Cruise Report
ZDLT1-02-2013

Square mesh panel (SMP) trials

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1.0 Introduction

Rock cod *Patagonotothen ramsayi* is a primary target species in Falkland Islands finfish fisheries since 2008. It is also the most important discard species – accounting for 88%-96% of reported discards in 2010-2012. Incidental catches of small rock cod below the minimum commercial size of 25 cm (total length) are currently occurring at a rate that may impact fishery sustainability. To ensure stock conservation, the Falkland Islands Fisheries Department (FIFD) has undertaken a series of experimental trials to assess whether modifications to fishing gear could improve size selectivity for rock cod and other species.

A first series of trials in 2011-2012 investigated whether an increase in trawl codend mesh size could serve to minimize unwanted by-catch of undersized rock cod (Brickle and Winter 2011, Roux et al. 2012a, Roux et al 2012b) Four diamond mesh sizes were assessed during three experimental surveys in November 2011, April 2012 and October 2012, including the standard 90 mm mesh (currently the minimum allowable codend mesh size for finfish trawlers in Falkland waters) and the larger 110 mm, 120 mm and 140 mm mesh sizes. Results from these trials demonstrated that a 90 mm diamond mesh codend has poor selectivity. Between 27% and 63% of rock cod caught using the 90 mm mesh were undersized (< 25 cm) fish. The 90 mm mesh likewise yielded higher probabilities of retaining undersized fish from most commercial species. An increase in mesh size to 120 mm in the codend significantly reduced by-catch of small rock cod. Daily reductions in discard rates of undersized rock cod in the 120 mm relative to 90 mm mesh ranged 65%-83% in 2012 trials. However larger mesh sizes (120 mm and 140 mm) also caused a reduction in total catch per unit effort (CPUE) and processed weights of rock cod, thus negatively affecting fishery efficiency. Daily reductions in CPUE in 120 mm relative to 90 mm mesh averaged 35% in mixed species (non rock cod dominant) trials (April 2012) and 72% when rock cod was targeted (rock cod dominant catches) (October 2012 trials). The 110 mm mesh codend yielded intermediate results, with average daily reductions in CPUE between 9% (April 2012 trials) and 44% (October 2012 trials) and a consistent reduction in daily discard rates of undersized rock cod equivalent to 43% among trials.

Based on these results, an additional set of experimental trials was designed to assess whether a trawl equipped with a 110 mm mesh codend and fitted with a square mesh panel (SMP) might provide a better compromise between reducing by-catch of undersized fish and sustaining fishery efficiency for rock cod and other species. SMP use in demersal trawls can facilitate the escapement of juvenile fish (Broadhurst and Kennelly 1996, Graham and Kynoch 2001, Graham et al. 2003, O'Neill et al. 2006, Bullough et al. 2007, MacBeth et al. 2012). SMP performance however, tends to be species-specific (under mixed-species conditions) and highly influenced by SMP configuration (dimensions, position in the trawl, mesh size, etc) (Broadhurst and Kennelly 1996, Graham and Kynoch 2001, Graham et al. 2003, Graham et al 2004, Bullough et al. 2007.)

For experimentation in Falkland waters, a 40 mm mesh size SMP was chosen and four different SMP configurations were investigated. SMP mesh size was chosen based on length-girth relationships for rock cod developed during October 2012 mesh size trials (Roux et al 2012b). This report presents the results of a first series of SMP trials and discusses potential implications for future experimentation and management actions.

1.1 Cruise objectives

1. To evaluate the performance of a 40-mm square mesh panel (SMP) for reducing by-catch of undersized (< 25 cm) rock cod in finfish fisheries.
2. To trial four different SMP-trawl configurations: i) SMP fitted in the net extension; ii) SMP fitted in net extension with diverter; iii) 2-m length SMP fitted inside the codend; and iv) 3-m length SMP fitted in the codend.
3. To compare fishery efficiency (total and species-specific) among SMP-trawl configurations and identify the configuration that results in improved selectivity for rock cod.
4. To collect oceanographic data and evaluate oceanographic conditions encountered in the survey areas during trials.
5. To collect biological information for dietary analyses and ageing purposes.

2.0 Methods

2.1 Research Vessel and Survey Area

Research was conducted onboard *FV Castelo* (total length 67.78 m, GRT 1,321) between February 9-23 2013. The same vessel was used during previous mesh size trials (Brickle and

Winter 2011, Roux et al. 2012a and 2012b). Two areas of potentially high rock cod density were selected for trials (Fig 2.1). Selected areas were located on commercial fishing grounds targeted by the finfish fleet in recent years. Areas were selected *a priori* based on examination of spatial distribution in rock cod catches during February months 2008-2012 and adjusted *in situ* by consultation with the captain. A total of 37 trawl stations (hauls) were completed (14 in Area1 and 22 in Area2) and 8 oceanographic (CTD) stations (4 in each area) (Table 2.1).

2.2 Trawl 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. Bridle length was 223 m. Door spread varied 193-209 m among hauls while net horizontal/vertical openings varied 59-63 m and 2.4-3.1 m, respectively.

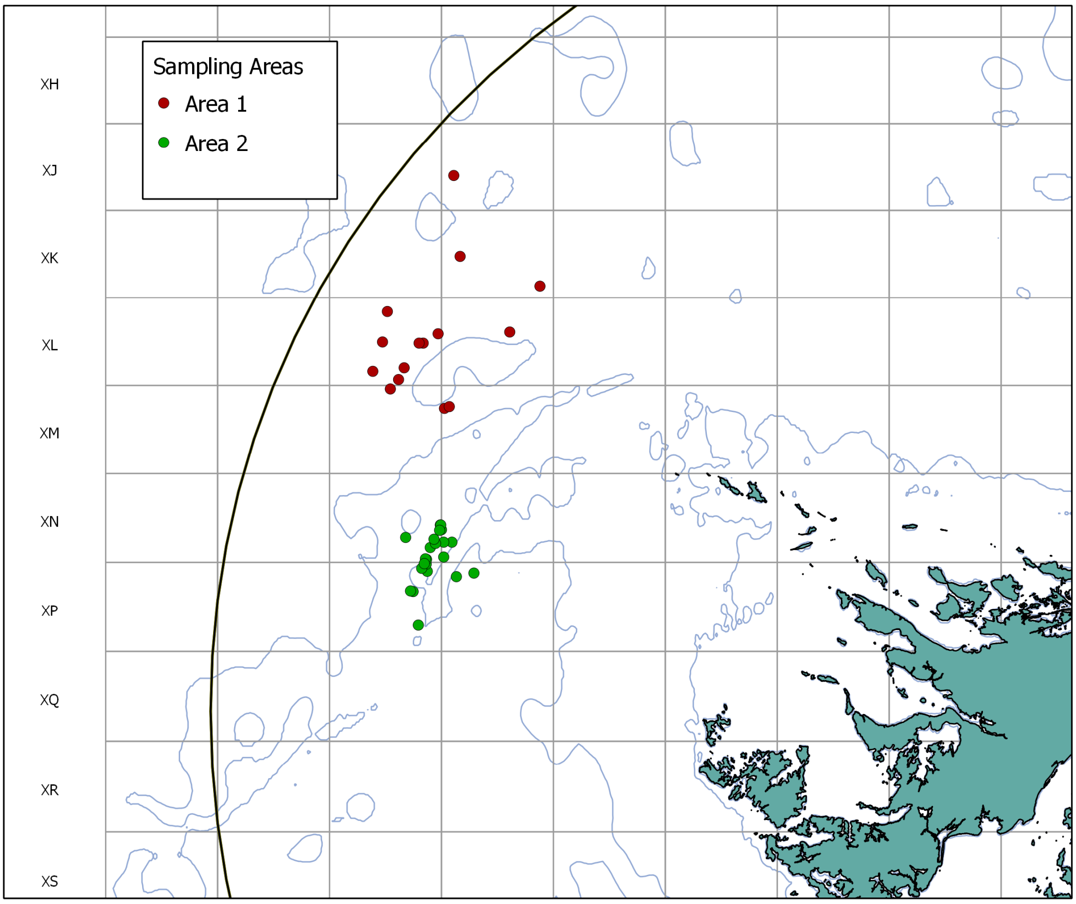


Figure 2.1. Location of fishing areas used for trials.

Table 2.1 Trawl and Oceanographic (CTD) stations on ZDLT1-02-2013. Activity B: bottom trawl; Activity C: CTD. Gear configuration 'Control' = standard trawl with 110 mm mesh codend; SMP = trawl with fitted square mesh panel (located in the extension (SMP-extension) or in the codend (SMP-codend); used in conjunction with a diverter (divert); and measuring 2 m or 3 m in length).

Station	Area	Date	Time Start	Lat (°S)	Long (°W)	Duration (min)	Modal depth (m)	Activity	Gear configuration
1056	1	10/02/2013	5:45 AM	50.28	62.02	180	162	B	Control
1057	1	10/02/2013	9:23 AM	50.25	62.24	-	155	C	
1058	1	10/02/2013	10:15 AM	50.24	62.25	180	155	B	SMP (extension)
1059	1	10/02/2013	2:20 PM	50.11	62.28	180	145	B	SMP+divert (extension)
1060	1	11/02/2013	5:45 AM	50.35	62.11	180	172	B	SMP+divert (extension)
1061	1	11/02/2013	9:17 AM	50.43	62.27	-	169	C	
1062	1	11/02/2013	10:20 AM	50.44	62.38	180	155	B	Control
1063	1	11/02/2013	3:00 PM	50.34	62.46	180	146	B	SMP (extension)
1064	1	12/02/2013	6:05 AM	50.38	62.34	180	155	B	SMP+divert (extension)
1065	1	12/02/2013	9:38 AM	50.45	62.52	-	154	C	
1066	1	12/02/2013	10:35 AM	50.43	62.5	35	154	B	SMP (extension)
1067	1	13/02/2013	6:05 AM	50.35	62.29	180	158	B	SMP (extension)
1068	1	13/02/2013	10:00 AM	50.46	62.43	180	159	B	SMP+divert (extension)
1069	1	13/02/2013	2:05 PM	50.37	62.35	180	155	B	Control
1070	1	13/02/2013	6:15 PM	50.46	62.46	180	164	B	SMP (extension)
1071	1	14/02/2013	5:55 AM	50.5	62.28	240	158	B	Control
1072	1	14/02/2013	10:23 AM	50.37	62.49	-	147	C	
1073	1	14/02/2013	11:00 AM	50.37	62.49	240	163	B	SMP (extension)
1074	1	14/02/2013	4:05 PM	50.49	62.27	180	166	B	SMP+divert (extension)
1075	2	15/02/2013	5:55 AM	51.16	62.33	180	187	B	SMP (extension)
1076	2	15/02/2013	9:25 AM	51.28	62.38	-	192	C	
1077	2	15/02/2013	10:05 AM	51.27	62.31	180	190	B	Control
1078	2	15/02/2013	2:15 PM	51.16	62.26	180	195	B	SMP (extension)
1079	2	16/02/2013	5:55 AM	51.16	62.2	180	198	B	Control
1080	2	16/02/2013	9:25 AM	51.27	62.29	-	199	C	
1081	2	16/02/2013	2:15 PM	51.13	62.28	240	191	B	SMP (extension)
1082	2	17/02/2013	6:10 AM	51.1	62.26	180	187	B	SMP (codend)
1083	2	17/02/2013	10:05 AM	51.22	62.39	180	185	B	SMP (codend)
1084	2	17/02/2013	2:40 PM	51.08	62.3	180	184	B	SMP (codend) (2m)
1085	2	18/02/2013	6:05 AM	51.08	62.29	180	184	B	Control
1086	2	18/02/2013	10:30 AM	51.21	62.39	180	184	B	SMP (codend) (2m)
1087	2	18/02/2013	3:15 PM	51.08	62.3	120	183	B	Control
1088	2	19/02/2013	9:00 AM	51.1	62.29	120	184	B	SMP (codend) (2m)
1089	2	19/02/2013	1:05 PM	51.1	62.3	120	184	B	SMP (codend) (3m)
1090	2	19/02/2013	5:20 PM	51.11	62.34	60	184	B	Control
1091	2	20/02/2013	7:20 AM	51.08	62.29	120	185	B	Control
1092	2	20/02/2013	9:59 AM	51.18	62.35	-	185	C	
1093	2	20/02/2013	11:00 AM	51.17	62.35	60	185	B	SMP (codend) (3m)
1094	2	21/02/2013	6:35 AM	51.16	62.35	60	184	B	SMP (codend) (3m)
1095	2	21/02/2013	8:55 AM	51.1	62.3	60	185	B	Control
1096	2	21/02/2013	11:30 AM	51.16	62.35	60	181	B	SMP (codend) (3m)
1097	2	22/02/2013	6:30 AM	51.18	62.36	60	183	B	SMP (codend) (2m)
1098	2	22/02/2013	8:01 AM	51.12	62.32	-	183	C	
1099	2	22/02/2013	8:30 AM	51.1	62.31	60	183	B	SMP (codend) (2m)
1100	2	22/02/2013	10:50 AM	51.17	62.36	60	183	B	Control

2.3 Experimental design

Fishing was carried out during daylight hours. Effort generally involved three trawls a day - exception of three days when only 2 trawls were performed (owing to gear problems or very large catches) and one day with four trawls.

Trawl duration varied between 1 and 4 hours. Duration was initially set at 3-4 hours but was reduced to two hours and one hour in some instances to avoid unnecessary large catches and lengthy processing. Trawling operations were paralleled by an oceanographic survey of the fishing areas that consisted of a number of vertical water profiling stations conducted immediately after the first morning haul.

Two sets of gear trials were performed: series-1 and series-2. Both sets were conducted using a 110 mm diamond mesh codend. Series-1 evaluated the performance of a SMP fitted in the net extension in the presence/absence of a diverter (Figure 2.2). The diverter consisted of a piece of 120 mm diamond mesh netting clipped to the side panels of the extension in an angle forcing fish to move upwards towards the SMP (Figure 2.2B).

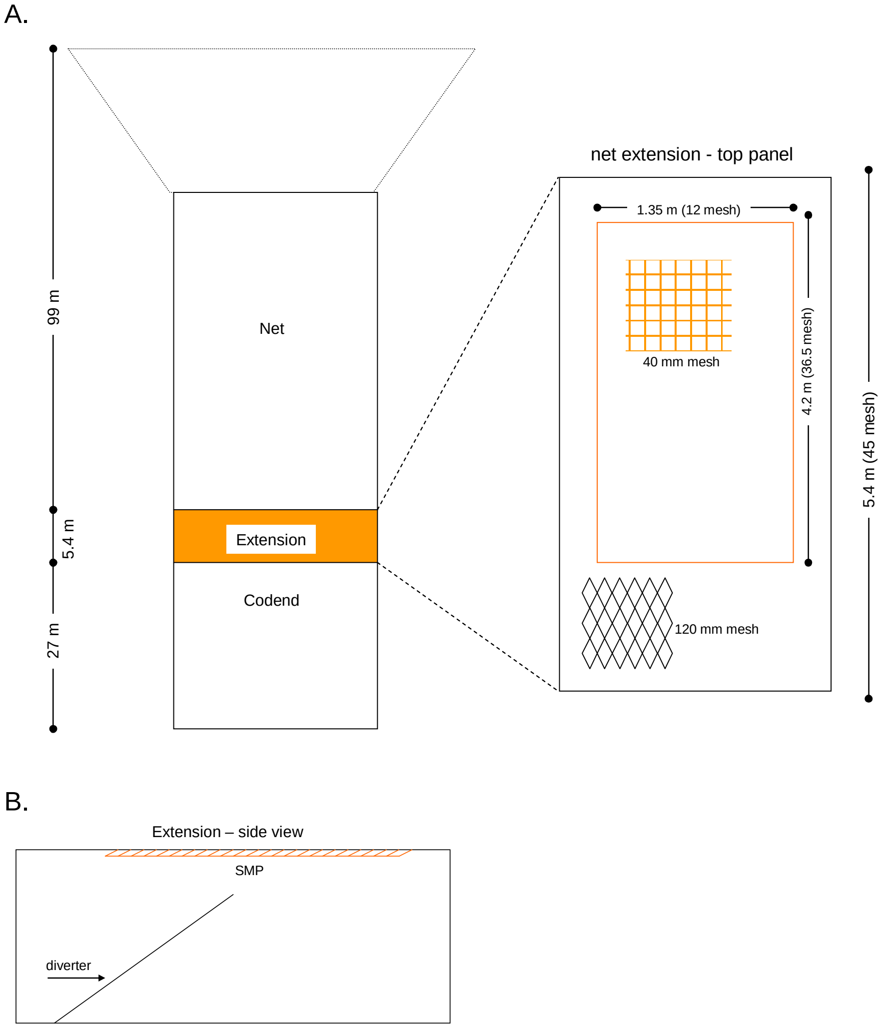


Figure 2.2. Trawl configurations tested during Series-1. A 40 mm mesh SMP was fitted inside the net extension (A) and used in the presence/absence of a diverter (B).

Series-1 was completed over 7 days in Area1 and Area2 and involved a total of 20 hauls (15 in Area1 and 5 in Area2). Control, SMP and SMP+diverter configurations were alternated over 5 days in Area1. Only control and SMP configurations were alternated over two days in Area2. Control hauls consisted in the standard trawl configuration (Section 2.2) with 110 mm mesh codend and no SMP.

Series-2 aimed to evaluate the performance of a SMP fitted inside the codend (Figure 2.3). These trials were completed over 6 days in Area2 and included a total of 17 hauls. A number of trials (5 hauls) were performed using a 2-m long SMP fitted between 6 m and 8 m distance from the codline (Fig. 2.3). Another 4 hauls were performed using a 3-m long SMP inserted between 5-8 m from the codline.

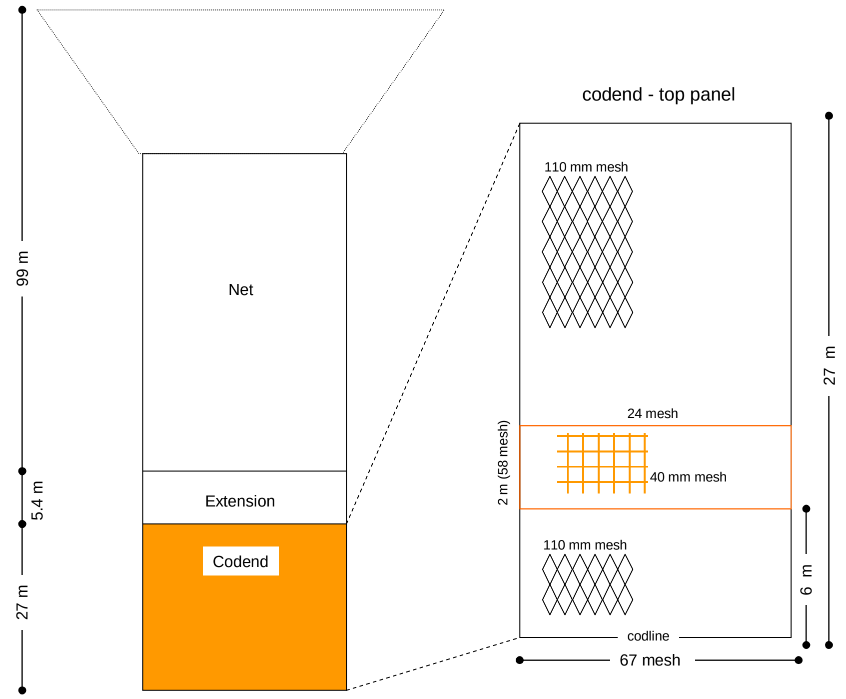


Figure 2.3. Trawl configuration tested during Series-2. A 40-mm mesh SMP was fitted inside the codend. Two panel lengths were tested: 2-m (inserted between 6-8-m from the codline) and 3-m (inserted between 5-8 m from the codline). SMP width was adjusted to spread the entire top panel of the codend (total width 24 square meshes). Two and three diamond meshes were alternatively attached to each square mesh.

2.4 Biological sampling

Catches were weighed using an electronic marine adjusted balance (POLS). All fish, squid and skates were weighed by species. In cases when catches exceeded 5 tonnes per species (as occurred for red cod and rock cod), total catch and discard weights for such species were estimated by determining the ratio of discard to retention-size fish in a random sample of the catch converting length to weight using species-specific length-weight functions (Appendix 1). This ratio was then multiplied by the factory production weight for the species in that trawl and by the round weight conversion factor. Length thresholds used to distinguish between discard and commercial size fish were 27-cm (red cod) and 24-cm (rock cod) (total length). For hauls involving catch weight estimation, the discarding process was observed and discard samples were taken to ascertain the validity of catch estimation methods and assumptions. In the case of rock cod, a correction was applied to account for frequent discarding of commercial-size fish. This involved multiplying the ratio of discard to retention by the proportion of retention-size fish that were discarded (if any), as determined from a random length frequency subsample of the discards.

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

Stomach contents were examined in a total of 810 fish specimens from 9 species. Stomach sampling involved recording length, sex and occurrence and numerical abundance of different prey items in stomachs (identified to lowest possible taxonomic level). Prey length was also recorded whenever possible.

Otoliths were collected from 433 fish specimens from 15 different species. Vertebrae and spines were collected from 26 specimens belonging to four different species of skates and sharks. All specimens sampled for otoliths/vertebrae/spines were also sampled for length, weight, sex and maturity.

2.5 Data Analyses

Fishery efficiency was compared among control and SMP-trawl configurations on the basis of standardized catch rates (CPUE (kg hr^{-1}) and species-specific length structures. Gear performance was evaluated using rock cod discard ratios and fitted retention probabilities at length.

2.5.1 Fishery efficiency

Catch rates (CPUE)

Trawl configuration effects on total and species-specific CPUE were assessed using generalized linear mixed models (GLMM) assuming log-normal errors (Gaussian family). This type of model was chosen to handle spatial correlation and over-dispersion in the data as a result of sampling design. CPUE data were log-transformed (base 10) for analyses. Sampling day, time-of-day and trawl depth (Series-1) were included as random effects. For Series-1, sampling area was included as a fixed effect together with trawl configuration. All GLMM were fitted using restricted maximum likelihood (REML) estimation. A backward model selection procedure was used starting with the saturated model (i.e. inclusion of all potential random effects) and progressive removals of non-significant terms. Model selection was done by minimizing the Bayesian (BIC) information criterion (Bolker 2008). Sampling day corresponded to calendar dates. Time-of-day was used as a 3-levels factor distinguishing between trawls that were hauled on or before 10:00 am (morning stations), those that were hauled between 10:05 am and 6:00 pm (daytime stations) and trawls completed after 6:00 pm (evening stations) - as distinguished based on trawl time finish on the seabed. Depth corresponded to modal trawling depth.

Species-specific length structure

Length structures were described and compared among trawl configurations in terms of median, first and third quartile (25th and 75th percentiles) and mean lengths. Counts of fish per 1-cm length intervals in each haul were smoothed and compared among gear configurations using generalized additive models (GAM) with Poisson error structure. Only hauls for which ≥ 90 specimens were sampled for length were considered.

2.5.2 Performance

Discard rates of rock cod

Rock cod catch composition by length/weight was used to estimate discard rates. The minimum commercial (or HGT size) threshold for rock cod is 25 cm (total length). Counts of rock cod per 1-cm length classes were converted to weights using the species length-weight function (Appendix1). A discard ratio (ratio of undersized to commercial size rock cod in kg) was calculated for each haul. Discard rates of rock cod (in kg per hour) were estimated by multiplying haul-specific CPUE by the discard ratio. Discard rates were compared among trawl configurations using GLMM with log-normal errors (Gaussian family). Discard rates were log-transformed (based 10) for analyses. Sampling day and time of day (Series-2) as well as trawl depth (Series-1) were included as random effects. For Series-1, sampling area was included as a fixed effect together with trawl configuration. Mixed models were fitted using restricted maximum likelihood (REML) estimation. A backward model selection procedure was followed and the best model selected by minimizing the Bayesian information criterion (BIC).

Rock cod 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).

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

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 ≥ 50% retention.

Counts of fish 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'. The available selection curve was defined as the maximum number of fish per length class 'L' among hauls 'i' in area 'j' ($MaxF_{Lij}$). This curve was used 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).

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

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

The double-logistic function was fitted to individual hauls RP_{Lij} and to treatment-specific RP_{Lij} (including data from all hauls of a given trawl configuration). Fitting was done by minimizing the residuals sum of squares using general purpose Nelder-Mead optimization. Initial values for slope and inflexion parameters were based on visual inspection of RP_{Lij}. Curve fitting was restricted to a representative size range of length classes for which the occurrence of zero-specimen observations was less than 10 hauls.

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

2.6 Oceanography

A logging CTDO (SBE-25, Sea-Bird Electronics Inc., Bellevue, USA) was deployed from the surface to 1-20 m above the bottom to obtain profiles of temperature (ºC), salinity (PSU), and density (kg m^{-3}). The CTD was deployed for the first one minute at about 10-11 m depth. It was then retrieved to 1 m depth and deployed again. The speed of deployment was c. 1m/s and was monitored by use of wire counter. For each station, vertical profiles of temperature, salinity and density were constructed using the Ocean Data View package v. 4.3.9-2011 (Schlitzer 2011).

3.0 Results

3.1 Oceanography

Oceanographic data were collected at 8 oceanographic stations, a total of four in each working area (Fig. 3.1). Temperature of surface waters varied from 8.89 to 10.38ºC, and bottom temperature varied between 5.44 and 6.29ºC being higher in the northern area. Because of relatively calm weather the upper isothermal layer extended only to 50 m depth (Fig. 3.2-A). Salinity in the northern area was 33.41-33.73‰, in the southern area – 33.63-33.94‰. Respective values of density were 25.79-26.55 (kg m^{-3}) and 26.06-26.83 (kg m^{-3}).
All the southern area was occupied by the Falkland Shelf Waters only (but a minor lens of waters of the Transient Zone that appeared at St. 1076). The northern area was a zone of contact between these shelf waters and the Argentinean Drift, which is seen by a 90-degree turn in directions of T-S curves (Fig. 3.2-B).

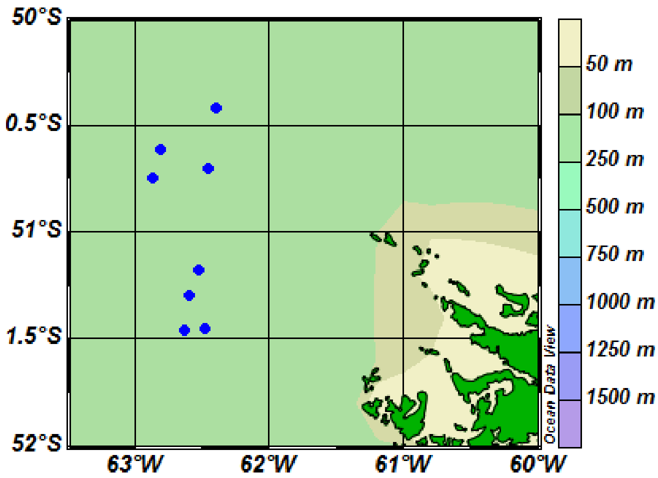


Figure 3.1 Oceanographic stations in February 2013.

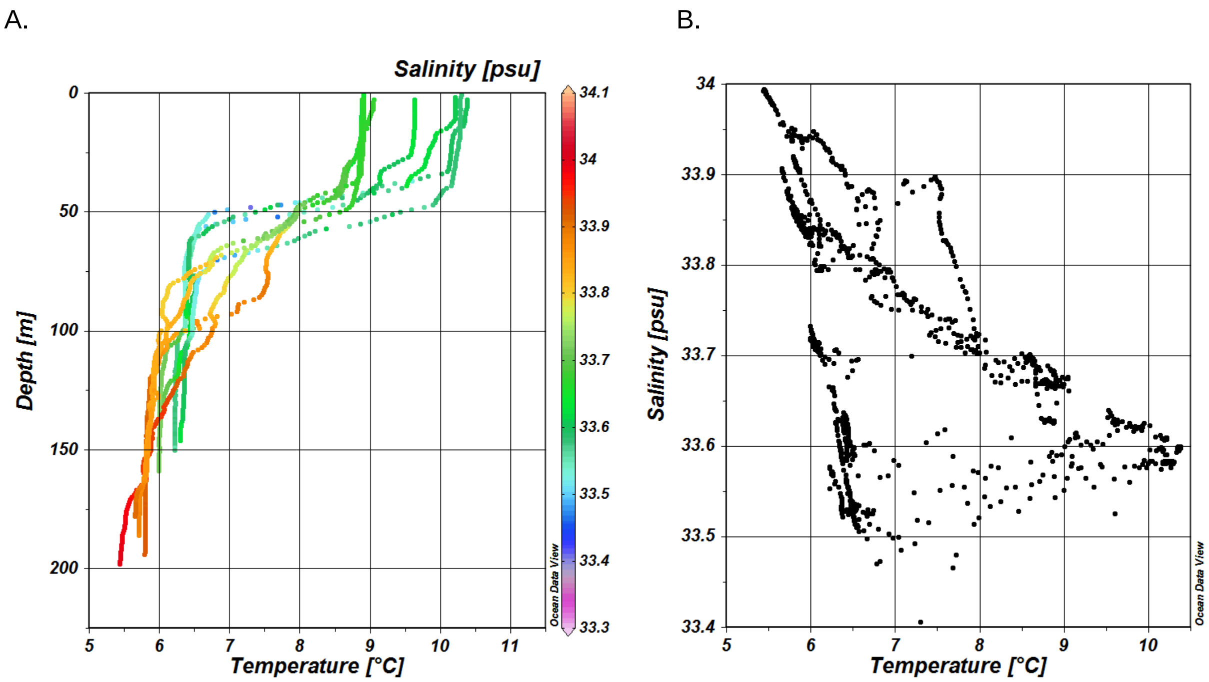


Figure 3.2 A) Changes in temperature and salinity with depth. B) T-S curves throughout the water column in the northern area (Area1) (lower "cloud" of dots) and southern area (Area2) (upper "cloud" of dots).

3.2 Catch composition

Total catch and sample/discard weights by species are summarized by area in Tables 3.1 and 3.2. Total catch in Area 1 was 61,166 kg and 189,486 kg in Area 2. Despite this large difference in total catch, species (or species grouping) composition between areas was similar, with 68 species recorded in Area 1 and 60 in Area 2. Species not shared between Areas included the skates *Bathyraja magellanica* (Area 1), *Bathyraja cousseauae*, *Raja trachyderma* (Area 2), the grenadier *Coelorhynchus fasciatus* (Area 2), and invertebrate and fish species that individually amounted to less that 0.01% total catch. Some of these differences may be explained in part, by the differences in average trawl depth between Areas.

Mean proportion of catch composition among hauls in Area 1 was highest in red cod (*S. australis*) (26%), rock cod (*P. ramsayi*) (22%), and cumulative RAY species (22%), although all of these varied widely between hauls (Fig 3.3). There were on average lower and more consistent catches of kingclip (*G. blacodes*) (9%), *M. ingens* (4%), common hake (*M. hubbsi*) (3%), hoki (*M. magellanicus*) (3%), and frogmouth (*C. gobio)* (2%). All remaining species (OTH) accounted for an average of 4% of total catch per haul (Fig 3.3). Noteworthy total catches in Area 1 of OTH species include sponges (Porifera) (576 kg), and Illex (*I. argentinus*) (297 kg), with the majority of the remaining catch being a mix of unidentified and identified invertebrates (Table 3.1).

Rock cod (*P. ramsayi*) dominated the catch in Area2, accounting for 86% of the total catch (163,605 kg) and averaging 81% of the catch proportion per haul (Fig 3.3). Other species were caught in relatively low (<5%) proportions. However, there were significant catches of other species in Area 2, and the rank order of catch composition differed between the 2 areas. The hoki (*M. magellanicus*) catch in Area 2 was the second highest (8255 kg), where as in Area 1 it was the fourth highest in terms of finfish catch. Conversely, total red cod catch ranked third in Area 2 but was lower (6560 kg) compared to Area 1. Catches of kingclip, *M. ingens*, and frogmouth were highly ranked, similar to Area 1. There were significant catches of toothfish (*D. eleginoides*) (250 kg) and Patagonian hake (*M. australis*) (187 kg) in Area 2, and the grenadier *C. fasciatus* (128 kg) was caught exclusively in Area 2. Despite larger over-all catch in Area 2, there were lower total catches of most ‘other’ species, eg sponges (58 kg) compared to Area 1.

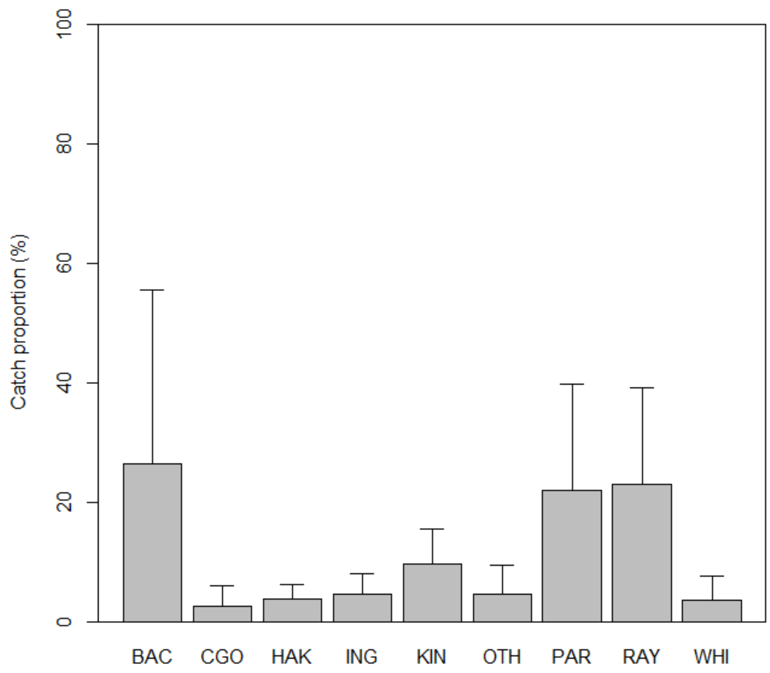
Table 3.1 Catch composition, sample, and discard weights (in kg) for Area 1, ZDLT1-02-2013.

Species code	Latin name	Catch Wt	Sample Wt	Discard Wt	Catch Proportion (%)
BAC	*Salilota australis*	27910.77	1127.81	396.59	45.63
PAR	*Patagonotothen ramsayi*	14366.93	496.56	4739.00	23.49
KIN	*Genypterus blacodes*	4403.32	2473.25	23.00	7.20
RBR	*Bathyraja brachyurops*	4150.11	4150.11	435.00	6.78
WHI	*Macruronus magellanicus*	1618.15	1120.33	45.22	2.65
ING	*Moroteuthis ingens*	1575.89	43.65	1575.89	2.58
HAK	*Merluccius hubbsi*	1541.74	1187.12	40.00	2.52
RMC	*Bathyraja macloviana*	1531.27	1531.27	210.00	2.50
RFL	*Raja flavirostris*	886.11	886.11	0.00	1.45
CGO	*Cottoperca gobio*	716.39	568.06	592.43	1.17
SPN	*Porifera*	576.23	0.00	576.23	0.94
RPX	*Psammobatis sp.*	502.55	192.27	316.08	0.82
ILL	*Illex argentinus*	297.66	95.26	118.34	0.49
RGR	*Bathyraja griseocauda*	228.97	228.97	0.00	0.37
RAL	*Bathyraja albomaculata*	187.43	187.40	0.00	0.31
SHT	*Mixed invertebrates*	126.39	0.00	126.39	0.21
DGH	*Schroederichthys bivius*	84.00	0.00	83.98	0.14
DGS	*Squalus acanthias*	81.30	17.04	81.21	0.13
RED	*Sebastes oculatus*	61.39	61.39	2.21	0.10
STA	*Sterechinus agassizi*	33.19	0.00	33.19	0.05
EGG	*Rays/skates Egg cases*	26.87	0.00	26.87	0.04
TOO	*Dissostichus eleginoides*	25.95	22.19	0.98	0.04
BUT	*Stromateus brasiliensis*	25.52	0.00	25.52	0.04
FUM	*Fusitriton magellanicus*	25.16	0.00	21.62	0.04
NEM	*Neophrynichthys marmoratus*	25.04	0.00	25.04	0.04
ANM	*Anemone*	20.98	0.00	20.98	0.03
AUC	*Austrocidaris canaliculata*	20.88	0.00	20.88	0.03
RDO	*Raja doellojuradoi*	17.09	17.09	11.73	0.03
SQT	*Ascidiacea*	14.35	0.00	14.35	0.02
ODM	*Odontocymbiola magellanica*	13.45	0.00	13.45	0.02
CAZ	*Calyptraster sp.*	10.51	0.00	10.51	0.02
CEX	*Ceramaster sp.*	9.23	0.00	9.23	0.02
THO	*Thouarellinae*	7.73	0.00	7.73	0.01
RSC	*Bathyraja scaphiops*	7.41	7.41	0.00	0.01
PAT	*Merluccius australis*	5.59	5.59	0.00	0.01
AST	*Asteroidea*	5.26	0.00	5.26	0.01
COL	*Cosmasterius lurida*	4.00	0.00	4.00	0.01
POA	*Porania antarctica*	3.21	0.00	3.21	0.01
MAV	*Magellania venosa*	2.70	0.87	1.83	< 0.01
RMG	*Bathyraja magellanica*	2.67	2.67	0.00	< 0.01
LOL	*Doryteuthis gahi*	2.16	0.00	1.77	< 0.01
BLU	*Micromesistius australis*	1.79	0.51	1.28	< 0.01
BAO	*Bathybiaster loripes*	1.71	0.00	1.71	< 0.01
MUE	*Muusoctopus eureka*	1.21	1.21	0.00	< 0.01
ZYP	*Zygochlamys patagonica*	1.20	0.00	1.20	< 0.01
RMU	*Bathyraja multispinis*	0.84	0.84	0.73	< 0.01
COP	*Congiopodus peruvianus*	0.78	0.00	0.78	< 0.01
CYX	*Cycethra sp.*	0.71	0.00	0.71	< 0.01
OCC	*Octocorallia*	0.70	0.00	0.70	< 0.01
SOR	*Solaster regularis*	0.57	0.00	0.57	< 0.01
EEL	*Iluocetes fimbriatus*	0.29	0.19	0.28	< 0.01
AUL	*Austrolycus laticinctus*	0.24	0.00	0.24	< 0.01
CRB	*Unid. Crab*	0.20	0.00	0.20	< 0.01
MED	*Medusae sp.*	0.13	0.00	0.13	< 0.01
BRY	*Bryozoa*	0.12	0.00	0.12	< 0.01
LIA	*Lithodes antarcticus*	0.12	0.00	0.12	< 0.01
NUD	*Nudibranchia*	0.11	0.00	0.11	< 0.01
XXX	*Unidentified animal*	0.10	0.00	0.10	< 0.01
AGO	*Agonopsis chilensis*	0.07	0.07	0.00	< 0.01
UHH	*Heart urchin*	0.06	0.00	0.06	< 0.01
TRX	*Trophon sp.*	0.04	0.00	0.04	< 0.01
GOC	*Gorgonocephalas chilensis*	0.02	0.00	0.02	< 0.01
PES	*Peltarion spinosulum*	0.02	0.00	0.02	< 0.01
CYA	*Cyphocaris anonyx*	0.01	0.00	0.01	< 0.01
CYP	*Cynomacrurus piriei*	0.01	0.00	0.01	< 0.01
EUO	*Eurypodius longirostris*	0.01	0.00	0.01	< 0.01
OPL	*Ophiuroglypha lymanii*	0.01	0.00	0.01	< 0.01
SRP	*Semirossia patagonica*	0.01	0.00	0.01	< 0.01
Totals		***61166.63***	***14425.25***	***9628.89***	

Table 3.2 Catch composition, sample, and discard weights (in kg) for Area 2, ZDLT1-02-2013.

Species code	Latin name	Catch Wt	Sample Wt	Discard Wt	Catch Proportion (%)
PAR	*Patagonotothen ramsayi*	163605.35	917.80	40553.01	86.34
WHI	*Macruronus magellanicus*	8255.15	978.98	0.48	4.36
BAC	*Salilota australis*	6560.27	1599.37	473.58	3.46
RBR	*Bathyraja brachyurops*	3931.60	3210.07	198.00	2.07
ING	*Moroteuthis ingens*	2376.95	0.00	2376.95	1.25
KIN	*Genypterus blacodes*	1314.24	1131.15	0.00	0.69
RFL	*Raja flavirostris*	522.73	522.73	0.00	0.28
RMC	*Bathyraja macloviana*	398.65	398.65	10.00	0.21
CGO	*Cottoperca gobio*	345.31	29.14	307.19	0.18
RGR	*Bathyraja griseocauda*	323.05	323.05	5.00	0.17
RAL	*Bathyraja albomaculata*	254.20	254.20	0.00	0.13
TOO	*Dissostichus eleginoides*	250.77	229.55	21.22	0.13
PAT	*Merluccius australis*	187.42	187.42	0.00	0.10
RPX	*Psammobatis sp.*	181.43	33.60	131.37	0.10
RSC	*Bathyraja scaphiops*	159.92	159.92	0.00	0.08
RDO	*Raja doellojuradoi*	150.39	150.39	9.00	0.08
GRF	*Coelorhynchus fasciatus*	128.90	30.00	128.90	0.07
RBZ	*Bathyraja cousseauae*	119.09	119.09	0.00	0.06
HAK	*Merluccius hubbsi*	72.00	7.86	0.00	0.04
SPN	*Porifera*	58.71	0.00	58.71	0.03
RMU	*Bathyraja multispinis*	58.61	58.61	0.00	0.03
BLU	*Micromesistius australis*	29.14	9.80	28.00	0.02
ANM	*Anemone*	28.66	0.00	28.65	0.02
NEM	*Neophrynichthys marmoratus*	22.74	0.00	22.73	0.01
STA	*Sterechinus agassizi*	20.34	0.00	20.34	0.01
CEX	*Ceramaster sp.*	18.34	0.74	17.60	0.01
DGS	*Squalus acanthias*	17.96	14.60	11.19	0.01
DGH	*Schroederichthys bivius*	15.53	3.60	13.45	0.01
RTR	*Raja trachyderma*	13.60	13.60	0.00	0.01
ODM	*Odontocymbiola magellanica*	10.80	0.00	10.80	0.01
SHT	*Mixed invertebrates*	10.19	0.00	10.19	0.01
CAZ	*Calyptraster sp.*	8.96	0.00	8.96	< 0.01
EGG	*Rays/skates Egg cases*	7.09	0.00	7.08	< 0.01
SQT	*Ascidiacea*	5.09	0.00	5.09	< 0.01
MED	*Medusae sp.*	3.77	0.00	3.77	< 0.01
AUC	*Austrocidaris canaliculata*	3.21	0.00	3.21	< 0.01
ILL	*Illex argentinus*	2.75	0.00	2.21	< 0.01
GOC	*Gorgonocephalas chilensis*	2.72	0.00	2.72	< 0.01
LOL	*Doryteuthis gahi*	2.52	0.00	2.52	< 0.01
COL	*Cosmasterius lurida*	2.19	0.00	2.19	< 0.01
MUE	*Muusoctopus eureka*	1.39	1.39	0.00	< 0.01
EEL	*Iluocetes fimbriatus*	1.12	0.99	0.13	< 0.01
BUT	*Stromateus brasiliensis*	0.70	0.00	0.70	< 0.01
PYX	*Pycnogonida*	0.61	0.00	0.61	< 0.01
MAV	*Magellania venosa*	0.54	0.27	0.27	< 0.01
COT	*Cottunculus granulosus*	0.42	0.00	0.41	< 0.01
MAR	*Martialia hyadesi*	0.31	0.31	0.00	< 0.01
FUM	*Fusitriton magellanicus*	0.30	0.00	0.30	< 0.01
ZYP	*Zygochlamys patagonica*	0.26	0.00	0.26	< 0.01
POA	*Porania antarctica*	0.23	0.00	0.23	< 0.01
CTA	*Ctenodiscus australis*	0.12	0.00	0.12	< 0.01
SRP	*Semirossia patagonica*	0.12	0.00	0.12	< 0.01
CYX	*Cycethra sp.*	0.09	0.00	0.09	< 0.01
AST	*Asteroidea*	0.07	0.00	0.07	< 0.01
THO	*Thouarellinae*	0.07	0.00	0.07	< 0.01
OPL	*Ophiuroglypha lymanii*	0.04	0.00	0.04	< 0.01
PES	*Peltarion spinosulum*	0.02	0.00	0.02	< 0.01
EUO	*Eurypodius longirostris*	0.01	0.00	0.01	< 0.01
OPH	*Ophiuroidea*	0.01	0.00	0.01	< 0.01
OIB	*Oidiphorus brevis*	0.00	0.00	0.00	< 0.01
Totals		***189486.74***	***10386.88***	***44477.57***	

A.



B.

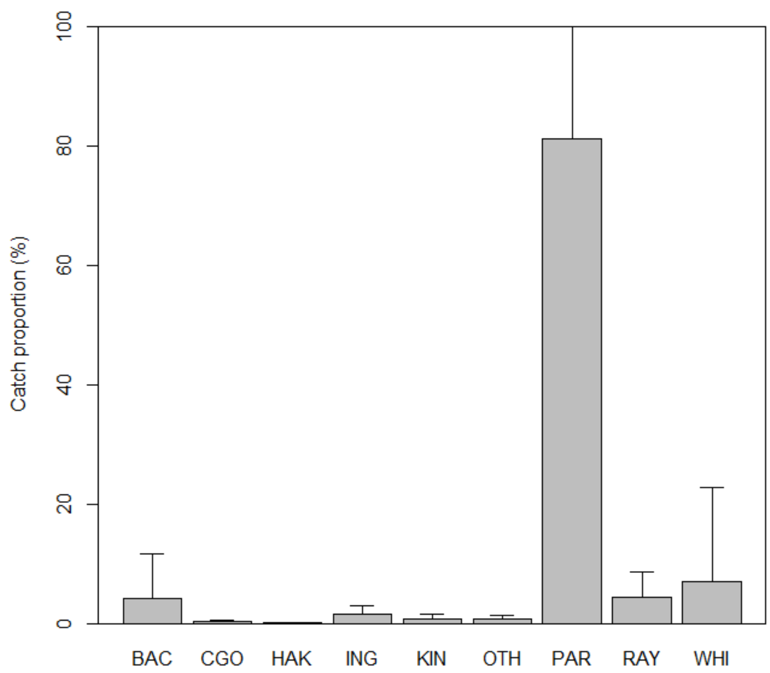
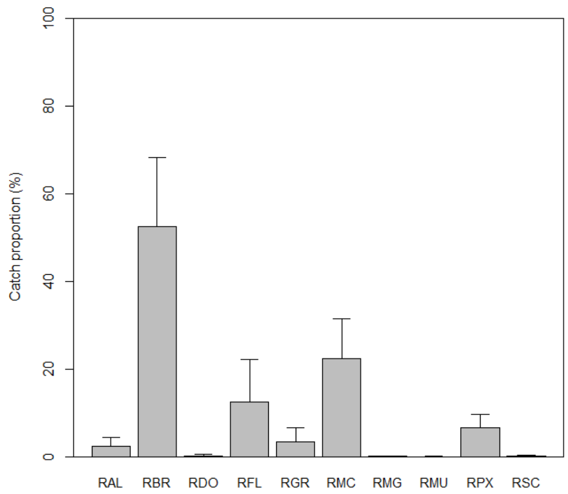


Figure 3.3 Catch composition by species (as percentage of total catch weight (mean ± sd among hauls)) in a) Area1; b) and Area2, ZDLT1-02-2013. BAC=*S. australis*; CGO=*C. gobio*; HAK=*M. hubbsi*; ING= *M. ingens*; KIN=*G. blacodes*; OTH = all other species; PAR= *P. ramsayi*; RAY =all skates/rays; WHI=*M. magellanicus.*

Total catches of skates were 7514 kg in Area 1 (12% total catch) and 6113 kg in Area 2 (3% total catch), comprising of 10 species in Area 1 and 11 species in Area 2 (Table 3.1, 3.2). Skate species composition varied slightly between Areas, with *Bathyraja magellanica* being found exclusively in Area 1, and *Bathyraja cousseauae* and *Raja trachyderma* found exclusively in Area 2. In both areas, *B. brachyurops* was the dominant species with average catch proportions of 52% in Area 1 and 67% in Area 2 per haul (Fig. 3.4). *B. macloviana* and *R. flavirostris* were of secondary importance in Area 1 (mean 22% and 12% per haul respectively), whilst in Area 2 all other skate species were of minor importance (7% or less mean proportion catch per haul).

A.



B.

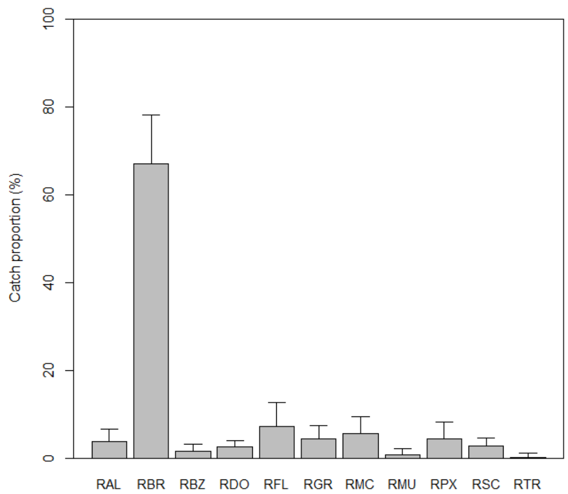


Figure 3.4 Skates species catch composition as percentage of total skates catch weight (mean ± sd among hauls) in a) Area1 and b) Area2, ZDLT1 : 03-2013 (see Tables 3.1-3.2 for legend).

3.3 SMP trials – Series 1: SMP in net extension

The net was broken during one haul (station 1066) in Area1 which was excluded from analyses. Trawling depth varied 145-198 m among hauls from Series-1.

3.3.1 Fishery efficiency

Total Catch ($CPUE_T$)

Total catch rate averaged 1.4 tonnes per hour (range 375-5383 kg hr^{-1} among hauls) during trials. Hauls with fitted SMP + diverter in the net extension had lower mean CPUE (< 1 t per hour) relative to control and SMP trawls (> 1 t per hour) however, this difference lacked statistical significance (Fig. 3.5, Table 3.3).

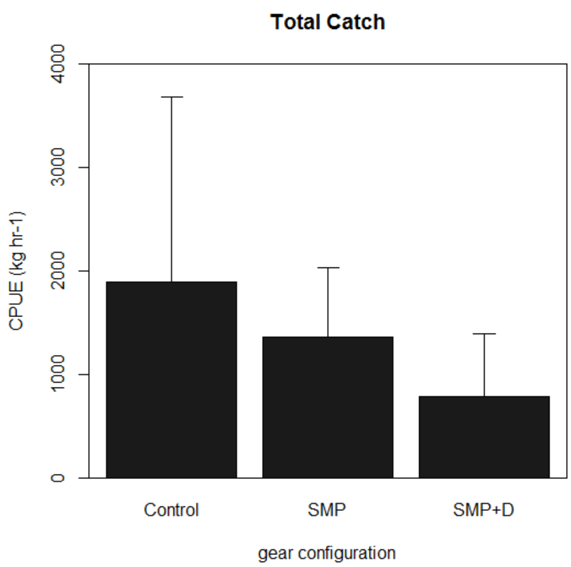


Figure 3.5. Total catch rates (mean ± sd) among trawl configurations from Series-1 of SMP trials. SMP = square mesh panel located in the net extension. SMP+D = SMP+diverter in the net extension.

Patagonotothen ramsayi (Patagonian rock cod)

Rock cod CPUE averaged 450 kg per hour (range 32-1260 kg hr^{-1} among hauls) and were similar between sampling areas (Table 3.3). The use of a SMP and SMP+diverter in the net extension had no effect on catches of rock cod (Fig. 3.6). Variability in catches of rock cod among hauls was greater than variability in catch among trawl configurations.

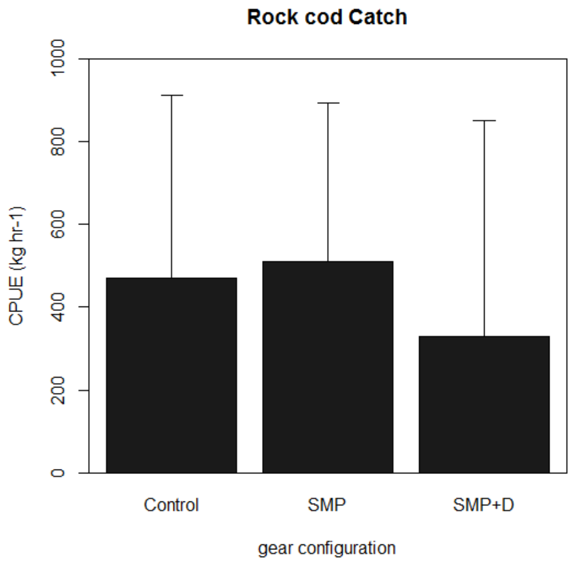


Figure 3.6. Catch rates of rock cod (mean ± sd) among trawl configurations from Series-1 of SMP trials. SMP = square mesh panel located in the net extension. SMP+D = SMP+diverter in the net extension.

Fitted length frequency distributions for rock cod are shown in Figure 3.7. Frequencies of small rock cod (< 20-cm) were slightly higher in trawls equipped with SMP in the net extension relative to controls (Fig. 3.7). Hence modal length decreased from 22 cm in control hauls to 21 cm in hauls with SMP (Table 3.4).

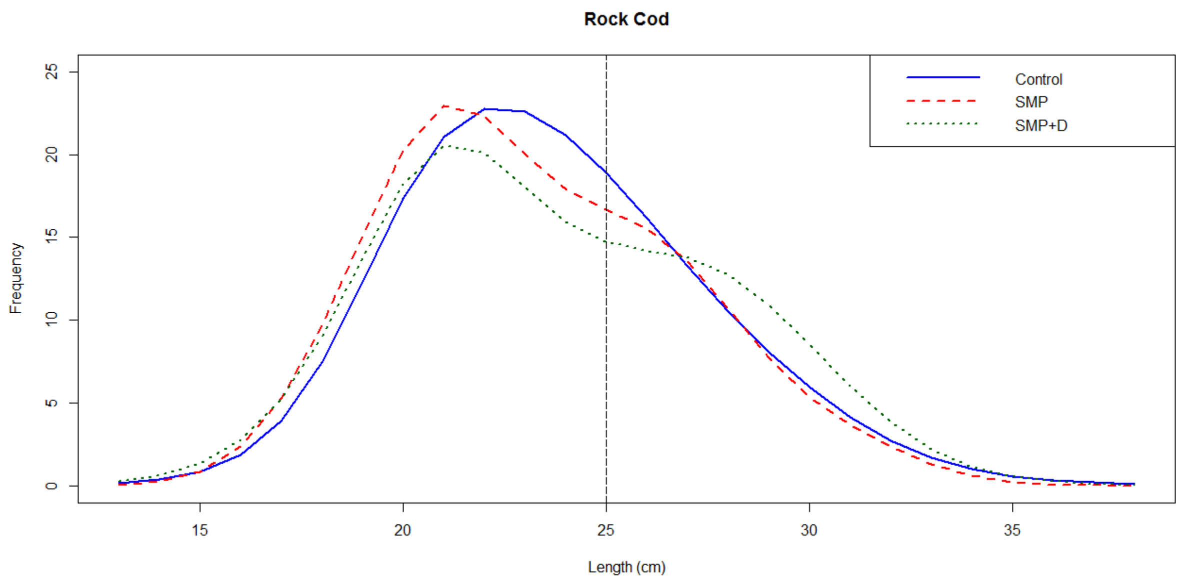


Figure 3.7 GAM-fitted length frequency distributions for rock cod among trawl configurations during series-1 of SMP trials (SMP in the net extension). Dashed line indicates the 25-cm threshold distinguishing between discard (< 25 cm) and commercial (HGT-size) rock cod.

Mean, median and first quartile lengths varied little among trawl configurations (Table 3.4). Third quartile length increased by 1-cm in hauls with SMP+diverter – indicating higher frequencies of commercial-size rock cod in the catch (Fig 3.7).

Table 3.3 Summary of GLMM for Series-1 of SMP trials (SMP in net extension). Fixed effects included gear (trawl configuration) and sampling area. Random effects included sampling day (day), time of day (tofday), time of day within sampling day (day:tofday) and trawling depth (Z). For fixed effects 'X' = significant effect (at α=0.05) and '-' = lack of statistical significance. For random effects '-' = no effect and ()% = percentage of residual variance explained by random effect. BIC is the Bayesian information criterion.

	Response	Fixed effects		Random effects				model	error structure	BIC
		gear	area	day	tofday	day:tofday	Z			
Total Catch	$logCPUE_T$	-	-	29%	-	-	-	GLMM	gaussian (log-normal)	29.58
P. ramsayi rock cod	logCPUE	-	-	57%	-	-	-	GLMM	gaussian (log-normal)	42.11
	log(Discard rate)	-	X	< 1%	-	-	-	GLMM	gaussian (log-normal)	47.52
S. australis red cod	logCPUE	-	-	21%	-	-	-	GLMM	gaussian (log-normal)	58.2
G. blacodes kingclip	logCPUE	X	X	<1%	-	95%		GLMM	gaussian (log-normal)	31.04
B. brachyurops (skates)	logCPUE	-	-	-	<1%	-	-	GLMM	gaussian (log-normal)	25.6
M. magellanicus hoki	logCPUE	X	X	51%	-	-	-	GLMM	gaussian (log-normal)	45.01
M. hubbsi hake	logCPUE	-	X	55%	-		-	GLMM	gaussian (log-normal)	19.29

Salilota australis (red cod)

Catches of red cod were highly variable during trials. Red cod CPUE ranged from 8 kg to 3.8 tonnes per hour among hauls and did not differ between sampling areas. Average CPUE in control hauls (885 kg hr^{-1}) was higher compared to trawls equipped with SMP (274 kg hr^{-1}) or SMP+diverter (76 kg hr^{-1}) in the net extension, however, this difference was not statistically significant (Fig. 3.8).

Red cod length structures are shown in Figure 3.9. Trawls equipped with a SMP+diverter in the net extension had a higher frequency of small-size (< 35-cm) red cod in the catch and a lower frequency of larger specimens (Figure 3.9). This was corroborated by lower mean, median and modal lengths and by reductions in first and third quartile lengths by up to 2-cm and 15-cm, respectively (Table 3.4). A trawl equipped with SMP+diverter in the net extension thus appears to reduce fishery efficiency for red cod by enhancing the occurrence of small-size (< 35-cm) fish in the catch. These results should be interpreted with caution however, owing to high variability in catches of red cod during trials.

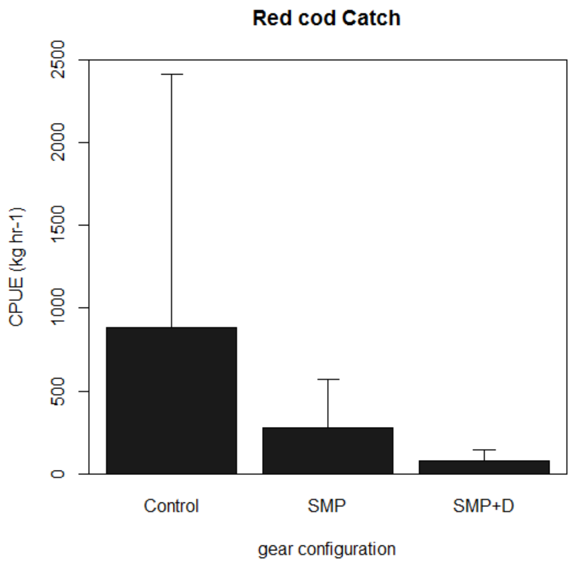


Figure 3.8. Catch rates of red cod (mean ± sd) among trawl configurations from Series-1 of SMP trials. SMP = square mesh panel located in the net extension. SMP+D = SMP+diverter in the net extension.

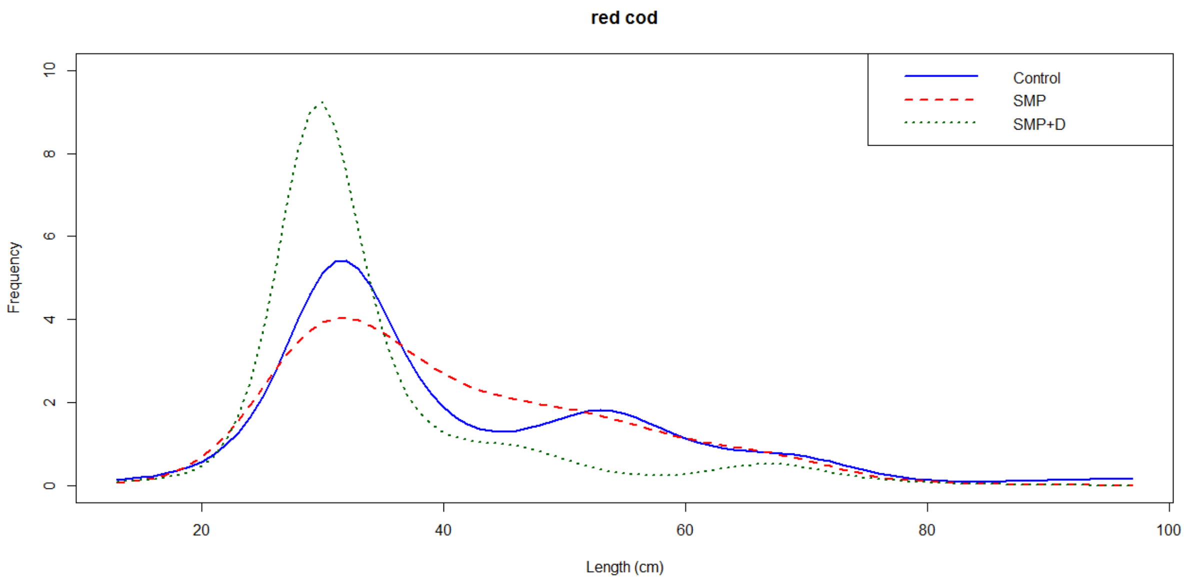


Figure 3.9 GAM-fitted length frequency distributions for red cod among trawl configurations during series-1 of SMP trials (SMP in the net extension).

Table 3.4 Species-specific length frequency distributions among trawl configurations during series-1 of SMP-trials, as described by mean, median, modal and first and third quartiles length.

	P. ramsayi	*S. australis*	*G. blacodes*	*B. brachyurops*	*M. magellanicus*	*M. hubbsi*
	rock cod	**red cod**	**kingclip**	**skates**	**hoki**	**hake**
Control						
25th percentile	21	30	66	26	27	46
median	23	35	73	39	32	49
75th percentile	26	51	82	52	35	53
mean	23.71	40.56	74.63	39.21	31.19	50.23
fitted mode	22	32	74	24	33	49
SMP in net extension						
25th percentile	21	31	65	25	26	47
median	23	38	72	35	32	50
75th percentile	26	50	80	51	34	53
mean	23.32	40.81	72.42	37.99	30.58	50.63
fitted mode	21	32	72	23	33	49
SMP+diverter (net extension)						
25th percentile	21	28	60	23	28	47
median	23	31	67	27	32	50
75th percentile	27	36	76	45	34	53
mean	23.83	34.41	69.12	33.42	31.26	50.61
fitted mode	21	30	64	23	33	50

Genypterus blacodes (kingclip)

Catches of kingclip were generally low and averaged 75 kg per hour (range 4-316 kg hr^{-1} among hauls). Area effects were significant with lower mean kingclip CPUE in Area2 (28 kg hr^{-1}) compared to Area1 (92 kg per hr^{-1}). Trawls equipped with a SMP+diverter in the net extension yielded lower mean kingclip CPUE (57 kg hr^{-1}) (Fig. 3.10, Table 3.3).

Kingclip length frequency distributions were similar between control and SMP hauls (Fig. 3.11). Trawls equipped with SMP+diverter had higher frequencies of smaller kingclip (< 70-cm) in the catch and lower frequencies of larger specimens. This was corroborated by a reduction in mean, median and modal lengths (Table 3.4). First and third quartiles lengths were also reduced by 6-cm in SMP+diverter relative to controls (Table 3.4).

A trawl equipped with SMP+diverter in the net extension thus appears to reduce fishery efficiency for kingclip.

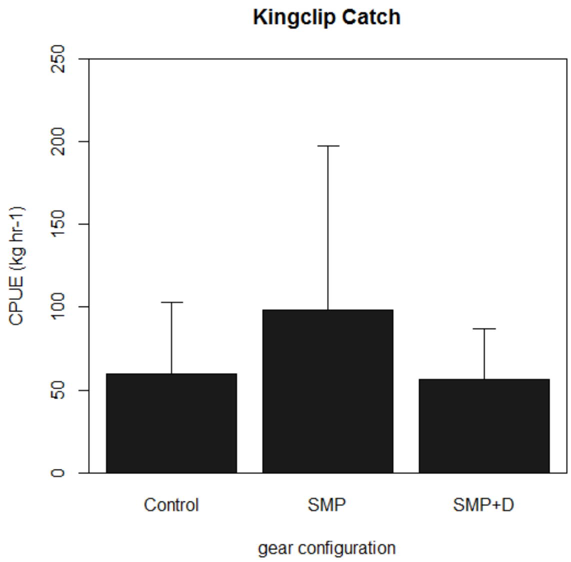


Figure 3.10 Catch rates of kingclip (mean ± sd) among trawl configurations from Series-1 of SMP trials. SMP = square mesh panel located in the net extension. SMP+D = SMP+diverter in the net extension.

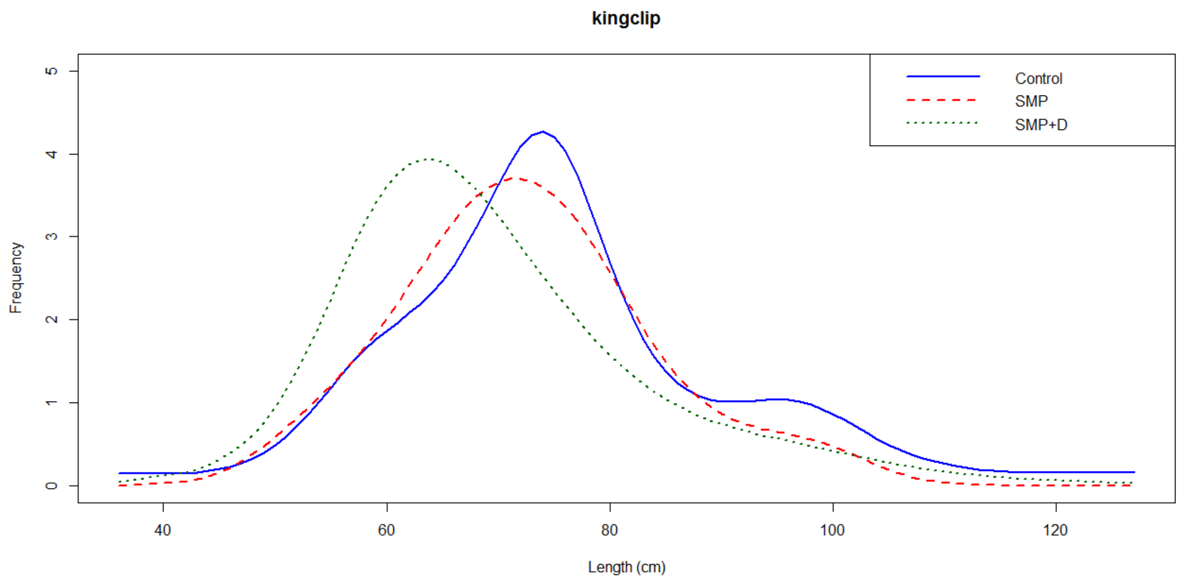


Figure 3.11 GAM-fitted length frequency distributions for kingclip among trawl configurations during series-1 of SMP trials (SMP in net extension).

Rajidae sp. (skates)

Catch rate (CPUE)

Fishery efficiency for skates was assessed using *B. brachyurops* (RBR) as indicator species. Relative abundance was generally low with mean CPUE ranging 81-97 kg per hour among trawl configurations (range 21-214 kg hr^{-1} among hauls) (Figure 3.12). Catches were similar between areas and variations in CPUE were independent from trawl configuration (Fig. 3.12, Table 3.3).

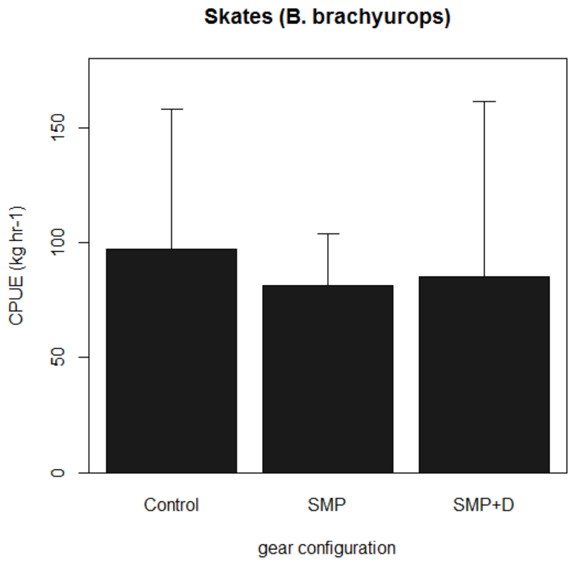


Figure 3.12 Catch rates of skates (mean ± sd) among trawl configurations from Series-1 of SMP trials. SMP = square mesh panel located in the net extension. SMP+D = SMP+diverter in the net extension.

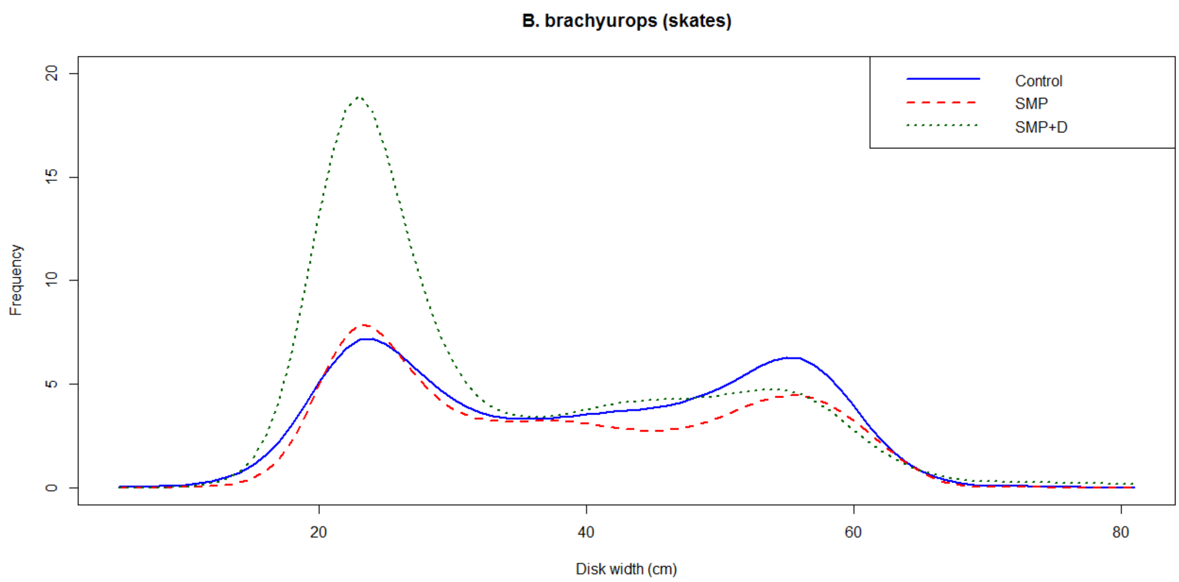


Figure 3.13 GAM-fitted length frequency distributions for *B. brachyurops* (skates) among trawl configurations during series-1 of SMP trials (SMP in net extension).

RBR size structure in control hauls was bimodal, peaking at 24-cm disk width and again at 55-cm (Fig. 3.13). A similar size composition was observed in hauls with SMP in the net extension, although with lower frequencies of larger (> 40-cm) specimens (Fig 3.13, Table

3.4). Diverter presence yielded a different size composition, with a strong mode at 23 cm and lower mean, median, and first and third quartiles lengths (Table 3.4). Increased frequencies of smaller-size skates (< 30-cm) suggest possible negative impacts of the SMP+diverter trawl configuration on fishery efficiency for skates.

*Macruronus magellanicus (*hoki*)*

Hoki CPUE averaged 165 kg per hour during trials and ranged 1-983 kg hr^{-1} among hauls. Area effects were significant with higher mean hoki CPUE in Area2 (526 kg hr^{-1}) relative to Area1 (36 kg hr^{-1}). Catches of hoki were affected by trawl configuration (Table 3.3, Fig. 3.14). Trawls equipped with SMP+diverter in the net extension had significantly lower mean CPUE relative to control and SMP hauls with no diverter (Fig. 3.14).

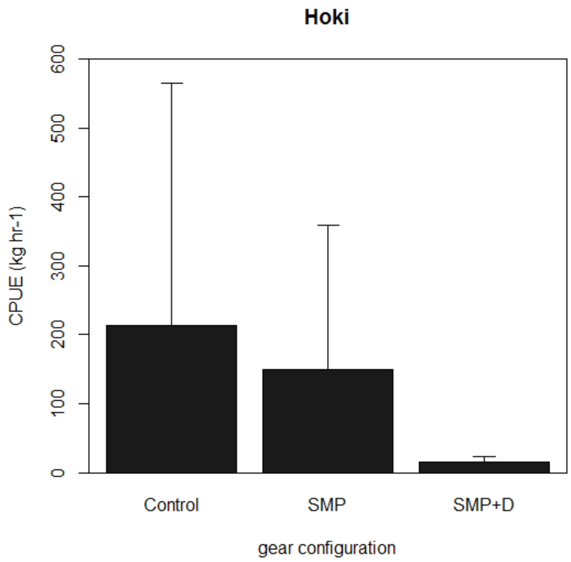


Figure 3.14 Catch rates of hoki (mean ± sd) among trawl configurations from Series-1 of SMP trials. SMP = square mesh panel located in the net extension. SMP+D = SMP+diverter in the net extension.

Hoki length structure was clearly bi-modal in control and SMP hauls and included a first peak at 25-cm and a second, dominant peak at 33-cm (Fig 3.15). Trawls equipped with SMP+diverter yielded a distinctive size composition characterized by the absence of the first (25-cm) mode (Fig. 3.15). This was accompanied by a 1-cm increase in first quartile length and little or no change in mean and modal lengths (Table 3.4). A SMP+diverter in the net extension thus affected fishery efficiency for hoki by causing a reduction in the occurrence of intermediate-size fish (23-27 cm pre-anal length) in the catch and a corresponding reduction in mean CPUE.

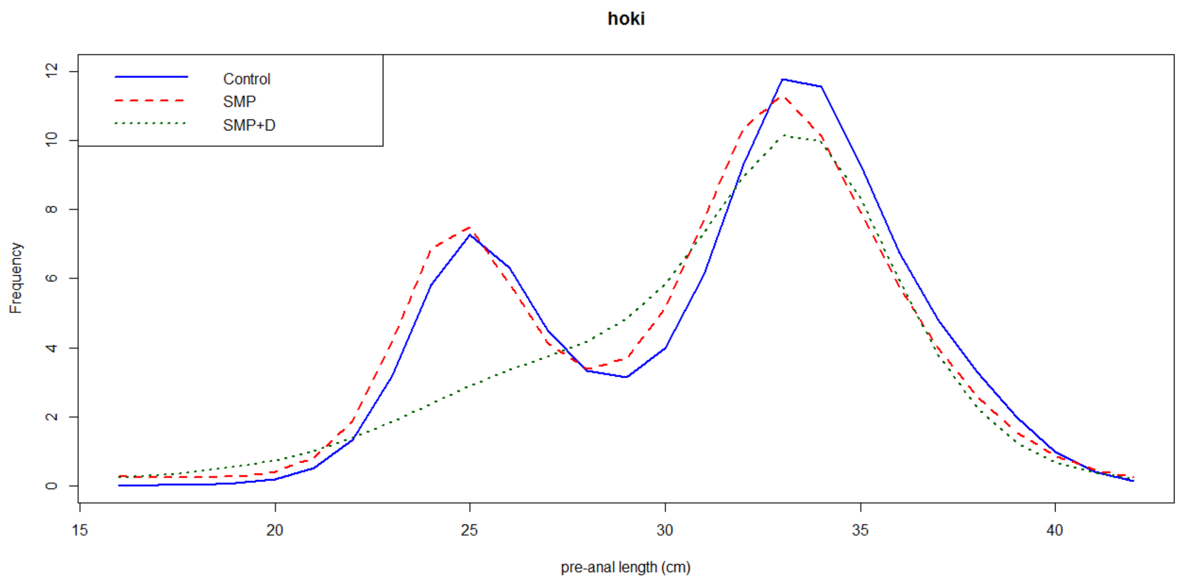


Figure 3.15 GAM-fitted length frequency distributions for hoki among trawl configurations during series-1 of SMP trials (SMP in net extension).

*Merluccius hubbsi (*hake*)*

Hake occurred in low numbers in the catch, as expected for this time of year. Hake CPUE averaged 25 kg per hour (range 0-54 kg hr^{-1} among hauls). The species was mainly caught in Area1 (mean CPUE 34 kg hr^{-1}). Catch rates were significantly lower in Area2 (mean CPUE <1 kg hr^{-1}) (Table 3.3). Under these conditions of low abundance, Hake CPUE were unaffected by trawl configuration (Fig. 3.16, Table 3.3). There was a visible trend however, towards higher mean CPUE in trawls equipped with SMP+diverter (Fig. 3.14).

Fitted length frequency distributions indicated lower occurrence of small hake (< 45-cm) in SMP trials relative to control hauls (Fig. 3.17). This was supported by a 1-cm increase in first quartile length in both SMP and SMP+diverter trials and by an increase in modal length in trawls with SMP+diverter (Table 3.4).

The results suggest possible improvement in fishery efficiency for hake (lower frequencies of small fish and higher catch rates) in trawls equipped with SMP+diverter in the net extension.

However these observations would require to be validated in the context of higher hake abundance.

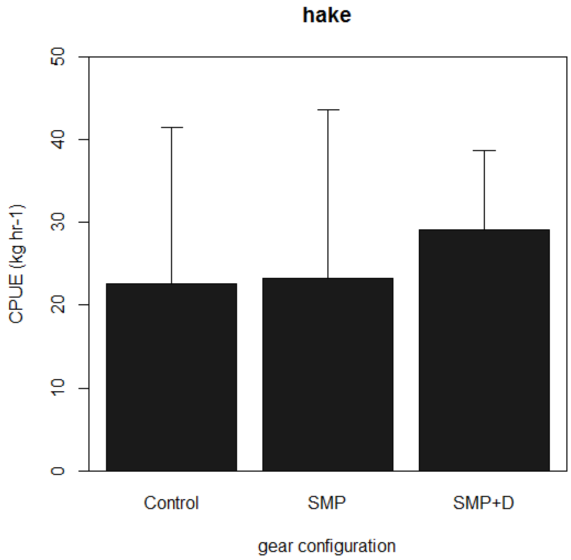


Figure 3.16 Catch rates of hake (mean ± sd) among trawl configurations from Series-1 of SMP trials. SMP = square mesh panel located in the net extension. SMP+D = SMP+diverter in the net extension.

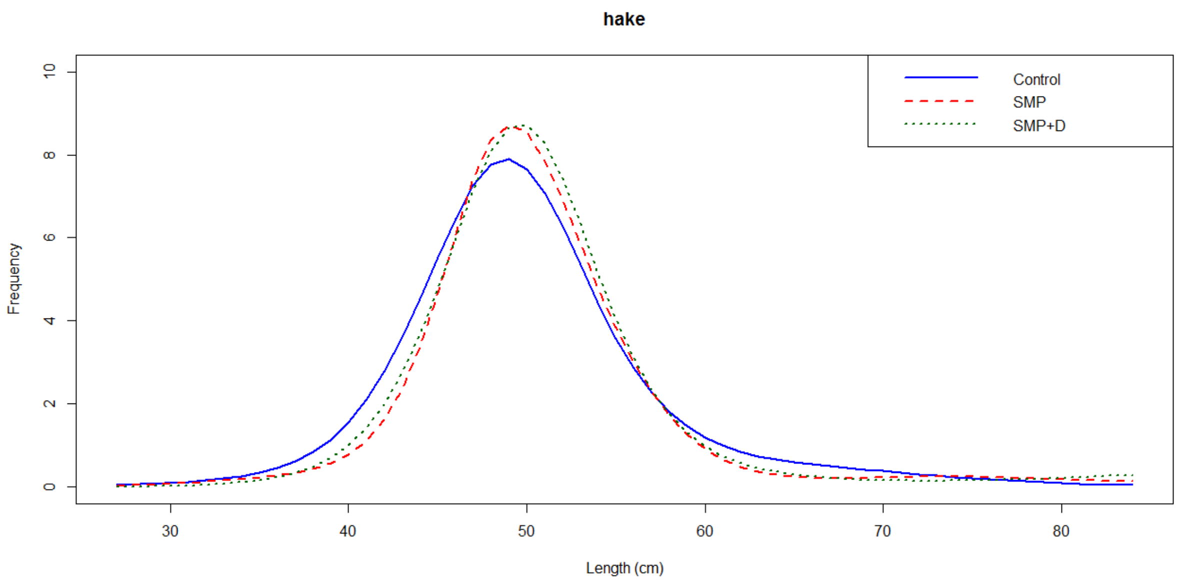


Figure 3.17 GAM-fitted length frequency distributions for hake among trawl configurations during series-1 of SMP trials (SMP in net extension).

3.3.2 Performance

Discard rates of rock cod

Average discard rates of undersized rock cod ranged from 231 kg per hour (control) to 216 kg hr^{-1} (SMP) and 132 kg hr^{-1} (SMP+diverter) and were statistically similar among treatments (Table 3.3, Fig 3.18). Inter-haul variability was important and exceeded variability among treatments (Fig 3.18). The area effect was significant and corresponded to higher mean discard rates in Area2 (Table 3.3). The presence of a SMP in the net extension had limited impact on estimated discard rates of rock cod.

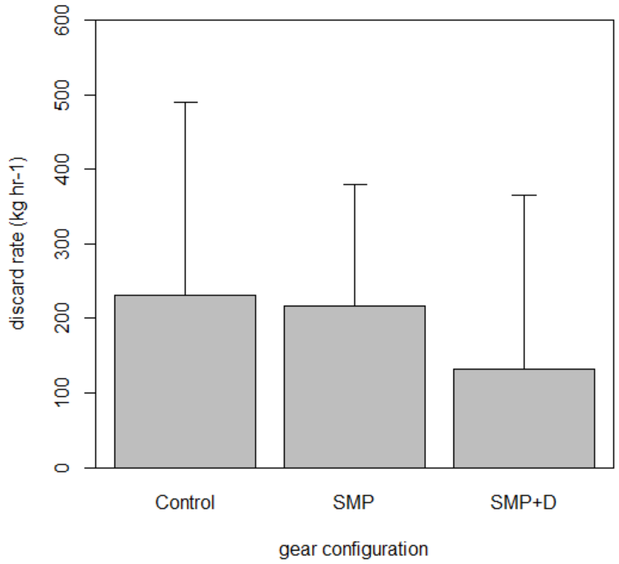


Figure 3.18 Discard rates of rock cod (mean ± sd) among control trawls and trawls equipped with square mesh panel (SMP) and SMP+diverter (SMP+D) in the net extension (Series-1).

Rock cod retention curves

To avoid an area-bias in the estimation of the available-selection curve for Series-1, only hauls from Area1 were considered for retention analyses. The size range used for fitting retention curves for rock cod from Series-1 was 15-34 cm.

Minimum length of 50% retention (L_{50}[1]) was generally similar among treatments and ranged 15-22 cm (mean 19 cm) in control hauls, 15-21 cm (mean 18 cm) in hauls with SMP in the net extension, and 11-22 cm (mean 19 cm) in hauls with SMP+diverter (Table 3.5). Inter-haul variability was important and showed no trends within treatments (Appendix 2).

Retention curves fitted using all data points for control and SMP hauls are shown in Figure 3.19. Trawls equipped with SMP yielded higher probabilities of retaining smaller rock cod (size range of maximum retention 17-27 cm) relative to control hauls (18-30 cm). Trawls equipped with SMP+diverter suggested some improvement, as indicated by an increase in L_{50}^1 to 19 cm and L_{50}^2 to 32 cm. However estimated probabilities of retaining small (< 18-cm) rock cod remained higher in trawls with SMP+diverter relative to controls (Fig. 3.19).

Table 3.5 Fitted parameters of the double logistic equation describing retention probability at length for rock cod during series-1 of SMP trials. A.slope and d.slope correspond to the ascending and descending limbs of the curve, respectively. L_{50}^1 and L_{50}^2 are minimum and maximum lengths of 50% retention. Fitted curves are shown in Appendix 2.

Haul/Station	date	Treatment	a.slope	d.slope	L_{50}^1	L_{50}^2
1056	10/02/2013	Control	6.77	0.1	15.7	26.1
1058	10/02/2013	SMP	321	0.19	15.0	25.3
1059	10/02/2013	SMP+D	4.14	0.15	11.1	25.0
1060	11/02/2013	SMP+D	0.28	0.74	21.2	32.5
1062	11/02/2013	Control	1.2	0.38	18.2	26.4
1063	11/02/2013	SMP	0.14	1.82	20.6	32.5
1064	12/02/2013	SMP+D	3.99	0.11	17.2	27.5
1067	13/02/2013	SMP	1.42	0.22	18.2	27.3
1068	13/02/2013	SMP+D	0.2	26.9	21.8	32.6
1069	13/02/2013	Control	0.16	1.36	22.0	44.8
1070	13/02/2013	SMP	0.81	0.42	17.0	25.7
1071	14/02/2013	Control	0.76	0.27	20.7	31.8
1073	14/02/2013	SMP	1.86	0.12	17.1	27.6
1074	14/02/2013	SMP+D	0.35	0.39	21.1	32.5
all combined		Control	0.51	0.14	18.3	30.4
all combined		SMP	0.67	0.17	16.6	27.0
all combined		SMP+D	0.25	0.22	19.1	31.7

3.3.3 Summary of findings - Series-1

Trawls equipped with a 40-mm SMP or SMP+diverter in the net extension did not contribute to significantly reduce discard rates of rock cod or improve selectivity for the species. The SMP+diverter configuration yielded higher frequencies of commercial-size rock cod in the catch but no reduction in frequencies of undersized fish.

Under the mixed-species conditions encountered during the trials, fishery efficiency was relatively independent from an SMP in the net extension. Significant effects on catch rates were observed only in kingclip and hoki and corresponded to lower mean CPUE in hauls with SMP+diverter. In kingclip this was accompanied by increased frequencies of smaller-size fish and a reduction in the occurrence of larger specimens in the catch – thus overall negative impacts on fishery efficiency for the species. Enhanced frequencies of smaller-size fish in hauls with SMP+diverter were also observed in red cod and skates – the reasons for which are unknown.

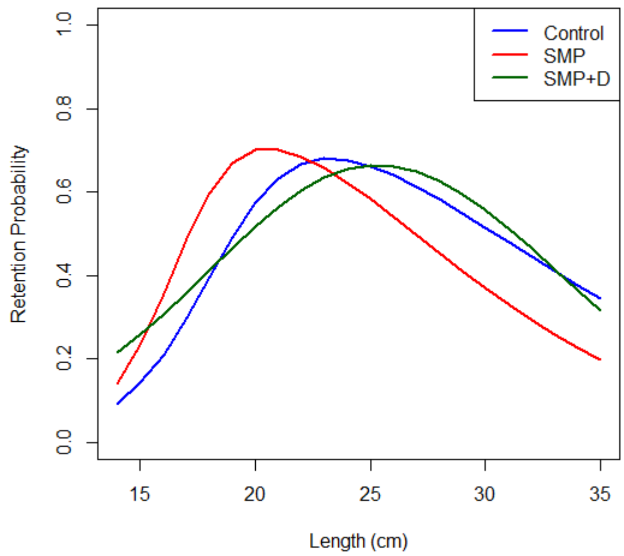


Figure 3.19 Fitted retention probability at length for rock cod in control hauls and trawls equipped with square mesh panel (SMP) and SMP+diverter in the net extension (Series-1).

In the case of hoki, the reduction in mean CPUE in SMP+diverter hauls was simultaneous to a reduction in the occurrence of intermediate-size fish in the catch. This may reflect a swimming response to diverter presence and escape of smaller specimens through the SMP.

Thus while SMP-trawl configurations in the net extension were ineffective for reducing by-catch of undersized rock cod in mixed species fisheries, a trawl equipped with SMP+diverter in the extension piece may potentially serve to improve size selectivity for hoki.

3.4 SMP trials – series 2: SMP in the codend

The SMP was initially inserted in the codend in a way that it did not cover the entire top panel. Since full cover was desired, initial trials (stations 1082 and 1083) were not retained for analyses.

Trawling depth was generally constant (181-185 m among hauls) during Series-2. Rock cod accounted for 93% of the catch (on average) (range 76-98% among hauls). The only other species that occurred in large enough numbers to allow length frequency sampling throughout the trials was red cod. SMP length (2-m and 3-m) was distinguished for analyses.

3.4.1 Fishery efficiency

Total catch ($CPUE_T$)

Average catch rates decreased from 7.8 t hr^{-1} in control hauls to 5.3 t hr^{-1} in trawls with SMP in the codend, however this reduction lacked statistical significance (Fig 3.20-A, Table 3.6). Panel size had a significant effect corresponding to lower mean CPUE in trawls equipped with the shorter (2-m) SMP (Fig 3.20-B, Table 3.6).

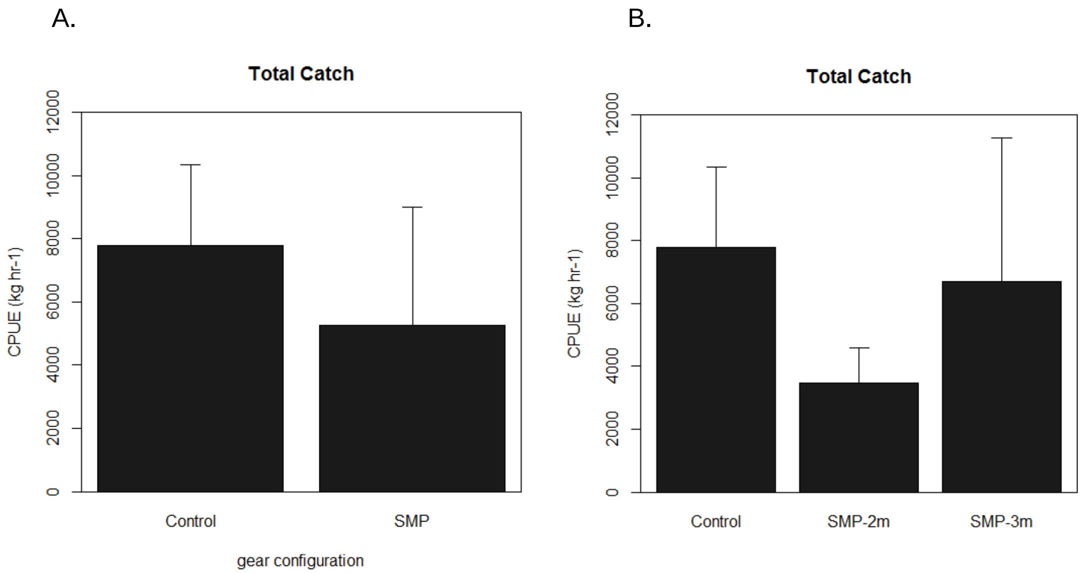


Figure 3.20 Total Catch rates (mean ± sd) among trawl configurations from Series-2. SMP = trawls with square mesh panel in the codend. A) distinction between Control and SMP hauls; B) distinction between Control and SMP of different lengths (2-m and 3-m).

Table 3.6 Summary of GLMM for Series-2 (SMP in codend). For fixed effects: 'X' indicates a significant effect (at α=0.05) and '-' indicates a lack of statistical significance. For random effects: '-' indicates no effect and ()% is the percentage of the residual variance explained by the random effect. BIC is the Bayesian information criterion.

	Response	Fixed effect	Fixed effect	Random effects			model	error structure	BIC
		gear	panel	day	tofday	day:tofday			
Total Catch	$\log CPUE_T$	-		30%	-	-	GLMM	gaussian	13.48
	$\log CPUE_T$		X	19%	-	-	GLMM	gaussian	16.65
P. ramsayi (rock cod)	logCPUE	-		27%	-	-	GLMM	gaussian	16.04
	logCPUE		X	18%	-	-	GLMM	gaussian	19.25
	log(Discard rate)	X		3%	-	-	GLMM	gaussian	19.81
	log(Discard rate)		X	3%			GLMM	gaussian	22.45
S. australis (red cod)	logCPUE	-		59%	-	-	GLMM	gaussian	13.17

*Patagonotothen ramsayi (*Patagonian rock cod*)*

Like total catch, average catch rates of rock cod were lower in trawls with SMP (4.98 t hr^{-1}) relative to control hauls (7.47 t hr^{-1}) but this reduction lacked statistical significance (Fig. 3.21-A, Table 3.6). Panel size had a significant influence on catches of rock cod with lower mean catch rates in trawls equipped with the smaller (2-m) SMP (Fig. 3.21-B, Table 3.6).

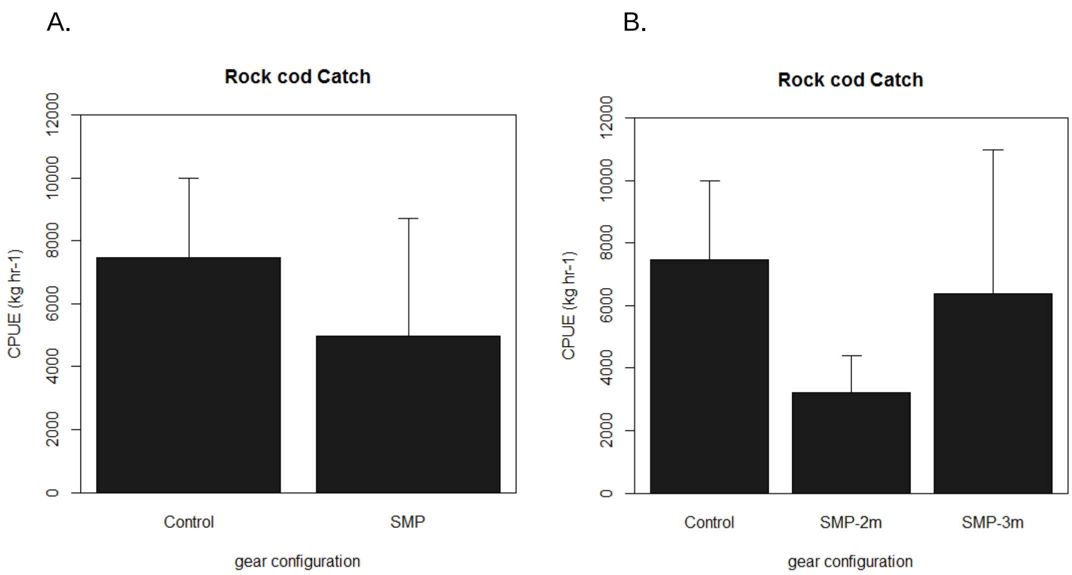
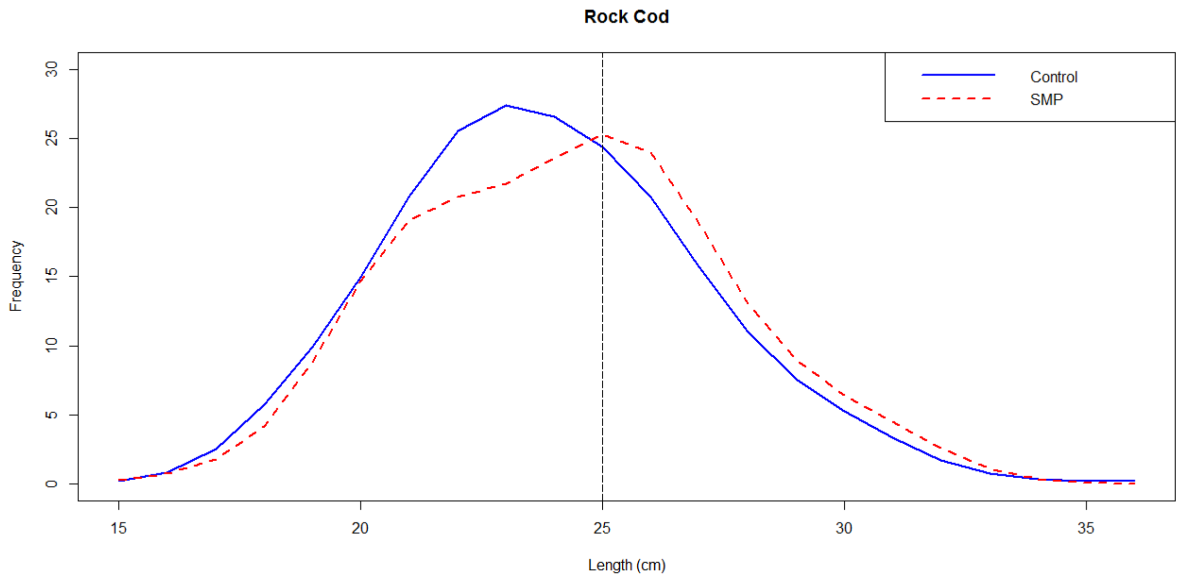


Figure 3.21 Catch rates of rock cod (mean ± sd) among trawl configurations from Series-2. SMP = trawls with square mesh panel in the codend. A) distinction between Control and SMP hauls; B) distinction between Control and SMP of different lengths (2-m and 3-m).

Catch composition by length differed between treatments (Fig 3.22). SMP-trawls yielded lower frequencies of undersized (< 25-cm) rock cod and higher frequencies of commercial size fish (Fig 3.22-A). This was especially marked in trawls fitted with the smaller (2-m) SMP (Fig 3.22-B). These observations were supported by an increase in mean, modal and 75th percentile lengths in trawls with SMP in the codend relative to control hauls (Table 3.7).

A.



B.

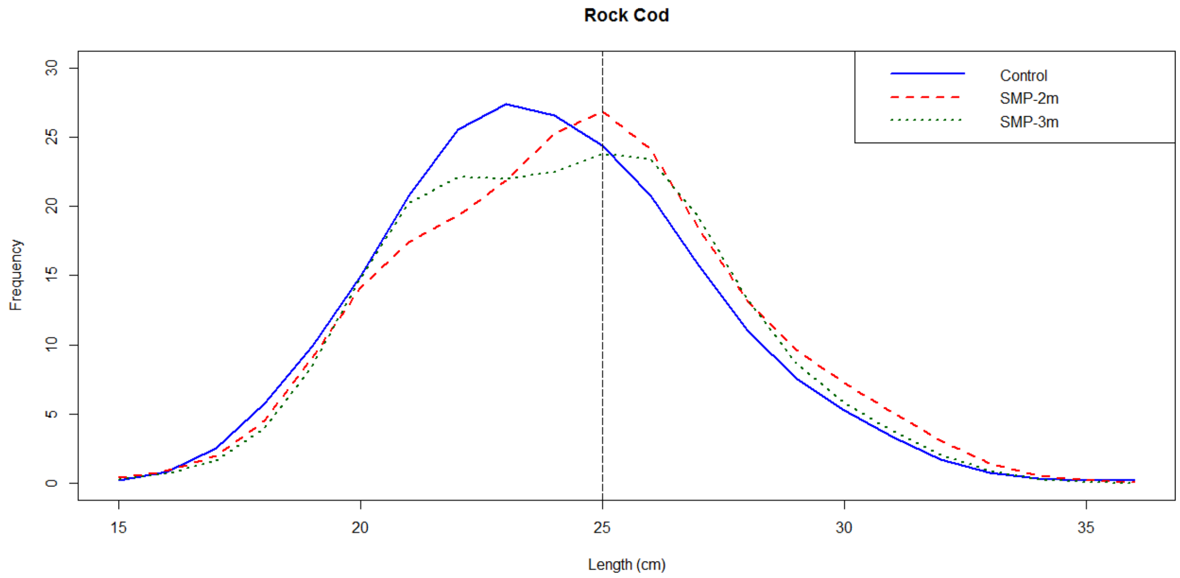


Figure 3.22 GAM-fitted length frequency distributions for rock cod from Series-2. A) Distinction between control trawls and trawls equipped with SMP inside the codend; B) Distinction between control trawls and trawls equipped with SMP of different lengths (2m and 3m).

Salilota australis (red cod)

Catches of red cod were similar between control and SMP trawls and averaged 68-73 kg per hour among treatments (Fig 3.23-A, Table 3.6). Panel length effects were not examined.

Red cod length structure differed between trawl configurations. Trawls equipped with SMP in the codend had higher frequencies of smaller-size fish and lower frequencies of larger red cod in the catch (Fig 3.24-A). This pattern was consistent between panels of different size (2-m and 3-m length) (Fig 3.24-B). First quartile, mean, median and modal lengths decreased in SMP trawls relative to controls (Table 3.7).

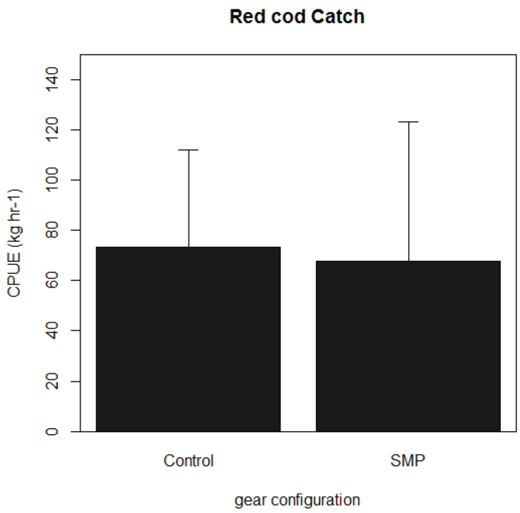
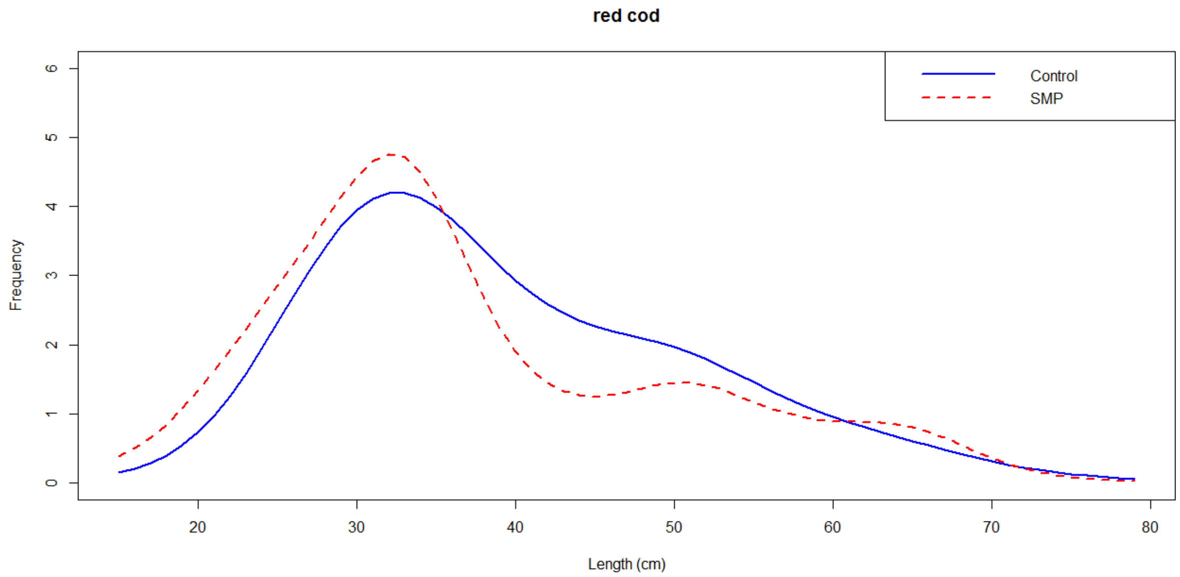


Figure 3.23 Catch rates of red cod (mean ± sd) between trawl configurations from Series 2. SMP = trawls equipped with square mesh panel in the codend.

Table 3.7 Length structures of rock cod and red cod between control and SMP-trawl configurations (SMP in codend - 2-m or 3-m length) from series-2, as described by mean, median modal and first and third quartile lengths.

	Control	SMP (all data)	2-m SMP	3-m SMP
***P. ramsayi* (rock cod)**				
25th percentile	22	22	22	22
median	24	24	24	24
75th percentile	26	27	27	26
mean	23.9	24.3	24.4	24.2
fitted mode	23	25	25	25
***S. australis* (red cod)**	**Control**	**SMP (all data)**	**2-m SMP**	**3-m SMP**
25th percentile	31	29	28	29
median	37	34	35	34
75th percentile	47	46	49	40
mean	39.5	37.5	38.8	35.9
fitted mode	33	32	32	32

A.



B.

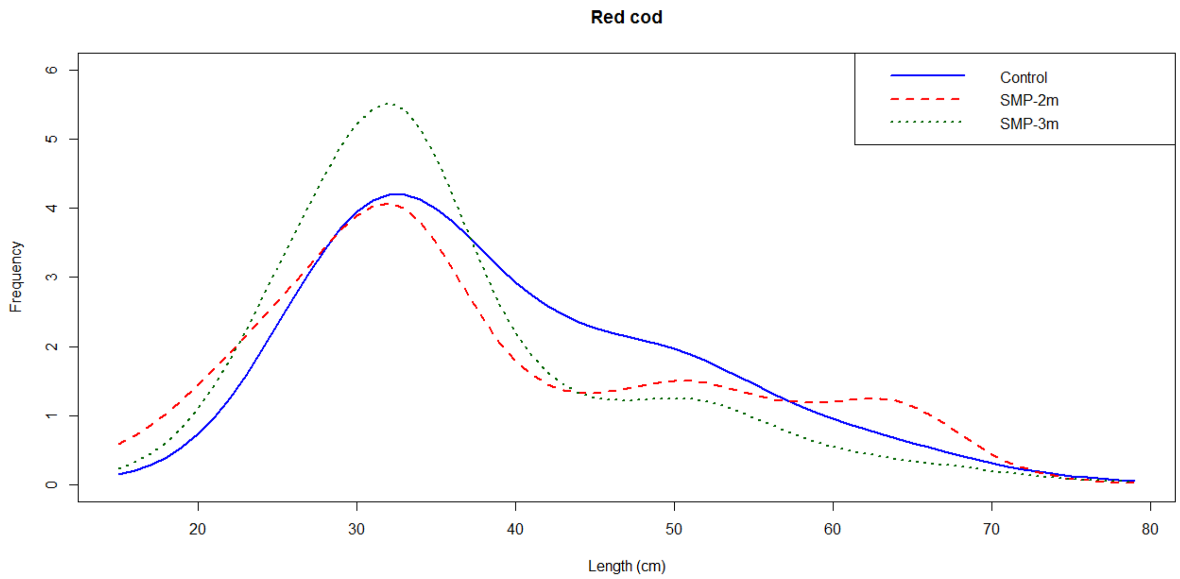


Figure 3.24 GAM-fitted length frequency distributions for red cod from Series-2. A) Distinction between control trawls and trawls equipped with SMP in the codend; B) Distinction between control trawls and trawls equipped with SMP of different lengths (2m and 3m).

3.4.2 Performance

Discard rates of rock cod

Mean discard rates decreased by nearly half in hauls with SMP (1,793 t hr^{-1}) relative to controls (3,187 t hr^{-1}) and this difference was statistically significant (Fig 3.25-A, Table 3.6). When panel size was considered, average discard rates decreased by a factor of 1.3 in the larger (3-m) SMP (relative to controls) and by a factor of 3.1 in the smaller (2-m) SMP (Fig 3.25-B). The reduction was only significant in the smaller (2-m) SMP.

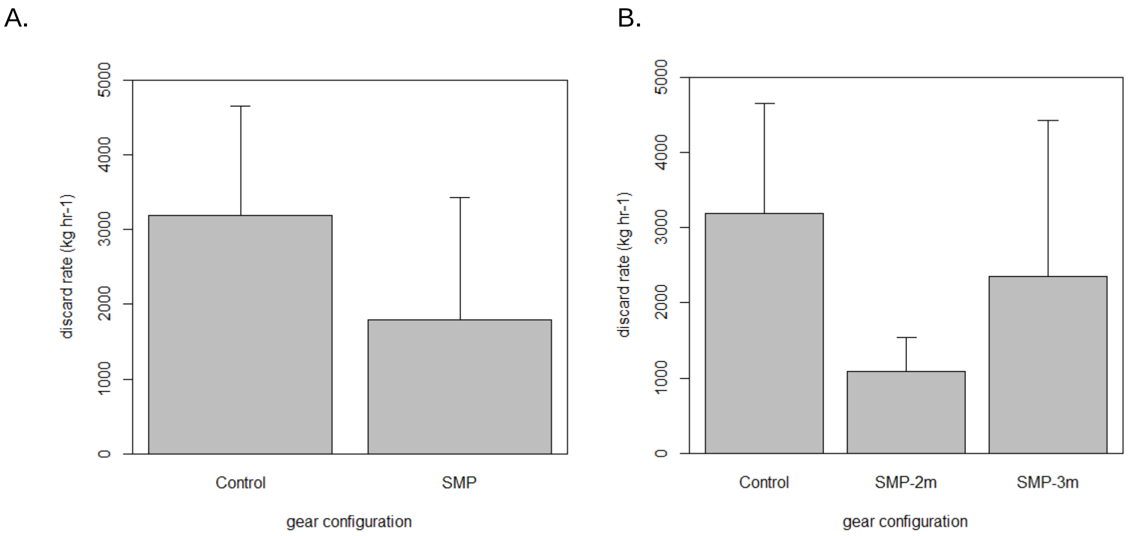


Figure 3.25 Discard rates of rock cod (mean ± sd) from Series-2 (SMP in codend). A) Distinction between control and SMP trawls; B) Distinction between control and different size SMP in the codend.

Retention probability at length

The size range used for fitting retention probability curves for rock cod from series-2 was 17-33 cm.

Minimum length of 50% retention (L_{50}^{1}) ranged 0-22 cm (mean 15 cm) in control hauls and 16-21 cm (mean 19 cm) in trawls with SMP in the codend (Table 3.8). Similarly, L_{50}^{2} ranged 26-39 cm (mean 29 cm) for controls and 27 cm to infinity (mean 31 cm) in SMP-codend hauls (Table 3.8). Thus in spite of important inter-haul variability, trawls equipped with a SMP in the codend generally yielded lower probabilities of retaining smaller rock cod and higher probabilities of retaining commercial-size fish (Appendix 3).

Retention curves fitted using all data points for control and SMP trawl configurations are shown in Figure 3.26. The size range of maximum retention increased from 14-29 cm in controls to 19-31 cm in trawls equipped with SMP in the codend (Fig. 3.26-A, Table 3.8). Different size panels (2-m and 3-m SMP) yielded similarly low probabilities of retaining undersized rock cod (Fig 3.26-B). The smaller (2-m) SMP most effectively retained commercial-size rock cod (Fig 26-B, Table 3.8).

Table 3.8 Fitted parameters of the double logistic equation describing retention probability at length for rock cod from Series-2 (SMP-codend trials). A.slope and d.slope correspond to the first (ascending) and second (descending) limbs of the curve, respectively. L_{50}^{1} and L_{50}^{2} are minimum and maximum lengths of 50% retention. Fitted curves are shown in Appendix 3.

Haul/Station	date	Treatment	a.slope	d.slope	L_{50}^{1}	L_{50}^{2}
1084	17/02/2013	SMP	0.36	inf	19.2	inf
1085	18/02/2013	Control	2.38	0.16	11.1	26.1
1086	18/02/2013	SMP	0.22	0.19	19.5	34.5
1087	18/02/2013	Control	0.07	0.44	inf	27.1
1088	19/02/2013	SMP	7.21	0.11	17.8	28.5
1089	19/02/2013	SMP	0.31	0.63	21.2	30.7
1090	19/02/2013	Control	3.55	0.14	9.0	26.7
1091	20/02/2013	Control	0.19	1.94	21.6	38.9
1093	20/02/2013	SMP	2.59	0.16	16.0	26.9
1094	21/02/2013	SMP	0.26	0.1	19.1	38.8
1095	21/02/2013	Control	13	0.23	17.1	26.2
1096	21/02/2013	SMP	0.42	0.37	19.6	28.8
1097	22/02/2013	SMP	0.47	0.3	19.4	29.0
1099	22/02/2013	SMP	15.09	0.08	17.1	32.4
1100	22/02/2013	Control	0.4	0.37	17.3	27.2
all stations combined		Control	0.12	0.34	14.1	29.4
		SMP	0.22	0.29	19.0	31.1
		SMP-2m	0.25	0.17	18.5	32.9
		SMP-3m	0.21	0.40	19.2	30.5

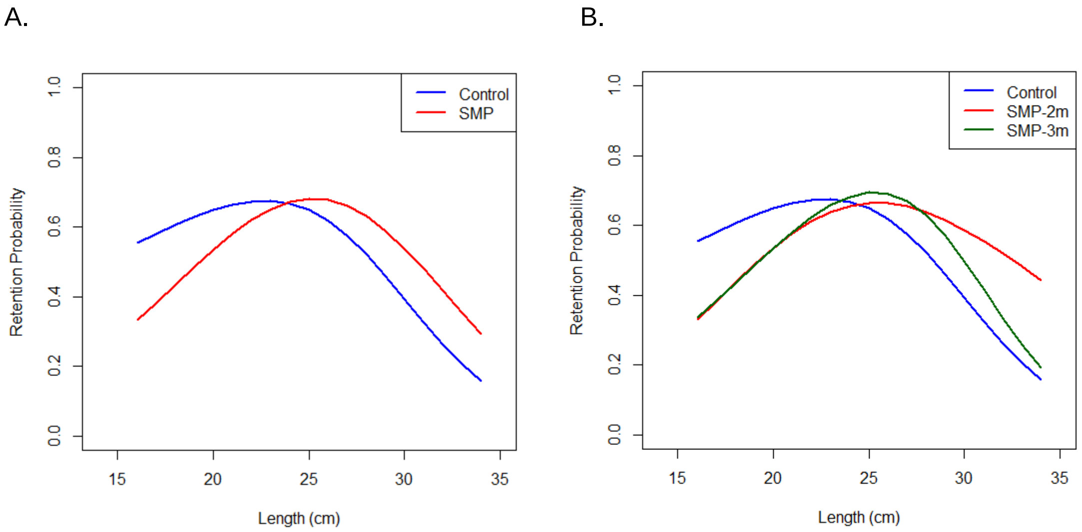


Figure 3.26 Fitted retention probability at length for rock cod from Series-2 (SMP in codend trials). A) Distinction between control trawls and trawls with SMP in the codend; B) Distinction between control and different size SMP in the codend.

3.4.3 Summary of findings – Series 2

A 40-mm SMP located in the codend significantly reduced discard rates of undersized rock cod and improved selectivity for the species by reducing retention probabilities for undersized fish and increasing probabilities of retaining commercial-size rock cod. The same trawl configuration had no impact on catches of red cod (under conditions of low red cod density). In contrast to rock cod, frequencies of small red cod in the catch were generally higher in trawls equipped with SMP in the codend relative to controls.

Reductions in mean discard rates of rock cod were equivalent to 44% and varied 26-66% with SMP size. The smaller SMP (2-m length) had the most important reduction (66%), however this was not independent from differences in total catch rates between hauls with 2-m and 3-m long SMP. Hence panel size effects were especially marked on fishery efficiency parameters (catch rates and length structure) and related performance evaluation using discard rates. By comparison, retention curves were relatively robust and showed only small variation in retention probabilities for commercial-size fish between 2-m and 3-m SMP. This suggests that panel size effects were mainly related to catch size.

Despite trials being conducted within a small area, large rock cod aggregations were encountered over two days when SMP-trials were performed using the larger (3-m) SMP. Catch rates exceeded 7 tonnes per hour in both control and SMP hauls on one day and trawl duration had to be reduced to one hour. Since the 3-m long SMP was inserted 1-m further inside the codend towards the codline, it was no longer situated forward of the catch in hauls with total catch exceeding 10 tonnes. SMP positioning forward of the catch has been shown to enhance their performance in certain fish species (Bullough et al 2007, Graham and Kynoch 2001). Our results suggest that catch size together with SMP-length and positioning inside the codend are likely to affect SMP performance in rock cod.

Thus while a trawl equipped with SMP inside the codend improved selectivity for rock cod during experimental trials, further testing is required to identify the SMP configuration that will better perform under commercial conditions.

4.0 General conclusions and recommendations

A first series of SMP trials was conducted using a 40-mm square mesh panel on trawls equipped with a 110 mm diamond mesh codend. Trials were conducted under both mixed species and targeted rock cod conditions on finfish fishing grounds in the north-west of the FICZ. The results demonstrated that trawls equipped with SMP or SMP + diverter in the net extension generally did not affect fishery efficiency or improve selectivity for rock cod and other commercial species – with the exception of hoki. These findings were achieved under mixed species conditions and low rock cod abundance in the catch. In contrast, trawls equipped with SMP inside the codend significantly reduced discard rates of undersized rock cod and improved selectivity for the species by reducing retention probabilities for undersized fish and increasing probabilities of retaining commercial-size rock cod. These findings were achieved under targeted rock cod conditions with rock cod accounting for > 75% of total catch.

The reduction in mean discard rates of rock cod was of 44% in trawls with SMP in the codend relative to controls. This was paralleled by a reduction in mean total catch of 33%. By comparison, an increase in codend diamond mesh size from 110 mm to 120 mm yielded average daily reductions in discard rates of rock cod and total catch of 79% and 71%, respectively, under targeted rock cod conditions. A trawl equipped with a 110 mm mesh codend and 40-mm SMP in the codend therefore appears as a better compromise permitting to reduce bycatch of small rock cod while retaining commercial size fish.

During trials, evidence of catch size and SMP size and position effects on SMP performance was observed. In consequence, it is recommended that further testing be conducted in order to identify the SMP-codend configuration most suitable to perform under commercial conditions – including both mixed species and targeted rock cod fisheries. Recommended configurations include further testing of a 2-m SMP inserted between 6-8 m from the codline; and testing of a 17-m SMP inserted 10-m from the codline and extending to the extension piece.

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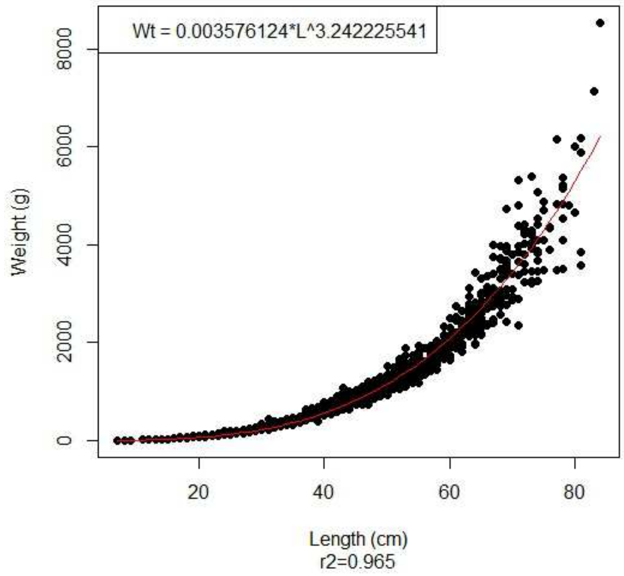
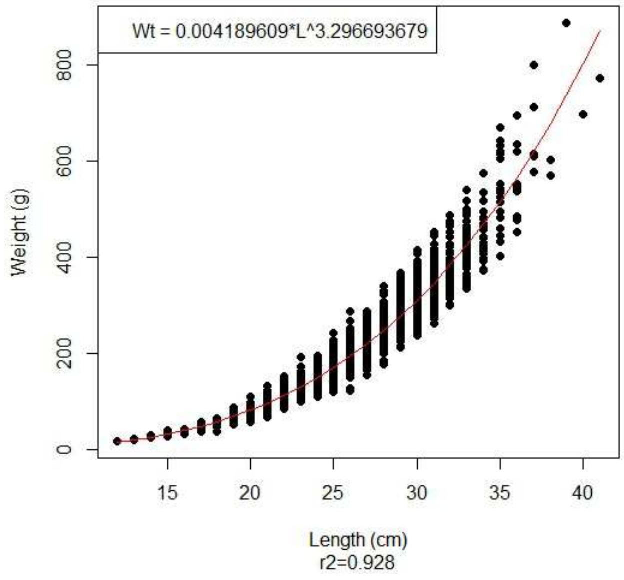
Appendix 1 - Length-Weight functions for red cod (A) and rock cod (B).

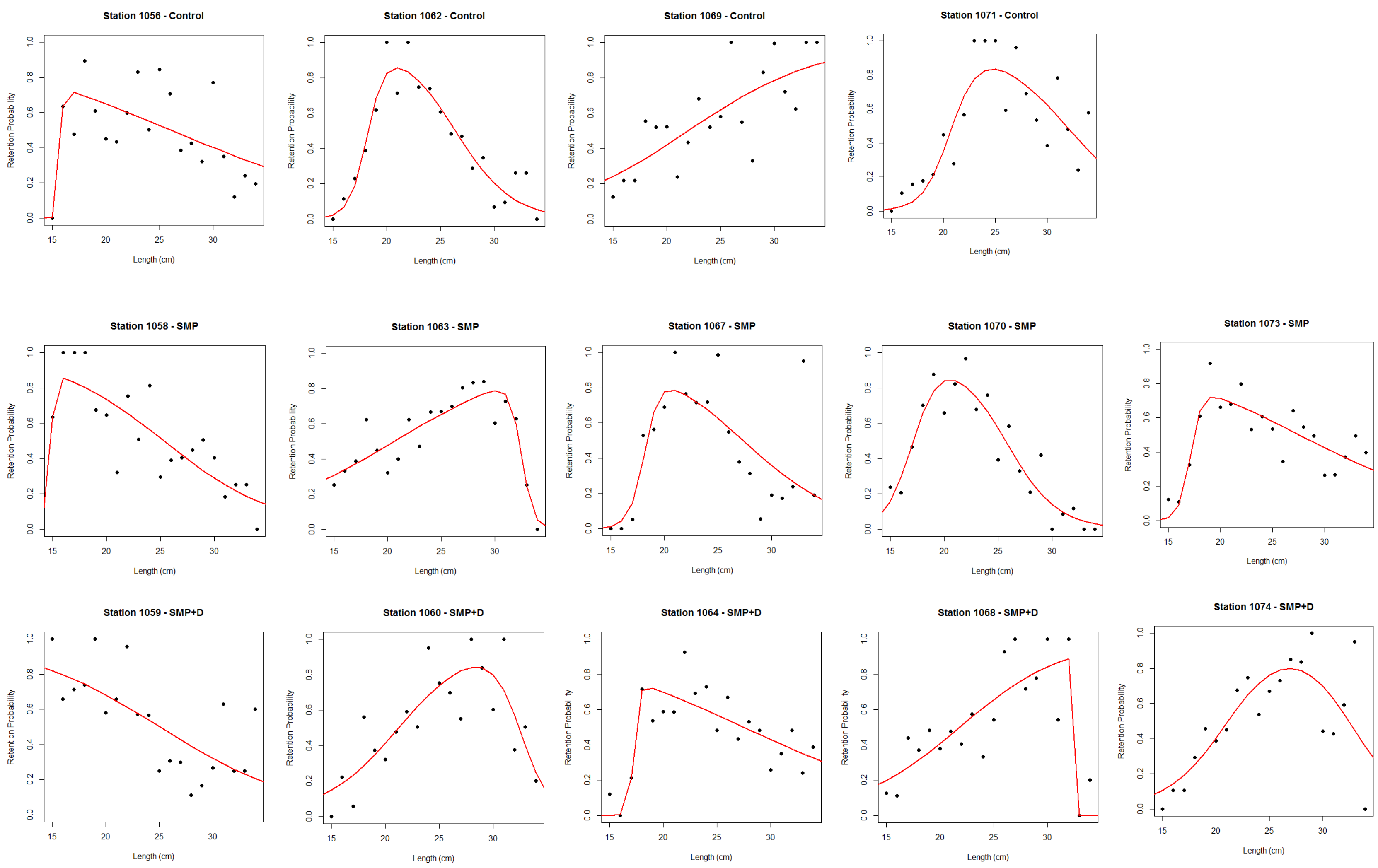
A. Red cod (*S. australis*) (data collected throughout 2011)



B. Rock cod (*P. ramsayi*) (data collected throughout 2011)



Appendix 2 – Fitted retention probability curves for rock cod in hauls from series-1 (SMP and SMP+diverter in net extension).



Appendix 3 – Fitted retention probability curves for rock cod in hauls from series-2 (SMP in codend).