Reducing bycatch:

Do hook shape and size matter?

CFL Hunter – 06/07 – 2017

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April 24th 2018

Summary

The Falkland Islands Fisheries Department aims to have a better understanding of the impacts of fishing on marine resources, habitats, and ecosystems. One of the conditions set out by the Marine Stewardship Council (MSC) as part of the successful application of CFL for MSC certification for Patagonian toothfish (*Dissostichus eleginoides*) is to research options that may lead to a decrease in bycatch. One of the commonest bycatch species in the toothfish longline fishery is grenadier (*Macrourus holotrachys*), a species making up over 6% of the total catch. A hook trial was undertaken to determine whether changing the size and shape of hooks could decrease grenadier bycatch without decreasing toothfish yields and negatively impacting on other bycaught species. The trial consisted on 52 lines deployed in 13 grid squares; each line consisting of three full replicates of four different types of hooks. Overall, preliminary analyses indicate that toothfish catch, average size of toothfish, and proportion of toothfish caught on a line is not affected statistically by hook type. Furthermore, analyses indicate that *Antimora* and grenadier bycatch and proportion of catch for the respective species are not statistically affected by hook type. However, hook type was shown to explain a proportion of the variance in averaged models of 10, 42, and 15% for toothfish catches, average weight, and proportion of the catch, respectively. For Antimora and grenadier, these values were 16, 1, and 0% for the former, and 22, 10, and 15% for the latter, respectively. These results highlight that a large proportion of the variance in the models remains unaccounted for. However, it must be noted that models including interactions between the different sets of variables have not been run. In conclusion, no single hook type investigated outperforms any other nor affect amount (by weight) of target or bycatch species. It seems that another survey on trials with different, perhaps larger, hook sizes and shapes would be necessary to reduce bycatch in the Falkland Islands toothfish longline fishery.

Introduction

The Falkland Islands Fisheries Department aims to have a better understanding of the impacts of fishing on marine resources, habitats, and ecosystems. The Marine Stewardship Council (MSC) has identified gaps in our understanding and has set conditions that we will need to meet in order to fill those gaps. Specifically, one of the *Conservation and Management Objectives* laid out in the **Sustainability Measures** as part of the successful application of CFL for MSC certification for Patagonian toothfish (*Dissostichus eleginoides*) is: "*To research options that may lead to the minimisation of toothfish by-catch on the shelf.*" In the Falkland Islands toothfish fishery by longline, common by-catch species are grenadier (*Macrourus holotrachys*), blue Antimora (*Antimora rostrata*), and skates (primarily *Amblyraja georgiana*, *Bathyraja meridionalis*, *B. multispinus*, and *B. papilonifera*). Less common are sleeper (*Somniosus pacificus*) and porbeagle (*Lamna nasus*) sharks. Overall, by-catch in this fishery accounts for approximately 11% of the total catch, but only grenadier exceed 5% (Table 1). In an effort to reduce by-catch, especially of grenadier, a hook trial was designed and tested during the June/July 2017 pulsed-tagging research cruise.

Objective

The objective of this trial was to determine the efficacy of different hook size/design on the reduction of grenadier bycatch without negatively impacting on toothfish catches and size or increasing by-catch of other bycatch species.

Study Area

The hook trial took place on the same 52 lines from which toothfish were tagged (four from each of 13 grid squares, respectively) (Randhawa et al 2017) (Fig 1). Adult Patagonian toothfish were targeted along the edge of the continental slope and deep water plains within the three regions of the FICZ/FOCZ as defined in Randhawa & Lee (2016). The Burdwood Bank was closed to fishing during the proposed timing of the pulsed-tagging research cruise. Hence, special permission was granted for limited sampling from this region (E-licence) in grid squares YCAT and YAAS.

Overall, four lines of 480 umbrellas each were set in one grid square (YCAT) and four lines of 432 umbrellas each were set in 12 grid squares (Fig 1), for a total of 52 individual

Table 1. Catch composition of the longline fishery (2008-2016) in Falkland Islands waters, including catch (kg) for each species group and percent of the total catch.

		2008	2009	2010	2011	2012	2013	2014	2015	2016
Toothfish	TOO	1,368,044	1,133,719	943,208	1,220,778	1,085,061	1,302,172	1,252,325	1,123,301	1,022,931
		90.56%	90.44%	89.13%	87.13%	89.25%	88.30%	91.21%	89.54%	88.69%
Grenadier Species	GRX	94,954	77,568	74,857	99,893	76,725	68,901	57,343	70,746	75,053
		6.29%	6.19%	7.07%	7.13%	6.31%	4.67%	4.18%	5.64%	6.51%
Skate/Ray	RAY	27,828	21,634	22,819	55,134	32,280	77,660	31,950	27,578	28,790
		1.84%	1.73%	2.16%	3.93%	2.66%	5.27%	2.33%	2.20%	2.50%
Blue Antimora	ANR	13,841	10,119	11,532	21,993	18,121	16,378	13,779	23,635	23,984
		0.92%	0.81%	1.09%	1.57%	1.49%	1.11%	1.00%	1.88%	2.08%
Greenland Shark	SOM	4,600	8,465	3,377	2,115	3,145	3,123	4,535	3,396	2,005
		0.30%	0.68%	0.32%	0.15%	0.26%	0.21%	0.33%	0.27%	0.17%
Porbeagle	POR	1,275	2,085	595	1,110	450	692	675	860	565
		0.08%	0.17%	0.06%	0.08%	0.04%	0.05%	0.05%	0.07%	0.05%
Red Cod	BAC	0	0	0	0	0	23	0	0	0
		0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Notothenid (*ramsayi*)	COX	0	0	3	0	0	0	0	0	0
		0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Hake (Common)	HAK	0	0	0	0	0	53	0	0	0
		0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Hake (Austral)	PAT	0	0	0	0	0	3	0	0	0
		0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Moonfish	LAR	0	0	55	0	0	0	0	0	0
		0.00%	0.00%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Jellyfish	MED	0	0	514	0	0	0	0	0	0
		0.00%	0.00%	0.05%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Crab	CRB	42	4	1,329	149	26	5,649	7,463	4,946	0
		0.00%	0.00%	0.13%	0.01%	0.00%	0.38%	0.54%	0.39%	0.00%
Total		**1,510,584**	**1,253,594**	**1,058,289**	**1,401,172**	**1,215,808**	**1,474,654**	**1,368,070**	**1,254,462**	**1,153,328**

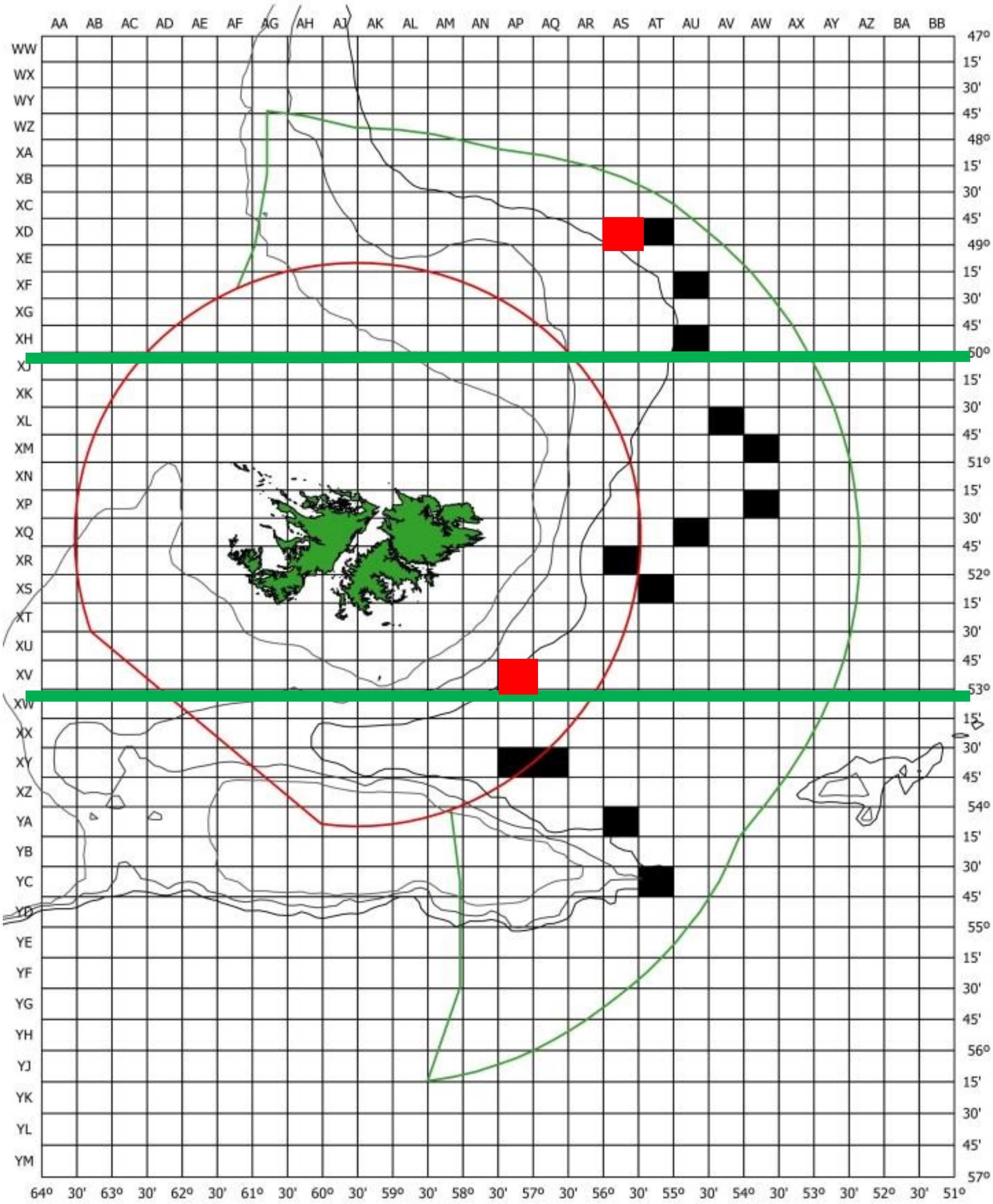

Figure 1. Map of the Falkland Islands Inner (red outline) and Outer (thin green outline) Conservation zones showing the distribution of proposed grid squares in which toothfish pulsed-tagging activities took place in June/July 2017 on board the CFL *Hunter*. Isobaths shown reflect the 200, 500, and 1,000m depth contours. The four grid squares lying south of 53.0° S (lower green line) are assigned to the southern area, the seven lying between 50.0 and 53.0° S are assigned to the eastern area, whereas the four lying north of 50.0° S (upper green line) are assignable to the north eastern area. Grid squares highlighted in red represent those dropped from the initial cruise plan due to mechanical and staffing issues.

lines or 22,656 umbrellas. Of these grid squares, 4 were from the southern area off Burdwood Bank, 6 in the eastern area, and 3 in the north eastern area (Fig 1).

Grid squares were selected on the basis of the CFL Gambler fishing effort and catches over the previous two years and are likely targets for the CFL Hunter as it commences commercial activities. As such, these areas are likely to yield good catches for tagging purposes and are likely to be areas of higher recapture probabilities due to the high site fidelity exhibited by toothfish.

Methods

The hook trial consisted of four different types of hooks: (1) current J-hook (APS A Poutada 10/0); (2) larger J-hook (J13/0); (3) circular hook (size 14/0); and (4) circular hook (size 15/0) (Fig 2). Each of the 52 lines included 12 different sections of 40 (or 36) umbrellas (six hooks per umbrella) for a total of 480 (or 432) umbrellas per line. Each section was assigned at random a hook type. Therefore, there were three replicates of each hook type randomly assigned on each line. Furthermore, all 52 lines were randomly assigned to a grid square and their order of setting within each grid square was also determined at random. Table 2 summarises the random set up of each line and the order in which they were set.

For each umbrella we collected the: (1) number of toothfish; (2) individual length of each toothfish; and (3) number of individual bycatch, recorded by species. Weights for individual toothfish were derived from total length using a relationship based on 20+ years of length-weight data in the Fisheries Observer database. Green weights (for toothfish and each bycatch species) were collated by section of line and then by hook type.

Data analyses

Historically, longline vessels have not weighed individual bycatch species. Rather, they have applied a weight coefficient of 10 kg per skate, 1.5 kg per grenadier and 1 kg per Antimora, respectively. Weights for sharks are generally estimated. Since these coefficients have not been reviewed in recent years, this cruise presented an opportunity, not only to review the coefficients, but to determine whether hooks of different shapes and sizes affect these

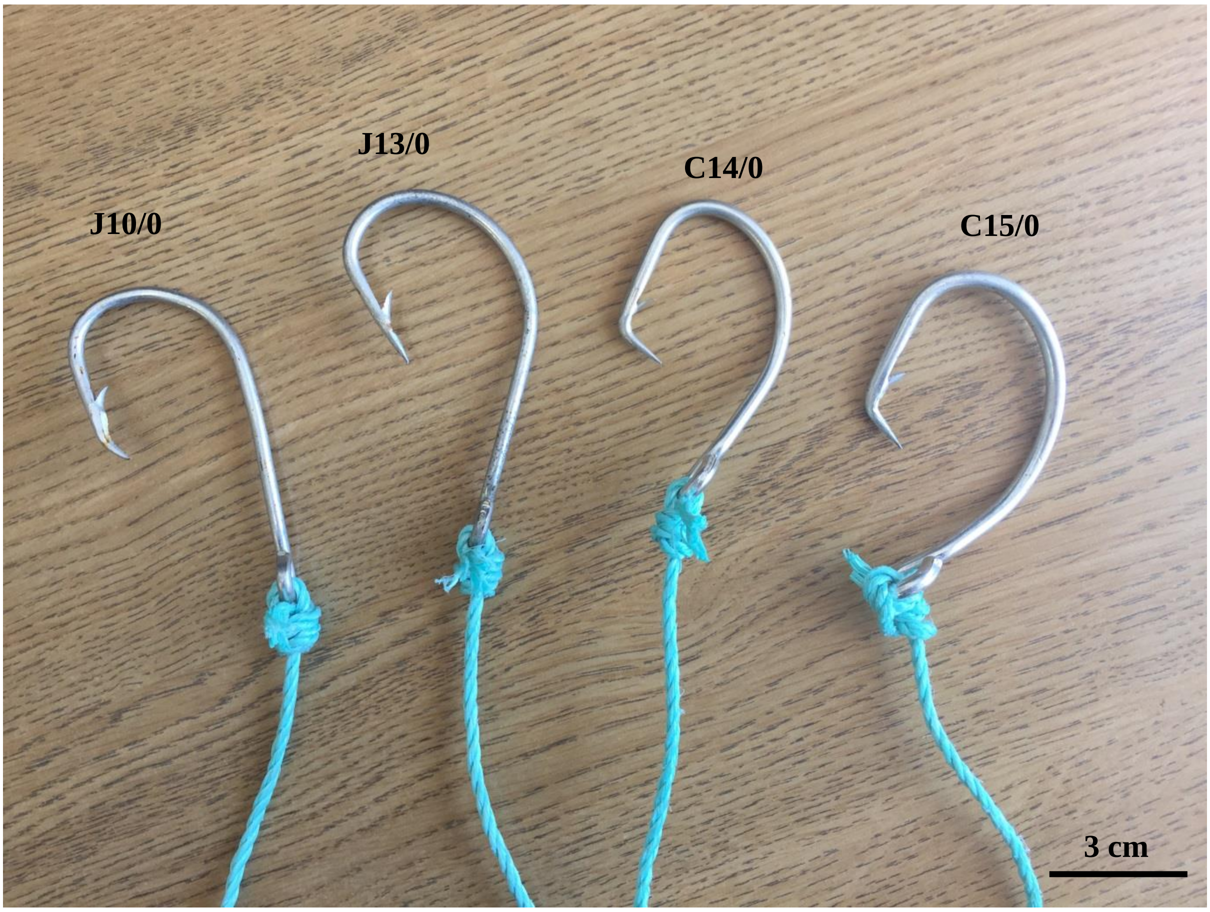

Figure 2. Photograph of the four hook types trialled during the research cruise: (left) current hook used in the longline fishery by CFL (J10/0); (second from the left) J13/0 hook, note the straight point, longer barb, shorter gap, and curved bend compared to J10/0 hook; (second from the right) C14/0 hook, note the curved throat, straighter bend, and curved point; and (right) C15/0, note the larger gap than the C14/0 hook.

coefficients. For the purpose of an initial exercise, we have applied two sets of revised coefficients to 2015/16 catches (combined). The first coefficient is based on Fisheries Observer data for 2015/16 and the second one is based on weights obtained from this research cruise for J10/0 hooks only. These hooks are the ones currently and historically used by the longline vessel exploiting waters in the FICZ/FOCZ to identify the different factors affecting catch (in kg) of the different species (toothfish and respective bycatch), the average weights of different species, and the proportion of the catch (response variables), we used generalized linear models (GLM) with Gaussian error distribution and identity-link function with latitude, depth, soak time, hook type, and hook shape as fixed effects. Analyses were re-run as generalized linear mixed models (GLMM) with hook type and shape as random effects. All second-degree interactions between predictor variables were compared using GLM to models incorporating main effects included in the interaction. The evidence ratio between the model including the interaction term and the "best" model from each set (based on AICc), was used to determine whether the inclusion of the interaction term improved the model significantly. A multi-model inference approach was performed using the package MuMIn implemented in R.

Table 2. Randomised design of each line where three full replicate of hook types are randomly assigned to sections of each line, each line is randomly assigned a line number, each line is randomly assigned to a grid square, and the order of setting within each grid square is randomised.

Grid	SetOrder	1	2	3	4	5	6	7	8	9	10	11	12
YCAT	1	Yellow	Black	Yellow	Yellow	Red	Black	Blue	Red	Black	Blue	Blue	Red
	2	Blue	Blue	Black	Yellow	Yellow	Black	Blue	Red	Yellow	Red	Red	Black
	3	Red	Yellow	Blue	Yellow	Red	Blue	Yellow	Red	Blue	Black	Black	Black
	4	Red	Blue	Yellow	Black	Red	Blue	Black	Blue	Black	Yellow	Red	Yellow
YAAS	1	Red	Blue	Yellow	Red	Black	Blue	Blue	Black	Red	Black	Yellow	Yellow
	2	Yellow	Yellow	Red	Blue	Yellow	Blue	Red	Red	Black	Black	Black	Blue
	3	Yellow	Black	Black	Blue	Red	Blue	Yellow	Black	Blue	Red	Yellow	Red
	4	Yellow	Yellow	Blue	Red	Black	Blue	Black	Blue	Red	Red	Black	Yellow
XYAQ	1	Yellow	Red	Blue	Black	Blue	Black	Yellow	Red	Yellow	Blue	Red	Black
	2	Yellow	Black	Blue	Blue	Yellow	Black	Blue	Black	Red	Red	Red	Yellow
	3	Black	Red	Yellow	Blue	Black	Yellow	Red	Blue	Blue	Red	Black	Yellow
	4	Blue	Yellow	Black	Yellow	Blue	Red	Red	Red	Blue	Black	Black	Yellow
XYAP	1	Red	Black	Yellow	Yellow	Black	Blue	Yellow	Red	Red	Blue	Blue	Black
	2	Red	Black	Black	Yellow	Black	Red	Blue	Red	Yellow	Yellow	Blue	Blue
	3	Yellow	Yellow	Red	Blue	Yellow	Blue	Red	Red	Black	Black	Black	Blue
	4	Black	Yellow	Black	Yellow	Blue	Red	Red	Blue	Black	Yellow	Blue	Red
XSAT	1	Black	Yellow	Black	Yellow	Blue	Red	Red	Red	Black	Yellow	Blue	Red
	2	Blue	Black	Blue	Yellow	Red	Yellow	Black	Yellow	Red	Black	Blue	Red
	3	Blue	Blue	Black	Yellow	Yellow	Black	Blue	Red	Yellow	Red	Red	Black
	4	Red	Yellow	Yellow	Blue	Black	Blue	Black	Black	Red	Yellow	Red	Blue
XRAS	1	Blue	Yellow	Red	Blue	Red	Black	Yellow	Black	Yellow	Blue	Red	Black
	2	Blue	Yellow	Yellow	Black	Red	Black	Blue	Blue	Red	Yellow	Red	Black
	3	Yellow	Black	Blue	Red	Black	Black	Yellow	Blue	Blue	Yellow	Red	Red
	4	Blue	Red	Yellow	Red	Black	Black	Black	Blue	Yellow	Yellow	Red	Blue
XQAU	1	Yellow	Red	Black	Yellow	Blue	Blue	Yellow	Black	Blue	Red	Red	Black
	2	Blue	Yellow	Red	Blue	Red	Black	Yellow	Black	Yellow	Blue	Red	Blue
	3	Blue	Black	Yellow	Blue	Red	Red	Red	Yellow	Yellow	Black	Black	Blue
	4	Red	Blue	Yellow	Black	Red	Blue	Black	Blue	Black	Yellow	Red	Yellow
XPAW	1	Red	Red	Yellow	Black	Yellow	Yellow	Red	Black	Blue	Black	Blue	Blue
	2	Black	Black	Black	Red	Yellow	Blue	Blue	Yellow	Red	Red	Blue	Yellow
	3	Black	Blue	Black	Yellow	Red	Blue	Red	Red	Yellow	Black	Blue	Yellow
	4	Black	Yellow	Blue	Black	Black	Yellow	Blue	Red	Red	Blue	Red	Yellow
XMAW	1	Yellow	Blue	Black	Red	Yellow	Red	Black	Black	Red	Yellow	Blue	Blue
	2	Red	Blue	Yellow	Red	Black	Blue	Blue	Black	Red	Black	Yellow	Yellow
	3	Black	Black	Yellow	Yellow	Blue	Yellow	Blue	Black	Red	Blue	Red	Red
	4	Red	Yellow	Blue	Yellow	Red	Blue	Yellow	Black	Blue	Black	Black	Black
XLAV	1	Yellow	Blue	Black	Red	Yellow	Red	Black	Black	Red	Yellow	Blue	Blue
	2	Blue	Red	Yellow	Red	Black	Black	Black	Blue	Yellow	Yellow	Red	Blue
	3	Black	Blue	Yellow	Black	Red	Black	Red	Red	Blue	Yellow	Blue	Yellow
	4	Red	Black	Black	Yellow	Black	Red	Blue	Red	Yellow	Yellow	Blue	Blue
XHAU	1	Yellow	Red	Blue	Yellow	Red	Yellow	Black	Red	Blue	Black	Blue	Black
	2	Blue	Yellow	Yellow	Black	Red	Black	Blue	Blue	Red	Yellow	Red	Black
	3	Blue	Red	Red	Black	Black	Blue	Yellow	Yellow	Red	Black	Blue	Yellow
	4	Red	Black	Yellow	Red	Blue	Black	Black	Blue	Yellow	Yellow	Red	Blue
XFAU	1	Yellow	Red	Blue	Yellow	Black	Black	Red	Red	Blue	Yellow	Blue	Black
	2	Blue	Red	Red	Black	Black	Blue	Yellow	Yellow	Red	Black	Blue	Yellow
	3	Black	Blue	Black	Yellow	Red	Blue	Red	Red	Yellow	Black	Blue	Yellow
	4	Red	Black	Yellow	Red	Blue	Black	Black	Blue	Yellow	Yellow	Red	Blue
XDAT	1	Yellow	Yellow	Blue	Red	Black	Blue	Black	Blue	Red	Red	Black	Yellow
	2	Yellow	Red	Blue	Yellow	Black	Black	Red	Blue	Black	Red	Yellow	Blue
	3	Yellow	Blue	Yellow	Red	Blue	Blue	Black	Black	Red	Black	Red	Yellow
	4	Red	Red	Blue	Black	Black	Black	Yellow	Red	Yellow	Blue	Yellow	Blue

Current J-hook; Larger J-hook; Circular hook (16/0); Circular hook (17/0)

Results

Overall, 52 lines, 624 sections, and 22,656 umbrellas were sampled. A total of 8,894 individual toothfish were measured, and 3,576 grenadiers and 3,003 Antimora were weighed. The total weight of toothfish measured was 98.04 mt.

Table 3 summarises the exercise of applying different coefficients to the 2015/16 cumulative catch. Applying the 2015/16 Fisheries Observer coefficients, we find that the average weights for rays, grenadiers, and Antimora are 11.6571 kg, 1.4924 kg, and 1.5697 kg, respectively. Applying the research cruise J10/0 hook coefficients, we find that the average weights for rays, grenadiers, and Antimora are 12.7540 kg, 1.4438 kg, and 1.5750 kg, respectively.

Catches

TOO

From the GLMM analyses, we found that hook type and shape explained 10% and 0% of the variance in toothfish catches, respectively. Using GLM, we determined that the interaction between Depth and Soak time (model weight > 0.99) outperformed the model including both main effects (delta-AICc of 10.97). Furthermore, our model averaging approach identifies this interaction and its main effects as the only predictors affecting toothfish catches in our study, i.e. toothfish catches are greater with both increasing depth and soak time.

GRH

From the GLMM analyses, we found that hook type and shape explained 22% and 0% of the variance in grenadier catches, respectively. Using GLM, we determined that the interaction between Latitude and Hook type (model weight = 0.50) outperformed the model including both main effects (delta-AICc of 0.11), albeit not significantly from a statistical perspective. Additionally, the interaction between Depth and soak time (model weight = 0.63) outperformed statistically the model including both main effects (delta-AICc of 2.07). Our model averaging approach determined that neither of these interactions explained a significant proportion of the variance in the model. In fact, only Latitude and Depth were identified as predictors affecting grenadier catches, i.e. grenadier catches are greater at lower latitudes (northern parts of the fishing area) and decrease substantially with depths exceeding 1500 m.

ANR

From the GLMM analyses, we found that hook type and shape explained 17% and 0% of the variance in Antimora catches, respectively. Using GLM, we determined that the interaction between Latitude and Soak time (model weight = 0.50) outperformed the model including both main effects (delta-AICc of 0.65), albeit not significantly from a statistical perspective. Also, we determined that the interaction between Latitude and Depth (model weight = 0.94) outperformed statistically the model including both main effects (delta-AICc of 6.01). The model averaging approach determined that neither of these interactions explained a significant proportion of the variance in the model. In fact, only Hook type was identified as a predictor affecting Antimora catches, i.e. Antimora catches are lowest using current J/10 hook type.

Average weights

TOO

From the GLMM analyses, we found that hook type and shape explained 42% and 0% of the variance in the average weight of toothfish caught on the line, respectively. Using GLM, we determined that the interactions between Latitude and Depth (model weight = 0.30), Latitude and Soak time (model weight = 0.67), and Depth and Soak time (model weight = 0.53) outperformed the model including both main effects (delta-AICc of 0.39, 1.60, and 0.23, respectively), albeit not significantly from a statistical perspective. Furthermore, our model averaging approach identifies Depth, Latitude, and Soak time as the only predictors affecting the average weight of a toothfish caught in our study, i.e. toothfish individual weights are greater with both increasing depth and soak time at latitudes nearer to the pole.

GRH

From the GLMM analyses, we found that hook type and shape explained 10% and 0% of the variance in the average weight of grenadier caught on the line, respectively. Using GLM, we determined that the interactions between Latitude and Soak time (model weight > 0.99), and Depth and Soak time (model weight = 1.00) outperformed statistically the model including both main effects (delta-AICc of 11.09 and 14.35, respectively). Furthermore, our model averaging approach identifies Depth, and the interaction between Depth and Soak time as the only predictors affecting the average weight of a grenadier caught in our study, i.e. grenadier individual weights are greater with increasing soak time, but in shallower waters only.

ANR

From the GLMM analyses, we found that hook type and shape explained 1% and 0% of the variance in the average weight of antimora caught on the line, respectively. Using GLM, we determined that the interaction between Latitude and Depth (model weight = 0.67) outperformed the model including both main effects (delta-AICc of 2.83), albeit not significantly from a statistical perspective. However, we determined that the interaction between Latitude and Soak time (model weight = 1.00) outperformed statistically the model including both main effects (delta-AICc of 25.20). Furthermore, our model averaging approach identifies this interaction and its individual effects as the only predictors affecting the average weight of an Antimora caught in our study, i.e. Antimora individual weights are greater with both shorter soak times at increasing latitudes.

Proportion of the catch

TOO

From the GLMM analyses, we found that hook type and shape explained 15% and 0% of the variance in the proportion of the catch made up of toothfish, respectively. Using GLM, we determined that no single interaction outperformed models including both main effects. Furthermore, our model averaging approach identifies Soak time as the only predictor affecting the proportion of the catch made up of toothfish, i.e. increasing soak time leads to increasing the toothfish proportion of the catch.

GRH

From the GLMM analyses, we found that hook type and shape explained 15% and 0% of the variance in the proportion of the catch made up of grenadier, respectively. Using GLM, we determined that no single interaction outperformed models including both main effects. Furthermore, our model averaging approach identifies Depth, Latitude, and Soak time as the only predictors affecting the proportion of the catch made up of grenadier, i.e. decreasing soak time at shallower depths at grater latitudes increases the grenadier proportion of the catch.

ANR

From the GLMM analyses, we found that hook type and shape explained none of the variance in the proportion of the catch made up of Antimora. Using GLM, we determined that the interaction between Latitude and Depth (model weight = 0.94) outperformed statistically the model including both main effects (delta-AICc of 6.01). However, our model averaging approach identifies only Soak time as the predictor marginally affecting the proportion of the catch made up of Antimora caught in our study, i.e. decreasing soak time increases the Antimora proportion of the catch.

Species summaries

Overall, no single hook outperforms any other in terms of toothfish catches, average weight, and respective proportion of the catch. However, there are some trends observed even if not statistically significant: large J-hooks (J13/0) catch more toothfish (Fig 3), but of smaller average size (Fig 4), whereas the currently used hooks (J10/0) catch fewer toothfish of larger average size (Figs 3, 4). In terms of the proportion of the catch, using large J-hooks leads to toothfish representing a smaller overall proportion of the catch (by weight), whereas the currently used hook leads to toothfish making up a larger proportion of the catch. Both types of C-hooks are intermediate in their catch, average size of toothfish, and proportion of the catch made up of toothfish (Fig 5).

For bycatch species, no single hook significantly decreases their catch, average weight, and their respective proportion of the catch. However, as above, there are some observed trends, albeit none is statistically significant. For Antimora, these trends are that larger J-hooks lead to greater catches of Antimora, whereas currently used J-hooks catch generally fewer Antimora (Fig 6). Once more, both types of C-hooks are intermediate in their catches of Antimora. Neither average Antimora size nor the proportion of the catch made up of Antimora is affected by hook size/shape. For grenadier, these trends are that C-hooks catch more (by weight) grenadier than J-hooks, with larger C- and J-hooks catching more (by weight) than their small counterparts (Figs 7), respectively. Furthermore, larger C- and J-hooks catch larger grenadier than their smaller counterparts (Fig 8), respectively, and grenadier make up a greater proportion of the catch when using C-hooks (Fig 9).

Table 3. Revised proportion of the catch (by species) only including toothfish, grenadiers, Antimora, sleeper sharks, porbeagle sharks, crabs, and skates. The revised coefficients are based on 2015/16 Fisheries observer data and J10/0 hooks calculated from this research cruise .

	Toothfish	**Grenadiers**	**Antimora**	***Somniosus* sp.**	***Lamna* sp.**	**Skates**	**Crabs**	**Total**
2015/16 (Current)	2,146,232 kg (89.33%)	145,748 kg (6.07%)	47,619 kg (1.98%)	5,416 kg (0.23%)	1,170 kg (0.05%)	56,368 kg (2.35%)	158 kg (<0.01%)	2,402,711 kg
Fisheries Observers	2,146,232 kg (88.01%)	145,009 kg (5.95%)	74,746 kg (3.07%)	5,416 kg (0.22%)	1,170 kg (0.05%)	65,814 kg (2.70%)	158 kg (<0.01%)	2,438,545 kg
J10/0 hook – this cruise	2,146,232 kg (87.95%)	140,287 kg (5.75%)	75,000 kg (3.07%)	5,416 kg (0.22%)	1,170 kg (0.05%)	71,891 kg (2.95%)	158 kg (<0.01%)	2,440,155 kg

Discussion

Overall, preliminary results herein demonstrate that there is no easy answer to reduce grenadier bycatch and that further efforts need to be conducted on several different fronts to adequately address this issue, e.g alternating hook shapes and sizes depending on area fished or better managing fishing effort by area to manipulate bycatch ratios. However, another key point is that none of the hooks trialled significantly reduces toothfish yields.

Comparing the different coefficients applied to the 2015/16 longline catch demonstrates the need to review these coefficients even though none of these result in grenadier bycatch falling below the 5% threshold. Assuming the same type of hook continues to be used by CFL, perhaps applying a coefficient derived from more contemporary Fisheries Observer data should be prioritised. Furthermore, these coefficients are likely to vary between areas, therefore, a spatial analysis of different species sizes needs to be undertaken to determine if this is the case and what coefficients need to be applied in different grid squares.

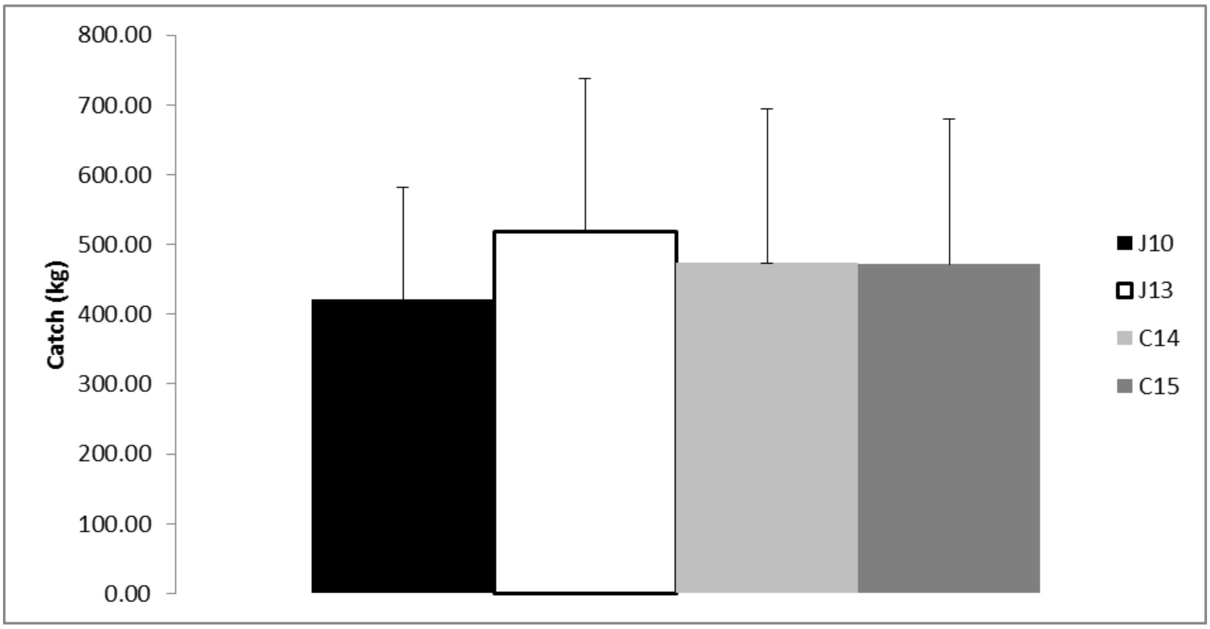

Figure 3. Comparison of average toothfish catch per line (three sections; 108 umbrellas) using different hook types. Error bars represent standard deviations. Hook type explains 10% of the overall variance in toothfish catches.

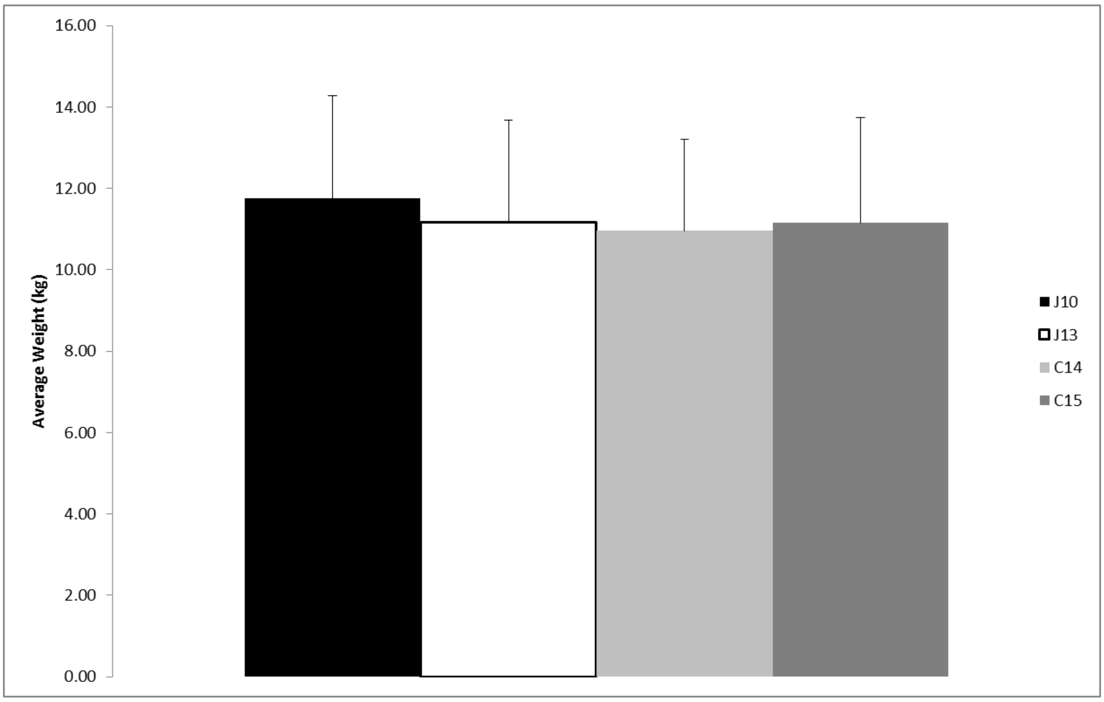

Figure 4. Comparison of average toothfish weights per hook type per line (three sections; 108 umbrellas). Error bars represent standard deviations. Hook type explains 42% of the overall variance in average toothfish weights.

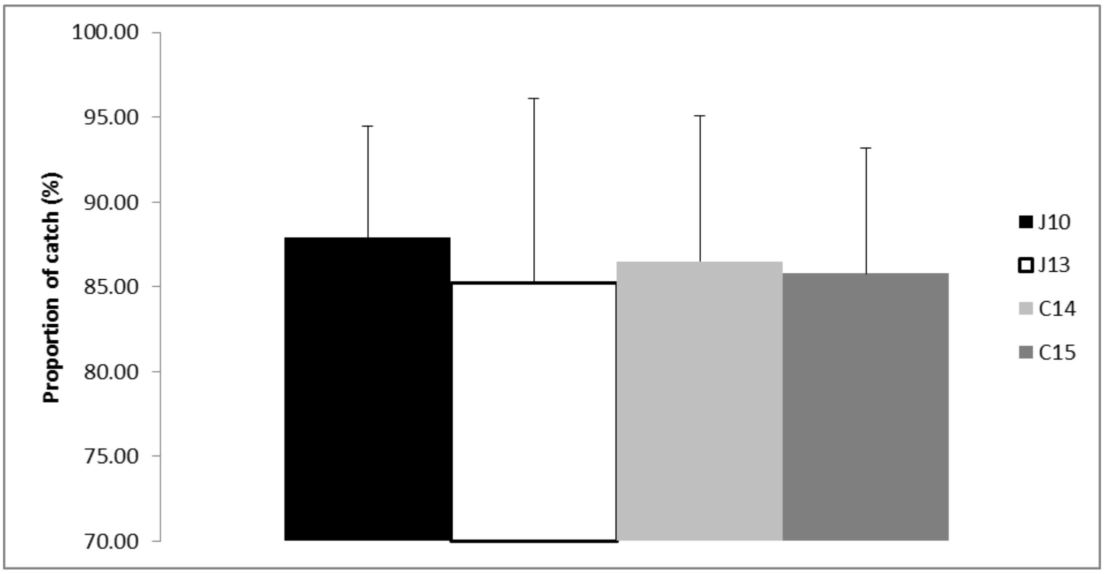

Figure 5. Comparison of average proportion of the catch made up of toothfish per hook type per line (three sections; 108 umbrellas). Error bars represent standard deviations. Hook type explains 15% of the overall variance in proportion of the catch made up of toothfish.

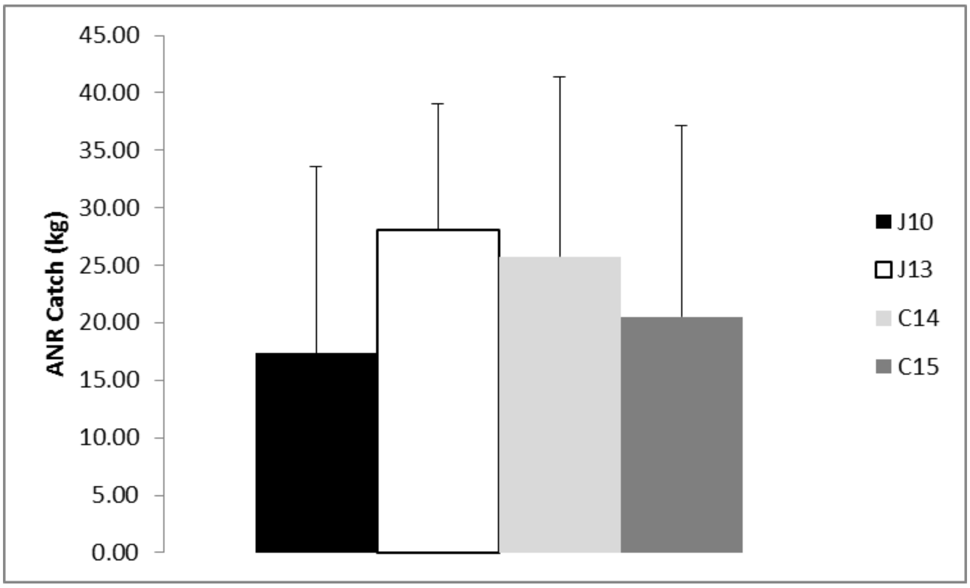

Figure 6. Comparison of average Antimora catch per line (three sections; 108 umbrellas) using different hook types. Error bars represent standard deviations. Hook type explains 17% of the overall variance in Antimora catches.

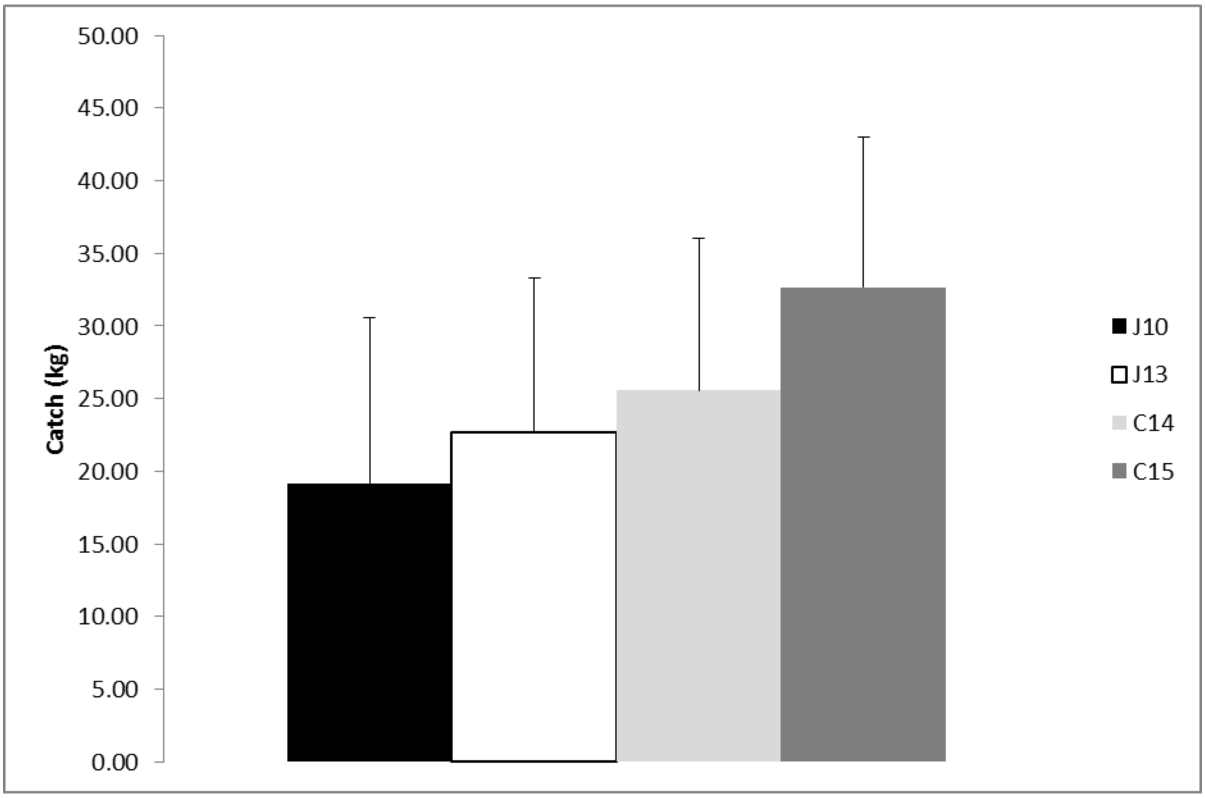

Figure 7. Comparison of average grenadier catch per line (three sections; 108 umbrellas) using different hook types. Error bars represent standard deviations. Hook type explains 22% of the overall variance in grenadier catches.

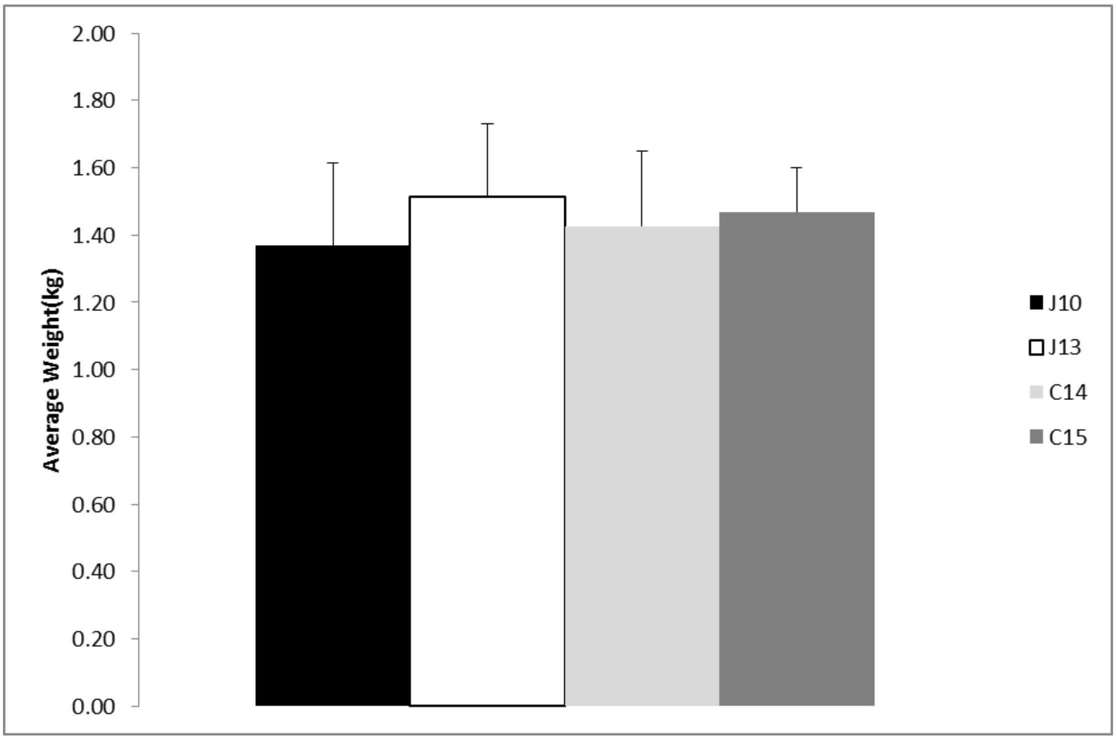

Figure 8. Comparison of average grenadier weights per hook type per line (three sections; 108 umbrellas). Error bars represent standard deviations. Hook type explains 10% of the overall variance in average grenadier weights.

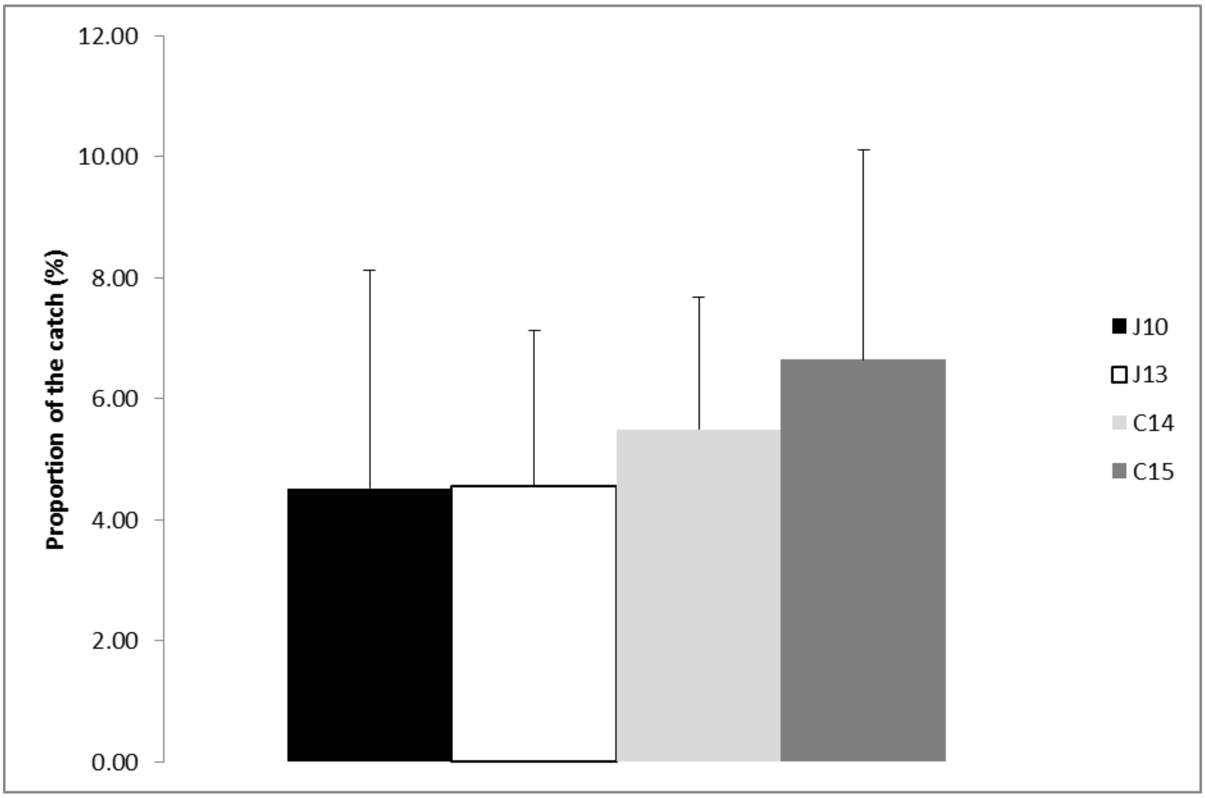

Figure 9. Comparison of average proportion of the catch made up of grenadier per hook type per line (three sections; 108 umbrellas). Error bars represent standard deviations. Hook type explains 15% of the overall variance in proportion of the catch made up of grenadier.

Generalized linear mixed model analyses do show that Hook type does explain differing amounts of variance across the different averaged models, whereas Hook shape is not relevant. However, neither Hook type nor Hook shape outperform ecological, environmental or behavioural predictors, i.e. Latitude, Depth, and Soak time. Furthermore, although interactions between variables were examined, no interaction involving Hook characteristics outperformed predictors aforementioned. In summary, there are no recommendations that can be made to the fishing industry. However, we do take this opportunity to provide the following non-binding suggestions for CFL to take under consideration:

1) We need to repeat the hook trial using a wider range of Hook types and/or shapes, i.e. much larger hooks with wider/narrower gape. However, this needs to be weighed against the logistical and operational aspects of baiting, setting, and hauling.

2) Perhaps a reduction in bycatch of grenadier can be achieved by better managing the zone in terms of depth, area, and varying soak times in response to cumulative catches of grenadier during the year. This involves much work and planning, but advice could be sought from the Fisheries Dept when planning fishing trip or in response to larger than anticipated catches of grenadiers

Acknowledgments

Foremost, we thank the officers and crew of CFL's *Hunter* for their hospitality and cooperation during this trip at sea. The cooperation and assistance of CFL's board of Directors is gratefully acknowledged. We thank staff of the Falkland Islands Fisheries Department for organising an E-licence for this trip.

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