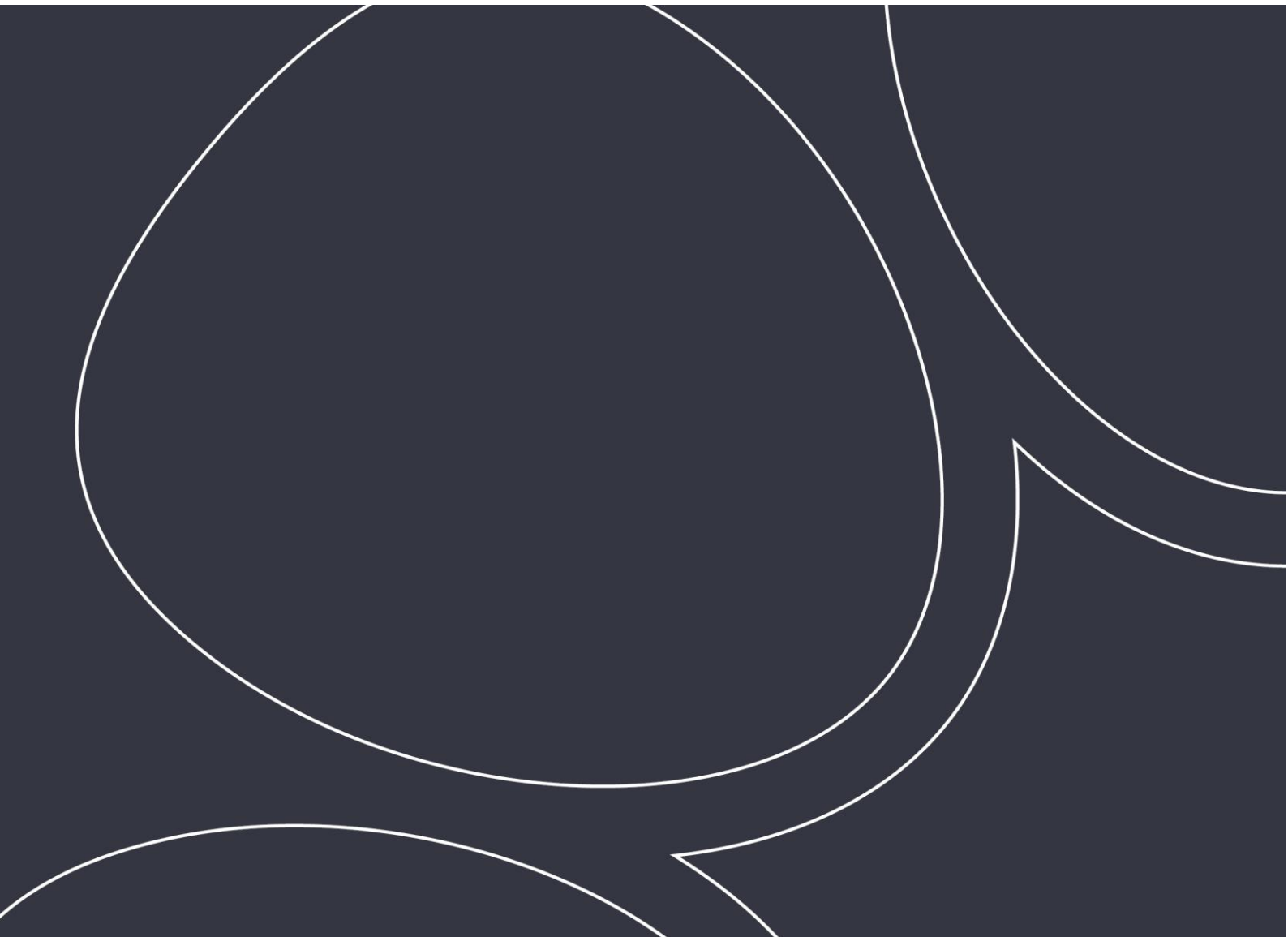


*Stock assessment of Sandfish (*Holothuria scabra*) in the Northern Territory 2024/2025*

Fishery Report No. 131



Document title	<i>Stock assessment of Sandfish (Holothuria scabra) in the Northern Territory 2024/2025</i>
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Date approved	1 October 2026
Document review	NA
TRM number	NA
ISSN	0158-2224 (print); 2205-667X (online)
ISBN	9780724547951
Fishery Report no	131
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Version	Date	Author	Changes made
1.01	20/9/2025	Jonathan Smart	Draft Created
1.02	23/10/2025	Jonathan Smart	Introduction and methods written
1.03	5/11/2025	Jonathan Smart	Results written
1.04	15/11/2025	Jonathan Smart	Appendices written
1.05	26/11/2025	Jonathan Smart	Discussion written
1.06	28/11/2025	Jonathan Smart	Draft finalised
1.07	08/05/2026	Malcolm Haddon	External reviewer
1.07	7/9/2026	Jonathan Smart	Report updated following external review
1.08	21/9/2026	Jonathan Smart	Report finalised

Stock assessment of Sandfish (*Holothuria scabra*) in the Northern Territory 2024/2025

Acronyms	Full form
CPUE	catch per unit effort
F_{MSY}	Fishing mortality that produces MSY
FRDC	Fisheries Research and Development Corporation
FTO	Fishing Tour Operator
GLMM	Generalised Linear Mixed Effect Model
LML	Legal Minimum Length
MSY	Maximum Sustainable Yield
NSW	New South Wales NSW
NT	Northern Territory
TAC	Total Allowable Catch
VBGF	von Bertalanffy growth function
WA	Western Australia

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Acknowledgements

This report was prepared by Smarter Fisheries Consulting under contract to the Northern Territory Government. The Department of Agriculture and Fisheries reviewed and approved the final report for publication. The Northern Territory Government acknowledges the contribution of Smarter Fisheries Consulting in undertaking the stock assessment modelling and preparing the report material. Responsibility for the final published content rests with the Northern Territory Government.

Professor Malcolm Haddon is thanked for providing the external independent review of the stock assessments and for previously providing R code that was used to establish the tuning algorithms used in this assessment. Dr Sandra Curin-Osorio and Michael Usher are thanked for their contributions to logbook data pre-processing and review of the author's responses to peer-review recommendations. Dr Matt Koopman and Dr Ian Knuckey are thanked for providing the data and analyses used to estimate population biomass from the surveys, and for constructive discussions on how to include this information in the assessment. The r4ss package, maintained by Ian Taylor (<https://github.com/r4ss/r4ss>), was instrumental in producing diagnostic outputs and supporting model-tuning activities.

1. Summary

This document provides quantitative assessments of Sandfish (*Holothuria scabra*) that estimate the status of two genetically distinct stocks in the Northern Territory for 2024/25. The East Stock and West Stock assessments were both conducted using Stock Synthesis models, representing the first application of this integrated stock assessment framework to NT Sandfish populations.

The Stock Synthesis model for the East Stock estimated that the relative spawning biomass in 2024/25 was 88%, which is well above both the biomass limit reference point of 30% (B_{30}) and the biomass target reference point of 60% (B_{60}). The stock reached its lowest point at 59% relative spawning biomass in 2006/07 following two years of unusually high catches in 2002/03 (124 t) and 2006/07 (165 t). However, the stock has been recovering consistently since then due to substantially lower catches and has maintained sustainable status in all years except those two periods of elevated harvest. In 2024/25 the fishing mortality (F) was well below the fishing mortality that equates to maximum sustainable yield (F_{MSY}), demonstrating that overfishing is not occurring.

Similarly, the West Stock assessment estimated a relative spawning biomass of 89% in 2024/25, also exceeding both the limit and target reference points. This larger stock experienced its lowest relative spawning biomass of 61% in 2006/07 following a period of elevated catches from 1999/00 to 2006/07. The stock has since recovered under reduced exploitation levels, with fishing mortality remaining below F_{MSY} in all but two years (1999/2000 and 2000/2001) throughout the assessment period.

Both assessments are considered data-limited, relying primarily on commercial catch history, standardised catch-per-unit-effort (CPUE) indices, and absolute biomass estimates from surveys conducted in 2024/25 with corresponding length compositions. The models demonstrated appropriate sensitivity to key assumptions but did not pass all diagnostic tests. Commentary on this is provided in the report. Notably some limitations were identified regarding growth parameter specification due to the lack of age data for this species. Despite these data limitations, the models adequately estimate stock status while the surveyed biomass estimates provide crucial information on stock scale.

On the basis of the evidence provided, both the East Stock and West Stock of Sandfish are unlikely to be depleted, and recruitment is unlikely to be impaired. Sandfish in both the East Stock and West Stock were classified as **Sustainable**.

2. Introduction

2.1. Species biology

Sandfish (*Holothuria scabra*) are a sea cucumber species from the family Holothuriidae that can grow as large as 40 cm and are often harvested at approximately 300 g live weight (Purcell et al., 2023). Sandfish are distributed throughout the Indo-Pacific and are bounded by the east African coast and the mid-Pacific Ocean, where they occur in the Tropics of Capricorn and Cancer (J.-F. Hamel et al., 2022; Purcell et al., 2023). In Australia, they occur along the north coast of Western Australia (WA), the Northern Territory (NT), Torres Strait and extend down the Queensland Coast to the New South Wales (NSW) border (Koopman & Knuckey, 2025).

Sandfish have different habitat preferences to most other tropical sea cucumber species, preferring soft benthic substrates (such as mud or sand) to coral reefs (J.-F. Hamel et al., 2022). They typically occur in shallow coastal waters in low energy environments such as protected bays and shores at depths of approximately 10 m (J.-F. Hamel et al., 2022; Hart et al., 2022; Koopman & Knuckey, 2025). They are relatively sedentary and exhibit burrowing behaviour (Koopman & Knuckey, 2025), with movements of less than 8 m per day and home ranges of less than 0.05 km² (Lee et al., 2018).

Growth (length-at-age) is unknown for wild Sandfish populations (J.-F. Hamel et al., 2022), as is generally the case for most sea cucumber species (Purcell et al., 2023). Some limited information from length frequency data from the Torres Strait indicates that Sandfish reach 18 cm at 2 years of age (Long et al., 1996). Therefore, Sandfish appear to be a reasonably fast-growing sea cucumber species, given their maximum size of 40 cm. Length-at-maturity is well studied, with plasticity occurring across its geographic distribution (13 – 20 cm; Hamel et al. (2022)) with 15 cm estimated in Australia (Long et al., 1996). Sandfish are therefore considered a productive species as evidence indicates that they mature within 2 years of age (Long et al., 1996).

Sandfish are highly fecund, averaging 9 – 17 million oocytes per female and spawning multiple times a year (J.-F. Hamel et al., 2022). The larval phase lasts 10 – 14 days (Waldie et al., 2024) but genetic dispersal appears quite limited (Uthicke & Benzie, 2001). High local retention of recruits was demonstrated in Papua New Guinea, where 50% of recruits settled within 6.7 km of their parents and 95% settled within 59 km (Waldie et al., 2024). These high rates of self-seeding and low potential for recruitment dispersal means that Sandfish can suffer from Allee effects, where recruitment depensation occurs when populations decline to low densities. As a result, Sandfish populations that have been overfished have struggled to recover, such as the Torres Strait (Skewes et al., 2000) and Fiji (Brown et al., 2022).

2.2. Stock structure

There are two genetically distinct Sandfish stocks in the NT, which occur in the Arafura Sea and the Gulf of Carpentaria and are divided by the Wessell Island group (Gardner et al., 2012). These stocks have been delineated using the 60 nm reporting grids used in logbook reports as the 'East' and 'West' stocks (Figure 1).

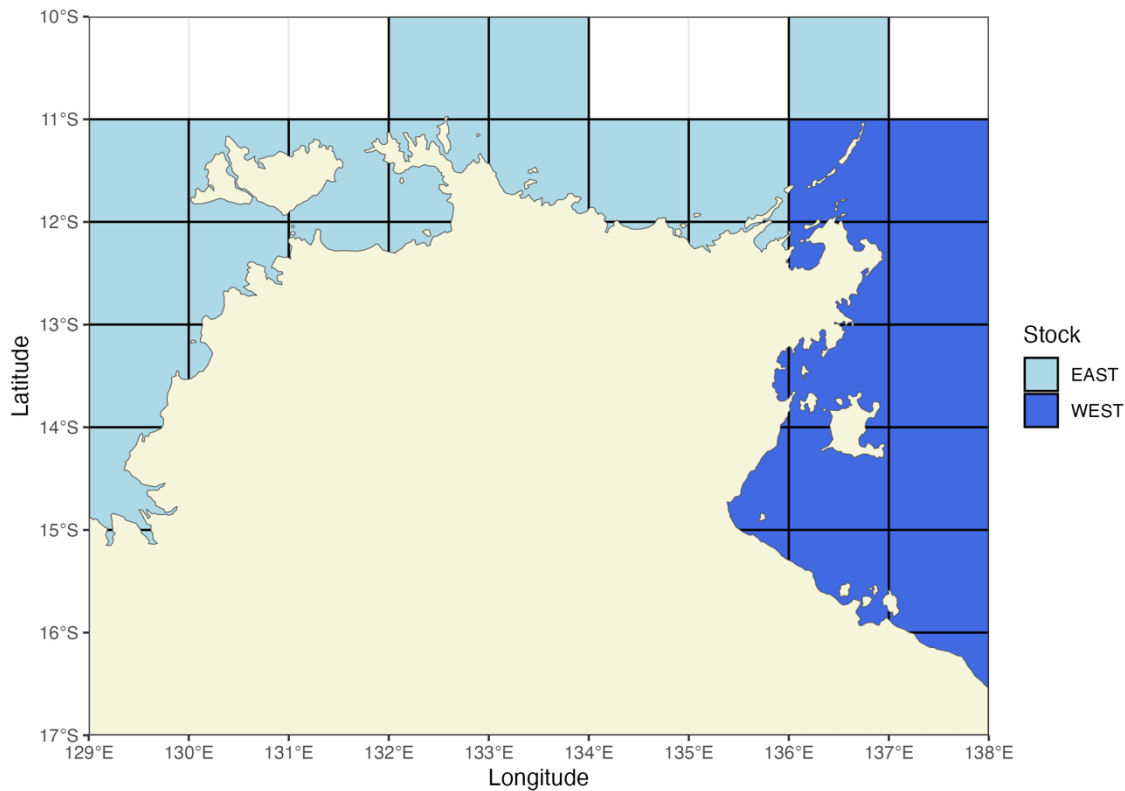


Figure 1: Stock structure of Sandfish in the NT Trepang Fishery.

2.3. Overview of the fishery

Sandfish are only caught by the NT Trepang Fishery which operates in waters extending seaward from the high-water mark to 3 NM seaward from the baseline. The majority of fishing effort occurs along Arnhem Land coast, with the primary harvest areas being Cobourg Peninsula and Groote Eylandt.

Sandfish are harvested by hand collection, typically by divers operating on hookah in shallow coastal waters (<10 m) (Koopman et al., 2024). Due to the highly selective nature of this method, there is no reported bycatch or interactions with Threatened, Endangered, and Protected Species (TEPS) (Koopman et al., 2024).

It is a limited entry fishery (six licences) with logbook records dating back to 1985. Although this is a mixed species fishery, almost all the catch (99 %) has been Sandfish. The NT sandfish fishery supplies Asian seafood markets where they are one of the highest value species (Purcell et al., 2018).

2.4. Management controls

The NT Trepang Fishery is managed via the Northern Territory Trepang Harvest Strategy (Adamson, 2025). A legal minimum length (LML) of 16 cm is implemented in NT. Since 2016 the fishery has been spatially managed with a 246-t total allowable catch (TAC) distributed over 32 60 nm x 60 nm grids (

Table 1).

Table 1: Summary of current management controls in the commercial sector of the Trepang Fishery.

Management tool	Instrument
-----------------	------------

Catch-grid limits	Individual catch limit per grid equating to the total allowable catch of 246 t whole weight.	Licence condition
Limited entry	Number of commercial licences capped at six.	Fisheries Regulations
Spatial restrictions	Licensees are restricted to waters within 3 nm of high-water mark	Fisheries Regulations Licence conditions
Method restrictions / Permitted gear	- Harvesting by hand collection only, which includes the use of SCUBA (Self-Contained Underwater Breathing Apparatus) and hookah. - Limitations on the number of assistants under each licence with a maximum of nine assistants, including four divers. - A maximum of four tenders is permitted under a licence.	Fisheries Regulations Licence conditions
Minimum size limit	16 cm	Licence condition

2.5. Catch history

Sandfish are only caught commercially in the NT Trepang Fishery, with no take by recreational or Fishing Tour Operator (FTO) sectors. A comprehensive analysis and description of catch history was undertaken by Koopman et al (2024) in advance of designing biomass surveys undertaken in 2024/2025. More than 90% of the catch is harvested from seven grids (four from the West Stock and three from the East Stock).

Sandfish harvest by the Aboriginal Traditional sector is poorly quantified in the NT and there are no contemporary harvest estimates available for this assessment. A modified creel survey was undertaken in 2001, which estimated fishing effort and harvest by Aboriginal fishers across northern Australia (Henry and Lyle, 2003). However, the survey contained no estimate of Sandfish harvest.

All catches presented in this assessment are in whole (i.e. unprocessed) wet weight.

2.5.1. East Stock

Catches in the East Stock peaked at 165 t in 2006/07 with another pronounced peak of 124 t in 2002/03 (Figure 2). In all other year's catches have been below 60 t and the annual mean from 1985/86 to 2024/25 is 24 t. Catches were negligible in the 1980's with the modern fishery effectively commencing in 1991/92 (Figure 2).

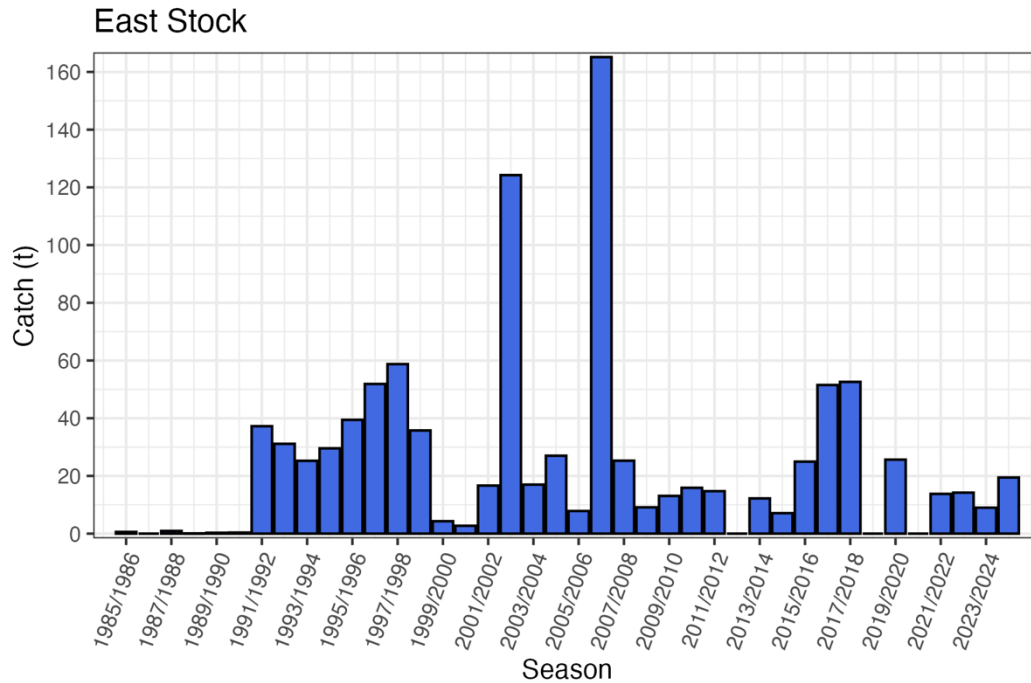


Figure 2: Catch history of Sandfish from the East Stock by financial year fishing season.

2.5.2. West Stock

The West Stock has historically had higher catches than the East Stock, peaking at 313 t in 2000 (Figure 3). Catches greater than 50 t have occurred in thirteen fishing seasons, although only two of these (2023/24 and 2024/25) have occurred in the past decade (Figure 3). The annual mean catch from 1991/92 to 2024/25 was 49 t (Figure 3).

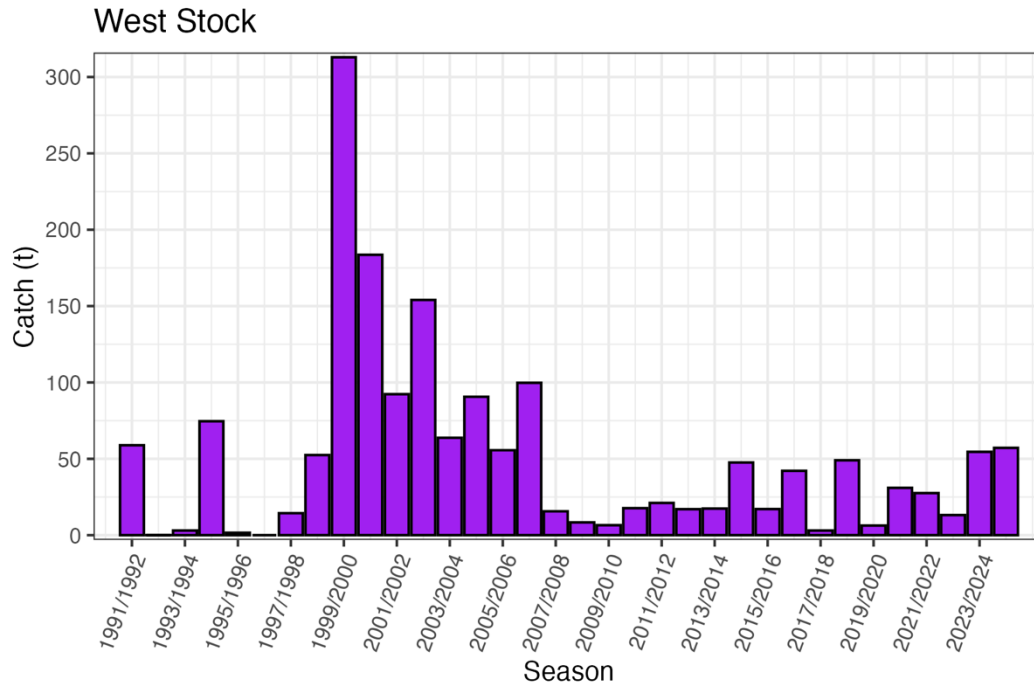


Figure 3: Catch history of Sandfish from the West Stock by financial year fishing season.

2.6. Stock assessment model

Stock Synthesis is a fisheries population dynamics and stock assessment modelling framework developed by NOAA (Methot & Wetzel, 2013). It is an age-and-size-structured integrated stock assessment model that can be readily adapted to suit a broad range of species and fisheries. Stock Synthesis integrates multiple data sources including catch records, length composition, age composition, abundance indices, and tagging studies into a unified population dynamics model. Its main advantages are that it is highly customisable but uses a consistent structure for model inputs and provides standardised outputs that are familiar to the wider stock assessment scientific community. As a result, models implemented in stock synthesis can be developed effectively, within shorter time periods than bespoke models, are easy to review by external scientists, and can easily be tailored to run detailed sensitivity scenarios and explore parameter uncertainty. A series of auxiliary packages including *r4ss* (Taylor et al., 2021) and *ss3diags* (Carvalho et al., 2021; Winker et al., 2025) are available to provide detailed model outputs such as estimated quantities, model fits to data, diagnostics and model comparisons. The Stock Synthesis model presented in this report is the first developed for NT Sandfish and makes full use of all these features. It follows on from recent application of this framework to Golden Snapper (Pazhayamadom et al., 2024) and Black Jewfish (Smart, in prep) in the NT.

2.7. Criteria for determining stock status

2.7.1. Reference points

The state of fish stocks is classified based on two indicators which are:

1) **B30%** - 30% of unfished biomass ($B_{30\%}$) is specified as the limit reference point in the Trepang Harvest Strategy. 2) F_{MSY} – Fishing mortality at Maximum Sustainable Yield (F_{MSY}) is the fishing mortality that would produce maximum sustainable yield (MSY).

2.7.2. Stock status

Stock Status was assigned according to the National Fishery Status Reporting Framework (Pidcocke et al., 2021). There are six stock status categories that can be assigned, with four of these determined through defined biological and exploitation reference points (Table 2).

Table 2: Stock Status categories defined according to the National Fishery Status Reporting Framework.¹

	Stock status	Description	Potential implications for management of the stock
	Sustainable	Biomass (or proxy) is at a level sufficient to ensure that, on average, future levels of recruitment are adequate (recruitment is not impaired) and for which fishing mortality (or proxy) is adequately controlled to avoid the stock becoming recruitment impaired (overfishing is not occurring).	Appropriate management is in place.
	Depleting	Biomass (or proxy) is not yet depleted and recruitment is not yet impaired, but fishing mortality (or proxy) is too high (overfishing is occurring) and moving the stock in the direction of becoming recruitment impaired.	Management is needed to reduce fishing mortality and ensure that the biomass does not become depleted.
	Recovering	Biomass (or proxy) is depleted and recruitment is impaired, but management measures are in place to promote stock recovery, and recovery is occurring.	Appropriate management is in place, and there is evidence that the biomass is recovering.
	Depleted	Biomass (or proxy) has been reduced through catch and/or non-fishing effects, such that recruitment is impaired. Current management is not adequate to recover the stock, or adequate management measures have been put in place but have not yet resulted in measurable improvements.	Management is needed to recover this stock; if adequate management measures are already in place, more time may be required for them to take effect.
	Undefined	Not enough information exists to determine stock status.	Data required to assess stock status are needed.
	Negligible	Catches are so low as to be considered negligible and inadequate information exists to determine stock status.	Assessment will not be conducted unless catches and information increase.

The reference points B_{30} and F_{MSY} are used to determine stock status and are provided in a phase plot to determine the appropriate category (Figure 4). The relative stock biomass for the most recent year ($B_{2024/25}/B_0$) is compared with B_{30} to determine whether the stock is 'recruitment overfished'³. The harvest from the same assessment year ($F_{2024/25}$) is compared with F_{MSY} .

¹ More information on the National Fishery Status Reporting Framework can be found at <https://www.fish.gov.au/about/how-are-the-status-of-australian-fish-stock-reports-done#:~:text=Toggle%20content,increased%20risk%20of%20recruitment%20failure>.

² The term ' B_0 ' represents the biomass of the stock at unfished level (virgin biomass), ' $B_{2024/25}$ ' indicates the biomass in 2024/25 fishing year and B_{30} is the biomass at 30% of unfished levels.

³ For the purposes of this assessment $B_{30\%}$ is used a proxy for 'recruitment overfished'.

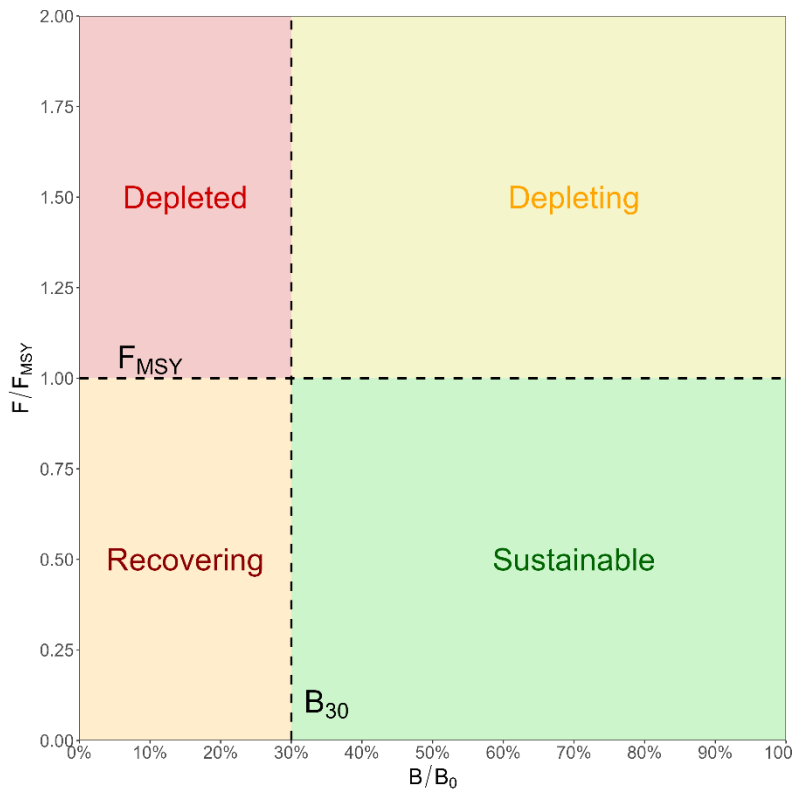


Figure 4: Stock status diagram indicating the categories species in the National Fishery Status Reporting Framework (Piddocke et al., 2021).

3. Stock Synthesis

3.1. Model structure

The Stock Synthesis model for Sandfish was performed with each stock (East and West) as separate populations. Each model had an underlying structure that encompassed a single area, combined sexes, and a population that reached a maximum age of 9 years with a plus group of 10 years. The growth, recruitment and mortality of the population were initially specified based on information determined by Smart et al (2025) using an annual time step based on a financial year (June to July) fishing season with recruitment occurring in January (a mid-year default). The data inputs included harvest estimates from a single commercial fishing fleet, an index of abundance estimated from standardised catch per unit effort (CPUE) (Smart, Koopman, et al., 2025), and absolute biomass estimated from surveys (Koopman & Knuckey, 2025) with corresponding length compositions collected. Many aspects of model structure draw from recent stock assessments for sea cucumber species in the Queensland Sea Cucumber Fishery, which operates in the Great Barrier Reef Marine Park (Smart et al., 2024b, 2024a). These Queensland assessments were also performed using Stock Synthesis and had biomass estimated from similar surveys to those undertaken on NT Sandfish (Koopman & Knuckey, 2025).

The Stock Synthesis assessment conducted in this report refers to a 'Base Case' model as well as sensitivity scenarios (Section 0). The Base Case is the final model used to infer all conclusions on Sandfish population trends and stock status. It represents culmination of model development where many iterations of Stock Synthesis models were created, explored and critiqued by using various data inputs, sources of information and structural decisions. Ultimately, the Base Case model made the best use of all available data, had judicious

and defensible decisions made and provided a final model that fit the data well, converged, was stable following tuning procedures and satisfactorily passed all diagnostic checks.

Sensitivity scenarios represent alternative models that would be presented as a Base Case if different decisions were made, or they provided superior data fits to the eventual Base Case. The purpose of presenting multiple sensitivity scenarios is to provide support for the Base Case model, demonstrate how and why key modelling decisions were made, provide transparency into the model development process, and demonstrate overall stock assessment thoroughness.

3.2. Fleets and length selectivity

Two fleets are included in the stock assessment models:

1. **Survey fleet** which includes the 2024/25 biomass estimate and length composition from Koopman and Knuckey (2025). No removals are included in this fleet
2. **Commercial fleet** which includes catch and CPUE up to 2024/25. No composition data are available from this fleet.

Length selectivity is estimated for the survey fleet by fitting to the length composition data available in 2024/25 using a logistic selectivity function. The selectivity of the commercial fleet is 'mirrored'⁴ to the survey selectivity above the LML of 16 cm and is pre-specified as zero before this length. This approach was taken as the biomass surveys were undertaken through commercial vessels and the surveyed length compositions approximate the commercial length structure, but only above the LML (Smart et al., 2024a, 2024b).

3.3. Data inputs

The East Stock assessment spanned from 1985/86 to 2024/25. The assessment includes standardised commercial CPUE as an index of abundance, a biomass estimate from a survey of grids 1236 and 1336 (denoted 'Survey' in Figure 5) with corresponding length compositions (Figure 5).

⁴ 'Mirroring' is an approach that estimates a model quantity (such as selectivity) for one fleet and then applies this to another. It is useful when data is only available for one fleet and it is understood to be consistent for other fleets.

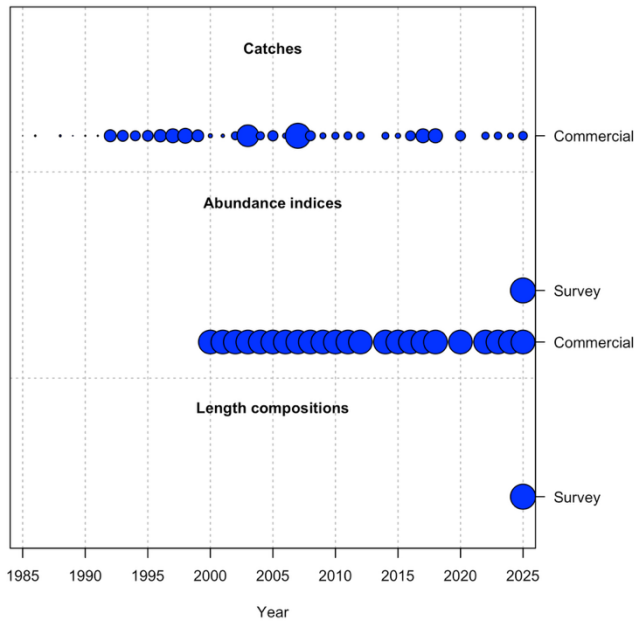


Figure 5: Time series of data availability by fleet for the East Stock assessment. The size of bubbles indicates the relative size of catches, magnitude of abundance indices or sample sizes of compositions. The x-axis displays integer years where 2025 corresponds to the 2024/25 fishing season, and so forth.

The West Stock assessment spanned from 1990/91 to 2024/25. The assessment includes standardised commercial CPUE as an index of abundance, a biomass estimate from a survey of grid 1132 (denoted 'Survey' in Figure 6) with corresponding length compositions (Figure 6).

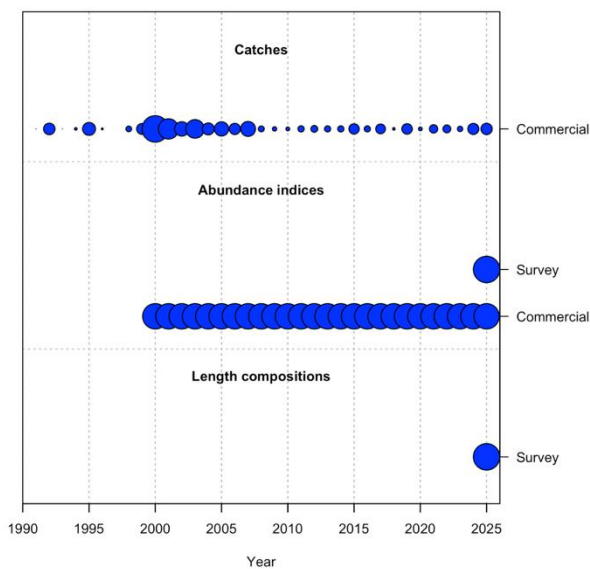


Figure 6: Time series of data availability by fleet for the West Stock assessment. The size of bubbles indicates the relative size of catches, magnitude of abundance indices or sample sizes of compositions. The x-axis displays integer years where 2025 corresponds to the 2024/25 fishing season, and so forth.

3.3.1. Harvest

Commercial catches presented in Section 2.5 are the only known harvests of NT Sandfish and are the only removals data considered in the model. As such, no initial equilibrium catches were estimated and catch reconstructions of historical commercial catches and recreational catch were not necessary.

Post-release mortality is not considered for Sandfish in the NT Trepang Fishery due to the hand harvest methods of the fishery, which allows for only legal-size individuals (>16 cm) to be harvested.

Illegal overseas harvest is a suspected (but officially unconfirmed) issue for Sandfish at Warrior Reef due to its close proximity to Australia's border with Papua New Guinea (Butler et al., 2023). The same degree of illegal harvest is not suspected for the East or West NT Sandfish stocks as their population range lies close to Australia's mainland. However, reports of illegal fishing activities have appeared in NT logbook comments.

The catch history of NT Sandfish is therefore relatively well known and does not include common issues such as uncertain estimates of recreational or historical commercial catches.

3.3.2. Abundance indices

3.3.2.1. Biomass estimates

Estimates of absolute biomass are available from surveys undertaken in 2024/25 by Koopman and Knuckey (2025). These occurred in grid 1132 (West Stock), and grids 1236 and 1336 (East Stock), which are the grids where the majority of fishing occurs. Commercial divers were involved with the survey, and therefore the biomass estimates are directly relatable to the stock available to the fishery.

Biomass estimates were calculated by determining abundance from Sandfish densities and available habitat and multiplying this by the average weight of sampled Sandfish (Koopman & Knuckey, 2025). The biomass within each grid was then extrapolated using two different methods:

1. Extrapolated biomass 1 - the mean density (across all strata combined) was scaled up to the area of all potential strata in the survey areas in which fishing effort had been recorded.
2. Extrapolated biomass 2 - the combined biomass estimates for strata in which fishing effort had been recorded was scaled up to the area of all potential strata in the survey areas in which fishing effort had been recorded but that were not surveyed.

This provided two biomass estimates for each grid which had opposing results depending on the grid. For example, Grid 1336 (East stock) had a lower estimate based on method 2 as a surveyed area with high density was omitted due to not having documented fishing effort. Conversely, Grid 1132 (West stock) had a lower estimate for method 1 as site specific density was more variable and scaling to biomass before area extrapolation led to a higher estimate for method 2. For consistency, method 1 was used as the Base Case stock assessment model input as: 1) biomass was calculated as the final step in the calculation, better accounting for variable densities across strata and 2) method 2 also appeared to underestimate the biomass for the East Stock as surveyed areas with high abundances were excluded from the calculations due to the lack of fishing activity in those areas. As two grids were surveyed in the East Stock, these biomass estimates were summed to 740.4 t, while the estimate used for the West stock was 1079.8 t (Koopman & Knuckey, 2025).

Grid level estimates were then scaled to the stock level estimates according to the percentage of catch that occurred over the last 5 years (2020/21 - 2024/25) between the surveyed and unsurveyed grids. This was 56.8 % for the West Stock and 95.9 % for the East Stock. This resulted in model inputs of 772 t for the East Stock (Figure 7) and 1901 t for the West Stock (Figure 8). This same approach has been used in Australian

sea cucumber stock assessments that used similar surveys requiring the same scaling (Hart et al., 2022; Smart et al., 2024b).

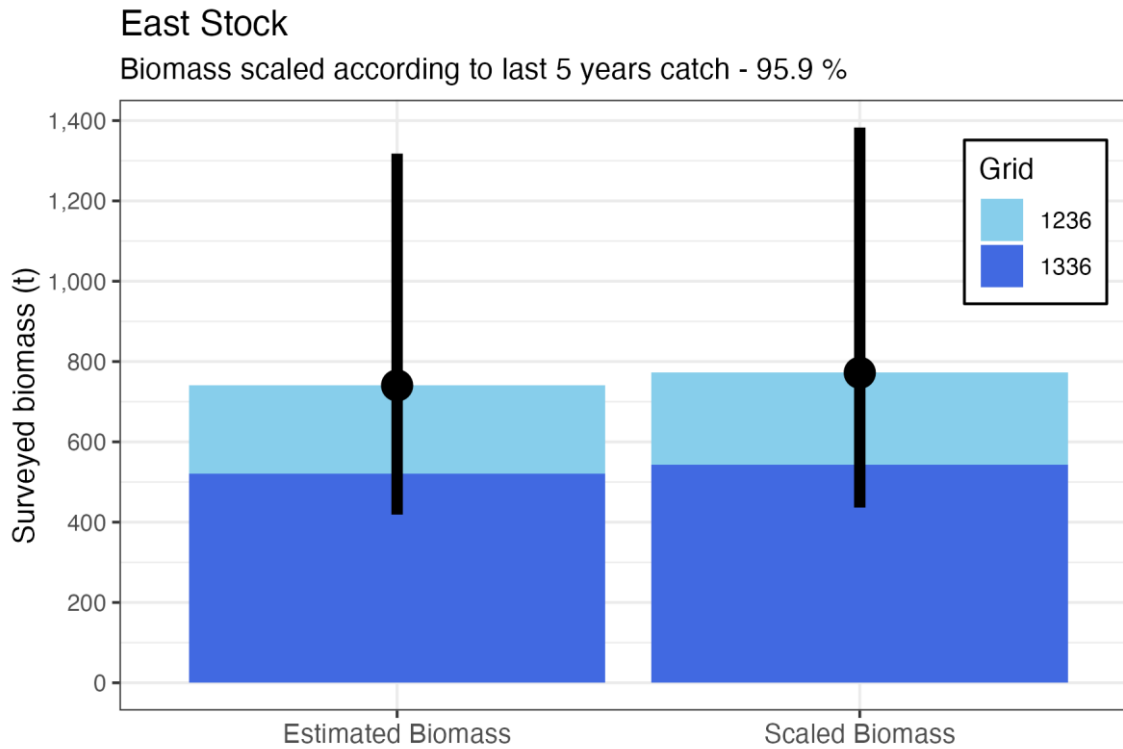


Figure 7: Biomass estimates for the East Stock used in the stock assessment model. The estimated biomass represents the sum of the grid level estimates (blue and light blue bars) according to extrapolation method 1 in Koopman and Knuckey (2025). The scaled biomass is the estimated biomass scaled according to the 5-year average catch proportion of surveyed and unsurveyed grids. The black points and error bars show the point estimates and corresponding error used as inputs to the Base Case and sensitivity scenarios.

West Stock

Biomass scaled according to last 5 years catch - 56.8 %

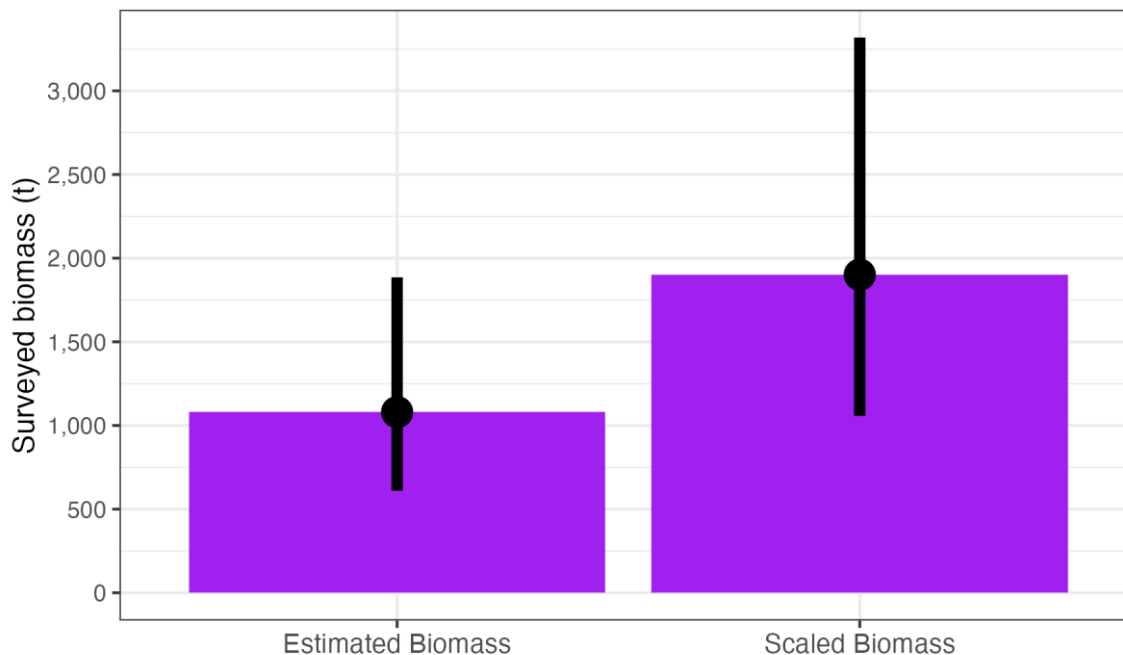


Figure 8: Biomass estimates for the West Stock used in the stock assessment model. The estimated biomass (left purple bar) is based on extrapolation method 1 in Koopman and Knuckey (2025). The scaled biomass (right purple bar) is the estimated biomass scaled according to the 5-year average catch proportion of surveyed and unsurveyed grids. The black points and error bars show the point estimates and corresponding error used as inputs to the Base Case and sensitivity scenarios.

The biomass estimates derived from extrapolation method 2 (Koopman & Knuckey, 2025) are included as sensitivity analyses, as well as estimates without further stock level scaling (Section 0).

The coefficient of variation (CV) associated with each biomass estimate was set at 0.3 and was applied as a lognormal standard error in the model. Convention is to use a CV of at least 0.3 in stock assessments for biomass estimates (Tuck, 2022). Consistently, applying the same CV across biomass estimates provides a simple and effective way to compare inputs in sensitivity analyses without needing to alter error estimates on each occasion, which is not possible based on the information presented in Koopman and Knuckey (2025).

Biomass estimates were fit to in Stock Synthesis by fixing catchability to 1 for the survey fleet. As length selectivity is estimated for this fleet the biomass estimate is automatically scaled to the biomass available to the survey, rather than being treated as total or spawning biomass which would be incorrect (Smart et al., 2024a, 2024b).

3.3.2.2. CPUE

Catch-per-unit-effort standardisation was developed through a generalised linear mixed model (GLMM) approach and developed by Smart et al (2025) for data up until 2022/23 inclusive. The GLMM for each stock was applied using the R programming environment (R Core Team, 2024) using the glmmTMB package (Brooks et al., 2017). The GLMM was fitted to catch in kg with financial year (henceforth year), grid, month of fishing, number of crew and licence number treated as independent variables and total fisher hours used as an offset. The GLMM was fitted using a Tweedie distribution with a log-link function and no model

intercept. A Tweedie distribution is an extension of the gamma distribution with a key difference being that it can include records where zero catch occurred. The same model was fitted using a normal distribution and the models were diagnostically compared for appropriate fits using the performance R package (Lüdecke et al., 2021) and ranked using Akaike's information criterion (AIC). The Tweedie distribution outperformed the normal distribution for both stocks.

Appropriate variables were selected through an AIC ranking analysis performed using the MuMIn R package (Bartoń, 2024) that was undertaken in a stepwise process to consider the random effects structure of the GLMM and to remove collinear variables. The best fitting model was used to produce a standardised index of abundance by predicting the year coefficients of the GLMM for each stock and grid while holding all other variables constant. This index is centred on a mean of 1 and can be compared with a nominal CPUE index that has also been centred.

This time series was extended for a further two years using the same methods and used as an index of abundance input from 2000/01 to 2024/25 in the stock assessment models (Figure 9). Following this process, the best fitting CPUE standardisation model for each stock was:

$\text{Catch} \sim 0 + \text{Year} + (1|\text{Grid:Year}) + \text{Number of crew} + (1|\text{licence}) + \text{offset}(\log(\text{Total effort hours}))$

for the West stock and,

$\text{Catch} \sim 0 + \text{Year} + \text{Grid} + (1|\text{Grid:Year}) + \text{Number of crew} + (1|\text{licence}) + \text{offset}(\log(\text{Total effort hours}))$

for the East stock. Note that Month was determined to be a collinear variable for both stocks and was excluded from the final models.

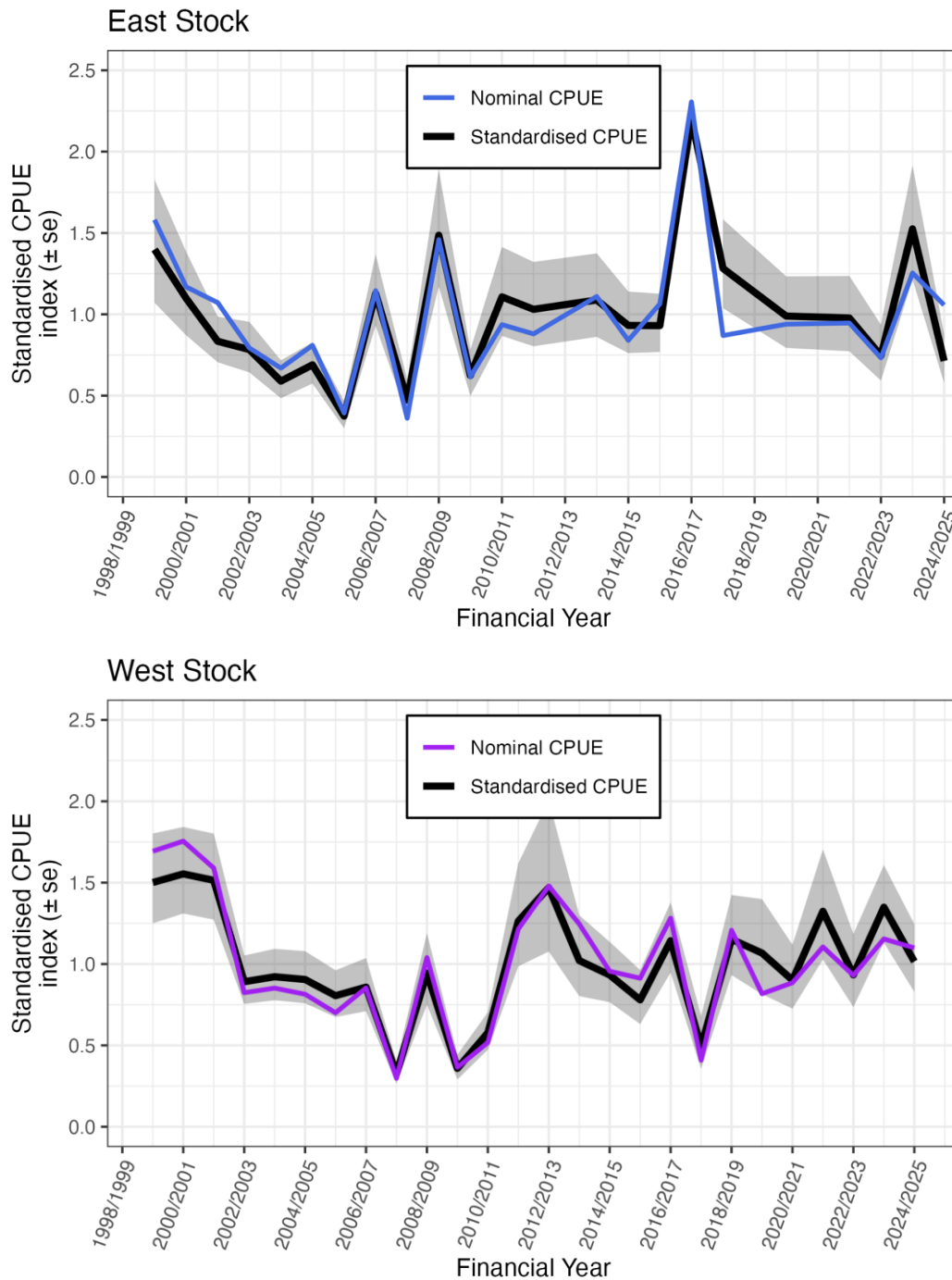


Figure 9: Nominal and standardised CPUE for the East Stock (Top panel) and West Stock (Bottom panel). Coloured lines represent the nominal CPUE and the black line and grey shading is the standardised CPUE and standard error. Both time series have been centred on a mean of one.

Standard errors estimated from a GLMM can be very small as they are based on a large number of data points. Therefore, a loess smoother was fit through the point estimates of the standardised CPUE (in log space) and the deviation between the two series was used to express the variability of the standardised CPUE (Punt, 2023). This approach has been used in previous NT stock assessments (Pazhayamadom et al., 2024; Smart, Randall, et al., 2025) and is used routinely in other Australian stock assessments (Tuck, 2022).

3.3.3. Length compositions

A single year of length composition is available for each stock from the surveys conducted by Koopman and Knuckey (2025) and were used as inputs from the stock assessment model for the survey fleet (Figure 10; Figure 11). These length compositions were used to estimate a logistic length selectivity for the survey fleet (see Section for 3.2 more details) and determine growth information internally within the stock assessment model (see Section 3.4.1). All fish were grouped into 2 cm total length (TL) bins to better estimate faster growth for earlier ages in Stock Synthesis.

All length measurements were taken onboard a research vessel rather than from sea cucumbers in situ on the sea bed (Koopman & Knuckey, 2025). Individual length measurements can be inaccurate as sea cucumbers can truncate and elongate their lengths, potentially biasing length compositions. This uncertainty was factored into the stock assessment through a sensitivity analysis where the length measurements were increased by 25 % to determine the potential under measurement of lengths, as has been performed in other sea cucumber stock assessments (Smart et al., 2024a, 2024b).

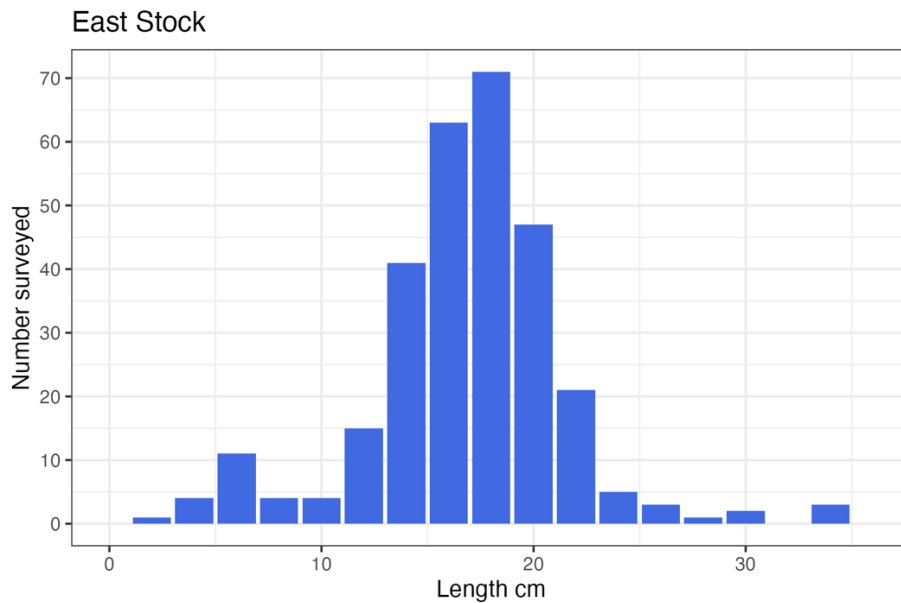


Figure 10: Length compositions (TL) for the East Stock of Sandfish surveyed in 2024/25 (Koopman & Knuckey, 2025)

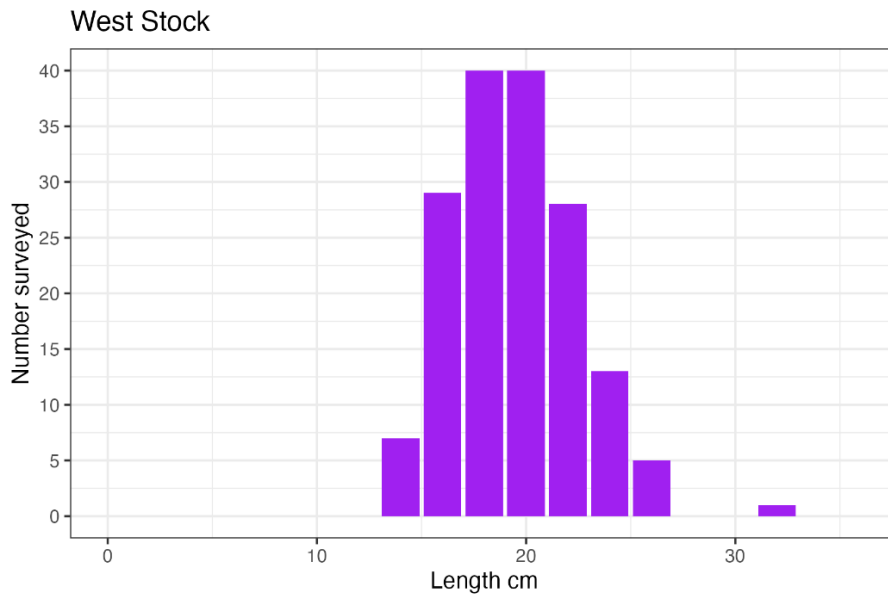


Figure 11: Length compositions (TL) for the West Stock of Sandfish surveyed in 2024/25 (Koopman & Knuckey, 2025)

3.4. Sandfish Biology

3.4.1. Growth, weight-length relationship, maturity & fecundity

Initial biological values for a Stock Synthesis stock assessment were determined by Smart et al. (2025) (Figure 12). Information on maturity was available from several sources (J.-F. Hamel et al., 2022; Yanti et al., 2020), and a length-at-50%-maturity (L_{50}) of 16 cm is considered to be the most appropriate value for NT sandfish based on estimates from nearby regions (Conand, 1989; Long et al., 1996). An estimate of length-at-95%-maturity (L_{95}) is not available and was therefore assumed to occur at 18 cm as this species is reasonably fast growing (Figure 12).

The weight-length relationship for both stocks was determined by Smart et al. (2025) from data collected by Koopman and Knuckey (2025) (Figure 12). No information on the relationship between fecundity (number of eggs) and size is available for Sandfish. Therefore, fecundity was pre-specified to be linear to length, such that larger females have higher reproductive output that is equivalent to the exponential curve of the weight-length relationship.

Stock Synthesis uses a different parameterisation to the typical von Bertalanffy growth function (VBGF) (Beverton & Holt, 1957; von Bertalanffy, 1938), where two specified lengths-at-age are estimated (L_1 and L_2) (Methot & Wetzel, 2013). These were defined as L_1 = the length at 0 years old and L_2 = the asymptotic length (L_∞). During model development, growth was pre-specified at assumed values determined by Smart et al. (2025). These were assumed values that were cohesive with other known biological aspects of Sandfish, such as maximum age and some growth information from length frequency data (Long et al., 1996; Smart, Koopman, et al., 2025). However, these values were sensitivity tested with alternative pre-specified growth parameters as they based on limited information (Section 0). The consequences of using assumed values is discussed in detail in Section 0. The coefficient of variation (CV) of length-at-age at L_1 and L_2 was pre-specified as 0.1 for both values.

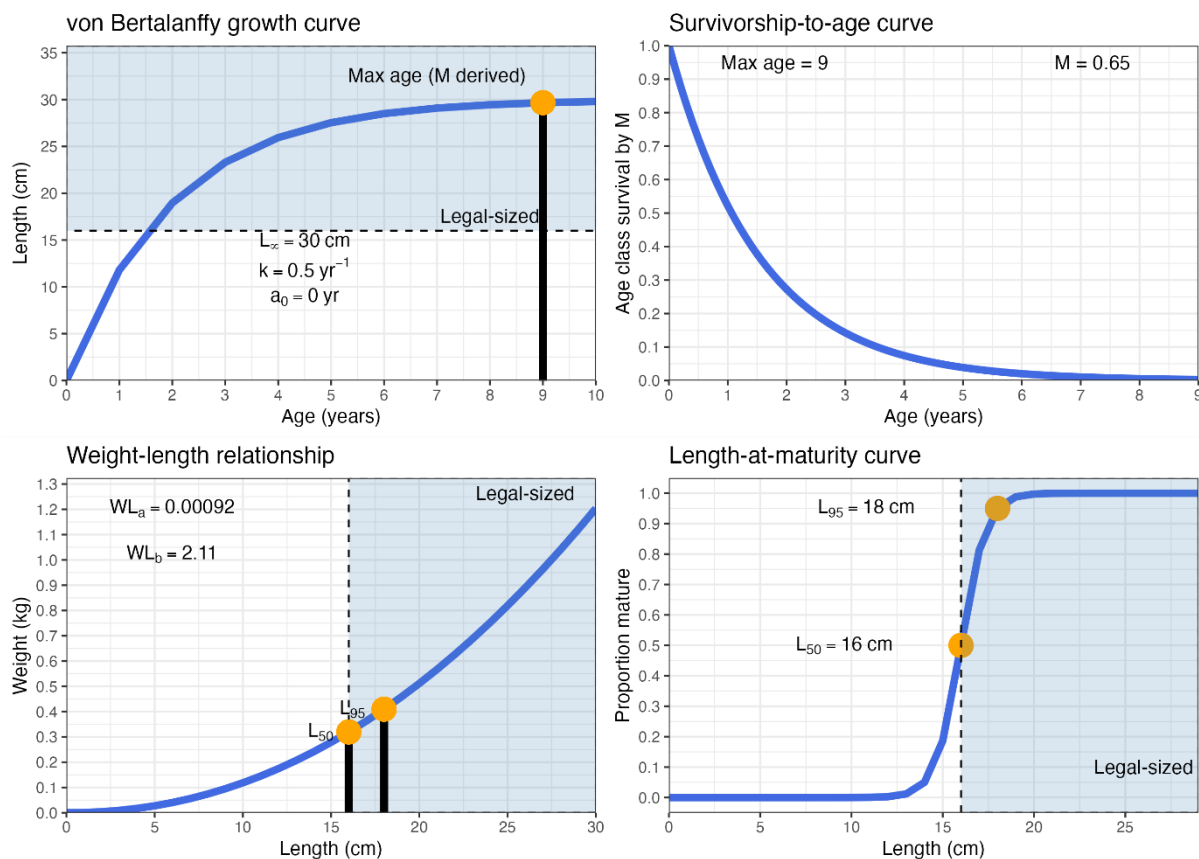


Figure 12: Information on Growth (top left), maturity (bottom right), weight-length (bottom left) and survivorship-to-age (top right) for Sandfish. Note that information on growth is assumed rather than estimated and was determined based on sensible values that match the known biology of the species. The blue shaded area shows the legal-sized portion of the population above the 16 cm LML. Various parameters of interest are shown as orange points on each panel.

3.4.2. Natural mortality

Natural mortality (M) was pre-specified in the model as $M = 0.65 \text{ yr}^{-1}$ (Figure 12) based on empirical estimators and information from Sandfish Aquaculture operations. Information on survivorship was available from released Sandfish from a commercial sea-ranching program. This was estimated to be 40.4% survival rate over a 10-month period which converts to an instantaneous natural mortality estimate of 0.71 yr^{-1} (Tasmanian Seafoods, unpublished data). However, this rate was noted as potentially being biased high as some Sandfish would evade being resighted due to low detectability during underwater visual surveys (Tasmanian Seafoods, unpublished data). This value therefore closely approximates other values determined through other indirect methods calculated using the natural mortality estimator tool (Cope & Hamel, 2022; <https://connect.fisheries.noaa.gov/natural-mortality-tool/>). The following empirical methods were applied (as per their names used in the natural mortality estimator tool): Then_nls, Then_lm, (Then et al., 2015), Hamel_Amax, (O. S. Hamel, 2015). These estimators provided values between 0.6 and 0.65 yr^{-1} . Natural mortality was assessed for appropriateness through parameter profiling (Appendix 7.2.3).

3.4.3. Recruitment

Recruitment was estimated within the model using a Beverton and Holt stock recruitment relationship (Beverton & Holt, 1957). The level of virgin (i.e., unfished) recruitment (R_0) was estimated in Stock Synthesis as a leading parameter while recruitment steepness (h) was pre-specified as 0.3. Steepness is a parameter that indicates recruitment compensation as spawning biomass decreases. An h value of 0.3 indicates that a recruitment equal to 30% of R_0 would be expected if spawning biomass were reduced to 20% of unfished levels. The value of 0.3 was determined as sea cucumber species are slow to recover following overexploitation and therefore steepness is likely to be low. This value has also been used in other Australian sea cucumber stock assessments (Smart et al., 2024a, 2024b). Steepness was assessed for appropriateness through parameter profiling (Appendix 7.2.3).

Recruitment deviations for the main time series were estimated between 2000/01 and 2020/21 for both stocks, while early phase recruitment deviations were estimated from the beginning of the time series. The timeframe of the main recruitment time series was determined based on the availability CPUE indices which are the key data that inform recruitment strength. The asymptotic standard error of annual recruitments (outputted using r4ss) was referred to when determining this period. Estimating recruitment in the most recent model years is rarely possible, as there should ideally be several years of composition data available to adequately estimate recruitment strength, which are never available for the most recent model timesteps.

The standard deviation of the natural log recruitment (σ_R) was initially pre-specified at 0.3 to represent that recruitment is unlikely to fluctuate to a reasonable degree around the stock recruitment relationship based on environmental influences. Previous sea cucumber stock assessments with similar data availabilities demonstrated that higher values of σ_R could lead to model overfitting (Smart et al., 2024a, 2024b). Therefore, this value was used for Sandfish to avoid similar issues and was assessed for appropriateness through parameter profiling (Appendix 7.2.3). The σ_R parameter was subsequently updated as part of the modelling tuning procedure (Section 3.5). The recruitment bias adjustment ramp was adjusted using recommended settings outputted through r4ss (Methot & Taylor, 2011; Taylor et al., 2021) and was also updated through the modelling tuning procedure (Section 3.5).

3.5. Model tuning

Following the estimation of a Base Case model, a series of model tuning procedures were performed. The purpose of these procedures was to ensure that different data inputs or model settings were appropriately weighted or optimised for the model. The model tuning procedures included:

- 1) Updating the recruitment bias adjustment ramp (Methot & Taylor, 2011) based on the alternative settings recommended by the initial Stock Synthesis Base Case run.
- 2) Updating the pre-specified value of σ_R based on recommendations from r4ss.

No composition tuning methods were applied as only one year of length composition data was available for each stock. Additional variance for the CPUE index was estimated and the results were examined. However, this led to a degree of underfitting that is prone to occur in stock assessments when only one CPUE index is available. Therefore, this tuning step was not included in the final tuned model. The methods outlined here follow the best practices recommended by Punt (2023) given the data available.

3.6. Sensitivity scenarios

Conducting sensitivity scenarios is an important component of any stock assessment, as population dynamics models need to be carefully specified, and the outcomes of different choices need to be considered. As a result, it is valuable and transparent to show the effect of different model specifications on the final outcomes. This builds support for the adoption of the Base Case model when the alternative model scenarios do not provide substantially different outcomes by using alternative specifications.

Numerous scenarios were conducted through the model development process, and seven of these are presented to demonstrate the impact of important model considerations. Each scenario used the model specifications of the Base Case model with updates made to specified components. Scenarios examining related specifications were grouped together and include 1) the use of different surveyed biomass inputs, and 2) different specifications for determining growth and fitting to length compositions.

Model parameter profiling was also undertaken to demonstrate the appropriateness of M , h and σ_R values that were pre-specified in the model. These are analogous to sensitivity scenarios and are performed by re-running the model across a larger number of potential values. Likelihood profiles and key model quantities are then examined to determine the impact of different parameter values on the assessment. These profiles are used to determine the most appropriate values to use in the model, rather than justify model specification and decision making. These profiles are therefore presented separately in Appendix 7.2.3.

3.7. Model outcomes

3.7.1. Base Case model

3.7.1.1. Summary

The spawning biomass for the East Stock was 686 t in 2024/25, equating to a relative spawning biomass of 88% (Figure 13). The stock was at its lowest level at 60% relative spawning biomass in 2006/07 before increasing to 98% in 2015/16 (Figure 13). This dynamic was driven by two abnormally high catch years in 2002/03 (124 t) and 2006/07 (165 t) which reduced the stock to this level (Figure 13). Substantially lower catches of 53 t or less since this period has led to the increase in biomass. The F/F_{MSY} threshold was breached in the two years of high catches (Figure 13). However, as these were anomalous years, the stock has maintained a sustainable status in all but those two years (when it would have been defined as “Depleting” based on harvest levels), as it was maintained above the limit reference point of 30% relative spawning biomass (Figure 13).

The West Stock had similar stock assessment results to the East stock. Its spawning biomass in 2024/25 was 1,644 t which equated to 89 % of relative spawning biomass (Figure 14). The lowest relative spawning biomass of 61% occurred in 2006/07 following nine years of higher catches (52 – 313 t) (Figure 14). The only two years where the F exceed F_{MSY} were 1999/2000 and 2000/2001, and accordingly the stock has had a sustainable status in all remaining years (Figure 14).

Given the data limited nature of the assessments (i.e., a single biomass estimate and length composition), the uncertainty around key parameters such as spawning biomass and recruitment is wide (Figure 13, Figure 14). This is appropriate given the level of data included in the models and identifies that these assessments were data-limited.

Stock assessment of Sandfish (*Holothuria scabra*) in the Northern Territory 2024/2025

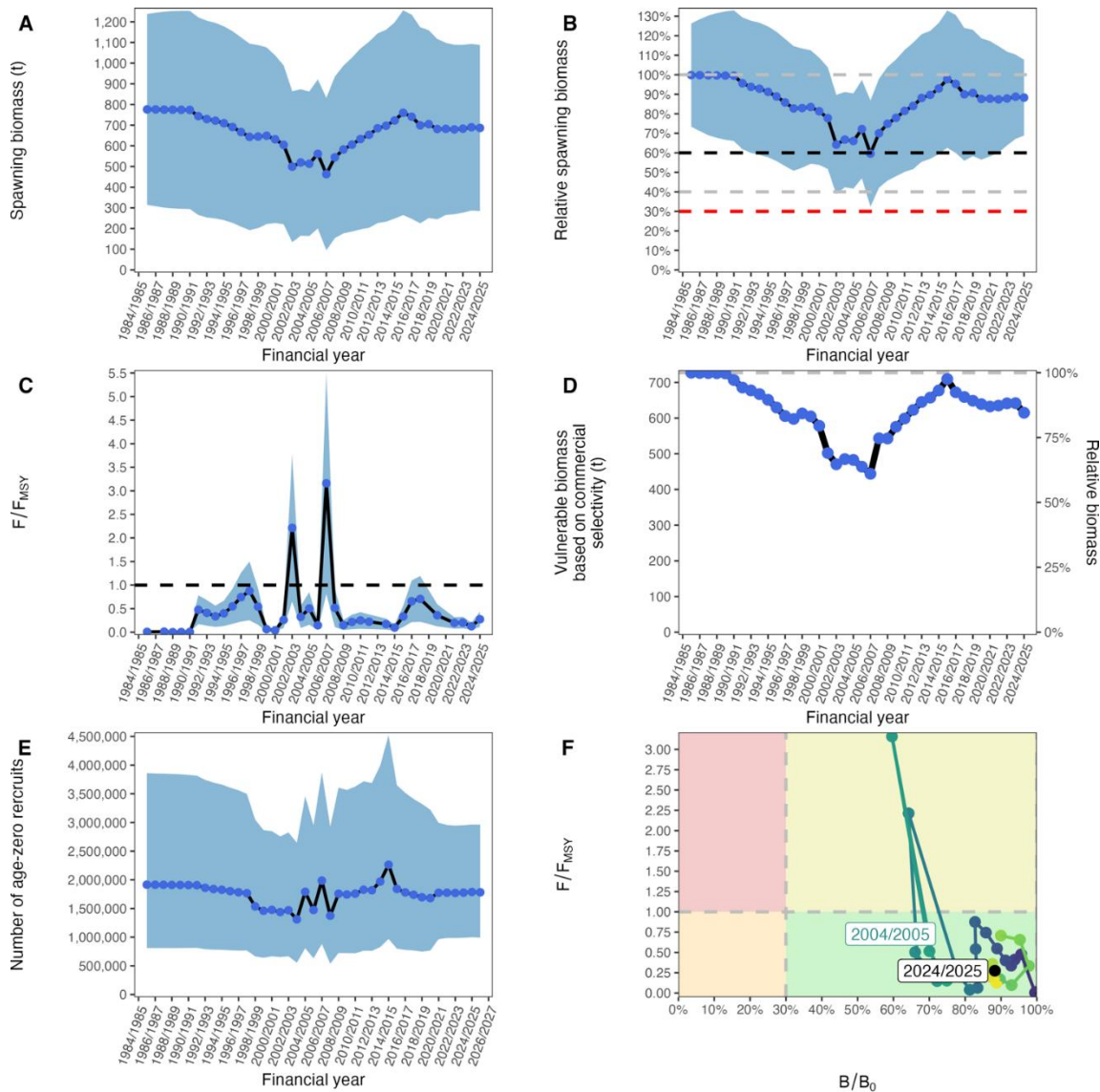


Figure 13: Key outcomes of the Base Case East Stock Sandfish model, where Panel A shows spawning biomass (tonnes) with blue shading indicating 95% confidence intervals; Panel B shows relative spawning biomass (B/B_0), with blue shading representing 95% confidence intervals, and dashed lines indicating B_{60} , B_{40} , and B_{30} reference points; Panel C shows F/F_{MSY} , with the dashed black line representing F_{MSY} ; Panel D shows vulnerable biomass; Panel E shows the number of age-zero recruits, with blue shading indicating 95% lognormal confidence intervals; and Panel F shows a phase plot of stock status changes over time.

Stock assessment of Sandfish (*Holothuria scabra*) in the Northern Territory 2024/2025

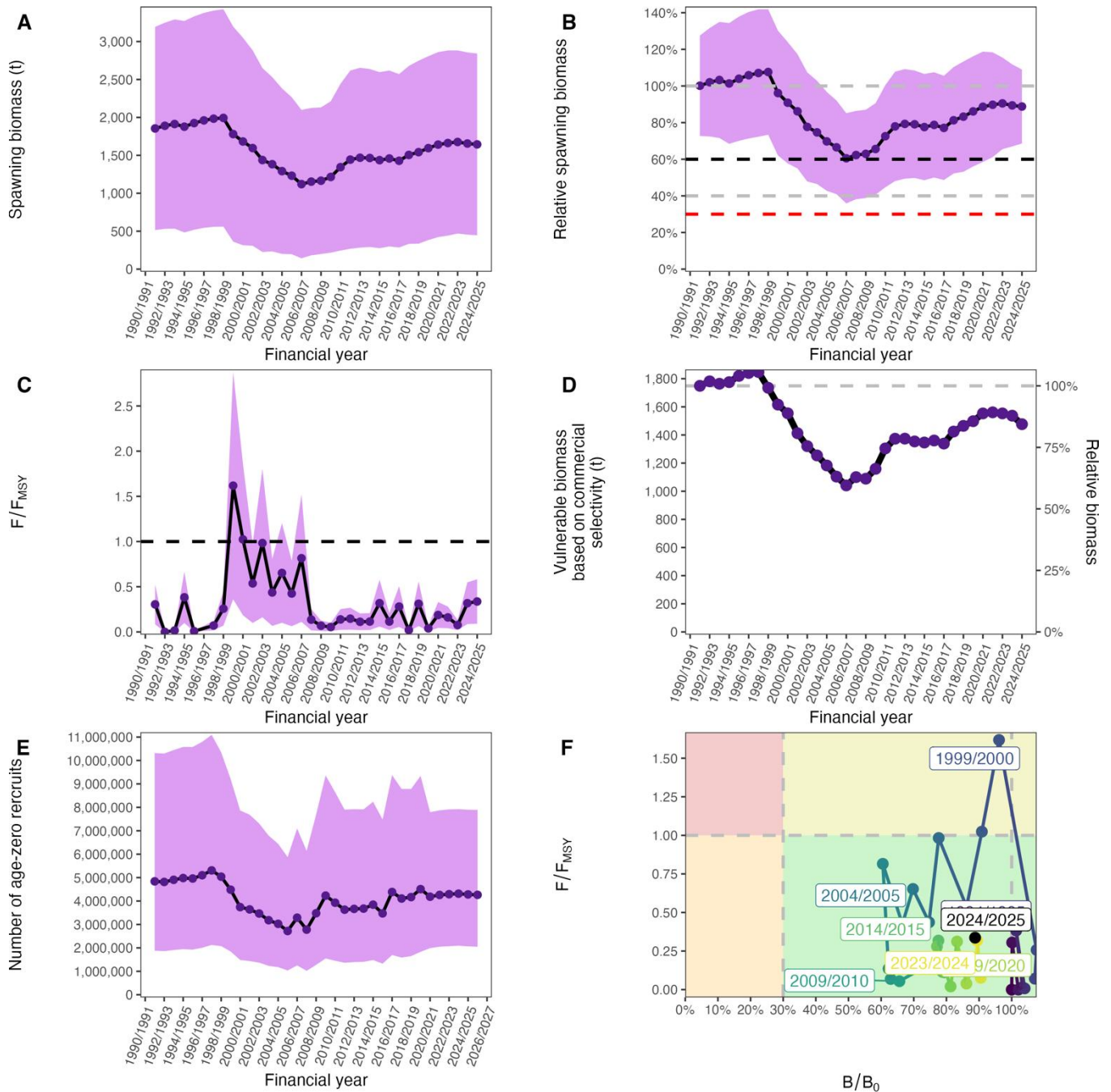


Figure 14: Key outcomes of the Base Case West Stock Sandfish model, where Panel A shows spawning biomass (tonnes) with purple shading indicating 95% confidence intervals; Panel B shows relative spawning biomass (B/B_0), with purple shading representing 95% confidence intervals, and dashed lines indicating B_{60} , B_{40} , and B_{30} reference points; Panel C shows F/F_{MSY} , with the dashed black line representing F_{MSY} ; Panel D shows vulnerable biomass; Panel E shows the number of age-zero recruits, with blue shading indicating 95% lognormal confidence intervals; and Panel F shows a phase plot of stock status changes over time.

3.7.1.2. Estimated quantities

Information on parameter estimates and pre-specified or mirrored quantities is provided in Table 3. The Base Case model converged and was successfully tuned. Detailed diagnostics, including model profiles, are provided in the appendices (Appendix 7.2.3).

Table 3: Model parameter results for the East Stock with specifications of how they were treated (estimated, mirrored, etc.) and other pertinent information.

Type	Parameter	Value	Treatment	Notes
Biology	Natural mortality (M)	0.65 yr^{-1}	Pre-specified	
	Length-at-age 2 (L_2)	30 cm TL	Pre-specified	Set as asymptotic length (L_∞)
	Length-at-age 1 (L_1)	1 cm TL	Pre-specified	Set as 0.5 years ($L_{0.5}$)
	Growth coefficient (k)	0.5 yr^{-1}	Pre-specified	
	CV at L_1	0.1	Pre-specified	
	CV at L_2	0.1	Pre-specified	
	Length-at-50%-mature	16 cm	Pre-specified	
	Length-at-95%-mature	18 cm	Pre-specified	
	WL_a	0.00092	Pre-specified	
	WL_b	2.11	Pre-specified	
Recruitment dynamics	Virgin recruitment ($\log R_0$)	7.56	Estimated	
	Steepness (h)	0.3	Pre-specified	
	Recruitment variability (σ_R)	0.31	Tuned	Tuned using SS alternative value
Fishery dynamics	Selectivity-at-length inflection - Survey	11.4 cm TL	Estimated	Logistic function
	Selectivity-at-length width - Survey	3.5 cm TL	Estimated	Logistic function
	Selectivity-at-length inflection Commercial -	-	Mirrored Survey to	Logistic function - zero below LML
	Selectivity-at-length width - Commercial	-	Mirrored Survey to	Logistic function - Zero below LML

Table 4: Model parameter results for the West Stock with specifications of how they were treated (estimated, mirrored, etc.) and other pertinent information.

Type	Parameter	Value	Treatment	Notes
Biology	Natural mortality (M)	0.65 yr^{-1}	Pre-specified	
	Length-at-age 2 (L_2)	30 cm TL	Pre-specified	Set as asymptotic length (L_∞)
	Length-at-age 1 (L_1)	1 cm TL	Pre-specified	Set as 0.5 years ($L_{0.5}$)
	Growth coefficient (k)	0.5 yr^{-1}	Pre-specified	
	CV at L_1	0.1	Pre-specified	
	CV at L_2	0.1	Pre-specified	
	Length-at-50%-mature	16 cm	Pre-specified	
	Length-at-95%-mature	18 cm	Pre-specified	
	WL_a	0.00092	Pre-specified	
	WL_b	2.11	Pre-specified	
Recruitment dynamics	Virgin recruitment ($\log R_0$)	8.42	Estimated	
	Steepness (h)	0.3	Pre-specified	
	Recruitment variability (σ_R)	0.31	Tuned	Tuned using SS alternative value
Fishery dynamics	Selectivity-at-length inflection - Survey	14.9 cm TL	Estimated	Logistic function
	Selectivity-at-length width -Survey	0.86 cm TL	Estimated	Logistic function
	Selectivity-at-length inflection - Commercial	-	Mirrored Survey to	Logistic function - zero below LML
	Selectivity-at-length width - Commercial	-	Mirrored Survey to	Logistic function - Zero below LML

3.7.1.2.1. Selectivity

The estimated selectivity-at-length was different for each stock, indicating that smaller individuals were more available for harvest for the East Stock (Figure 15). However, the commercial selectivity-at-length was very similar for each stock given that it has a knife edge selectivity on the LML of 16 cm. Sandfish of this length were fully selected for both stocks, given the selectivity-at-length curve estimated for the surveys, which was used to mirror the commercial selectivity (Figure 15).

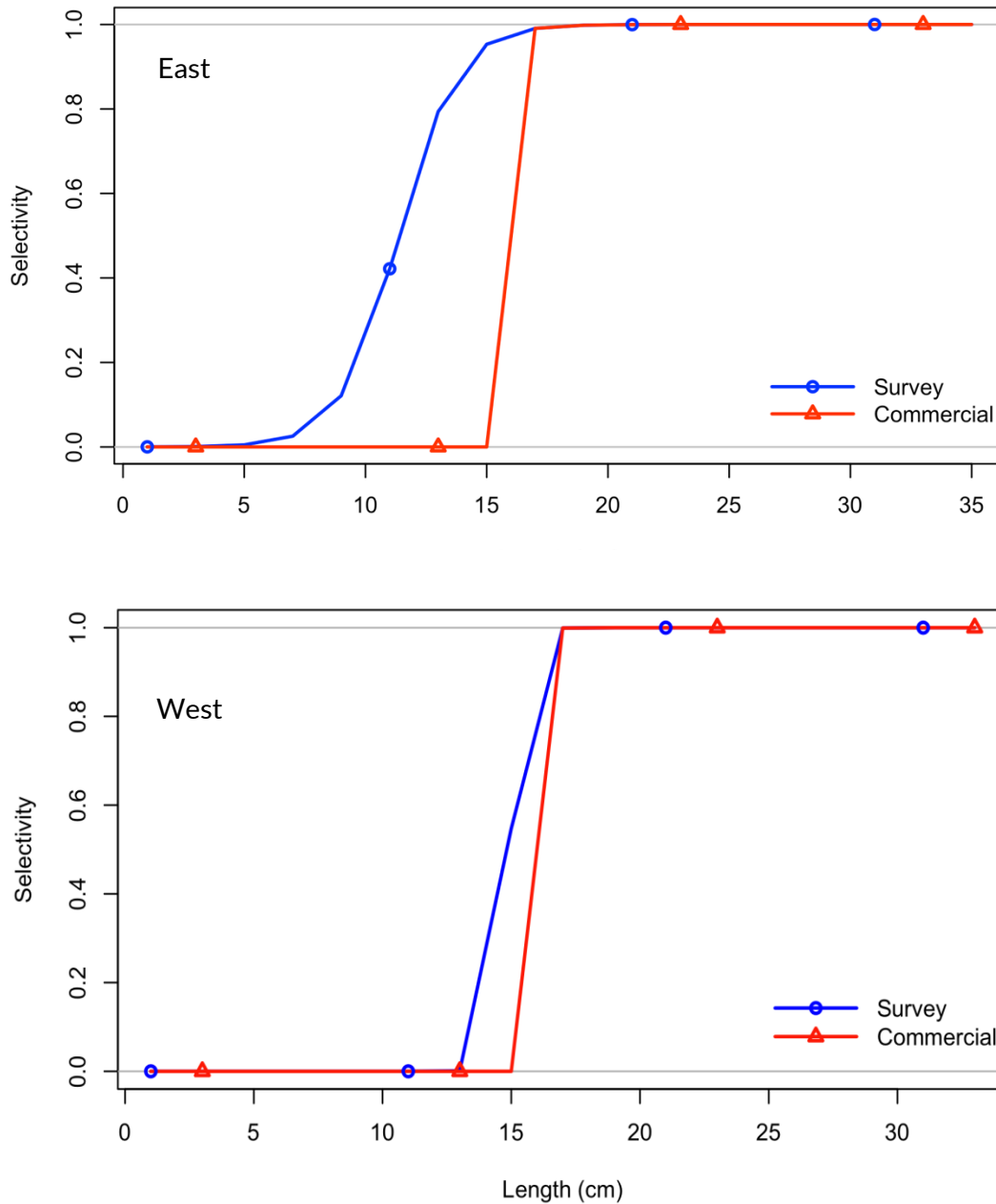


Figure 15: Selectivity-at-length estimated within the Stock Synthesis model for the East Stock (Top) and West Stock (Bottom). Note that the commercial selectivity is mirrored to survey selectivity above the LML of 16 cm.

3.7.1.2.2. Recruitment

The East Stock had an unfished recruitment (R_0) in log-space of 7.56 (Table 3) which converts to 1,919,846 age-zero recruits. Similarly, the West Stock had an unfished recruitment (R_0) in log-space of 8.42 (Table 4) which converts to 4,536,903 age-zero recruits. The σ_R was initially pre-specified as 0.3 for both stocks and was subsequently tuned to 0.31 for both stocks (Table 3, Table 4). The steepness (h) of both stocks was pre-specified as 0.3. The bias adjustment ramps for both stocks show that limited information was provided to the model to estimate recruitment, very likely due to only a single year of length information being available (Figure 16, Figure 17). Therefore, pre-specifying σ_R reduces the opportunity for the model to overfit to CPUE estimates (Section 3.7.1.3.1).

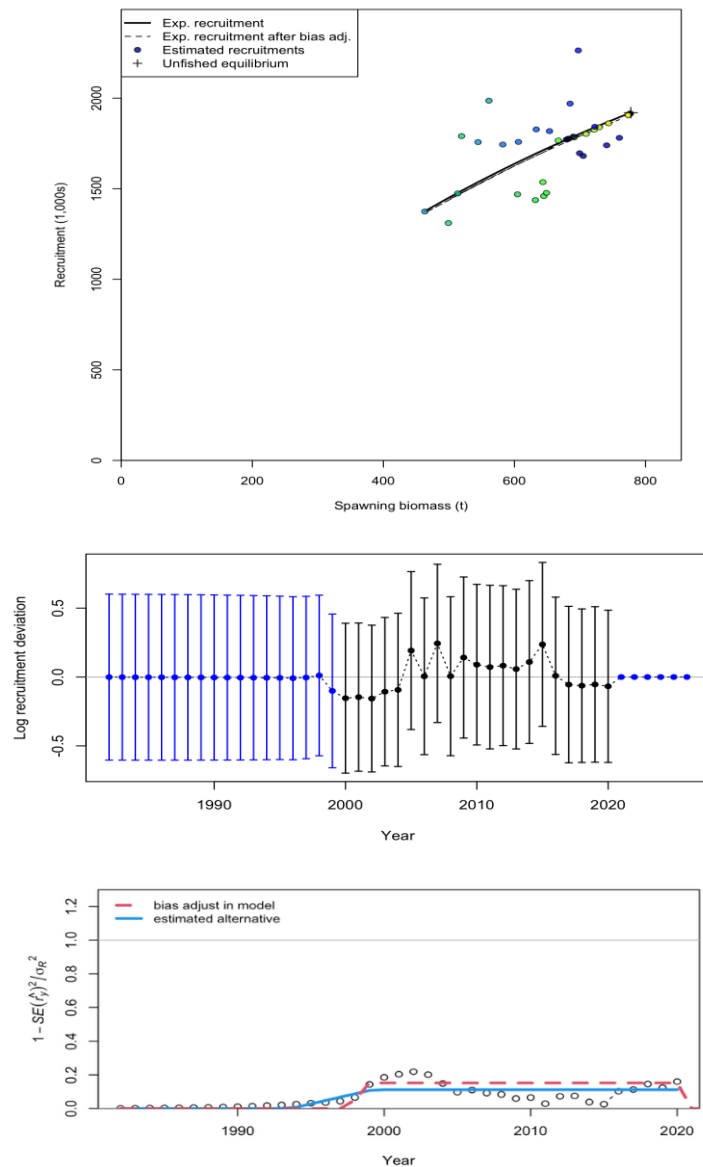


Figure 16: Stock recruitment relationship (Top), recruitment deviations and estimated standard error (Middle), and the recruitment bias adjustment ramp (Bottom) for the East Stock. The x-axis displays integer years where 2020 corresponds to the 2019/20 fishing season, and so forth.

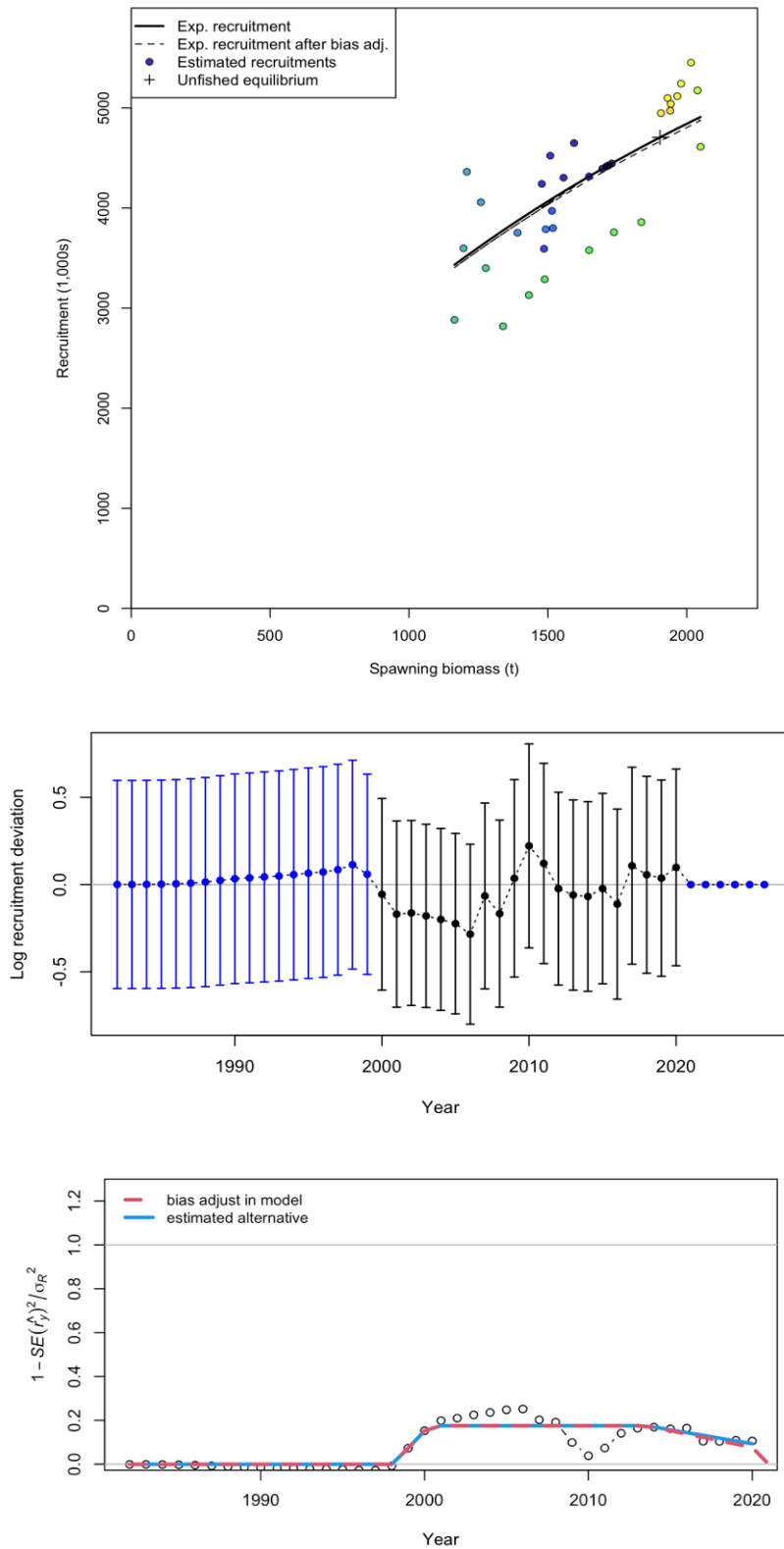


Figure 17: Stock recruitment relationship (Top), recruitment deviations and estimated standard error (Middle), and the recruitment bias adjustment ramp (Bottom) for the West Stock. The x-axis displays integer years where 2020 corresponds to the 2019/20 fishing season, and so forth.

3.7.1.3. Model fits to data

3.7.1.3.1. Abundance indices

The model fit closely the surveyed biomass estimates of both stocks available in 2024/25, effectively conditioning the model on these data points (Figure 18,

Figure 20). The model fit to the commercial abundance index determined through CPUE standardisation was adequate for both stocks. The model fits passed within the standard errors for all years except 2016/17 for the East Stock, and 2007/08 and 2009/10 for the West Stock (Figure 19, Figure 21).

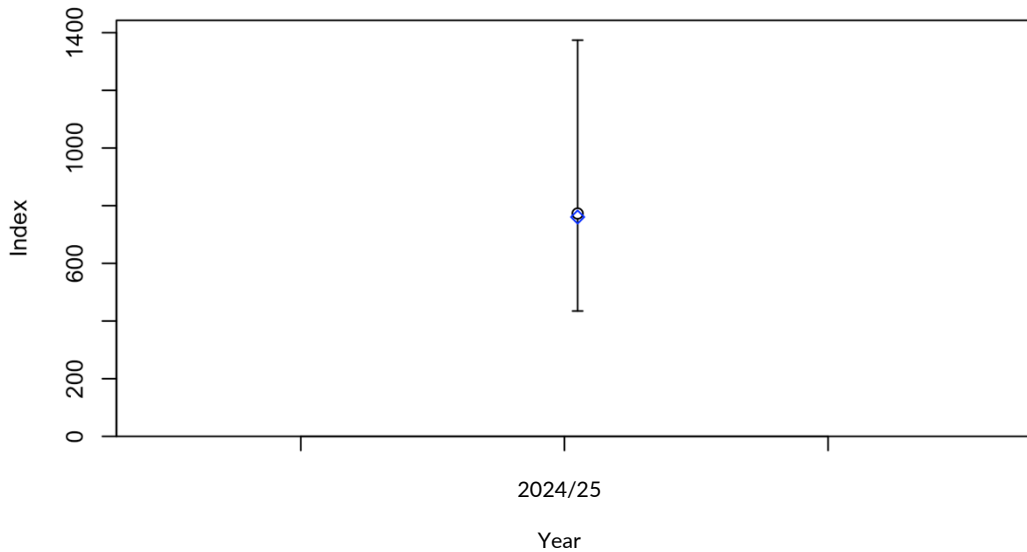


Figure 18: Model fit (blue point) to the survey biomass estimate index (open point) for the East Stock. The error bars represent lognormal standard errors input to the model.

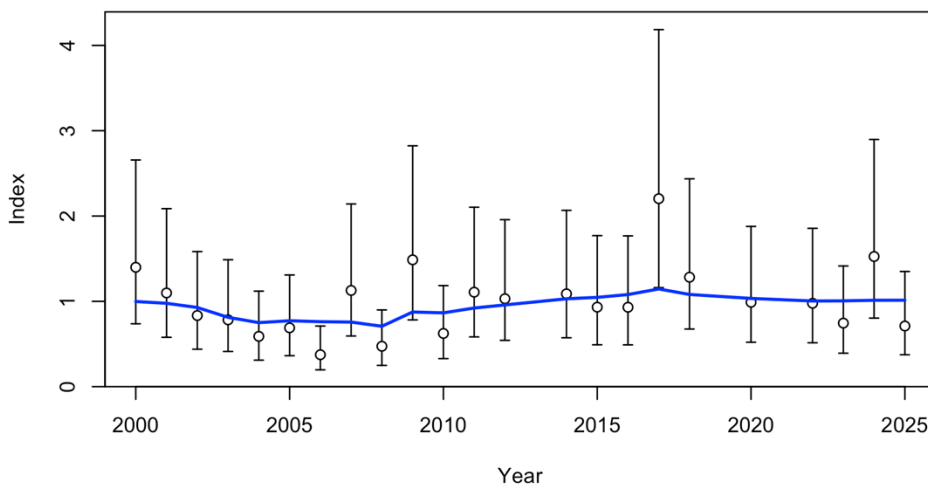


Figure 19: Model fit (blue line) to the CPUE index (points) for the East Stock commercial fleet. The error bars represent lognormal standard errors input to the model. The x-axis displays integer years where 2020 corresponds to the 2019/20 fishing season, and so forth.

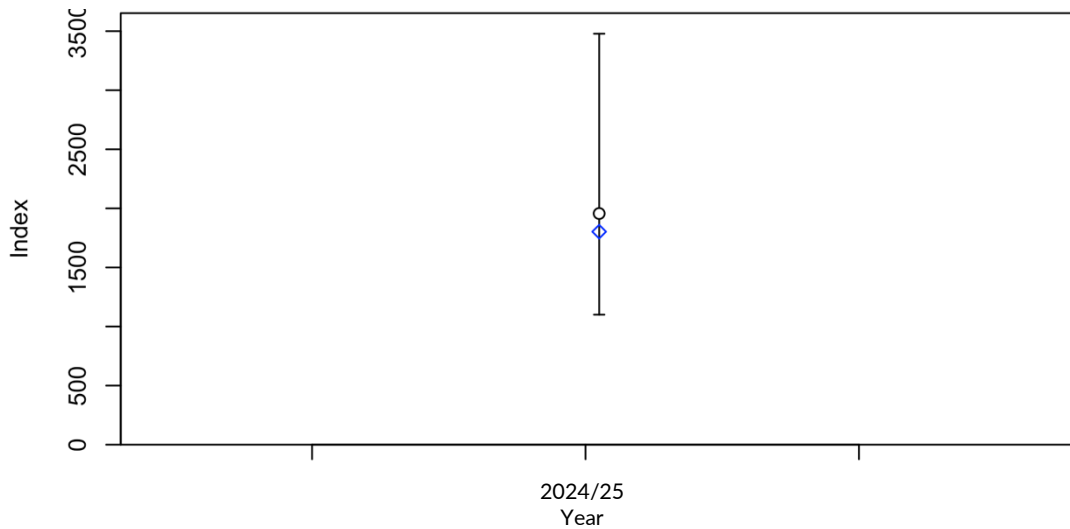


Figure 20: Model fit (blue point) to the survey biomass estimate index (open point) for the West Stock. The error bars represent lognormal standard errors input to the model.

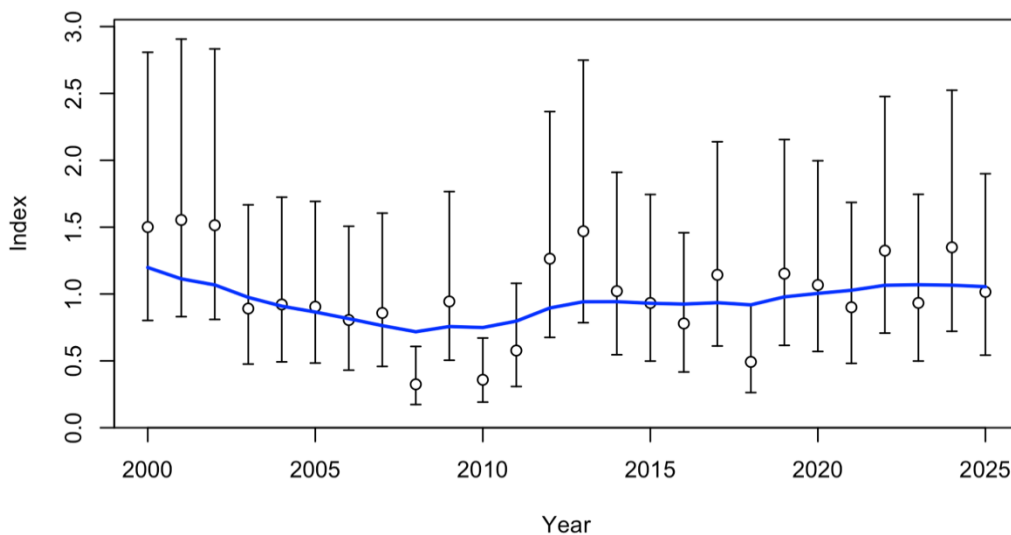


Figure 21: Model fit (blue line) to the CPUE index (points) for the West Stock commercial fleet. The error bars represent lognormal standard errors input to the model. The x-axis displays integer years where 2020 corresponds to the 2019/20 fishing season, and so forth.

3.7.1.3.2. Length compositions

The fit to length compositions for both stocks was reasonably poor, especially to the peak and right-hand limbs (Figure 22, Figure 23). The better fit to the left-hand limb of each stock indicates that selectivity was well estimated (Figure 22, Figure 23). However, the poor right-hand limb suggests that growth is poorly specified for the model. A number of sensitivity analyses were undertaken to explore this (Section 3.7.2.2), and further discussion is provided in Section 0.

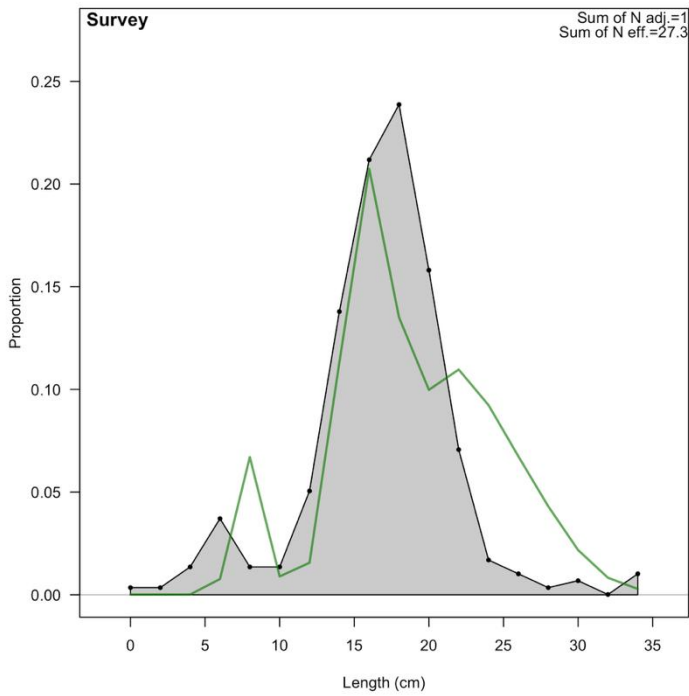


Figure 22: Model fit (green line) to survey length compositions for the East Stock in 2024/25. Lengths were grouped into 2cm bins.

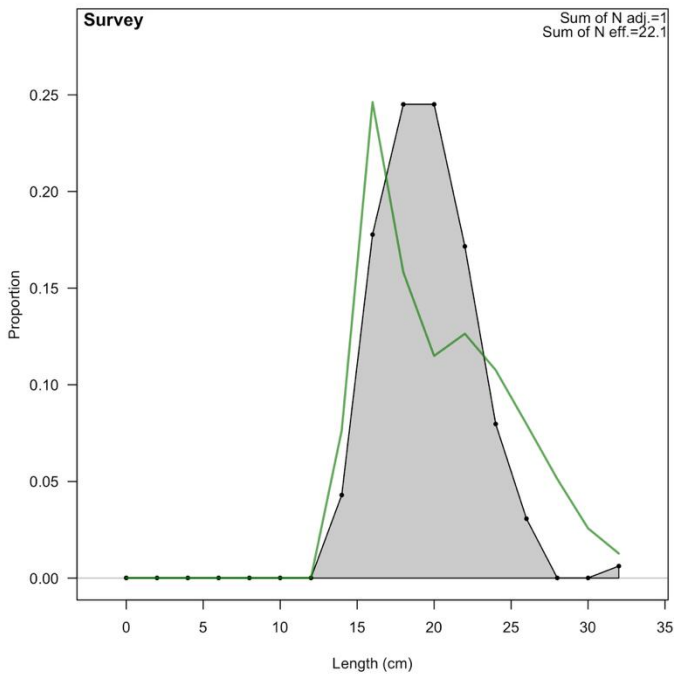


Figure 23: Model fit (green line) to survey length compositions for the West Stock in 2024/25. Lengths were grouped into 2cm bins.

3.7.2. Sensitivity scenarios

Seven sensitivity scenarios are presented to demonstrate the impact of decision making and data exploration that was part of the stock assessment modelling process. Each of the scenarios presented use alterations to the tuned Base Case model to examine the effect of specific considerations. Each scenario culminates in one of three conclusions: 1) The scenario did not differ to the Base Case, indicating that the model is uninfluenced by this decision or consideration, 2) a scenario provides a different outcome to the Base Case model, but the scenario provided a poorer fit to the data or did not achieve convergence and therefore should be dismissed, 3) a scenario provides a different outcome to the Base Case model with appropriate convergence and model fit, but cannot be accepted as its considerations are not reasonable. Model convergence was determined based on whether any model had a final gradient less than 0.0001 (a standard threshold for Stock Synthesis).

Given the number of scenarios performed, these were grouped accordingly for clear presentation and exploration of results. The scenarios, groupings, descriptions, and a summary of convergence and stability are provided in Table 5. All seven sensitivity scenarios were performed for both stocks.

Table 5: List and description of modelled sensitivity scenarios, whether they converged and if they were stable following model tuning procedures. Convergence was determined based on whether the final gradient was lower than 0.0001 and the model variance could be estimated.

Group	Scenario	Description	Converged (East Stock)	Converged (West Stock)
Alternative biomass inputs	1 – No biomass scaling	No scaling from grid level to stock level biomass applied	Yes	Yes
Alternative biomass inputs	2 – Biomass extrapolation method 2	Alternate biomass estimated from Koopman and Knuckey (2025) applied	Yes	Yes
Alternative biomass inputs	3 – Scenario 3 - Biomass extrapolation method 2 without scaling	Alternate biomass estimated from Koopman and Knuckey (2025) applied and no scaling from grid level to stock level biomass applied	Yes	Yes
Alternate growth/length treatment	4 – Dome shaped selectivity	Dome shaped selectivity used instead of logistic selectivity for survey and commercial fleet	Yes	No gradient was 0.0003
Alternate growth/length treatment	5 – Length shrinkage	Length measurements used in compositions increased by 25% to test potential impacts of sea cucumbers shrinking when measured.	Yes	No gradient was 0.0002
Alternate growth/length treatment	6 – Larger L_{∞}	L_{∞} increased to 35cm	Yes	Yes

length treatment				
Alternate growth/length treatment	7 – Smaller L_{∞}	L_{∞} reduced to 25cm	No gradient was 0.0007	Yes

3.7.2.1. Alternative biomass inputs

As discussed in Section 3.3.2.1, two estimates of biomass were available for each stock, and both required scaling from the grid to stock level. Accordingly, three sensitivity scenarios explored the impact of 1) the selected biomass estimate for the Base Case model and 2) the effect of the grid to stock scaling on both biomass estimates.

Scenario 1: No biomass scaling – As described in Section 3.3.2.1, surveyed biomass estimates were scaled from the grid to stock level before input to the Base Case models. This scenario examines the impact of removing this scaling. Little to no change in key spawning biomass nor relative spawning biomass occurred for the East Stock as the applied scaling was 95.9 % (Figure 24). Whereas a reduction in relative spawning biomass and spawning biomass occurred for the West Stock as the applied scaling was 56.8 % (Figure 25). This scenario for the West Stock therefore represents a very conservative scenario where the surveys account for the entire biomass. Despite the conservativeness of this approach no changes in stock status for 2024/25 were determined for either stock.

Scenario 2: Biomass extrapolation method 2 – The second available biomass estimate from Koopman and Knuckey (2025) was used as an input to the stock assessment models, rather than extrapolation method 1. This provided opposing results for the two stocks, as extrapolation method 2 provided a lower biomass estimate for the East Stock and a higher biomass for the West Stock (Figure 24, Figure 25). However, no changes in stock status for 2024/25 were determined for either stock.

Scenario 3: Biomass extrapolation method 2 with no scaling applied – This scenario is a combination of scenario 1 and 2 and was undertaken for completeness. No changes in stock status were determined for either stock.

In summary, the differences in biomass inputs to the models produced the expected outcomes. Given that these models were conditioned on the survey biomass estimates, the R_0 is scaled up and down accordingly with the inputs used (Figure 24, Figure 25). However, the stock status remains unchanged as only the scale of the biomass is affected. This has two important conclusions: 1) stock status is unchanged by the biomass inputs, and 2) the resulting catch advice will be affected given the stock size is directly related to these values. Therefore, careful consideration was taken in selecting extrapolation method 1 for the Base Case models (Koopman & Knuckey, 2025), as outlined in Section 3.3.2.1.

Stock assessment of Sandfish (*Holothuria scabra*) in the Northern Territory 2024/2025

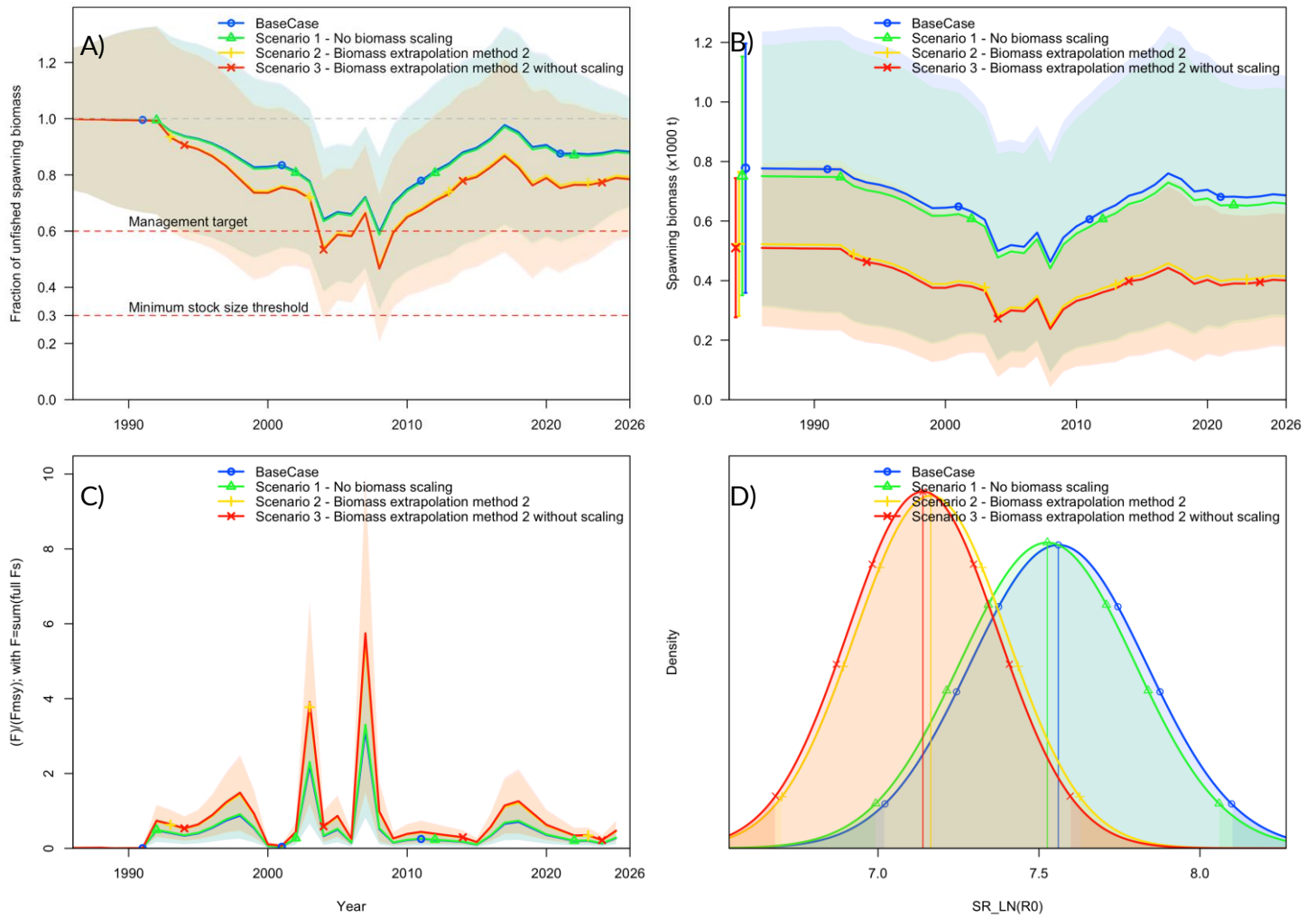


Figure 24: East Stock model outputs for sensitivity scenarios examining alternative biomass inputs: A) relative unfished spawning biomass, B) absolute spawning biomass (x 1000 t), C) F/F_{MSY} , and D) densities of estimated $\log(R_0)$. Three sensitivity scenarios are displayed (red, yellow and green lines and shading) and compared to the tuned Base Case (blue line and shading). Shading on panels A, B and C shows 95% confidence intervals.

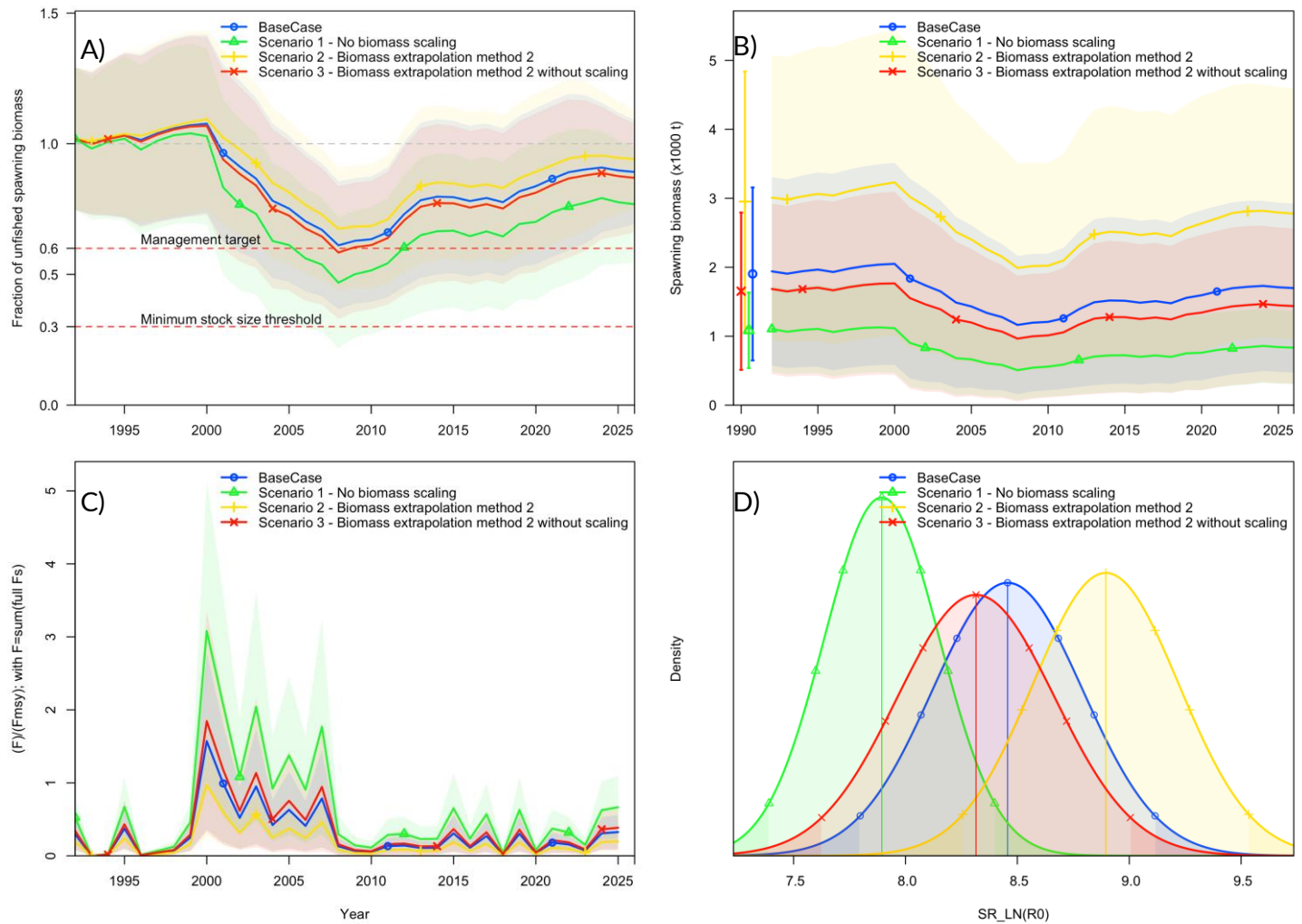


Figure 25: West Stock model outputs for sensitivity scenarios examining alternative biomass inputs: A) relative unfished spawning biomass, B) absolute spawning biomass (x 1000 t), C) F/F_{MSY} , and D) densities of estimated $\log(R_0)$. Three sensitivity scenarios are displayed (red, yellow and green lines and shading) and compared to the tuned Base Case (blue line and shading). Shading on panels A, B and C shows 95% confidence intervals.

3.7.2.2. Alternative growth or length treatments

A variety of scenarios were undertaken to determine alternative approaches to growth or length composition treatment in the models:

Scenario 4: Dome shaped selectivity – A poor initial fit to the right-hand limb of the length composition data could be due to miss-specified selectivity. A logistic function will not capture a reduction in selectivity at larger lengths, and this can be addressed by fitting a dome shaped selectivity function instead. This accounts for a right-hand limb of length compositions that occur before the L_∞ . However, without a logistic selectivity function included in the model, this approach can create “cryptic” biomass which is not detectable by any data element and is freely and unreliably estimated by the model. This occurred here for both stocks and did not result in an improved fit to the length compositions (Figure 26, Figure 27), and this scenario did not converge for the West Stock (Table 5). These scenarios were subsequently rejected as their purpose was mostly for exploration.

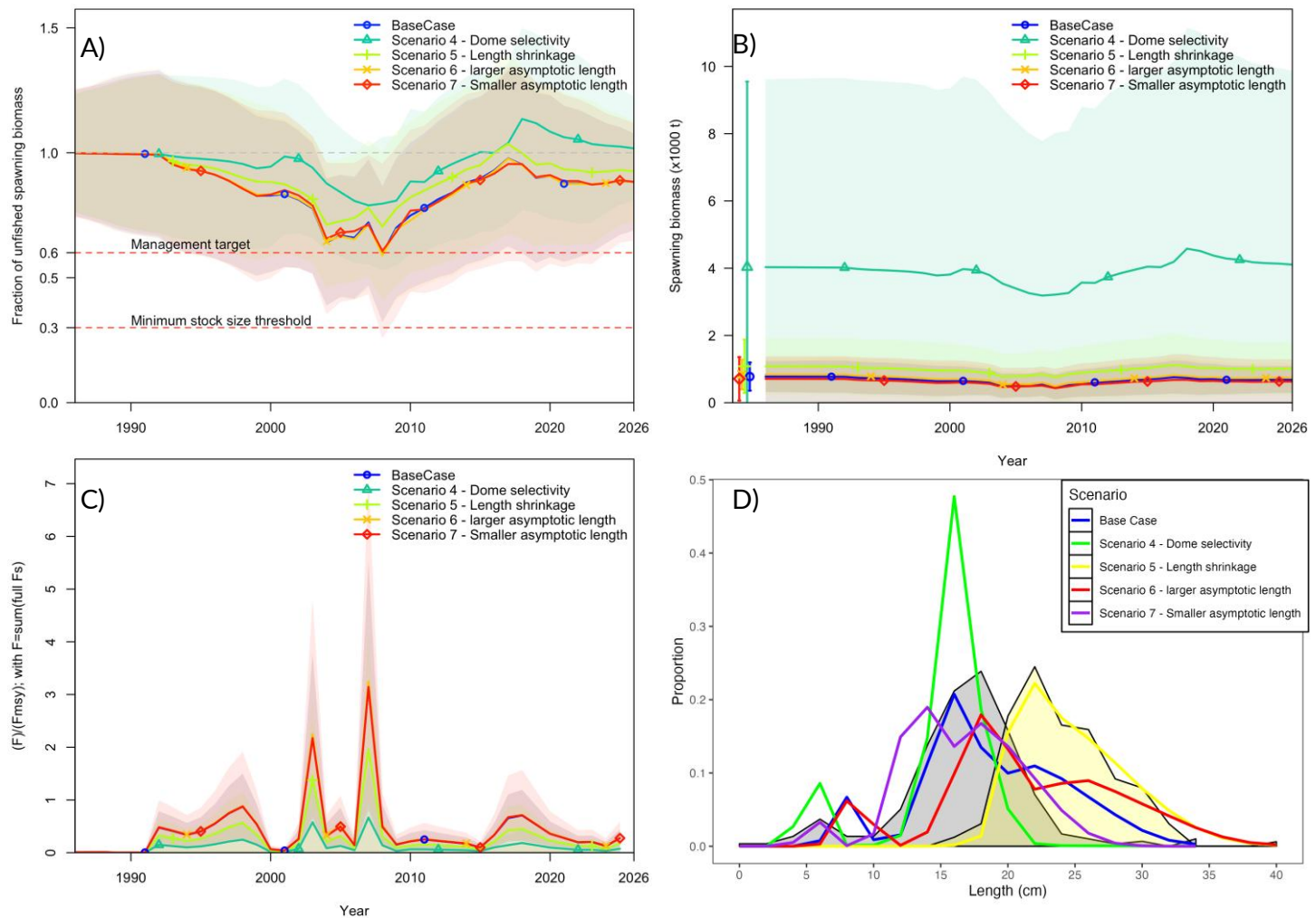


Figure 26: East Stock model outputs for sensitivity scenarios examining alternative growth and length treatments: A) relative unfished spawning biomass, B) absolute spawning biomass (x 1000 t), C) F/F_{MSY} , and D) model fits (coloured lines) to length compositions (grey shading) and adjusted length compositions for scenario six (yellow shading). Four sensitivity scenarios are displayed (red, teal, yellow and green lines and shading) and compared to the tuned Base Case (blue line and shading). Shading on panels A, B and C shows 95% confidence intervals.

Scenario 5: Length shrinkage – Sea cucumbers are unusual in that they can elongate and shrink in length, making precise measurements difficult to undertake. While care was taken by Koopman and Knuckey (2025) to collect accurate length measurements there remains a possibility that onboard measurements could be underestimates. A similar uncertainty was experienced by Smart et al (2024a, 2024b) and was addressed through a sensitivity analysis where raw lengths were increased by 25% and the length composition was recalculated. This same scenario was applied here, given that the larger individuals collected by Koopman and Knuckey (2025) were substantially smaller than the known species maximum size. A better fit occurred to these data for the East Stock (Figure 26), but not the West Stock (Figure 27), while very similar relative spawning biomasses occurred for both stocks (Figure 26, Figure 27). Therefore, these scenarios were subsequently rejected as their purpose was mostly for exploration.

Scenario 6: Larger L_{∞} – Given that assumed values of L_{∞} were used in the Base Case models, a larger value of 35 cm was applied to examine the effect of these strong growth assumptions. A larger L_{∞} will likely negatively bias stock assessments outcomes by creating the appearance of length class truncation when applied with the same length composition data as the base case. However, the sensitivity analyses show

little sensitivity to this with relative and spawning biomass estimates that are similar to the Base Case models for each stock (Figure 26, Figure 27). The length compositions are notably poorer for both stocks, indicating that the model cannot explain length class truncation from the information available (Figure 26, Figure 27). This is due to the models being conditioned on absolute biomass estimates that demonstrate light exploitation when considered to the levels of catch.

Scenario 7: Smaller L_{∞} – This scenario demonstrates the opposing effect to Scenario 6 as a smaller L_{∞} was pre-specified in the stock assessment models. A smaller L_{∞} will positively bias stock assessment outcomes by making a length composition appear less truncated when applied with the same length composition data as the base case. Similar to Scenario 6, this results in little sensitivity to the models due to their conditioning on absolute biomass estimates (Figure 26, Figure 27). However, an improved fit to the length composition is apparent for the West Stock as the smaller L_{∞} allows a better fit to the right-hand limb (Figure 27).

In summary, both Base Case models justify the use of a logistic length selectivity function and poor fits to length compositions occur due to a lack of good quality information on growth parameters. However, both Base Case models are insensitive to these poor fits compositions, and the key quantities of interest (spawning biomass and relative spawning biomass) are not altered under different growth parameter assumptions.

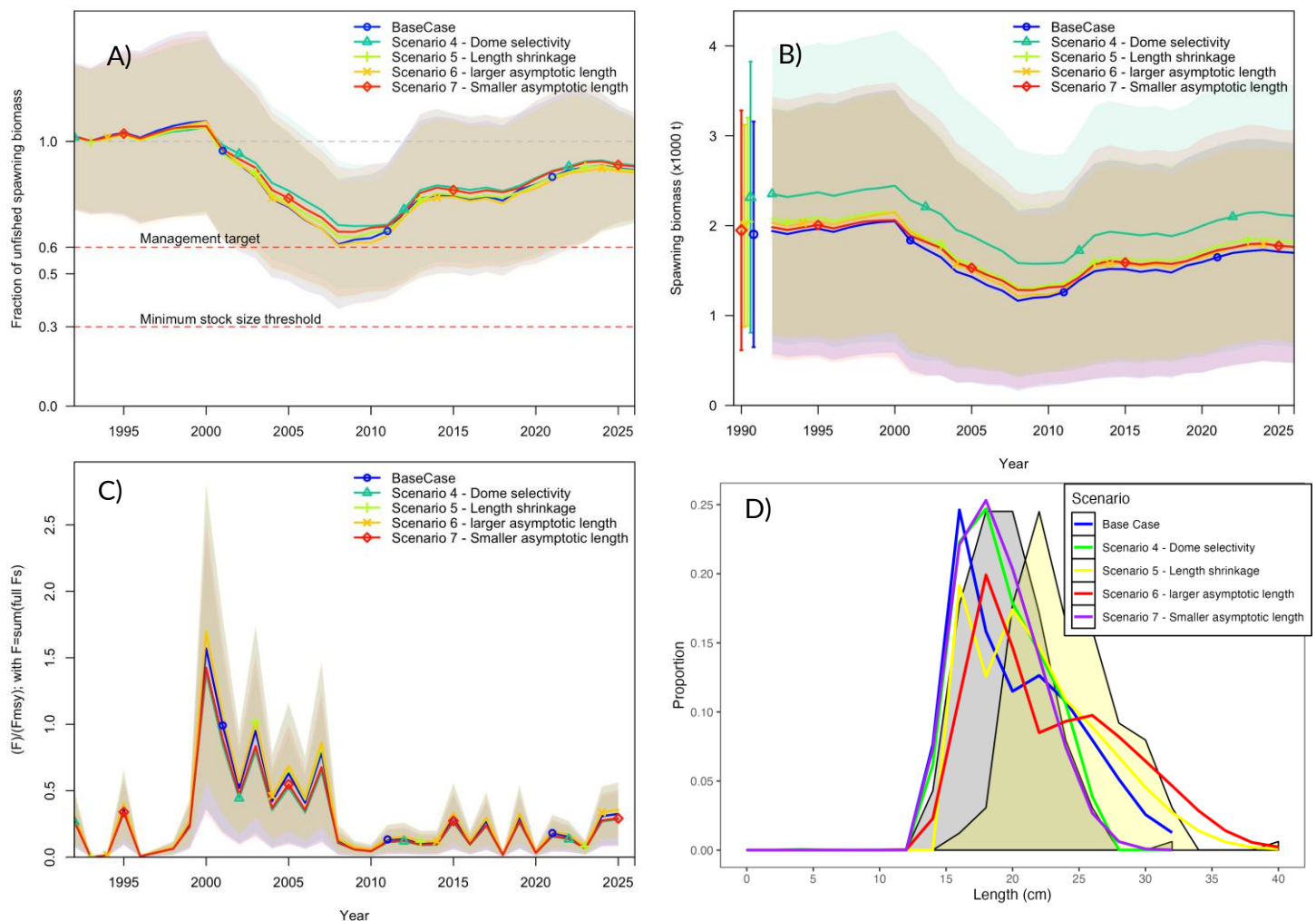


Figure 27: West Stock model outputs for sensitivity scenarios examining alternative growth and length treatments: A) relative unfished spawning biomass, B) absolute spawning biomass (x 1000 t), C) F/F_{MSY} , and D) model fits (coloured lines) to length compositions (grey shading) and adjusted length compositions for

scenario six (yellow shading). Four sensitivity scenarios are displayed (red, teal, yellow and green lines and shading) and compared to the tuned Base Case (blue line and shading). Shading on panels A, B and C shows 95% confidence intervals.

4. Discussion

4.1. Stock status

4.1.1. East Stock

The Stock Synthesis model estimated that the relative spawning biomass was 88% in 2024/25, which is above the target of 60%. The relative spawning biomass has never breached the target reference point despite two years of high catches in 2002/03 and 2006/07. These were the only years where $F > F_{MSY}$ and where the stock would have been considered 'depleting' according to the National Fishery Status Reporting Framework (Piddocke et al., 2021).

On the basis of the evidence provided above, the stock is unlikely to be depleted, and the recruitment is unlikely to be impaired. Sandfish from the East Stock was classified as **Sustainable**.

4.1.2. West Stock

The Stock Synthesis model estimated that the relative spawning biomass was 89% in 2024/25, which is above the target of 60%. Similar to the East Stock, the relative spawning biomass has never breached the target reference point despite a period of high catches from 1999/00 to 2006/07. However, only two of these years had $F > F_{MSY}$ and where the stock would have been considered 'depleting' according to the National Fishery Status Reporting Framework (Piddocke et al., 2021). The West Stock is larger than the East Stock and as a result has supported higher levels of catch through time.

On the basis of the evidence provided above, the stock is unlikely to be depleted, and the recruitment is unlikely to be impaired. Sandfish from the West Stock was classified as **Sustainable**.

4.2. Assessment development and remaining uncertainties

4.2.1. Model uncertainties

Stock Synthesis models are often comprehensive assessments applied to data-rich stocks. However, the Stock Synthesis framework can be applied to data-limited stocks and has a growing number of approaches that can accomplish this (Cope, 2013, 2024; Cope et al., 2015). The Stock Synthesis models applied to the East and West Sandfish stocks were a data-limited application which more closely resemble an age-structured surplus production model, rather than an integrated assessment. This is because these models only included catch, CPUE as an index of abundance, limited biological information and a single estimate of biomass and length composition from a recent survey. Similar models have been successfully applied to sea cucumber species in Queensland (Smart et al., 2024b, 2024a) and Sandfish in WA (Hart, 2023). Therefore, the models applied here were based on processes developed in those assessments.

A key concept of data-limited stock assessment modelling is that assumptions replace unavailable data during model development. Accordingly, any strong assumptions that were required for the East and West Stock models were assessed through sensitivity scenarios that explored alternate options. Model diagnostics using the ss3diags package were also examined to assess model specification and performance. These diagnostics (Section 7.2) highlighted some degree of model instability and sensitivity to key inputs. The likelihood profile for R_0 determined that the models had issues estimating scale (i.e. absolute spawning

biomass) and have the potential to underestimate stock size. This is indicated by the right-hand limb of the profile remaining within 1.96 likelihood points of the Base Case models. However, the R_0 profiling also demonstrated that status (i.e., relative spawning biomass) could be better estimated and different R_0 values had little influence on this quantity. This is common for data-limited approaches as more sources of information are required to inform scale versus status (Cope, 2024). It is particularly common for stocks that have been lightly exploited as there is less information available on productivity which is particularly important for estimating scale. This is the case for both the East and West stock assessment models, where a lower bound for R_0 was confidently estimated but an upper bound was not. In this situation, it is unlikely that either model has over-estimated the absolute spawning biomass which would be sufficient to reject the stock assessments due to increased risk of overfishing (Punt et al., 2020).

The model diagnostics and the sensitivity scenarios demonstrated consistent estimates of relative biomass, indicating that status can be well estimated by these models. This is typical of data-limited approaches which are often used as performance indicators with other empirical methods used to adjust harvests. However, the models for the East and West Stocks included recent estimates of absolute biomass, differentiating them from the majority of data-limited approaches. These biomass estimates were used to condition the model and the sensitivity scenarios and the diagnostics demonstrated that this was the strongest information available to the models to inform scale. This caused the models to fail the retrospective analyses, as the surveyed biomass estimates occurred in the final model year. Therefore, the spawning biomass estimates immediately deviated from those of the Base Case during the first retrospective peel. Effectively, the estimates of biomass from the surveys provide the information on scale while the stock assessment model extends this to provide an estimate of status. As a result, the level of confidence that fisheries managers would place on the surveyed biomass estimates should match the confidence that they should have in these assessment models.

Given that different biomass estimates were provided by Koopman and Knuckey (2025), the choice of which biomass estimates to include as inputs was a key decision. Biomass method 1 was selected for the Base Case as: 1) biomass was calculated as the final step in the calculation, better accounting for variable densities across strata and 2) method 2 also appeared to underestimate the biomass for the East Stock as surveyed areas as high abundances were excluded from the calculations due to the lack of fishing activity in those areas. Method 1 provided the lowest biomass estimate for the West Stock, therefore making it a more conservative choice. While method 2 provided the lowest biomass estimate for the east stock, this occurred as sampled areas were removed from the calculations, likely underestimating stock size. The biomass scaling applied to the West Stock was larger than the East Stock (which received on a minor scaling) and increased the estimates of spawning biomass. However, a scaled method 1 for the West Stock provided similar results to an unscaled method 2, making it the more conservative choice. Therefore, the scaled biomass for method 1 was deemed appropriate for use for both stocks. The choice of biomass input did not greatly effect estimates of status for either stock, but they did determine scale which is important for determining harvest estimates.

In summary, some of the model diagnostics indicated degrees of uncertainty that are typical of data-limited models, and there is opportunity for the East and West Stock assessments to be improved through subsequent data collection. However, these diagnostics also indicated that the stock assessment models could adequately estimate stock status, while the biomass estimates used as inputs scaled the models accordingly based on stock size. The choice of biomass estimate to include is a key consideration, with method 1 described by Koopman and Knuckey (2025) (scaled to catch percentage) being the most justifiable choice.

4.2.2. Growth parameterisation

Growth information is difficult to ascertain for sea cucumbers due to their morphology and ecology (Battaglione et al., 1999). They have the ability to change shape and size, creating imprecision in length estimated. They are also difficult tag, mark and age, creating difficulties for determining length-at-age (Conand, 1991). As a result, specifying growth for both the East and West Stocks was complicated and formed a key focus of model development. Very limited growth information was available for Sandfish which was summarised to provide sensible parameters by Smart et al. (2025).

The maximum length of Sandfish is 40 cm (Purcell et al., 2023) which was used to justify an indicative L_{∞} of 35 cm (Smart, Koopman, et al., 2025). However, the length compositions from both stocks were considerably smaller than this value. Truncated length compositions can indicate a degree of stock depletion (Froese et al., 2018). However, this contrasts to available information on the stocks that suggests that both Sandfish stocks are lightly exploited when catches and surveyed biomass are simultaneously considered. High density estimates (>100 individuals per hectare) from the surveys also indicate that these populations are unlikely to be heavily exploited (Koopman & Knuckey, 2025). The models were also unable to estimate higher levels of fishing mortality which would have improved fits to the right-hand limb of the length compositions. This further indicates that there is little support for truncated length distributions occurring due to stock depletion.

A dome shaped selectivity was examined as part of a sensitivity analysis, which could explain the absence of larger individuals in the length compositions. However, these scenarios had a worse fit to length compositions and estimated large 'cryptic biomasses' (portions of the population that have no empirical evidence of existence). This can occur when a single dome shaped selectivity is applied without a logistic selectivity being applied to another fleet (Punt, 2023). This situation should be avoided in stock assessments as it creates a large risk for overfishing to occur through catches that are set based on overestimated stock sizes.

Next a scenario examined the potential for length measurement imprecision to have occurred during the surveys. All Sandfish were measured and weighed after being removed from the water which can cause animals to shrink. Efforts were taken to minimise this risk (Koopman & Knuckey, 2025), but given the resulting compositions this possibility required examination. A similar sensitivity scenario was undertaken for other sea cucumber stock assessments for similar reasons (Smart et al., 2024b, 2024a). This provided a better fit for the East Stock length compositions but did not improve the West Stock model. This analysis was done for exploratory purposes and cannot be reasonably considered as a Base Case for the East Stock without greater consideration.

Based on the available evidence, the last remaining hypothesis is that Sandfish in the East and West Stocks are exhibiting density dependent growth. Therefore, as densities are high (> 100 individuals per hectare in the surveys (Koopman & Knuckey, 2025)) and exploitation is reasonably light, individuals do not grow as large as other populations of Sandfish. This phenomenon is documented for sea cucumbers (Hannah et al., 2013) and has been observed for Sandfish in aquaculture systems, albeit at small sizes (Battaglione et al., 1999).

The concept of density dependent growth can be incorporated into Stock Synthesis assessments through cohort specific growth deviations. This has been used in other Australian stock assessments when density dependent growth has been evident (Tuck, 2022). However, this requires large sample sizes of composition data (age and length) to be collected through time. This is highly unlikely to be achievable for sea cucumber species such as sandfish. Therefore, an important area of future work would be to determine the degree to which density dependent growth could occur for adult populations and its implications on stock assessment outcomes

While growth parameters remain highly uncertain for NT Sandfish, the Stock Synthesis models were not sensitive to different values. This was due to the models being conditioned on absolute estimates of biomass from the recent surveys. These large biomass estimates in combination with relatively low catches indicate light exploitation for the stocks. The fits to the left-hand limb of the length compositions were reasonable given the single year of data, while the fit to the right-hand limbs were poor. This demonstrates that selectivity was reasonably well estimated (providing the good fit to the left-hand limb) while the growth and mortality information pre-specified in the model did not allow for a good fit to be obtained for the right-hand limb. More information on growth and natural mortality is required to address this.

5. Option to improve assessments

There are two main options to improve these stock assessment models:

1. **Undertake biomass surveys every three to five years and apply the next stock assessment with these estimates.** Multiple estimates of biomass may improve model stability by providing more information on stock scale. It would also improve diagnostics such as retrospectives and the R_0 parameter profiles. Given the importance of the surveys to the stock assessment, there is little point in updating the stock assessment models without further estimates being available.
2. **Investigate growth dynamics.** Growth was a key focus of this assessment given the uncertainty in this process for sea cucumbers. Given the substantial aquaculture operations for Sandfish, there may be the potential to estimate growth parameters (i.e. length-at-age) from reared individuals. Wild stocks could also be examined to determine if length frequencies changed with relative densities, which would provide some hypothesis testing around density dependent growth.

6. References

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7. Appendices

7.1. CPUE standardisation

7.1.1. Coefficient of variation for CPUE

Stock Synthesis requires a standard error in log space of the abundance index. This was achieved by fitting a loess smoother to the point estimates of the abundance indices. The standard error of the abundance indices (constant across years) was calculated as the standard error of the residuals between the abundance indices and the loess smoother (Punt, 2023).

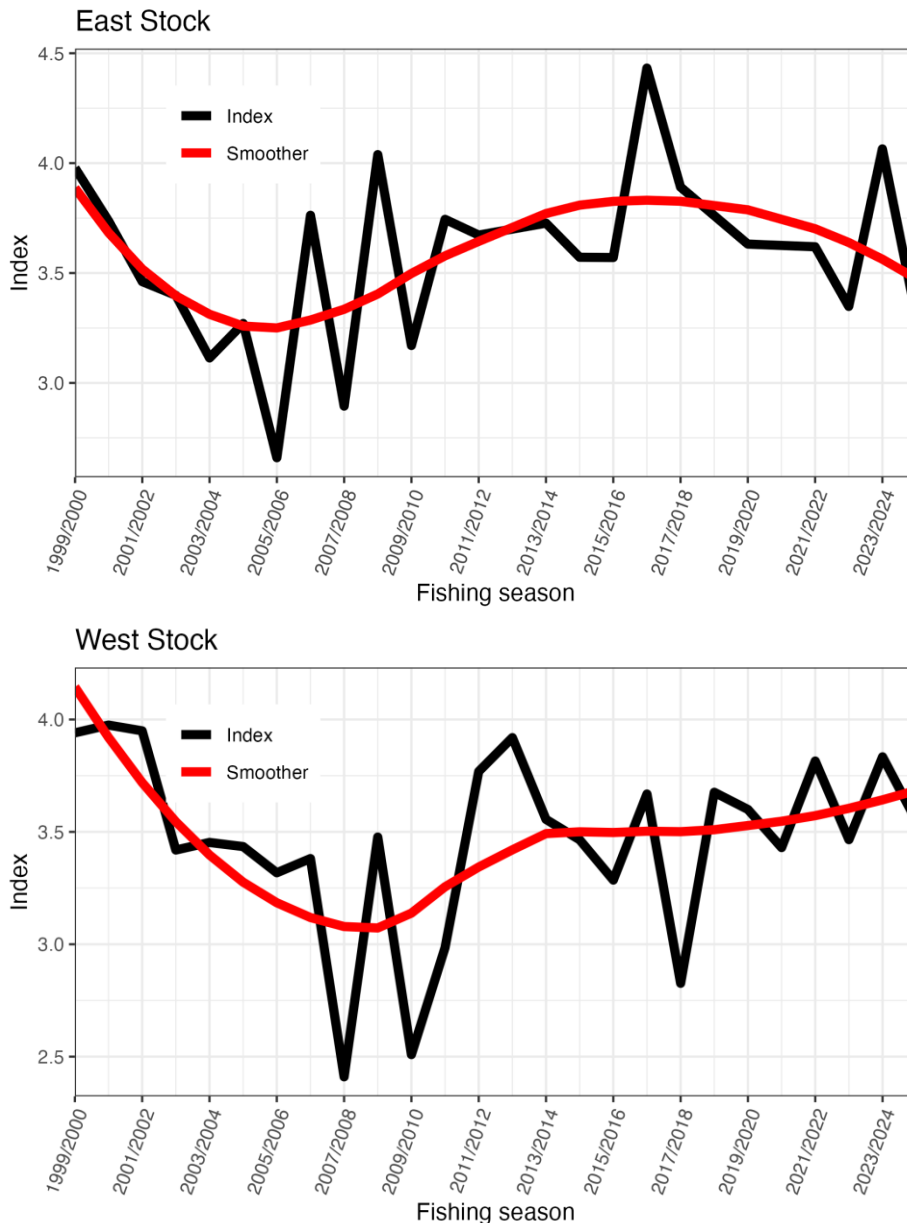


Figure 28: Standardised abundance index (log scale) and the smooth curve fitted using loess for the East Stock (Top panel) and West Stock (Bottom panel).

7.2. Model diagnostics

Model diagnostics were performed for the Stock Synthesis model using the processes outlined in (Carvalho et al., 2021) which use the supporting R packages of *r4ss* and *ss3diags* (Taylor et al., 2021; Winker et al., 2025). Two diagnostic tests, hindcast validation and runs test, were not performed in this assessment as the *ss3diags* package requires more than one year of composition data as inputs to these approaches.

7.2.1. Jitter test

A jitter test was conducted to determine whether models are sensitive to the initial parameter values and that the model converged to a global minimum rather than at local minimum. Jitter analysis is a technique used to test the optimality, robustness and stability of the maximum likelihood estimate obtained for a particular model. This involves randomly changing the starting values used for all estimated parameters and re-running the model, to test what alternative solutions may be found by the optimisation algorithm from different initial locations, which is sometimes referred to as sensitivity to initial conditions. Two diagnostics are of interest with a jitter analysis, a check on whether a better “optimal solution” may be found, with a higher likelihood value, and also to see how frequently the optimal solution is found. As all estimated parameters are randomly modified, or “jittered,” simultaneously, this can sometimes result in a model either failing to converge or finding a local maximum in a different (suboptimal) part of the multi-dimensional parameter space. A jitter analysis was conducted with 50 replications, modifying initial parameter values by 10%. Jittering was implemented in using the *r4ss* R package (Taylor et al., 2021) and followed the process outlined by Carvalho et al. (2021).

The jitter test did not provide evidence to reject the hypothesis that the parameter optimization converged to a global solution for either Stock with only one run for the East stock reaching a local minima (Figure 29, Figure 30).

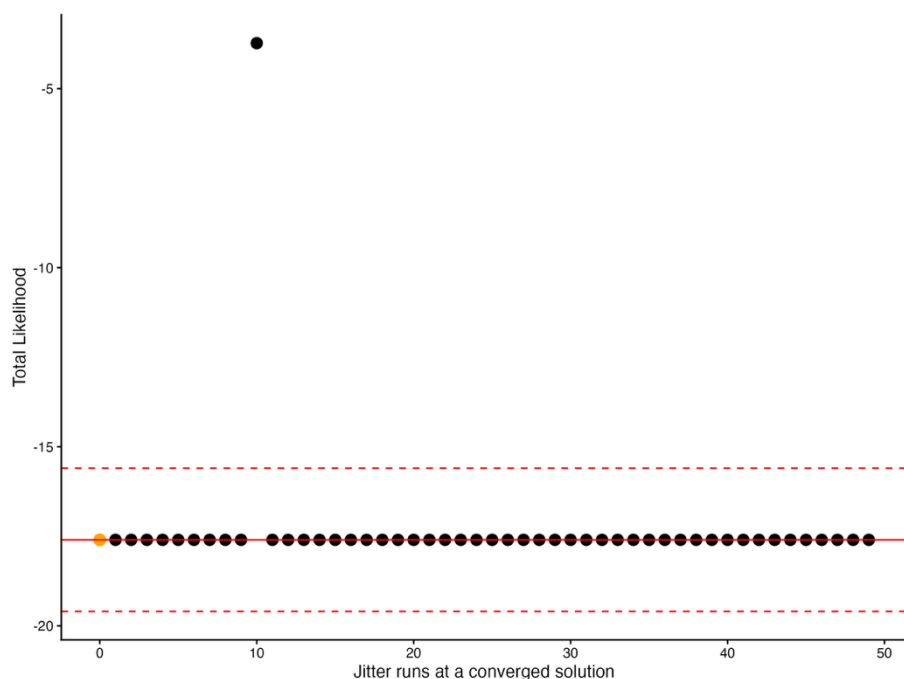


Figure 29: Log-likelihood estimates of reference model for the East Stock that converged during the jitter analysis. The solid red line and orange point indicate the log-likelihood estimate from the Base Case model run. The Dashed red lines show 1.96 log-likelihood points above and below the Base Case estimate.

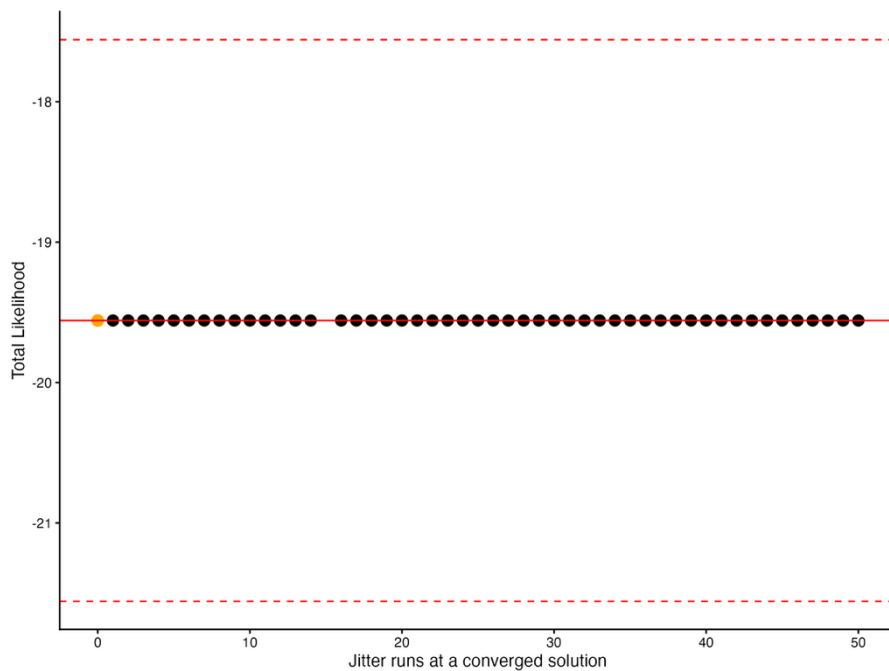


Figure 30: Log-likelihood estimates of reference model for the East Stock that converged during the jitter analysis. The solid red line and orange point indicate the log-likelihood estimate from the Base Case model run. The Dashed red lines show 1.96 log-likelihood points above and below the Base Case estimate.

7.2.2. Goodness of fit

7.2.2.1. Root mean-square error

Root mean-square error (RMSE) describes the standard deviation of residuals, such that:

$$RMSE = \sqrt{\frac{\sum_t (\hat{y}_t - y_t)^2}{n}}$$

Where $\hat{y}_t$ is the predicted value at the time step t , y_t is the observed value, and n is the number of observations. A relatively small RMSE (30%) indicates a reasonably precise model fit to relative abundance indices (Winker et al., 2018).

Table 6 shows the RMSE score obtained for the model fit for the East and West stocks to the relative abundance index (CPUE, biomass and combined). Results indicate a reasonable fit to the abundance indices as the combined RMSE was slightly above 30% (Figure 31).

Table 6: Root Mean Square Error indicating the Goodness-of-fit statistic of reference model.

Data type	Stock	RMSE	Number of observations
CPUE index	East	32.4%	23
Biomass index	East	1.6%	1
Combined indices	East	31.7%	24
CPUE index	West	31.5%	26
Biomass index	West	8.2%	1
Combined indices	West	31 %	27

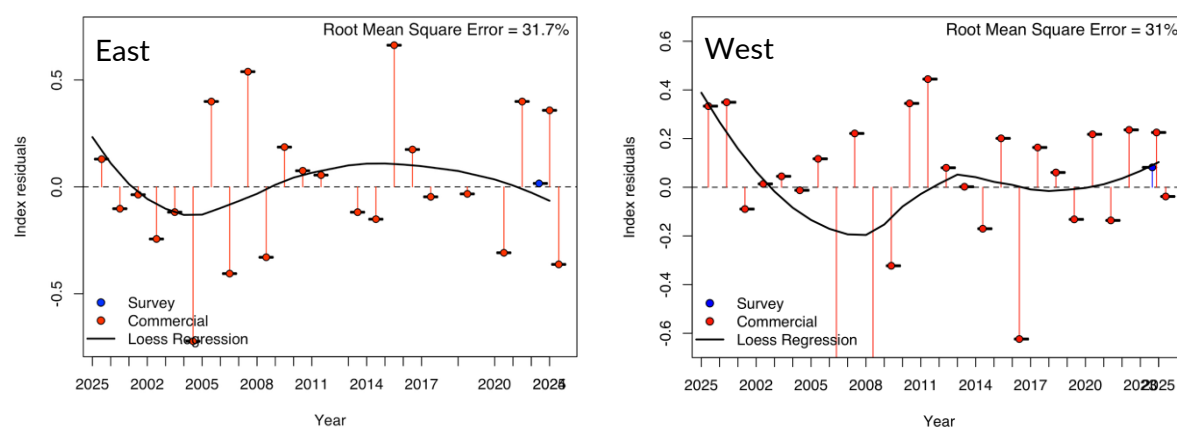


Figure 31: Joint residual plots for the annual mean CPUE and biomass index residuals for the East and West stocks. Solid black line show loess smoother through all residuals. The x-axis displays integer years where 2020 corresponds to the 2019/20 fishing season, and so forth.

7.2.3. Parameter profiling

Parameter profiling involves examining model parameters or quantities individually, by pre-specifying them across a range of values and re-running the model to determine the differences that may occur. These differences were examined here using the change in total likelihood and likelihood components, as well as changes in relative spawning biomass (Figure 32; Figure 33; Figure 34; Figure 35). Parameter profiling demonstrates that a model parameter or quantity has been suitably estimating or pre-specified if changes in negative log-likelihoods change by less than 1.96.

Similarly, if the range of parameter values examined produce similar quantities of interest (such as relative spawning biomass), then consideration of alternative values or settings becomes less consequential. Profiling of leading parameters such as R_0 can be a useful exercise in determining which data or model components are providing the most information. For both stocks, the Base Case model was profiled for R_0 (Figure 32), M (Figure 33), h (Figure 34) and σ_R (Figure 35) which are all important parameters.

The profile for R_0 (estimated in the Base Case as 7.56 for the East Stock and 8.42 for the West Stock) demonstrated that the index likelihoods had the greatest influence. This was to be expected given that the models were conditioned of the biomass index from the 2024/25 survey. The right-hand limb of the

likelihood profile did not increase above the 1.96 log-likelihood point threshold for either stock, indicating that both Base Case models struggled to estimate an upper limit for R_0 (Figure 32). This situation commonly occurs for stocks that are lightly exploited as the available data provides little contrast for estimating R_0 . This is not ideal as R_0 is a key parameter and a well-defined likelihood profile is important for model certainty. However, this result indicates that these models have a low probability of over-estimating stock size and a moderate probability of under-estimating stock size. Relative spawning biomass was not overly influenced by changes in R_0 for either stock, indicating that these models are still able to estimate stock status (Figure 32).

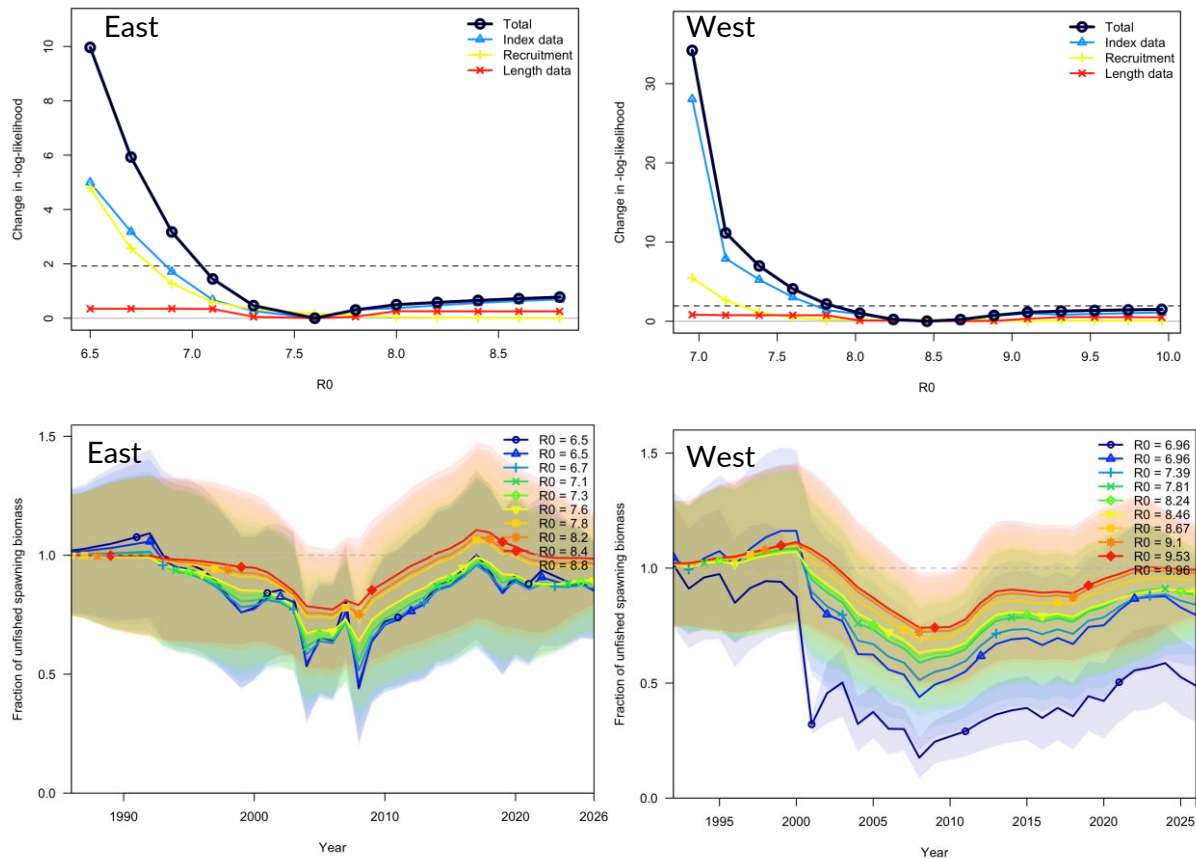


Figure 32: Parameter profiling for the East (left panels) and West (right panels) stocks for log virgin recruitment (R_0) (top panels) and estimates of relative spawning biomass ($\pm$ standard error) using different R_0 values (bottom panels). The dashed horizontal line on the top panels indicates a -log-likelihood change cutoff of 1.96. The x-axis displays integer years on bottom panels where 2020 corresponds to the 2019/20 fishing season, and so forth.

M was pre-specified in the model as 0.65 yr^{-1} , for both stocks. Both likelihood profiles demonstrated that the model has little information with which to inform M given that similar negative log-likelihoods occurred across a large range of values (Figure 33). Values of M were not overly influential on relative spawning biomass (Figure 33), due to the model being conditioned on the 2025 biomass estimate.

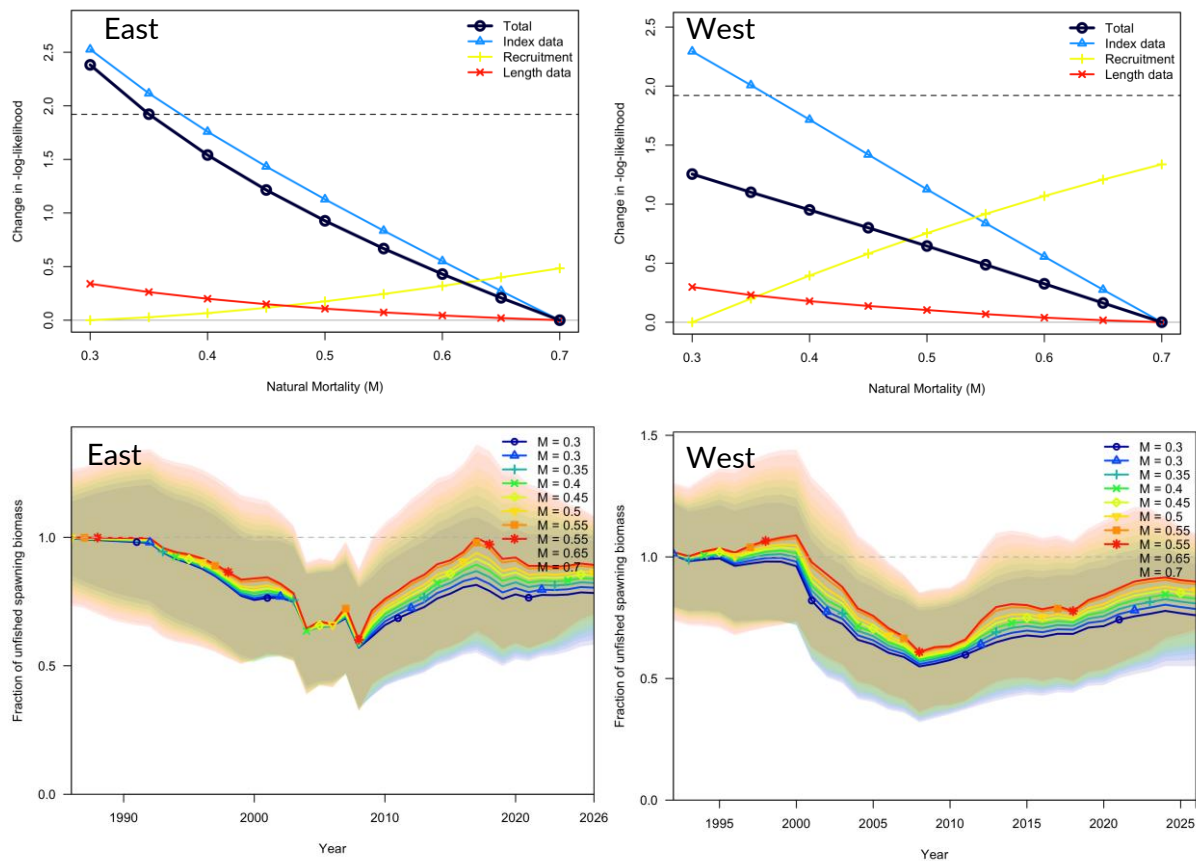


Figure 33: Parameter profiling for the East (left panels) and West (right panels) stocks for natural mortality (M) (top panels) and estimates of relative spawning biomass ($\pm$ standard error) using different M values (bottom panels). The dashed horizontal line on the top panels indicates a -log-likelihood change cutoff of 1.96. The x-axis displays integer years on bottom panels where 2020 corresponds to the 2019/20 fishing season, and so forth.

A wide range of h values had similar support in the Base Case models as differences in log-likelihoods were less than 1.96 for all values, for both stocks (Figure 34). The value pre-specified in the in Base Case model was 0.3 which provided similar relative biomass estimates to all other values for both (Figure 34). Therefore, the profiling indicates no reason to update this value for either stock

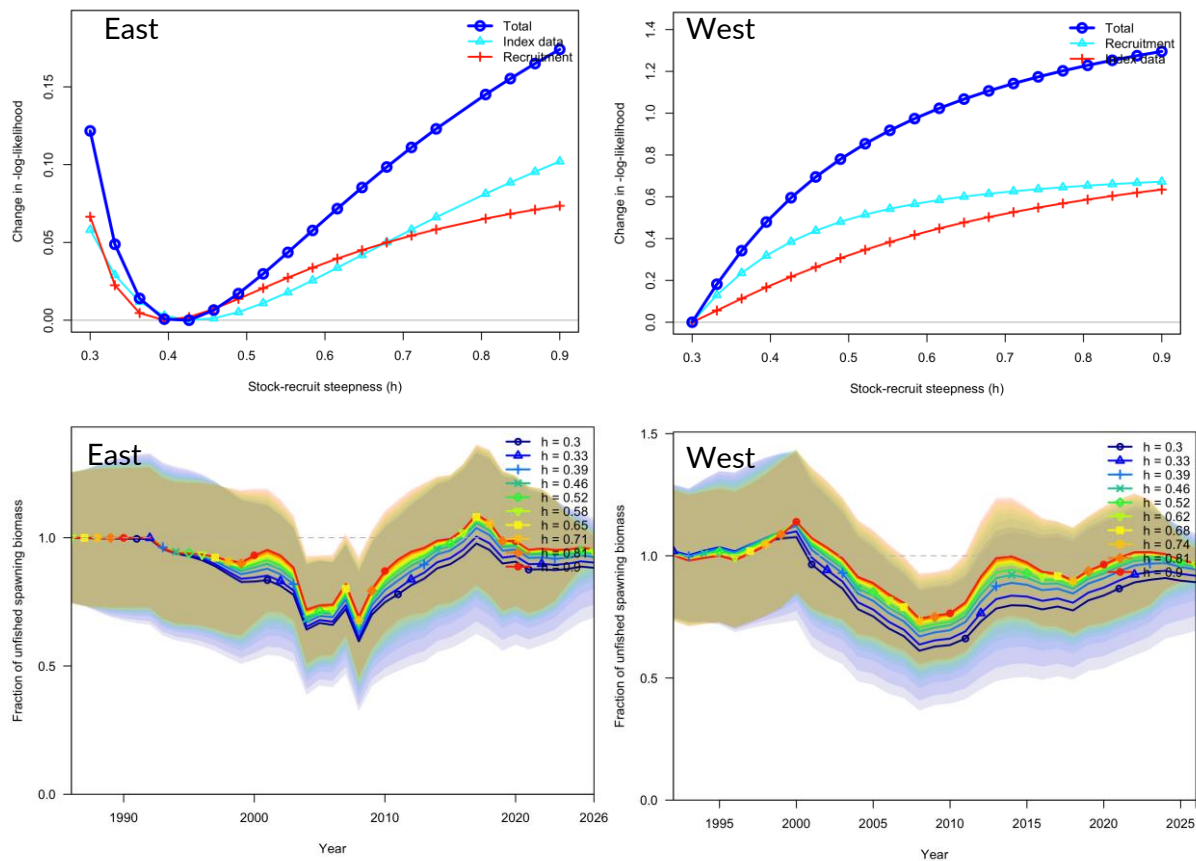


Figure 34: Parameter profiling for the East (left panels) and West (right panels) stocks for steepness (h) (top panels) and estimates of relative spawning biomass ($\pm$ standard error) using different h values (bottom panels). The dashed horizontal line on the top panels indicates a $-\log$ -likelihood change cutoff of 1.96. The x-axis displays integer years on bottom panels where 2020 corresponds to the 2019/20 fishing season, and so forth.

The σ_R profile demonstrated that higher values had greater support for both stocks (Figure 35). This trend was driven by the index likelihood, which is to be expected, as it would mean a closer model fit to these data (Figure 35). While the profile suggests that values of σ_R above that pre-specified (and subsequently tuned) in the Base Case model (0.3) could be considered as there were no large changes in relative spawning biomass nor other key model quantities that occurred through different values of σ_R (Figure 35).

The value of σ_R was not updated based on these profiles as it is recognised that σ_R cannot be estimated nor solved for within a stock assessment model and that a suitable value must be determined externally (A. Punt, pers comms). Therefore, the pre-specified and tuned value of σ_R used in the Base Case model was not further refined for these reasons.

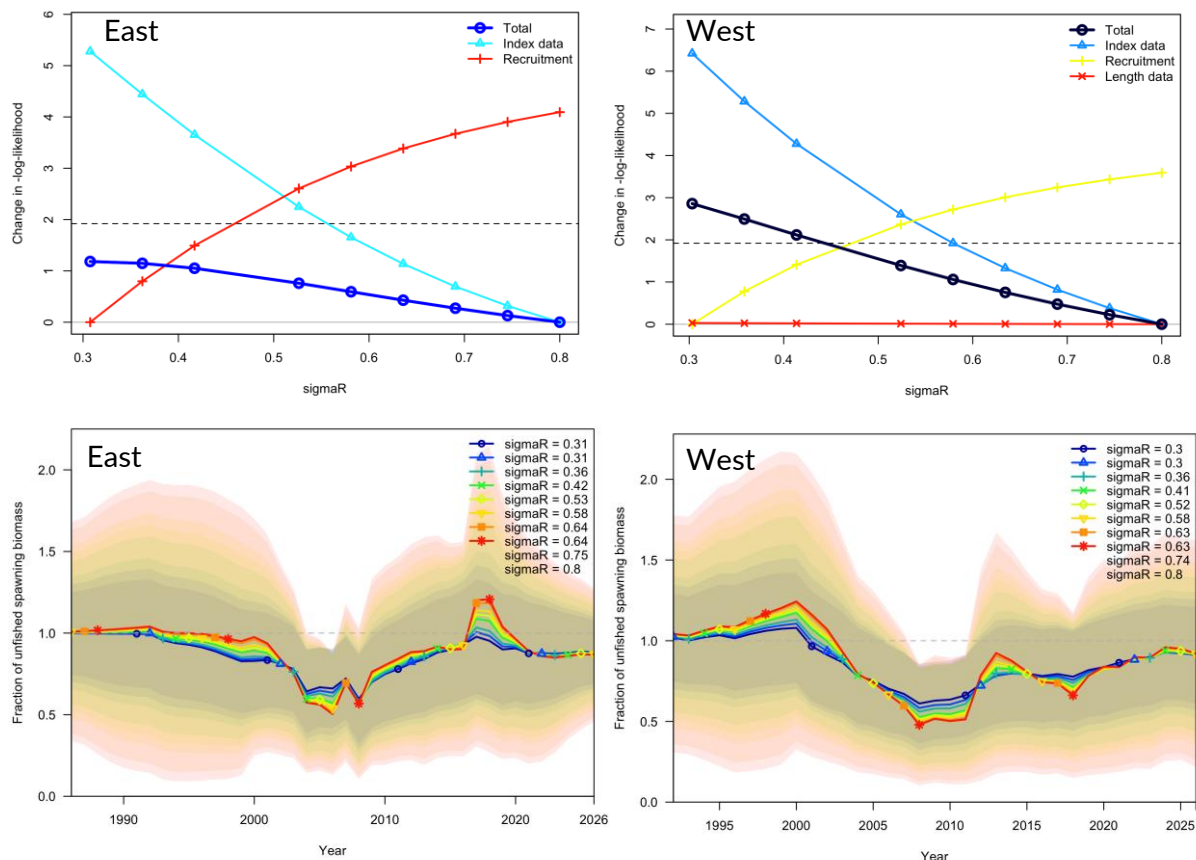


Figure 35: Parameter profiling for the East (left panels) and West (right panels) stocks for recruitment deviations (σ_R) (top panels) and estimates of relative spawning biomass ($\pm$ standard error) using different σ_R values (bottom panels). The dashed horizontal line on the top panels indicates a $-\log$ -likelihood change cutoff of 1.96. The x-axis displays integer years on bottom panels where 2020 corresponds to the 2019/20 fishing season, and so forth.

7.2.4. Age structured surplus production model

The Age-Structured Production Model (ASPM) diagnostic serves as an effective tool for identifying misspecifications in key processes that shape production functions in fisheries modelling. This approach compares whether trends in abundance indices can be explained by the balance between surplus production and observed catches, or if a more sophisticated model incorporating recruitment fluctuations provides better explanatory power (Carvalho et al., 2021). When implementing the ASPM, selectivity parameters were fixed to values from the Base Case model, deliberately excluding length composition data and not estimating recruitment deviations. A good fit to abundance indices with significant variation suggests that stock dynamics are primarily driven by the production function, and these indices likely provide reliable information about absolute abundance. Conversely, poor fit may indicate several possibilities: the stock is predominantly influenced by recruitment patterns, catch has minimal impact on abundance, the model oversimplifies complex dynamics like stock structure, or the abundance indices fail to accurately represent true abundance. An ASPM with recruitment deviations estimated (ASPM_dev) evaluates whether composition data is necessary for estimating recruitment variability by fitting abundance indices while estimating recruitment deviations without composition data. Significant differences between ASPM_dev results and those from the Base Case model would suggest that composition data plays a crucial role in accurately estimating recruitment fluctuations.

For both stocks, both the ASPM and ASPM_dev estimated similar relative spawning biomass trajectories to the Base Case model, indicating the underlying production function of the Base Case model was informative (Figure 36)

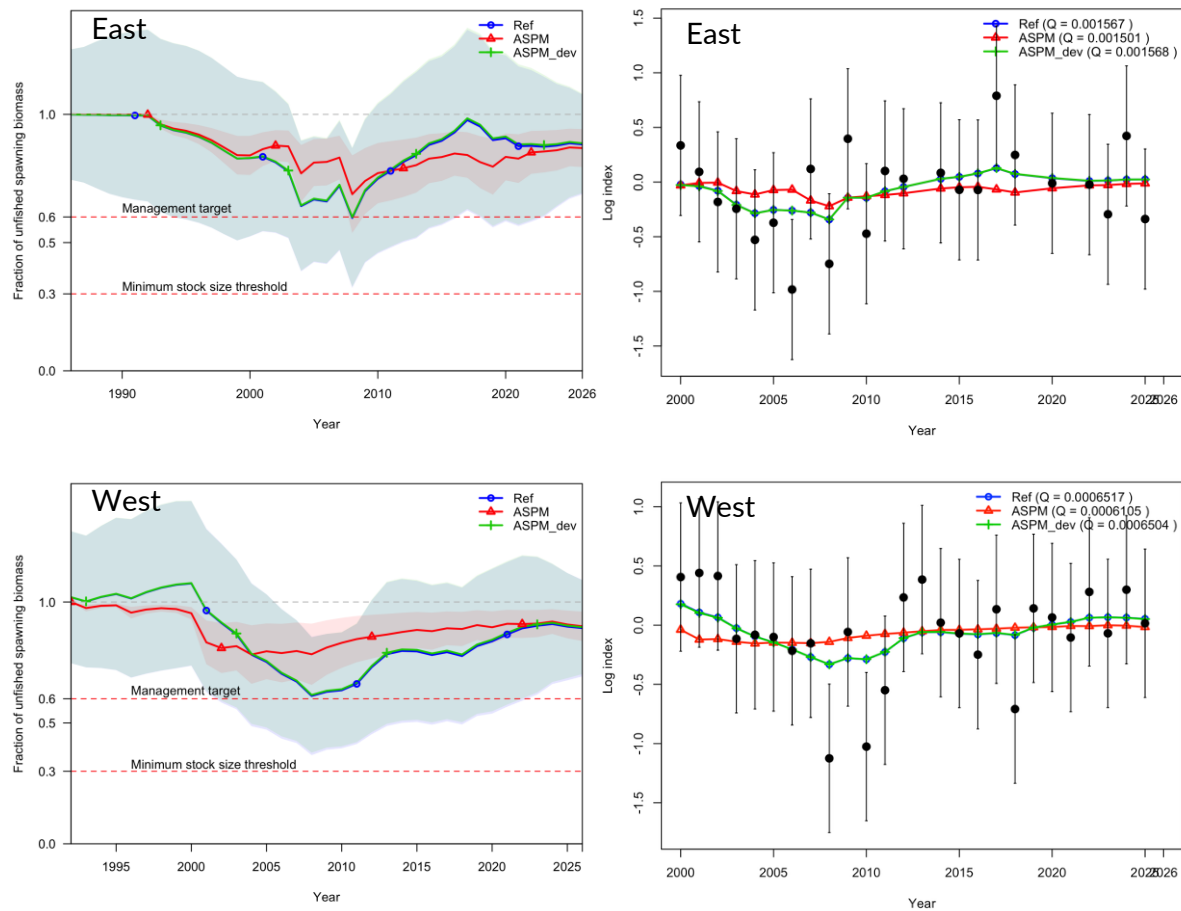


Figure 36). The fit to the log index data was poor for the ASPM but improved for the ASPM_dev (Figure 36). However, conclusions regarding the improvement in fit of the ASPM_dev are limited given then short series of index data versus the total model timeframe.

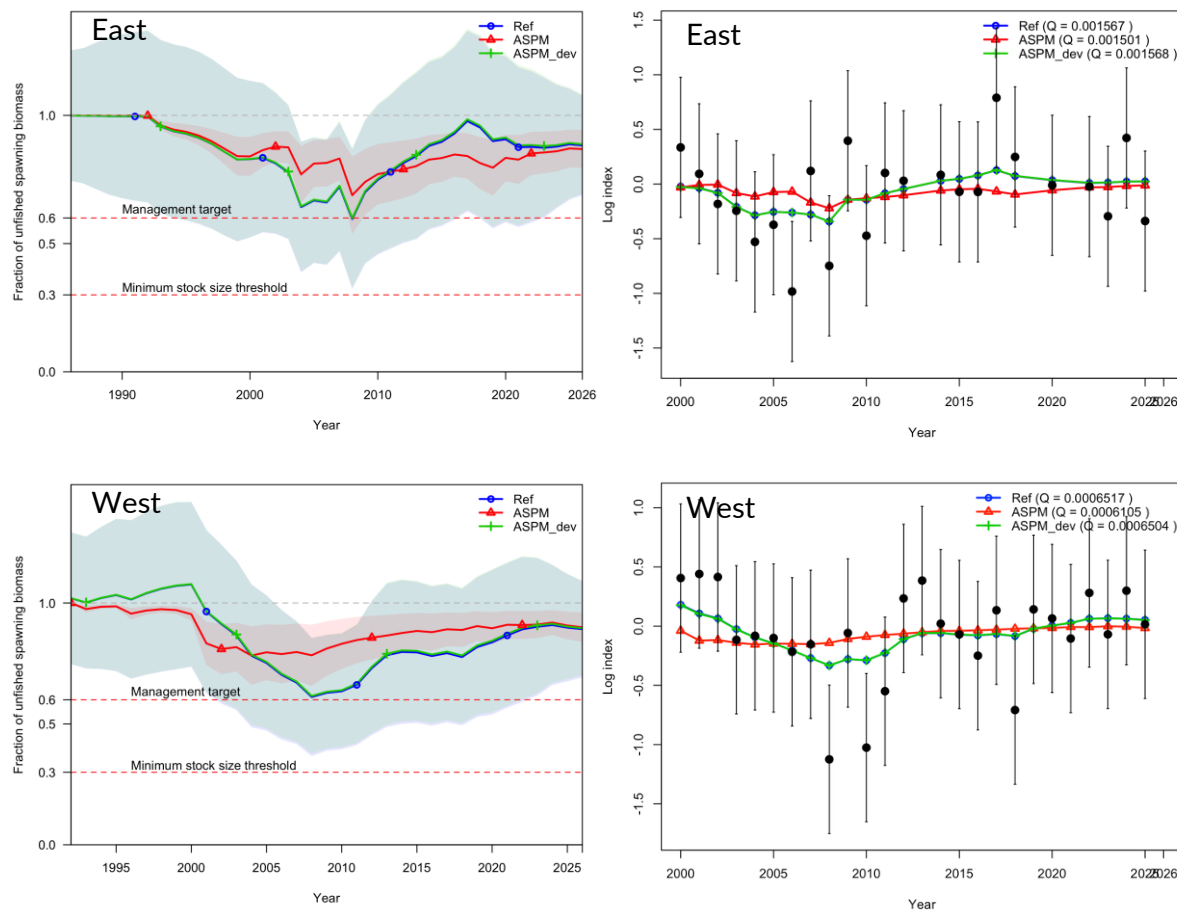


Figure 36: Comparison of the Base Case model (Blue line and shading) to an age structured surplus production model (ASPM; red line and shading) and an ASPM with recruitment deviation estimated (green line and shading) for the East (top panels) and West (bottom panels) stocks. Left hand panels show relative spawning biomass, and right-hand panels show fits to log CPUE index (black points and error bars). The x-axis displays integer years where 2020 corresponds to the 2019/20 fishing season, and so forth.

7.2.5. Retrospective analysis

A retrospective analysis (Cadrian, 1997; Mohn, 1999) has been undertaken to identify whether assessment outcomes change as data is removed from the assessment. The retrospective analysis was undertaken using the following procedure:

- 1) One year of data was removed sequentially from the Base Case model, while maintaining the same assumptions and tuning.
- 2) Time dependent model parameters (e.g. the last year of estimated recruitment) were changed to be one year earlier.
- 3) The model was run to determine stock status estimates when less data is available (i.e. in the past).
- 4) Steps 1–3 were repeated five times (i.e. sequentially removing five years of data).

Trends in biomass, stock status, fishing mortality and recruitment are then examined to help understand how reliable the assessment is at estimating the relative biomass in recent years.

The severity of retrospective patterns can be quantified using Mohn's rho (ρ_M), which is defined as the average of relative differences between an estimate from assessment using a truncated time series and an estimate from assessment using the full time series (Hurtado-Ferro et al., 2015). As a general rule of thumb, values of ρ_M that fall outside -0.22 to 0.30 for shorter-lived species indicates an undesirable retrospective pattern or cause for concern in an assessment (Hurtado-ferro et al., 2015).

The ρ_M for the spawning biomass of the East Stock was -0.23 indicating that model failed the retrospective analysis as patterns were present when data are removed from the terminal years (Figure 37). The 'peeled' estimates of biomass from models with fewer numbers of years removed differed immediately to the Base Case as the only biomass estimate was available in 2025 and was removed in the first peel. This result was expected given that the model is intentionally conditioned on this estimate and removing it would result in large changes to biomass. This analysis therefore demonstrates the importance of the biomass estimate as an input, rather than raising concerns about model performance.

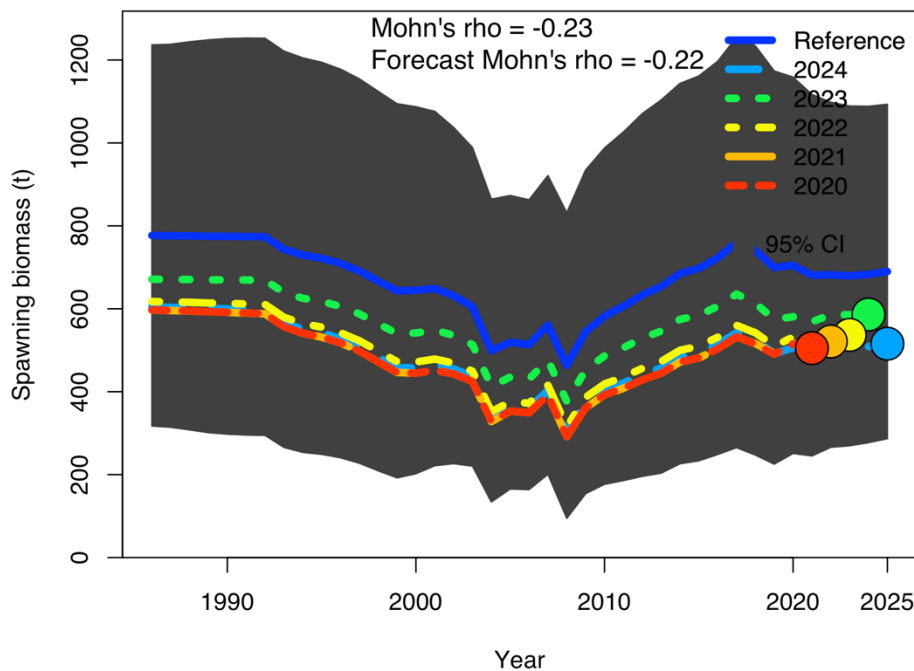


Figure 37: Retrospective analysis of spawning biomass estimates to the East Stock when one to five years of data were sequentially removed from the Base Case model. The x-axis displays integer years where 2020 corresponds to the 2019/20 fishing season, and so forth.

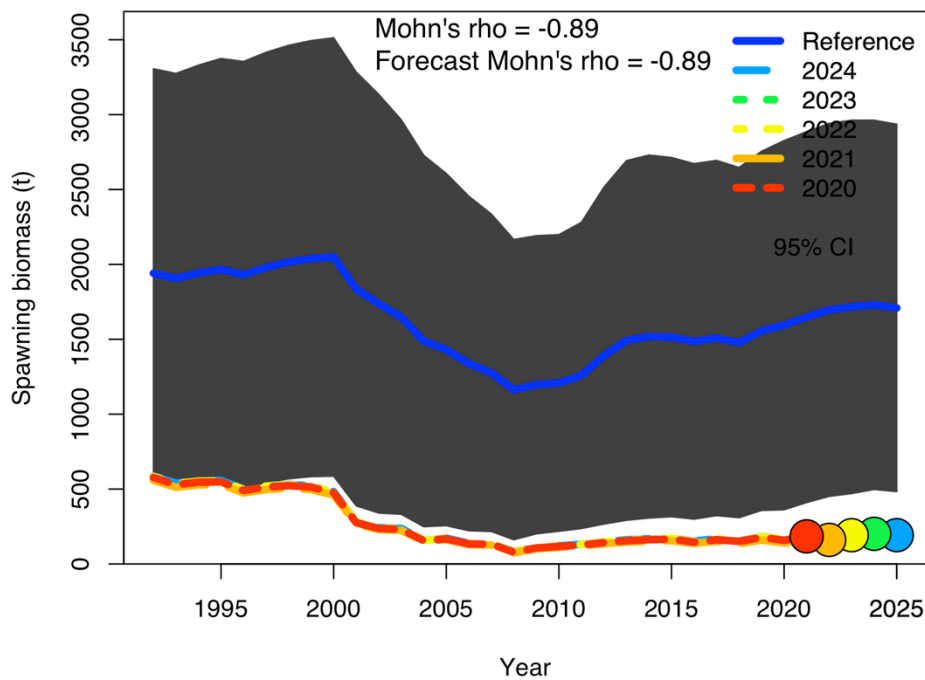


Figure 38: Retrospective analysis of spawning biomass estimates to the West Stock when one to five years of data were sequentially removed from the Base Case model. The x-axis displays integer years where 2020 corresponds to the 2019/20 fishing season, and so forth.

The ρ_M for the spawning biomass of the West Stock was -0.89 indicating that that model also failed the retrospective analysis as retrospective patterns were present when data are removed from the terminal years (Figure 38). The same effects in the retrospective occurred between the stocks, although this had a much greater effect for the West Stock. Indicating that the model was far more dependent on the biomass estimate. Again, this result was expected given that the model is intentionally conditioned on this biomass estimate and the same conclusions for the East Stock can be drawn here.