Stock assessment of Queensland east coast dusky flathead (*Platycephalus fuscus*), Australia, with data to December 2020

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Queensland Government

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Summary

This stock assessment indicates that biomass declined between 1901 and 2000 to 30% unfished spawning biomass. The stock level at the beginning of 2021 was estimated to be 46% unfished biomass.

In Queensland, dusky flathead (*Platycephalus fuscus*) are found in inshore waters of east coastal regions from south of Cairns to the New South Wales (NSW) border and targeted by commercial, charter and recreational fishers. Dusky flathead are a gonochore (born male or female and does not change sex) and spawn primarily in the summer months. Female dusky flathead grow much larger and live longer than males. For Queensland's east coast, they generally attain maximum average length of 85 cm (total length) and live for 11 years. Dusky flathead are believed to be a single population on the east coast of Queensland.

This is the second stock assessment of dusky flathead and covers the whole of Queensland's east coast. The previous stock assessment was conducted in 2019 and covered only South East Queensland from Baffle Creek (24.5 $^\circ S$) to the NSW border (about 28.2 $^\circ S$). It reported the 2017 spawning biomass was 36% and 70% of unfished biomass in the Moreton region and Fraser region, respectively.

This stock assessment was conducted on calendar years and included input data through to December 2020. All assessment inputs and outputs will be referenced on a calendar year basis.

This stock assessment implemented a two-sex population model within the modelling framework of Stock Synthesis and fit to the fishery catch and catch rate data as well as the age and length data. The model incorporated data spanning the period from 1945 to 2020, including the Queensland commercial logbook data (1988–2020), Queensland Fish Board commercial harvest size estimates (1945–1980), recreational survey harvest estimates (1997, 1999, 2000, 2002, 2005, 2011, 2014, 2019), length-frequency and age-at-length data (2007–2020) from boat ramp surveys and Fisheries Monitoring Program of Fisheries Queensland.

Over the last five years (2016 to 2020), the Queensland total harvest averaged 137 tonnes (t) per year, including 37 t by *Gillnetting*, *Tunnel Netting* and *Commercial Line* of the commercial sector, 4 t by *Charter Line* of the charter sector, and 96 t by *Recreational* of the recreational sector in Figure 1. The commercial and charter harvest in recent years were based on logbook reporting whereas the recreational harvest were estimated from surveys and interpolated between survey years.

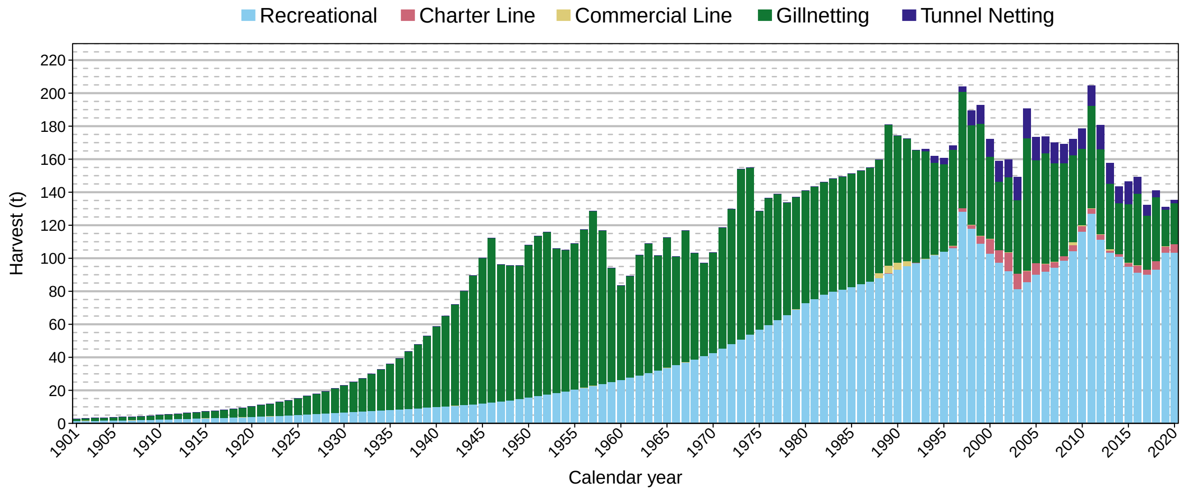

Figure 1: Annual estimated harvest (retained catch) from the commercial sector (*Gillnetting*, *Tunnel Netting*, and *Commercial Line*), recreational sector (*Recreational*) and charter sector (*Charter Line*) between 1901 and 2020 for dusky flathead.

The commercial catch rates of Gillnetting and Tunnel Netting were standardised to estimate indices of dusky flathead through time (Figure 2). The unit of standardisation was kilograms per fisher-day. For Gillnetting, the catch rate standardisation model included effects for year, month, location, net mesh size, net length and fisher; for Tunnel Netting, the model included effects for year, month, net length and fisher.

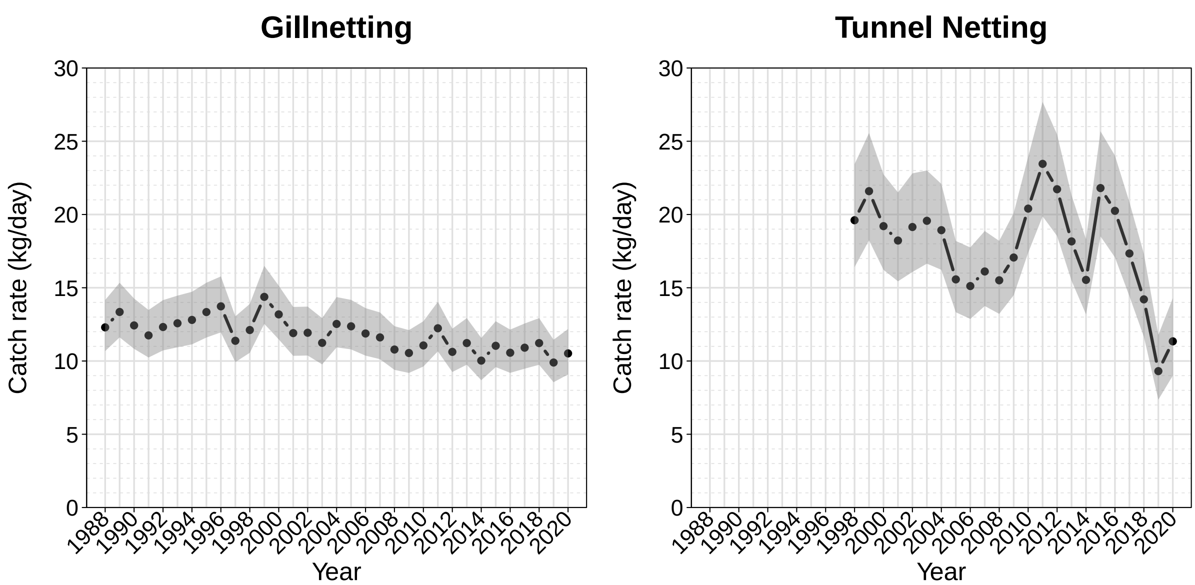

Figure 2: Annual standarised catch rates and 95% confidence intervals for Gillnetting (1988–2020) and Tunnel Netting (1998–2020) when the imputed net mesh size and net length were included in the standardised catch model.

Eighteen scenarios were run to cover a range of modelling assumptions and sensitivity tests for the stock model. Base case (most plausible) results suggested that the dusky flathead biomass experienced a decline in the period of 1901–2000 to reach 30% unfished spawning biomass (Figure 3). At the beginning of 2021, the stock level was estimated to be 46% unfished biomass with the 95% confidence interval between 31% and 62%.

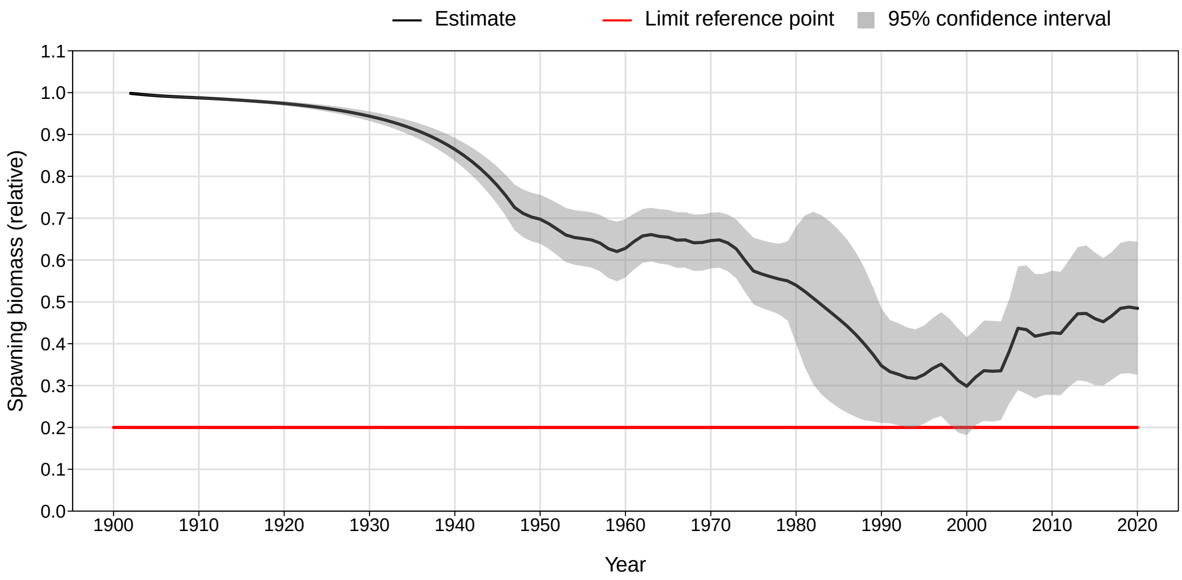

Figure 3: The estimated biomass trajectory relative to unfished for dusky flathead based on the base case scenario from 1901 to 2020.

The East coast inshore fishery harvest strategy: 2021–2026 identifies a target reference point ($\mathbf{B_{targ}}$) of between 50 and 60 % for tier 2 species within the fishery which applies to dusky flathead (Fisheries Queensland (2021b)). This variation in biomass targets for tier 2 species recognises different biological and economic characteristics among target species in the fishery. The equilibrium yield curve produced as part of this assessment suggests that a 50 % target reference point would maintain the stock in a more productive state than a 60 % target, and is therefore likely to be the most reflective of MEY.

The harvest consistent with maintaining a spawning biomass of 50% was estimated at 138 t and for rebuilding the stock back to 50% target, the assessment recommends a biological catch of 106 t for 2021. The harvest consistent with maintaining a spawning biomass of 60% was estimated at 112 t. For a 60% target, the assessment recommends a biological catch of 60 t for 2021(Table 1).

The suggested uncertainty discount factor for this assessment is 0.87.

Table 1: Current and target indicators for Queensland east coast dusky flathead.

Indicator	Estimate
Biomass◇ (relative to unfished) at the start of 2021	46% (31% to 62%)
Biomass (relative to unfished) at MSY⋆	22%
MSY⋆	189 t
Retained catch component of MSY⋆	184 t
Retained catch in 2020	135 t
Retained catch at 60% biomass target	112 t
Retained catch at 50% biomass target	138 t
RBC† for 2021 to achieve 60% biomass target	60 t
Retained component of RBC	58 t
RBC† for 2021 to achieve 50% biomass target	106 t
Retained component of RBC	102 t
Time to achieve 60% biomass target	10 years
Time to achieve 50% biomass target	6 years

◇ Biomass is defined to be spawning stock biomass.

⋆ MSY (maximum sustainable yield) is defined to be the maximum sustainable dead catch—that is, retained catch plus catch that dies following discarding.

† RBC (recommended biological catch) is the recommended catch according to the control rule. This is dead catch: retained catch plus catch that dies following discarding

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Glossary

B_{60}	60% of unfished spawning biomass, a proxy for biomass at maximum economic yield
B_{50}	50% of unfished spawning biomass
biomass	spawning biomass, the total weight of all adult (reproductively mature) fish in a population, an indicator of the status of the stock and its reproductive capacity
CFISH	Commercial Fisheries Information System, which is the compulsory commercial logbook database managed by Fisheries Queensland
CI	confidence interval
dead catch	retained catch (‘harvest’) plus catch that dies following discarding
fisher-day	a day of fishing by a fishing operator, corresponding to a single daily logbook record (commercial)
fleet	a Stock Synthesis modelling term used to distinguish types of fishing activity—typically a fleet will have a unique curve that characterises the likelihood that fish of various sizes (or ages) will be caught by the fishing gear, or observed by the survey
FRDC	Fisheries Research and Development Corporation
GLM	generalized linear model
harvest	see ‘retained catch’
LTMP	Long Term Monitoring Program
M	Natural mortality
MCMC	Markov chain Monte Carlo
MLS	maximum legal size
mLS	minimum legal size
MSY	maximum sustainable yield, is defined to be the maximum sustainable dead catch—retained catch plus catch that dies following discarding.
NRIFS	the National Recreational and Indigenous Fishing Survey conducted by the Australian Department of Agriculture, Fisheries and Forestry
RBC	recommended biological catch, is the recommended catch according to the control rule. This is dead catch—retained catch plus catch that dies following discarding.
retained catch	component of the catch that is kept by fishers, also referred to as ‘harvest’ and ‘landed catch’
RFish	recreational fishing surveys conducted by Fisheries Queensland
SFS	Sustainable Fisheries Strategy
SRFS	Statewide recreational fishing surveys conducted by Fisheries Queensland
SS	Stock Synthesis
TL	total length measured from the tip of the snout to the very end of the tail
year	1 January to 31 December

1 Introduction

Dusky flathead *Platycephalus fuscus* are endemic in Australia and distributed along the coast from Cairns in Queensland to Gippsland Lakes in Victoria (Keenan 1988; Froese et al. 2022). In Queensland, they are found in inshore waters of east coastal regions and are a popular target species for both commercial and recreational fishers. The Queensland commercial catch for dusky flathead might occur in the early 20th century (Darcey 1990). However, the earliest official records of harvest in Queensland begin from about the 1940s.

Dusky flathead are predators inhabiting inshore coastal waters ranging from brackish to marine (Barnes et al. 2011). They are usually found over soft substrates in estuaries, shallow bays and inlets (Kerby et al. 1994). The species is brown and mottled in colour and dorso-ventrally flattened with an upturned mouth and eyes. This specially-adapted body plan allows flathead to partially bury themselves in soft substrates (e.g. mud, sand, and seagrass) and ambush passing-by invertebrates (e.g. crabs, prawns, and squid) and fish (Randall et al. 1997).

Adult dusky flathead largely remain within the same estuary for their entire lives although a limited number of individuals can migrate longer distances (e.g. between estuaries). Tagging experiments conducted in New South Wales by Gray et al. (2015) showed that more than 90% of dusky flathead were recaptured within the same estuary, but a small number of individuals did move between estuaries. The longest migration recorded in the study was 280km between the Clarence River (NSW) and Moreton Bay (QLD) demonstrating the potential for genetic mixing between states (Gray et al. 2015).

Some researchers suggest that dusky flathead inhabiting estuaries from Queensland to Victoria may constitute a single genetic stock (Taylor et al. 2020). In a study of eight estuaries spanning the NSW coast, Taylor et al. (2020) showed that dusky flathead populations in NSW were likely interbreeding. It was suggested that the sharing of genetic material between populations is predominantly maintained by the recruitment of larvae from distant estuaries, and adult migrations to a lesser degree (Taylor et al. 2020).

Flathead are known to form spawning aggregations at river mouths where eggs and larvae can be dispersed long distances (i.e., hundreds of kilometres) by prevailing ocean currents (Pollock 2014). More genetic studies sampling dusky flathead populations across multiple jurisdictions are needed to confirm the absence of genetic substructure. Currently, limited evidence for genetic exchange and interbreeding in dusky flathead adult populations between state jurisdictions means that each state's populations are managed separately from the others (Leigh et al. 2019).

Dusky flathead are gonochoristic (i.e., born male or female and do not change sex, Gray et al. (2015)). Across the east coast of Australia, dusky flathead are believed to spawn multiple times between September and May, with slight differences in the exact timing and duration of spawning between locations (Gray et al. 2015). In Queensland waters north of Baffle Creek, spawning was determined to occur between September and March (Russell 1988). The gonadosomatic index (i.e., the weight of gonads as a percentage of total body mass) for male and female dusky flathead in southern Queensland were highest between December and March, indicating peak spawning activity during these months (Gray et al. 2015; Pollock 2014). Meanwhile, in Moreton Bay, Dredge (1977) identified the spawning season as November to February. Pollock (2014) also noted the presence of degenerate ovaries in some larger females at Jumpinpin in southern Queensland.

Dusky flathead display sexually dimorphic growth with females growing larger and faster than males. Gray et al. (2015) found that juveniles were typically <20 cm TL, males ranged between 20–50 cm, and females ranged from 20–70 cm. Dusky flathead females also appear to live longer than males. The oldest fish aged by the Fisheries Queensland monitoring team was an 11 year old female. The oldest male was six years. The largest dusky flathead officially reported was 120 cm TL (Kailola et al. 1993).

Male and female dusky flathead also mature at different rates. The study of Gray et al. (2015) in NSW showed the length at 50 percent maturity of dusky flathead was 31.72 ± 1.08 cm TL for males and 56.75 ± 0.60 cm TL for females. The corresponding ages were 1.22 ± 0.44 yr for males and 4.55 ± 0.13 yr for females. However, Hicks et al. (2015) showed the length at 50 percent maturity of female dusky flathead in Victoria was 32.8 ± 2.4 cm TL. They stated that their estimate was similar to an earlier one for Queensland by Russell (1988). An unpublished and unavailable study by the Queensland Department of Primary Industries from the early 1990s found that the age at maturity of female flathead was about 45 cm (Kerby et al. 1994).

Dusky flathead are commonly confused with the following closely related and co-occurring species:

- Northern sand flathead (*Platycephalus endrachtensis*) (previously classified as *Platycephalus arenarius*) (see Imamura 2008).
- Yellowtail flathead (*Platycephalus westraliae*) (previously classified as *Platycephalus endrachtensis*) (see Imamura 2008).
- Australian bartail flathead (*Platycephalus australis*) (previously classified as *Platycephalus indicus*) (see Imamura 2015).

In Queensland, commercial fishing for dusky flathead is predominantly by nets. Most of the annual commercial dusky flathead harvest is caught with gillnets and tunnel nets, while smaller harvests are also taken by beach seine netting. For the recreational sector, dusky flathead are predominantly line-caught from boats or the shore. Dusky flathead are also harvested by the charter sector. CFISH logbooks began delineating the charter harvest from commercial harvest in 1996.

Technological advances over time have benefited commercial, charter and recreational fisheries for many species including dusky flathead. In the 1950s, fishing gear developments including nylon fishing lines, waders, chemically sharpened hooks, as well as new traces and baits afforded increased access to fishing grounds and improved catch rates (Claydon 1996, pp. 11–15). For South East Queensland beach-based fishing, Leigh et al. (2017) inferred a technological or 'fishing power' increase for recreational fishing of 4.6% per year from 1954 (the first year for which fishing-club data were available) to 1974, 2.3% per year from 1974 to 1997 and no further increase after 1997.

Various management measures have been applied to the flathead fishery in Queensland since the late 19th century. Key management measures in Queensland are summarised in Table 1.1. A minimum legal size (MLS) of 13 inches TL (about 33 cm) for flathead was imposed early in the fishery's history. The metric measurement from December 1976 was 30 cm. In December 2002, MLS for dusky flathead was increased to 40 cm, and a maximum legal size (MLS) of 70 cm was imposed. In 2009, MLS for dusky flathead was increased to 75 cm. In 2008, an in-possession limit of five dusky flatheads was imposed for the recreational fishery.

The total fishing effort on dusky flathead in Queensland is not currently limited. Recreational fishers are currently managed under in-possession limits. A number of licences are available to commercially target flathead. There are various spatial and temporal closures, a total allowable commercial catch (TACC) of 41 tonnes is currently in place.

Table 1.1: Management measures applied to dusky flathead in Queensland waters. Source: Queensland (Qld) state government legislation. This table includes only fisheries legislation that is available online: Qld Acts from 1914 and Qld Regulations from 1991.

Date	Measure
1877–1974	Numerous measures relating to fishing gear and practices; e.g., mesh size, net length, allowed species, closed seasons, powers of inspectors.
3 Dec 1914	Minimum legal sizes: flathead 12 in. (30.5 cm) TL (*The Fish and Oyster Act of 1914*).
1926–1933	Minimum legal sizes: flathead 13 in. (33.0 cm) TL (*Amendments 1926, 1929 and 1933 by Order in Council to The Fish and Oyster Act of 1914*).
18 Apr 1957	Minimum legal sizes: flathead 13 in. (33.0 cm) TL (*Fisheries Act 1957*).
16 Dec 1976	Minimum legal sizes: flathead 30 cm TL (*Fisheries Act 1976*).
10 Mar 1990	Confirm minimum legal sizes from 1976 (*Fisheries Organization and Marketing Regulations, 1990*).
1 Jul 1993	Confirm minimum legal sizes from 1976 (*Fishing Industry Organization and Marketing Amendment Regulation No. 3, Subordinate Legislation 1993 No. 235*).
1 Dec 1995	Closure to commercial net fishing of most of Moreton Bay foreshore and waterways in the City of Brisbane (Manly to Brighton); Great Sandy Strait, all foreshore south of Double Island Point and all of Moreton Bay at weekends; and the eastern (ocean beach) shore of Fraser Island from 1 September to 1 April (*Fisheries Regulation, 1995 No. 325*). No change to minimum legal sizes set 1976.
9 Dec 2002	Legal sizes (TL) dusky flathead minimum 40 cm, maximum 70 cm; other flathead species remain at 30 cm minimum, no maximum (*Fisheries Amendment Regulation (No. 4), Subordinate Legislation 2002 No. 339*).
1 Apr 2008	In-possession limit 5 dusky flathead; no change to legal sizes for flathead set 1993–2002 (*Fisheries Regulation, 2008 No. 83*).
1 Mar 2009	*Marine Parks (Moreton Bay) Zoning Plan 2008* closed 16 percent of the area of Moreton Bay Marine Park to all fishing and a further eight percent to net fishing. This Marine Park is not confined to Moreton Bay itself and includes ocean beaches.
22 May 2009	Change maximum legal size to 75 cm; no change to minimum legal size from 2002. In-possession limits: dusky flathead 5, other flatheads combined 5 (*Fisheries Legislation Amendment Regulation (No. 2), 2009 No. 61*).
September 2021	Implementation of a 41t total allowable commercial catch (TACC)

The stock was previously assessed with data through to 2017 by Leigh et al. (2019) in 2019. The previous assessment covered South East Queensland from Baffle Creek (24.5 $^{\circ}S$) to the NSW border (about 28.2 $^{\circ}S$). It reported the 2017 spawning biomass was 36% and 70% of unfished biomass in the Moreton region and Fraser region, respectively.

This assessment contains updates to data and methodology. Key updates include:

- Assess the dusky flathead population on the Queensland east coast as one stock.
- Include the charter data recorded in the CFISH logbook.
- Make fishing starting in 1901.

- Use a new method to estimate the recreational harvest before 1997.
- Update the model for standardising the commercial catch rates.
- Model the dusky flathead stock using the Stock Synthesis modelling framework.
- Use data updated to the end of December 2020.

This assessment aims to determine current stock biomass relative to an unfished state, provide estimates of sustainable harvests to support Queensland's East coast inshore fishery harvest strategy: 2021–2026 (Fisheries Queensland (2021b)), and to inform fishery management agencies and stakeholders on estimates of sustainable harvest that will build and maintain the fishery in the long term.

2 Methods

2.1 Data sources

Data used for this assessment are given in Table 2.1. They were used to determine catch rates, age and length compositions, and estimate annual harvests. The data were summarised by fishing method and sector: commercial gillnetting (Gillnetting), commercial tunnel netting (Tunnel Netting), commercial line (Commercial Line), charter (Charter Line), and recreational line fishing (Recreational). Data are described in more detail in the following sections.

Table 2.1: Data used in the Queensland dusky flathead stock assessment.

Type	Year	Source
Commercial harvest	1988–2020	Logbook data collected by Fisheries Queensland
	1945–1980	Historical Queensland Fish Board Data (Halliday et al. 2007)
Recreational harvest	1997, 1999, 2002, 2005	RFish Recreational fishing surveys conducted by Fisheries Queensland (Higgs 1999; Higgs 2001; Higgs et al. 2007; McInnes 2008)
	2011, 2014, 2019	Statewide Recreational Fishing Survey conducted by Fisheries Queensland (Taylor et al. 2012; Webley et al. 2015; Teixeira et al. 2021)
	2000	Recreational fishing surveys conducted by the Australian Department of Agriculture, Fisheries and Forestry (the National Recreational and Indigenous Fishing Survey) (Henry et al. 2003)
Charter harvest	1994, 1996–2020	Logbook data collected by Fisheries Queensland
Biological data	2007–2020	Biological monitoring (sex, age, length and weight from the commercial and recreational harvests) undertaken by Fisheries Queensland (Department of Primary Industries and Fisheries 2008)
	2015–2020	Boat ramp survey conducted by Fisheries Queensland (Fisheries Queensland 2017)

2.1.1 Regions

The dusky flathead population on the Queensland east coast was modelled as a single stock, and the spatial extent covers Management region 1–5 (Figure 2.1). The map represents mean annual harvest based on the CFISH log book data from 1988–2020. The highest mean annual harvest is 27.5 t in CFISH grid W37 in Moreton Bay. The following two are 7.9 t in W38 and 4.4 t in W34 at the south of Fraser Island.

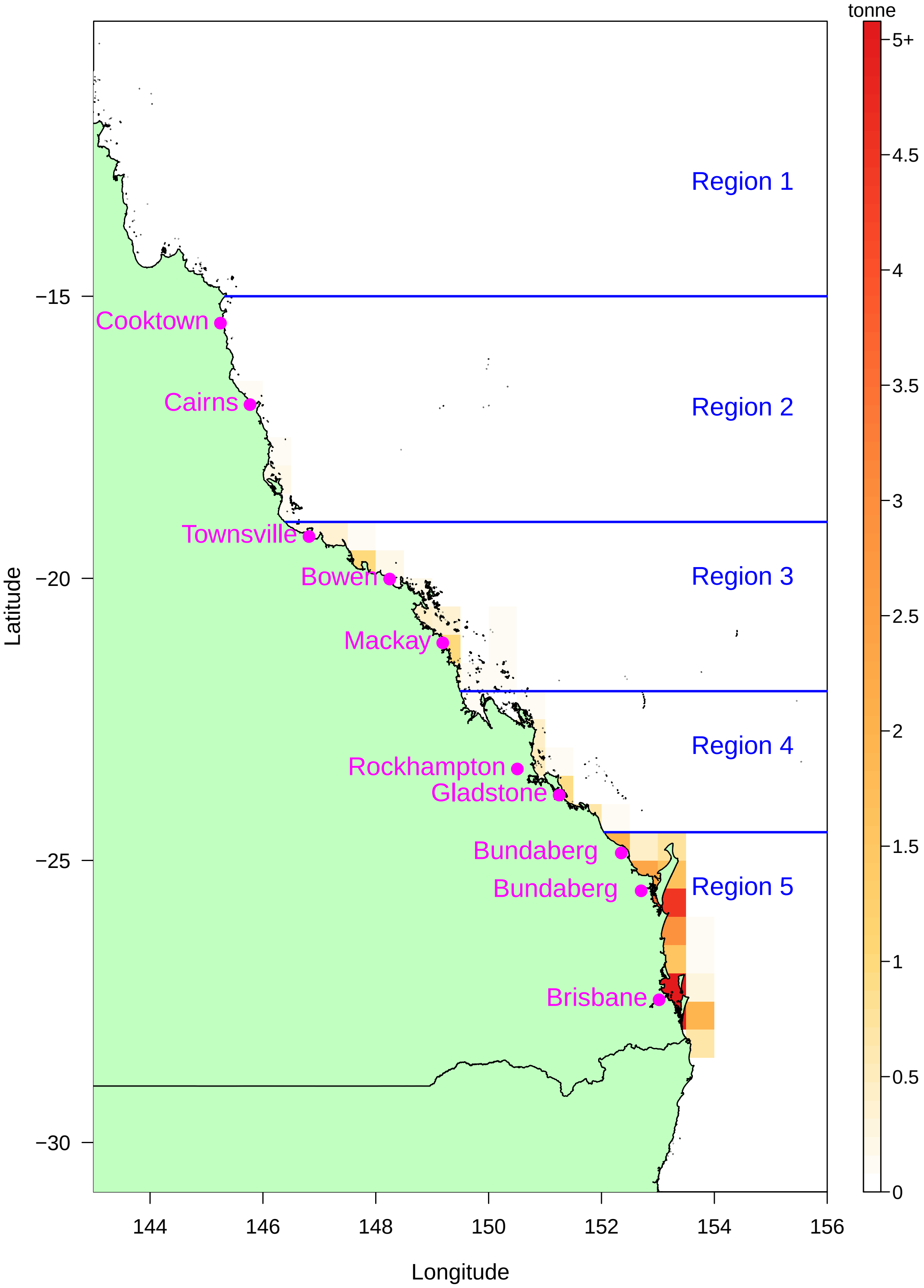

Figure 2.1: Spatial distribution of mean annul harvest of 1988–2020 using the CFISH log book data in management regions 1–5.

2.1.2 Commercial

Fishery data for dusky flathead are available from

- 1945–1980: Queensland estimated harvest sizes from annual reports by the Queensland Fish Board state-owned marketing agency (Halliday et al. 2007).
- 1988–2020: Queensland daily harvest records by fisher from the CFISH logbook.

The CFISH logbook database is maintained by Fisheries Queensland and records location, fishing gear, net mesh size and net length of the catch. The information allows estimation of harvest sizes and standardised catch rates from 1988 to 2020. The CFISH logbook records show dusky flathead are caught all year round in Queensland with a commercial peak in the winter months. Most of dusky flathead harvests were from Region 5 (Figure 2.2).

Commercial harvests between 1981 and 1988 had to be interpolated as no data were available. The interpolation was done linearly on the log scale (see Section 2.2).

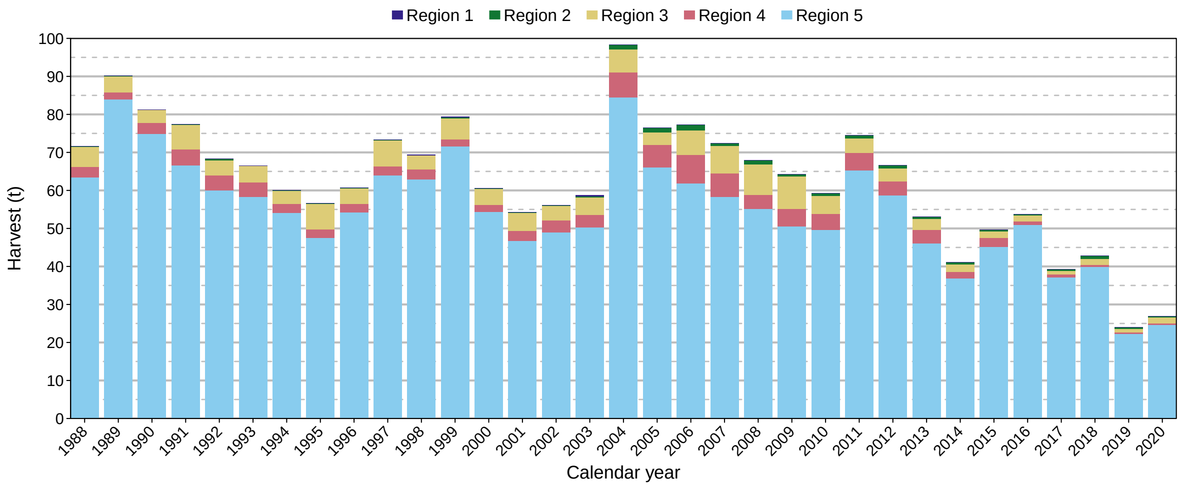

Figure 2.2: Commercial harvest of dusky flathead in years 1988–2020 from the CFISH logbook by management region.

2.1.3 Recreational

2.1.3.1 Recreational fishing surveys

Statewide recreational catches of fish in Queensland have been quantified by telephone–diary surveys since 1997:

- 'RFISH' surveys conducted by Fisheries Queensland in 1997, 1999, 2002 and 2005 (Higgs 1999; Higgs 2001; Higgs et al. 2007; McInnes 2008).
- Australian national survey (the National Recreational and Indigenous Fishing Survey, NRIFS) in 2000 (Henry et al. 2003).

- State-Wide Recreational Fishing Surveys (SWRFS) by Fisheries Queensland using the NRIFS methodology in 2011, 2014, and 2019 (Taylor et al. 2012; Webley et al. 2015; Teixeira et al. 2021).

All of these surveys used two-stage sampling methodology: a preliminary telephone survey to measure recreational fishing participation rate of residents in each statistical area, followed by a year-long diary survey of telephone respondents who participated in recreational fishing.

The RFISH surveys are regarded as generally providing overestimates of the catch size, mainly due to memory recall bias towards high catches by fishers who participated in them, as the RFISH surveys had less regular prompting of participants (Lawson 2015). They were included in the assessment but were adjusted to match the NRIFS and SWRFS catch levels (see Section 2.2). These surveys provided only harvest size estimates, not catch rates.

2.1.3.2 Proxies for recreational fishing effort

Prior to 1997 the recreational catch had to be extrapolated, as there were no surveys from which it could be formally estimated.

The Queensland state-wide human population was used as a recreational fishing effort proxy up to 1997. State population records were available from the Australian Bureau of Statistics (ABS), record number 3105.0.65.001 (ABS 2014).

2.1.3.3 Boat ramp survey

Boat ramp surveys conducted by Fisheries Queensland collected recreational data from 2015 to 2020 in 18 different regions, extending along the entire Queensland coast. Fifteen of these regions were along the Queensland east coast with Cooktown being the northern most region. Staff were trained in the survey protocol to identify fish and interview recreational fishers at boat ramps during a survey shift. The surveys recorded day and location fished, catch of key species (including discards), and length of retained key species (Fisheries Queensland 2017).

2.1.4 Indigenous

The National Recreational and Indigenous Fishing Survey (NRIFS) conducted in 2000 involved Indigenous communities to collect Indigenous fishing information on a national level. Estimates of total harvest and discard for Indigenous communities followed similar procedures to those in the recreational component of the survey (Henry et al. 2003).

The NRIFS reported the estimated annual harvest (numbers) of flathead is 2,384. This is about 1.36 t when weight of a fish is 0.57 kg (see Section 2.2). However, term ‘Flathead’ in the NRIFS report represents the flathead family including not only dusky flathead but also bar tailed flathead, sand flathead and others. The survey studies the area of the Gulf of Carpentaria and the north east coast (north of Cairns) in Queensland. With these two concerns and small harvest size, the NRIFS data were not included in this stock assessment.

2.1.5 Charter

The CFISH logbook has included harvest of dusky flathead from the charter fishery since 1996 (although 38 kg reported in 1994). Most of charter fishing for dusky flathead is by line.

Different from the 2019 assessment (Leigh et al. 2019), the charter data were used in the current assessment and denoted as Charter Line.

2.1.6 Age and length compositions

Age and length data for dusky flathead were collected by Fisheries Queensland's Fishery Monitoring team from 2007 onwards. The data used in this assessment were from 2007 to 2020. These data were fishery-dependent with samples taken from recreational and commercial harvests and measured by scientific staff. The data contained information including: location of catch, date caught, region, fishing method, total length, age class (number of birthdays a fish is assumed to have had on date of capture; the nominal birth date of dusky flathead is 1 November), age group (maximum age a fish would have reached in a sampling year) and sex. It is important to note that sex could be unknown.

In addition, the boat ramp surveys have contributed length frequency information from the recreational fishery since 2017.

2.2 Harvest estimates

Commercial and recreational harvest data were analysed to reconstruct the history of harvest from 1901 to 2020. The harvest reconstruction procedure followed Leigh et al. (2019), but some modifications and improvement were made in the current assessment and will be highlighted in **bold** in the following two sub-sections.

2.2.1 Commercial harvest

Commercial harvests were estimated from the CFISH logbook (1988–2020) and Queensland Fish Board records (1945–1980) data (see Table 2.1). The commercial harvests were grouped by fishing method: Gillnetting for commercial gillnetting, Tunnel Netting for commercial tunnel netting, and Commercial Line for commercial line. The Fish Board harvest were assumed from Gillnetting.

Steps to reconstruct annual harvest time series 1901–2020 were the following:

- Step 1: Convert Queensland Fish Board harvests from financial years (July to June) to calendar years (January to December).
- Step 2: Interpolate commercial harvests between 1978 and 1988.
- Step 3: **Extrapolate commercial harvests from 1944 to 1901.**
- Step 4: Combine the estimated harvests from Steps 1–3 and the CFISH logbook harvests 1988–2020.

Steps 1–3 were regarding reconstructing the harvests of Gillnetting in years 1901–1987.

Step 1 was accomplished by assuming that the harvest was taken in the months July to December. Although this assumption was not perfect, it fitted to the seasonal patterns of the commercial catch for dusky flathead, which generally peaked in July or August. For example, data for the 1955–56 financial year were assigned to the 1955 calendar year.

Step 2 was accomplished by interpolating the harvests of years 1979–1987 by fitting a straight line to the logs of the commercial harvests in 1978 and 1988. Note that the commercial harvest in 1988 refers to Gillnetting. Fish Board records contained harvest sizes for 1979 and 1980 but these were much lower than preceding years. They were not used due to assumed changes in marketing of dusky flathead outside of the Fish Board.

Step 3 was a new step to extrapolate commercial harvests from 1944 to 1901. This was accomplished by assuming that the harvest one year before was proportional to the harvest in the current year on the log scale and the multiplier was set to 0.989; that is, $log(C_{t-1}) = 0.989 \times log(C_t)$, where C_t is the harvest in year t. Multiplier value 0.989 was the quotient of the logarithm of 1945 harvest divided by the logarithm of the 1946 harvest (i.e., $0.989 = log(C_{1945})/log(C_{1946})$).

Working on the log scale allowed the interpolation to fit a constant percentage rate of increase or decrease of the harvest over the interpolated period, which we regarded as more realistic than a constant number of tonnes.

2.2.2 Recreational harvest

Estimating recreational harvests used data from different sources, and the procedure of estimating recreational harvests followed Leigh et al. (2019). However, two different methods were employed to extrapolate the harvests before 1997. Before the estimating procedure was given, the data used were listed in the following:

- National Recreational and Indigenous Fishing Survey (NRIFS): diary period 1 May 2000 to 30 April 2001; assumed to come from calendar year 2000 in the population model.
- State-Wide Recreational Fishing Surveys (SWRFS):
  - Diary period 1 October 2010 to 30 September 2011: assume to represent year 2011.
  - Diary period 1 November 2013 to 31 October 2014: assume to represent year 2014.
  - Diary period 29 April 2019 to 28 April 2020: assume to represent year 2019.
- RFISH surveys: calendar years 1997, 1999, 2002 and 2005.
- Queensland population statistics: 1945–1997 from the Australian Bureau of Statistics, record number 3105.0.65.001 (ABS 2014).

By using the data described above, recreational harvest estimates were carried out through the following steps. Note that modifications from Leigh et al. (2019) were **bolded**.

Step 1: Estimate species splits in order to exclude related species, and estimate harvests only of the species assessed.
Step 2: **Convert recreational harvests from numbers to weights.**
Step 3: Adjust the RFISH recreational harvest estimates to match the methodology used by NRIFS and SWRFS.
Step 4: Interpolate recreational harvests in years between 1997 and 2017 in which surveys were not undertaken.
Step 5: **Extrapolate recreational harvests backward in time from 1997 back to 1901**.

For Step 1, those associated species are northern sand flathead, yellowtail flathead, and Australian bartail flathead (see Section 1).

Step 2 was accomplished that catch numbers were multiplied by average weights of recreationally caught fish,

- 0.571 kg up to 2002
- 0.825 kg from 2003 to 2009.
- 0.860 kg from 2010 onwards (Webley et al. 2015).

Different from Leigh et al. (2019) just using 0.825 kg from 2003 onwards, this assessment used 0.860 kg of Webley et al. (2015) from 2010 onwards to match with the SWRFS estimates. This is not perfect but expresses the management measure change of maximum legal size from 70 cm to 75 cm in May of 2009.

Step 3 is for the RFISH estimation. The estimates from all years (1997, 1999, 2002 and 2005) were all multiplied by the factor $C_{2000}/(C_{1999}^{2/3} \times C_{2002}^{1/3})$. The factor is the ratio of the NRIFS harvest estimate (denoted C_{2000}) in 2000 to the estimated RFISH harvest in 2000. The latter is a geometric mean of the RFISH surveys before and after, as RFISH was not conducted in 2000. The 1999 RFISH survey received a higher weighting ($2/3$) than the 2002 survey ($1/3$) because it was one year from the target year, as opposed to two years. This scaling factor follows the assumption of Leigh et al. (2019) to cut back the RFISH estimates because they were overstated by the same ratio in all years.

Step 4 is regarding interpolating recreational harvests between 1997 and 2019 using the recreational harvest estimates of years 1997, 1999, 2000, 2002, 2005, 2011, 2014, and 2019. The interpolation was established on the logarithm of the available harvest estimates using a linear interpolation (see Martinson (2018), Chapter 4). The interpolated log-harvests were then exponentiated (i.e., back-transformed) to produce harvest estimates. The harvests of 2019 and 2020 were assumed to be the same.

Step 5 is for extrapolating the harvests in years 1901–1996. At this step, the human population of Queensland was used as a proxy of fishing effort and adjusted for a fishing power increase of 3% per year from 1901 to 1980 and then, a constant fishing power after 1980 and up to 1997. Year 1980 was chosen as the last year of fishing-power increase with the assumption that involvement of recreational fishers in fishing clubs declined and the major technological innovations of nylon fishing line, waders and modern fishing rods had all been introduced (see Leigh et al. (2019) for details). The adjusted fishing effort proxy was then multiplied by a reference harvest to acquire harvest estimates of 1901 to 1996. Two methods were used to define the reference harvest. Method 1 applied the estimate of 1997 which was used by Leigh et al. (2019), and Method 2 used the average of 1997–2002. The recreational estimates by these two methods (i.e., harvest estimates) were compared in the sensitivity tests (Section 2.5.4).

The procedure of recreational harvest estimates was assumed that a potentially important additional source of recreational fishing power was the rise in use of soft plastic lures, and it could take place mainly after 1997. Hence any increase in harvest size promoted by soft plastic lures would be included in the recreational diary surveys. Besides, only the trend in the recreational harvest proxy was important to the reconstruction of historical harvests, not the absolute level of the values. The recreational harvest proxy was scaled to match the recorded harvests from the diary survey in 1997.

2.3 Standardised indices of abundance

2.3.1 Commercial catch rates

The CFISH logbook data were available from 1988 to 2020. The catch-rate analysis for dusky flathead was conducted only for net fishing (i.e., Gillnetting and Tunnel Netting) because there was very little catch from line fishing. Because Tunnel Netting catch rates were identifiable in the database only from the late 1990s, they were combined in with Gillnetting before then (Leigh et al. 2019).

In the logbook data, there were numerous records with missing information of net mesh size and net length, especially in the period of 1998 and 2005. To take those records into account within the standarised catch rate modelling, a nearest neighbor method of imputation was used to impute missing mesh size and net length by gear and fisher. The missing value was filled with the value of the highest frequency of five nearest records in terms of days. The standardised catch rates were generated using the data sets with and without imputed net mesh size and net length, separately. The comparison between them was performed in the sensitivity tests (Section 2.5.4).

Following Leigh et al. (2019), the logbook data were collated into one record per fisher-day and analysed by a quasi-Poisson regression with log link in which the dispersion parameter was estimated. However, the residual analysis from the quasi-Poisson regression showed the residual variance was heteroscedasticity (i.e., higher variance of residuals for higher fitted catch rates). Leigh et al. (2019) applied a squared-root transformation to the harvest before catch rate modelling to moderate heteroscedasticity, but required more calculation (i.e., back-transformation) and addition assumptions to obtain catch rates and the associated standard errors.

Instead, we modified a quasi-Poisson regression assumption such that variance is equal to the dispersion parameter multiplying the mean to the power of a value between one and two. Note that the variance of the quasi-Poisson regression is the dispersion parameter multiplying the mean to the power of one. This modification took advantages of quasi modelling and flexible quasi-settings in the R environment (R Core Team 2021). In such, back-transformation was not needed, and obtaining catch rates and the associated standard errors was as same as using the quasi-Poisson regression. The value of power was obtained by: 1) fitting to the quasi-Poisson regression; 2) squaring the response residuals and obtaining the fitted values; 3) taking logarithm on the squared response residuals and fitted values; 4) regressing the logarithm of the squared response residuals on the logarithm of the fitted values; 5) using the regression slope as the value of power for the modified quasi-Poisson regression model. We note that there are other methods available to estimate the value of power such as using iteration methods to achieve optimal estimates (or maximum likelihood estimates) but the current method have met the need to lesson heteroscedasticity. The power values used for Gillnetting and Tunnel Netting were 1.90 and 1.95, respectively.

In terms of associated species, there was no associated species, so no zero catches in the analysis (Leigh et al. 2019).

The catch rate models included effects for fisher, year, month, location, net mesh size and net length. All terms in the catch rate models were treated as factors (i.e., variables with discrete levels). Location was grouped into the small regions used by the Fisheries Queensland Fishery Monitoring team for their sampling and denoted as LTMPregion. Mesh size and net length were not analysed as continuous variables because their relationships to catch size are often complex. Each factor level comprised an interval around a very frequent value (e.g., 50 mm or 75 mm mesh size, or 400 m or 600 m net length). Mesh size and net length were denoted as MeshSize and NetLength. The model structure and components for Gillnetting were represented in the R formula format as follows,

$$\text{harvest} \sim \text{year} + \text{month} + \text{LTMPregion} + \text{MeshSize} + \text{NetLength} + \text{fisher},$$

and the model structure and components for Tunnel Netting were represented in the following,

$$\text{harvest} \sim \text{year} + \text{month} + \text{NetLength} + \text{fisher}.$$

The annual catch rates of Gillnetting and Tunnel Netting were generated based on an approach called ‘marginal prediction’ (Lane et al. 1982). This approach has been embedded in Genstat (International 2019) and ASReml-R (Butler et al. 2017). The marginal prediction took the influence of the data unbalance into account and formed weightings for factors other than year. The weightings were multiplied to the model predictions to output weighted model predictions. Then, the annual catch rates were generated by aggregating the weighted model predictions over the other factors.

2.4 Biological information

2.4.1 Total length

All length measurements were provided in total length (TL) and the population models were run using TL.

2.4.2 Fecundity and maturity

Maturity values in the model were age-based and following the the data in Leigh et al. (2019).

- 0% mature at age 0+,
- 0% mature at age 1+,
- 0% mature at age 2+,
- 5% mature at age 3+,
- 35% mature at age 4+,
- 65% mature at age 5+,
- full mature from age 6+.

Hicks et al. (2015) studied fecundity of female dusky flathead and found no statistically significant deviation from the hypotheses that egg production is proportional to body mass and that egg quality does not depend on body size. They found a fecundity and body size relationship

$$log_{10}(\text{fecundity}) = 8.4203 \times ln(log_{10}(\text{TL} + 1)) - 2.654,$$

where TL is measured in cm. However, this equation form is not in the options of Stock Synthesis. Thus, an approximation to it,

$$\text{fecundity} = 0.168 \times \text{TL}^{3.787},$$

was used in the Stock Synthesis modelling in this stock assessment. This approximation was built using a simulation method conducted in the R environment with version 4.1.2 (R Core Team 2021). In the simulation, 49,550 samples were drawn from the equation of Hicks et al. (2015) with random seed set to 56789 in R (i.e., `set.seed(56789)`), and then, the parameter estimates of the approximation was acquired from the linear regression modelling (i.e., using R command `lm`). An illustration of the two equations is given in Figure 2.3.

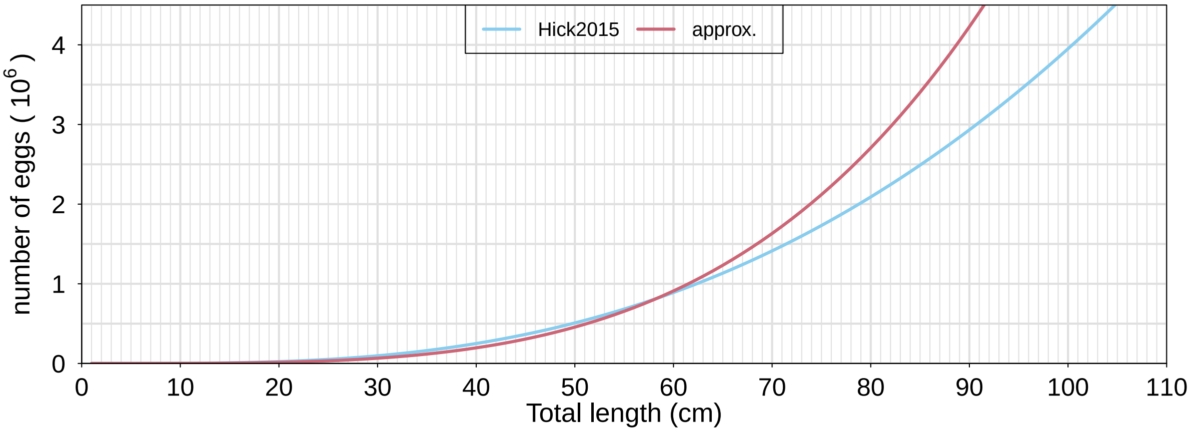

Figure 2.3: Illustration of the equation of Hicks et al. (2015) and the approximation for the relationship between fecundity and body size.

2.4.3 Weight and length

Length-weight relationships are different between male and female dusky flathead (Gray et al. 2015). The relationship for males is

$$W = 2.76 \times 10^{-6} \mathrm{TL}^{3.223},$$

and for females is

$$W = 2.09 \times 10^{-6} \mathrm{TL}^{3.282},$$

where TL is measured in cm and weight W in kg.

2.4.4 Length and age data

Length data were input to the population model in one-centimetre length bins. Age data were input as conditional age-at-length samples.

2.5 Population model

A two-sex dynamic population model was fitted to the data to determine the number of dusky flathead in each year and each age group using the software package Stock Synthesis (SS; version 3.30.18.00). A full technical description of SS is given in Methot et al. (2021).

Four fleets were specified in the model:

- Fleet *Com_Gillnet* for commercial gillnetting.
- Fleet *Com_Tunnel* for commercial tunnel netting.
- Fleet *Rec_Line* for recreational line fishing.
- Fleet *Com_Line* for the combination of commercial line and charter line fishing.

Combining commercial line and charter line fishing as one fleet is to mitigate influences of limitations in data of both fishing methods and to reduce number of parameters in the population model such as parameters of selectivity curves.

2.5.1 Model assumptions

Assumptions were made when formulating inputs to the SS model for the dusky flathead assessment. These included:

1. The Queensland east coast stock is reproductively isolated.
2. The fishery began from an unfished state in 1901.
3. The fraction of fish that are female at birth is 50%.
4. Growth occurs according to the von Bertalanffy growth curve.
5. The weight and fecundity of dusky flathead are parametric functions of their size.
6. The proportion of mature fish depends on age, and the first possible mature age is 3.
7. The instantaneous natural mortality rate depends on sex but not size, age and other factors.
8. Deterministic annual recruitment follows the Beverton-Holt function of stock size.
9. Selectivity and retention depend on fleet and time.

For assumption 2, this assumption was investigated through a sensitivity test (see Section 2.5.4) and compared with starting year 1945, which was considered in Leigh et al. (2019).

For assumption 4, female and male growth curves were different, but the size at age 1+ was assumed to be the same based on the study of Gray et al. (2015). Their study formulated growth functions for male and female, and the functions showed the sizes of male and female at age 1+ are almost the same (i.e., female is about 1.5 cm larger than male). Besides, the age and length data used in the current stock assessment were fishery-dependent and limited because of management measures (i.e., minimum legal size), and they provided less sufficient information of the male and female size at younger age. For these reasons, assuming the same size at age 1+ should be sensible and could reduce the number of parameters in the SS model.

For assumption 5, the weight-length function of both sex in Section 2.4.3 were used, and the approximation of Hicks et al. (2015) in Section 2.4.2 was used for for the fecundity and length relationship.

For assumption 6, the relationship between maturity and age was given in Section 2.4.2.

Assumption 9 was not just about selectivity and retention but also to cope with management measures regarding MLS, and in-possession limits of five dusky flathead for the recreational fishery. MLS of 70 cm was imposed in December 2002 and then, increased to 75 cm (see Tabel 1.1). With this regard, the time period of 1901–2020 was segmented into two time blocks: 1901–2002 and 2003–2020. Selectivity and retention for time block 2003–2020 were setup in the SS model to take into account of MLS and in-possession limits. Scenarios regarding in-possession limits were considered in the sensitivity test (Section 2.5.4). We note that this setting was not perfect but accounted for the upmost effects of two management measures in the SS modelling framework.

2.5.2 Model parameters

A variety of parameters were included in the model, with some of these fixed at specified values and others estimated. Table 2.2 gives the list of parameters estimated in the SS model and the setting for estimating these parameters. Parameter were labels using a Stock Synthesis specific naming convention.

The first five parameters at the top of Table 2.2 are related to the von Bertalanffy growth curve for female dusky flathead. Parameters L_at_Amin_Fem_GP_1 and L_at_Amax_Fem_GP_1 represent length at age 1+ and 13+ and were specified normal priors. The female growth function of Gray et al. (2015) (denoted as Gray2015F) were used as reference to specify prior parameter values. The prior of L_at_Amin_Fem_GP_1 was given a mean value of 31.610 and standard deviation of 2.000. The mean value was acquired when the Gray2015F age was set to one. The prior of L_at_Amax_Fem_GP_1 was given a mean value of 86.158 and standard deviation of 5.000. The mean value was equal to the length value of Gray2015F when the age was set to 11. The two-standard-deviation interval around the mean of this prior covers the Gray2015F length values when age was set to between 9 to 14. On the other hand, parameter VonBert_K_Fem_GP_1 was specified a log-normal prior with mean equal to 0.084 equal to the K value of Gray2015F (Gray et al. 2015). Note that Prior μ and Prior σ are not the mean and standard deviation but the two parameters of a log-normal prior (see Johnson et al. (1995) for detail).

The sixth parameter is natural mortality for male specified a log normal prior with mean and standard deviation equal to 0.800 and 0.300. The 2.5% and 97.5% quantiles of this log-normal prior are about 0.368 and 1.526. A initial value of 1.200 was given to be close to the male natural mortality estimates of Leigh et al. (2019).

The next four parameters are related to the von Bertalanffy growth curve for male dusky flathead. Parameter L_at_Amax_Mal_GP_1 represents length at age 13+ and was specified a normal prior. The male growth function of Gray et al. (2015) (denoted as Gray2015M) were used as reference to specify prior parameter values. The normal prior was given a mean value of 43.200 and standard deviation of 2.000. The mean value was equal to the length value of Gray2015M when the age was set to 11. The one-standard-deviation interval around the mean of this prior covers the Gray2015M length values when age was set to larger than three. Besides, parameter VonBert_K_Mal_GP_1 was specified a log-normal prior with mean equal to 0.714 equal to the K value of Gray2015F (Gray et al. 2015).

The following two parameters are the natural logarithm of unfished recruitment (SR_LN(R0)) and recruitment steepness (SR_BH_steep). Parameter SR_LN(R0) was specified a normal prior with values 16.000 and 5.000 for mean and standard deviation. The prior mean was set to close to the estimates of SR_LN(R0) by Leigh et al. (2019), and the standard deviation was set to large enough that potential values for SR_LN(R0) were able to be explored in the SS model fitting process. Recruitment steepness (SR_BH_steep) is a metric relating to the productivity of the stock. It was specified a log-normal prior with values 0.668 and 0.071 for mean and standard deviation. The mean value was based on the meta-analysis by Thorson (2020). The small standard deviation was given to make this prior strong to reduce uncertainty and weaken a relationship with female natural mortality.

The last six parameters are related to dome-shaped length-based selectivity by fleet (i.e., *Com_Gillnet* and *Rec_Line*). A double normal curve (pattern 24 in SS) was used to construct the selectivity for each fleet. These parameters control peak, ascending width, and descending width of the double normal selectivity. Additionally, fleet *Com_Gillnet* and *Com_Tunnel* were assumed to share the same selectivity; fleet *Rec_Line* and *Com_Line* were assumed to share the same selectivity.

A brief explanation of those labels are given in Table B.1.

Table 2.2: Parameters with associated minimum bound (Min), maximum bound (Max), initial value (Init) and prior type (Prior) as well as prior's parameters μ and σ—note that values of Min are presented to four decimal places to show values close to zero.

Parameter	Min	Max	Init	Prior	Prior μ	Prior σ
L_at_Amin_Fem_GP_1	20.0000	40.000	30.000	Normal	31.610	2.000
L_at_Amax_Fem_GP_1	80.0000	125.000	95.000	Normal	86.158	5.000
VonBert_K_Fem_GP_1	0.0010	1.500	0.100	Log-normal	−2.629	0.551
CV_young_Fem_GP_1	0.0001	1.000	0.200	Uniform		
CV_old_Fem_GP_1	0.0001	1.000	0.200	Uniform		
NatM_uniform_Mal_GP_1	0.0100	2.000	1.200	Log-normal	−0.289	0.363
L_at_Amax_Mal_GP_1	35.0000	55.000	40.000	Normal	43.200	2.000
VonBert_K_Mal_GP_1	0.0100	1.500	0.500	Log-normal	−0.375	0.275
CV_young_Mal_GP_1	0.0001	1.000	0.200	Uniform		
CV_old_Mal_GP_1	0.0001	1.000	0.200	Uniform		
SR_LN(R0)	8.0000	25.000	12.000	Normal	16.000	5.000
SR_BH_steep	0.2100	1.000	0.700	Log-normal	−0.409	0.106
Size_DblN_peak_Com_Gillnet(1)	25.0000	60.000	41.500	Normal	40.000	2.000
Size_DblN_ascend_se_Com_Gillnet(1)	−5.0000	10.000	2.000	Normal	2.000	1.000
Size_DblN_descend_se_Com_Gillnet(1)	−5.0000	10.000	4.000	Normal	4.000	1.000
Size_DblN_peak_Rec_Line(3)	25.0000	60.000	41.500	Normal	40.000	2.000
Size_DblN_ascend_se_Rec_Line(3)	−5.0000	10.000	2.000	Normal	2.000	1.000
Size_DblN_descend_se_Rec_Line(3)	−5.0000	10.000	4.000	Normal	4.000	1.000

2.5.3 Model weightings

The adjustment of Francis (2011) was applied to all the age and length compositions fits, to attempt to achieve a suitable effective sample size (and thus relative weighting).

2.5.4 Sensitivity tests

A set of additional model runs were undertaken to determine sensitivity to fixed parameters, assumptions and model inputs. They (including the base case) were give in (Table 2.3).

- $\mathbf{Ren_{max}}$ is regarding the in-possession limits of five dusky flathead for the recreational fishery. Three values 0.95, 0.97, and 0.99 were considered for $\mathbf{Ren_{max}}$, and represent that the in-possession limits of five dusky flathead is 95%, 97% and 99% of the total catch of a day.
- $\mathbf{M_{female}}$ refers to female natural mortality. The values used are 0.70, 0.75, and 0.80. In particular, Leigh et al. (2019) used 0.70 and 0.75 as fixed values for natural mortality of female dusky flathead in the Moreton region.
- $\mathbf{Z_{discard}}$ is discard mortality. Values 0.10, and 0.20 were considered. Leigh et al. (2019) used 0.20 and suggested other values smaller.
- **Impute** is regarding if the commercial standardised catch rates were generated using the data of imputed net mesh size and net length or not (see Section 2.3.1). 'Yes' means that the generated catch rates were based on the imputed data, and 'No' means that the data of missing net mesh size and net length were not included in the standardised catch model.
- $\mathbf{Year_{start}}$ is the starting year, and two starting years were used: 1901 and 1945.

- $\mathbf{Harv_{est}}$ is about which reconstructed harvest time series was used. Two methods were adopted to extrapolate the recreational harvests before 1997 (see Section 2.2). Method 1 refers to the method used by Leigh et al. (2019), and Method 2 was implemented in this stock assessment.
- $\mathbf{CPUE_{tunnel(2017-2020)}}$ is regarding if the standardised catch rates of Tunnel Netting in 2017–2020 were included or not. The Tunnel Netting catch rates were decreasing in these years. This examined if the SS model results were sensitive to the decreasing of the Tunnel Netting catch rates.

Table 2.3: Table of scenarios tested to determine sensitivity to parameters, assumptions and model.

Scenario	$\mathbf{Ren_{max}}$	$\mathbf{M_{female}}$	$\mathbf{Z_{discard}}$	Impute	$\mathbf{Year_{start}}$	$\mathbf{Harv_{est}}$	$\mathbf{CPUE_{tunnel(2017-2020)}}$
1 (Base case)	0.97	0.75	0.20	Yes	1901	Method 2	No
2	0.95	0.75	0.20	Yes	1901	Method 2	No
3	0.99	0.75	0.20	Yes	1901	Method 2	No
4	0.97	0.70	0.20	Yes	1901	Method 2	No
5	0.97	0.80	0.20	Yes	1901	Method 2	No
6	0.97	0.75	0.10	Yes	1901	Method 2	No
7	0.97	0.75	0.20	Yes	1945	Method 2	No
8	0.97	0.75	0.20	Yes	1901	Method 2	Yes
9	0.97	0.75	0.10	Yes	1901	Method 2	Yes
10	0.97	0.75	0.20	Yes	1945	Method 2	Yes
11	0.97	0.75	0.20	Yes	1901	Method 1	No
12	0.97	0.75	0.20	No	1901	Method 2	No
13	0.97	0.75	0.20	Yes	1945	Method 1	No
14	0.97	0.75	0.20	No	1945	Method 2	No
15	0.97	0.75	0.20	Yes	1901	Method 1	Yes
16	0.97	0.75	0.20	No	1901	Method 2	Yes
17	0.97	0.75	0.20	Yes	1945	Method 1	Yes
18	0.97	0.75	0.20	No	1945	Method 2	Yes

2.5.5 Harvest control rule

Stock Synthesis's forecast sub-model was used to provide forward projections of spawning biomass and future harvest targets, following a harvest control rule. This rule has a linear ramp in fishing mortality between 20% spawning biomass, where fishing mortality is set at zero, and a target spawning biomass, where fishing mortality is set at the equilibrium level that achieves the target spawning biomass (F_{Btarg}). Below 20% spawning biomass fishing mortality remains set at zero, and above the target spawning biomass fishing mortality remains set at F_{Btarg} (Figure 2.4).

Dusky flathead is a tier 2 species under the East coast inshore fishery harvest strategy: 2021–2026, so two harvest control rule scenarios have been constructed:

- a 20:60:60 control rule, in which the spawning biomass target is set to 60%, and
- a 20:50:50 control rule, in which the spawning biomass target is set to 50%.

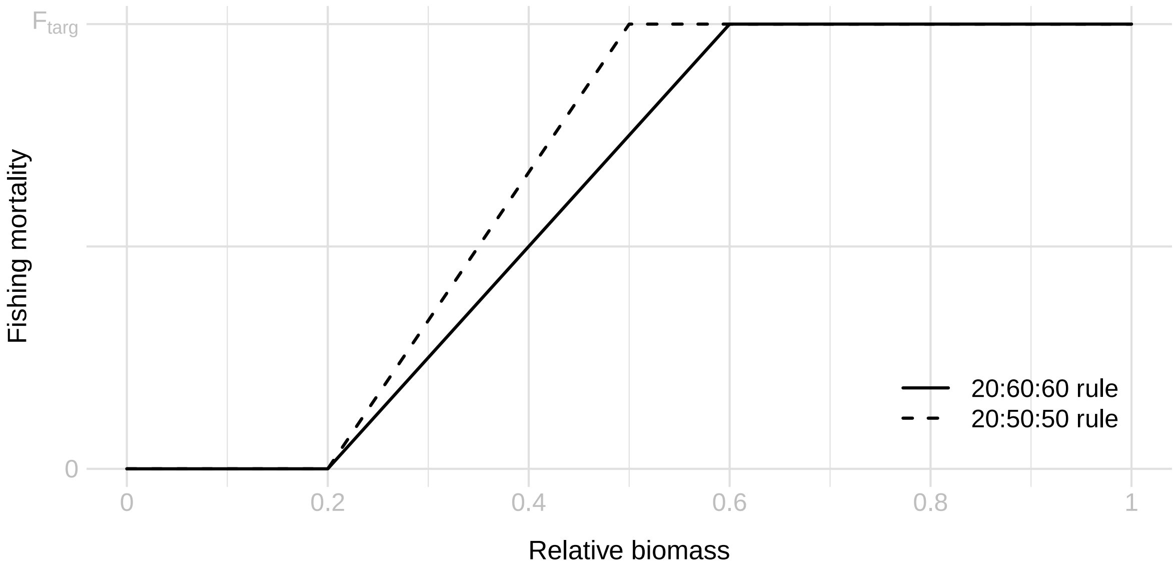

Figure 2.4: The 20:60:60 and 20:50:50 harvest control rules—note that F_{targ} for B_{50} is not the same as F_{targ} for B_{60} (i.e., vertical axis scale is not consistent between harvest control rules).

3 Results

3.1 Model inputs

An illustration of data presence as data inputs for the SS model shows in Figure 3.1. The data presence is corresponding to the four fleets defined for the SS model. This illustration represents the base case scenario. Please note that the base case scenario was not included with the catch rates of Tunnel Netting in 2017–2020 in the SS modelling (see Section 2.5.4).

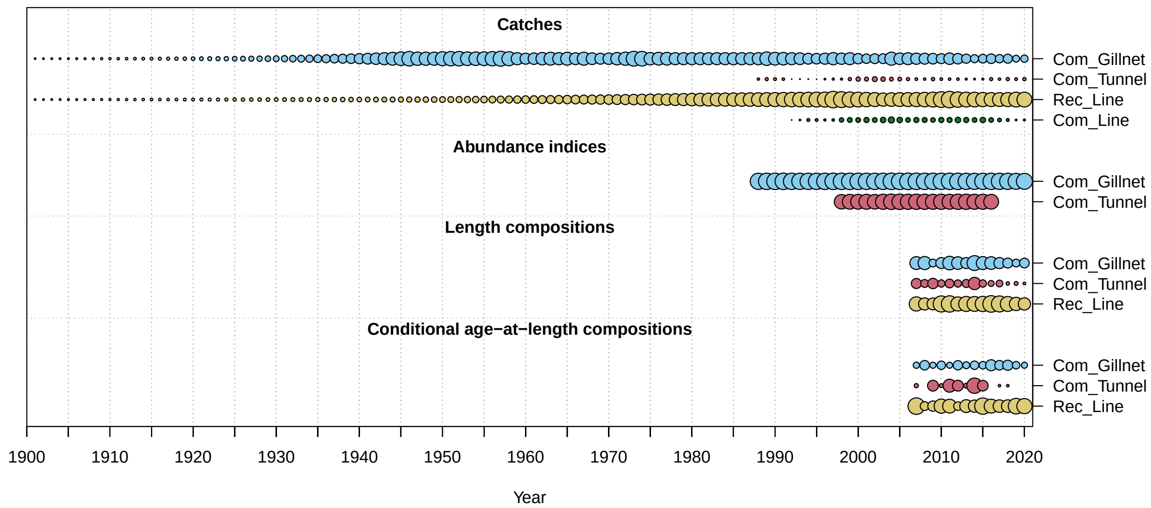

Figure 3.1: Data presence by year for each category of data type and Stock Synthesis fleet.

Stock Synthesis uses the term 'fleet' to distinguish data sets (and model processes) associated with different selectivity curves (proportions of fish at different lengths vulnerable to the fishing gear). This assessment involves four fleets: *Com_Gillnet* for Gillnetting; *Com_Tunnel* for Tunnel Netting; *Rec_Line* for Recreational; and *Com_Line* for the combination of Commercial Line and Charter Line. This plot shows data presence by year for each fleet, where circle area is relative within a data type. Circle areas are proportional to total harvest for harvests; to precision for indices; and to total sample size for compositions. Note that since the circles are scaled relative to maximums within each data type, the scaling within separate plots should not be compared.

3.1.1 Harvest estimates

Total harvest estimates from commercial (Commercial Line, Gillnetting, and Tunnel Netting), recreational (Recreational) and charter (Charter Line) sectors by the two methods are shown in Figure 3.2. The estimated total harvest by Method 2 was used for the base case scenario.

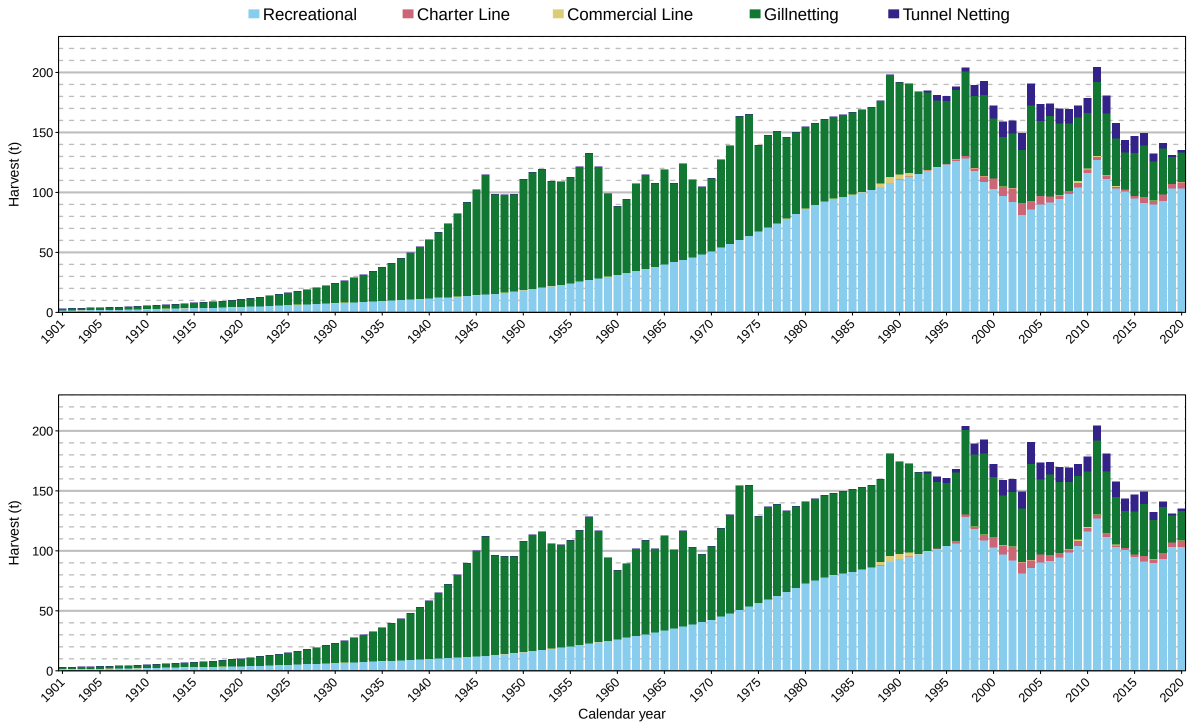

Figure 3.2: Harvest reconstruction by two methods: Method 1 (the top panel) and Method 2 (the bottom panel).

3.1.2 Standardised catch rates

The standardised catch rates of Gillnetting and Tunnel Netting are presented in Figure 3.3. For Gillnetting, the catch rates (Line —) accounting for the information of the data with missing net mesh size and net length were higher in the years 2004–2005 due to most of these data occurring in these two years. Therefore, the base case scenario was applied for the catch rates taking these data into account.

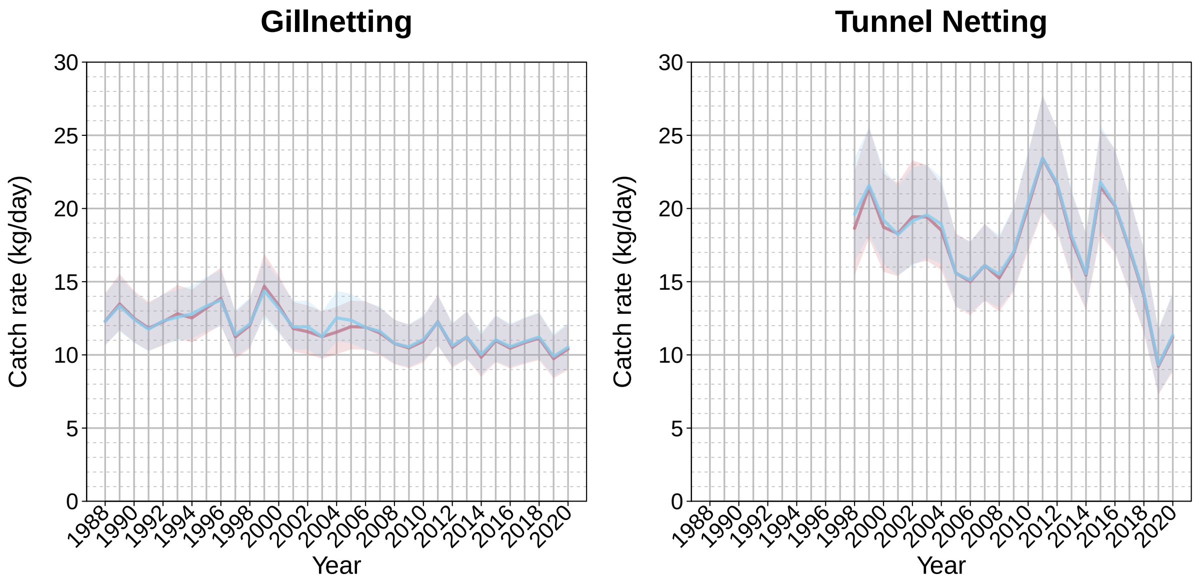

Figure 3.3: Standardised catch rates of Gillnetting and Tunnel Netting. Line — represents the catch rates generated when the imputed net mesh size and net length data were implemented in the standardised catch rate model, and line — represents the catch rates generated when the missing net mesh size and net length data were not included in the standardised catch rate model. The shaded areas represent the 95% confidence intervals accordingly.

3.1.3 Age and length composition

Of the 4630 fish aged by the Fisheries Queensland monitoring team between 2007 and 2020, only three fish (of which none were male) were of age 10+ and older. Besides, only nine males were older than four years compared to 401 females.

Fishery age-at-length composition data by sex and fishing method are given in Figure 3.4. There was a clear difference in age distributions between sexes for dusky flathead. Gillnetting was assigned to fleet *Com_Gillnet*, Tunnel Netting to fleet *Com_Tunnel*, and Recreational to fleet *Rec_Line* in the SS modelling.

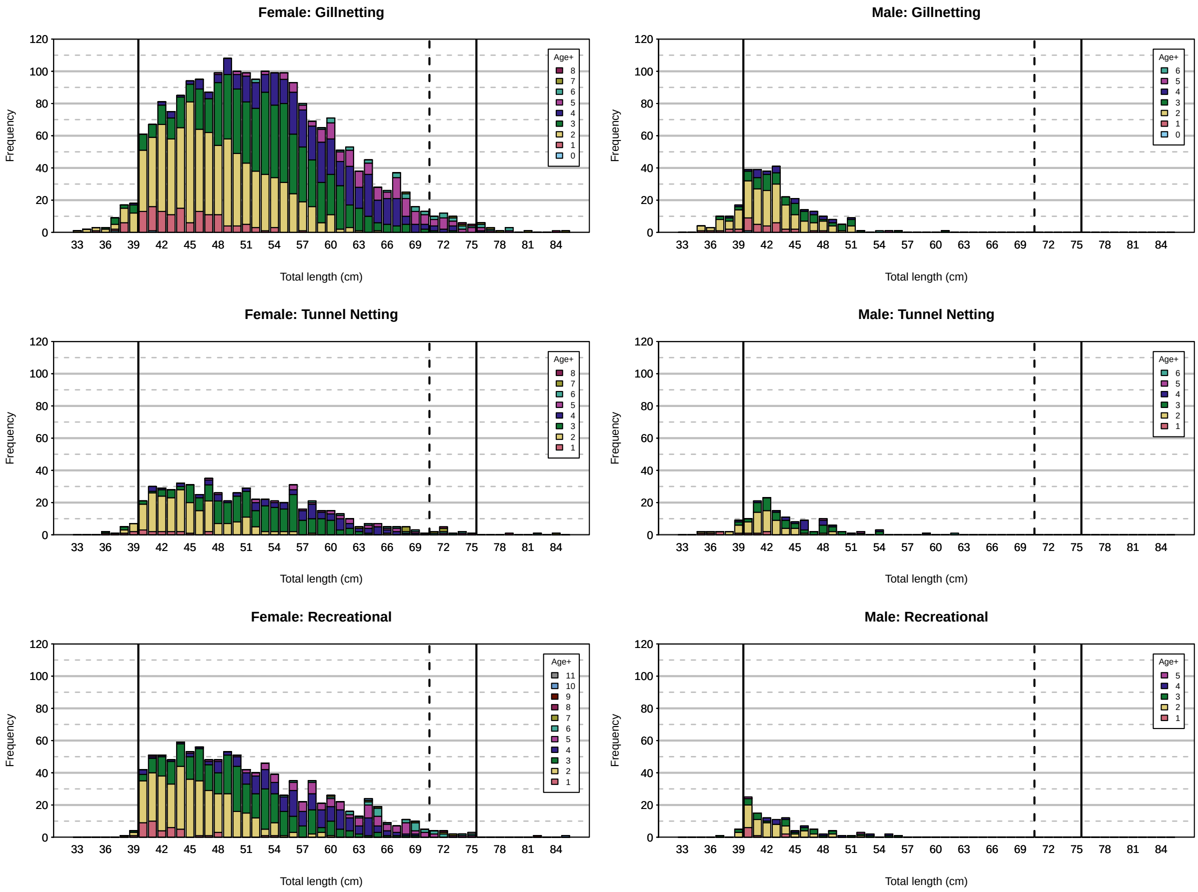

Figure 3.4: Age-at-length frequency by sex and fishing method.

3.1.4 Length composition

Fishery length compositions were input to the SS model for fleet *Com_Gillnet* (Figure 3.5), *Com_Tunnel* (Figure 3.6), and *Rec_Line* (Figure 3.7).

The length composition data show that female dusky flathead are larger than male dusky flathead. The largest female was 85 cm TL, and the largest male was 66 cm TL.

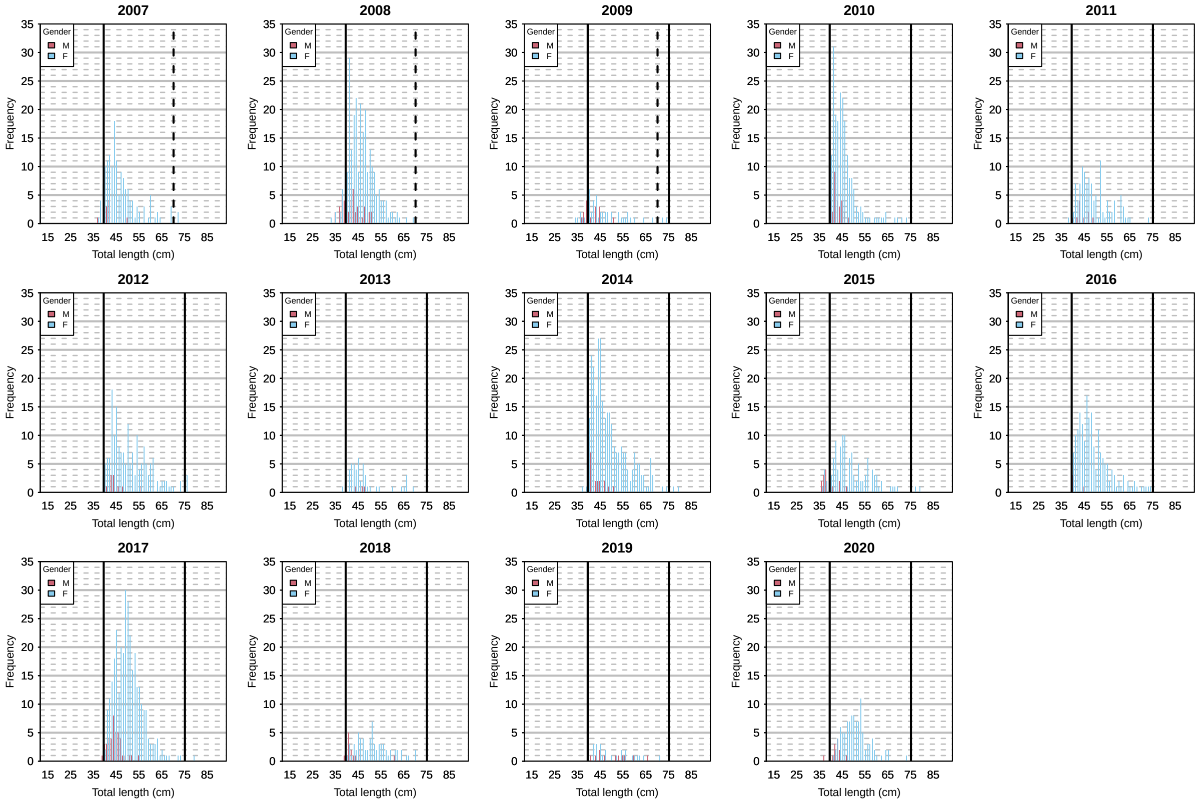

Figure 3.5: Length frequency of duksy flathead by sex and year for Gillnetting.

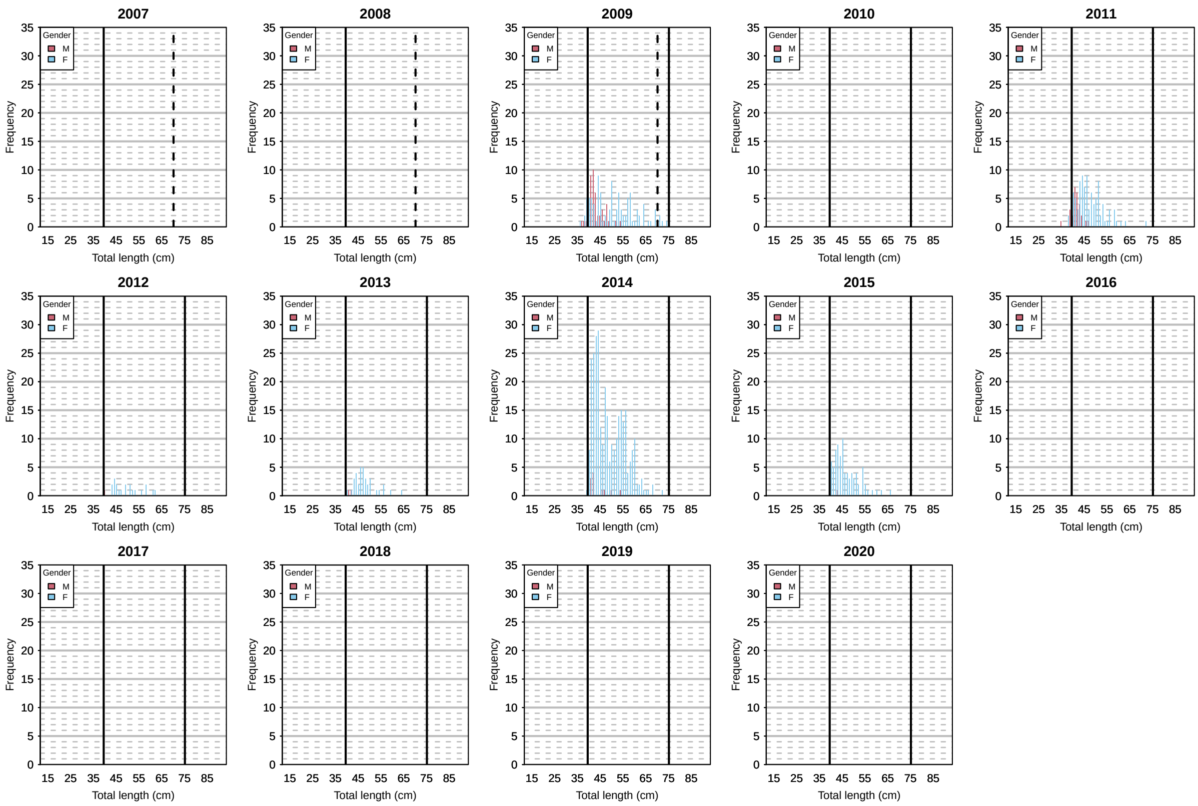

Figure 3.6: Length frequency of duksy flathead by sex and year for Tunnel Netting.

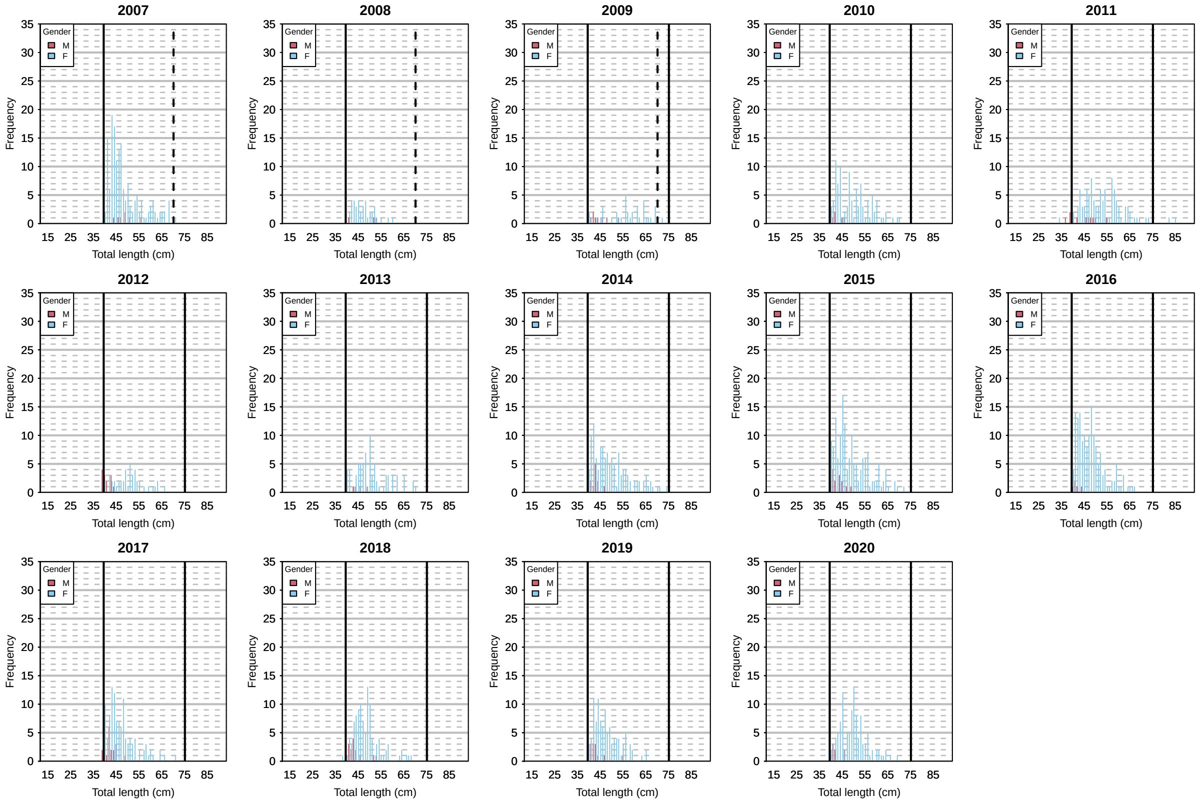

Figure 3.7: Length frequency of duksy flathead by sex and year from line fishing.

3.1.5 Other model inputs

The other model inputs such as length composition by sex and gear, conditional age-at-length by sex, and fixed biological relationships are provided in Appendix A.

3.2 Model outputs

3.2.1 Model parameters

The parameter estimates of the SS model from the base case scenario were listed in Table 3.1. The comparison of parameter estimates amongst the 18 scenarios are given in Figure B.16.

In Figure B.16, the estimates of most parameters were consistent across the 18 scenarios; except male natural mortality (NatM_uniform_Mal_GP_1), the logarithm of the number of unfished recruitment (SR_LN(R0)), and stock recruitment steepness (SR_BH_steep). These parameters were sensitive to the change of female natural mortality (i.e., $\mathbf{M_{female}}$ in Table 2.3).

Table 3.1: Parameter estimates and standard errors of the SS model based on the setting of the base case scenario.

Parameter	Estimate	Standard error
L_at_Amin_Fem_GP_1	27.067	1.078
L_at_Amax_Fem_GP_1	92.240	3.136
VonBert_K_Fem_GP_1	0.165	0.020
CV_young_Fem_GP_1	0.197	0.016
CV_old_Fem_GP_1	0.048	0.019
NatM_uniform_Mal_GP_1	1.305	0.080
L_at_Amax_Mal_GP_1	43.096	1.935
VonBert_K_Mal_GP_1	0.603	0.119
CV_young_Mal_GP_1	0.140	0.025
CV_old_Mal_GP_1	0.198	0.051
SR_LN(R0)	8.986	0.110
SR_BH_steep	0.684	0.067
Size_DblN_peak_Com_Gillnet(1)	43.407	0.390
Size_DblN_ascend_se_Com_Gillnet(1)	2.435	0.197
Size_DblN_descend_se_Com_Gillnet(1)	6.112	0.545
Size_DblN_peak_Rec_Line(3)	44.747	0.507
Size_DblN_ascend_se_Rec_Line(3)	3.542	0.172
Size_DblN_descend_se_Rec_Line(3)	4.053	0.960

3.2.2 Model fits

Reasonable fits were achieved for all data sets, including abundance indices, length compositions, and conditional age-at-length compositions across the eighteen scenarios. For some years between 2015 and 2020, there were differences between the model fitted values and the abundance index data of Tunnel Netting (i.e., fleet *Com_Tunnel*). Goodness of fit for the model of the base case scenario is given in Appendix B.2. Besides, across the eighteen scenarios, all parameter estimates were inside the specified parameter space (i.e., not hit the boundary of the specified range), and the model was claimed convergence when all parameter gradients were close to 0 (i.e., absolute values of the gradients are smaller than $< 10^{-4}$).

3.2.3 Selectivity

Selectivity of dusky flathead was estimated within the SS model, and retention was set up to accommodate management measures and the assumption that fishers were likely to release large fish back to the sea because they are essential breeders. The selectivity and retention curves for fleet *Com_Gillnet* and *Rec_Line* in two time blocks (i.e., 1901–2002 and 2003–2020) are given in Figure 3.8 and 3.9. Note that in the SS model, the selectivity of fleets *Com_Tunnel* and *Com_Gillnet* was assumed to be the same, and fleets *Rec_Line* and *Come_Line* had the same selectivity.

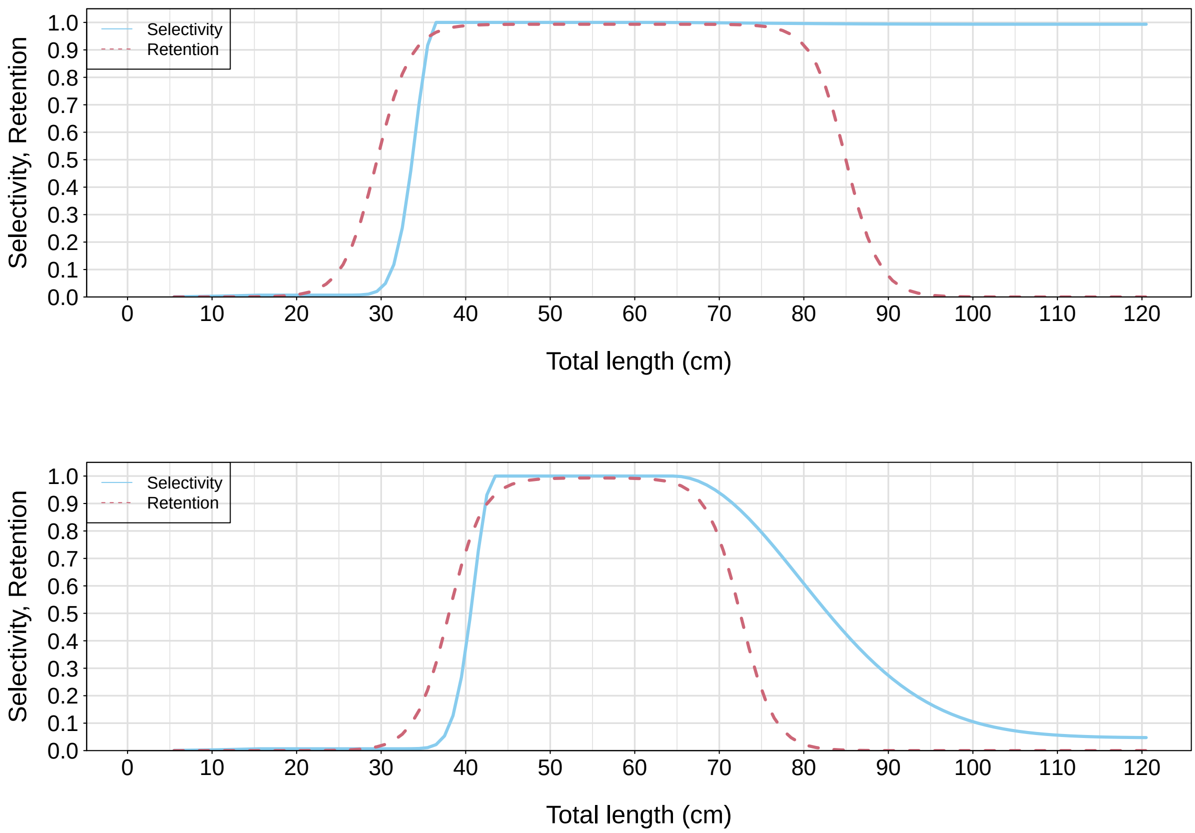

Figure 3.8: Size-based selectivity and retention for fleet *Com_Gillnet* in two time blocks: 1901–2002 (top) and 2003–2020 (bottom).

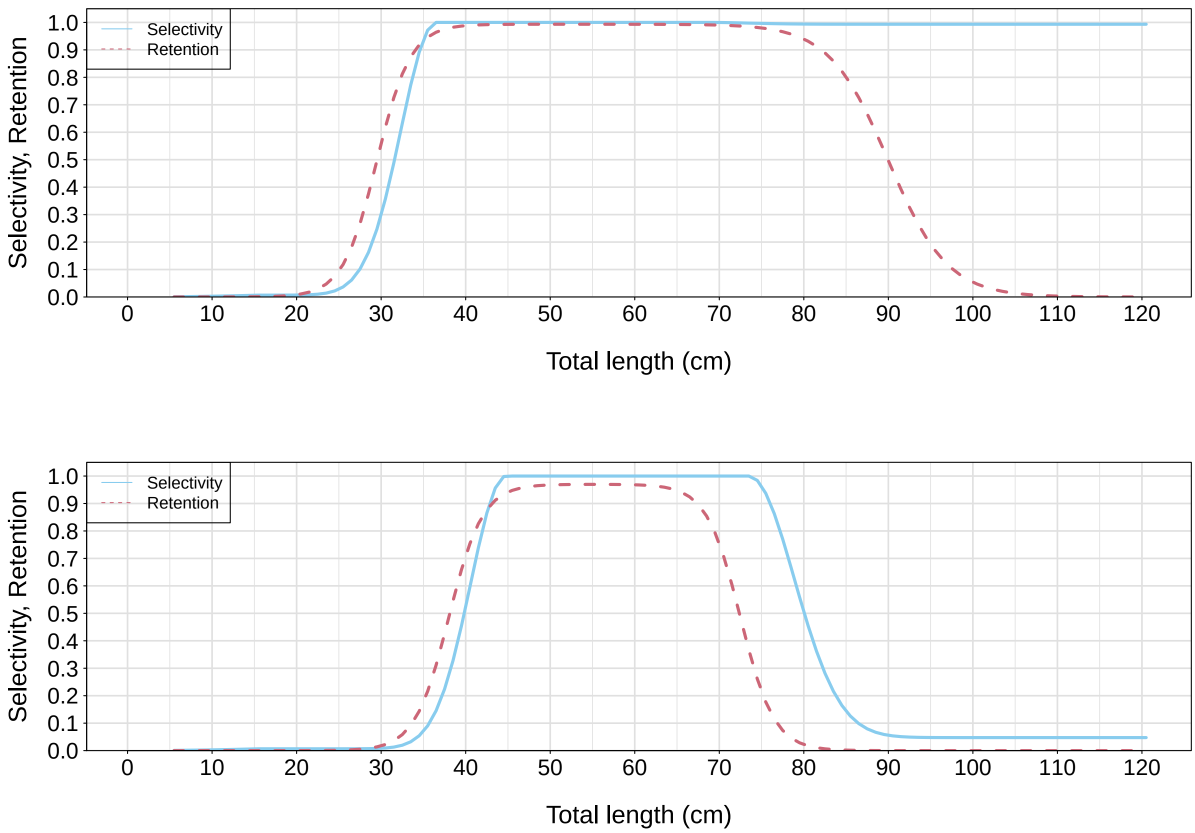

Figure 3.9: Size-based selectivity and retention for fleet *Rec_Line* in two time blocks: 1901–2002 (top) and 2003–2020 (bottom).

3.2.4 Growth curve

The von Bertalanffy growth curve, including coefficients of variation of old and young fish, was estimated within the model for both males and females (Figure 3.10).

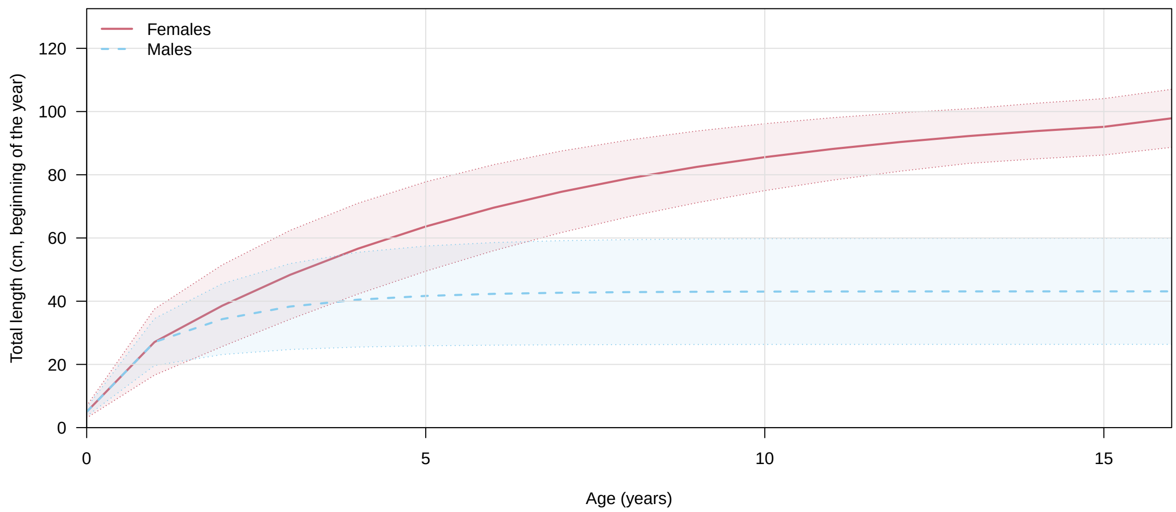

Figure 3.10: Model estimated von Bertalanffy growth curve for female and male dusky flathead. The shading area represent 95% confidence interval.

3.2.5 Biomass

The base case model shows that the spawning biomass declined between 1901 and 2000 to 30% unfished spawning biomass in Figure 3.11. At the beginning of 2021, the stock level was estimated to be 46% unfished biomass.

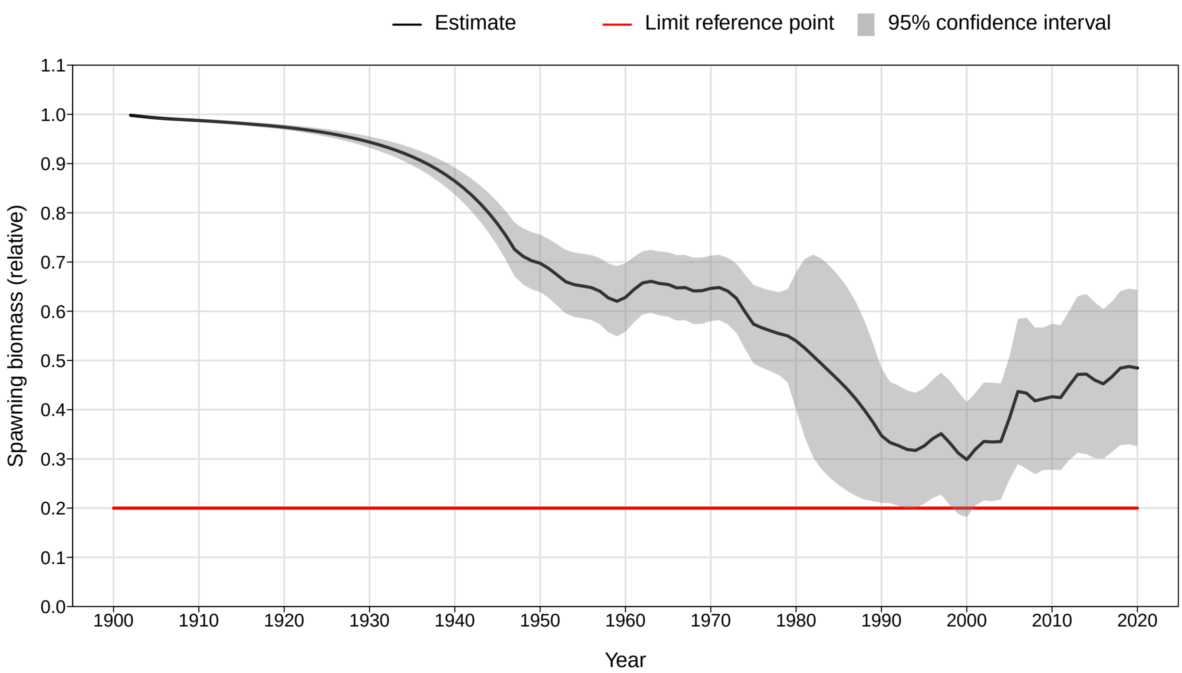

Figure 3.11: Estimated biomass trajectory relative to unfished for dusky flathead based on the base case scenario from 1901 to 2020.

Relative biomass trajectories for the 18 scenarios that resulted in parameters estimating freely of their bounds are presented in Figure 3.12.

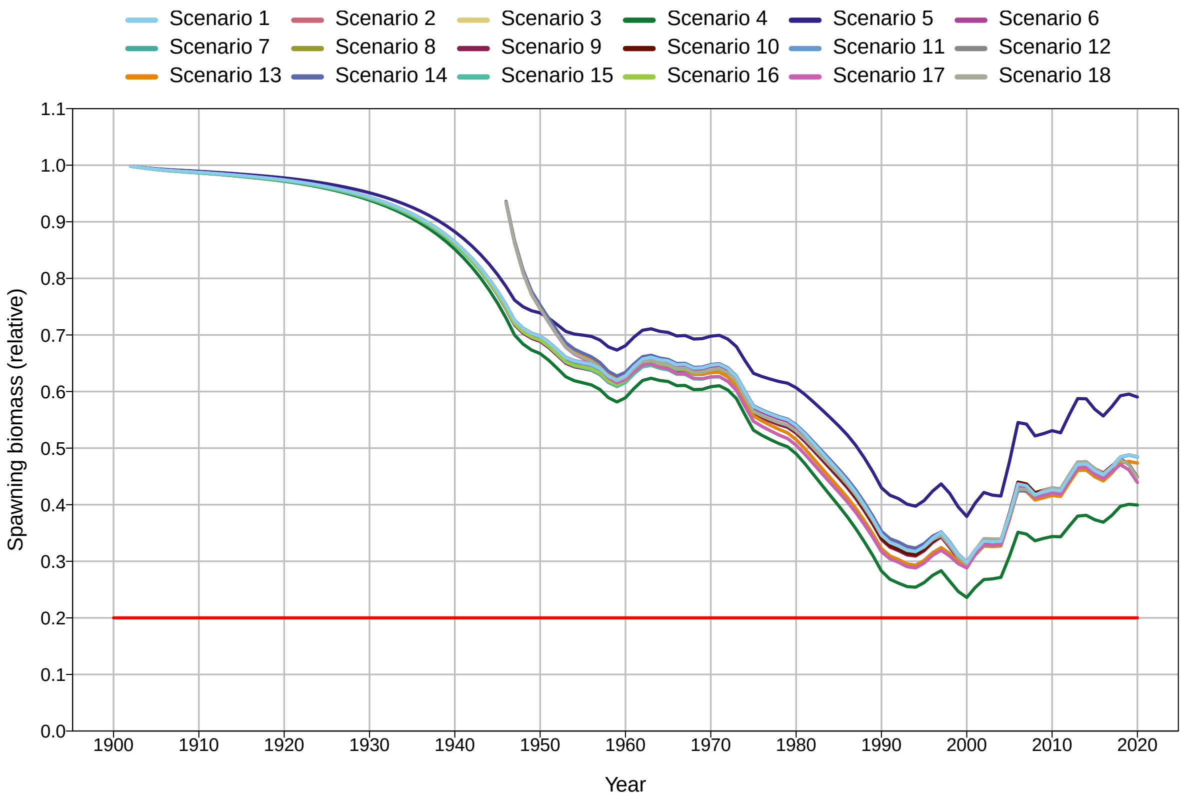

Figure 3.12: Estimated spawning biomass trajectory relative to virgin for dusky flathead for the 18 scenarios.

The effect of female natural mortality ($\mathbf{M}_{\mathbf{female}}$) on the relative spawning biomass is evident by the clear division of scenarios into three groups. Relative spawning biomass was greatest in scenario 5 with $\mathbf{M}_{\mathbf{female}}$ fixed to 0.8, the lowest in scenario 4 with $\mathbf{M}_{\mathbf{female}}$ fixed to 0.7, and the middle group of scenarios had a $\mathbf{M}_{\mathbf{female}}$ value of 0.75. Scenarios 7, 10, 13, 14, 17 and 18 began in 1945, with an initial depletion based on the equilibrium state associated with the reconstructed catch level at that time. Despite this significantly different methodology for the historical period, these scenarios lead to a final spawning biomass ratio almost indistinguishable from scenarios that began in 1901 (Figure 3.12).

The relationship between the spawning biomass estimate and fishing mortality from the base case model scenario is presented in a phase plot (Figure B.12).

The equilibrium harvest informs on the productivity of the stock at different biomass levels (Figure 3.13). For dusky flathead the equilibrium yield curve indicates that a biomass level of 60 % would result in the species being maintained at a relatively unproductive state. As a result, a 50 % biomass target is likely to represent a more productive state and therefore be more reflective of MEY.

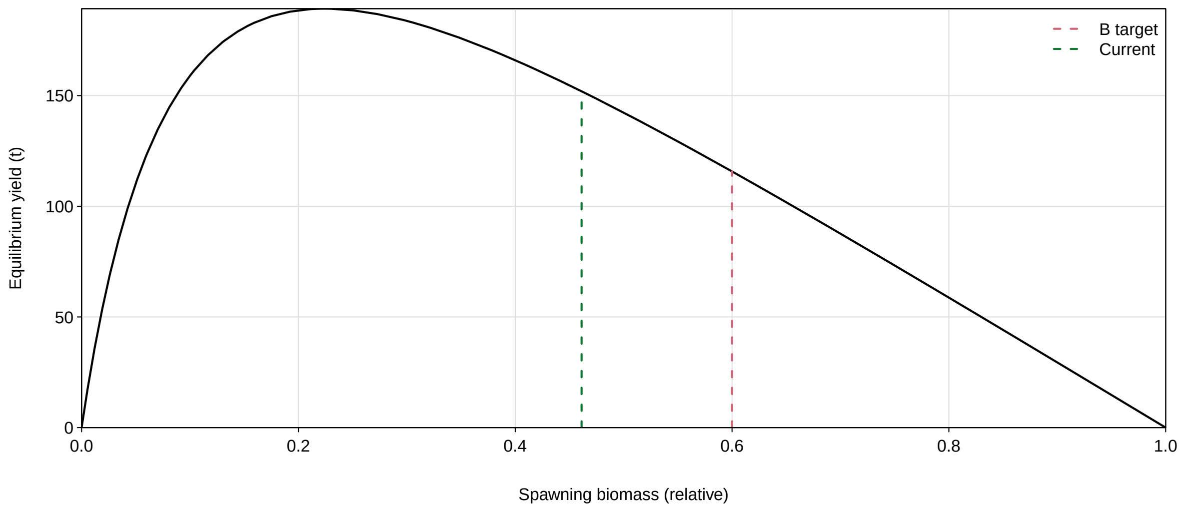

Figure 3.13: Equilibrium yield and equilibrium retained catch curves for dusky flathead based on the base case scenario.

3.2.6 Harvest targets

Harvest targets have been calculated to maintain spawning biomass at the two target reference points for the base model—60% spawning biomass and 50% spawning biomass—resulting in recommended biological retained catch (RBC) of 58 t and 102 t respectively for 2021. These RBCs are the first in a schedule of projected recommended harvests following a 20:60:60 or 20:50:50 harvest control rule. The schedules are presented here for the base case in Tables 3.2 and 3.3. Note that these RBC values have not had an uncertainty discount factor applied. For discounted harvest values see Section 4.3.2.

Table 3.2: Estimated total harvests and biomass ratios of dusky flathead for the base case scenario to rebuild to the target reference point of 60% unfished spawning biomass in 20 years, following a 20:60:60 control rule.

Year	Harvest (t)	Biomass ratio
2021	58	0.46
2022	70	0.49
2023	78	0.50
2024	90	0.53
2025	98	0.56
2026	106	0.58
2027	108	0.59
2028	109	0.59
2029	110	0.59
2030	111	0.60
2031	111	0.60
2032	112	0.60
2033	112	0.60
2034	112	0.60
2035	112	0.60
2036	112	0.60
2037	112	0.60
2038	112	0.60
2039	112	0.60
2040	112	0.60

Table 3.3: Estimated total harvests and biomass ratios of dusky flathead for the base case scenario to rebuild to the target reference point of 50% unfished spawning biomass in 20 years, following a 20:50:50 control rule.

Year	Harvest (t)	Biomass ratio
2021	102	0.46
2022	108	0.46
2023	110	0.45
2024	121	0.47
2025	130	0.48
2026	137	0.50
2027	137	0.50
2028	136	0.50
2029	136	0.50
2030	137	0.50
2031	138	0.50
2032	138	0.50
2033	138	0.50
2034	138	0.50
2035	138	0.50
2036	138	0.50
2037	138	0.50
2038	138	0.50
2039	138	0.50
2040	138	0.50

4 Discussion

This assessment was the second assessment of the Queensland east coast dusky flathead. Results from this assessment suggested the dusky flathead population east coast experienced decline in the period from 1901 to 1960. Population levels stabilised in the period 1961–1972 and then, declined again from 1973 to 2000, followed by stock recovery from 2001 to 2020. The timing of the stocks recovery suggests that it may be a result of the increase in the minimum legal size limit and introduction of an upper size limit for dusky flathead in 2002. Without these size limits in place to protect both immature and large female fish it is likely that the biomass trajectory would not have been characterised by recent increases. The results of the base case scenario suggest that the population level at the start of 2021 was estimated to be 46% unfished biomass.

4.1 Performance of the population model

The population model for this stock assessment was a two-sex and age-based stock model within the modelling framework of Stock Synthesis. Eighteen scenarios were constructed for sensitivity tests to examine the robustness and performance of the model. The scenarios included changes in some crucial parameters and data inputs (see Table 2.3).

Scenario 1 was chosen by the project team to be the base case (most plausible) model; however other scenarios were also considered plausible. This can be best understood by considering the following key contributors to the overall uncertainty.

Across the eighteen scenarios, the estimates of the parameters regarding male and female growth curves were consistent (Figure B.16). In the base case scenario, the length estimate of female dusky flathead at age 13+ was statistically the same as the female growth function output of Gray et al. (2015), but the von Bertalanffy growth coefficient estimate was larger than the estimates of Gray et al. (2015) and Leigh et al. (2019). On the other hand, the estimates of male dusky flathead at age 13+ and growth coefficient were statistically the same as the results of Gray et al. (2015), but the growth coefficient estimate of Leigh et al. (2019) is higher. Note that proper priors based on the study of Gray et al. (2015) were specified to these parameters to shrink uncertainty such that the SS model could produce male and female growth curves, which is biologically sensible.

The estimates of male natural mortality across the eighteen scenarios were influenced by specified values of female natural mortality, even though those estimates were statistically indifferent. Male natural mortality increased along with increasing in female natural mortality. In the base case scenario, the estimate of male natural mortality was 1.305 year^{-1} (Table 3.1). This value is lower than estimates of Leigh et al. (2019) for the Moreton region given female natural mortality fixed to 0.75 year^{-1}.

The estimates of two parameters for recruitment were also influenced by the change in female natural mortality values. The estimates of the logarithm of unfished recruitment increase when female natural mortality values increase. On the other hand, the estimates of recruitment steepness increased when female natural mortality values decreased. The dependency was not apparent due to the strong prior specified (i.e., the prior distribution's variance was small, see Section 2.5.2). In the base case scenario, the estimate of the logarithm of unfished recruitment was 8.986, which is smaller than the estimate of Leigh et al. (2019) even though the prior was specified accordingly. The estimate of steepness was slightly larger but statistically equal to the value 0.668 of Thorson (2020).

In terms of spawning biomass ratio, the estimates across the eighteen scenarios show that female natural mortality was a crucial parameter driving the estimated trajectory level. Amongst the eighteen scenarios, the lowest spawning biomass ratio occurred when female natural mortality was 0.70 year^{-1}, and the highest occurred when female natural mortality was 0.80 year^{-1}. In addition, the two methods for harvest estimation (i.e., regarding the recreational harvests) influenced the estimates before 2000. Recall that Method 2 gave smaller recreational harvest estimates than Method 1 before 1997 and caused slightly higher spawning biomass ratio estimates. Last, the decreasing of Tunnel Netting catch rates in years 2017–2020 pulled the estimates down but not significantly in the period.

In sum, female natural mortality played an influencing role and drove the spawning biomass ratio trajectory level. Attempts to estimate this parameter in the SS stock model were unsuccessful because it was confounding with the two recruitment parameters (i.e., steepness and the logarithm of unfished recruitment). Hence, the project team decided to estimate the two recruitment parameters but control the value of female natural mortality. The values for female natural mortality were chosen based on two factors: firstly, whether or not values were compatible with stable parameter estimation for the model; secondly with reference to the 2019 stock assessment (Leigh et al. 2019). The value of female natural mortality in the base case scenario was reported by Leigh et al. (2019). The project team was aware of that choosing this value is critical and the uncertainty of female natural mortality should be taken into account.

In addition, the SS stock model was built based on several settings to reduce and manage uncertainty. For example, steepness of the recruitment was specified a strong prior (i.e., a prior with small variance); female natural mortality was not estimated but fixed to a value. The uncertainty was due to lack of contrast in data such as catch rates and harvest sizes; that is, the data could not provide sufficient information to help the model decide parameter values.

4.2 Unmodelled influences

There are a number of possible drivers of the dusky flathead population that have not been directly modelled, but should be taken into consideration when interpreting model outputs and considering future assessments and management arrangements. These include change of environment and recreational catch rates. Two key influences are discussed below:

- **Change of environment:** Some studies had identified several environmental variables correlating to the commercial catch rates of dusky flathead (Gillson et al. 2009; Holbrook et al. 2014; Meynecke et al. 2011). Those variables are sea surface temperature, rainfall, freshwater flow, and drought. They might be an additional source of uncertainty and can be taken into account for future assessments.
- **Recreational catch rate:** The boat ramp survey conducted by Fisheries Queensland has collected recreational data since 2015 in 18 different regions along the entire Queensland coast (Fisheries Queensland 2017). Using the data to build the abundance index for the recreational fishery can improve future assessments. The index can be used either as a stock model input or as auxiliary information to improve the recreational harvest estimation from 2016.

4.3 Recommendations

4.3.1 Research and monitoring

Research and monitoring recommendations for dusky flathead focus on prioritising the reduction in model uncertainty and the rectification of caveats. These recommendations are given below:

- **Tagging experiment for natural mortality:** Female natural mortality was the most influencing and uncertain parameter in the present SS model and drove the level of spawning biomass ratio trajectory. Although female natural mortality was fixed to values close to the value used in Leigh et al. (2019), the uncertainty of female natural mortality was hard to ignore. Hence, a rigorous tagging experiment can be conducted to improve the estimates of natural mortality rates for both male and female flathead. The acquired natural mortality estimates can improve the SS model performance and reduce uncertainty.
- **Length and age monitoring:** Fishery-dependent length and age data collected by the Queensland Fishery Monitoring team were advantageous to this assessment. Continued monitoring of age and length information of dusky flathead is crucial for the ongoing assessment and management of dusky flathead.
- **Fishery-independent length and age survey:** The fishery-dependent length and age data were skewed due to the constraints of minimal and maximum legal sizes. The data showed the length distribution was truncated at the minimum legal size of 40 cm (see Table 1.1). Because the maximum legal size of 75 cm currently applies in Queensland, female dusky flathead that grow larger than this size were not allowed to be retained by fishers and so generally not be measured by the monitoring team. Hence, the data lack some large and old fish which Gray et al. (2015) were able to sample in NSW through a fishery-independent survey over the whole length range of dusky flathead. The fishery-independent survey should provide sufficient information on the length and age of dusky flathead as well as the population structure.
- **Fecundity and maturity:** No fecundity and maturity data were available for dusky flathead on Queensland's east coast. These are two important components of the SS stock model. Studies of fecundity and maturity had been done in Victoria (Hicks et al. 2015) and NSW (Gray et al. 2015). In terms of maturity, (Gray et al. 2015) reported the median size of maturity of female dusky flathead is between 56.2 cm and 57.4 cm, which is larger than the minimum legal size of 40 cm. However, (Hicks et al. 2015) gave a result of a much smaller size (i.e., between 30.4 cm and 35.2 cm). These two studies notify a need for a maturity study on dusky flathead on Queensland's east coast to evaluate the current minimum legal size. For fecundity, the SS model applied an approximation of the fecundity function by Hicks et al. (2015). Hence, future research is needed to investigate relationships between fecundity and size (or age) of dusky flathead on Queensland's east coast and the number and quality of eggs per unit body mass. Hicks et al. (2015) implied that behaviours of large females could influence the number and quality of eggs per unit body mass. Such a study may provide an invaluable source of data for future assessments.
- **Discards:** Data of discards, if available, can improve the model estimation of fishing mortality.

4.3.2 Management

The base case scenario predicted the 2021 stock biomass level of dusky flathead to be 46% of unfished spawning biomass. The harvest consistent with a spawning biomass ratio of 50% was estimated at 138 t, and the recommended harvest in 2021 is 102 t in order to reach the target. The harvest consistent with maintaining a spawning biomass ratio of 60% was estimated at 112 t, and the recommended harvest in 2021 is 58 t in order to reach the target. Based on the equilibrium yield curve it is recommended that a 50 % target level will result in a productivity most closely reflective of MEY.

The recommended discount factor for this assessment (Fisheries Queensland 2021a) is 0.87 based on a qualitative tier assignment process and Ralston et al. (2011) (σ is 0.54, P^* (risk aversion) is 0.40).

Table 4.1: Current and target indicators for Queensland east coast dusky flathead.

Indicator	Estimate
Biomass$^\diamond$ (relative to unfished) at the start of 2021	46% (31% to 62%)
Biomass (relative to unfished) at MSY*	22%
MSY*	189 t
Retained catch component of MSY*	184 t
Retained catch in 2020	135 t
Retained catch at 60% biomass target	112 t
Retained catch at 50% biomass target	138 t
RBC† for 2021 to achieve 60% biomass target	60 t
Retained component of RBC	58 t
RBC† for 2021 to achieve 50% biomass target	106 t
Retained component of RBC	102 t
Time to achieve 60% biomass target	10 years
Time to achieve 50% biomass target	6 years

$^\diamond$ Biomass is defined to be spawning stock biomass.
* MSY (maximum sustainable yield) is defined to be the maximum sustainable dead catch—that is, retained catch plus catch that dies following discarding.
† RBC (recommended biological catch) is the recommended catch according to the control rule. This is dead catch: retained catch plus catch that dies following discarding

4.3.3 Assessment

Limitations to the current model's performance have been discussed in this document. Specific recommendations for a future assessment are as follows:

- Revisit and utilise data sets collected by DAF in 1990s (also suggested by Leigh et al. (2019)). Those data sets might provide biological relationships of Queensland's east coast dusky flathead.
  - Coastal Streams project with data from 1993, 1997 and 1998.
  - Integrated Stock Assessment and Monitoring Program (ISAMP) with data from 1995, 1996 and 1997 (Hoyle et al. 2000).
  - A DAF study on fecundity in the early 1990s (Kerby et al. 1994).
- Utilise fishing club data. As a suggestion in Leigh et al. (2019), the fishing club catch data were available from 1951 to 2003. They covered the rise in harvest sizes of dusky flathead before the beginning of the commercial logbook database in 1988. Therefore, the data might provide information on fishing pressure on dusky flathead from the 1950s to the 1980s. Leigh et al. (2019) built models to generate fishing club catch rates. The catch rates could be used as a stock model input or as auxiliary information to improve the harvest estimation in the period 1951–2003. However, more efforts are still needed to identify a proper model for fishing club catch rates regarding changes in fishing club practices over time (see Section 3.1 in Leigh et al. (2019)).

- Use the boat ramp survey data (Fisheries Queensland 2017) to build the abundance index for the recreational fishery. This index can be used either as a stock model input or as auxiliary information to improve the recreational harvest estimation from 2016.
- Female natural mortality was the most influencing and uncertain parameter in the present SS model. It drove the spawning biomass ratio trajectory level and, furthermore, changed harvest targets for the next 20 years under the 20:60:60 harvest control rule or others. Although female natural mortality was fixed to values close to the value used in Leigh et al. (2019), the project team was aware of uncertainty of female natural mortality; that is, actual mortality could be lower because dusky flathead can live for up to 11 years on Queensland's east coast.
- In addition, the present SS model displayed parameter estimation problems with female natural mortality lower than 0.70 year^{-1}. In particular, low $\mathbf{M_{female}}$ caused problems with estimation of Fmsy. Future assessments should re-examine the assumptions and setting of the present SS model. For example, the fraction of female fish at birth is 50%, and the maturity at age.

4.4 Conclusions

This assessment was commissioned to establish the stock status of dusky flathead on Queensland's east coast and inform the Sustainable Fisheries Strategy. The base case model scenario suggested spawning biomass is currently around 46% of unfished levels. The results provide recommended biological harvests using 20:60:60 and 20:50:50 control rules. Some limitations of the assessment have been noted, and recommendations for management and a repeat assessment have been made.

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Appendix A Model inputs

A.1 Age and length sample sizes

These sample sizes are input to the model and form a starting point for data set weighting.

Table A.1: Raw sample size of aged fish input to the model for dusky flathead by fleet.

	Com_Gillnet		*Com_Tunnel*		*Rec_Line*	
Year	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**
2007	20	86	0	16	9	119
2008	52	193	0	0	4	32
2009	27	76	44	63	8	42
2010	40	154	7	7	15	79
2011	17	81	58	96	11	78
2012	36	202	22	85	12	22
2013	23	109	2	20	6	71
2014	7	188	6	209	3	67
2015	7	147	3	98	10	115
2016	11	320	0	0	2	88
2017	24	221	0	6	8	66
2018	21	259	0	6	9	66
2019	12	141	0	0	10	104
2020	11	89	0	0	6	101

Table A.2: Raw sample size of fish length input to the model for dusky flathead by fleet.

	Com_Gillnet			*Com_Tunnel*			*Rec_Line*		
Year	**Male**	**Female**	**Unknown**	**Male**	**Female**	**Unknown**	**Male**	**Female**	**Unknown**
2007	10	151	1423	0	0	455	8	159	653
2008	44	249	1287	0	0	282	3	39	629
2009	22	48	537	45	101	280	10	40	600
2010	29	201	846	0	0	237	10	98	1052
2011	10	110	1708	27	93	161	10	102	1084
2012	14	180	1291	1	20	198	13	45	870
2013	3	46	1168	2	36	221	6	76	935
2014	26	293	1721	11	300	80	12	123	817
2015	14	113	1518	1	81	78	15	154	813
2016	4	181	1319	0	0	159	5	154	1013
2017	42	324	632	0	0	207	19	112	1013
2018	13	67	899	0	0	54	15	103	865
2019	12	25	593	0	0	71	15	101	651
2020	12	104	765	0	0	34	8	111	501

A.2 Length composition by sex and gear

The length frequency of dusky flathead by sex and gear are presented in Figure A.1.

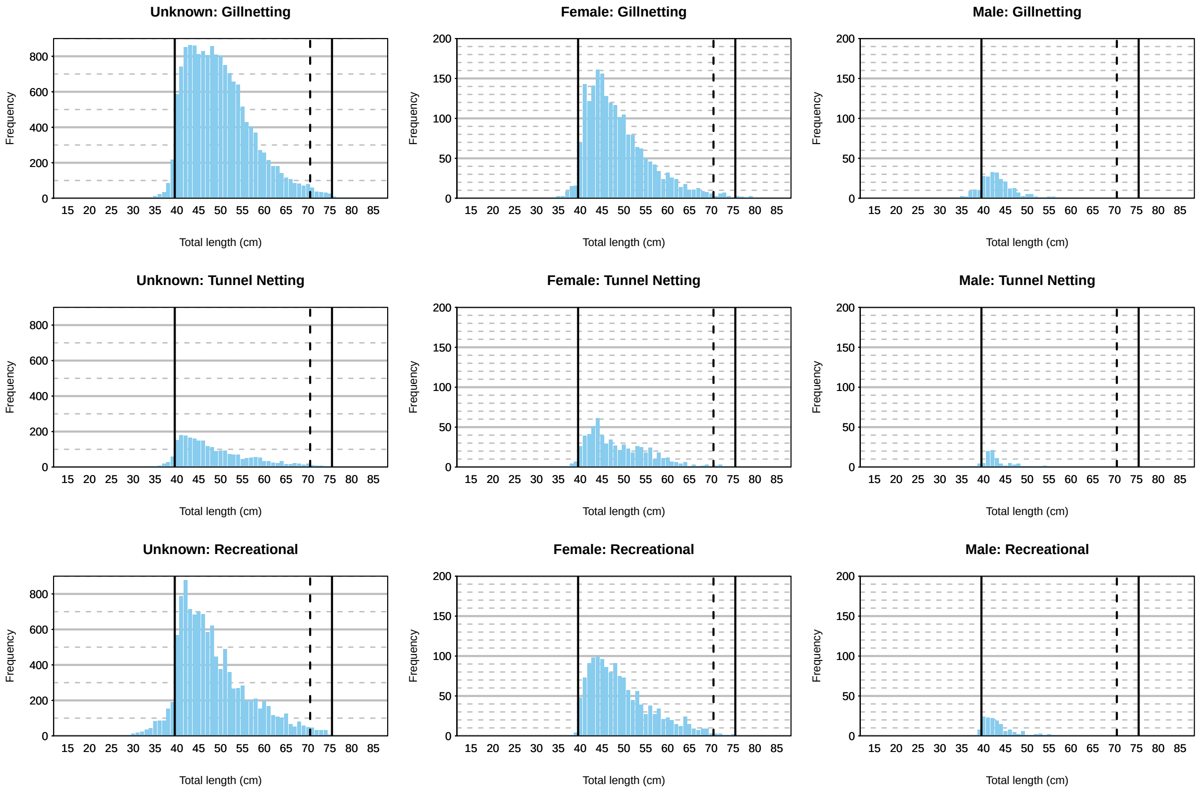

Figure A.1: Length frequency of duksy flathead by sex and gears.

A.3 Conditional age-at-length

The age-length frequency of dusky flathead by sex are presented in Figure A.2.

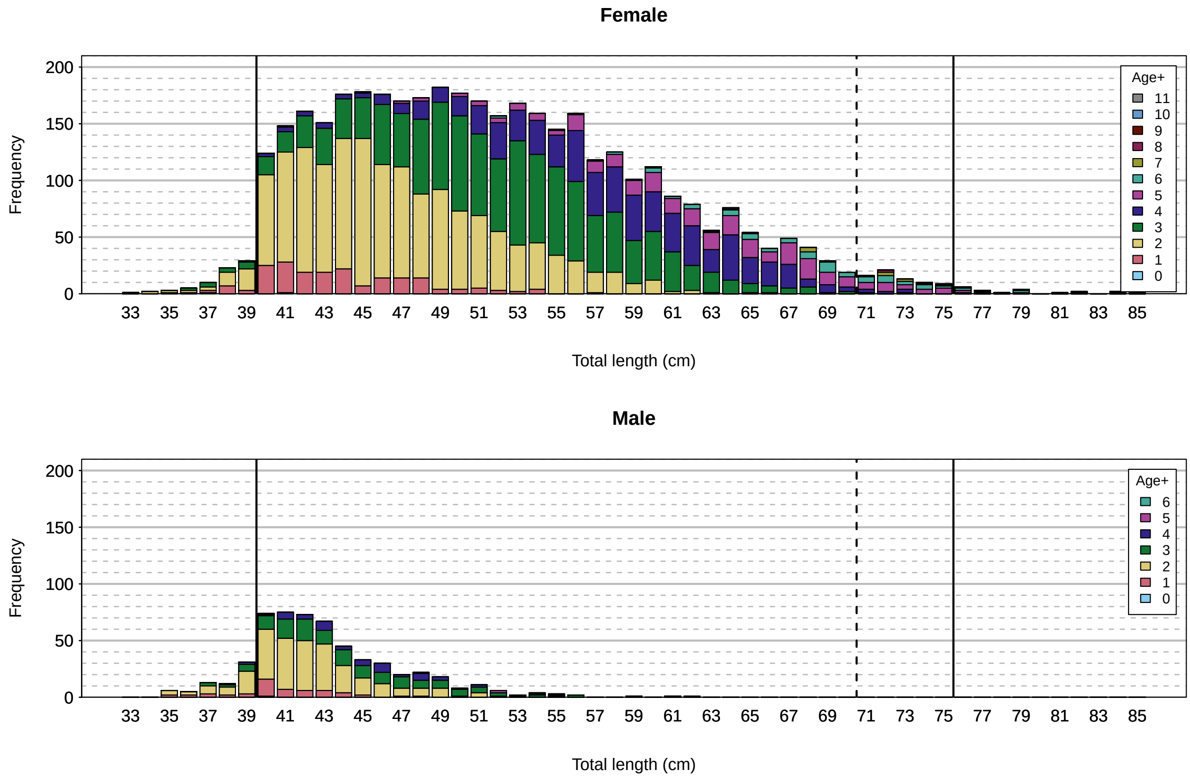

Figure A.2: Age-Length frequency of duksy flathead by sex.

A.4 Biological data

A.4.1 Fecundity and maturity

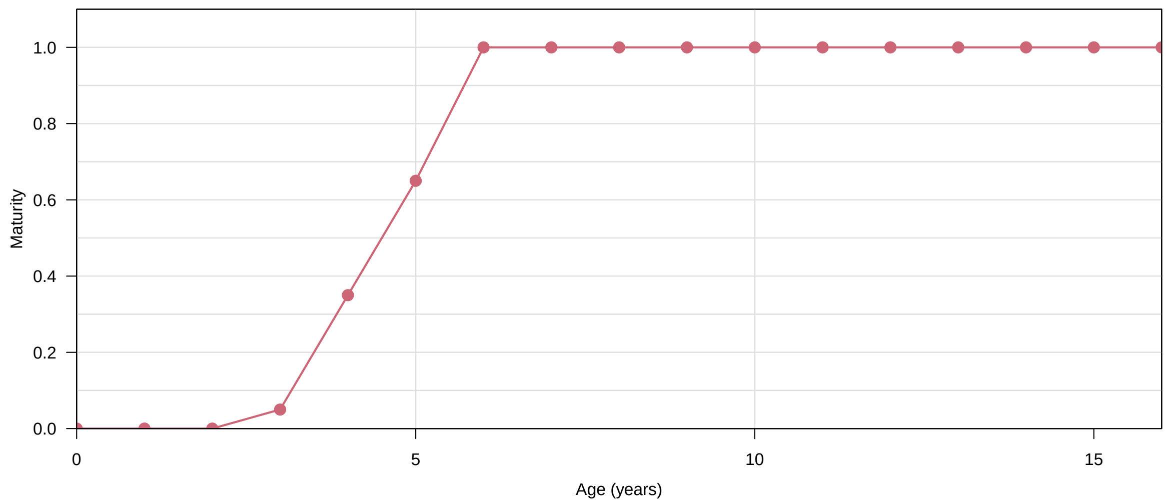

Figure A.3: Maturity at age.

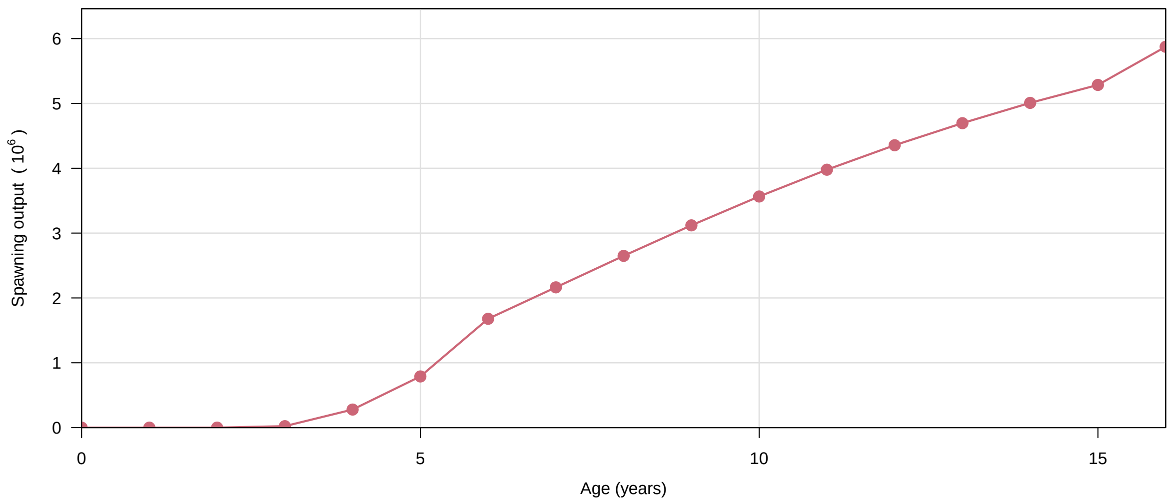

Figure A.4: Spawning output (maturity times fecundity) at age.

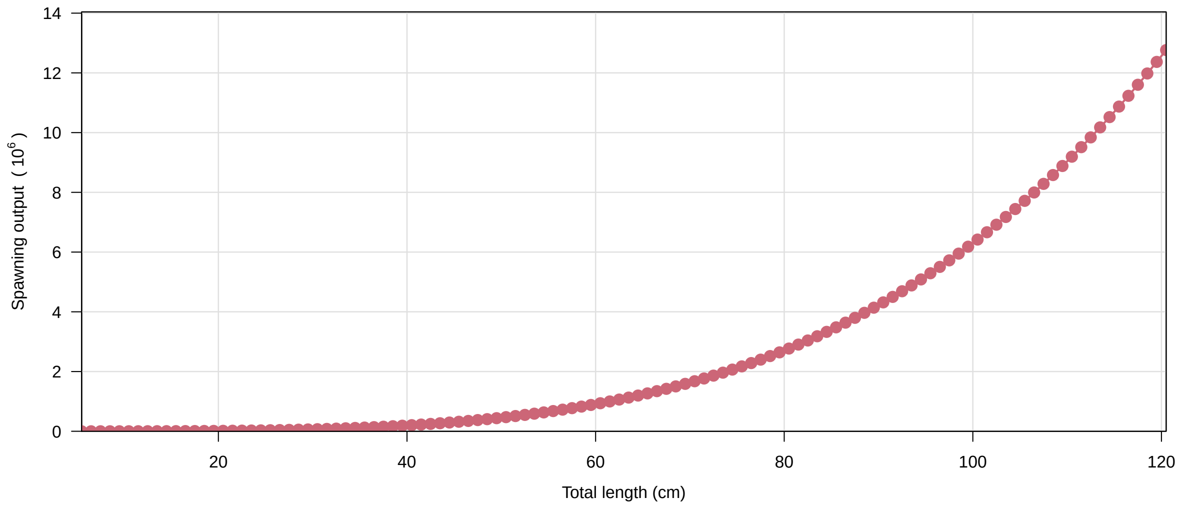

Figure A.5: Spawning output (maturity time fecundity) at length.

A.4.2 Weight and length

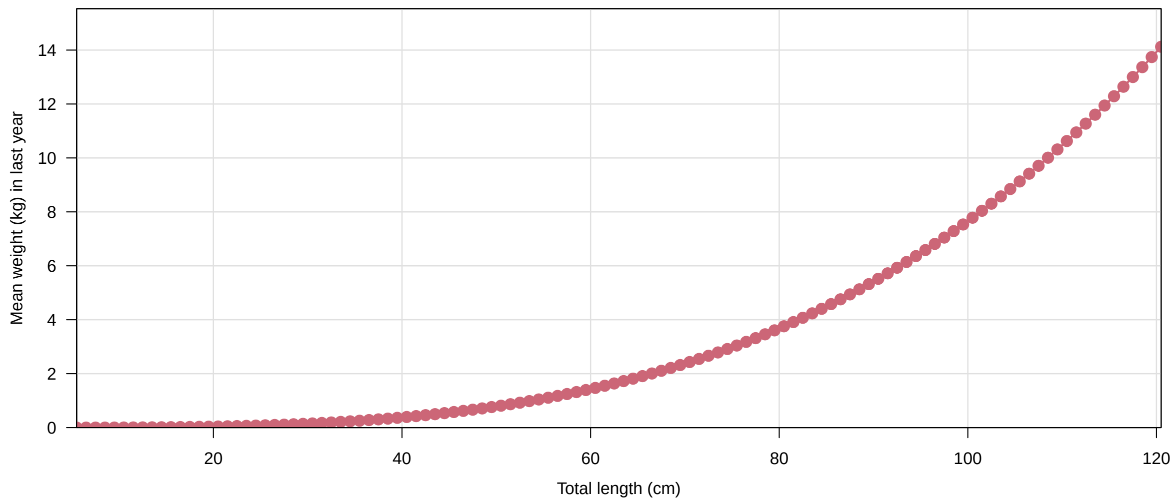

Figure A.6: Weight-Length relationship.

Appendix B Model outputs

B.1 Parameter estimates

Model parameters contained in Table B.1 were estimated by Stock Synthesis, and parameter labels follow a Stock Synthesis specific naming convention. Note that some model parameters included in the population model were fixed at certain values rather than estimated. Any parameters that were fixed (not estimated) are not listed below. In addition, recruitment deviations were estimated between 1976 and 2020.

Table B.1: Stock Synthesis parameter label explanation for dusky flathead.

Stock Synthesis parameter Label	Explanation
L_at_Amin_Fem_GP_1	Length at age 1+ (female)
L_at_Amax_Fem_GP_1	Length at age 13+ (female)
VonBert_K_Fem_GP_1	von Bertalanffy growth coefficient (female)
CV_young_Fem_GP_1	Coefficient of variation in length at age 1+ (female)
CV_old_Fem_GP_1	Coefficient of variation in length at age 13+ (female)
NatM_uniform_Mal_GP_1	Natural mortality (male)
L_at_Amax_Mal_GP_1	Coefficient of variation in length at age 13+ (male)
VonBert_K_Mal_GP_1	von Bertalanffy growth coefficient (male)
CV_young_Mal_GP_1	Coefficient of variation in length at age 1+ (male)
CV_old_Mal_GP_1	Coefficient of variation in length at age 13+ (male)
SR_LN(R0)	Beverton-Holt unfished recruitment (logarithm of the number of recruits in 1900)
SR_BH_steep	Stock recruitment steepness
Size_DblN_peak_Com_Gillnet(1)	Peak of double normal selectivity for fleets *Com_Gillnet* and *Com_Tunnel* in 2003–2020
Size_DblN_ascend_se_Com_Gillnet(1)	Ascending width of double normal selectivity for fleets *Com_Gillnet* and *Com_Tunnel* in 2003–2020
Size_DblN_descend_se_Com_Gillnet(1)	Descending width of double normal selectivity for fleets *Com_Gillnet* and *Com_Tunnel* in 2003–2020
Size_DblN_peak_Rec_Line(3)	Peak of double normal selectivity for fleets *Rec_Line* and *Com_Line* in 2003–2020
Size_DblN_ascend_se_Rec_Line(3)	Ascending width of double normal selectivity for fleets *Rec_Line* and *Com_Line* in 2003–2020
Size_DblN_descend_se_Rec_Line(3)	Descending width of double normal selectivity for fleets *Rec_Line* and *Com_Line* in 2003–2020

B.2 Goodness of fit

B.2.1 Abundance indices

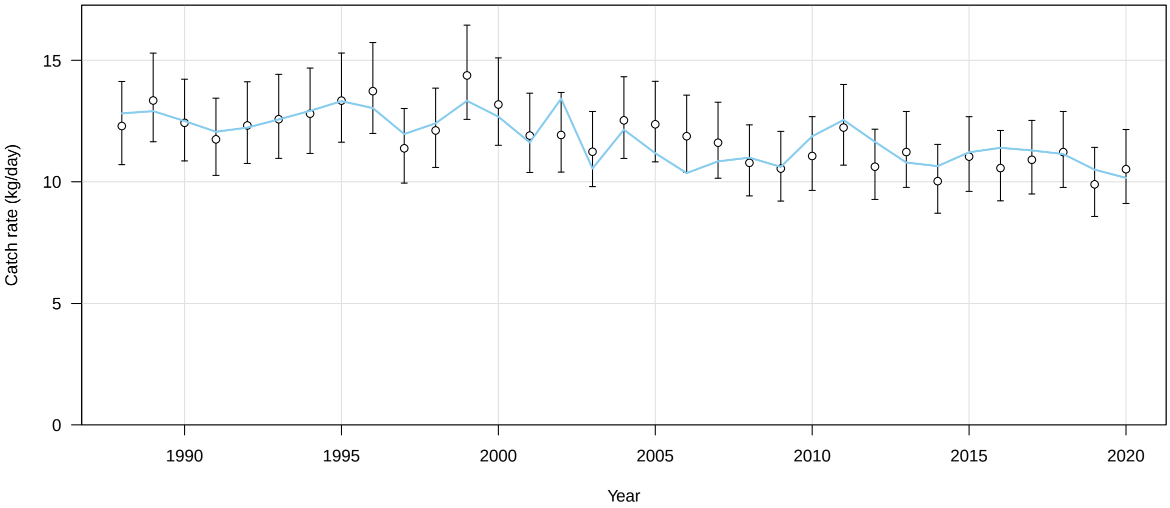

Figure B.1: Model predictions (blue line) of the base case scenario to the catch rates of commercial gillnetting for dusky flathead.

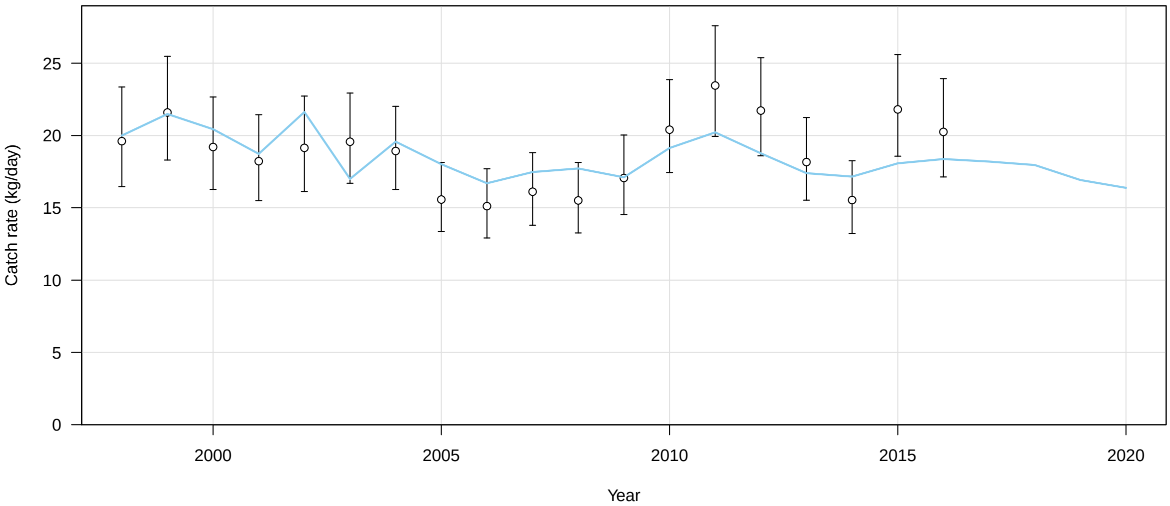

Figure B.2: Model predictions (blue line) of the base case scenario to the catch rates of commercial tunnel netting for dusky flathead.

B.2.2 Length compositions

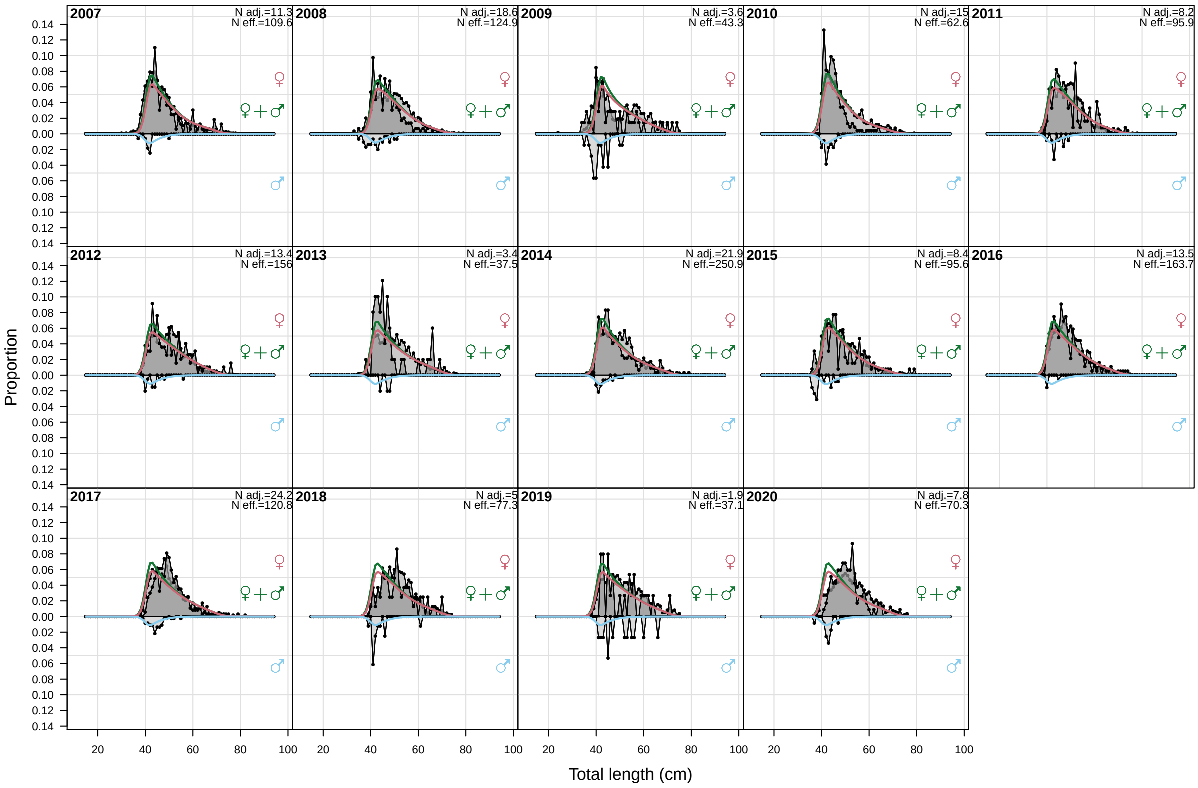

Figure B.3: Fits to length structures for fleet *Com_Gillnet*.

Note: 'N adj.' is the input sample size after data-weighting adjustment, and 'N eff.' the calculated effective sample size used in the McAllister-Ianelli tuning method.

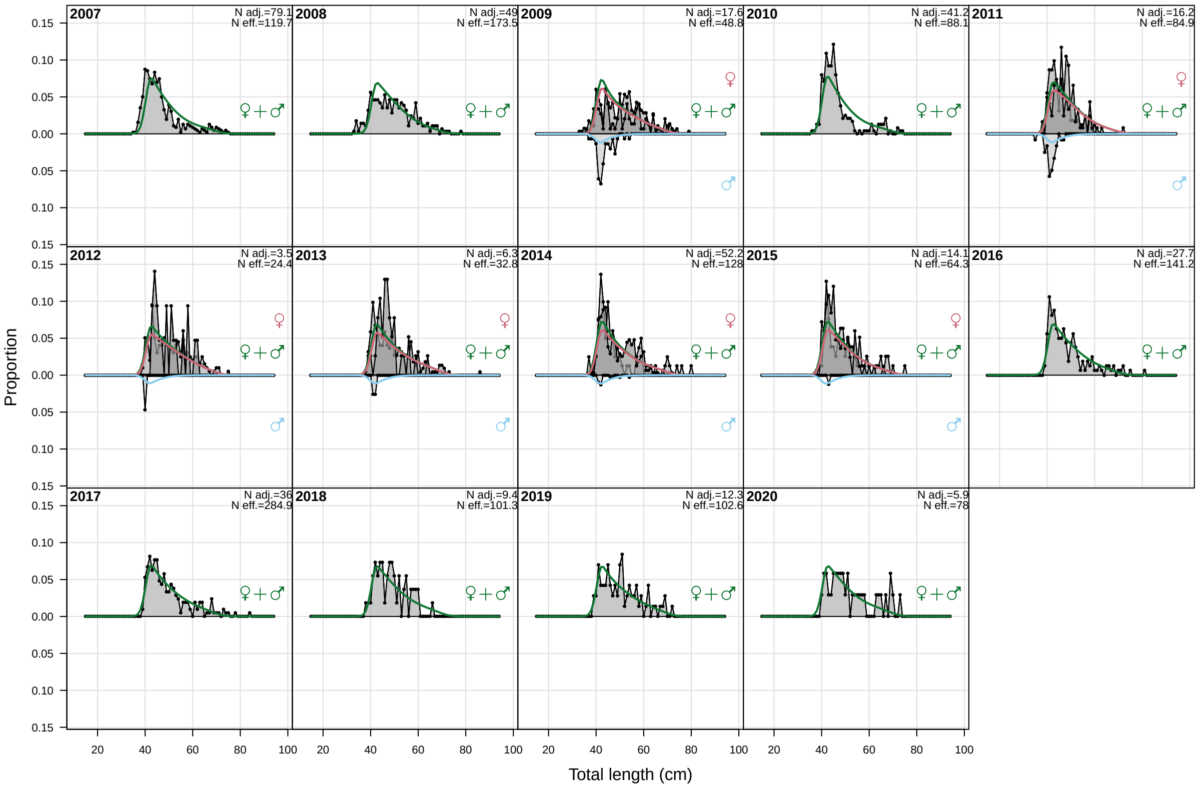

Figure B.4: Fits to length structures for fleet *Com_Tunnel*.

Note: 'N adj.' is the input sample size after data-weighting adjustment, and 'N eff.' the calculated effective sample size used in the McAllister-Iannelli tuning method.

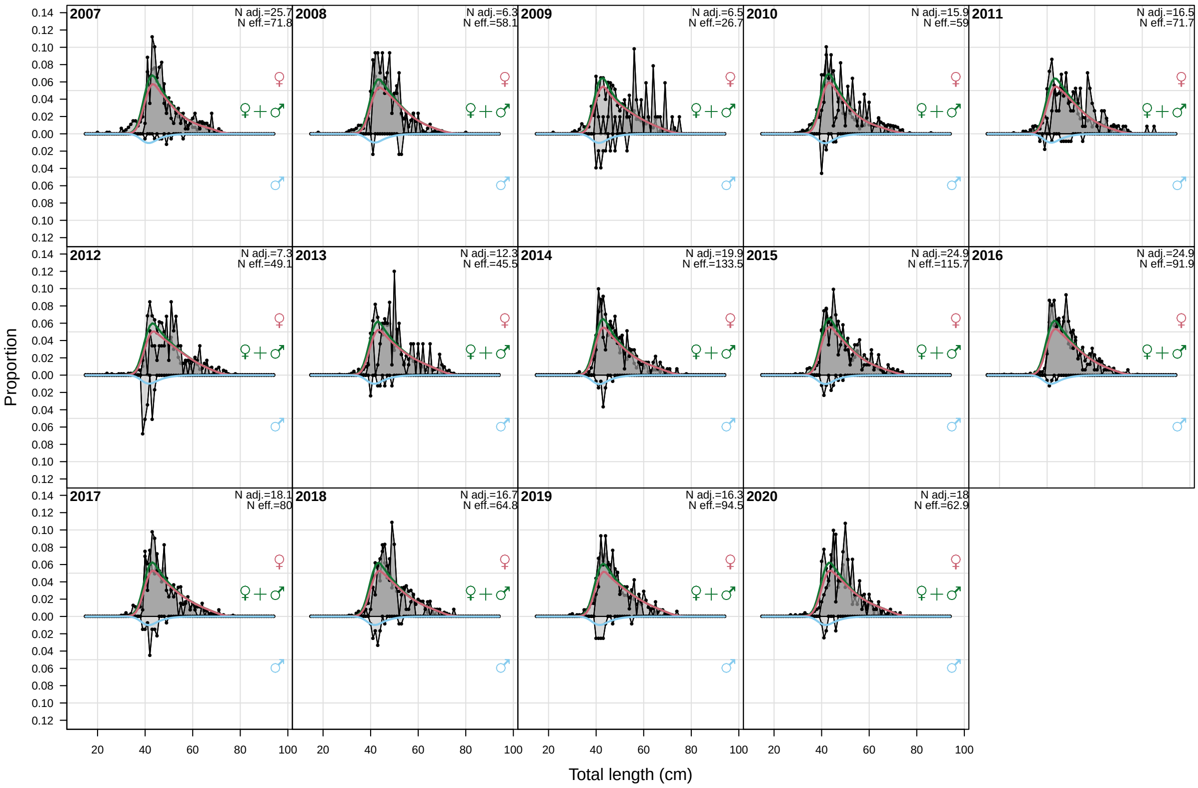

Figure B.5: Fits to length structures for fleet *Rec_Line*.

Note: 'N adj.' is the input sample size after data-weighting adjustment, and 'N eff.' the calculated effective sample size used in the McAllister-Iannelli tuning method.

B.2.3 Conditional age-at-length compositions

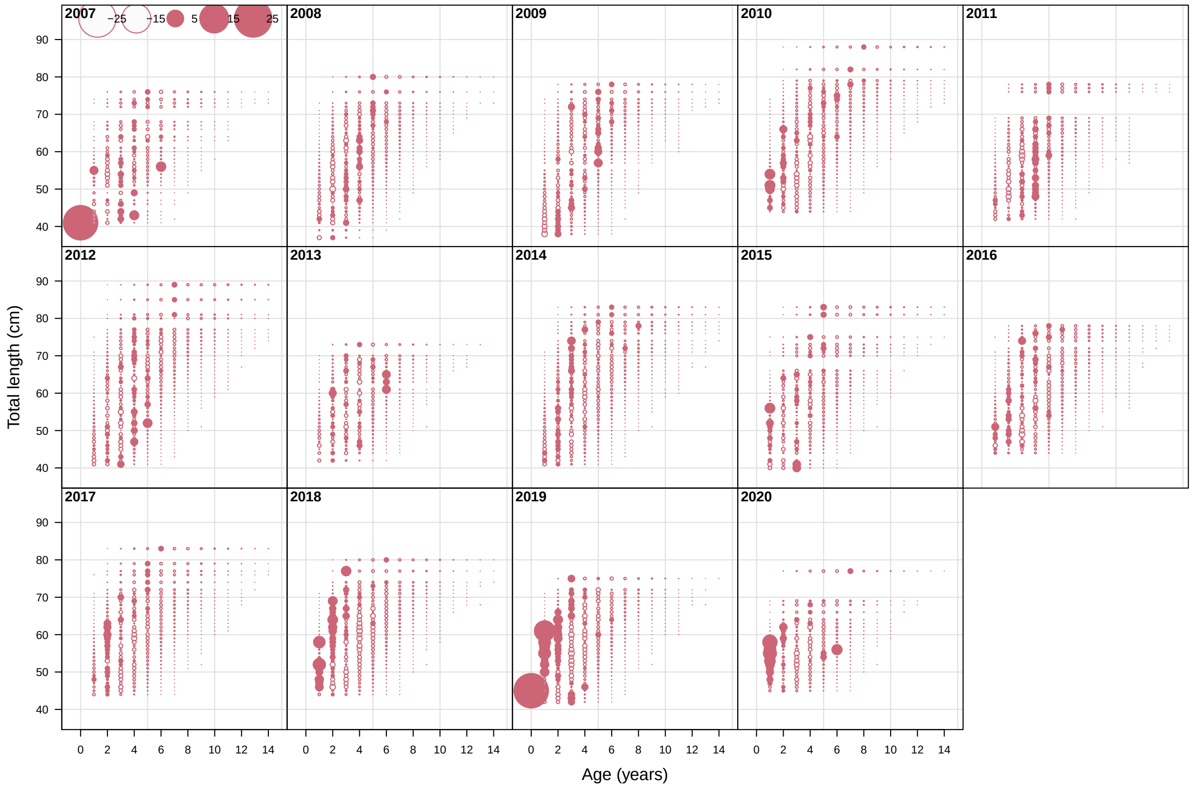

Figure B.6: Pearson residuals for age-at-length compositions of female dusky flathead for fleet *Com_Gill*. Circle size represents the magnitude of the Pearson residuals.

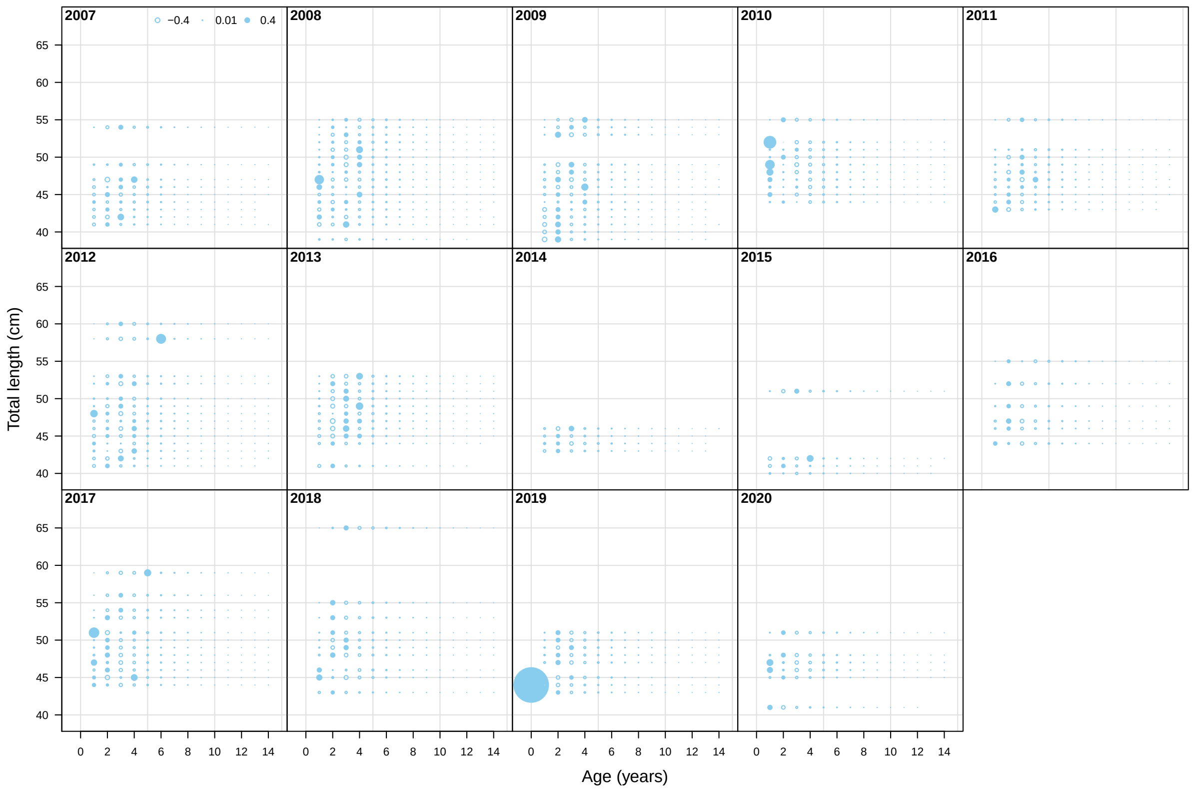

Figure B.7: Pearson residuals for age-at-length compositions of male dusky flathead for fleet *Com_Gill*. Circle size represents the magnitude of the Pearson residuals.

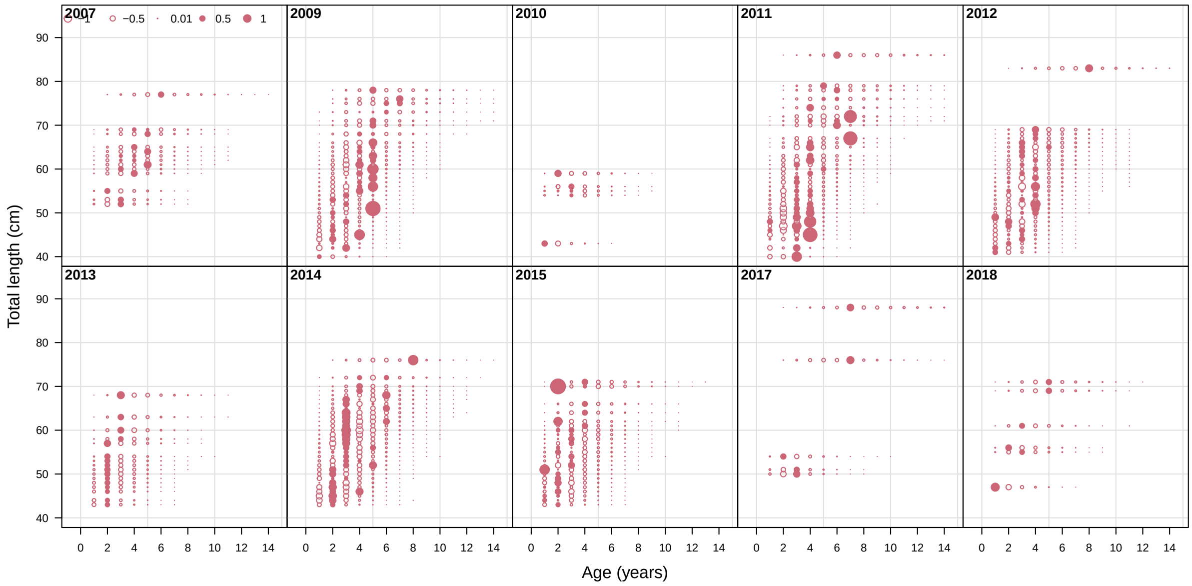

Figure B.8: Pearson residuals for age-at-length compositions of female dusky flathead for fleet *Com_Tunnel*. Circle size represents the magnitude of the Pearson residuals.

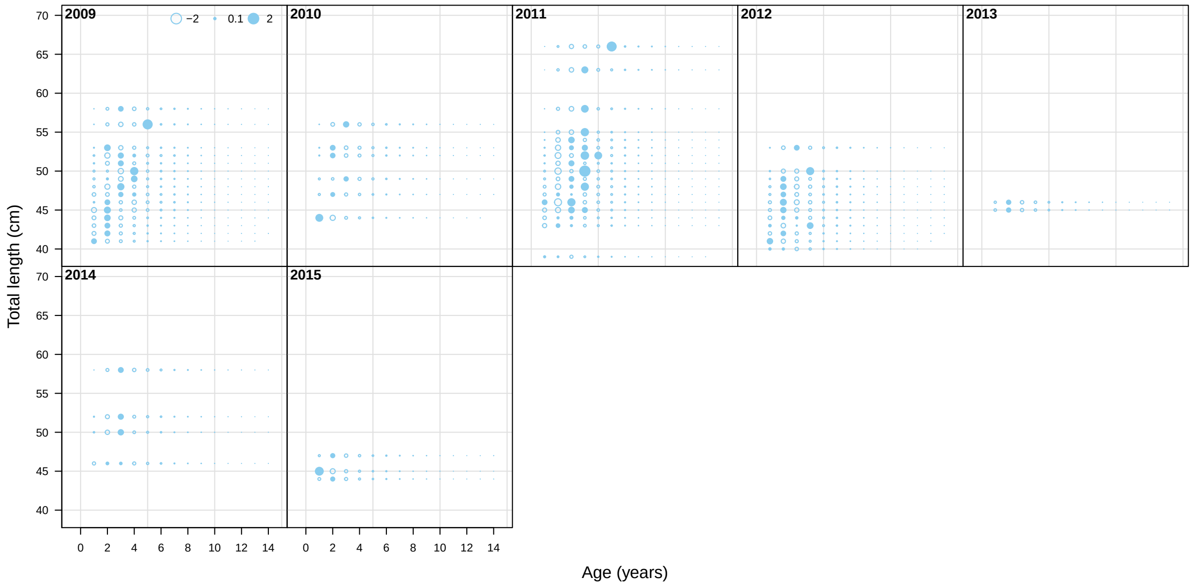

Figure B.9: Pearson residuals for age-at-length compositions of male dusky flathead for fleet *Com_Tunnel*. Circle size represents the magnitude of the Pearson residuals.

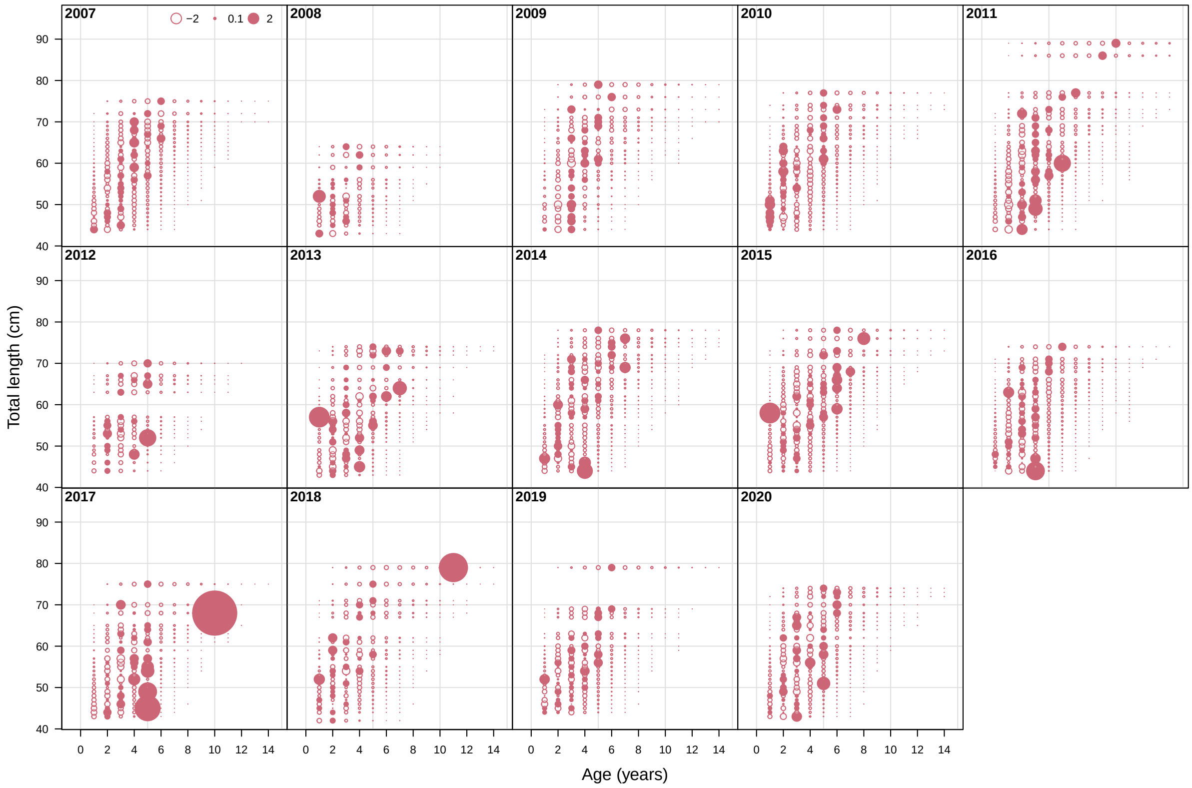

Figure B.10: Pearson residuals for age-at-length compositions of female dusky flathead for fleet *Rec_Line*. Circle size represents the magnitude of the Pearson residuals.

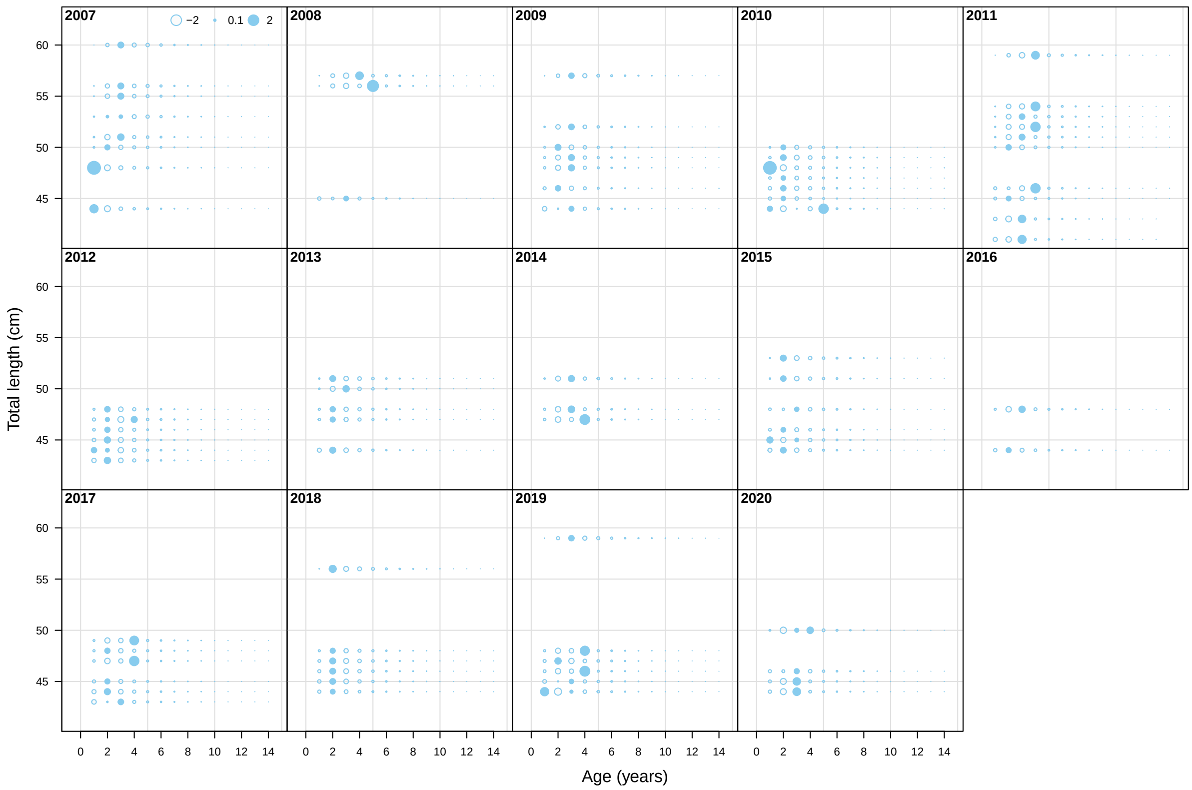

Figure B.11: Pearson residuals for age-at-length compositions of male dusky flathead for fleet *Rec_Line*. Circle size represents the magnitude of the Pearson residuals.

B.3 Other outputs

B.3.1 Phase plot

The purpose of this stock assessment was to report on the health of the stock and provide information to support fishery management. Results were assessed and classified against fishery target and limit reference points outlined in the harvest strategy and harvest strategy policy for Queensland.

Separate to this report and other Queensland government reporting, stock assessment results may be used and cited in separate 'Status of Australian Fish Stocks' (SAFS) reports (www.fish.gov.au). The SAFS classification system applies different inferences and reference points.

The SAFS classification system was designed by the Status of Australian Fish Stocks Reports Advisory Group. The classification system evaluates the status of a stock based on the fishing mortality (F) and biomass (B) relative to a 20% biological limit reference point. The status of a stock is classified as sustainable, depleting, depleted, recovering, negligible or undefined. The terms 'sustainable stock' and 'stock status' in the Status of Australian Fish Stocks Reports 2020 refer specifically to the biological status against the limit reference point.

Broader biological, economic or social considerations are not yet classified in SAFS, such as biomass reference points at maximum sustainable yield (B_{MSY}) or biomass at maximum economic yield (B_{MEY}). B_{MEY} generally ranges 35–40%, when harvest from surplus production (the annual amount by which the fish population would increase from growth and recruitment) is maximized (Punt et al. 2014). B_{MEY} generally ranges 50–60%, minimising potential loss in profit (Punt et al. 2014).

A phase plot assists in defining SAFS stock status relative to limit reference points for biomass and fishing mortality (FRDC 2021). The plot tracks the annual stock biomass ratio relative to the unfished level, and fishing mortality relative to the target reference point for the biomass limit (Figure B.12).

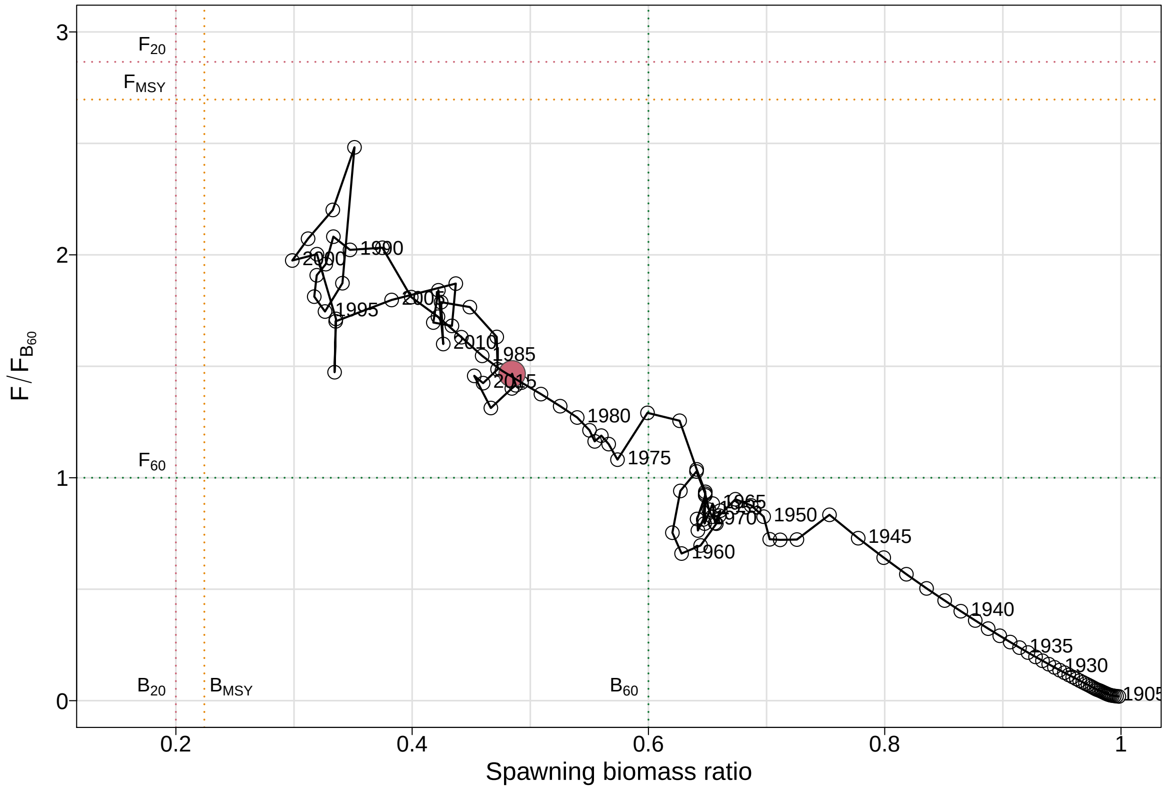

Figure B.12: Phase plot for dusky flathead based on the base case scenario.

The horizontal axis is the spawning biomass ratio of Queensland dusky flathead relative to unfished and the vertical axis is the fishing mortality relative to the fishing mortality which would produce the SAFS spawning biomass target of 60%. The red dotted vertical line is the limit reference point (20% relative spawning biomass) and the green and yellow dotted vertical lines are the potential target reference points (60% and 40% relative spawning biomass).

B.3.2 Stock-recruit curve

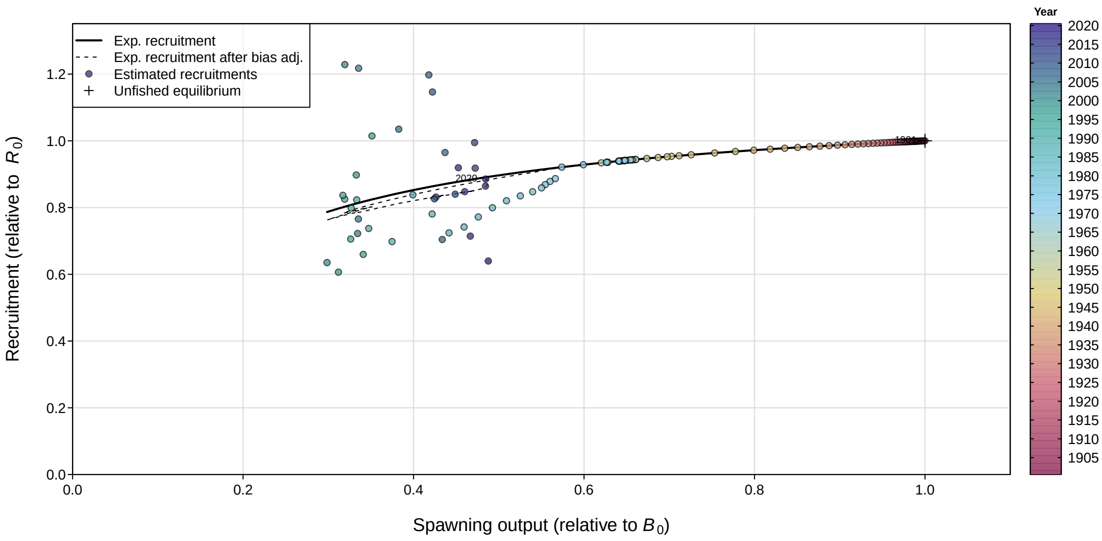

Figure B.13: Stock-recruit curve for dusky flathead based on the base case scenario.

B.3.3 Discard fraction

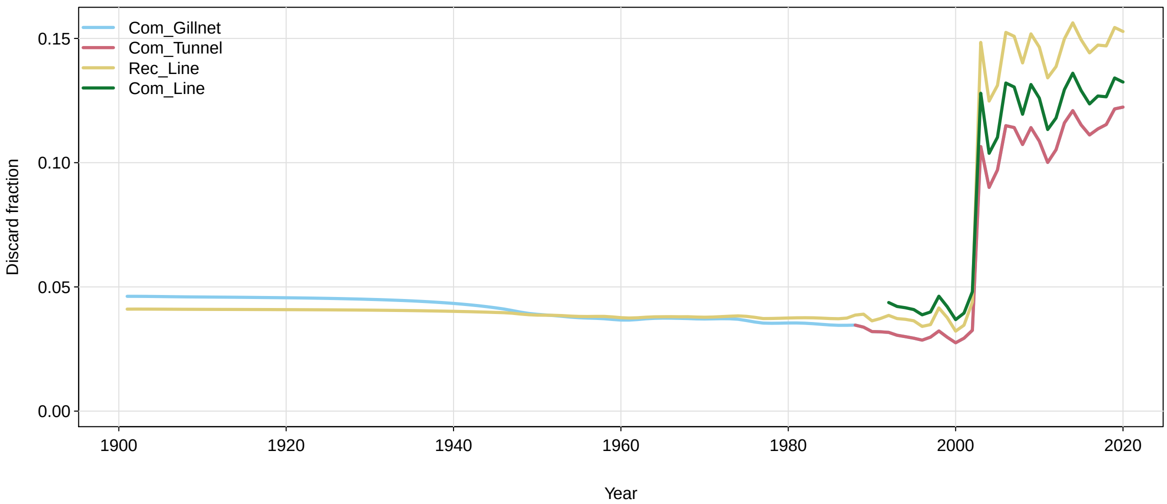

Figure B.14: Time series of estimated discard fraction by fleet based on the base case scenario.

B.3.4 Fishing mortality

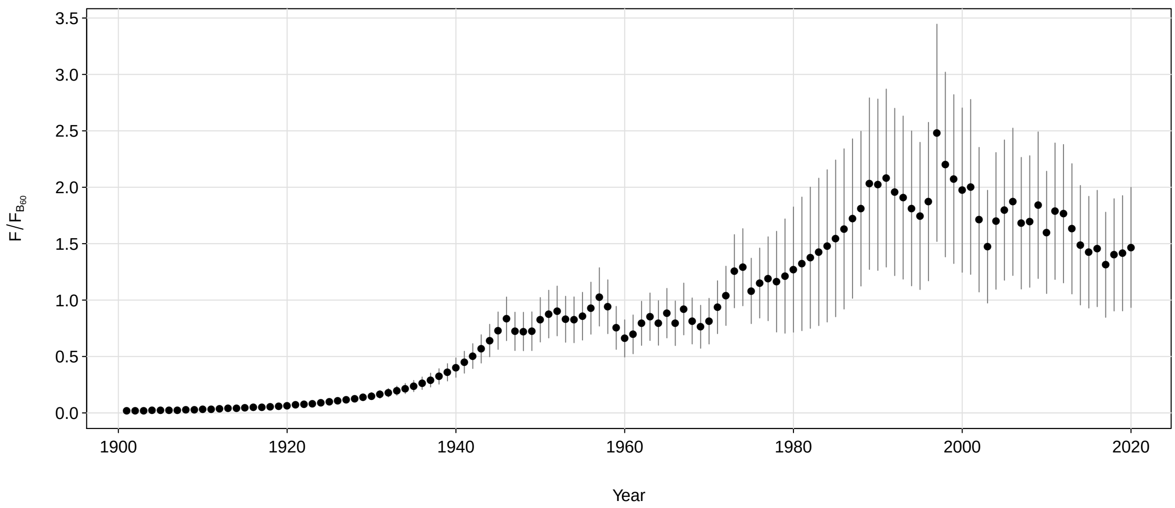

Figure B.15: Time series of fishing mortality ratio ($F/F_{B_{60}}$) from the base case scenario.

B.3.5 Sensitivity test: parameter estimates

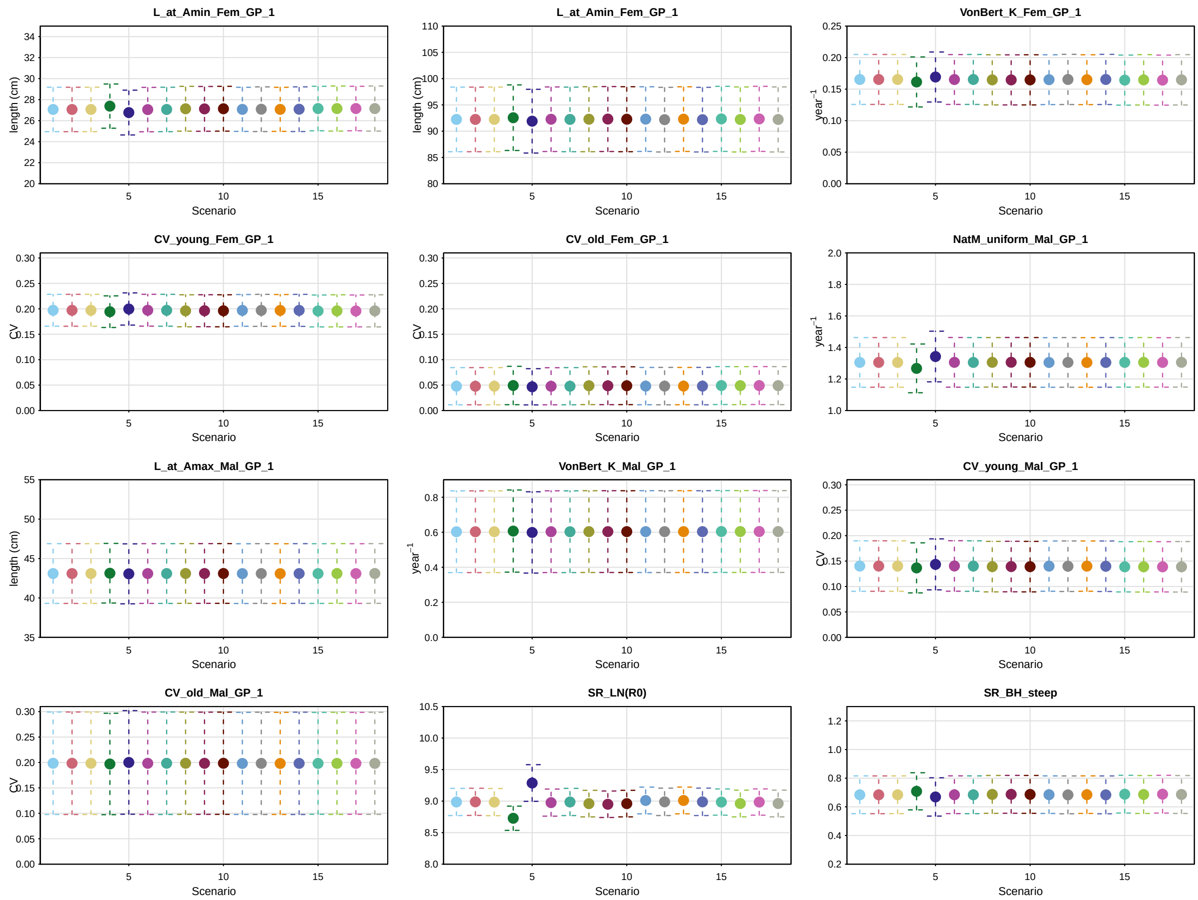

Figure B.16: Comparison of parameter estimates regarding the male and female growth curves and Beverton-Holt recruitment function amongst the 18 scenarios.

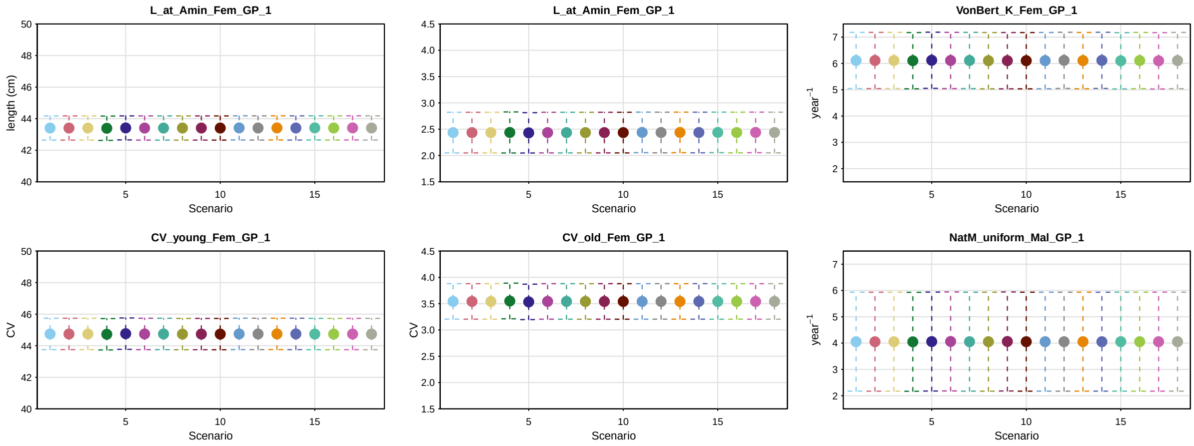

Figure B.17: Comparison of parameter estimates regarding selectivity amongst the 18 scenarios.