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# Draft Dynamic Tier 4 assessment for Blue-eye Trevalla in the SESSF (data to 2022)

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# Acknowledgements

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# 1 Executive Summary

The Dynamic Tier 4 (DT4) assessment method has been applied to two stocks in the Southern and Eastern Scalefish and Shark Fishery (SESSF) for the first time. This method is used for stocks that have limited available information, namely catch and standardized catch-per-unit-effort (CPUE), akin to the long-standing traditional Tier 4 assessment method that has been used in the SESSF for many stocks for over 10 years. A major difference between these two methods is that the DT4 method is based on a Surplus Production Model (SPM) which can be fitted to multiple CPUE series, while the traditional Tier 4 method is empirically based.

The two DT4 assessments were applied to the below listed stocks and/or fisheries:

- Blue-eye Trevalla (*Hyperoglyphe antarctica*)
- Eastern Deepwater Sharks

Blue-eye Trevalla: The 2023 estimated RBC is 147.76 t based on the DT4 assessment. Note that the 2023 RBC is less than the reported catch of approximately 263.2 t in 2022. The 2023 stock status is estimated to be 34%.

Eastern Deepwater Sharks: The 2023 estimated RBC is 8.19 t based on the DT4 assessment. Note that the 2023 RBC is less than the reported catch of approximately 12.2 t in 2022. The 2023 stock status is estimated to be 27%.

# 2 Introduction

The Dynamic Tier 4 (DT4) assessment method has recently been developed for Australia's Southern and Eastern Scalefish and Shark Fishery (SESSF) (Bessell-Browne et al., 2023). The DT4 method is used for stocks that have limited available information, namely catch and standardized catch-per-unit-effort (CPUE), akin to the long-standing traditional Tier 4 assessment method (Little et al., 2009) that has been used in the SESSF for many stocks for over 10 years. A major difference between these two methods is that the DT4 is based on a Surplus Production Model (SPM) which can be fitted to multiple CPUE series, while the traditional Tier 4 method is empirically based.

SPMs have a long history in fisheries science (e.g., Pella and Tomlinson 1969; Schaefer 1954, 1957). These models estimate the change in biomass through time by combining effects of growth, recruitment and mortality into one production function and are considered the simplest method that can assess stock status based on maximum sustainable yield (MSY) reference points.

In the SESSF, the Tier 4 assessment method uses expert opinion to set the range of years (the reference years) corresponding to the MSY. Similarly, the DT4 assessment method is based on a SPM that specifies MSY to occur during a historical period of pre-determined reference years. Depending on data availability, this assessment method can estimate all the parameters of the production function, or fewer. It can also accommodate multiple CPUE series over various time periods. Three error options have also been incorporated, with a basic deterministic version, an option to include stochastic variation in annual deviations in productivity based on penalized likelihood estimation, and a full state-space implementation.

Two Dynamic Tier 4 assessments were conducted: Blue-eye Trevalla (*Hyperoglyphe antarctica*) slope and Eastern Deepwater Sharks using data to 2022 inclusive. The species included in the Eastern Deepwater Sharks group can be found in Sporcic (2023b).

# 3 Methods

## 3.1 Dynamic Tier 4

The underlying population dynamics model employed is from Bessell-Browne et al., (2023) and presented below.

$$B_{t+1} = (B_t + rB_t(1-(B_t/K)^z) - F_tB_t)e^{\varepsilon_t} \quad \varepsilon_t \sim N(0,\sigma_R^2) \tag{1}$$

where:

$B_t$ is the exploitable biomass at the beginning of year $t$ (and $B_{initial} = K$),

$r$ is the intrinsic growth rate,

$K$ is the carrying capacity,

$z$ is the shape parameter (i.e., allows asymmetry) of the production curve and

$F_t$ is the exploitation rate during year $t$, parameterized as $F_t = \left(1 + exp\left(-\tilde{F}_t\right)\right)^{-1}$ where $\tilde{F}_t$ is an estimated parameter that ensures that the exploitation rate never exceeds 1 and prevents pre-current extinction.

The objective function contains log-likelihood contributions of catch, CPUE and in some cases a penalty on the annual productivity deviations. The catch and CPUE log-likelihoods are:

$$lnL_1 = \sum_t \left(ln\sigma_C + \frac{1}{2\sigma_C^2}\left(lnC_t^{obs} - ln\hat{C}_t\right)^2\right) \tag{2}$$

$$lnL_2 = \sum_t \left(ln\sigma_I + \frac{1}{2\sigma_I^2}\left(lnI_t^{obs} - ln(qB_t)\right)^2\right) \tag{3}$$

where:

$C_t^{obs}$ is the observed catch for year $t$,

$\hat{C}_t$ is the model-estimate of the catch for year $t$ (i.e., $\hat{C}_t = F_tB_t$ ),

$\sigma_C$ is the (pre-specified) extent of uncertainty in catches,

$I_t^{obs}$ is the observed abundance index for year $t$,

$q$ is the catchability coefficient, and

$\sigma_I$ is the (estimated) extent of variation in the abundance index.

The value of $B_{MSY}/K$ can be pre-specified, so the parameter $z$ is not estimated but set, so Equation $1 = (z+1)\left(\frac{B_{MSY}}{K}\right)^z$ is satisfied. If MSY is specified, then r is not estimated but set to $r = \frac{MSY}{B_{MSY}\left(1-\left(\frac{B_{MSY}}{K}\right)^2\right)}$.

If the range of years $\upsilon$ (corresponding to the period when the stock is assumed to be at $B_{MSY}$) is pre-specified then a penalty of the following form is added to the objective function:

$$P_1 = 2000(\bar{B}_\upsilon - B_{MSY})^2 \tag{4}$$

where $\bar{B}_{\upsilon}$ is the is the average model biomass over the year range $\upsilon$, and the "2000" reflects that the model is forced to fit the constraint closely. The model is implemented in Template Model Builder (TMB, Kristensen et al., 2016). Analyses were set up in the statistical software, R Core Team (2022) and used associated package dependencies.

## 3.2 Process Error Types

The three types of process error types are:

- Deterministic: $\epsilon_t$ in Equation 1 is set to zero.
- Penalized likelihood: the values for $\epsilon_t$ in Equation 1 are estimated as fixed effects parameters and penalty of the form $\sum_y \left( In(\sigma_R) + 0.5\epsilon_t^2/\sigma_R^2 \right)$, where $\sigma_R$ is pre-specified, is added to the objective function.
- State-space: as for penalized likelihood, except that the objective function is the marginal likelihood and $\sigma_R$ is estimated.

## 3.3 Harvest Control Rules

The standard Tier 1 harvest control rules (HCR; 20:35:48) developed by Smith et al. (2008) are used with the DT4 assessment method. The method and associated HCR have been Management Strategy Evaluation (MSE) tested (Bessell-Browne et al., 2023).

## 3.4 Dynamic Tier 4 Assumptions

The assumptions of the DT4 assessment method are similar to those of the traditional Tier 4 assessment method. The DT4 assessments require total annual catch and standardized CPUE time series, along with an agreed reference period and reference points.

### 3.4.1 Informative CPUE

The method assumes that there is a linear relationship between CPUE and exploitable biomass; if there is hyper-stability (CPUE remains stable while stock size changes) or hyper-depletion (CPUE declines much faster than stock size changes) then the assessment would provide biased results.

### 3.4.2 Consistent CPUE Through Time

The character of the estimated catch rates has not changed in significant ways through the period from the start of the reference period to the end of the most recent year. If there has been significant effort creep altering the catchability, or there have been changes to the fleet that have altered the relative efficiency of the vessels fishing, or the catchability of the species by the fleet has been altered by other changes then the comparability of recent catch rates with the target period may be compromised. Such changes would obviously reduce the responsiveness of the method to change and may generate inappropriate management advice. Included in this clause are the effects of targeting or not targeting of aggregated species.

### 3.4.3 Target Reference Period

The reference period provides an estimate of the stock when at a depletion level of 48% unfished spawning biomass; the method is based on CPUE and thus relates to exploitable biomass and not spawning biomass. The model specifies MSY to occur during a historical period of pre-determined reference years to set the target catch level, with this approach akin to the traditional Tier 4 method. The model reduces biomass, and therefore stock status, to reach the MSY level during the reference years.

### 3.4.4 Accurate Total Catch History

Accurate estimates are required for all catches from the stock under consideration, irrespective of what method is used or whether it was retained or discarded. This assumption is especially vulnerable to being breached when large proportions of catches are discarded. While there is a procedure for adjusting the standardized CPUE for these missed catches, the uncertainty over the actual amount of harvested fish remains.

### 3.4.5 Some Implications of the Assumptions

The outcomes of the DT4 assessment should not be regarded with the same confidence as those from a Tier 1 assessment. Any uncertainty in the catch or CPUE time series is propagated directly through to the outputs of the assessment. For quota species the catches and reported CPUE is usually relatively well founded because of the quota catch disposal records and other compliance requirements. However, where there is a relatively high degree or variable discarding of catches this can lead to much greater levels of uncertainty. The assessments for those species that are conducted using a DT4 assessment should be reviewed for their inter-annual consistency and how the fishery has been responding to the management advice derived from these assessments.

# 4 Blue-eye Trevalla (*Hyperoglyphe antarctica*)

## 4.1 Input data

Table 1: Blue-eye Trevalla data for the Dynamic Tier 4 calculations. Total (t) is the sum of State, Non Trawl and SEF2 catches, where applicable. CE is the standardized CPUE (Sporcic, 2023a). *: 2023 catch copied from 2022 catch.

| Year | Total (t) | CE |
|---:|---:|---:|
| 1997 | 952.843 | 1.8588 |
| 1998 | 617.481 | 1.5397 |
| 1999 | 667.203 | 1.5036 |
| 2000 | 737.814 | 1.2457 |
| 2001 | 596.198 | 1.2633 |
| 2002 | 569.181 | 1.0395 |
| 2003 | 579.572 | 0.8990 |
| 2004 | 686.863 | 1.0715 |
| 2005 | 544.358 | 0.8199 |
| 2006 | 594.286 | 1.0437 |
| 2007 | 642.430 | 1.2696 |
| 2008 | 411.155 | 0.9175 |
| 2009 | 440.247 | 1.0311 |
| 2010 | 374.359 | 0.6600 |
| 2011 | 358.488 | 0.7676 |
| 2012 | 261.825 | 0.7620 |
| 2013 | 243.751 | 0.9332 |
| 2014 | 316.948 | 1.1800 |
| 2015 | 267.657 | 1.1119 |
| 2016 | 251.957 | 1.0043 |
| 2017 | 373.373 | 0.9893 |
| 2018 | 347.793 | 1.0065 |
| 2019 | 292.711 | 0.7944 |
| 2020 | 221.200 | 0.7157 |
| 2021 | 207.017 | 0.6607 |
| 2022 | 263.181 | 1.0816 |
| 2023 | 263.181* | |

Table 2: Blue-eye Trevalla inputs for the Dynamic Tier 4 calculations.

| Name | Value |
|---:|---:|
| MSY | 0.4 |
| Reference Start Year | 1997 |
| Reference End Year | 2006 |
| B_Target | 0.48 |
| CV_MSY | 0.1 |
| Process Error Type | State Space |
| Last Year TAC (t) | 241 |

## 4.2 Results and Discussion

Standardized CPUE (catch per hook) employed in this assessment excluded records from the Cascade Plateau as requested by SERAG meeting in 2022 (Sporcic, 2023a). The catch series employed in this assessment is based on Sporcic & Day (2021).

The SPM fitted well to standardized CPUE (Figure 1). The model estimated (i) an overall decline in biomass and (ii) the 2023 stock status to be 34%, just below the breakpoint of the HCR (i.e., between the limit reference point of 20% $B_0$ and target reference point of 48% $B_0$) (Figure 2). The SPM estimated the biomass to be at the target reference point (48% $B_0$) between 2000 and 2001 (Figure 2). The MSY was estimated to be 237.1 t (Figure 4). The estimated 2023 RBC is 147.76 t (Table 3), which is below the logbook catch of 263.2 t in 2022 (Table 1).

Blue-eye Trevalla is managed as a single stock, but its stock status is difficult to assess because, as a species, its adults are widely but patchily distributed, and its juvenile stages are widely dispersed. In addition, the fishery differs markedly by area through the application of different methods and histories of exploitation. The differences in exploitation history along with sampling different areas in different years may have been sufficient to have led to the appearance of heterogeneity in the biological characteristics of different populations. When previously examined, there was little consistency between consecutive years in the age and length composition data; for example, cohort progression was difficult or impossible to follow. This lack of consistency has prevented previous successful attempts at applying a Tier 1 integrated assessment to Blue-eye Trevalla and has made the application of the Tier 3 catch-curve approach equally problematic (Fay, 2007a; Fay, 2007b). Such spatial heterogeneity has been reviewed and further evidence presented, all of which supported the notion that there were spatially structured differences between Blue-eye Trevalla populations between regions around the south-east of Australia (Williams et al., 2007). While developing an integrated assessment has been attempted, there is now a longer time series of available data and more powerful assessment methods that may make potential future attempts more viable.

The traditional Tier 4 approach which utilizes catch and CPUE has been used until 2022 (based on data to 2021). This traditional Tier 4 method produced variable inter-annual RBCs as it is influenced by the most recent average CPUE that is used to generate the RBC. As such, the alternative Dynamic Tier 4 approach was agreed by SERAG (26-27 September 2023) and employed in this report.

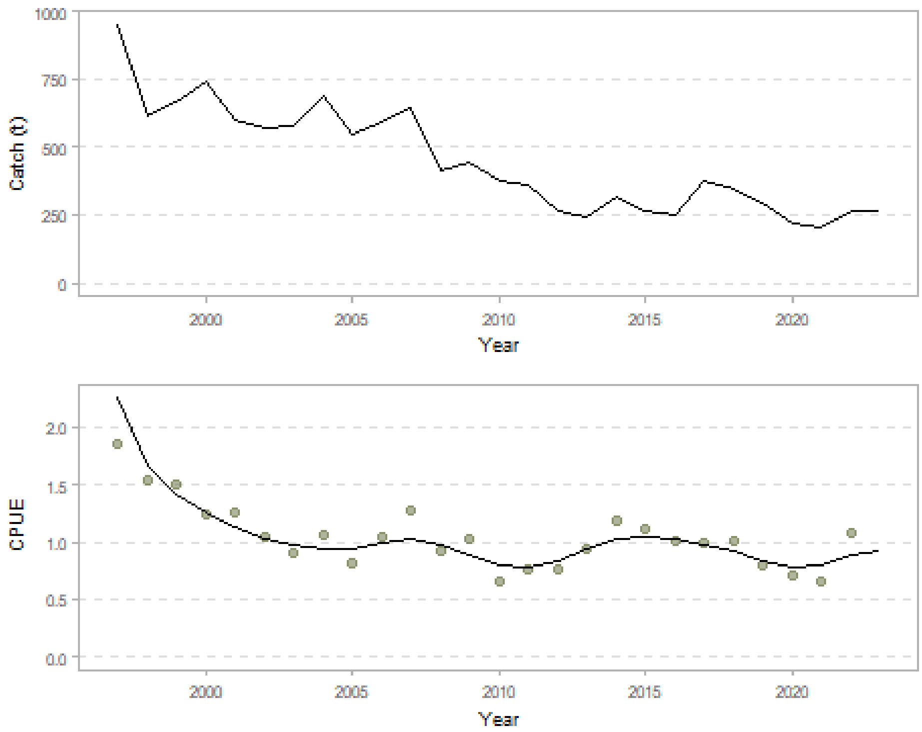


Figure 1: Blue-eye Trevalla Slope. Total annual removals (t) (top), relative standardized CPUE (green circles) and model fitted CPUE (black line) (bottom).

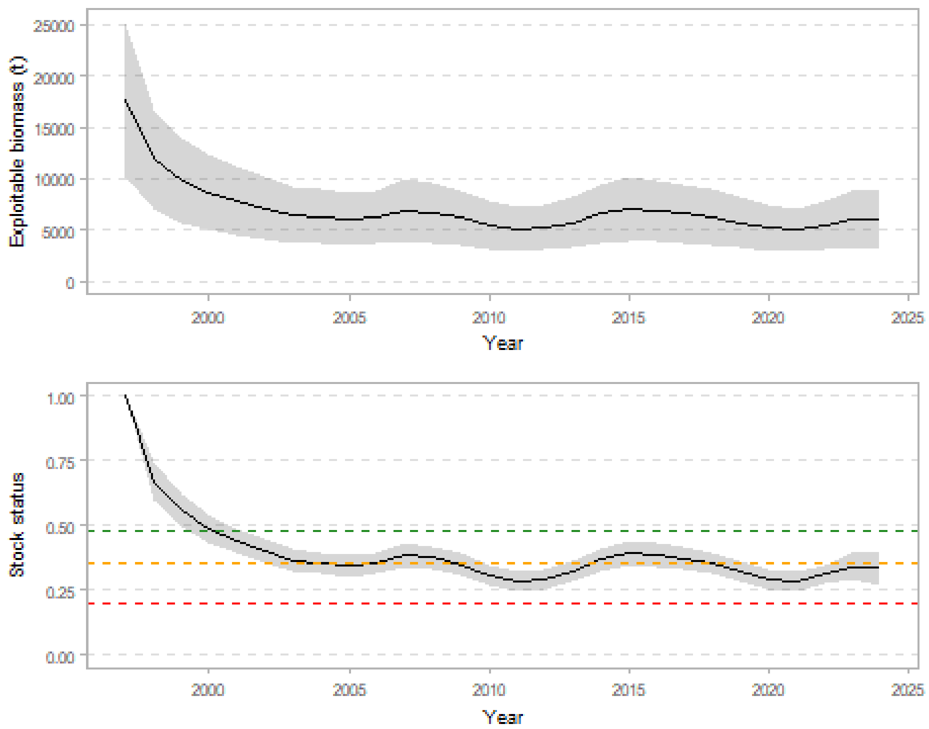


Figure 2: Blue-eye Trevalla Slope. Annual exploitable biomass (t) (top). Stock status, target reference point (green dashed line), breakpoint of the HCR (orange dashed line) and the limit reference point (red dashed line) (bottom).

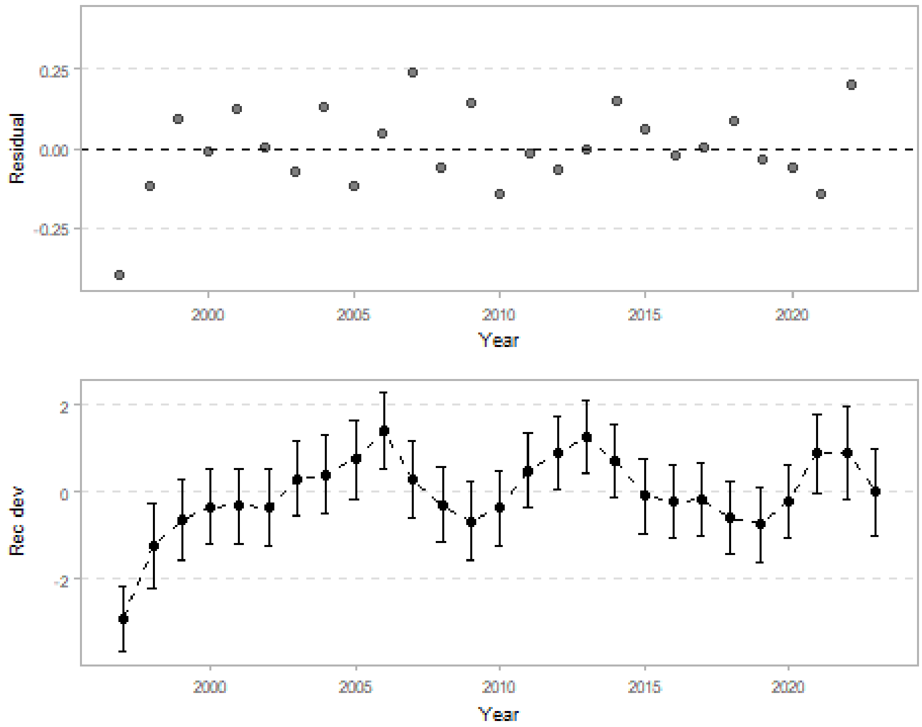


Figure 3: Blue-eye Trevalla Slope. Estimated annual residuals from fits to CPUE (top) and estimated annual production/recruitment deviations (bottom).

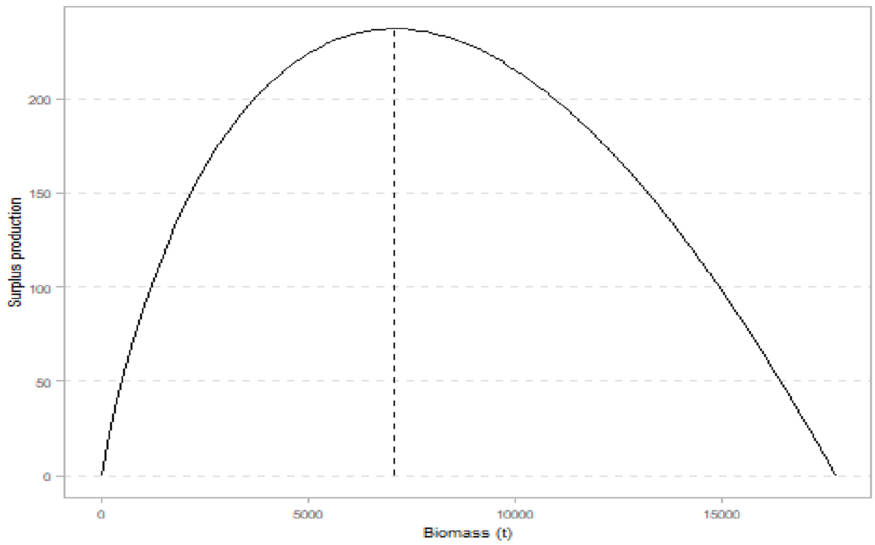


Figure 4: Blue-eye Trevalla Slope. Surplus production curve. The mode refers to the maximum production to achieve MSY (dashed vertical line).

Table 3: Blue-eye Trevalla Slope. Estimated $r$ (intrinsic growth rate), $K$ (carrying capacity), z (production curve shape parameter) and associated standard errors. Recommeded Biological Catch (RBC) (t).

| Parameter | Estimate | Standard Error |
|---:|---:|---:|
| *r* | 0.211 | 0.099 |
| *K* | 17716.500 | 7550.129 |
| *z* | 0.188 | 0.000 |
| RBC | 147.761 | |

# 5 Eastern Deepwater Sharks

## 5.1 Input data

Table 4: Eastern Deepwater Sharks data for the Dynamic Tier 4 calculations. Total (t) is the sum of State, Non Trawl and SEF2 catches, where applicable. CE is the standardized CPUE (Sporcic, 2023b). *: 2023 catch copied from 2022 catch.

| Year | Total (t) | CE |
|---:|---:|---:|
| 1992 | 4.232 | |
| 1993 | 22.950 | |
| 1994 | 42.750 | |
| 1995 | 82.200 | 2.3930 |
| 1996 | 287.900 | 2.6448 |
| 1997 | 157.200 | 1.5226 |
| 1998 | 192.400 | 1.2757 |
| 1999 | 146.600 | 1.0913 |
| 2000 | 170.200 | 1.3026 |
| 2001 | 126.100 | 1.2193 |
| 2002 | 146.000 | 1.2920 |
| 2003 | 105.300 | 0.8702 |
| 2004 | 83.500 | 0.9050 |
| 2005 | 55.147 | 0.8578 |
| 2006 | 45.146 | 0.8395 |
| 2007 | 13.043 | 0.9448 |
| 2008 | 18.428 | 1.1313 |
| 2009 | 48.294 | 1.1925 |
| 2010 | 25.803 | 0.6757 |
| 2011 | 31.865 | 0.6543 |
| 2012 | 30.133 | 0.6107 |
| 2013 | 21.444 | 0.5783 |
| 2014 | 23.040 | 0.5986 |
| 2015 | 18.063 | 0.5952 |
| 2016 | 26.442 | 0.5930 |
| 2017 | 21.545 | 0.6389 |
| 2018 | 22.325 | 0.6416 |
| 2019 | 25.047 | 0.6159 |
| 2020 | 15.443 | 0.7543 |
| 2021 | 17.683 | 0.6853 |
| 2022 | 12.171 | 0.8757 |
| 2023 | 12.171* | |

Table 5: Eastern Deepwater Sharks inputs for the Dynamic Tier 4 calculations.

| Name | Value |
|---:|---:|
| MSY | 0.4 |
| Reference Start Year | 1997 |
| Reference End Year | 2004 |
| B_Target | 0.48 |
| CV_MSY | 0.1 |
| Process Error Type | Penalized Likelihood |
| Last Year TAC (t) | 24 |

## 5.2 Results and Discussion

Standardized trawl-CPUE employed in this assessment can be found in Sporcic (2023b). Annual catches have been less than 100 t since 2004 (Table 4).

The SPM fitted well to standardized CPUE (Figure 5). The model estimated (i) an overall decline in biomass and (ii) the 2023 stock status to be 27%, between the breakpoint of the HCR and the limit reference point (Figure 6). The MSY was estimated to be 30.9 t (Figure 8). The estimated 2023 RBC is 8.19 t (Table 6), which is below the recorded catch of 12.2 t in 2022 (Table 4).

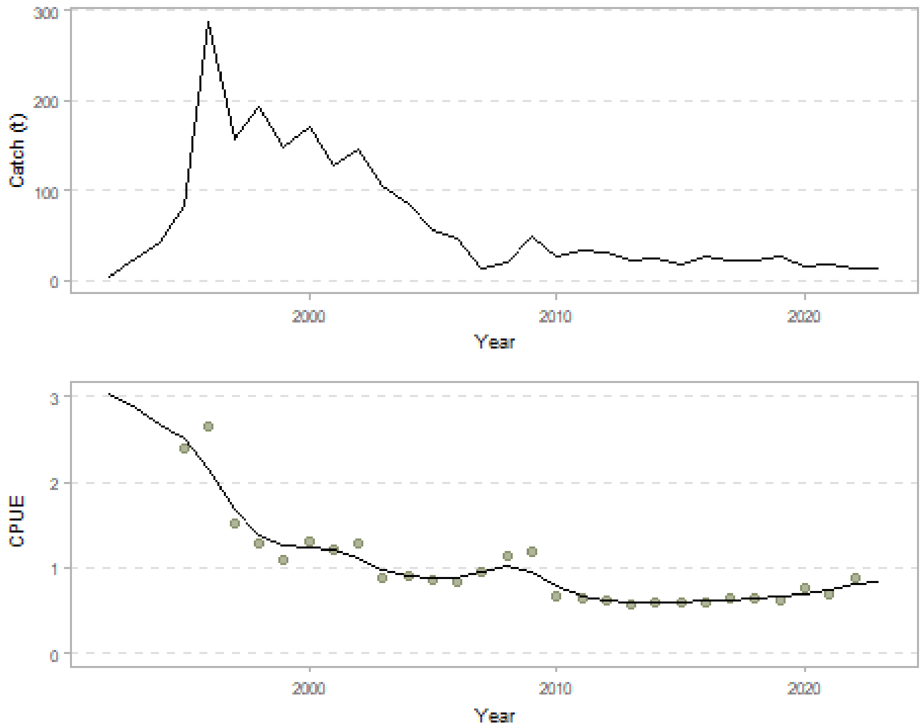


Figure 5: Eastern Deepwater Sharks. Total annual removals (t) (top), relative standardized CPUE (green circles) and model fitted CPUE (black line) (bottom).

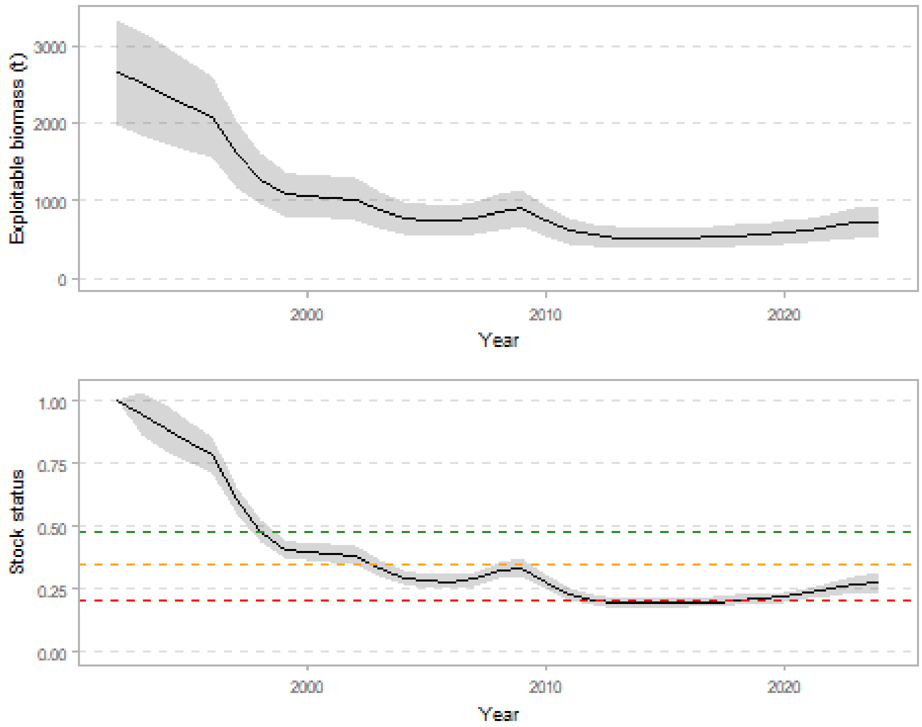


Figure 6: Eastern Deepwater Sharks. Annual exploitable biomass (t) (top). Stock status (t), target reference point (green dashed line), breakpoint of the harvest control rule (orange dashed line) and the limit reference point (red dashed line) (bottom).

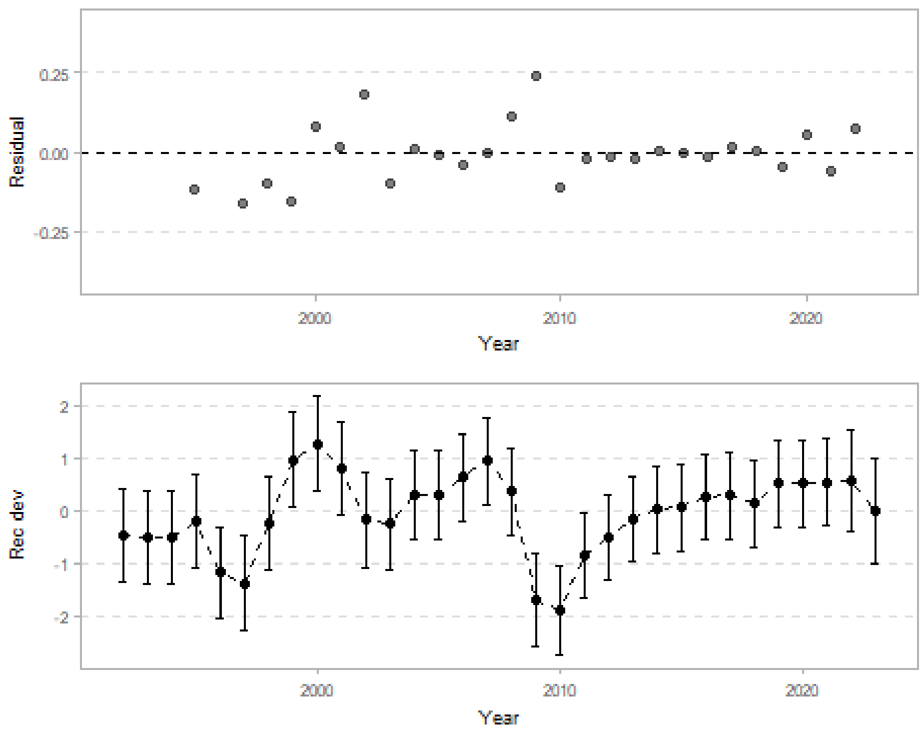


Figure 7: Eastern Deepwater Sharks. Estimated annual residuals from fits to CPUE (top) and estimated annual production/recruitment deviations (bottom).

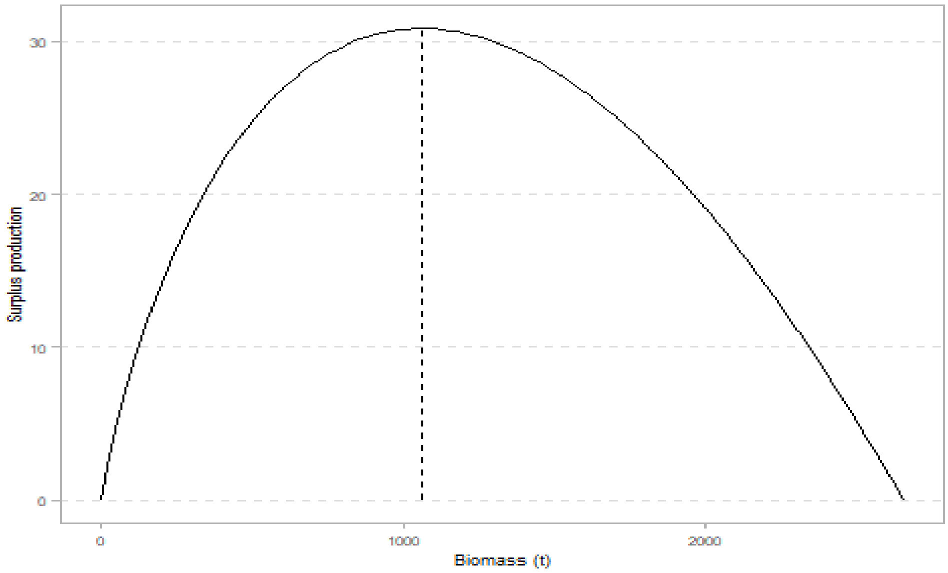


Figure 8: Eastern Deepwater Sharks. Surplus production curve. The mode refers to the maximum production to achieve MSY (dashed vertical line).

Table 6: Eastern Deepwater Sharks. Estimated $r$ (intrinsic growth rate), $K$ (carrying capacity), z (production curve shape parameter) and associated standard errors. Recommeded Biological Catch (RBC) (t).

| Parameter | Estimate | Standard Error |
|---:|---:|---:|
| *r* | 0.183 | 0.080 |
| *K* | 2655.155 | 688.906 |
| *z* | 0.188 | 0.000 |
| RBC | 8.192 | |

# 6 General Discussion and Conclusions

Management strategies have traditionally mainly been implemented in high value, highly managed fisheries that are assessed using complex, integrated stock assessment methods. However, there is an increasing desire to use these management approaches, particularly HCRs, in situations where stocks are assessed using more basic assessments such as those based on catch and CPUE. Therefore, management strategies that can be used with limited data inputs that also meet the key criteria of many management strategies are required. The DT4 management strategy used here is based on a SPM that uses reference years to a set the time period when the fishery was believed to be at (or at least close to) MSY. The DT4 assessment method is used here instead of the current empirical CPUE-based traditional Tier 4. The method has the same data inputs, namely catch, CPUE and a reference year period, while also offering the flexibility of fitting to multiple CPUE series, which is not possible using the currently adopted Tier 4 management strategy. Moreover, the DT4 management strategy produces an estimate of stock status, which also increases flexibility in the types of HCRs that can be applied, because it involves fitting a population dynamics model, rather than being empirically based. While considered an improvement over the traditional Tier 4 assessment method, the DT4 method uses less data compared to data rich integrated assessments, and as such, there is greater uncertainty in model estimates using this approach.

In MSE testing, the DT4 method outperformed the traditional Tier 4 method in terms of (i) performance measures and (ii) the risk-cost-catch trade-off (Bessell-Browne et al., 2023). In particular, DT4 results showed that there was (i) a reduced risk of falling below the limit reference point, (ii) no significant trade-off in catch, (iii) reduced catch variability and (iv) the same data collection cost compared with the traditional Tier 4 method.

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