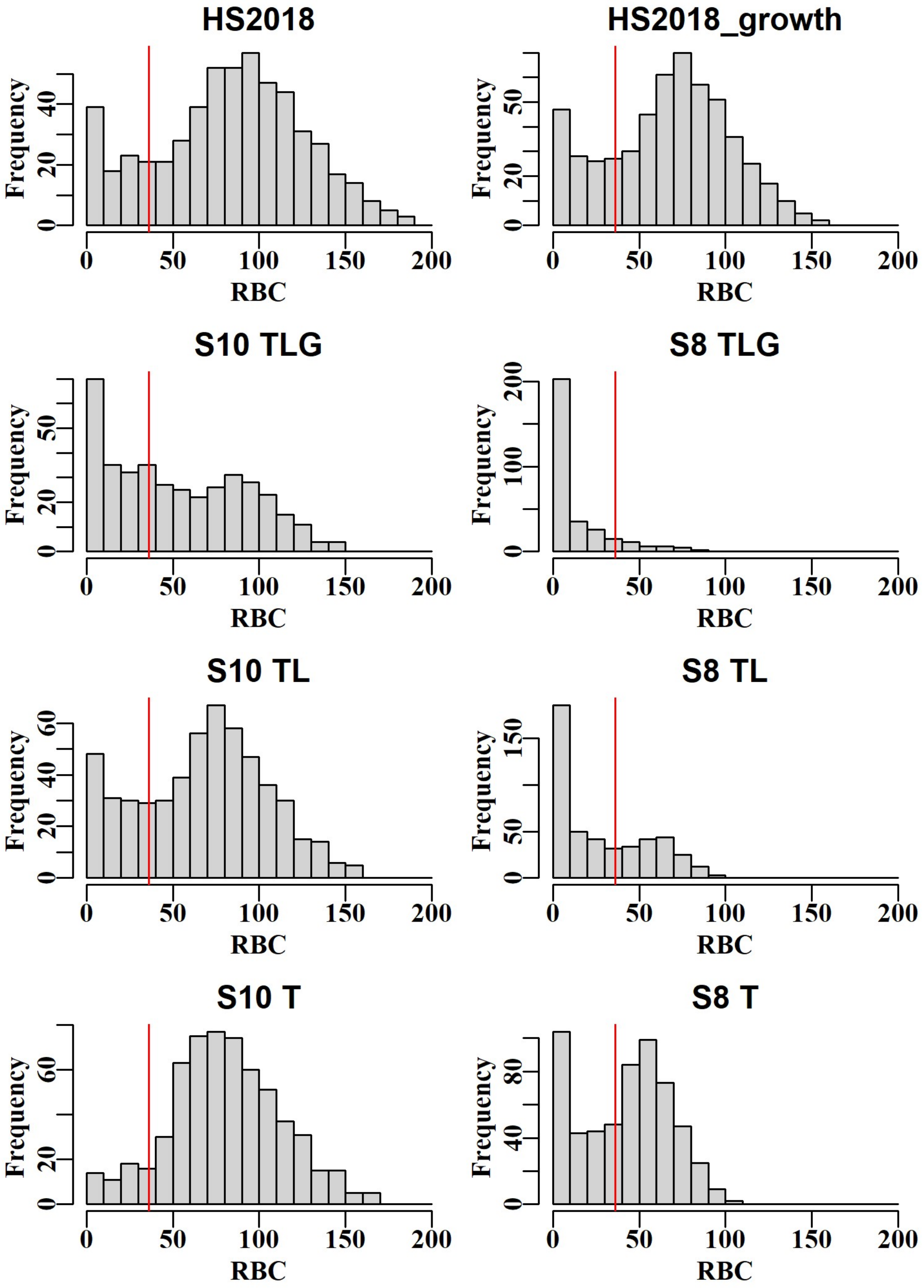

Figure 15 Histograms of RBC values resulting from the range of steepness *h*, natural mortality *M*, *R0* and maximum harvest rates for several alternative catch time series and two selectivity curves. RBCs were calculated from a Tier 1-like HCR (see text for details). The vertical red lines are show the current allowed annual take of 36t.

# 8 Future work

- The range of uncertainty in the results shown here could be somewhat narrowed by reducing parameter uncertainty i.e. by reducing the ranges considered for steepness and natural mortality. However, steepness is notoriously difficult to estimate; the 0.6-0.8 range used here is unlikely to be narrowed by meta-analysis. The range for natural mortality *might* somewhat narrowed by further investigation. The 'base case with sensitivities' approach typically used by SESSF Tier 1 assessments could be adopted, but that approach would ignore the true uncertainty in model results. The Tier 1 method has been MSE tested, which is not (perhaps yet) true for Tier 5 methods in the SESSF.
- Data-limited methods typically make strong assumptions therefore it is best to apply several methods of differing types, and to seek a consensus among those results. A decision support tool such as FishPath is a useful aid in choosing suitable data-limited methods. Two methods that could be considered are Froese et al (2017)'s CMSY method that addresses some of the shortcomings of the original Catch MSY method (Martel & Froese, 2013) and provides estimates of stock status. This method should be used with caution, however, as it some bias towards estimating higher productivity. Another method to consider is the Optimised Catch-Only method (OCOM, Zhou et al 2018) which uses SRA and also provides estimates of stock status. Length-only assessment methods could also be considered.
- The results of the age-structured model were very sensitive to the assumed selectivity curve, a choice that was made by eye. Blue-Eye length frequencies typically show a bimodal pattern in which fish are first caught when they settle at 65cm, grow for another 10cm and then become less available until they have grown sufficiently to once again become more prevalent in the catches at a larger size range (Thomson & Baelde 2002). More selectivity patterns, based on length rather than age, should be explored when age-structured SRA models are used. Dome-shaped selectivity (i.e. declining availability at largest sizes) is also a possibility (Thomson & Baelde, 2002) although must be used with care as it can lead to overconfidence through the estimation of an invisible 'cryptic biomass' of highly fecund mature fish that are not vulnerable to fishing pressure.
- Ultimately, the collection of data that can support assessments, in particular an index of abundance, would be of most benefit to sustainable management of this stock. Close Kin Mark Recapture might provide such an index but will not be available for several years (if at all).
- Further consideration of HCRs might lead to (MSE tested) rules that use less formal performance indicators than those used by Tier 1 assessments. These could be based on indicators e.g. catches as a proportion of TAC, length data (if available) and would also be useful for the setting of TACs for 'weight of evidence' species in the SESSF.

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**Contact us**

1300 363 400
+61 3 9545 2176
csiroenquiries@csiro.au
csiro.au

**For further information**

**Ocean and Atmosphere**
Insert contact name
+61 03 6232 5133
robin.thomson@csiro.au