Stock assessment of Ballot's saucer scallops (*Ylistrum balloti*) in Queensland, Australia, with data to October 2022

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Queensland Government

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Contents

Summary

This stock assessment indicates that biomass declined between 1956 and 2016 to 10% unfished biomass. In 2022, the stock level was estimated to be 15% unfished biomass (95% confidence interval 10–25%).

The Queensland east coast Ballot's saucer scallop (*Ylistrum balloti*, formerly *Amusium balloti*) is a marine bivalve mollusc with a hinged shell. They are mainly found between 22° South and 27° South in shelf water depths of 20 to 60 metres. Saucer scallops can potentially grow to about 12 to 14 cm in shell height and, in some instances, live for up to 4 years. Scallops generally mature between 11 and 18 months of age.

Saucer scallop are a largely sedentary broadcast spawner that form spatially distinct population aggregations where the habitat is suitable. In general these aggregations are reproductively connected, however there is some evidence to suggest that saucer scallops on the fishing ground east of K'gari, Fraser Island, are less connected to those on the fishing grounds between Yeppoon and Hervey Bay.

This is the fifth saucer scallop stock assessment. This stock assessment builds on previous assessments that estimated the unfished biomass at 5–10%, 9% and 15% in 2016, 2018 and 2022 respectively. It includes updates to the input data but keeps the methodology in line with the 2018 assessment.

This stock assessment was conducted on fishing year, the saucer scallop fishing year is defined as November of the preceding year to October of the named year. Annual assessment inputs and outputs are all referenced on fishing year (i.e. '2022' always means November 2021–October 2022).

This stock assessment used an age structured population model with a monthly time step. The model incorporated data spanning the period from 1956 to 2022 including total annual meat weight harvest (1956–1987), the Queensland historical trawl database (1977–1987), Queensland commercial logbook data (1988–2022), and survey data providing densities of saucer scallop in two size classes (1997–2000, 2017–2022).

Over the last 5 years, 2018 to 2022, total harvest averaged 211 t (Figure 1).

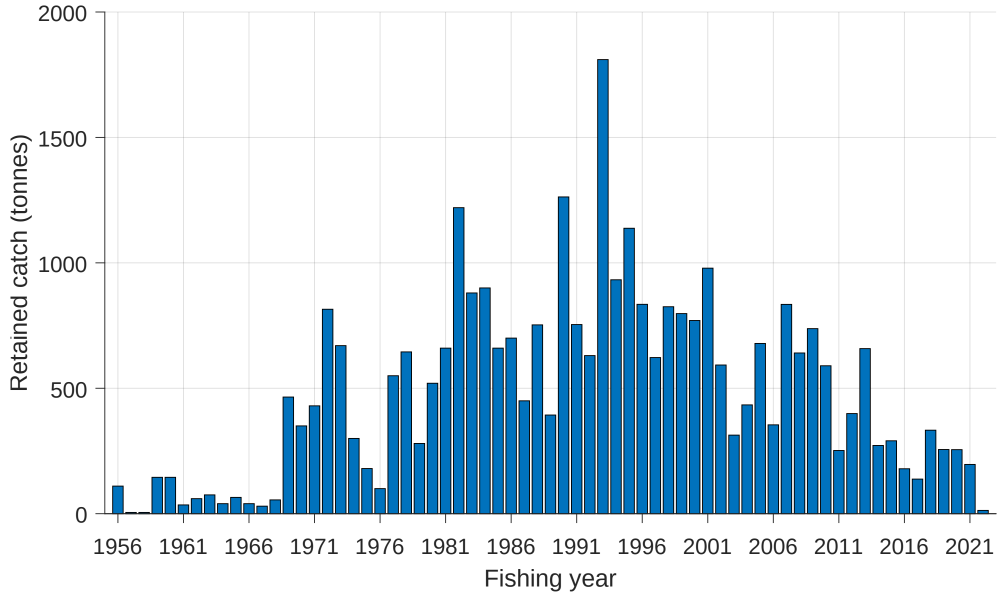

Figure 1: Annual estimated saucer scallop harvest (retained catch) from 1956 to 2022

Commercial catch rates were standardised to estimate an index of saucer scallop abundance through time (Figure 2). The unit of standardisation was baskets of saucer scallop per 'boat-day', defined to be a single day of fishing by a primary vessel. Year, month, area (Yeppoon, Bustard Head, Hervey Bay, K'Gari), spatial grid, vessel, hours fished, engine horse power, vessel speed, use of sonar, use of GPS, net type, ground gear type and combinations of these were included explanatory terms.

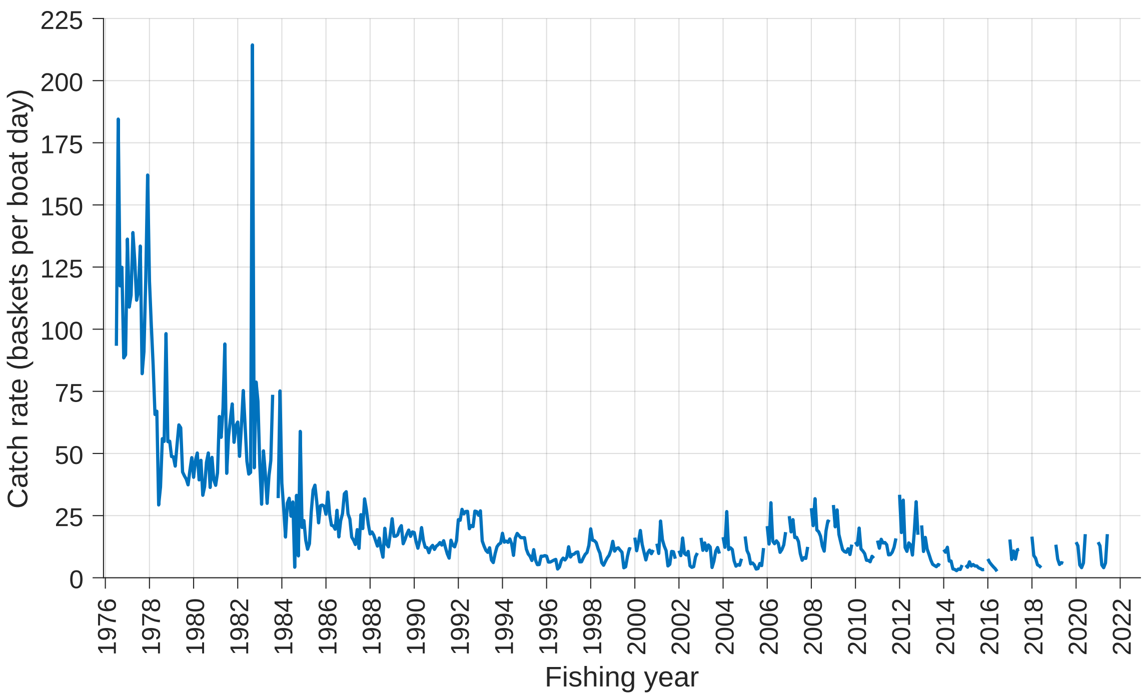

Figure 2: Standardised monthly catch rates from 1977 to 2022

Survey density data were also standardised, to estimate annual densities of two age groups of saucer scallop (Figure 3). The unit of standardisation was the number of saucer scallops per hectare.

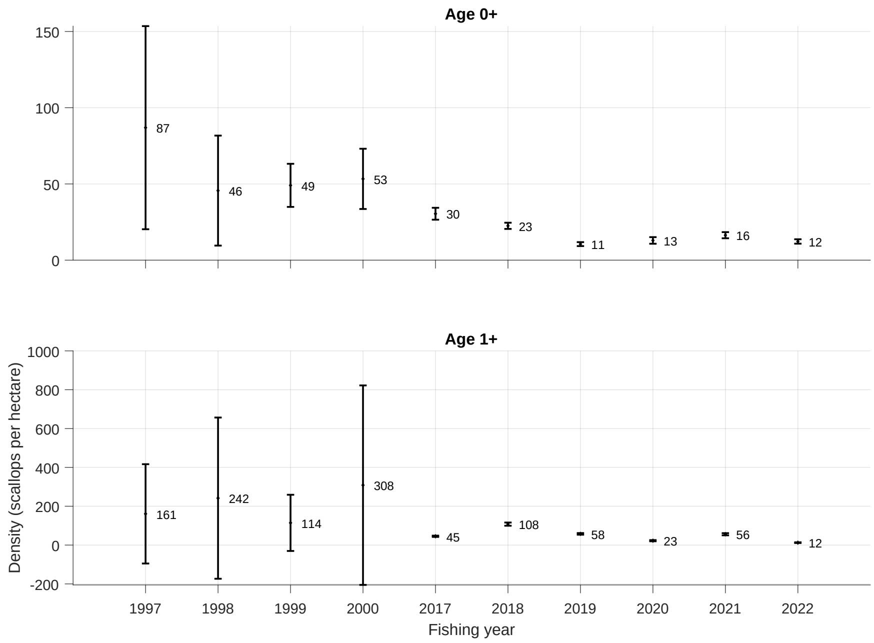

Figure 3: Mean modelled saucer scallop densities per hectare

Model results indicate that biomass[1] declined between 1956 and 2016 to 10% unfished biomass. This comparison between yearly biomass and unfished biomass is known as the 'biomass ratio'. After increasing to 18% in 2018, the biomass ratio in 2022 was estimated at 15% (95% confidence interval 10–25%) (Figure 4).

[1] Biomass always means spawning biomass unless indicated otherwise.

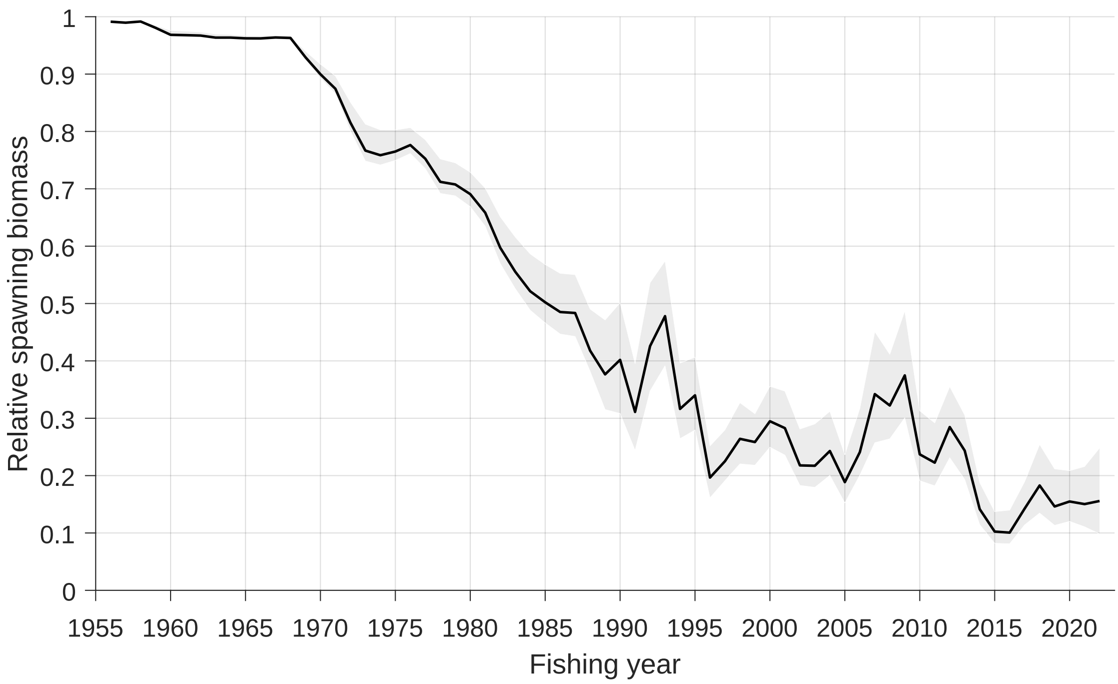

Figure 4: The estimated spawning biomass trajectory relative to unfished for saucer scallop from 1956 to 2022

While the biomass ratio provides an indication of where the stock is, the fishing pressure ratio provides an indication of where the stock is heading. This is the calculated as the yearly fishing pressure divided by the fishing pressure that would maximise catch indefinitely, a quantity known as F_{MSY}. Fishing at F_{MSY} eventually results in biomass B_{MSY}, and yearly biomass divided by B_{MSY} is another way to report the biomass ratio (Table 1, Figure 5).

Table 1: Stock status indicators for saucer scallop in 2022

Indicator	**Estimate**
Biomass	15% of unfished
Biomass at MSY	44% of unfished
Retained catch	13 t
Fishing pressure	11% of F_{MSY} (i.e. fishing pressure is below F_{MSY})

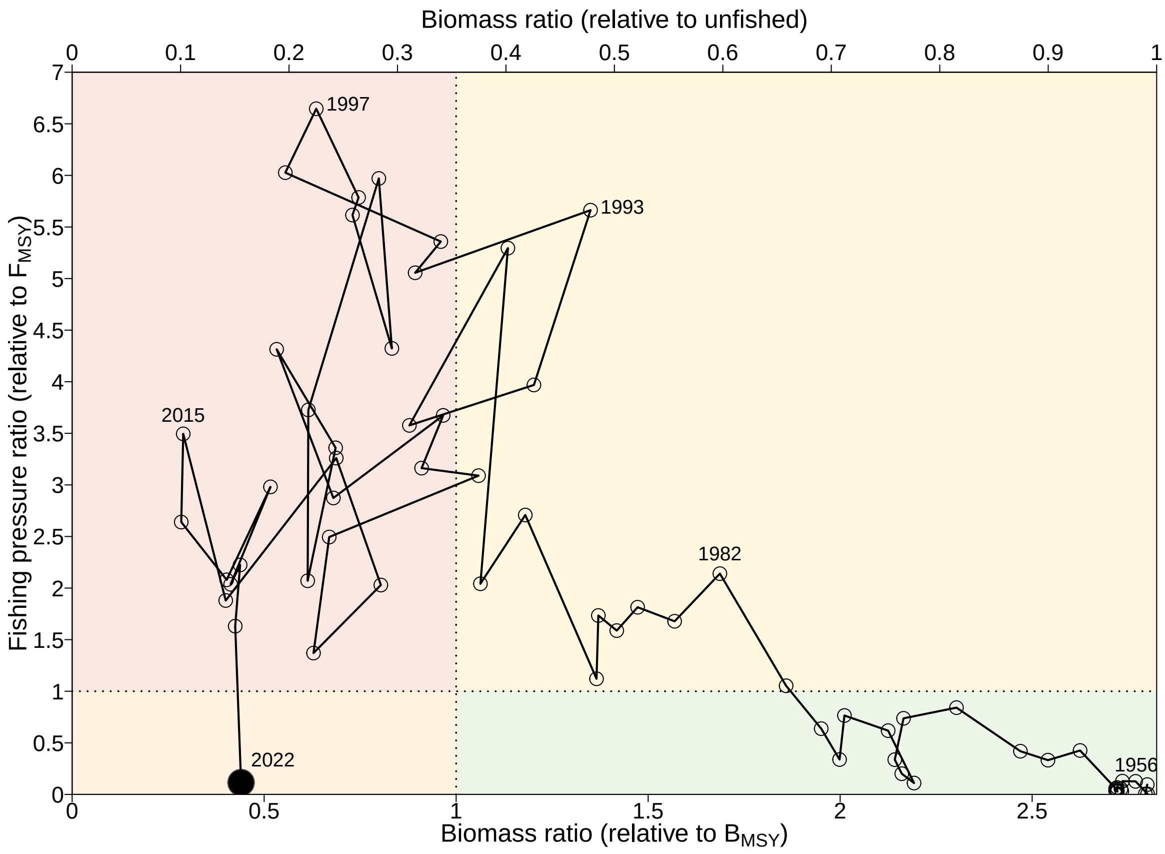

Figure 5: Stock status indicator trajectory for saucer scallop

Acknowledgements

The author would like to thank Marlee Jesson Kerr and Jason McGilvray for the provision and analysis of 2022 survey density data, and additionally with Dylan Moffitt for the sampling strata review.

This report is an update of Wortmann (2022) and hence much of the text is reproduced here.

The author would also like to acknowledge and thank the many fishers and scientists who have contributed to past research on saucer scallop.

We would finally like to thank Alex Campbell, Sam Williams, and Dallas D'Silva for reviewing and providing comments on parts of the draft report. This assessment was funded by the Queensland Department of Agriculture and Fisheries.

Glossary

Term	Definition
Ballot's saucer scallop	*Ylistrum balloti*, formerly *Amusium balloti*, referred to as saucer scallop in this document
biomass	spawning biomass—number of eggs (spawning egg production), an indicator of the status of the stock and its reproductive capacity
BRD	bycatch reduction device
CSH	commercial shell height—maximum shell diameter, from any angle
eu	effort units = standardised boat-days × standardised hull units
density	number of scallops per hectare
fishing year	defined as November of the previous year to October of the named year—fishing year label 2020 was from November 2019 to October 2020, where November was fishing month 1 and October was fishing month 12
FRDC	Fisheries Research and Development Corporation www.frdc.gov.au
GLM	generalised linear model
HP	power of an engine measured in terms of horsepower
Htrawl	Queensland historical trawl database containing voluntary daily trawl logbook records of prawn and scallop catch rates prior to 1988
M	natural mortality
LMM	linear mixed model to standardise catch rates
MCMC	Markov chain Monte Carlo methods
ML	maximum likelihood
MLS	minimum legal size—commercial shell measure
MSY	maximum sustainable yield
-LL	negative log likelihood
NOAA	National Oceanic and Atmospheric Administration—an American scientific agency
region 3	southern inshore trawl region—scallop fishery for the main fishing zones of Yeppoon, Bustard Head and Hervey Bay
region 4	southern offshore trawl region—scallop fishery for the K'gari, Fraser Island, fishing zone
REML	restricted maximum likelihood, an estimation method in linear mixed models
retained catch	component of the catch that is kept by fishers, also referred to as 'harvest' and 'landed catch'
SH	shell height—vertical scientific measure
SRA	scallop replenishment area
SST	sea surface temperature
t	tonnes of scallop meat
TED	turtle exclusion device

1 Introduction

The Australian east coast Ballot's saucer scallop (*Ylistrum balloti*, formerly *Amusium balloti*) is a marine bivalve mollusc with a hinged shell. They belong to the taxonomic family Pectinidae. Saucer scallop shells are white on the lower side and brown on the upper half shell. They can potentially grow to about 14 cm in shell height and, in some instances, live for up to 4 years (Campbell et al. 2010; Dredge 1985). In this document, Ballot's saucer scallop is referred to as 'saucer scallop'.

Saucer scallops on the main fishing ground between Yeppoon and Hervey Bay are a single stock (Dredge 2006), with scallops that spawn east of K'gari, Fraser Island, likely to be less connected to the main ground. K'gari is associated with irregular and infrequent scallop catches. Southward ocean currents do not appear to support a linkage from spawning in K'gari to recruitment to the main fishing grounds Hervey Bay and north.

The east coast otter trawl fishery is divided into five management units. The main scallop fishery is region 3, south of 22° S to Hervey Bay (Figure 1.1). There are six scallop replenishment areas (SRAs) located off Yeppoon, Bustard Head and Hervey Bay. The SRAs were originally implemented as the *Fisheries (emergency closed waters) Declaration 1997* (Queensland Government 1994). The declaration was put in place due to concerns of overfishing as evidenced by low survey numbers of young scallop (low recruitment). In 1999 industry pushed for a rotational harvest system and this was set up under the *Fisheries (East Coast Trawl) Management Plan 1999* (Queensland Government 1999). The aim was to allow industry to rotationally harvest the larger legal sized shell from ten SRAs while still retaining a certain level of protection to the stock. This was in place from 2001–2003. The opening and closing of ten areas was considered too complicated and the Plan was amended with the SRAs changed to the current format on 31 October 2003. The current format consists of six SRAs with two in each major zone. The rotation for these SRAs occurred every September and January allowing for an open period of 9 months and a closed period of 15 months each rotation. In January 2017 the SRAs were permanently closed because of low stock levels.

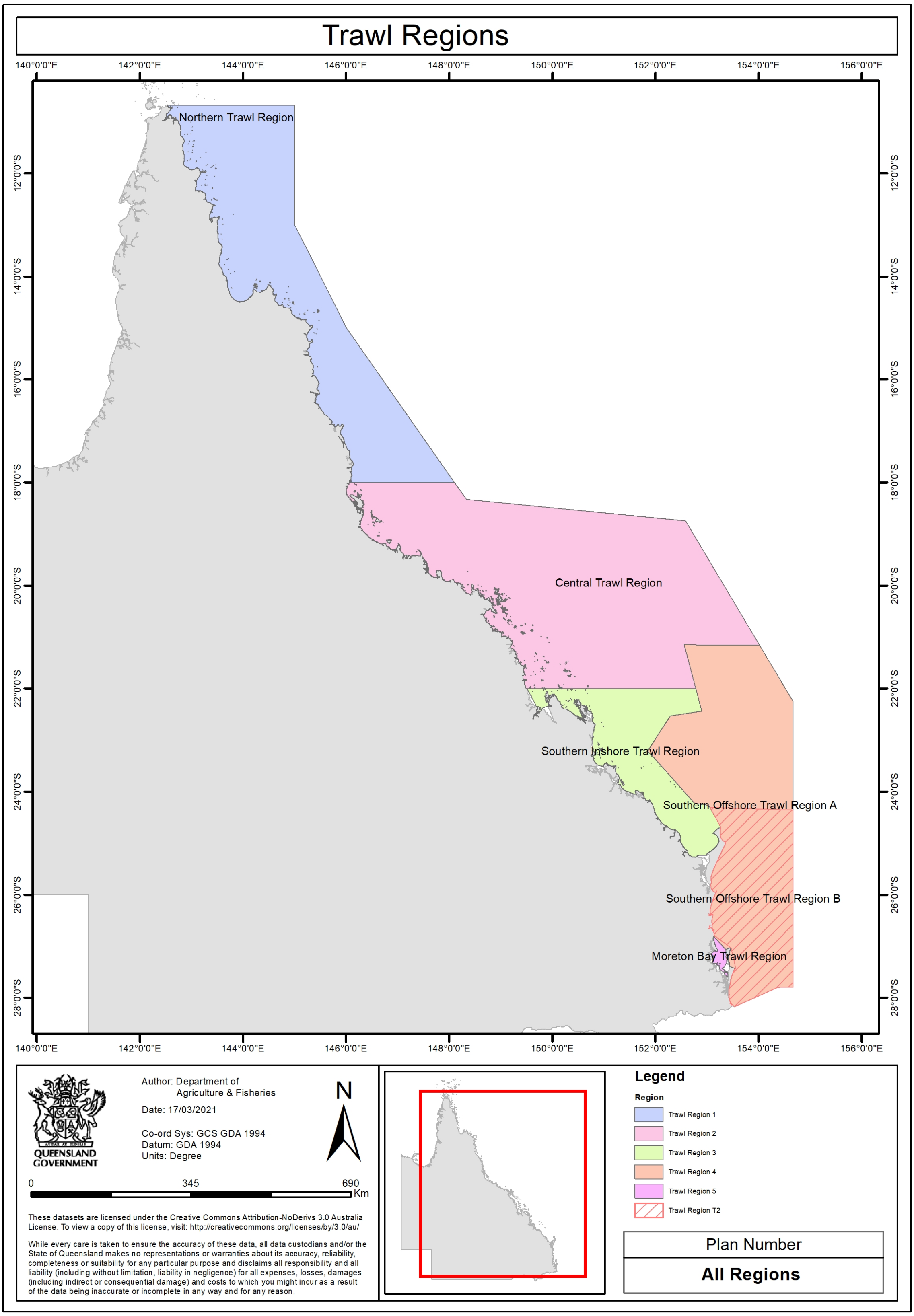

Figure 1.1: East coast trawl fishery divided into five management units (Department of Agriculture and Fisheries 2019)—the main saucer scallop fishing sector is the southern inshore trawl region, region 3, south of 22° S to Hervey Bay (shaded green)

Scallop spawning success and survival can vary depending on environmental conditions. Scallops normally spawn during winter and spring, and release eggs and sperm into the water where fertilisation takes place (Dredge 1981). Most scallops with a shell height greater than 9 cm can spawn during the season. By November, spawning is normally complete, and most scallops then allocate energy into growth before spawning again next winter.

Small scallop larvae hatch from the fertilised eggs. After about one day, larvae enter a pelagic phase and spatially disperse with ocean currents. Generally, scallops have a larval phase of up to 30 days. After this time, they settle to the sea floor. Once settled, the juvenile shells, known as 'spat', grow rapidly into juvenile scallop of 5 cm shell height (SH) and appear to create aggregations or beds of scallops. By about 12 months of age, they grow to about 9 cm shell height as adults, mature and spawn.

Otter trawling for scallops in Queensland is generally by vessels 15–20 m length. The vessels typically have main engines of 300–400 horsepower (HP) and tow nets (combined main nets plus try gear) up to 55 m wide at a speed of 2.3–2.6 knots (Yang et al. 2016). The main trawl nets are spread by kilfoil/lourve otter boards with 88 mm square mesh net cod-end for bycatch reduction device (BRD). In 2016–2018, about 100 vessels per year reported scallop harvest, compared to around 300 vessels per year in 1995–1997 (O'Neill et al. 2020).

Management of scallop fishing has varied over time (Table 1.1, O'Neill et al. (2020)). Harvests before 1987 had smaller minimum legal size (MLS) limits (commercial shell height, CSH, of less than 9 cm). From 1987, seasonal minimum legal sizes of 9 cm (CSH) and 9.5 cm (CSH) applied. A number of spatial closures have applied since 1997, including the current permanent closures, although these were fished rotationally from 2001 to 2016. As of November 2021 there was to be no take of scallops in the southern inshore and central trawl regions, the southern offshore trawl region remained open from 20 January to 1 May for scallop fishing in 2022.

Table 1.1: Management changes applied to saucer scallop in Queensland waters

Description	Date	Management change
Commerial shell height (CSH)	Pre-November 1980	No minimum legal size (MLS)
	November 1980	8 cm
	July 1984	8.5 cm
	October 1987	9 cm
	March 1989	9.5 cm April–October, 9 cm November–March
	May 1989	9.5 cm May–October, 9 cm November–April
	Post-May 2009	9 cm year-round
Net and mesh sizes	Pre-1984	No restrictions
	July 1984	7.5 cm mesh restriction
	Post-November 1984	8.2 cm mesh restriction, 109 m combined head and foot rope length restriction
	March 2015	8.8 cm square mesh cod-end
Daylight trawl	October 1987–December 1987	Daylight trawl ban
	Post-February 1989	Daylight trawl ban
Effort	November 2019	Annual effort cap of 118 635 eu (2145 boat-days) in region 3
	November 2020	Annual effort cap of 80 000 eu (1454 boat-days) in region 3
Closures	November 1988	Designated shucking areas
	February 1989	Three 10 × 10 minute closed areas
	May 1989	Closed areas removed
	1997–2000	3 permanently-closed 'scallop replenishment areas'
	September 2000	Southern closure (south of 22° S) 20th September–30th October annually
	January 2001	Scallop replenishment areas open rotationally to trawling
	January 2017	Scallop replenishment areas closed, and May to October whole-of-scallop-fishery closure
	November 2019	Additional southern closure (south of 22° S) November annually, no fishing 20 September–1 November
	November 2020	No take scallops 1 May–20 November south of 22° S or earlier if effort cap of 80 000 eu reached, no fishing 23 December–3 January
	November 2021	No take scallops in southern inshore and central trawl regions, southern offshore region open for scallop fishing 20 January–1 May

In 2018 and 2019 the Queensland Department of Agriculture and Fisheries and the University of Queensland conducted work to improve stock model predictions to estimate the current population size of saucer scallops and develop management procedures. Previous assessments estimated the spawning biomass at 5–10%, 9% and 15% in 2016, 2018 and 2022 respectively (Yang et al. 2016; O'Neill et al. 2020; Wortmann 2022).

A stock assessment was conducted in 2021 analysing data through to the end of the 2020 fishing year (Wortmann 2021), however it considered the southern inshore trawl region only, so it is not directly comparable.

This stock assessment estimates spawning biomass for region 3 (southern inshore trawl region) and region 4 (southern offshore trawl region) combined, in line with the 2016, 2018 and 2022 assessments. It includes updates to the input data but keeps the methodology in line with the 2018 assessment (O'Neill et al. 2020).

This assessment aims to determine current biomass relative to an unfished state, and current fishing pressure relative to the level that would maximise catches at equilibrium.

2 Methods

2.1 Data sources

Data sources included in this assessment are detailed in Table 2.1 and are described in more detail in the following sections. Data sources were used to determine catch rates, density of scallops for two age classes, and create annual retained catch estimates. Data sets were compiled by fishing year[1] and all references to year should be assumed to be fishing year. The assessment period began in 1956 up until and including 2022 based on available information.

Table 2.1: Data inputs for the population model

Type	Fishing year	Source
Commercial	1956–1987	Total annual meat weight harvest (Dredge 2006)
	1977–1987	Historical trawl (‘HTrawl’) catch rate data (O’Neill et al. 2005)
	1988–2021	Compulsory CFISH logbook data collected by Fisheries Queensland
	2022	Proportion of the 2021 CFISH logbook data
Fishery independent survey	October 1997–2000, 2017–2022	Agri-Science Queensland survey data FRDC project 2017-048 (Courtney et al. 2020)

2.2 Retained catch

Historical commercial catch data 1956–1987 was calculated from data from Dredge (2006). Section 3.1 of O’Neill et al. (2020) outlined the methods used to calculate the historical catch data. Ruello (1975) reported that the trawl fishery for saucer scallops commenced in the mid-1950s off the central Queensland coast, between 23° S and 25° S. Dichmont et al. (1998) reported that fishing of scallops commenced in the mid-1950s, when prawn trawlers worked out of Hervey Bay taking appreciable quantities.

Between 1956 and 1977 there were small amounts of scallop retained catch. This was catch data only, as effort data was not recorded then. The scallop fishery did not start seriously until the late 1960s when export markets for the product were identified. The fishery grew during the 1970s to a mature operation in the 1980s and may have been overexploited by the mid- to late 1990s (Dredge 1988). Regardless of the amount of scallop catch between 1956 and 1977, it was still retained catch and therefore, cannot be excluded in the scallop stock assessment as the stock was not in a virgin state.

While more than 90% of average annual landings from the Queensland fishery have been taken between 23° S and 25° S, grounds in the vicinity of Hydrographer’s Passage (22° S) and off Townsville (19° S) receive intermittent recruitment and occasionally produce substantial quantities of saucer scallops (Dredge 2006) (Appendix A.1). These areas do not form part of region 3 or region 4 and were not included in

[1] Fishing year was defined as November of the previous year until October of the named year. For example, fishing year label 2020 was from November 2019 to October 2020, where November was fishing month 1 and October was fishing month 12.

model input data. For these regions to be included in the stock assessment the fishery-independent surveys (French et al. 2021) would need to include these areas.

Commercial catch data 1988–2021 was from CFISH logbooks. The logbook system consists of daily retained catch (landed baskets of saucer scallops) from each individual fishing operator (license) since 1989. In addition to landed baskets, logbooks also record the location of the catch (30 minute or 6 minute grid identifier). The commercial catch data included catch from the SRAs and was from logbook records for baskets per fishing year per fishing month for region 3 and region 4. Commercial catch data for 2022 was not complete at the time of this assessment, therefore the commercial catch data in 2022 was calculated by multiplying the 2021 commercial catch data by 0.0667. This proportion was obtained by dividing the available retained catch from each month in 2022, although incomplete, by the retained catch from the corresponding month in 2021, then average the proportions across those months.

In the data extraction from CFISH logbooks for the 2020 stock assessment (up to October 2019, Appendix 6.1 in Wortmann et al. (2020)), there were catch records from the closed months of scallop fishing. These catch records were present in the current data extraction, as well as 60 baskets recorded in November 2019 which was closed to scallop fishing. As in Wortmann et al. (2020), any scallop catch recorded during a closure time was included in the retained catch data.

The CFISH logbooks recorded the number of baskets, and a conversion from number of baskets to meat weight was done using the formula in Table 2.2. The formula is a monthly formula, with baskets in January–March having a higher meat weight.

2.3 Density data

A fishery independent trawl survey estimated scallop densities (number of scallops per hectare) (French et al. 2021). The survey focused on scallops grouped by age (0+ or 1+, depending on their size) in October. Age group 0+ were for shell heights $<$ 7.8 cm, and age group 1+ were for shell heights $\geq$ 7.8 cm. The spatial abundance of the two age groups supplied provided insight on scallop recruitment of small shell, and on mortality rates of large scallop.

The scallop trawl survey was based on a stratified random design that was first implemented in 1997 (Dichmont et al. 2000). From 1997–2000 the survey was comprehensively implemented, but from 2001-–2006 the number of strata and sample sites were reduced, and the survey ceased in 2006. In 2017 the full survey design was reintroduced and included two additional strata in the southern part of the fishery (K'gari) (French et al. 2021).

Survey density data was done in region 3 only, including SRAs, for 1997–2000 surveys and in region 3 and region 4, including SRAs, for surveys after 2017. The age 0+ survey data informed recruitment in the model, thus recruitment from the SRAs was accounted for in the model.

Justification for the timing of the fishery independent survey comes from Dichmont et al. (2000). Early October was chosen to optimise the catch of recruits (less than 7.8 cm shell height) following the winter spawning (June–August), before the main fishing season. Early October has favourable seasonal weather conditions required for a trawl survey. Undertaking the survey in October also enhances the availability of vessels for chartering, as most vessels are not fishing at this time due to a regional trawl closure. The timing of the survey was centred around the neap tides to minimise the low scallop catch rates during the strong tidal currents associated with spring tides.

The stock assessments in O'Neill et al. (2020) and Wortmann et al. (2020) used mean scallop densities from each October survey. They were estimated using local kriging (geo-statistical interpolation) models on the survey data (O'Neill et al. 2020). The stock assessments in Wortmann (2021) and Wortmann (2022), as well as this assessment, used new methods from French et al. (2021) to derive mean scallop densities using a Quasi-Poisson generalised linear model (GLM) with the predictive variables year, strata, lunar phase and time-of-night. A detailed description of these methods may be found in French et al. (2021).

The survey data from strata T29 and T30, and data collected during the day for the years 1997–2000 were excluded from GLM. This is due to the calibration beign complete during the day in sites with known scallop aggregations in the early years, wheres for the later years (2017–2022) the calibration was done in randomly selected sites, thus inflating the early survey density estimates. This filtering was not applied prior to the 2021 stock assessment.

The adjusted means from the GLM provided a more robust and reliable index of abundance for detecting change and trends in the scallop population size. The adjusted means were similar to the means from local kriging in O'Neill et al. (2020) and Wortmann et al. (2020). Predictions were derived for three groups:

- 0+ age group for scallop sizes $<$ 7.8 cm SH
- 1+ age group for scallop sizes $\geq$ 7.8 cm SH
- Commercial legal sized scallops $\geq$ 8.8 cm SH (8.8 cm SH was equivalent to 9 cm in commercial shell height measurement).

The predictions were for the saucer scallop fishing grounds between Yeppoon and K'gari, including scallop replenishment areas, in the month of October for the years 1997–2000 and 2017–2022. Surveys in the years 2001–2006 were from scallop replenishment areas only and were excluded from the input data for this stock assessment.

The densities were scaled up by a trawl efficiency factor of 0.3 (Wortmann et al. 2020).

Detailed results from the latest survey, completed in October 2022, are presented in Appendix D.

2.4 Commercial catch rates

The datasets and methods for the catch rate standardisations were collated and developed from the projects Yang et al. (2016), O'Neill et al. (2020), Wortmann et al. (2020) and Wortmann (2021).

Fishing trips do not differentiate between scallop and bug trips, and all scallop catch data was used whether fishing for bugs or scallops to calculate the scallop catch rate. A target factor for bugs or scallops was explored in the previous stock assessment Wortmann (2022). The definition of whether a fishing day was targeting bugs or scallops was based on weight caught of the group, and the results using this definition did not change the catch rate trend. The new trawl commercial fishing logbook will have the option for fishers to nominate scallop and bug fishing trips.

Low scallop catch rates, even if the fishers were targeting bugs cannot be omitted, because it still provides important information on the stock biomass. Furthermore, excluding low scallop catch rate data may artificially inflate the scallop catch per unit effort.

A list of the filters applied to the CFISH data to obtain the data for catch rate standardisation are listed in Appendix A.2. When the SRAs were open and logbook records recorded catch in the SRAs, these records were included in the standardisation. Area was a factor (Yeppoon, Bustard Head, Hervey Bay and K'gari) in the standardisation model and influenced the catch rates.

The catch rate standardisations used the statistical application of linear mixed models (LMM) using restricted maximum likelihood (REML). The analyses used daily logbook information per vessel operation. The catch rate standardisation was programmed in Genstat (VSN International 2021).

As in previous projects, catch rates were standardised for changes in fishing power through time to account for shifts in the fleet's vessel-profile (e.g. changing number of higher versus lower catching vessels) and variation in gear technologies (e.g. engine sizes, net types, and the use of global positioning systems). Trends in vessel gears from 1988–2022 and changes in fishing power from gear changes, technology upgrades and hours fished from 1988–2022 are shown in Appendix A.

The catch rate standardisation followed analysis 3 and 4 in section 3.1 of O'Neill et al. (2020). The two analyses evaluated catch rates for 1988–2021 and 1977–2021. The 1977–2021 analysis used fishing power parameter estimates from the first 1988–2021 analysis. The catch rate data for 1977–1987 came from voluntary daily trawl logbook records by 30×30 minute grids. The data collections were from research projects prior to 1988, and known as the historical catch rate data or Htrawl. This dataset was based on 5–30% per year of fishers voluntary participation in the logbook program (O'Neill et al. 2005; Yang et al. 2016). Section 8.2.1.2 of Yang et al. (2016) gives a description of the Htrawl data. As 2022 data was not complete at the time of the assessment, the catch rates from 2021 were used as a proxy for the 2022 catch rates.

Catch rates were standardised for 1988–2021 (analysis 3 from O'Neill et al. (2020)) using:

$$\begin{aligned} log(baskets\ per\ boat\ day) = fishing\ year \times fishing\ month \times area + log(hours\ per\ boat\ day) + log(hp) + \\ log(speed) + sonar + gps + nettype + ggear + random(boat\ label\ code) \end{aligned} \tag{2.1}$$

where

- *area* = Yeppoon, Bustard Head, Hervey Bay, K'gari
- *hours* = hours fished
- *hp* = engine horsepower
- *ggear* = ground gear (drop chain, looped ground chain, drop rope with chain or other less used types)
- *nettype* = net type (twin, triple, quad or five gear).

The catch rates for 1988–2021 were standardised to a modern-day boat. The standardisation factors were:

- Use of GPS and sonar
- Net type of quad gear (Figure A.4)
- Ground gear of drop chain (Figure A.3)
- Hours fished equal to the average of log hours fished for 2007–2021 (12 hours) (Figure A.6)
- Engine power equal to the average 2021 engine power of 343 HP (Figure A.2)
- Boat that matched the maximum annual average boat effect—for this catch rate analysis, this was in 2007 (Figure A.7).

Catch rates were standardized for 1977–2021 using analysis 4 of O'Neill et al. (2020):

$$\begin{aligned} offsetlog = log(hp) * 0.3792 + sonar * 0.1450 + gps * 0.03512 + (nettype.eq.3) * 0.2791+ \\ (nettype.eq.4) * 0.2277 + (nettype.eq.5) * 0.2784 + (ggear.eq.3) * 0.07386+ \\ (ggear.eq.4) * -0.02462 + (ggear.eq.5) * -0.13147 \end{aligned} \tag{2.2}$$

$$lognoffset = log(baskets) - offsetlog \tag{2.3}$$

$$lognoffset = fishing\ year \times fishing\ month + log(hours\ per\ boat\ day) + +random(boat\ label\ code) + random(grid) \tag{2.4}$$

where

- The coefficients were estimated from the 1988–2021 catch rate standardisation model, a high positive coefficient means many scallops would be caught
- *ggear.eq.3* is looped ground chain
- *ggear.eq.4* is drop rope with chain
- *ggear.eq.5* is other less used types
- *nettype.eq.3* is triple gear
- *nettype.eq.4* is quad gear
- *nettype.eq.5* is five gear.

Catch rates for 1977–2021 were standardised to the same modern boats setting as above. Fishing year by month trend for January 1977 to October 2021 for region 3 and region 4 was calculated. The result focused on a single *fishing year* × *fishing month* catch rate index.

2.5 Natural mortality

Findings from the tagging study Courtney et al. (2022) indicated the natural mortality rate (M) was significantly higher than previously measured by Dredge (1985). The recent stock assessments (Wortmann et al. 2020; Wortmann 2021; Wortmann 2022) and this stock assessment included an updated estimate of M based on the logistic model developed in Courtney et al. (2022) (i.e. M = 1.461 per year or 0.1217 per month). The natural mortality was assumed constant. The effect of this increase in natural mortality from Dredges estimate was spawning biomass ratios approximately 2% higher.

2.6 Population model

The non-spatial model from O'Neill et al. (2020), Wortmann et al. (2020), Wortmann (2021), and Wortmann (2022) was used for this stock assessment. This model described the scallops as a single stock across region 3 and region 4 combined. No environmental effects were included. The model was an age-based population dynamic model that assessed scallops monthly from the fishing years 1956 to 2022, counting scallop age classes from one to 48 months (4-year life cycle), with a Beverton-Holt stock-recruitment relationship. The model accounted for the processes of scallop births, growth, reproduction and mortality in every fishing year-month. The model was written in MATLAB version 2022a (Mathworks 2020).

Number of scallops N_{ta}:

The number of scallops N_{ta} at age a at monthly time-step t was modelled with the following recursive equation,

$$N_{ta} = \begin{cases} R_t & \text{for } a = 1 \\ N_{t-1,a-1} \exp(-Z_{t-1,a-1}) & \text{for } a = 2, \dots, 48 \end{cases} \tag{2.5}$$

Note that N_{ta} represented the number of scallops at the beginning of time-step t; in addition, it also represented the number of scallops at the end of time-step $t-1$.

Recruitment number R_t:

The number of scallops recruited R_t at age group $a = 1$ at time-step t was defined as follows,

$$R_t = \frac{E_{y-1}}{(\alpha_k + \beta_k E_{y-1})} \exp(\eta_y)\phi_t, \tag{2.6}$$

where η_y was annual recruitment deviation of fishing year y and $\eta_y = 0$ for $y = 1956, \dots, 1987$.

Annual number of eggs E_y:

The number of eggs E_y produced in fishing year y was defined by,

$$E_y = 0.5 \sum_t \sum_a N_{ta} \times \text{Mat}_a \times \text{Fec}_a \times \text{Spawn}_t \tag{2.7}$$

- Mat_a was the proportion of scallop mature at age a.
- Fec_a was the number of eggs produced by a scallop at age a.
- Spawn_t was the 12 month spawning pattern, defining proportion of annual egg production produced at time-step t. It was important to note that the sum of Spawn_t over the 12 fishing months of fishing year y was equal to 1.
- The value 0.5 represented the assumption that half of N_{ta} were females.

Recruitment pattern ϕ_t:

For each fishing month t, within each fishing year, the proportion of recruitment was modelled as follows,

$$\phi_t = \exp(\kappa \cos(2\pi(m_t - \theta)/12)) / \sum_{m_{t'}=1}^{12} \exp(\kappa \cos(2\pi(m_{t'} - \theta))) \tag{2.8}$$

where m_t was the fishing month at time-step t in fishing year y and ranged from 1 (November) to 12 (October). For each fishing year, the sum over 12 months was equal to $\sum_t \phi_t = 1$. Notice that Equation 2.8 is a modification version of the von Mises distribution for discrete variables, and circumvents the use of the modified Bessel function of order 0 to reduce computation cost.

Survival rate $\exp(-Z_{ta})$:

Survival rate $\exp(-Z_{ta})$ at age a at monthly time-step t was the product of the survival rates from natural mortality M and harvest rates u_t. The mathematical expression was written with the following form:

$$\exp(-Z_{ta}) = \exp(-M)(1 - v_{ta}u_t) \tag{2.9}$$

The equation factors represented survival rates from natural mortality and fishing, respectively.

Harvest rate u_t:

$$u_t = C_t / (B_t^{(1)} b_t^{-1}), \tag{2.10}$$

where C_t represented the total harvest (retained catch in baskets) at time-step t, and b_t was the converter for basket and meat weight.

Midmonth exploitable biomasses—forms $B_t^{(1)}$ and $B_t^{(2)}$:

$$B_t^{(1)} = \sum_a N_{ta} w_a v_{ta}^* \exp(-0.5M), \tag{2.11}$$

$$B_t^{(2)} = \sum_a N_{ta} w_a v_{ta}^* \exp(-0.5M)\sqrt{1-u_t} \tag{2.12}$$

$B_t^{(1)}$ and $B_t^{(2)}$ were presented in kilograms. The difference between the two was that $B_t^{(1)}$ expressed the midmonth exploitable biomass before fishing and $B_t^{(2)}$ the exploitable biomass in the middle of a fishing pulse. $B_t^{(1)}$ was used to calculate harvest rates and should be larger than C_t. $B_t^{(2)}$ was used to connect catch rates. Use of equation $B_t^{(1)}$ with fixed last year values of v_{ta}^*, described biomass trends without MLS changes.

Vulnerability to fishing—v_{ta} and v_{ta}^*:

Vulnerabilities v_{ta} and v_{ta}^* of age a at time-step t incorporated the probability density of length $f_a(\ell)$ at age a, selectivity of nets $v_t(\ell)$, and selectivity of tumbler $G_t(\ell, \mathrm{MLS}_t)$ with respect to minimum legal size MLS_t. v_{ta} also included discard mortality d_t. v_{ta}^* was used to formulate midmonth exploitable biomasses (Equations 2.11 and 2.12) and v_{ta} was used for survival rate of Equation 2.9.

$$v_{ta} = \int_\ell f_a(\ell) v_t(\ell)(G_t(\ell, \mathrm{MLS}_t) + (1 - G_t(\ell, \mathrm{MLS}_t))d_t)d\ell, \tag{2.13}$$

$$v_{ta}^* = \int_\ell f_a(\ell) v_t(\ell) G_t(\ell, \mathrm{MLS}_t) d\ell. \tag{2.14}$$

Specifically, for the period prior to 1981, there was no minimum legal size, and $v_{ta} = v_{ta}^*$, that is,

$$v_{ta} = v_{ta}^* = \int_\ell f_a(\ell) v_t(\ell) d\ell. \tag{2.15}$$

Fishery data indicators—midmonth catch rates $c_t^{(f)}$, density for 0+ $c_t^{(s_{0+})}$ and 1+ $c_t^{(s_{1+})}$:

$$c_t^{(f)} = q_t B_t^{(2)} b_t^{(-1)}, \tag{2.16}$$

$$c_t^{(s_{0+})} = \frac{q^{(s_{0+})}(\sum_{a=1}^{48} N_{ta} \exp(-0.5M) P_a(\ell < 78mm))}{A}, \tag{2.17}$$

$$c_t^{(s_{1+})} = \frac{q^{(s_{1+})}(\sum_{a=1}^{48} N_{ta} \exp(-0.5M) P_a(\ell \geq 78mm))}{A} \tag{2.18}$$

where q_t was the catchability at time-step t, $q^{(s_{0+})}$ and $q^{(s_{1+})}$ were the catch efficiency for 0+ and 1+ scallop, respectively, and A was the area of region 3. The units of $c_t^{(f)}$ was baskets per standardised boat-day, and $c_t^{(s_{0+})}$ and $c_t^{(s_{1+})}$ were numbers per hectare. Catchability q_t was modelled to reflect the closure effect (see model parameters). We note that $q^{(s_{1+})}$ was a fixed setting at 0.3 (Wortmann et al. 2020).

Fishery log standardised catch rates or log survey densities:

$$l = \frac{n}{2}(\log(2\pi) + 2\log(\sigma) + (\hat{\sigma}/\sigma)^2), \tag{2.19}$$

where $\sigma = \max(\hat{\sigma}, \sigma_{\min})$, $\sigma_{\min}$ was the standard error from the LMM (REML) log predictions $\hat{c}$ of catch rates c or densities, $\hat{\sigma} = \sqrt{\sum(\log(c) - \log(\hat{c}))^2/n - 1}$, and n was the number of monthly data.

h steepness:

$$l_h = \begin{cases} 0.5(\frac{\xi - \log(19)}{1.2})^2 & \text{, if } \xi > \log(19) \\ 0.5(\frac{\xi - \log(19)}{1.2 * 0.3333})^2 & \text{, if } \xi < 0 \end{cases} \tag{2.20}$$

(O'Neill et al. 2018)

θ:

$$l_\theta = 0.5(\frac{\theta - 5}{0.5})^2, \text{ if } \theta > 15 \text{ or } \theta < 0 \tag{2.21}$$

κ:

$$l_\kappa = 0.5(\frac{\kappa - 20}{0.5})^2, \text{ if } \kappa > 20 \tag{2.22}$$

harvest rate u:

$$l_u = 0.5 \sum(\frac{\log(C_t + 0.1) - \log(\frac{B_t^{(1)}}{b_t} * 0.8)}{0.005})^2, \text{ if } u \geq 0.8 \tag{2.23}$$

Log recruitment deviations η_y for $y = 1988, ..., 2020$:

$$nssRec = 2020 - 1988$$

$$sigmaRhat = \sqrt{\frac{\sum(\eta_y)^2}{nssRec}}$$

$$sigmaR = \min(\max(sigmaRhat, 01), 0.2)$$

$$l_r = \frac{nssRec}{2}(\log(2\pi) + 2\log(sigmaR) + (\frac{sigmaRhat}{sigmaR})^2)$$

Recruitment parameters to ensure log deviations sum to zero with standard deviation. $\eta = \xi e$, where e = zeros(nparRresid, nparRresid+1);

for $i = 1 : nparRresid$

$hh = \sqrt{(0.5 * i)./(i + 1)}$

$e(i, 1 : i) = -hh./i$

$e(i, i + 1) = hh$

end

$e = e./hh$

ξ were the estimated parameters known as barycentric or simplex coordinates, distributed $NID(0, \theta)$ with number nparRresid = number of recruitment years – 1 (Möbius 1827; Sklyarenko 2002). e was the coordinate basis matrix to scale the distance of residuals (vertices of the simplex) from zero (O'Neill et al. 2011).

2.6.1 Model assumptions

Notations to represent time and scallop age were:

- Fishing year y started from 1956 and finished in 2022. Fishing year y was defined as a time interval starting from November of calendar year $y-1$ to October of calendar year y.
- Population dynamics were presented in monthly time steps t from 1 to 804 (i.e. 12 months × 67 fishing years).
- Scallop ages were stratified into 48 months denoted by a=1,...,48. Saucer scallops were assumed to live for up to four years of age.

2.6.2 Model parameters

Parameters used in the model are listed in Table 2.2. Attempts were made to estimate as many of the parameters as possible and not fix them outside the model.

Table 2.2: Population model parameters and definitions

	Equations and values	Notes
Known		
ℓ_a	$\ell_a = 104.587(1-\exp(-0.159a))$	Shell height (length, mm) at age a. The estimate of standard deviation of the error term was 2.285 mm (Campbell et al. 2010).
$f_a(\ell)$		The normal probability density of length at age a, with mean ℓ_a and variance 2.2852.
$P_a(\ell \leq L)$	$\int_0^L f_a(\ell) d\ell$	The probability of length less than or equal to L at age a.
Mat_ℓ	$\text{Mat}_\ell = \frac{\exp(-8.72+0.1085\ell)}{1+\exp(-8.72+0.1085\ell)}$	Proportion mature at length l, estimated on Dredge (1981) data. For the data, the maturity asymptote was less than one.
Mat_a	$E_a(\text{Mat}_\ell) = \int f_a(\ell)\text{Mat}_\ell d\ell$	Proportion mature at age a, based on Mat_ℓ and $\ell_a \sim N(\ell_a, 2.285^2)$.
Fec_a	$\zeta_a = 3220.708\ell_a^{1.354}$	Fecundity of shell height at age a (Dredge 1981; O'Neill et al. 2005), used in Equation 2.7 to produce annual number of eggs.
Spawn_t	0.0072, t ∈ November 0.0000, t ∈ December 0.0144, t ∈ January 0.0288, t ∈ February 0.0899, t ∈ March 0.1331, t ∈ April 0.1403, t ∈ May 0.1439, t ∈ June 0.1439, t ∈ July 0.1403, t ∈ August 0.0863, t ∈ September 0.0719, t ∈ October	Monthly spawning pattern (Dredge 1981; O'Neill et al. 2005), used in Equation 2.7 to produce annual number of eggs.

Continued on next page

Table 2.2 – *Continued from previous page*

	Equations and values	Notes
w_a	$w_a = 1.259 \times 10^{-9} \ell_a^{3.485}$	Meat weight (kg) at age a (O'Neill et al. 2005), used in Equation 2.11 and 2.12.
b_t	6.5, t ∈ November 7, t ∈ December 7, t ∈ January 7.5, t ∈ February 7, t ∈ March 6.5, t ∈ April 6, t ∈ May 5, t ∈ June 5, t ∈ July 5, t ∈ August 5.5, t ∈ September 6, t ∈ October	Baskets to meat-weight conversion (kg per basket) (O'Sullivan et al. 2005), used in Equation 2.10 and 2.16.
$v_t(\ell)$	Logistic retention curves $v_t(\ell) = \frac{\exp(a_t + b_t \ell)}{1+\exp(a_t + b_t \ell)}$ Prior to November 2015, $a_t = -11.287$ and $b_t = 0.2412$. These values represented 88 mm diamond mesh with a Turtle Excluder Device (TED) After November 2015, $a_t = -7.9716$ and $b_t = 0.1136$, for 100 mm mesh with TED and a square-mesh cod-end.	See Figure 9–4 in Campbell et al. (2010) for 88 mm diamond mesh and TED (in brown colour) and 100 mm mesh with TED and a square-mesh cod-end (in blue colour). In effect, Courtney et al. (2008) figures 1 and 3 suggested selectivity had not changed

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Table 2.2 – *Continued from previous page*

	Equations and values	Notes
$G(\ell, \mathrm{MLS}_t)$	List of MLS_t imposed: • No MLS prior to November 1980. • 80 mm: November 1980 to October 1984. • 85 mm: November 1984 to October 1987. • 90 mm: – November to April in the period of November 1987 to December 1999. – January to April in the period of January 2000 to October 2004. – November to April in the period of November 2004 to October 2009. – November 2009 to October 2018. • 95 mm: – May to October in the period of November 1987 to December 1999. – May to December in the period of January 2000 to October 2004. – May to October in the period of November 2004 to October 2009.	Probability of retention by a tumbler (Campbell et al. 2010). Tumbler use was sporadic in the 1970s, but was utilised from late 1980.
d	3.3%	Discard mortality (Campbell et al. 2010).
A	1 256 473.72 (Region 3) + 231 445.4 (Region 4)	Area from monthly TrackMapper effort maps for January 2000 to April 2018, where fishing effort > 1 hour. Measured in hectares.
Unknown		
R_0 and h	$\alpha_k = E_0(1-h)/(4hR_0)$, $\beta_k = (5h-1)/(4h)$, $R_{0,k} = \exp(\gamma) \times 10^9$, $h = \frac{1+\exp(\xi)}{5+\exp(\xi)}$.	R_0 was recruitment in virgin years prior to fishing. E_0 was the equilibrium total egg production in virgin years, from Equation (3). h was steepness defined as a fraction of R_0 at 20% of the egg production of the population in virgin years. h is in the interval [0.2, 1].

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Table 2.2 – *Continued from previous page*

	Equations and values	**Notes**
κ and θ		θ and κ were parameters of centre location and concentration of Equation 2.8.
$\exp(-M)$	The survival rate of monthly natural mortality M	Monthly natural mortality is equal to 0.1217 according to the tagging study of Courtney et al. (2022).
q_t	Scallop catchability composed of three components with the form: $\exp(\gamma_q + \gamma_{jan}\delta_t + \gamma_s \cos(\frac{2\pi t}{12})) \times 10^{-7}$, where; δ_t was the indicator function of t with value 1 when time-step t was at the month of closure open (i.e. January, fishing month 3) of fishing years 2002–2016; γ_{jan} was the associated coefficient; γ_s was the seasonal effect of the 12-month cycle at phase equal to November (i.e. fishing month 1).	Catchability at time-step t. Note that the seasonal effect γ_s was set to zero in the current analysis.
$q^{(s_{0+})}$	$q^{(s_{0+})} = \exp(\gamma_{q^{(s_{0+})}})$	Catchability of 0+ scallop.

2.6.3 Parameter estimation

The parameter estimation process consisted of a maximum likelihood (ML) step followed by Markov chain Monte Carlo sampling (MCMC). The maximum likelihood step used MATLAB global optimisation, followed by a customised simulated annealing program to find and check the parameter solutions and estimate the parameter covariance matrix. The maximum likelihood step was effective for identifying optimal estimates for the negative log-likelihood (combined -LL fitting functions). The simulated annealing started from a -LL scaling factor of 100 and then reduced to 10, 1, 0.1 and finally 0.01. For each scaling factor, the annealing process ran for 2 thousand iterations of each parameter. The covariance matrix was built from the differences in the negative log-likelihood with each parameter jump. A customised MCMC followed on from the simulated annealing using a -LL scaling factor of one with fixed covariance. The MCMC used parameter-by-parameter jumping following the Metropolis-Hastings algorithm (Metropolis et al. 1953; Hastings 1970). The final parameter distributions were for 200 000 posterior MCMC samples thinned from one solution stored per 100 samples. MCMC parameter traces were reviewed.

All three fitting procedures (MATLAB optimisation, custom simulated annealing, and custom MCMC) confirmed model convergence and parameter estimates. The three procedures ensured checking and consistency in model fitting.

The model estimated an indicator of scallop spawning biomass abundance for region 3 and region 4 and reference points.

Reference points were calculated to a standardised boat-day according to a modern day vessel, defined by a boat with 344 HP, fishing 12 hours a night, with sonar, GPS, quad gear and drop chain, and equal to the maximum average fleet profile. Overall, the boat settings equated to around 55 standardised hull units (effort units = standardised days × standardised hull units (O'Neill et al. 2006)). Reference point estimates assumed the 2021 pattern of monthly fishing. The estimates for the equilibrium reference points were medians from MCMC, with 95% confidence intervals calculated.

3 Results

3.1 Model inputs

3.1.1 Retained catch estimates

Before 2002, annual retained catch estimates were normally greater than 700 t of meat weight per fishing year, and peaked in 1993 at over 1800 t (Figure 3.1). Since 2011, annual retained catch estimates were mostly less than 400 t. Retained catch of legal sized scallops in the 2019, 2020, 2021 and 2022 fishing years were 256 tonnes, 255 tonnes, 196 tonnes and 13 tonnes (meat weight) respectively for the management stock in region 3 and region 4 combined.

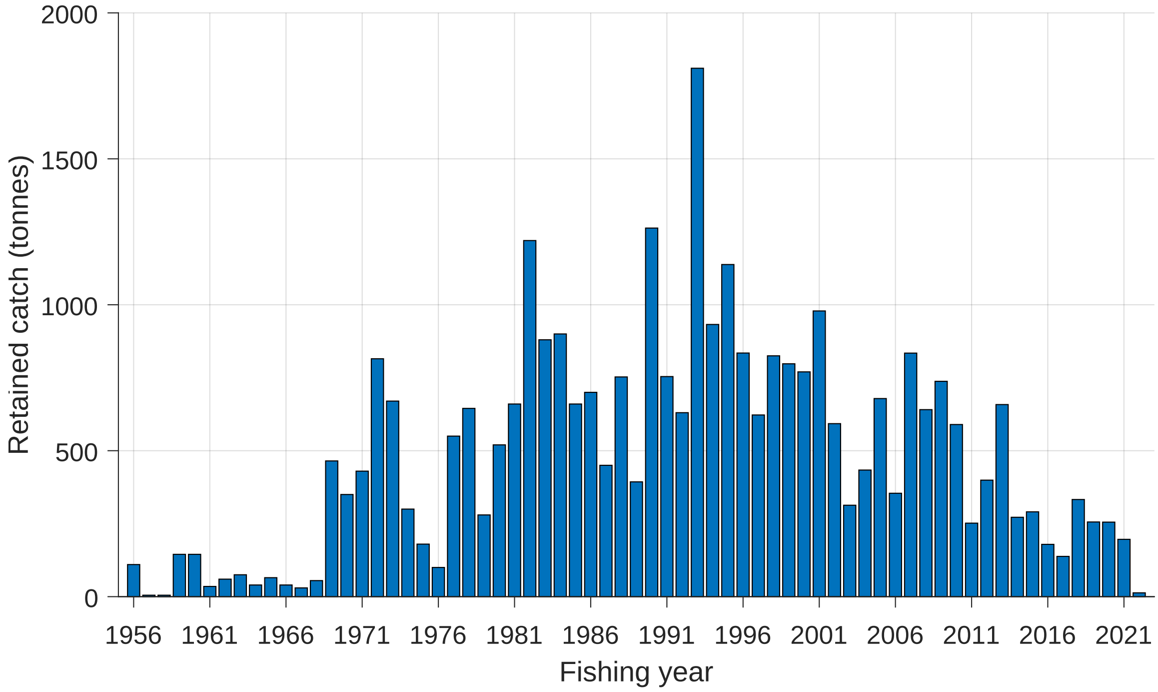

Figure 3.1: Annual estimated saucer scallop harvest (retained catch) 1956–2022

Figure 3.2 shows the typical seasonal change in scallop retained catch, with scallop catches by month for the period 1956–2022. Between 1956 and 1970, a very small amount of retained catch was recorded. Since 2002, clear spikes in retained catch occurred in the months of November–January. In the 2022 fishing year, 74% of the scallop retained catch was taken in November and December 2021.

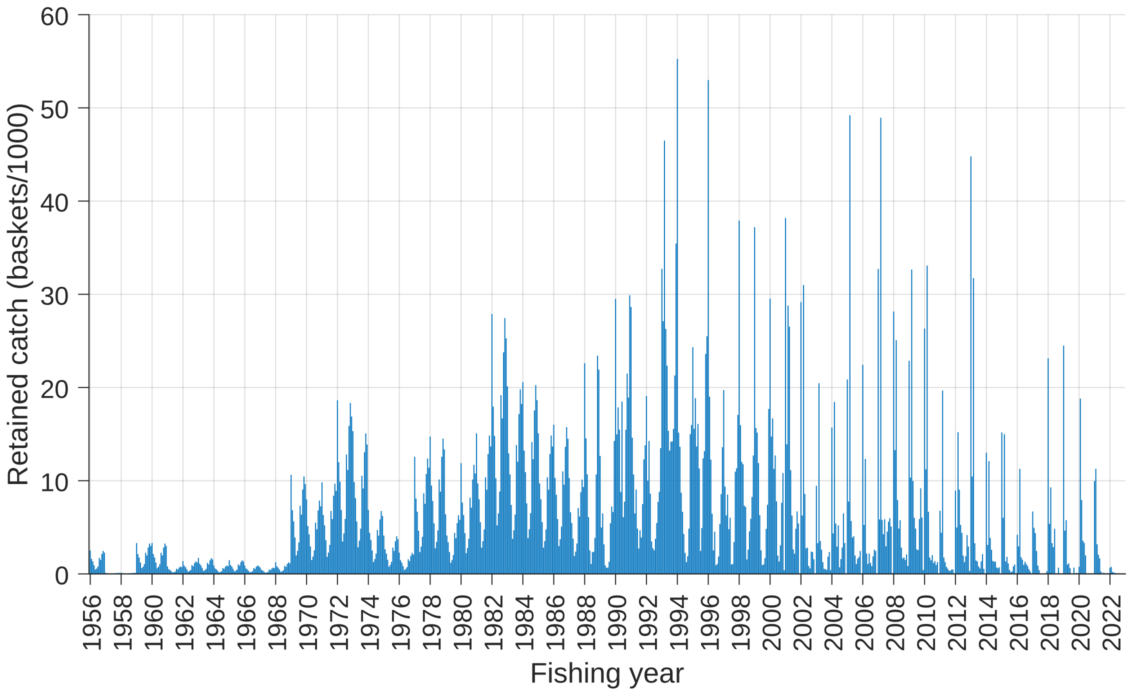

Figure 3.2: Monthly estimated saucer scallop harvest (retained catch) 1956–2022

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Harvest input data for the model was the number of baskets by fishing month and fishing year (Figure 3.2). The graph in Figure 3.1 applied a conversion formula (Table 2.2) to summarise the harvest by meat weight by fishing year.

3.1.2 Standardised catch rates

Abundance measures of standardised catch rates of legal sized scallop for region 3 and region 4 combined were on average 5 baskets per boat day for November 2021–January 2022 and went up to 17 baskets per boat day in February 2022 (Figure 3.3). The 95% confidence intervals on catch rates were generally in the range of ±14–21 baskets per boat day pre-1988, and ±3 baskets per boat day thereafter.

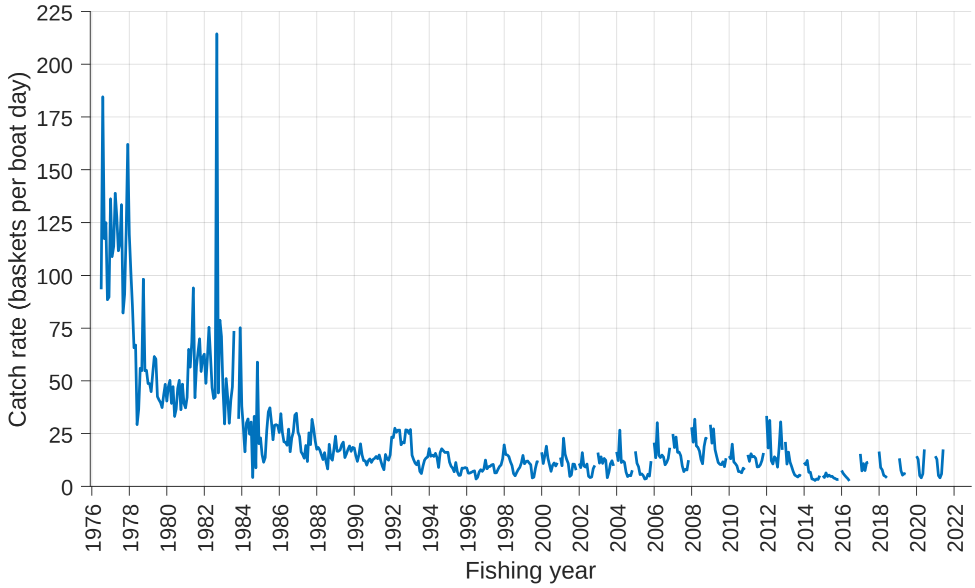

Figure 3.3: Standardised monthly catch rates from 1977 to 2022

3.1.3 Survey estimates

Scallop density (number of scallops per hectare) from the October survey decreased from 2021 to 2022 for age 0+, age 1+ and legal sized groups (Figure 3.4). For age group 0+ the estimated 2022 density was 12 scallops per hectare (down from 16 in 2021), for age group 1+ the estimated 2022 density was 12 scallops per hectare (down from 56 in 2021) and for legal sized group the estimated 2022 density was 10 scallops per hectare (down from 45 in 2021).

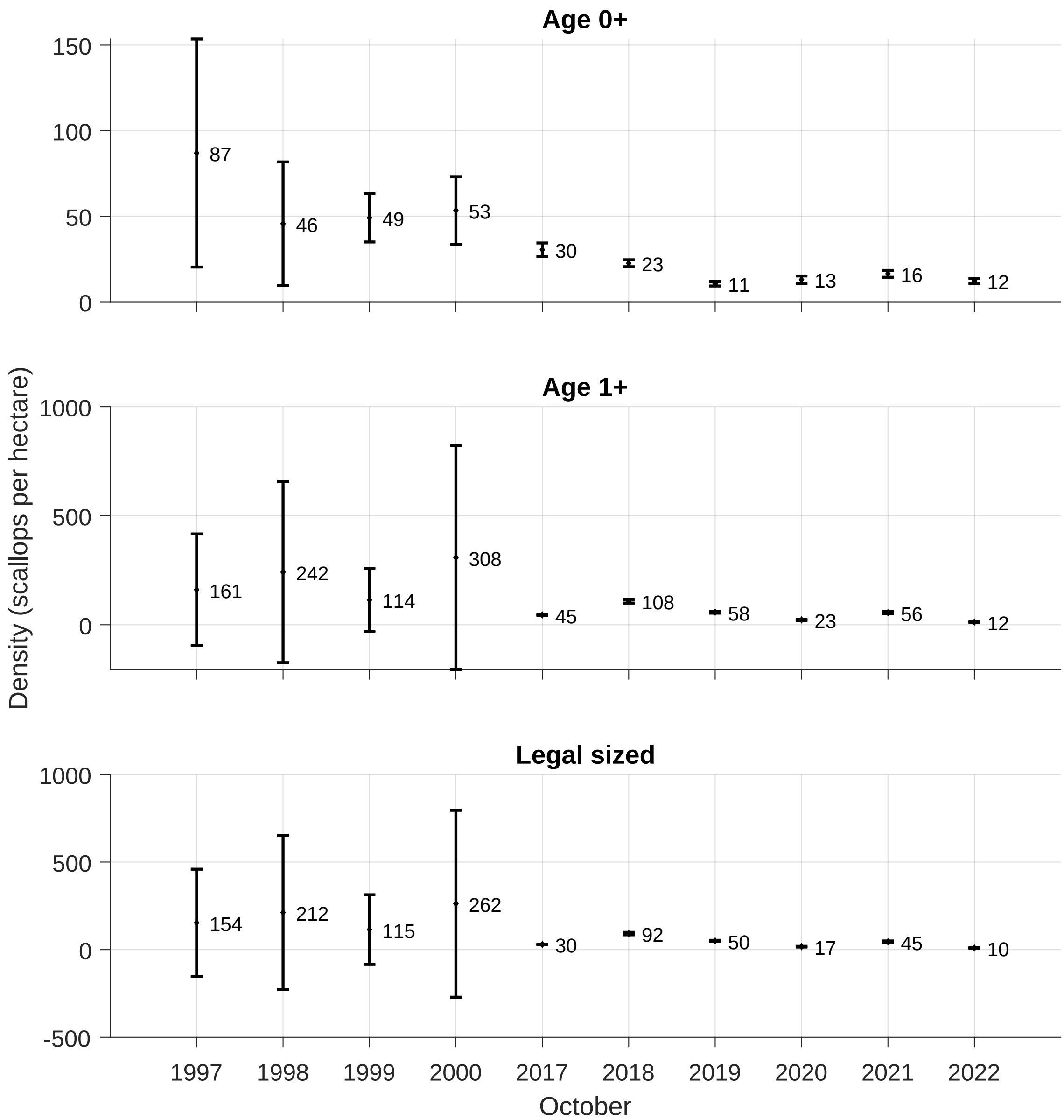

Figure 3.4: Annual mean modelled densities by year for age 0+, 1+ and legal sized saucer scallops

3.2 Model outputs

3.2.1 Model parameters

Parameters estimated in the model are listed in Table 3.1. Where possible parameters were estimated within the model. MCMC parameter distributions are shown in Figure B.5 and the negative log likelihood MCMC trace is shown in Figure B.6

Table 3.1: Parameter estimates for the six main parameters from the median MCMC parameters

Parameter	Estimated value (s.e.)
Virgin recruitment R_0	2.229×10^9 (0.005×10^9)
Steepness h	0.233 (2×10^{-4})
Amplitude of seasonality a	0.303 (0.001)
Closure effect on January q_{Jan}	0.208 (0.002)
Von Mises mode of monthly recruitment θ	1.777 (0.0093)
Von Mises variance of monthly recruitment κ	0.992 (0.0048)

3.2.2 Biomass

The estimated 2022 spawning biomass was 15% of unfished levels, with 95% confidence interval of 10–25% (Figure 3.5). The fish down of the biomass in the early years was minimal (in 1970 the estimated spawning biomass was at 90% of unfished spawning biomass in 1956).

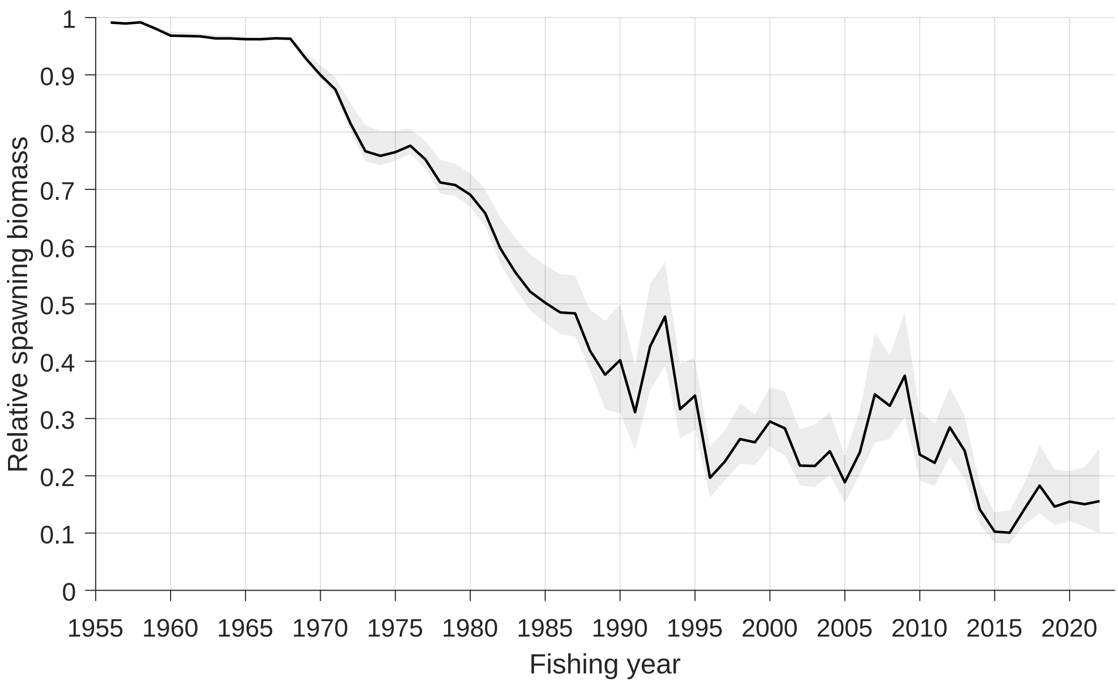

Figure 3.5: Annual spawning biomass ratio (± 95% CI) from 1956 to 2022

While the biomass ratio provides an indication of where the stock is, the fishing pressure ratio provides an indication of where the stock is heading. This is calculated as the yearly fishing pressure divided by the fishing pressure that would maximise catch indefinitely, a quantity known as F_{MSY}. Fishing at F_{MSY} eventually results in a biomass of B_{MSY}, a yearly biomass divided by B_{MSY} is another way to report the biomass ratio. These three quantities—biomass relative to unfished biomass, fishing pressure relative to F_{MSY}, and biomass relative to B_{MSY}—provide a stock status summary (Table 3.2; Figure 3.6).

Table 3.2: Stock status indicators for saucer scallop in 2022

Indicator	Estimate	Range
Biomass ratio (relative to unfished)	15%	10%–25%
Fishing pressure ratio (relative to F_{MSY})	11%	8%–15%
Biomass ratio (relative to B_{MSY})	35%	18%–52%

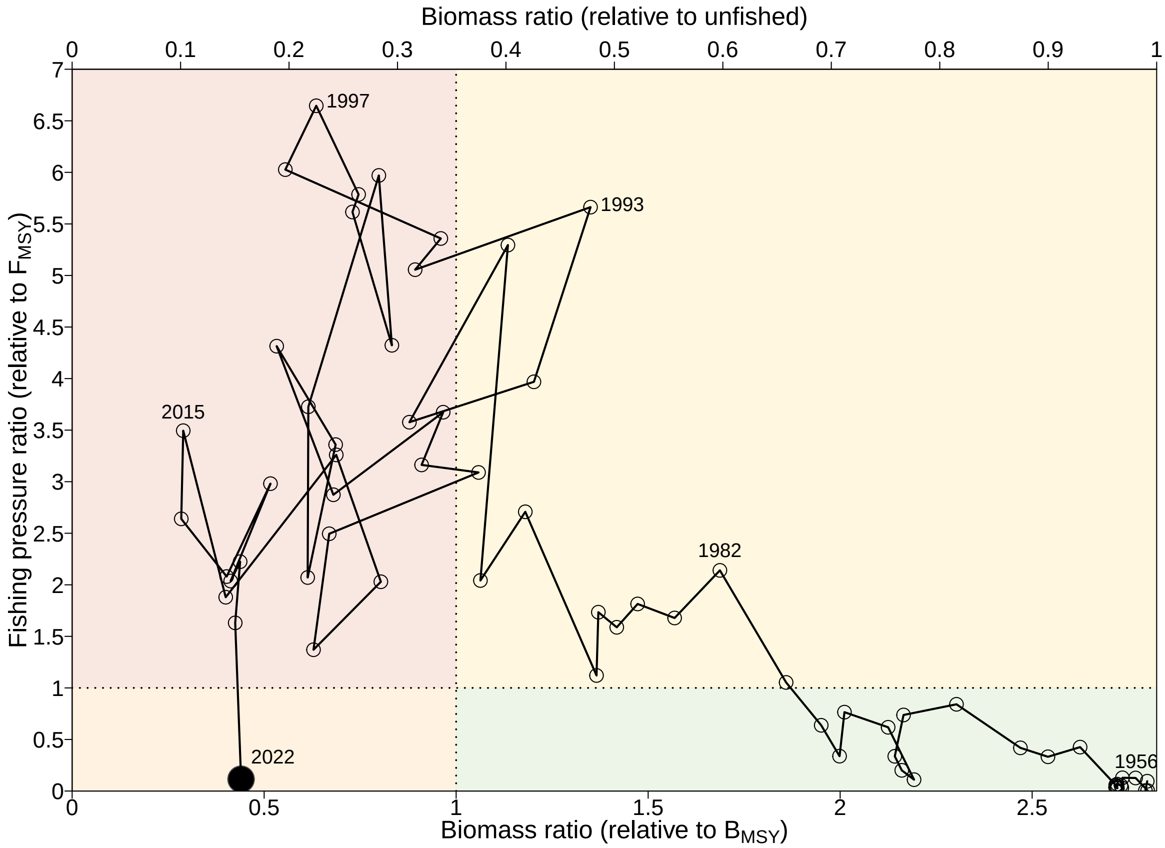

Figure 3.6: Stock status indicator trajectory for saucer scallop

The equilibrium yield (catch) informs on the productivity of the stock at different biomass levels (Figure 3.7). For saucer scallop the maximum equilibrium yield is achieved at a biomass level of around 44% of unfished biomass.

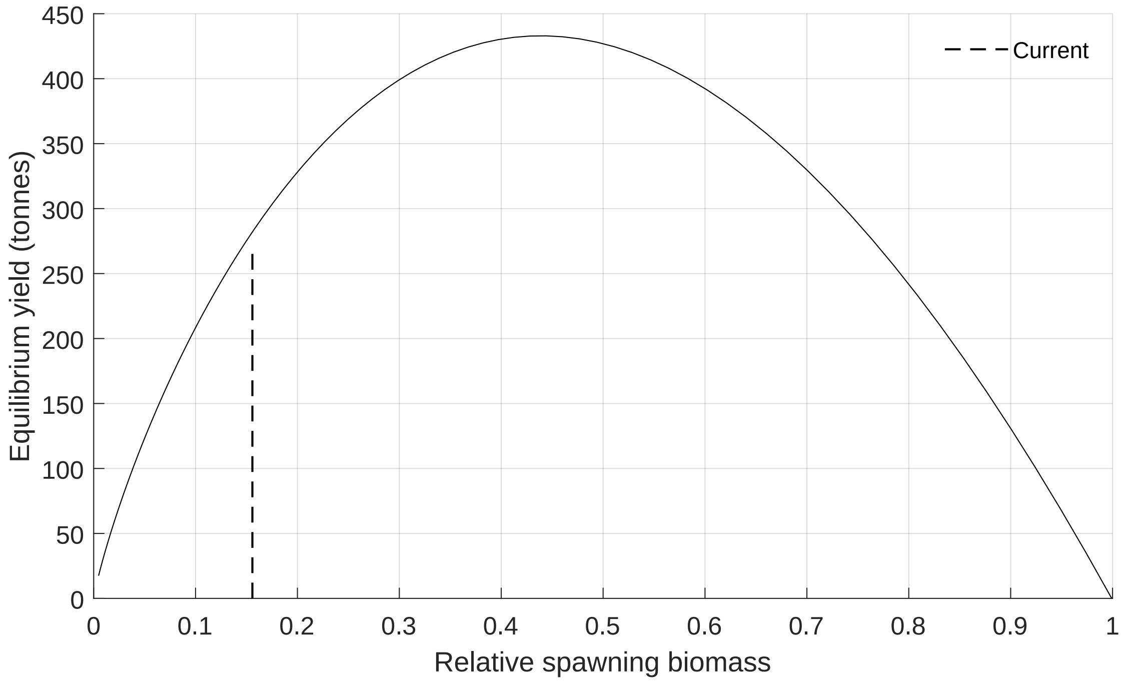

Figure 3.7: Equilibrium yield curve for saucer scallop

4 Discussion

4.1 Stock status

This assessment was the fifth assessment of the Queensland east coast Ballot's saucer scallop. Results from this assessment suggested the saucer scallop population declined between 1956 and 2016 to 10% unfished biomass. The results suggest the population level in 2022 for region 3 and region 4 was estimated to be 15% unfished spawning biomass.

4.2 Performance of the population model

There was model convergence (maximum likelihood estimates), and satisfactory goodness of fit to the trends in data. The model could not predict all catch rates or densities perfectly. This indicates some variance in the data remained unexplained. Estimates of steepness were close to the theoretical (linear) low limit of 0.2 and estimates of steepness and virgin recruitment were highly correlated.

One limitation of the model is that it is non-spatial and therefore unable to represent partial or asymmetric connectivity between the aggregations. Oceanographic modelling suggests that the scallop aggregations off K'gari and further south may be unable to contribute recruits back to the rest of the stock (Courtney et al. 2015; O'Neill et al. 2020). The precise impact of this is unclear without an explicitly spatial model, however it does suggest that the confidence intervals should be treated as underestimates.

4.3 Environmental influences

Statistical analyses in O'Neill et al. (2020) focused on measuring associations between catch rates of scallops and two variables: sea surface temperature (SST) and chlorophyll (Chl-a). Above average winter SST was negatively associated with scallop catch rates during the next season. Chlorophyll associations were inconsistent.

Results in O'Neill et al. (2020) showed significant effects of rising winter SST on natural mortality. However, it was unclear if this relationship was a primary cause of the scallop population decline, or a coincidental long-term association. The SST data were confounded with abundance, with SST rising at the same time that abundance was falling. As a result, any change in abundance maybe may have been overly ascribed to SST, rather than to other elements such as another undocumented environmental effect, or a greater effect of fishing than the model estimated.

In addition, the scale of increase in sea surface temperatures (SST anomalies) over years was not large (up to one degree Celsius), and Queensland scallops have not suffered high sea surface temperature anomalies between two and four degrees Celsius like experienced in Western Australia in 2010–2011 which had a catastrophic impact on scallops.

The modelled consequence of increased SST in O'Neill et al. (2020) was for reduced scallop survival, abundance and fishery yield. This result, in the context of future fishery management and harvest strategies, suggested effort control rules might need allowance for high natural mortalities.

4.4 Recommendations

4.4.1 Monitoring

The annual fishery independent abundance surveys to validate stock status and to optimise management procedures need to continue. The importance of regular fishery independent surveys for stock assessments is highlighted in Kangas et al. (2022). Digital instruments are required to better measure the depth, position and swept area of each survey trawl and vessel, and improve calibration measures between survey vessels. Camera-based surveys of the seafloor result in higher detection efficiency of Atlantic sea scallops compared to dredge surveys, and may also be more efficient than the trawl method used in Queensland surveys (NEFSC Sea Scallop Working Group 2018). Experiments designed to measure scallop catchability would improve interpretation of each year's survey densities. If completed, recommended biological catches can come directly from the survey information.

Sea surface temperature/ocean anomalies should be monitored and assessed. The deployment of site-specific sea-floor water temperature sensors should be considered.

4.4.2 Assessment

The time-series data on trawl fishing power through compulsory logbook gear sheets should be reviewed. The impact of improved technology is an important consideration for standardising catch rates. Some fishing technologies have been included in this assessment, but others have not due to lack of information (e.g. use of bycatch reduction device, use of turtle exclusion device, net size). In many fisheries, there are advances in technologies in addition to those assessed in this report. Fishing effort continues to change with ongoing technological advancement.

The time series of standardised catch rates should continually be improved. Validation of catch data is a priority for fisheries management across all commercial fisheries. Improved information on hours fished, the fishing gear used, and precise fishing location information (through VMS and TrackMapper) will enable modelling of the changing dynamics of fishing and produce better standardised catch rates. Dedicated work is also required to analyse the Htrawl catch rate data for the years 1977–1987. The quality of the HTrawl data may improve by further checking and verification.

Future assessments might be improved by considering the spatial variation in natural mortality detected in the study, and possible seasonal variation. *Ylistrum balloti* has a relatively narrow temperature tolerance and results from the study in Courtney et al. (2022) indicated that M was higher over summer. Although speculative, the increase in M over the last 40 years may be related to the increase in winter sea surface temperature (SST) in the fishery over this period (O'Neill et al. 2020). If M increases with SST then it may affect the target reference points used for managing fishing effort and potential yields (Wortmann et al. 2020).

Further work is required to investigate low steepness, possible hyperdepletion in early catch rates and behaviour of other recruitment equations such as the Ricker form (Haddon 2001).

As discussed in Section 4.2, a limitation of the current model is that it is non-spatial. There is evidence the aggregations are not globally connected and future work should reconsider the case for some level of spatial structure.

4.5 Conclusions

This assessment was commissioned to establish the stock status of saucer scallop on Queensland's east coast and inform the Sustainable Fisheries Strategy. The base case model scenario suggested spawning biomass is currently around 15% of unfished spawning biomass. Some recommendations for management, monitoring and the next assessment have been made.

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Appendix A Model inputs

A.1 Retained catch from trawl regions

Retained catch from the southern offshore trawl region was associated with irregular and infrequent scallop catches. In 2020, 2021 and 2022 fishing years more than half the total saucer scallop retained catch came from the southern offshore trawl region in (152, 139 and 9 tonnes (meat weight) respectively) (Figure A.1). It should be noted that since the CFISH logbook data was not complete at the time of this assessment, the retained catch for each region in 2022 was calculated by multiplying the 2021 commercial catch data by 0.0667.

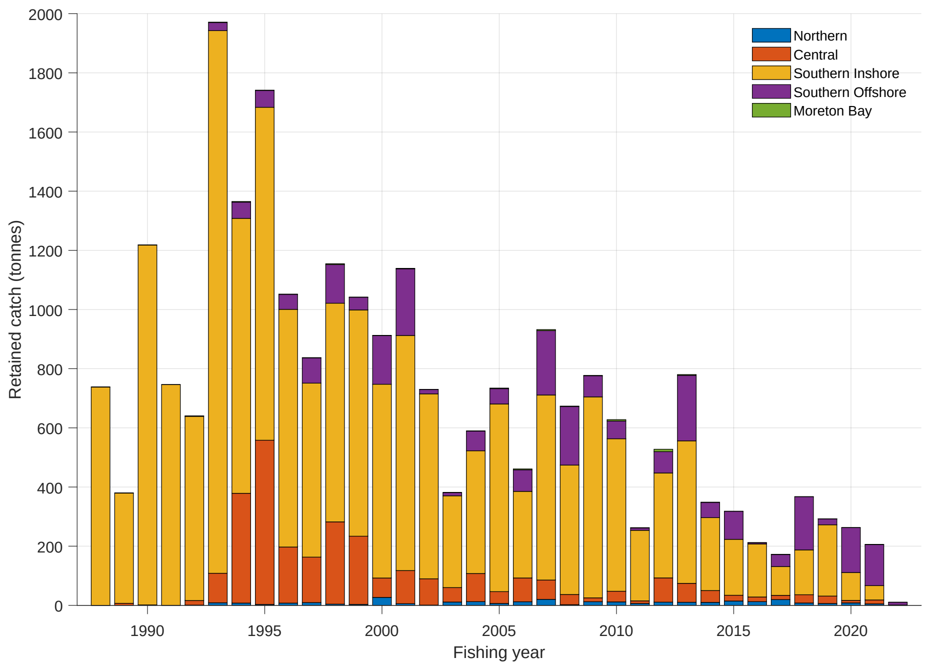

Figure A.1: Annual estimated saucer scallop harvest (retained catch) 1988–2022 from trawl regions

A.2 Data filters for catch rate standardisation

The following filters were applied to the CFISH logbook data to get the data set for catch rates:

- Baskets > 0
- FishingMethodType is trawl (99.9% of records were trawl) or trawl beam (0.1% records were trawl beam)
- CaabSpeciesID is 23270001 (Scallop – unspecified) or 23270000 (Scallop – saucer) (95% of CFISH logbook records of total scallop retained catch were in these categories). For catch data the CaabSpeciesID of 23270003 (Scallop – mud) and 23270005 (Scallop – queen) were also included
- Grid is ”V32” Or ”T30” Or ”S28” Or ”S29” Or ”U31” Or ”T29” Or ”T28” Or ”U32” Or ”S30” Or ”V31” Or ”T31” Or ”U30” Or ”W34” Or ”W32” Or ”W33” Or ”W34” Or ”W35” (main scallop fishing grounds of Yeppoon, Hervey Bay, Bustard Head, K’gari)

- Net type not equal to Beam
- BoatMark is not ”FVNA” or blank
- Hours $\leq$ 24

A.3 Vessel configurations

Information on vessel gear and technologies from the catch rate data set showed a number of continuing trends, in agreement with those reported in the 2020, 2021 and 2022 stock assessments (Wortmann et al. 2020; Wortmann 2021; Wortmann 2022).

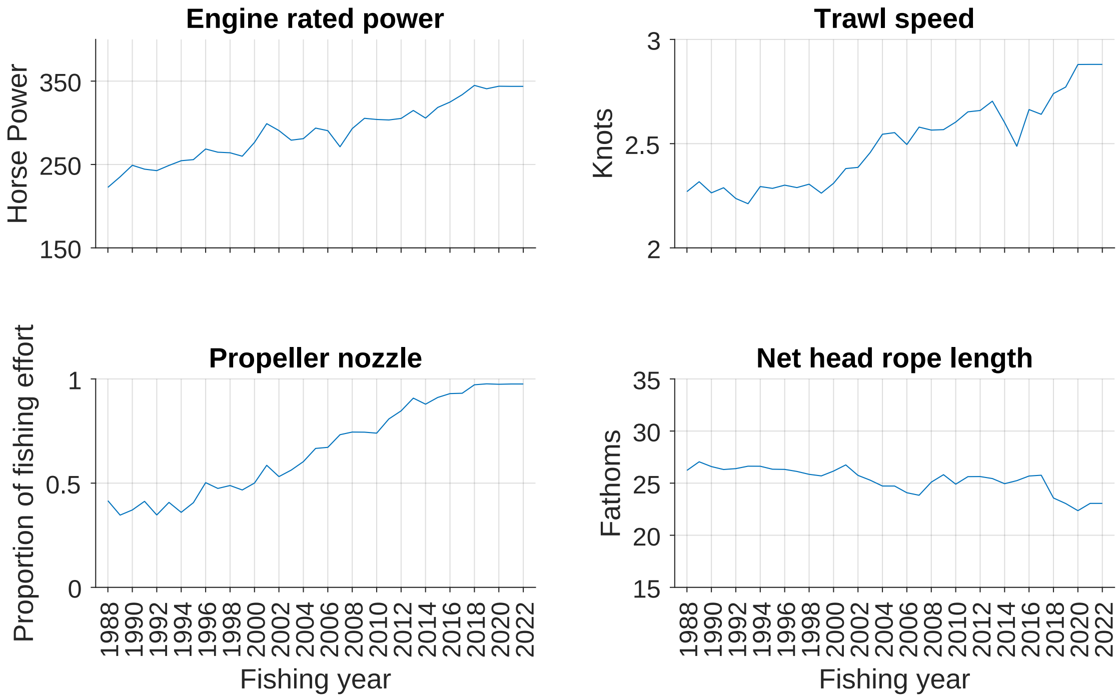

Figure A.2: The fleet average engine rated power, trawling speed, use of propeller nozzles and net size by fishing year—averages were weighted according to the number of days fished by each vessel in each fishing year

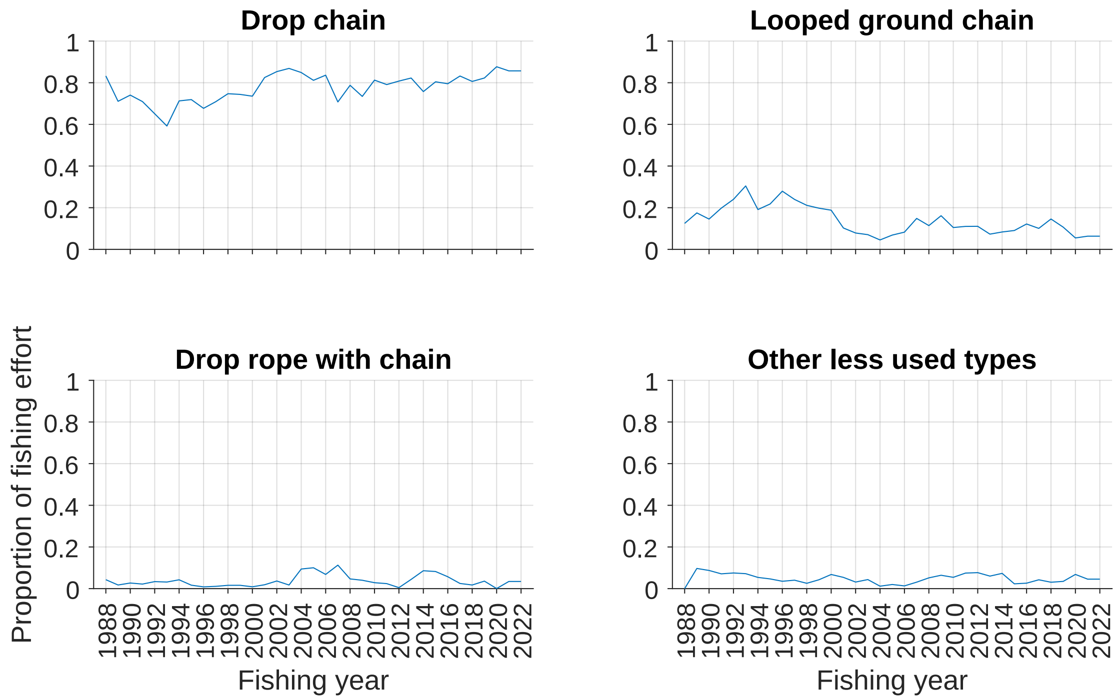

Figure A.3: The proportion of total annual fishing effort by vessels using various ground gear configurations

Figure A.4: The proportion of total annual fishing effort by vessels using various net configurations

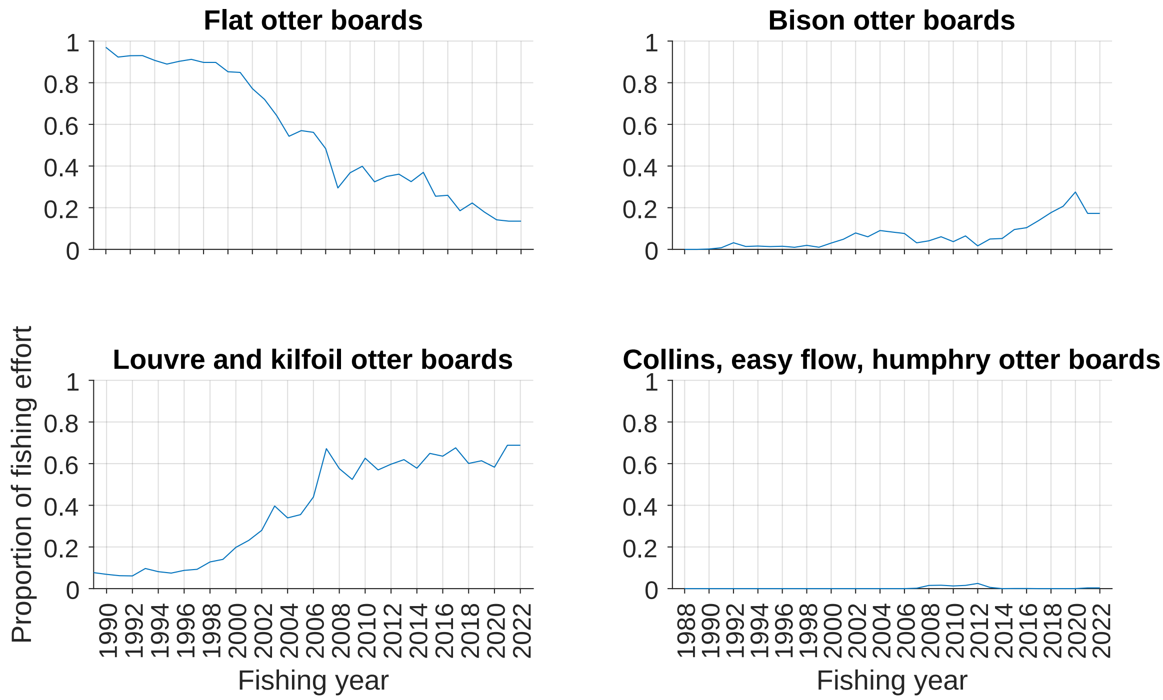

Figure A.5: The proportion of total annual fishing effort by vessels using various otter board configurations

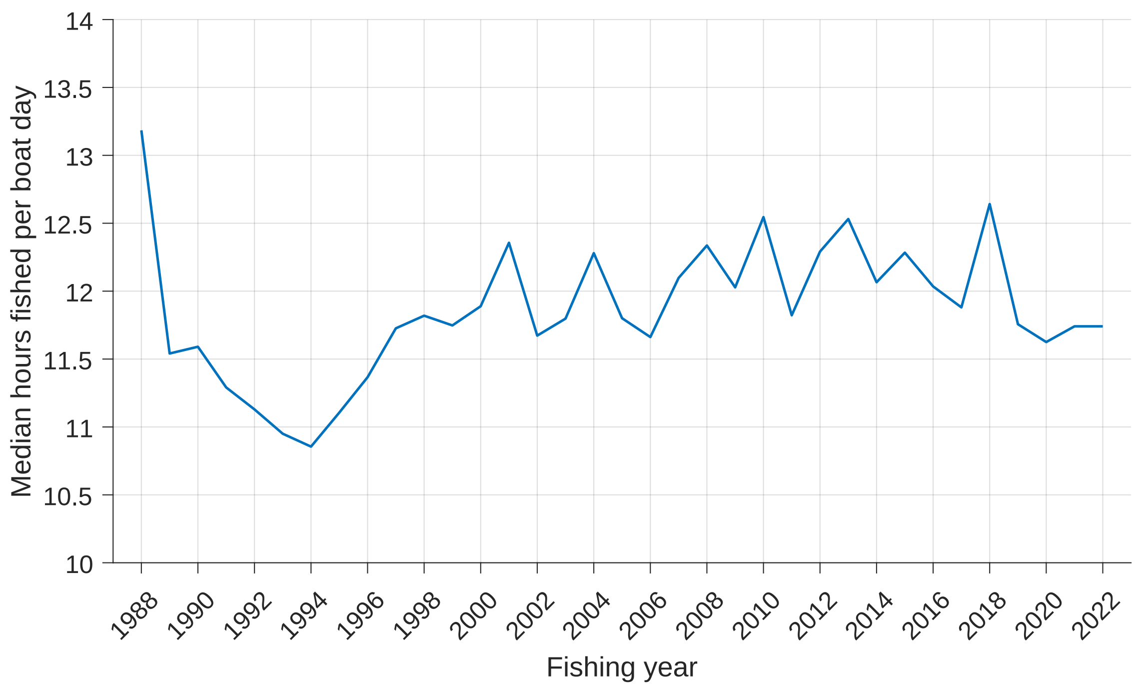

Figure A.6: Median hours fished per boat-day from the linear mixed model data

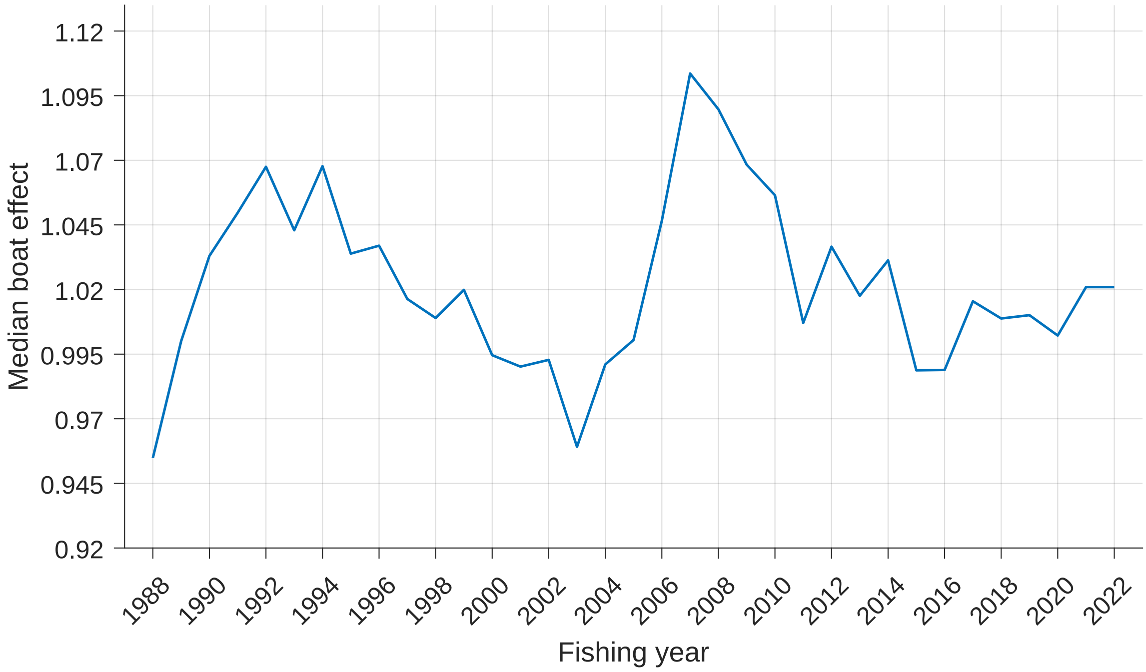

Figure A.7: Median annual boat effect from the linear mixed model data

A.4 Fishing power

The 1988–2022 catch rate standardisation measured annual changes in fishing power, based on fixed and random model components (O'Neill et al. 2007). The product was a measure of annual fleet fishing power, scaled as the proportional change relative to 1989.

Gear changes, technology upgrades and hours fished were the fixed terms from the model. For the fixed terms, the variability in fishing power was represented by the dashed line in Figure A.8, where fishing power increased by about 16% from 1989–2022. This annual increase associated with vessels having higher HP, increased use of GPS and sonar, and quad trawl gear.

The overall fishing power estimate including both gear and vessel terms, showed that fishing power increased by about 25% from 1989–2022. The increase in fishing power from 2019–2022 is likely due to worse boats leaving the scallop fishery (Figure A.7).

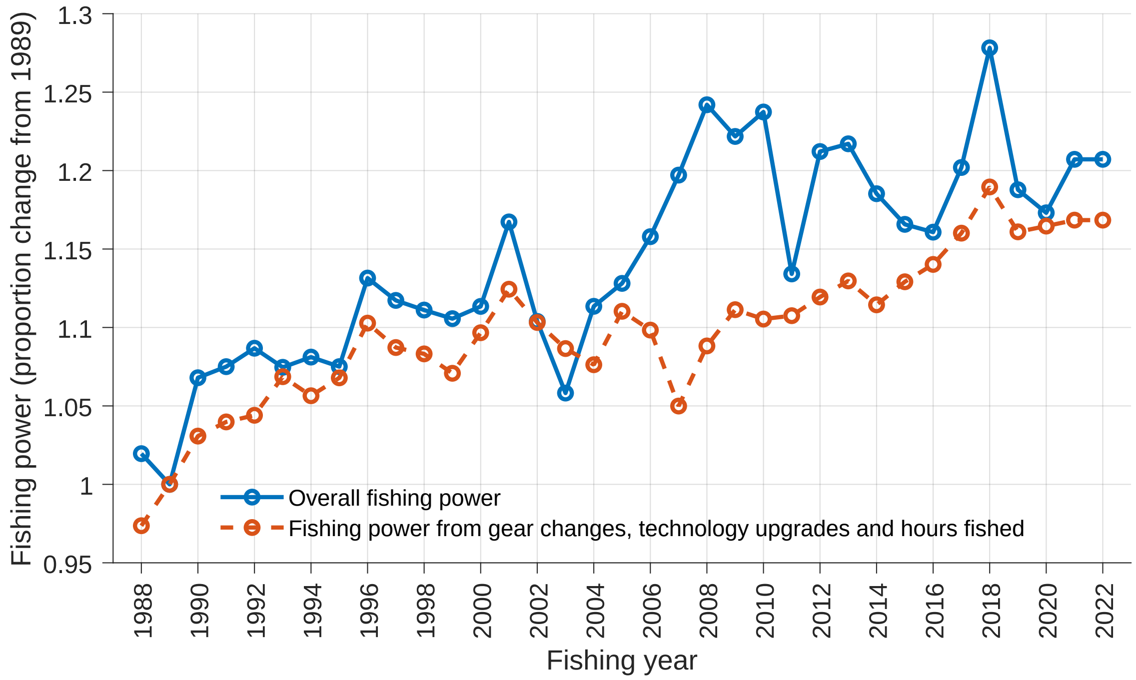

Figure A.8: Annual fleet fishing power on saucer scallops

Appendix B Model outputs

B.1 Catch rate diagnostics

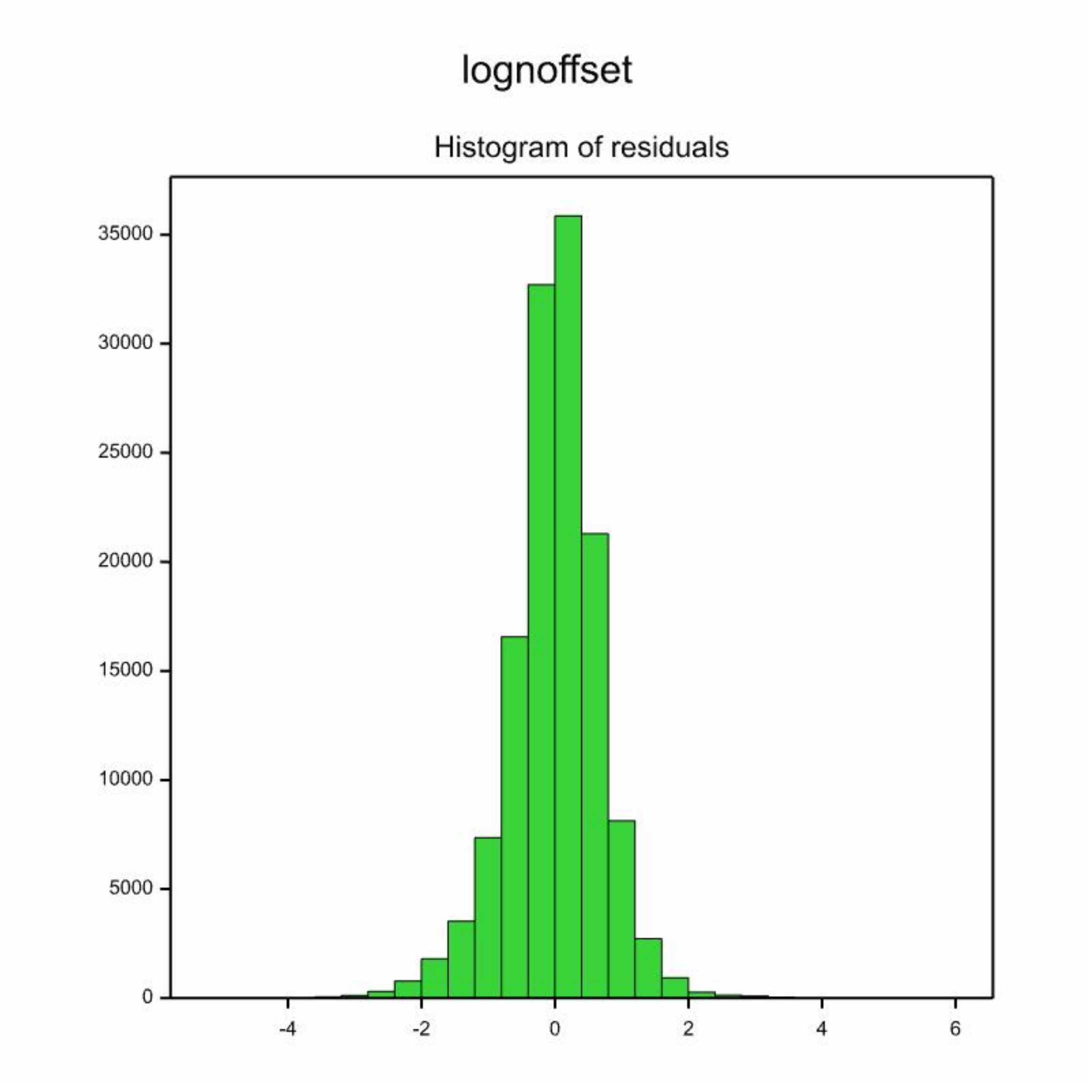

Figure B.1: Residuals for the saucer scallop catch rate analysis 1977–2021

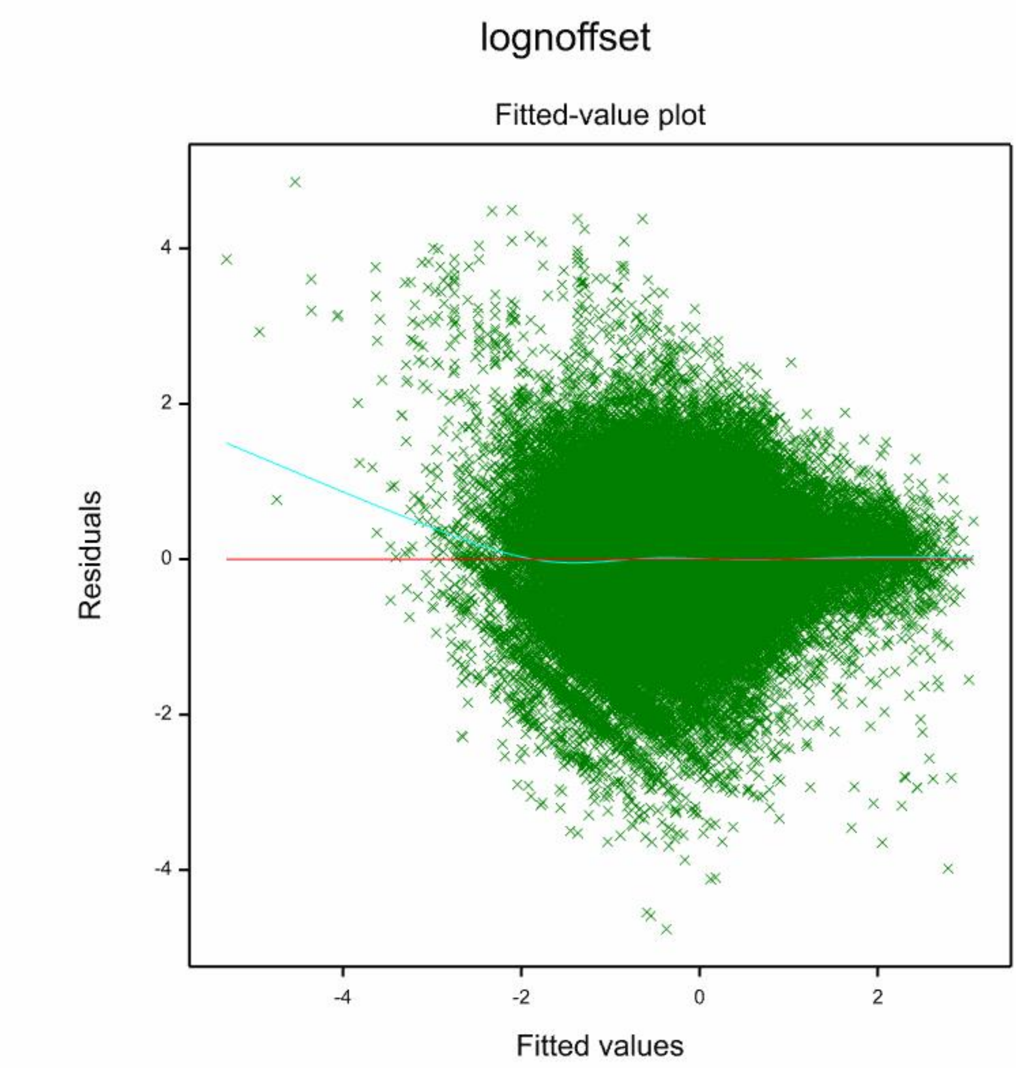

Figure B.2: Fitted values for the saucer scallop catch rate analysis 1977–2021

B.2 Model fit

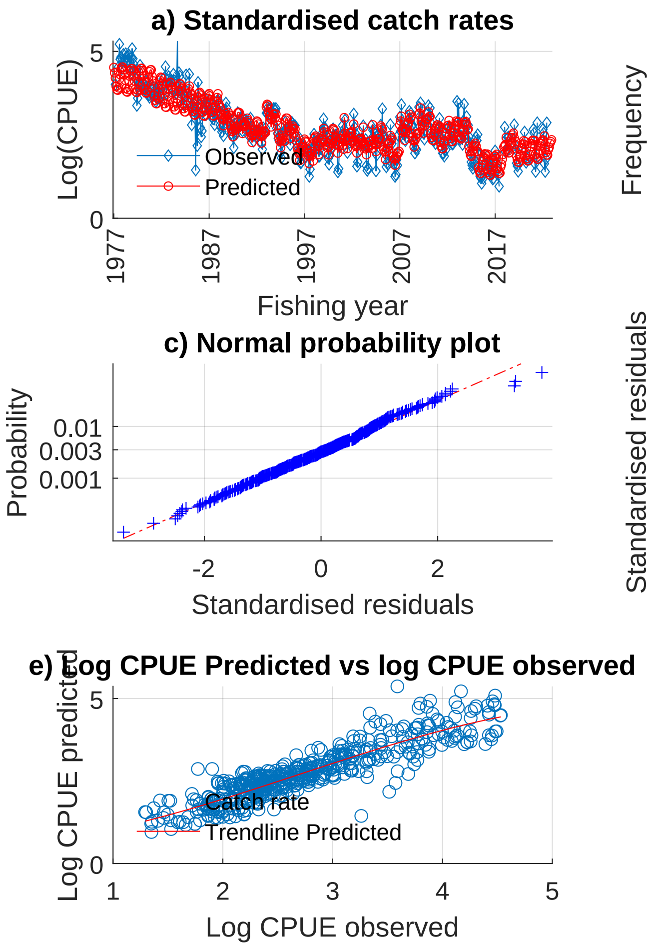

Figure B.3: Catch rate fit-diagnostics

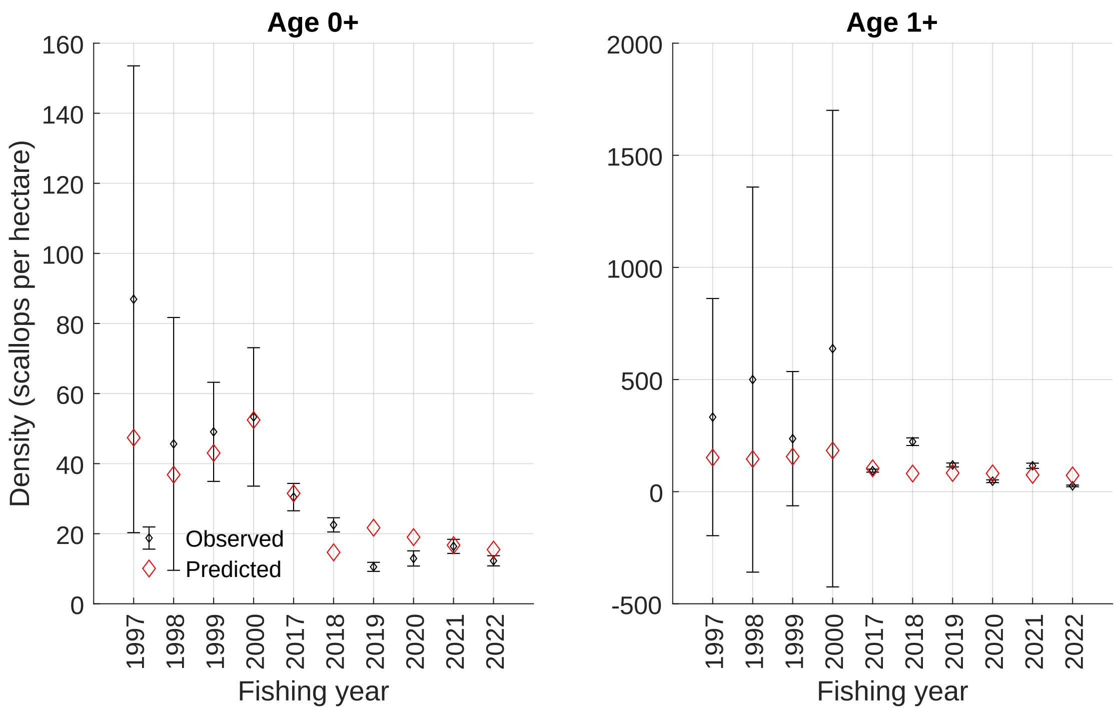

Figure B.4: Age 0+ and 1+ densities from the model (± one standard error)

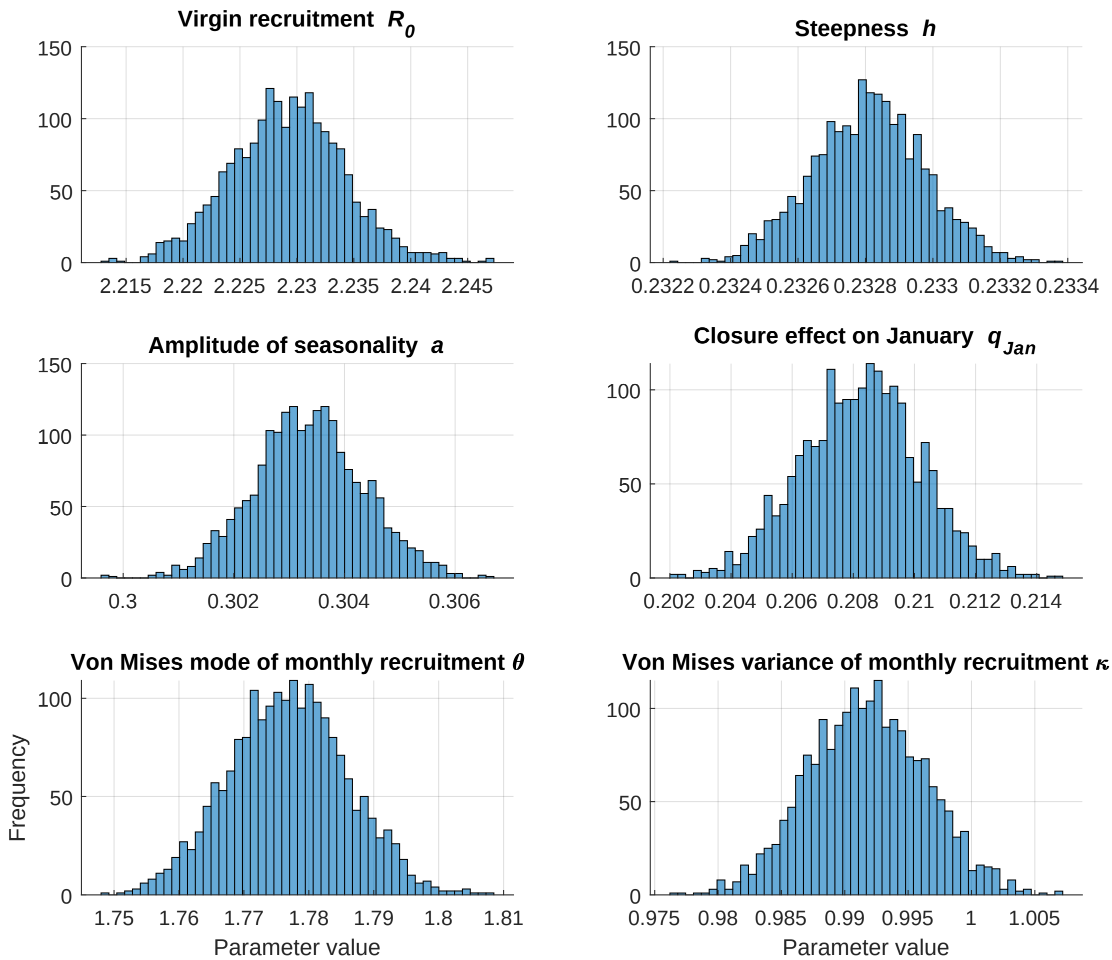

Figure B.5: MCMC parameter estimates for the six main parameters from the model

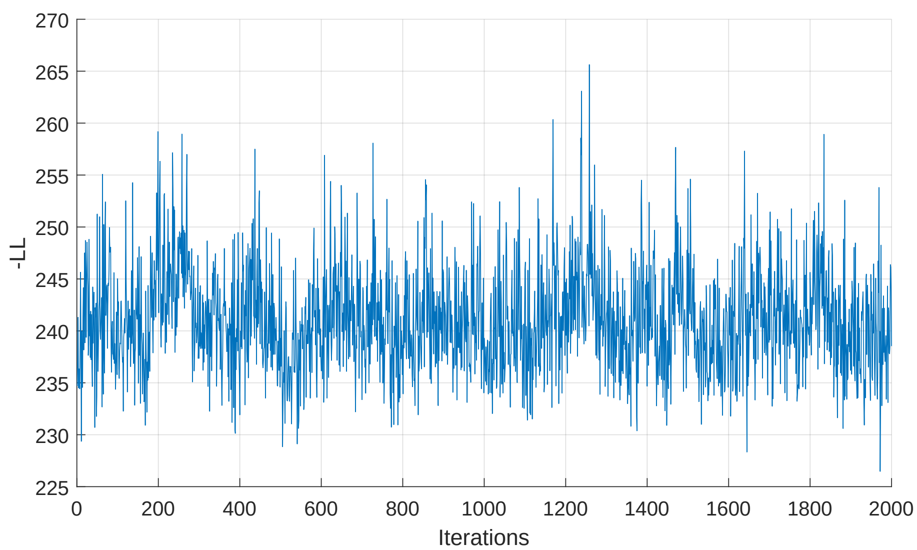

Figure B.6: MCMC –LL trace for the model

Appendix C Fishery Independent Otter Trawl Survey: Preliminary Results for Ballot's saucer scallop

Marlee Jesson-Kerr and Jason McGilvray

C.1 Summary

The fishery independent otter trawl survey was completed in October 2022. One objective of the survey is to determine abundance and recruitment of Ballot's saucer scallops. Three chartered commercial vessels sampled 337 sites between Yeppoon and Noosa for a combined vessel total of over 26 non-consecutive nights. The survey was spread out over 18 different survey areas including the six (6) scallop replenishment areas (SRAs).

Adjusted numbers of scallops were lower in 14 out of the 18 survey areas in 2022 compared to the 2021 survey. Only four areas had higher adjusted numbers of scallop compared to the 2021 survey, three of which were SRAs. The adjustment factors of Vessels 2 and 3 were lower in 2022 compared to 2021 due to similar levels of catch between vessels in the calibration area (Hervey Bay A) (Table C.2).

This was the first survey conducted since the recent (September 2022) review and modification of the sampling areas included in the Fishery Independent Otter Trawl (FIOT) Survey (Department of Agriculture and Fisheries 2022). The review removed sections with poor trawling conditions in 8 of 18 survey areas. The largest modification was made to T28 which had 37% of the original area removed. The review determined that the modifications had no effect on the historical trend in abundance, and as a result, the modifications have been incorporated into the ongoing survey structure.

C.2 Methods

C.2.1 Survey design

The survey is conducted in October which is after the scallop winter spawning season and within the historic southern trawl fishery closure. The scallop fishery is broken up into smaller survey areas (Figure C.1). The number of sites sampled within a survey area is determined by the commercial catch and effort reported in that area. Sites are randomly selected, and sampling consists of a one nautical mile tow, using common east coast commercial prawn trawl fishery net configurations. Survey staff count every scallop collected in the trawl tow.

C.2.2 Vessel calibration

Vessel calibration is conducted to account for differences between vessel fishing power (e.g. number of nets used, and gear set up/type). Side-by-side trawls are completed in a pre-determined, randomised arrangement, to enable comparison of catch rates from each of the different boats. In 2022, 12 sites were sampled within the Hervey Bay A SRA. The data were used to calculate the vessel adjustment factor for each vessel and is based on the vessel (Vessel 1) with the longest history in undertaking the survey.

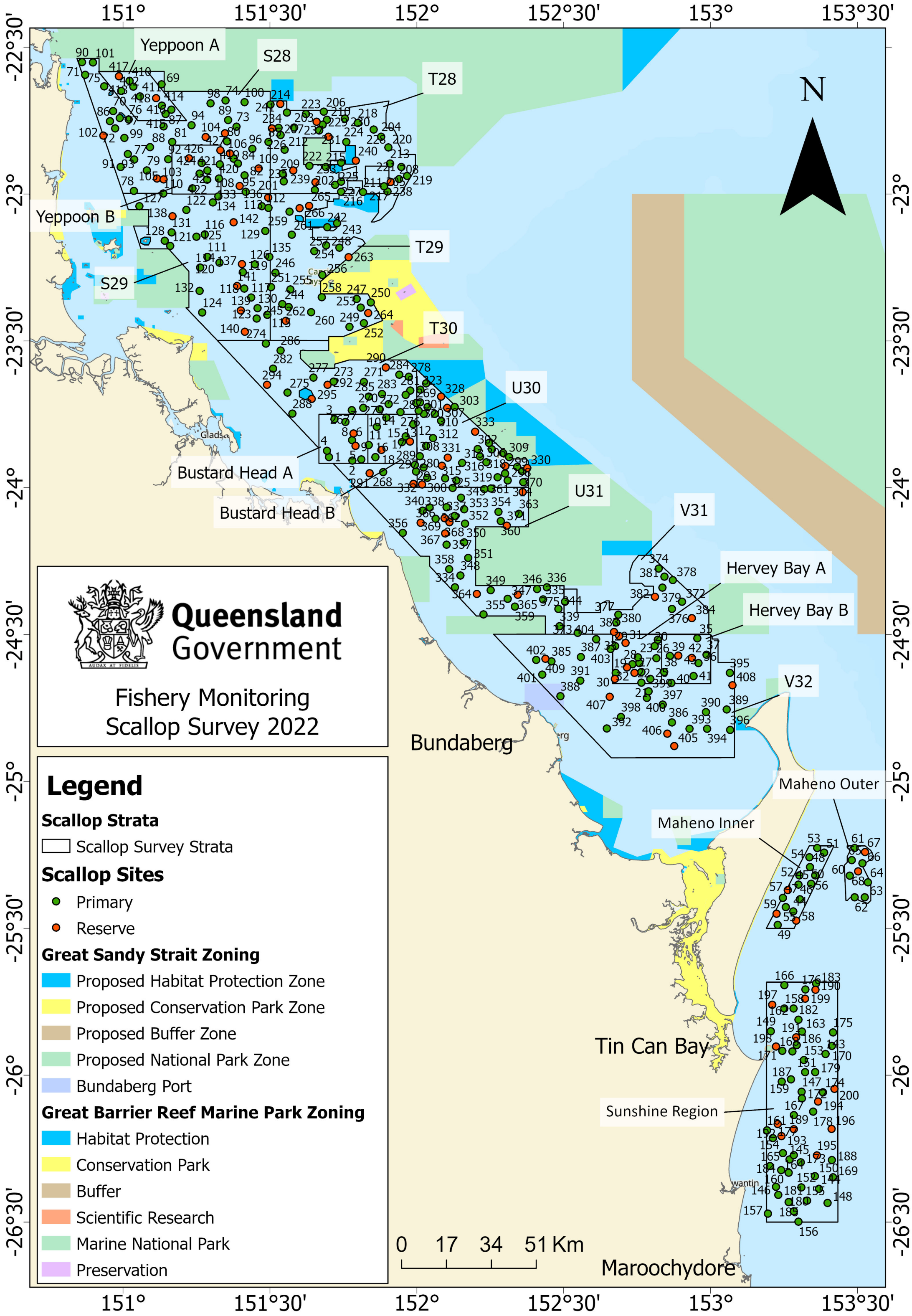

Figure C.1: Randomly selected sites within each 2022 survey area (green dots). Red/orange sites are reserves, which are trawled in circumstances where the intended site is unsuitable for trawling

C.3 Results

The vessel specific calibration multiplier was applied to the total catch of scallops at each site (Table C.1). The adjustment factors used to calculate adjusted numbers of scallop for all recent surveys (2018–2022) are provided (Table C.2). The number of scallops caught at each site were adjusted (based on the vessel adjustment factor), then added together to get a total for each survey area (Table C.3).

	Number of calibration trawls in Hervey Bay A	Mean total density (number/ha)	Adjustment factor 2022
Vessel 1	12	72.319	1.000
Vessel 2	12	68.878	1.050
Vessel 3	12	60.094	1.203

Table C.1: Estimated mean density of scallops during calibration shots and calibration multiplier (adjustment factor) (2022 survey)

	2018	2019	2020	2021	2022
Vessel 1	1.000	1.000	1.000	1.000	1.000
Vessel 2	0.992	1.226	1.648	2.041	1.050
Vessel 3	1.650	1.103	1.256	2.896	1.203

Table C.2: Adjustment factors (2018–2022 surveys)

C.3.1 Length frequency

The number of scallops at a given length was counted and adjusted by vessel. In the FIOT survey, length is measured from hinge (base) to the highest point and is given as shell height (SH) in millimetres. A shell height of 88 mm is equivalent to the commercial size limit (determined by measuring the maximum diameter) of 90 mm. The smallest scallop observed in 2021 was 20 mm SH and the largest was 131 mm SH. In 2022, the smallest scallop was 24 mm SH and the largest was 126 mm SH.

Length frequency counts were presented (instead of length frequency proportions) so that figures from different years were able to be compared. Length frequency was bimodal (two peaks) for both years (2021 and 2022; Figure C.2 and C.3). Peaks occurred at approximately 50 mm and 90 mm in both years, although there were fewer observed 90 mm scallops in 2022 (peaks at approximately 1500 observed scallops compared to 4500 in 2021).

Length frequency counts were also presented for SRA areas compared to non-SRA areas (Figures C.4 and C.5). More 90 mm scallops were observed in SRA areas, although overall, less scallops were observed in 2022 compared to 2021. More 50 mm scallops were observed in SRA areas in 2022 compared to 2021.

Area	2018		2019		2020		2021		2022	
	Shots	Scallops	Shots	Scallops	Shots	Scallops	Shots	Scallops	Shots	Scallops
Yeppoon A	7	5262	13	5078	7	124	7	173	7	348
Yeppoon B	8	7346	7	10767	7	5933	7	28413	8	2843
S28	30	19195	31	8012	30	4546	27	14903	34	3779
T28	42	3809	35	1163	34	717	46	4998	32	2175
S29	27	10076	22	4819	23	1950	25	2202	26	963
T29	22	4788	23	4208	17	2709	24	4763	15	1726
T30	15	2043	18	3214	15	874	21	4573	22	1169
U30	22	1616	17	373	17	362	24	718	21	403
Bustard Head A	8	8262	3	651	7	620	7	1404	7	104
Bustard Head B	8	31342	7	5525	8	887	7	4230	7	412
U31	17	9689	23	520	22	303	23	339	26	103
V31	9	1821	11	851	9	8	12	593	10	76
Hervey Bay A**	31	48621	32	37555	30	7077	32	4999	36	15366
Hervey Bay B	7	690	7	1449	7	446	7	112	7	363
V32	17	8413	17	1344	24	1198	17	208	20	1689
Maheno Outer	9	183	9	527	9	435	5	57	4	29
Maheno Inner	17	2531	15	8423	10	179	11	77	9	22
Sunshine Region	37	6191	40	15250	50	17245	45	2976	46	1333
Totals	**333**	**171878**	**330**	**109729**	**326**	**45613**	**347**	**75742**	**337**	**32901**

Table C.3: Adjusted total catch of scallops and number of shots completed within each survey area, 2018–2022. ** Hervey Bay A survey area is the calibration location (i.e. multiple shots occurred through the same sites).

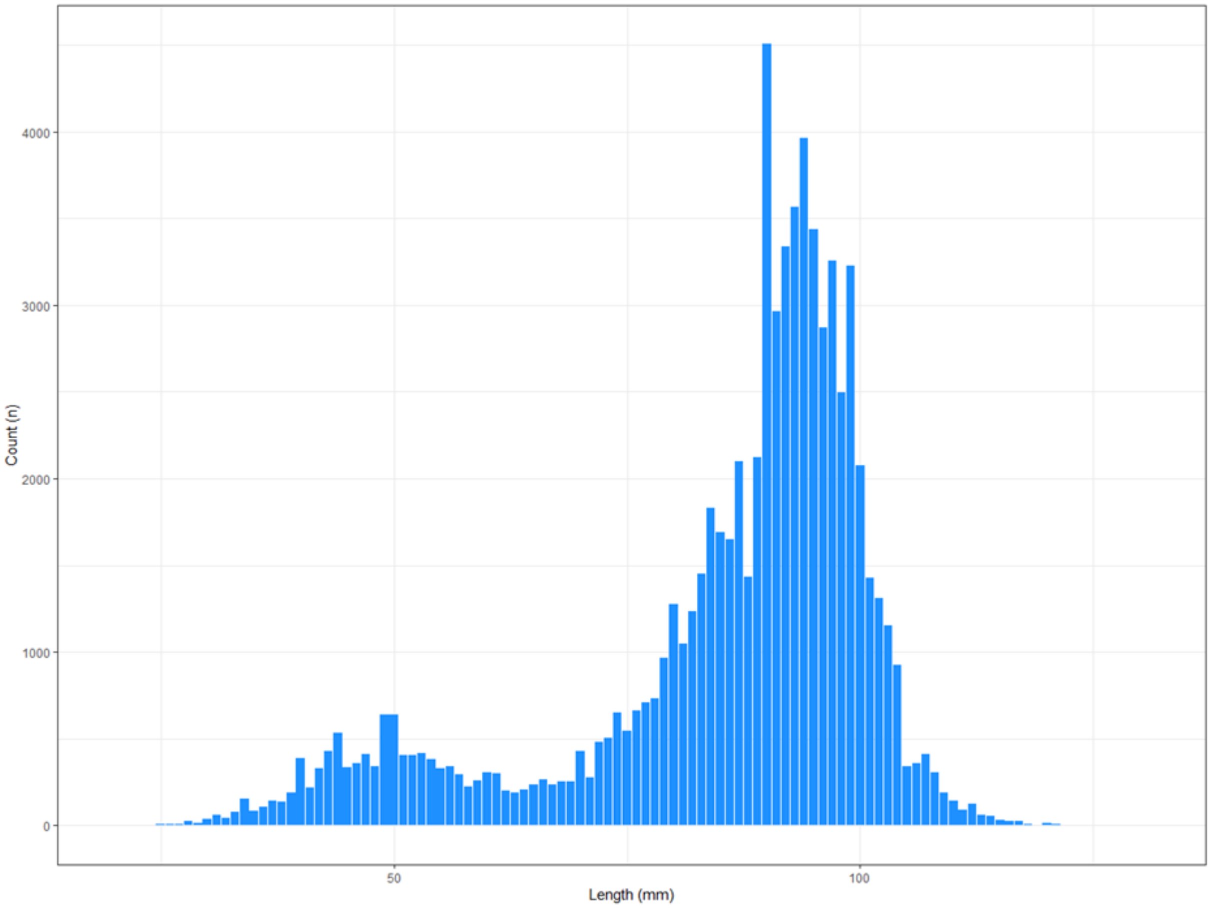

Figure C.2: Length frequency (number of observations for each length) for the QLD saucer scallop in the 2021 FIOT survey

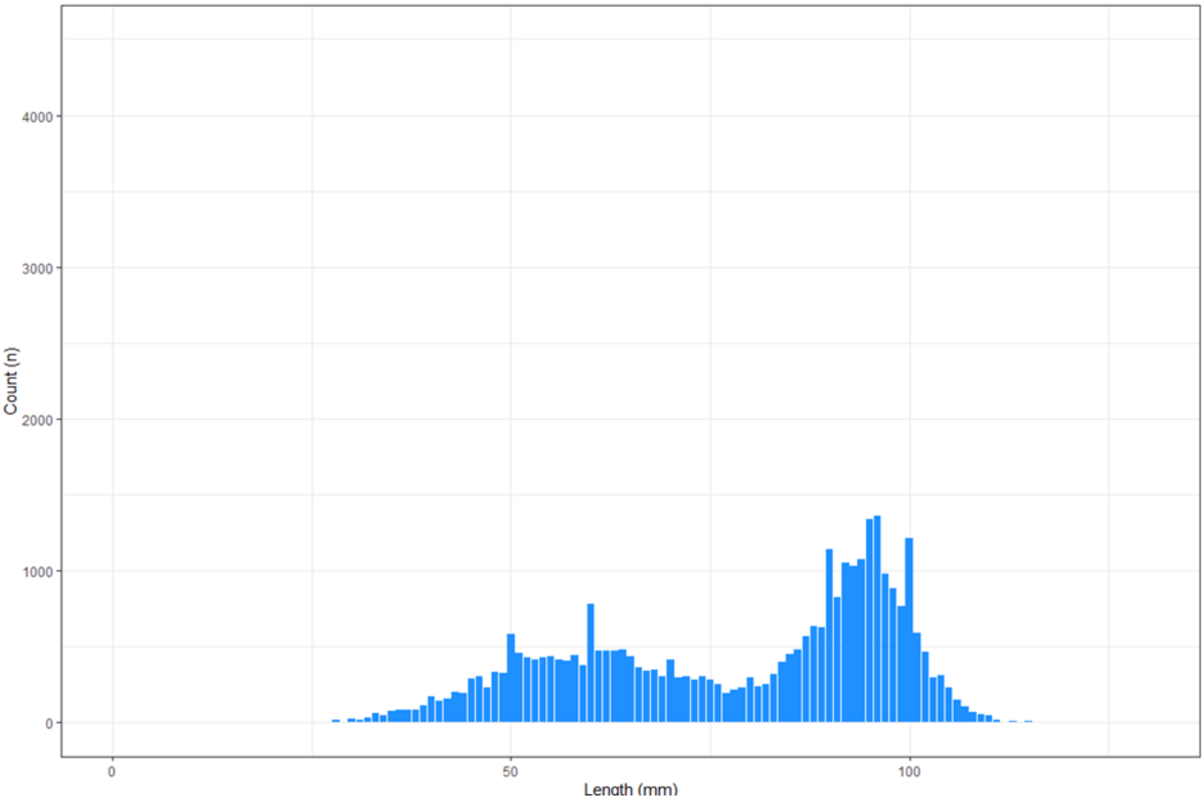

Figure C.3: Length frequency (number of observations for each length) for the QLD saucer scallop in the 2022 FIOT survey

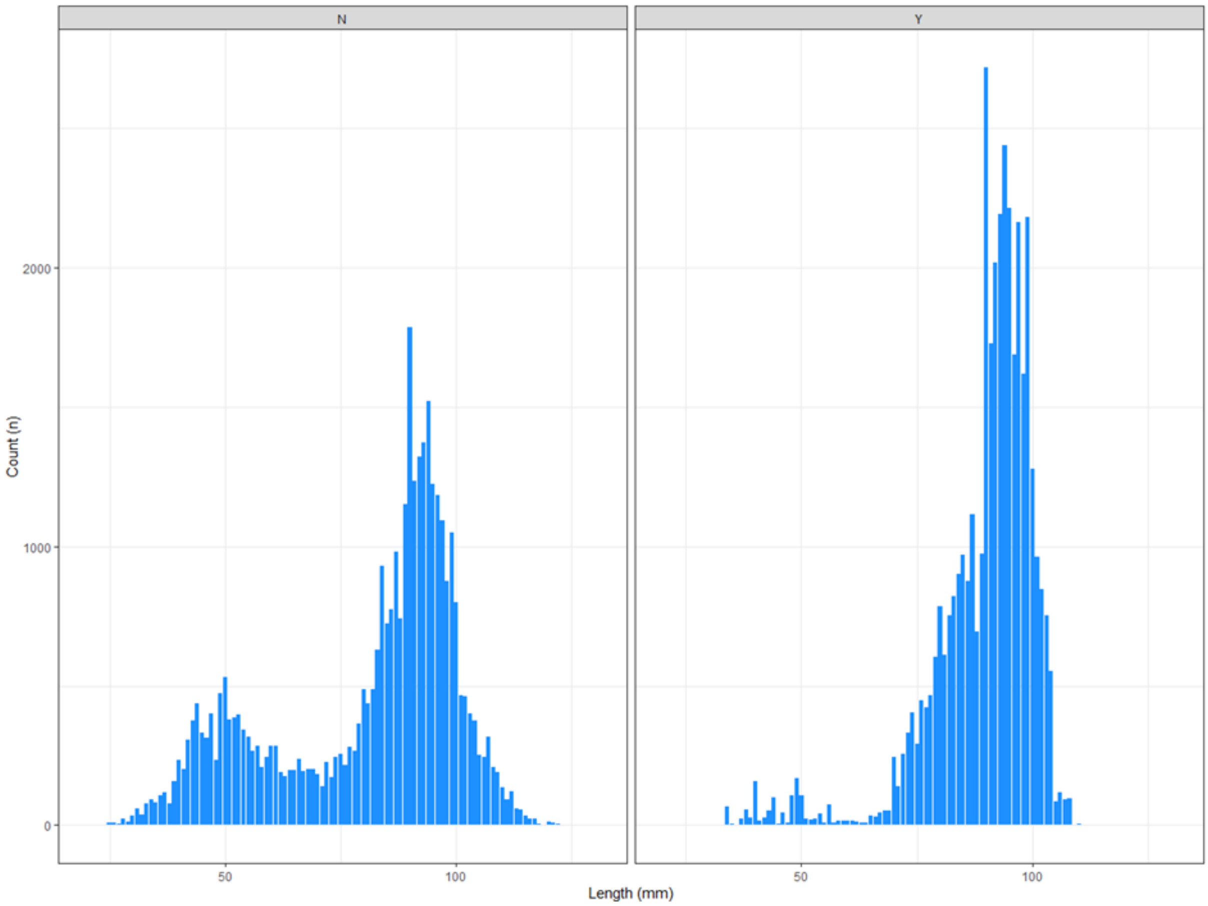

Figure C.4: (*Left*) non-SRA areas (N) compared to (*right*) SRA areas (Y). Length frequency (number of observations for each length) for the QLD saucer scallop in the 2021 FIOT survey

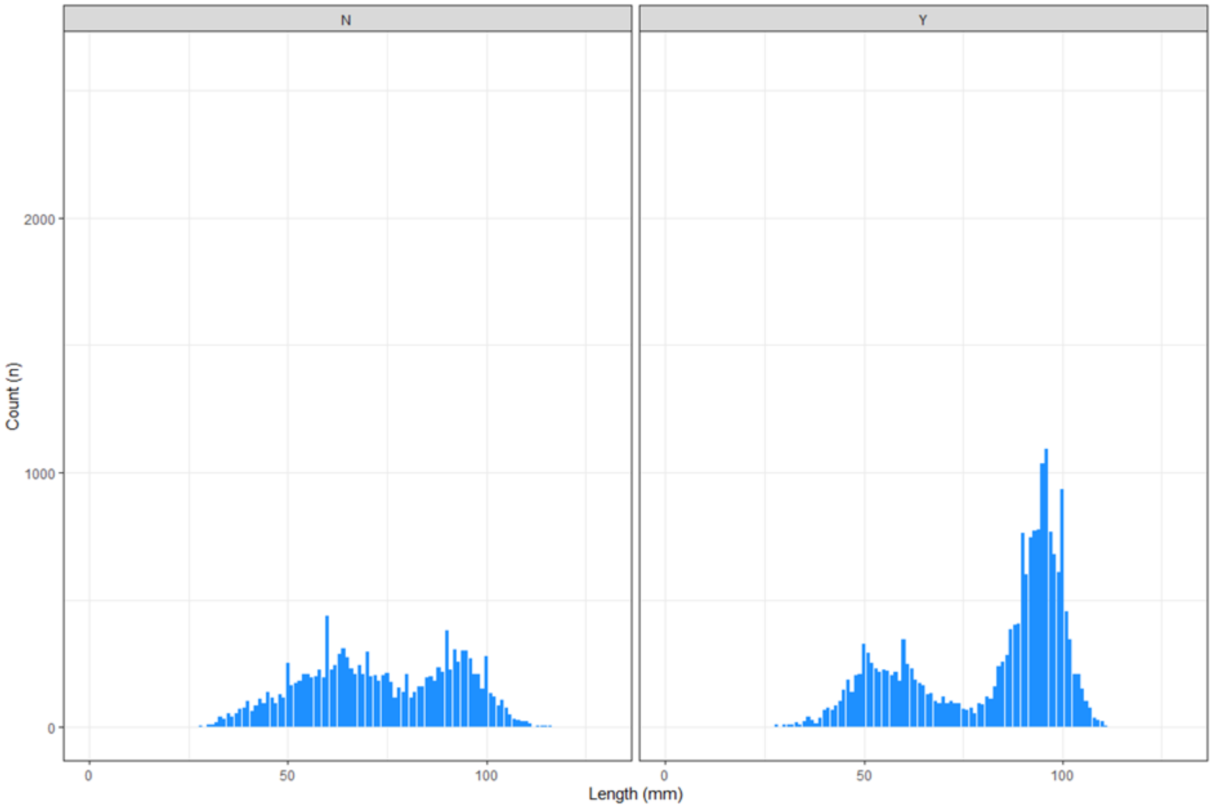

Figure C.5: (*Left*) non-SRA areas (N) compared to (*right*) SRA areas (Y). Length frequency (number of observations for each length) for the QLD saucer scallop in the 2022 FIOT survey

Appendix D Fishery Independent Otter Trawl Survey: Sampling Strata Review

Marlee Jesson-Kerr, Dylan Moffitt and Jason McGilvray

D.1 Abstact

Fisheries Queensland conducts an annual fishery independent otter trawl (FIOT) survey for the Queensland saucer scallop, *Ylistrum balloti*, a key target species in the East Coast Otter Trawl Fishery. Biological data collected during the survey is vital for stock assessment and fishery management. The sampling design of the FIOT survey is stratified into spatial strata across the scallop fishing grounds. Historically, survey effort has been allocated to areas within certain survey strata with low scallop harvest, and these areas are often associated with increased damage to trawl gear, likely due to unsuitable and/or hazardous seafloor topography. The aims of this project were to 1) identify and exclude problematic areas from survey strata and 2) to assess whether amending the survey to exclude these areas would substantially affect sampling effort allocation, scallop density estimates and/or the historic trend signal from the survey. Vessel Monitoring System (VMS) data of commercial vessel tracks were used to identify and exclude areas within survey strata with low reported scallop harvest. A theoretical dataset for the revised survey design was created using past FIOT survey datasets, removing data from any trawls located in the excluded areas. Scallop density estimates and trend signals were then calculated for the theoretical FIOT dataset and compared to the original FIOT survey estimates. In total, eight survey stratum were modified resulting in no substantial change in predicted or observed scallop densities (number of scallops per hectare), the overall biomass trend, or the final biomass estimates. The largest modification was made to survey stratum T28 (37.03% excluded) which resulted in a 4.49% reduction in the proportion of sampling effort allocated to this stratum compared to the 2021 survey. The final biomass estimate using the unaltered-survey design to 2020 was 14.15% and the final biomass using the modified survey design was 14.35%, demonstrating the modified design had minimal impact on historic stock assessment results. It is recommended that future surveys proceed using the modified survey design as this will result in greater sampling efficiency and potentially reduce damage to gear. The results highlight the importance of reviewing survey design used in routine monitoring to ensure it remains fit for purpose and addresses industry concerns.

D.2 Introduction

D.2.1 Fishery History

In Queensland Australia, Ballot's saucer scallop *Ylistrum balloti* (formerly *Amusium balloti*) are targeted in the East Coast Otter Trawl Fishery (ECOTF). High abundance of scallops occurs between 22° South and 27° South latitudes in water depths of 20 to 60 metres, and the majority of the scallops harvested come from 20° South latitude to the New South Wales border. Decreasing catch and catch rates despite consistently high effort between 1993 and 1996 led to the implementation of Scallop Replenishment Areas (SRAs) from 1997. SRAs were a precautionary management measure designed to provide areas within the trawling grounds closed to fishing where scallops could recruit and help replenish Queensland scallop stocks. In 2001 the SRAs were expanded and opened to fishing on a rotational harvest strategy that allowed fishers access to high densities of post-recruitment scallops. In 2017, the SRAs were permanently closed due to low abundance of scallop stock.

D.2.2 Historic Survey Design

The Fishery Independent Otter Trawl (FIOT) survey was first undertaken in 1997 (overview provided in Dichmont et al. (2000)). The purpose of the FIOT survey was to provide an annual index of the relative abundance of scallops in 0+ and 1+ age classes. These indices of scallop abundance could be compared between survey years to identify trends in stock status. Since 1997, the FIOT survey has been conducted every year between 1997–2000 and 2017–2019 with minor changes to the survey design over that time period. Surveys were also carried out between 2001–2006 but were designed to assess the efficacy of the SRAs in improving scallop recruitment. No surveys were undertaken between 2007 and 2016.

The initial survey was stratified into 12 discrete spatial units (i.e. strata) within the traditional scallop fishing grounds between Yeppoon and Hervey Bay, Queensland (Figure D.1—left panel). Nine of the strata were based on commercial logbook grids (30’ x 30’) while a further three strata were located in areas with historically high scallop densities that were closed to fishing (i.e. Scallop Replenishment Areas). These SRAs were nested within some of the other strata and were included in the survey to assess the effect of fishing closures in SRAs on scallop recruitment.

From 2001 to 2006, a subset of strata were sampled including T30 and the SRA strata due to the aim of assessing efficacy of the implemented SRAs. During this period, the FIOT survey was re-designed twice with SRA strata modified to account for changes in management over this period (i.e. the implementation of a rotational harvest strategy in the SRAs, changes to the Great Barrier Reef Marine Park zoning in 2004). For an overview of changes to the sampling design during this period, see Jebreen et al. (2008).

In 2017, the survey was re-instated after a decade of absence. Survey strata were kept as close as possible to those in the original survey design, so that survey data collected in the later years (2017 onwards) were comparable to earlier years of the survey (1997–2000) (French et al. 2021). However, some modifications to strata were necessary. These modifications included exclusions of areas in some strata that were closed to fishing as a consequence of changes to Great Barrier Reef Marine Park zoning in 2004, the inclusion of more SRA strata and the inclusion of three additional strata to the survey to account for an increase in catch rates in the southern extent of the fishing grounds between 1989 and 2014 (Figure D.1—right panel).

Each year, sampling effort in the FIOT survey was distributed among strata in a way that was proportional to the Catch Per Unit Effort (CPUE) and area of each stratum. Thus, strata with large areas and high CPUE received a high allocation of sites. For example, stratum T28 typically received a high site allocation each year due to its comparatively large size and high CPUE. In practice, this stratum contained large areas of untrawlable ground and the high CPUE was maintained by high effort in small productive patches within the stratum. Sampling in T28 was thus problematic. Since trawl sites were assigned across the entire stratum area randomly, a considerable number of sites were located on marginal trawl grounds leading to many damaged trawl nets in T28 over consecutive survey years.

From 1999 onwards, the trawl fishery has been required to have vessel tracking units installed on all vessels. This provided a tool for incorporating effort signatures into the survey design. In the years following 1999, catch data were integrated with vessel tracking data to create a footprint of the scallop fishery (Courtney et al. 2020). This footprint clearly shows much of grid T28 receives little or no com-

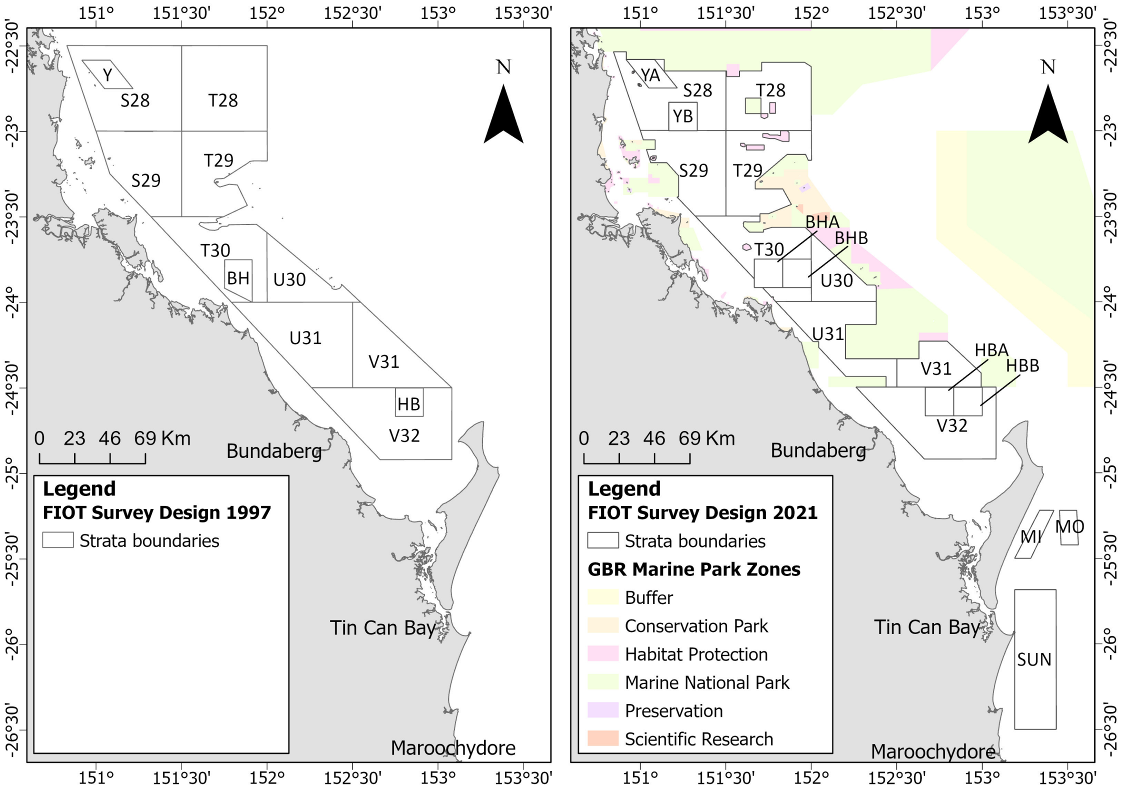

Figure D.1: Comparison of strata configurations for the Fishery Independent Otter Trawl (FIOT) survey between the original design in 1997 (left) and the most recent iteration in 2021 (right). Map shows the key changes in survey design between 1997 and 2021 which predominantly consisted of exclusions from some strata to account for rezoning of the Great Barrier Reef (GBR) Marine Park in 2004, the addition of new strata to estimate scallop densities in scallop replenishment areas and the inclusion of three new strata in the southern extent of the survey area.

Acronyms: Y—Yeppoon, BH—Bustard Head, HB—Hervey Bay, YA—Yeppoon A, YB—Yeppoon B, BHA—Bustard Head A, BHB—Bustard Head B, HBA—Hervey Bay A, HBB—Hervey Bay B, MI—Maheno Inner, MO—Maheno Outer, SUN—Sunshine Coast

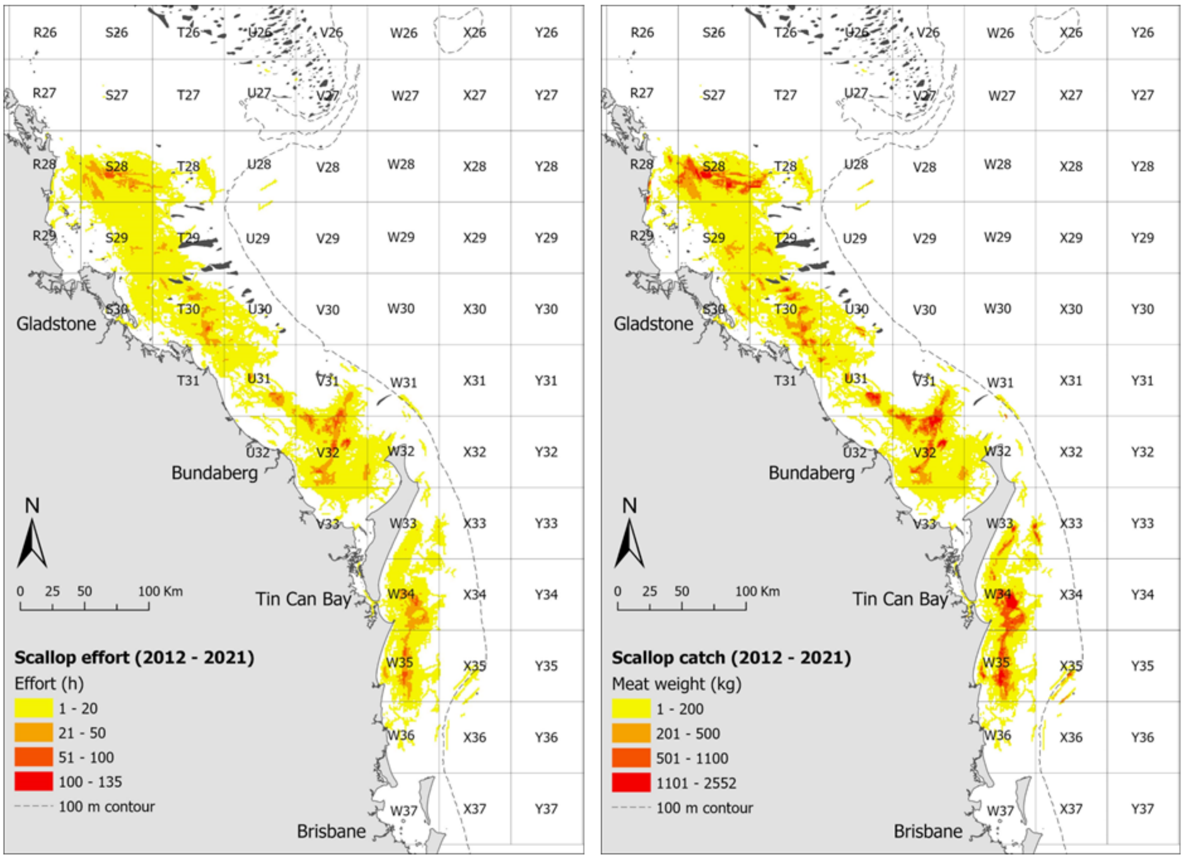

Figure D.2: CPUE for the Queensland Saucer Scallop (left) and scallop catch (by weight) (right) in the East Coast Otter Trawl Fishery from 2007 to 2021

mercial fishery effort but in the small area that is worked, catch rates can be high (Figure D.2). The vessel tracking data shows a similar pattern in other strata (T29 and V31) where high CPUE values are maintained by effort over a protracted area of the strata. This means large areas of untrawlable ground are being included when calculating the number of sites allocated to some strata.

In this project, we seek to address this design anomaly by using the effort footprints from vessel tracking data to exclude areas of strata which have received little to no fishing effort over the past two decades. To determine whether strata modifications are appropriate, we examined the effect of proposed exclusions on scallop density estimates in all survey years between 1997–2000 and 2017–2020.

D.3 Methods

To identify areas of strata for possible exclusion, the existing survey strata boundaries were overlayed with a spatial layer of vessel tracking data which displays the historical distribution of commercial scallop catch, effort and CPUE. The vessel tracking data was extracted from TrackMapper software using the following search criteria (Courtney et al. 2016):

1. Spatial extent: FIOT scallop survey boundary 2017
2. Date range: 01 Jan 2000–31 Dec 2020
3. Species included: Scallop – Saucer (CAAB Code: 23270001), Scallop – Mud (2327003), Scallop – Queen (23270005), Scallop – Unspecified (23270000)
4. Catch type: Targeted

Once the vessel tracking data for otter trawling was overlayed, the survey strata were inspected for any areas with no reported catch or effort between 2000 and 2020. Anecdotal evidence from experienced trawler operators suggests such areas were likely avoided due to unfavourable trawling conditions and low likelihood of encountering scallops. The identified areas were then excluded from the strata, by modifying the strata boundaries in ArcGIS Pro version 2.7.3 (ESRI 2011). This resulted in modifications to T28, T29, V31, V32 and Maheno Outer (Figure D.3). Minor modifications were also made to S28, S29 and T30 to exclude areas that were erroneously included in those strata such as an island.

D.3.1 Effects of strata alterations on sampling effort allocation

To determine the potential effect of altering the survey strata, the altered strata were intersected with the data from all previous surveys (1997–2000, 2017–2020) in ArcGIS Pro version 2.7.3 (ESRI 2011). For each survey year, any trawl sites that fell outside the boundaries of the modified strata were retrospectively excluded. The number of sites per stratum in the modified strata were then compared to the actual number of sites that were assigned to each stratum for each year of the survey. The number of sites that could have been reallocated within each survey year could then be calculated. The site allocations for the 2022 FIOT survey were calculated twice, once based on the unmodified strata and then for altered strata. The site allocations between the unmodified strata and the altered strata were then compared to determine how the modification would affect the distribution of sites allocated between strata.

D.3.2 Effects of strata alterations on survey key parameter estimates

To determine the potential effect of strata alterations on scallop density estimates and the overall scallop density trend between survey years, a theoretical dataset was created for the altered strata by retrospectively removing any data from trawls located at sites that were excluded by the strata alterations. Standard calibrations and density calculations were then input to the same methodology applied to previous stock assessments on the altered strata dataset. Similarly, the altered strata dataset were used in the same stock assessment models applied in previous years (Wortmann et al. 2020; Wortmann 2021; Wortmann 2022). Key survey parameters were compared between the unmodified strata dataset and the altered strata dataset to assess the impact of the proposed strata alterations on historic trends. These parameters included the total catch, scallop density indices and mean catch weight estimates. All analyses were completed using R Statistical Software (Version 4.2.1; R Core Team 2018).

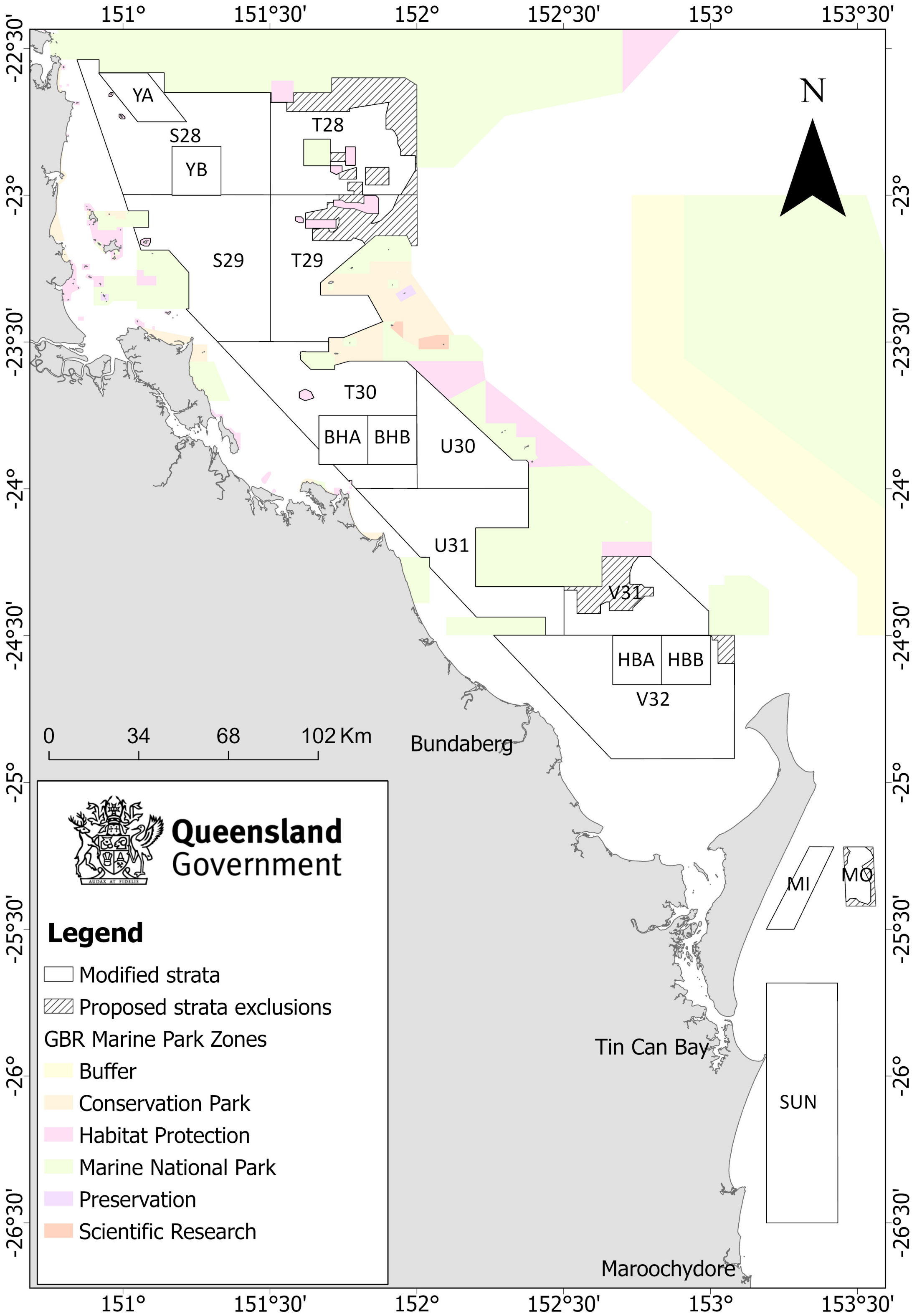

Figure D.3: Modified strata for the revised sampling design of the Fishery Independent Otter Trawl Survey

D.4 Results and Discussion

D.4.1 Strata alterations

In total, eight strata were modified and an area of 1.64 x 10^9 m^2 was removed from the total surveyable area (Table D.1). The largest modification was made to T28 where 37.03% of the original strata area found to contain no reported harvest between 2000 and 2020 was excluded (Table D.1). There were also considerable exclusions to Maheno Outer, T29 and V31 (29.54%, 23.48% and 29.75% of strata area excluded respectively). Small areas of S28, S29 and V32 were also excluded, usually comprising the removal of small island land masses.

Closure Name	Area (% diff.)
Bustard Head A	0.00
Bustard Head B	0.00
Hervey Bay A	0.00
Hervey Bay B	0.00
Maheno Inner	0.00
Maheno Outer	**-29.54**
S28	**-0.07**
S29	**-0.02**
Sunshine Region	0.00
T28	**-37.03**
T29	**-23.48**
T30	0.00
U30	0.00
U31	0.00
V31	**-29.75**
V32	**-2.81**
Yeppoon A	0.00
Yeppoon B	0.00

Table D.1: Summary of modifications to survey strata, including % area difference

Where the effects of the strata alterations on the sampling allocations in previous survey years were examined, the highest number of sites excluded occurred in year 2017 (13.2%), followed by 2019 (5.2%) (Table D.2). A number of sites within GBRMPA zoned “green zone” were, however, included in 2017 to address the commercial fishing industry interest in scallop abundance in these areas. The “green zone” sites were excluded by the modified strata, suggesting that the high site reduction and catch reduction (13.2% and 11.3%, respectively) was an artefact and is not of concern. Further investigation confirmed that 23 of the 45 sites that were excluded in 2017 came from declared “green zone” sites. Excluding 2017, there was no reduction in survey effort (number of sites) greater than 5.2%, notably this was associated with a very low reduction in catch of only 0.9%. There was no reduction in catch greater than 3% (excluding 2017).

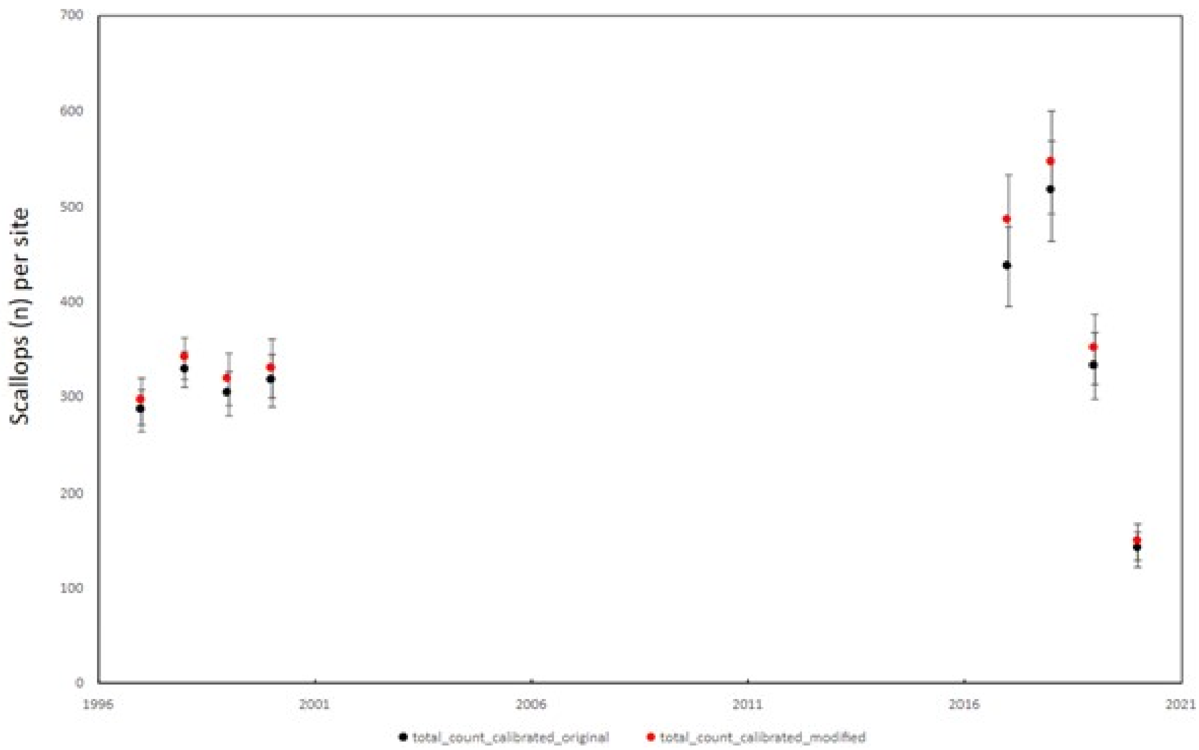

Figure D.4: Comparison of calibrated total scallop count for history FIOT dataset showing mean ± SE, for original (black) and modified (red) strata

Year	No. of strata modified	No. of sites excluded	% Site reduction	Original catch	Catch reduced to	% Catch reduction
1997	3	22	4.95%	18524	18014	2.75%
1998	3	20	4.17%	19708	19361	1.76%
1999	3	26	4.81%	21620	21408	0.98%
2000	2	12	2.61%	17294	17220	0.43%
2017	7	45	13.2%	13008	11534	11.3%
2018	3	2	0.6%	14869	14620	1.7%
2019	3	17	5.2%	14515	14384	0.9%
2020	2	15	4.6%	12240	12195	0.4%

Table D.2: Sites removed by modified strata by year and resulting reduction in catch

D.4.2 Strata alterations and effect on survey parameter estimates

Using the 2021 stock assessment model (Wortmann 2021; Wortmann 2022), the final unfished biomass estimate using the historic dataset to 2020 was 14.15% (95% confidence interval 9.66–20.85%) and using the modified strata was 14.35% (95% confidence interval 9.84–22.12%). There were no substantial changes in mean total scallop count or predicted and observed density for any size/age group (Figure D.4; Figure D.5; Figure D.6). Notably, the standard error for legal scallop were large for both the historical data and the modified strata data (Figure D.5; Figure D.6). Raw calibrated counts of scallops did not change substantially, and the overall trend remained the same (Figure D.4).

Modified and predicted scallop density did not change substantially for either age class and the overall trend remained the same across all years (Figure D.5). Similarly, density estimates for all age classes

Figure D.5: Observed survey density compared to predicted density for age 0+ and 1+, from left to right a) original strata and b) modified strata

were not substantially changed (Figure D.6). Mean values increased slightly in all years, however the overall trend remained the same.

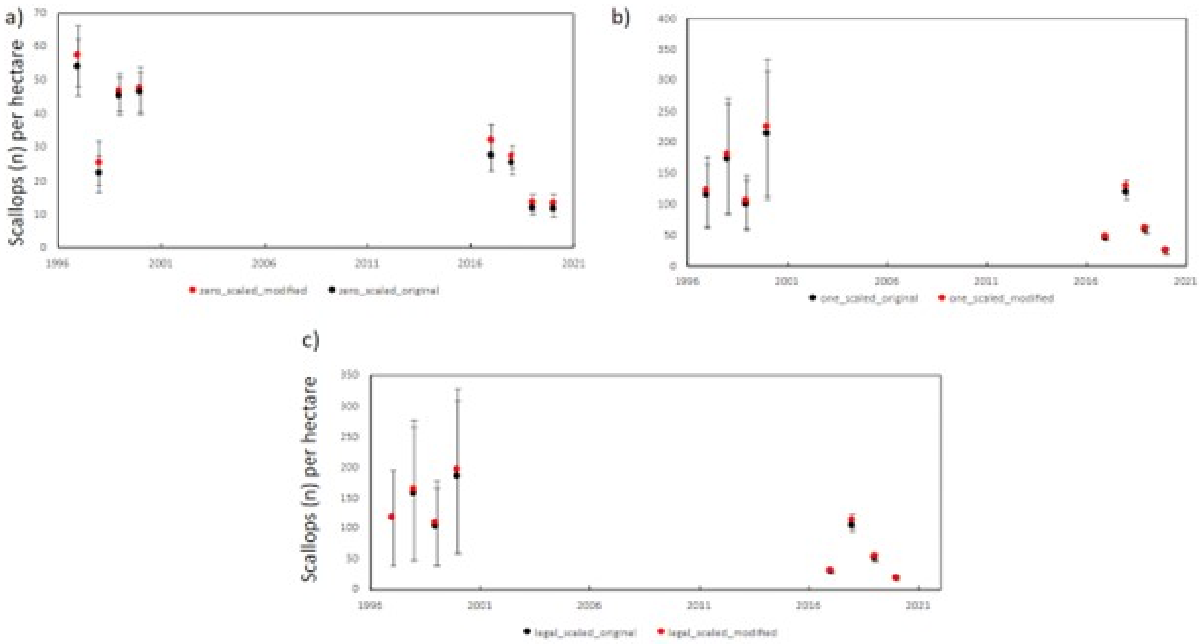

Figure D.6: Comparison of density predictions for scallop size/age groups: a) legal size, b) 0+ and c) 1+ age

D.5 Recommendations and Conclusion

D.5.1 Industry feedback and Survey design

Reviewing feedback from industry may also assist in identifying future objectives and research priorities. Project staff have received additional feedback on the survey design for the FIOT survey, from the commercial trawler operators involved in the 2022 survey, as well as some of the technical staff involved in the survey. Some of the feedback received and their considerations are listed below.

D.5.2 Site allocation to take into consideration environmental factors

Industry representatives have suggested that some sites fall in areas where the environmental conditions are not suitable for scallops to be caught. However, the present strata revision may address this issue. By excluding areas which had little to no commercial effort, it may be unlikely that many sites fall where it is unsuitable for catching scallops. Due to the sampling design, sites fall in areas where scallops have been caught at some point in the last 10 years. It may be the case that scallops are less likely to be caught in some of these areas in more recent years. However, as the survey is intended to capture long term trends, it is important to include areas where scallops have historically been caught. Abiotic conditions (such as oceanography) associated with scallop catch have been investigated in the past (Courtney et al. 2015). Similarly, recent investigation into the Moreton Bay bugs demonstrated how sediment grain size and composition can explain the distribution of two species, sand bugs (*Thenus australiensis*) and mud bugs (*Thenus parindicus*) (McMillan et al. draft 2023). Future research could investigate the use of environmental factors, such as substrate composition, as a tool to improve the sampling design of the FIOT survey. It may also be useful to compare the catch and effort footprint of the FIOT survey, with the commercial catch and effort footprint, to determine if it is necessary to exclude additional sites where scallops are unlikely to be encountered both now and historically.

D.5.3 Maheno Outer stratum to be reviewed for suitability

There have been low numbers of scallop caught in Maheno Outer stratum in the recent surveys. It has been suggested by trawler operators that the Maheno Outer stratum be reviewed to determine if it should continue to be included in future years. However, there has been some commercial catch and FIOT catch in this region. It is important that the survey remains independent from changes in commercial trawling activity and aligns instead with the distribution of the scallop stock. However, it may be worth investigating catch distribution (both commercial and FIOT) in the Maheno Outer stratum to address this concern.

D.5.4 Removal of sites that fall in shipping lanes

A number of sites were either not suitable or were aborted in the recent survey due to falling within shipping lanes. In all cases a reserve site was used instead. However, for efficiency and the safety of everyone involved in the survey it is recommended that excluding shipping lanes in future surveys be investigated.

D.5.5 Conclusion

The findings suggest that amending the strata for the FIOT survey sampling design to remove areas that have historically received little to no CPUE has little impact on the trend signal in the data and better aligns sampling effort to actual commercial fishing effort. Using the amended survey design in future years is recommended as it will improve sampling efficiency, save costs, reduce the likelihood of damage to trawl gear and may improve relationships with industry through addressing their concerns regarding the survey design. It may be beneficial to monitor trends in these data into the future, ensuring the sampling design remains fit for purpose.