Stock assessment of white teatfish (*Holothuria fuscogilva*) in Queensland, Australia

2021

Queensland Government

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Summary

White teatfish (*Holothuria fuscogilva*) is a species of sea cucumber broadly distributed throughout the tropical Indo-Pacific (Conand 1990). In Australia, its distribution extends from Ningaloo in Western Australia to Brisbane, Queensland (Atlas of Living Australia 2018). White teatfish commonly inhabits outer barrier reef slopes, reef passes and sandy areas in semi-sheltered reef habitats in 0 to 50 m water depth (Roelofs 2004; Purcell et al. 2012), but most animals are caught between 15 m and 30 m (`fish.gov.au`). Female white teatfish mature at around 4 years of age at a length of 320 mm total length (Roelofs 2004). Individuals live to about 12 years of age and reach a maximum size of 570 mm total length (Roelofs et al. 2020).

A stock assessment model was used to assess the population status of white teatfish in the Queensland Sea Cucumber Fishery (East Coast). The assessment incorporated commercial catch and effort data and used an age structured surplus production model with annual time steps. The key population performance indicator was an annual estimate of biomass (both spawning and exploitable biomass). Previously, a quantitative analysis was conducted in 2014, as part of a Management Strategy Evaluation framework (Skewes et al. 2014). Although this was not intended as an assessment of the stock it included a surplus production model and estimated a total biomass of approximately 1000 tonnes in 2011. Skewes et al. (2014). In keeping with the 2014 analysis, the current assessment also used a surplus production model that was formulated to be age structured (R package 'apsm', Haddon et al. (2019)) The model was used to assess the stock and was fitted to catch rate data. Some adjustments were made to the prepackaged aspm model, by the addition of parameters to improve the model fit. Fishing years were from 1 July to 30 June the following year, henceforth the second year would be used to refer to fishing year (e.g. 1995/96 fishing year is termed 1996 fishing year). The current assessment included harvest data from 1996 to 2021 fishing years, and catch rate data from 1999 to 2021 fishing years.

Harvest data from 1996 were assumed, for modelling purposes, to represent the commencement of significant fishing mortality, i.e. near virgin state of white teatfish in 1995 in Queensland waters (Eriksson et al. 2015). Harvest data from the years 1996–2021 (inclusive) was from CFISH data (vessel and buyer logbooks).

Over the last 5 fishing years, 2017 to 2021, the Queensland total harvest averaged 52 tonnes per year, ranging from 49 to 53 tonnes, all caught by the commercial sector due to the total allowable commercial catch (TACC) quota applied by management.

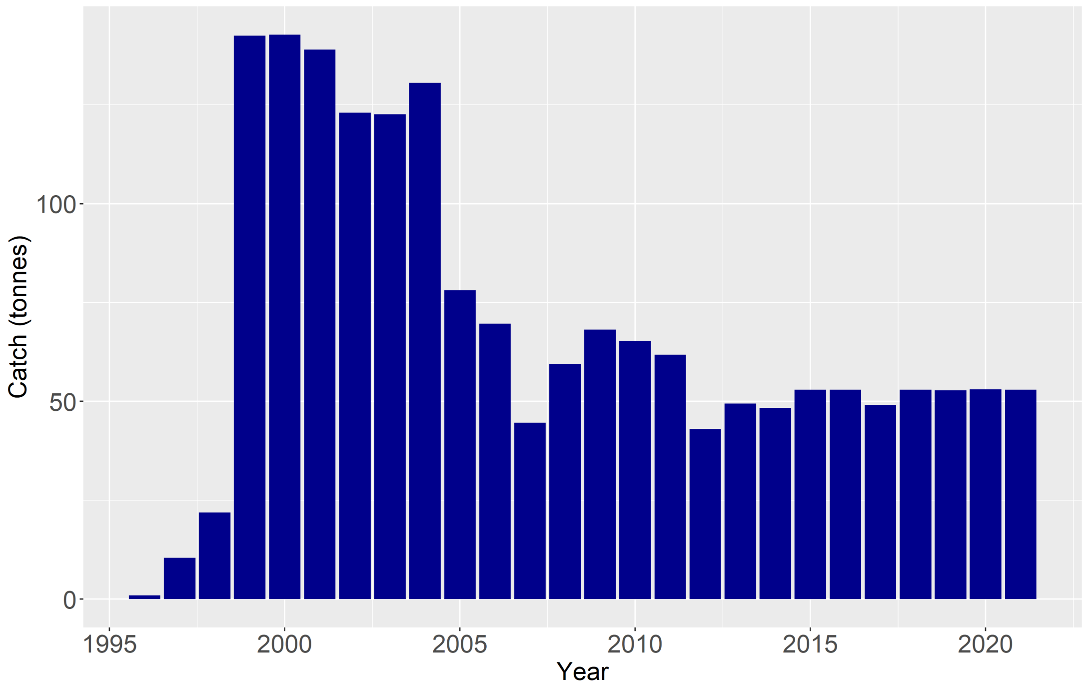

Figure 1: Total annual estimated landed catch between 1996 and 2021 for white teatfish in the Queensland Sea Cucumber Fishery (East Coast)

Commercial catch rates were standardised and used to fit the stock assessment model (Figure 2). The explanatory terms were year, month, vessel, and an offset was applied for hours fished. The unit of operation was defined to be a single day of fishing by each vessel (referred to as 'boat-day').

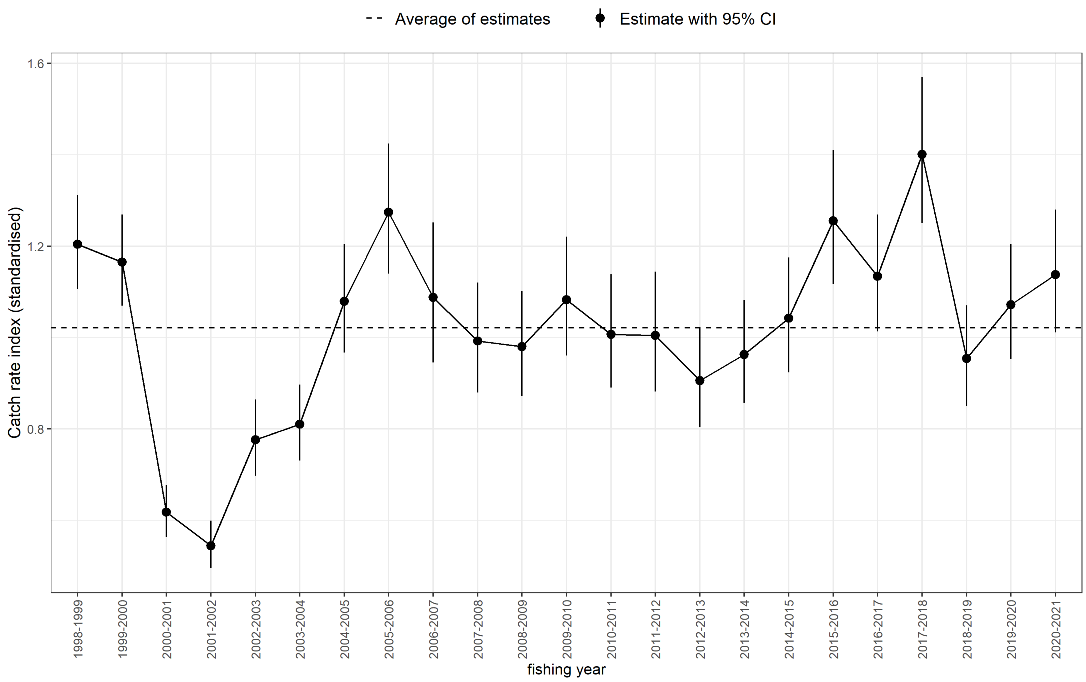

Figure 2: Annual standardised catch rates with ± 2 s.e (equivalent to 95% confidence intervals) for white teatfish in the Queensland Sea Cucumber Fishery (East Coast)

The target reference point for white teatfish, and all sea cucumber species, is 60% exploitable biomass as defined by the sea cucumber fishery harvest strategy (State of Queensland 2020). This is defined in Queensland's Sustainable Fisheries Strategy 2017–2027 (State of Queensland 2017). The assessment estimated that the 2021 biomass ratio was 78% of the unfished 1995 level (Figure 3).

This report contains information required for the assessment of white teatfish stocks as an approved wildlife trade operation under the provisions of the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act).

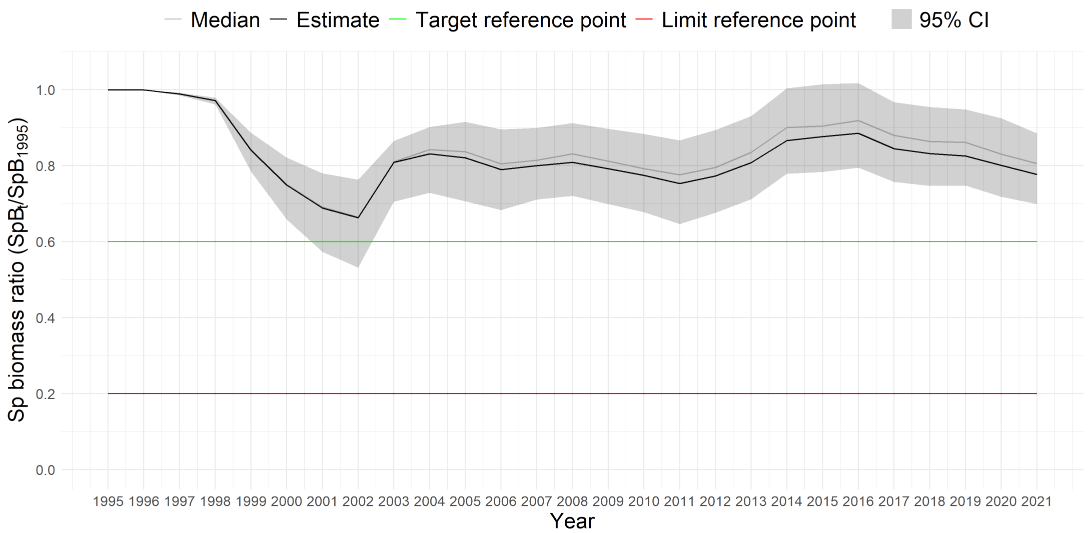

Figure 3: Annual spawning biomass ratio (with 95% confidence intervals) for white teatfish in the Queensland Sea Cucumber Fishery (East Coast)

The biomass ratio is above the target biomass (B_{targ}) of 60%. There is a likelihood that this is overoptimistic if hyperstability is present. In addition the biomass ratio was higher than that estimated by Skewes et al. (2014) for the years in common (1996–2011). For future assessments it is recommended to analyse for hyperstability according to Carruthers et al. (2011).

The current harvest levels are consistent with the goals of the harvest strategy of maintaining the stocks at or above the 60% exploitable biomass ratio target reference point.

Table 1: Current and target indicators

Parameter	Estimate
Current spawning biomass (relative to unfished, SpB_{2021}/SpB_{1995})	78%
Current exploitable biomass (relative to unfished, ExB_{2021}/ExB_{1995})	76%
Current harvest (2021)	53 tonnes

Acknowledgements

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Glossary

aspm	age structured production model
B_{targ}	target reference point for biomass (biomass is spawning biomass in this assessment)
CI	confidence interval
CFISH	Queensland commercial fishery information system (logbook database)
DAF	Department of Agriculture and Fisheries (Queensland)
Fishing year	1 July to 30 June, the labelling of fishing year is the second year (e.g. July 2000 to June 2001 was labelled '2001 fishing year')
ExB_0	unfished exploitable biomass (unfished biomass of the portion of stock that is above the minimum size taken by fishers)
FRDC	Fisheries Research and Development Corporation
GBR	Great Barrier Reef
GBRMP	Great Barrier Reef Marine Park
ITQ	individual transferable quota
GLM	generalized linear model
MLS	minimum legal size
MSY	maximum sustainable yield
operation-day	a single day of fishing by a primary vessel
RAP	Representative Areas Program
RHA	Rotational Harvest Arrangement; previously referred to as the Rotational Zoning plan
SFS	Sustainable Fisheries Strategy
SpB_0	unfished spawning biomass
TACC	total allowable commercial catch
TL	total length
Zone 1	white teatfish zone located north of 19° S
Zone 2	white teatfish zone located south of 19° S
WTO	Wildlife Trade Operations

1 Introduction

White teatfish (*Holothuria fuscogilva*) is a species of sea cucumber found in northern Australia and is broadly distributed throughout the tropical Indo-Pacific (Conand 1990). There is very little information on the distribution, abundance and stock structure (Roelofs et al. 2020). Current records indicate that its distribution extends from Ningaloo in Western Australia to Brisbane, Queensland (Atlas of Living Australia 2018). The known depth range of this species is 0–50 m, but most animals are caught between 15 m and 30 m (Conand et al. 2013). White teatfish commonly inhabits outer barrier reef slopes, reef passes and sandy areas in semi-sheltered reef habitats in 10 to 50 m water depth (Roelofs 2004; Purcell et al. 2012). Female white teatfish mature at around 4 years of age at a length of 320 mm total length (TL) (Roelofs et al. 2020). Spawning occurs once a year during the warm season (Roelofs 2004). Individuals live to about 12 years of age and reach a maximum size of 570 mm TL (Roelofs et al. 2020).

The Queensland Sea Cucumber Fishery (East Coast) is a commercial fishery that uses hand collection, with underwater breathing apparatus to collect various sea cucumber species. The hand collection method is highly selective, resulting in minimal risk to non-target species, including parts of the Great Barrier Reef Marine Park (GBRMP). There is no or negligible recreational or indigenous catches. The fishery extends from the tip of Cape York to the southern limit of Tin Can Bay. Management in Queensland applies a range of input controls including catch limits, vessel entry limitations, rotational fishing that consist of spatial-yearly closures (Table 1). Since 2004 a rotational harvest strategy was introduced in the fishery to distribute the catches spatially. Fishing for white teatfish in Queensland predominantly occurs in the Queensland Sea Cucumber Fishery (East Coast). Six species of sea cucumber are targeted with other target species being burrowing blackfish, black teatfish, prickly redfish, sandfish and blackfish. This report focuses on white teatfish only.

White teatfish harvests are approximately 52 tonnes (t) annually in the last five years, and with a total annual landed value of about $0.5 million AUD in 2013 (Skewes et al. 2014).

Table 1.1: Management changes applied to white teatfish in the Queensland Sea Cucumber Fishery (East Coast)

Year	Fisheries Management, Regulations and Operations
1988	Compulsory commercial catch logbook reporting commenced
1991	Introduction of quota Compulsory commercial fishing logbook in place
1995	Introduction of logbook version BD01; number and weight required
1997–1998	Total allowable commercial catch (TACC) of 500 t; 380 t allocated and 120 t unallocated
1998–1999	TACC was reduced to 380 t (all sea cucumber species)
1999–2000	TACC white teatfish is 127 t
July 2000	Introduction of logbook version BD02; reports numbers of sea cucumbers (however other reports state that only weight required) Logbooks - improved species differentiation among ’other species’ TACC of white teatfish is 158 t; increase quota by 25%

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Table 1.1 – *Continued from previous page*

Year	Fisheries Management, Regulations and Operations
2001–2002	TACC white teatfish is 127 t
2003–2004	TACC white teatfish is 89 t (56.8 t in Zone 1 and 32 t in Zone 2) . Introduction of White teatfish zones. Zone 1 is north of 19° S and Zone 2 is south of 19° S
2003	Authorities made transferable in sea cucumber and aquarium fish fisheries
2004	Rotational Zoning plan introduced (now Rotational Harvest Arrangement; RHA), but not necessarily recorded in logbook • TACC white teatfish is 127 t (57 t in Zone 1 and 70 t in Zone 2)—catch trends follow this and decrease accordingly • The TACC for white teatfish is based on gutted wet weight distributed in a fixed proportion between north and south. Each licence has an allocated portion of the white teatfish TACC Representative Areas Programme (RAP) 1 July: comprehensive rezoning of the whole Great Barrier Reef
March 2005	TACC for white teatfsish reduced from 127 t to 89 t (56.8 t in Zone 1 and 32 t in Zone 2)—catch trends follow this and decrease accordingly
July 2006	Introduction of logbook version BD03; only numbers of sea cucumbers required (weights recorded on buyer return logbook) TACC white teatfish maintained at 89 t (57 t in Zone 1 and 32 t in Zone 2)
August 2007	TACC white teatfish 70 t (57 tonnes in Zone 1 and 13 t in Zone 2; reduced quota in Zone 2) TACC weights adjusted to reflect processed—salted or blanched—weights
May 2008	TACC white teatfish 53 t; reduced from 89 t (40 t in Zone 1 and 13 t in Zone 2; reduced quota in Zone 1)
July 2009	Fishers to report rotational zone
2010	TACC white teatfish increased to 64 t (51 t in Zone 1 and 13 t in Zone 2)
July 2011	New conversion rate for quota TACC white teatfish reduced to 53 t
November 2013	Introduction of logbook version BD04; reporting weights and further improved species differentiation among ’other species’ Data from here onwards likely to be more accurate due to commercial logbooks reporting weights
March 2014	Investment and increased fishing effort warnings released White teatfish; removal of north south zonation, the requirement to return to port and unload catch before crossing into the other zone was lifted
2019–2020	TACC white teatfish; 53 t (40 t in Zone 1 and 13 t in Zone 2)
September 2021	BD05 Commercial Logbook to be implemented; will report estimated weights and number of containers

In 2004, an ecological assessment investigated the ecologically sustainable management of the fishery (Roelofs 2004). Results suggest a slight downward trend in catch rates between 1999–2003 from Melville to Cooktown although catches were stable. No trend was apparent for other areas (Cairns to Shoalwater Bay) and catches are not of concern. In 2014, a Management Strategy Evaluation for the fishery included aa surplus production model (Skewes et al. 2014). Results for white teatfish suggest that the spawning biomass ratio in 2011 was approximately 50% relative to 1995 levels (1038 t in 2011 and 1983 t in 1995) and the spawning biomass ratio was projected to be between 60–76% in 2021. Similar to Skewes et al. (2014) this assessment the current assessment also used a surplus production model that was formulated to be age structured (R package 'apsm', Haddon et al. (2019)). The key population performance indicator was an annual estimate of biomass.

The purpose of this report is to fulfill condition 6 of the WTO application and to fulfill the Queensland Harvest Strategy Policy for sea cucumber (State of Queensland 2020). Condition 6 of the WTO application states that "By 30 September 2021, the Queensland Department of Agriculture and Fisheries must complete and publish stock assessment(s) for the Black Teatfish (*Holothuria whitmaei*) and White Teatfish (*H. fuscogilva*) in the Queensland Sea Cucumber Fishery (East Coast). The stock assessment for Black Teatfish must be based on the results of the survey undertaken as part of Condition 4."

This report provides estimates of white teatfish biomass to provide advice needed to manage the fishery at sustainable levels, and support the goals defined in *Queensland Sustainable Fisheries Strategy: 2017-2027* (State of Queensland 2017) and the Status of Australian Fish Stocks framework (`fish.gov.au`). The target reference point for white teatfish, and all sea cucumber species, is 60% exploitable biomass as defined by the sea cucumber fishery harvest strategy (State of Queensland 2020). In addition, the goals of the Sustainable Fisheries Strategy are to set sustainable harvest or fishing limits to achieve 60% biomass.

2 Methods

There is a single management region for white teatfish within the Queensland Sea Cucumber Fishery (East Coast) (State of Queensland 2020)(2.1). Previously the fishery was divided into zones Figure 2.2. Queensland Fisheries removed the north/south boundary which separated the fishery into a northern zone (Zone 1) and a southern zone (Zone 2) on 1 July 2014. The boundary was established at the request of industry to promote collection of white teatfish south of the traditionally targeted areas located north of Townsville. The boundary commenced at the same time as the Rotational Zoning Scheme. The existence of the zone was increasing some costs for fishers in terms of the requirements to return to port and unload catch before crossing into the other zone. In 2014, Queensland Fisheries agreed to the request of the Queensland Sea Cucumber Association that the boundary be removed for these reasons

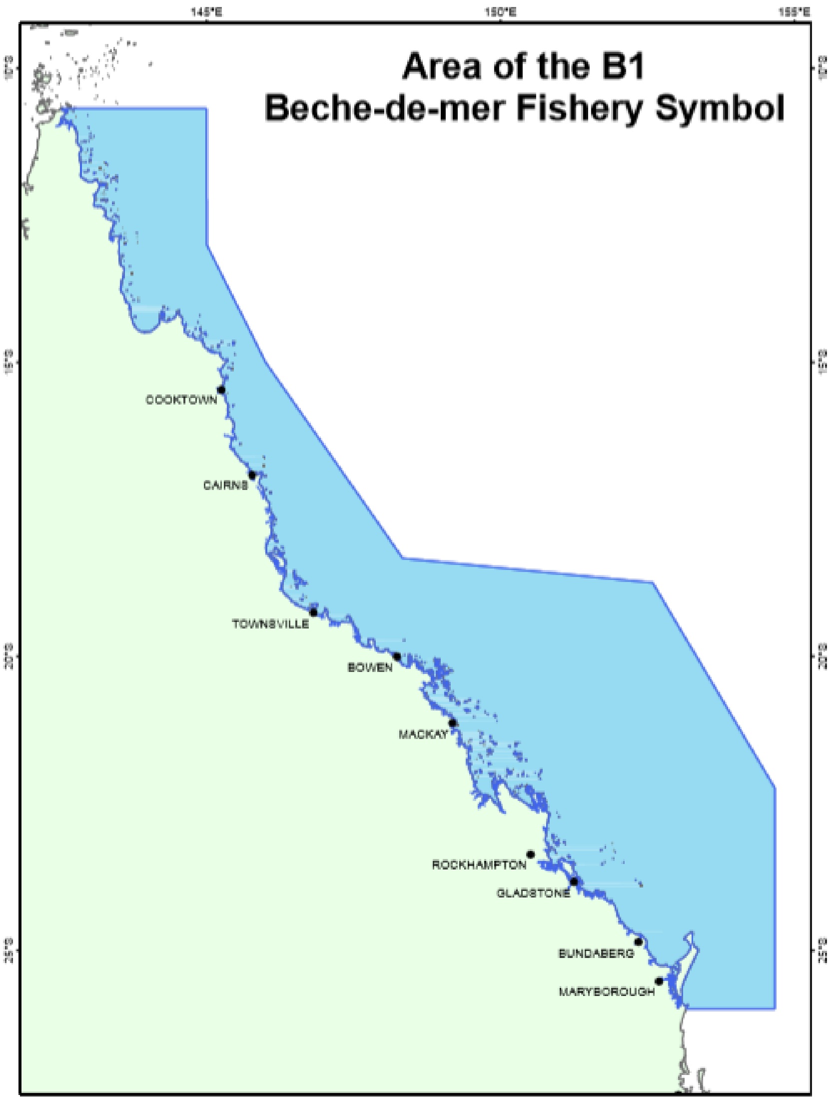

Figure 2.1: Map of the Queensland Sea Cucumber Fishery (East Coast)

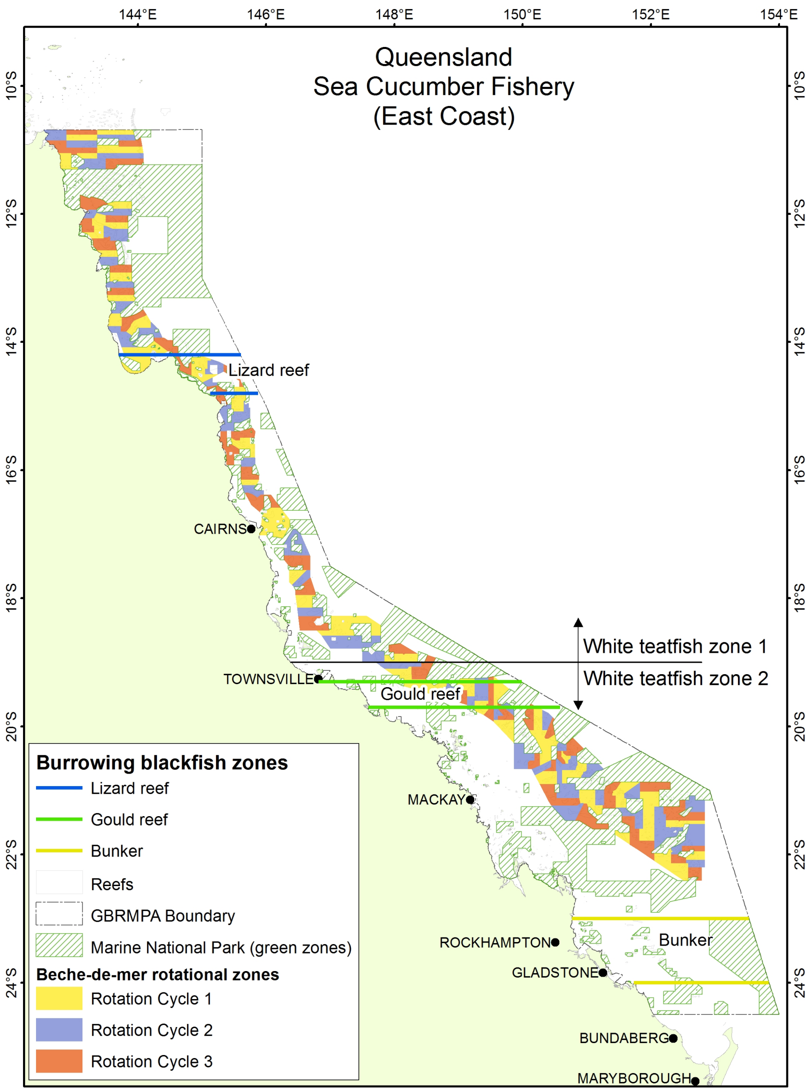

Figure 2.2: Map of the broadscale zones (no longer current) and the finer scale rotational zones in Queensland Sea Cucumber Fishery (East Coast)

2.1 Data sources

Two sources of catch data were available: one from the commercial vessel logbook records and a second source from the commercial buyer logbook records (Table 2.1). Commercial catch and effort data were sourced from the Queensland Fisheries compulsory logbook records (CFISH) over the time period of 20/08/1995 to 21/03/2021 (Table A.1). The data were used to determine catch rates and total annual harvests. The Queensland data contained daily entries for each boat for harvest in kilograms and the geographic location within the sea cucumber fishery.

Table 2.1: Data compiled for input into the white teatfish population model

Type	Year	Source
Commercial vessel data	1996–2021	Commercial logbook data collected by Fisheries Queensland Data extracted 1/4/2021, no fishing occurred after the data was extracted and this represents the full fishing year to end of June 2021
Commercial buyer data	2001–2021	Commercial buyer logbook data collected by Fisheries Queensland

2.2 Harvest estimates

For the commercial catch two sources of data were used. One source was from the commercial vessel logbook records collected between 1996 to 2021 fishing years, and the second source was from the commercial buyer logbook records collected between 2001 to the present (2021). The data from commercial vessel logbook records were considered to under represent the actual catch (Figure 2.3). The vessel data has been recorded for 26 years whereas the buyer data has been recorded for 21 years. There were differences in features between the two sources. Vessel data offered the longest time series (longevity) while the buyer data offered more accuracy. In order to combine the two features of longevity and accuracy, the harvest data was reconstructed from buyer data and vessel data. This was achieved by adjusting the vessel data to match the buyer data for the years with no buyer data and then using the buyer data henceforth. Details as follows:

- calculate the mean of the difference of buyer and vessel catch over the first five overlapping years (2001–2004) = 0.256
- adjust catch from vessel data, for 1996–2000, by: vessel data * (1 + mean of the difference)
- use buyer data for 2001–2021

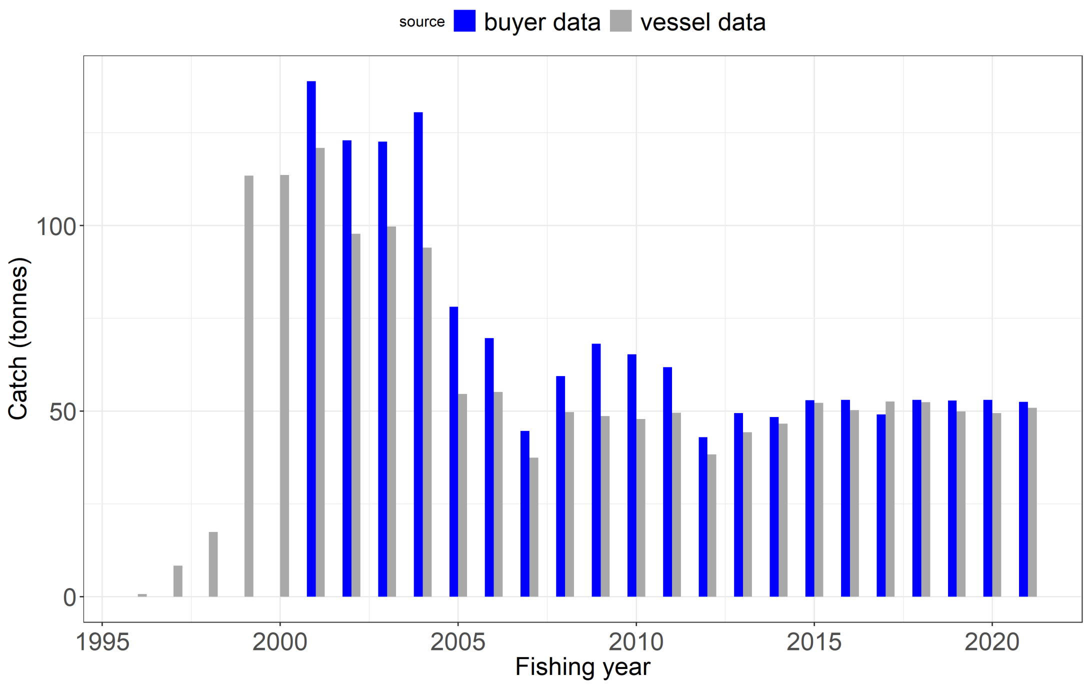

Figure 2.3: Annual total catches between the 1996 and 2021 fishing years for white teatfish in the Queensland Sea Cucumber Fishery (East Coast)

2.3 Abundance indices

2.3.1 Data filtering

Logbook vessel records were analysed and identified as the same operation date and end date of fishing. Data were grouped by vessel and operation date to generate daily harvests for white teatfish. Most of the data on white teatfish was used in the catch rate analysis, but a few filtering criteria were applied

- records with catch but zero effort were removed
- records with effort but zero catch were removed
- the first three years of records were removed due to unreliable records (1995–1996, 1996–1997, 1997–1998)

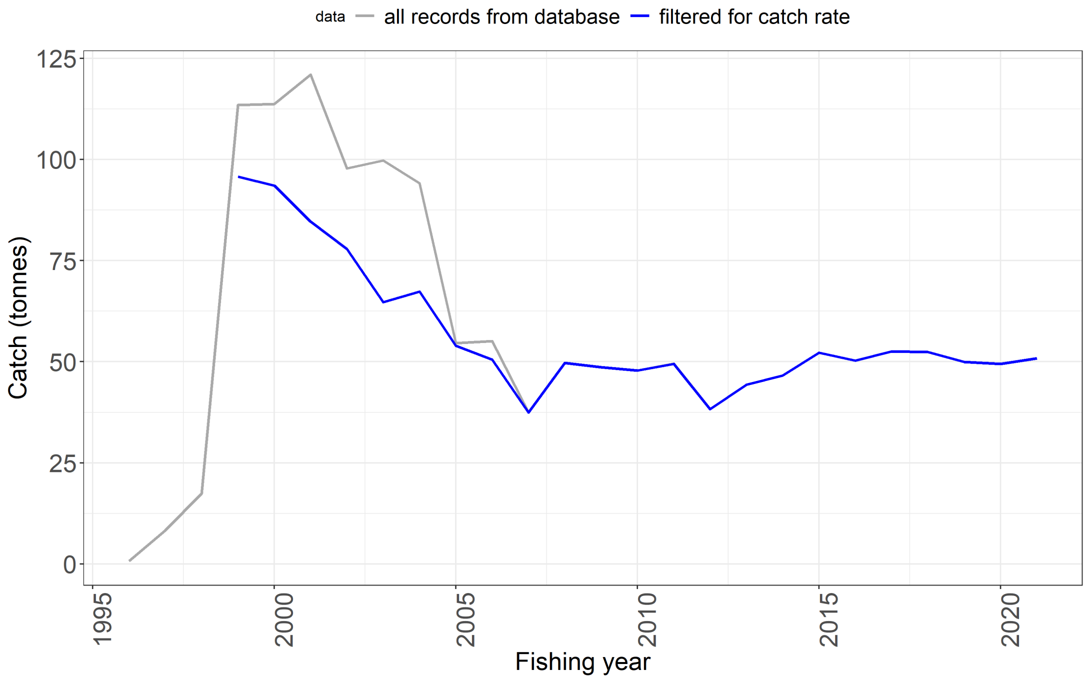

Figure 2.4: Catches recorded in the commercial vessel logbook data for white teatfish in the Queensland Sea Cucumber Fishery (East Coast)

2.3.2 Standardised commercial catch rates

Standardised catch rates were calculated using 'glm' in R and assumed normally distributed errors on the log scale. A quasi-poisson distribution was used with a log-link to take into account overdispersion, which better captures the higher distribution present in the data (R Core Team 2020). In the generalized linear model, an effort offset is applied, meaning there is a known relationship between catches and effort rather than allowing the coefficient for effort to be estimated (Maunder et al. 2004).

The following model was used:

$$\log(\text{catch}) \sim \text{year} + \text{month} + \text{vessel} + \text{offset (loghrs)} \tag{2.1}$$

where $\log(\text{catch})$ is the log of the catch, fishing year (year) and fishing month (month) relate to the fishing season for white teatfish which is the same as the financial year and the effects of the main vessels were included by the vessel term. Effort, (loghrs), is the log of the hours fished per boat per day.

2.4 Biological parameters

The biological information and parameters required for the age-structured production model were similar to those used in Skewes et al. (2014). Most of these parameters have been used again for this assessment (Table 2.2) and any differences presented in Table 2.3.

2.4.1 Growth

Growth in mean bodyweight-at-age was a two step process. First, the von Bertalanffy age-at-length model was applied (Equation 2.2) and second, length was converted to weight using the length to weight equation (Equation 2.3, Appendix A.1). For white teatfish, the age (a) is defined in terms of year.

$$L_t = L_\infty(1 - \exp(-k(t - t_0))) \tag{2.2}$$

where L_t is the length at age t, L_∞ is the asymptotic maximum length, k is the growth coefficient, and t_0 is the time (age) at length zero. The parameter for L_∞ was 583 mm TL (female) and the parameter for k was 0.324 (female).

$$W_L = \alpha L^\beta \tag{2.3}$$

where W_L is weight to length, and α and β were 0.000254329 and 2.6435, respectively.

2.5 Population model

An age structured production model was used that operated on a yearly time step. The age structured surplus production model was selected from the FRDC toolbox written by Haddon et al. (2019) (R package 'aspm', age-structured production model, http://toolbox.frdc.com.au/). Some adjustments were made to the prepackaged aspm model, by the addition of parameters, to improve the model fit as described below and in Appendix B.2.

The current packaged model includes an option that consisted of two parameters (initial recruitment and standard deviation for catch rate). The results of the model fits, between observed and predicted catch rate, captured the overall large-scale changes but not the fine scale interannual changes (Figure B.3). The model was reformulated slightly to include annual recruitment deviates, thus adding an additional 22 parameters, which improved the fit. In total there were 22 parameters estimated by the model, R_{init} and 21 annual recruitment deviates.

2.5.1 Population dynamics

The dynamics of the age production model tracked numbers (N), biomass (B) and recruitment in every year (t) (Haddon et al. 2019). Biomass was the total biomass of age 0 and older animals after harvest was applied.

Recruitment numbers—Beverton-Holt formulation

Recruitment numbers (R) were assumed to follow an annual Beverton and Holt function with lognormal deviations. The model was firstly initialised to generate an unfished stock in equilibrium using virgin recruitment (R_0), estimated on the log scale using the parameter R_{init} (Equation 2.4). After the model was initialised, a series of equations were used to estimate annual recruitment numbers over the current time series of the fishery (1996–2021).

- use steepness (h) of 0.7 (Skewes et al. 2014))
- estimate the number of female white teatfish spawning each year (S_y, Equation 2.5)
- use steepness (h) and virgin recruitment (R_0) and the number of female spawners (S_y) to estimate α and β (Equation 2.6)
- use α, β in the Beverton-Holt stock recruitment equation to estimate annual recruitment (Equation 2.7)

$$R_0 = \exp\left(R_{\text{init}}\right) \times 10^8 \tag{2.4}$$

$$S_y = 0.5 \sum_{t=1}^{12} \theta \frac{1 - \exp(-Z_t)}{Z_t} N_t \tag{2.5}$$

$$\alpha = \frac{S_0(1-h)}{4hR_0} \qquad \beta = \frac{5h-1}{4hR_0} \tag{2.6}$$

The number of annual recruits from the Beverton-Holt equation was

$$\text{rec}_y = \frac{S_y}{\alpha + \beta S_y} \tag{2.7}$$

Harvest rate

In the population model, harvest rate is used instead of instantaneous fishing mortality, to account for time-varying fishing mortality (Hilborn et al. 1992) and is the observed catch divided by predicted exploitable biomass (Equation 2.8).

$$u_t = C_t / B_t \tag{2.8}$$

where C_t is the annual catch in year t and B_t is the predicted annual exploitable biomass.

2.5.2 Model assumptions

The main assumptions of the model were:

- Growth in mean body length at age is described by a von Bertalanffy equation;
- All animals aged r and older are equally vulnerable to fishing, implying knife-edged selectivity at age r;
- All animals have the same annual natural mortality rate;
- All animals aged r and older have the same catchability;
- Catch rates were proportional to abundance; and,
- Mean growth in weight was the same for both sexes.

2.5.3 Model parameters

Table 2.2: Fishery constants and biological parameters used in the revised age based surplus production model

Parameter	Value	fixed / estimated	Description
Fishery constants			
unfished year	1995	fixed	the start year in the model, being the year prior to the commencement of fishing
start year	1996	fixed	commencement of the fishery
end year	2021	fixed	final year of data
recfishyr	21	fixed	number of years of recruitment deviations (2001–2021)
rec_fyr	2001	fixed	First year to estimate recruitment deviations
Biological parameters			
Natural Mortality			
M (year^{-1})	0.44	fixed	one parameter for instantaneous natural mortality per year (Skewes et al. 2014)
Recruitment			
R_{init}	-9.9	estimated	used to determine R_0 (Equation 2.4)
R_0 scaler	10^7	fixed	scaler for R_0
R_0	exp(R_{init})xR_0 scaler	estimated	average recruitment of the unfished stock.
ζ	mean = 0, sd = 0.27	estimated	21 recruitment deviates, normal random, for n recruitment years (see recfishyr)
Stock Recruitment			
steepness	0.7	fixed	for Beverton-Holt stock recruitment curve (Skewes et al. 2014)
Length to weight			
α	0.00245	fixed	average weight (g) at length l (divide by 1000 for kg)
β	2.19	fixed	(see Equation 2.3)
Other parameters			
maxAge	12	fixed	maximum age
L_∞	583	fixed	maximum length for von Bertalannfy growth model
k	0.324	fixed	for von Bertalanffy growth model
t_0	0.9	fixed	for von Bertalanffy growth model
SM50	320 mm	fixed	size at maturity (total length)
AM50	4	fixed	age at maturity
deltaM	2	fixed	the difference in ages between the age at 50% and the age at 95% maturity
selectivity	400	fixed	selectivity minimum legal size
deltaS	2	fixed	the difference in ages between the age at 50% and the age at 95% selectivity
resilience	low	fixed	population resiliance for age structured model
number of ages	13	fixed	for the age structured model
rho	0.2	fixed	Brody growth coefficient used in the delay difference model which was an extra analysis

Table 2.3: Comparison of fishery constants and biological parameters with Skewes et al. (2014)

Parameter	Value	Skewes et al. (2014)
Biological parameters		
Natural Mortality		
M (year^{-1})	0.44	0.3-0.6
Stock Recruitment		
steepness	0.7	0.5-0.7
Length to weight		
Other parameters		
max weight (kg)	3	5
max length (mm TL)	583	570
max Age	12	12
SM50	320 mm	320 mm
selectivity	400	400

3 Results

3.1 Model inputs

The parameters for the model input are presented in Appendix B.1. The development of the biological inputs for growth and maturity are presented in Appendix A.1

3.1.1 Harvest estimates

The highest harvest occurred between 1999 and 2004 (Figure 3.1). Harvests decreased in 2005 which coincided with the introduction of the rotational management in 2004 (Skewes et al. 2014) and the Representative Areas Program. Catches fluctuated slightly between 2005 and 2012 but subsequently remained relatively stable at or below 53 t due to the total allowable commercial catch (TACC) quota applied by management.

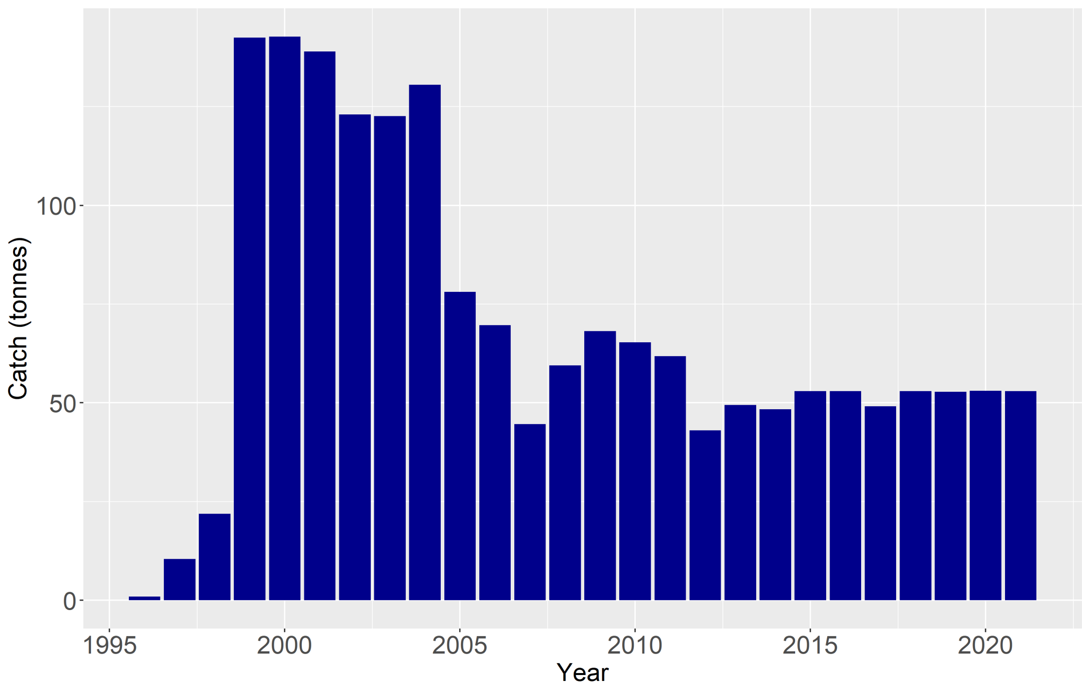

Figure 3.1: Total annual estimated landed catch between 1996 and 2021 for white teatfish in the Queensland Sea Cucumber Fishery (East Coast)

3.1.2 Standardised catch rates

Catch rates were standardised to represent trends in the abundance of white teatfish (Figure 3.2). Annual catch rates were used as a model input to characterise the trend of the time series. Annual catch rates declined sharply between 2001 and 2002. This was followed by an increase between 2004 and 2006 which coincided with the introduction of the rotational management in 2004. Catch rates remained relatively stable for the next decade with greater variation from 2016 onwards.

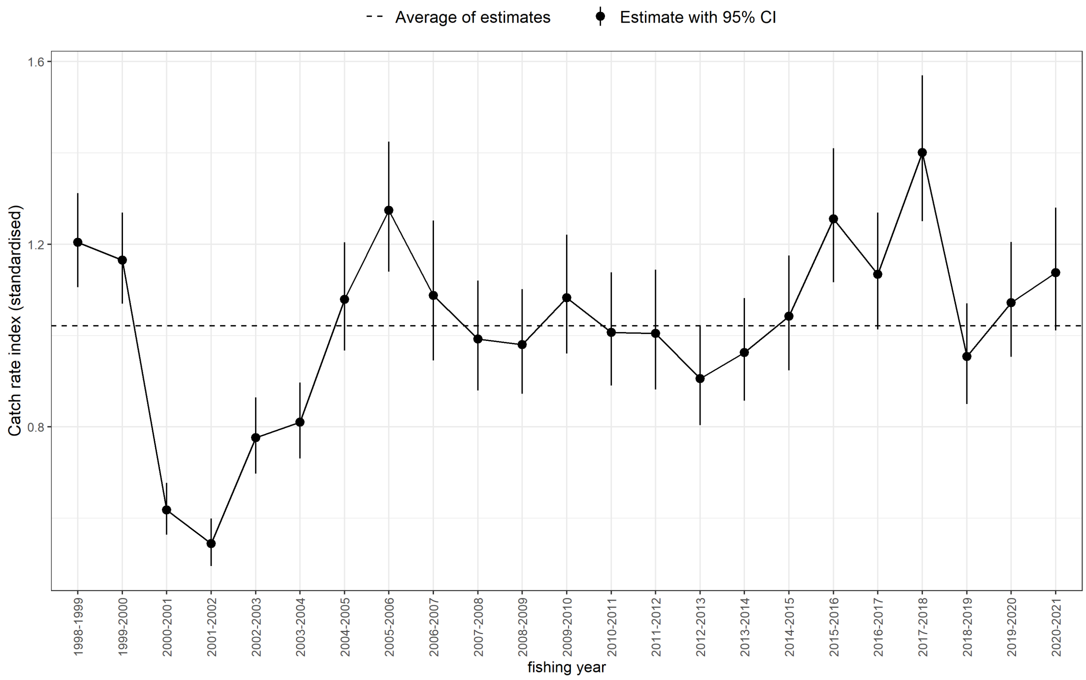

Figure 3.2: Annual standardised catch rates (95% confidence intervals) for white teatfish in the Queensland Sea Cucumber Fishery (East Coast) between the years of 1999 and 2021

3.2 Model outputs

Results from the model outputs are informed by input data for annual harvests, catch rates and by fixed model parameters (Table 2.2).

3.2.1 Model parameters

In total there were 22 parameters estimated by the model including 21 for annual recruitment and one for initial recruitment (R_{init}). The fitted parameter values are presented (excluding the 21 annual recruitments) as a table of median values and confidence intervals after the fitting procedure resulting from the hessian. The initial starting parameter for (R_{init}) varied markedly after model fit (Figures B.1,B.2). This may suggest that the biological recruitment levels are naturally low (Table 3.1).

Table 3.1: Estimated model parameters with upper and lower confidence intervals—estimated recruitment deviates from the 21 annual recruitment estimates are not presented

Parameter	Description	Median	2.5%	97.5%
R_{init}	initial recruitment	-9.38	-10.27	-9.61

3.2.2 Model fits

The model was fitted to standardised commercial catch rates (Figure 3.3). The predicted catch rate fitted the data reasonably well capturing the inter-annual fine scale and broad scale variation. This fitting behaviour was consistent throughout the majority of time series.

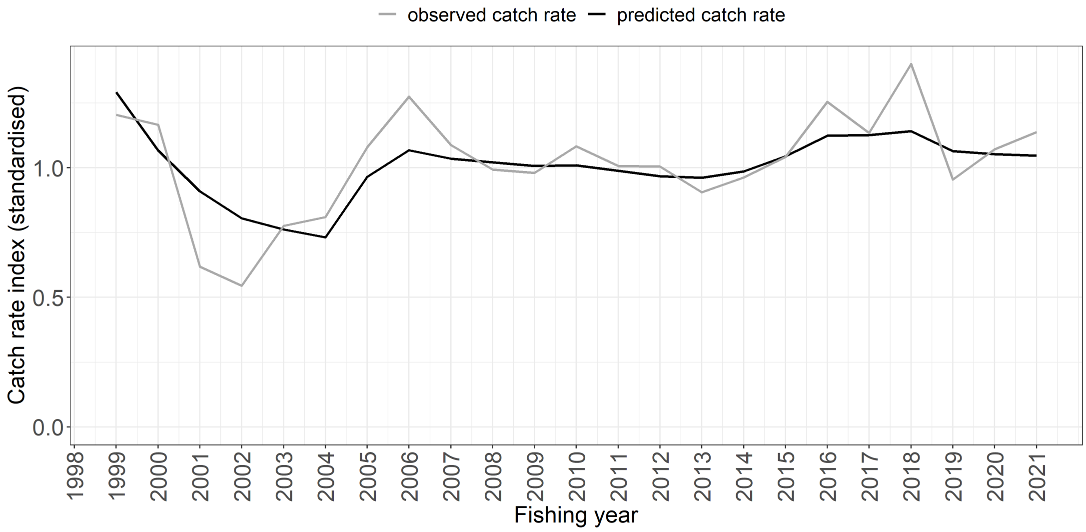

Figure 3.3: Observed and predicted standardised catch rates between 1999 and 2021 for white teatfish in the Queensland Sea Cucumber Fishery (East Coast)

3.2.3 Biomass

The model estimated exploitable and spawning biomass. Both aspects of biomass were presented as a ratio of biomass relative to 1995, estimated from the best fitted parameters (also presented is the median). For both exploitable and spawning biomass ratios, the estimated biomass has remained above the 60% target. The exploitable biomass declined to roughly 56% in 2003 and has fluctuated around 80% since 2014. It is currently 76% in 2021 (Figure 3.4). The spawning biomass declined to 67% in 2002 and has fluctuated around 80% since 2003. It is currently 78% in 2021 (Figure 3.5).

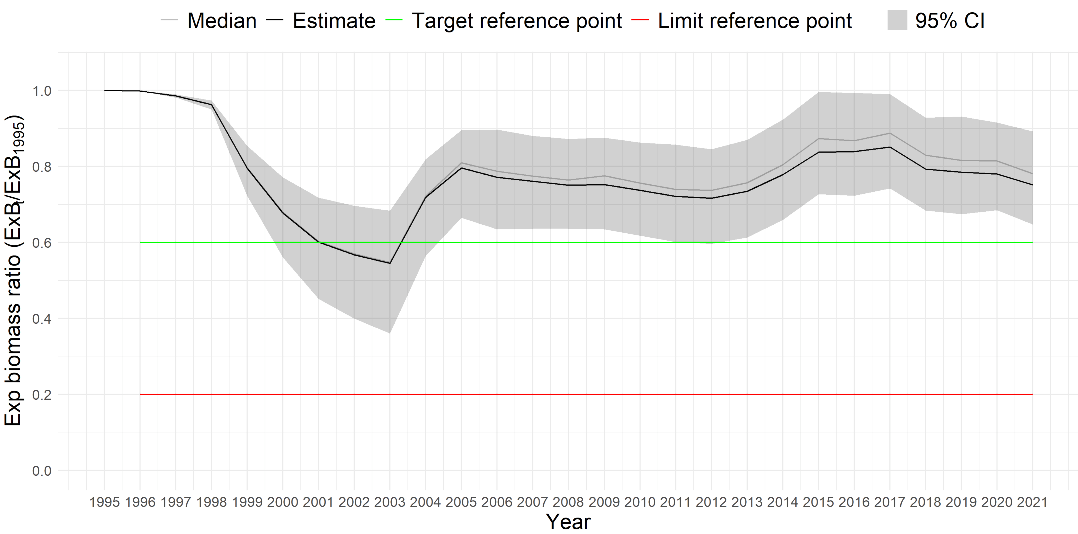

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Figure 3.4: Annual exploitable biomass ratio (95% confidence intervals) between 1995 and 2021 for white teatfish in the Queensland Sea Cucumber Fishery (East Coast)

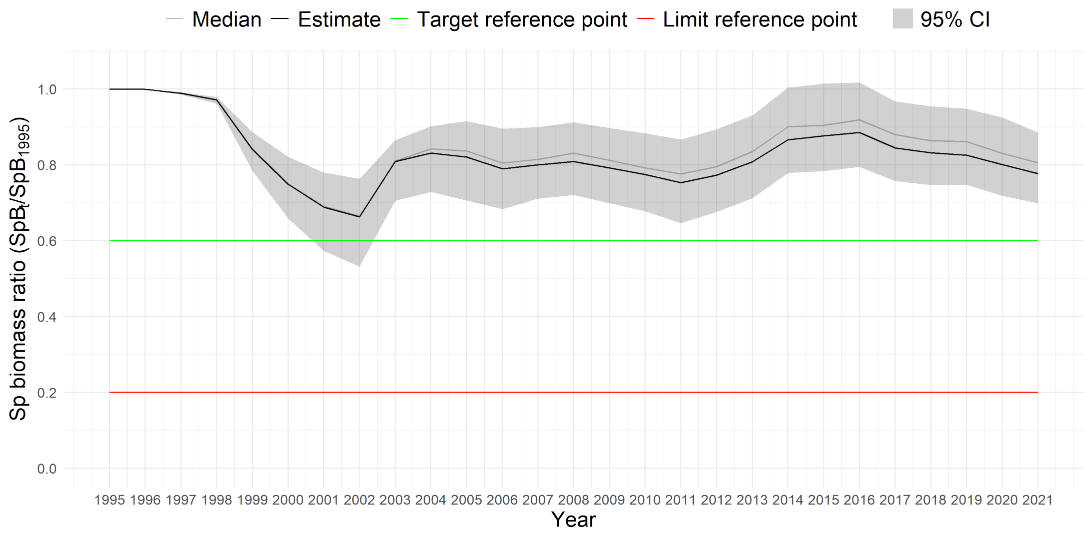

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Figure 3.5: Annual spawning biomass ratio (95% confidence intervals) between 1995 and 2021 for white teatfish in the Queensland Sea Cucumber Fishery (East Coast)

4 Discussion

Under the current harvest strategy, annual catches of white teatfish in the Queensland Sea Cucumber Fishery (East Coast), over the past nine years, have been limited by the TACC and remained relatively stable at 53 t. The current estimated biomass was 76% for exploitable biomass and 78% for spawning biomass in 2021 relative to unfished biomass in 1995. Both these relative biomass estimates have fluctuated around 80% during this period, well above the target to achieve 60% exploitable biomass by 2027 and within the goals of the harvest strategy (State of Queensland 2020).

Often there are various aspects within a fishery that usefully describe dynamics in a qualitative way that may not have been captured in the quantitative analyses. These are important considerations when interpreting results. For example the format of the logbooks and management arrangements have changed over the history of the fishery.

Subsequent to the implementation of the rotational zone in 2004 (Skewes et al. 2014), catch rates remained relatively stable for about a decade. Larger fluctuations began after 2016.

4.1 Biomass

The target reference point for white teatfish, and all sea cucumber species, is 60% exploitable biomass as defined by the sea cucumber fishery harvest strategy (State of Queensland 2020). The current estimated biomass ratio was 76% for exploitable biomass in 2021 and 78% for spawning biomass. Currently the exploitable biomass ratio is above the target and within the goal of Queensland's Sustainable Fisheries Strategy 2017–2027 (State of Queensland 2017) which is to achieve 60% biomass by 2027 (State of Queensland 2020).

Over the last nine years annual catches have remained relatively stable at 53 t. Over this time period the biomass ratio has slightly fluctuated by about 10% and this indicates the degree of observation error in stock dynamics when the biomass ratio is at around 80% even though the catches had not changed. These results are based on the assumption that that there was no fishing prior to 1996. If there was fishing prior to 1996 it would be expected that the biomass ratio would vary from the current estimate.

Previously, a quantitative analysis was conducted in 2014, as part of a Management Strategy Evaluation framework (Skewes et al. 2014). Although this was not intended as an assessment of the stock, the MSE consisted of biomass simulations for white teat fish in Queensland. The model in Skewes et al. (2014) was developed using different approaches to the approach used for the current assessment. While it can be interesting to compare biomass ratios between results herein to those presented in Skewes et al. (2014), important caveats apply. Mainly, the model by Skewes et al. (2014) was not a fitted model and the assessment herein was fitted to time series of catch effort data. Instead, Skewes et al. (2014) conditioned and tested their model against better known dynamics of another sea cucumber species, black teatfish

Also, to simulate the starting model standing stock, Skewes et al. (2014) used density estimates of white teat fish from Torres Strait as model starting population estimates. In the assessment herein the standing stock was initiated within the model by generating a unfished biomass in equilibrium. The model by Skewes et al. (2014) was tuned to whole-stock results from separate fishery independent studies, for each sea cucumber species. The assessment herein was fitted to catch rate data from the fishery only (the open area) and not from the whole stock, and represents a different spatial scale than Skewes et al. (2014) which is on a larger spatial scale. The model by Skewes et al. (2014) then converted the results from separate studies into a spawning biomass for each sea cucumber species including white teatfish. All these differences considered it may be nevertheless interesting to compare outputs. A decline in biomass was reported by Skewes et al. (2014) Figure B.6, and this raised the question as to whether the current assessment overestimated biomass or whether Skewes et al. (2014) underestimated biomass. Skewes et al. (2014) explains the decrease was due to heavy historic fishing for white teatfish.

4.2 Model fit

The assessment was conducted under the tight timeframes stipulated by the WTO conditions. The robustness of the model was determined by evaluating the fit to the standardised catch rate and was considered to be satisfactory. Analysis of standardised residuals indicated that the age structured production model fitted the data reasonably well and that the assumed error structures were valid. No concerning correlations of key parameter estimators were evident. Furthermore, an alternative delay-difference model (Appendix B.2) that was run in parallel, yielded similar results with respect to biomass ratio.

The catch rates predicted by the model, captured the overall large scale and fine scale interannual changes in the observed catch rate. The predicted estimates were consistent with the observed estimates in the years where there were not high extremes but did not fit to the extreme low levels which occurred between 2001 and 2004. After this period the predicted catch rate was within the range of the overall variability. Overall, the fitting behaviour was relatively consistent throughout the time series and would not have affected the resulting biomass trend deferentially. The high and low extremes in the catch rates can be suggestive of some of the limitations of the method including the catch rate standardisation.

4.3 Model uncertainty

Throughout the entire time series the stock dynamics are informed by observed catch rates and not by average recruitment. There are a number of key assumptions. Growth rates and natural mortality were assumed to be constant throughout the period. Other key assumptions are related to the recruitment aspects of stock dynamics and include:

- the assumption that the stock was in an equilibrium, unfished state in 1995 (from Figure 3.5)
- the assumption that the Beverton-Holt stock recruitment relationship (with associated recruitment residual structure) provided an acceptable description of recruitment dynamics. That is, the equations were capable of capturing the biological recruitment dynamics as well as variations introduced by environmental factors, which may be influential.

These results of the assessment are based on the assumption that the white teatfish stock was at virgin biomass in 1995. The collection of current logbook records commenced in 1988, and indicate no fishing of white teatfish prior to 1996. Prior to the commencement of logbook records in 1988, it is unknown if fishing for white teatfish occurred but considered unlikely. Fishing most likely increased when the more valuable black teatfish fishery was closed (in 1999) following concerns for the status of the black teatfish, reflected in significant catch rate declines.

It was also apparent, in conducting this assessment, that many of the biological parameters used as inputs into the assessment (growth, mortality, length-weight relationships etc.) were determined many decades ago. If these aspects of white teatfish have not changed then it is immaterial, but it is possible that the recent coral bleaching events during 2016 (Schiermeier 2018) may have impacted on the population biology in some manner. It was apparent that catch rates, which were relatively steady for the prior decade, fluctuated more noticeably during and subsequent to this event. This may warrant further investigation.

The other aspect of the assessment that may warrant further investigation is consideration of the influence that the GBR protected areas (i.e. 'green zone') may have on the assessment assumptions. It is currently assumed that the effects of the green zone such as higher recruitment level may have been distributed spatially outside of the protected areas and population in open areas may have incorporated the beneficial effect of populations in the protected green zone, into their population biology.

4.4 Observation uncertainty

Another consideration for stock assessments in general might be hyperstability in catch rates. Hyperstability can be due to changes in the spatial distribution of fishing, resulting in biases in catch rate trend. As a sedentary species that is relatively vulnerable to hand harvest fishing, there are concerns about the potential for hyperstability of catch rates masking trends in abundance. Exploration of this aspect of the assessment can be confounded by the potential influence of the rotational zoning scheme (Roelofs 2004), which requires that divers only fish a particular zone for a maximum of 15 days once every three years. It is worth noting that from 2022 fishing year, industry has introduced a voluntary code of practice where divers are being assigned certain zones to fish. In an industry where only two companies own all of the licences, they have recognised that this may encourage even higher levels of stewardship by divers to ensure optimal fishing is maintained and potential for localised depletion might be minimised. The presence of localised depletion and the potential for hyperstablity of catch rates, can be explored using available published methods (Carruthers et al. 2011).

4.5 Recommendations

The time frame available for the assessment permitted only a limited number of data and model explorations and further work is recommended to incorporate rotational zone in the analysis.

4.5.1 Data

The Queensland Sea Cucumber Fishery (East Coast) is a hand collection fishery with no by-catch or discards. However it is unknown if any discarding occurs by other fishery operations such as trawling and it is recommended that this be investigated. Future analyses could also consider if a longer time series of catches exists.

4.5.2 Monitoring/Research

Fishery independent surveys will improve the robustness of the model. Updating the length-to-weight conversion formula by collecting length and weight data will improve the robustness of the model. Temperature may affect the population biology of marine ectotherms. An updated collection of biological data such as growth and maturity is required.

4.5.3 Assessment

It is recommended to explore hyperstability and evaluate the standardised catch rates using published methods (Carruthers et al. 2011). Hyperstability can be due to changes in the spatial distribution of fishing, resulting in biases in catch rate trend.

Assessment outcomes, particularly biomass ratio, can be affected by changes in the start year of the fishery with regards to the time series of catches. In this assessment, the start year of 1996 is quite recent. There are indications that it might have been fished previously with reports that sea cucumbers have been fished since 1880 and is the oldest fishery in Queensland (Eriksson et al. 2015). The report by Eriksson et al. (2015) groups all sea cucumbers together and does not differentiate between species however there is a strong suggestion that the captures were mostly of black teatfish. It is considered that white teatfish occur too deep to have been fished historically, and most of the divers would have preferred the shallower black teatfish.It is recommended that the starting year for future assessments be revisited to determine if 1996 or an alternate year is most appropriate.

4.6 Conclusions

The white teatfish fishery is a commercially valuable stock in Queensland. This is the first quantitative assessment of white teatfish in the Queensland Sea Cucumber Fishery (East Coast). The model appears to be reasonably robust and fitted the available data reasonably well. The model estimates that stock has been fluctuating around 80% of the unfished biomass in 1995. This assessment has informed the status of the white teatfish population in the Queensland Sea Cucumber Fishery (East Coast). The current harvest levels appear not to exceed the goals of the harvest strategy of maintaining the stocks at 60% exploitable biomass ratio target reference point.

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Appendix A Data sources

Table A.1 shows a description of data sources used and procedures applied to prepare the data.

Table A.1: Data procedures used to define the fishery data that was included in the analysis of catch effort

Data	Details	Notes
CFISH data extraction	Data extracted 1/4/2021; SQL script held by Assessment and Monitoring	
	Fisheries Policy and Sustainability, Fisheries; Primary Industries Building Brisbane	Catches, effort, Year, month, start Date, end Date, Vessel ID (authority chain number), licence ID, fishing method, depth, sector / spatial location, operation ID, conversion rate. request: all sea cucumber species
Time period	20/08/1995 to 21/03/2021	
Data sets	Separate tables were provided for commercial vessel catch-effort, commercial buyer returns	
Daily records	Only daily records were analysed and were identified by the same operation date and end date of fishing.	Data were grouped by Authority Chain Number and operation date to make daily (harvests > 0 for each species group).

A.1 Biological data

A.1.1 Growth

Growth in mean body weight-at-age was required as a model input for the age structured surplus production model (Figures A.1 and A.2). Estimating growth in terms of weight-at-age was a two step process. The von Bertalanffy age-at-length model was applied (Equation 2.2) and secondly, length was converted to weight using a length to weight equation (Equation 2.3). For white teatfish, the age (a) is defined as years.

A second growth model which estimated weight from age directly (not requiring a two step process) was used for estimation rho in the the delay difference model. The equation for the second growth model could have been used for the age structured model, however it was used for estimating rho in the delay difference model. The rho parameter was estimated by fitting the Brody growth equation (which requires rho) to the weight-at-age data (the second growth equation). The fitting procedure was done in MS Excel using the Solver function and minimizing the sum of squares. Also presented is the published results on growth (based on weight-at-age) (Reichenbach 1999) for comparison and validation of results.

Figure A.1: Comparison of weight-at-age estimates from published literature, and the inputs in the delay difference model (weight at age) and the surplus production models (weight at length at age) for white teatfish in Queensland

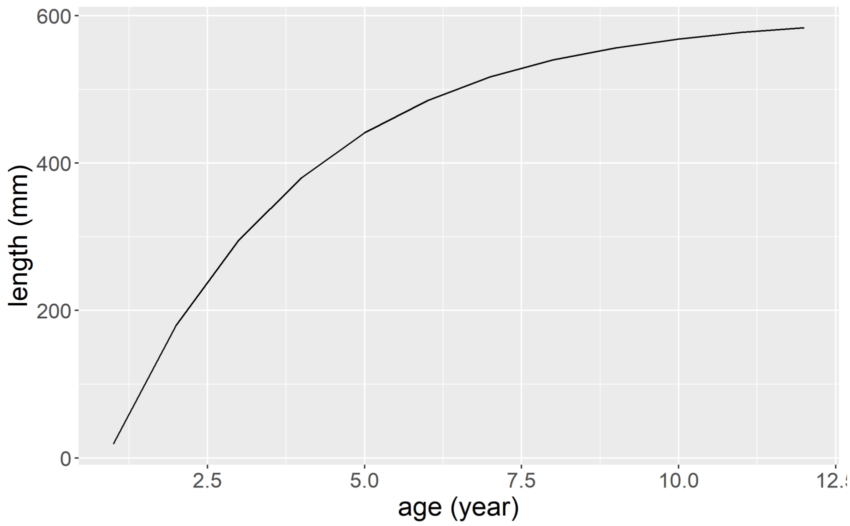

Figure A.2: Growth as length-at-age using the von Bertalanffy model for white teatfish in the Queensland Sea Cucumber Fishery (East Coast)

A.1.2 Fecundity and maturity

Maturity at length is estimated using a logistic function (Figure A.3). The assessment model was in annual time steps (in whole years) therefore to determine maturity at length, the input into the logistic function used length based on age in whole years. This resulted in coarser maturity ogive than the smoothed result which used lengths of 1 mm and are also presented here for comparison.

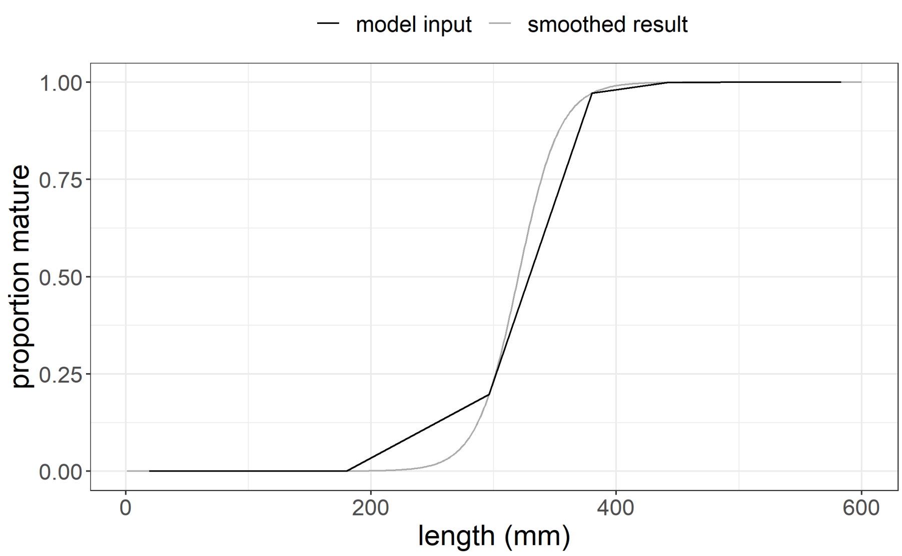

Figure A.3: Proportion mature at length for white teatfish in the Queensland Sea Cucumber Fishery (East Coast)

A.1.3 Weight and length

Estimating growth in terms of weight at age was a two step process. After applying the von Bertalanffy model to obtain length at age (Equation 2.2) the lengths were converted to weight using a length to weight equation (Equation 2.3) (Figure A.4).

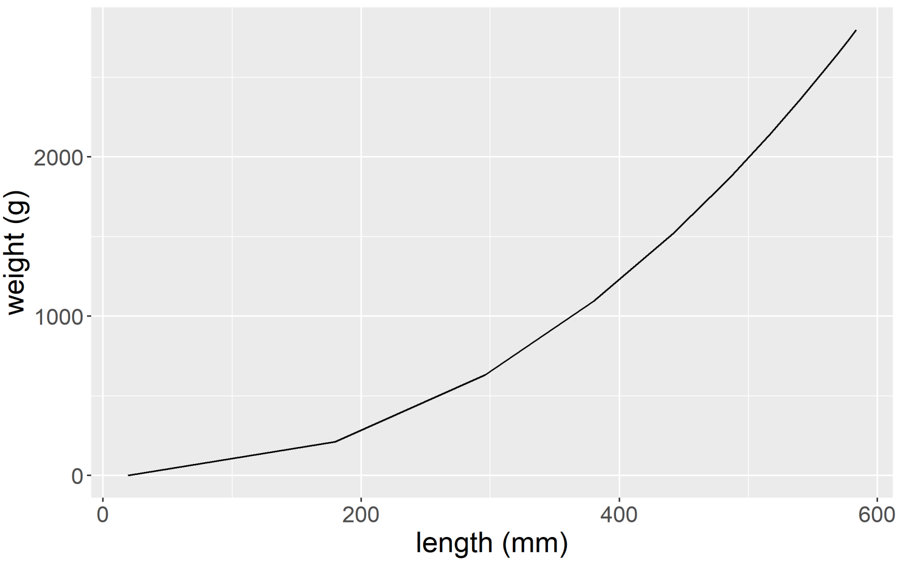

Figure A.4: Growth as weight-at-length for white teatfish in the Queensland Sea Cucumber Fishery (East Coast)

Appendix B Model outputs

B.1 Parameter estimates

There were 22 parameters estimated; one parameter for initial recruitment (R_{init}), and 21 parameters for recruitment deviates Appendix B.1. This section will focus on initial recruitment (R_{init}) only. The initial starting parameter for R_{init} varied markedly after model fit (Figure B.1). This may suggest that the biological recruitment levels are naturally low. (Figure B.2).

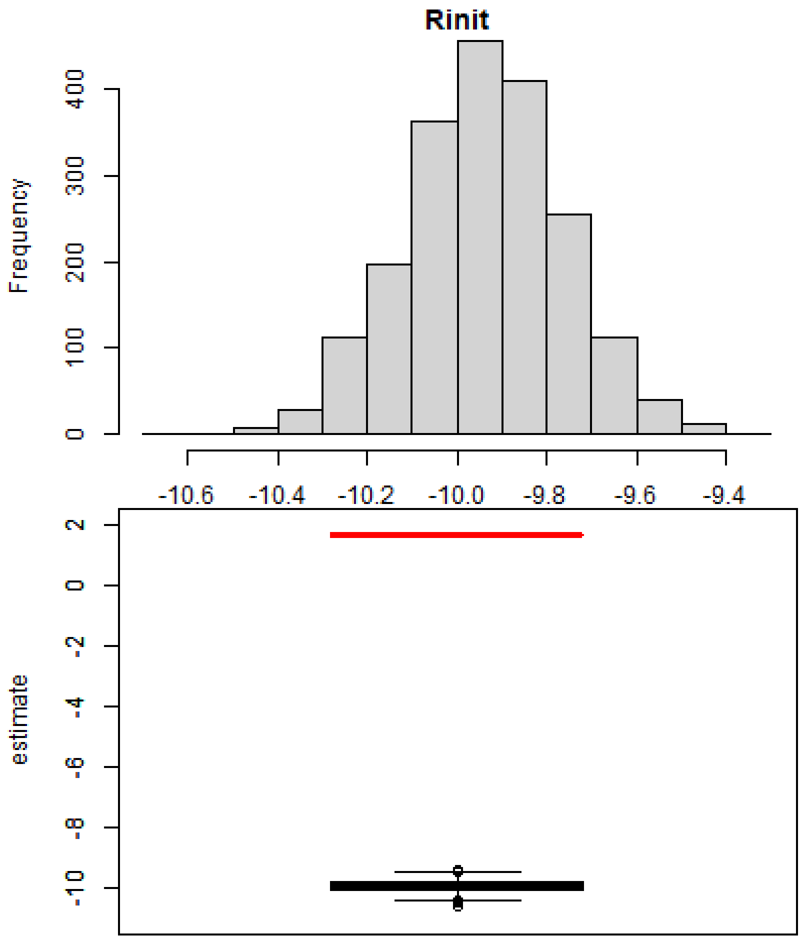

Figure B.1: The starting value (red) and the best fitting value (95% confidence interval) for the estimated parameter R_{init}

The number of recruits is a function of fertilisation success. Sea cucumbers need to be in close proximity to each other to ensure fertilisation success (Hart et al. 2018). Fertility success decline with decreasing density due to reduced probabilities of egg sperm encounters (Hart et al. 2018). The number of viable recruits can be as high as the million of viable egges but reduced success can lead to lower levels (Figure B.2).

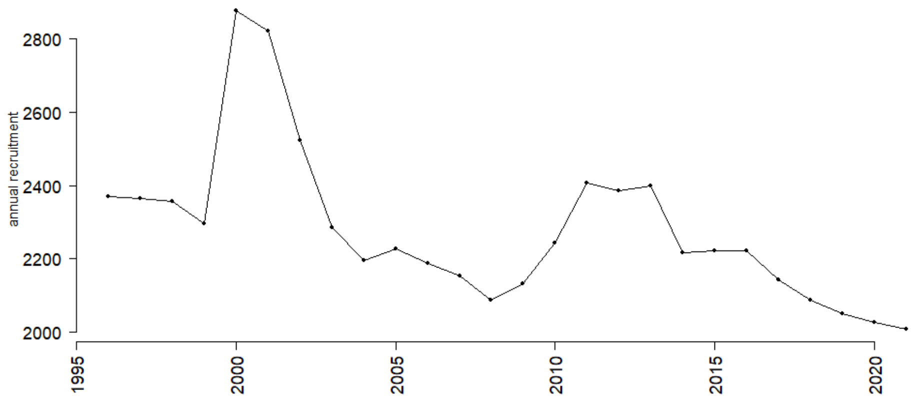

Figure B.2: Annual recruitment levels estimated by the model for white teatfish in the Queensland Sea Cucumber Fishery (East Coast)

B.2 Model development and goodness of fit

An age structured surplus production model (aspm) was downloaded from the FRDC toolbox (Haddon et al. 2019). It was applied to white teatfish. The resulting model fits between observed and predicted catch rate were capturing the overall large scale changes but not the fine scale interannual changes (Figure B.3). The resulting fit appeared sub-optimal and this prompted a study to develop the model and explore methods to improve the fit. A different different model, a delay difference model, was also applied to experiment with, as it gave satisfactory results when used for the stock assessment of tiger prawns (Helidoniotis 2021). At first results of the fit from the delay difference model resembled the aspm. However, further experimentation with the delay difference model improved the fit and captured the large scale and fine scale changes very well. These experimental changes were then applied to the aspm model. The aspm model was revised by adding the experimental changes and this revised model became the base case model for the assessment of white teatfish. The spawning biomass was estimated from the aspm and delay difference models to compare and determine the level of agreement (Figure B.5). Results indicate good agreement between the two models and this provided confidence in the assessment results.

The result indicated an improvement in the fit between the observed and predicted catch rate in the age structured surplus production model (Figure B.4).

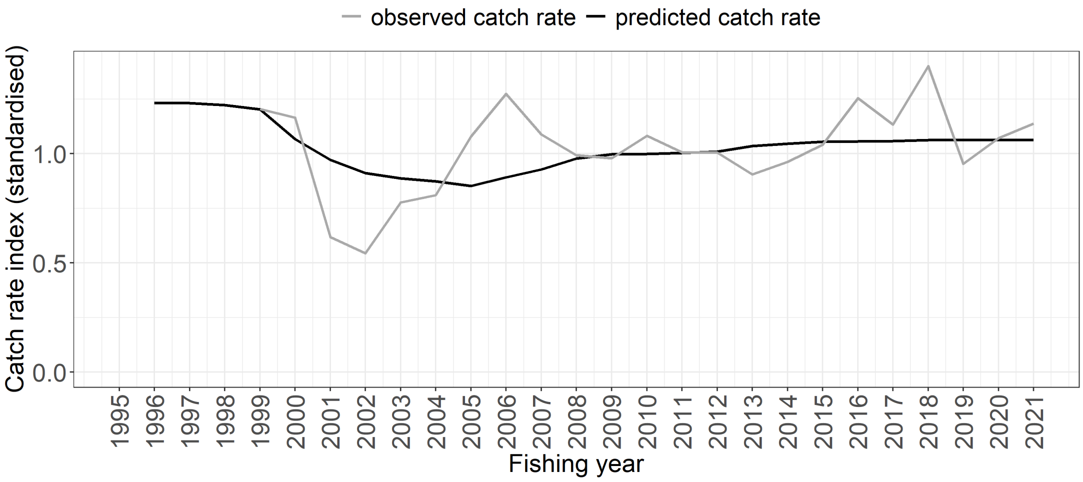

Figure B.3: Model fit (original 2 parameter aspm model) to catch rates for white teatfish

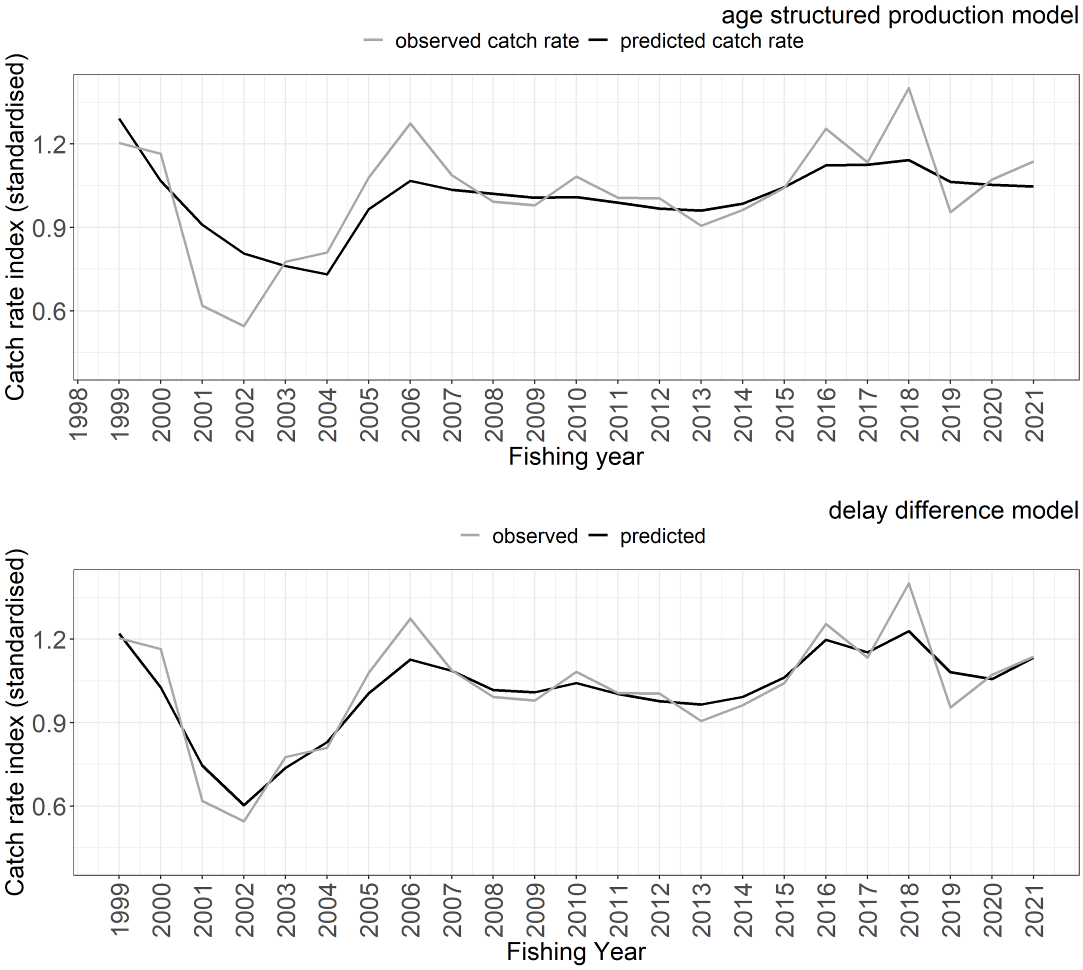

Figure B.4: Model fit to white teatfish catch rates for the aspm model (top panel) and the delay difference model (bottom panel)

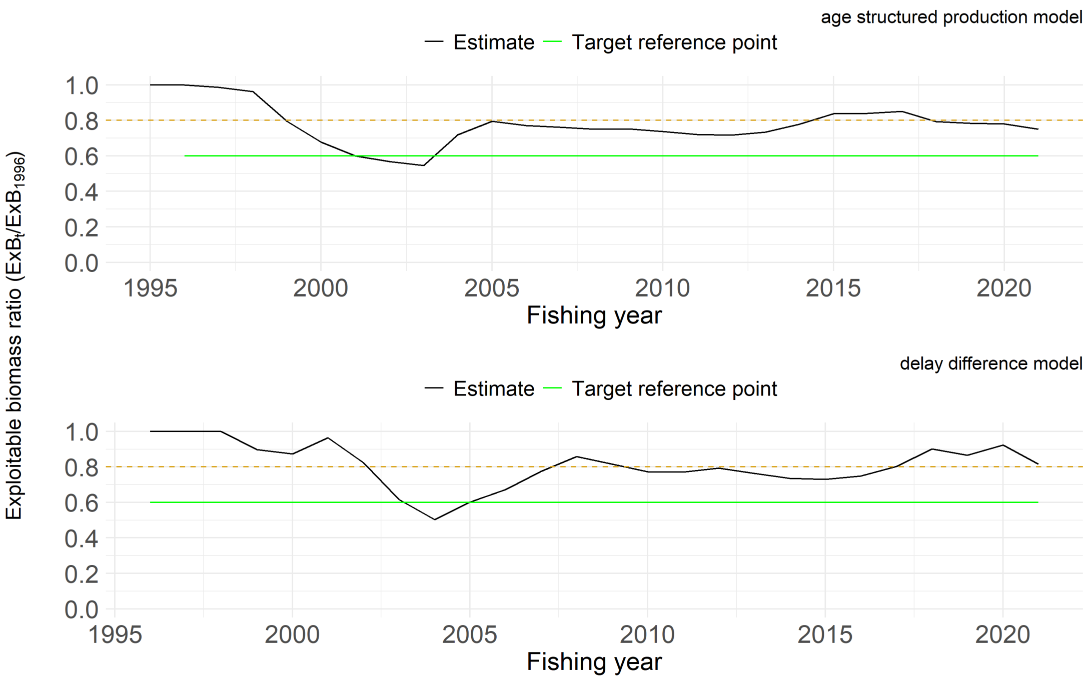

Figure B.5: Comparison of exploitable biomass ratio for white teatfish between two models: the aspm model and the delay difference model

The total biomass ratio was compared with a previous analysis (Skewes et al. 2014) and results indicate that the biomass ratio from the current analysis was above that estimated previously (Figure B.6).

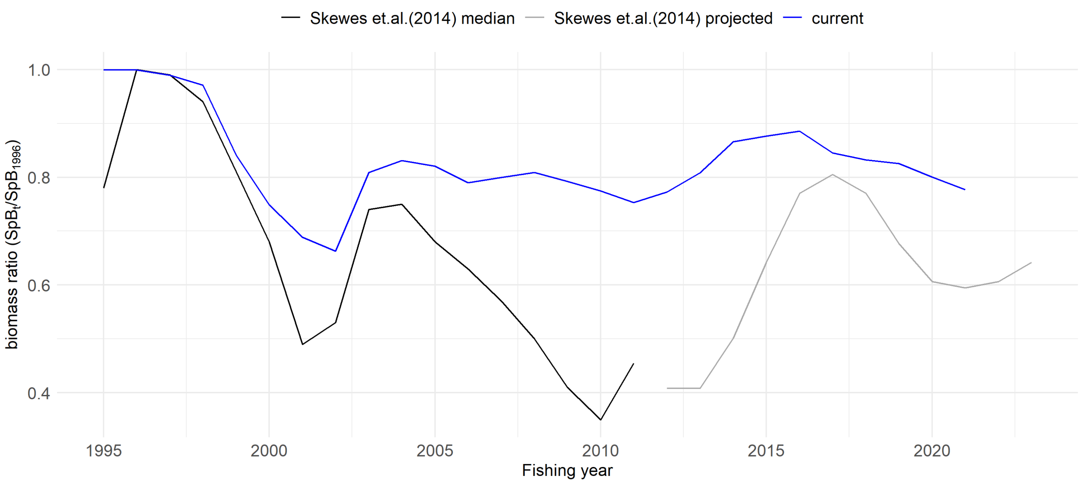

Figure B.6: Comparison of annual spawning biomass ratio estimated by Skewes et al. (2014) and the current analysis between 1995 and 2021 for white teatfish in the Queensland Sea Cucumber Fishery (East Coast)