CCAMLR Science, Vol. 19 (2012): 17–30

ESTIMATING UNACCOUNTED FISHING MORTALITY IN THE ROSS SEA REGION AND AMUNDSEN SEA (CCAMLR SUBAREAS 88.1 AND 88.2) BOTTOM LONGLINE FISHERIES TARGETING ANTARCTIC TOOTHFISH

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Abstract

Stock assessments rely on estimates of total mortality resulting from fishing activities. However, fish that are captured by fishing gear that is not subsequently retrieved are generally not counted in estimates of total fishing removals or otherwise accounted for in stock assessment models. The mortality resulting from the loss of sections of bottom longline gear in the Ross Sea region and Subarea 88.2 Antarctic toothfish (*Dissostichus mawsoni*) fisheries is not currently known. A method to estimate unaccounted fishing mortality from lost lines in these fisheries is provided. These estimates suggest that on average 208 tonnes of Antarctic toothfish mortality may be unaccounted for annually. While the current estimates may be improved through the adoption of better data reporting practices, these estimates were incorporated as sensitivity analyses in the 2011 stock assessments for the Ross Sea region and Subarea 88.2 toothfish fisheries.

Introduction

Stock assessments rely on estimates of the total mortality resulting from fishing activities. While mortality associated with landed and discarded catch is routinely monitored, the mortality resulting from the loss of sections of bottom longline gear in the Ross Sea region and Subarea 88.2 Antarctic toothfish (*Dissostichus mawsoni*) fisheries is currently not known and has not previously been considered in stock assessments (SC-CAMLR, 2007a; Dunn and Hanchet, 2009; Mormede et al., 2011a, 2011b).

Lost fishing gear is known to have a variety of impacts on marine ecosystems, including the continued catch of target and by-catch species, impacts to benthic habitats, the introduction of synthetic materials to the marine food web, the accumulation of fishing debris and associated costs to the industry (Macfadyen et al., 2009). However, few studies provide quantitative estimates of unaccounted mortality caused by lost fishing gear.

Any longline gear that is baited and set, but not successfully retrieved, may result in unaccounted mortality of toothfish or other species. In the Ross Sea region and Subarea 88.2, bottom longline gear is most often lost due to interactions of downlines (lines connecting surface floats with anchors) with moving sea-ice, but may also result from tidal currents submerging floats, or gear failure during line retrieval (J. Fenaughty, Silvifish Inc., Wellington, pers. comm.). The fate of fish hooked on lost lines is unknown.

Lost gear is currently reported in order to evaluate how well CCAMLR meets its management objectives relating to human impacts on the Antarctic environment (CCAMLR, 1986, paragraphs 37 to 41; Secretariat, 2011). Many of the materials used in the construction of fishing gears are designed to be stable in seawater and may retain their structural integrity for many years. In this sense, marine debris from lost gear may be considered cumulative. Furthermore, bottom longline gear is expensive to replace and its loss is a cost to the fishing industry. Collecting and analysing data to better understand longline gear loss, its causes, and any fishery or environmental effects, may be important to evaluate fishing impacts in the Antarctic. Therefore, the purpose of this paper is to:

(i) characterise bottom longline gear loss in the Ross Sea and Subarea 88.2 fisheries spatially and temporally, by gear type, vessel, depth and small-scale research unit (SSRU)

(ii) quantify the number of hooks lost attached to sections of line each year, and the associated length of longline lost

(iii) provide an initial estimate of unaccounted fishing mortality of Antarctic toothfish associated with lost lines, including associated uncertainty

(iv) make recommendations to improve gear loss reporting.

Methods

Data grooming

Fishing years are assigned to the year in which the fishing season ended (i.e. the 2007/08 season is referred to as the 2008 fishing year). The CCAMLR C2 (longline gear catch and effort database) reporting form was modified for the 2008 fishing year to include reporting of hooks lost during fishing activities (SC-CAMLR, 2007b (paragraph 13.12, Annex 5), 2007c (paragraph 7.5)). The database field 'hooks lost attached to sections' of longline gear was used for this analysis. There is also an 'other hooks lost' field, which reports 'hooks lost not attached to sections of longline'. These data were not used in this analysis as it was assumed that these hooks were unlikely to cause further fish mortality after being lost. The following terminology is used to distinguish categories of gear loss as reported to CCAMLR:

(i) 'gear', which describes entire segments of longline gear or its components (floats, downlines, anchors, mainline, or snoods and hooks)

(ii) 'hooks lost attached to sections', which is a measure of the length of longline lost that may contribute to unaccounted fish mortality. Hereafter this is referred to as 'hooks lost'.

Catch and effort data were extracted from the CCAMLR C2 database for the 2008–2011 fishing years. The data were then used to estimate hook loss for the entire area on an annual basis and separately for the Ross Sea region and Subarea 88.2 fisheries.

Data reporting for hooks lost attached to sections was variable among years, gear types and vessels with some vessels failing to report the number of hooks lost (as opposed to reporting zero hook loss) for a high proportion of sets. Data grooming was necessary to address apparent non-reporting and to remove implausible data. For instance, it was assumed that it was highly unlikely that an individual vessel operating in the Ross Sea region could fish for several years without ever losing any hooks attached to sections of line. Vessels reporting only zero or null values for lost hooks for all years (four of 21 total vessels in the dataset) were removed from the analysis.

If a vessel reported any non-zero value for lost hooks in any year, then any individual sets reporting a zero value for lost hooks were retained, while sets for which no value for lost hooks was reported were assigned the season-specific average hook loss rate calculated from those vessels and sets where loss rates were reported. In addition, a 'lower-bound' hook loss rate was included as a sensitivity where sets for which no value for hooks lost was reported were assigned a zero value (but only for those vessels that reported non-zero hook loss on other sets).

Hook loss rate

The groomed data were used to calculate season- and SSRU[1]-specific hook loss rates which were then applied to estimate the expected loss where data was missing. The ratio-of-means (Bradford, 2002) hook loss rate ($\bar{L}_{hi}$), with units hooks lost per hook set, was estimated for each season h and SSRU i as:

$$\bar{L}_{hi} = \frac{\sum_{jk} l_{hijk}}{\sum_{jk} u_{hijk}} \qquad (1)$$

where l_{hijk} was the number of hooks lost during season h in SSRU i by vessel j in set k and u_{hijk} was the number of hooks set during season h in SSRU i

[1] SSRU boundaries were redefined in CM 41-01 in 2011 (CCAMLR, 2011).

by vessel j in set k. This hook loss rate was estimated for all reported sets and applied to sets with no reported hook loss for all fishing effort within the fleet, including vessels that did not report hook loss for the entire fishing season. Hook loss rates were estimated at the scale of individual SSRUs because average catch rates may vary at the scale of SSRUs, but applying the estimates at finer spatial resolution would have resulted in insufficient data with which to estimate gear loss rates for each combination of season-vessel-SSRU. Although initially investigated, loss rates were not estimated separately for each gear type (i.e. autoline versus Spanish line versus trotline) because levels of gear loss reporting between gear types were inconsistent.

Groomed data were tabulated by fishing season, gear type, depth, vessel and SSRU. The spatial distribution of the number of sets with positive hook loss and the number of hooks lost per unit effort were summarised by 0.2° latitude × 0.7° longitude cells. In addition, an index of hook loss was calculated as the product of the loss rate within a spatial cell multiplied by the number of sets with positive hook loss in that cell, to identify areas where a high hook loss rate (per set) coincided with a high frequency of sets with lost hooks.

Components of lost gear

The total gear loss (G_{hij}) as number of hooks lost and associated length of longline lost (K_{hij}) in km during season h in SSRU i for vessel j was calculated as:

$$G_{hij} = \overline{L}_{hi} \times \overline{u}_{hij} \quad (2)$$

and

$$K_{hij} = \overline{L}_{hij} \times \overline{u}_{hij} \times \overline{s}_{hij} \quad (3)$$

where $\overline{s}_{hij}$ was the mean hook spacing in km during season h in SSRU i for vessel j and $\overline{u}_{hij}$ was the mean number of hooks set during season h in SSRU i for vessel j. Total hook loss and associated length of longline lost were then summed by season.

Estimating unaccounted fishing mortality

To estimate mortality associated with lost fishing gear, the hook loss rate by season, SSRU and vessel was multiplied by the average reported catch per unit effort (CPUE) reported for each season-SSRU-vessel. The CPUE ($\overline{y}_{hij}$), with units tonnes per hook, during season h in SSRU i for vessel j was calculated using the ratio-of-means estimator (Bradford, 2002):

$$\overline{y}_{hij} = \frac{\sum_k c_{hijk}}{\sum_k u_{hijk}} \quad (4)$$

where c_{hijk} was the catch in tonnes during season h in SSRU i by vessel j in set k and u_{hijk} was the effort, or number of hooks set, during season h in SSRU i by vessel j in set k. The unaccounted fishing mortality (M_{hij}) in tonnes per season h, per SSRU i, per vessel j was calculated as:

$$M_{hij} = \overline{L}_{hi} \times \overline{y}_{hij} \times \overline{u}_{hij} \quad (5).$$

Unaccounted fishing mortality was then summed across all SSRUs and vessels by season.

Bootstrap resampling of the observed values was used to estimate the variance of the ratio-of-means estimates for hook loss, length of longline lost and unaccounted fishing mortality. Here, the numerator and the denominator for a given set were kept together for bootstrapping (see Bradford, 2002) and 10 000 bootstrap samples were produced per season-SSRU-vessel. The variance was recorded as the 10th and 90th percentile of each bootstrap distribution.

Although season-, SSRU- and vessel-specific catch rates were estimated, the catch rate observed on a successfully retrieved longline may be different from the unaccounted mortality on a lost longline left on the bottom, due to the longer soak time. Catch rates were plotted against soak time to characterise to what extent longer soak times resulted in higher catch rates. A positive relationship between catch rate and soak time would suggest that unaccounted mortality estimates be adjusted upwards to account for higher catch rates associated with longer soak times.

The L8 observer program data table (extracted 8 June 2011) was also summarised by year to characterise the frequency of loss of particular longline gear components as noted by the observer (versus reported by the vessel on the C2 form).

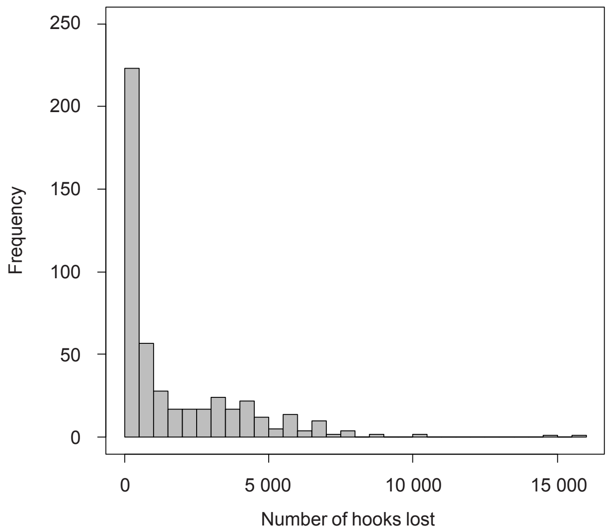

Figure 1: Frequency distribution of the number of hooks lost attached to sections of longline. These figures do not include sets reporting zero hooks lost and are summarised in 500-hook intervals.

Results

Data grooming

The initial data grooming procedure removed vessels that reported null or zero hook loss for every year of the 2008–2011 fishing seasons. Four out of 21 vessels were removed. Subsequent data grooming to eliminate null (non-reported) values for individual vessel-seasons removed between 23% and 74% of sets each season (Table 1). The grooming process removed 19% of sets for autoline gear, 94% for Spanish line and 59% for trotline gear (Table 2). In the groomed data, 85% of sets recorded zero hooks lost attached to sections of longline gear. A histogram of the remaining 15% of sets that recorded non-zero hook loss shows that when hook loss was reported, it was typically fewer than 1 500 hooks, but had been as high as 16 000 hooks (Figure 1).

Hook loss rate

The season-specific hook loss rate from 2008 to 2011 ranged from 3% to 8% (Table 3). The hook loss rate was greatest in 2010 but the greatest number of hooks was lost in 2008, the year that the most hooks were set.

The data were inadequate to make comparisons of hook loss rate among different gear types. Reported hook loss rates by gear type are shown in Table 4, but the estimates for Spanish line and trotline are based on the very small proportion of the sets that were retained by the grooming process. The hook loss rate for Spanish line is dominated by estimated loss rates of more than 77% during 2009 and 2010. These high loss rates are clearly not representative of actual average loss rates of Spanish longline vessels, and cannot be used to extrapolate loss rates for all Spanish line effort as a whole. To illustrate, if an individual vessel sets five identical sets, suffers a complete loss of four sets and stops fishing, the hook loss rate for that vessel is 80%. Subsequently, if other vessels fail to report hook loss, those sets are not retained by the grooming procedure. However, the 80% hook loss estimate cannot then be applied to all effort of that gear type as that would imply that 80% of all sets made in the fishery by that gear type were lost. With such high loss rates it would be impossible for any vessel using this gear type to finish a fishing season. The data suggest that for some vessels hook loss was only reported in those instances in which the entire set, or the majority of the set, was lost and that sets with zero hook loss, or with lower proportions of line loss, were not recorded.

Only one vessel reported use of more than one gear type (Spanish line and trotline), and only two vessels used trotline gear in the groomed dataset, one of which reported gear loss on 100% of sets in 2010. The average hook loss rate by individual vessels was generally low, with the exception of vessels 13, 14 and 15 (Table 5). These three vessels fish autoline, Spanish line and trotline respectively; and these high loss rates correspond to a low number of sets for which gear loss was reported.

The hook loss rate generally increased with depth (Table 6), reflecting the higher loss rates occurring in the more northern SSRUs 881B and 881C (Table 7). Areas with the highest effort (number of sets per unit area) are found in SSRUs 881C and 881H (Figure 2); these two SSRUs also contain individual cells with high loss per unit effort (Figure 3). In general these are not cells with high total effort, hence the high loss rates per unit effort may be an artefact of low sample size. However, there are some individual cells in SSRUs 881C and 882E where a high hook loss rate coincides with a high total number of sets with non-zero hook loss (Figure 4).

Components of lost gear

Table 8 summarises the base-case and lower-bound estimates of numbers of hooks lost attached to sections of longline for all fishing effort by season, and the length of the line associated with those lost hooks. The base case refers to the number of hooks lost if non-reported sets were assumed to have experienced average hook loss rates, as calculated using only those sets for which vessels reported zero or non-zero hook loss. The lower-bound estimate refers to the number of hooks lost if hook loss on non-reported sets was assumed to be zero.

Observer logbook data provide some additional information on gear loss but do not provide sufficient data to inform quantitative estimates of gear loss in the Ross Sea region. Of the observer data available, most fishing gear components were judged to be lost ‘occasionally’, which is more frequently than ‘weekly’, but less frequently than ‘daily’ (Table 9). Only the loss of sections of mainline, which was reported ‘occasionally’ or ‘weekly’, has implications for unaccounted mortality. These data support the assumption, at least for autoline vessels, that some non-zero loss of mainline is very likely to occur sometime during a season in the Ross Sea and Subarea 88.2 fisheries where vessels routinely fish in conditions of partial or high ice cover.

Estimating unaccounted fishing mortality

The reported CPUE in each season-SSRU-vessel category was adjusted to account for the increase in CPUE with increased soak time (Figure 5). If the calculated CPUE for any season-SSRU-vessel was less than the 75th percentile of the overall CPUE distribution (approximately 0.45 kg per hook; see Figure 5), then this value was replaced with the 75th percentile value. The 75th percentile value was chosen because this was the value at which CPUE began to asymptote with increasing soak times (comparing the mean catch rate at longer soak times with the 75th percentile line in Figure 5). Applying the same 75th percentile CPUE adjustment on a season-cell-vessel-specific basis (with cells measuring 0.2° latitude 0.7° longitude) was considered but was not deemed necessary because, although higher catch rates were observed in particular locations at scales smaller than SSRUs, the cell-specific catch rates varied little within SSRUs.

Estimates of the unaccounted fishing mortality with bootstrap variances for all vessels in the years 2008–2011 were determined (Table 10) by applying the mean season-SSRU-specific estimated hook loss rates ($\overline{L}_{hi}$) to the season-SSRU-vessel-specific estimated CPUE ($\overline{y}_{hij}$). These estimates were also generated separately for the shelf, slope and northern areas for the Ross Sea fishery and the slope and north areas of the Subarea 88.2 fishery, to be used in a sensitivity analysis in the Antarctic toothfish stock assessments (Tables 11 and 12; see Mormede et al., 2011a, 2011b).

Discussion

The data show that gear loss varies spatially, with higher hook loss rates and absolute numbers occurring in particular localised cells (detailed in Figure 4), primarily in northern areas (i.e. SSRUs 881C and 882E). The reasons for the high loss index in these particular cells is not clear, but it is thought that gear loss is mainly a consequence of fishing floats being overtaken by moving ice (J. Fenaughty, Silvifish Inc., Wellington, pers. comm.), and that the apparent spatial patterns in Figure 4 are therefore likely to reflect seasonal ice conditions prevailing in those locations when vessels were present. That is, gear loss will be highest in areas where vessels routinely fish in conditions of high ice cover or at times when ice is moving more rapidly (e.g. early in the fishing season prior

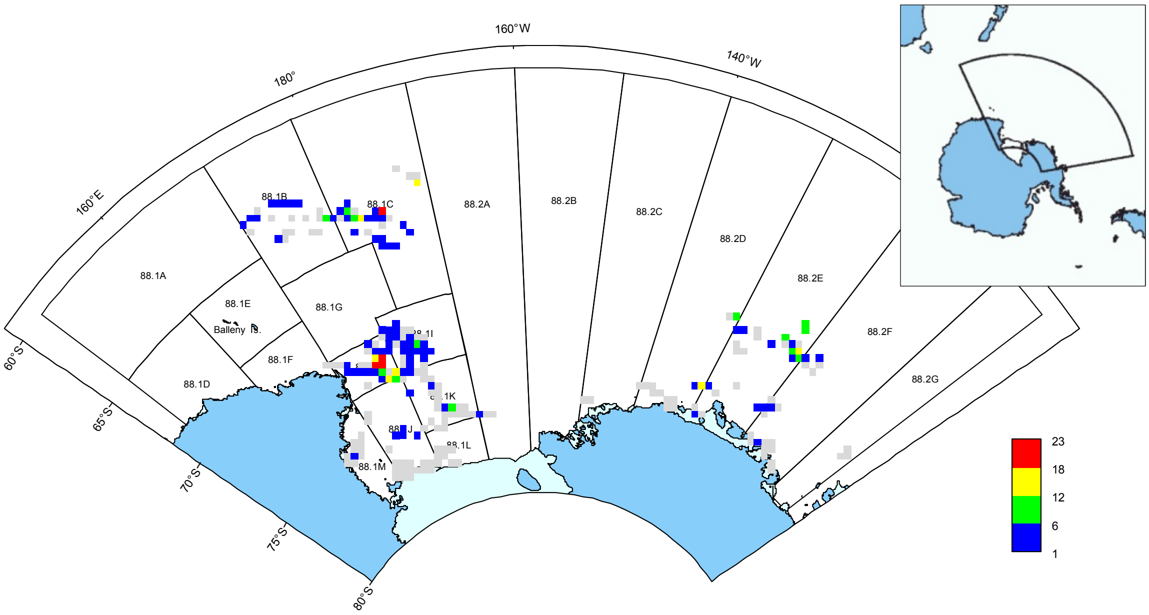

Figure 2: Spatial distribution of the number of sets reporting non-zero hook loss from 2008 to 2011 in Subareas 88.1 and 88.2. Data are summarised by cells measuring 0.2° latitude × 0.7° longitude. Grey cells represent the footprint of the entire fishery since 2008 (i.e. areas where fishing occurred but vessels did not report lost hooks). Insert (top right) shows the location of the study area in relation to the continent of Antarctica.

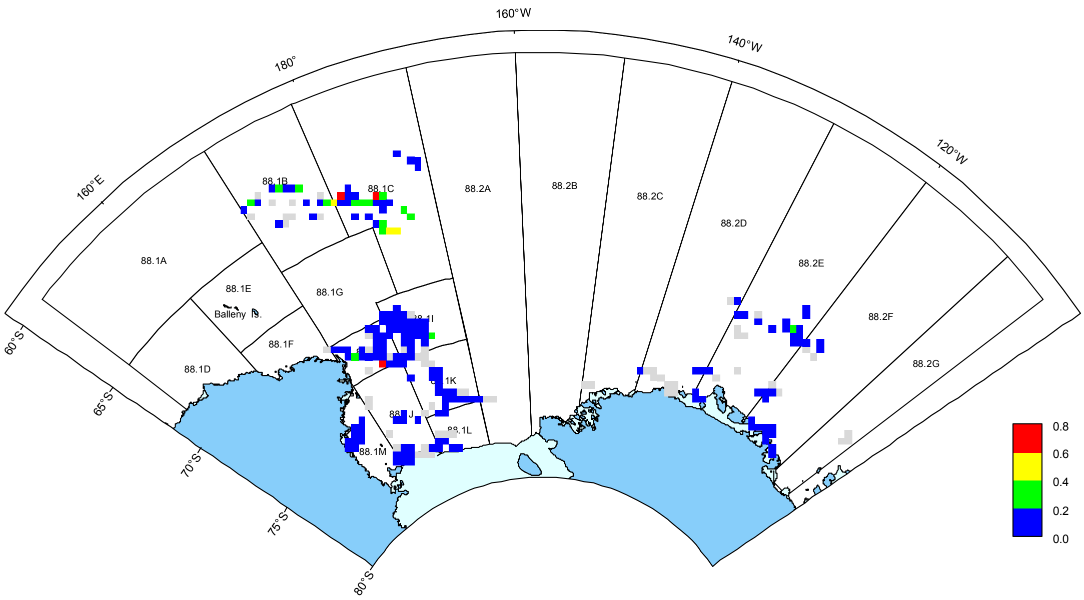

Figure 3: Spatial distribution of estimated hook loss rates (with units hooks lost per hook set) from 2008 to 2011 in Subareas 88.1 and 88.2. Data are summarised by cells measuring 0.2° latitude × 0.7° longitude. Grey cells represent the footprint of the entire fishery since 2008 (i.e. areas where fishing occurred but vessels did not report lost hooks).

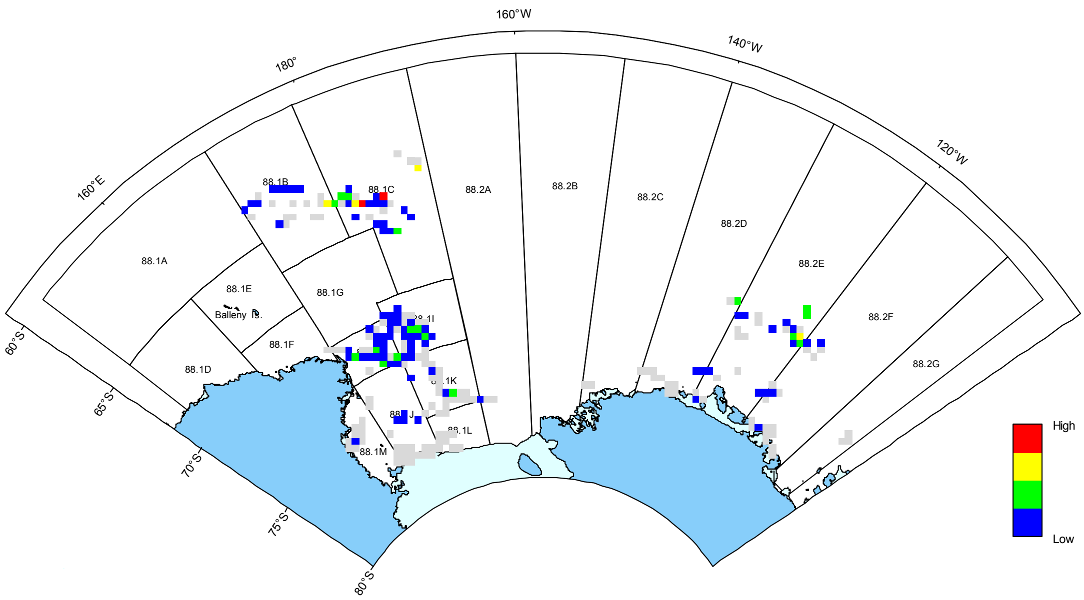

Figure 4: Spatial distribution of the index of hook loss from 2008 to 2011 in Subareas 88.1 and 88.2. The index of hook loss was calculated as the loss rate within a cell multiplied by the number of sets with positive hook loss in that cell. Data are summarised by cells measuring 0.2° latitude × 0.7° longitude. Grey cells represent the footprint of the entire fishery since 2008 (i.e. areas where fishing occurred but vessels did not report lost hooks).

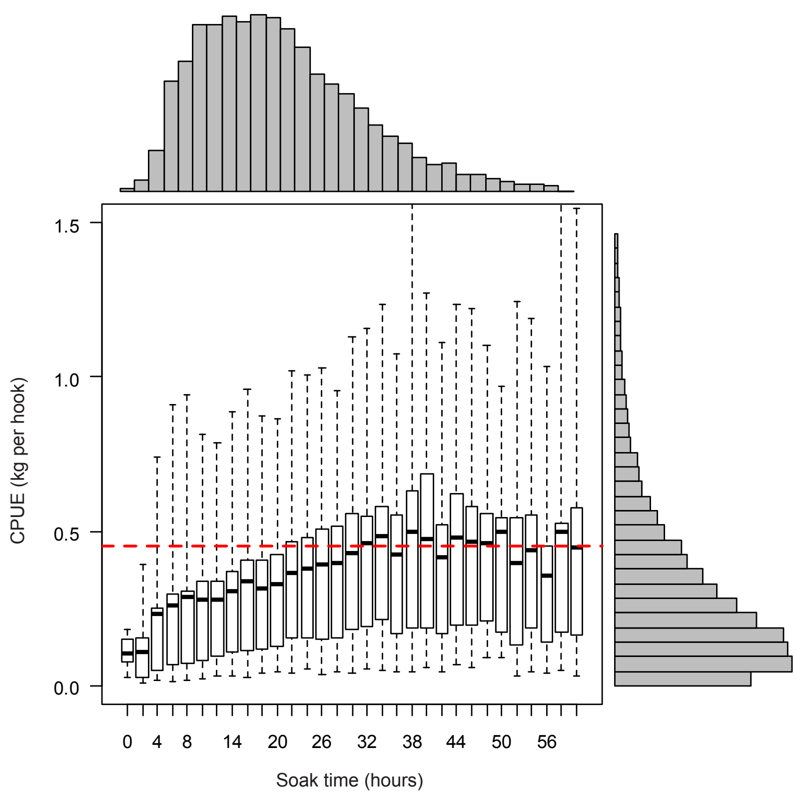

Figure 5: Relationship between soak time (in two-hour intervals) and mean catch rate (kg per hook). The boxes represent the 25th and 75th quantiles, and the whiskers the 5% and 95% quantiles. The dashed line represents the overall 75th quantile. Bars on the top and right axes show the frequency distribution of observations for each variable.

to, and during, the break-out of the Ross Sea polynya). Furthermore, vessels operating in these northern SSRUs are fishing their gear deeper which is also correlated with higher gear loss (Table 6).

More comprehensive reporting of gear loss by all vessels is clearly required to derive more reliable estimates of gear loss for all gear types. The major requirement for reliably estimating unaccounted toothfish mortality associated with lost longline gear is obtaining sufficient data to inform accurate estimates of hook loss rates as a function of season, area and fishing gear type. At present these data are inadequate in the Ross Sea region and Subarea 88.2. An emphasis on improved reporting of the numbers of hooks lost attached to sections of longline gear, as required on the C2 form, is recommended, in particular, to report zero values routinely for sets in which no hooks attached to sections of line are lost. It is further recommended that the C2 instructions clarify the difference between reporting 'hooks lost attached to sections of line' and 'other hooks lost' (i.e. not attached to sections of line) as an aid to improve reporting compliance.

Although more accurately reporting and monitoring the rates of gear loss by fishing vessels would generate better estimates of unaccounted fishing mortality, the number of hooks lost alone does not inform our understanding of the reasons why gear is lost. It is recommended that for every set in which gear is lost, the following information should be recorded by the vessel and/or by the CCAMLR observer (if during an observation period):

(i) the number of hooks lost
(ii) other gear components lost
(iii) a categorical reason for the loss of gear
(iv) the set number.

The categorical reasons could include 'floats lost due to sea-ice', 'floats lost not due to sea-ice', 'mainline broken during gear retrieval' and 'other'. Creating a set-level summary would allow a more quantitative analysis to inform estimates of unaccounted fishing mortality, and may inform actions to reduce the loss of fishing gear in the CAMLR Convention Area.

Quantitative estimates of the mortality associated with lost longline gear are rare. The International Halibut Commission (IPHC) used logbook data to estimate Alaskan halibut (*Hippoglossus stenolepis*) mortality due to lost bottom longline gear, reporting a loss of 1 860 individuals during the 1990 fishing openings (see Barlow and Baake, undated). In another region, the Secretariat of the Pacific Community (SPC) collects data on gear loss in pelagic longline fisheries, but have not yet characterised mortality associated with this gear loss (Macfadyen et al., 2009). If gear loss is a common fishery event, then the mortality of catch (and by-catch) associated with lost gear should be characterised to better inform management decisions.

Conclusion

This analysis suggests that up to 271 tonnes (CPUE-adjusted estimate for the 2010 season) of Antarctic toothfish may be caught and not retrieved in association with lost longline fishing gear in Subareas 88.1 and 88.2 each year. While this may comprise a relatively low proportion of the total fishery harvest, these unaccounted mortality estimates could be included in total fisheries mortality estimates for stock assessment purposes.

Although not considered here, this analysis could also be applied to by-catch species to determine the potential levels of unaccounted fishing mortality from lost gear for other species, for incorporation into future stock assessments. This kind of analysis may also be broadly applicable to other bottom longline fisheries if the loss of fishing gear is reported or can be estimated.

Acknowledgements

We thank vessel operators and scientific observers for the collection of data, and David Ramm and Eric Appleyard for extracting the data and assisting with data interpretation. We also thank members of the New Zealand Antarctic Fisheries Stock Assessment Working Group for helpful discussions and input into this paper. We also thank Mark Belchier and Stephane Thanassekos for their thoughtful review. The project was funded by the New Zealand Ministry of Fisheries under project ANT2010/01.

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Table 1: Total number of hooks set before grooming, number of hooks on those sets retained after the grooming procedure and the proportion of data remaining after grooming by season.

Season	Before	After	Proportion
2008	7 508 266	5 798 834	0.772
2009	8 519 566	4 667 698	0.548
2010	10 185 876	2 595 514	0.255
2011	9 810 586	4 921 213	0.502
Total	36 024 564	17 983 259	0.499

Table 2: Total number of hooks set before grooming, number of hooks on those sets retained after the grooming procedure and the proportion of data remaining after grooming by gear type.

Gear	Before	After	Proportion
Autoline	20 595 962	16 705 357	0.811
Spanish line	14 441 231	874 154	0.061
Trotline	987 371	403 748	0.409
Total	36 024 564	17 983 259	0.499

Table 3: Total number of hooks reported set in the groomed dataset, number of hooks reported lost attached to sections of longline, and estimated hook loss rate from 2008 to 2011.

Season	Hooks set	Hooks lost	Proportion lost
2008	5 798 834	294 754	0.051
2009	4 667 698	192 459	0.041
2010	2 595 514	212 475	0.082
2011	4 921 213	137 794	0.028
Total	17 983 259	837 482	0.047

Table 4: Reported hook loss rate from 2008 to 2011 for each gear type, along with the total number of hooks set, total number of hooks reported lost and overall hook loss rate for all years. The number of sets from which each proportion was derived is shown in parenthesis.

Gear type	2008	2009	2010	2011	Hooks set	Hooks lost	Proportion lost
Autoline	0.050 (805)	0.040 (928)	0.056 (415)	0.030 (744)	16 705 357	714 704	0.042
Spanish line	0.054 (102)	0.778 (1)	0.785 (10)	-	874 154	115 826	0.133
Trotline	-	-	1 (1)	0.011 (94)	403 748	6 952	0.017
Total	0.051 (906)	0.041 (929)	0.082 (426)	0.028 (838)	17 983 259	837 482	0.047

Table 5: Reported hook loss rate by individual vessels each season since 2008. If a vessel did not report any hook loss within a season, then all sets for that season-vessel were removed. The number of sets from which each proportion is derived for each vessel and season is shown in parentheses. A – autoline, S – Spanish line and T – trotline refer to the gear type each vessel fished. 'na' denotes that the vessel did not fish that year while '-' denotes that only zeroes or no data were reported that year.

Vessel	2008	2009	2010	2011
1 A	0.013 (108)	na	na	na
2 A	0.023 (70)	0.001 (91)	0.085 (104)	0.040 (112)
3 A	0.044 (157)	-	-	-
4 A	0.048 (135)	0.028 (163)	na	na
5 S	0.054 (81)	-	-	-
6 S	0.057 (21)	na	na	na
7 A	0.059 (88)	0.011 (113)	0.059 (108)	0.016 (118)
8 A	0.071 (83)	0.066 (146)	-	0.017 (127)
9 A	0.087 (88)	0.034 (150)	na	na
10 A	0.092 (76)	0.028 (74)	0.043 (143)	0.013 (120)
11 A	-	0.029 (64)	na	-
12 A	na	0.055 (111)	0.043 (60)	0.024 (151)
13 A	na	0.390 (16)	na	na
14 T/S	-	0.778 (1)	0.578 (6)	-
15 S	na	-	0.969 (5)	na
16 T	na	na	na	0.011 (94)
17 A	na	na	na	0.063 (116)

Table 6: Total number of hooks reported set, number of hooks reported lost, and estimated hook loss rate by depth (200-m intervals).

Depth (m)	Hooks set	Hooks lost	Proportion lost
500–700	571 845	7 000	0.012
700–900	1 758 129	38 532	0.022
900–1 100	3 942 974	128 549	0.033
1 100–1 300	3 777 748	171 690	0.045
1 300–1 500	5 233 236	209 552	0.040
1 500–1 700	1 899 673	189 498	0.100
1 700–1 900	754 186	73 790	0.098
1 900–2 100	45 468	18 871	0.415

Table 7: Total number of hooks reported set, number of hooks reported lost, and estimated hook loss rate by SSRU. Note that SSRU boundaries were redefined in CM 41-01 in 2011.

SSRU	Hooks set	Hooks lost	Hook loss rate
881B	472 829	76 450	0.162
881C	1 146 913	268 817	0.234
881H	4 969 871	166 407	0.033
881I	3 296 276	111 920	0.033
881J	553 765	3 763	0.007
881K	1 332 095	43 002	0.032
881L	310 160	0	0
881M	1 230 300	2 800	0.002
882C	4 800	0	0
882D	207 697	14 386	0.069
882E	3 223 834	136 963	0.042
882F	1 234 719	12 974	0.011

Table 8: The estimated number of hooks lost by fishing season for the base-case and lower-bound estimates. 'Length' refers to the estimated length of line (km) associated with the number of lost hooks. The 10th and 90th percentiles of the bootstrap distributions are given in parentheses.

Season	Lower bound		Base case	
	Hooks lost	Length	Hooks lost	Length
2008	294 754 (227 787–364 864)	408 (309–509)	387 682 (309 017–466 486)	532 (416–651)
2009	192 212 (151 096–236 587)	281 (222–344)	377 005 (305 030–449 795)	558 (452–668)
2010	212 475 (160 737–266 757)	274 (202–350)	503 138 (399 240–611 378)	613 (477–754)
2011	137 794 (104 931–172 357)	181 (137–228)	268 057 (205 253–330 713)	358 (271–449)

Table 9: Frequency of components of gear loss reported by observers in the Ross Sea region on the L8 form from 2008 to 2011. LD – lost daily, LO – lost occasionally, LW – lost weekly. These data are from six vessels (New Zealand and South Africa).

Gear component	2008			2009			2010			2011		
	LD	LO	LW	LD	LO	LW	LD	LO	LW	LD	LO	LW
Floats/buoys/bobbins	-	4	-	-	5	-	-	3	-	-	3	1
Rope	-	4	1	-	5	1	-	6	-	-	3	1
Sections of mainline	-	4	1	-	7	1	-	6	-	-	3	1
Snoods	5	1	-	7	-	1	7	1	-	5	1	-
Snoods and hooks	6	1	-	7	-	1	7	1	-	5	1	-
Streamer line sections	-	5	-	-	3	-	-	3	-	-	2	-
Weights and anchors	-	4	1	-	7	-	-	5	-	-	3	1
Totals	11	23	3	14	27	4	14	25	0	10	16	4

Table 10: Estimated unaccounted fishing mortality (tonnes) of Antarctic toothfish in Subareas 88.1 and 88.2 combined for the base-case, lower and CPUE-adjusted scenarios from 2008 to 2011. 'Mean annual' refers to the mean estimate derived by analysing by SSRU-vessel (rather than season-SSRU-vessel). The 10th and 90th percentiles of the bootstrap distributions are given in parentheses.

Season	Lower		Base case		CPUE adjusted	
2008	105	(76–137)	129	(97–163)	196	(155–237)
2009	62	(48–76)	129	(100–159)	186	(150–224)
2010	95	(57–135)	199	(140–262)	271	(208–338)
2011	44	(31–58)	88	(60–118)	135	(101–169)
Mean annual	31	(25–37)	156	(124–190)	208	(175–244)

Table 11: Estimated unaccounted fishing mortality (tonnes) of Antarctic toothfish in the Ross Sea fishery using CPUE-adjusted estimates (see Table 10), segregated by 'shelf', 'slope' and 'north'. The 10th percentile and 90th percentile unaccounted catches refer to the 10th and 90th percentiles of the bootstrap distributions.

Year/ area	Fishery catch (tonnes)	10th percentile unaccounted mortality			Mean unaccounted mortality			90th percentile unaccounted mortality		
		Tonnes	% of fishery catch	Total catch	Tonnes	% of fishery catch	Total catch	Tonnes	% of fishery catch	Total catch
Shelf										
2008	60.6	0	0	60.6	0	0	60.6	0	0	60.6
2009	134.5	0.1	0.1	134.6	0.1	0.1	134.6	0.2	0.1	134.7
2010	327.9	20.0	6.1	347.9	45.0	13.7	372.9	73.0	22.3	400.9
2011	483.2	0	0	483.2	0	0	483.2	0	0	483.2
Slope										
2008	1939.0	56.0	2.9	1995.0	78.0	4.0	2017.0	100.0	5.2	2039.0
2009	1904.0	46.0	2.4	1950.0	57.0	3.0	1961.0	68.0	3.6	1972.0
2010	2171.0	148.0	6.8	2319.0	197.0	9.1	2368.0	249.0	11.5	2420.0
2011	2052.0	9.0	0.4	2061.0	14.0	0.7	2066.0	19.0	0.9	2071.0
North										
2008	251.0	91.0	36.3	342.0	117.0	46.6	368.0	142.0	56.6	393.0
2009	392.9	52.0	13.2	444.9	74.0	18.8	466.9	97.0	24.7	489.9
2010	370.0	31.0	8.4	401.0	66.0	17.8	436.0	104.0	28.1	474.0
2011	347.0	51.0	14.7	398.1	75.0	21.6	422.1	100.0	28.8	447.1

Table 12: Estimated unaccounted fishing mortality (tonnes) of Antarctic toothfish for the Subarea 88.2 fishery using CPUE-adjusted estimates (see Table 10), segregated by 'slope' and 'north'. The 10th percentile and 90th percentile unaccounted catches refer to the 10th and 90th percentiles of the bootstrap distributions.

Year/ area	Fishery catch (tonnes)	10th percentile unaccounted mortality			Mean unaccounted mortality			90th percentile unaccounted mortality		
		Tonnes	% of fishery catch	Total catch	Tonnes	% of fishery catch	Total catch	Tonnes	% of fishery catch	Total catch
Slope										
2008	0	0	0	0	0	0	0	0	0	0
2009	156.8	3.0	1.9	159.8	5.0	3.2	161.8	7.0	4.5	163.8
2010	0	0	0	0	0	0	0	0	0	0
2011	161.5	0	0	161.5	1.0	0.6	162.5	2.0	1.2	163.5
North										
2008	415.8	0	0	415.8	6.0	1.4	421.8	11.0	2.6	426.8
2009	326.9	34.0	10.4	360.9	51.0	15.6	377.9	70.0	21.4	396.9
2010	314.3	0	0	314.3	0	0	314.3	0	0	314.3
2011	406.2	35.0	8.6	441.2	50.0	12.3	456.2	65.0	16.0	471.2