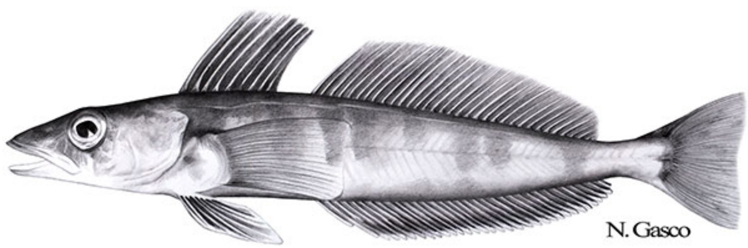
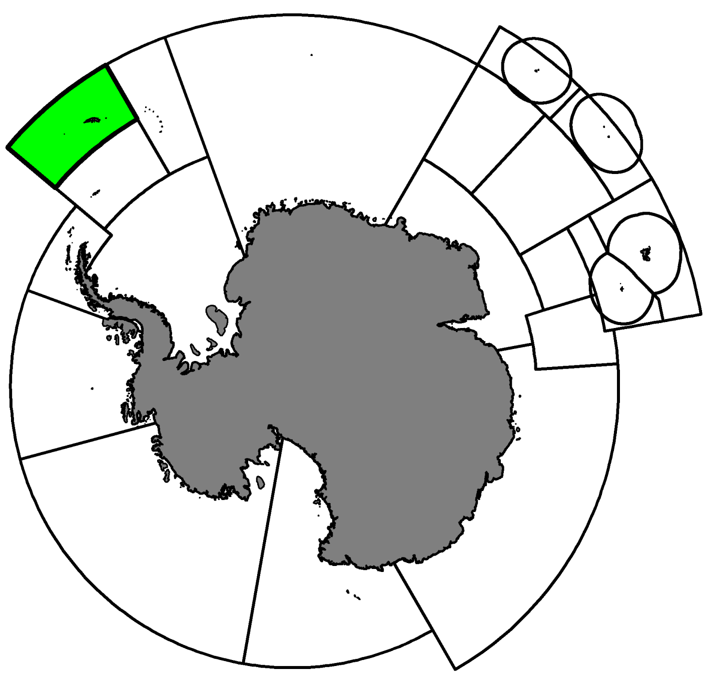
Stock Assessment Report 2022: *Champsocephalus gunnari* in Subarea 48.3

CCAMLR Secretariat

14 March 2023



Mackerel icefish, *Champsocephalus gunnari* Lönnberg, 1905.



Map of the management areas within the CAMLR Convention Area. The region discussed in this report is shaded in green.

Commission for the Conservation of Antarctic Marine Living Resources
Commission pour la conservation de la faune et la flore marines de l'Antarctique
Комиссия по сохранению морских живых ресурсов Антарктики
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Preliminary assessment of mackerel icefish (Champsocephalus gunnari) in Subarea 48.3 based on the 2021 Groundfish Survey

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EN

Preliminary Assessment of Mackerel Icefish (*Champsocephalus gunnari*) in Subarea 48.3 Based on the 2021 Groundfish Survey

Tim Earl

Abstract

The CCAMLR Statistical Subarea 48.3 icefish assessment was conducted by applying the standard projection methodology that has been agreed for this stock by CCAMLR Scientific Committee and its Working Groups. The stratified bootstrap of UK 2021 demersal fish survey icefish catch density and catch rate data indicate a precautionary biomass estimate of 22,047 tonnes (lower one sided 5th percentile: 13,279 tonnes) within Subarea 48.3. Projections for the 2022[1] and 2023 seasons applying the CCAMLR Decision Rule imply catch limits (TAC) of 1,457 tonnes for 2022 and 1,708 tonnes for 2023.

The assessment would lead to a recommendation from Working Group FSA to Scientific Committee that the catch limit for *C. gunnari* in Subarea 48.3 should be set at 1 457 tonnes for 2021/22 and 1 708 tonnes for 2022/23.

Introduction

CCAMLR has agreed that, for mackerel icefish (*Champsocephalus gunnari*), henceforward icefish) in Subarea 48.3, future catch limit advice should be given in accordance with the CCAMLR Decision Rules (WG-FSA 2010 §.5.164), as implemented by the length-based method described in Edwards et al. (2010a), with minor changes agreed in 2017 (Earl, 2017, WG-FSA 2017 §3.4). Diagnostics are presented in Appendix 1 consistent with Maschette et al. (2018) as recommended by WG-SAM (2018 §.3.10-11).

Studies of the application of the Decision Rule to icefish have demonstrated that the length-based approach provides robust, precautionary estimates of catch limits (Hillary et al., 2009, Hillary et al., 2010, Edwards et al., 2010a, Edwards et al., 2010b, Darby et al., 2013a). CCAMLR WG-SAM (2013 §.4.33) noted that the biomass projections upon which the catch advice is based are consistent with the objectives of the CCAMLR Convention Article II and that the rule generates future levels of exploitation that are considered precautionary.

The UK demersal fish trawl survey, which is used as the basis of the assessment and catch forecast, is undertaken annually or bi-annually at the beginning of the calendar year as part of its regular monitoring program. The survey is typically run every two years in January or

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[1] The seasons are labelled according to calendar year in which the season finishes e.g. the 2022 season refers to the season from 1st December 2021 to 30th November 2022.

February, however the 2021 survey occurred in May due to disruption resulting from the Covid-19 pandemic. The results of the 2021 survey are described in Collins et al. (2021).

Based on the demersal trawl icefish density data collected by the survey, this paper presents a preliminary assessment of the Subarea 48.3 demersal icefish biomass and applies the CCAMLR length-based method to derive catch limit advice for the 2022 and 2023 seasons.

Catch History

In recent years, the effort directed towards catching icefish has been low, resulting in a low percentage uptake of the catch (Figure 1). There was no fishing effort in 2020, and the only fishing in 2019 and to date in 2021 was during the surveys.

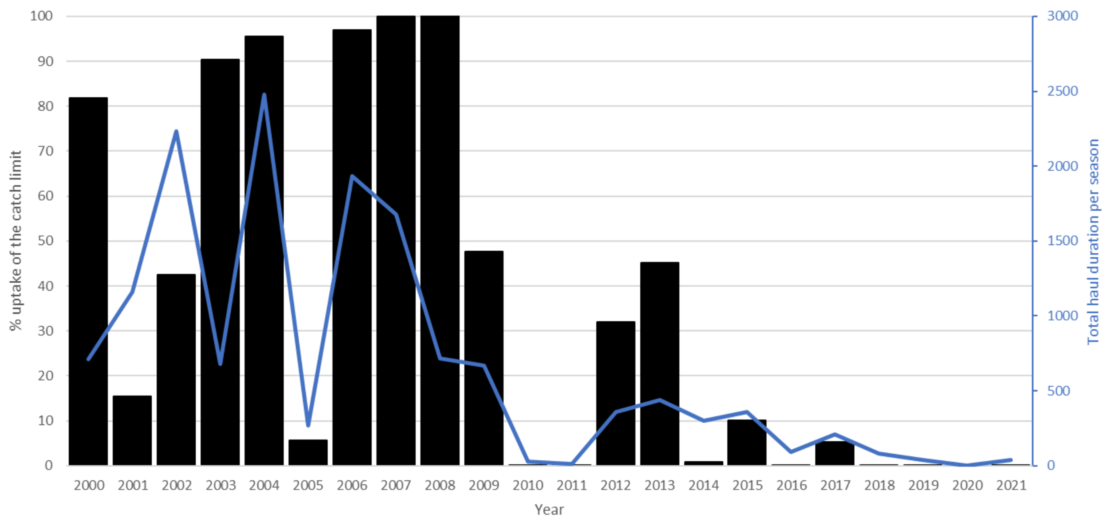

Figure 1: Uptake of the Catch Limit (black, left axis) and effort (blue, right axis)

Survey Demersal Biomass Estimates - Methods

The 2021 survey comprised 77 successfully completed demersal trawls within Subarea 48.3, as described in the cruise report (Collins et al., 2021). Of particular note is that the survey was carried out later in the year due to disruption from the Covid-19 pandemic; it took place in May compared to typically in January or February. The only previous survey around this time of year was in April 2008, which had catch rates similar to the average of the January and February surveys; there is no information to suggest that the timing of the survey affects catch rates.

For each haul in the survey, the total weight of icefish caught was recorded. Full biological information was taken from 30 representative samples, and the lengths of the remaining fish (or a subsample for large catches) were recorded. The survey is stratified into five areas, each with two depth bands, as shown in Figure 2.

The survey data are bootstrapped in accordance with the method used in Mitchell and Martin (2011). The weightings used in the bootstraps are based on the number of hauls by stratum and the fishable area within each stratum, as shown in Table 1. A correction factor of 1.241 is applied to the UK survey data following comparative studies with the Russian survey in 2002 (WG-FSA 2002 paragraphs 5.103 – 5.111). The R code used in this assessment is provided as an appendix. The assessment was run in R version 4.0.0 (R Core Team, 2020).

The biomass estimates using the agreed CCAMLR assessment method in this paper differ slightly from the survey biomass estimates presented in Collins et al. (2021). The bootstrap in that work is performed separately within each strata, whereas the assessment presented here weights the data from each stratum, and then a bootstrap is then performed from all the weighted hauls.

Table 1: Icefish in Subarea 48.3 - Characteristics of the ten strata used within the stratified bootstrap of biomass estimates.

Strata	**Description**	**Stratum area (km2)**	**Number of hauls**	**Weighting**
SR1	Shag Rocks <200m	2,553	10	0.52
SR2	Shag Rocks ≥200m	1,438	9	0.33
NW1	North West <200m	3,371	14	0.49
NW2	North West ≥200m	2,059	13	0.32
NE1	North East <200m	2,766	4	1.42
NE2	North East ≥200m	3,576	6	1.22
SW1	South West <200m	4,276	8	1.10
SW2	South West ≥200m	6,637	6	2.27
SE1	South East <200m	6,617	4	3.39
SE2	South East ≥200m	3,780	2	3.87

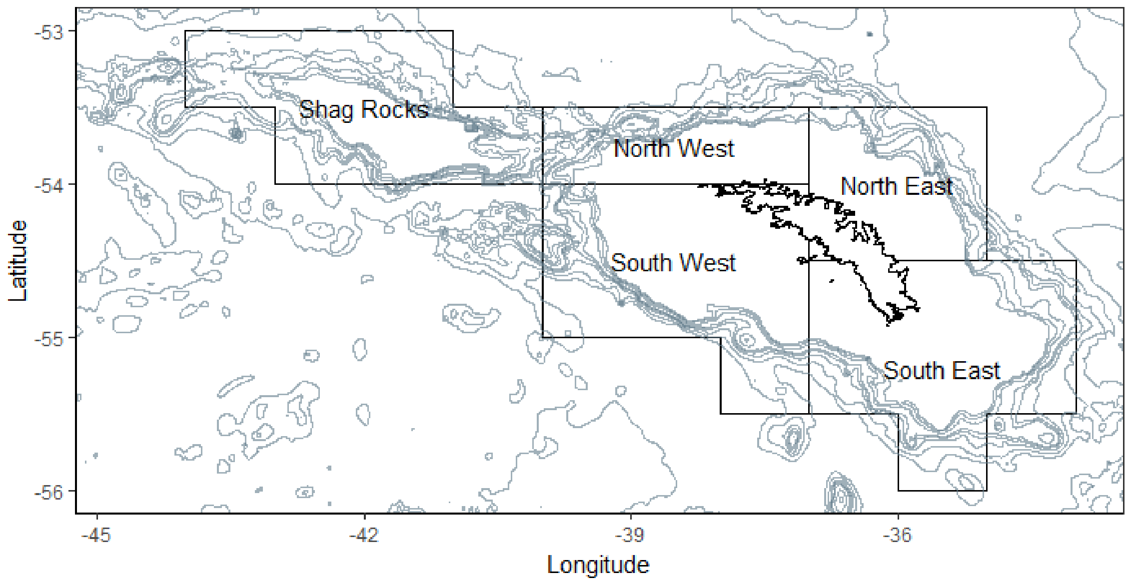

Figure 2: Icefish in Subarea 48.3 - The five area strata used in the demersal biomass bootstrap.

Survey Demersal Biomass Estimates – Results

The bootstrap approach provides an estimate of biomass at the time of the 2021 demersal fish survey at 22,047 tonnes with the lower and upper 5%iles at 13,279 and 32,689 tonnes respectively (Figure 3). The biomass is estimated to be similar to that seen in 2000, the lowest of the time series (Figure 4). The biomass estimates are a known underestimate of the actual icefish biomass, due to the presence of icefish in the water column at the time of the survey (Darby et al., 2013a).

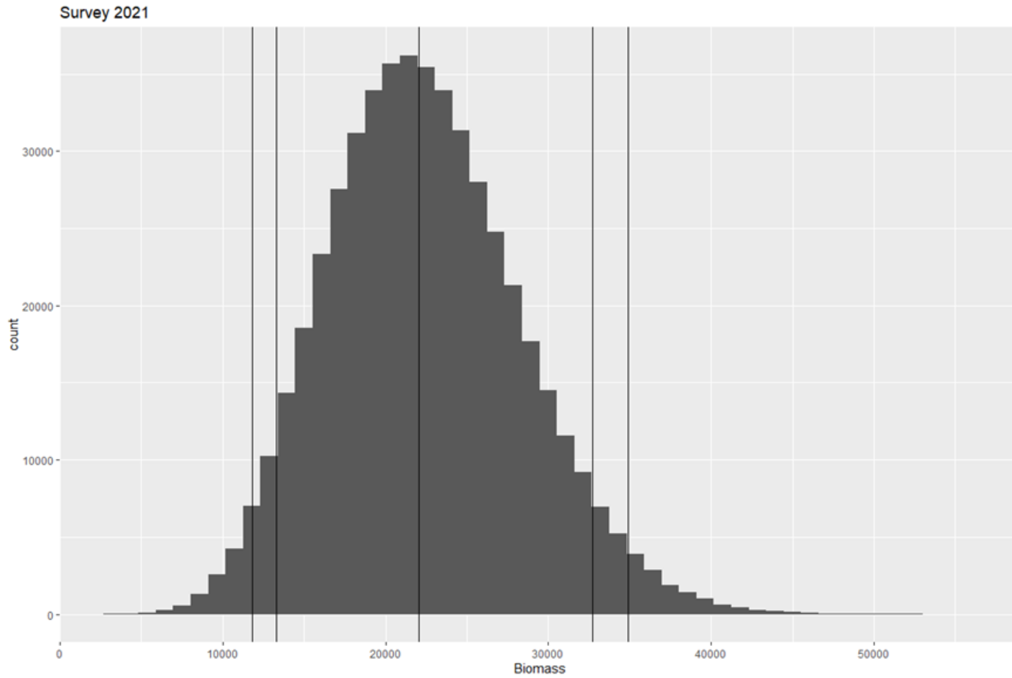

Figure 3: Icefish in Subarea 48.3 - Bootstrap estimation of biomass (tonnes) at the time of the 2021 survey. Vertical lines indicate bootstrap estimates of the one sided 2.5, 5, 50, 95 and 97.5th percentiles of the mean. Vertical scale indicates the number of simulations (from 500,000) in each biomass interval.

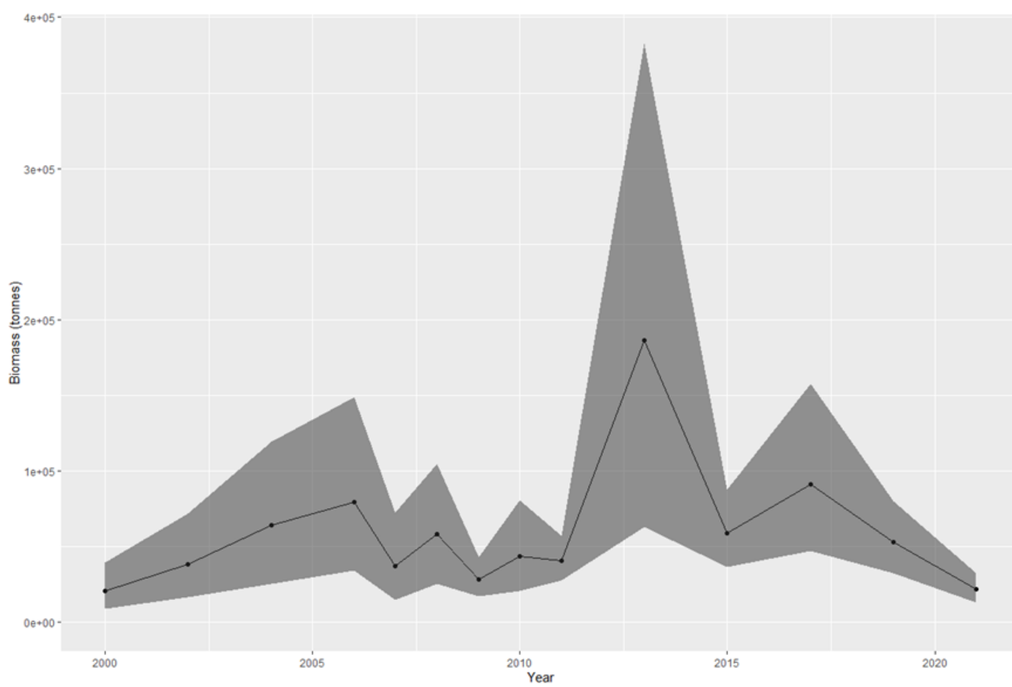

Figure 4: Icefish in Subarea 48.3 – Biomass estimates from demersal surveys. The shaded area indicates the 5%ile to 95%ile range. The dotted line indicates the lower 5%ile of the lowest estimated biomass.

Length Distribution Estimation

The length distribution data from individual hauls has been combined using a weighted average since 2010, as described in Edwards et al. (2010a), and revised in 2017 (Earl, 2017) and endorsed by WG-FSA-17 (§3.4).

Figure 5 shows the simple aggregation of length data by area stratum. The differences in distribution can be seen – in the North East, the South East and the South West there is a large proportion of small (<20cm) fish. Larger fish make up a greater proportion of the catch in the North West and Shag Rocks. The weighted average of binned numbers at length across all strata is shown in Figure 6.

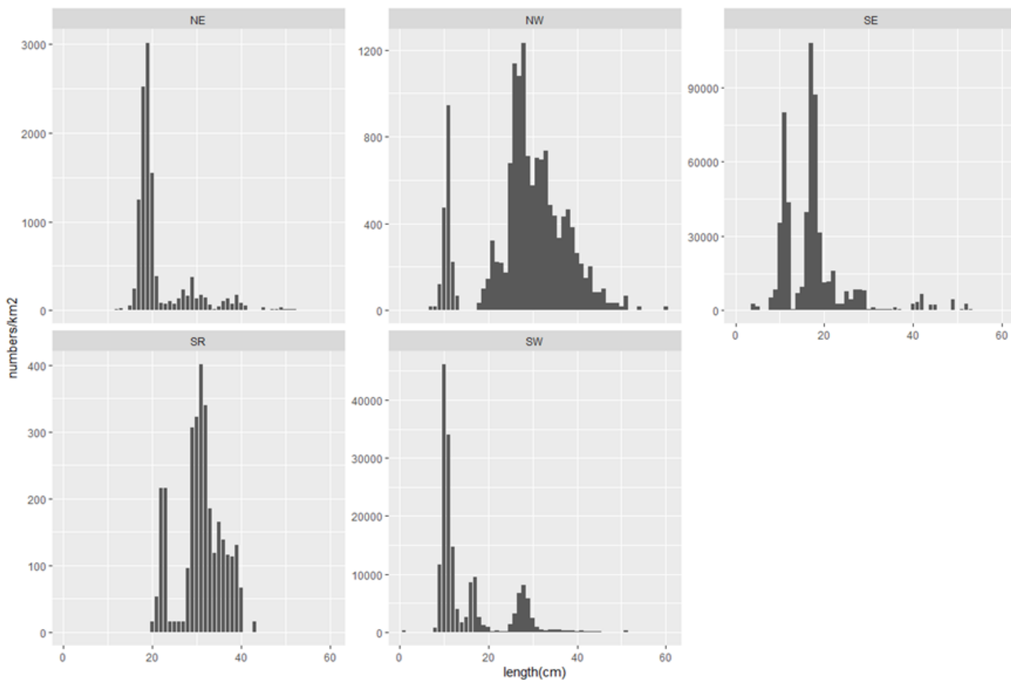

Figure 5: Icefish in Subarea 48.3 – Sum of haul numbers/km² in the survey by length (cm).

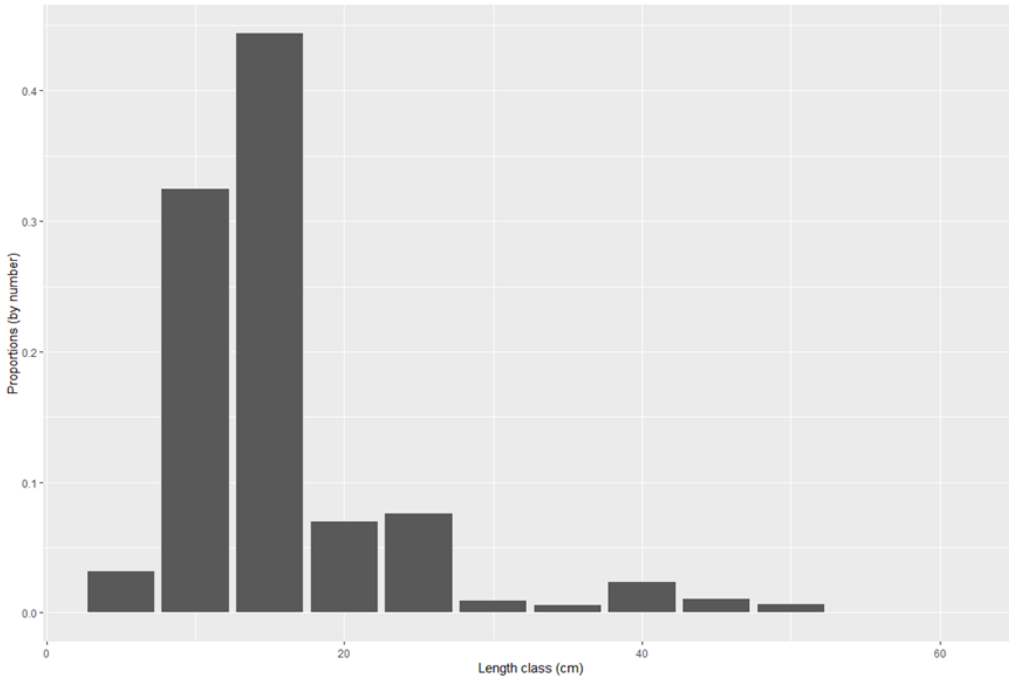

Figure 6: Icefish in Subarea 48.3 - 2021 proportions (by number) in the survey by length class (cm).

Catch Projections

The CCAMLR agreed Decision Rule for icefish calculates a Catch Limit that leaves on average 75% of the stock biomass that would be expected after two seasons if there were no fishing. To be conservative, the lower 5%ile of survey biomass is used for this projection, and no recruitment is assumed. The parameters used are shown in Table 4. Figure7 shows the length and weight data from the 2021 survey, and the fitted length-weight relationship (n=1,900).

Table 2: Icefish in Subarea 48.3 - Assumptions made in projection of current biomass.

Parameter	**Value**	**Justification**
Recruitment	0	Precautionary assumption given a lack of knowledge about stock-recruit dynamics
Catch after survey in current season	2,132 t	2021 CCAMLR Catch Limit – none was taken prior to survey

Proportion of natural mortality that occurs after survey	0.54	Based on Season starting 1st December, survey mid May
Biomass at time of survey	13,279 t	Lower 5%ile of biomass bootstrap
Selectivity of fishery	Knife edged at age 2.5	Edwards et. al. (2010a)
Length-weight parameters	$W = 0.00163L^{3.406}$ (cm to g)	Estimated from 2021 survey data
Age-length parameters	$L = 55.7\left(1 - e^{-0.17(a+0.58)}\right)$	CCAMLR (2010) in Edwards et. al. (2010a)
Natural mortality	0.71 (y^{-1})	Edwards et. al. (2010a)

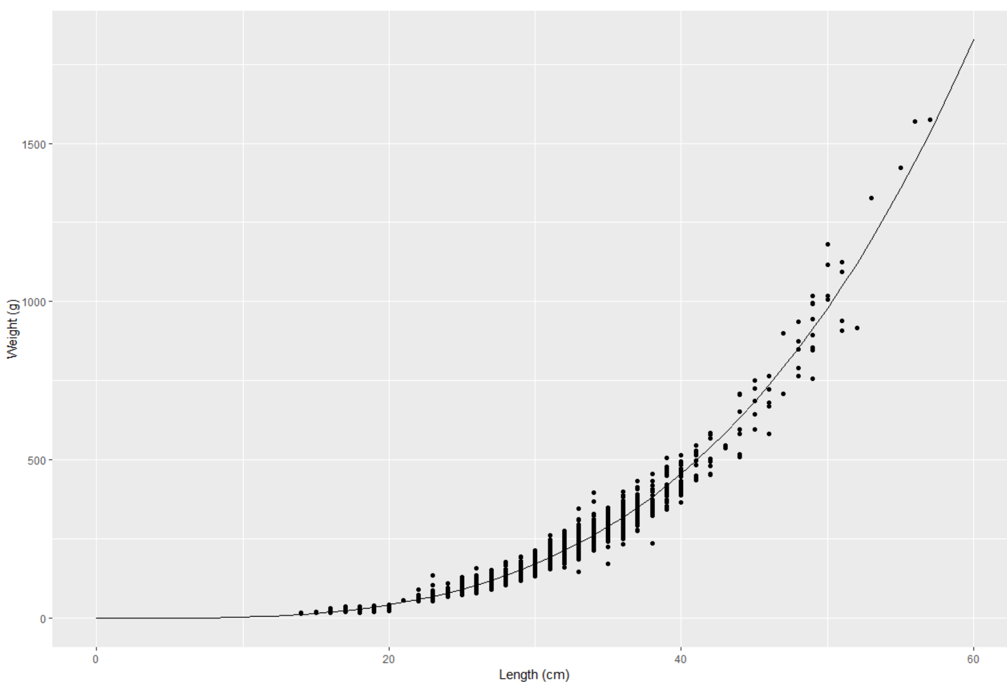

Figure 7: Icefish in Subarea 48.3 - Length-weight data from 2019 South Georgia icefish survey.

Catch Projections – Results

Table 3: Icefish in Subarea 48.3 - Stock projections under the 'fishing' and 'no fishing' scenarios, showing the effect of fishing on biomass over the next two seasons.

Quantity	No fishing	Fishing
Harvest rate (year 1&2)	0	0.234
Biomass at time of survey (t)	13,279	13,279
Biomass at time of survey (t) reduced by remaining available catch	11,147	11,147
Biomass one year after survey (t)	10,695	9,501
Biomass two years after survey (t)	8,956	6,717
Catch in year 1 (t)	0	1,457
Catch in year 2 (t)	0	1,708

These rules are implemented in R, in the files shown in Appendix 1. Catches of 1,213 tonnes in 2022 and 1,499 tonnes in 2023 at a harvest rate of 0.212 in both seasons would be consistent with the Decision Rule application as agreed by CCAMLR WG-FSA (2010). In previous assessments, the catch has generally been higher in the first year than the second, that is not the case in this assessment because of the relatively high proportion of small fish that are too small to be caught by the fishery in the first year, and are growing rapidly.

Summary

The UK Subarea 48.3 trawl survey conducted in May 2021 (Collins et al., 2019) indicated that the estimated icefish stock biomass is similar to the value seen in 2000, and continuing the decline observed in recent years.

The predictions from the 2019 assessment (Earl, 2019) under the scenario of no fishing in 2020 and 2021 seasons indicated an expected lower 5%ile biomass at the end of this period of 16,373 tonnes. The current estimate of the lower 5%ile at this the end of the season is 11,146 tonnes, lower than was projected, either due to sampling variation, or the timing of the survey coinciding with a period when icefish are less catchable.

The CCAMLR agreed HCR using the length-based approach has previously been demonstrated to provide robust, precautionary estimates of catch limits and exploitation rates for Subarea 48.3 icefish (Darby et. al., 2013). Application of the method to the UK 2021 demersal trawl survey indicates a catch limit for icefish in Subarea 48.3 of 1,213 tonnes in 2022 and 1,499 tonnes in 2023.

References

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R Core Team (2020). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.

Appendix 1 - Icefish assessment

Tim Earl

June 2021

Libraries

```
library(ggplot2)
library(FLCore)
library(bootstrap)
library(rgdal)
library(gtable)
library(rgeos)

path <- "c:/Users/te01/OneDrive - CEFAS/c drive/icefish/2021"
set.seed(0)
```

Parameters

```
surv <- "21"
pcs <- c(2.5,5,50,95,97.5)
nrep <- 500000   # number of boostrap samples
linc  <- 5
lbins <- seq(linc,60,linc)

TAC <- 2132         #2021 TAC, tonnes
catch_taken <- 0    #before survey, tonnes

# growth parameters
t0 <- -0.58
k <- 0.17
Linf <- 55.7

# SELECTIVITIES

# survey selectivity
selsurv <- 1+0*lbins
selsurv

##  [1] 1 1 1 1 1 1 1 1 1 1 1 1

# commercial selectivity
commsel <- 0*lbins

# assumed knife-edge selectivity at age
asel <- 2.5
```

```r
# equivalent length
lsel <- Linf*(1-exp(-k*(asel-t0)))

commsel[lbins>lsel] <- 1
commsel

##  [1] 0 0 0 0 1 1 1 1 1 1 1 1

#Maturity
matl <- 1+0*lbins
matl

##  [1] 1 1 1 1 1 1 1 1 1 1 1 1
```

Biomass Estimation

Read in data

```r
a.df <- read.csv(file.path(path,"hist data","stratum_area.csv"),header=T)
sectors <- as.character(a.df$Strata)

# biomass data
dat <- read.csv(file.path(path,"hist data",paste0("ani_bm_dataSG",surv,".csv"
)),header=T)
names(dat) <- c("SURVCODE", "EVENTNUM","SECTOR", "CombinedStrata",  "SumOfANI
_KG_km2",  "SumOfANI_n_km2")
dat$CombinedStrata <- paste0(dat$SECTOR,substr(dat$CombinedStrata,7,7))  #Con
vert to previous style of strata

# correct for pelagic component
dat[,'SumOfANI_KG_km2'] <- dat[,'SumOfANI_KG_km2'] * 1.241
dat <- unique(dat[,1:5])  ##Duplicate haul records appear when only a sample
measured, remove these


biomass.prev <- read.csv(file.path(path,"hist biomass 2019.csv"), stringsAsFa
ctors=TRUE)
```

Haul data

	SURVCODE	EVENTNUM	SECTOR	CombinedStrata	SumOfANI_KG_km2
1	SG21	1	SR	SR2	0.000000
2	SG21	2	SR	SR2	8.406534
3	SG21	3	SR	SR2	43.752696
4	SG21	5	SR	SR1	39.933022
5	SG21	6	SR	SR1	0.000000
6	SG21	7	SR	SR1	33.256194

7	SG21	8	SR	SR2	6.579037
8	SG21	9	SR	SR1	59.733425
9	SG21	10	SR	SR1	9.598018
10	SG21	11	SR	SR1	49.545808
11	SG21	12	SR	SR2	0.000000
12	SG21	13	SR	SR1	74.103709
13	SG21	14	SR	SR2	12.467707
14	SG21	15	SR	SR2	0.000000
15	SG21	16	SR	SR1	63.067000
16	SG21	17	SR	SR2	261.982174
17	SG21	18	SR	SR2	39.643124
18	SG21	19	SR	SR1	19.209191
19	SG21	20	SR	SR1	80.816526
20	SG21	21	NE	NE2	6.978143
21	SG21	22	NE	NE2	11.413849
22	SG21	23	NE	NE1	16.626546
23	SG21	24	NE	NE2	70.777829
24	SG21	25	NE	NE2	7.517482
25	SG21	26	NW	NW1	110.564289
26	SG21	27	NW	NW1	62.947491
27	SG21	28	NW	NW1	661.710259
28	SG21	29	NW	NW2	9.820902
29	SG21	30	NW	NW2	53.606856
30	SG21	31	NW	NW1	78.495856
31	SG21	32	NW	NW2	13.276094
32	SG21	33	NW	NW2	137.266141
33	SG21	34	NW	NW1	13.554947
34	SG21	35	NW	NW1	79.644526
35	SG21	36	NW	NW2	341.947126
36	SG21	37	NW	NW2	77.567588
37	SG21	38	NW	NW1	106.031288
38	SG21	39	NW	NW1	292.401318
39	SG21	40	NW	NW2	216.214590
40	SG21	41	NW	NW1	177.991666
41	SG21	42	NW	NW1	761.664867
42	SG21	43	NW	NW2	9.958901

43	SG21	44	NW	NW2	0.000000
44	SG21	45	NW	NW2	0.000000
45	SG21	46	NW	NW2	0.000000
46	SG21	47	NW	NW2	26.600339
47	SG21	48	NW	NW1	62.947491
48	SG21	49	NW	NW1	37.273559
49	SG21	50	NW	NW2	19.907998
50	SG21	51	NW	NW1	284.116650
51	SG21	52	NW	NW1	247.094393
52	SG21	53	SW	SW1	118.584996
53	SG21	54	SW	SW1	2642.249213
54	SG21	55	SW	SW1	5921.834453
55	SG21	56	SW	SW2	2555.269757
56	SG21	57	SW	SW2	1145.847690
57	SG21	58	SW	SW1	2987.840783
58	SG21	59	SW	SW2	96.248733
59	SG21	60	SW	SW2	711.338594
60	SG21	61	SW	SW2	240.639828
61	SG21	62	SW	SW1	29.602069
62	SG21	63	SW	SW1	190.345201
65	SG21	64	SW	SW1	45.521245
66	SG21	65	SW	SW1	1766.305868
67	SG21	66	SW	SW2	411.863825
68	SG21	67	SE	SE2	1674.033423
69	SG21	68	SE	SE1	526.924381
70	SG21	69	SE	SE1	445.016147
72	SG21	70	SE	SE1	459.245701
75	SG21	71	SE	SE1	82.485423
76	SG21	72	SE	SE2	996.601183
77	SG21	73	NE	NE2	239.974652
78	SG21	74	NE	NE2	41.282113
79	SG21	75	NE	NE1	163.798845
80	SG21	76	NE	NE1	504.435103
81	SG21	77	NE	NE1	106.247967

Haul CPUEs

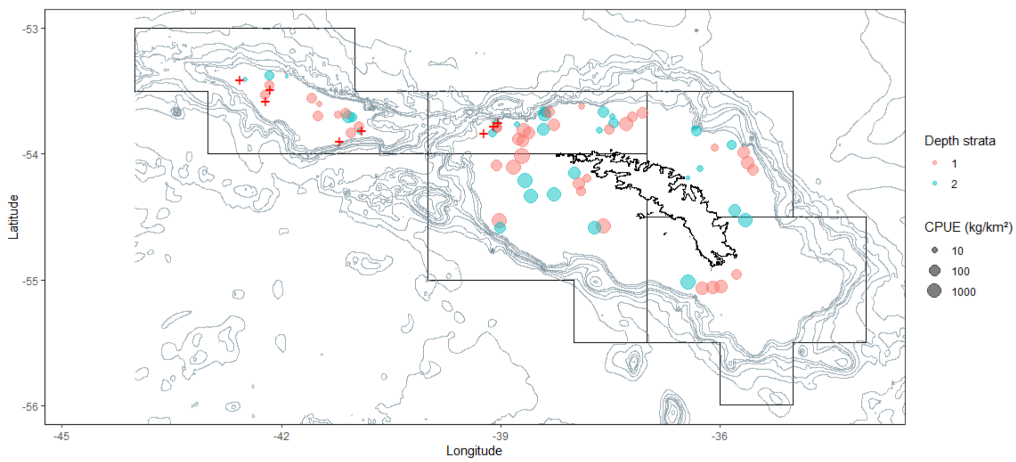
Haul by haul CPUE

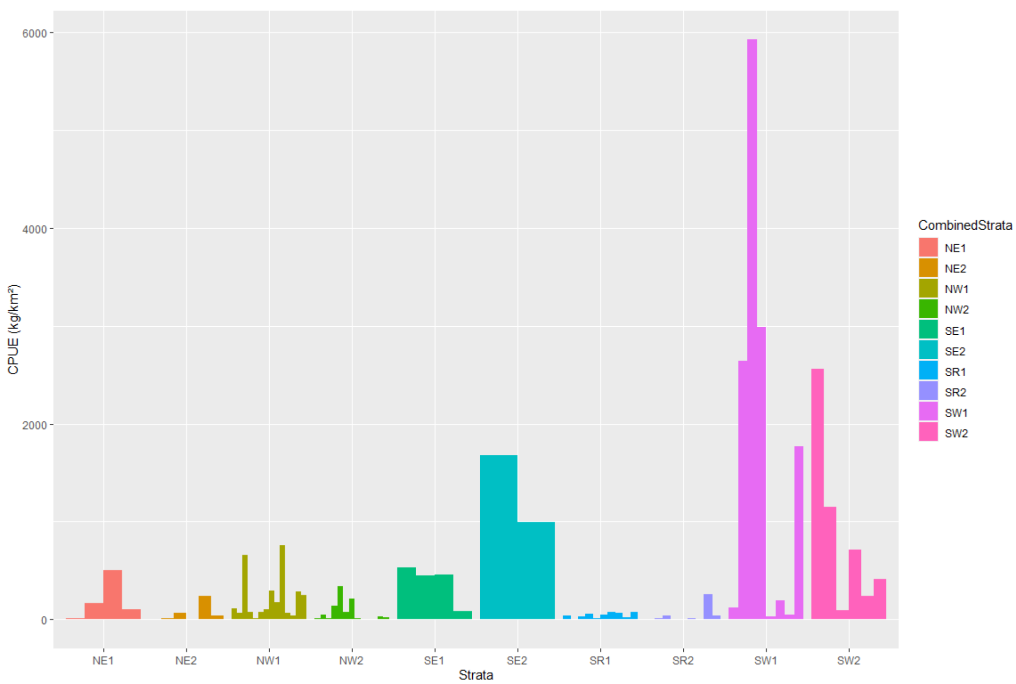
```
#Map plots
load(file.path(path, "SG_basemap.rdata"))

###get haul locations from database
locs <- read.csv(file.path(path,"hist data",paste0("ani_ev_dataSG",surv,".csv
")),header=T)
colnames(locs)[c(1,2,5,6)] <- c("SURVCODE", "EVENTNUM", "STLAT", "STLON")
locs <-merge(locs, dat, all.x=TRUE)

locs$cat <- cut(locs$SumOfANI_KG_km2, c(0,100,10000,Inf))
locs$depth <- substr(locs$CombinedStrata,3,3)
```

```
## OGR data source with driver: ESRI Shapefile
## Source: "Y:\FCOSO\Working_Area\GIS_open\shapefiles", layer: "48_bathy_SG_s
ub"
## with 1447 features
## It has 2 fields
## Integer64 fields read as strings:  ID CONTOUR
```

```
## OGR data source with driver: ESRI Shapefile
## Source: "Y:\FCOSO\Working_Area\GIS_open\shapefiles", layer: "COAST"
## with 816 features
## It has 9 fields
```

```
## OGR data source with driver: ESRI Shapefile
## Source: "Y:\FCOSO\Working_Area\GIS_open\shapefiles", layer: "SGSSI_researc
hstrata_boxes"
## with 33 features
## It has 4 fields
```





Apply weighting

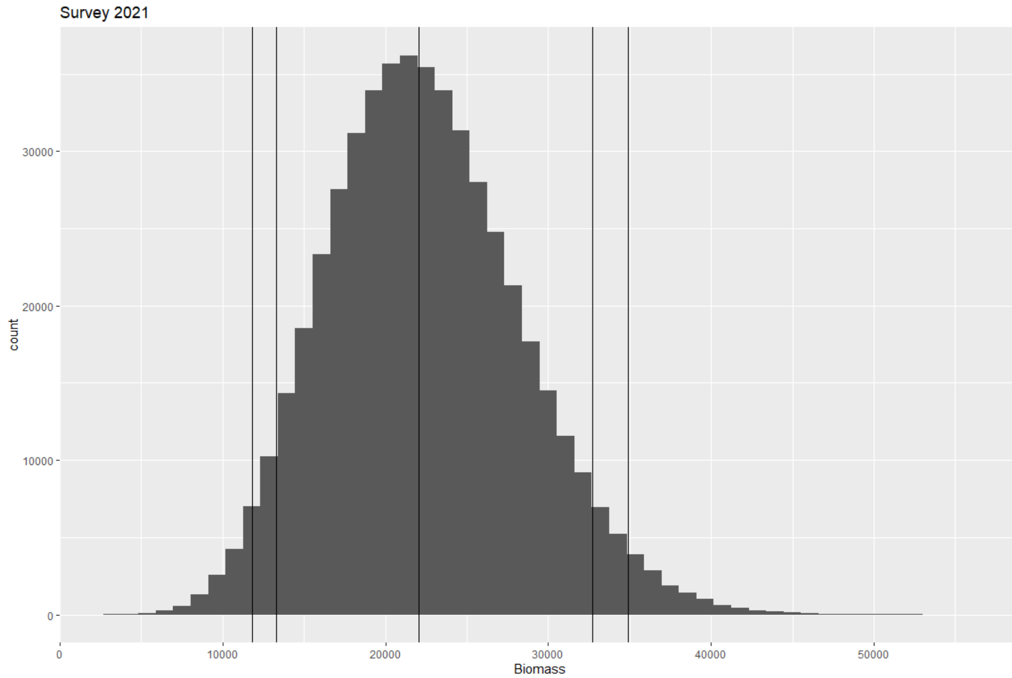
See de la Mare and Williams WG-FSA-96/38

```
dat$CombinedStrata <- factor(dat$CombinedStrata, levels=a.df$Strata)
a.df$nhaul <- table(dat$CombinedStrata)
```

```r
a.df$nweight <- (a.df$Area / sum(a.df$Area)) * (sum(a.df$nhaul) / a.df$nhaul)
dat$weighted <- dat$SumOfANI_KG_km2 * a.df$nweight[dat$CombinedStrata]
```

Strata1	Strata2	Strata	Area	nhaul	nweight
SD48321	SR	SR1	2553	10	0.5233674
SD48322	SR	SR2	1438	9	0.3275460
SD48331	NW	NW1	3371	14	0.4936130
SD48332	NW	NW2	2059	13	0.3246900
SD48341	NE	NE1	2766	4	1.4175815
SD48342	NE	NE2	3576	6	1.2218056
SD48351	SW	SW1	4276	8	1.0957300
SD48352	SW	SW2	6637	6	2.2676521
SD48361	SE	SE1	6617	4	3.3912281
SD48362	SE	SE2	3780	2	3.8745178

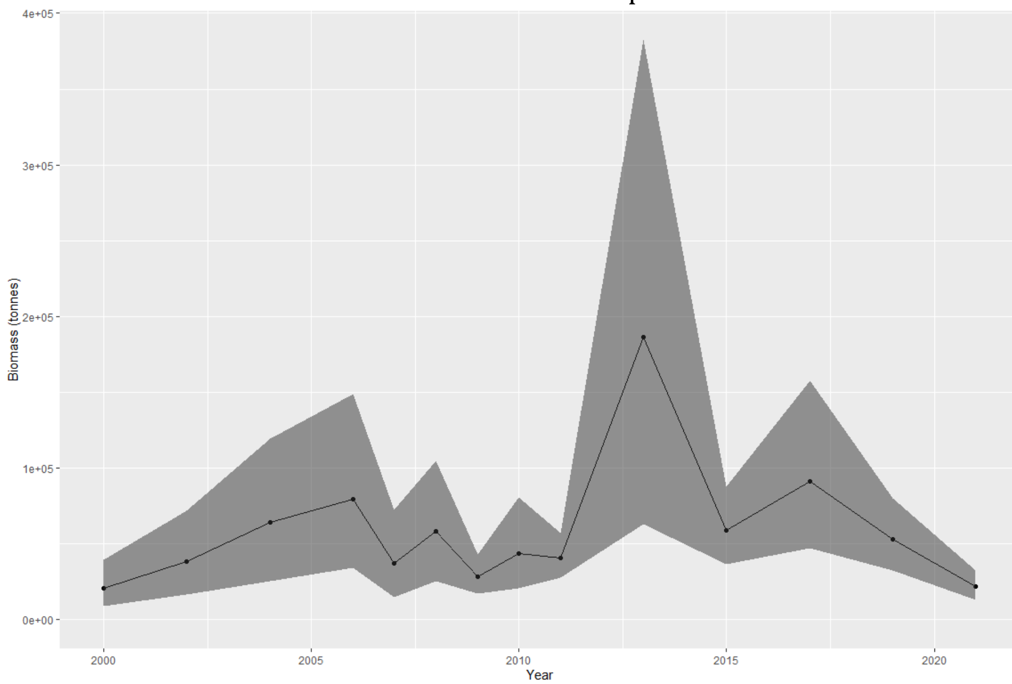
```r
btstrap <- bootstrap(dat$weighted, nrep, mean)[['thetastar']]  ##weighted ver
sion
btstrap.biomass <- btstrap * sum(a.df$Area) *0.001 #tonnes
biomass <- quantile(btstrap.biomass,pcs/100,na.rm=T)
save(biomass, file=file.path(path, "biomass.rdata"))
biomass

##     2.5%       5%      50%      95%    97.5%
## 11827.65 13278.96 22047.35 32689.23 34919.35

mean(btstrap.biomass)

## [1] 22394.06
```



Comparison to previous years

```
biomass.all <- rbind(biomass.prev, data.frame(X5=biomass["5%"], X50=biomass["
50%"], X95=biomass["95%"], n=length(dat[[1]]), year=2000+as.numeric(surv), pr
oj_1=NA, proj_2=NA, row.names="current"))
```

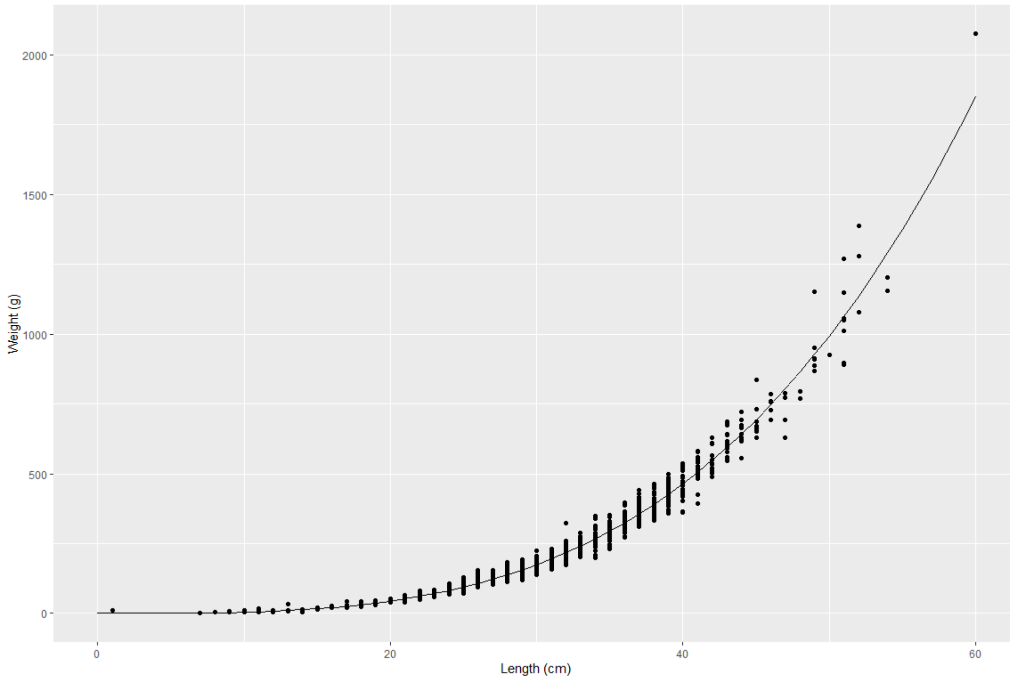
Median estimates of biomass with 5-95% bootstrap mean estimates shaded.



Length Distribution

Calculate length-weight parameters

```
lw.data <- read.csv(file.path(path,"hist data",paste0("ani_lw_dataSG",surv,".
csv")),header=T)


lw.model <- nls(Weight.g. ~ a * Length.cm. ^b, data = lw.data, start=list(a=0
.001, b=3))
lw.pred <- data.frame(Length.cm.=0:60)
lw.pred$Weight.g. <- predict(lw.model, lw.pred)


# weight-at-length (mm and kg) in mid-point of length partition
ggplot(lw.data, aes(x=Length.cm., y=Weight.g.)) + geom_point() +
  geom_line(aes(x=Length.cm., y=Weight.g.), lw.pred) + labs(x="Length (cm)",
y="Weight (g)")
```




```
a <- coef(lw.model)[["a"]]
b <- coef(lw.model)[["b"]]
a

## [1] 0.001626788

b

## [1] 3.40558

wtl <- predict(lw.model, list(Length.cm.=lbins+linc/2))
```

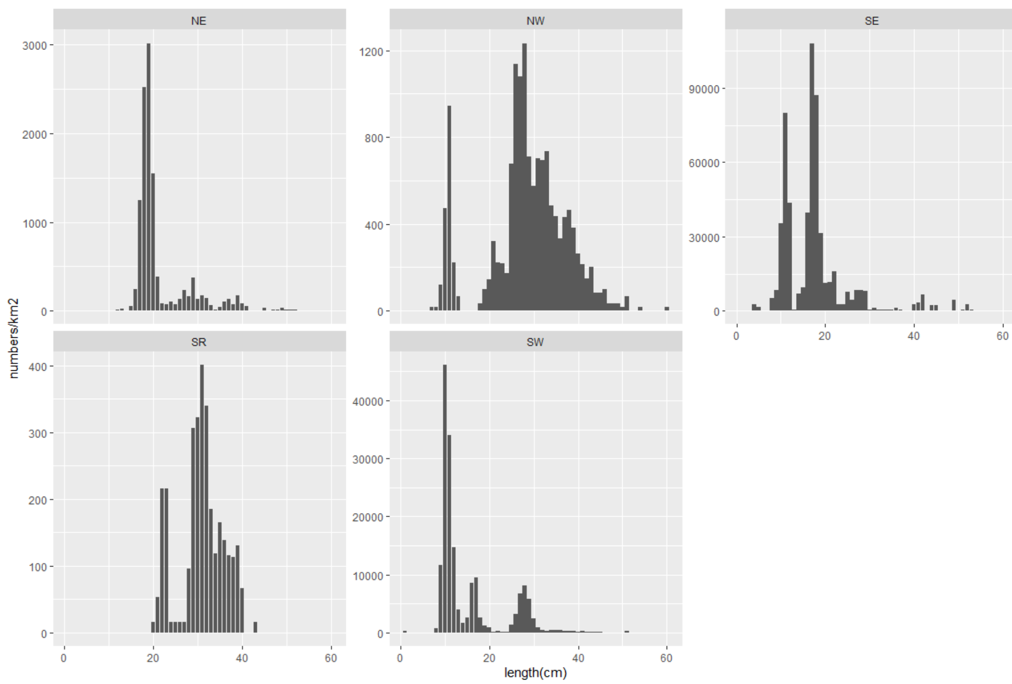
Load data

```
###Length Data
  raw.data <- read.csv(file.path(path,"hist data",paste0("ani_ld_dataSG",surv
,".csv")),header=T)
  names(raw.data) <- c("Survcode", "EVENTNUM", "SECTOR", "CombinedStrata", "W
ater.Dep", "CM", "numbers_km2")
  # strata (no depth stratification)

  a.df <- read.csv(file.path(path, "hist data","stratum_area.csv"),header=T)
  a.df <- aggregate(a.df$Area, list(Strata=a.df$Strata2), sum)
  names(a.df)[2] <- "Area"
  a.df$Nhaul <-  sapply(a.df$Strata, function(x)length(unique(raw.data$EVENTN
UM[raw.data$SECTOR==x])))

  #see de la Mare and Williams WG-FSA-96/38
  a.df$Weight <- a.df$Area / sum(a.df$Area) * (sum(a.df$Nhaul) / a.df$Nhaul)
```

Strata	Area	Nhaul	Weight
NE	6342	10	1.3001160
NW	5430	27	0.4122797
SE	10397	6	3.5523247
SR	3991	19	0.4306099
SW	10913	14	1.5979824

Raw length Frequencies

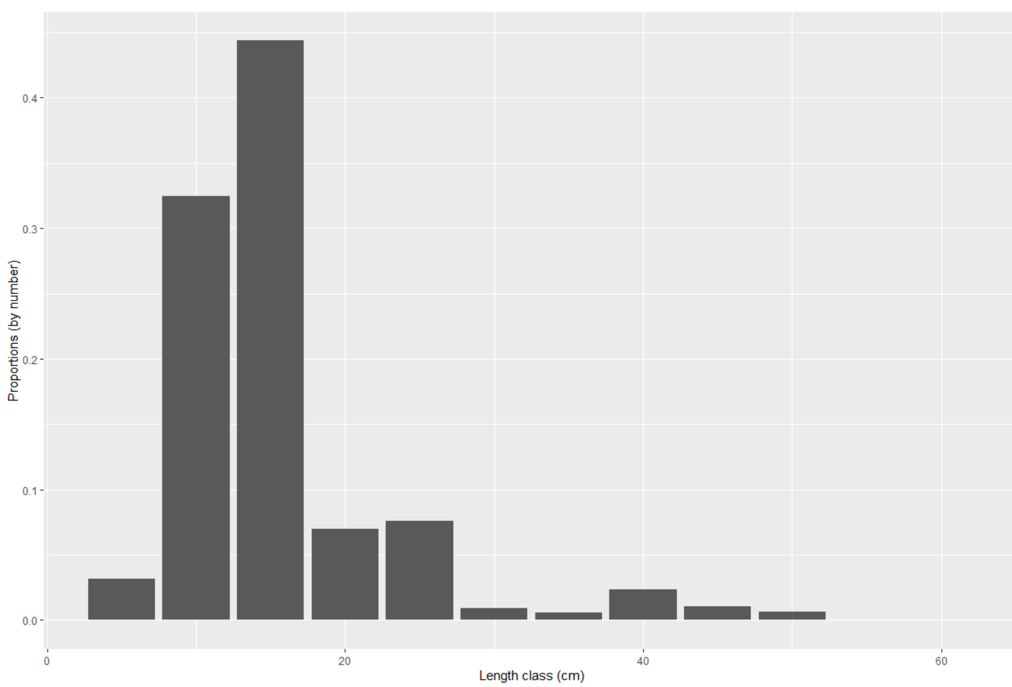
```
ggplot(dat=raw.data, aes(x=CM, y=numbers_km2, group=SECTOR)) + geom_col() +facet_wrap(~SECTOR, scale="free_y") + labs(y="numbers/km2", x="length(cm)")

## Warning: Removed 7 rows containing missing values (position_stack).
```




```
raw.data <- merge(raw.data, a.df[,c("Strata","Weight")],all.x=TRUE, by.x="SECTOR",by.y="Strata")
raw.data$Weighted_n <- raw.data$numbers_km2 * raw.data$Weight

  raw.data$lbin <- factor(linc*floor(raw.data$CM/linc) , levels=lbins)
  lfreq <- aggregate(raw.data$Weighted_n, list(lbin=raw.data$lbin), sum, drop
                     =FALSE)
  lfreq$x[is.na(lfreq$x)] <- 0
  lfreq <- merge(data.frame(lbin=lbins), lfreq, all.x=TRUE)
  lfreq$density <- lfreq$x/sum(lfreq$x, na.rm=TRUE)
  lfreq$density[is.na(lfreq$density)] <- 0
```

```r
lfreq$numbers <- lfreq$density * biomass["5%"] / sum(wtl*selsurv*lfreq$dens
ity,na.rm=T) * 10^6
```

lbin	x	density	numbers
5	7.346708e+04	0.0317348	6.681755e+06
10	7.511051e+05	0.3244468	6.831223e+07
15	1.027151e+06	0.4436873	9.341830e+07
20	1.623218e+05	0.0701164	1.476300e+07
25	1.751841e+05	0.0756724	1.593281e+07
30	2.082764e+04	0.0089967	1.894252e+06
35	1.255590e+04	0.0054236	1.141947e+06
40	5.361862e+04	0.0231611	4.876559e+06
45	2.462208e+04	0.0106357	2.239353e+06
50	1.417349e+04	0.0061224	1.289064e+06
55	0.000000e+00	0.0000000	0.000000e+00
60	6.360362e+00	0.0000027	5.784684e+02



Biomass Projection

Parameters

```
Cpsurv <- TAC - catch_taken

# define fraction of a year after survey in which catch is taken
# (survey is in mid-May and season starts 1st Dec)
TACtime <- 0.54


# natural mortality - pre-fishery/post-fishery division
Mtot <- 0.71
```

Useful functions

```
# UTILITY CODE FOR 48.3 ICEFISH LENGTH BASED ASSESSMENT

###################
# Projection code #
###################
pop.proj <- function(Nsurv,Cpsurv,N,M,k,Linf,wtlen,sel,ftime,tmat1,tmat2,H) {

  # number of seasons and length-classes

  dm <- dim(N)
  dmn <- dimnames(N)
  n <- array(dim=dm)
  m <- array(dim=dm)
  wtl <- array(dim=dm)
  commsel <- array(dim=dm)
  TAC <- vector(length=2)

  # set up the initial population from the survey
  # (strip data from FLQuants)

  n[,1,1,1,1,1] <- Nsurv@.Data[,,,,,]
  m[] <- M@.Data[]
  wtl[] <- wtlen@.Data[]
  commsel[] <- sel@.Data[]

  # calculate post-survey harvest rates
  cat("\nH",H,"\n")
  cat("Initial biomass: ", sum(n[,1,1,1,1,1]*wtl[,1,1,1,1,1])/1e6, '\n')

  hpsurv <- n[,1,1,1,1,1]
  Hpsurv <- Cpsurv/sum(n[,1,1,1,1,1]*wtl[,1,1,1,1,1]*commsel[,1,1,1,1,1])
  for(l in 1:dm[1])
    hpsurv[l] <- commsel[l,1,1,1,1,1] * Hpsurv
```

```
  # adjust population size assuming the remaining catch from previous year is
taken
  # instantaneous after survey

  n[,1,1,1,1,1] <- n[,1,1,1,1,1] * (1 - hpsurv)
  cat("Biomass at start of Year 1: ", sum(n[,1,1,1,1,1]*wtl[,1,1,1,1,1])/1e6,
'\n')

  # given fixed harvest rate H we adjust population (via growth and M) to whe
n catch was taken
  # then remove the relevant proportion of each length class

  for(l in 1:dm[1])
    n[l,1,1,2,1,1] <- sum(n[,1,1,1,1,1]*exp(-m[,1,1,1,1,1])*tmat1[,l])

  # calculate the catch taken from population at this time given the harvest
rate

  TAC[1] <- sum(n[,1,1,2,1,1]*wtl[,1,1,2,1,1]*H*commsel[,1,1,2,1,1])

  # THE SECOND YEAR

  # adjust the population to 1 year after survey using growth and remaining M

  for(l in 1:dm[1])
    n[l,2,1,1,1,1] <- sum(n[,1,1,2,1,1]*exp(-m[,1,1,2,1,1])*(1-H*commsel[,1,1
,2,1,1])*tmat2[,l])

  cat("Biomass at start of Year 2: ", sum(n[,2,1,1,1,1]*wtl[,1,1,1,1,1])/1e6,
'\n')
    # move the population forward to the time of fishing via M and growth

  for(l in 1:dm[1])
    n[l,2,1,2,1,1] <- sum(n[,2,1,1,1,1]*exp(-m[,2,1,1,1,1])*tmat1[,l])

  # calculate the catch taken from population at this time given the harvest
rate

TAC[2] <- sum(n[,2,1,2,1,1]*wtl[,2,1,2,1,1]*H*commsel[,2,1,2,1,1])

  # calulate the numbers after the second TAC is taken
  # with the extra M accounted for to complete the 2 year projection

  nfin <- n[,1,1,1,1,1] * 0

  for(l in 1:dm[1])
    nfin[l] <- sum(n[,2,1,2,1,1]*exp(-m[,2,1,2,1,1])*(1-H*commsel[,2,1,2,1,1]
)*tmat2[,l])
```

```
  cat("Biomass at end of Year 2: ", sum(nfin*wtl[,1,1,1,1,1])/1e6, '\n')

  TAC <- TAC/1e6 #kg to tonnes

  return(list(N=nfin, harvest=H, TAC=TAC,
              B=c(sum(n[,2,1,1,1,1]*wtl[,1,1,1,1,1])/1e6, sum(nfin*wtl[,1,1,1
,1,1])/1e6)))
}

#####################################################
# TAC calculator                                    #
# - Estimate 75% escapement after 2 year projection #
#####################################################

tac.ani483 <-  function(Nsurv,Cpsurv,N,M,k,Linf,wtlen,matlen,sel,ftime,H.min,
H.max,TAC.only=TRUE) {
  # calculate the transition matrices given the time at which the fishery wil
l operate

  lbins2 <- vector(length=length(lbins)+1)
  del <- lbins[2]-lbins[1]
  lbins2[-c(length(lbins2))] <- lbins[]
  lbins2[length(lbins2)] <- lbins[length(lbins)]+del
  tmat1 <- tmat.calc(k,Linf,ftime,lbins2)
  tmat2 <- tmat.calc(k,Linf,1-ftime,lbins2)

  # call the projection code with zero catch

  stk.unfished <- pop.proj(Nsurv,Cpsurv,N,M,k,Linf,wtlen,sel,ftime,tmat1,tmat
2,as.double(0))

  # extract final SSB values

  ssb.unfished <- as.vector(quantSums(stk.unfished[['N']][]*wtlen[,2,,2,,]*ma
tlen[,2,,2,,]))

  # define the objective function

  obj.fn <- function(x) {

    # call the projection code with zero catch

    stk.fished <- pop.proj(Nsurv,Cpsurv,N,M,k,Linf,wtlen,sel,ftime,tmat1,tmat
2,x)
    ssb.fished <- as.vector(quantSums(stk.fished[['N']][]*wtlen[,2,,2,,]*matl
en[,2,,2,,]))
```

```
    # calculate the conditions for the HCR - probability that ssb.TAC < 0.75
* ssbzer0TAC = 0.05

    tmp <- ssb.fished-0.75*ssb.unfished
    cat(ssb.fished/1e6,'\n', ssb.unfished/1e6, '\n', ssb.fished/ssb.unfished,
"\n\n")

    return(tmp)
  }

  # use uniroot to solve for the target harvest rate
  # (find H so that fished biomass is equal to 75% unfished biomass)
  Htarg <- uniroot(obj.fn,interval=c(H.min,H.max))[['root']]
  cat("Target exploitation rate: ",Htarg,"\n")

  # calculate TAC given target harvest rate

  if(!TAC.only) return(pop.proj(Nsurv,Cpsurv,N,M,k,Linf,wtlen,sel,ftime,tmat1
,tmat2,Htarg))
  #browser()
  TAC <- pop.proj(Nsurv,Cpsurv,N,M,k,Linf,wtlen,sel,ftime,tmat1,tmat2,Htarg)[
['TAC']]
  return(TAC)
}

################################
# Transition matrix calculator #
# - Hillary 2010 Biometrics    #
################################

tmat.calc <- function(k,Linf,tau,lbins2) {
  # LVB growth increment

  lvbinc <- function(lrel,tau,k,Linf) {

    return(max((Linf-lrel)*(1-exp(-k*tau)),0))
  }

  tmat <- matrix(nrow=length(lbins2)-1,ncol=length(lbins2)-1)

  for(i in 1:dim(tmat)[1]) {

    lx <- lbins2[i]
    ly <- lbins2[i+1]

    for(j in 1:dim(tmat)[2]) {

        llj <- lbins2[j]
        luj <- lbins2[j+1]
```

```
        lli <- lx + lvbinc(lx,tau,k,Linf)
        lui <- ly + lvbinc(ly,tau,k,Linf)

        # need to work out Lebesgue measure of intersection
        # of image and actual length bin / length bin

        if(lli > llj & lui < luj) {
          ptmp <- 1
        } else {
          tmp <- c(max(llj,lli),min(luj,lui))
          mu <- ifelse(tmp[1] < tmp[2],tmp[2]-tmp[1],0)
          nu <- lui-lli
          ptmp <- mu/nu
        }

        tmat[i,j] <- ptmp
      }
    }

  return(tmat)
}
```

Setup structures

```
# set up the FLQuant for the initial survey length distribution
Nsurv <- FLQuant(quant='length',dim=c(length(lbins),1,1,1,1,1),units='numbers
')
dimnames(Nsurv)[['length']] <- as.character(lbins)
N <- FLQuant(quant='length',dim=c(length(lbins),2,1,2,1,1))
dimnames(N)[['length']] <- as.character(lbins)
 # commercial selectivity
sel <- N
sel[] <- commsel

# weight-at-length
wtlen <- N
wtlen[] <- wtl

# maturity
matlen <- N
matlen[] <- matl

M <- N
M[,,,1,,] <- Mtot * TACtime
M[,,,2,,] <- Mtot * (1-TACtime)
```

Run

```
H.min <- 0
H.max <- 0.9999

TAC_proj <- matrix(NA,2,1,TRUE,list(c("y1","y2"),surv))
ssbfwd <- TAC


NatL <- list()

##Read in catch data, line up years, add NAs
  y <- as.numeric(surv)
  Nsurv[] <- lfreq$numbers
  proj.results <- tac.ani483(Nsurv,Cpsurv*1e6,N,M,k,Linf,wtlen,matlen,sel,TAC
time,H.min,H.max,
                             TAC.only = FALSE)

##
## H 0
## Initial biomass:  13278.96
## Biomass at start of Year 1:  11146.96
## Biomass at start of Year 2:  10694.64
## Biomass at end of Year 2:  8955.864
##
## H 0
## Initial biomass:  13278.96
## Biomass at start of Year 1:  11146.96
## Biomass at start of Year 2:  10694.64
## Biomass at end of Year 2:  8955.864
## 8955.864
##  8955.864
##  1
##
##
## H 0.9999
## Initial biomass:  13278.96
## Biomass at start of Year 1:  11146.96
## Biomass at start of Year 2:  5611.184
## Biomass at end of Year 2:  1851.685
## 1851.685
##  8955.864
##  0.2067568
##
##
## H 0.3151303
## Initial biomass:  13278.96
## Biomass at start of Year 1:  11146.96
## Biomass at start of Year 2:  9092.527
## Biomass at end of Year 2:  6031.86
```

```
## 6031.86
##  8955.864
##  0.6735095
##
##
## H 0.2413013
## Initial biomass:  13278.96
## Biomass at start of Year 1:  11146.96
## Biomass at start of Year 2:  9467.871
## Biomass at end of Year 2:  6660.344
## 6660.344
##  8955.864
##  0.7436852
##
##
## H 0.2348214
## Initial biomass:  13278.96
## Biomass at start of Year 1:  11146.96
## Biomass at start of Year 2:  9500.814
## Biomass at end of Year 2:  6717.157
## 6717.157
##  8955.864
##  0.7500289
##
##
## H 0.2348825
## Initial biomass:  13278.96
## Biomass at start of Year 1:  11146.96
## Biomass at start of Year 2:  9500.504
## Biomass at end of Year 2:  6716.62
## 6716.62
##  8955.864
##  0.749969
##
##
## H 0.2348214
## Initial biomass:  13278.96
## Biomass at start of Year 1:  11146.96
## Biomass at start of Year 2:  9500.814
## Biomass at end of Year 2:  6717.157
## 6717.157
##  8955.864
##  0.7500289
##
## Target exploitation rate:  0.2348214
##
## H 0.2348214
## Initial biomass:  13278.96
## Biomass at start of Year 1:  11146.96
```

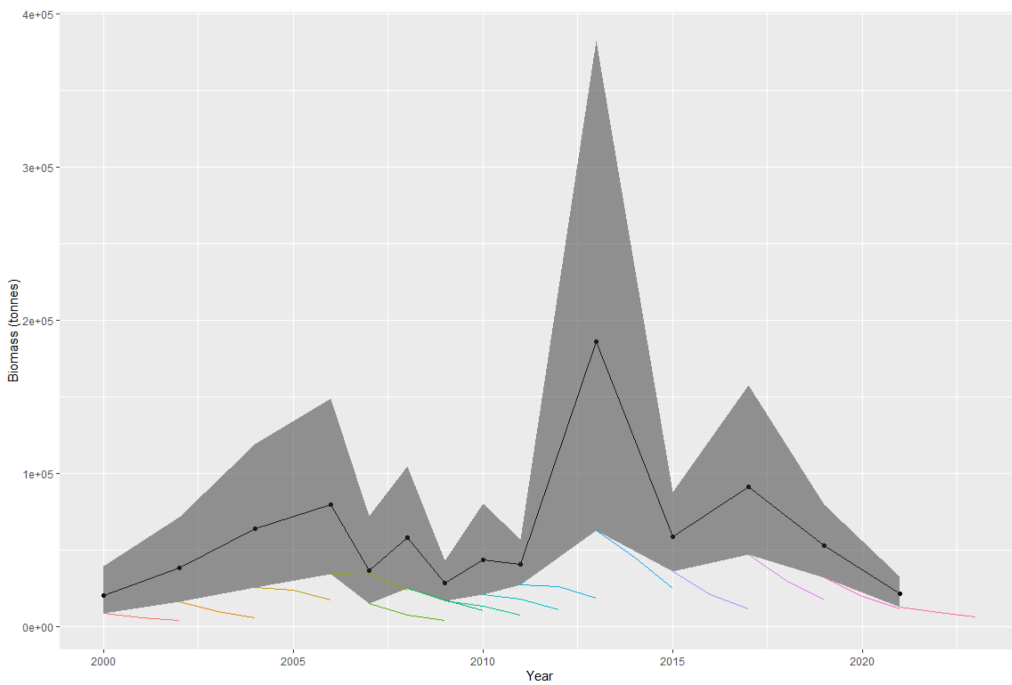
```
## Biomass at start of Year 2:  9500.814
## Biomass at end of Year 2:  6717.157
```

```
  TAC_proj[,surv] <- proj.results$TAC
  biomass.all["current",c("proj_1","proj_2")] <- proj.results$B

  write.csv(biomass.all, paste0(path, "/hist biomass 20",surv,".csv"), row.na
mes = FALSE)
```

Previous performance of assessment

A plot of the projections based on each assessment, compared to the subsequent survey.

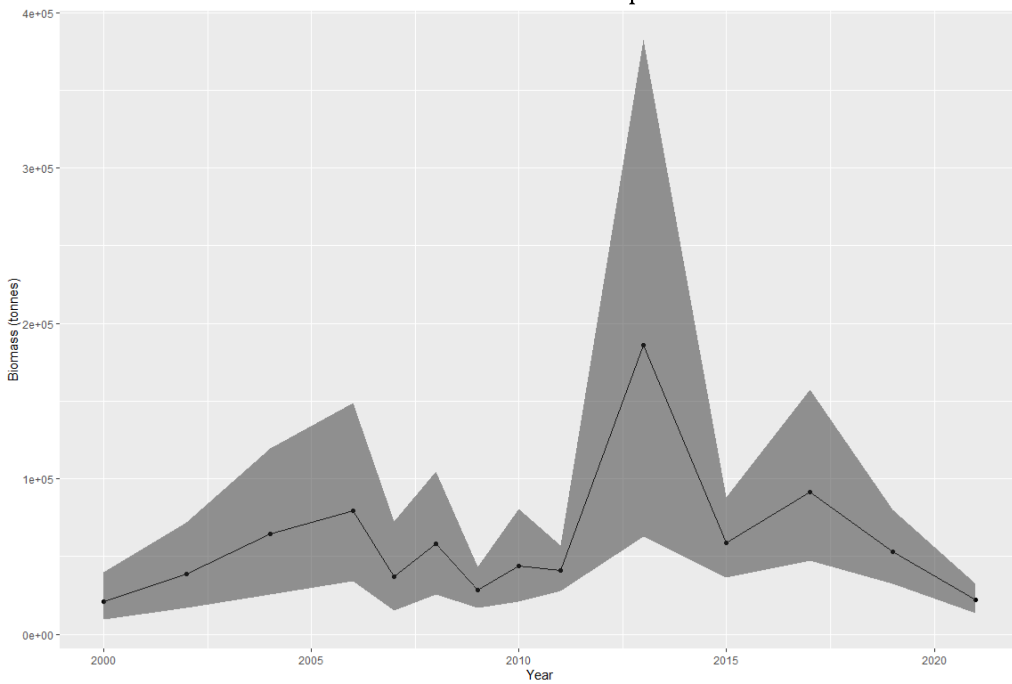
```
## Warning: It is deprecated to specify `guide = FALSE` to remove a guide. Pl
ease
## use `guide = "none"` instead.
```



Final answer

```
TAC_proj

##            21
## y1 1456.631
## y2 1707.733
```

Median estimates of biomass with 5-95% bootstrap mean estimates shaded.



Additional Resources

- Fishery Summary: pdf, html
- Fishery Report: pdf, html
- Species Description: pdf, html
- Fisheries Documents Browser