Cruise Report ZDLT1 : 10-2012

3rd Cod-end Mesh Size Experiment

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Contents

1.0 Introduction

Bycatch reduction in major fisheries is essential to ensure their sustainability. The largest bycatch reported in Falkland fisheries in recent years is that of undersized (small and juvenile) rock cod (*Patagonotothen ramsayi*). Research surveys have been undertaken by the Falkland Islands Fisheries Department in 2011 to assess whether an increase in the minimum allowable mesh size of trawl codend could assist in reducing bycatch of undersized fish in finfish fisheries.

A first ‘mesh size trials’ research cruise in November 2011 (Brickle and Winter 2011) revealed a lower occurrence of undersized rock cod and other commercial finfish species in the catch when using ≥ 120 mm mesh in the codend. A second ‘mesh size trials’ research cruise in April 2012 (Roux et al 2012) confirmed enhanced retention of commercial-size rock cod and lower catches of undersized fish in 120 mm and 140 mm mesh, with limited impacts on fishery efficiency for Illex during the period of G-licence fishery. In this third ‘mesh size trials’ research cruise, we aimed to validate previous results of mesh size effects on catches of rock cod and other commercial species in areas of high rock cod density and while controlling for spatial variability in species and length-class availability to the fishery.

An additional set of trials was conducted to examine potential effects of the use of a “top chafer” on the codend. Codend attachments such as top chafers are generally used to reduce wear and tear and provide extra strength (Kynoch et al. 2004, Stewart and Robertson 1985). There is evidence however that the extra layer of netting provided by top chafers may affect codend selectivity as well as fish behaviour by introducing a further visual barrier (Kynoch et al. 2004). Current FIFD legislation allows for the use of top chafer in finfish fisheries, with the requirement that top chafer mesh size be equivalent to (or greater than) 1.5 times the minimum allowable mesh size in the codend (currently 90 mm).

During this cruise we also investigate the length-girth relationships for three important species; *Patagonotothen ramsayi*, *Genypterus blacodes*, and *Merluccius hubbsi*. Length frequency distributions are currently used in fisheries for the estimation of size selectivity in bottom trawls. However, other biological parameters such as girth size also contribute to the size selectivity of fishing gears (Stergiou and Karpouzi, 2003). The change in the length-girth relationship throughout ontogenetic growth is investigated here.

1.1 Cruise objectives

1. To ascertain the effects of codend mesh sizes of fishery efficiency for rock cod and other commercial species in areas of high rock cod density.

2. To assess potential effects of top chafer use on fishery efficiency.

3. To characterize length-girth relationships for selected commercial species and confirm the effectiveness of length as a primary measure to assess retention in trawl fisheries.

4. To collect oceanographic measurements in the survey areas to gain environmental information that might impact gear selectivity.

2.0 Methods

2.1 Research Vessel and Survey Area

Research was carried out onboard the *RV Castelo* between October 14th-29th 2012. Three areas were used for sampling (Fig 2.1). Cod end mesh size trials were performed in Area1 and Area2. Top chafer trials were performed in Area2 and Area3. Station details are shown in Table 2.1. A total of 43 trawl stations were completed (12 in Area1, 24 in Area2 and 7 in Area3) and twelve oceanographic (CTD) stations (2 in Area1, 8 in Area2 and 2 in Area3). Stations 1015-1019 in Area2 were 'prospecting' stations located in a different grid square and were labelled 'Area2a' to be distinguished from sampling stations 1020-1046 (Area2b) (Fig 2.1).

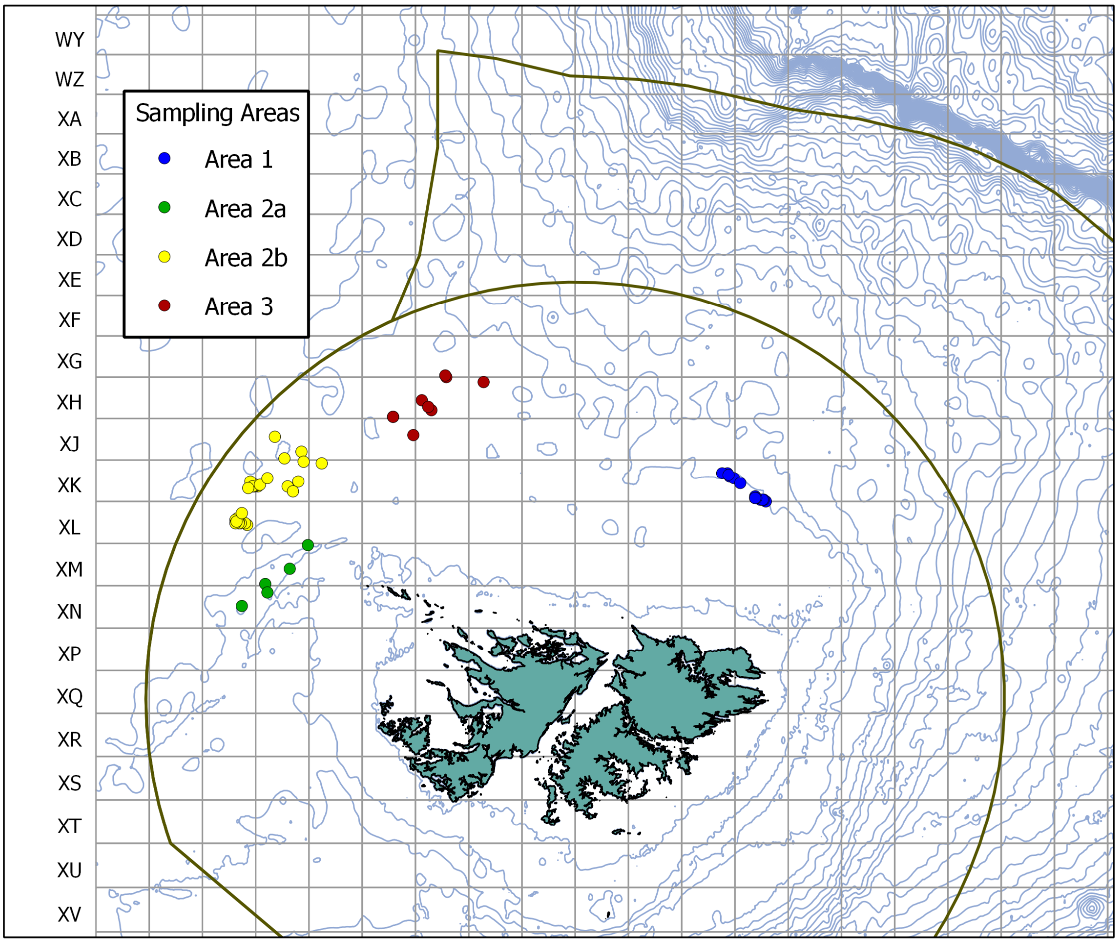


Figure 2.1. Location of sampling Areas 1, 2 and 3.

Table 2.1 Trawl and Oceanographic (CTD) stations conducted on ZDLT1-10-2012. Activity B: bottom trawl; Activity C: CTD. Codend Mesh "90-Chafer" indicates a 90 mm diamond mesh cod end was used with a 140 mm mesh top chafer.

Station	Area	Date	Time Start	Lat (°S)	Long (°W)	Modal Depth (m)	Duration (min)	Activity	Codend Mesh (mm)
1001	1	15/10/2012	6:50 AM	50.47	57.81	149	180	B	90
1002	1	15/10/2012	10:45 AM	50.33	58.07	139	180	B	110
1003	1	15/10/2012	3:45 PM	50.48	57.81	139	180	B	120
1004	1	15/10/2012	7:26 PM	50.33	58.12	140	-	C	-
1005	1	16/10/2012	6:25 AM	50.35	58.05	140	180	B	140
1006	1	16/10/2012	10:30 AM	50.50	57.71	150	180	B	90
1007	1	16/10/2012	2:30 PM	50.36	58.01	142	180	B	110
1008	1	17/10/2012	5:30 AM	50.34	58.06	148	180	B	120
1009	1	17/10/2012	9:30 AM	50.49	57.76	163	180	B	140
1010	1	17/10/2012	2:15 PM	50.39	57.95	161	120	B	90
1011	1	17/10/2012	5:20 PM	50.49	57.73	170	-	C	-
1012	1	18/10/2012	5:55 AM	50.49	57.74	142	120	B	110
1013	1	18/10/2012	9:55 AM	50.48	57.80	141	120	B	120
1014	1	18/10/2012	1:35 PM	50.48	57.81	139	120	B	140
1015	2a	19/10/2012	7:50 AM	50.76	62.01	188	180	B	90
1016	2a	19/10/2012	11:50 AM	50.90	62.18	185	180	B	110
1017	2a	19/10/2012	3:50 PM	50.99	62.41	180	180	B	120
1018	2a	19/10/2012	7:37 PM	51.12	62.63	176	-	C	-
1019	2a	20/10/2012	5:45 AM	51.04	62.39	182	180	B	140
1020	2b	20/10/2012	10:25 AM	50.64	62.58	155	180	B	90
1021	2b	20/10/2012	2:25 PM	50.41	62.48	155	180	B	110
1022	2b	20/10/2012	6:04 PM	50.63	62.60	158	-	C	-
1023	2b	21/10/2012	5:45 AM	50.63	62.64	152	180	B	120
1024	2b	21/10/2012	9:45 AM	50.40	62.50	152	180	B	140
1025	2b	21/10/2012	1:45 PM	50.62	62.66	154	180	B	90
1026	2b	21/10/2012	5:24 PM	50.41	62.51	150	-	C	-
1027	2b	22/10/2012	5:35 AM	50.41	62.52	152	180	B	110
1028	2b	22/10/2012	9:30 AM	50.60	62.67	149	180	B	120
1029	2b	22/10/2012	1:30 PM	50.38	62.55	150	180	B	140
1030	2b	22/10/2012	5:13 PM	50.61	62.69	156	-	C	-
1031	2b	23/10/2012	5:35 AM	50.63	62.66	130	180	B	90
1032	2b	23/10/2012	9:30 AM	50.41	62.53	152	180	B	110
1033	2b	23/10/2012	1:35 PM	50.63	62.69	152	180	B	120
1034	2b	23/10/2012	5:20 PM	50.42	62.57	148	-	C	-
1035	2b	24/10/2012	5:35 AM	50.62	62.68	154	180	B	140
1036	2b	24/10/2012	11:05 AM	50.41	62.20	157	180	B	90-Chafer
1037	2b	24/10/2012	3:05 PM	50.27	61.88	160	120	B	90-Chafer
1038	2b	24/10/2012	5:50 PM	50.38	62.10	160	-	C	-
1039	2b	25/10/2012	5:40 AM	50.44	62.15	157	180	B	90-Chafer
1040	2b	25/10/2012	9:30 AM	50.24	62.23	150	180	B	90
1041	2b	25/10/2012	1:25 PM	50.40	62.46	151	180	B	90-Chafer
1042	2b	25/10/2012	5:10 PM	50.57	62.63	153	-	C	-
1043	2b	26/10/2012	5:30 AM	50.20	62.07	155	180	B	90
1044	2b	26/10/2012	9:25 AM	50.36	62.39	148	180	B	90-Chafer
1045	2b	26/10/2012	1:20 PM	50.11	62.32	150	180	B	90
1046	2b	26/10/2012	5:07 PM	50.26	62.05	158	-	C	-
1047	3	27/10/2012	5:45 AM	49.78	60.36	165	180	B	90-Chafer
1048	3	27/10/2012	9:40 AM	49.75	60.71	164	180	B	90
1049	3	27/10/2012	1:40 PM	49.89	60.94	160	180	B	90-Chafer
1050	3	27/10/2012	5:25 PM	49.99	61.21	160	-	C	-
1051	3	27/10/2012	5:40 PM	49.99	61.21	159	145	B	90
1052	3	28/10/2012	5:40 AM	49.95	60.85	163	180	B	90-Chafer
1053	3	28/10/2012	9:40 AM	49.74	60.72	163	180	B	90
1054	3	28/10/2012	1:45 PM	49.93	60.88	160	180	B	90-Chafer
1055	3	28/10/2012	5:29 PM	50.10	61.02	160	-	C	-

2.2 Trawling gear

A bottom trawl equipped with 1,800 kg Oval-Foil doors (OF-14) was used at all stations. No ground gear (e.g. bobbins/rockhoppers) was used. The footrope consisted of a cable protected by cord. An 8 m length of chain weighting 150 kg was attached to the footrope to increase contact between the footrope and the sea bed. See Brickle and Winter (2011) for net configuration details.

2.3 Biological sampling

Catches were weighed using an electronic marine adjusted balance (POLS). All fish and skates were weighed by species. When trawl catch was in excess of 5 tonnes, rock cod catch weight was estimated by determining the ratio of discard to retention in a random length frequency subsample of the catch. This ratio was then multiplied by the factory production weight for that trawl, then by the round weight conversion factor, and then by the proportion of retention-size fish that were discarded (if any), as determined from a random length frequency subsample of the discards.

Random samples (100-200 individuals) of commercially important species were taken whenever possible. Length (L_T, L_M and L_{DW}), sex and maturity stage were recorded for all specimens in the sample.

2.4 Survey design

The survey was conducted in areas of high rock cod density similar to those targeted by the finfish fleet in recent years, as determined from examination of spatial distribution of rock cod catches during October months in 2008-2011; from close monitoring of daily catch reports by commercial fishing vessels during weeks preceding the cruise; and by consultation with the captain. Fishing was carried out during daylight hours. Sampling effort involved three trawls a day (exception of one day when four trawls were completed). Trawl duration was set at 3 hours but was reduced to two hours in some instances to avoid unnecessary large catches and discard weights. Trawling operations were paralleled by an oceanographic survey of the fishing areas that consisted of daily vertical water profiling stations.

2.4.1. Codend mesh size trials

As in previous trials, four codends of differing diamond mesh sizes were used: the 90 mm mesh (currently the minimum allowable codend mesh size in finfish fisheries), and the larger 110 mm, 120 mm and 140 mm mesh sizes. The four codends were alternated each trawl following the sequence: 90 mm, 110 mm, 120 mm and 140 mm mesh – corresponding to four possible daily sequences of three trawls. Three replicates of each mesh size were realized over 4 fishing days in Area1 and Area2b. This allowed rotation of each mesh size between different time of day (morning trawl, midday trawl and afternoon trawl). Four trawls (one of each mesh size) were also completed over 1.5 fishing days in Area2a. Trawling depth was kept relatively constant within sampling areas.

2.4.2. Chafer trials

Top chafer trials were conducted using only the 90 mm diamond mesh codend. The top chafer (or topside chafer) consisted in a 140 mm square mesh net tied to the sides of the terminal portion (last 7 m) of the codend (Fig 2.2).

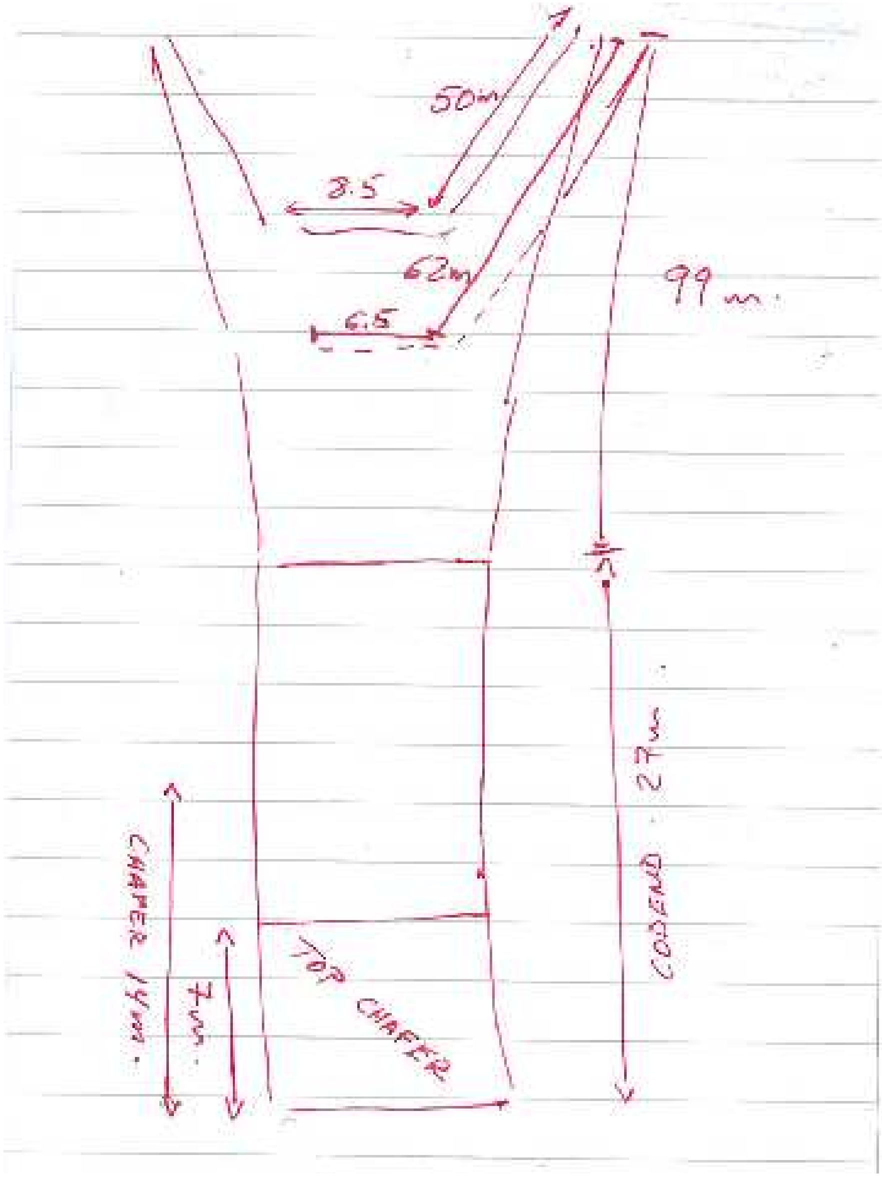


Figure 2.2. Net and codend configuration during top chafer trials. Only the 7 m chafer was used (Drawing by J.V.S. Reiriz).

Trawls with/without top chafer were alternated over 2.5 fishing days in Area2b and 2 fishing days in Area3. In total, 12 trawls were completed during chafer trials, including 3 trawls without chafer in each of the sampling areas and 5 and 4 trawls with chafer in Area2b and Area3, respectively. Trawling depth was kept relatively constant within fishing areas.

2.5 Data Analyses

2.5.1 Codend mesh size trials and fishery efficiency

Effects of codend mesh sizes were assessed by sampling area for relevant commercial species and for a non-target species (CGO) which was omnipresent in the catch.

Impacts of codend mesh sizes on fishery efficiency were evaluated using three indicators: (i) catch weight per unit effort (CPUE (kg hr^{-1})); (ii) catch composition by length/weight and contributions of commercial-size fish to total catch; and (iii) retention probabilities at length.

Catch weight (CPUE)

Mesh size effects on CPUE were assessed using generalized linear mixed models (GLMM) assuming Poisson errors (log-link function) with mesh size as the only fixed effect and haul and/or sampling day as random factors. CPUE data were rounded to the nearest kg. GLMM were fitted using the Laplace approximation. Three models with varying random effects were fitted and compared for each species: a model using both haul and sampling day as random factors and two models including either day or haul as random factor. Model selection was done by minimizing the Bayesian information criterion (BIC). In cases where the inclusion of random effects did not contribute to reducing the unexplained variance, the GLMM structure was deemed inappropriate and the data were fitted using standard Generalized Linear Models (GLM) with error structure (either Poisson or gamma) determined based on lowest AIC.

Catch composition by length/weight

Length frequency distributions (1-cm intervals) were smoothed by mesh size using generalized additive models (GAM) with Gaussian error structure.

Ratios of commercial or HGT-size to undersized fish (commercial stock fraction - CSF) were estimated from length-frequency distributions and species-specific length-weight relationships (Appendix 1). CSF was fitted by mesh size using GLMM with binomial error structure (logit-link function) and haul and/or sampling day as random effects. GLMM were fitted by means of the Laplace approximation and model selection was based on lowest BIC. In the case of rock cod, estimated CSF (from length frequencies) were compared to 'observed' CSF determined based on factory production weight multiplied by the round weight conversion factor of 2.0. Conversion factor validity was assessed twice during the survey (once in each sampling area) by weighing a random sample of process-size fish before and after processing.

Trawl-specific CPUE data were multiplied by fitted CSF ratios in order to estimate process (or HGT) catch weights and discard (or undersized) catch weights (in kg hr^{-1}) among codend mesh sizes. The significance of mesh size effects on estimated process/undersized catch weights were assessed using GLM with error structure (either Poisson or gamma) determined based on lowest AIC.

Retention probability at length

A four-parameter double-logistic function (combining an increasing and a decreasing logistic curve) was used to estimate retention probability at length (R_L) (equation 2.1).

$$R_L = [1 / (1 + e^{(s1(L - p1))})] * [1-1 / (1 + e^{(s2(L - p2))})] \quad (2.1)$$

Where L is length, p1 and p2 are inflexion points corresponding to lengths of 50% retention and s1 and s2 are slope parameters. This function allows great flexibility in the shape of selectivity curves (Quinn and Deriso 1999). When discussing model outputs, p2 is referred to as the minimum length of 50% retention (L_{50}^1) and p1 is the maximum length of 50% retention (L_{50}^2). Length classes comprised between L_{50}^1 and L_{50}^2 correspond to the size range of maximum (≥ 50%) retention.

Only hauls with sample sizes ≥ 100 specimens measured for length were considered. Counts of fish (or squid or skates) per 1-cm length class in haul 'I' (F_{Li}) were related to total sample size ($TFreq_i$) (equation 2.2) and maximized over area 'j' ($MaxF_{Lij}$ – maximum number of fish of length 'L' among hauls 'i' in area 'j') to estimate observed retention probabilities at length (RP_{Lij}) (equation 2.3). Maximization accounts for the fact that smaller and larger mesh sizes are more retentive of smaller and larger specimens, respectively (Brickle and Winter 2011).

$$F_{Li} = Freq_i/TFreq_i \quad (2.2)$$

$$RP_{Lij} = F_{Li}/MaxF_{Li} \quad (2.3)$$

The double-logistic function was fitted to mesh-size specific RP_{Lij} using general purpose Nelder-Mead optimization. Curve fitting was restricted to a representative size range corresponding to length classes with $MaxF_{Li}$ ≥ 0.035 (or ≥ 0.045 for rock cod)). Fitting was done by minimizing the residuals sum of squares. Maximum number of iterations was 10,000. The initial value for slope parameters (s1 and s2) in all cases was set at 0.5. Starting values for inflexion parameters (p1 and p2) were defined based on visual inspection of RP_{Lij}.

2.5.2 Top chafer trials and fishery efficiency

Top chafer effects were assessed by sampling area for relevant commercial species. Impacts of top chafer use on fishery efficiency were evaluated on the basis of two indicators: (i) catch weight per unit effort (CPUE (kg hr^{-1})) and (ii) length structure of the catch/retention probabilities at length.

Catch weight (CPUE)

The assessment of top chafer effects on CPUE was carried out using the same procedure as codend mesh size trials (see section 2.5.1).

Retention probability at length

Length frequency distributions (1-cm intervals) were smoothed for hauls with/without top chafer using generalized additive models (GAM) with Gaussian error structure. Retention probabilities at length were estimated using the double-logistic equation and following the method described in section 2.5.1. The double-logistic equation was fitted to area-specific RP_{Lij} calculated for hauls with and without top chafer, respectively.

All statistical analyses were implemented in 'R' software (R Core Development Team 2012). Specific packages used were 'lme4' (GLMM) and 'mgcv' (GAM).

2.7 Length-girth relationships

Length-girth relationships were characterized for three species: *Patagonotothen ramsayi* (rock cod), *Genypterus blacodes* (kingclip) and *Merluccius hubbsi* (hake). *P. ramsayi* and *M. hubbsi* have a fusiform body shape, while *G. blacodes* has an eelform body shape. Samples were collected during both mesh size and chafer trials bottom trawls. For all three species 100 fish were randomly collected from the last trawl of the day. Additional non-random samples were collected to ensure a full range of sizes were measured. Total length (TL) measurements were estimated using electronic measuring board. Girth height (H) and width (W) measurements were taken behind the gill-cover with the callipers and estimated to the nearest mm. The ratio of width to height was calculated for each species and plotted against the length (TL).

2.8 Oceanography

The survey was aimed to assess the oceanographic situation where mesh and chafer trials were carried out. Conductivity (salinity), temperature and depth were measures using a CTD SBE-25. The CTD was deployed from the surface within 20 m off the bottom. The CTD was deployed for the first one minute at about 20 m depth, then retrieved to 7 m depth and deployed again to the bottom. The speed of deployment was approximately 1m/s and was monitored by use of wire counter. Raw data *.HEX files were processed (format conversion, removing noise, calculating derived variables) using standard routines in Seasoft, and vertical profiles of temperature, salinity and density were plotted using the "oce" (v. 0.9-3) package in R (R Core Development Team 2012 v. 2.15.2).

3.0 Results

3.1 Catch composition

Total catch and sample/discard weights by species are summarized by area in Tables 3.1, 3.2 and 3.3. Total catch was 42,195 kg in Area1, 82,909 kg in Area2 and 19,051 kg in Area3. Trawling depth was relatively constant within areas with inter-trawl variations not exceeding 30 m. Average trawling depth was 147 m (range 139-163 m among hauls) in Area 1; 182 m (range 180-188 m) in Area2a; 153 m (range 130-160 m) in Area2b; and 162 m (range 159-165 m) in Area3.

Rock cod (*P. ramsayi*) dominated the catch in Area1 and Area2, where it accounted for 82% and 53% of total catch weight on average among hauls (Fig 3.1a and 3.1b). In Area3, rock cod was third in importance explaining 20% of the catch behind hake (*M. hubbsi*) (39%) and skates/rays (27%) (Fig 3.1c).

Area1 had comparatively limited species diversity with rock cod and loligo squid (*D. gahi*) explaining nearly all catch weight (98%) (Table 3.1, Fig 3.1a). In Area2, finfish species such as hake, red cod (*S. australis*), kingclip (*G. blacodes*) and frogmouth (*C. gobio)* on average explained between 3%-13% of the catch (total 19%) while loligo squid and skates/rays explained 4% and 12%, respectively (Fig 3.1b, Table 3.2).

Area2a had a different species composition relative to Area2b (Fig. 3.2). Skates/rays were dominant in Area2a, on average explaining 35% of the catch, followed by rock cod (24%) and kingclip (21%) (Fig 3.2a). In Area2b, rock cod accounted for 59% of the catch (on average) while skates/rays explained 8% and other finfish explained between 2%-16% (Fig. 3.2b).

In Area3, species dominance was shared between hake, skates/rays and rock cod, while kingclip and loligo squid on average accounted for 4% and 2% of the catch among hauls (Fig. 3.1c). Dogfish (*S. acanthias*) was omnipresent with 356 kg caught (2% of total catch weight) (Table 3.3). Sponge (*Porifera*) bycatch was relatively important in Area2 and Area3 with total catches of 665 kg and 172 kg, respectively – corresponding to 1% of total catch weight in both areas (Tables 3.2 and 3.3).

Skate contribution to total catch was highest in Area3 with 4.1 tonnes caught (22% of total catch weight) and lowest in Area1 with 242 kg (0.6% of total catch) (Fig 3.1c and 3.1a respectively). In Area2, the skates catch totalled 6.2 tonnes (7% of total catch) and were more important in Area2a than Area2b (Fig. 3.2). Eleven different species of skates were caught. Richness was highest in Area2 with 10 species relative to 8 and 9 species in Area1 and Area3, respectively. In all areas, *B. brachyurops* (RBR) was a dominant species explaining between 56%-72% of skates catches by weight (Fig 3.3). Sand rays (*Psammobatis Sp.* (RPX)) were second in importance in Area1 (Fig 3.3a). In Area2, yellow-nose skate (*R. flavirostris* (RFL)) and Falkland skate (*B. macloviana* (RMC)) were in second-place, each explaining approximately 12% of the skates catch (Fig 3.3b). In Area3, yellow-nose skate, Falkland skate and white-spotted skate **(***B. albomaculata* RAL)) accounted for 21%, 9% and 8% of the skates catch, respectively (Fig 3.3c).

Table 3.1 Catch composition, sample, and discard weights (in kg) for Area 1.

Species code	Latin name	Catch Wt	Sample Wt	Discard Wt	Catch Proportion (%)
PAR	*Patagonotothen ramsayi*	37329.99	475.01	17116.94	88.468
LOL	*Doryteuthis gahi*	4054.73	170.65	745.90	9.609
BLU	*Micromesistius australis*	157.76	8.00	158.76	0.374
RBR	*Bathyraja brachyurops*	155.58	155.58	130.94	0.369
ING	*Moroteuthis ingens*	86.62	86.62	30.00	0.205
RPX	*Psammobatis sp.*	65.89	0.00	65.89	0.156
SHT	*Mixed invertebrates*	65.28	0.00	65.28	0.155
MED	*Medusae sp.*	47.68	0.00	47.68	0.113
CGO	*Cottoperca gobio*	41.36	0.00	41.35	0.098
TOO	*Dissostichus eleginoides*	33.56	33.56	11.50	0.080
BAC	*Salilota australis*	30.91	13.08	15.56	0.073
DGH	*Schroederichthys bivius*	14.15	0.00	14.15	0.034
SPN	*Porifera*	14.13	0.00	14.13	0.033
RSC	*Bathyraja scaphiops*	9.12	9.12	7.21	0.022
ANM	Anemone	8.92	0.00	8.92	0.021
RMC	*Bathyraja macloviana*	8.14	8.14	8.14	0.019
KIN	*Genypterus blacodes*	8.03	8.03	0.00	0.019
STA	*Sterechinus agassizi*	7.82	0.00	7.82	0.019
ZYP	*Zygochlamys patagonica*	7.48	0.00	7.48	0.018
MXX	*Myctophidae spp.*	7.33	0.00	7.33	0.017
RED	*Sebastes oculatus*	4.79	4.79	1.30	0.011
EGG	Bathyraja sp. Egg cases	4.51	2.50	2.01	0.011
CAZ	*Calyptraster sp.*	4.11	0.00	3.66	0.010
HAK	*Merluccius hubbsi*	3.96	0.00	0.00	0.009
MUE	*Muusoctopus eureka*	3.50	3.50	0.00	0.008
MAV	*Magellania venosa*	3.24	3.19	0.05	0.008
AST	*Asteroidea*	3.03	0.00	3.03	0.007
GOC	*Gorgonocephalus chilensis*	2.17	0.00	2.17	0.005
ODM	*Odontocymbiola magellanica*	2.16	0.00	2.16	0.005
RDO	*Raja doellojuradoi*	1.87	1.87	1.87	0.004
SQT	*Ascidiacea*	1.44	0.00	1.44	0.003
RFL	*Raja flavirostris*	1.43	1.43	0.00	0.003
NEM	*Neophrynichthys marmoratus*	1.07	0.00	1.07	0.003
MLA	*Muusoctopus longibrachus akambei*	1.00	1.00	0.00	0.002
COT	*Cottunculus granulosus*	0.58	0.00	0.58	0.001
FUM	*Fusitriton magellanicus*	0.53	0.00	0.53	0.001
AUC	*Austrocidaris canaliculata*	0.37	0.00	0.37	0.001
OCC	*Octocorallia*	0.37	0.00	0.37	0.001
NOW	*Paranotothenia magellanica*	0.36	0.36	0.36	0.001
RMU	*Bathyraja multispinis*	0.31	0.31	0.31	0.001
POA	*Porania antarctica*	0.24	0.00	0.24	0.001
EEL	*Iluocetes fimbriatus*	0.10	0.00	0.10	< 0.001
RGR	*Bathyraja griseocauda*	0.07	0.07	0.07	< 0.001
EUL	*Eurypodius latreillei*	0.06	0.00	0.06	< 0.001
EUO	*Eurypodius longirostris*	0.06	0.00	0.06	< 0.001
THN	*Thysanopsetta naresi*	0.03	0.03	0.00	< 0.001
ISO	*Isopoda*	0.01	0.01	0.00	< 0.001
Totals		***42195.85***	***986.85***	***18526.79***	

Table 3.2 Catch composition, sample, and discard weights (in kg) for Area 2.

Species code	Latin name	Catch Wt	Sample Wt	Discard Wt	Catch Proportion (%)
PAR	*Patagonotothen ramsayi*	56775.85	1047.00	12251.17	68.480
HAK	*Merluccius hubbsi*	7898.66	4008.80	26.68	9.527
RBR	*Bathyraja brachyurops*	4356.74	4356.74	198.36	5.255
BAC	*Salilota australis*	3394.30	561.43	539.29	4.094
KIN	*Genypterus blacodes*	2695.12	1819.34	0.00	3.251
LOL	*Doryteuthis gahi*	2675.51	208.57	314.28	3.227
CGO	*Cottoperca gobio*	1713.57	1236.50	1652.84	2.067
RFL	*Raja flavirostris*	776.71	776.71	22.00	0.937
RMC	*Bathyraja macloviana*	711.10	711.10	542.84	0.858
SPN	*Porifera*	664.96	0.00	664.96	0.802
DGH	*Schroederichthys bivius*	414.30	0.00	414.30	0.500
RPX	*Psammobatis sp.*	234.90	0.00	234.90	0.283
NEM	*Neophrynichthys marmoratus*	77.40	0.00	77.40	0.093
SHT	*Mixed invertebrates*	73.89	0.00	73.89	0.089
RAL	*Bathyraja albomaculata*	67.70	67.69	29.02	0.082
DGS	*Squalus acanthias*	62.70	2.94	62.70	0.076
SAR	*Sprattus fuegensis*	35.33	0.00	35.33	0.043
FUM	*Fusitriton magellanicus*	26.04	0.00	26.04	0.031
ANM	Anemone	19.85	0.00	19.85	0.024
TOO	*Dissostichus eleginoides*	19.80	19.80	3.21	0.024
RBZ	*Bathyraja cousseauae*	18.15	18.15	0.00	0.022
CEX	*Ceramaster sp.*	17.28	0.00	17.28	0.021
EGG	Rays/skates Egg cases	15.40	14.05	1.35	0.019
RGR	*Bathyraja griseocauda*	15.29	15.29	7.88	0.018
OCM	*Octopus megalocyathus*	14.44	14.44	0.00	0.017
AUL	*Austrolycus laticinctus*	13.91	13.91	13.91	0.017
ING	*Moroteuthis ingens*	13.01	0.00	13.01	0.016
ODM	*Odontocymbiola magellanica*	12.03	0.00	12.03	0.015
SQT	*Ascidiacea*	10.74	0.00	10.74	0.013
STA	*Sterechinus agassizi*	9.72	0.00	9.72	0.012
CAZ	*Calyptraster sp.*	9.61	0.00	9.61	0.012
AST	*Asteroidea*	7.44	0.00	7.44	0.009
MUE	*Muusoctopus eureka*	7.03	7.03	0.00	0.008
AUC	*Austrocidaris canaliculata*	6.41	0.00	6.41	0.008
COP	*Congiopodus peruvianus*	5.62	0.00	5.62	0.007
PAT	*Merluccius australis*	4.84	4.84	0.00	0.006
RSC	*Bathyraja scaphiops*	4.33	4.33	0.37	0.005
BUT	*Stromateus brasiliensis*	3.89	0.00	3.89	0.005
COL	*Cosmasterius lurida*	3.85	0.00	3.85	0.005
RMG	*Bathyraja magellanica*	3.00	3.00	0.00	0.004
RED	*Sebastes oculatus*	2.85	2.85	2.85	0.003
WHI	*Macruronus magellanicus*	2.51	2.51	2.14	0.003
RDO	*Raja doellojuradoi*	2.19	2.19	2.19	0.003
CYX	*Cycethra sp.*	1.69	0.00	1.69	0.002
ALC	*Alcyoniina*	1.29	0.00	1.29	0.002
POA	*Porania antarctica*	1.10	0.00	1.10	0.001
THO	*Thouarellinae*	0.93	0.00	0.93	0.001
BRY	*Bryozoa*	0.90	0.00	0.90	0.001
MAV	*Magellania venosa*	0.78	0.78	0.00	0.001
SUN	*Labidaster radiousus*	0.69	0.00	0.69	0.001
ZYP	*Zygochlamys patagonica*	0.59	0.00	0.59	0.001
SRP	*Semirossia patagonica*	0.51	0.51	0.00	0.001
EEL	*Iluocetes fimbriatus*	0.47	0.15	0.32	0.001
OCC	*Octocorallia*	0.40	0.00	0.40	<0.001
EUL	*Eurypodius latreillei*	0.25	0.00	0.25	<0.001
LIA	*Lithodes antarcticus*	0.22	0.00	0.22	<0.001
EUO	*Eurypodius longirostris*	0.22	0.00	0.22	<0.001
MXX	*Myctophidae spp.*	0.20	0.00	0.20	<0.001
XXX	Unidentified	0.20	0.10	0.10	<0.001
GOC	*Gorgonocephalus chilensis*	0.16	0.00	0.16	<0.001
BRA	*Brachyura*	0.04	0.00	0.04	<0.001
HYD	*Hydrozoa*	0.02	0.00	0.02	<0.001
AGO	*Agonopsis chiloensis*	0.01	0.00	0.01	<0.001
ISO	*Isopoda*	0.01	0.00	0.01	<0.001
POL	*Polychaeta*	0.01	0.00	0.01	<0.001
PYX	*Pycnogonida*	0.01	0.00	0.01	<0.001
Totals		***82908.68***	***14920.75***	***17328.51***	

Table 3.3 Catch composition, sample, and discard weights (in kg) for Area 3.

Species code	Latin name	Catch Wt	Sample Wt	Discard Wt	Catch Proportion (%)
HAK	*Merluccius hubbsi*	8164.08	1562.78	0.00	42.853
PAR	*Patagonotothen ramsayi*	4082.49	261.48	510.89	21.429
RBR	*Bathyraja brachyurops*	2075.65	2075.65	225.00	10.895
KIN	*Genypterus blacodes*	1217.78	465.18	0.00	6.392
RFL	*Raja flavirostris*	1017.53	1017.53	0.00	5.341
LOL	*Doryteuthis gahi*	536.30	47.34	50.00	2.815
RMC	*Bathyraja macloviana*	430.89	430.89	220.00	2.262
DGS	*Squalus acanthias*	355.96	121.97	355.96	1.868
RAL	*Bathyraja albomaculata*	350.25	350.25	10.00	1.838
SPN	*Porifera*	172.39	0.00	172.39	0.905
RPX	*Psammobatis sp.*	115.43	0.00	115.43	0.606
DGH	*Schroederichthys bivius*	69.52	0.00	69.52	0.365
RSC	*Bathyraja scaphiops*	65.40	65.40	0.00	0.343
FUM	*Fusitriton magellanicus*	49.94	0.00	49.94	0.262
MED	*Medusae sp.*	41.76	0.00	41.76	0.219
RMU	*Bathyraja multispinis*	32.69	32.69	13.60	0.172
RDO	*Raja doellojuradoi*	31.19	31.19	31.19	0.164
SQT	*Ascidiacea*	29.69	0.00	29.69	0.156
CGO	*Cottoperca gobio*	24.55	16.71	24.55	0.129
RGR	*Bathyraja griseocauda*	24.21	24.21	0.20	0.127
ING	*Moroteuthis ingens*	20.24	0.00	20.24	0.106
ANM	Anemone	18.02	0.00	18.02	0.095
BAC	*Salilota australis*	16.50	0.00	13.59	0.087
CAZ	*Calyptraster sp.*	16.24	0.00	16.24	0.085
GOC	*Gorgonocephalus chilensis*	16.01	0.00	16.01	0.084
SHT	*Mixed invertebrates*	13.16	0.00	13.16	0.069
EEL	*Iluocetes fimbriatus*	10.62	0.17	10.45	0.056
WHI	*Macruronus magellanicus*	8.90	8.90	8.90	0.047
TOO	*Dissostichus eleginoides*	8.70	8.70	0.00	0.046
STA	*Sterechinus agassizi*	5.68	0.00	5.68	0.030
EGG	Rays/skates Egg cases	4.06	4.06	0.00	0.021
AST	*Asteroidea*	4.06	0.00	4.06	0.021
NEM	*Neophrynichthys marmoratus*	3.87	0.00	3.87	0.020
ODM	*Odontocymbiola magellanica*	2.91	0.00	2.91	0.015
COL	*Cosmasterius lurida*	2.53	0.00	2.53	0.013
MUE	*Muusoctopus eureka*	2.02	2.02	0.00	0.011
CEX	*Ceramaster sp.*	1.78	0.00	1.78	0.009
OCM	*Octopus megalocyathus*	1.68	1.68	0.00	0.009
SUN	*Labidaster radiousus*	1.37	0.00	1.37	0.007
AUC	*Austrocidaris canaliculata*	1.09	0.00	1.09	0.006
CYX	*Cycethra sp.*	0.98	0.00	0.98	0.005
COP	*Congiopodus peruvianus*	0.86	0.00	0.86	0.004
RED	*Sebastes oculatus*	0.76	0.76	0.76	0.004
POA	*Porania antarctica*	0.59	0.00	0.59	0.003
BUT	*Stromateus brasiliensis*	0.34	0.00	0.34	0.002
GRF	*Coelorinchus fasciatus*	0.25	0.00	0.25	0.001
SAR	*Sprattus fuegensis*	0.17	0.00	0.17	0.001
BLU	*Micromesistius australis*	0.11	0.00	0.11	0.001
MAV	*Magellania venosa*	0.08	0.08	0.00	<0.001
ALC	*Alcyoniina*	0.04	0.00	0.04	<0.001
EUL	*Eurypodius latreillei*	0.02	0.00	0.02	<0.001
EUO	*Eurypodius longirostris*	0.01	0.00	0.01	<0.001
NUD	*Nudibranchia*	0.01	0.00	0.01	<0.001
PYX	*Pycnogonida*	0.01	0.00	0.01	<0.001
THO	*Thouarellinae*	0.01	0.00	0.01	<0.001
Totals		***19051.38***	***6529.64***	***2064.18***	

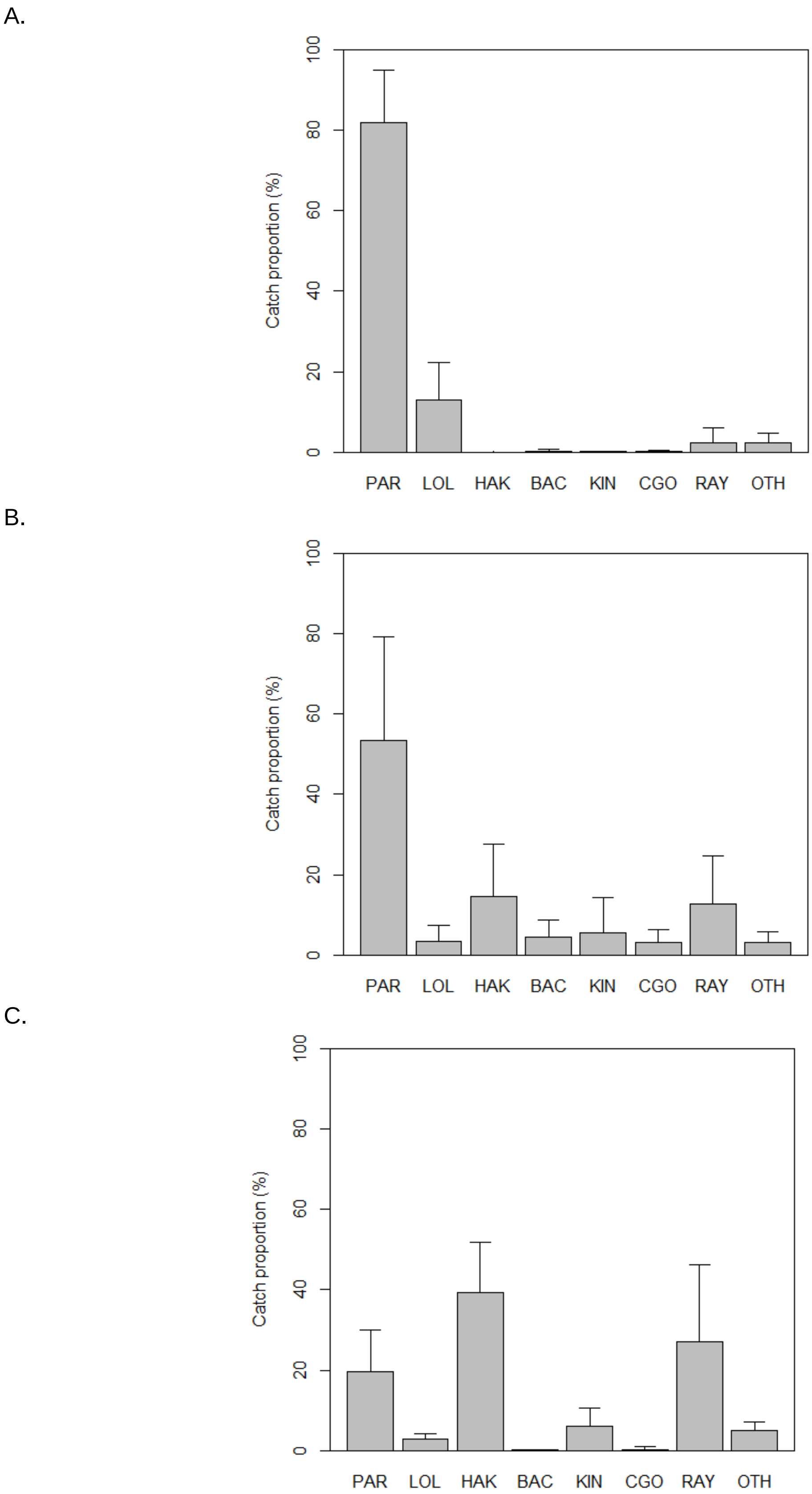
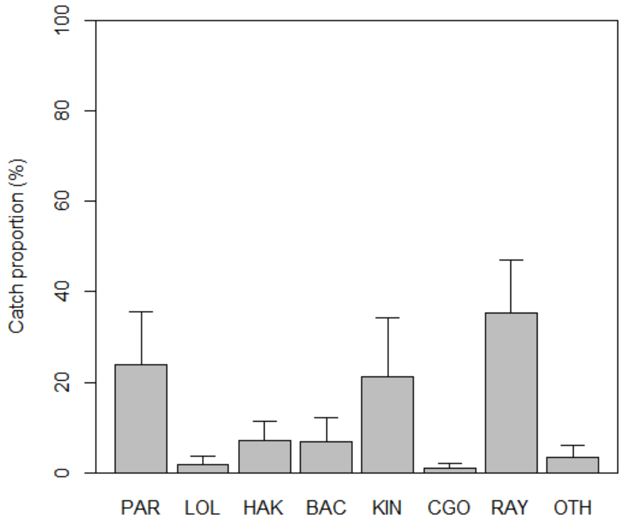


Figure 3.1 Catch composition by species (as percentage of total catch weight (mean ± sd among hauls)) in a) Area1; b) Area2; and c) Area3. PAR= *P. ramsayi*; LOL= *D. gahi*; HAK=*M. hubbsi*; BAC=*M. australis*; KIN=*G. blacodes*; CGO=*C. gobio*; RAY =all skates/rays; OTH = all other species.

A.



B.

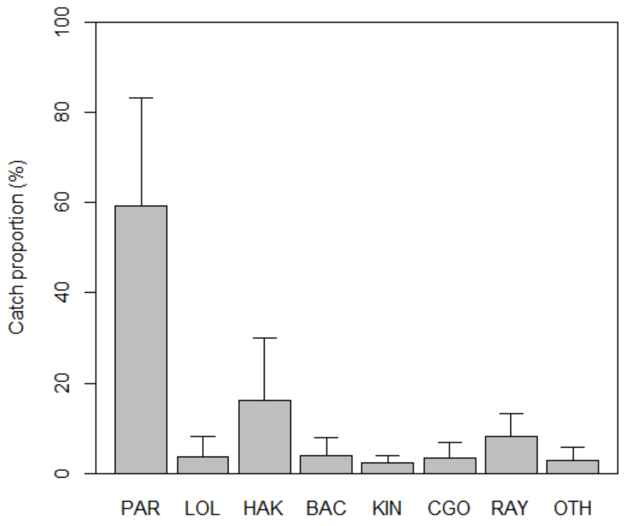
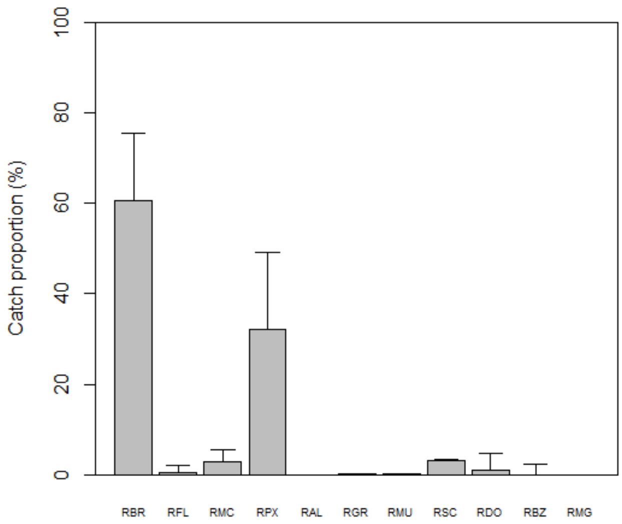
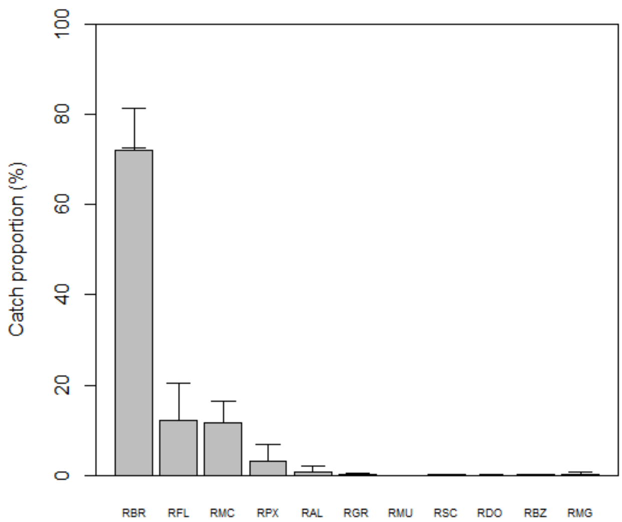


Figure 3.2 Catch composition by species (as percentage of total catch weight (mean ± sd among hauls)) in Area2 – distinguishing between a) sub-Area2a and b) sub-Area2b. PAR= *P. ramsayi*; LOL= *D. gahi*; HAK=*M. hubbsi*; BAC=*M. australis*; KIN=*G. blacodes*; CGO=*C. gobio*; RAY =all skates/rays; OTH = all other species.

A.



B.



C.

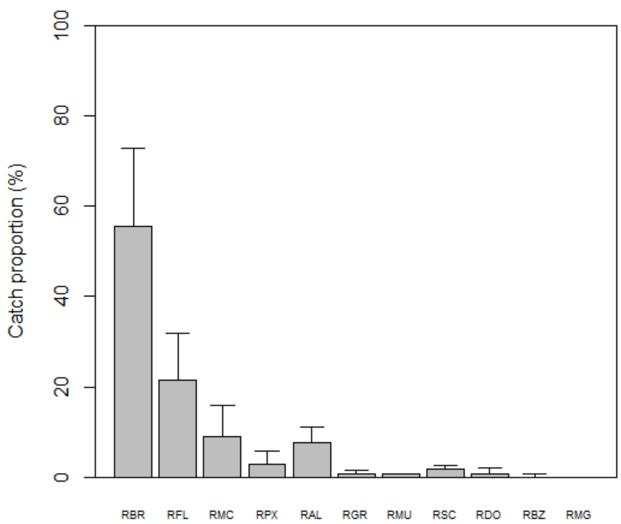


Figure 3.3 Skates species catch composition (as percentage of total skates catch weight (mean ± sd among hauls)) in a) Area1; b) Area2; and c) Area3. (see Tables 3.1-3.3 for species code legend).

3.2 Codend mesh size trials

A summary of analyses involved in the assessment of codend mesh size effects is presented by species and area in Table 3.4. Owing to differences in catch composition and trawling depth, prospecting trawls from Area2a were not retained for analyses. Thus ‘Area2’ only refers to ‘Area2b’ in the following text.

Table 3.4. Summary of mesh size effects and random effects (where applicable) on catch weight (CPUE); on ratios of commercial to undersized fish in the catch (CSF); and on estimated process or HGT catch weight ($CPUE_C$) and discard or undersized catch weight ($CPUE_U$). For fixed (mesh size) effects, 'x' indicates a significant effect at α = 0.05. For random effects, 'x' indicates presence of random effect contributing to reduce residual variance.

Species	Area	Response variable	Fixed Effect	Random effects		model	error structure
			codend mesh size	Haul	Day		
all species	1	$CPUE_T$	x	x	-	GLMM	poisson
	2b	$CPUE_T$	x	x	x	GLMM	poisson
P. ramsayi	1	CPUE	x	x	-	GLMM	poisson
(PAR)	1	CSF	x	x	-	GLMM	binomial
	1	$CPUE_C$	x			GLM	gamma
	1	$CPUE_U$	x			GLM	gamma
	2b	CPUE	x	x	x	GLMM	poisson
	2b	CSF	x	x	-	GLMM	binomial
	2b	$CPUE_C$	-			GLM	gamma
	2b	$CPUE_U$	x			GLM	gamma
D. gahi	1	CPUE	x	x	-	GLMM	poisson
(LOL)	2b	CPUE	x	-	-	GLM	poisson
M. hubbsi	2b	CPUE	-	x	-	GLMM	poisson
(HAK)	2b	CSF	-	-	x	GLMM	binomial
	2b	$CPUE_C$	-			GLM	gamma
S. australis	2b	CPUE	x	x	-	GLMM	poisson
(BAC)	2b	CSF	x	x	-	GLMM	binomial
	2b	$CPUE_C$	-			GLM	gamma
	2b	$CPUE_U$	x			GLM	gamma
G. blacodes	2b	CPUE	x	-	-	GLM	gamma
(KIN)	2b	CSF	x	x	-	GLMM	binomial
	2b	$CPUE_C$	x			GLM	poisson
	2b	$CPUE_U$	x			GLM	gamma
B. brachyurops	2b	CPUE	-	-	x	GLMM	poisson
(RBR)	2b	CSF	-	x	-	GLMM	binomial
	2b	$CPUE_C$	-			GLM	gamma
C. gobbio (CGO)	2b	CPUE	x	x	-	GLMM	poisson

3.2.1 Total Catch

Total catch per unit effort ($CPUE_T$) averaged 1,292 kg per hour (range 90-3,228) in Area1 and 1,360 kg per hour (range 188-3,888) in Area2. Mesh size effects were significant and corresponded to lower mean $CPUE_T$ (< 1 tonne per hour) in larger mesh codends (120 mm and 140 mm) in both areas (Fig 3.4A). Smaller mesh sizes (90 mm and 110 mm) yielded statistically similar $CPUE_T$ between 1.3-2.1 tonnes per hour (Area1) and 1.8-2.6 tonnes per hour (Area2). On average, total catch was reduced by a factor of 4 to 7 in 120 mm relative to 90 mm mesh and by a factor of 6 to 13 in the 140 mm. Variability in $CPUE_T$ was comparatively reduced in the larger mesh codends (120 mm and 140 mm) relative to smaller mesh sizes (Fig. 3.4A).

3.2.2. *Patagonotothen ramsayi* (Patagonian rock cod)

Mesh size and CPUE

Rock cod CPUE averaged 1,140 kg per hour (range 50-2,916 kg hr^{-1}) in Area1 and 987 kg per hour (range 12-3,453 kg hr^{-1}) in Area2. Larger mesh codends (120 mm and 140 mm) yielded significantly lower mean CPUE in both areas (Fig 3.4B). Catches of rock cod were statistically similar between 90 mm and 110 mm mesh with means of 2.1-2.2 tonnes per hour (90 mm) and 1.3-1.6 tonnes per hour (110 mm), depending on area. In larger mesh sizes, rock cod CPUE did not exceed 870 kg per hour (120 mm) and 380 kg per hour (140 mm). Overall, rock cod CPUE was reduced by a factor of 4 - 6 in 120 mm relative to 90 mm mesh and by a factor of 13 - 15 in 140 mm mesh.

Mesh size and catch composition by length/weight

Rock cod length ranged 13-37 cm (median 24 cm) in Area1 and 13-39 cm (median 26 cm) in Area2. Length frequency distributions by mesh size illustrate area differences in size composition of the catch, corresponding to a higher occurrence of smaller-size rock cod in Area1 (Fig 3.5). Modal length increased with codend mesh sizes from 22 cm (90 mm) to 23 cm (110 mm), 24 cm (120 mm) and 28 cm (140 mm) in Area1 (Figure 3.5A). In Area2, modal length increased from 25 cm (in 90 mm and 110 mm mesh) to 26 cm (120 mm) and 27 cm (140 mm) (Fig. 3.5B).

Ratios of commercial/discard size rock cod in the catch (CSF) were significantly higher in 120 mm and 140 mm mesh in Area1 and in 140 mm mesh in Area2 (Fig 3.6A). Commercial size (≥ 25 cm) rock cod on average accounted for 37%-50% of the catch in 90 mm and 110 mm mesh in Area1 compared to 70%-86% in larger mesh sizes (Fig 3.6A). In Area2, commercial-size fish explained a higher proportion of the catch in smaller mesh sizes (between 73%-76%) while larger mesh yielded a similar 79%-88%. Daily catch reports (based on factory process weights) gave comparable, albeit slightly higher CSF, with somewhat reduced variability in 120 mm trials (Fig. 3.6B).

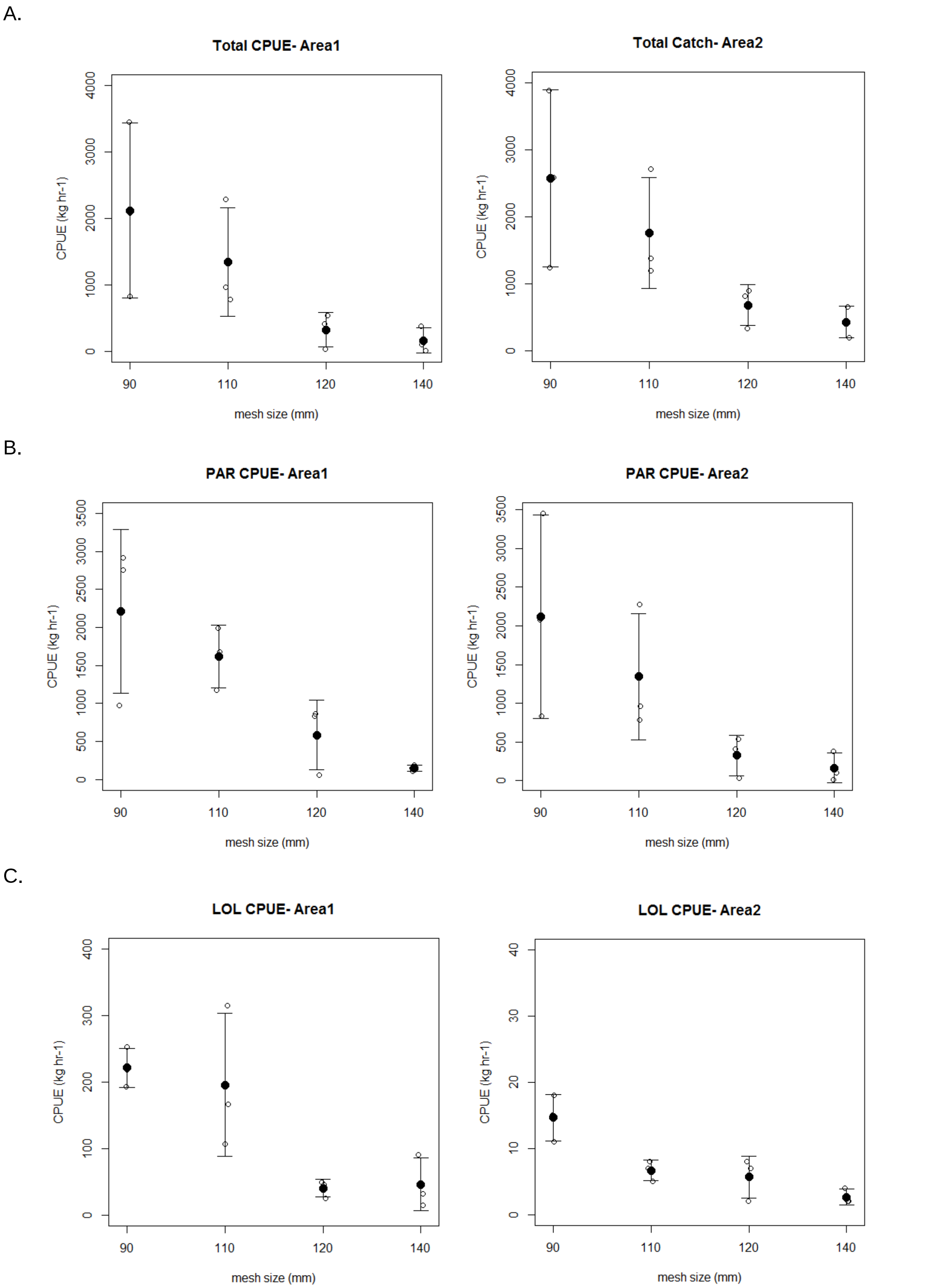
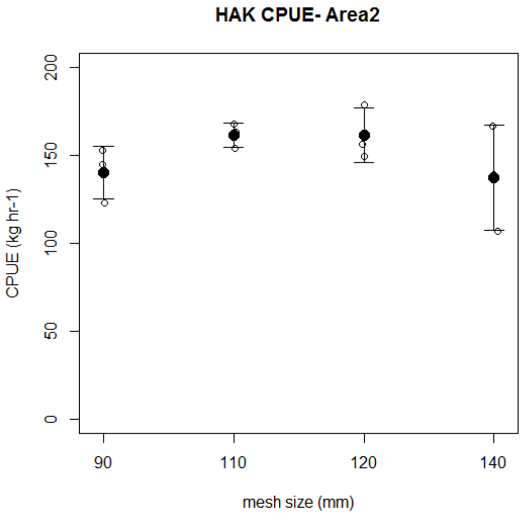
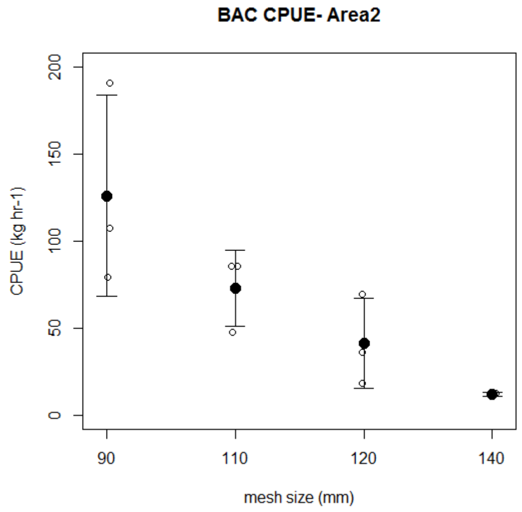


Figure 3.4. Fitted CPUE by mesh size and area. Dark circles and error bars are means ± sd. Empty circles are trawl-specific values.

D.



E.



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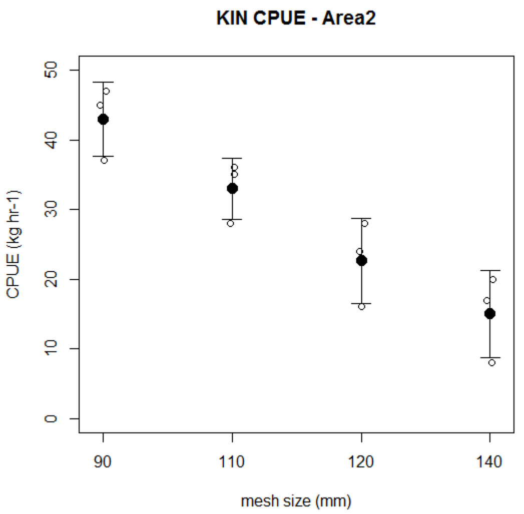
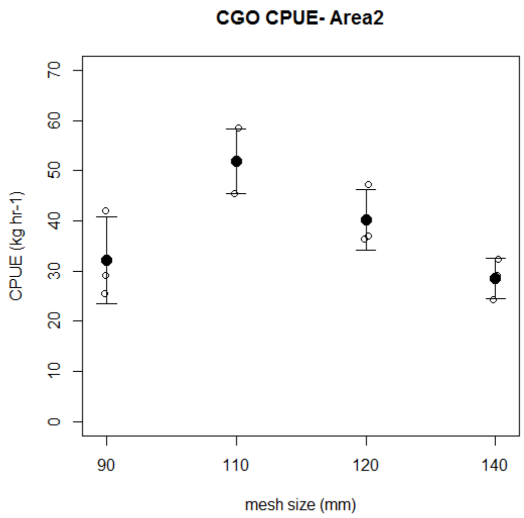


G.



H.

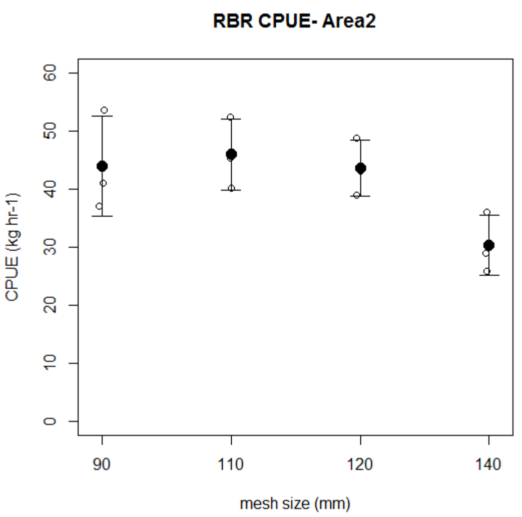


Figure 3.4. (continued)

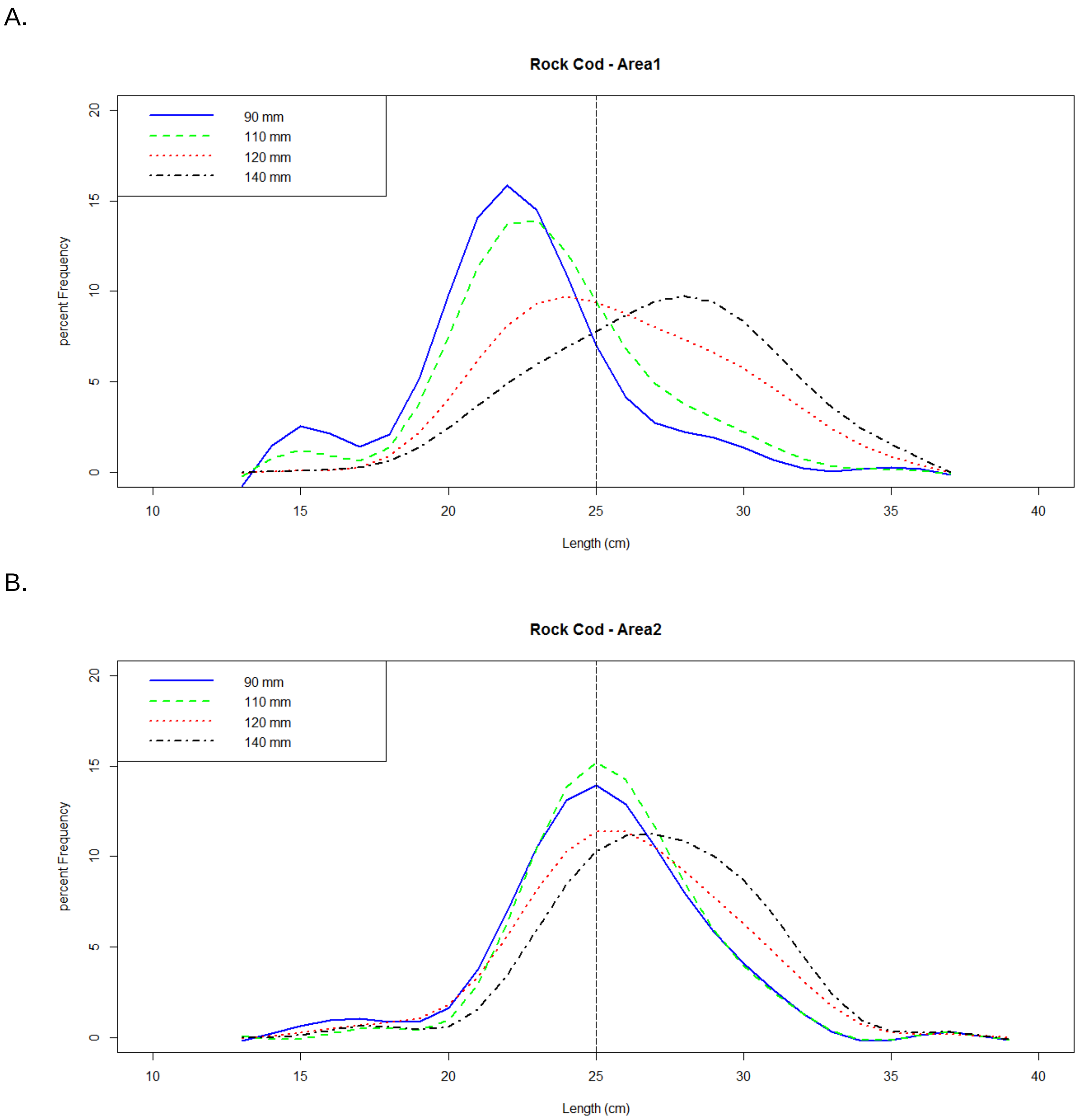


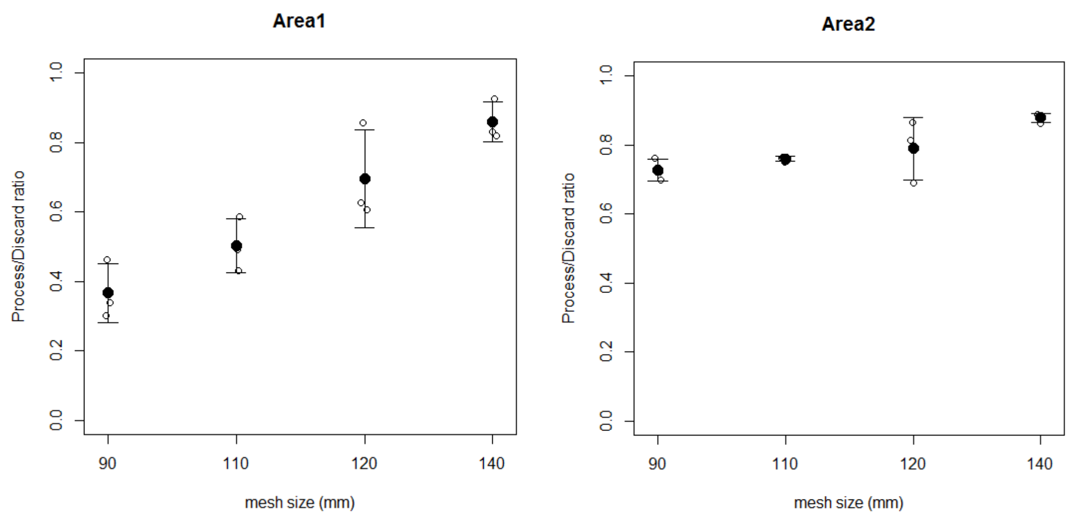
Figure 3.5. GAM-smoothed length frequency distributions by mesh size for rock cod in Area1 (A) and Area2 (B). Dashed line indicates the 25-cm threshold for discard (< 25 cm) versus commercial-size (≥ 25 cm) rock cod.

Average process weights decreased from 754-1,513 kg hr^{-1} in 90 mm mesh trials to 823-1,022 kg hr^{-1} in 110 mm, 248-362 kg hr^{-1} in 120 mm and 126-144 kg hr^{-1} in 140 mm, depending on area (Fig 3.7A). The larger mesh codend (140 mm) yielded a significant reduction in rock cod process weight only in Area1. Estimated discard weights decreased from an average on 607-1,459 kg hr^{-1} in 90 mm mesh to 320-792 kg hr^{-1} in 110 mm, 76-220 kg hr^{-1} in 120 mm and 19-23 kg hr^{-1} in 140 mm. This represented a reduction by a factor of 7 - 8 in 120 mm relative to 90 mm mesh and by a factor of 32 - 63 in 140 mm (Fig 3.7B). Both 120 mm and 140 mm mesh yielded a significant reduction in average discard weights of rock cod in the sampling areas (Fig 3.7B).

Mesh size and retention probability

Rock cod retention probability was related to rock cod length following the double-logistic function with maximum retention (≥ 50%) between 17-34 cm depending on mesh size (Fig 3.8, Table 3.5). The probability of retaining commercial-size (> 25 cm) rock cod increased with codend mesh size. Minimum length of 50% retention ($L_{50}{}^{1}$) increased from 17 cm (Area1) and 19 cm (Area2) in 90 mm mesh trials to 24 cm in the larger mesh (140 mm) codend. In both areas, $L_{50}{}^{1}$ increased by 2 cm in the 110 mm relative to 90 mm mesh. Results were more variable in 120 mm mesh trials, which yielded a reduction in retention probability of smaller (< 20 cm) rock cod in Area1 but an increase in Area2 (Fig 3.8). Only the 140 mm mesh consistently selected commercial size rock cod in the sampling areas (i.e. yielded ≥ 50% retention probabilities for ≥ 24 cm fish). The smaller mesh (90 mm) codend mainly retained undersized fish (Fig. 3.8, Table 3.5).

A.



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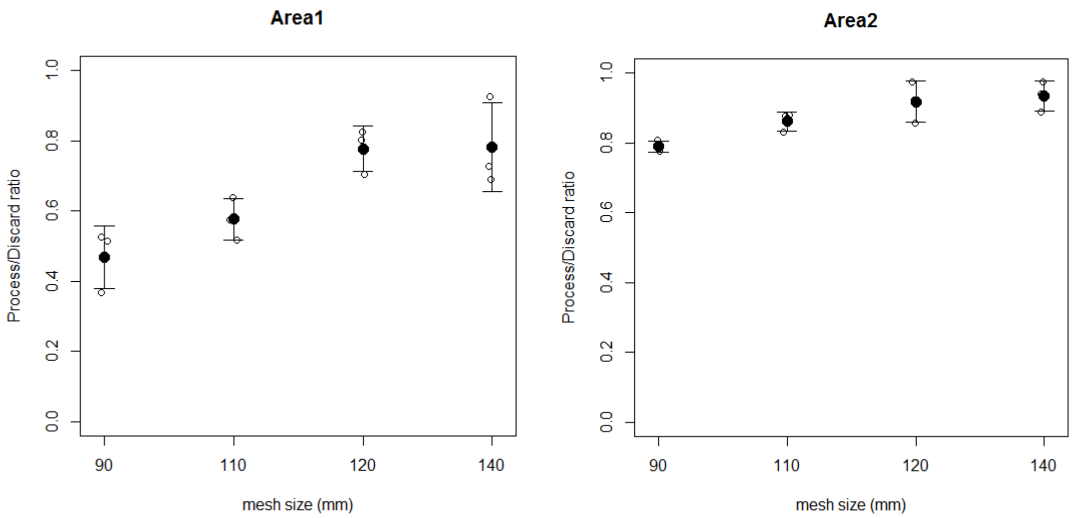
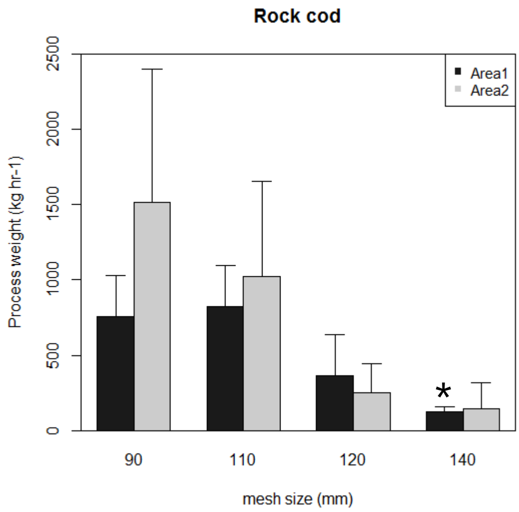


Figure 3.6. Fitted ratios of commercial (≥ 25 cm) to discard-size (< 25 cm) rock cod among codend mesh sizes in the sampling areas, as estimated from length frequencies (A) and catch reports (B).

A.



B.

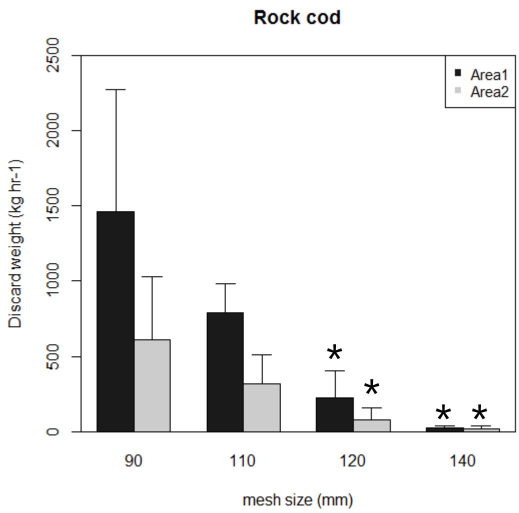


Figure 3.7. Average rock cod process weight (A) and discard weight (B) by unit effort among mesh sizes in the sampling areas. Asterisks (*) indicate statistically significant departures from the overall mean.

Rock cod summary

The results corroborate earlier findings from Brickle and Winter (2011) and Roux et al (2012) of a decreased probability of retaining undersized rock cod and significant reduction in discard weights of rock cod in larger (≥ 120 mm) mesh codends. The present trials conducted in areas of high rock cod density however demonstrated that improved retention of commercial-size fish was accompanied by a reduction in total catch (and reduced process weights for rock cod in the 140 mm mesh in one area). Factors that may explain such reduction include fish behaviour and differences in the mechanics of the trawling gear when using ≥ 120 mm mesh sizes in the codend. As in earlier trials, the 90 mm and 110 mm mesh yielded statistically similar rock cod CPUE, discard and process weights, while minimum length of 50% retention was increased by 2 cm in 110 mm relative to 90 mm mesh.

Overall, the findings indicate that increasing the minimum allowable codend mesh size to 120 mm in finfish fisheries will improve fishery sustainability for rock cod by minimizing discards and catches of undersized fish, but will likely cause a reduction in fishery efficiency in terms of CPUE.

Table 3.5 Fitted parameters of the double logistic equation describing retention probability at length among codend mesh sizes and sampling areas. L_{50}^1 and L_{50}^2 are minimum and maximum lengths of 50% retention, respectively

Species	Area	mesh size	s1	s2	L_{50}^1	L_{50}^2
P. ramsayi	1	90	0.58	0.42	**17**	**25**
	2b	90	0.66	0.25	**19**	**29**
	1	110	0.56	0.44	**19**	**27**
	2b	110	0.66	0.48	**21**	**29**
	1	120	0.28	0.54	**22**	**30**
	2b	120	0.52	0.11	**18**	**32**
	1	140	0.34	0.44	**24**	**34**
	2b	140	1.13	0.35	**24**	**33**
D. gahi	1	90	2.14	0.003	**0**	**18**
	2b	90	0.18	6.44	**11**	**16**
	1	110	0.48	0.72	**13**	**19**
	2b	110	0.31	1.04	**12**	**17**
	1	120	1.87	0.22	**12**	**19**
	2b	120	0.20	1.80	**12**	**17**
	1	140	0.69	0.25	**12**	**20**
	2b	140	0.17	1.38	**13**	**20**
M. hubbsi	2b	90	0.02	0.09	**0**	**47**
	2b	110	2.43	0.01	**53**	**80**
	2b	120	0.11	0.78	**48**	**60**
	2b	140	0.10	0.10	**48**	**71**
S. australis	2b	90	0.16	4.65	**13**	**30**
	2b	110	0.18	0.59	**23**	**33**
	2b	120	0.24	0.41	**26**	**38**
	2b	140	2.74	0.12	**30**	**45**
C. gobio	2b	90	0.05	0.58	**0**	**34**
	2b	110	0.88	0.06	**35**	**62**
	2b	120	1.46	0.07	**31**	**65**
	2b	140	2.14	0.10	**32**	**64**

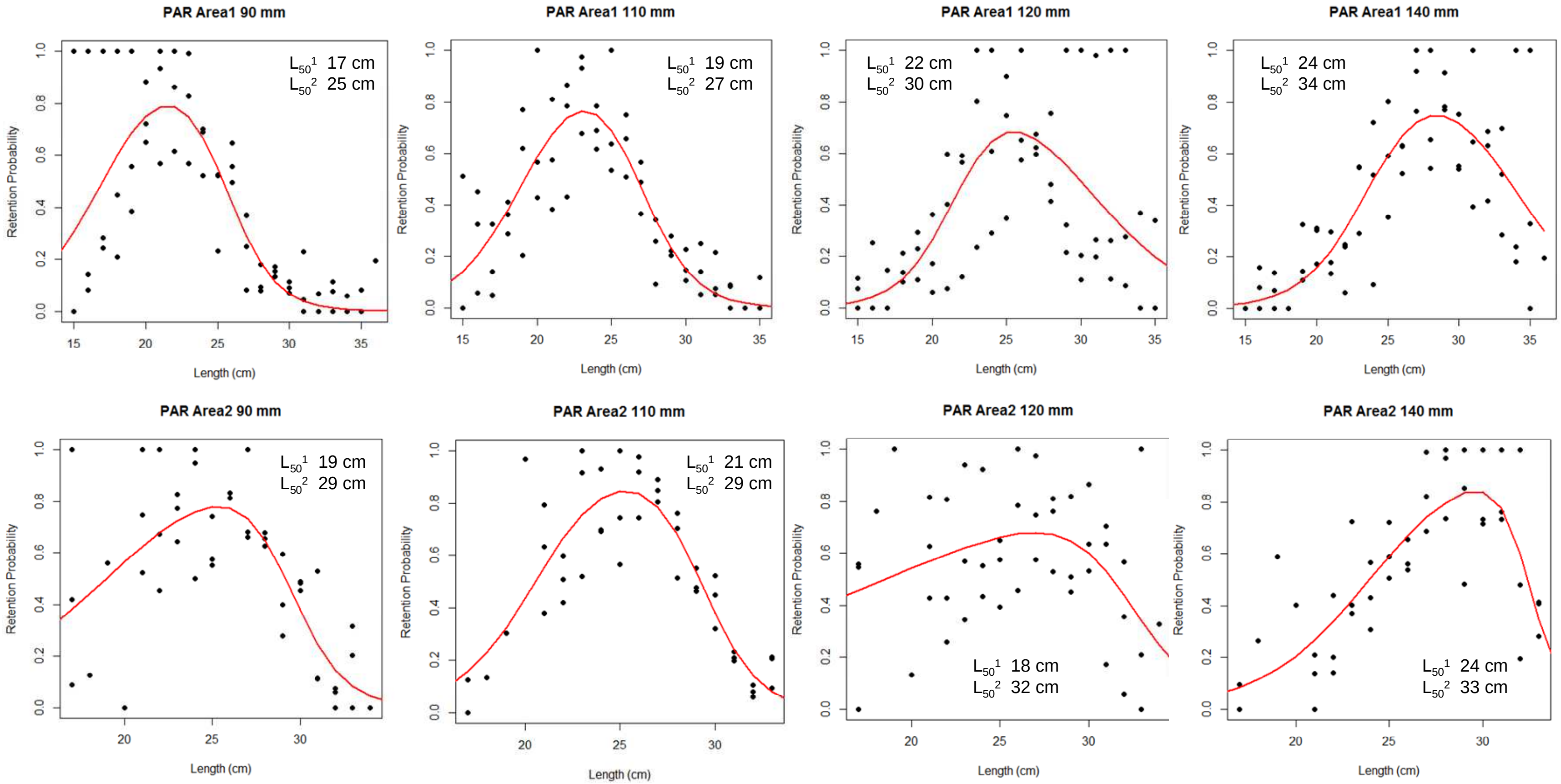


Figure 3.8. Retention probability at length among codend mesh sizes for rock cod in Area1 (top) and Area2 (bottom). Red lines are fitted probability curves obtained using the double logistic equation. L_{50}^1 and L_{50}^2 are minimum/maximum lengths of 50% retention, respectively.

3.2.3 *Doryteuthis gahi* (Loligo squid)

Mesh size and CPUE

Loligo CPUE ranged 11-317 kg per hour among hauls in Area1 (mean 126 kg hr^{-1}) and 2-18 kg per hour (mean 7 kg hr^{-1}) in Area2. In Area1, loligo CPUE decreased from 196-221 kg hr^{-1} in 110 mm and 90 mm mesh to 40-46 kg hr^{-1} in 120 mm and 140 mm mesh. In Area2, mesh sizes ≥ 110 mm yielded lower loligo CPUE between 3-7 kg hr^{-1} compared to an average of 15 kg hr^{-1} in the smaller 90 mm mesh (Fig 3.4C).

Mesh size and length composition of the catch

Loligo mantle length ranged 6-34 cm (median 15 cm) in Area1 and 8-39 cm (median 16 cm) in Area2. Length structure was consistent among mesh sizes in Area1. Modal mantle length was 15 cm in all mesh sizes (Fig. 3.9A). In Area2, modal mantle length increased from 14.5-15 cm in 90 mm and 110 mm mesh to 16-16.5 cm in 120 mm and 140 mm mesh codends (Fig 3.9B).

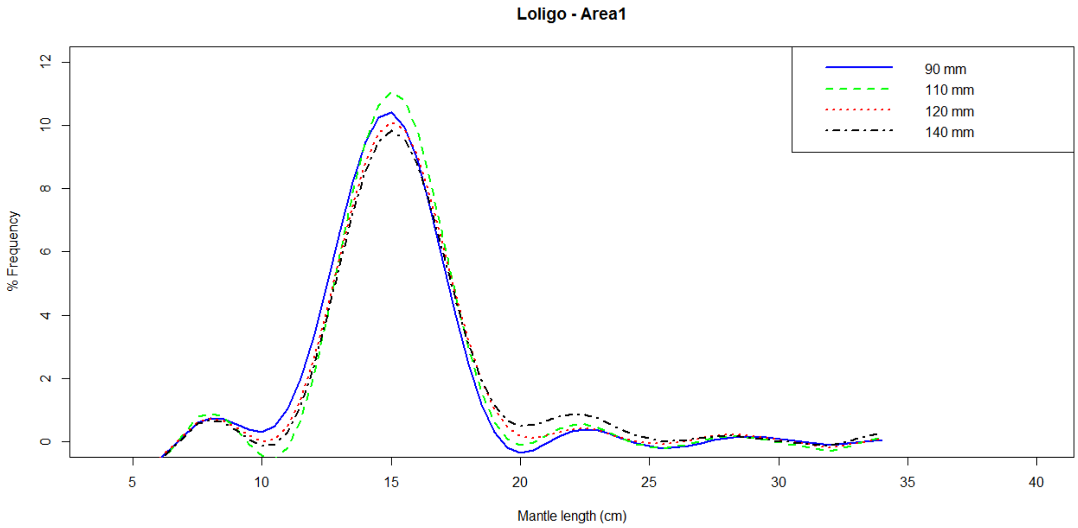
Mesh size and retention probability

Despite important inter-haul variability, loligo retention probability varied with mantle length following the double logistic function (Fig 3.10). The probability of retaining loligo > 18 cm increased with codend mesh size in both areas (Fig 3.10). Minimum mantle length of 50% retention (L_{50}^{1}) was relatively independent from mesh size effects (Table 3.5). All squid up to 18 cm had a 50% chance of being retained by the 90 mm mesh codend in Area1 (L_{50}^{1} 0 cm). In Area2, the same codend yielded an L_{50}^{1} of 11 cm. Larger mesh sizes yielded a similar range of 50% retention between areas (Fig. 3.10, Table 3.5).

Loligo summary

The results confirm earlier findings by Roux et al (2012) of a reduction in fishery efficiency for loligo in terms of CPUE in larger mesh codends (≥ 110 mm or ≥ 120 mm, depending on area). Within the loligo size range encountered in this study (10-24 cm mantle length), mesh size effects on size composition of the catch were generally limited, although larger mesh sizes improved retention of larger (> 18 cm) squid.

A.



B.

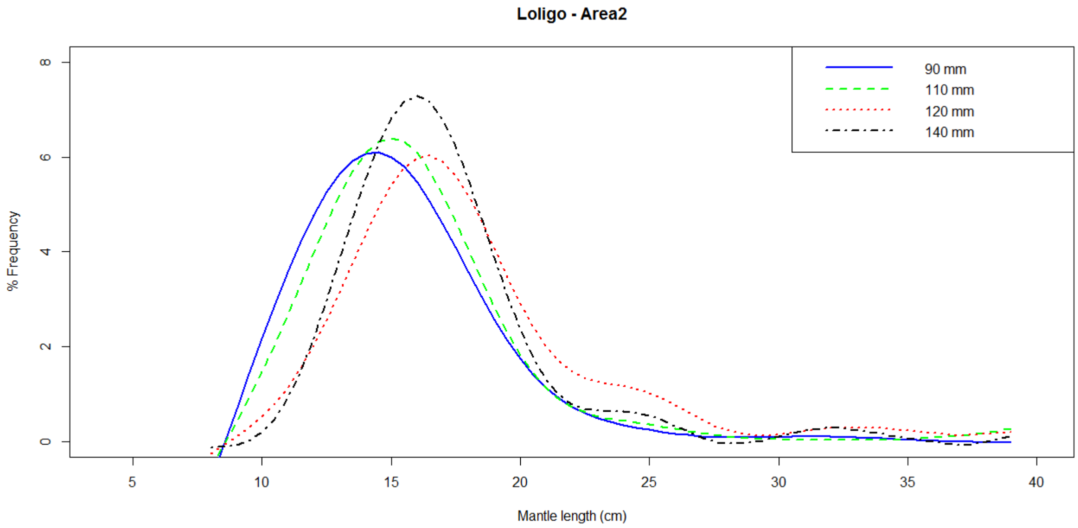


Figure 3.9. GAM-smoothed mantle length frequency distributions by mesh size for loligo squid (*D. gahi*) in Area1 (A) and Area2 (B).

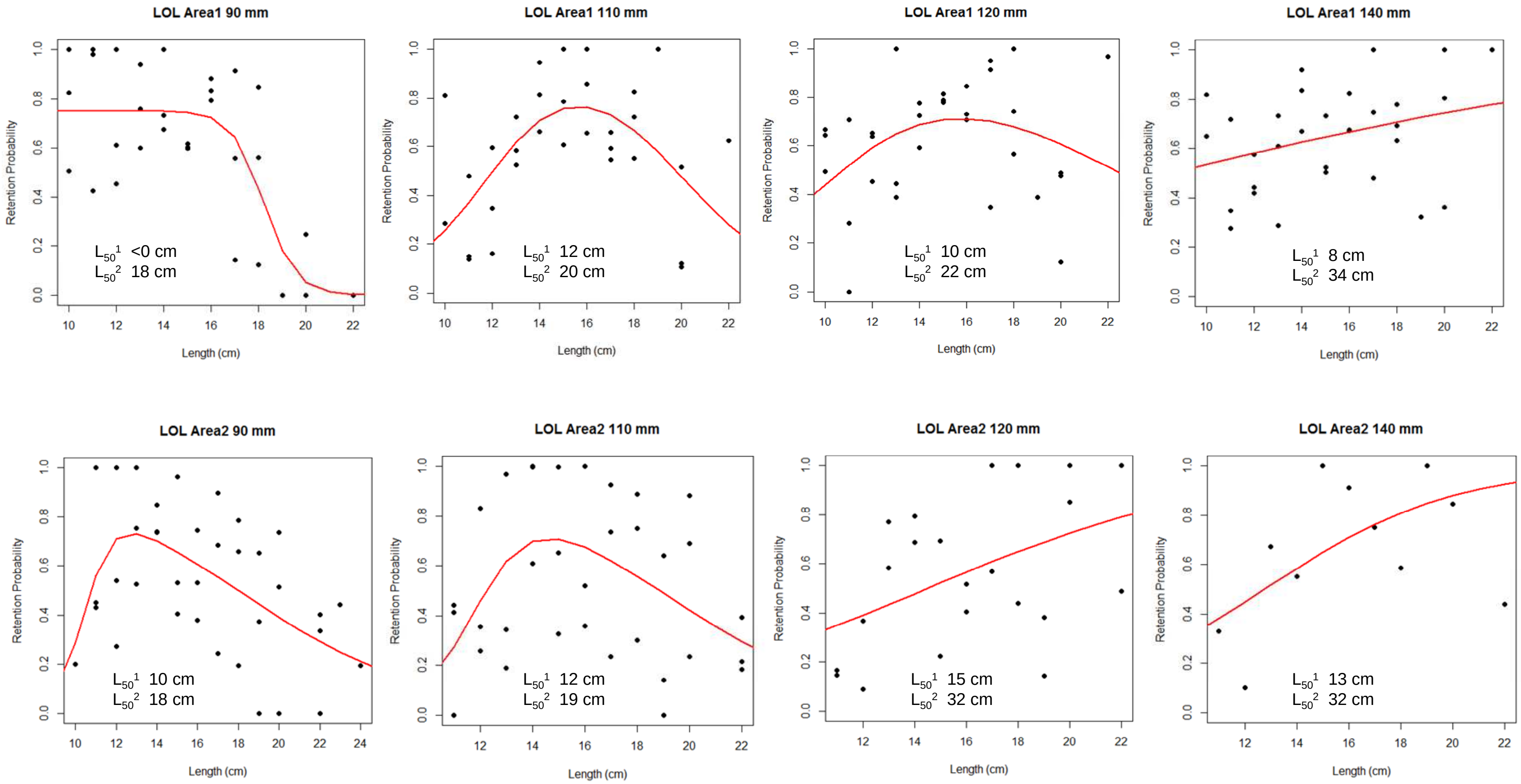


Figure 3.10. Retention probability at mantle length among codend mesh sizes for loligo squid in Area1 (top) and Area2 (bottom). Red lines are fitted probability curves obtained using the double logistic equation. L_{50}^{1} and L_{50}^{2} are minimum/maximum lengths of 50% retention, respectively.

3.2.4 *Merluccius hubbsi* (Hake)

Mesh size and CPUE

Hake was caught in Area2. Relative abundance averaged 150 kg per hour (range 93-185 kg hr^{-1} among hauls). There were no effects of codend mesh sizes on Hake CPUE, which varied from a low of 138 kg hr^{-1} (in 140 mm mesh) to a high of 162 kg hr^{-1} (in 110 mm and 120 mm mesh) (Fig 3.4D).

Mesh size and catch composition by length/weight

Hake length ranged 35-93 cm (median 59 cm). No directional changes in length structure were observed with increasing codend mesh sizes. Hake modal length varied from a low of 54 cm in 120 mm mesh trials to a high of 59 cm in the smaller, 90 mm mesh (Fig 3.11).

The HGT-size threshold for hake is 400 g (760 g green weight) or 47 cm. Catch ratios above/below the HGT-threshold (CSF) were similar among mesh sizes with HGT-size hakes accounting for 97%-99% of the catch. Estimated HGT-CPUE were likewise independent from mesh sizes and ranged from 136 kg per hour (in 140 mm mesh) to 158 kg per hour (in 110 mm mesh) (Fig 3.12)

Mesh size and retention probability

Within the size range encountered in this study, hake retention probability was generally independent from hake length and codend mesh size (Fig 3.13). Most of the available length classes had retention probabilities $\geq$ 40% according to double-logistic fitting. The model suggested a size range of 50% retention below the minimum HGT-size (47 cm) only in the 90 mm mesh codend (Table 3.5). Enhanced selectivity for intermediate size (48-60 cm) hake was visible in 120 mm mesh trials (Fig. 3.13).

Hake summary

Fishery efficiency for hake was independent from codend mesh sizes in this survey. This confirms earlier findings from Brickle and Winter (2011). Roux et al (2012) demonstrated limited mesh size effects where hake aggregations were dominated by larger size (> 50 cm) fish, as was the case in the present survey.

Based on these findings, an increase in the minimum allowable codend mesh size in finfish fisheries can be expected to have limited or no influence on fishery efficiency for hake. There was improved retention of HGT-size fish, especially in areas where hake aggregations are dominated by smaller-size (< 50 cm) individuals.

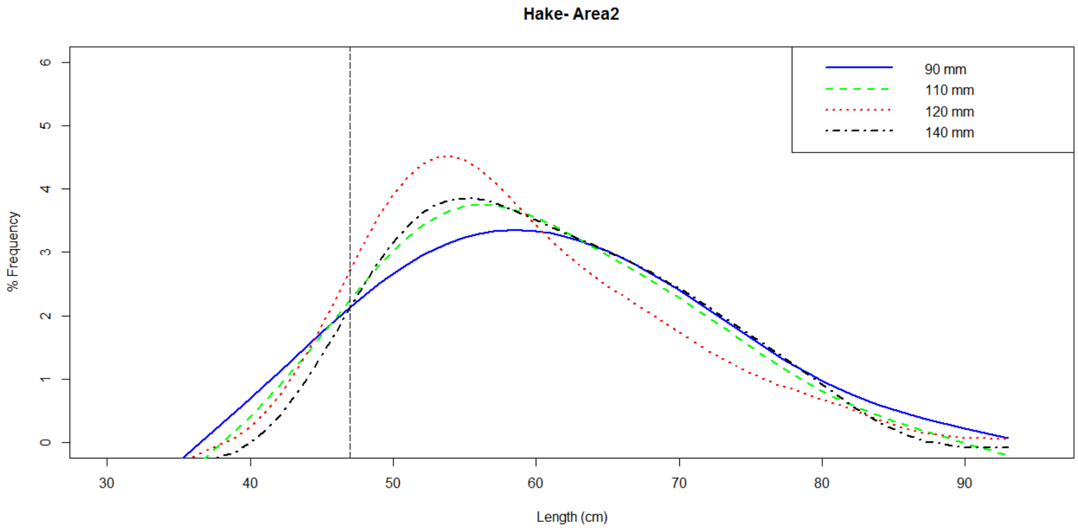


Figure 3.11. GAM-smoothed length frequency distributions by mesh size for hake (*M. hubbsi*) in Area2. Dashed line indicates the 47-cm threshold corresponding to length at minimum HGT-weight (760 g (green weight)) for the species.

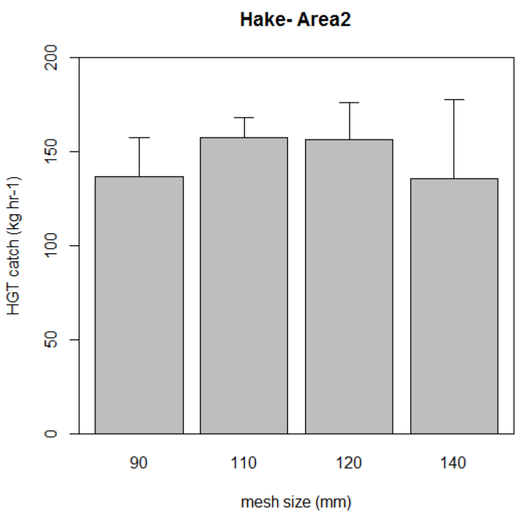


Figure 3.12. HGT-CPUE (mean ± sd) among mesh sizes for Hake in Area2.

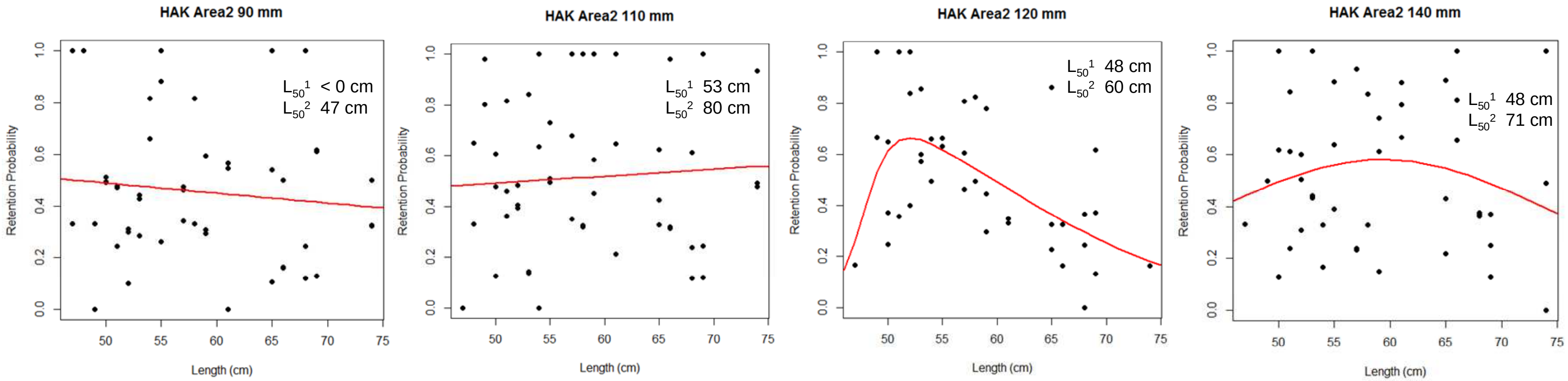


Figure 3.13. Retention probability at length among codend mesh sizes for hake in Area2. Red lines are fitted probability curves obtained using the double logistic equation. L_{50}^{1} and L_{50}^{2} are minimum/maximum lengths of 50% retention, respectively.

3.2.5 *Salilota australis* (Red cod)

Mesh size and CPUE

Red cod was mainly encountered in Area2. CPUE averaged 63 kg per hour (range 10-194 kg hr^{-1} among hauls). Mesh size effects were significant with lower catches of red cod in 120 mm (41 kg hr^{-1}) and 140 mm (12 kg hr^{-1}) relative to 110 mm (73 kg hr^{-1}) and 90 mm (126 kg hr^{-1}) mesh (Fig 3.4E). Variability in CPUE was reduced in 140 mm relative to smaller mesh trials (Fig 3.4E).

Mesh size and catch composition by length/weight

Red cod length ranged 15-73 cm (median 29 cm). Length frequency distributions varied with codend mesh sizes with modal length increasing from 27 cm (in 90 mm mesh) to 28 cm (in 110 mm) and 29 cm (in 120 mm and 140 mm mesh) (Fig 3.14). The HGT-size threshold for red cod is 300 g (600 g green weight) or 40 cm. Most (92%) of the red cod harvested during the survey was smaller than the minimum HGT-size for the species.

Catch ratios above/below the HGT-threshold (CSF) were comparable in 90 mm, 110 mm and 120 mm mesh and ranged 15%-22% (Fig 3.15). The larger mesh (140 mm) codend yielded significantly higher proportions of HGT-size red cod in the catch (mean of 48%) (Fig 3.15).

Estimated HGT-catch weights were statistically similar among mesh sizes however catches of undersized red cod were significantly lower in 120 mm and 140 mm mesh trials (Fig 3.16).

Mesh size and retention probability

Red cod retention probability was related to red cod length according to double-logistic fitting. Both minimum and maximum length of 50% retention (L_{50}^1 and L_{50}^2) increased with codend mesh size, indicating a decreased probability of retaining undersized red cod and increased probability of retaining commercial-size fish in larger mesh (Fig. 3.17, Table 3.5). Within the size range available to fit retention probabilities (18-40 cm), only the larger mesh (140 mm) yielded 50% retention above the minimum HGT-size (40 cm) for red cod (Table 3.5).

Red cod summary

The results demonstrate that larger codend mesh sizes (≥ 120 mm) tend to improve fishery efficiency for red cod by reducing the relative abundance of undersized fish in the catch and by increasing the probability of retaining red cod of commercial size. An increase in the minimum allowable codend mesh size in finfish fisheries can thus be expected to enhance fishery efficiency and ensure fishery sustainability for red cod.

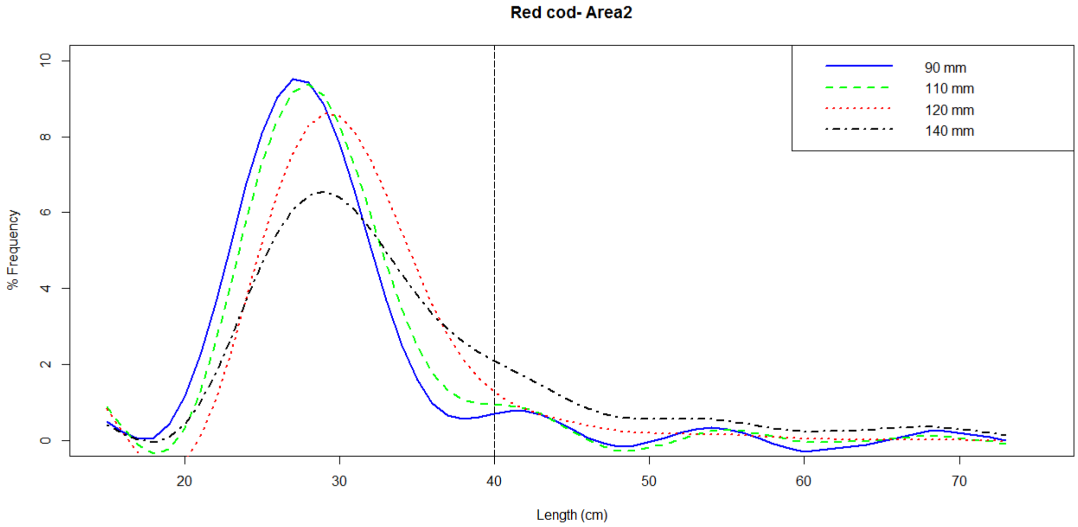


Figure 3.14. GAM-smoothed length frequency distributions by mesh size for red cod (*S. australis*) in Area2. Dashed line indicates the 40-cm threshold corresponding to length at minimum HGT-weight (600 g (green weight)) for the species.

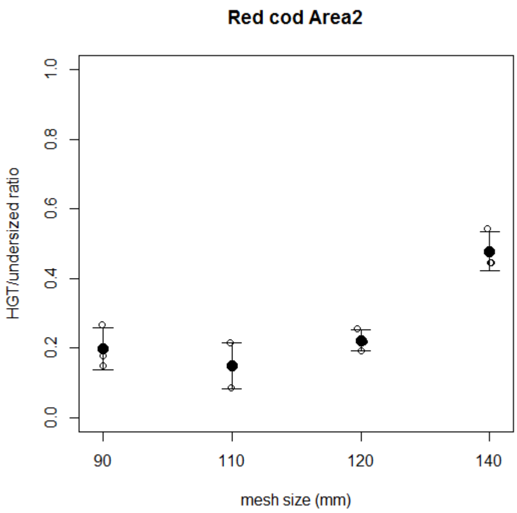


Figure 3.15. Red cod catch ratios above/below the HGT-size threshold among codend mesh sizes in Area2.

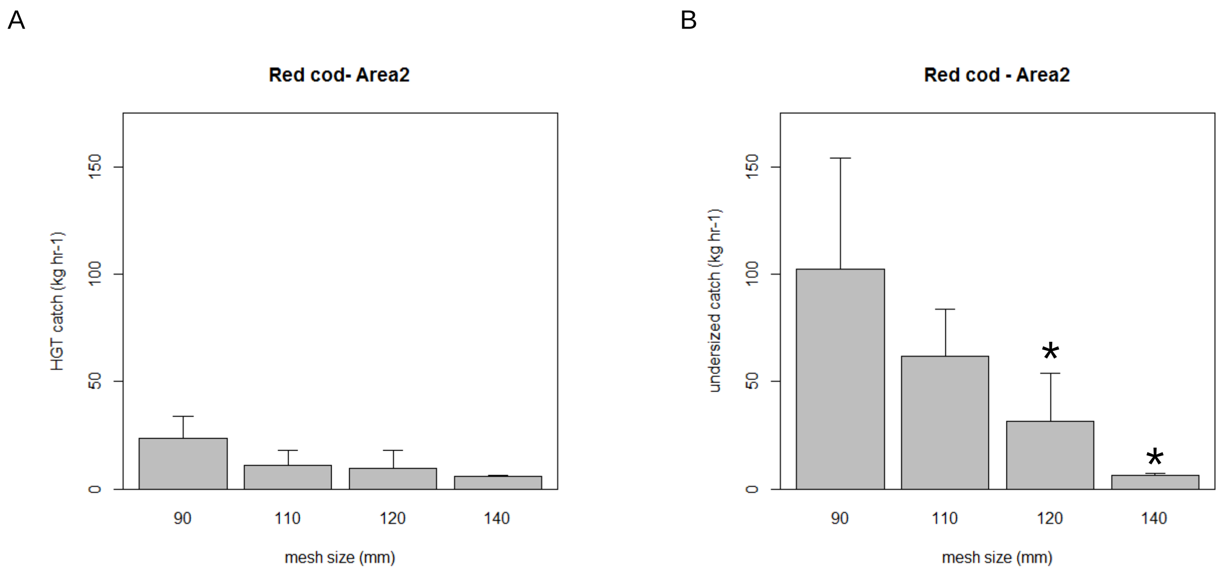


Figure 3.16. Estimated CPUE for HGT-size red cod (A) and below HGT-size red cod (B) among codend mesh sizes in Area2. Asterisks indicate significant departures from the overall mean.

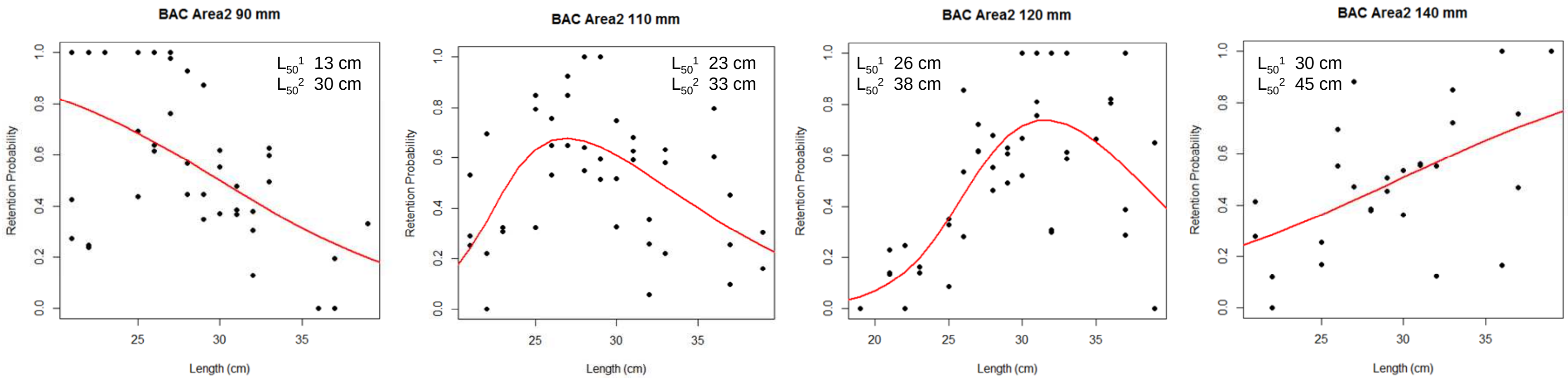


Figure 3.17. Retention probability at length among codend mesh sizes for red cod in Area2. Red lines are fitted probability curves obtained using the double logistic equation. L_{50}^{1} and L_{50}^{2} are minimum/maximum lengths of 50% retention, respectively.

3.2.6 *Genypterus blacodes* (Kingclip)

Mesh size and CPUE

Kingclip was mainly caught in Area2. Its relative abundance was generally low, averaging 28 kg per hour (range 8-47 kg hr^{-1} among hauls). Kingclip CPUE decreased with increasing codend mesh sizes, reaching significantly lower mean values in 120 mm (22 kg hr^{-1}) and 140 mm (15 kg hr^{-1}) relative to smaller mesh codends (range 33-43 kg hr^{-1} in 110 mm and 90 mm, respectively) (Fig. 3.4F).

Mesh size and catch composition by length/weight

Kingclip length ranged 36-128 cm (median 61 cm). The majority of the catch (69%) was smaller than the minimum HGT-size of 70 cm (corresponding to 600 g or 1380 g green weight). Length frequency distributions varied with codend mesh sizes (Fig 3.18). Modal length increased from 56 cm in 90 mm mesh trials to 61 cm (in 110 mm and 120 mm) and 63 cm (in 140 mm mesh) (Fig 3.18).

Ratios of HGT-size to undersized kingclip (CSF) were relatively constant in 90 mm, 110 mm and 120 mm mesh, with HGT-size fish on average accounting between 46%-49% of the catch (Fig 3.19). Larger mesh (140 mm) trials yielded a significantly higher CSF (79%) (Fig 3.19). These results should be interpreted with caution however, owing to small kingclip length frequency sample sizes (generally less than 100 individuals per haul).

Estimated HGT-CPUE were reduced by a factor of more or less 1.5 in larger mesh (means of 11-12 kg hr^{-1} in 120 mm and 140 mm) relative to the 110 mm and 90 mm mesh (means of 16 and 20 kg hr^{-1}, respectively) (Fig 3.20). Reductions in undersized fish CPUE were more important, with mean values decreasing by a factor of 2 in 120 mm (12 kg hr^{-1}) relative 90 mm trials (23 kg hr-1) and by a factor of 8 in 140 mm (3 kg hr^{-1}). Here again, these results should be interpreted with caution owing to small sample sizes.

Mesh size and retention probability

Kingclip sample sizes per haul and numbers of individuals per 1-cm length classes were too small to allow double logistic fitting.

Kingclip summary

At relatively constant low relative abundance, larger mesh sizes (≥ 120 mm) yielded a reduction in fishery efficiency for Kingclip in terms of CPUE, corresponding to a slight decrease in process weight and a more important reduction in the relative abundance of undersized fish in the catch. Previous trials likewise reported lessened proportions (Brickle and Winter 2011) and reduced retention probabilities (Roux et al 2012) for small (< 60 cm) kingclip in 120 mm and 140 mm mesh, however with no reductions in catches of commercial-size fish.

Roux et al. (2012) underlined the variable character of kingclip aggregations and related fishery efficiency. Thus while mesh size effects on fishery efficiency for kingclip are likely to vary in time and space, combined findings from all three mesh size trials indicate that an increase in codend mesh size ≥ 120 mm in finfish fisheries will contribute to lessen catches of undersized kingclip. This may serve to enhance fishery sustainability for the species over the long term.

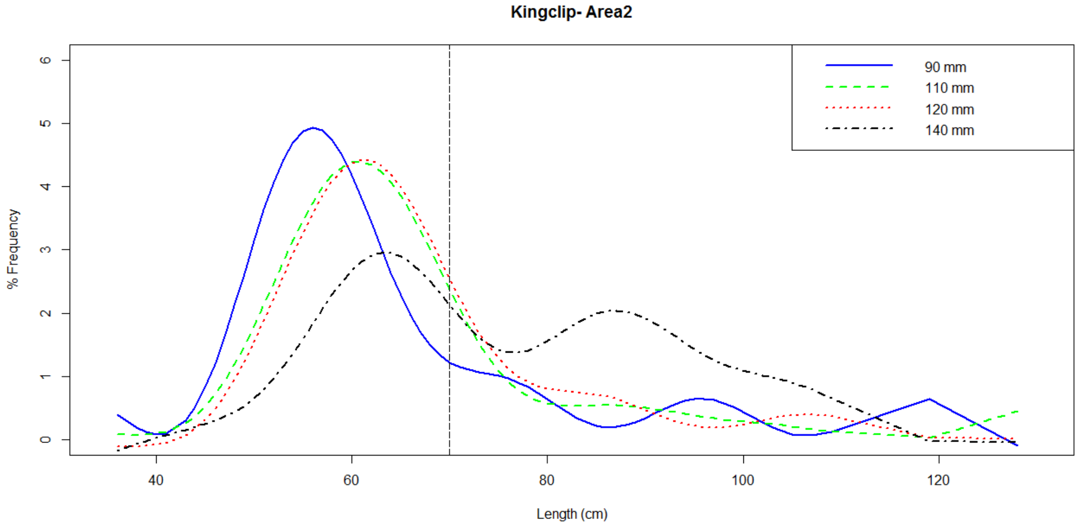


Figure 3.18. GAM-smoothed length frequency distributions by mesh size for kingclip (*G. blacodes*) in Area2. Dashed line indicates a 70-cm commercial threshold corresponding to length at minimum HGT-weight (1380 g (green weight)).

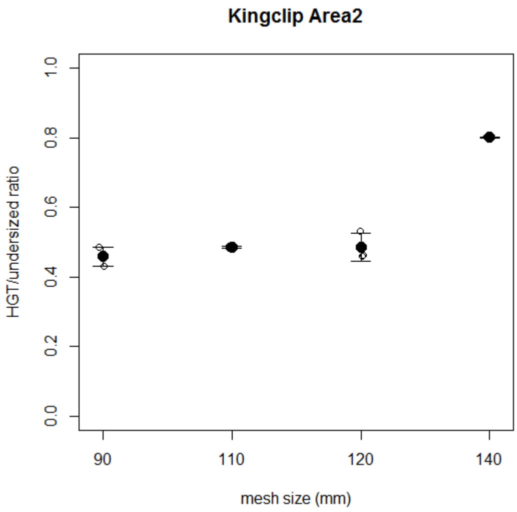


Figure 3.19. Ratios of kingclip catches above/below the HGT-size threshold among codend mesh sizes in Area2.

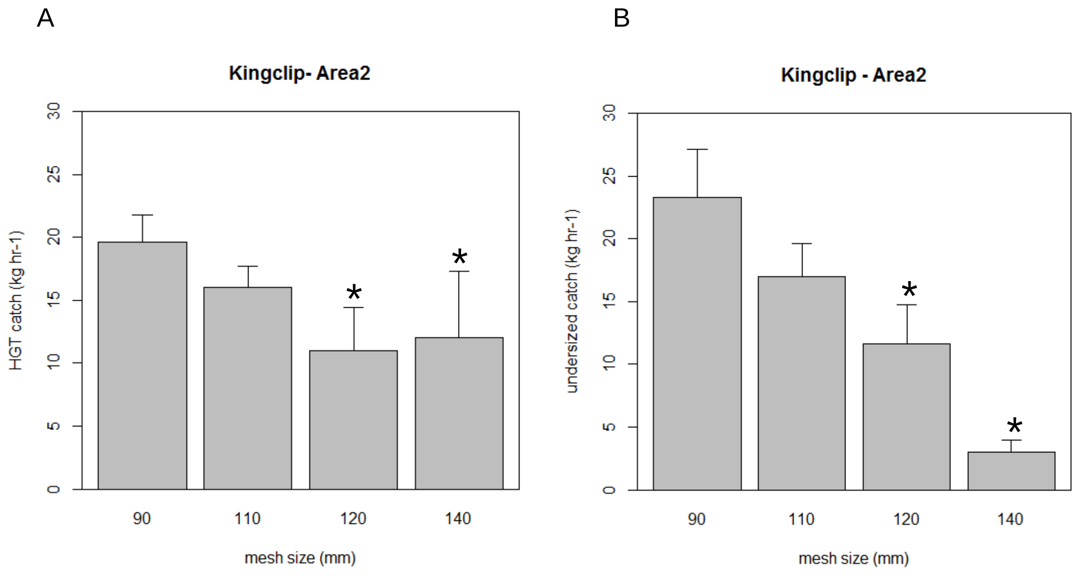


Figure 3.20. Estimated HGT-CPUE (A) and undersized CPUE (B) for kingclip among codend mesh sizes in Area2. Asterisks indicate significant departures from the overall mean.

3.2.7 *Cottoperca gobio* (Frogmouth)

Mesh size and CPUE

Frogmouth was ubiquitous in catches from Area2 with an average CPUE of 38 kg per hour (range 20-62 kg hr^{-1} among hauls). Higher frogmouth CPUE (mean 52 kg hr^{-1}) were observed in 110 mm mesh trials compared to means of 29-40 kg hr^{-1} in other mesh sizes (Fig. 3.4G).

Mesh size and length composition of the catch

Frogmouth length ranged 11-70 cm (median 37 cm). Length structure differed among mesh sizes with smaller (90 mm) mesh trials yielding a bimodal length frequency distribution peaking at 18 cm and 35 cm (modal length) (Fig 3.21). The occurrence of < 30 cm frogmouth in the catch was clearly reduced in larger mesh sizes, with modal lengths peaking at 37-38 cm (Fig. 3.21).

Mesh size and retention probability

Frogmouth retention probability was clearly independent from individual length above 30-cm (Fig. 3.22). The double-logistic function could nonetheless be fitted to the data and suggested that all frogmouth up to 34 cm had a ≥ 50% chance of being retained in the smaller (90 mm) mesh while minimum length of 50% retention in larger mesh sizes ranged 31-35 cm (Fig. 3.22, Table 3.5).

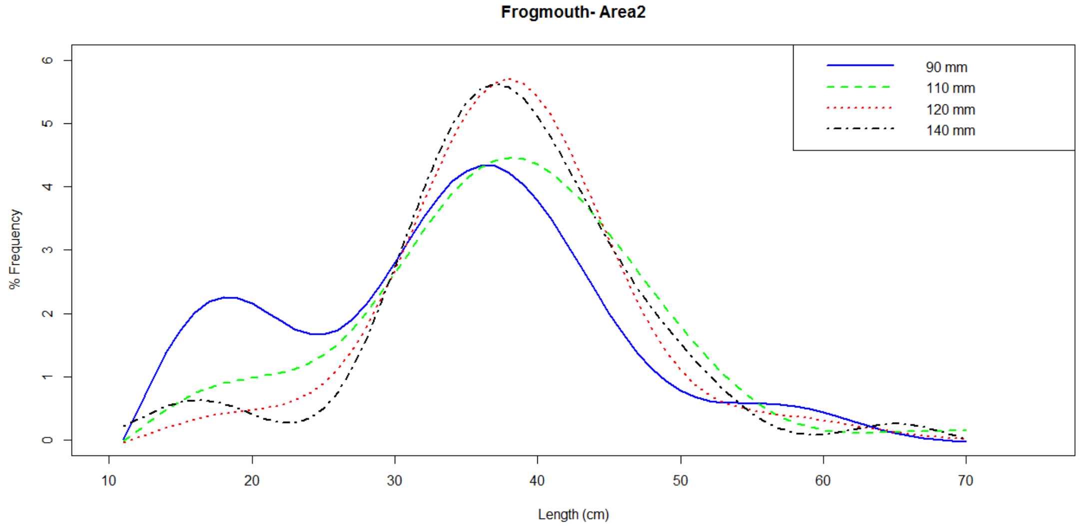


Figure 3.21. GAM-smoothed length frequency distributions by mesh size for frogmouth (*C. gobio*) in Area2.

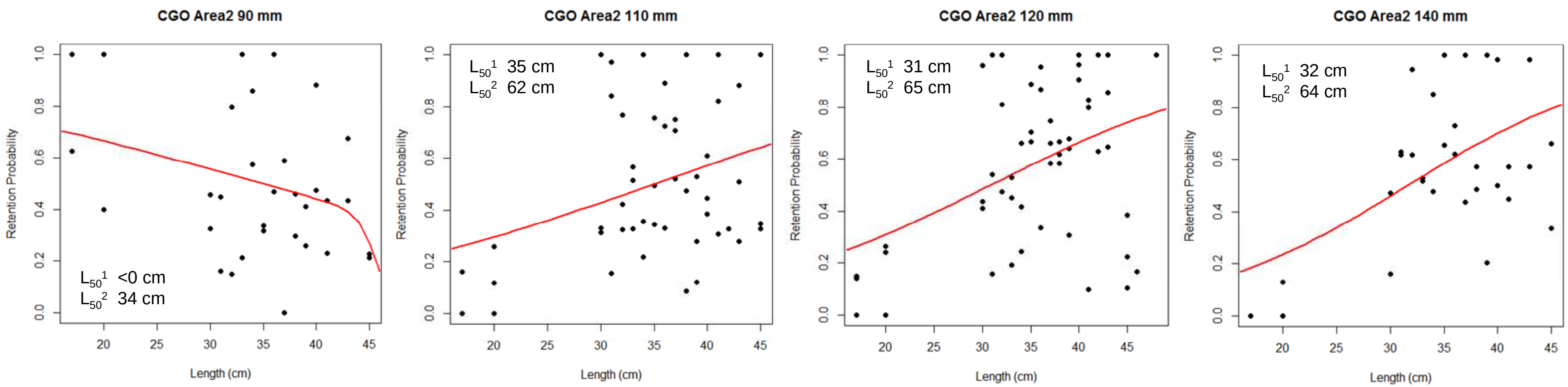


Figure 3.22. Retention probability at length among codend mesh sizes for frogmouth in Area2. Red lines are fitted probability curves obtained using the double logistic equation. L_{50}^1 and L_{50}^2 are minimum/maximum lengths of 50% retention, respectively.

Frogmouth summary

Frogmouth currently is not a commercial species in Falkland waters however its occurrence was relatively high in Area2 where it accounted for 2% of the catch. At such incidence, changes in fishery efficiency for this non-target species are likely to have indirect impacts on the structure/function of the marine food web.

The results indicate that an increase in the minimum allowable codend mesh size in finfish fisheries is unlikely to affect frogmouth CPUE but will contribute to reduce catches of undersized (< 30 cm) fish, which will likely benefit population dynamics in the long-term.

3.2.8 Rajidae sp. (Skates)

Mesh size and CPUE

B. brachyurops (RBR) was mainly caught in Area2. Small catches (total 156 kg) occurred in Area1. RBR relative abundance in Area2 averaged 41 kg per hour (range 20-64 kg hr^{-1} among hauls). RBR CPUE were independent from codend mesh sizes and varied from a lower mean of 30 kg hr-1 (in 140 mm mesh) to a high of 46 kg hr-1 (in 110 mm mesh) (Fig. 3.4H).

Mesh size and catch composition by length/weight

A broad range of RBR sizes were caught in Area2, with disk width ranging 10-71 cm (median 55 cm). Modal disk width was relatively constant (57 cm) in all mesh sizes but 110 mm (59 cm) (Fig. 3.23). Over 90% of the RBR catch was of commercial-size (≥ 30 cm disk width). For this reason, proportions of commercial/discard size RBR in the catch were independent from mesh size effects and estimated process weights were nearly identical to total CPUE (Fig 3.24).

Mesh size and retention probability

Small length frequency samples sizes (average of 45 individuals per haul) did not permit to fit retention curves for *B. brachyurops.*

Skates summary

There were no effects of codend mesh sizes on fishery efficiency for skates, as assessed using RBR as indicator species. This agrees with earlier findings by Roux et al (2012) of limited impacts of increasing codend mesh sizes on skates fishery efficiency within the mesh size range considered (90-140 mm). Previous trials however reported lower discard weights and reduced probabilities of retaining undersized skates in ≥ 120 mm mesh trials (Roux et al. 2012) as well as an increase in length of 50% retention (as estimated from logistic fitting) for all skates combined (Brickle and Winter 2011). These findings could not be verified here due to small sample sizes and the prevalence of commercial-size skates in the catch. Combined results nonetheless suggest that an increase in the minimum allowable codend mesh size to

120 mm in finfish fisheries is unlikely to affect skates CPUE but may contribute to reduce catches of undersized skates.

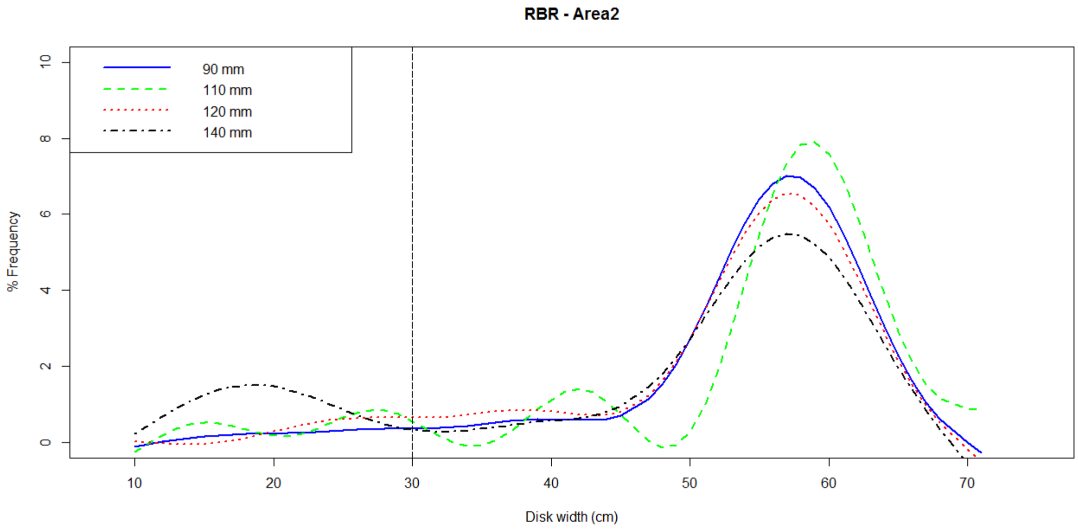


Figure 3.23. GAM-smoothed disk-width frequency distributions by mesh size for RBR (*B. brachyurops*) in Area2. Dashed line indicates an approximate 30-cm threshold for discard (< 30 cm) versus commercial-size skates.

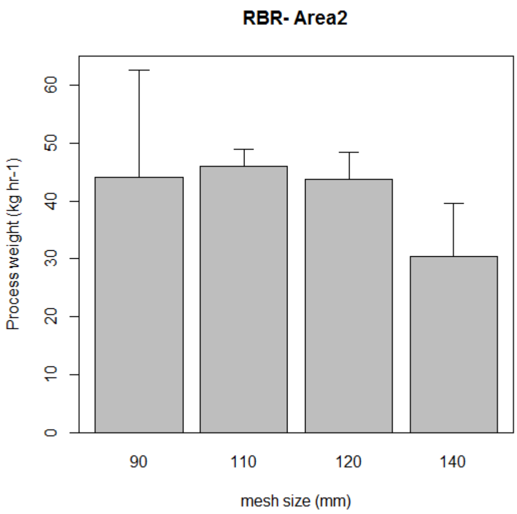


Figure 3.24. Estimated process weights standardized by unit effort among codend mesh sizes for RBR (*B. brachyurops*) in Area2.

3.3 Top Chafer trials

3.3.1 Total Catch

Analyses of top chafer effects on total and species-specific CPUE are summarized in Table 3.6.

Total CPUE ($CPUE_T$) during chafer trials averaged 1,217 kg hr^{-1} (range 622-2,314 kg hr^{-1} among hauls) in Area2 and 918 kg hr^{-1} (range 384-1,393) in Area3. The presence/absence of a top chafer on the codend had no significant influence on total catch. $CPUE_T$ without chafer averaged 1,086 kg hr^{-1} in Area2 and increased to 1,295 kg hr^{-1} when a chafer was used, but this increase was not significant (Fig. 3.25A). In Area3, average $CPUE_T$ decreased from an average of 977 kg hr^{-1} without chafer to a mean of 874 kg hr^{-1} with chafer (Fig. 3.25A).

Table 3.6 Summary of top chafer effects and random effects (where applicable) on catch weight (CPUE). For fixed (chafer) effects, 'x' indicates a significant effect at α = 0.05. For random effects, 'x' indicates presence of random effect contributing to reduce residual variance.

Species	Area	Response variable	Fixed Effect	Random effects		model	error structure
			top chafer	Haul	Day		
all species	2b	$CPUE_T$	-	x	-	GLMM	poisson
	3	$CPUE_T$	-	x	-	GLMM	poisson
P. ramsayi	2b	CPUE	-	x	-	GLMM	poisson
	3	CPUE	-	x	-	GLMM	poisson
D. gahi	2b	CPUE	-	x	-	GLMM	poisson
	3	CPUE	-	x	-	GLMM	poisson
M. hubbsi	2b	CPUE	x	x	-	GLMM	poisson
	3	CPUE	-	x	-	GLMM	poisson
S. australis	2b	CPUE	-	x	-	GLMM	poisson
G. blacodes	2b	CPUE	-	-	x	GLMM	poisson
	3	CPUE	x	x	-	GLMM	poisson
B. brachyurops	2b	CPUE	-	x	-	GLMM	poisson
	3	CPUE	-	x	-	GLMM	poisson

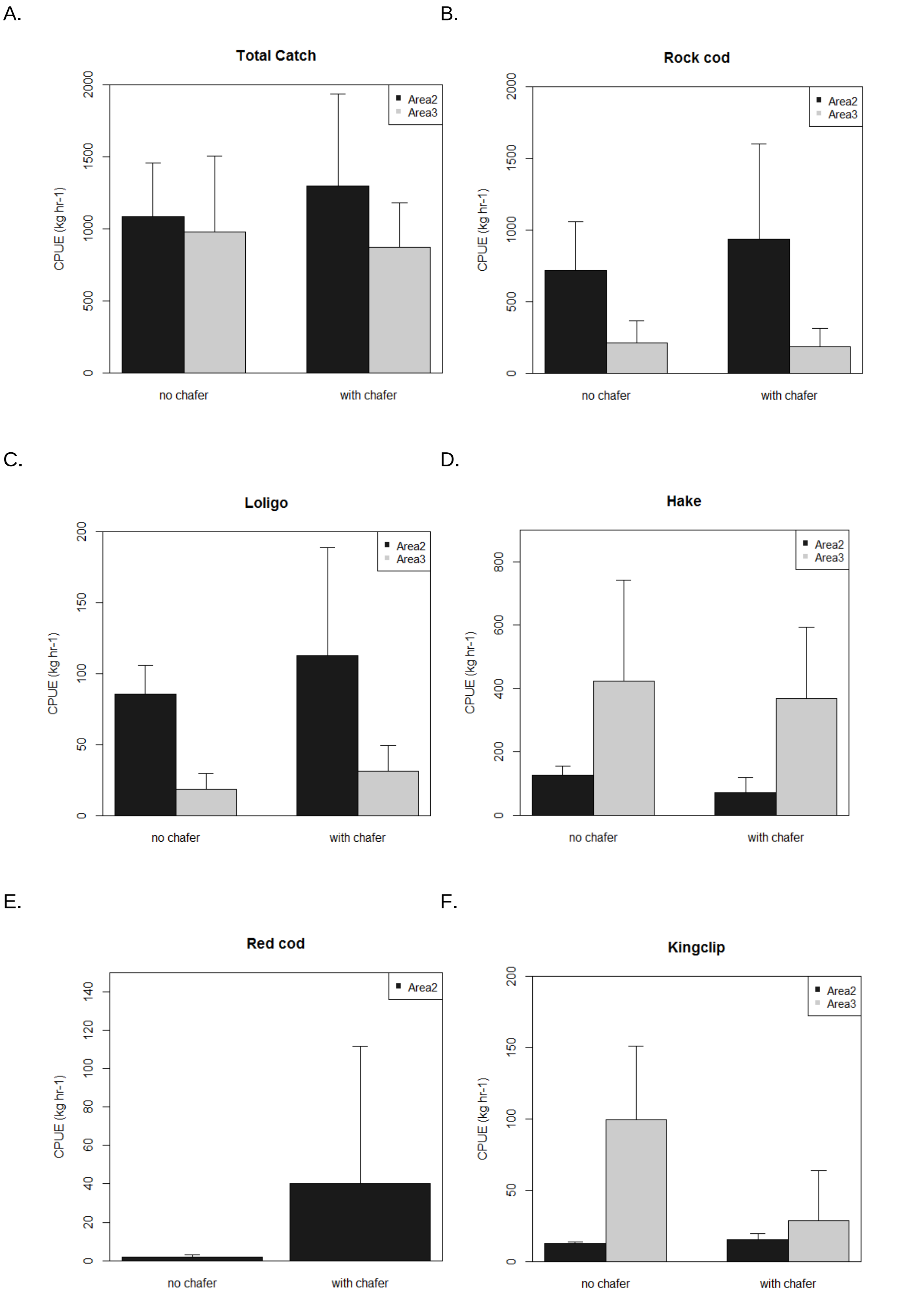


Figure 3.25. Average CPUE (total and species-specific) among hauls with/without the presence of a top chafer on the codend.

G.

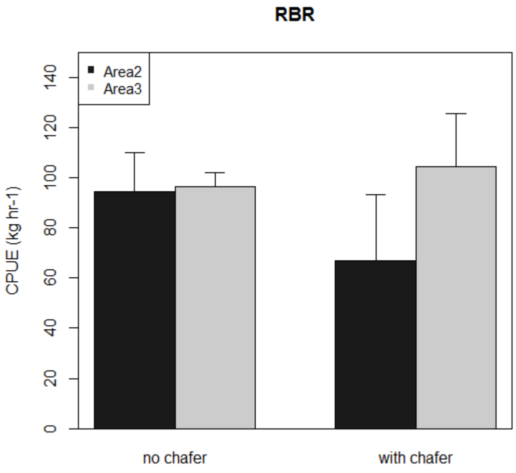


Figure 3.25. (continued).

3.3.2. *Patagonotothen ramsayi* (Patagonian rock cod)

Top chafer and CPUE

Catches of rock cod during chafer trials averaged 853 kg hr^{-1} (range 322-1,972) in Area2 and 196 kg hr^{-1} (range 23-344) in Area3. The presence/absence of a top chafer on the codend had no significant effect on rock cod CPUE (Table 3.6). In Area2, rock cod CPUE increased from a mean of 714 kg hr^{-1} without chafer to 936 kg hr^{-1} with chafer and this increase was not statistically significant (Fig 2.25B). In Area3, rock cod CPUE with/without chafer were almost equivalent (185 kg hr^{-1} and 209 kg hr^{-1} respectively).

Top chafer and retention probability

Rock cod length structure differed between the sampling areas (Fig. 3.26). Modal length was 24 cm in Area2 and 26 cm in Area3. Frequency occurrence of smaller rock cod (< 20 cm) was generally higher in Area2 while Area3 had larger numbers of commercial-size (> 25 cm) fish (Fig. 3.26).

The use of a top chafer improved retention of commercial-size fish in Area2. The size range of maximum (> 50%) retention was 18-30 cm with chafer relative to 7-28 cm without chafer (Fig. 3.27A, Table 3.7). Smaller rock cod had a higher probability of being retained in the absence of a chafer. In Area3, the absence/presence of a top chafer on the codend had no effect on rock cod retention probability. Size range of maximum retention was equivalent between treatments and ranged 17-31 cm (without chafer) and 18-31 cm (with chafer) (Fig. 3.27B, Table 3.7).

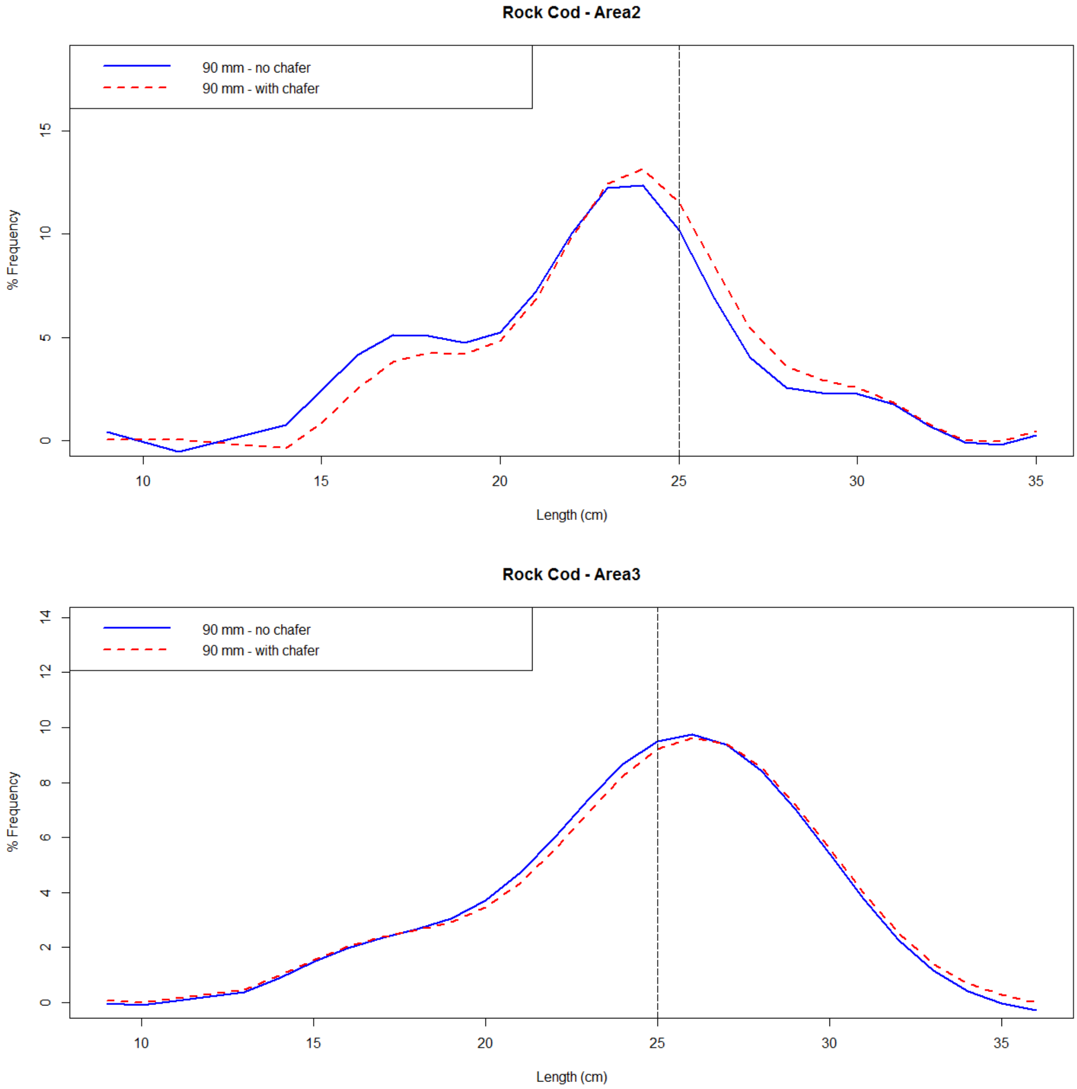


Figure 3.26 GAM-fitted length frequency distributions for rock cod between hauls conducted with and without the use of a top chafer on a 90 mm mesh codend in Area2 (top) and Area3 (bottom).

Rock cod summary

The use of a top chafer on the codend is unlikely to affect fishery efficiency for rock cod but may enhance the retention of commercial-size fish in areas where undersized individuals are more abundant.

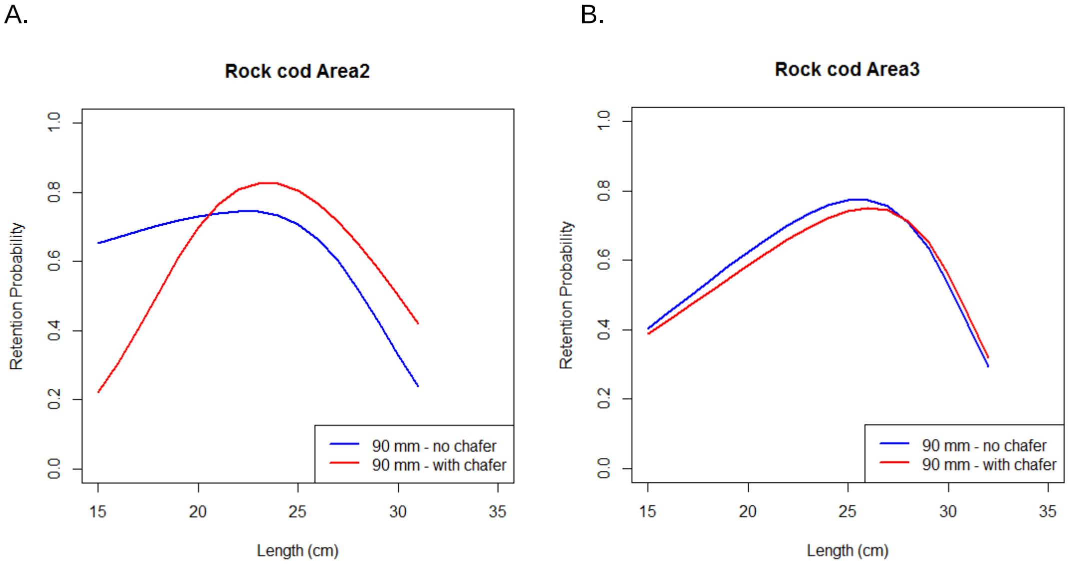


Figure 3.27. Fitted retention probability curves for rock cod using a 90 mm diamond mesh codend with and without a 140 mm square mesh top chafer. Fitting was done using the double-logistic equation.

Table 3.7 Fitted parameters of the double logistic equation describing retention probability at length with and without the use of a top chafer on a 90 mm mesh codend. L_{50}^{1} and L_{50}^{2} are minimum and maximum lengths of 50% retention, respectively

Species	Area	Treatment	s1	s2	L_{50}^{1}	L_{50}^{2}
P. ramsayi	2b	no chafer	0.48	0.08	**7**	**28**
	2b	with chafer	0.33	0.45	**18**	**30**
	3	no chafer	0.56	0.18	**17**	**31**
	3	with chafer	0.59	0.16	**18**	**31**
D. gahi	2b	no chafer	0.68	0.59	**12**	**18**
	2b	with chafer	0.36	0.70	**11**	**17**
	3	no chafer	0.41	0.74	**11**	**17**
	3	with chafer	0.38	0.43	**10**	**18**
M. hubbsi	2b	no chafer	2.79	0.06	**52**	**81**
	2b	with chafer	0.20	0.06	**45**	**72**
	3	no chafer	0.05	0.44	**53**	**72**
	3	with chafer	0.07	0.21	**52**	**72**
G. blacodes	3	no chafer	0.03	0.23	**45**	**109**
	3	with chafer	0.14	1.12	**28**	**68**
B. brachyurops	2b	no chafer	0.01	0.41	**6**	**65**
	2b	with chafer	-0.01	0.74	**1**	**54**
	3	no chafer	0.002	0.42	**14**	**81**
	3	with chafer	3.32	-0.003	**0**	**63**

3.3.3 *Doryteuthis gahi* (Loligo squid)

Top chafer and CPUE

Loligo CPUE during chafer trials averaged 103 kg per hour (range 14-223 among hauls) in Area2 and only 26 kg per hour (range 5-46 among hauls) in Area3. Chafer effects on catches of Loligo were not significant, although an increase in mean CPUE in trials with chafer was observed in both areas (from 85 to 113 kg hr^{-1} in Area2 and from 19 to 31 kg hr-1 in Area3) (Fig. 3.25C, Table 3.6).

Top chafer and retention probability

Loligo size composition was similar between areas, although larger squid (> 20 cm mantle length) were found in small numbers in Area2 (Fig 3.28). Modal mantle length was similar between treatments and equivalent to 15 cm in Area2 and 14.5 cm in Area3 (Fig 3.28).

The presence/absence of a top chafer on the codend had little influence on retention probabilities for loligo within the size range considered (9-23 cm). Minimum mantle length of 50% retention (L_{50}[1]) was reduced by 1-cm in hauls with chafer relative to hauls without chafer in both areas, suggesting enhanced retention of smaller squid (Fig. 3.29, Table 3.7).

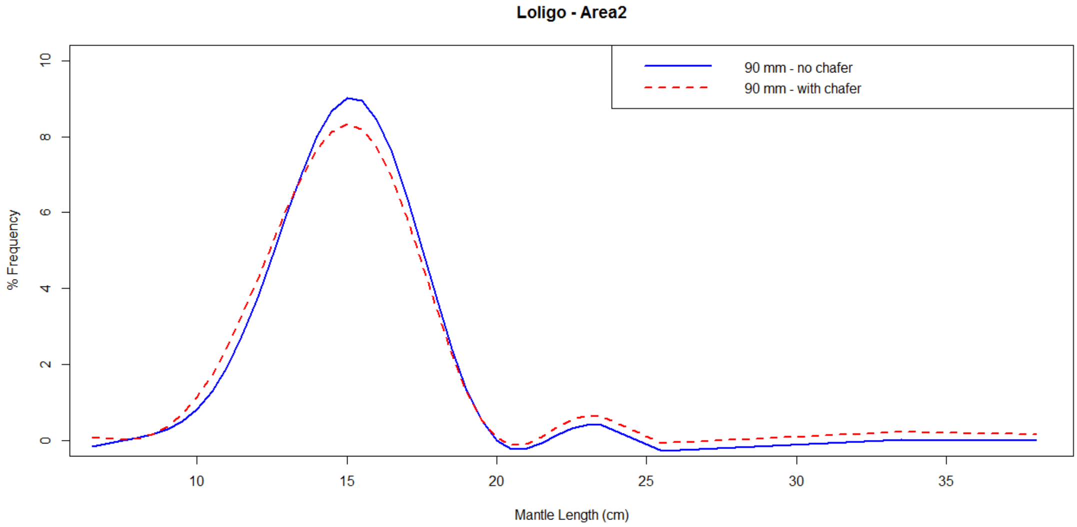
Loligo summary

The use of a top chafer is unlikely to affect loligo bycatch in finfish fisheries but may enhance retention of smaller-sized squid.

3.3.4 *Merluccius hubbsi* (Hake)

Top chafer and CPUE

Catches of hake during chafer trials ranged from a lower mean of 92 kg per hour (range 32-155 kg hr^{-1} among hauls) in Area2 to a high of 392 kg per hour (range 103-745 kg hr^{-1} among hauls) in Area3. In both areas, the use of a top chafer on the codend was linked to a reduction in hake CPUE (Fig 3.25D). This reduction was only statistically significant in Area2, with mean CPUE decreasing from 125 kg hr^{-1} (no chafer) to 71 kg hr^{-1} (with chafer) (Fig. 3.25D) (Table 3.6).



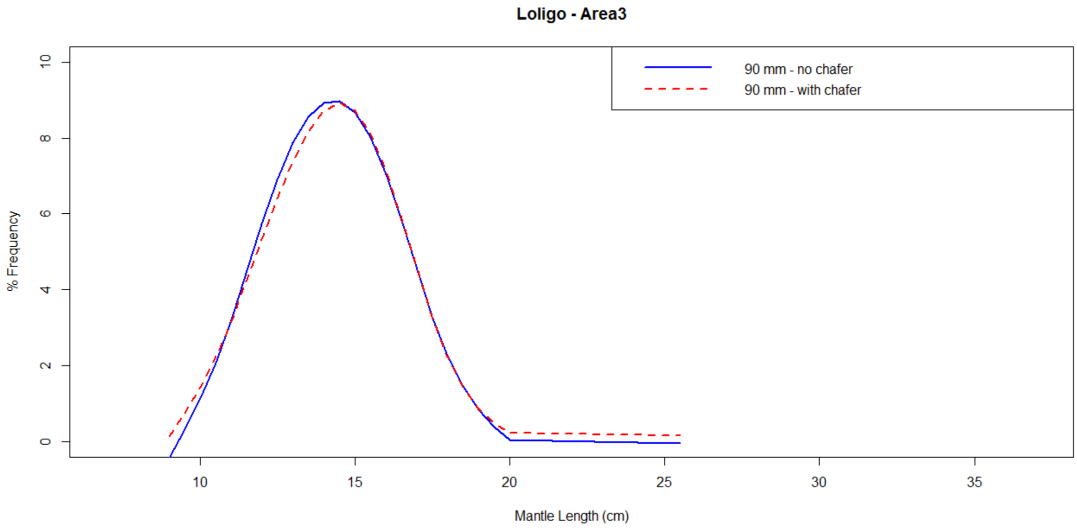


Figure 3.28. GAM-fitted length frequency distributions for loligo squid between hauls conducted with and without the use of a top chafer on a 90 mm mesh codend in Area2 (top) and Area3 (bottom).

Top chafer and retention probability

Area-differences in hake length structure were not independent from chafer effects (Fig 3.30). Modal length was equivalent to 65 cm in Area2 and 64 cm in Area3 however, hauls with top chafer in Area2 yielded a bi-modal length distribution first peaking at 53 cm (Fig 3.30). Fitted retention probabilities indicated a smaller minimum length of 50% retention (L_{50}^{1}) equivalent to 45 cm with chafer in Area2, relative to 52 cm without chafer (Fig 3.31A, Table 3.7). A similar trend towards higher retention probabilities for smaller hakes in hauls with chafer was visible in Area3 but < 52 cm fish were not available in sufficient numbers for fitting. Instead, the size range of maximum (> 50%) retention was 52-72 cm (with chafer) and 53-72 cm (without chafer) (Fig 3.31B, Table 3.7).

A.

B.

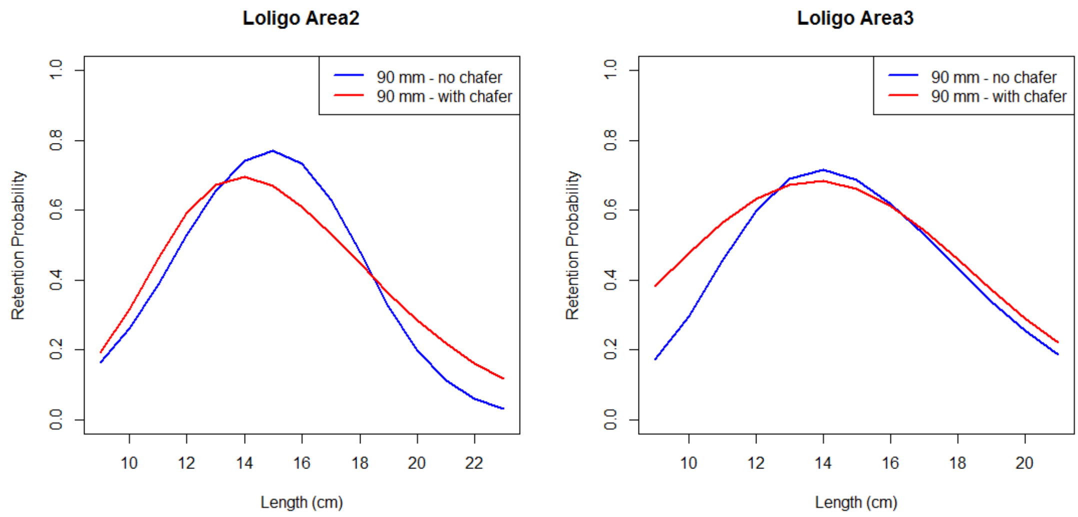


Figure 3.29. Fitted retention probability curves for loligo squid using a 90 mm diamond mesh codend with and without a 140 mm square mesh top chafer. Fitting was done using the double-logistic equation.

Hake summary

The use of a top chafer may enhance the retention of smaller-size hake and reduce fishery efficiency for the species in terms of CPUE.

3.3.5 *Salilota australis* (Red cod)

Top chafer and CPUE

Catches of red cod were minimal in Area3 (total 16.5 kg) thus chafer effects were assessed only in Area2.

Red cod CPUE averaged 26 kg per hour (range 0-166 kg hr^{-1} among hauls). Higher catches of red cod (mean 40 kg hr^{-1}) were observed in hauls with top chafer relative to hauls without chafer (mean 1.6 kg hr^{-1}) but this difference was not statistically significant (Fig. 3.25E) (Table 3.6).

Top chafer and retention probability

Length frequency sample sizes for red cod (range 0-33 individuals in hauls without chafer) were too small to allow meaningful comparisons and double-logistic fitting.

Red cod summary

Insufficient data was available to assess chafer effects on red cod.

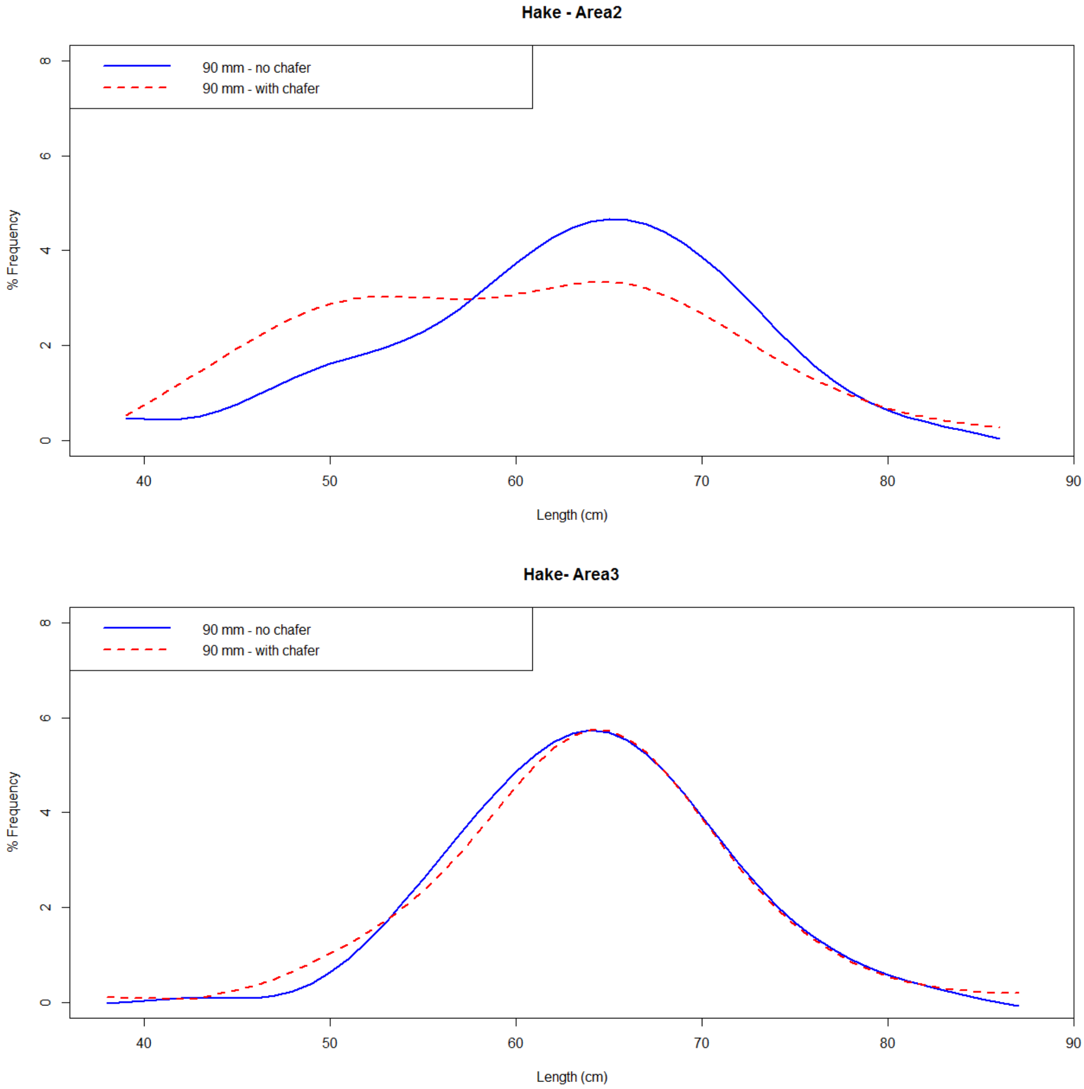


Figure 3.30. GAM-fitted length frequency distributions for hake (*M. hubbsi*) between hauls conducted with and without the use of a top chafer on a 90 mm mesh codend in Area2 (top) and Area3 (bottom).

3.3.6 *Genypterus blacodes* (Kingclip)

Top chafer and CPUE

Kingclip CPUE during chafer trials averaged 14 kg per hour (range 10-22) in Area2 and 59 kg per hour (range 2-136) in Area3. A chafer effect was observed only in Area3 and corresponded to a significant reduction in mean kingclip CPUE in hauls with top chafer (mean 28.5 kg hr^{-1}) relative to hauls without chafer (mean 100 kg hr^{-1}) (Fig. 3.25F, Table 3.6). In Area2, average kingclip CPUE was comparable between treatments (12-15 kg hr^{-1}).

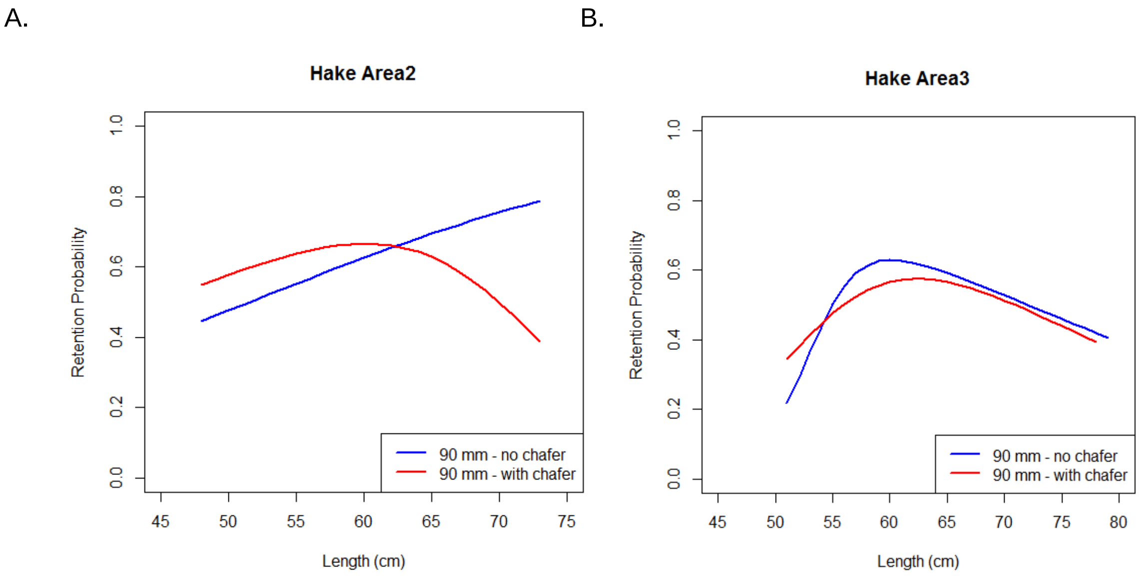


Figure 3.31. Fitted retention probability curves for hake (*M. hubbsi*) using a 90 mm diamond mesh codend with and without top chafer. Fitting was done using the double-logistic equation.

Top chafer and retention probability

The size composition of kingclip catches was generally similar between areas (Fig 3.32). Chafer effects were evident in Area3 and corresponded to a reduction in modal length (54 cm) in hauls with chafer relative to hauls without chafer (58 cm) (Fig 3.32). In Area2, modal length differed only by 1 cm between treatments (55 cm with chafer and 56 cm without chafer) (Fig. 3.32).

Kingclip sample sizes in Area2 (25-57 individuals per haul) were too small to fit retention probability curves. Small sample sizes was also a problem in Area3 however two hauls (one of each treatment) were available for fitting. Minimum length of 50% retention (L_{50}[1]) was 28 cm with top chafer and 45 cm without, suggesting enhanced retention of smaller kingclip in the presence of a top chafer (Fig 3.33, Table 3.7).

Kingclip summary

The use of a top chafer may enhance retention of smaller-size kingclip and reduce fishery efficiency for the species in terms of CPUE.

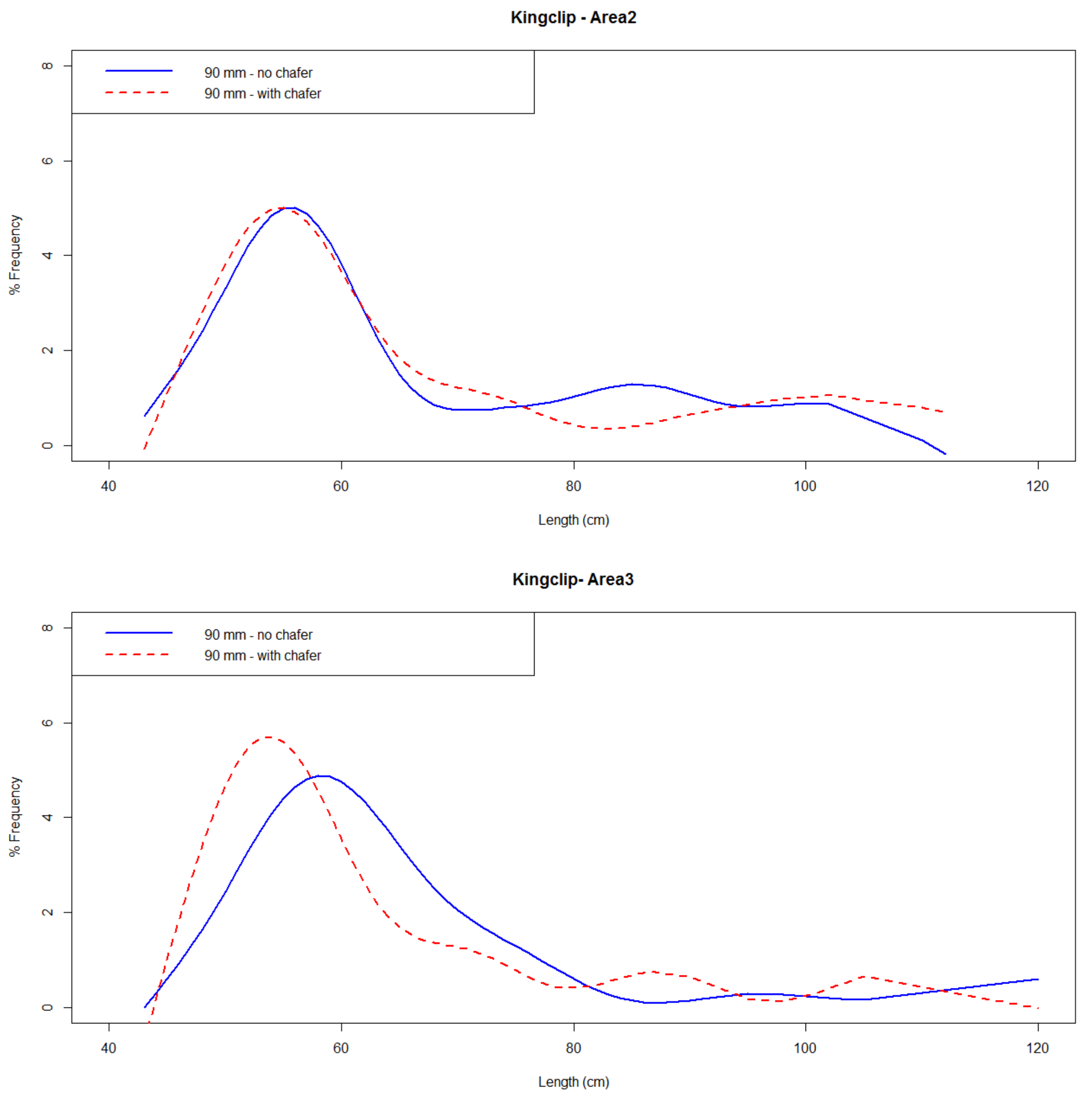


Figure 3.32. GAM-fitted length frequency distributions for kingclip (*G. blacodes)* between hauls conducted with and without the use of a top chafer on a 90 mm mesh codend in Area2 (top) and Area3 (bottom).

3.3.7 Rajidae sp. (Skates)

Top chafer and CPUE

B. brachyurops (RBR) CPUE during chafer trials averaged 77 kg hr^{-1} in Area2 and 101 kg hr^{-1} in Area3. There were no effects of top chafer on RBR CPUE, although different trends were observed between areas (lower mean CPUE with top chafer in Area2 and the converse in Area3) (Fig. 3.25G, Table 3.6).

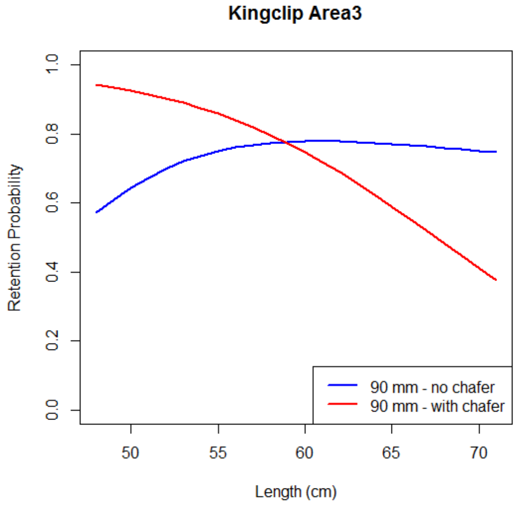


Figure 3.33. Fitted retention probability curves for kingclip (*G. blacodes*) using a 90 mm diamond mesh codend with and without top chafer in Area3. Fitting was done using the double-logistic equation.

Top chafer and retention probability

RBR length structure differed between the sampling areas with Area2 having a bimodal size distribution peaking at 17-18 cm disk width and again at 56-58 cm, depending on treatment (Fig 3.34). The occurrence of smaller skates was higher in hauls without top chafer (modal disk width 18 cm) (Fig. 3.34). In contrast, hauls with top chafer had a higher incidence of larger skates in the catch (modal disk width 56 cm) (Fig 3.34). In Area3, RBR size structure was similar between treatments with modal disk width peaking at 20 cm (with chafer) and 21 cm (without chafer) (Fig 3.34).

Skates retention probabilities were generally independent from disk width within the size range available for fitting (12-62 cm in Area2 and 13-44 cm in Area3). The double-logistic equation predicted a smaller minimum disk width at 50% retention (L_{50}[1]) in the presence of a top chafer in both areas (Fig 3.35, Table 3.7).

Skates summary

The use of a top chafer in finfish fisheries is unlikely to affect fishery efficiency for skates (as assessed using RBR as indicator species), but may enhance the retention of smaller-sized skates.

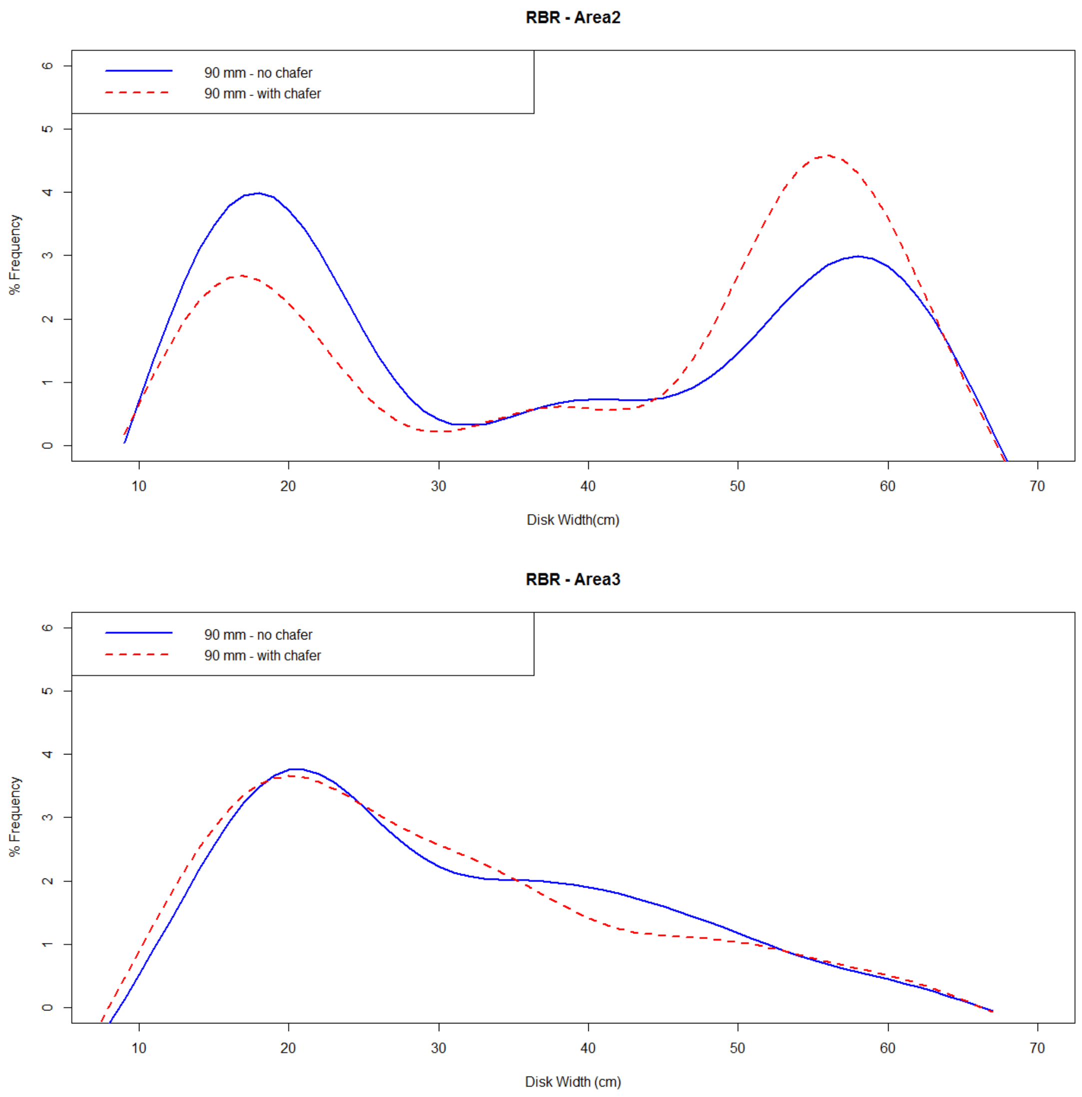


Figure 3.34. GAM-fitted size frequency distributions for RBR (*B. brachyurops)* between hauls conducted with and without the use of a top chafer on a 90 mm mesh codend in Area2 (top) and Area3 (bottom).

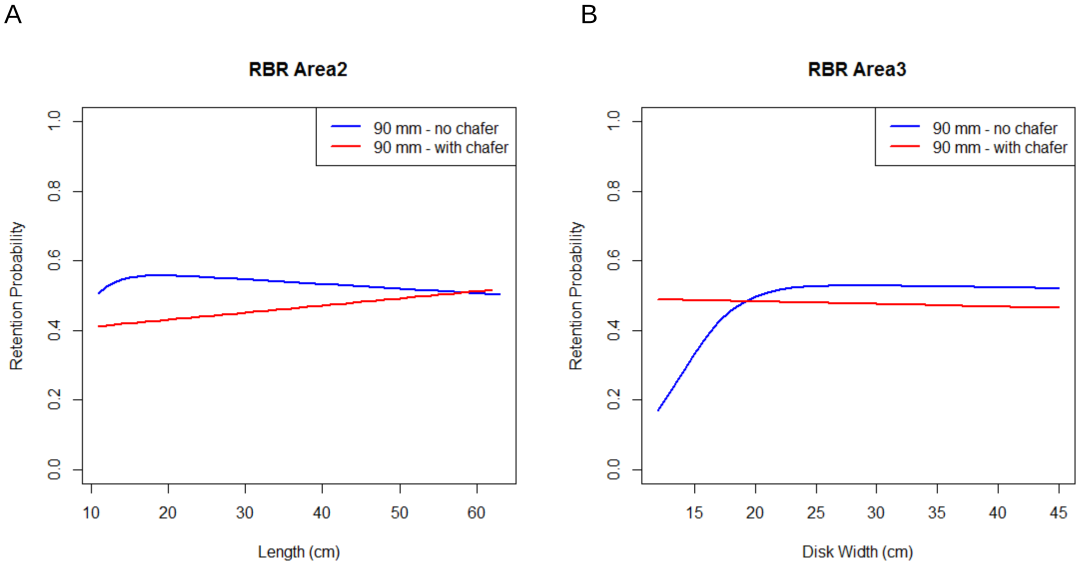


Figure 3.35. Fitted retention probability curves for RBR (*B. brachyurops)* using a 90 mm diamond mesh codend with and without top chafer. Fitting was done using the double-logistic equation.

3.4 Length-girth relationships

3.4.1 *Patagonotothen ramsayi* (Rock cod)

Rock cod length ranged 8-39.5 cm. Head width (G_W) ranged between 0.8-5.6 cm and height (G_H) ranged 0.9-6.9 cm.

Width and height increased linearly with length (Fig 3.36). The ratio of width to height was not related to length indicating that head shape is consistent throughout the species ontogeny (Fig 3.37).

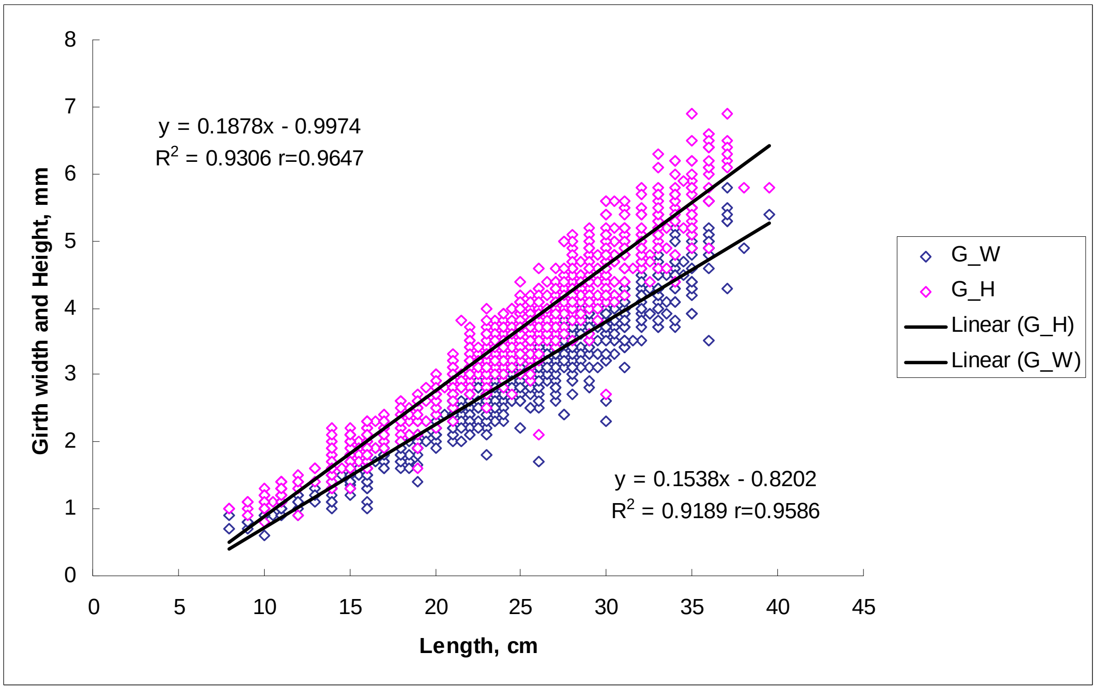


Fig 3.36. Relationships between total length (TL) and girth width (W) and height (H) for *P. ramsayi.*

3.4.2 *Genypterus blacodes* (Kingclip)

Kingclip length ranged 39.5-119.5 cm. Within this size range, girth width only ranged 2.3-3.0 cm and girth height ranged 12.0-14.8 cm.

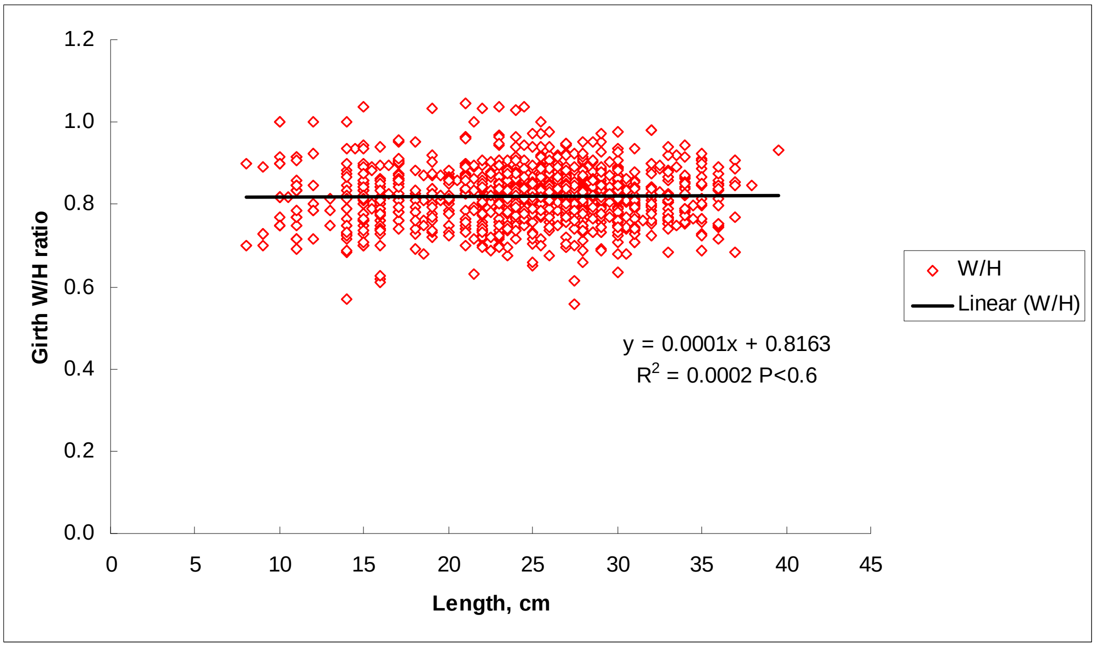


Fig 3.37. Ratio of girth width: height versus total length in *P. ramsayi*.

Girth width and height increased linearly with total length (Fig 3.38). Kingclip girth shape undergoes allometric changes corresponding to a flattening of the head with increasing size, as indicated by a weak negative correlation between the girth width:height ratio and total length (Fig 3.39).

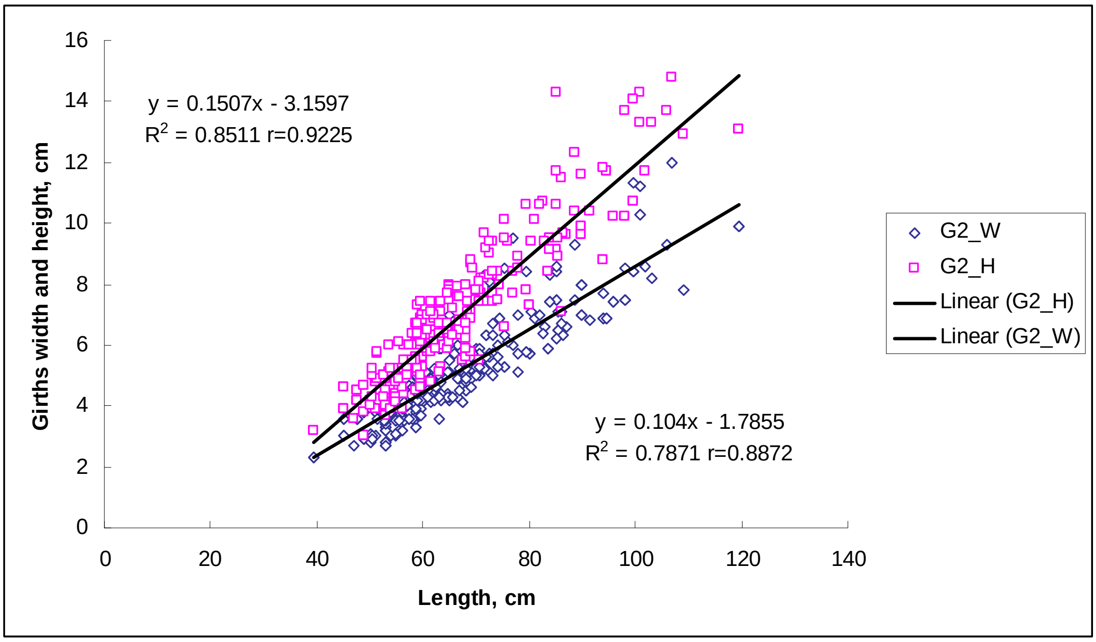


Fig 3.38. Relationships between length (TL) and girth width (W) and height (H) for *G. blacodes*.

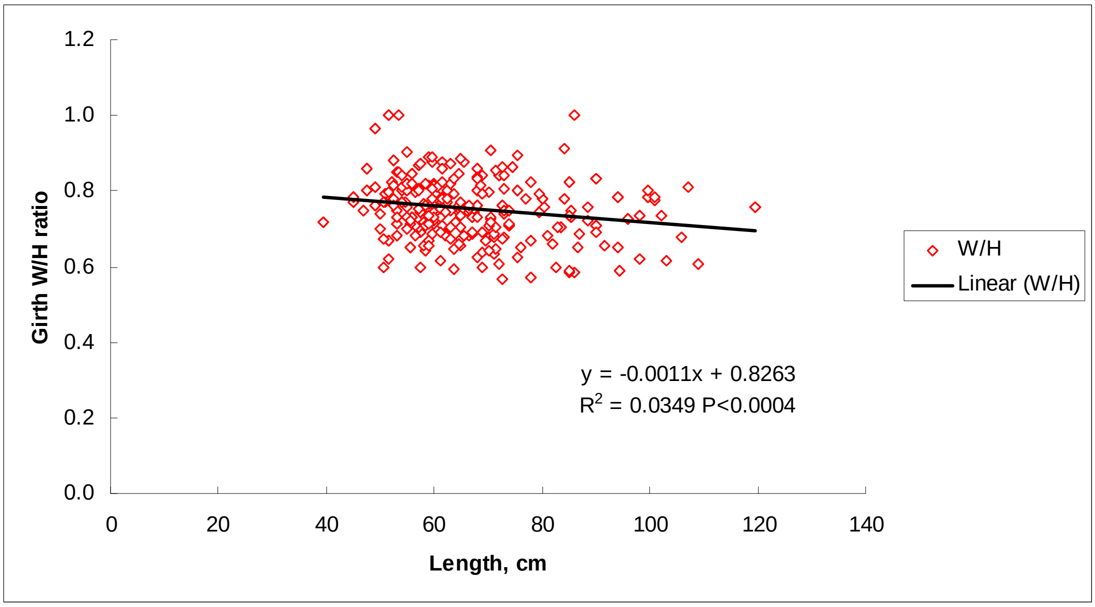


Fig 3.39. Ratio of girth width:height versus total length (TL) in *G. blacodes.*

3.4.3 *Merluccius hubbsi* (common Hake)

Hake length ranged 42-93 cm (TL). Girth width and height varied between 4.1-5.4 cm and 12.9-13.6 cm, respectively.

Girth width and height increased linearly with hake length (Fig 3.40). The ratio of width to height was independent from total length (Fig. 3.41), suggesting that head shape was consistent within the available size range.

3.4.4 Summary

In all three species considered, the results confirm that changes in head proportions are linearly related to length, thus supporting the use of length as a proxy to study mesh size effects on retention probabilities.

The absence of juveniles of *G. blacodes* and *M. hubbsi* in Falkland waters precludes the assessment of ontogenetic changes in girth size for those species. For *P. ramsayi*, preliminary results suggest that girth shape remains consistent throughout the species ontogeny. Further work is required however to ascertain potential area-differences in length-girth relationships, how they relate to observed patterns in size distribution, and to explore potential relationships between girth size and parameters such as condition, prey selectivity and swimming capacities.

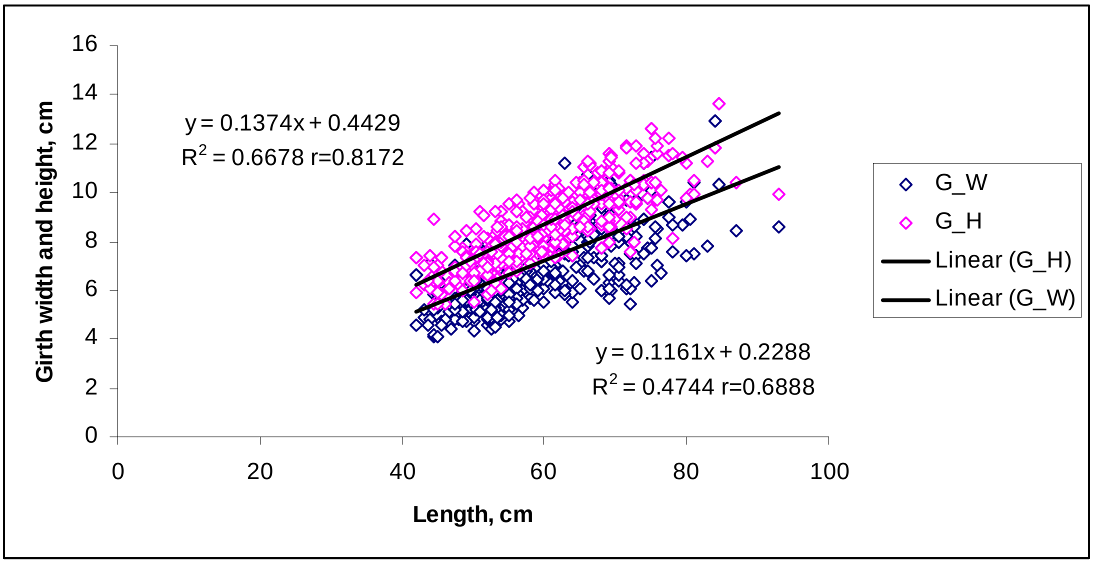


Fig 3.40. Relations ships between length (TL) and girth width (W) and height (H) in *M. hubbsi*

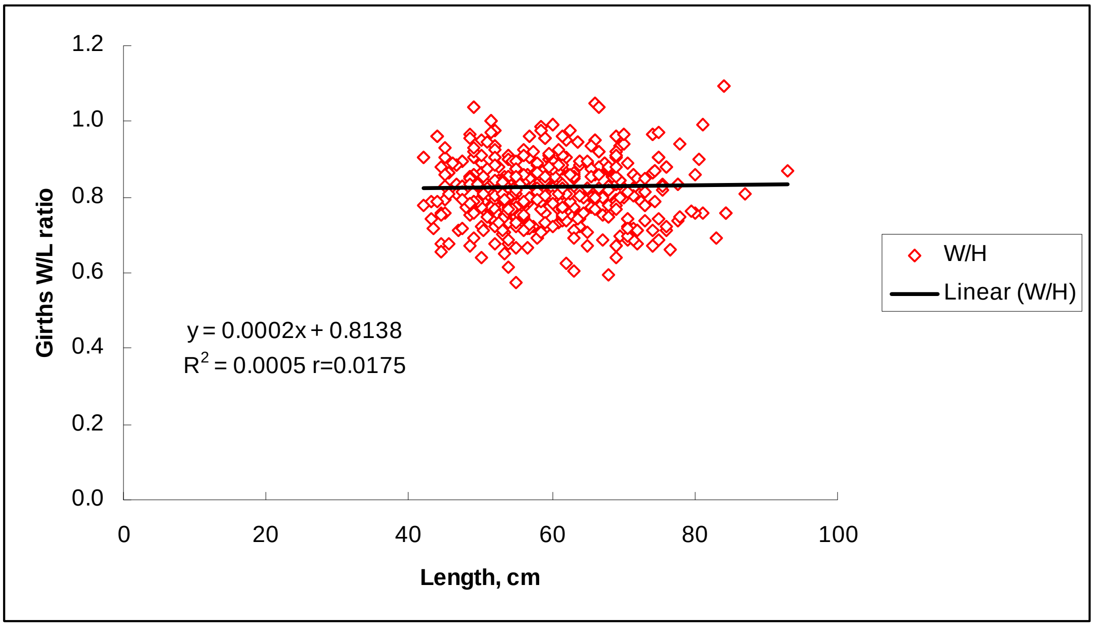


Fig 3.41. Ratio of girth width:height versus total length (TL) in *M. hubbsi.*

3.5 Oceanography

Oceanographic data were collected at 12 stations. Data from station 1046 was corrupted and not used.

Bottom temperatures were slightly colder in Area1 (approx 4.95 ^{o}C) compared to Area 2 and 3 (approx 5.12 ^{o}C) (Figure 3.42). Bottom salinities varied more widely between areas and were highest in Area 1 (33.907 psu), lowest in Area 2 (33.640 psu) and intermediate in Area 3 (33.780 psu). Both temperature and salinity were highly structured throughout the water column, resulting in strong pycnolines at approximately 20-50m depth and a second at 50-100m depth (Figure 3.42).

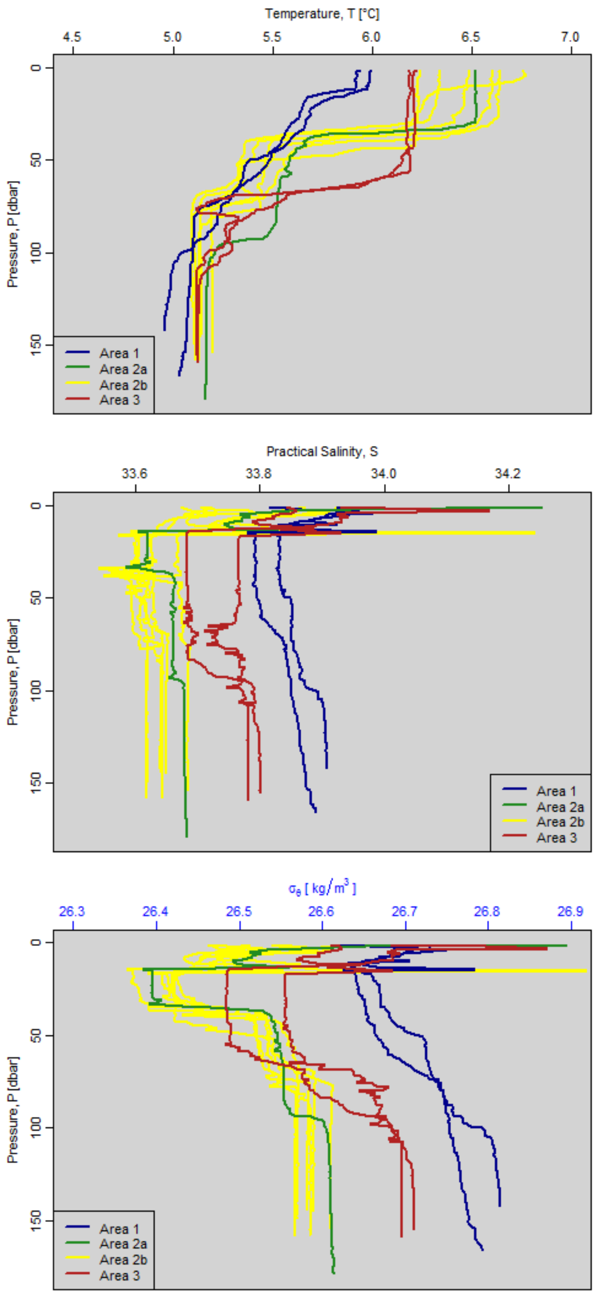


Fig 3.42. Temperature (top), salinity (middle) and density (lower) profiles in Areas 1, 2 and 3.

Oceanographic data shows typical structures for the Falkland Shelf (Figure 3.43), with cooler, higher salinity water in the east influenced by sub-Antarctic Superficial Water (SASW) flowing northward via the Falkland Current (FC), and warmer less saline water to the west flowing southward across the Patagonian shelf. Area 3 shows features of a likely FC intrusion on the northern part of the Shelf.

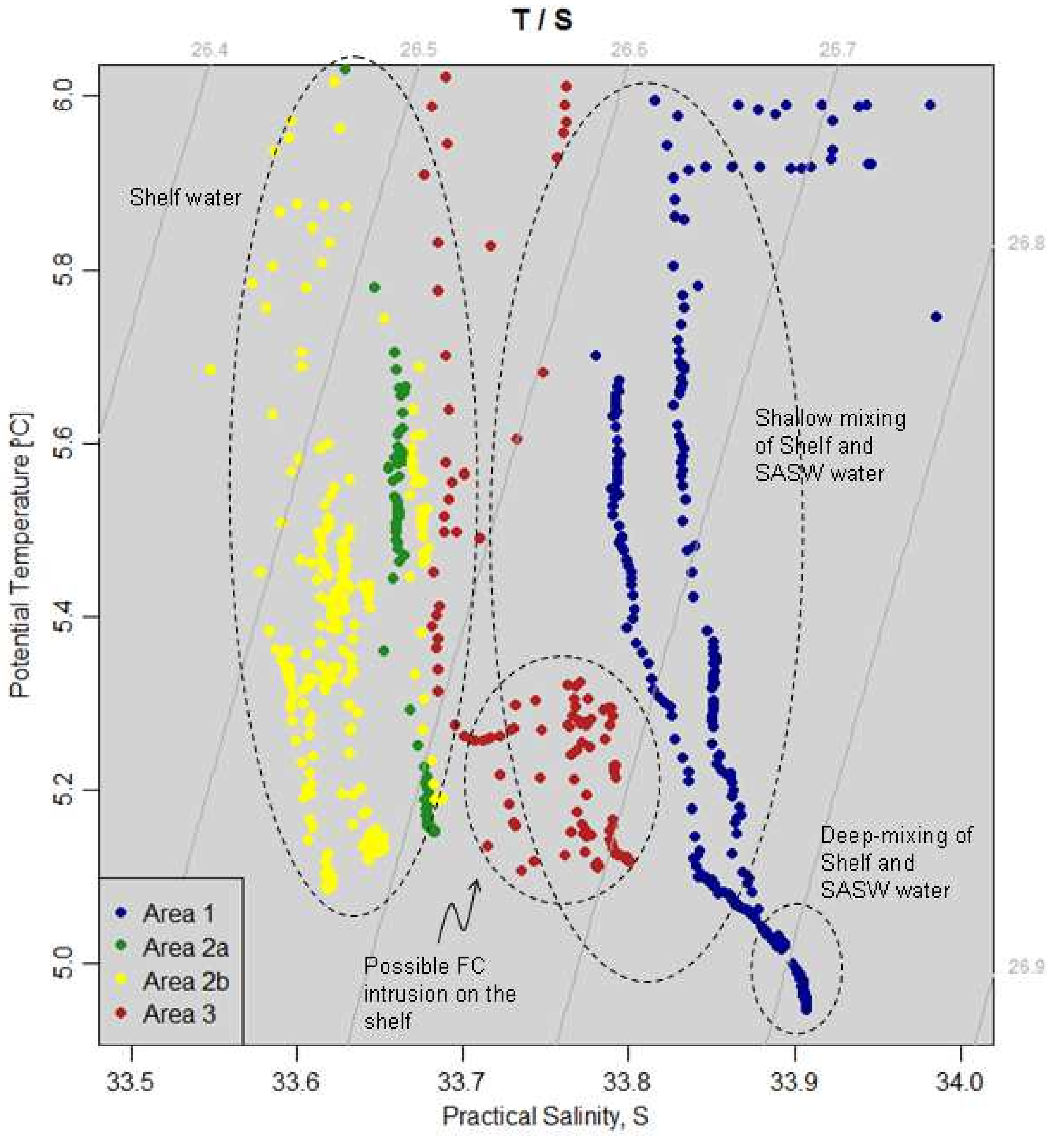


Fig 3.43. T/S plots of all Areas with identification of water masses in October 2012.Isopycnals are overlaid on the plot. SASW – Sub-Antarctic Superficial Water. FC – Falkland Current.

3.6 Penguin interactions

Penguin interactions occurred in Area1. All interactions involved the gentoo penguin *Pygoscelis papua*. The occurrence of penguins around the fishing vessel at the time of hauling was observed from the bridge. Numbers of penguins were roughly estimated and ranked into three abundance categories (Table 3.8). Behavioural responses to trawl hauling noise were observed at most stations, with penguins surfacing and congregating around the vessel during hauling.

Table 3.8 Summary of penguin interactions and relevant station information in Area1. 'Occurrence' refers to penguin abundance around the vessel at the time of hauling (1=1-10 animals; 2=10-50 animals; 3=50-200 animals). $Course_S$=course at the start of the trawl; $Course_F$=course at the end of the trawl. Trawls with penguins in the codend are indicated in bold.

Station	Date	Time of day	$Course_S$	$Course_F$	Species	Occurrence	n release	n mortalities	Notes
1001	15/10/2012	am	285	310	PYP (gentoo)	1	2	0	
1002	**15/10/2012**	**midday**	**140**	**160**	**PYP (gentoo)**	**1**	**1**	**1**	
1003	15/10/2012	pm	280	315	PYP (gentoo)	1	1	0	
1005	**16/10/2012**	**am**	**125**	**105**	**PYP (gentoo)**	**1**	**3**	**0**	1 specimen released alive from codend
1006	16/10/2012	midday	290	255	PYP (gentoo)	1	1	0	
1007	16/10/2012	pm	130	335	PYP (gentoo)	1	0	0	
1008	**17/10/2012**	**am**	**130**	**70**	**PYP (gentoo)**	**2**	**0**	**3**	
1009	17/10/2012	midday	305	330	PYP (gentoo)	0	0	0	
1010	**17/10/2012**	**pm**	**145**	**170**	**PYP (gentoo)**	**3**	**9**	**2**	
1012	18/10/2012	am	280	310	PYP (gentoo)	0	0	0	
1013	18/10/2012	midday	300	340	PYP (gentoo)	0	0	0	
1014	18/10/2012	pm	300	355	PYP (gentoo)	1	0	0	
						totals	***17***	***6***	

Penguin occurrences increased over time from 1-10 animals during the first two days and up to 50-200 penguins surrounding the vessel on the third day of sampling (Table 3.8). Reduced or no occurrences at station 1009 (day 3) and at all stations on day 4 reflect the implementation of mitigation measures.

Penguin interactions with fishing activities occurred at 7 stations (Table 3.8). A total of 17 animals were released alive from the fishing gear at 6 stations (16 from the upper net/wings and 1 from the codend). Six mortalities were recorded at three stations (one in midday trawl on day 1, three in the morning trawl on day 3 and two in the afternoon trawl on day 3 (Table 3.8)). All dead animals were found in the codend were presumed drowned. A higher mortality (n=3) occurred in the first (morning) trawl on day 3 (station 1008) when the vessel was not discarding for several hours and had been navigating away from the transect area overnight. The incidence of mortalities was not related to time of day or codend mesh size. There was, however, a correlation between trawl course and the presence of penguins in the codend (r=-0.695 for course finish and r=-0.402 for course start). Penguins were found in the codend only in stations in which trawling was done in the south-easterly direction (course start 125-145 degrees) and hauling completed between 70-170 degrees (northeast, east and southeast direction) (Table 3.8). This indicated that trawling direction, vessel position during hauling and possibly local currents were determinants of penguins being retained in the codend. For this reason, all trawling and hauling operations on day 4 were conducted in the north-westerly direction, which yielded no interactions. A first mitigation measure on day 3 consisted in navigating away from the transect area for > 1 hour between trawls and yielded only limited success (no penguin occurrences or interactions in the midday trawl (station 1009) but 2 casualties in the afternoon trawl (station 1010) (Table 3.8)).

Post-mortem examinations of all casualties were conducted by G. Parker at the FIFD laboratory following the cruise. Biological information on all specimens is summarized in Table 3.9. Stomach contents analyses provided evidence of penguin feeding on fishery discards in 2 specimens - with discards accounting for about 30% of stomach contents by weight in both cases (Table 3.10). Loligo, squid remains and *Munida* sp. were the most important prey items.

Table 3.9. Biological information on penguin casualties as determined from post-mortem examination.

Station	Specimen	Sex	Bill length	Weight	Reproductive status	Brood patch	Sub-cutaneous fat
1002	1	Female	59.0	5900	8x30mm ovary cluster	Exposed 60x5mm	~5mm
1008	2	Female	56.0	6200	8x30mm ovary cluster	Exposed 40x8mm	~5mm
1008	3	Male	58.5	6500	20mm testes	Exposed 200x8mm	~5mm
1008	4	Male	60.0	6600	20mm testes	Exposed 200x10mm	~5mm
1010	5	Female	49.4	5700	8x30mm ovary cluster	Fully exposed	~5mm
1010	6	Female	57.1	6800	8x30mm ovary cluster	Fully feathered	~5mm

Table 3.10. Stomach contents of penguin casualties in Area1.

Station	Specimen	Stomach contents	Weight	%Weight	Detailed contents	Weight	Length
1002	1	Rock cod	217.8	53.4	1 x entire PAR	63.8	180
		Fishery discards	129.8	31.8	1 x entire PAR	73.7	210
		Munida and others	60	14.7	1 x headless PAR	80.3	180
					1 x PAR head	56.9	70
					1 x PAR head	72.9	100
					mostly digested munida/squid/fish bones	55.2	
					3 small stones	4.8	
					Total	*407.6*	
1008	2	Loligo	52.1	32.9	1 x entire loligo	52.1	220
		Munida	106.3	67.1	digested munida	106.3	
					Total	*158.4*	
1008	3	Loligo	83.2	33.3	1 x entire loligo	83.2	240
		Squid remains	23.9	9.6	1 x partly digeted squid mantle	23.9	170
		Fish remains	81.2	32.5	1 x partly digested fish (not PAR)	64.6	170
		Munida and others	61.7	24.7	1 x partly digested fish (not PAR)	16.6	100
					mostly digested munida/fish bones	61.7	
					Total	*250*	
1008	4	Squid remains	43.8	100.0	1 x squid mantle	30.4	130
					1 x squid guts and tentacles	13.4	
					Total	*43.8*	
1010	5	Loligo	176.9	68.8	1 x entire loligo	102.6	300
		Fishery discards	80.4	31.2	1 x entire loligo	74.3	220
					1 x PAR head	35.3	80
					1 x PAR head	45.1	80
					Total	*257.3*	
1010	6	Munida	158.8	54.8	partially digest munida	158.8	
		Squid remains	131.2	45.2	partially digested squid	131.2	
					Total	*290*	

4.0 General conclusions and recommendations

4.1 Codend mesh sizes

Codend mesh size experiments in Falkland waters indicate that relative to the 90 mm mesh (currently the minimum allowable codend mesh size in finfish fisheries) only the larger 120 mm and 140 mm mesh contribute significant reductions in catches and retention of undersized fish. The 110 mm mesh in some cases yielded intermediate results however not differing from the 90 mm mesh in any of the fishery efficiency indicators considered and for all commercial species under study.

In areas of high rock cod density, mesh sizes ≥ 120 mm caused a reduction in total catch and average process weights of rock cod and kingclip per trawling hour, while other species (hake and skates) were unaffected or benefited from enhanced retention of commercial-size fish (red cod).

Overall, the results indicate that the increase in minimum allowable mesh size of trawl codend permitting to reduce bycatch of undersized fish in finfish fisheries will likely cause a reduction in fishery efficiency for rock cod but contribute to ensure fishery sustainability in all species.

Effects of varying codend mesh sizes used in conjunction with a square mesh panel (permitting to enhance escapement of undersized fish) should be investigated, as this may ultimately provide a better compromise to ensure both sustainability and profitability in Falkland islands finfish fisheries.

4.2 Top chafer

Top chafer trials using a 140 mm square mesh chafer on a 90 mm diamond mesh codend suggested limited or no impacts of top chafer on total catch and on catches of rock cod. Skates and loligo squid bycatch likewise were unaffected. Significant reductions in larger finfish (hake and kingclip) CPUE were observed in hauls with top chafer and were concurrent to enhanced retention of smaller-sized fish. The potential for top chafer to enhance the retention of undersized skates was likewise demonstrated. Contrasting results for rock cod (lower probability of retaining undersized rock cod with top chafer) again suggest some interactions of fish behaviour and gear mechanics acting to determine gear effects on the species.

Based on the findings, prohibiting the use of top chafer in finfish fisheries will have no impact on CPUE but contribute to ensure sustainability in larger-size species such as hake and kingclip by ensuring minimal retention of undersized fish.

4.3 Length-girth relationships

The relationship between length and girth (here measured as the ratio of head width:height behind gill cover) confirmed that fish length is an appropriate measure for estimating mesh retention probability in rockcod, kingclip and hake.

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