CCSBT-ESC/2008/13
(ESC Agenda item 9)

Oceans & Atmosphere
www.csiro.au

Information breakdown for steepness parameter in the CCSBT OM

Rich Hillary, Ann Preece, Campbell Davies

CSIRO Oceans & Atmosphere
Battery Point, Hobart 7000, Tasmania, Australia.

Copyright and disclaimer

Important disclaimer

Contents

1 Background

The steepness parameter, h, in the CCSBT OM is of vital importance to understanding the resilience and likely recovery potential and overall levels of sustainable yield of the SBT stock. It is also, for practically all fisheries, a *very* difficult parameter to estimate. In a stock that exhibits the classic "one-way trip" dynamics in the SSB (i.e. it goes consistently down with increasing exploitation) it is essentially inestimable. Decoupling resilience from abundance in this case essentially is impossible. Over the years, the general feeling has been that that to *really* estimate steepness you need the following conditions:

- You need the SSB to have demonstrated meaningful recovery from low levels (e.g. back above 20% B_0 with high probability) **at least once**
- You need to have informative abundance data (be it relative or absolute)
- You need to understand the other life-history parameters (growth, maturity, M etc.) reasonably well

The first condition is the difficult one: ideally if you managed the stock correctly you would likely *never* be able to estimate steepness. If you manage to recover the stock the importance of needing to know the steepness decreases again, but you would not want to then deplete the stock and recover it a second time to get the kind of data you realistically would need to robustly estimate of steepness. It's a problem for all assessments that attempt to include a stock-recruit relationship and it has certainly been problematic for the specific case of SBT. Over the years the OMMP and ESC has done a lot of work trying to decide how best to treat the steepness parameter in the OM grid: both in terms of sensible ranges and weighting schemes. After the work done in 2013 [1] the decision since then has *generally* been to follow a path of modifying the range of values as evidence appears, but avoid objective function weighting in the grid sampling process.

While not used explicitly in an SSB rebuilding objective sense, MSY is a variable derived from the OM that we do report on for stock assessment purposes. Arguably the biggest determinant of both $F_{\rm msy}$ and $SSB_{\rm msy}$ - and their associated ratios with respect to current and unfished estimates - is the steepness. Higher/lower values of steepness are strongly linked to lower/higher MSY-to-unfished SSB depletion ratio and higher/lower levels of $F_{\rm msy}$. Indeed, the main argument against using MSY explicitly in the MP tuning objective process was that, because we understood so little about steepness, the variation in the MSY-to-unfished ratio made it ill suited for this purpose.

In this year's OMMP meeting it seemed that lower levels of steepness were possible than in prior years, and that the higher end of the steepness range was getting less weight [2]. After some deliberation the decision was taken to widen the steepness range to lower levels (minimum of 0.55 *versus* 0.6) but maintain the upper level of 0.8 and have four equally spaced values between these extrema. In this paper we try and do two things: (i) take a more detailed decadal analysis of the steepness penalty over time; and (ii) explore how correcting for autocorrelation in the recruitment residuals might affect what we currently think about steepness.

2 Methods

The recruitment penalty in the OM does not account explicitly for autocorrelation - only in the most recent years does this occur. It is also factored into the projections in various ways. The penalty assumes that the historically recruitment residuals are normally distributed i.i.d. (independent and identically distributed) random variables. Figure 2.1 clearly shows significant time trends within the recruitment residuals from the current [3] reference set of OMs.

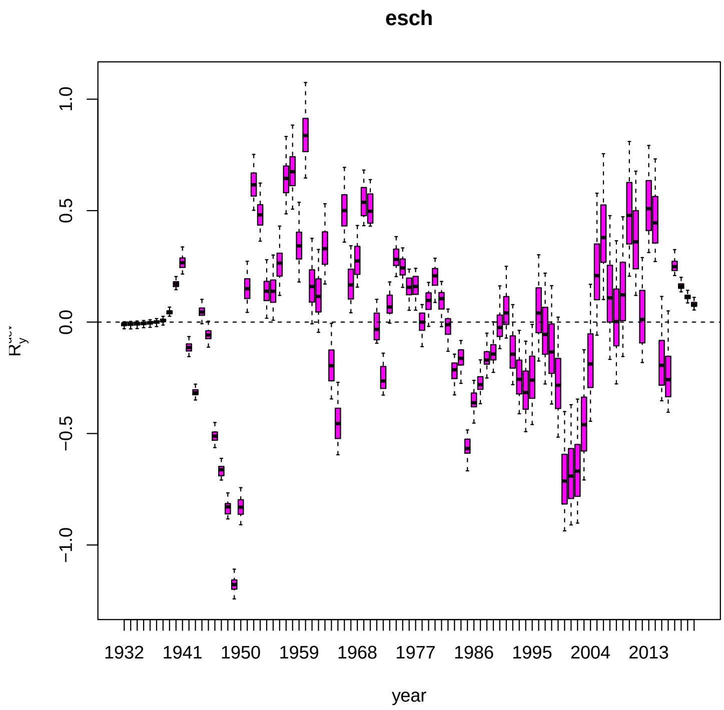

Figure 2.1: *Recruitment residuals from the current reference set of OMs.*

Clearly from Figure 2.1 there are prolonged (nearly decades long) periods of either high or low recruitment residuals. These are indicative of either recruitment 'regimes' or strong positive levels of autocorrelation. They don't look *a priori* like obvious regimes as they lack the characteristic plateaus in the moving average of the residuals. Though, realistically, it would be statistically very very difficult to comprehensively rule out regimes as well as autocorrelation - for high levels of autocorrelation or limited regimes (ones that deviate little from the overall mean) they would be at some level indistinguishable.

Figure 2.2 shows the decadal average recruitment multipliers (bias corrected exponential residual) moving back from 2016 (last year the recruitment residuals are based on actual data). Note we also omitted the very early residuals prior to 1952 based on previous uncertainty in the length frequency data that drive these residuals. The 1960s and 1970s seemed to be a prolonged period of above average recruitment but from around 1977–2006 recruitment was way below average - especially in the 1997–2006 period. The most recent decade (2006–2016) has been just above average. Obviously, these decadal periods can be altered and a slightly different picture would emerge. However, the high level conclusions are clear: recruitment doesn't really look like an i.i.d. random process as modelled in the OM.

In one sense, this is a topic of far wider interest than just the steepness estimation issue. How-

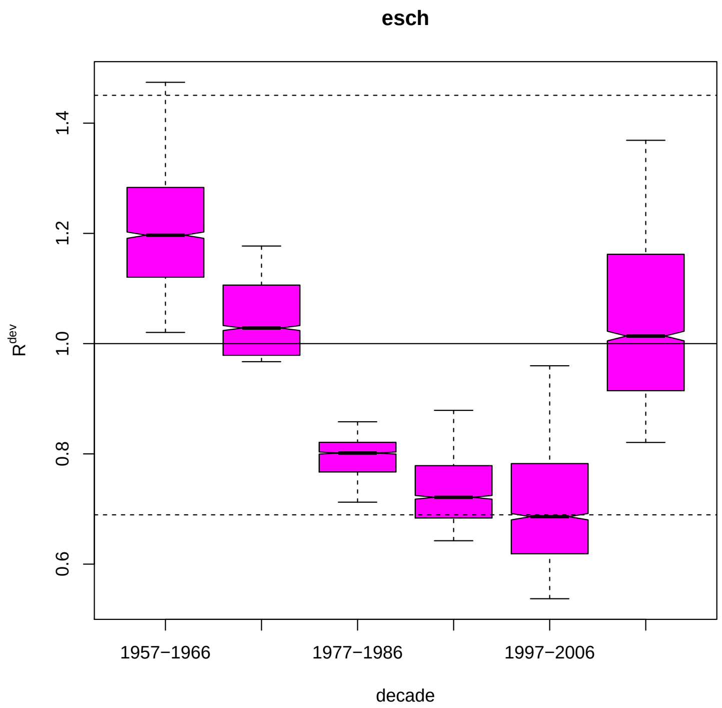

Figure 2.2: *Average recruitment multiplier from the current reference set of OMs. The dotted line denotes where a 10 year average's upper and lower 95%ile would be.*

ever, we often make judgment calls about steepness plausibility and range based on the overall objective function weight across the range of values so we do need to question how sensible it is to have a recruitment penalty that we know is clearly wrong. Not so much because it strongly impacts the recruitment estimates - it clearly doesn't force time-independence on the estimated residuals - but because the penalty contributes very strongly to the objective function weighting [2].

So if we were to at least move to accounting for autocorrelation in the calculation of the recruitment penalty what would that look like? The simplest case is where we assume that the recruitment residuals, ϵ_y are a Gaussian process (GP) so $\pi(\epsilon_y) \sim N(\mathbf{0}, \mathbf{\Sigma})$ and $\mathbf{\Sigma}$ is the covariance matrix. If $\mathbf{\Sigma}$ was a diagonal matrix with a single value σ_r^2 this model reduces to what we have now. To deal with covariance we use what's called the Ornstein-Uhlenbeck kernel for the covariance matrix:

$$\Sigma_{ij} = \sigma_r^2 \rho^{|i-j|}$$

where $\rho \in (-1, 1)$ is the temporal autocorrelation and $|i - j|$ is the time-separation of the residuals for years i and j. The OM assumes that $\sigma_r = 0.6$ and to calculate the autocorrelation-corrected recruitment penalty we use the empirical autocorrelation calculated from the residuals for each of the 2,000 grid estimates.

3 Results

The median (and approximate 80% CI) for the empirical estimates of ρ was 0.69 (0.67–0.74) - as expected a high value of autocorrelation. The one thing we cannot do is compute the grid sampling distribution of steepness when using this corrected recruitment penalty as this happens within the `ADMB` code `sample.tpl` not in `R`. That being said, we can compute the corrected penalty profiles and objective function profiles which will be very informative. We computed the steepness penalty (for both the OM and generalised GP process), as well as the likelihood, overall penalty and objective function profiles for the four current steepness values: $h \in \{0.55, 0.63, 0.72, 0.8\}$.

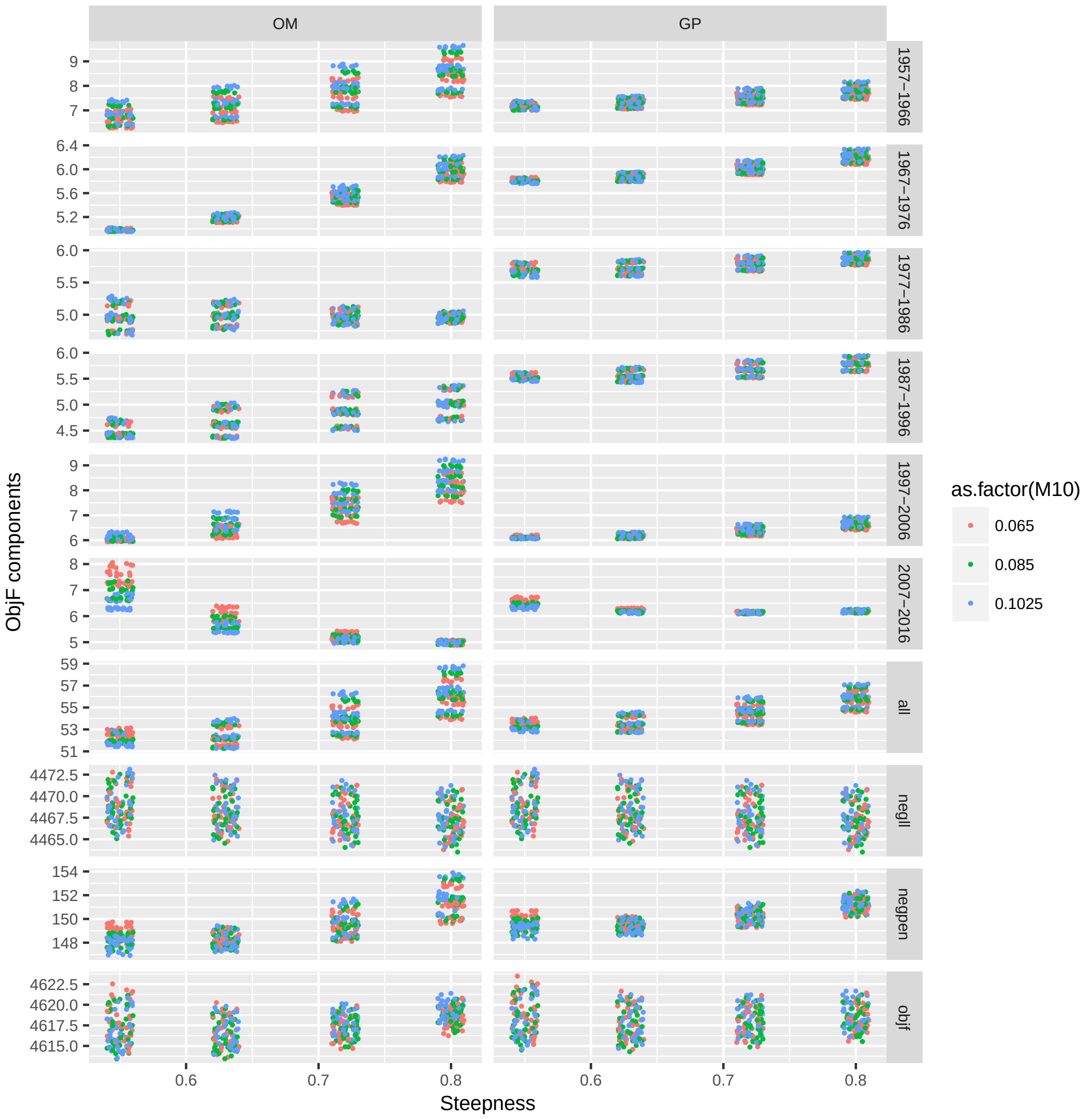

Figure 3.1: *Recruitment penalty profiles by decade and overall for the OM and GP recruitment penalties, overall penalty profile, negative loglikelihood, and objective function profile.*

Figure 3.1 details the decadal and overall recruitment penalties, for both the OM and GP options, as well as the overall penalty, the negative log-likelihood, and the overall objective function steepness profiles. The decadal recruitment penalty shows, perhaps not surprisingly, strong differences across decades. Early on (1957–1976) the preference was for lower steepness values.

In the 1977–1986 decade the preference was largely flat. The 1987–1996 decade showed the stronger preference for lower values across all decades. The most recent decade (2007–2016) showed a fairly strong preference for higher values of steepness. Overall, the preference is for the two lower levels of steepness with the least weight to the highest level of steepness (0.8). One clear difference between the OM and the GP is that the GP process dramatically reduces the absolute differences in preference across the steepness values. The qualitative preferences are the same (as you would expect) but when accounting for the autocorrelation in the penalty the magnitude of the preference differences are much smaller. The overall penalty looks very close to the recruitment penalty, albeit with slightly less preference for the lowest value of steepness. In terms of negative log-likelihood, the preference is for the higher values of steepness and is approximately linear from the lowest to the highest steepness values. When looking at the overall objective function we see probably the strongest contrast between the OM and GP recruitment penalty options. As noted in the OMMP report [2], the OM objective function preference is for lower levels of steepness and lowest for the highest steepness level. When using the GP penalty there is a *marginal* preference for the lower-middle value of 0.6 but, beyond that, **very** little meaningful preference across the steepness values. It would be reasonable to infer that the associated sampling distribution of steepness, when using objective function weighting, would be far flatter - and closer to being essentially flat rather than informative - than seen for the OM version [2].

4 Discussion

In this paper we explore decadal patterns in the recruitment residuals and in the steepness penalty used in the OM. We also explore how a modified recruitment penalty, which accounts explicitly for auto-correlation, affects the influence of the recruitment penalty in the overall OM preferences for steepness. There are strong and long-lasting time trends in the recruitment residuals with extended (i.e. decadal) periods of strong and weak recruitments currently estimated in the updated OMs. While very difficult to *definitively* distinguish between strong auto-correlation and more regime dominated time trends, the trends look more auto-correlated than regime driven. Within the OM, apart from the last two years, the auto-correlation is not included in the penalty term that contributes to the overall objective function and, hence, the preference for steepness. While we do not use objective functioning weighting when it comes to resampling steepness, we do look at the objective function weighted sampling distribution when considering an appropriate range for the steepness in the OM grid [2].

While the qualitative trends, including the decadal breakdown, in the OM and Gaussian process (GP) penalty terms are essentially the same, there are clear differences when it comes to both the absolute preference in the recruitment penalty and how that influences the overall objective function preferences for steepness. As noted in the most recent OMMP report [2] the current objective function preference for steepness is for the lower two values, and at its lowest for the highest value driven very much by the recruitment penalty. Conversely, the data themselves show a general trend for increasing preference for higher steepness values. When accounting for the auto-correlation in the recruitment penalty the overall objective function profile shows a weak preference for the central two steepness values, but nowhere near as strong as the OM penalty case. When comparing the lowest to the highest value of steepness there is little to no difference - again noticeably different to the current OM scenario. While we cannot compute the actual sampling density of the steepness for the GP penalty it would be reasonable to infer that it would not be so different from the flat prior we currently use.

There are no obvious signs that the current recruitment penalty, which doesn't account for auto-correlation across the years, is constraining the recruitment deviations. Even when assumed to be *a priori* a normal i.i.d. random process the estimates themselves are clearly not normal when it comes to their auto-correlation properties. Where the misspecified recruitment penalty does play a role is in the information sources contributing to the objective function across steepness values. When correcting for auto-correlation then penalty preference for lower steepness values is much lower; when combined with the data in the overall objective function there is very little preference for any particular value of steepness and no general preference for the lower levels. This analysis does nothing to suggesting altering the view of the ESC that we should **not** be using objective function weighting for steepness. It does, however, clearly suggest that we should **not** be inferring plausible ranges for steepness based on the objective function sampling distribution for steepness when using the current OM recruitment penalty. Using the auto-correlation corrected penalty doesn't suggest clear preference for any of the current four steepness values so, while not telling us anything more with respect to plausible ranges, it does somewhat justify staying with the uniform prior resampling approach for this parameter.

5 Acknowledgements

This work was funded by CSIRO and the Australian Fisheries Management Authority.

References

[1] Anonymous (2013). Report of the 4th Operating Model and Management Procedure group. CCSBT, Canberra, Australia.

[2] Anonymous (2020). Report of the 11th Operating Model and Management Procedure group. CCSBT, Canberra, Australia.

[3] Hillary, R.M., Preece, A., Takahashi, N. *et al.*. (2020) Southern bluefin tuna stock assessment. *CCSBT-ESC/2009/12*.

CONTACT US

t 1300 363 400
+61 3 9545 2176
e csiroenquiries@csiro.au
w www.csiro.au

WE DO THE EXTRAORDINARY EVERY DAY

We innovate for tomorrow and help improve today for our customers, all Australians and the world.

Our innovations contribute billions of dollars to the Australian economy every year. As the largest patent holder in the nation, our vast wealth of intellectual property has led to more than 150 spin-off companies.

With more than 5,000 experts and a burning desire to get things done, we are Australias catalyst for innovation.

WE IMAGINE. WE COLLABORATE. WE INNOVATE.