A preliminary assessment for mackerel icefish (*Champsocephalus gunnari*) in Division 58.5.2, based on results from the 2025 random stratified trawl survey

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Recommendations

We recommend the catch limits in Conservation Measure 42-02 be set at 1 429 t in the 2025/26 season and 1 126 t in the 2026/27 season.

Abstract

The annual random stratified trawl survey was undertaken in Division 58.5.2 in the vicinity of Heard Island and McDonald Islands during March 2025. Based on data from this survey, this paper provides a preliminary assessment for mackerel icefish (*Champsocephalus gunnari*) population structure, abundance and yield in Division 58.5.2 using standard CCAMLR methods (CMIX and Grym).

The 2025 survey showed a large 3+ cohort in the population and a high biomass. Based on the Grym implementation, catches of 1 429 t in the 2025/26 season and 1 126 t in the 2026/27 season satisfy the CCAMLR decision rules.

Introduction

The fishery for mackerel icefish (*Champsocephalus gunnari)* around Heard Island and McDonald Islands in Division 58.5.2 began in 1997 (CCAMLR 2020). A random stratified trawl survey (RSTS) has been undertaken each year on the shallow plateau (<1000 m) in Division 58.5.2 to collect data on the distribution, abundance and population structure of Patagonian toothfish, mackerel icefish and other species.

Prior to 2011, the population of mackerel icefish in Division 58.5.2 generally exhibited one or two cohorts which dominated in abundance and biomass, and these were separated in age by one or two years (Welsford 2010, Welsford 2015, Williams *et al.* 2001). Since the maximum age of mackerel icefish in this region is thought to be around five years, strong cohorts have resulted in large variation of population abundance and the amount of production available to the fishery (SC-CAMLR 2010). However, between 2011 and 2016 at least four and often five cohorts were apparent in the population simultaneously, with no single cohort being overwhelmingly dominant (Maschette & Welsford 2019). Since 2016 there have been at least four cohorts present with normally the 2+ and 3+ being cohorts being the largest (Maschette & Welsford 2019, Appendix A Figure A.3).

This study provides an analysis of data collected in the 2025 survey to estimate the current abundance and cohort structure in the mackerel icefish population in Division 58.5.2 and its implications for yields in the fishery in 2025/26 and 2026/27 seasons.

Methods

2025 survey

The design of the survey conducted in 2025 used the same principles as previous surveys in Division 58.5.2 (Coghlan *et al.* 2025). The three strata where mackerel icefish are abundant (Gunnari Ridge, Plateau West and Plateau Southeast) were surveyed in daylight when icefish are close to the seafloor and most effectively sampled by demersal trawls (van Wijk *et al.* 2001). Survey hauls were allocated at random within each stratum, however a minimum spacing of 5 nautical miles between survey stations was specified to ensure hauls would not overlap. Station locations and catches are detailed in Coghlan *et al.* (2025) with density estimates ranging from 0 – 116 tons per km^2. Survey diagnostic information as outlined in Maschette *et al.* (2018) and endorsed by WG-SAM-18 (para. 3.11) are presented in Appendix A.

Assessment methods

The assessment method followed those agreed by SC-CAMLR (SC-CAMLR-XVI, para 5.70) for assessing yield in mackerel icefish, as published by de la Mare *et al.* (1998), and is identical to that used to estimate yields for mackerel icefish in Division 58.5.2 in previous years. Work undertaken as part of the krill management strategy (SC-CAMLR-38 Table 1, para 3.34) re-implementing the Generalized Yield Model software in an open source software has resulted in the R package 'Grym' (Wotherspoon & Maschette 2020). Briefly, the Grym implements the same projections as the GYM software but uses an explicit solution with the composite trapezoidal quadrature rule rather than an adaptive Runge Kutta method, resulting in a more accurate projection (Maschette *et al.* 2020).

Assessment diagnostic information as outlined in Maschette *et al.* (2018) and endorsed by WG-SAM-18 (para. 3.11) are presented in Appendix B.

Cohort structure

A mixture analysis was undertaken using the CMIX procedure (de la Mare 1994, de la Mare *et al.* 2002) to estimate the density of fish in each age class. The contribution of each age class to the overall biomass was estimated by scaling each age class by its mean weight at length. The survey data were pooled to a single survey data set. As in previous years the sampling effort across strata was un-equal and the data are re-scaled so that the mean of the re-scaled data is the same as the stratified mean of the raw data. For each haul in *k* strata, the density data are re-scaled by the composite sampling fraction following de la Mare & Williams (1996):

$$D_{i,j} = d_{i,j}\frac{A_i}{\sum_k A_k} \times \frac{\sum_k n_k}{n_i}$$

where $D_{i,j}$ is the re-scaled density for haul *i* in stratum *j*, $d_{i,j}$ is the original density estimate for that haul, and A_i and n_i are the area and the number of hauls in stratum *i* respectively.

Weight-at-length relationship

The parameters of the weight-at-length relationship, *a* and *b* were re-estimated using the *nls*() function in R (R Development Core Team 2025) to fit the relationship:

$$W=aL^b$$

where *W* is the weight (kg) and *L* is the length (mm) of individual icefish taken during the 2025 survey.

Length-at-age

Maschette *et al*. (2024) evaluated growth parameters using survey data. Here, we use their estimate for the period 2018-2024 as agreed by WG-FSA-IMAF-2024 (para. 3.7). The growth function estimated L_∞ of 559.1 mm, a growth rate (K) of 0.294 and t_0 of 0.066.

Maturity

For the assessment, all fish (aged 1 – 3 years) were assumed to be mature so that the status of the whole stock is monitored.

Natural mortality

Natural mortality was assumed to be 0.4 (de la Mare 1998).

Survey biomass and preliminary yield estimation

Using the method described in Constable *et al.* (2005, Appendix 1), a bootstrap algorithm was implemented in R to estimate the uncertainty in the total biomass (tonnes) of mackerel icefish over the survey area (Appendix B). The lower one-sided 95% confidence bound of the biomass estimate was then used as the estimate of the standing stock at the start of the projection period.

In combination with the biological parameters and other input settings shown in Appendix B (Table 3), the Grym package in R (Wotherspoon & Maschette 2020) was used to estimate the fishing mortality and corresponding catch that satisfies the short-term decision rule, i.e. that will result in a 75% escapement relative to a two-year projection with zero fishing mortality (Figure 1).

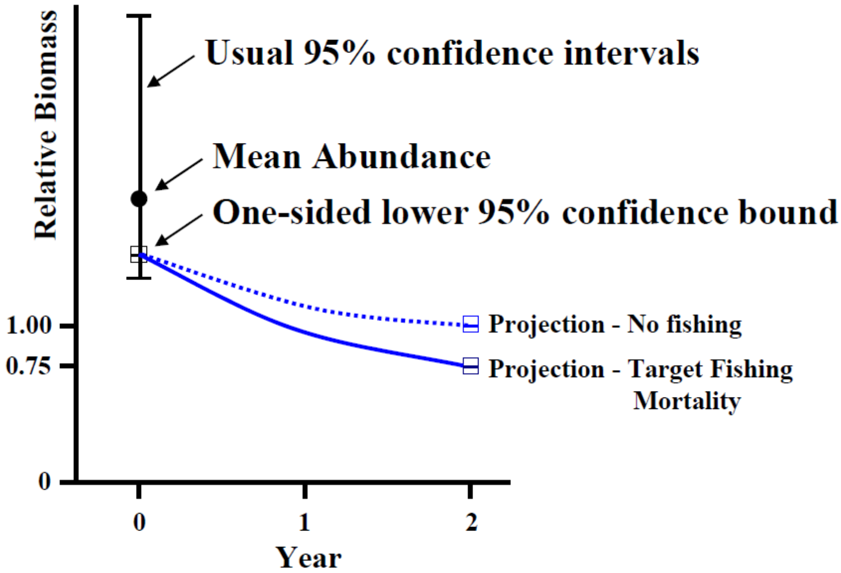

Figure 1. Decision rule for determining yield for mackerel icefish in year 1 and 2 after a survey (from Constable *et al.* 2005).

Few fish in the mackerel icefish population in Division 58.5.2 survive beyond age 4, with a drop in abundance between 3+ and 4+ cohorts observed in consecutive surveys (Welsford 2011, Welsford 2015). Consequently, the assessment scenarios run here only includes the biomass estimated from the 0+ to 3+ cohorts.

Results

Cohort structure

The best CMIX fit to the survey length density data was achieved when the population was assumed to consist of four components, i.e. year classes 1+ through 4+ (Tables 1 and Appendix B). A substantial 3+ cohort dominated the 2025 survey (Figure 2). Overall fish density was estimated to be lower than last year (Table 2).

Table 1. Results of CMIX analysis of mackerel icefish from the 2025 random stratified trawl survey in Division 58.5.2.

	Mixture Components			
	1 (1+)	2 (2+)	3 (3+)	4 (4+)
Mean length (mm)	168	263	338	386
SD (mm)	13	16	18	20
Intercept of CV	8.3			
Slope of CV	0.03			
Total density (n.km^{-2})	73	494	3517	37
SD (n.km^{-2})	58	119	793	77
Sum of observed densities	4156			
Sum of expected densities	4121			

Table 2. Comparison of mean density of mackerel icefish (n.km^{-2}), and the CMIX estimate of overall and cohort density in the surveys conducted in 2023, 2024 and 2025 in Division 58.5.2. Note that the age of each year cohort increments by one year after the nominal birthdate of 1 December. For example, the 2+ cohort observed in 2023 is the same as 3+ cohort observed in 2024.

Year	Month	Overall Density		Cohort Density			
		Expected	Observed	1+	2+	3+	4+
2023	March	4670	4680	292.3	539.7	1843.2	2004.5
2024	March	23155	23221	2331	20339	226	260
2025	March	4121	4156	73	494	3517	37

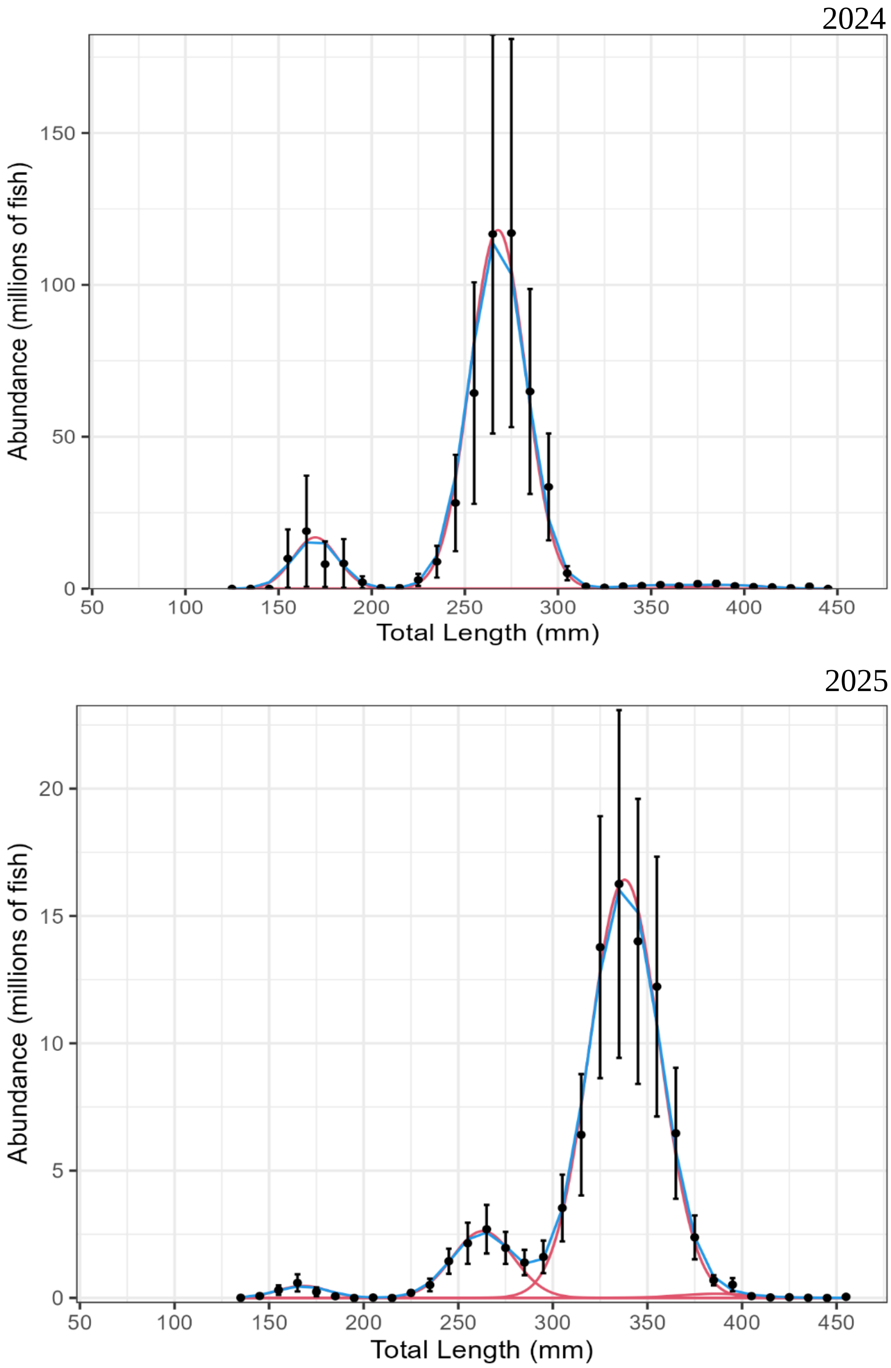

Figure 2. Observed and estimated length densities using CMIX for mackerel icefish in the surveys from March 2024 (upper panel) and March 2025 (lower panel). Shown are observed mean abundances at length (black circles, + SE), fitted total abundances at length (blue lines), and fitted abundances at length for the different components (red lines).

Weight-at-length relationship

The weight-at-length relationship was re-estimated based on 4 772 icefish measured during the survey. The re-estimated weight-at-length relationship closely followed that of last year (Table 3, Figure 3).

Table 3. Estimates of the weight-at-length parameters of mackerel icefish fitted to data from each survey conducted in 2024 and 2025 in Division 58.5.2.

Model	Parameter	
	a	*b*
2024	3.406E-09	3.090
2025	2.842E-09	3.123

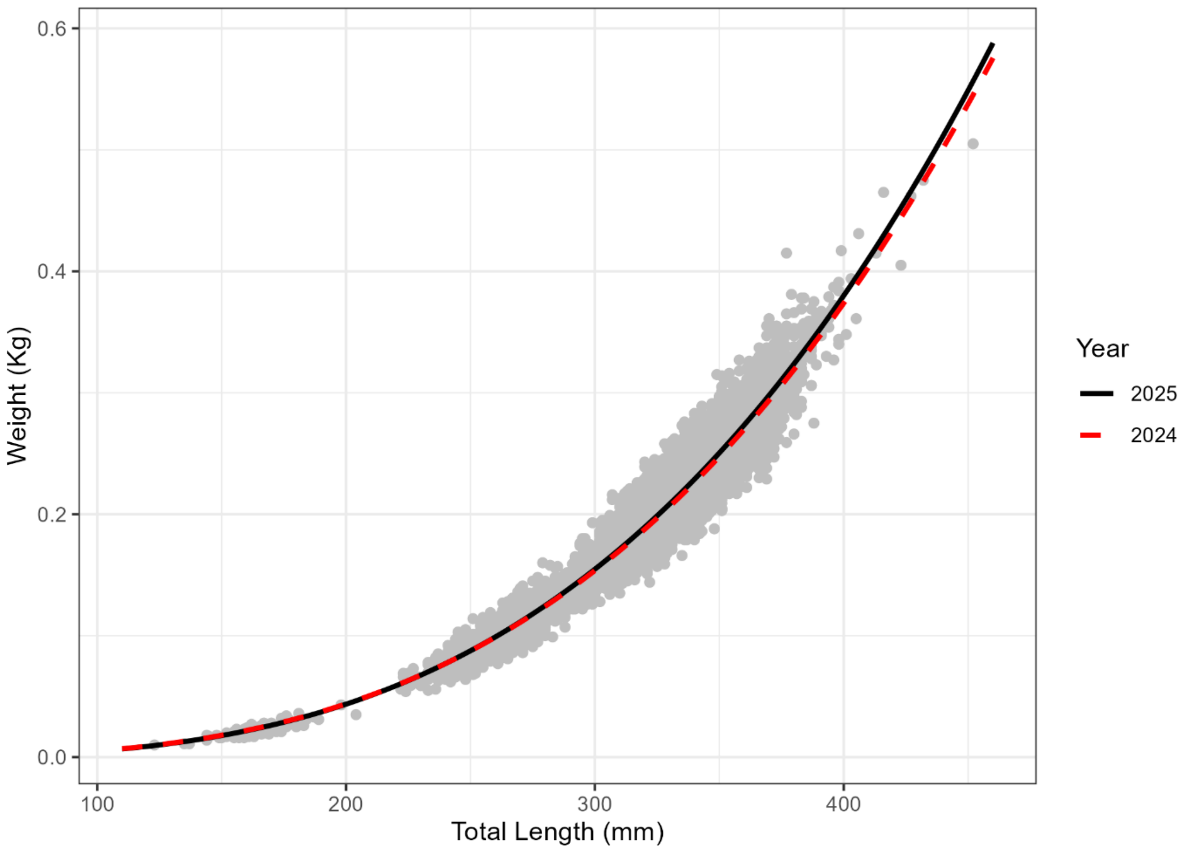

Figure 3. Weight-at-length data for mackerel icefish sampled during the 2025 random stratified trawl survey in Division 58.5.2 (grey dots) with fitted non-linear least squares regression (solid black line), and fitted regression to the 2024 survey (dashed red line, Maschette *et al*. 2024).

Using the estimated weight-at-length relationship for 2025, the contribution of each age class to the overall biomass present during the survey was estimated, indicating that fish up to 3+ constituted around 98.52% of the biomass present across the three icefish strata (Table 4).

Table 4. Proportion of mackerel icefish biomass at age in the 2025 random stratified trawl survey in Division 58.5.2.

Age class	Mean length (mm)	Density ($n.km^{-2}$)	Mean weight (kg)	Proportion of biomass (%)
1+	168	73	0.025	0.22
2+	263	494	0.103	5.92
3+	338	3517	0.225	92.38
4+	386	37	0.340	1.48

Survey biomass and preliminary yield estimation

The biomass estimates with bootstrapped uncertainty for each icefish survey stratum and overall are shown in Table 5. The 2025 survey showed a slightly higher mean biomass, and a similar lower one-sided 95% confidence interval biomass as 2024 (Appendix 1, Figure B.2).

Table 5. Abundance (tonnes) of mackerel icefish in Division 58.5.2 estimated by bootstrapping hauls from the 2025 random stratified trawl survey. SE = standard error; Lower CI & Upper CI = lower and upper confidence intervals respectively; LOS 95% CI = lower one-sided 95% confidence interval.

Stratum	Mean	SE	Lower CI	Upper CI	LOS 95% CI
Gunnari Ridge	15 127	5 710	5 393	26 726	6 645
Plateau SE	3 111	1 376	970	6 138	1 179
Plateau W	1 488	578	694	2 706	760
Pooled	19 726	6 491	8 663	33 598	10 049

The stock projection used the proportion of overall biomass made up by the 1+, 2+ and 3+ cohorts (98.52%, Table 4). This means that 9 901 t of the overall 10 049 t lower 95% CI (Table 5) was used in the Grym projection. The Grym projection indicated that catches of 1 429 t in the 2025/26 season and 1 126 t in the 2026/27 season satisfy the CCAMLR decision rules depending on the growth curve used (Table 6).

Table 6. Target fishing mortality rate and annual yields of mackerel icefish in Division 58.5.2, estimated to ensure 75% escapement over a 2-year projection period for the 1+, 2+ and 3+ cohorts using the Grym package, using the parameters shown in Table B.2.

Initial biomass estimate (t)	**Target fishing mortality rate (yr^{-1})**	**Catch after survey**	**Yield (tonnes)**	
			2025/26	**2026/27**
9 901	0.1447	0	1429	1126

Discussion

Robustness of harvest strategy

Mackerel icefish are known to be a highly plastic species with differing population parameters across its geographic range (Kock 2005). Recent stock assessments indicate that population parameters vary through time within the same population (Maschette & Welsford 2019), which can pose a challenge for stock assessments (SC-CAMLR 2001). However, the current harvest strategy appears sufficiently conservative to avoid harvesting that would be inconsistent with the CCAMLRs objectives (Appendix Figure B.4). Estimating biological parameters regularly (see also Maschette *et al*. 2024) ensures that long-term environmental changes, such as those which are predicted to occur due to global climate change and may impact population characteristics, are accounted for.

Management Advice

The 2025 survey showed a large 3+ cohort in the mackerel icefish population in Division 58.5.2. This was to be expected given that the same cohort was present in the 2024 assessment as a 2+ cohort. As in previous years, this preliminary assessment removes the 4+ cohort as it is unlikely that it will be available to the fishery in the coming years and only uses the 1+ to 3+ cohorts in the forward projections.

Following the previous advice of CCAMLR, given the plasticity of this species and the differences seen in growth between time periods presented in Maschette *et al*. (2024), we estimated the catch limits using the most recent period of estimated growth (2018-2024).

The projections of the Grym indicated that catches of 1 429 t in the 2025/26 season and 1 126 t in the 2026/27 season satisfy the CCAMLR decision rules. We recommend that catch limits be set for the 2025/26 and 2026/27 seasons based on this assessment, and a revised assessment be conducted based on survey data collected in 2026 since cohorts younger than age 3+ are not well selected by the survey gear.

Acknowledgements

We would like to express our thanks to the members of the Australian Sub-Antarctic Resource Assessment Group for helpful comments on the analyses and text in this manuscript. We would also like to thank Tim Lamb for assistance with the data, as well as Austral Fisheries Pty Ltd, and the crew, observers aboard the FV *Cape Arkona* for conducting the survey hauls and collecting the data upon which this paper was based.

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Appendix 1: Diagnostic Information for 2024 *Champsocephalus gunnari* preliminary assessment

Diagnostics

During the 2018 Working Group of Statistics, Assessments and Modelling (WG-SAM) the working group agreed to the standard diagnostic examples presented in Maschette et al. (2018) for future Mackerel Icefish (*Champsocephalus gunnari*) Assessments presented to WG-FSA. Here we present the diagnostic information for the assessment presented in the main text.

Survey information:

1. Haul data - Location (map with bubbles) and catch and CPUE (table) including strata.
2. Haul by haul CPUE (kg/km^2) column chart including strata.
3. Number of fish measured and weighed from the survey used in the assessment.
4. Time series of length frequency distribution.

Assessment:

5. Distribution plot of the bootstrap runs.
6. Survey biomass time series plot (Estimates of biomass with confidence intervals and lower one-sided 95th percentile).
7. CMIX plots
8. Code used for conducting calculations and assessment.
9. Table of parameters used and their source.
10. Previous lower 95th stock assessment projection vs survey estimated time series.

Appendix A Survey Diagnostics

Diagnostic A1: Haul data

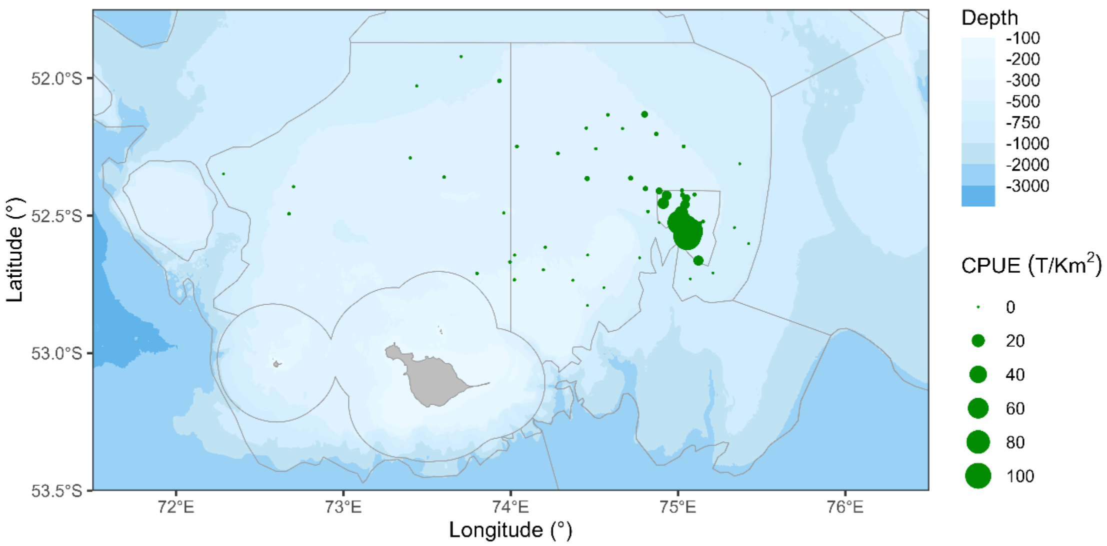

Figure A.1: Catch rates (t/km2) in the 2025 RSTS for mackerel icefish (Champsocephalus gunnari) in Division 58.5.2

Table A.1: Haul details from the 2025 Random Stratified Trawl Survey mackerel icefish (Champsocephalus gunnari) in Division 58.5.2.

Haul	Strata	Catch Weight (Kg)	CPUE (T/Km2)
16	Plateau West	32.77	0.62
17	Plateau West	4.06	0.07
18	Plateau West	2.84	0.05
27	Plateau West	0.00	0.00
28	Plateau West	7.66	0.14
30	Plateau West	3.42	0.05
31	Plateau West	3.03	0.05
32	Plateau West	6.92	0.12
34	Plateau Southeast	10.57	0.20
35	Plateau Southeast	10.59	0.18
36	Plateau Southeast	65.32	1.09
37	Plateau Southeast	2.91	0.05
38	Plateau Southeast	4.83	0.09
39	Plateau Southeast	8.16	0.15
40	Plateau Southeast	1.61	0.03
41	Plateau Southeast	171.42	2.86
42	Plateau Southeast	29.47	0.55
43	Plateau Southeast	14.83	0.26
44	Plateau Southeast	22.87	0.40
49	Plateau Southeast	0.00	0.00
52	Plateau West	6.46	0.12
53	Plateau Southeast	1.45	0.02
58	Plateau Southeast	5.28	0.09
59	Plateau West	8.51	0.16
61	Plateau West	3.41	0.06
62	Plateau Southeast	2.81	0.05
66	Plateau Southeast	0.00	0.00
67	Plateau Southeast	0.85	0.01
68	Plateau Southeast	2.45	0.04

Haul	Strata	Catch Weight (Kg)	CPUE (T/Km2)
69	Plateau Southeast	0.26	0.00
74	Plateau Southeast	50.16	0.95
75	Plateau Southeast	73.01	1.29
76	Gunnari Ridge	176.64	3.13
77	Gunnari Ridge	519.64	9.22
78	Gunnari Ridge	793.71	14.09
79	Gunnari Ridge	5.08	0.07
81	Gunnari Ridge	637.76	10.06
85	Plateau Southeast	0.29	0.00
86	Gunnari Ridge	1,097.20	19.48
87	Gunnari Ridge	435.15	7.92
88	Gunnari Ridge	311.08	5.52
89	Gunnari Ridge	62.09	1.03
90	Gunnari Ridge	22.35	0.37
91	Plateau Southeast	7.04	0.13
92	Gunnari Ridge	0.00	0.00
93	Gunnari Ridge	5,010.78	89.00
94	Gunnari Ridge	1,918.32	41.93
95	Gunnari Ridge	12.21	0.20
102	Plateau Southeast	0.00	0.00
103	Plateau Southeast	0.00	0.00
104	Plateau Southeast	0.00	0.00
105	Plateau Southeast	0.26	0.00
106	Plateau Southeast	0.48	0.01
108	Gunnari Ridge	0.00	0.00
109	Gunnari Ridge	6,531.13	116.00
110	Gunnari Ridge	17.75	0.29
111	Gunnari Ridge	6,014.00	98.79

Diagnostic A2: Haul catch per unit effort

```
ggplot(dat, aes(x=Area.Name, y=cpue_tkm2,fill=Area.Name,group=reorder(Haul,-cpue_t
km2)))+
  geom_col(position="dodge")+ scale_fill_discrete(guide="none")+
  labs(x="Strata", y=expression(CPUE~(t/km^{2})))
```

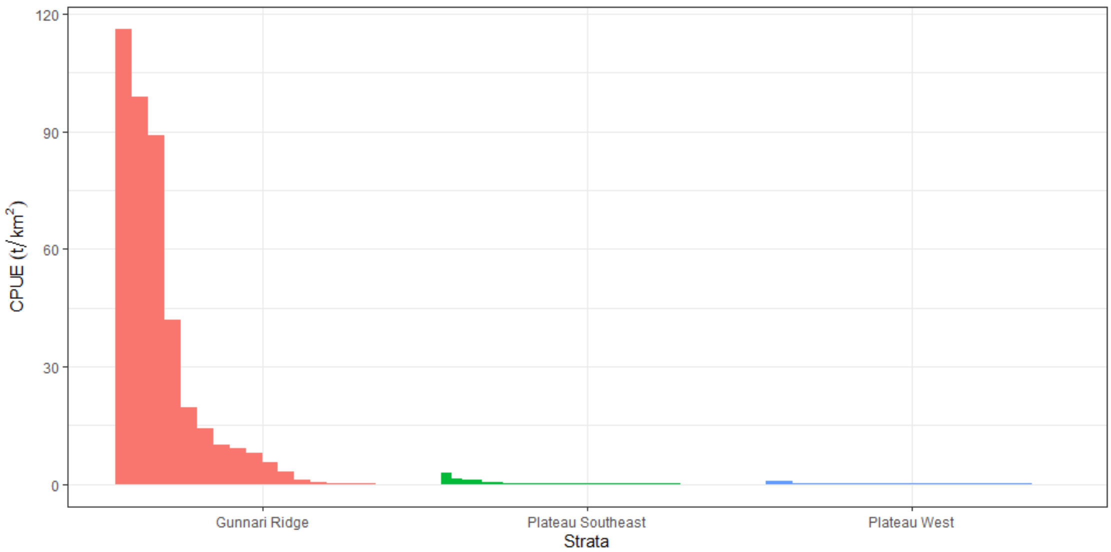

Figure A.2: Catch rate (t/km^2) by haul within strata in the 2025 Random Stratified Trawl Survey for mackerel icefish (Champsocephalus gunnari) in Division 58.5.2.

Diagnostic A3: Number of fish measured and weighed from the survey used in the assessment.

During the survey the length weight data from 4 772 fish caught were available and used.

Diagnostic A4: Time series of length frequency distribution

```
len<-length %>% filter(Year >= max(Year)-4) %>%  group_by(Strata,Year,Bins) %>% su
mmarise(Dens= mean(Density))

## `summarise()` has grouped output by 'Strata', 'Year'. You can override using
## the `.groups` argument.

ggplot(dat=len, aes(x=Bins, y=Dens)) + geom_col(width=10) +
  facet_grid(Year~Strata, scale="free_y") +
  labs(y=expression(Numbers/km^{2}), x="Length (mm)")+
  theme_bw()
```

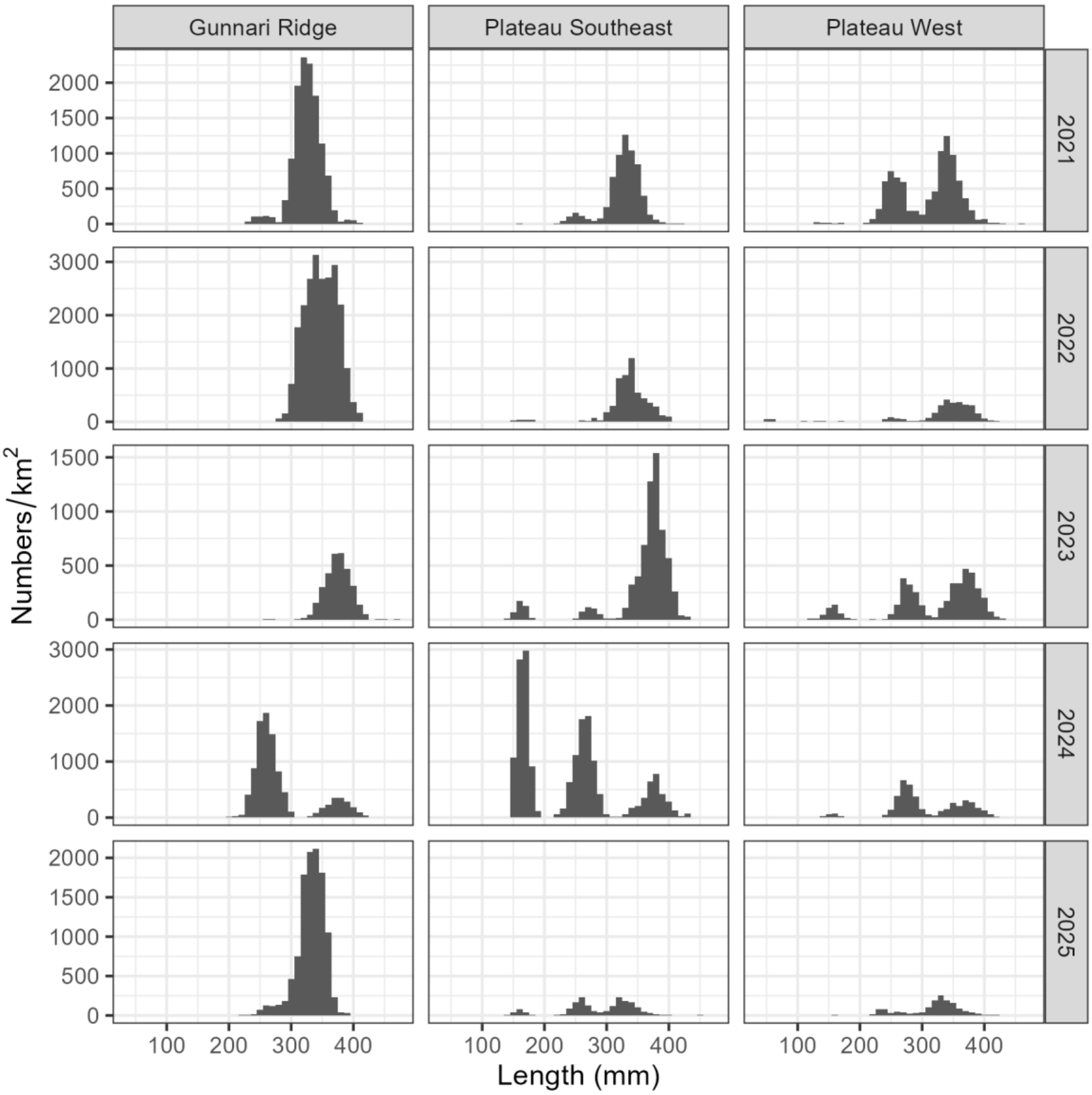

Figure A.3: Fish length distribution by strata in the 2025 Random Stratified Trawl Survey for mackerel icefish (Champsocephalus gunnari) in Division 58.5.2.

Appendix B Assessment Diagnostics

Diagnostic B1: Distribution of bootstrap run

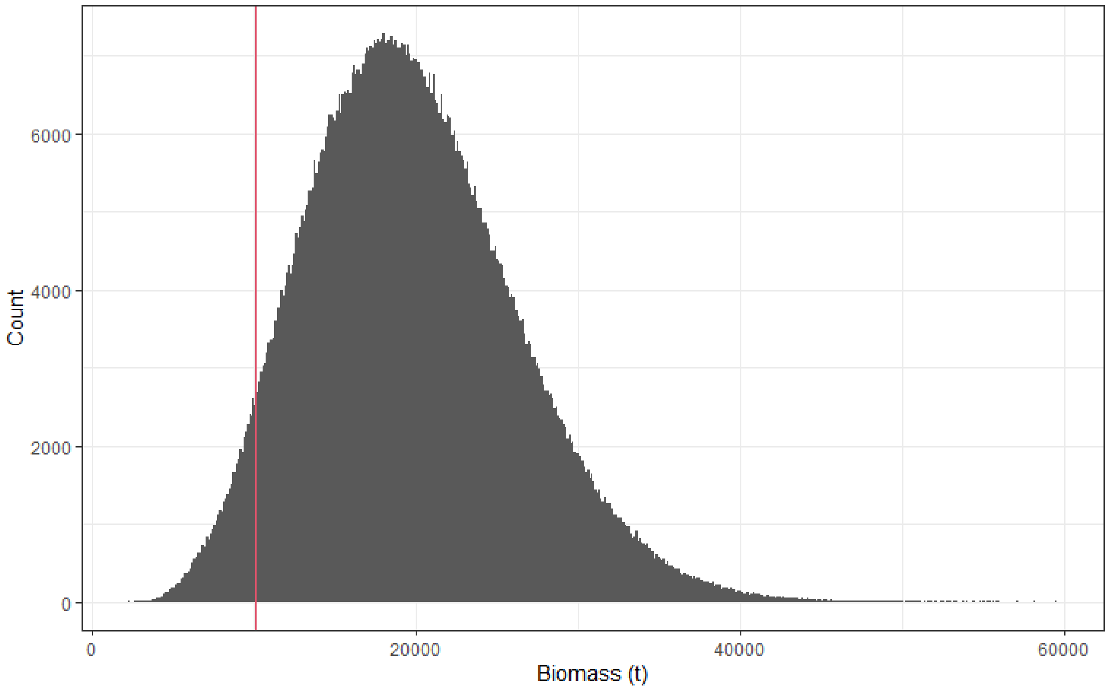

Figure B.1.1: Distribution of bootstrapped biomass estimates for 2025 mackerel icefish (Champsocephalus gunnari) in Division 58.5.2 after removal of one large haul in stratum Plateau SE with lower one-sided 95th confidence bound (red).

Diagnostic B2: Survey biomass time series

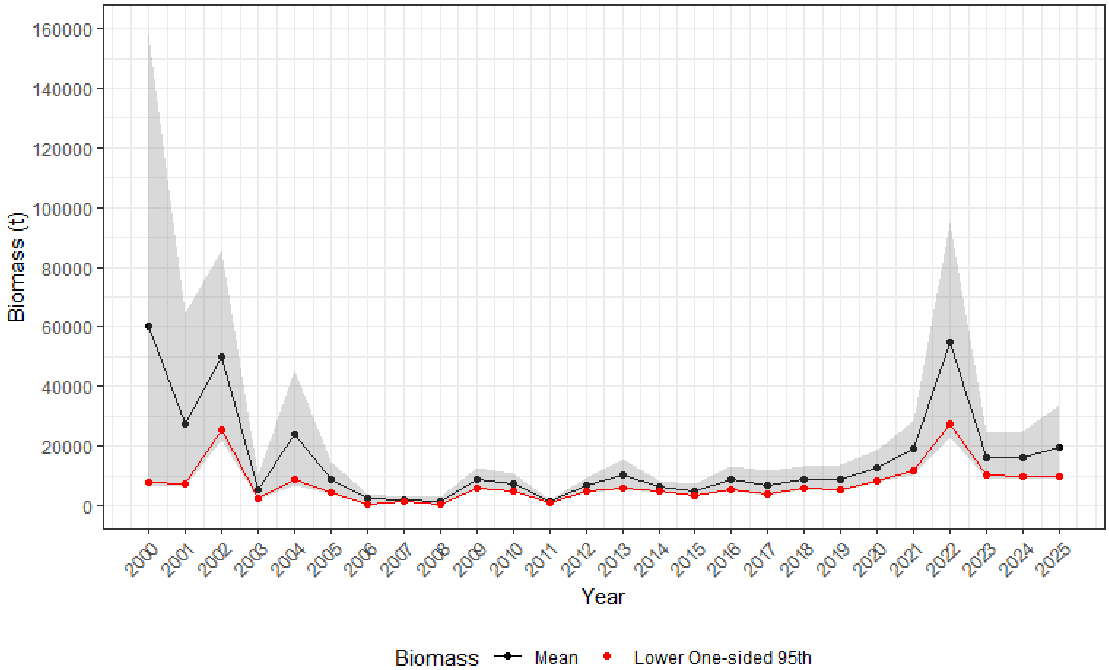

Figure B.2: Time series of estimated biomass for mackerel icefish (Champsocephalus gunnari) in Division 58.5.2 with mean (black) and lower one-sided 95th confidence bound (red).

Diagnostic B3: Length Cohorts

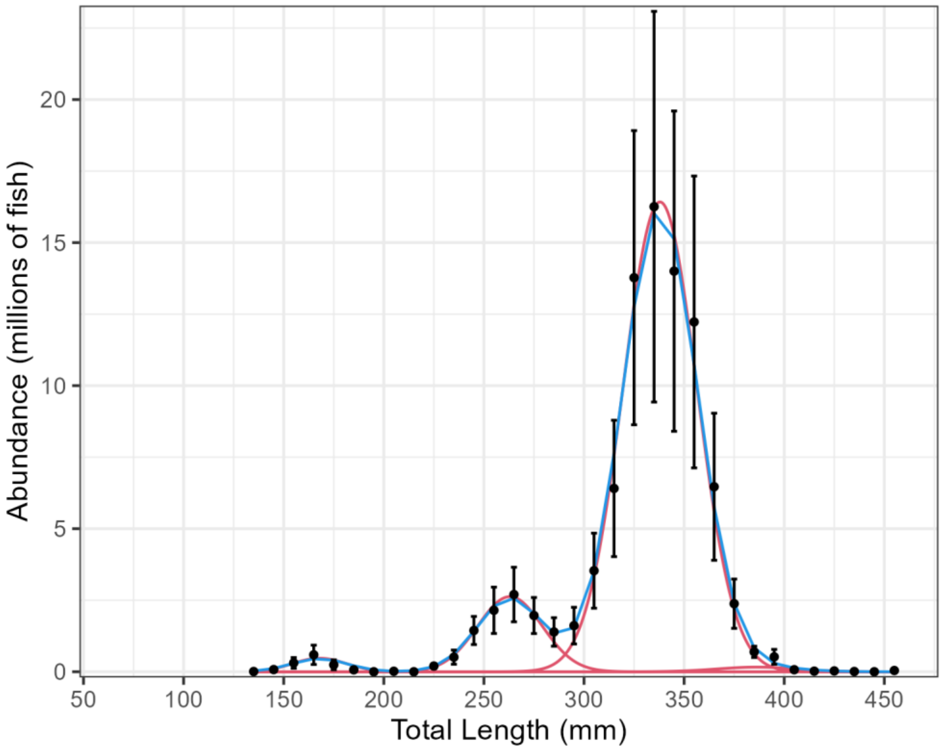

Figure B.3: Observed and estimated length densities using CMIX for mackerel icefish in the 2025 Random Stratified Trawl Survey. Shown are observed mean abundances at length (black circles, +SE), fitted total abundances at length (blue line), and fitted abundances at length for the different components (red lines).

Diagnostic B4: CMIX Code for calculations

```
path<- "./CMIX/"
data<-paste0(path,'ANI_2025.csv')
input<-paste0(path,'2025CMIXinput.dat')
output<-paste0(path,'2025CMIXoutput.dat')
buildCMIX(infilepath=input, hauldatafilepath = data,
          components=matrix(c(140,180,250,300,310,360,365, 430), ncol=2, byrow=TRU
E),
          linearlyRelated = TRUE, upLinIntr= 10, upLinSlope=0.03, stepLenSlope=0.0
01, stValIntr=3, stValSlope=0.01, skipLeadInts=0,stoppingCrit=1E-10)

###Run CMIX
runCMIX(input, output)
resultsCMIX(output)
```

Length to weight parameters

```
library(CMIX)
library(plotrix)

LW<-read.csv(paste0(Data.dir,'ANI Assessment LW.csv'))
W<-LW$Weight/1000 #gram to kg
L<-LW$TL
model<-nls(W~a*L^b,start=c(a=1.3E-9,b=3.26),  trace=TRUE)
summary(model)
```

Components biomass

```
ANI<-resultsCMIX(output)                                    ## Get results fro
m CMIX Output file.
Comps<-round(ANI$components$mean, digits = 0)               ## Get mean length
from each component.
CompsWeight<-round(predict(model,data.frame(L=Comps)), digits=5)## Use Length Weig
ht Model to predict weight of each components mean length.
NDens<-round(ANI$components$totaldensity, digits = 5)       ## Get the total d
ensity of each component from CMIX output.
WDens<-round(CompsWeight*NDens, digits=5)                   ## Multiply the de
nsity of each component by its calculated weight.
TotalWeight<-round(sum(WDens), digits=5)                    ## Sum the weights
of all components together.
Proportion<-round(WDens/TotalWeight*100, digits=2)          ## Calculate the p
roportion of biomass each components makes up.
Components<-as.data.frame(cbind(Comps,CompsWeight,NDens,WDens,Proportion))
## Proportion of Biomass made up by the 1+ - 3+ components.
ProportionOfBiomass<-sum(Components[1:4,"Proportion of Biomass"])
ProportionOfBiomass
```

Bootstrap

Table B.1: Bootstrap summary from 2025 mackerel Icefish (Champsocephalus gunnari) assessment in Division 58.5.2

Area	Mean	SE	LowerCL	UpperCL	OneSided95
Gunnari Ridge	8,456.3	3,362.5	2,841.9	15,487.1	3,525.2
Plateau Southeast	5,500.7	2,232.0	1,935.2	10,381.0	2,306.6
Plateau West	2,093.8	791.5	715.8	3,630.5	905.0
Plateau strata	13,957.1	4,109.3	6,812.3	22,663.0	7,755.9
All Strata	16,050.9	4,178.6	8,756.7	24,883.6	9,731.1

Grym Running Code

The Icefish assessment aims to determine the fishing mortality and hence a total allowable catch that yields a prescribed two year escapement relative to an unfished population.

```
library(Grym)
library(CMIX)
```

Data

Set the year of the assessment

```
year <- 2025
```

Define the reference date that sets the start of the season

```
SeasonDate <- as.Date(paste0(year-1,"-12-01"))
```

Define the survey date and the corresponding time increments, and the observed relative numbers and biomass. Note that GYM averages over the start and end of the survey increment, so to match we provide two survey increments.

Load the cmix data and biomass data.

```
path<- "./CMIX/"
output<-paste0(path,year,'CMIXoutput.dat')
ANI<-resultsCMIX(output)

boot_summ<-read.csv(file="./Output data/Bootstrap_summary.csv")

SurveyDate <- as.Date("2025-03-20")
surveyI <- as.numeric(SurveyDate-SeasonDate)+c(0,1)
surveyN <- c(round(ANI$components$totaldensity, digits = 5)[1:3],rep
(0,7))
surveyB <- boot_summ$OneSided95[5]
```

Adjust the survey biomass for proportion of 0-3 year olds

```
surveyB <- surveyB*0.9852
```

Check the numbers.

```
SurveyDate
[1] "2025-03-20"
surveyI
[1] 109 110
surveyN
 [1]   73.1428  493.5510 3516.9800    0.0000    0.0000    0.0000
0.0000
 [8]    0.0000    0.0000    0.0000
surveyB
[1] 9900.584
```

Define the spawning date and the corresponding time increments.

```
#SpawnDate <- as.Date("2022-11-30")
spawnI <- c(364,365) #as.numeric(SpawnDate-SeasonDate) + c(0,1)
```

Projection

The current strategy is to project forward two years for a range of potential fishing mortalities, and then subsequently determine the mortality that yields the target relative escapement by inverse interpolation.

The population is projected forward for two years with a range of potential fishing mortalities to determine the mortality that yields the target escapement by inverse interpolation.

Determine target Escapement

The above process is easily extended to automate the search for the fishing mortality that yields a target escapement.

The function *icefishRE* uses *uniroot* to determine the fishing mortality that produces a desired relative escapement and then projects forward for both zero fishing and the target fishing mortality. The arguments are

- `target` - target escapement
- `M` - natural mortality
- `F` - range of fishing mortalities to search
- `Catch` - remaining catch allocation after survey in survey year
- `surveyN` - relative numbers in each cohort from survey
- `surveyB` - biomass estimate from survey
- `surveyI` - increments (ie days of season) over which survey is taken
- `spawnI` - increments (ie days of season) over which spawning numbers and biomass are estimated
- `VB.t0`, `VB.K`, `VB.Linf` - parameters for von Bertalanffy length at age relation
- `WLa`, `WLb` - parameters for allometric weight at length relation
- `age.selectivity` - age selectivity function.
- `Fmax` - maximum allowable fishing mortality
- `tol` - error tolerance for `uniroot`

```
icefishRE <- function(target,M,F,
                      Catch=0,surveyN,surveyB,surveyI,spawnI,
                      VB.t0=0.06671238,VB.K=0.36842178,VB.Linf=489.7
3706791,
                      WLa=1.150e-10,WLb=3.275,
                      age.selectivity=approxfun(c(0,2.5,3),c(0,0,1),
rule=2),
                      Fmax=2.5,tol=1.0E-6) {

  ## Extract summary data from a projection
  annualSummary <- function(yr,F,pr) {
  }

  ## Ensure 0 included in test fishing mortalities
  F <- sort(union(0,F))

  ## Two year projections of 10 age classes with a daily time step
  n.yr <- 2
  n.inc <- 365
  Ages <- 1:10
  Days <- seq(0,1,length=n.inc+1)

  ## Matrices of ages, lengths and weights for each day and age clas
s
  as <- outer(Days,Ages,FUN="+")
  ls <- vonBertalanffyAL(as,t0=VB.t0,K=VB.K,Linf=VB.Linf)
  ws <- powerLW(ls,a=WLa,b=WLb)

  ## Constant intra-annual natural mortality
  ms <- matrix(1,n.inc+1,length(Ages))
  Ms <- ctrapz(ms,1/n.inc)
  MMs <- M*Ms
```

```
  ## Within year fishing mortality is determined by an age based sel
ectivity
  fs <- array(age.selectivity(as),dim(as))
  Fs <- ctrapz(fs,1/n.inc)

  ### Projection to end of year from survey data
  if(Catch>0) {
    ## Adjust with-year fishing mortality for post-survey Catch
    fs0 <- rep.int(c(0,1),c(max(surveyI),n.inc+1-max(surveyI)))
    fs0 <- fs0/trapz(fs0,1/n.inc)*fs
    Fs0 <- ctrapz(fs0,1/n.inc)
    pr0 <- projectC(ws,MMs,Fs0,fs0,Catch,surveyN,surveyI,surveyB,sur
veyI,yield=1,Fmax=Fmax)
    if(pr0$F==Fmax) warning("Target catch could not be recovered")
  } else {
    pr0 <- project(ws,MMs,0,0,surveyN,surveyI,surveyB,surveyI,yield=
0)
    pr0$F <- 0
  }
  ## Numbers at end of survey year - no recruitment
  N0Survey <- advance(pr0$N)
  SSB0 <- meanStock(pr0$B,1,spawnI)

  ## Project ahead and return final SSB
  ProjectSSB <- function(F,target=0) {
    ## Project and compute SSB for final year
    N0 <- N0Survey
    for(yr in seq_len(n.yr)) {
      pr <- project(ws,MMs,F*Fs,F*fs,N0,yield=0)
      N0 <- advance(pr$N)
    }
    SSB <- meanStock(pr$B,1,spawnI)
    SSB-target

  }

  SSB1 <- ProjectSSB(0)
  r <- uniroot(ProjectSSB,F,target=target*SSB1)
  F <- c(0,r$root)

  ## Annual cohort totals
  d <- data.frame(Year=c(rep(0:n.yr,length(F))),F=0,Nf=0,Bf=0,Y=0,SS
N=0,SSB=0,Bmon=0,Escapement=0)
  k <- 0

  ## Project forward for prescribed fishing mortalities.
  for(Fk in F) {
    ## Reset to survey year
    pr <- pr0
    d[k <- k+1,] <- data.frame(Year=0,F=pr$F,Nf=sum(final(pr$N)),Bf=
sum(final(pr$B)),Y=sum(pr$Y),
```

```
                                              SSN=meanStock(pr$N,1,spawnI),SSB=SSB0
,Bmon=meanStock(pr$B,1,305),Escapement=1)
    for(yr in seq_len(n.yr)) {
      ## Project
      N0 <- advance(pr$N)
      pr <- project(ws,MMs,Fk*Fs,Fk*fs,N0,yield=1)
      SSB <- meanStock(pr$B,1,spawnI)
      BMon <- meanStock(pr$B,1,305)
      d[k <- k+1,] <- data.frame(Year=yr,F=Fk,Nf=sum(final(pr$N)),Bf
=sum(final(pr$B)),Yield=sum(pr$Y),
                                                SSN=meanStock(pr$N,1,spawnI),SSB=SS
B,Bmon=BMon,Escapement=SSB/SSB0)
    }
  }
  d
}
```

No Remaining Allocation

Estimate the fishing mortality that gives 75% escapement after two years relative to unfished, assuming no catch allocation remains after the survey.

```
d <- icefishRE(target=0.75,M=0.4,F=c(0,0.5),Catch=0,surveyN,surveyB,
surveyI,spawnI,
               WLa=3.406e-09,WLb=3.090, VB.t0=0.06585126 ,VB.K=0.294
0745 ,VB.Linf=559.1367)
d$RelEscapement <- d$SSB/d$SSB[1:3]
```

Year	Fishing Mortality	Yield (tonnes)	Spawning Stock Biomass	Escapement	Relative Escapement
0	0.0000000	0.000	10,729.291	1.0000000	1.0000000
1	0.0000000	0.000	10,317.222	0.9615940	1.0000000
2	0.0000000	0.000	8,839.482	0.8238644	1.0000000
0	0.0000000	0.000	10,729.291	1.0000000	1.0000000
1	0.1447365	1,429.315	8,940.341	0.8332648	0.8665454
2	0.1447365	1,125.541	6,629.604	0.6178976	0.7499992

The recommended TAC will be 1429 t in year 1 and 1126 t in year 2.

Diagnostic B5: Table of parameters used and their source.

Table B.2: Parameters used within the 2025 mackerel Icefish (Champsocephalus gunnari) assessment in Division 58.5.2.

Category	Parameter	Values	Source
Age Structure	Recruitment age	2 years	de la Mare et al. 1998
	Plus class accumulation	10 years	de la Mare et al. 1998
	Oldest age in initial structure	11 years	de la Mare et al. 1998
Initial population structure	Age class density	See tables 2,3 and 4	Estimated in this paper
	Biomass	9901	Estimated in this paper
	Date of estimate (survey)	20-Mar-25	
Natural Mortality	Mean Annual M	0.4	de la Mare et al. 1997
von Bertalanffy growth	t0	0.06	Maschette et al. 2024
	Linf	559.8 mm	Maschette et al. 2024
	k	0.29	Maschette et al. 2024
Weight at Length (kg, mm)	Weight-length parameter – A (kg)	2.482 x 10-09 kg	Estimated in this paper
	Weight-length parameter - B	3.123	Estimated in this paper
Maturity	Lm50 (set so that the status of the whole stock is being monitored)	0 mm	
	Range: 0 to full maturity	0 mm	
Fishery parameters	Age fully selected	3	de la Mare et al. 1998
	Age first selected	2.5	de la Mare et al. 1998
	Season	1 Dec – 30 Nov	CCAMLR Season
	Catch between survey and season (mt)	0	Fishery reports
Spawning Season	Set so that status of the stock is determined at the end of each year	30 Nov – 30 Nov	
Simulation specifications	Number of runs in simulation	1	
Individual trial specifications	Years to remove initial age structure	0	
	Reference Start Date in year	1-Dec	
	Increments in year	365	
	Years to project stock in simulation	2	
	Reasonable upper bound for Annual F	5	
	Tolerance for finding F in each year	0.000001	

Diagnostic B6: Previous lower 95th stock assessment projection vs survey estimated time series.

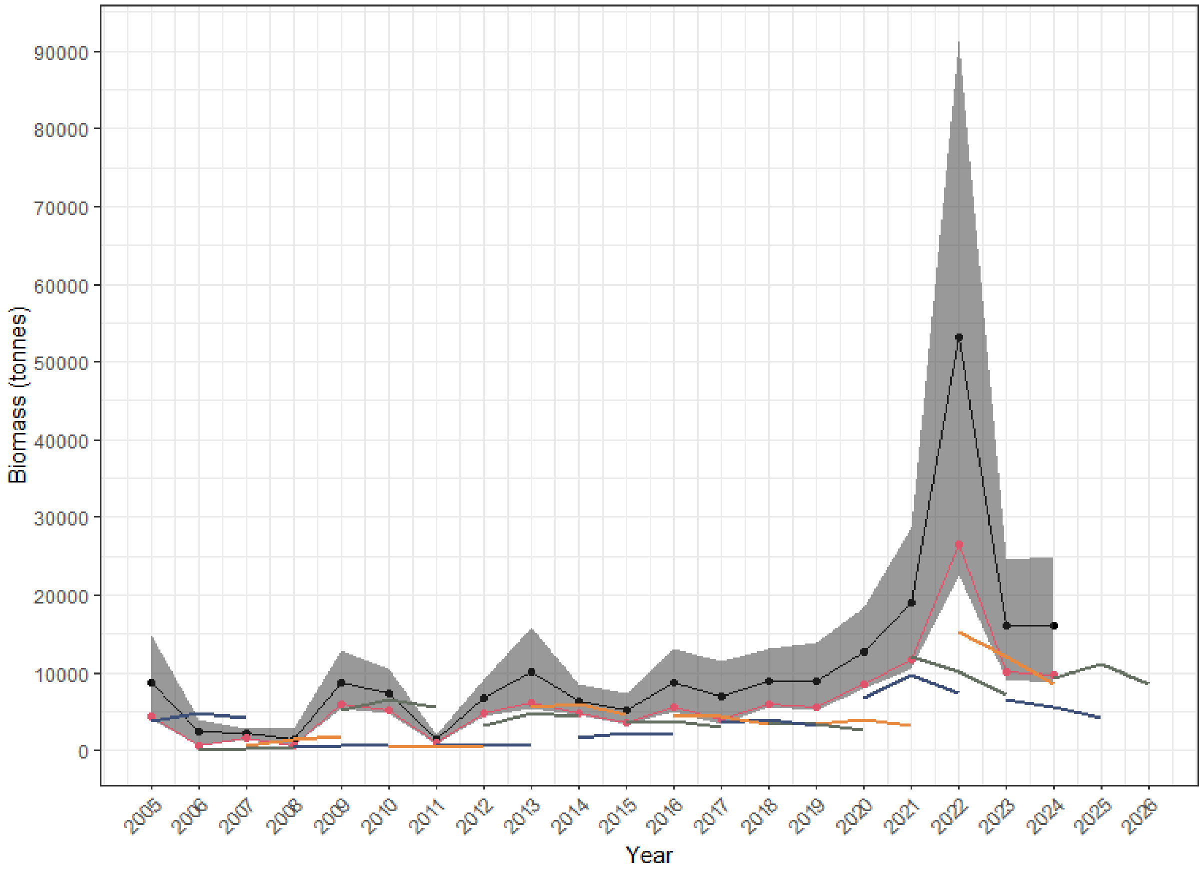

Figure B.4: Mean time series of estimated biomass (including 4+ and 5+ cohorts; black) with confidence intervals (grey) and lower one-sided 95th confidence bound (red), and stock assessment projections (excluding 4+ and 5+ cohorts; colors) that were used to determine catch limits for mackerel icefish (Champsocephalus gunnari) in Division 58.5.2.

```
sessionInfo()
R version 4.4.1 (2024-06-14 ucrt)
Platform: x86_64-w64-mingw32/x64
Running under: Windows 10 x64 (build 19045)

Matrix products: default


locale:
[1] LC_COLLATE=English_Australia.utf8  LC_CTYPE=English_Australia.utf8
[3] LC_MONETARY=English_Australia.utf8 LC_NUMERIC=C
[5] LC_TIME=English_Australia.utf8

time zone: Australia/Hobart
tzcode source: internal

attached base packages:
[1] stats     graphics  grDevices utils     datasets  methods   base
```

```
other attached packages:
 [1] CMIX_0.5.7      Grym_0.1.2      flextable_0.9.7 knitr_1.48
 [5] lubridate_1.9.3 forcats_1.0.0   stringr_1.5.1   dplyr_1.1.4
 [9] purrr_1.0.2     readr_2.1.5     tidyr_1.3.1     tibble_3.2.1
[13] ggplot2_3.5.1   tidyverse_2.0.0
```

Appendix C changes in stock assessment parameters

Table C1: Table summarising evidence for changes in stock assessment and population parameters or processes that could be due to the effects of environmental variability or climate change in the mackerel icefish fishery in Division 58.5.2.

Parameter or process	**Population**	**Stock assessment**
<u>Recruitment:</u> Mean recruitment, Recruitment variability (σ_R and autocorrelation)	Icefish surveys show high interannual variability in year class strength. The drivers for interannual changes in recruitment have not been fully explored. Maschette & Welsford (2019) provided and initial hypothesis for the apparent shift in recruitment which occurred between 2008-2011.	Stock assessments for icefish assume no future recruitment in the two-year projection period. The stock assessments are based on the most recent estimate of recruitment from an annual trawl survey and therefore account for interannual variability in recruitment.
Biomass	As a result of highly fluctuating recruitment the population has show highly variable biomass through time showing up to three-fold increases or decreases from one year to another (See appendix B2).	The lower one-sided 95^{th} confidence interval from a bootstrapped biomass estimate from the most recent trawl survey is used as the initial biomass in the stock assessment. This is done to account for the large interannual variability in observed in biomass estimates.
Length at maturity	Length at maturity has been investigated as part of Maschette *et al*., (2024) and has shown fluctuation in the size of maturity through time for both males and females with a generally increasing size of 50% maturity since 2008.	There is no maturity component in the stock assessment.
Stock-recruit relationship	The relationship between spawning stock and recruitment has not been thoroughly investigated.	Due to the stock assessment having no recruitment component there is no stock-recruitment relationship in the stock assessment.
Natural mortality	Natural mortality is uncertain. De la Mare (1998) estimated M to be around 0.30 for age 2 and above, and 0.64 for age 3 and above based on a Heincke estimate for survivorship from age a to all older ages but acknowledge that these estimates were highly uncertain due to recruitment and sampling variability.	Within the stock assessment M is fixed at 0.4.

Growth rates	Growth rates appear to have changed through time, with an increasing asymptotic average length ($L\infty$) and a decreasing growth rate coefficient (K) (Maschette *et al*., 2024).	Within the time series of assessments growth has been estimated four times, as part of the 1997, 2010, 2017 stock assessments and in Maschette *et al.*, (2024)
Length-weight relationship	Annual Length-Weight relationships have shown some fluctuation through time although this is likely due to the presence or absence of size classes in the population (Maschette *et al.*, 2024).	In the stock assessment, estimates from the most recent trawl survey are used.
Sex ratio changes	No evidence of changes in sex ratio in the survey data through time (Maschette *et al.,* 2024).	The stock assessment is an unsexed model.
Spatial distribution	No evidence in the change of spatial distribution through time has been observed (Maschette *et al.,* 2024).	The stock assessment has no spatial components in the model.
Stock structure	Within Division 58.5.2 there have historically been three populations hypothesised. One on Shell Bank to the east of the plateau, one on Pike Bank to the north-west of the plateau and one on the southern part of the plateau centred on Gunnari Ridge. The Pike bank population was heavily over fished prior to the establishment of the Australian and French EEZs and shows little signs of recovery. The fishery is limited to the population on the southern part of the plateau. Gunnari Ridge consistently shows the largest aggregations of adult icefish with Plateau Southeast and Platea West showing a patchier distribution with all age classes present.	
Locations of spawning and site fidelity	Gunnari Ridge is the primary area for spawning mackerel icefish. Icefish seem to move in and out of this area throughout the year.	