SPRFMO
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SC9-DW04

Final Report on NZ's Exploratory Fishery for Toothfish

New Zealand

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South Pacific Regional Fisheries Management Organisation

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Report on the New Zealand exploratory bottom longline fishing for toothfish in the SPRFMO Convention Area 2019 to 2021.

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Abstract

In 2019 the Commission of the South Pacific Regional Fisheries Management Organisation (SPRFMO) approved a proposal by New Zealand to extend its previous (2016 and 2017) exploratory bottom longline fishing for toothfish for the 2019 to 2021 period (CMM-14a-2019) further eastward along the southern SPRFMO boundary. The authorised New Zealand vessel *San Aspiring* carried out this research programme for toothfish in the SPRFMO Convention Area during 2019, 2020 and 2021.

Analyses of information collected during this research reinforced previous results showing localised but very high catch-rates of Antarctic toothfish in the southern SPRFMO Convention Area, similar in magnitude to catch rates locally observed in the north regions of Convention for the Conservation of Marine Living Resources (CCAMLR) in the Ross Sea and Amundsen Sea regions (CCAMLR Subareas 88.1 and 88.2). The toothfish catch was almost entirely Antarctic toothfish (*Dissostichus mawsoni*) although 6 Patagonian toothfish (*Dissostichus eleginoides*) were also caught. Also consistent with previous records was a high proportion of males to females in Antarctic toothfish.

Fish were in poor body condition compared to those from the more southern continental slope as assessed using both Fulton’s condition factor (CI) and a modified Fulton’s condition factor (SCF) which uses somatic weight to account for large differences in body weight due to gonad maturation over a season. Gonad maturity indices also indicate that Antarctic toothfish are generally in a pre-spawning condition during the late Austral summer sampling, and in a post-spawning condition during late winter and early spring.

The 2016 and 2017 research reported a similar result from this area and considered this to be consistent with a spawning event prior to the sampling in late winter. Body condition was slightly better in 2017, when sampling occurred about 5 weeks later in the year than in 2016. The 2020 and 2021 results indicated that while gonad development was occurring consistent with a winter spawning, Antarctic toothfish somatic condition was still poor during the pre-spawning summer sampling. The lowest values (worst body condition) occurred in 2016 when sampling was closest to the hypothesised spawning time. Antarctic toothfish body length and mass relationships indicating physical condition, sex ratio and gonad condition from this sampling match previous observations from the northern Ross Sea region in CCAMLR Subareas 88.1 and 88.2 (Fenaughty 2006, Fenaughty et al. 2008, Parker & Marriott 2012, Stevens et al. 2016, Parker et al 2014, 2019, 2020). As the southern SPRFMO area is one of the few areas accessible to fishing during the winter period, it is a unique and important source of information to improve our knowledge on Antarctic toothfish spawning.

All information collected so far indicates that Antarctic toothfish spawning extends to waters north of the SPRFMO - CCAMLR boundary at 60° S, a wider geographic area than initially hypothesised in earlier CCAMLR stock distribution studies.

Introduction

Antarctic and Patagonian toothfish (*Dissostichus mawsoni* and *Dissostichus eleginoides*) have circumpolar distributions and can move over large distances (CCAMLR Secretariat 2016). The observed distribution of Antarctic toothfish in the SPRFMO Convention Area immediately north of the CCAMLR Convention Area in Area 88 is consistent with current stock hypotheses for Antarctic toothfish (Parker et al. 2014, Hanchet et al. 2008 and 2015).

New Zealand presented a proposal to the third meeting of the SPRFMO Scientific Committee in 2015 (MPI 2015, SC03-DW-01) to undertake a 2-year exploratory fishery for Patagonian toothfish and Antarctic toothfish using the bottom longlining fishing method (autoline variant). This research was designed to cover key gaps in our knowledge of the distribution and life cycle of Antarctic toothfish in the South Pacific Ocean and in the Ross and Amundsen Seas to underpin understanding and management of those stocks. Following an assessment by the Scientific Committee this proposal was deemed acceptable under Article 22 (then CMM2.03, currently CMM 03- 2021) and the Bottom Fishery Impact Assessment Standard (BFIAS). The Compliance and Technical Committee and Commission considered the proposal in early 2016 and the Commission approved a 2-year exploratory fishery with a retained catch limit of 30 tonnes of *Dissostichus* spp. (both species combined) for each of the two years (CMM-14-2016). The initial area surveyed as shown in Figure 2, being the two red rectangles labelled Area A and Area B.

As part of this research, two exploratory fishing voyages were completed, the first in August 2016 (Fenaughty & Cryer 2016, SC-04-DW-02), the second in August/September 2017. Detailed results from both voyages were presented to SC-06 as part of the proposal for the continuation of the exploratory fishery (SC-06-DW-03-rev2). Those results indicated that catch-rates in the SPRFMO exploratory fishery were higher than those typically recorded from much of the adjoining CCAMLR Convention Area to the immediate south. Most fish caught were large Antarctic toothfish and in relatively poor body condition, with gonad states indicating a likely spawning ground in the area. Two Patagonian toothfish were caught and fish bycatch was less than 1% of the total catch by weight in both years (161 kg for both years). Invertebrate bycatch was less than 1 kg in total for both years.

In 2019, the SPRFMO Commission approved the continuation of the New Zealand exploratory fishing for toothfish under CMM-14a-2019, to commence in 2019, This exploratory fishery in SPRFMO was designed to complement earlier CCAMLR studies from 2016 and 2019 (Parker et al 2019, Parker et al. 2020) in the northern region the Amundsen Sea (CCAMLR Subarea 88.2) which lies immediately south of the SPRFMO fishing area. The 2019 to 2021 survey area is shown in Figure 2 as the blue research blocks labelled L through O. Note that the 2019 to 2021 research area encompasses the original research blocks from 2016 and 2017. This is to enable the continued chance of recovery of previously tagged Antarctic toothfish from those areas.

As part of this research, SPRFMO and CCAMLR signed an arrangement in 2019 to facilitate co-operation between the two organisations and to manage stocks and species which are within the competence and/or mutual interest of both organisations. However, from the inception of the project in 2016 the methodology and sampling requirements have been integrated and aligned with existing CCAMLR research to provide an integrated approach.

The conditions for operation of this second research approval are covered under CMM-14a-2019. Paragraph 6 of the measure states: '*The first exploratory trip each year may occur any time in 2019, 2020, and 2021, with a maximum of four trips each year, with some of the trips between August and October each year to characterise post-spawning dynamics. The remainder of the trips between March and October will provide additional information on spawning dynamics, distribution, and movement patterns.*

Review of results is covered under Paragraph 7. '*The Scientific Committee will review results each year at its annual meeting and advise the Commission on progress, including whether any stock indicators show sustainability concerns and what, if any, additional measures might be required to restrict the likely bycatch of deepwater sharks or other non-target species.'*

In 2020 we reported interim results from our 2019 and 2020 activities in this fishery (Fenaughty 2020). This 2021 report completes the analysis of the three years of the current research approval (2019-2021) for submission to Scientific Committee.

The report also provides summarises results to date to accompany a further application to continue this research (SC9-DW01).

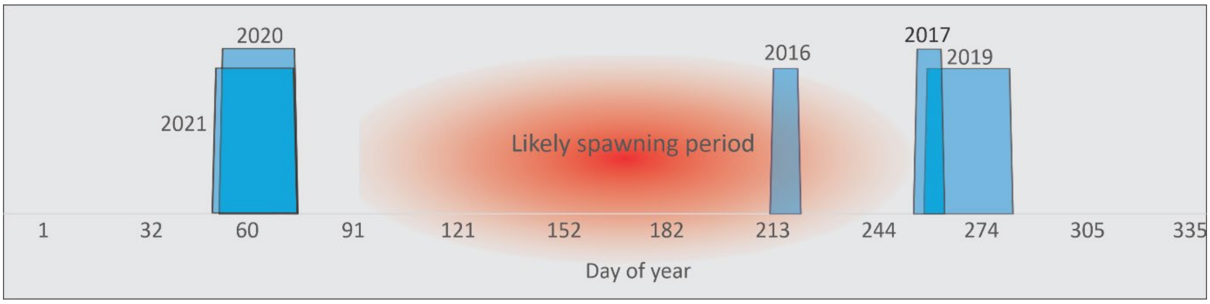

Figure 1. Annual seasonal timings of the five research periods 2016, 2017 and 2019 - 2021 referenced to the likely spawning period for Antarctic toothfish Dissostichus mawsoni. The labelled blue boxes identify the timing (day of year) for each of the five research trips made to date.

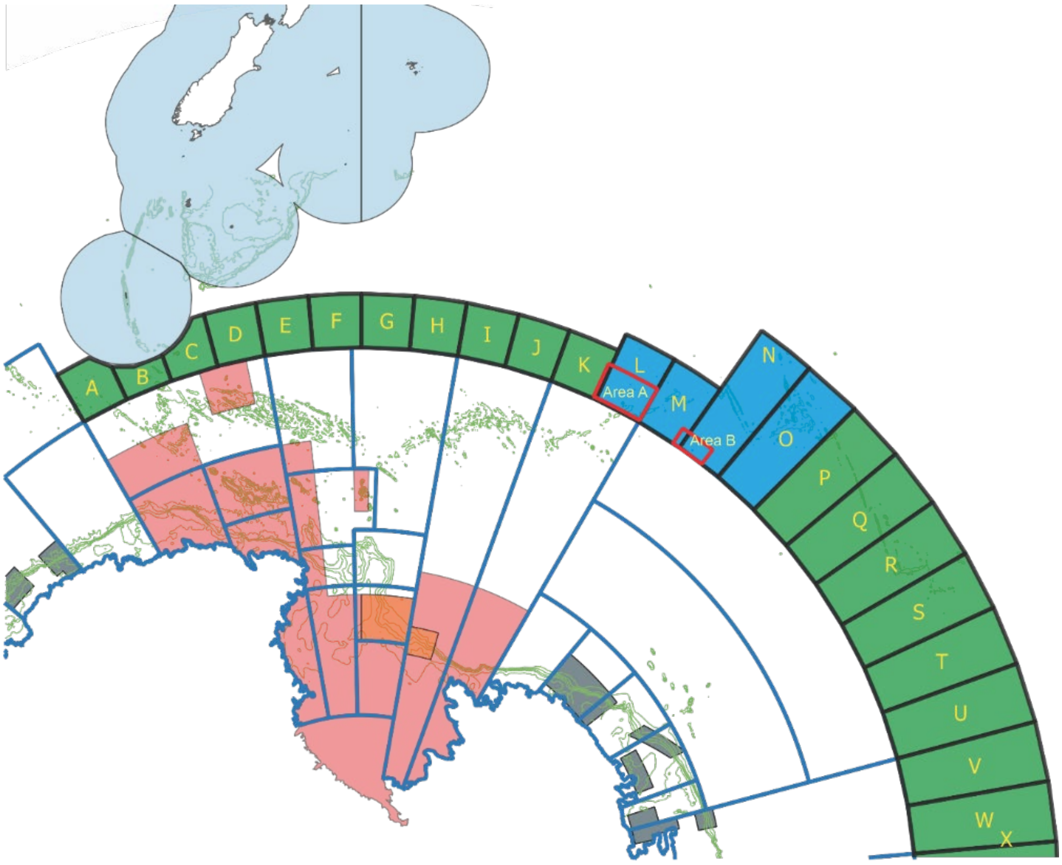

Figure 2. 2019 to 2021 research areas available for fishing coloured blue as defined by CMM-14a-2019. The red boxes (Area A and Area B) show previous research areas from 2016 and 2017.

Methods

The 2019 to 2021 SPRFMO research surveys were carried out by the authorised New Zealand vessel San *Aspiring* during the Austral spring period (September - October) of 2019 and the late summer of 2020 and 2021 (February - March). A key objective of the project is to fish (as feasible) similar locations before and after the assumed spawning period to explore spatial seasonal trends (Figure 1). The figure includes the previous 2016 and 2017 research periods for complete context.

The approved research design (CMM-14a-2019) for this three years' research, restricted sampling to four fishing Blocks close to the southern border of the SPRFMO Convention Area, shown in blue in Figure 2. The vessel uses the bottom longline method employing an autoline system with integrated-weight line to minimise seabird interactions with fishing gear. This is the identical fishing gear configuration is used for fishing operations and research fishing within CCAMLR enabling direct comparability with CCAMLR research. Fenaughty 2008 provides more detail on the fishing method used.

Biological data were collected from *Dissostichus* spp. and bycatch species from each set. Antarctic toothfish were sampled for length, weight, sex, gonad stage and gonad weight (Table 1). Stomachs were examined to provide information on feeding and otoliths were subsampled from each line. The five Patagonian toothfish brought aboard were also sampled for full biological data and otoliths. Biological data were collected from some key bycatch species. As toothfish ageing is a priority focus, bycatch species were not sampled for otoliths. One Patagonian toothfish was tagged and released in 2021.

Table 1. Biological measurements recorded for 2019 to 2021 research.

Fishing season	Common name	Species name	Species Code	Total Length	Snout-Anus Length	Standard Length (cm)	Weight (kg)	Sex	Stage	Gonad Weight (g)	Otolith(s) collected	Stomach fullness
2019	Abyssal grenadier	*Coryphaenoides armatus*	CKH	2	2	2	2	2	0	0	0	2
	Antarctic Toothfish	*Dissostichus mawsoni*	TOA	473	0	473	473	473	473	473	122	473
	Bigeye grenadier	*Macrourus holotrachys*	MCH	217	218	218	218	218	209	0	218	218
	Caml genadier	*Macrourus caml*	QMC	134	135	135	135	135	135	0	135	135
	Lantern sharks	*Etmopterus spp*	SHL	43	0	43	43	43	0	0	43	43
	Patagonian Toothfish	Dissostichus eleginoides	TOP	3	0	3	3	3	2	2	2	3
	Rattail	*Macrourus carinatus*	MCC	1	1	1	1	1	1	0	1	1
	Rattail	*Macrourus whitsoni*	WGR	21	21	21	21	21	21	0	21	21

	Sharks, skates and rays	*Elasmobranchii*	SKX	3	0	3	3	3	0	0	3	3
2019 Totals				**897**	**377**	**899**	**899**	**899**	**841**	**475**	**899**	**899**
2020	Abyssal grenadier	*Coryphaenoides armatus*	CKH	4	4	4	4	4	4	0	4	4
	Antarctic Toothfish	*Dissostichus mawsoni*	TOA	510	1	510	509	510	510	510	218	510
	Bigeye grenadier	*Macrourus holotrachys*	MCH	193	193	193	193	193	193	0	193	193
	Caml genadier	*Macrourus caml*	QMC	104	104	104	104	104	104	0	104	104
	Lantern sharks	*Etmopterus spp*	SHL	72	72	72	0	72	0	0	72	72
	Patagonian Toothfish	*Dissostichus eleginoides*	TOP	1	1	1	0	1	1	1	1	1
	Rattail	*Macrourus carinatus*	MCC	4	4	4	4	4	4	0	4	4
	Rattail	*Macrourus whitsoni*	WGR	43	43	43	43	43	43	0	43	43
	Unidentified bony fish	*Osteichthyes spp*	MZZ	7	7	7	0	7	6	0	7	7
2020 Totals				**938**	**429**	**938**	**857**	**938**	**865**	**511**	**938**	**938**
2021	Abyssal grenadier	*Coryphaenoides armatus*	CKH	2	2	0	2	1	1	0	2	0
	Antarctic Toothfish	*Dissostichus mawsoni*	TOA	158	0	158	158	158	158	99	57	158
	Bigeye grenadier	*Macrourus holotrachys*	MCH	14	14	0	14	14	14	0	14	0
	Caml genadier	*Macrourus caml*	QMC	33	33	0	33	32	31	0	33	0
	Deep-water catsharks	*Apristurus spp*	API	3	0	0	3	3	3	0	3	0
	Lantern sharks	*Etmopterus spp*	SHL	64	0	0	64	64	64	0	64	0
	Lepidion codlings	*Lepidion spp*	LEV	1	0	0	1	0	0	0	1	0
	Patagonian Toothfish	*Dissostichus eleginoides*	TOP	1	0	1	1	1	1	1	1	1
	Rattail	*Macrourus carinatus*	MCC	69	69	0	69	68	68	0	69	0
	Rattail	*Macrourus whitsoni*	WGR	36	36	0	36	36	36	0	36	0
2021 Totals				**381**	**154**	**159**	**381**	**377**	**376**	**100**	**381**	**159**

Results

Toothfish catch

Table 2 summarises the timing and effort of research sets made in three Research Blocks[2] (L, N, and O) surveyed during the 2019 to 2021 period. Overall, a total of 100 sets were made during the three years for a total catch of Antarctic toothfish of 101.5 tonnes. The average soak-time (the duration over which the baited hooks were allowed to passively fish) was 11.3 hours which is broadly consistent with CCAMLR toothfish research projects such as the New Zealand winter toothfish research and the annual shelf (pre-recruit) surveys.

Table 2. Station summary for the 2019 to 2021 toothfish research. There were 35 sets made in 2019, 32 sets in 2020 and 33 in 2021. Start and end dates referred to the beginning and end of all recorded fishing operations. TOA is the FAO/CCAMLR code for Antarctic toothfish. Catch rates are shown both in kg (retained) per 1000 hooks recovered and in numbers of TOA per 1000 hooks recovered to account for toothfish released with tags.

Fishing Year	Fishing Block	Number of sets	Start date	End date	TOA catch	No of fish	Number of hooks set	Average Soak Time	TOA Catch rate (weight)	TOA Catch rate (number)	Mean TOA fish weight
2019	L	10	7/10/2019	11/10/2019	452.58	14	31709	12.24	13.2	0.4	34.81
	N	12	25/09/2019	5/10/2019	36048.77	1265	41803	12.29	1209.6	42.7	31.29
	O	13	16/09/2019	23/09/2019	0	0	50617	11.69	0	0	0
2020	L	10	23/02/2020	27/02/2020	2978.34	115	29138	12.30	86.9	3.4	29.20
	N	12	28/02/2020	7/03/2020	37980.93	1399	42421	12.65	951.4	35.0	29.81
	O	10	11/03/2020	15/03/2020	0	0	26567	11.56	0	0	0
2021	L	10	24/02/2021	5/03/2021	484.23	17	36851	10.06	8	0.3	28.48
	N	11	1/03/2021	9/03/2021	23598.22	824	36148	9.06	733.3	27.7	28.64
	O	12	11/03/2021	16/03/2021	0	0	33423	10.02	0	0	0

Bycatch

Bycatch (Table 3) was about 7.8% of the total catch by weight in 2019, 4.2 % in 2020 and 5.9% in 2021. The increase in the proportion of bycatch from a very low level recorded in 2016 and 2017 is largely attributable to a much wider survey area during the 2019 to 2021 periods, reflecting many more sets made in areas where toothfish were not located (but other species caught). The depth range fished was also increased to extend the survey deeper. Typically bycatch levels for all non-target species combined in the CCAMLR target fishery immediately south are about 5% of the overall catch.

Non-toothfish bycatch comprised mostly Macrourids (grenadiers or rattails). Macrourids are generally recorded under a collective category by the vessel for reporting, however these were further identified by the scientific observers as Caml rattail, Whitson's grenadier, bigeye grenadier, ridge scaled rattail and cosmopolitan rattail. In 2019, bigeye grenadier was found to dominate the

[2] To date no fishable ground has been located in Research Block M.

species group north of 57°S latitude, while Caml grenadier and Whitson's grenadier were mainly found south of 56°S latitude. Two cosmopolitan rattails and one ridge scaled rattail were caught In Fishing Block O.

Other main bycatch taxa included moray cods (*Muraenolepididae*), blue antimora, and Lepidions. Six Patagonian toothfish were taken over the three years although one was tagged and released. All *Etmopterus* were identified by observers in 2020 as blue-eyed lantern shark *Etmopterus viator* see Figure 3.

Table 3. Catch and proportions by species for the 2019 to 2021 research sets. Data are from the vessel reported catches.

Common name	**Species name**	**2019**		**2020**		**2021**		**Total 2019-2021 catch**	
		Total weight	% 2019 season catch	Total weight	% 2020 season catch	Total weight	% 2021 season catch		% 2019 - 2021 season catch
Antarctic Toothfish	*Dissostichus mawsoni*	36501.35	91.97%	40946.48	95.65%	24082.45	94.32%	101530.28	93.98%
Rattails, Grenadiers	*Macrourus spp*	1244.19	3.13%	939.42	2.19%	549.11	2.15%	2732.72	2.53%
Blue Antimora	*Antomora rostrata*	1284.1	3.24%	386.85	0.90%	375.79	1.47%	2046.74	1.89%
Lepidion codlings	*Lepidion spp*	553.5	1.39%	400.5	0.94%	456.33	1.79%	1410.33	1.31%
Patagonian Toothfish	*Dissostichus eleginoides*	80.12	0.20%	65.44	0.15%	22.24	0.09%	167.8	0.16%
Lantern sharks	*Etmopterus spp*	16.68	0.04%	34	0.08%	37.35	0.15%	88.03	0.08%
Moray Cods	*Muraenolepis spp*			20.25	0.05%	3.34	0.01%	23.59	0.02%
Cusk-eels, brotulas	*Ophidiidae*	2.93	0.01%	15.7	0.04%			18.63	0.02%
Deep-water catsharks	*Apristurus spp*	2.71	0.01%			3.36	0.01%	6.07	0.01%
Slickheads	*Alepocephalus spp*	1	<0.01%			1.14	<0.01%	2.14	<0.01%
Cutthroat eels	*Synaphobranchidae*	0.6	<0.01%	0.8	<0.01%			1.4	<0.01%
Sea cucumber	*Holothuria spp*			0.4	<0.01%	0.94	<0.01%	1.34	<0.01%
Starfish	*Asteroidea*					0.72	<0.01%	0.72	<0.01%
Crab spp.	*Lithodidae*					0.5	<0.01%	0.5	<0.01%
Pearleyes	*Benthalbella elongata*					0.31	<0.01%	0.31	<0.01%
Lumpfishes and snailfishes	*Cyclopteridae*					0.12	<0.01%	0.12	<0.01%
TOTAL		39687.18		42809.84		25533.7		108030.72	

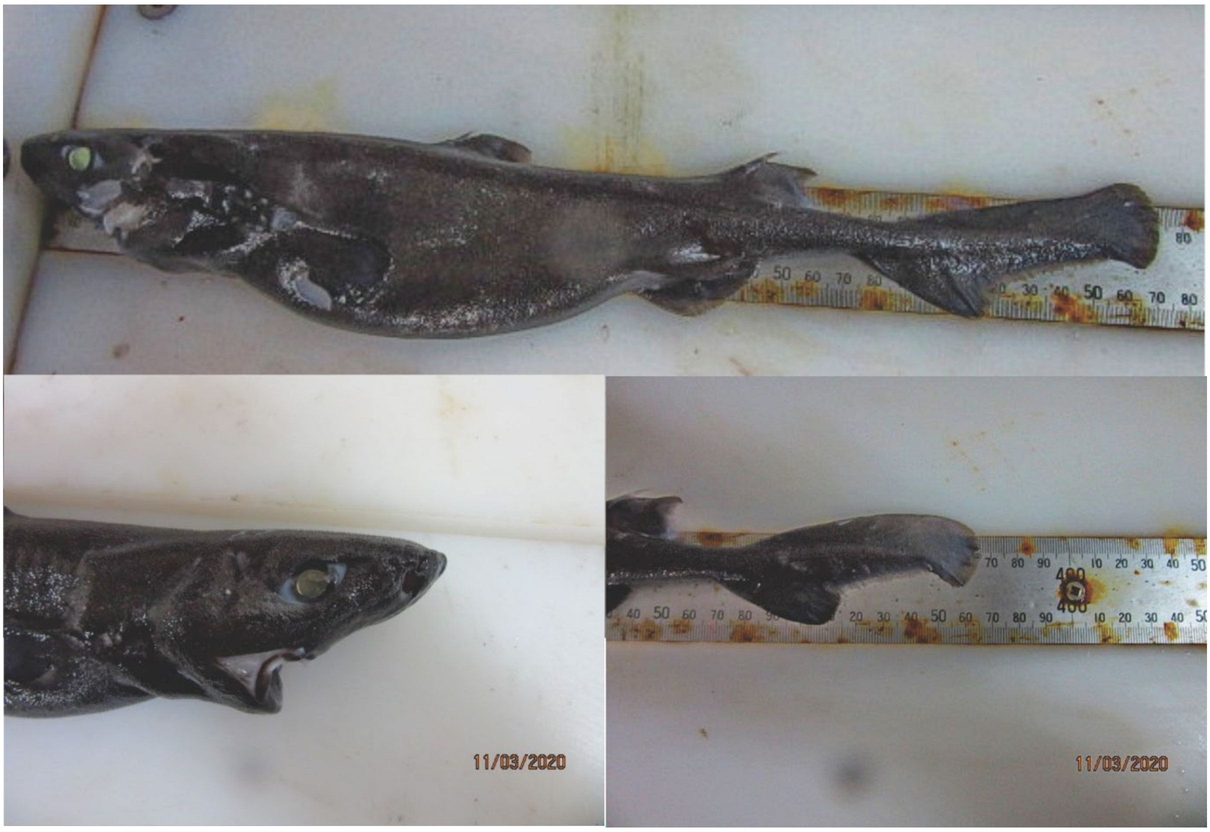

Figure 3. The most common small shark caught during the three years of the survey - tentatively identified as E. viator.

Figure 4 shows the relationship between average depth of fishing (equivalent to bottom depth) and catch for the 2019 to 2021 research. The number of zero values in bottom plot in the figure highlights a relatively high proportion of lines with no toothfish caught.

As the total catch of Antarctic toothfish by set varied greatly (22 to 16,400 kg) the upper plot showing the observed catch weight by mean depth is plotted on a logarithmic scale for precision (with zero values ignored). The lower plot by numbers of toothfish shows the zero values for all lines and thus shows the range of depths sampled during the 2019 to 2021 years.

This research was intentionally designed to spread effort widely through the research area fishing in a range of depths (as deep as 2027 m. in 2019). The highly variable catch rates of toothfish reflect the exploratory nature of this project as the region is almost totally unexplored - there is no previous fishing information or accurate bathymetry available. This effect is also reflected in the generally higher bycatch levels seen in Table 3 when compared with the CCAMLR target fishery immediately south in which bycatch is typically about 5% of the overall catch.

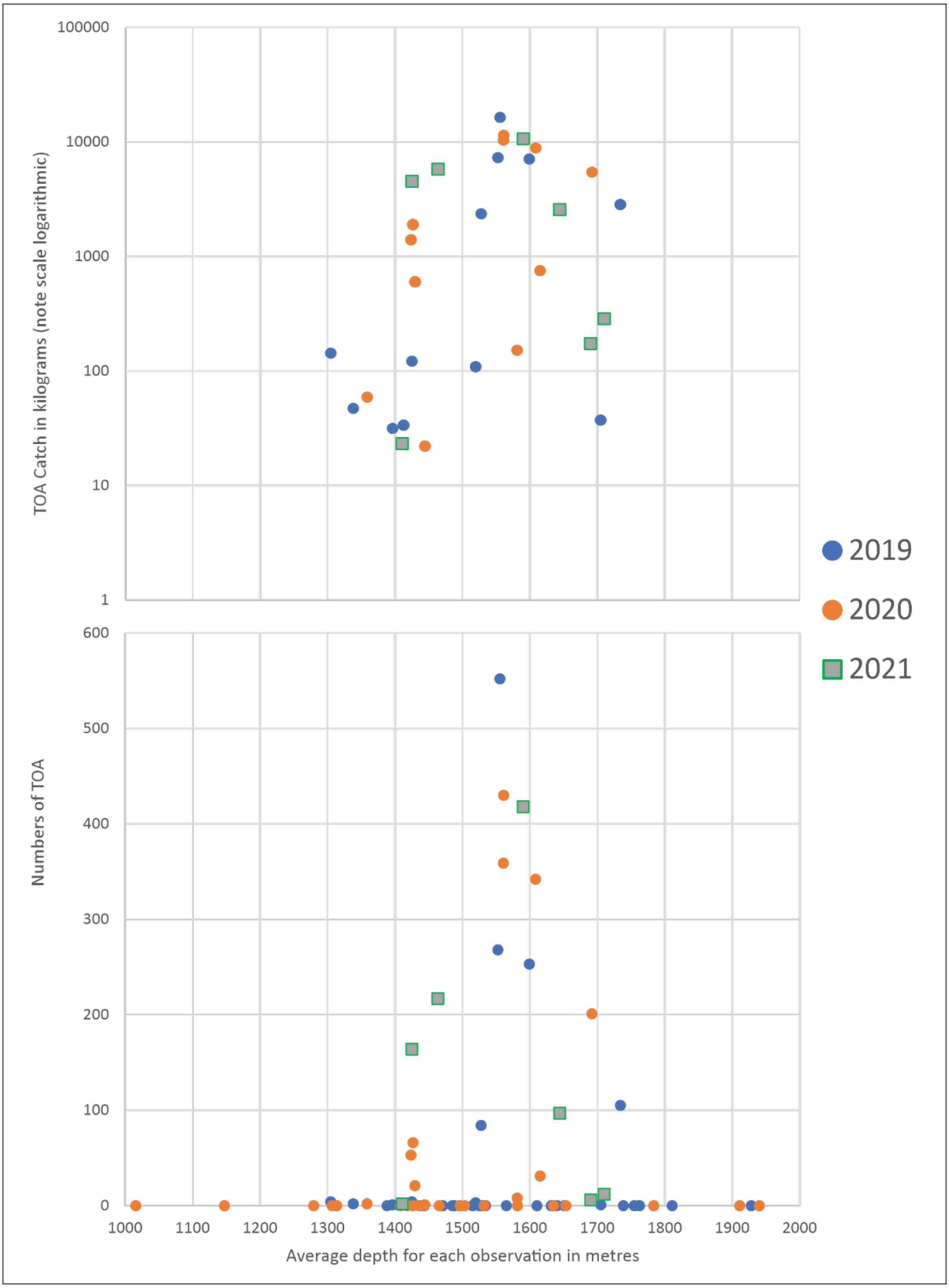

Figure 4. Retained catch (kg) per set of Antarctic toothfish (top) and numbers of Antarctic toothfish caught including tagged and released fish (bottom) in relation to the average recorded fishing depth for each observation during New Zealand's exploratory fishing in the SPRFMO Area in 2019 to 2021. Note the y-axis on the top plot is logarithmic.

Toothfish biology

Antarctic toothfish total lengths ranged from 108 -190 cm over the three years of the research (Figure 5).

Only about 1.2% of the catch-weighted samples (and raw data) for all three years were fish shorter than 120 cm total length indicating a population of almost entirely reproductively mature adult toothfish. Reinforcing previous data from 2016 and 2017 research, the length distribution of males during 2019 to 2021 was slightly smaller than females which is also consistent with records from the northern areas of Area 88 to the south-west and south. The sex ratio was skewed to males at 60.3% in 2019, 64.2% in 2020 and 62.7% in 2021 of the catch-weighted sample. This also reflects results from previous analyses from this area in 2016 and 2017, observations from the northern hills area of CCAMLR Subarea 88.1, and CCAMLR winter survey results.

Figure 5 shows the scaled length distribution (numbers weighted by the overall number of fish caught for each line) information collected from the *San Aspiring* research within SPRFMO during 2019 to 2021. Figure 6 shows the same data presented as a line plot[3] for increased ease of comparison. While the number of length observations collected are relatively low (a function of the highly variable catch rates resulting from the exploratory nature of the research), the length distribution between the three seasons is very similar.

The 2020 and 2021 samples were collected in the late austral summer (March) and likely reflect a pre-spawning population compared with the 2019 sample taken from late spring (September - October); a post spawning population. Despite the differences in timing, the relative size range, overall sex ratio and general length distributions are very similar (Figure 7) over all three years.

[3] Two-value running average trendline

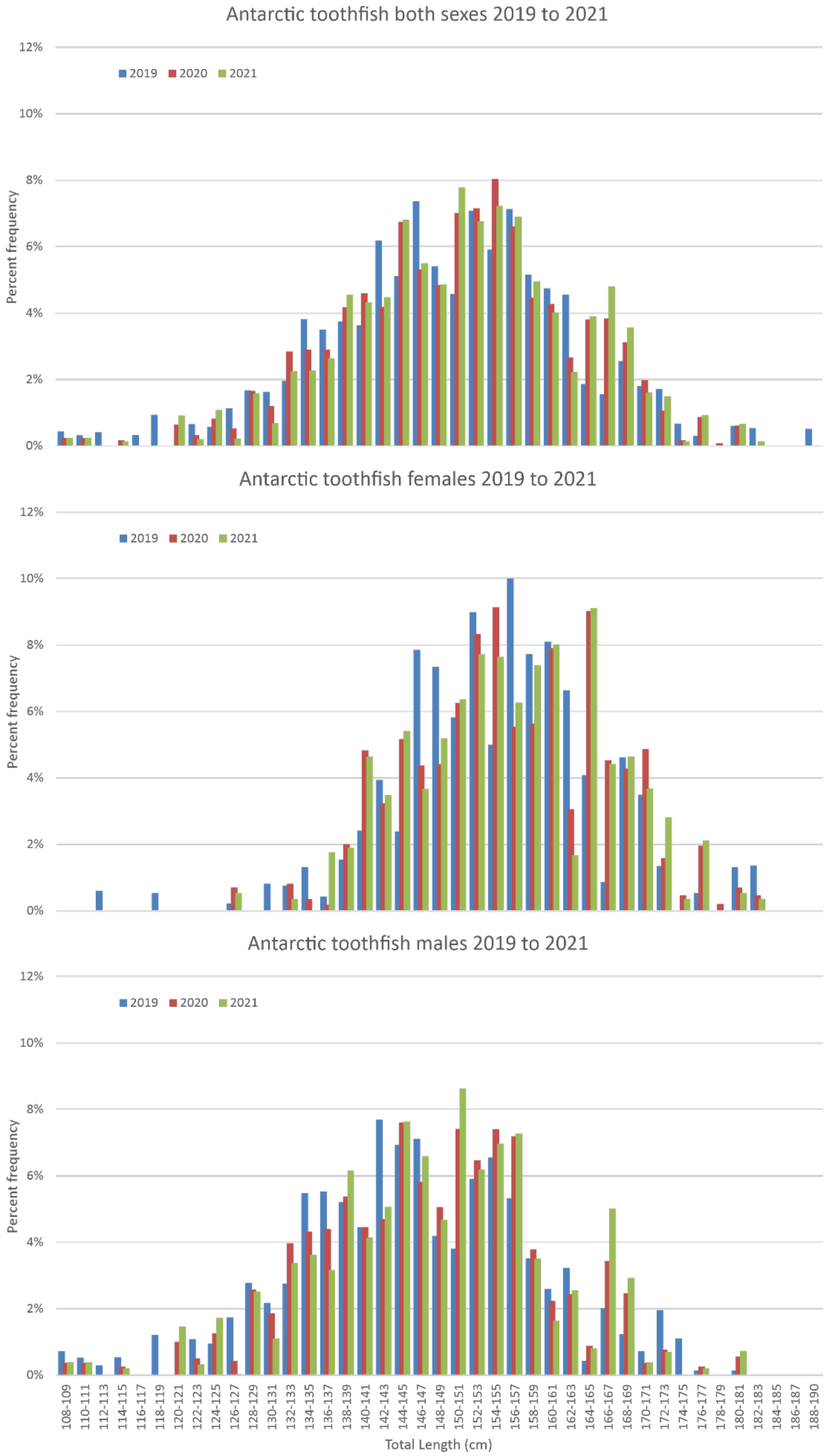

Figure 5. Antarctic toothfish (Dissostichus mawsoni) length frequency by sex and sexes combined for 2019 to 2021 research. Scaled to total catch numbers. The total scaled sample is 1279 fish for 2019, 1513 fish in 2020 and 917 fish in 2021.

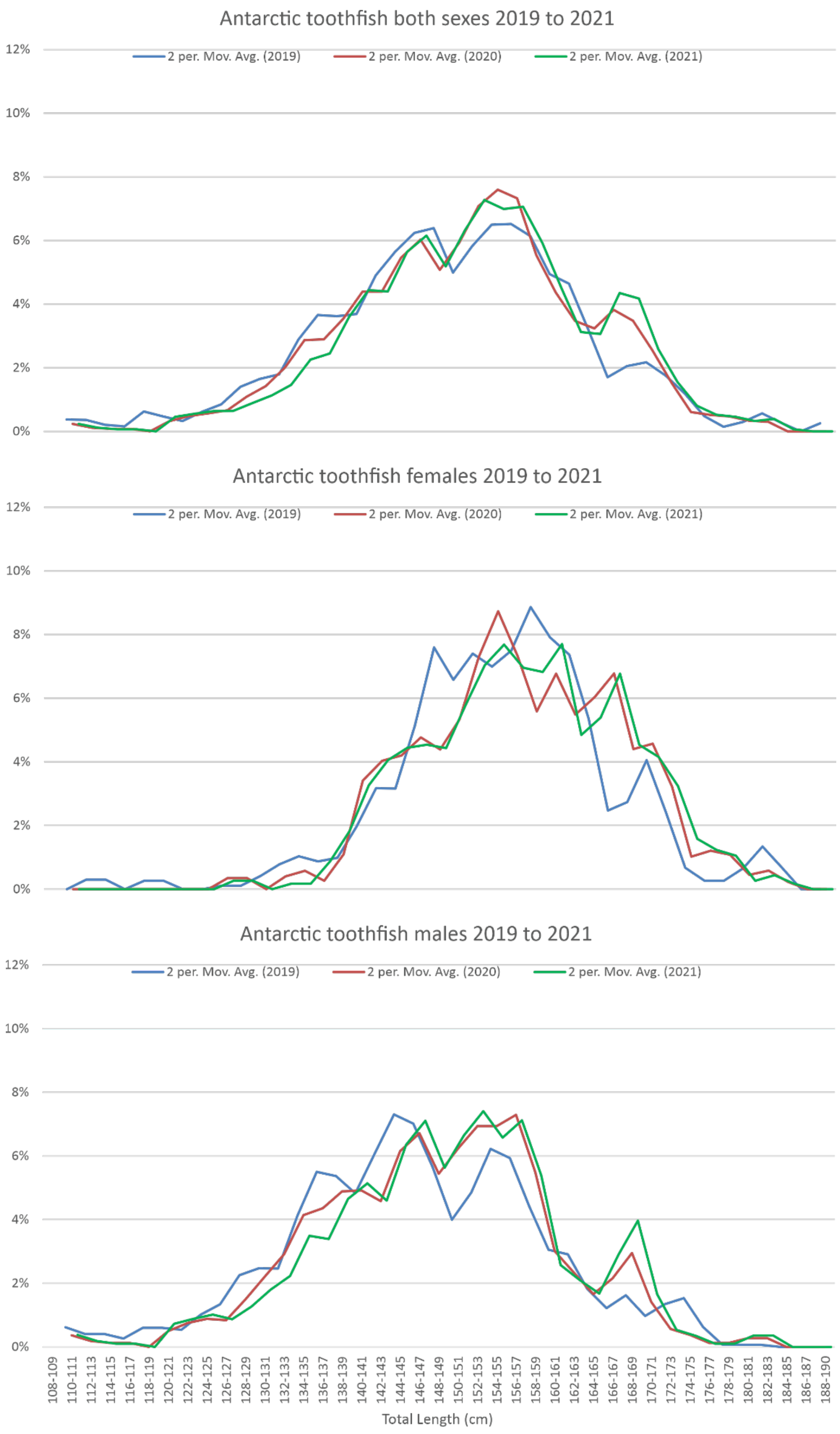

Figure 6. Antarctic toothfish (Dissostichus mawsoni) length frequency by sex and sexes combined for 2019 to 2021 research shown as a moving average of each two values for clarity. Scaled to total catch numbers. The total scaled sample is 1279 fish for 2019, 1513 fish in 2020 and 917 fish in 2021.

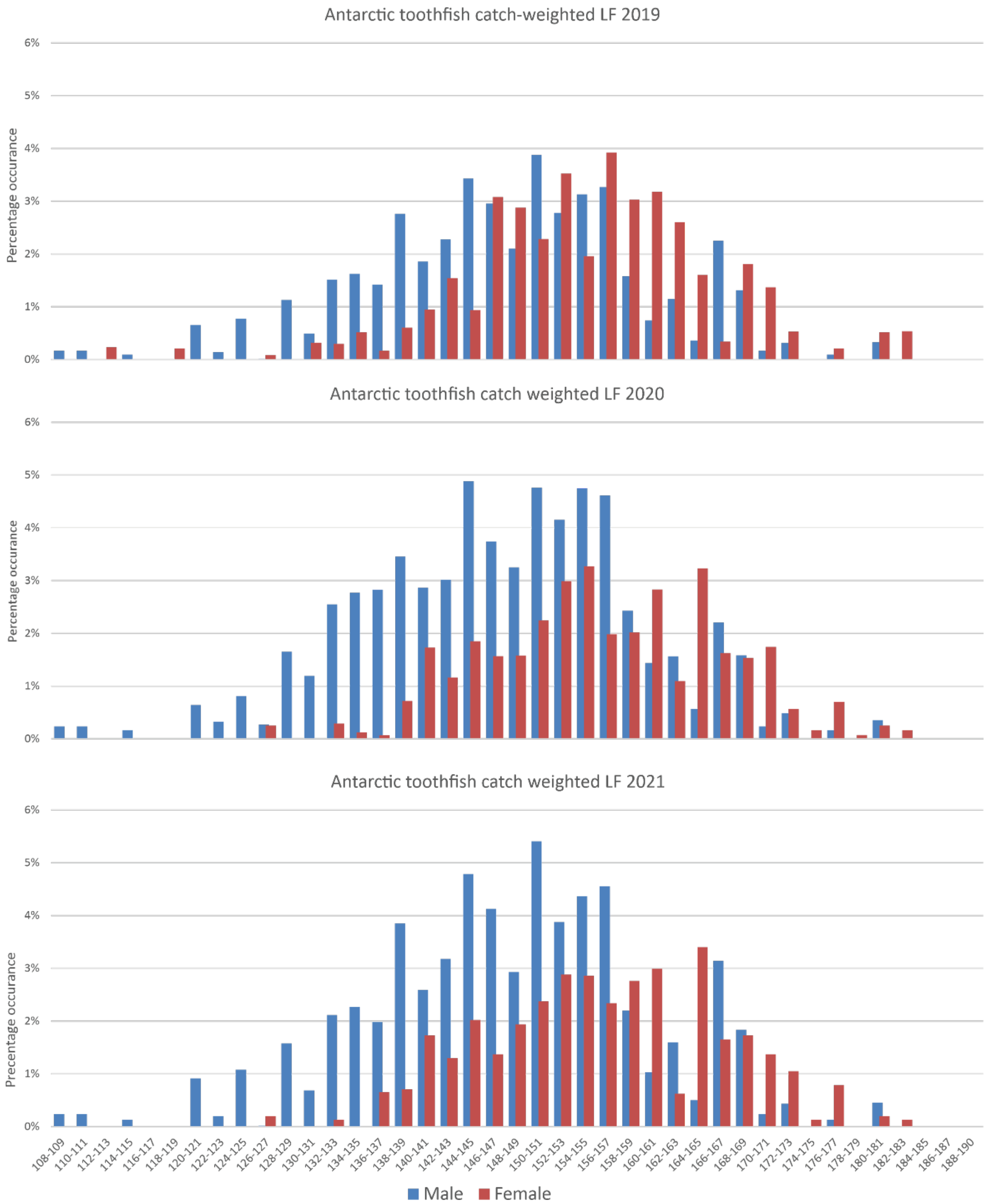

Figure 7. Antarctic toothfish Dissostichus mawsoni scaled length frequency by sex for 2019 to 2021 research. Proportions are of the total sample of both sexes. The total scaled sample is 1279 fish for 2019, 1513 fish in 2020 and 917 fish in 2021.

Gonad developmental stage (GMI) records for Antarctic toothfish are routinely collected by observers as part of the sampling protocol. Staging criteria and numbers by year are shown in detail in Appendix 1. These generally indicate that Antarctic toothfish were mostly in a post spawning state during the 2019 sampling in September - October but developing toward spawning during the

February - March sampling period in 2020 and 2021. GMI is regarded as a less precise measure of reproductive maturity as the measure is subjective and prone to variation in individual interpretations (Williams, 2007). In addition, some reproductive stages cannot be reliably identified by macroscopic methods (Hunter and Macewicz, 2001). It is difficult to macroscopically distinguish between stage 5 (spent) and stage 2 (recovering/resting) except immediately before and after the peak spawning.

The Gonadosomatic Index (GSI) represents the gonad mass as a proportion of the total somatic body mass. When analysed by season GSI provides an additional and more objective metric to measure spawning status - a more robust and reliable indicator of reproductive status.

Figure 9 shows the calculated GSI by season and sex plotting the median, interquartile range, and the range of values recorded for each year-sex combination, providing additional evidence that males and females caught during the 2020 and 2021 February-March period are in a phase of reproductive development progressing toward spawning with the ratio of reproductive tissue increasing as a proportion of body mass; this in contrast to the 2019 data from September-October showing mainly a decrease in proportion of reproductive tissue to somatic body mass.

However, when both GSI and GMI measurements are available, both metrics can also be combined effectively in the manner as shown in Figure 8 to further describe the reproductive state. Zero values calculated for GSI (resulting from a null measurement for gonad weight) are not included. Despite the potential for subjective differences in observer interpretation of staging, the trend shown still clearly indicates more post spawning stages during the 2019 sampling and more developing stages during 2020 and 2021.

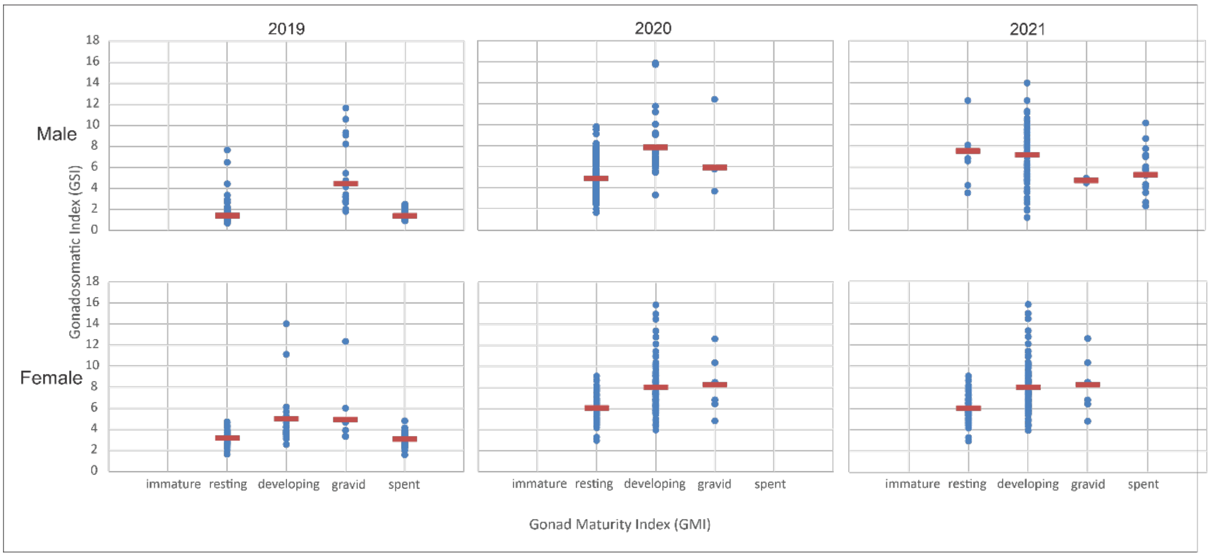

Figure 8. GSI plotted by sex and fishing year. Red bars indicate the mean value of GSI grouped by the observer's recorded gonad maturity index. See Appendix 1 for gonad staging detail.

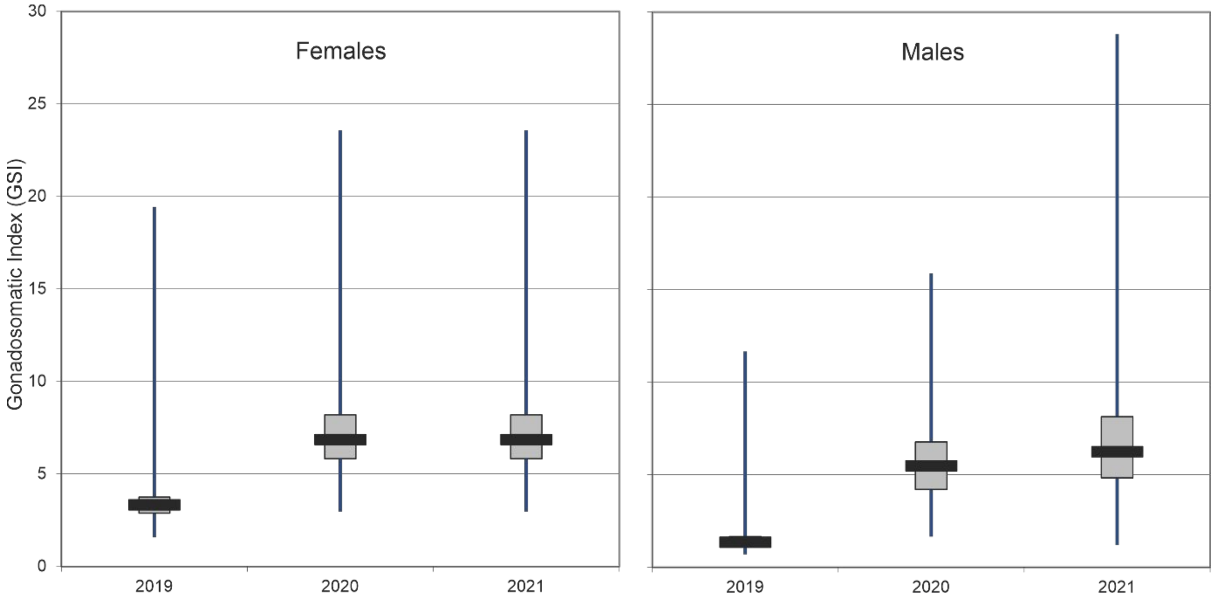

Figure 9. Gonadosomatic indices plotted by season and sex. The black bar in each plot shows the median of these values, the grey boxes show the interquartile range, and the whiskers show the range of values recorded for each year-sex combination.

In summary the 2020 and 2021 data indicate a population generally in a phase of reproductive development consistent with during a pre-spawning phase and the 2019 data represent late spawning to post spawning fish with a spawning period likely between June and August (see Figure 1).

The relative body condition ('fatness') of a toothfish also appears to be correlated with spawning and reproduction and is an additional indicator available for analysis. Fulton's condition factor or Condition Index (CI) is often used to define general fish body condition. This is traditionally based on the relationship between the fish length and body weight for fish species that that grow isometrically, of which the toothfish species are a good example. The CI for Antarctic toothfish has been calculated and shown in Figure 10. As toothfish species have both a large egg size and massive gonad mass, fish condition can be biased by including the gonads in the calculation. For this reason, a modified somatic condition factor (SCF) was also calculated by subtracting the recorded gonad weight from each fish to better approximate the somatic weight[4]. This is premised on the recorded data from the Antarctic toothfish biological record within SPRFMO showing very few sampled fish with any stomach contents that could further bias the analysis and assumes that liver mass remains relatively constant and is a minor contributor to overall body mass. These data are summarised in the bottom panels of Figure 10 and indicate that the pre-spawning fish in 2020 and 2021 have a lower (worse) body condition measured through (SCF), but almost identical condition (measured through CI) than the post-spawning fish from 2019. This was particularly evident for the male fish in 2021.

This lower condition of Antarctic toothfish seen in the SPRFMO area over all five seasons fished generally reflects the 'poor' condition of spawning Antarctic toothfish typically seen in other areas

[4] SCF Somatic body mass here is calculated as the recorded fish weight less the weight of the gonads. Toothfish in general have large gonads at spawning – in females this can be up to 25% of body mass. For this reason, to remove any bias caused by gonad development over a season in this calculation, a separate analysis based on the somatic body weight (i.e. the body weight less weight of reproductive tissue) is used.

such as the northern Ross Sea 'hills' and the South Sandwich Islands (CCAMLR Subarea 48.4). In those other areas we have established a loose inverse relationship between gonad maturity and condition factor. In the Ross Sea this is postulated to be an effect caused by a migration of well-conditioned mature fish that had been feeding in the southern slope area moving northward into an area of low food abundance for spawning (Fenaughty 2006 and Fenaughty et al 2008).

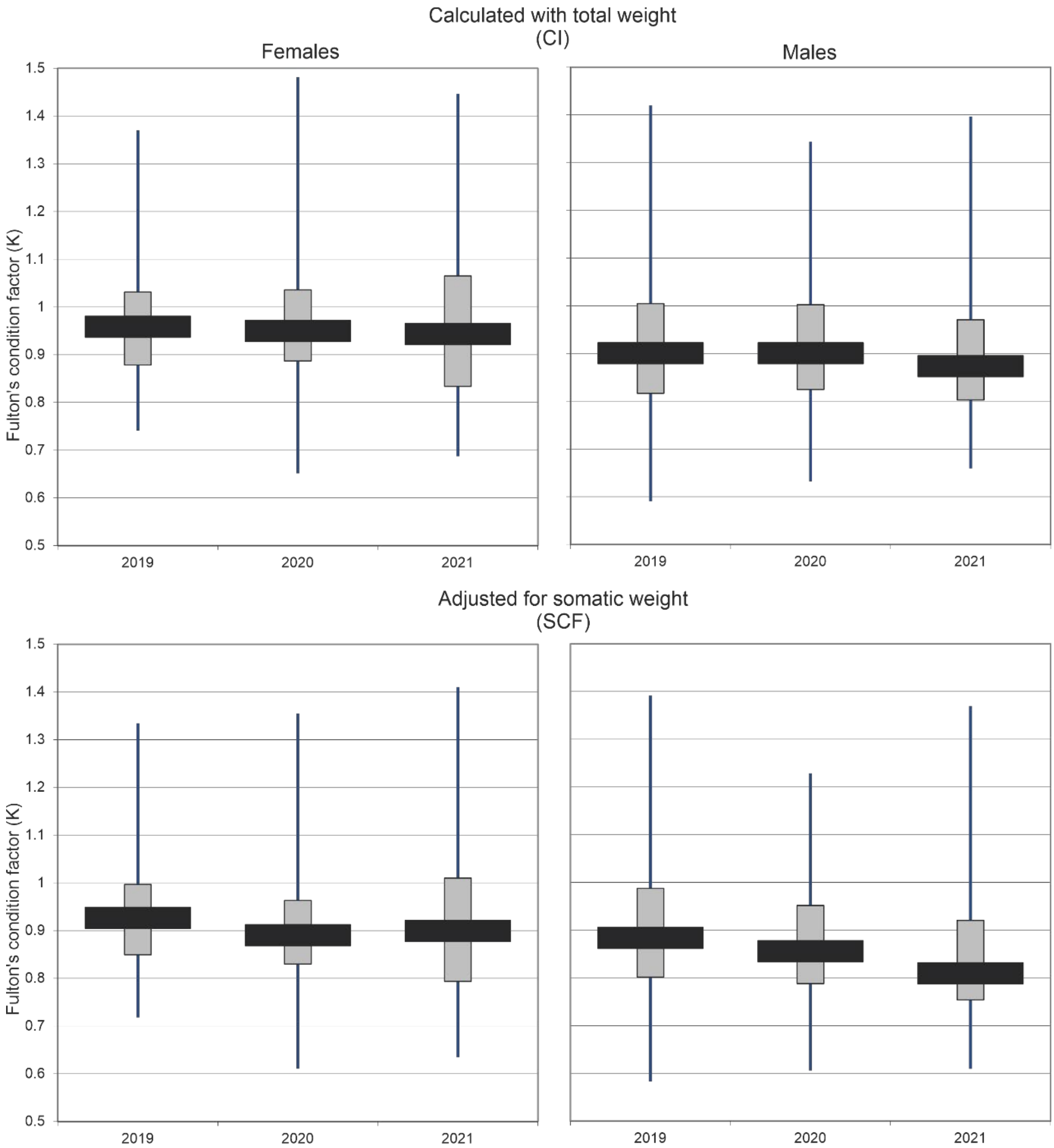

Figure 10. Fulton's condition factor plotted by sampling year and by sex. The black bar in each plot shows the median of these values, the grey boxes show the interquartile range, and the whiskers show the range of values recorded for each year-sex combination.

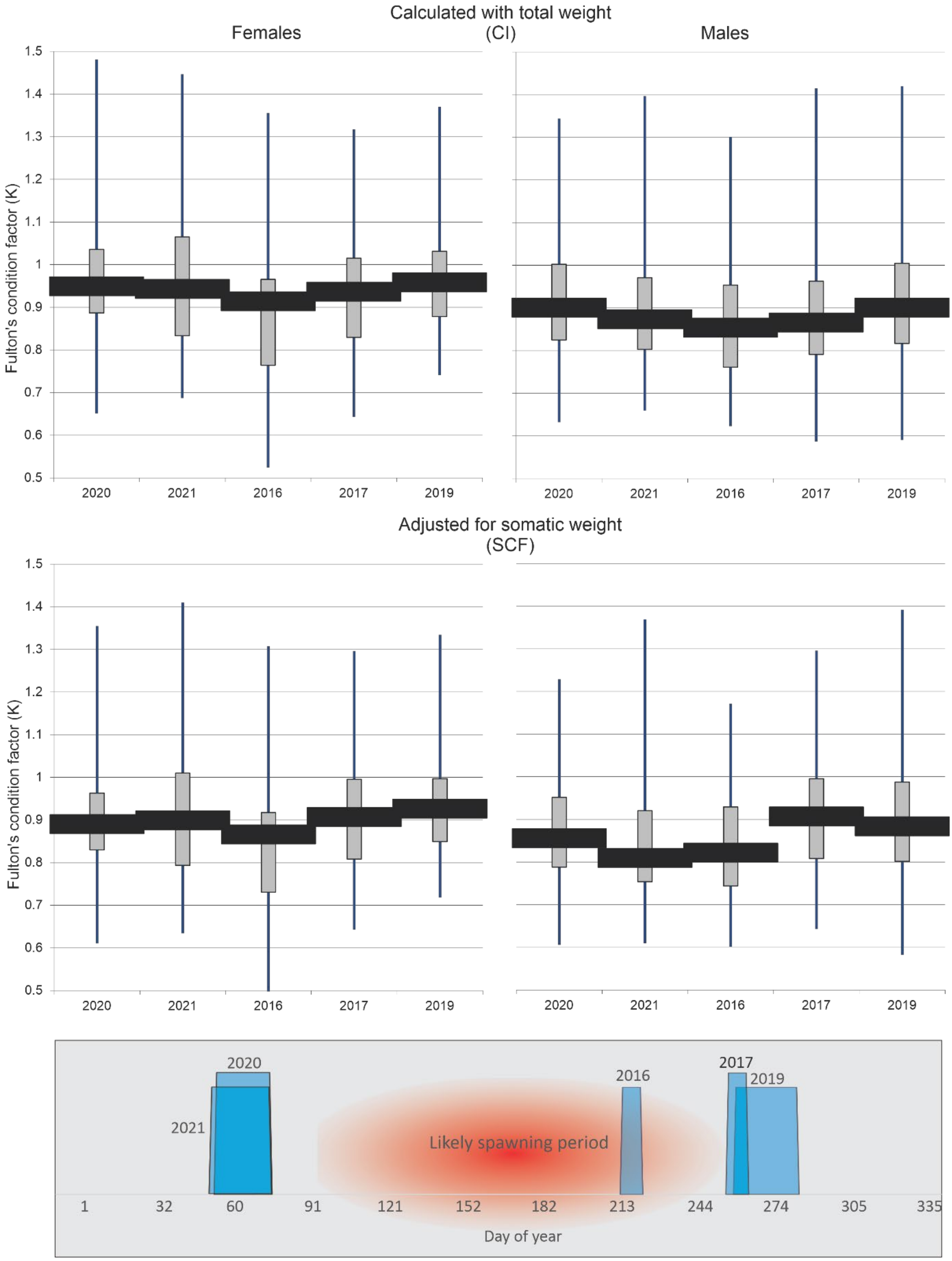

Figure 11. Fulton's condition factor plotted by sampling year and by sex including the previous 2016 and 2017 survey data. The years of sampling are placed on the x-axis in general order of sampling time over a standard year to better show the changes with the hypothesised peak winter spawning period. To assist, figure 1 is reproduced in the lower section of the plot to show the sampling date ranges for each of the five sampling periods. The black bar in each plot shows the median of these values, the grey boxes show the interquartile range, and the whiskers show the range of values recorded for each year-sex combination.

To provide additional context, Figure 11 shows the previous 2016 and 2017 data plotted alongside the 2019 - 2021 data (as shown in Figure 10) but with the five years of data loosely arranged by the sampling time of year. Generally, the 2016 data which are closest to the hypothesised winter spawning period show the lowest values. The male condition adjusted to somatic weight for 2017 is an outlier and appears to be a result of higher overall male gonad weights recorded in this season – an area for future investigation.

This result is also consistent with results from the 2016 and 2019 CCAMLR winter survey conducted further south of the SPRFMO research area in the CCAMLR convention area. From the 2016 winter survey, the sex-specific fish condition factor for males was 5% lower than that observed in the summer fishery in SSRUs 881B–C, although females showed the same median value as in the summer fishery (Stevens et al 2016). Parker et al (2020) reported that sex-specific condition factors from the 2019 survey were lower than those observed in the summer or pre-spawning winter periods, and much lower than those observed on the Ross Sea slope during the summer fishery.

Length-weight relationships by sex for the 2019 to 2021 research can also be used to show relative body condition for each sex, Figure 12.

The trendlines from this figure are subsequently incorporated into Figure 13 which additionally provides a comparison of length-weight regression trendlines from other research sampling by Sanford vessels from CCAMLR subarea 88.1[5], where much of the previous research on spawning fish has been carried out. While not shown here, Fenaughty et al. (2018, figure 7) also showed that pre-spawning Antarctic toothfish sampled from the South Sandwich Islands show a similar (and consistent) trend over time to that seen in the northern area of Subarea 88.1. The 2016-17 records from SPRFMO research had previously indicated that Antarctic toothfish sampled during the post-spawning period were in poorer condition than seen in either 88.1 north or in the South Sandwich Islands pre-spawning sample and are a close match with the 2019-2021 results. The length-weight regression coefficients used to produce these plots are summarised in Table 4.

In particular, the trendline from the southern area of 88.1 (labelled 88.1 south in Figure 12) provides a good basis to compare a ‘spawning’ ground with a ‘feeding’ ground. 88.1 south is a slope area supporting a large population of mostly mature Antarctic toothfish, feeding in an area of relatively high productivity/prey density. This population is thought to be feeding and enhancing body condition in preparation for spawning. The better fish condition of these fish is clear; a fish of a given length in the south of 88.1 is proportionally heavier than one of the same length in the spawning areas. Clearly fish sampled from this SPRFMO area (both pre-spawning and post-spawning) are in an even poorer condition than those seen in other spawning fisheries such as the north of 88.1 (and although not shown here, from the South Sandwich Islands fishery in CCAMLR Subarea 48.4). A similar very low condition factor was also observed by Parker et al. (2020) during the 2019 winter survey in CCAMLR to the south.

[5] CCAMLR subarea 88.1, data as used by Fenaughty et al. 2008.

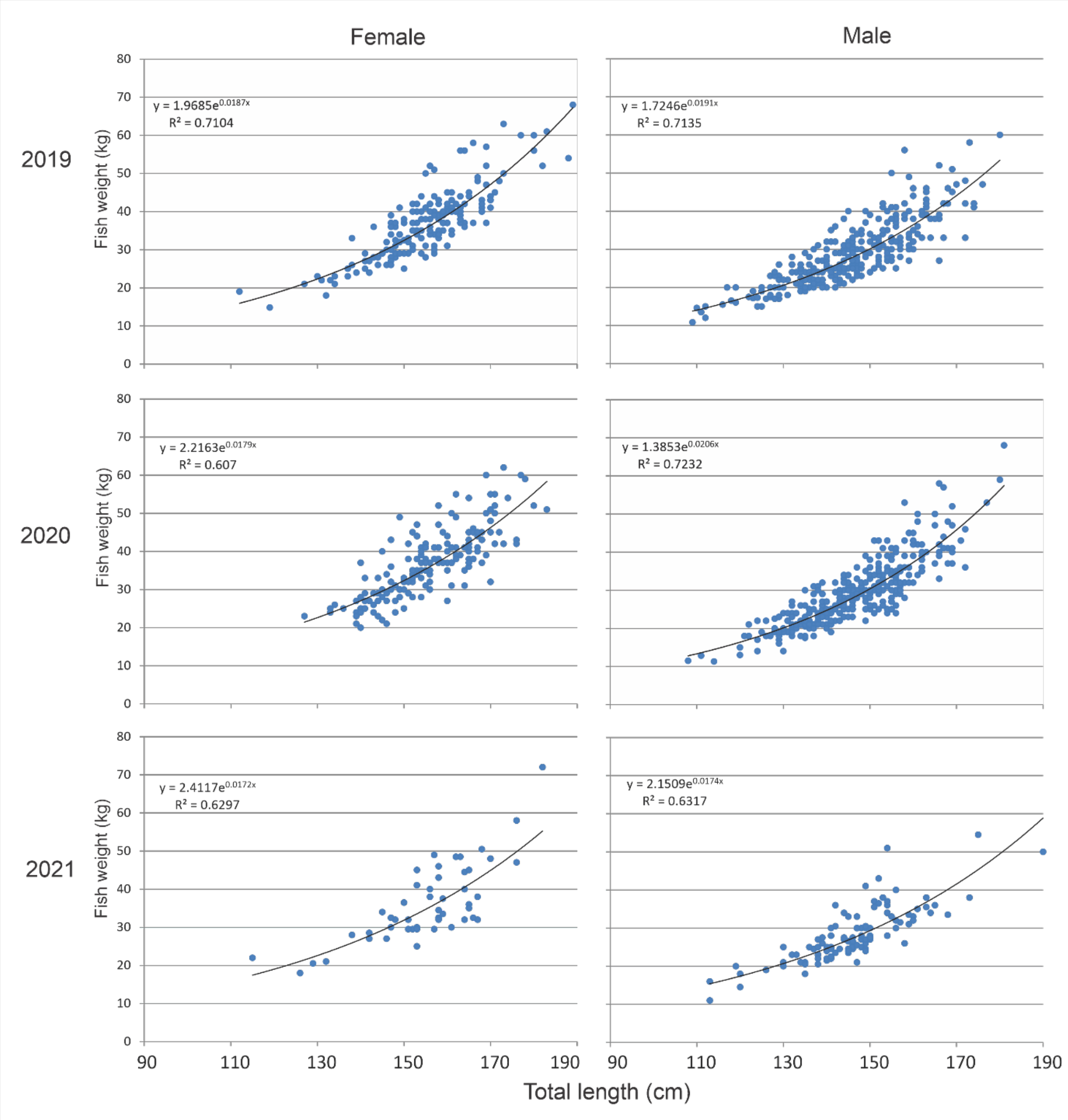

Figure 12. Length weight relationship of male and female Antarctic toothfish sampled during the SPRFMO exploratory toothfish fishery in 2019 to 2021.

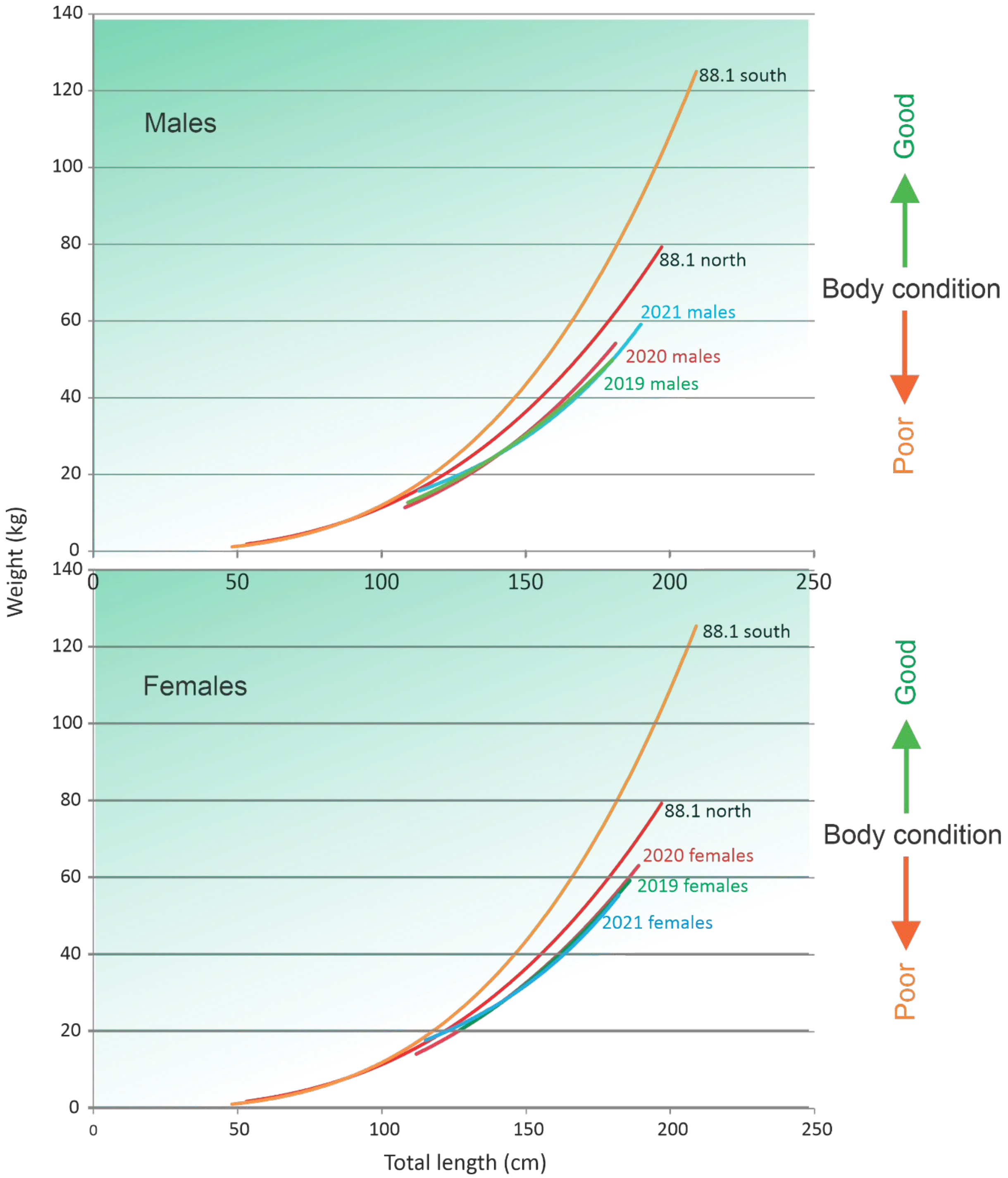

Figure 13. Length weight regression trendlines (power) from CCAMLR 88.1 data 2001 to 2006 (data from Fenaughty et al 2008) with the 2019 to 2021 SPRFMO data plotted for comparison. The colour of the trendline is match by the year label. The data used to produce these plots are summarised in Table 4.

Table 4. Length-weight regression coefficients calculated from records taken from Sanford research sets in Subarea 88.1 (Ross Sea) north and south of 70 degrees S between 2001 and 2006 and from SPRMO Research for 2016 and 2017 combined, and SPRFMO research from 2019 to 2021. The weight is in grams and total length in centimetres. The standard equation is $W=aL^b$

Sex	Area	Season	*a*	*b*	N	R^2
All	88.1 North	2001-2006	0.0176	2.9045	13 073	0.78
	88.1 South	2001-2006	0.0046	3.2068	40 657	0.96
	SPRFMO	2016-17	0.0180	2.8540	565	0.77
	SPRFMO	2019	0.0147	2.9079	473	0.78
	SPRFMO	2020	0.0075	3.0405	509	0.75
	SPRFMO	2021	0.0441	2.6828	158	0.71
Male	88.1 North	2001-2006	0.0326	2.7708	6 547	0.73
	88.1 South	2001-2006	0.0048	3.1979	16 247	0.96
	SPRFMO	2016-17	0.0357	2.7123	365	0.76
	SPRFMO	2019	0.0346	2.7315	293	0.75
	SPRFMO	2020	0.0099	3.0297	282	0.75
	SPRFMO	2021	0.0897	2.5357	109	0.70
Female	88.1 North	2001-2006	0.0188	2.8474	6 496	0.80
	88.1 South	2001-2006	0.0043	3.2178	24 092	0.97
	SPRFMO	2016-17	0.0177	2.8637	200	0.73
	SPRFMO	2019	0.0208	2.8611	179	0.75
	SPRFMO	2020	0.0295	2.7768	173	0.63
	SPRFMO	2021	0.1027	2.5261	48	0.64

Otoliths

During the 2019 to 2021 survey period, 397 otolith pairs have been collected for ageing. This is in addition to the 287 previously taken during the 2016 and 2017 research. Once these have been read, this age information will be available to be incorporated in the overall New Zealand research assessment on Antarctic toothfish which covers both the SPRFMO and CCAMLR areas.

Interactions with seabirds, marine mammals, turtles, or other species of concern

Seabirds

All line setting was carried out after nautical dusk with no deck lighting and with a tori line deployed. The vessel uses integrated weighted main line (50 grams per metre). A bird exclusion device (Brickle curtain) is permanently deployed to protect the immediate area of water near the hauling position. Offal, used bait, and bycatch is minced and then discharged on the opposite side to the haul room only when no setting or hauling is taking place. Sump grates are used to prevent the accidental discharge of offal from the factory floor.

The scientific observer carries out a minimum of one bird observation period during all daylight hauls. The numbers of birds seen varied depending on location and time spent in an area. Most birds were observed circling the vessel or sitting on the water astern of the vessel. The most seen bird species were Wandering albatross or non-specified great albatross, Cape and Antarctic petrels, black browed albatross, grey petrel, and blue petrel. Also present in the three years of observations were giant petrel, light mantled sooty albatross, sooty shearwaters, and Antarctic fulmar. Less commonly recorded were white chinned petrels, Salvin's albatross, Westland petrel, Buller's albatross, and grey headed albatross.

One blue petrel was found alive on deck and released unharmed in 2019. There were no seabird interactions in 2020 and 2021 during fishing operations within SPRFMO.

CMM 14a-2019 governing the Conservation and Management Measure for Exploratory Fishing for Toothfish by New Zealand-Flagged Vessels in the SPRFMO Convention Area requires that the vessel be equipped with a video monitoring and recording system located over the hauling position to ensure that all hauled lines and hooks are observed or recorded on video.

As part of this monitoring the New Zealand government has arranged to have 50% of the hooks hauled from the three-year research reviewed. No protected species captures were seen during this reviewing.

Marine mammals, turtles, or other species of concern

No marine mammals were observed in 2019 and 2021. One small pod of pilot whales was seen in 2020 while the vessel was not carrying out fishing operations. No other marine mammals were observed in 2020.

Tagging

Toothfish are required to be tagged at a rate of 3 fish per tonne of green weight catch retained (approximately 1 in each 10 fish captured). In both seasons the required rate was met.

CMM-14a-2019 par b) requires that: *A minimum tagging rate of three fish of each Dissostichus species per greenweight (live weight) tonne shall be implemented. The rules applied by CCAMLR in the immediately adjacent 88.1 A and B North region, where tagged fish were released starting in early 2015, shall be applied (CM 41-01 Annex C). These rules require a minimum overlap statistic (a comparison between the observed length frequency from vessel biological information and the size composition of fish returned alive with tags, see CCAMLR's calculator) of at least 60% once 30 or more Dissostichus of a species have been successfully released with tags.*

In all seasons the required rate and overlap statistic was met. These are shown by year in Figure 14. Over the five years of the exploratory fishery to date, 516 Antarctic toothfish have been tagged and released.

Tagging was carried out by crew members experienced in retrieving large fish in harsh weather conditions while still preserving them in suitable physical condition for tagging. Oversight is provided by the scientific observer. To ensure that fish to be tagged were randomly selected by size, the haul room crew were instructed at regular intervals in the hauling process[6] (well prior to the fish coming on board) to tag the next suitable[7] fish caught. The fish was then carefully removed from the water using a net, placed on a mat on the haul room floor and assessed for condition. If the condition was suitable for tagging and release, the hook was removed, the fish was then measured for total length and two white CCAMLR t-bar tags inserted (one tag either side of the anterior part of the second dorsal fin) following the CCAMLR tagging protocol. Once the tag data had been accurately recorded the fish was released back into the water.

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[6] Having regard to the tagging rate and general size of the toothfish in the catch.

[7] Conforming to the suitability requirements specified in the CCAMLR Toothfish and Skate tagging instructions - https://www.ccamlr.org/en/system/files/Toothfish%20and%20Skate%20Tagging%20Instructions.pdf

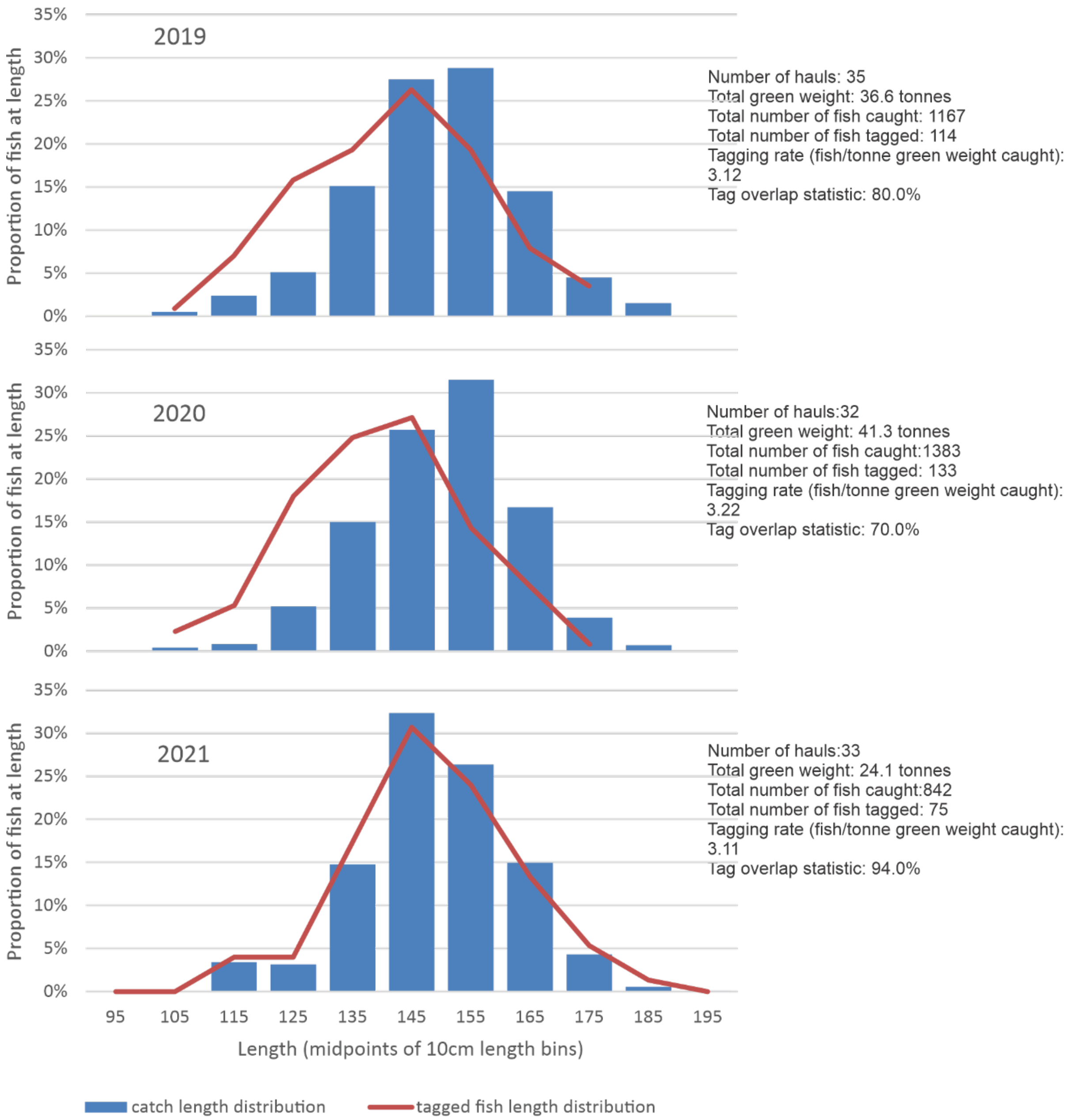

Figure 14. Tagging size overlap statistic for Antarctic toothfish from the SPRFMO exploratory toothfish fishery 2019-2021. Weights are for all toothfish retained.

In 2019 one Antarctic toothfish tagged during the trip was recaptured the following day. In 2020 there were five recoveries; four had been tagged by *San Aspiring* the previous year and one was tagged in the Ross Sea (88.1 K) in 2005, having grown from 73cm to 143cm. There was an additional recovery 8 March 2021 of a 135 cm Antarctic toothfish tagged the previous year on 6 March 2020 and released very close to the recovery location.

Ongoing tagging and recovery of tagged Antarctic toothfish from SPRFMO research when combined with the use of the CCAMLR tagging protocols will enable SPRFMO tagging results to be incorporated in the integrated stock assessment. This work also increases the geographical area covered by the tagging programme and consequently the enhances our ability to investigate geographical movements of toothfish.

Benthic interactions and potential interactions with VMEs

Following the CCAMLR benthic sampling protocol[8] for bottom longline, lines are divided into numbered segments of 1200 m (equivalent to one magazine of 857 hooks). Any benthos found on a segment are placed by the crew into a 10-litre bucket marked with that segment's number. Benthic species are then identified to taxa level by the observer and weighed to the nearest 10 grams.

Gorgonians were the most common organisms recovered (85% of the three-year sample by weight (Table 5.) Glass sponges (*Hexactinellida)* were the next most prevalent class by weight (about 1% of the overall sample).

Table 5. Observer identified and recorded benthic species from required benthic sampling protocols. VME codes are FAO codes as used by CCAMLR. The CCAMLR VME guide is available for reference at: https://www.ccamlr.org/en/system/files/VME-guide.pdf

Season	Area Name	VME Species Code	Class	Common name	Number	Weight (kg)
2019	L	DMO	*Demospongiae*	Siliceous sponges	1	0.41
		HXY	*Hexactinellida*	Glass sponge	3	0.16
	N	AJZ	*Alcyonacea*	Alcyonacea soft corals	1	0.01
		GGW	*Gorgoniidae*	Gorgonians	7	1.09
		HXY	*Hexactinellida*	Glass sponge	2	0.19
		OEQ	*Euryalida*	Basket stars	6	0.9
	O	AJZ	*Alcyonacea*	Alcyonacea soft corals	2	0.06
		ATX	*Actiniaria*	Sea anemones	1	0.01
		BVH	*Brachiopoda*	Brachiopods, lamp shells	1	0.02
		CSS	*Scleractinia*	Hard corals, stony corals	1	0.03
		CWD	*Crinoidea*	Feather stars and sea lilies	3	1.08
		DMO	*Demospongiae*	Siliceous sponges	1	0.01
		GGW	*Gorgoniidae*	Gorgonians	24	21.62
		HXY	*Hexactinellida*	Glass sponge	5	0.24
				2019 TOTAL		**25.83**
2020	L	BZN	Bryozoa	Bryozoans	2	0.02
		CWD	Crinoidea	Feather stars and sea lilies	1	0.03
		GGW	Gorgoniidae	Gorgonians	3	0.99
		HXY	Hexactinellida	Glass sponge	13	2.27
	N	ATX	Actiniaria	Sea anemones	1	0.02

[8] This protocol is consistent with SPRFMO CMM 02-2020 Conservation and Management Measure on Standards for the Collection, Reporting, Verification and Exchange of Data, section H and provides comparability with CCAMLR reports from bottom longline fishing.

		AXT	Stylasteridae	Hydrocorals	2	0.04
		AZN	Anthoathecatae	Hydroids, hydromedusae	1	0.02
		CSS	Scleractinia	Hard corals, stony corals	1	0.02
		GGW	Gorgoniidae	Gorgonians	7	0.57
		HXY	Hexactinellida	Glass sponge	1	0.03
		OEQ	Euryalida	Basket stars	6	0.93
		ZOT	Zoanthidea	Zoanthids	1	0.03
	O	AZN	Anthoathecatae	Hydroids, hydromedusae	1	0.02
		CWD	Crinoidea	Feather stars and sea lilies	2	0.18
		GGW	Gorgoniidae	Gorgonians	14	5.4
		HXY	Hexactinellida	Glass sponge	3	0.14
				2020 TOTAL		**10.71**
2021	L	ATX	Actiniaria	Sea anemones	1	0.06
		BZN	Bryozoa	Bryozoans	1	0.01
		CWD	Crinoidea	Feather stars and sea lilies	3	0.56
		DMO	Demospongiae	Siliceous sponges	3	0.19
		GGW	Gorgoniidae	Gorgonians	1	0.02
		HXY	Hexactinellida	Glass sponge	2	0.05
	N	ATX	Actiniaria	Sea anemones	1	0.22
		AXT	Stylasteridae	Hydrocorals	2	0.91
		CWD	Crinoidea	Feather stars and sea lilies	1	0.04
		GGW	Gorgoniidae	Gorgonians	10	17.59
		HXY	Hexactinellida	Glass sponge	1	0.01
		NTW	Pennatulacea	Pennatulacea sea pens	1	0.02
	O	GGW	Gorgoniidae	Gorgonians	2	3.59
		NTW	Pennatulacea	Pennatulacea sea pens	1	0.04
				2021 TOTAL		**23.31**
				2019 - 2021 TOTAL		**59.85**

Discussion

An exploratory longline fishery for toothfish in CCAMLR Subareas 88.1 and 88.2 has been in operation since 1997. The more than two decades of research undertaken during the Austral summer in this CCAMLR fishery now provides a good and ever-increasing understanding of the biology and ecology of Antarctic toothfish. There are however several important aspects of the spawning behaviour and early life history of Antarctic toothfish are still relatively unknown (Hanchet et al. 2015). Until 2016 there had been little fishing, and consequently, limited research sampling carried out during the late autumn and winter period when the spawning of Antarctic toothfish is thought to take place. The historical timeline moving towards a better understanding of the spawning behaviour and early life history of Antarctic toothfish is summarised here.

Fenaughty (2006) used four separate biological measurements to analyse toothfish biological data from five summer seasons from 2000/01 to 2004/05. This work indicated that there were clear differences between the Antarctic toothfish populations found on the hills and ridges of the Pacific-Antarctic Ridge to the north and from the main Ross shelf to the south of Subarea 88.1. A key indicator was that the body condition of Antarctic toothfish in the northern hills and ridges was much poorer for both sexes. An extended, asynchronous spawning in the northern area outside the polar summer season was suggested as the best explanation for these differences.

A further paper in 2008 (Fenaughty et al. 2008) attributed the body condition differences seen in the northern area to metabolic loss of muscular and subcutaneous lipid stores, and probably proteins, from white muscle. This paper considered energy metabolism as related to migration, feeding and reproduction. An important conclusion was that both lipid and protein stores of the axial portion of Antarctic toothfish were metabolically volatile and were mobilised for energetic and/or gametogenic purposes during spawning. Neutral buoyancy which had been previously considered to be based on the relative age of fish of this species was considered more likely an ephemeral phenomenon that is gained and lost cyclically in sexually mature adults. As in other species, once feeding is resumed and forage species are abundant, it was suggested that both lipid stores and muscular protein could be restored rapidly (Jobling 1994).

A review of existing knowledge on Antarctic toothfish biology coupled with ocean circulation was also carried out by Hanchet et al. (2008) to predict where larvae and juvenile Antarctic toothfish might be found. Additional work by Dunn et al. (2012) and Ashford et al. (2012) further supported the hypothesis that spawning is likely to occur on ridges and banks to the north of the Ross Sea during the austral winter (June to October) and that eggs spawned in this region would be retained within the wider Ross Sea region through entrainment in the Ross Gyre.

In 2013 the Scientific Committee of CCAMLR (SC-CAMLR) acknowledged the need for research fishing in the northern Ross Sea region during winter to address uncertainties in toothfish life-cycle movements and spawning dynamics (SC-CAMLR-XXXII, para 3.76 (iv)), and requested proposals be developed by Members to address this need.

Up to then, while there were strong indications that toothfish spawn in the northern region of Subareas 88.1 and 88.2 during the winter months (Hanchet et al 2008, Stevens et al. 2016), the spatial and temporal distribution of spawning activity was still theoretical. The collection of better information to inform these inferred aspects of spawning ecology to improve the structural assumptions of the spatially explicit operating model was identified in the CCAMLR medium-term research plan for the Ross Sea region (Delegations of New Zealand, Norway, and the United Kingdom 2014) as a key task which was subsequently endorsed by the Scientific Committee (SC-CAMLR XXXII, para 3.76 (iv)).

Progress advanced considerably when the New Zealand vessel FV *Janas* carried out research fishing operations in the northern Ross Sea region between June and July 2016 to investigate timing and locations of spawning Antarctic toothfish. Spawning and spent Antarctic toothfish were captured late in the survey on undersea features. Gonad staging and gonadosomatic indices suggested that males in spawning condition may aggregate earlier than females and that spawning had begun in early July. Nineteen toothfish eggs were captured using a plankton net in the top 200 m of the water column, and eggs from two running ripe females were successfully fertilised and reared for several days in flow through incubators. Egg buoyancy measurements conducted with fertilised eggs in density gradient cylinders were carried out. As part of this project Antarctic toothfish reproductive status, gonadosomatic index (GSI), histological characteristics, sex ratio, and condition factor were collected. The sex-specific fish condition factor for males was seen at this time was 5% lower than that observed in the summer fishery in SSRUs 881B–C. However, females showed the same median value as in the summer fishery.

A second winter survey for Antarctic toothfish in the Ross Sea region was conducted from the FV *Janas* during September and October 2019. This survey followed the northern extent of sea ice from SSRU 882B through 881B. Antarctic toothfish sampled during this survey were in spent condition by the beginning of September, gonadosomatic indices were less than 5%, suggesting spawning had ended by mid-August. This research also indicated that sex-specific condition factors were lower than those observed in the summer or pre-spawning winter periods, and much lower than those observed on the Ross Sea slope during the summer fishery. Antarctic toothfish eggs were also found during this survey but rare in the areas sampled with the bongo nets, captured in six tows.

The initial SPRFMO research plan to carry out exploratory fishing on toothfish was carefully developed using to harmonise with existing and future CCAMLR research. This integrated approach has continued through the course of the five years of research on Antarctic toothfish within the SPRFMO region. In August 2016 the first SPRFMO research on toothfish was carried out during the winter period further north (and east) in the SPRFMO area immediately north of the CCAMLR Convention Area by the New Zealand vessel *San Aspiring*, noting that the first CCAMLR winter survey also took place in this year. This was followed by a second SPRFMO survey in September 2017. Both *Janas* and *San Aspiring* use very similar gear and used a similar research methodology enabling ease of comparison of results. CCAMLR and SPRFMO research programmes are thus complimentary and provide an increased geographical and temporal spread of data available for analysis.

A key finding from the first two *San Aspiring* voyages in 2016 and 2017 was that significant quantities (with catch rates over 2.5 kg per hook) of post-spawning Antarctic toothfish exist north of the Convention boundary at 60°S.

This work has been continued with this three-year 2019 to 2021 SPRFMO programme.

Analysis of all biological information from the *San Aspiring* SPRFMO research to date has shown a high proportion of males to females and that toothfish in the area are in poor body condition; potentially representing full or partial starvation. Nearly 97% of Antarctic toothfish fish sampled in 2016 and 2017 and over 99% during 2019-2021 period were adults (defined as having a total length of 120 cm or greater). Antarctic toothfish body condition as represented by both Fulton's Condition Index (CI) and a modified somatic condition index (SCF) (Figure 11) show the lowest values during the 2016 sampling which is closest to the hypothesised spawning period. This is consistent with the hypothesis that spawning fish are not feeding but instead metabolise stored muscular and subcutaneous lipid stores, and probably body tissue during this spawning time. The data here, while still based on a limited temporal spread generally indicate a gradual increase in body condition after spawning to a similar level seen in the pre-spawning sampling periods. When body condition measurements are adjusted to somatic weight there is a slight anomaly in the male sample for 2020 which appears to be a result of a relatively high GSI for males during this specific sampling period. We have identified this as an area for future investigation. Collection of this seasonal data to map these differences in condition and GSI continued to show the potential of these measurements to better pinpoint the timing of spawning and collect other information associated with spawning of toothfish. Most Antarctic toothfish examined in all seasons had either empty stomachs or only contained bait with less than 2% of the sample from 2019 to 2021 containing any food, although a higher proportion (about 7%) of the 2017 sample were found with prey in the gut during the suggested post spawning period. Again, the apparent lack of feeding is entirely consistent with results from the northern hills area of CCAMLR Subarea 88.1.

The current working hypothesis for the species life history in the general area of Area 88 (Figure 15) postulates that eggs and larvae spawned on the seamounts in in CCAMLR subareas 88.1 and 88.2 are advected to the east and then to the south of Subarea 88.3. The juvenile toothfish are then believed to grow and slowly move west back towards Subarea 88.2 and 88.1. As they develop into adults on the slope (500 to 1200 m) they undergo maturation and then migrate to the northern seamounts again to spawn (Parker et al. 2014). Juvenile (50–80 cm) toothfish have been recorded from Subarea 88.3, but until recently, few subadult toothfish have been caught there (Delegations of Korea and New Zealand, 2017). This SPRFMO research carried out north of the CCAMLR Convention Area in concert with the CCAMLR winter surveys infers that spawning is potentially more extensive than originally postulated - possibly taking place throughout much of the of the southern section of the Pacific Antarctic Ridge.

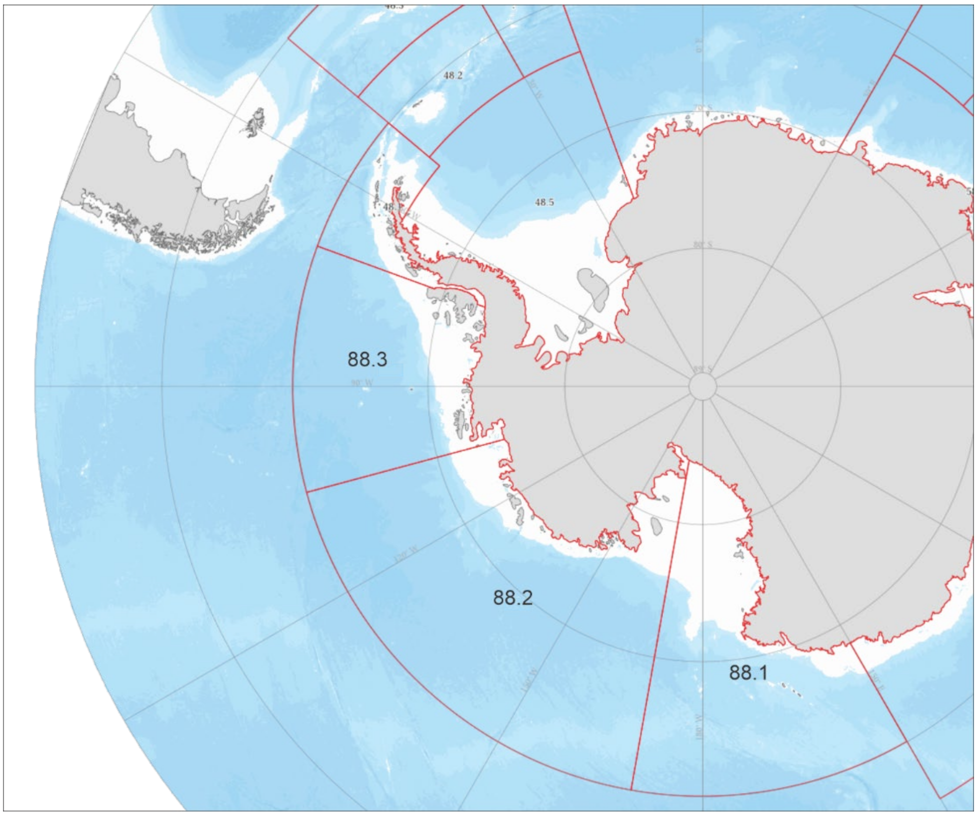

Figure 15. FAO Area 88 showing CCAMLR Subareas 88.1. 88.2 and 88.3

It is possible that this most northern SPRFMO spawning cohort is not substantially supported by migration from the south or alternatively, that any migration from more southern regions takes place later in the year during autumn and early winter - possibly associated with seasonal sea ice movement northward and southward. The collection of liver weights during biological sampling as has been the case within CCAMLR may assist in this work as this may provide a good independent signal of fish condition.

This highlights a continued need to better understand the biology and connection of Antarctic toothfish caught in both the SPRFMO and CCAMLR Convention Areas; particularly referencing the northern regions of FAO Area 88. To refine our understanding of these relationships we need to continue biological collection using established methodology and in addition we need to increase focus on stock structure by collecting Antarctic toothfish tissue for genetics, samples for otolith microchemistry, and increase otolith collection. The ageing of SPRFMO Antarctic toothfish otoliths should be given increased priority. Continuing the planned research within the SPRFMO and CCAMLR areas should also increase our understanding of the geographical, temporal, and depth range of Antarctic toothfish in the Southern and Antarctic Oceans north of FAO area 88. The two associated programmes will also provide opportunities for increased collection of similar information on main bycatch species such as Rajiids and *Macrourus*.

In summary, spatial and temporal trends in GSI, fish size and age, sex ratio, and body condition from this *San Aspiring* research SPRFMO north of the CCAMLR Convention Area in Area 88, combined with previous analyses from CCAMLR Subarea 88.1 and 88.2, and additional observations from winter surveys within CCAMLR by the vessel *Janas,* give strong indications that Antarctic toothfish spawn during winter months not only in the northern hills of the Ross Sea region within CCAMLR Convention Area 88 (Fenaughty 2006, Fenaughty et al. 2008, Parker & Marriott 2012, Stevens et al. 2016, Parker et al 2019) and also further north into the SPRFMO Convention Area. Currently, the precise timing, duration, and spatial extent of spawning over the extent of both regions remains imprecise. The continuation of complementary research programmes within CCAMLR and SPRFMO during the winter period will provide additional information to increase our understanding of Antarctic toothfish spawning dynamics and population structure within and north of Area 88. These projects additionally provide a good platform to increase the collection of samples such as genetics and otolith microchemistry to enhance our understanding of toothfish populations in the Southern Ocean. Increasing the pool of tagged fish in both these areas should also be a research priority. The research also provides opportunities for increased presence and biological data collection for bycatch species; particularly those more prevalent such as Rajiids and *Macrourus*. Plankton tows will also be considered under appropriate circumstances to extend the CCAMLR winter survey work.

Summary of key results

- Relatively high catch rates of Antarctic toothfish were seen over the three years particularly in Research Blocks L and M. The high catch rates are similar to those found in two (assumed) spawning areas in the northern regions of CCAMLR subareas 88.1 and 88.2.

- The toothfish catch was almost entirely of Antarctic toothfish. Six Patagonian toothfish were taken, three large specimens in the NE sector of Research Block O in 2019, a small specimen in the south of Research Block L in 2020, and two in Research Block N in 2021 – one of which was tagged and released.

- Antarctic toothfish sex ratios were skewed with males dominating. Males were 60.3% of the total sample in 2019, 64.2% in 2020, and 62.7% in 2021.

- Fish were in poor body condition and low GSI as observed during previous years. While the presumption for this result from the 2016, 2017 and 2019 data was that this was a consequence of a spawning event shortly before the exploratory fishing was carried out; the 2020 and 2021 sample collected during late summer, and presumably pre-spawning, also showed similar poor body condition but gonad condition indicated development for spawning.

- 397 otolith pairs have been collected for ageing from 2019 to 2021 – from 140 female and 257 male Antarctic toothfish.

- 516 Antarctic toothfish have been tagged since 2016 and six previously tagged fish recovered after at least one season. One of these had come from the Ross Sea slope area and had been at liberty for 15 years.

- Antarctic toothfish size is indicates the population is almost entirely adult fish; consistent with this being a spawning area for Antarctic toothfish.

- There have been no seabird interactions resulting from research fishing and only common and widely distributed seabird species have been recorded attending the vessel. One passing pod of pilot whales was observed in 2020 while the vessel was not fishing.

- There has been little benthic bycatch, quantities are well short of both CCAMLR and SPRFMO notification thresholds.

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References

Ashford, J., Dinniman, M., Brooks, C., Andrews, A., Hofmann, E., Cailliet, G., Jones, C. & Ramanna, N. (2012). Does large-scale ocean circulation structure life history connectivity in Antarctic toothfish (*Dissostichus mawsoni*)? *Canadian Journal of Fisheries and Aquatic Sciences 69:* 1903–1919.

CCAMLR Secretariat 2016. Long-distance movements of tagged Patagonian (*Dissostichus eleginoides*) and Antarctic toothfish (*D. mawsoni*). WG-FSA-16/25 Rev. 1.

Dunn, A., Rickard, G.J., Hanchet, S.M., Parker, S.J. (2012). Models of larvae dispersion of Antarctic toothfish (*Dissostichus mawsoni*). *WG-FSA-12/48*.

Dutil J.-D., Y. Lambert, G.A. Chouinard, and A . Fréchet. Fish condition : what should we measure in cod (Gadus morhua)?

Fenaughty J.M. (2006) Geographical differences in the condition, reproductive development, sex ratio, and length distribution in Antarctic toothfish *Dissostichus mawsoni* from the Ross Sea, Antarctica (CCAMLR statistical Subarea 88.1). CCAMLR Science, 13: 27-45.

Fenaughty, J. (2008). The autoline system – an updated descriptive review of the method with recommendations to clarify CCAMLR Conservation Measures regulating longline fisheries within the Convention Area. CCAMLR, Hobart, Australia: 27 p.

Fenaughty J.M., Joseph T. Eastman, and Bruce D. Sidell (2008). Biological implications of low condition factor "ax handle" specimens of the Antarctic Toothfish, Dissostichus mawsoni, from the Ross Sea. Antarctic Science 20 (6), 537–551 (2008).

Fenaughty, J.M., Cryer, M. (2016). Report on the first year's fishing under New Zealand's exploratory fishery for toothfish within the SPRFMO Convention Area. SC-CAMLR-XXXV/BG/32. 8p.

Fenaughty J.M., M. Cryer and A. Dunn (2018). Research results from the SPRFMO exploratory fishing program for Antarctic toothfish 2016 and 2017. CCAMLR WG-FSA-18/39.

Fenaughty J.M., 2020. Interim research report from the New Zealand bottom longline research carried out in the SPRFMO area 2019 and 2020. SC8-DW09

Hanchet, S.M., Rickard, G.J., Fenaughty, J.M., Dunn, A.; Williams, M.J. (2008). A hypothetical life cycle for Antarctic toothfish Dissostichus mawsoni in Antarctic waters of CCAMLR Statistical Area 88. CCAMLR Science 15: 35–54.

Hanchet, S.M., Dunn, A., Parker, S.J., Horn, P.L., Stevens, D.W. & Mormede, S. 2015. The Antarctic toothfish (*Dissostichus mawsoni*): biology, ecology, and life history in the Ross Sea region. Hydrobiologia, 761, 397–414.

Hansson T., J. Thain, C. Martínez-Gómez, K. Hylland, M. Gubbins, L. Balk. 2017. Supporting variables for biological effects measurements in fish and blue mussel. ICES Techniques in Marine Environmental Sciences. No. 60. 22 pp. http://doi.org/10.17895/ices.pub.2903.

Hunter, J.R. and B.J. Macewicz 2001. Improving the accuracy and precision of reproductive information used in fisheries: modern approaches to assess maturity and fecundity of warm- and cold-water fish squids. Fish. Bull., 90: 101-128.

Jobling M. 1994. Fish bioenergetics. London: Chapman and Hall, 309 pp

New Zealand 2021. Proposal for exploratory bottom longlining for toothfish by New Zealand vessels 2022-2024. SC9-DW01

Parker, S.J.; Marriott, P. (2012). Indexing maturation of Antarctic toothfish *(Dissostichus mawsoni*) in the Ross Sea region. *WG-FSA-12/40.*

Parker, S.J., Hanchet, S.M., Horn, P.L. (2014). Stock structure of Antarctic toothfish in Statistical Area 88 and implications for assessment and management. WG-SAM-14/26.

Stevens, D., DiBlasi, D., Parker, S.J. (2016). Results of the first winter longline survey to the northern Ross Sea region to investigate toothfish reproductive life history. *WG-FSA-16/37*.

Parker, S.J., Stevens, D.W., Ghigliotti, L., La Mesa, M., Di Blasi, D., Vacchi, M. (2019). Winter spawning of Antarctic toothfish *Dissostichus mawsoni* in the Ross Sea region. Antarctic Science. Antarctic Science 2019: 1–11. https://doi.org/10.1017/S0954102019000282

Parker, S.J., DiBlasi, D. (2020). Second winter survey of Antarctic toothfish (*Dissostichus mawsoni*) in the Ross Sea region. CCAMLR Document SC-CAMLR-39/BG/29. CCAMLR, Hobart, Aus. 24p.

Williams, K., 2007. Evaluation of macroscopic staging method for determining maturity of female walleye pollock, *Theragra chalcogramma* in Shelikof Strait, Alaska. Alaska Fish Res. Bull., 12: 252-263.

Appendix 1: Reproductive summary

The following describes the CCAMLR staging that is applied in assessing the fish caught within SPRFMO.

Females

Maturity stage Description

F1. Immature Ovary small, firm, no eggs visible to the naked eye.

F2. Maturing virgin or resting Ovary more extended, firm, small oocytes visible, giving ovary a grainy appearance.

F3. Developing Ovary large, starting to swell the body cavity, colour varies according to species, contains oocytes of two sizes.

F4. Gravid Ovary large, filling or swelling the body cavity, when opened large ova spill out.

F5. Spent Ovary shrunken, flaccid, contains a few residual eggs and many small ova.

Males

Maturity stage Description

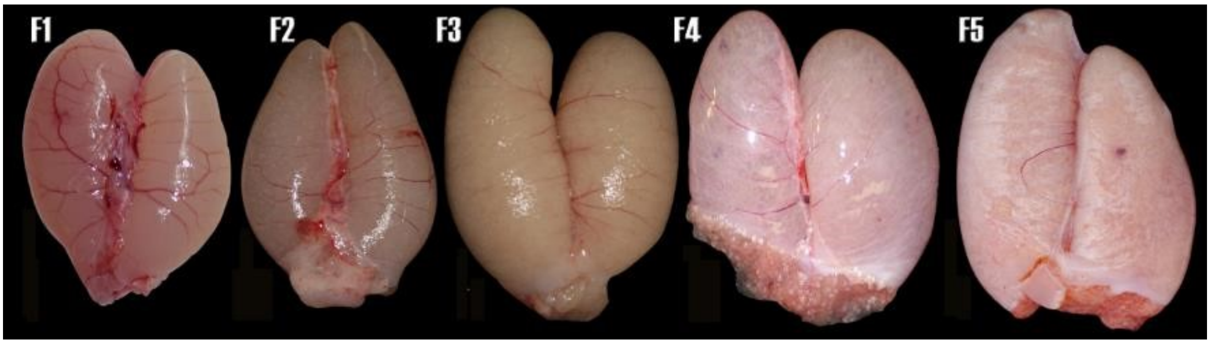
M1. Immature Testis small, translucent, whitish, long, thin strips lying close to the vertebral column.

M2. Developing or resting Testis white, flat, convoluted, easily visible to the naked eye, about 1/4 length of the body cavity.

M3. Developed Testis large, white and convoluted, no milt produced when pressed or cut.

M4. Ripe Testis large, opalescent white, drops of milt produced when pressed or cut.

M5. Spent Testis shrunk, flabby, dirty white in colour.



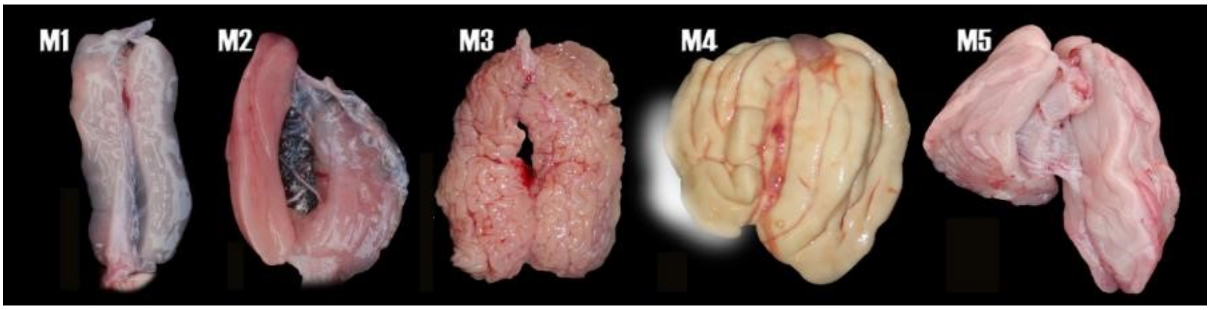


Table 6. Reproductive information collected in 2019 by see in conjunction with Figure 8

Stage	**Description males**	**Males**	**Males % of sample**	**Description females**	**Females**	**Females % of sample**
2	Developing or resting Testis white, flat, convoluted, easily visible to the naked eye, about 1/4 length of the body cavity	182	62.1%	Maturing virgin or resting. Ovary more extended, firm, small oocytes visible, giving ovary a grainy appearance.	89	49.9%
3	Developed - Testis large, white and convoluted, no milt produced when pressed or cut.		0.0%	Developing - Ovary large, starting to swell the body cavity, colour varies according to species, contains oocytes of two sizes	26	14.4%
4	Ripe - Testis large, opalescent white, drops of milt produced when pressed or cut	21	7.2%	Gravid Ovary large, filling or swelling the body cavity, when opened large ova spill out.	7	3.8%
5	Spent -Testis shrunk, flabby, dirty white in colour	90	30.7%	Spent Ovary shrunken, flaccid, contains a few residual eggs and many small ova.	58	32.2%
Grand Total		**293**			**180**	

Table 7. Reproductive information collected in 2020 by see in conjunction Figure 8

Stage	**Description males**	**Males**	**Males % of sample**	**Description females**	**Females**	**Females % of sample**
2	Developing or resting Testis white, flat, convoluted, easily visible to the naked eye, about 1/4 length of the body cavity	274	81.8%	Maturing virgin or resting. Ovary more extended, firm, small oocytes visible, giving ovary a grainy appearance.	62	35.4%
3	Developed - Testis large, white and convoluted, no milt produced when pressed or cut.	54	16.1%	Developing - Ovary large, starting to swell the body cavity, colour varies according to species, contains oocytes of two sizes	107	61.1%
4	Ripe - Testis large, opalescent white, drops of milt produced when pressed or cut	7	2.1%	Gravid Ovary large, filling or swelling the body cavity, when opened large ova spill out.	6	3.4%
5	Spent -Testis shrunk, flabby, dirty white in colour	0	0.0%	Spent Ovary shrunken, flaccid, contains a few residual eggs and many small ova.	0	0.0%
Grand Total		**335**			**175**	

Table 8. Reproductive information collected in 2020 by see in conjunction Figure 8

Stage	Description males	Males	Males % of sample	Description females	Females	Females % of sample
2	Developing or resting Testis white, flat, convoluted, easily visible to the naked eye, about 1/4 length of the body cavity	8	7.3%	Maturing virgin or resting. Ovary more extended, firm, small oocytes visible, giving ovary a grainy appearance.	2	4.1%
3	Developed - Testis large, white and convoluted, no milt produced when pressed or cut.	83	76.1%	Developing - Ovary large, starting to swell the body cavity, colour varies according to species, contains oocytes of two sizes	33	67.3%
4	Ripe - Testis large, opalescent white, drops of milt produced when pressed or cut	2	1.8%	Gravid Ovary large, filling or swelling the body cavity, when opened large ova spill out.	7	14.3%
5	Spent -Testis shrunk, flabby, dirty white in colour	16	14.7%	Spent Ovary shrunken, flaccid, contains a few residual eggs and many small ova.	7	14.3%
Grand Total		**109**			**49**	