2020 Sustainability Measures

Patagonian Toothfish *(Dissostichus eleginoides)*

SM – 2020 – TOO

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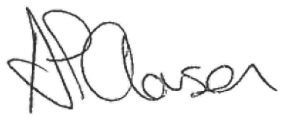

Andrea Clausen
Director of Natural Resources

Date: 31 August 2020

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1. Toothfish fishery

Overview

Designated on Schedule 2: Falkland Islands Gazette Vol 16 No. 17 15 September 2005
Amended: Falkland Islands Gazette Vol 16 No. 24 23 December 2005
ITQ Register Opened: 1 January 2006, Falkland Islands Gazette Vol. CXIV No. 18 31 December 2005

Dates within which the Fishery Operates: 1st January - 31st December
Valid Fishing Areas: Falkland Island Conservation Zones in depths greater than 600 m (Figure 1).
Seasonally Closed area: 32,412 km^2, closed 01 June - 31 August (Figure 1).

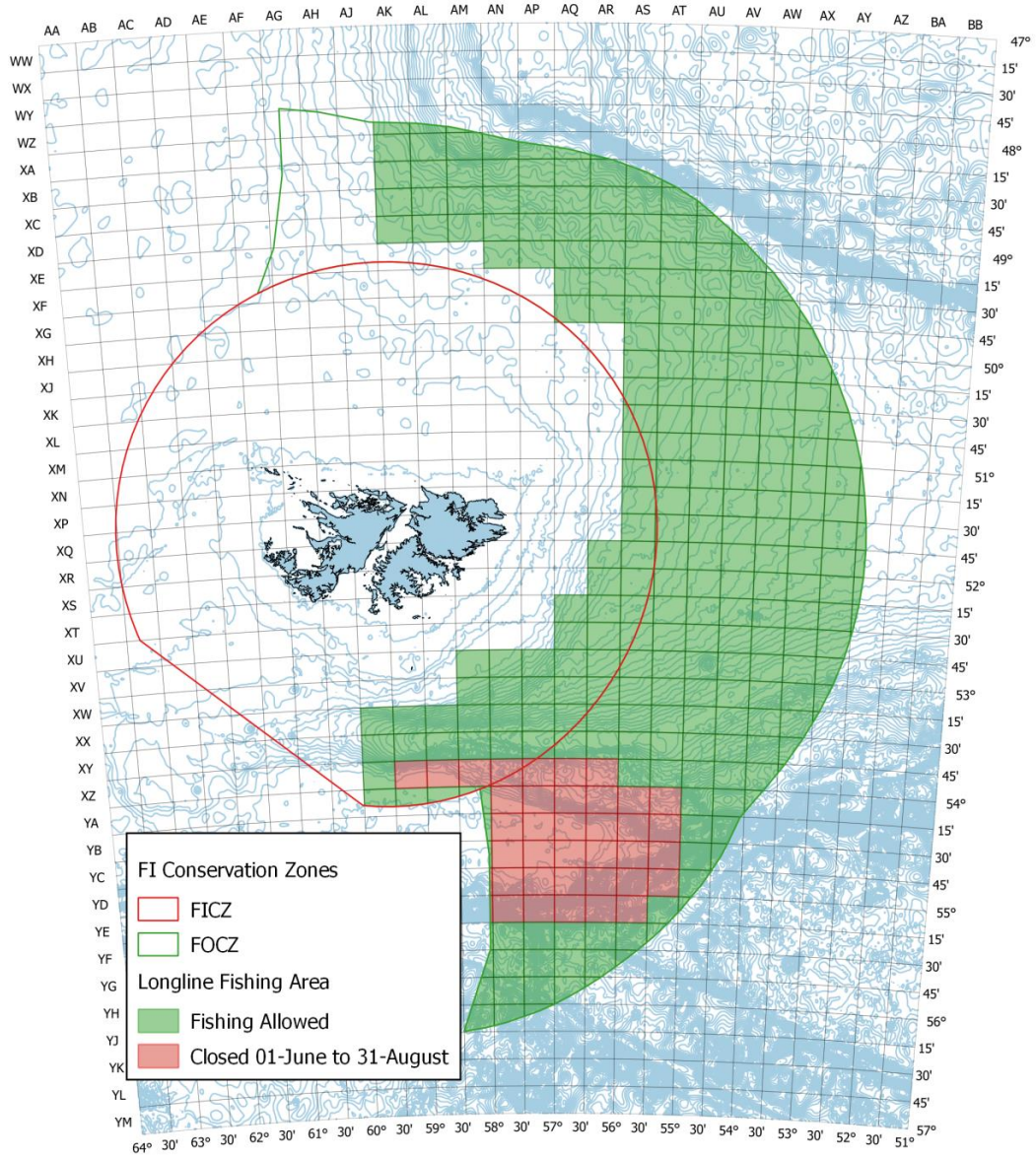

Figure 1. Map of the FICZ, FOCZ and seasonally closed area for the toothfish longline fishery

Fishery Timetable

Date	Event
1st January	Fishery opens
March	Data review on previous year's fishery
April/May	Stock Assessment
Jun/July	Industry presentation and consultation
August	Final review and gazetting of TAC/TAE information
September	Advise ITQ holders of TAC or TAE and Catch Entitlements for forthcoming year
By 1st October	Set Vessel Units, Allowable Effort and Allowable Catch Complete VU, TAE and TAC Report for Industry Input to Fisheries Department Budget Proposals Allocation of staff and resources
November	ITQ holders to submit information as to how catch entitlements will be exercised
31st December	Fishery Closes

Vessels (2020)

There is currently one longliner operating full time in the Falkland Islands fishing zones, the *CFL Hunter* which replaced the *CFL Gambler* in May 2017. The CFL Gambler had been operating in the Falklands since 2004. In 2017, longline fishing took place on 181 days; the *CFL Hunter* was not ready to fish commercially until July 2017, therefore two other longline vessels were chartered in order to reach the TAC, and these accounted for 23% of the toothfish longline catch. In 2018 and 2019, only the *CFL Hunter* fished in the FICZ/FOCZ, accounting for all 185 and 206 fishing days, respectively.

TAC (2020 and 2021)

- 1,040 t green weight per year
- TAC to be reviewed every year as new information becomes available
- Up to 15% of the TAC may be carried forward to the following year or brought forward from the next year. Such carryovers can only operate from one year to the next and cannot accumulate over multiple years. Any revision of the TAC could override any such carryover in TAC

2. Harvest Control Rules

Harvest levels are set using a precautionary approach in two ways. First, the major sources of uncertainty in harvest levels, namely unreported (IUU) catches and whale depredation, are now explicitly taken into account (see Toothfish Stock Assessment). Secondly, the fishing mortality ratio (F/F_{MSY}) is capped at 2/3 F_{MSY} as suggested by the UN Food and Agriculture Organization (Caddy and Mahon 1995, Doubleday 1976) and used for species like carangids (Khalifa and Mehanna 2006), and Greenland halibut (ICES 2001) which live in deep cold waters and have a long life span. This provides a buffer between the estimated catch that ensures MSY and the actual harvest of toothfish.

The age-structured production model in CASAL generates annual estimates of biomass and spawning stock biomass (SSB) and can calculate forward projections of these estimates pursuant to assumptions of future catches. Based on the CASAL model output, the following illustrative figure (Figure 2) and decision matrix of harvest control rules (HCR) have been established to manage the Falkland Islands toothfish longline fishery:

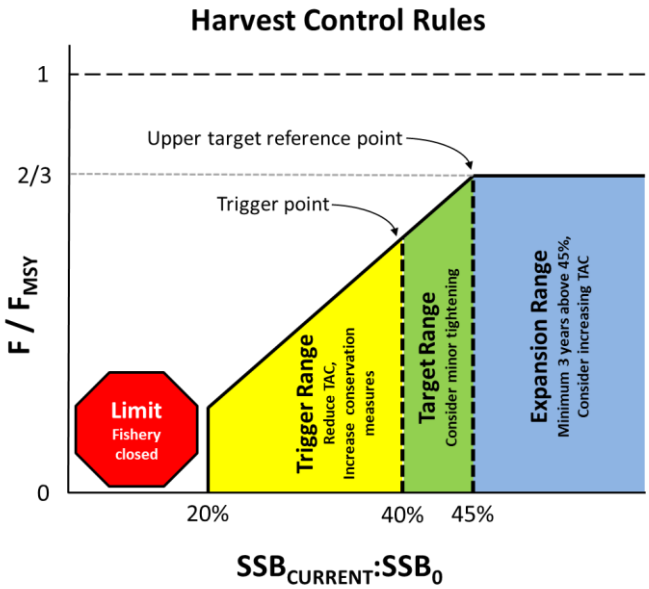

Figure 2. Diagram of FIFD toothfish fishery harvest control rules (HCR), illustrating the relative spawning stock biomass ($SSB_{current}/SSB_0$) reference points and ranges. Fishing mortality is capped at 2/3 F_{MSY} as a precautionary approach. See decision matrix for more detailed description of each reference point/range. Diagram is illustrative only and not to scale.

1. *Expansion range:* If the ratio of $SSB_{current}/SSB_0$ has remained above the upper target reference point (45%) for 3 consecutive years and the SSB projection with the current TAC shows no decrease below 45% for at least 10 years (one generation) under precautionary assumptions, the Director may authorize an increase in longline TAC to a level that continues to show no projected $SSB_{current}/SSB_0$ decrease to below 40% (trigger point) for at least 10 years under precautionary assumptions.

2. *Target range:* If the ratio of $SSB_{current}/SSB_0$ is between 40% and 45% (within the target range), current longline TAC is reviewed in relation to stock trends. Current TAC may be maintained

if $SSB_{current}/SSB_0$ has increased from the previous assessment, or if the SSB ratio projection shows a level status under precautionary assumptions. TAC may not be increased, but it may be decreased if age-structure distributions anticipate weak recruitment.

3. *Trigger point and range:* If the ratio of $SSB_{current}/SSB_0$ falls to ≤ 40% (trigger point), longline TAC will be decreased to a level that projects an increasing SSB trend under precautionary assumptions. The magnitude of the proposed TAC reduction will be examined using three methods (adapted from ICES, 2017):

    a. Indexed to the reduction of the MSY estimates:
    $$TAC_{year} = TAC_{year-1} * \left(MSY_{year}/MSY_{year-1}\right)$$
    b. Indexed to the reduction of the SSB estimates:
    $$TAC_{year} = TAC_{year-1} * \left(SSB_{year}/SSB_{year-1}\right)$$
    c. Indexed to the reduction in SSB ratios:
    $$TAC_{year} = TAC_{year-1} * \left(SSB\ ratio_{year}/SSB\ ratio_{year-1}\right)$$

    TACs obtained from all three methods will be projected forward in the stock assessment model and the trends in SSB will be compared. The final method will be chosen based on it returning the SSB ratio to above 40% within 10 years (one generation) of the SSB ratio falling below 40%. If more than one method meets this requirement, the chosen method will also depend on discussions between the Fisheries Department and industry.

4. *Limit reference point:* If the ratio of $SSB_{current}/SSB_0$ is ≤ 20%, the longline fishery will be closed pending comprehensive evaluation of conditions required to rebuild the stock. The Director may authorize test fishing to measure biological parameters of the stock, subject to close monitoring by the Fisheries Department.

The HCRs will be reviewed every year along with the stock assessment model to ensure that they are in line with the current and projected stock status.

3. Conservation and Management Priorities

- **Ensure the long-term sustainability and prevent the over-fishing of toothfish**
  - Maintain the Spawning Stock Biomass (SSB) at 45% or higher of SSB0.
  - Limit the toothfish catch by longliners (or potters) to the sustainable catch limit (annual TAC).
  - Minimize toothfish bycatch in other fisheries, particularly of juveniles on the shelf.
  - Keep spawning areas protected from impacts of fishing during spawning season (i.e. Burdwood Bank spawning grounds closure). Limited access may be granted for research purposes.
  - Continue research on the biology and ecology of toothfish, and on the prosecution of the fishery (e.g. conversion factor of toothfish HGT to green weight, bycatch conversion factors, etc.).

- **Reduce impacts on seabirds, marine species (including bycatch), habitats and VMEs**
  - Continue to implement the management strategy on reducing incidental seabird mortalities set out in the National Plan of Action - Longlining plan, and achieve all targets set out in the plan.
  - Maintain coverage by Scientific Observers to collect data and enforce other procedures which reduce impacts.
  - Encourage and help maintain the culture of "good housekeeping" on longliners with respect to seabirds, bycatch and other best-practice licence conditions.
  - Better understand the habitats and VMEs in the areas where longlining takes place.
  - Reduce the impacts of fishing on sensitive benthic ecosystems.

- **Management, compliance and catch documentation**
  - Maintain full VMS coverage in and out of Falkland Islands Government Conservation Zones.
  - Ensure full compliance with the *Dissostichus* Catch Documentation Scheme.
  - Maintain monthly fisheries monitoring reports for toothfish.
  - Maintain the regular monitoring of TAC usage within the longline fishery.
  - Ensure daily catch reporting via e-log books is continuous and accurate.

4. Sustainability Strategies and Research Objectives

4.1. Target species

1. Update and refine the stock assessment model as needed.

2017 update:

- *IUU catches were estimated along with unrecorded whale depredation; Spanish-system longline and umbrella-system longline were modelled as different fisheries; and the two components of the objective function were re-weighted to equalize between the CPUE index fits and the catch-at-age distribution fits.*

2018 update:

- *Most recent data used, model essentially the same, but report has added figures and descriptions based on external review recommendations.*

2019 - 2020 update:

- *CPUE time series were revised and several changes were introduced regarding CPUE data selection and standardization (for details see Skeljo and Winter 2020)); assumed IUU catches were corrected as some of the values used in the previous assessment erroneously included reported catches as IUU; ageing data was restricted to otoliths collected and aged in 2015-2019 as only these were considered reliable; selectivity of the calamari trawl fishery was described by empirical curve where a single selectivity parameter is estimated for each age class, instead of double-normal curve.*
- *Following the external review recommendations (Bergh 2018), additional model sensitivity analyses and CPUE-standardization tests were carried out, and relevant outputs included in the stock assessment report.*

<u>Current objectives:</u>

- Explore more options for the longline CPUE standardization (e.g. including explanatory variable interactions in GLM, binning continuous variables in GLM, increasing the resolution of spatial data, modelling CPUE using GAM, etc.).
- Explore the conflict that exists between different observations used in the assessment model, namely between CPUE and catch-at-age datasets.
- Explore the option of modelling calamari trawl fishery as two separate fisheries with different selectivity, pre-2007 and post-2007, as toothfish catch-at-age structure is markedly different between the two.

<u>Future objectives:</u>

- Review the maturity-at-age estimates and underlying data; if needed, collect new samples and attempt to model maturity ogive based on these data alone.
- Explore whether the data from the research surveys could be helpful in estimating toothfish year class strength.

2. Conduct focused research projects to address knowledge gaps in the biology and ecology of toothfish, particularly for issues related to the fishery. These projects should lead to peer-reviewed publications.

2017 - 2018 update:

- *Ongoing research projects to better understand toothfish stock discrimination in the south Atlantic (otolith microchemistry and shape analysis, toothfish morphology, tagging, and*

demography). Other research projects include toothfish growth, age-structure, and recruitment index.

- *A survey of juvenile toothfish distribution was undertaken in January 2017 (report ZDLT1-01-2017), which found some juvenile toothfish (10-12 cm total length) in shallow waters of the southern part of the Falkland Shelf at depths 70-110 m. Two additional cruises in similar areas were conducted in 2018 and 2019 but failed to find large abundances of small toothfish.*
- *Peer-reviewed paper published on the use of otolith shape to reveal Patagonian toothfish stock structure in the SW Atlantic (Lee et al. 2018)*
- *A total of 3,332 toothfish have been tagged to date, of which 52 have been recaptured. 20 satellite tags have also been deployed since June 2017, 5 of which are still at liberty.*

2019 - 2020 update:

- *Peer-reviewed paper published on the impact of Patagonian toothfish longline fishing on VMEs (Brewin et al. 2020).*
- *Peer-reviewed paper produced and submitted, on the Patagonian toothfish demography using otolith microchemistry (Randhawa et al., In Review).*
- *Report produced on the genomic analysis of Patagonian toothfish population structure in SW Atlantic.*
- *The toothfish tagging programme continued during observer deployments and research cruises; a total of 3,541 toothfish have been tagged to date, of which 134 have been recaptured. All 20 satellite tags deployed since June 2017 have been either recovered (17) or are considered lost (3).*

Current objectives:

- Complete the project 'Application of Bayesian spatial predictive models to describe juvenile Patagonian toothfish abundance dynamics across the Falkland Islands Shelf'.
- Complete the work on the 'Patagonian toothfish morphology and morphometry in the SW Atlantic'.
- Continue toothfish tagging programme during observer deployments and research cruises.

Future objectives:

- Continue work on the project 'Recruitment and ontogenetic migration pathways for juvenile Patagonian toothfish using otolith elemental profiles'.
- Continue work on the project 'Life-history strategies and connectivity in Patagonian toothfish in the SW Atlantic and SE Pacific'.
- Continue toothfish tagging programme during observer deployments and research cruises.

3. Maintain a toothfish sample collection.

2018 update:

- *The FIFD collection is currently holding 33,145 otolith samples going back to 1999 (of which 6,632 have been aged), and 1,088 histological slides of gonads since 2004.*

2019 - 2020 update:

- *A total of 1,661 otolith samples have been collected in 2019 (of which 920 have been aged).*

Future objectives:

- Continue collecting otolith samples.

4. Explore potential improvements to fishing gear to better target toothfish.

2017 update:

- *A hook trial experiment was conducted aboard the CFL Hunter during the June 2017 research cruise. Four hook types were randomly assigned to sections of longlines and all toothfish and bycatch were measured.*

2018 update:

- *The hook trial data was analysed (Randhawa et al. 2018) and no significant differences in catch of toothfish or bycatch species were found, suggesting that hook size and shape do not significantly influence catch rates. Reduction of grenadier bycatch would therefore need to be done by changing fishing behaviour or finding other gear modifications to test.*

2019 - 2020 update:

- *No further gear modifications were tested; results of the hook trial study were not promising, and further testing of a more substantial increase in hook size was discouraged due to the difficulties it would cause to the fishing operation. As the main goal of the hook trial was reduction of the grenadier bycatch, efforts have been made to describe the spatial distribution of catch and CPUE of this species and produce its stock assessment.*

5. Build science capacity at FIFD to address current and future research questions on toothfish.

2018 update:

- *CFL continues to support 50% of a toothfish scientist position (Brendon Lee) who enrolled in a PhD programme in January 2017. His topic of research is: "Spatial and temporal delineation in the population structure of Patagonian toothfish (Dissostichus eleginoides) around the Falkland Islands: ontogenetic and environmental effects".*

2019 - 2020 update:

- *CFL continues to support 50% of a toothfish scientist position (Brendon Lee)*

6. Monitor and minimize toothfish catch in finfish and calamari trawl fishery.

2018 update:

- *High bycatch rates of toothfish were seen in late 2016 and 2017, and a new toothfish bycatch limit of 1.5% was instituted in the finfish trawl fishery. Toothfish bycatch in the calamari trawl fishery remains lower, but this fishery usually catches smaller toothfish, so the numbers of fish removed are probably greater than in the finfish fishery.*

2019 update:

- *Unlike any other years previously, toothfish bycatch at the beginning of 2019 was very high. An emergency closure of 14 grid squares in the southwest of the FICZ was implemented in February/March. Since then, toothfish catches have returned to levels consistent with previous years.*

2019 - 2020 update:

- *Toothfish bycatch threshold of 1.5% in the trawl fisheries (coupled with the enforcement of a move-on rule when this threshold is exceeded) is being reviewed to determine has it proven to be an effective management tool. Report has been produced (Randhawa 2020) on the merits of the currently used and the three alternative approaches, and will be used to inform internal discussions as we evaluate the best option to implement a long term management strategy on the issue of toothfish bycatch.*

<u>Current objectives:</u>

- *A comprehensive analysis of the toothfish bycatch in trawl fisheries is being undertaken, aiming to synthesize all data we have available to estimate the actual numbers of juvenile*

toothfish caught, and create an overview of how toothfish bycatch trends may change inter-annually. This will include extrapolating bycatch rates from vessels that have observer coverage to those that do not.

4.2. Habitat and ecosystem species

1. Maintain 50% Scientific Observer coverage annually for the longline fleet.

2017 update:

- *The observer coverage in 2016 was 49.7%, just below the target.*

2018 update:

- *The observer coverage in 2017 and 2018 was 55.5% and 56.5%, respectively.*

2019 update:

- *The observer coverage in 2019 was 40.8%, below the target of 50%; this can partially be attributed to one of the three observed trips being notably shorter than usual, as vessel had to depart for transhipment to Montevideo, Uruguay.*

2020 update:

- *The observer coverage in the first half of 2020 was 46.7%.*

Current objectives:

- Continue to assess scientific observer coverage and ensure that it is at least 50%.
- Reassess the duties of observer to make sure that they are collecting the most important data while at sea (explore having them spend more time on quantifying benthic bycatch).

2. Continue to collect bycatch data.

2018 update:

- *Biological data (length, sex, maturity) are collected for Macrourus holotrachys, Antimora rostrata and skate species on a regular basis. Catches of these species remain low with no changes in trends over recent years (FIFD observer data). Opportunistic data are collected from other species and the collection of invertebrate by-catch continues to grow.*
- *Seabird observations continue by observers at roughly 25% of their time on the vessel. In 2016, 2017 and 2018 no sea bird mortalities were observed.*

2019 update:

- *Bycatch data collection and seabird observations continue as in previous year; no seabird mortalities were observed in 2019.*
- *Bigeye grenadier (M. holotrachys) stock assessment for 2018 was produced using JABBA model framework.*

2020 update:

- *Bycatch data collection and seabird observations continue as in previous year.*
- *Bigeye grenadier stock assessment for 2019 was produced using JABBA model framework; model was refined by introducing a few changes to the input data and priors. The most substantial modification compared to previous assessment was inclusion of the Spanish-system longline CPUE data for the period 1997-2007 in the analysis. This informed the model about the stock abundance in the early years of the fishery, and notably reduced the uncertainty of the estimates.*

- *ID placards for the Falkland Islands skate species have been produced (outsourced to the SharkTrust UK) and delivered to the FIFD.*

Current objectives:

- Ongoing data collection of invertebrates, fish and ETP species caught in the longline fishery.
- Distribute the skate ID placards on the vessel (CFL Hunter).

Future objectives:

- Studies of the main population parameters such as age, growth and reproductive potential for by-catch species including antimora, grenadiers and skates.

3. Gather habitat and VME species information during longlining operations; develop a predictive model for the presence of VME species and determine the impact of the fishing gear on habitats and VMEs.

2017 update:

- *A program to deploy CTDs on a subset of lines off the CFL Hunter was initiated. These data will be used to monitor seasonal and annual temperature and salinity changes.*
- *Underwater cameras were deployed on longlines during and after the 2017 CFL Hunter research cruise. The primary aims are to assess the benthic biodiversity in areas targeting toothfish in the FICZ/FOCZ and to assess the impacts of the longline on the benthos.*

2018 update:

- *Cameras were deployed during two research cruises, and a total of over 80 hours of underwater footage has now been collected.*
- *A predictive VME model has been developed (Brewin 2018) and shown that the longline gear is most likely having a small impact on VME species inside the FICZ/FOCZ.*

2019 - 2020 update:

- *Peer-reviewed paper published on the impact of Patagonian toothfish longline fishing on VMEs (Brewin et al. 2020).*

Current objectives:

- Analyse the existing CTD data, develop a protocol for future CTD data collection, and develop a method to review underwater footage.

4. Examine options to further reduce longline bycatch.

2017 update:

- *A hook trial experiment was conducted aboard the CFL Hunter during the June 2017 research cruise, but no effect of hook size or shape on bycatch rates was found.*

2018-2019 update:

- *A grenadier stock assessment report for 2018 was produced, which showed the hot spots of grenadier catch, and found that the longline fishery is not endangering the stock.*

2020 update:

- *A grenadier stock assessment report for 2019 was produced, which showed the hot spots of grenadier catch-per-unit-effort in longline fishery and confirmed the last year's assessment that the longline fishery is not endangering the stock.*
- *Analysis of the 'bycatch conversion factor' in toothfish longline fishery was conducted and summarized in a FIFD report. 'Bycatch conversion factor' refers to the average individual weight of the most common bycatch species (antimora, grenadier and skates), and is used to*

calculate their total annual bycatch weight (numbers caught × average weight). Analysis revealed that antimora and skates' conversion factors need to be updated.

Current objectives:

- Finalize the 'Interim strategy for managing bycatch and bait species in Patagonian toothfish longline fishery (2020/2021)'.

Future objectives:

- Implement the 'Interim strategy for managing bycatch and bait species in Patagonian toothfish longline fishery (2020/2021)'.

5. Develop the invertebrate and fish taxonomic collection held at FIFD.

Current objectives:

- FIFD is organising the collection, with the aim of incorporating it into larger institutional curatorial databases overseas, such as the British Natural History Museum in London.

6. Regularly update observer manuals and NPOA documents.

2018 - 2019 update:

- *Both the observer manual and NPOA for seabirds have been revised to ensure that they reflect the current management and research strategies of the FIFD.*

Future objectives:

- An NPOA for sharks and skates should be developed in the future.

4.3. Management, compliance and catch documentation

1. Ensure that the fishing fleet is equipped with technologies and amenities that allow observer and research operations and facilitate compliance with management regulations.

2017 update:

- *FIFD provided input during the planning and development of the CFL Hunter. This input ensured adequate observer and research accommodations on the vessel.*

2018 update:

- *The efficacy of the tori line was examined during a research cruise. Interaction rate increased when tori line was absent, but this did not seem to have any impact on the seabirds. Further observations would be necessary to examine the impact on diving birds.*

2019 update:

- *Grading of the 'observer working conditions' and 'observer accommodation' by the fisheries observers aboard CFL Hunter has been analysed for 2017-2020. Both criteria received the highest score (5/5) from all eleven observers on all twelve observed fishing trips.*

Current objectives:

- Continue to suggest modifications to facilitate the work by observers and researchers.

2. Regularly assess the harvest control rules (HCR) to ensure that they are adequately responsive to potential changes in the stock status.

2017-2018 update:

- *HCRs were refined and clarified to better describe the actions that will be taken under different stock conditions.*

2019-2020 update:

- *No changes to HCRs.*

Current objectives:

- Simulations from a range of stock depletion levels to evaluate the efficacy of the HCRs to increase or rebuild a hypothetically depleted stock.

3. Develop move-on rules for by-catch and VME species.

2019 update:

- *FIFD was working with CFL to determine whether 'move-on' rules are the most appropriate method to reduce VME bycatch. These rules would dictate what actions should be taken to identify and respond to situations where a longline set captures an unusually high amount of certain species (e.g. sharks, corals, sponges, etc…). Several models are being explored, including the CCAMLR Conservation Measures 22-06 and 22-07.*

Current objectives:

- Finalize the 'Interim strategy for managing bycatch and bait species in Patagonian toothfish longline fishery (2020/2021)'. This strategy includes testing of the 'move-on' rules to reduce fish bycatch.

Future objectives:

- In cooperation with SAERI, explore the potential of the 'move-on' rules to reduce VME bycatch.

4. Ensure adequate reviews of FIFD take place.

2017 update:

- *Regular internal audits and reviews of specific fisheries measures (stock assessment, licensing advice, ITQ program, etc…) are being conducted.*

2018 update:

- *An external review of the longline toothfish fishery was completed, and a list of recommendations produced which are currently being addressed. The need for such an external review should be examined every 3-5 years.*

2019 - 2020 update:

- *An external review of the current Falkland Island finfish (excluding toothfish) fishery objectives, management and management processes has been completed in June 2020.*

5. Maintain the excellent compliance record of the fishing fleet.

2018 update:

- *No compliance issues have been found in recent years.*

2019 update:

- *The level of catch verification has been increased substantially. Since November 2018, 100% of the catch has been verified, making the longline fishery the most verified fishery in the Falkland Islands*
- *Three fishing trips had the observer on-board, and the CFL Hunter compliance with the licence conditions was reported to be excellent (FIFD 2019a, 2019b, 2019c).*

2020 update:

- *In the first half of 2020 one out of the two catch transhipments has been verified.*
- *In the first half of 2020 two fishing trips had the observer on-board, and the CFL Hunter compliance with the licence conditions was reported to be excellent (FIFD 2020a, 2020b).*

Current objectives:

- Continue to encourage the culture of compliance and cooperation with industry.

6. Meet the Marine Stewardship Council milestones, requirements and principles.

2017 update:

- *Dr Thomas Farrugia was hired on a 2-year contract as a dedicated toothfish stock assessment scientist. He will dedicate part of his time to ensuring that the MSC principles are met and that the fishery evolves along with the changes in MSC.*

2019 update:

- *Dr Thomas Farrugia extended his contract for 1 year to continue ensuring that the fishery meets the MSC principles and a work plan is in place for the new certification period.*

2019 - 2020 update:

- *Dr Thomas Farrugia ended his contract in September 2019. Dr Frane Skeljo was employed on a 2-year contract as a stock assessment scientist, starting from January 2020. He will dedicate part of his time to undertake and supervise the Department's tasks to meet MSC standards on Patagonian toothfish and prepare the fishery for re-certification assessment in 2023.*

5. Stock Assessments

5.1. Stock management history

2005: FIFD/RRAG	The first attempt at assessing toothfish in the Falkland Islands was conducted in 2005 (FIFD) using Fox and Schaefer Production and CEDA models. The models indicate a strong stock decline with the standing stock being reduced to about 50% of initial size with CPUE expressed in numbers of fishing days, and down to 35–38% with CPUE expressed in numbers of hooks recovered. Two ASPMs were used (RRAG); one with a Beverton-Holt stock recruitment relationship and another using trawler CPUE to estimate yearly recruitment. Their estimates showed similar declines in biomass as the fishery progressed. Current biomass was at between 38% and 46% of its pre-exploitation level and MSY was between 912 and 3000 t. There was a poor fit to CPUE between 1994 and 1996 which was attributed to IUU catches or changes in catchability and/or mortality. During this time (mid 90s), there was considerable IUU activity in the SW Atlantic, and when their model was adjusted to allow an estimated level of extra catch, the fit improved and 5000 t of extra catch was estimated.
2006: First year of ITQ systems. **TAC = 1,500 t**	Establishment of Burdwood Bank Seasonally Closed Area.
Assessment for 2007: FIFD/RRAG **TAC = 1,500 t**	ASPM (RRAG) and Fox and Schaefer production models (FIFD) tested. RRAG assessment showed spawning stock biomass between 18,000 to 18,500 t with MSY estimates at 1,468 and 1,640 t. FIFD assessment (CEDA v3.0) MSY ranged between 1,293 and 1,569 t.
Assessment for 2008: FIFD/RRAG **TAC = 1,200 t**	ASPM model tested under different parameterisations and with/without recruitment index. Stock assessments produced a range of MSY estimates leading to the reduction of the toothfish TAC from 1,500 t in 2007 to 1,200 t for 2008.
Assessment for 2009: FIFD **TAC = 1,200 t**	ASPM (Payá & Brickle 2008) was used. The updated stock assessment had similar results to the previous one (MSY 879-1,757 t). There was no strong evidence that 1,200 t TAC should be modified.
Assessment for 2010: FIFD **TAC = 1,200 t**	ASPM (Payá & Brickle 2008) was used. The spawning biomass in 2008 was estimated between 14,575 and 21,216 t and corresponds to 42-53% of the virgin spawning biomass. MSY was estimated between 1,130 and 1,312 t. Fixed catch projection showed that the current 1,200 t TAC produced surplus production slightly greater than the catches. There is no strong evidence that 1200 t TAC should be modified.
Assessment for 2011: FIFD **TAC = 1,200 t**	ASPM. Umbrella CPUE was transformed to line CPUE using the ratio between line CPUE to umbrella CPUE. The ratio value was the mode (0.263) of a gamma distribution fitted to data 2007, 2008 and 2009 (Payá and Brickle 2009). MSY (879-1,757 t) was 2-34% greater than 2007 MSY. Fixed catch projection showed that the current 1,200 t TAC produced surplus. There is no strong evidence that 1,200 t TAC should be modified.
Assessment for 2012: FIFD **TAC = 1,200 t**	An age-structured production model (ASPM) using CASAL (Bull et al 2012) was used for the first time. The main assumption is that the stock comprises two fisheries; trawl and longline. Umbrella line correction factor (0.263) was used. The global MSY (trawlers and longliners) was calculated as 1,610 t. To estimate the proportion available to longliners the mean trawler catch over the last 5 years (174 t) was removed from the global MSY leaving 1,436 t. As this is a new model and due to some uncertainty coupled with the continued decline in SSB we recommend that the TAC for 2012 remain at 1,200 t. We also recommend that the

	temporal spawning area closure on the Burdwood Bank continue during 2012.
Assessment for 2013: FIFD **TAC = 1,200 t**	ASPM using CASAL. The same methodology as last year's assessment was applied with the addition of catch and effort data to 31st December 2011. We also recommend that the temporal spawning area closure on the Burdwood Bank continue during 2013.
Assessment for 2014: FIFD **TAC = 1,200 t**	ASPM using CASAL. Two changes: a) model assumption that there are four 'fisheries'; longline, finfish trawlers, Loligo trawlers (early season), and Loligo trawlers (late season). Loligo separated because of the different catch selectivities of the two seasons. b) A statistical anomaly may be having an effect of standardised CPUEs from early years. Until this effect can be better statistically accounted for, pre-1996 CPUE data are excluded. There is no basis for either decreasing or increasing the TAC from 2013. The temporal closure of the Burdwood Bank should continue for the foreseeable future as an important fishery management tool.
Assessment for 2015: FIFD **TAC = 1,040 t**	ASPM using CASAL. Two versions of the model were tested: a) including the CPUE tuning indices of all three fisheries in the optimization: longline, finfish trawl, and Loligo trawl similar to the previous assessment, and b) including the CPUE tuning index of only the longline fishery (but still including the actual toothfish catches taken in those fisheries). This takes into account uncertainty caused by toothfish being a non-targeted in finfish and Loligo fisheries, such that catch does not have a definitive proportionality with the fishing effort. The Patagonian toothfish stock in the Falkland Islands appears to be in decline. The probability of being below 0.45 ratio is 33%, while the probability of being below 0.40 (a commonly used guideline by the Marine Stewardship Council; Stuart Hanchet, NIWA, pers. comm.), is 23%. A 13.3% reduction in TAC was thought to be prudent. This reduction is indexed to the reduction in MSY between 2012 and 2014. To increase protection of toothfish aggregations on their spawning ground (Burdwood Bank) the fishing ban was extended to June 1st - August 31st, and the area of closed fishing was expanded considerably on the eastern part of Burdwood Bank with closure of areas south of 54 S and shallower than 1700 m.
Assessment for 2016: FIFD **TAC = 1,040 t**	Assessment was continued with the CASAL ASPM, using model version II: CPUE tuning index of only the toothfish longline fishery but catches of all three fisheries that take toothfish (longline, finfish trawl and Loligo trawl). Three changes were made to the stock assessment: (a) inclusion of catches out-of-zone, to better represent time-series impacts on the toothfish population, (b) optimizing natural mortality within the ASPM, (c) empirically evaluating the umbrella factor of the longline fishery and applying the best umbrella factor fit in the final stock assessment model. Total biomass continued to show a declining trend since the start of the fishery, but the rate of decline has slowed. CPUE in the longline fishery (which represents the abundance tuning index for the ASPM) has been increasing slowly since 2006. Maximum sustainable yield (MSY) allowable to the longline fishery was estimated at 1276.5 t. Total biomass and spawning stock biomass in 2015 was calculated by the CASAL ASPM at 24,243 t and 7,079 t respectively. The ratio of SSB_{2015}/SSB_0 (current spawning stock biomass to unfished spawning stock biomass) was 0.445, just below the prescribed threshold reference point. However, a retrospective analysis of $SSB_{current}/SSB_0$ showed a continual improvement of the ratio with

	every yearly addition of data. Accordingly, even though the historic depletion of the toothfish stock has not been fully arrested as of 2015, the biomass trend is correcting itself along with increasing CPUE in the longline fishery. Based on the evidence of a slowly recovering toothfish stock, the recommendation from this stock assessment is to maintain the TAC for longline fishing at its current level of 1,040 t.
Assessment for 2017: FIFD **TAC = 1,040 t**	Assessment was continued with the CASAL ASPM. Three modifications were made to the stock assessment: (a) Non-FK-licensed longline catches, including out-of-zone catches, were estimated as a separable factor in the stock assessment, together with unrecorded whale depredation, (b) Spanish-system longline and umbrella-system longline were now modelled as different fisheries, rather than empirically adjusting their CPUEs through a scaling factor, (c) the two components of the CASAL ASPM objective function were re-weighted to equalize between the CPUE index fits and the catch-at-age distribution fits. Total biomass and spawning stock biomass in 2016 were calculated by the CASAL ASPM at 30,288 t and 10,337 t respectively. The ratio of SSB_{2016}/SSB_0 (current spawning stock biomass to unfished spawning stock biomass) was 0.452, just above the upper target reference point. However, a retrospective analysis of $SSB_{current}/SSB_0$ showed a continual improvement of the ratio with every yearly addition of data. The standardized longline CPUE index also shows a decline. The modal catch age in the longline fishery has shown a small but statistically significant increase over the past 10 years. Natural mortality was estimated by the CASAL ASPM at 0.168 $year^{-1}$, close to the composite average previously used for the Falkland Islands toothfish stock. Forward-calculation of the CASAL ASPM projects that SSB will decline to 40.6% - 41.6% of SSB_0 in 2022, before increasing. Thus, SSB is not projected to decrease below the trigger threshold, and the recommendation from this stock assessment is to maintain the TAC for longline fishing at its current level of 1,040 t.
Assessment for 2018: FIFD **TAC = 1,040 t**	Assessment was continued with the CASAL ASPM. Four modifications were made to the stock assessment: a) adjusting the maturity data to take into account that "immature" and "mature resting" fish are not distinguishable, b) changing the gear type of six longline sets in 2013 that were conducted with a Spanish-system longline rather than an umbrella-system longline, c) using a lower whale depredation rate in line with the most up-to-date data, and d) including ageing data through the end of the stock assessment year (2017). All other procedures were followed from the previous stock assessment. At 0.482, the $SSB_{current}/SSB_0$ ratio is well above the prescribed target reference range. MCMC projections show that SSB is likely to continue to decrease until 2024, at which point it will be 0.436 of SSB_0, still above the trigger range that would require additional conservation measures. SSB ratio is then projected to increase back above 0.45 by 2029. Over 74% of the MCMC projections show that the SSB ratio will be above 0.45 by 2052. Based on the evidence of a toothfish stock that stands at an acceptable level of abundance, and projected to increase in the near future under current fishing pressure, the recommendation from this stock assessment is to maintain the TAC for longline fishing at its current level of 1,040 t. An additional recommendation is to develop a strategy to address the bycatch of toothfish in the trawl fisheries, specifically the finfish fishery. There has been a shift in fishing behaviour of the finfish fishery in the last two years, which had led that fishery to catch much more toothfish

	than in previous years. To minimize the threat to the toothfish stock from bycatch, this change in behaviour could be addressed by closing certain areas or depths to trawling.
Assessment for 2019: FIFD **TAC = 1,040 t**	Assessment was continued with the CASAL ASPM. All procedures were followed from the previous stock assessment. Catch, effort and observer length /frequency measurements were updated through 2018. Total biomass and spawning stock biomass in 2018 were calculated by the CASAL ASPM at 30,485 t and 10,596 t respectively. The ratio of SSB_{2017}/SSB_0 (current spawning stock biomass to unfished spawning stock biomass) was 0.467. Natural mortality was estimated at 0.176 $year^{-1}$, close to the composite average previously used for the Falkland Islands stock. At 0.467, the $SSB_{current}/SSB_0$ ratio is above the prescribed target reference range. MCMC projections show that SSB is likely to continue to decrease until 2024, at which point it will be 0.425 of SSB_0, still above the trigger range that would require additional conservation measures. SSB ratio is then projected to increase back above 0.45 by 2031. Over 70% of the MCMC projections show that the SSB ratio will be above 0.45 by 2053. Based on the evidence of a toothfish stock that stands at an acceptable level of abundance, and projected to increase in the near future under current fishing pressure, the recommendation from this stock assessment is to maintain the TAC for longline fishing at its current level of 1,040 t.

5.2. Current stock assessment (2020)

Assessment was done using a Bayesian age-structured production model (ASPM) implemented in CASAL software. Toothfish catch, age, length and maturity data, as well as longline fishing effort data, were updated through 2019.

Besides the regular data updates, several model modifications were made: a) longline CPUE time series were revised (only Falkland Islands flagged vessels were used in the analysis of umbrella-system fishery, data from tagging trips and trips at depths <600 m were excluded, soak-time was standardized per line or hook), b) IUU catches were corrected, as some of the values used in the previous assessment erroneously included reported catches as IUU, c) only age readings from otoliths collected and aged in 2015-2019 were considered reliable and used to construct the age-length key, and d) the double-normal selectivity curve used for the calamari trawl fishery was replaced with empirical curve.

In order to better understand the potential implications of modelling decisions on the results of the stock assessment, several sensitivity analyses were carried out, exploring the effects of using: alternative values of fixed input parameters, alternative model structure, alternative relative weighting of the observations, and alternative future catches.

Results

The key output parameters estimated by the stock assessment model for year 2019 are:

Parameter	MPD value	MCMC 95% CI
SSB_0	24,199 t	21,316 - 92,249 t
SSB_{2019}	10,637 t	7,877 - 78,504 t
SSB_{2019}/SSB_0	0.440	0.364 - 0.875
MSY	1,890 t	1,665 - 7,205 t
M	0.186 y^{-1}	0.171 - 0.241 y^{-1}

The current spawning stock biomass (SSB) estimate was slightly higher than in the previous year (SSB_{2019} = 10,637 t vs. SSB_{2018} = 10,596). However, the ratio of current spawning stock biomass to initial spawning stock biomass (SSB_{2019}/SSB_0) estimate was lower than the last year's (SSB_{2019}/SSB_0 = 0.440 vs. SSB_{2018}/SSB_0 = 0.467). This decline was anticipated by the previous assessment, and although minor, it places the SSB_{2019}/SSB_0 ratio below the 0.45 threshold, i.e. under the *target range* of harvest control rules (HCR), as defined by Farrugia and Winter (2018, 2019). The future trend of SSB/SSB_0 was projected based on the constant future annual catches (longline 1,040 t, finfish trawl 300 t, calamari trawl 30 t), and showed that further decline can be expected, until reaching the minimum point of 0.424 in 2023. However, this is still within the HCR target range, and the median SSB/SSB_0 ratio is expected to slowly start increasing afterwards, reaching 0.45 by 2029.

Maximum sustainable yield (MSY), estimated under the assumption of a constant future catch partition (longline 1,040 t, finfish trawl 300 t, calamari trawl 30 t), was almost the same as in the previous year (MSY_{2019} = 1,890 t vs. MSY_{2018} = 1,899 t). Deducting from the MSY 300 t for finfish trawl and 30 t for calamari trawl fishery leaves 1,560 t, well above the current longline toothfish TAC (1,040 t).

Sensitivity analyses

In order to test the robustness of the assessment model, several alternative modelling assumptions were investigated. Changing the Beverton-Holt steepness parameter, selectivity ogive for calamari fishery, or level of IUU fishing had relatively low impact on the assessment outcome. However, different assumptions regarding year class strength (YCS) had more substantial effects, and this issue will require further analytical work. The difficulty of estimating YCS in toothfish stock assessment was reported by several authors (Candy and Constable 2008, Hillary et al 2006, Mormede et al 2014), concluding that over-parameterisation of the model is commonly observed along with seemingly spurious YCS estimates. The YCS issue was also brought up in the external review of Falkland Islands toothfish assessment and identified as a challenging problem that would mostly likely take a year or two to resolve (Bergh 2018).

The sensitivity analyses giving different relative statistical weights to CPUE and catch-at-age data revealed that there is a 'tension' in the model, i.e. these two datasets (or specific components thereof) are giving conflicting information about the stock status. This will need to be explored in more detail, perhaps by omitting the observations from the model one by one (there are 4 catch-at-age and 2 CPUE components) and analysing how this affects the assessment outcome. Once the understanding of the relative merits of different dataset components is improved, alternative model structures that would reduce the tensions between the data should be explored.

Recommendation

Estimated SSB_{2019}/SSB_0 ratio of 0.440 is in the HCR *target range*. Although the model projects a further decrease in SSB_{2019}/SSB_0 ratio in the next few years, it is nevertheless expected to stay above in the *target range*. While the stock is at this level, the total allowed catch (TAC) should not be

increased, but further conservation measures are not required either. Therefore, the recommendation for the toothfish longline fishery is to maintain the annual TAC at its current level of 1,040 tonnes.

A second recommendation is to maintain the existing '1.5% toothfish bycatch limit', as toothfish bycatch in both finfish and calamari trawls decreased in 2018/2019 compared to 2016/2017, coinciding with the introduction of this regulation. A longer time period is needed to ascertain the effectiveness of the bycatch limit, as recent bycatch decline could be a consequence of natural variability in toothfish recruitment. Therefore, close monitoring of toothfish bycatch, especially in the finfish trawl fishery where larger quantities are taken, needs to be continued.

TAC = 1,040 t

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