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TASMANIAN BANDED MORWONG FISHERY ASSESSMENT 2019/20

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This assessment of the Tasmanian Banded Morwong Fishery is produced by the Institute for Marine and Antarctic Studies (IMAS), using data downloaded from the Department of Primary Industries, Parks, Water and Environment (DPIPWE) Fisheries Integrated Licensing and Management System (FILMS) database. The information presented here includes all logbook returns that were entered prior to June 2019.

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Executive Summary

STOCK STATUS	SUSTAINABLE
Spawning stock biomass (SSB) of Banded Morwong in Tasmania was estimated to be at 41% of initial SSB. Modelling indicated that the current harvest strategy is sufficient to maintain SSB above the limit reference point of 30% of initial SSB within a 5-year period. The above estimates indicate that the biomass of Banded Morwong is unlikely to be depleted and that the current level of fishing mortality is unlikely to cause the stock to become recruitment impaired. We note that an ongoing review of the assessment model highlighted structural uncertainties and data limitations that will be addressed through research for increased confidence in SSB predictions in future assessments.	

This assessment of the Tasmanian Banded Morwong Fishery covers the period from 1st March 2019 to 28th February 2020. The assessment examines trends in biological characteristics, catch, effort and standardised catch per unit effort (CPUE), and forecasts biomass levels under current management arrangements.

In Tasmania, Banded Morwong are commercially harvested by a small-scale coastal gillnet fishery. Prior to 1990, the species had little commercial value. In the early 1990s, a targeted fishery for Banded Morwong started to supply domestic live fish markets. All holders of a Tasmanian Fishing Boat Licence were able to take Banded Morwong and, as a result, there was a dramatic increase in effort directed at the species, with reported catches peaking at 145 t in 1993/94. Catches fell dramatically in the late 1990s, with 34.6 t landed in 1999/2000.

A quota management system with a Total Allowable Catch (TAC) was introduced in late 2008 to regulate fishing mortality at key fishing grounds on the east coast. The TAC has undergone a staged reduction from 38.8 t in 2012/13 to 31 t in 2017/18. The TAC has remained at 31 t for the last three fishing seasons. In addition, a temporal closure is in place for 1st March to 30th April each year, encompassing the species' peak spawning period. The species is subject to keyhole size limits, which are currently set at a minimum legal size of 360 mm and a maximum legal size of 460 mm.

A sampling program commenced in 1995 to obtain biological information, in particular size and age compositions, to better inform Banded Morwong assessments. Truncations in length and age compositions have been observed over the course of this sampling program. In recent years, age compositions appear to have stabilised. However, old fish (> 20 years) are rarely observed. Relative proportions of fish < 8 years old have increased. Changes in mean length at age of individuals aged between 2–10 years, and fluctuations in length at maturity, have also been observed.

State-wide catches in 2019/20 were estimated at 35.6 t. The total catch in the TAC area was 30.7 t (6.1 t from the north-east coast (Area 1), 15.2 t from the east coast (Area 2) and 9.4 t from the south-east coast (Area 3)), which represented 99.0% of the 2019/20 TAC (i.e. a TAC under-catch of 1.0%). The total catch outside of the TAC area was 4.9 t. State-wide effort, in terms of both days fished and gear units (100 m net hour), stayed roughly equivalent to effort in 2018/19. Catch remained similar as well while standardised catch per unit effort (CPUE) in the TAC area increased by 4% relative to 2018/19.

An ongoing review of the assessment model highlighted several updates required to reflect our best current understanding of species growth and recruitment characteristics. It also highlighted multiple sensitivities in spawning stock biomass (SSB) predictions that can be addressed through targeted research for more robust assessments in the future. Based on the updated model, SSB was estimated at 41% of initial SSB, with the current harvest strategy (i.e. 26 kg / quota unit and a TAC of 31 t) thus maintaining SSB above the limit reference point of 30% of initial SSB. The biomass of Banded Morwong in Tasmanian waters is unlikely to be depleted and the current level of fishing mortality is unlikely to cause the stock to become recruitment impaired. Banded Morwong in Tasmanian waters is thus classified as a sustainable stock.

Acknowledgements

This assessment was funded by the Department of Primary Industries, Parks, Water and Environment (DPIPWE) and the Institute for Marine and Antarctic Studies (IMAS), University of Tasmania, through the Sustainable Marine Research Collaboration Agreement (SMRCA). Graeme Ewing (IMAS) provided the biological sampling data.

1. Introduction

Species biology

Banded Morwong (*Cheilodactylus spectabilis*; Figure 1) is a large, sedentary fish that inhabits temperate reefs around south-eastern Australia and New Zealand (Gomon et al 1994). In Australia, the species distribution extends from Sydney, through Victorian and Tasmanian waters, to eastern South Australia. The species has occasionally been observed in Western Australia. Banded Morwong are long-lived, and can reach ages of at least 97 years (Ewing et al. 2007). While longevity is similar among sexes, the species displays strong sexual dimorphism in growth, with males growing substantially faster and reaching larger maximum sizes than females (Ziegler et al. 2007a).

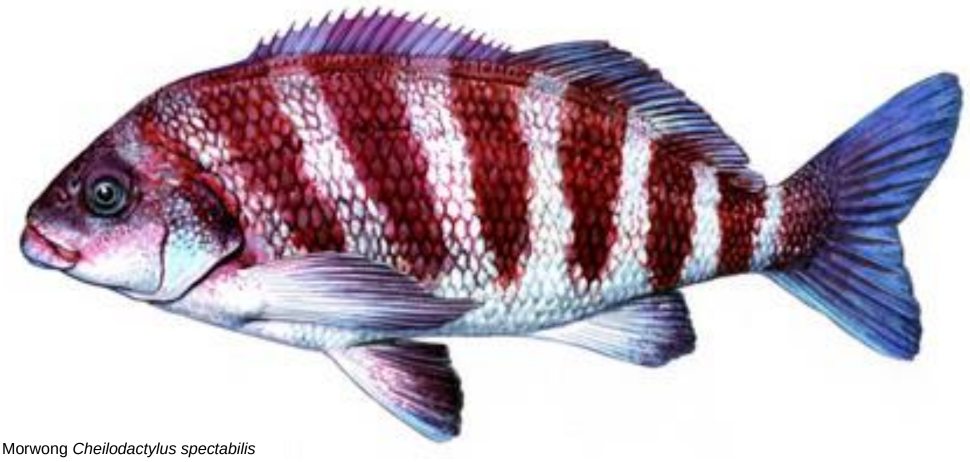

Figure 1. Banded Morwong, *Cheilodactylus spectabilis*.

The stock structure of Banded Morwong in Australian waters is presently undefined, however observations of a long pelagic larval stage (around 6 months; Wolf 1998) suggests that single genetic stocks may occur over large areas. After settlement, fish are relatively sedentary, with tagging studies indicating little exchange among reefs (Murphy and Lyle 1999) (see Table 1 for a summary of species biology).

Commercial fishery

In Tasmania, Banded Morwong are commercially harvested by a small-scale coastal gillnet fishery. Prior to 1990, the species had little commercial value apart from use as bait by rock lobster fishers (Ziegler et al. 2007a). In the early 1990s a targeted fishery for Banded Morwong started to supply domestic live fish markets, primarily in Sydney and Melbourne. All holders of a Tasmanian Fishing Boat Licence were able to take this species and, as a result, there was a dramatic increase in effort directed at the species, with reported catches peaking at 145 t in 1993/94. Catches fell dramatically in the late 1990s, with 34.6 t landed in 1999/00.

Table 1. Biology of Banded Morwong, *Cheilodactylus spectabilis*.

<table>
<tr><th>Parameters</th><th>Estimates</th><th>Reference</th></tr>
<tr><td>Habitat</td><td>• Rocky reefs down to 50 m depth. Females and juveniles inhabit the shallow section of the reef while males dominate in the deeper section of the reef.</td><td>McCormick (1989a, b)</td></tr>
<tr><td>Distribution</td><td>• South Sydney (New South Wales) through Victoria and Tasmania to eastern South Australia, also in New Zealand.</td><td>Gomon et al. (1994)</td></tr>
<tr><td>Diet</td><td>• Invertebrates, algae, crabs.</td><td>McCormick (1998)</td></tr>
<tr><td>Movement and stock structure</td><td>• Limited movement of juveniles and adults, generally restricted to within 5 km of the release site.
• No information on the stock structure.</td><td>Murphy and Lyle (1999)
Ziegler et al. (2006)
Buxton et al. (2010)</td></tr>
<tr><td>Natural mortality</td><td>• Low. Estimated at M = 0.05.</td><td>Murphy and Lyle (1999)</td></tr>
<tr><td>Maximum age</td><td>• Females: 94 years
• Males: 97 years</td><td>Ewing et al. (2007)</td></tr>
<tr><td>Growth</td><td>• Males grow to larger sizes than females
• Growth described by the Schnute and Richards (1990 growth function:
$L = L_\infty(1+\alpha e^{(-at^c)})^{-\frac{1}{b}}$
where L is the length (mm), t is the age (years), L_∞ is the average maximum length for the species and α, a, b and c are (year-specific) constants.

• Parameters estimates (for 2007) are:
<table>
<tr><th>Sex</th><th>L_∞</th><th>a</th><th>b</th><th>c</th><th>α</th></tr>
<tr><td>Female</td><td>442</td><td>18.8</td><td>3.3e⁻⁷</td><td>0.05</td><td>51.4</td></tr>
<tr><td>Males</td><td>516</td><td>2.3</td><td>0.0088</td><td>0.33</td><td>0.1</td></tr>
</table>
• Length-weight relationship for 2007 was estimated at $W = 3.563E^{-5}L^{2.875}$ for females and $W = 3.729E^{-5}L^{2.852}$ for males, where W is weight (g) and L is the fork length (cm).</td><td>Schnute and Richards (1990)

Ziegler et al. (2007a)</td></tr>
<tr><td>Maturity</td><td>• Size-at-50% maturity estimated at 320 mm for females (~2.5 years of age).</td><td>Ziegler et al. (2007a)</td></tr>
<tr><td>Spawning</td><td>• Spawning occurs between mid-February to late May.
• Species is a serial spawner.</td><td>Murphy and Lyle (1999)</td></tr>
<tr><td>Early life history</td><td>• Eggs and larvae are concentrated on the surface.
• Banded Morwong has a pelagic larval stage that is distributed offshore, as suggested by the large amounts of larvae caught off the shelf break of eastern Tasmania.
• Juveniles appear in shallow water on rocky reefs and tide-pools between September and December, after a pelagic phase of 4-6 months.</td><td>B. Bruce, pers. comm.
Wolf (1998)</td></tr>
<tr><td>Gillnet post release survival</td><td>• High: 97% irrespective of gillnet soak duration</td><td>Lyle et al. (2014a)</td></tr>
</table>

Banded Morwong are currently targeted almost exclusively for the live fish market with large mesh gillnets, primarily of 130–140 mm stretched mesh. The fishery is centred mainly along the east coast of Tasmania, between St. Helens in the north and the Tasman Peninsula in the south, with the largest catches traditionally coming from around Bicheno. Smaller catches have been taken along the south coast and around Flinders Island. While Banded Morwong inhabit depths down to at least 50 m (May and Maxwell 1986), fishing operations are conducted over inshore reefs, with gear set primarily in the 5–20 m depth range, in order to minimise effects of barotrauma and maximise survival for the live fish trade.

The Banded Morwong Fishery in Tasmania is managed using a combination of input and output controls (Table 2). The fishery has undergone numerous management changes over time (summarised in Table 3). The commercial fishery in Tasmania is currently managed as two areas: an area in which individual transferable quotas are used to limit a total allowable catch (TAC; the TAC area), and an area in which it does not (the non-TAC area) (Figure 2). In order to fish for Banded Morwong within the TAC area a person must hold a fishing licence (Banded Morwong) which has uncaught quota units authorised on it. There is no quota management outside the TAC area and any holders of a fishing licence (Banded Morwong) can fish in this region with or without quota authorised to their licence. A temporal closure is in place for 1st March to 30th April in each year, encompassing the species' peak spawning period. The species is subject to keyhole size limits, which are currently set at a minimum legal size of 360 mm fork length (FL) and a maximum legal size of 460 mm FL. A bag limit of two fish and a possession limit of four fish is in place for recreational fishers. For management and assessment purposes, a limit reference point has been implemented whereby a spawning stock biomass (SSB) of 30% that of initial spawning stock biomass (SSB0) must be exceeded in five years (2024) with a 90% probability.

Table 2. Summary of management controls for Banded Morwong in Tasmanian waters.

FISHING METHODS	Mainly gillnet
MANAGEMENT METHODS	**Input control:** • Gear licence (Scalefish fishing licence) • Species licence (Banded Morwong licence) • Temporal closure (March-April) **Output control:** • Possession limit of 4 and bag limit of 2 individuals for recreational fishers • Minimum and maximum size (360–460 mm fork length) • TAC of 31.0 t for the 2019/20 quota year
MAIN MARKET	Interstate

The quota management system with a TAC was introduced in late 2008. Up to and including the 2015/16 quota year a given number of fish were allocated to each quota unit and the tonnage associated with the TAC was inferred based on an assumed average weight of 1.3 kg per fish. From 2016/17 onwards quota has been set in weight. Until 2017/18, the TAC has undergone a staged reduction since 2012/13 (Table 4).

Post-release survival of Banded Morwong under current maximum permitted gillnet soak durations is very high (Lyle et al. 2014a). Gillnetting was considered a medium risk activity to Banded Morwong populations in the Ecological Risk Assessment (ERA) of Bell et al. (2016), with the authors recognising that current management arrangements (namely the TAC and individual catch quotas) have the objective of gradually rebuilding biomass.

Table 3. Management changes in the Tasmanian Banded Morwong Fishery over time (from DPIPWE 2017).

Date	Management changes
Pre 1987	Unrestricted access to Tasmanian Fishing Boat Licences (TFBL); unlimited access to scalefish and shark using all gear types; no restrictions on the amount of gillnet net that could be used; and unrestricted access to all other gear types (i.e. beach seine, purse seine, dipnet, squid jig, fish traps, small mesh gillnets, mullet nets, longlines, droplines and spears).
1987	Tasmanian Fishing Boat Licences were capped at 850.
1990	Restricted gillnetting in Shark Nursery Areas (SNAs). Commercial access to SNAs is limited to holders of non-transferable endorsements (38 endorsees).
31 May 1994	Ministerial warning issued explaining that any catches of Banded Morwong and wrasse taken after that date would not be used towards catch history, should previous catches be used to determine future access to the live fishery.
1994	Minimum size limit of 330 mm fork length and maximum size limit of 430 mm fork length introduced for Banded Morwong.
1995	An annual closed season in March and April was introduced to coincide with the peak spawning period of Banded Morwong.
1996	An interim non-transferable 'live fish' endorsement to take Banded Morwong and wrasse was introduced. Eligibility was based on a demonstrated history of taking one or both species (at least 50 kg between 1 January 1993 to 31 May 1994), and around 90 endorsements were issued.
November 1998	Introduction of a species-specific licence for the Banded Morwong Fishery (live or dead) in State waters. There were 29 licences issued. The minimum size limit was increased to 360 mm and the maximum size limit increased to 460 mm fork length.
November 2001	A daily bag limit of two fish was introduced for recreational fishers.
November 2004	The recreational bag limit of two fish was changed to a personal possession limit of two fish.
October 2008	Introduction of a quota management system for east coast waters from Low Head to Whale Head (excluding the Furneaux Group). A total of 1,169 Banded Morwong quota units were issued.
July 2009	An additional 24 Banded Morwong quota units were issued following a review of a quota allocation, bringing the total number of units to 1,193.
November 2009	Introduction of a 6-hour soak time for commercial gillnets
March 2011	Introduction of the Commercial Banded Morwong Quota Docket for all Banded Morwong fishers.
November 2015	New gillnet free areas for the protection of seabirds such as little penguins (applies to both commercial and recreational gillnets). Bag and possession limits were revised for the recreational fishery – bag limit of two individuals and possession limit of four individuals. New quota management arrangements for the Banded Morwong Fishery introduced as it moved from a number- to a weight-based quota management system for the 2016/17 quota year.
May 2017	New Commercial Banded Morwong Quota Docket and new Commercial Catch, Effort and Disposal Logbook for all Banded Morwong fishers.

Table 4. Total Allowable Catch (TAC) in the Tasmanian Banded Morwong Fishery since 2012/13.

Quota year	TAC (in t)	TAC (in no. fish)	No. of Fish/Quota Unit	kg / Quota Unit
2012/13	38.8	29,825	25	-
2013/14	37.2	28,632	24	-
2014/15	35.7	27,439	23	-
2015/16	35.7	27,439	23	-
2016/17	32.2	N/A	-	27
2017/18	31.0	N/A	-	26
2018/19	31.0	N/A	-	26
2019/20	31.0	N/A	-	26

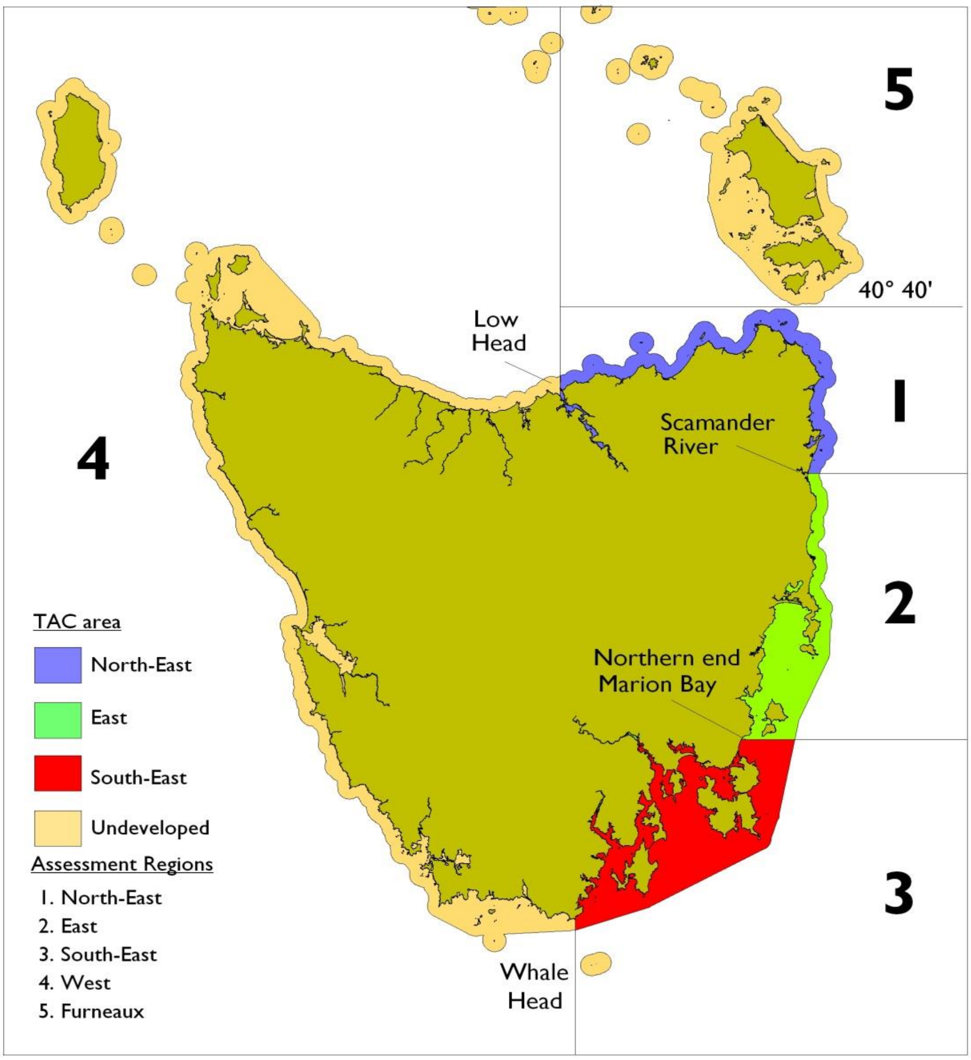

Figure 2. Designated TAC areas and assessment regions for Banded Morwong (Areas 1, 2 and 3) from Low Head on the north coast to Whale Head in the south. Assessment regions 4 and 5 are currently undeveloped.

Recreational fishery

Banded Morwong are a relatively minor component of the recreational fishery in Tasmania. The most recent survey in 2017/18 estimated the recreational landings of Banded Morwong at 2 tonnes (1,522 fish), making up slightly more than 5% of the total catch (commercial + recreational) during that season (Lyle et al. 2019). A total of 298 individuals were estimated as retained in the 2012/13 recreational fishing survey of Lyle et al. (2014b), equating to a total harvest of 0.5 tonnes, or around 1% of the total Banded Morwong landings for that year. An estimated 1,082 Banded Morwong were retained in 2010 (Lyle and Tracey 2012), representing almost 4% of total Banded Morwong landings in that year. No species-specific catch estimates for Banded Morwong were available in the two previous recreational fishing survey reports (Lyle 2005, Lyle et al. 2009).

2. Methods

Data sources

Biological characteristics

A sampling program commenced in 1995 to obtain biological information, in particular size and age composition, to inform assessments for Banded Morwong. Sampling was conducted annually in 1996, 1997 and between 2001–2005, then every second year from 2007 onwards (i.e. 2007, 2009, 2011, 2013, 2015, 2017, 2019). In this sampling program, fish are collected during the spawning closure by commercial fishers working under permit and contracted to the Institute for Marine and Antarctic Studies. Sampling sites and general fishing practices (including the use of standard commercial 'Banded Morwong nets') have been standardised as much as possible. Approximately 400 fish were collected in each sampling year. For each fish collected, FL (to the nearest 1 mm) and weight (to the nearest 1 g) were measured and the pair of sagittal otoliths (hereafter otoliths) were removed, cleaned, and stored dry in plastic vials. Gonads were dissected, weighed (to the nearest 0.1 g), sexed and staged macroscopically according to West (1990). As sampling was conducted in 2019, the results of the sampling program up to 2019 are included here.

Commercial fishery data

Commercial catch and effort data are collected through compulsory Tasmanian Commercial Catch, Effort and Disposal Returns. The catch and effort logbooks have been amended several times (1995, 1999, 2007, 2010 and 2013) in an effort to report at finer spatial scales and provide greater operational detail. While the offshore fishing blocks are still at the 30 nm (1/2 degree) spatial resolution, the logbooks introduced in 2010 have redefined the scale of the coastal blocks (Figure 3).

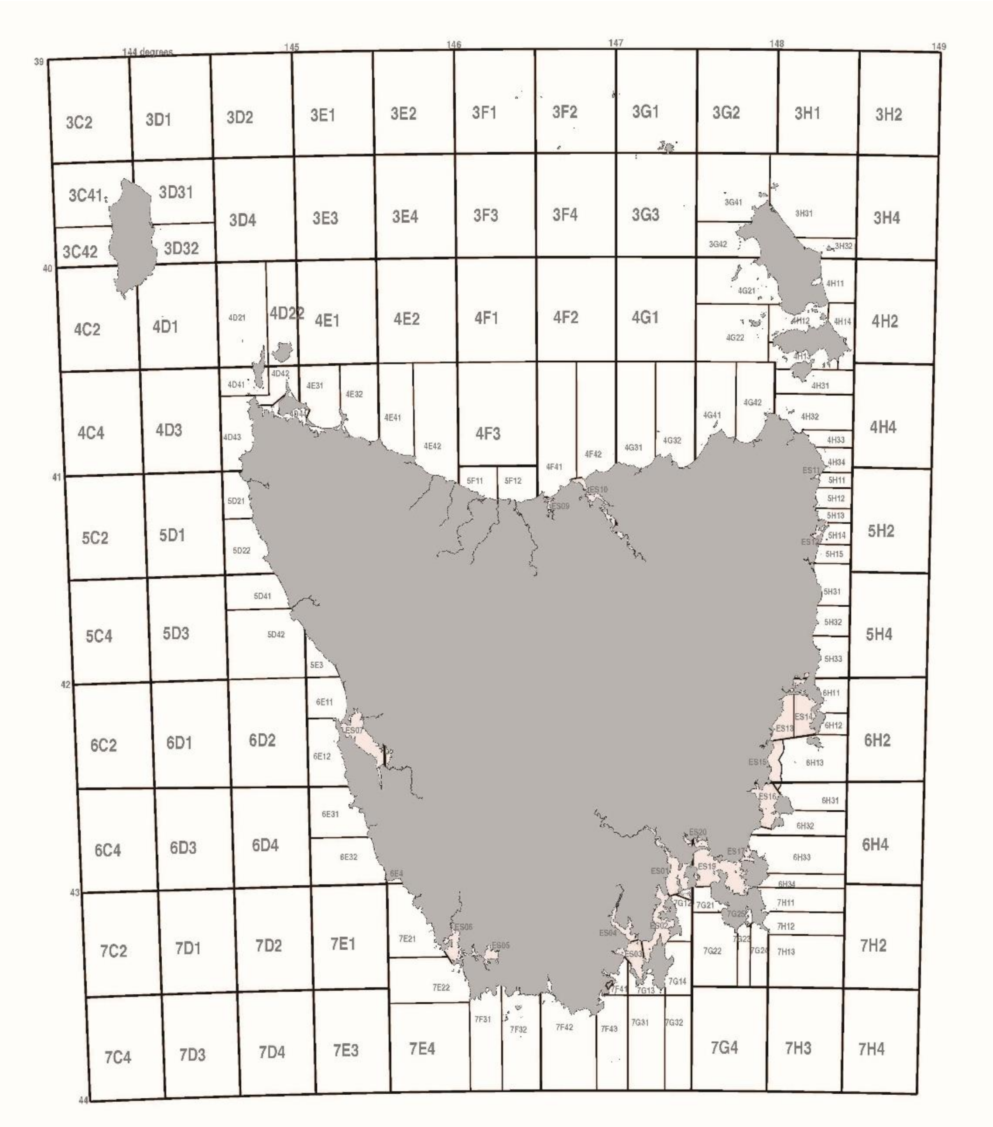

Figure 3. Map of Tasmania displaying the fishing blocks.

Data analysis

Biological characteristics

Length and age frequency plots were developed for each sampling year. Sex and sampling-year specific patterns in growth of Banded Morwong were modelled using a modified version of the Schnute and Richards (1990) growth function fitted by nonlinear least-squares regression of FL on age. A sample of six recently settled juveniles collected from Bicheno in 1996, estimated to be around 6 months old, were used to anchor the growth functions for all years and sexes.

Generalised linear mixed-effect models (GLMMs) were used to model the length at maturity of female Banded Morwong. Maturity state (immature or mature) was treated as a binomial response variable with logit link function and modelled as a function of FL. Area (i.e. TAC Areas 1, 2 and 3; Figure 2) was modelled as a random effect term in all models to eliminate potential bias or pseudoreplication resulting from the non-independence of samples collected within the same area. Due to low numbers of immature females in the samples, sampling years were combined as follows: 1996–1997, 2001, 2002–2003, 2004–2005, 2011 & 2013, and 2015 & 2017 & 2019. Samples collected in 2007 and 2009 were excluded due to small numbers of immature females.

Catch and Effort

For the purposes of this assessment, catch, effort and catch per unit effort (CPUE) analyses are restricted to commercial data provided for the period March 1995 to February 2020. The assessment year for Banded Morwong is based on the quota year (1st March to the last day of February the following year) rather than the financial year (July to June) as for other scalefish species. The current Banded Morwong assessment includes data up to and including the 2019/20 quota year (which ended 28 February 2020).

Under the quota management system, commercial catches prior to 2016/17 were reported as numbers of fish rather than weight. These numbers were converted to weight based on a conversion ratio of 1.3 kg per fish. In addition, and particularly prior to the introduction of the quota management system, fish were landed in a variety of forms, including gilled and gutted, trunked, and filleted. In these instances, the equivalent whole weight was estimated by applying a standard conversion factor[1].

Two measures of effort have been examined in this and previous assessments: (i) days fished (i.e. number of days on which a catch of Banded Morwong was reported); and (ii) quantities of gear/time fished using the method (effort gear units). For gillnets (the main fishing method for Banded Morwong), effort gear units are measured in 100 m net hours.

Catch returns for which effort information was incomplete or unrealistically high or low (either due to data entry error or misinterpretation of information requirements by fishers) were flagged and excluded when calculating effort levels based on gear units or catch rates based on catch per unit of gear. No fishing records for 2019/20 needed to be excluded in this manner.

Catch per unit effort

In the Banded Morwong Fishery, the amount of gear set and the fishing duration is recorded by fishers, however these data have not been reported consistently over time and among fishers. Accordingly, for the purposes of this assessment, CPUE is calculated using days fished as a measure of effort. Previous work has shown that this is highly correlated with CPUE derived from using gear and soak time where that data is reliably available (IMAS unpublished data).

Following Ziegler et al. (2007b), CPUE for Banded Morwong was standardised in order to remove the influence of confounding effects such as area, depth, season and operator on relative trends in abundance. CPUE was standardised using general linear models (GLMs). Standardisation of CPUE was conducted for an annual time scale, and at four spatial scales (whole of TAC area, and individual north-east, east and south-east areas within the TAC area). Data were restricted to skippers who had reported catches for at least two years.

The GLMs were fitted to different combinations of factors for which information were available, namely skipper, vessel, fishing block, depth zone fished (0–10 m, 11–20 m, 21–30 m, > 30 m), bimonthly period and reported seal interactions (presence or absence). A bimonthly period rather than month was included as a temporal factor to ensure there were sufficient records in each period to give reliable results. Due to the annual spawning season closure in March and April, five bimonthly periods were available for each year. Interaction terms between some of the factors were also considered, but these were limited to combinations for which sensible interpretations could be ascribed.

Standardised CPUE were fitted to natural log-transformed (Ln) catch rate data (assuming a lognormal distribution), using a normal distribution family with an identity link. All GLMs were fitted using a forward approach by manual stepwise addition of each factor starting with the time-step. The optimal model was chosen by minimisation of the Akaike's Information Criterion (AIC;

[1] Conversion factors to whole weights are 2.50 for fillet; 1.50 for trunk; and 1.18 for gilled and gutted.

Burnham and Anderson 1998). Adding new data from 2019/20 resulted in the same model selection used in the 2018/19 assessment (Table 5).

Table 5. General Linear Models (GLMs) used to standardise catch per unit effort of Banded Morwong across the whole TAC area in the 2019/20 assessment, and in Area 1 (north-east coast), Area 2 (east coast) and Area 3 (south-east coast) as defined in Figure 2. Ln = natural log.

TAC Area	Model
Whole TAC area	Ln CPUE = Lnweight ~ BMWyear + Vessel + seals+ bimonth+ Block + ClientID + depth + Vessel:Block
North-East	Ln CPUE = Lnweight ~ BMWyear + Vessel + bimonth + seals + Block + depth + bimonth:Vessel
East	Ln CPUE = Lnweight ~ BMWyear + Vessel + bimonth + seals + Block + ClientID + depth + bimonth:Vessel
South-East	Ln CPUE = Lnweight ~ BMWyear + Vessel + bimonth + Block + ClientID + seals + Vessel:bimonth

Stock modelling

Model structure

The 2019/20 assessment was conducted using the Banded Morwong population model implemented in CASAL v 2.30 (Bull et al. 2012) (See Appendix A for model specifications). The CASAL framework is widely used for fisheries assessments, including a number of New Zealand's fish stocks. The implementation of the Banded Morwong model in CASAL is mathematically equivalent to the previous model used to assess Banded Morwong stocks developed by Ziegler et al. (2007b). The model for the 2019/20 assessment was updated with catch and effort information along with several methodological changes (Table 6). As previous assessments of Banded Morwong have stressed that a greater emphasis should be placed on the whole of fishery model for TAC setting purposes, models were run using data for the entire TAC area. Because the distribution of Banded Morwong extends beyond the depth of the fishery, there is potential for an unfished component of each 'stock' to be located in a depth refuge. The model accounted for this by specifying a fished population inshore and an unfished population offshore. The spatial configuration, key dynamical processes, and migration rate assumptions are illustrated in Figure 4.

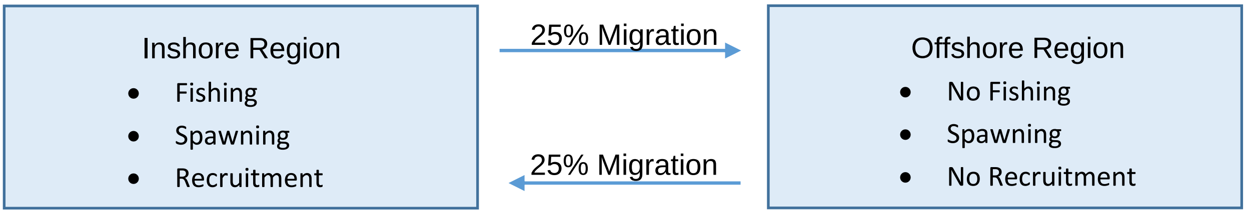

Figure 4. Diagram of spatial configuration of the two-area model implemented in CASAL. The Offshore Region represents a depth refuge where fish avoid exploitation. Migration rates are assumed to be 25% annually from Inshore to Offshore and vice versa. Spawners are assumed to be present in both regions and recruitment only occurs Inshore.

The model also separates processes into two time steps to reflect a 10-month fishing period and a 2-month spawning period during which the fishery is closed.

Model inputs

Biological components: Sex-specific lengths-at-ages 1–16 were modelled using the Schnute and Richards (1990) growth function across all fishery areas during the years when biological sampling was conducted (1990–1998 (='1990' in model), 1999–2001 (='1999'), 2002–2003 (='2002'), 2004–2006 (='2004'), 2007, 2009, 2011, 2013, 2015, 2017 and 2019). Early sampling years were aggregated based on similar growth trends and to ensure a large enough sample size following Ziegler et al. (2007b). Interpolated growth was assumed for non-biological sampling years within the time series and extrapolated from the most recent sampling year for projected years. Sex-specific patterns in age-at-maturity were modelled using a logistic function. Natural mortality was assumed to be constant across ages and time at $M = 0.05$.

Consistent with preceding assessments, the fishing selectivity-at-length was assumed to follow a knife-edge curve, selecting fish of both sexes between lengths 360 and 460mm with 100% probability. This selectivity function is a rough approximation to the true selectivity, reflecting the keyhole size limit currently in place for the commercial fishery. The survey selectivity-at-length was specified to follow a dome-shaped curve that reflects every fish retained using a net identical to the commercial net (Murphy and Lyle, 1999). The model converts these selectivity-at-length specifications to sex-specific selectivity-at-age using the length-at-age data.

Fishery (harvest) components: Annual total catches within the TAC area for the period 1990/91–2019/20 and standardised CPUE (described above) for the period 1995/96–2019/20 were used in the model run. Catchability was estimated in the model from the relationship between observed CPUE and exploitable biomass.

Recruitment: Recruitment was modelled to occur at the start of each year and was assumed to be equal between males and females and occur uniformly along the entire coastline of the modelled area. All recruitment in the model was assumed to occur to inshore populations, consistent with observations of juvenile Banded Morwong in inshore shallow waters and a gradual outward migration with increasing size (Leum and Choat 1980; McCormick 1989b). Recruitment year class strength (YCS) was estimated in the model from the survey catch-at-age data. The mean and variability from YCS estimates during the period 1986-2015 were resampled by the model to project SSB into the future.

Model outputs

The model was used to estimate SSB trajectories within the TAC area at present and into the future under the current management scenario (i.e. a total allowable catch of 31 t at a unit value of 26 kg / quota unit). Model fits to the CPUE (Figure 12) and age composition (Figure 13) indices were evaluated by visual inspection and examination of residuals

Table 6. Changes made to the Banded Morwong assessment model data inputs since 2018/19.

Year	Type	Alteration
2019/20	Data inputs	Inclusion of catch and standardised CPUE data for 2019/20
		Inclusion of sex-specific growth biological data for 2019
	Model parameters	Recalculate sex-specific growth from previous sampling years
		Improve the incorporation of juvenile data for calculating growth
		Update the calculation of age composition data for 2019
		Recalculate age composition data for all previous sampling years
		Adjust the recruitment period used for projections back to the pre-2017/18 assessment period of 1986-2015
		Explicitly model SSB as a function of mature females
		Revert the assumed proportion of mortality during data collection back to the pre-2017/18 level of 50%

Assessment of stock status

Stock status definitions

In order to assess the Banded Morwong Fishery in a manner consistent with the national approach (and other jurisdictions) we have adopted the national stock status categories used in the 2018 Status of Australian Fish Stocks (SAFS) reporting (Table 7). These categories define the assessed state of the stock in terms of recruitment impairment, which is often treated as a limit reference point. Depleted stocks are not collapsed but they do have reduced productivity. The scheme used here does not attempt to assess the fishery against any target outcomes.

Performance indicators and reference points

The determination of stock status is based on the consideration of model outputs and the commercial catch and effort data, which are assessed by calculating fishery performance indicators and comparing them with the limit reference point (SSB of 30% of initial SSB must be exceeded in five years (i.e. 2024 for the current assessment) with a 90% probability).

Other measures are also taken into consideration in the determination of stock status such as changes in biological characteristics of the stock, indicators of stock stress and significant external factors related to fishing activity.

Table 7. The stock status classifications that were adopted for this assessment.

Stock status	Description	Potential implications for management of the stock
SUSTAINABLE	Biomass (or proxy) is at a level sufficient to ensure that, on average, future levels of recruitment are adequate (recruitment is not impaired) and for which fishing mortality (or proxy) is adequately controlled to avoid the stock becoming recruitment impaired.	Appropriate management is in place.
RECOVERING ↑	Biomass (or proxy) is depleted and recruitment is impaired, but management measures are in place to promote stock recovery, and recovery is occurring.	Appropriate management is in place, and there is evidence that the biomass is recovering.
DEPLETING ↓	Biomass (or proxy) is not yet depleted and recruitment is not yet impaired, but fishing mortality (or proxy) is too high (overfishing is occurring) and moving the stock in the direction of becoming recruitment impaired.	Management is needed to reduce fishing mortality and ensure that the biomass does not become depleted.
DEPLETED	Biomass (or proxy) has been reduced through catch and/or non-fishing effects, such that recruitment is impaired. Current management is not adequate to recover the stock, or adequate management measures have been put in place but have not yet resulted in measurable improvements.	Management is needed to recover this stock; if adequate management measures are already in place, more time may be required for them to take effect.
UNDEFINED	Not enough information exists to determine stock status.	Data required to assess stock status are needed.

3. Results

Biological characteristics

Length frequency composition

Significant changes in the length frequency composition between the late 1990s and the early 2000s raised concerns about the Banded Morwong stock (Figure 5 and Ziegler et al. 2007a). Length frequency composition appears to have stabilised since, with an average length of Banded Morwong around 36–40 cm and fewer large, legal sized fish being present in landings. However, there were more large fish outside the upper size limit in 2019 than the previous sampling year (Figure 5).

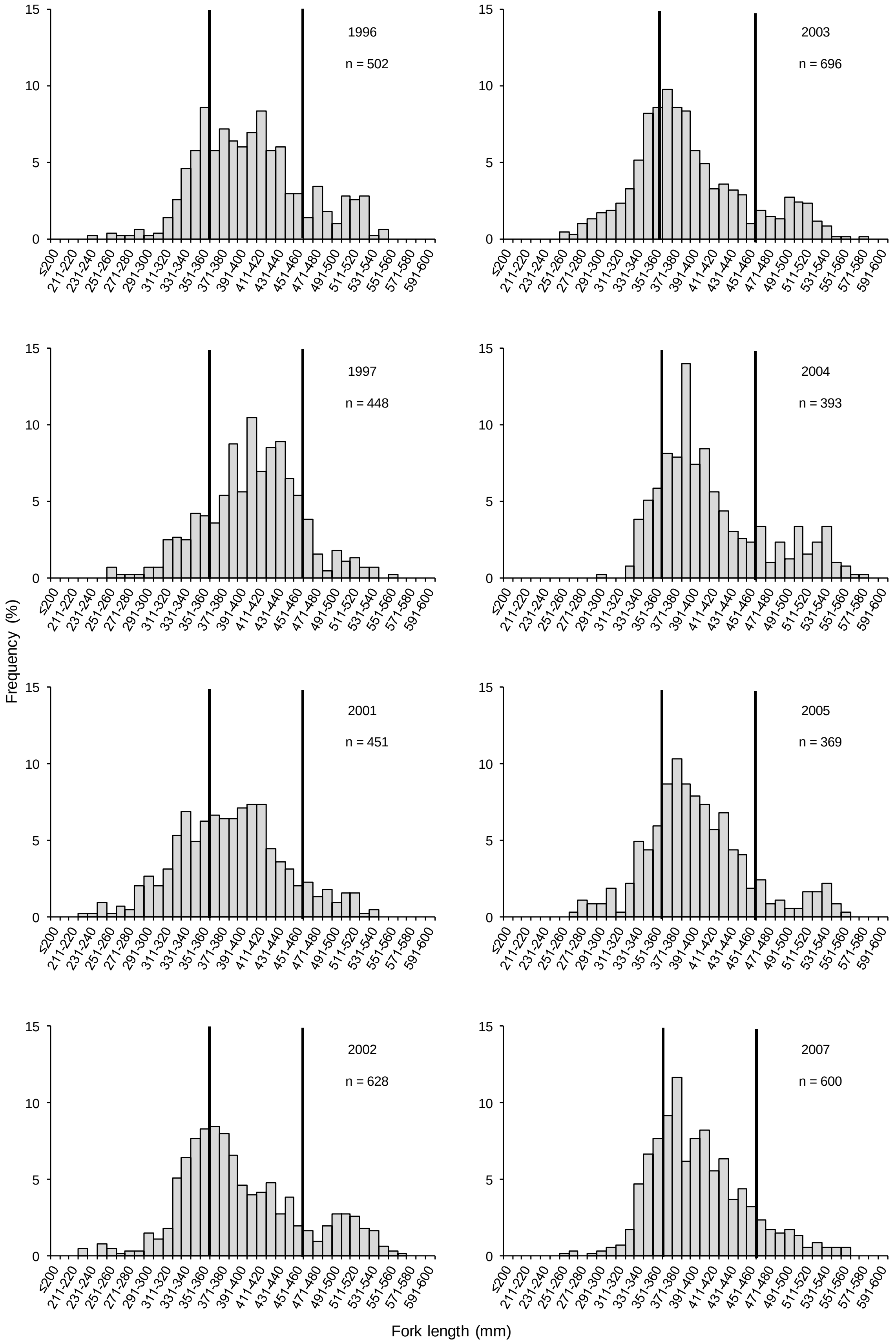

Figure 5. Length composition of sampled Banded Morwong by year. 'n' is the sample size. The solid lines represent minimum and maximum size limits. Year is the year in which sampling was conducted.

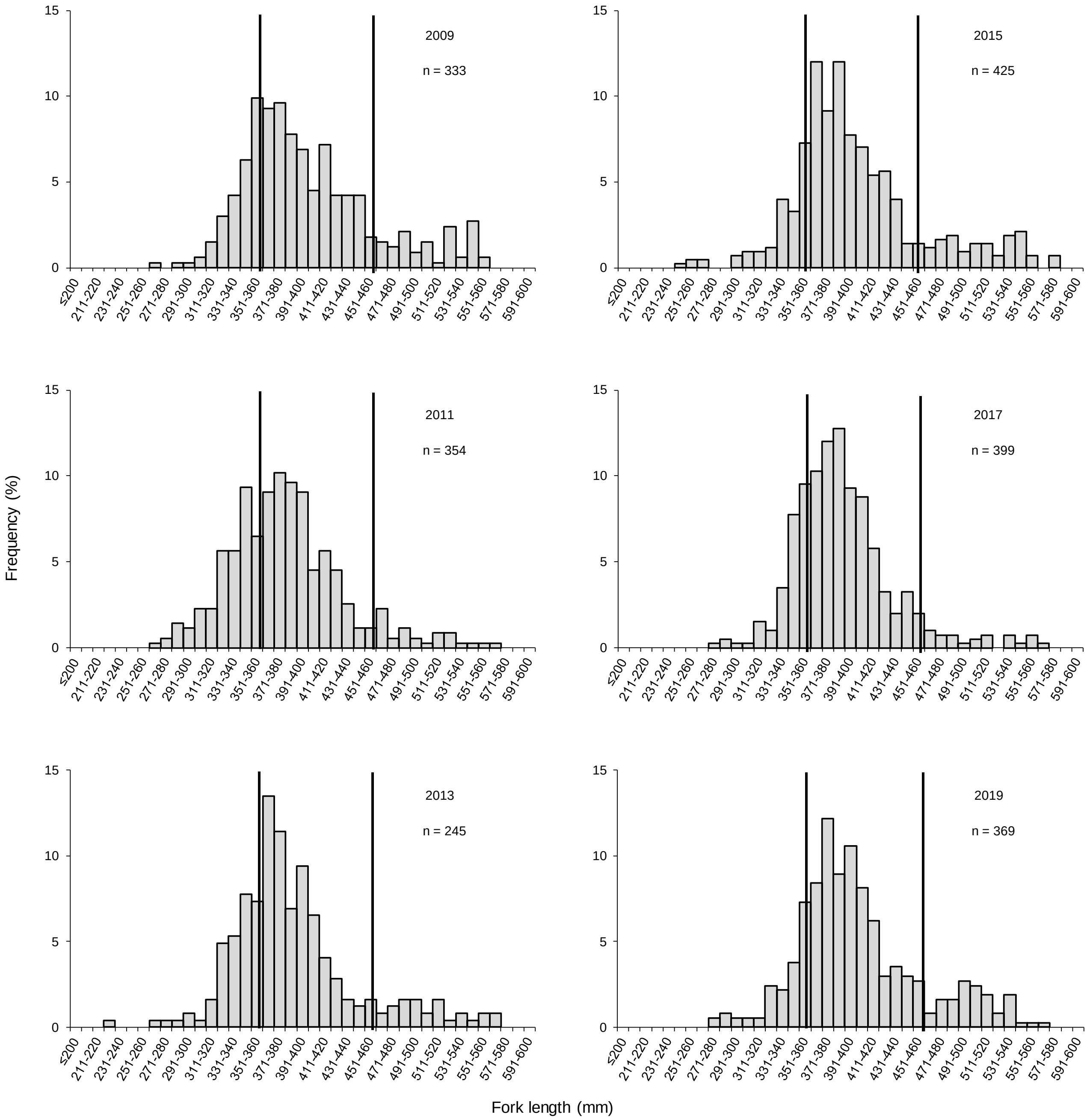

Figure 5. - continued.

Age frequency composition

Age frequency composition also showed signs of change from the late 1990s (Figure 6 and Ziegler et al. 2007a). The age structure is now dominated by young fish around 4–5 years old (Figure 6), with very few individuals older than 15 years old in current population samples compared to the late 1990s. In 2019, several fish older than 80 years were observed for the first time since 2007.

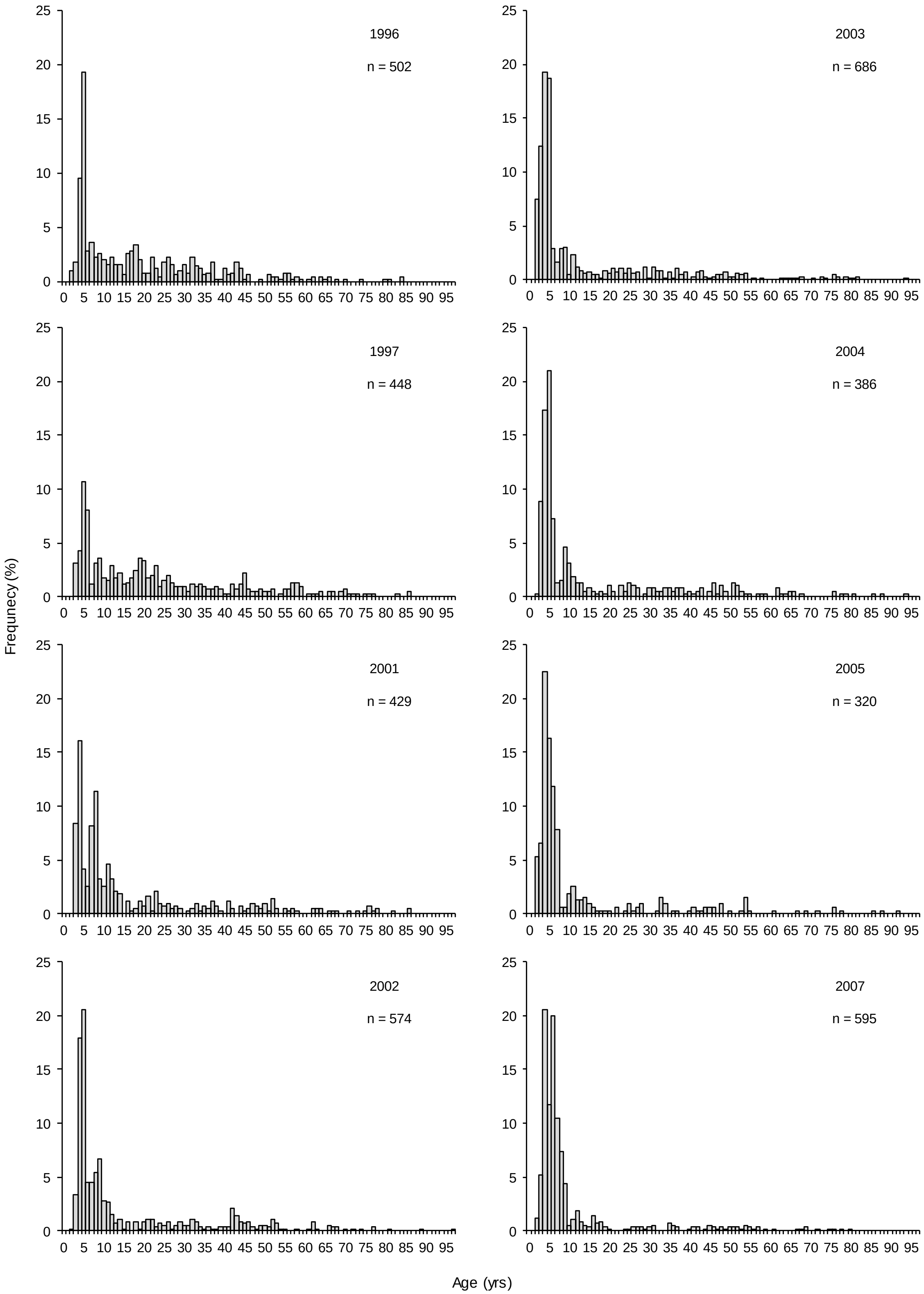

Figure 6. Age composition of sampled Banded Morwong by year. 'n' is the sample size. Year is the year in which the sampling was conducted.

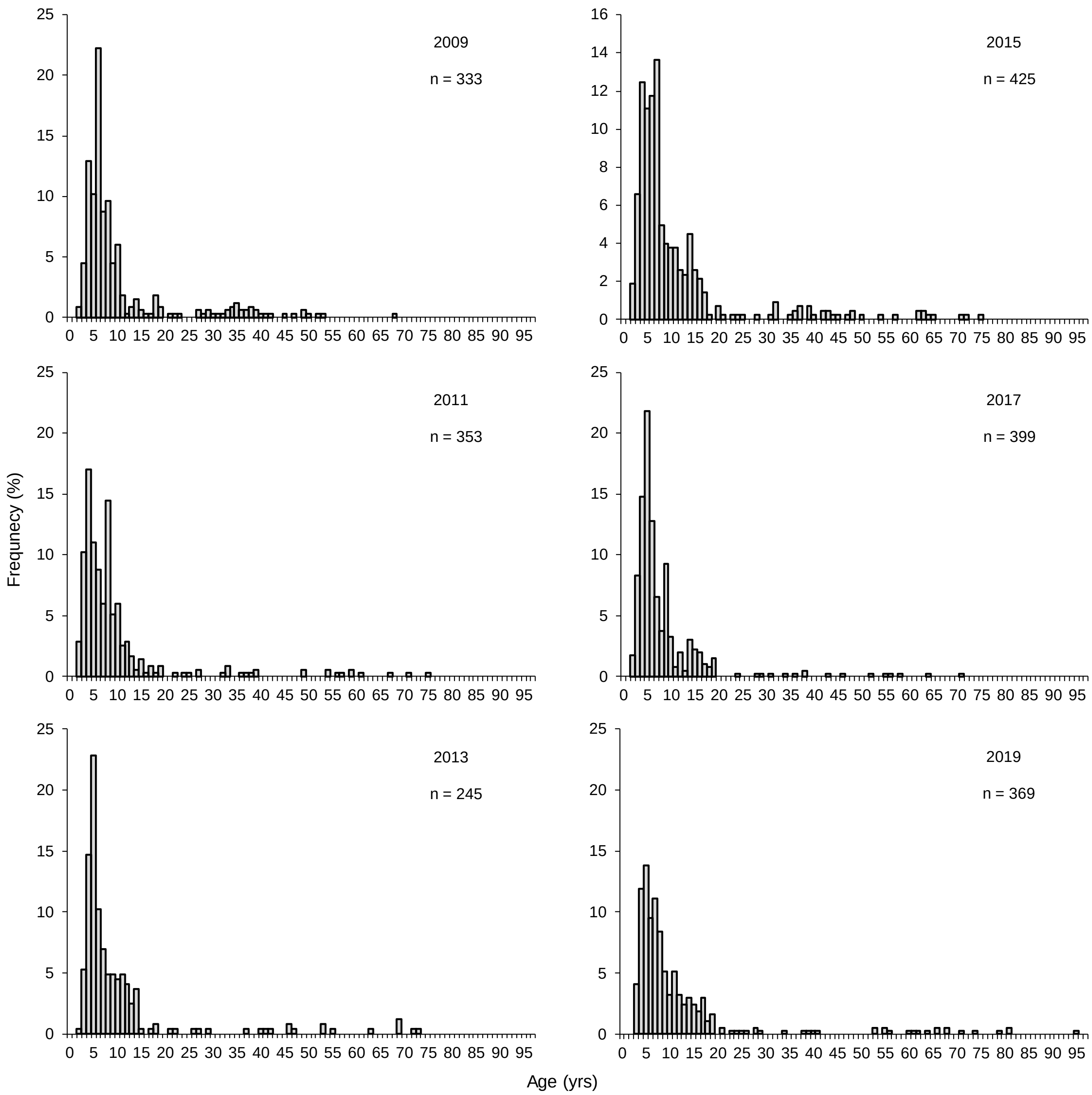

Figure 6. – continued.

Growth rates

Growth functions fitted to the length at age data provided evidence for fluctuations in growth over the sampling period (Figure 7). Based on initial sampling between the early 90's and 2007, previous studies found that growth rates for Banded Morwong younger than 10 years old increased through time, possibly indicating impacts of fishery-induced evolution (Ziegler et al. 2007a). However, since 2007, growth rates have fluctuated between 1990 and 2007 levels, suggesting that environmental effects could be another important driver of interannual variation in growth rates. For example, variation in sea surface temperature is a demonstrated driver of fluctuations in temperate fish size (Audzijonyte et al. 2020).

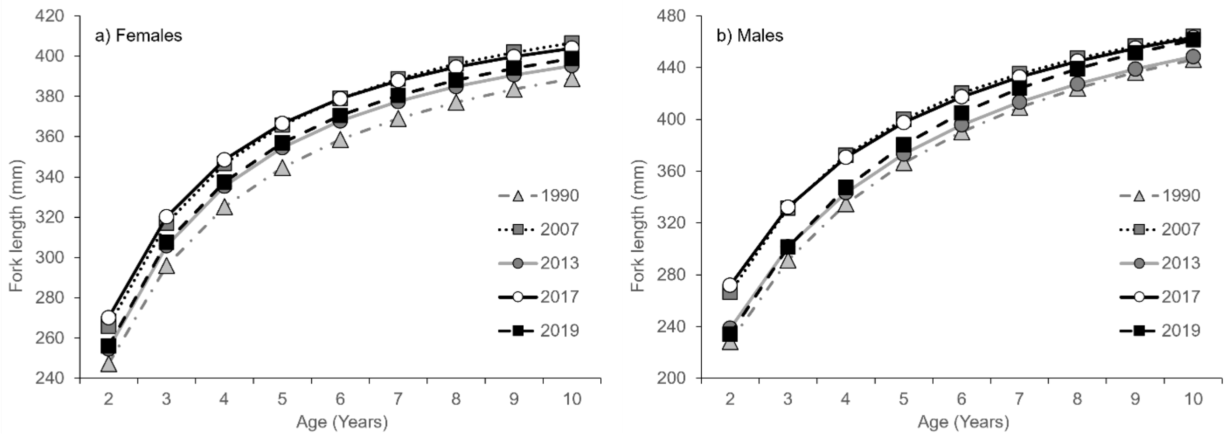

Figure 7. Predicted lengths for female (left) and male (right) Banded Morwong aged 2–10 years from the Schnute and Richards (1990) growth model for samples collected in 1990, 2007, 2013, 2017 and 2019.

Length at female maturity

Fluctuations in the length at which female Banded Morwong mature are evident among sampling years. Length at 50% maturity declined from around 325 mm in 1996–1997 to around 315 mm in 2001, and to below 305 mm in 2002–2003 (Figure 7; Ziegler et al. 2007a). In 2004–2005 length at maturity returned to a similar level to that observed in 1996–1997, a result Ziegler et al. (2007a) attributed to increased length at age by 2004–2005. Since then, length at maturity has subsequently decreased, with 50% of females maturing at around 316 mm in 2011–2013 and 310 mm in 2015–2019 (Figure 8).

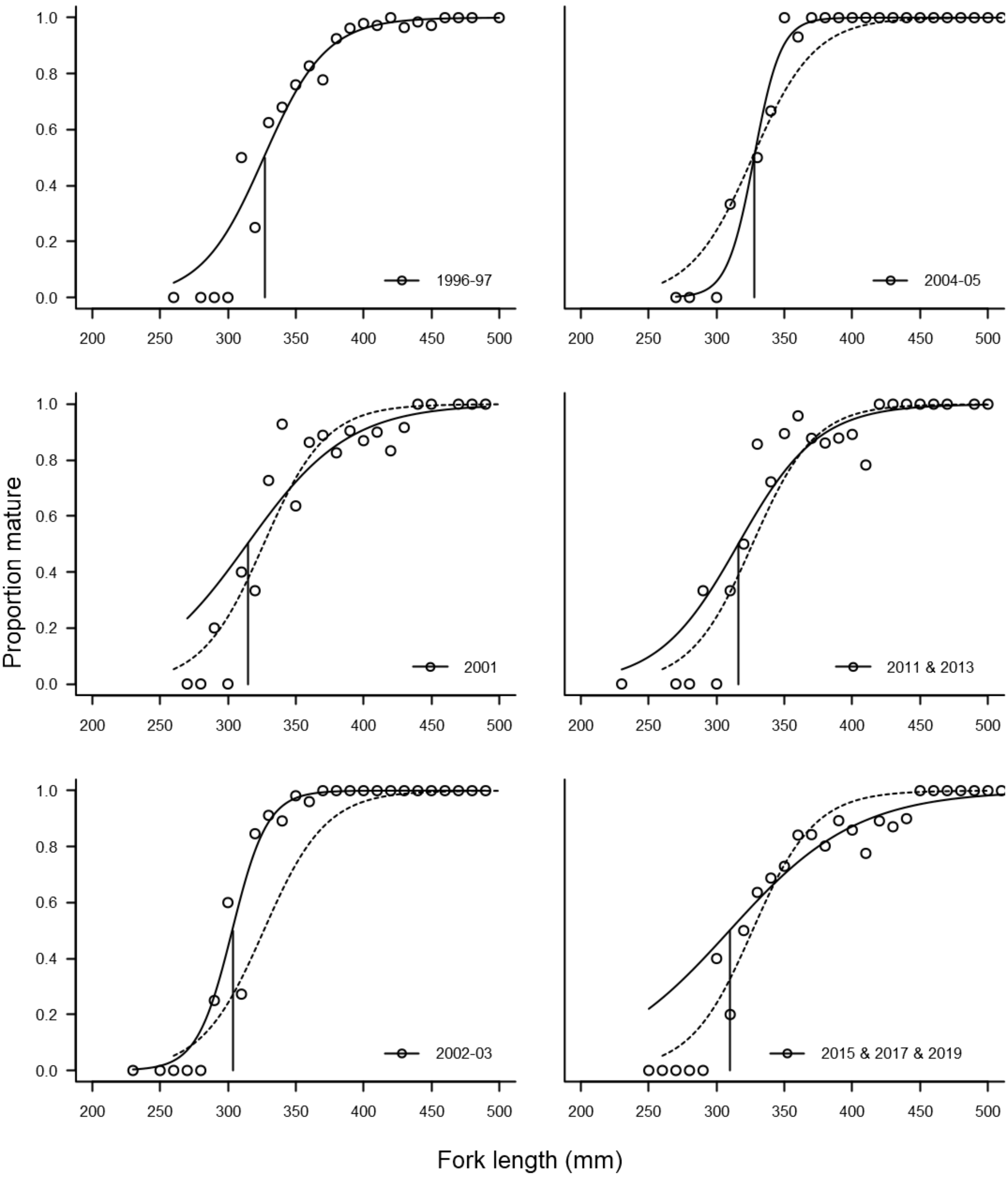

Figure 8. Predicted proportion of mature female Banded Morwong from generalised linear mixed-effects models examining the effect of fork length and sampling period on maturity. Circles represent the proportion of mature females in each 10 mm length class. Data were pooled into the period 1996–1997, 2001, 2002–2003, 2004–2005, 2011 & 2013 and 2015 & 2017 & 2019. The model fitted to the 1996–1997 data is shown in plots for subsequent sampling years as a dashed line as a reference. The solid vertical line represents the length at 50% maturity. Note data collected in 2007 and 2009 were excluded due to small numbers of immature individuals.

Catch, effort and catch rates

Catch and effort

State-wide commercial catches have been relatively stable since the introduction of the quota system in 2008/09, and in 2019/20 were estimated at 35.6 t (Figure 9). The total catch in the TAC area (Areas 1–3 in Figure 2) in 2019/20 was 30.7 t (comprising 6.1 t from the north-east coast (NEC; Area 1), 15.2 t from the east coast (EC; Area 2) and 9.4 t from the south-east coast (SEC; Area 3), which represented 99.0% of the 2019/20 TAC (i.e. a TAC under-catch of 1.0%). Catches on the east coast decreased relative to 2018/19 whereas they increased slightly on the north-east and south-east coasts (Figure 9). The total catch in the non-TAC area (Areas 4 and 5 in Figure 2) in 2018/19 was 4.9 t. The estimated recreational catch during the 2017/18 season was 2 t (Lyle et al. 2019).

In 2019/20 State-wide effort in both days fished and gear units (100 m net hour) didn’t change relative to 2018/19 (Figure 10). Effort (in days fished) increased on the north-east coast relative to 2018/19, decreased slightly on the east-coast, and increased on the north-east coast (Figure 10, Figure 11).

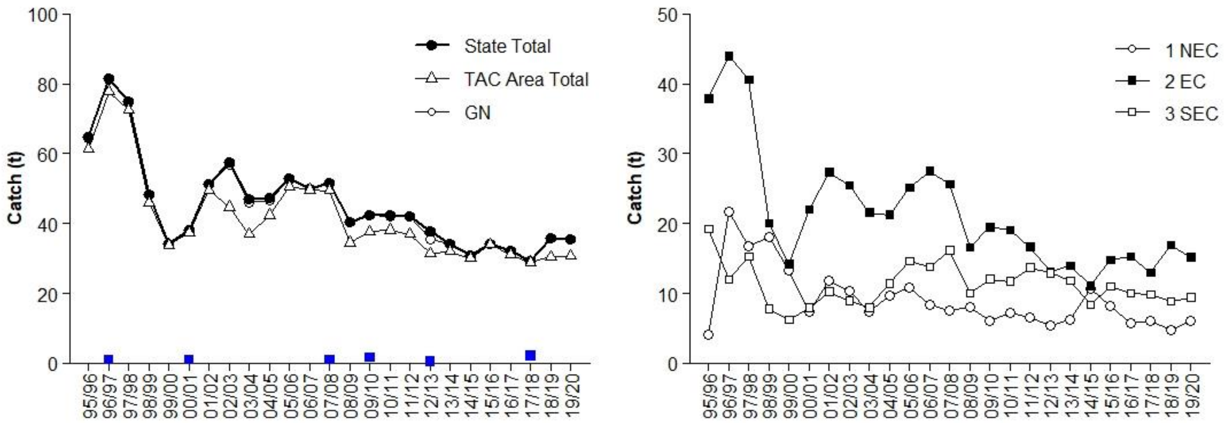

Figure 9. Banded Morwong commercial catches (t). Left: Total state-wide (State Total) and gillnet (GN) catches, Total TAC Area catches, and best estimates of recreational catches (blue squares); Right: regional gillnet catches in the TAC areas 1 NEC, 2 EC and 3 SEC.

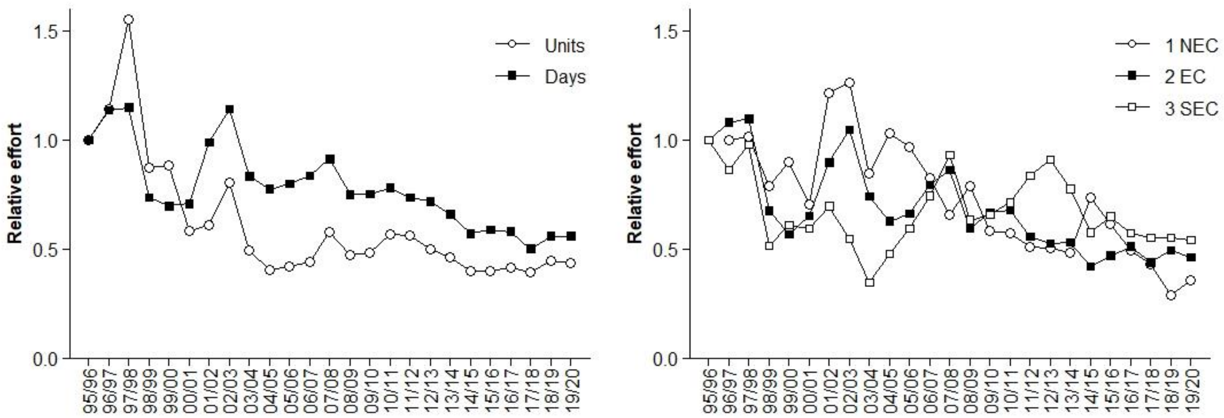

Figure 10. Left: State-wide commercial effort based on gear units and days fished relative to 1995/96. Right: Commercial effort in days fished in the TAC areas 1 NEC, 2 EC and 3 SEC relative to 1995/96.

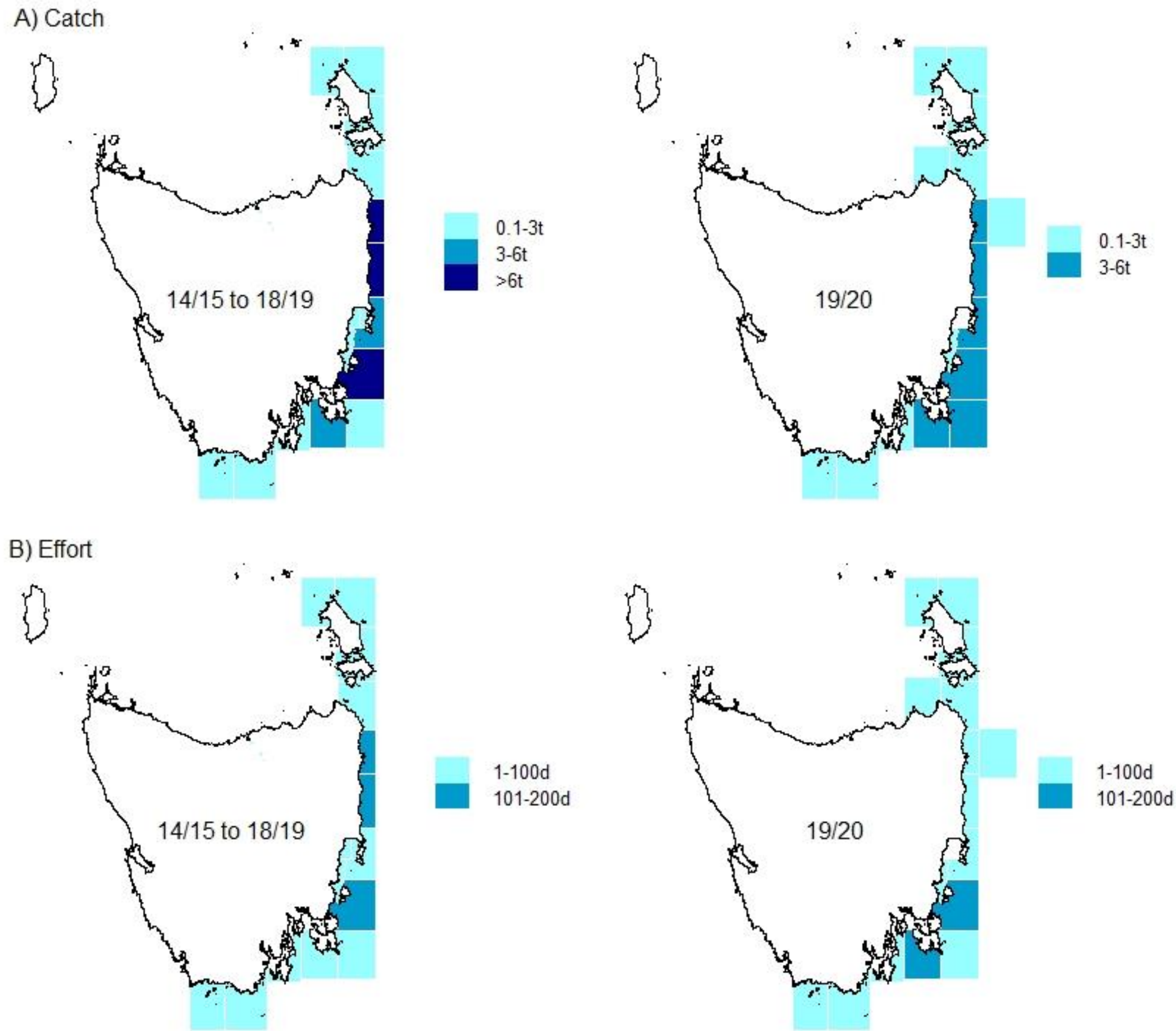

Figure 11. A) Banded Morwong total catches (tonnes per year) and B) effort (days per year) by fishing block. The left-hand column displays spatial patterns in total catch (top) and effort (below) by block averaged from 2014/15 to 2018/19, while the right-hand column displays spatial patterns in total catch (top) and effort (below) observed by block during 2019/20.

Standardised catch per unit effort

Standardised CPUE in the whole TAC area increased to 81% of the 1995/96 level in 2019/20 (Figure 12). Regionally, standardised CPUE remained unchanged on the north-east coast relative to 2018/19, while it increased slightly on the east and south-east coasts. There remains a general trend of increasing standardised CPUE since 2013/14 (Figure 12).

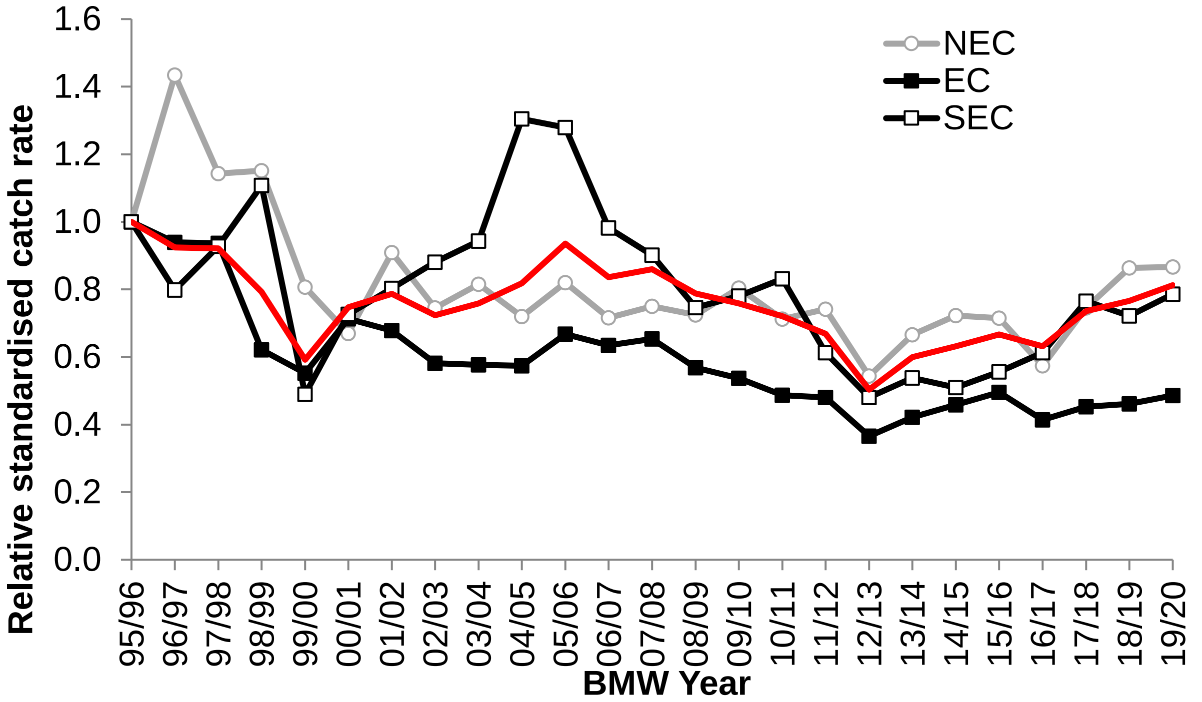

Figure 12. Banded Morwong standardised gillnet catch per unit effort (CPUE by days fished) relative to 1995/96, in the TAC areas North-East Coast (NEC), East Coast (EC) and South-East Coast (SEC), and from the whole TAC area (red line).

Selected stock modelling results and stock status

Overall, the model generally fitted the CPUE and age composition indices fairly well (Figure 13; Figure 14), although the model struggled to fit the sharp declines in CPUE observed in 1999 and 2012 (Figure 13).

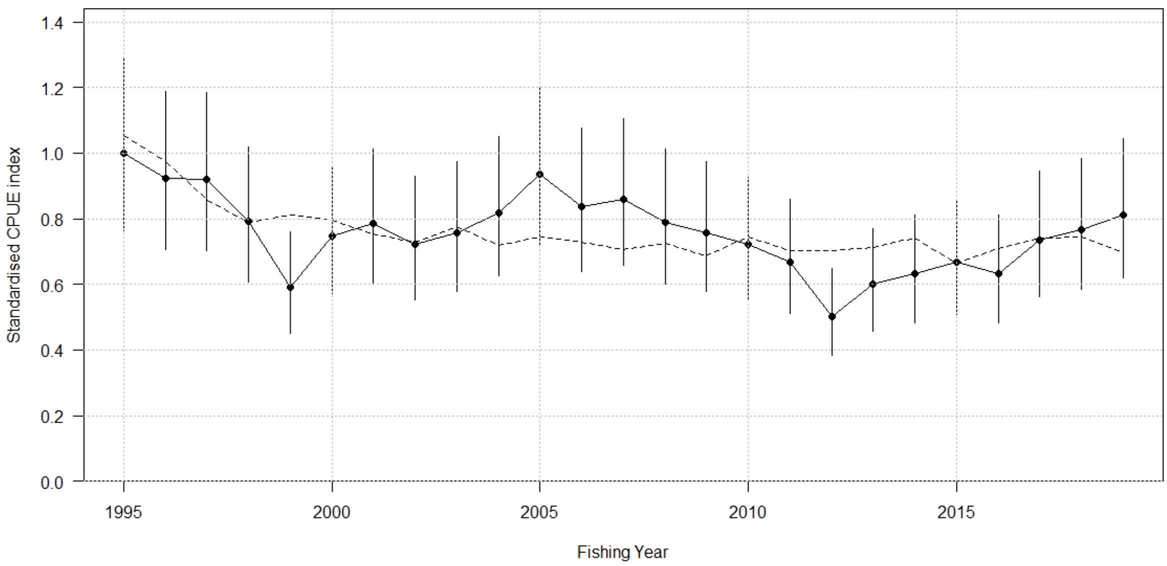

Figure 13. CASAL model fits to the catch per unit effort (CPUE) index. The solid line is the observed (standardised) CPUE, and the dashed line is the model fit. Solid bars represent 95% confidence intervals (including a process error of 0.1) around the observations.

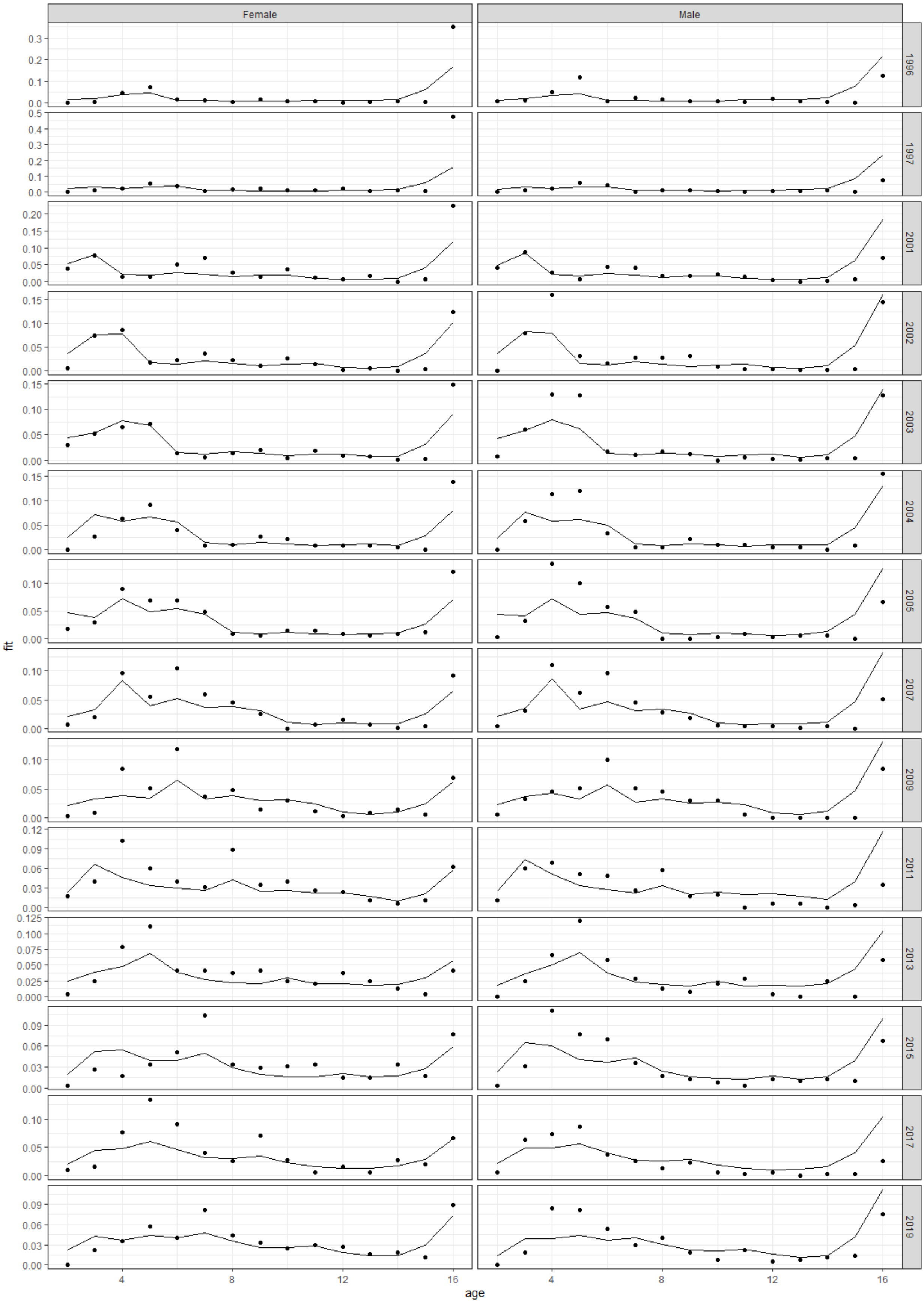

Figure 14. CASAL model fits to the age composition data. The dots represent the observed age class proportional abundances for females (left) and males (right), and the solid line is the model fit.

In 2019/20, the model estimated SSB to be at 41% of initial SSB, representing a slight decrease compared to 2018/19. Modelling indicated that the current harvest strategy (i.e. 26 kg / quota unit and a TAC of 31 t) with 0% projected future TAC under-catch is sufficient to meet the limit reference point of 30% of that of initial SSB within a 5-year period with 90% probability (Figure 15). It was agreed in 2019 that future biomass projections assume no under-catch as the TAC has been successfully reached in all recent years. The above estimates indicate that at a jurisdictional stock level the biomass of Banded Morwong is unlikely to be depleted, and that the current level of fishing mortality is unlikely to cause the stock to become recruitment impaired. Based on the estimates provided above, Banded Morwong in Tasmanian waters is classified as a **sustainable stock**.

We note that the stock assessment model supporting our evaluation of stock status is under ongoing review (first initiated in 2016/17). This review was advanced in 2020 and is due for completion in 2021, aiming to strengthen biomass predictions and prevent unsustainable levels of fishing (last reported in 2016/17). Several key model sensitivities resulting from the review are highlighted in section 4 below. More detailed information on procedures and decision making processes will documented in a separate report.

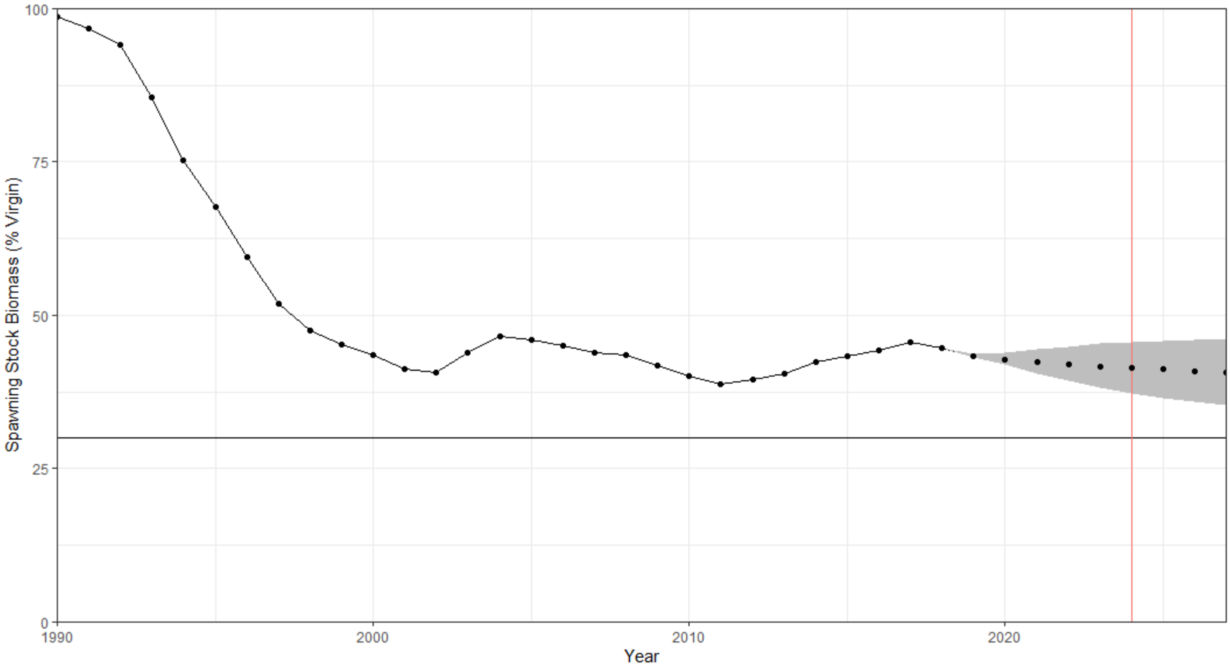

Figure 15. Current status and forward projections (to 2027) of Banded Morwong spawning stock biomass (SSB) expressed as a percentage of the unfished SSB, based on the 2019/20 harvest strategy of 26 kg / quota unit and a future under-catch of 0%. The red vertical line indicates the 5-year period in which SSB is required to meet the limit reference point of 30% of initial SSB (indicated by the grey horizontal line) with a 90% probability (as shown by the dark shaded area).

4. Model Review Summary

The Banded Morwong model has been implemented using the CASAL stock assessment software since 2016. The CASAL model is considered a state of the art stock assessment tool capable of integrating many sources of information and explicitly modelling spatio-temporal stock structures and dynamics. The primary sources of information that enter the Banded Morwong model are life history parameters (namely length-at-age, age-at-maturity, allometric weight-length and natural mortality rate), catch data, standardised CPUE and survey catch-at-age frequency data. The model also includes two timesteps and two areas. Each of these parameter specifications is associated with uncertainty and has variable and partially interactive impacts on biomass predictions (SSB). The review process undertaken in 2019/20 aimed at rigorously quantifying and in some cases updating aspects of the structure and parameterization of the stock assessment model. Updated components concern, for example, length-at-age (growth), recruitment, and survey catch-at-age data (see table 6 for an overview). This section provides more information on model updates and it highlights several key sensitivities that were flagged as a research priority for more robust parameterization during the last Scalefish Fishery Advisory Committee (SFAC) meeting number 72, held on 20 October 2020.

Updates and changes in 2019/20

Growth

Growth has traditionally been modelled externally from CASAL using the SR function (discussed above) applied over each survey period and then included in the model. Including different growth rates for every survey year in the model allows for capturing plasticity in growth rates throughout the fishery history. The model also uses the most recent growth information in projected calculations of SSB.

Regular updates of growth data from biannual samples are included in the model to strengthen SSB predictions. In 2019/20, average growth was modelled by applying the SR function to data from the 2019 survey year. Adding the 2019 growth data resulted in a slight increase in biomass projected into the future.

Changes in parameter calculations incorporated into the 2019/20 assessment model included a recalculation of average growth using the SR function for survey years prior to 2019. This was done in two stages: (1) including recalculated values from 2007-2017 and (2) including recalculated values from 1990-2005. Outcomes showed a moderate overall decrease in SSB.

We then changed the treatment of juvenile data in growth curve analyses by updating the inclusion criteria for young fish, establishing an overall more robust anchor to fit the SR model. These adjustments resulted in a net moderate increase in SSB predictions.

Recruitment

The model relies on a specified period of mean and uncertainty in recruitment strength to estimate how strong recruitment will be in the future. This period was changed from the last 10 years to the full range (30 years) of estimated recruitment. Covering the full range of data helps utilize the maximum amount of recruitment information along with a more realistic characterization of uncertainty. This change resulted in a slightly lower projected SSB and it doubled the width of the projected uncertainty interval.

Key model sensitivities

The model review highlighted several assumptions with a substantial impact on SSB predictions, which will need to be addressed for more robust model predictions and future assessments of stock status. A research priority to address these modelling assumptions and sensitivities through a combination of desktop studies and field data collections has been proposed and reiterated for consideration by DPIPWE and the Research Advisory Committee (RAC) at SFAC 72.

Depth-refuge assumption

The Banded Morwong model separates the stock into two areas and assumes a fixed migration rate of 25% between them (Figure 4). The model has traditionally been specified as a two-area model due to the relatively shallow depth in which the fishery operates, and the deeper depths Banded Morwong have been observed to occur (Table 1). The two-area model therefore splits the population dynamics into an inshore (shallow) region where fishing occurs and an offshore (deep) region that acts as a refuge to adult individuals. However, there is little empirical evidence to support this parameterization, including relative population sizes in or migration rates between the two areas. We investigated the impact of relaxing the depth-refuge assumption by condensing the stock into a single area. The outcomes highlight stronger initial depletion prior to 2000, with SSB then approaching the limit reference point at 30% of unfished levels (Figure 16).

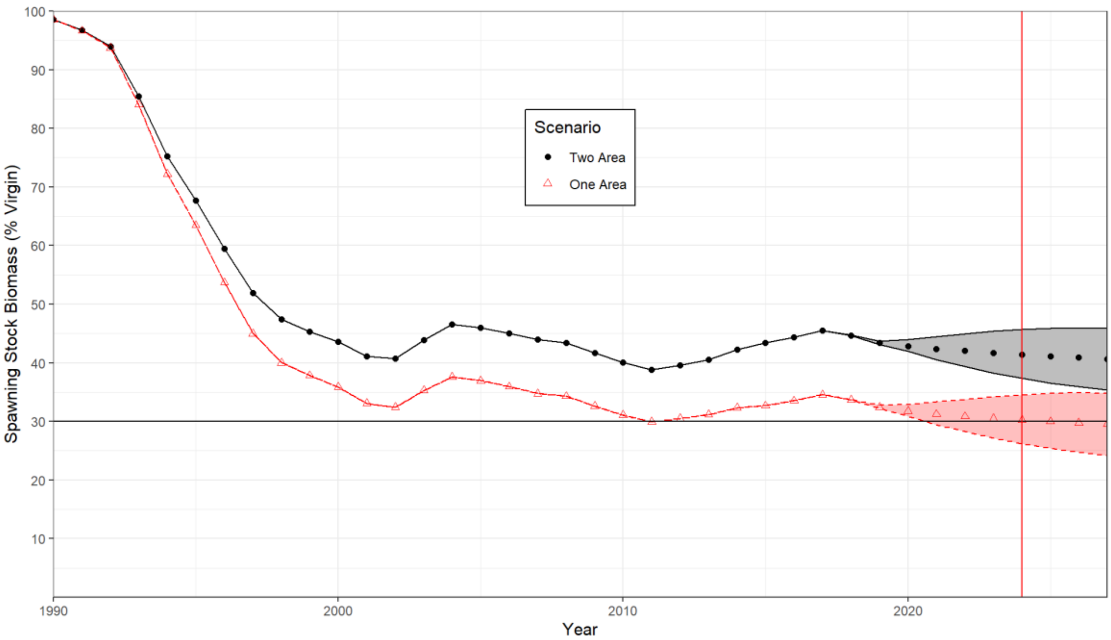

Figure 16. Current status and forward projections of Banded Morwong spawning stock biomass (SSB) assuming a two-area model (grey) and a one area model (red).

In light of these findings, the two-area model (depth-refuge assumption) should either be replaced by a one area model or updated through empirically supported parameterization, i.e. measurements of relative population sizes and migration rates between shallow and deep areas.

Selectivity Assumptions

Fishing selectivity is specified in the model to analyse catch and effort data while accounting for the impact of fishing on specific age-classes within the population. Fishing selectivity is specified separately for survey data, in this case complementing age-composition data to estimate other biological characteristics, including recruitment strength. Selectivity ogives traditionally assumed for the fishery and survey data take on a knife-edge and dome shape, respectively (Figure 17). The knife-edge selectivity ogive specified for catch data is aimed at reflecting legal size limits and negligible post-release mortality of non-legal sized fish. While routine measurements of length-composition data from fishery catches are lacking, biological surveys have been conducted with the same net type and deployment practices as standard fishing activities. Selectivity ogives should therefore be similar. However, given that surveys retain all fish caught while the fishery only retains legal sized fish, selectivity ogives are parameterized differently. The knife-edge selectivity ogive for catch data implicitly assumes that (1) fish within the keyhole size limit are removed with 100% probability, and that (2) fish outside the keyhole limit are caught with 0% probability and thus experience 0% fishing-related mortality. This latter assumption is supported by studies highlighting negligible (3%) post-release mortality of undersized and oversized Banded Morwong (Lyle et al. 2014a). Currently unconsidered is the frequency of seal interactions, which are recorded for about 20% of all fishing operations (see Figure 22). Seal interactions raise concerns about the currently optimistic discard mortality assumption (0%), because seals are likely to prey upon released fish. Data on seal depredation rates are currently unavailable.

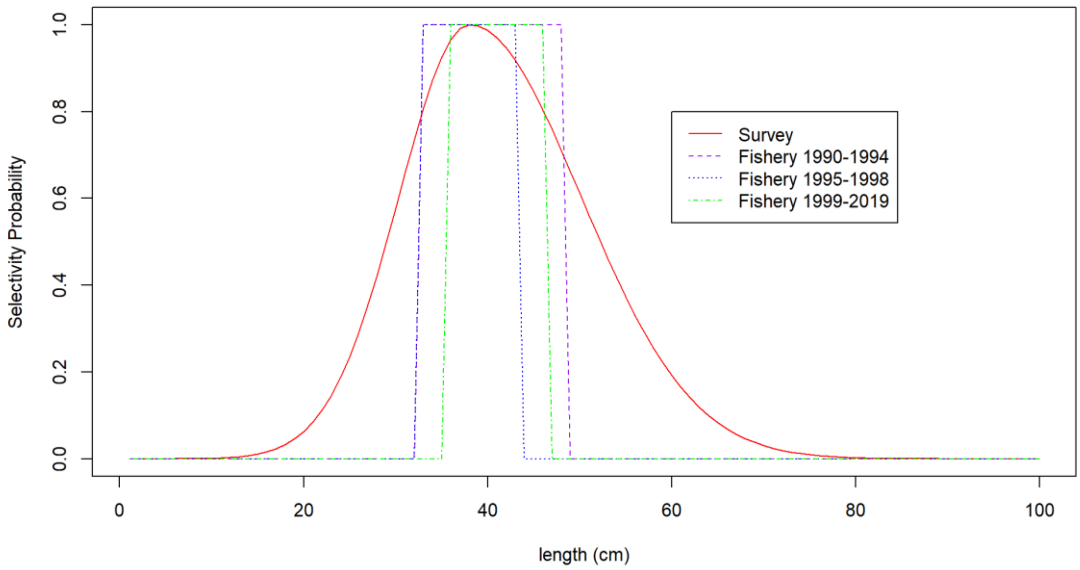

Figure 17. Selectivity ogives traditionally assumed for the historic and present fishery (broken lines) and survey (solid line). The changes in the knife-edge fishing selectivities reflect historical changes in the keyhole size limit.

Furthermore, the general assumption that fishing selects all fish within the legal size limit with an equal probability is in contrast to the selectivity data available from surveys, which employs the same practices as the fishery. To quantify the impact of these assumptions, we tested model sensitivity to changes of the assumed fishing selectivity. The most conservative alternative assumption (a dome-shaped selectivity ogive with 100% discard mortality) revealed a strong impact on SSB predictions, highlighting similar initial but fundamentally different trajectories over recent years (Figure 18). We conclude that selectivity ogives should be re-estimated and that likely levels of discard mortality due to seal interactions should be estimated through targeted research.

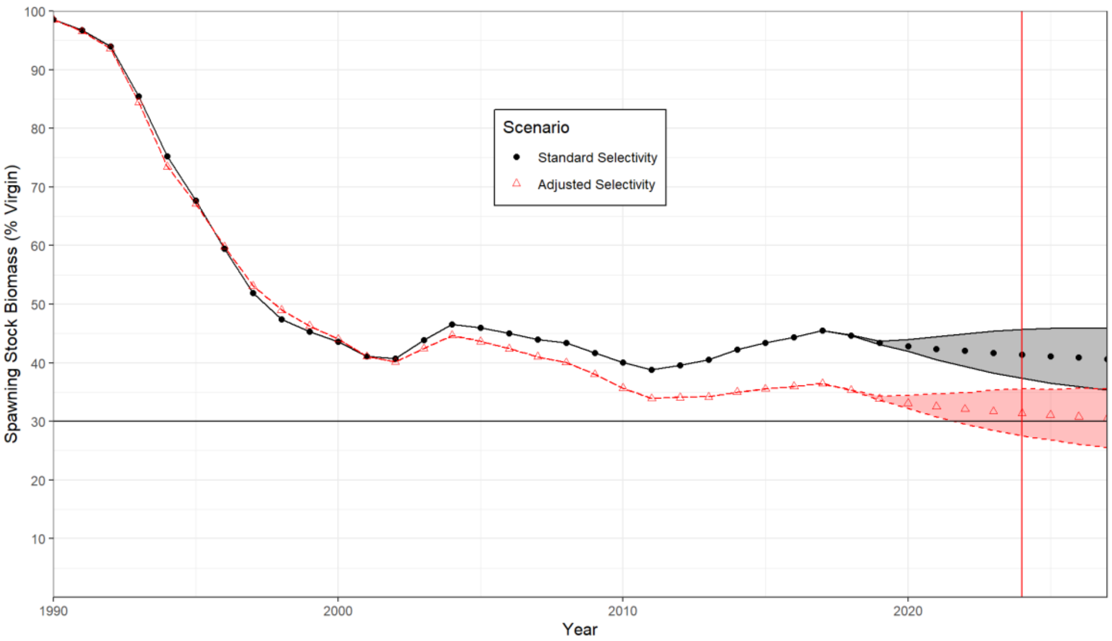

Figure 18. Current status and forward projections of Banded Morwong spawning stock biomass (SSB) assuming traditional fishing selectivity (grey) and adjusting fishing selectivity to match survey selectivity (red).

Data on juvenile fish

Most of the survey data used to calculate the length-at-age growth curves for Banded Morwong is comprised of fish exceeding 300mm. Fish below this length are unlikely to be selected by the survey nets and are thus rare in the data set. Growth curve estimation has traditionally incorporated only a small number of juvenile fish collected in 1996, which anchor the growth curves for each survey year to a realistic value for fish under 300mm. Growth curve fitting without juvenile data fails to represent realistic estimates of lengths-at-ages for fish under 300mm (Figure 19), resulting in a substantial difference in SSB projections (Figure 20). Given this sensitivity in modelling outcomes, an updated, more extensive collection of data on juvenile fish would help strengthen confidence in growth curve estimates and associated SSB predictions.

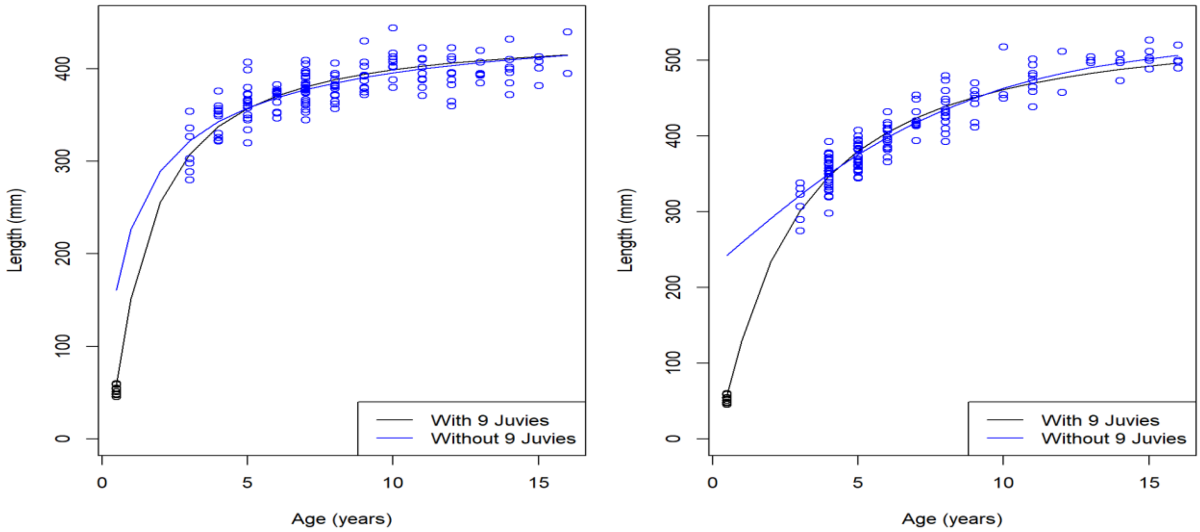

Figure 19. Schnute and Richards growth curves estimated for females (right) and males (left) including the juvenile data set (black line) and omitting it (blue line) for 2019 survey data.

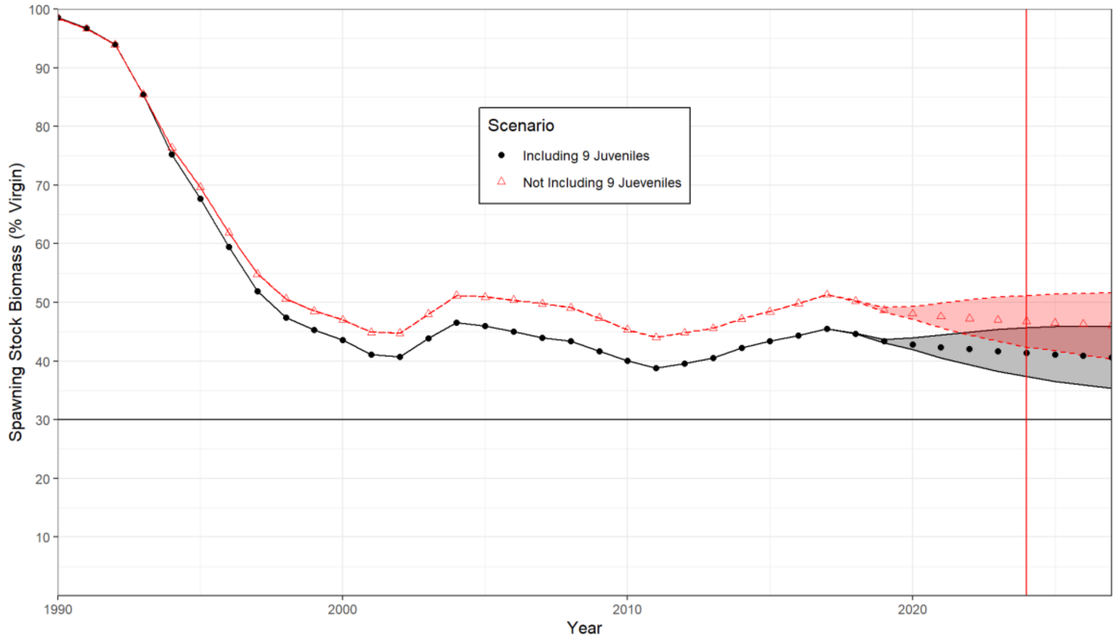

Figure 20. Current status and forward projections of Banded Morwong spawning stock biomass (SSB) including (grey) and omitting (red) juvenile data in growth curve estimates.

5. By-product and protected species interactions

By-product in the Banded Morwong Fishery is low, which is due in part to the large mesh sizes used for Banded Morwong fishing (~140 mm mesh size). In the ERA of Bell et al. (2016), no species achieved a ranking of high vulnerability within the Banded Morwong Fishery due to the minimal gillnet effort on the west coast, the shallow nature of fishing operations relative to depths inhabited by bycatch species, low selectivity of smaller by-product and bycatch species given the large mesh sizes imposed in the fishery, and high post-release survival of many of the key by-product and bycatch species.

During the 2018/19 quota year, Banded Morwong comprised 82% (up 6% compared to the previous quota year) of all fish caught during targeted Banded Morwong fishing trips, with Bluethroat Wrasse and Bastard Trumpeter constituting the most commonly caught by-product species (9% the total catch for 2018/19, respectively) (Figure 21).

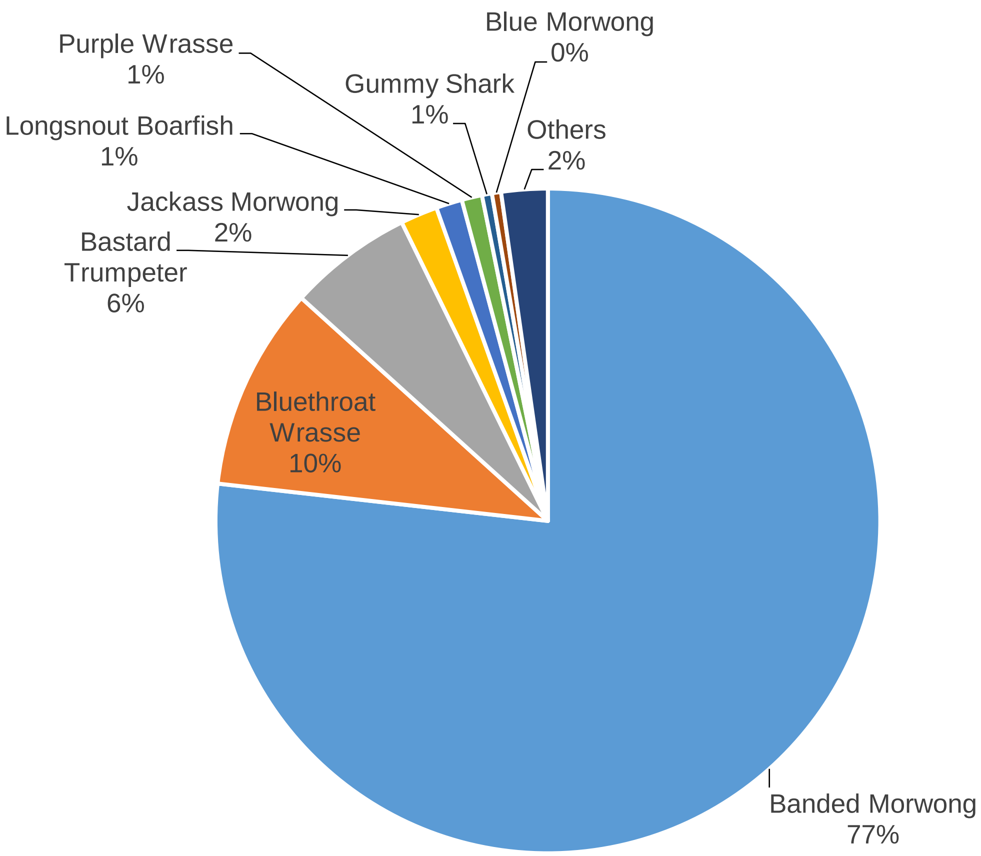

Figure 21. Catch composition of targeted Banded Morwong gillnet fishing trips in 2018/19. A targeted Banded Morwong fishing trip was defined as a trip on a given day by a given fisher where Banded Morwong were retained.

Mortality of Banded Morwong and other scalefish species due to predation and fishery interactions with Australian and New Zealand fur seals is largely unknown and represents another source of uncertainty in the assessment. Seals can cause substantial mortality to Banded Morwong, damage fishing gear and influence fishers behaviour, all of which can impact catches and catch rates. This is believed to be caused predominantly by individual ‘rogue’ seals which learn to target Banded Morwong gillnet fishing. The proportion of shots in which fishers reported a seal interaction increased slightly in 2018/19 relative to 2017/18, with seal interactions being reported for around 22% of all shots (Figure 22). However, from the current data collection program it is unclear how fishers interpret a seal interaction, how consistently fishers report seal interactions, or the effect seal predation has on catches (i.e. how many fish are lost). Additionally, effects on fisher behaviour are poorly understood. A number of fishers have indicated that they are setting a proportion of their nets as a decoy to reduce catch losses through seal interactions. The remainder of their gear is set elsewhere, but the effect of additional nets on seal interactions, or on fisher catch metrics (e.g. effort), is poorly understood.

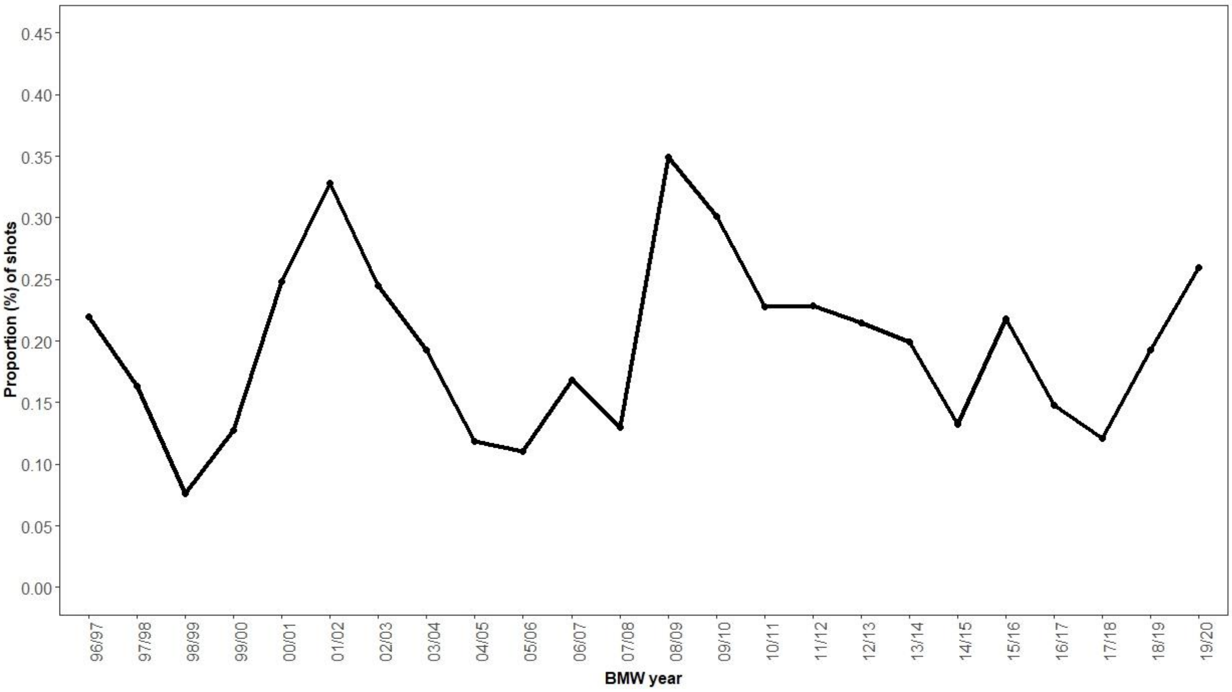

Figure 22. The proportion of shots in which fishers reported an interaction with a seal or seals.

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