Cruise Report ZDLT1 – 04-2012

2nd Cod-end Mesh Size Experiment

Marie-Julie Roux, Vlad Laptikhovsky, Paul Brewin, Alexander Arkhipkin, Andreas Winter

Falkland Islands Government
Directorate of Nature Resources
Fisheries Department
Stanley, Falkland Islands

Participating Scientific Staff

Dr. Alexander Arkhipkin
Dr. Marie-Julie Roux
Dr. Vlad Laptikhovsky
Dr. Paul Brewin
Zhanna Shcherbich
Lars Jurgens
Emily Hancox

Acknowledgements
We thank Captain Jose Vincente Santos Reiriz and the crew of the *FV Castelo* for all of their help.

For citation purposes this publication should be referenced as follows:

Roux et al. (2012). Scientific Report, Fisheries Cruise ZDLT1-04-2012. Stanley, Fisheries Department, Directorate of Natural Resources, Falkland Islands Government.

Contents

1.0 Introduction

One conservation aim of the Falkland Island Fisheries Dept is to reduce by-catch and discard of small and juvenile fish during all major fisheries. The largest by-catch reported in recent years has been that of under-sized rock cod (*Patagonotothen ramsayi*), perhaps achieving 15,000 – 20,000 t per annum.

One means of reducing the under-sized rock cod by-catch is to increase the mesh size of the trawl codends. The first 'mesh trial' research cruise in November 2011 (FIG 2011) revealed significant reduction of small rock cod and other juvenile fish by-catch when using 120-mm diamond mesh in the codend, compared to 90-mm mesh that is currently being used in all trawl fisheries except *Loligo*. In this second 'mesh trial' research cruise, we targeted two fishing areas to conduct the mesh trials, carrying out trawls equipped with codends of four different mesh sizes in each area. We have tested the effect of various codend mesh sizes on catch of rock cod and *Illex* during the period of G-licensed fishery. In the short term, we aim to assess the effectiveness of larger codend mesh sizes for reducing bycatch/discards of small rock cod in the finfish fishery while sustaining fishery efficiency for other commercial species. In the long-term objective, we will use these results to evaluate differences in fishing patterns with increasing mesh sizes and the potential for long-term impacts on selected commercial species (i.e. changes in sex ratio and age and maturity structure of the catch).

1.1 Cruise objectives

1. To trial 4 codends with different diamond mesh size (90 mm, 110 mm, 120 mm, 140 mm) in order to identify the mesh size that results in the retention of commercially sized rock cod and *Illex.*

2. To examine the effect of codend mesh sizes on the selectivities of the other main commercial finfish species

3. To collect oceanographic measurements in the survey areas to gain information that might impact catch selectivity.

2.0 Methods

2.1 Research Vessel and Survey Area

The research cruise was carried out on the *RV Castelo* between16th April – 1st May 2012. Figure 2.1 depicts sampling Areas 1 and 2, and Table 2.1 gives location and activities carried out at trawl stations. Of the 42 trawl stations (18 in Area1 and 24 in Area2), the net was damaged during trawl operations at station 960 and the trawl was not considered for analyses. There were eight CTD stations, four in each area.

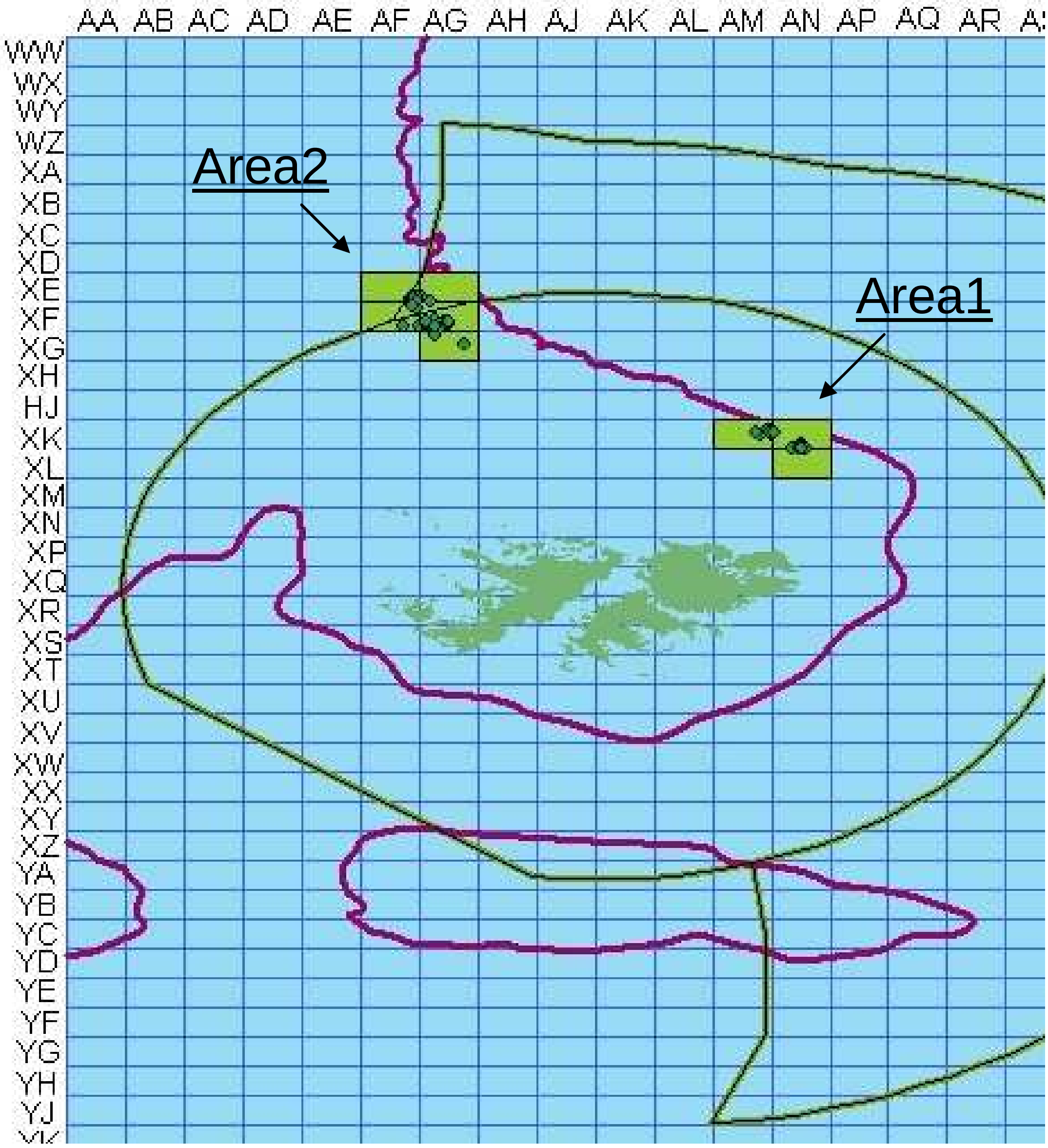


Figure 2.1. Location of sampling Areas 1 and 2.

Table 2.1. Trawl and Oceanographic stations conducted on ZDLT1-04-2012.
Activity B: bottom trawl; activity C: CTD.

Station	Date	Time (00hrs)	Lat (°S)	Lon (°W)	Modal Depth (m)	Codend Mesh (mm)	Durration (mins)	Activity
951	17/04/2012	0745	50.47	57.75	154	90	180	B
952	17/04/2012	1155	50.38	58.00	152	110	195	B
953	17/04/2012	1630	50.48	57.73	153	120	220	B
954	17/04/2012	2160	50.38	58.08	138	-	-	C
955	18/04/2012	0700	50.48	57.72	163	140	200	B
956	18/04/2012	1110	50.35	57.98	171	90	180	B
957	18/04/2012	1520	50.48	57.73	150	110	180	B
958	18/04/2012	1859	50.35	58.03	150	-	-	C
959	19/04/2012	0700	50.35	57.98	162	120	180	B
960	19/04/2012	1100	50.48	57.72	164	140	180	B
961	19/04/2012	1600	50.48	57.73	155	90	180	B
962	19/04/2012	2022	50.37	58.12	139	-	-	C
963	20/04/2012	0700	50.48	57.73	150	110	180	B
964	20/04/2012	1100	50.37	58.00	137	120	180	B
965	20/04/2012	1530	50.50	57.82	139	140	175	B
966	21/04/2012	0700	50.35	57.98	155	140	180	B
967	21/04/2012	1100	50.48	57.72	171	140	180	B
968	21/04/2012	1550	50.37	58.02	138	90	180	B
969	21/04/2012	1848	50.50	57.77	139	-	-	C
970	22/04/2012	0700	49.62	60.62	167	90	180	B
971	22/04/2012	1150	49.45	61.00	167	110	180	B
972	22/04/2012	1550	49.23	61.00	169	120	180	B
973	22/04/2012	1847	49.42	60.78	169	-	-	C
974	23/04/2012	0700	49.20	60.97	174	140	180	B
975	23/04/2012	1120	49.40	60.87	169	90	180	B
976	23/04/2012	1535	49.23	61.07	165	110	180	B
977	24/04/2012	7000	49.43	60.93	168	120	180	B
978	24/04/2012	1100	49.25	61.02	168	140	180	B
979	24/04/2012	1550	49.45	60.88	171	90	180	B
980	24/04/2012	1850	49.22	60.98	169	-	-	C
981	25/04/2012	700	49.43	60.80	167	110	180	B
982	25/04/2012	1115	49.22	61.02	167	120	180	B
983	25/04/2012	1520	49.42	60.93	166	140	180	B
984	26/04/2012	0700	49.20	61.05	166	90	180	B
985	26/04/2012	1100	49.45	61.13	165	110	180	B
986	26/04/2012	1550	49.25	61.02	167	120	180	B
987	26/04/2012	1845	49.43	60.82	167	-	-	C
988	27/04/2012	0730	49.50	60.83	168	140	180	B
989	27/04/2012	1130	49.30	61.02	171	90	180	B
990	27/04/2012	1525	49.48	60.82	170	110	180	B
991	28/04/2012	0730	49.25	61.02	168	120	125	B
992	28/04/2012	1115	49.53	60.85	166	140	180	B
993	28/04/2012	1535	49.28	61.05	166	90	180	B
994	28/04/2012	1911	49.47	60.87	169	-	-	C
995	29/04/2012	0730	49.43	60.75	170	110	180	B
996	29/04/2012	1130	49.25	60.90	172	120	180	B
997	29/04/2012	1535	49.42	60.75	169	140	180	B
998	30/04/2012	0730	50.37	57.97	141	90	180	B
999	30/04/2012	1145	50.50	57.70	146	120	180	B
1000	30/04/2012	1625	50.50	57.73	150	140	120	B

2.2 Trawling gear

At all stations a bottom trawl was used equipped with two 1800 kg Oval-Foil doors (OF-14). Four codends were used and were interchanged each trawl during the experimental period. The trawl did not employ any ground gear (e.g. bobbins/rockhoppers); instead the footrope consisted of a cable protected by cord. To increase the contact between the footrope and the seabed, an 8 m length of chain weighing 150 kg was attached to the footrope. See Brickle and Winter (2011) for net configuration details.

2.3 Biological sampling

Catches were weighed using an electronic marine adjusted balance (POLS, min 10 g, and max 80 kg). All finfish and skate were weighed by species. Jellyfish catch weights were estimated when in excess of 1.5 tonne. Random samples (100-200 individuals) of commercially important species were measured (L_T, L_{PA}, L_{DW}) to the nearest cm below and sex and stage of maturity were recorded for all specimens subsampled.

2.4 Survey design

A first investigation of the effects of codend mesh sizes on fishery selectivity for a number of commercial species in Falkland waters (Brickle and Winter 2011) revealed inter-trawl variability, which may in part relate to spatial variability in species- and length-class availability to the fishery. In order to minimize such spatial variation, the present survey was conducted within two separate areas (Figure 2.1).

As in the previous survey, four codends of differing diamond mesh sizes were used: the standard 90 mm mesh (currently used in the fishery) and the larger 110 mm, 120 mm and 140 mm mesh sizes.

Sampling effort was similar between areas and involved three, 3-hours trawls per day. Codend mesh sizes were alternated each trawl following the sequence: 90 mm, 110 mm, 120 mm and 140 mm - corresponding to four possible daily sequences of three trawls. Six replicates of each codend mesh sizes were realized in Area2 over 8 consecutive days. In Area1, 5 replicates of the smaller (90 mm) and larger (140 mm) mesh sizes, 3 replicates of the 110 mm and 4 replicates of the 120 mm were realized over a period of 6, non-consecutive days.

Biological sampling was paralleled by an oceanographic survey which consisted of eight vertical water profiling stations (four in each area).

2.5 Mesh size trials and species catch composition

We define 'catch diversity' as the species composition in each catch, and their relative abundances standardised to kg per trawling hour (CPUE). Principal component analysis (PCA) was used to visualise the effects of Area and mesh size on catch diversity, as either the presence of species caught among stations, or their CPUE. PCA reduces multi-dimensional data (species, stations, Areas, mesh sizes) into 2-dimensional space. It is able to demonstrate detectable groupings of treatment effects, and the important species driving the observed pattern. These analyses were carried out on the whole catch and on the skate catch separately. Data were presence/absence transformed for analysis of species composition. For analysis of species relative abundance, data were 4^{th}-root transformed to reduce the influence of extreme low or high catches of some species. To reduce data noise, only commercial species were used to assess difference in total catch composition between Areas and among mesh sizes. To further reduce data noise in the total catch composition analysis, skates were pooled. Skate species catch composition is analysed separately.

2.6 Mesh size trials and fishery efficiency

The effects of codend mesh sizes on fishery efficiency were evaluated using three indicators: (i) catch weight; (ii) catch composition by length/weight (and related contributions of commercial-size fish to total catch); and (iii) retention probabilities at length.

Catch weight

Trawl catch was determined by summing individual species catch in each trawl. Species-specific catch weights were measured and standardized in kg per trawling hour (CPUE). Generalized linear mixed models (GLMM) were used to evaluate mesh size effects on catch data whilst accounting for random variation in sampling design. GLMM are an extension of generalized linear models (GLM) used to handle correlated and overdispersed data by including random effects on the linear predictor (fixed effect) (Bolker et al. 2008, Crawley 2007). This type of model was chosen to handle repeated measures and unbalanced design resulting from replicate trials (trawls) of different mesh sizes conducted over successive and non-successive days, at different time of day and variable trawling depth, in two areas.

GLMM were fitted to log-transformed catch data assuming Gaussian error structure. Individual trawls were assumed to constitute independent measures - a reasonable assumption considering the dynamic character of fish/squid aggregations in both time and space. Logarithmic transformation (base 10) was used in order to meet homogeneity of variance assumptions. Day, time of day and trawling depth were included as predictors potentially affecting mean CPUE and as random factors likely explaining variation within treatments (individual mesh sizes). 'Day' corresponded to 6 and 8 different calendar dates in Area1 and Area2, respectively. 'Time of day' was used as a 3-level factor comprising morning trawl (7-10 am), midday trawl (11am-2 pm) and afternoon trawl (3-6 pm). Modal trawling depth varied between 137 m 171 m in Area1 and 165-174 m in Area2 and was used as a continuous variable in GLMM.

Two types of GLMM were fitted for each species: a first one to quantify area and day within area effects on catch weight by mesh size (i.e. variance components analysis) and a second one to assess the significance of mesh size effects while maximizing fit. For variance components analysis, GLMM were fitted using restricted maximum likelihood (REML), to quantify explained versus unexplained variance independently from fixed (mesh size) effects on the mean. To evaluate the significance of mesh size effects, GLMM were fitted using maximum likelihood (ML), as this method allows comparing models with varying fixed effects. In this context a top-down approach was used, starting with beyond-optimal models (i.e. inclusion of all potential covariates and random effects) and progressive removals of non-significant covariates to reveal the significance of mesh size influences and interaction terms (ie backward selection). In this context, significant mesh size effects corresponded to a significant departure from the overall mean whose variance was partly explained by sampling design. Model selection was done by minimizing the Bayesian (BIC) information criterion (Bolker 2008). In cases where the inclusion of random factors did not improve the fit or contribute to reduce within-treatment variance, the mixed effect model (GLMM) structure was deemed inappropriate and the data were fitted using standard Generalized Linear Models (GLM).

Catch composition by length/weight

Random samples of 100 to 200 individuals were measured for length in each trawl, whenever possible. Catch composition by length was assessed from length frequency distributions in 1-cm length intervals in fish, 1-cm disk width intervals in skates and 0.5-cm mantle length intervals in squid. For each species and area, length frequency distributions from individual trawls were fitted by mesh size using generalized additive models (GAM) assuming Gaussian error structure.

Commercial length thresholds were defined for finfish and skates (see individual species results for specifications). The thresholds were used to estimate and compare proportions of commercial-size fish in the catch among mesh sizes. Similar to CPUE, catch proportion data were fitted using GLMM assuming binomial error structure and using Laplace approximation for parameter estimation. Mesh size effects on catch proportions were evaluated by area and relative to day, time of day and trawling depth influences, with model selection based on lowest BIC.

Fitted numbers of individuals per length-class in each mesh size were converted to weights using species length-weight data (year 2011) available in the FIFD database. Converted weights were applied to individual trawl data, standardized for species catch (in kg), and used to approximate trawl-specific discard versus commercial (process) weights. Differences in average estimated discards and process weights among mesh sizes were tested using GLM assuming positive (Gamma) errors. Such error structure was better suited to weight data, as indicated by improved fit as assessed from AIC (Akaike information criterion).

Retention probability

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

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

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), permitting to fit decreasing retention probability in larger length classes as well as asymptotic retention (in cases where s1 tends towards infinity and p1 reaches beyond realistic biological values).

Retention probabilities were estimated from GAM-fitted length frequency distributions by mesh size (previous section), maximized over area. As such, the maximum number of individuals in length class ‘L’ in area ‘x’ was assumed to be proportional to the abundance of size ‘L’ specimens in this area. Maximization accounts for the fact that smaller and larger mesh sizes are more retentive of smaller and larger specimens, respectively (Brickle and Winter 2011). Within this framework, estimated retention probabilities are relative probabilities permitting inference on treatment (mesh size) effects as opposed to inference on population size-structuring.

The double-logistic function was fitted to observed retention probabilities using general-purpose Nelder-Mead optimization. Curve fitting was restricted to a representative size range for each species/area, corresponding to a minimum acceptable sample size per length interval (see individual species results for specifications). Fitting was done by minimizing 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 raw data.

2.7 Statistical Analyses

All statistical analyses were implemented in ‘R’ software (R Core Development Team 2012). Specific packages used were ‘vegan’ (PCA), ‘lme4’ (GLMM), and ‘gam’ (GAM). The critical alpha level of statistical significance throughout was 0.05.

2.8 Oceanography

The survey assessed oceanographic conditions where the mesh selectivity trials were carried out. 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 dissolved oxygen (ml l-1). 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 to the bottom. The speed of deployment was c. 1 m/s and was monitored by wire counter. For each station, vertical profiles of temperature, salinity and density were constructed using the Seasoft software. Profiles for each transect and iso-surfaces were constructed using the VG gridding method including in the Ocean Data View package v. 3.4.3-2009 (Schlitzer 2009).

3.0 Results

3.1 Total catch composition

Total catch and sample/discard weights by species are summarized by area in Tables 3.1 & 3.2. Total catch was 37,321 kg in Area1 and 85,887 kg in Area2. Kingclip (*G. blacodes*) was the most abundant species (by weight) in Area1, accounting for 46% of the catch (Figure 3.1a). Common hake (*M. hubbsi*) was the most abundant species in Area2, representing 37% of total catch (Figure 3.1b). The occurrence of MED (most likely the jellyfish *Cyanea sp*. and *Chrysaora sp*.) was important in both areas, representing between 14%-15% of total catch by weight (Figure 3.1). These numbers should be regarded with caution however, owing to uncertainty in proportions of MED effectively weighted by trawl (versus MED discarded prior to weighting) or roughly estimated weights (for trawls in which MED abundance was in excess of 1.5 tonnes).

Together, common hake, kingclip, *Illex* squid and MED represented between 73% to 82% of total catch weight in the sampling areas. The abundance of skates was relatively high, representing 9% and 14% of total catch weight in Area1 and Area2, respectively. Twelve species of skate were caught with *Bathyraja brachyurops* (RBR) being the most abundant (Figure 3.2). *B. brachyurops* accounted for >40% of the skate catch in both areas and between 4% and 6% of total catch weight in Area1 and Area2, respectively. White spotted skate (*Bathyraja albomaculata* - RAL) was also relatively important in Area2 (Figure 3.2b). Because of its abundance and commercial value, *B. brachyurops* was used as an indicator species for the assessment of mesh size effects on fishery efficiency for skate.

Rock cod (*P. ramsayi*) abundance was generally low, representing 1% of total catch weight in Area 1 (421 kg) and 8% of total catch weight in Area2 (6.5 t).

3.1.1. Mesh size and species catch composition.

Catch diversity is shown in Figure 3.3. This “reduced-space ordination” technique shows how stations are “clustered” with respect to either Area (1 and 2) or Mesh size (90, 110, 120, 140 mm). On a presence / absence basis, stations within Areas 1 and 2 overlap somewhat in their species compositions, as indicated by overlap of their site scores (Fig 3.3a). The observed pattern represents 37% of the total variation in the data. Areas 1 and 2 differed in the species occurrence in catch, where catch in Area 1 was characterised by the presence of *Sebastes oculatus* (RED) and *Merluccius australis* (PAT), and Area 2 catch was characterised by the presence of *Stromateus brasiliensis* (BUT), *Moroteuthis ingens* (ING) and *Micromesistius australis australis* (BLU).

Table 3.1 Catch composition, sample, and discard weights for Area 1.

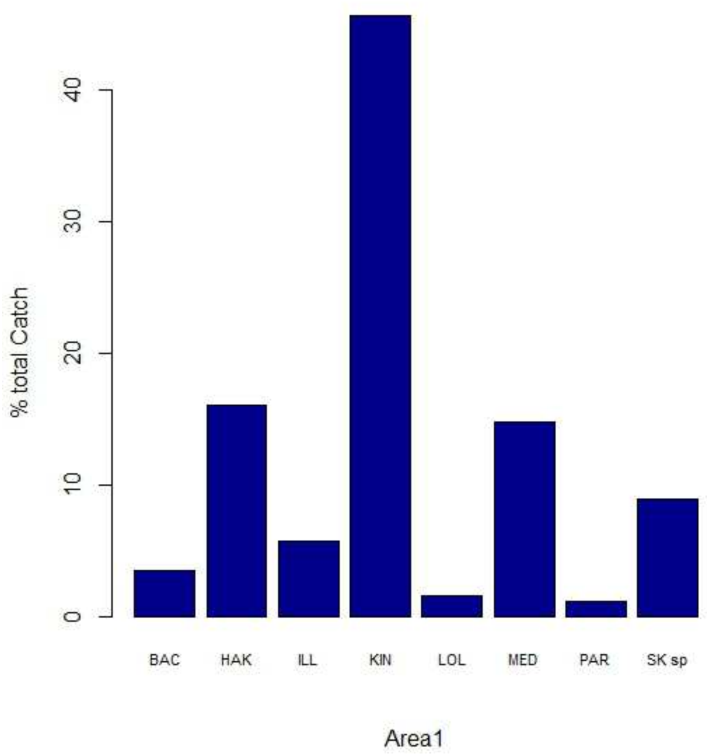
Area1					
Species code	Latin name	Catch (kg)	Sample (kg)	Discard (kg)	Catch Proportion (%)
KIN	*Genypterus blacodes*	17061.02	2087.97	0	45.7139
HAK	*Merluccius hubbsi*	5989.28	2960.83	0	16.0479
MED	*Medusae sp.*	5511.13	0	5511.13	14.7667
ILL	*Illex argentinus*	2139.53	1274.25	1123.98	5.7327
RBR	*Bathyraja brachyurops*	1459.77	1459.77	287.42	3.9114
BAC	*Salilota australis*	1295.83	648.1	20.09	3.4721
LOL	*Doryteuthis gahi*	598.38	98.08	185.69	1.6033
RPX	*Psammobatis sp.*	518.11	144.74	518.11	1.3882
RFL	*Raja flavirostris*	453.4	453.4	5.03	1.2149
PAR	*Patagonotothen ramsayi*	420.95	336.09	281.43	1.1279
RAL	*Bathyraja albomaculata*	376.36	376.36	139.31	1.0084
RMC	*Bathyraja macloviana*	343.86	343.86	279.69	0.9214
WHI	*Macruronus magellanicus*	290.95	185.56	251.32	0.7796
CGO	*Cottoperca gobio*	175.31	0	175.31	0.4697
TOO	*Dissostichus eleginoides*	150.91	146.11	0	0.4044
RSC	*Bathyraja scaphiops*	90.1	90.1	27.66	0.2414
DGS	*Squalus acanthias*	86.88	0	86.88	0.2328
PAT	*Merluccius australis*	71.57	71.57	0	0.1918
SHT	*Mixed invertebrates*	47.44	0	47.44	0.1271
DGH	*Schroederichthys bivius*	39.3	0	39.3	0.1053
RED	*Sebastes oculatus*	35.36	3.6	32.91	0.0947
RBZ	*Bathyraja cousseauae*	27.34	27.34	20.44	0.0733
RTR	*Raja trachyderma*	25.64	25.64	0	0.0687
MLA	*Muusoctopus longibrachus akambei*	22.48	22.48	0	0.0602
BUT	*Stromateus brasiliensis*	16.81	0	16.81	0.0450
RDO	*Raja doellojuradoi*	16.1	16.1	16.1	0.0431
RMU	*Bathyraja multispinis*	11.59	11.59	11.59	0.0311
ING	*Onykia ingens*	10.95	4.89	6.06	0.0293
MUE	*Muusoctopus eureka*	8.28	8.28	0	0.0222
RGR	*Bathyraja griseocauda*	6.86	6.86	3.78	0.0184
NEM	*Neophrynichthys marmoratus*	4.16	0	4.16	0.0111
BLU	*Micromesistius australis*	2.8	0	2.8	0.0075
GRC	*Macrourus carinatus*	2.8	0	2.8	0.0075
GAY	*Gastropoda*	2.61	0	2.61	0.0070
ODM	*Odontocymbiola magellanica*	2.07	0	2.07	0.0055
ALC	*Alcyoniina*	1.79	1.79	0	0.0048
SPN	*Porifera*	1.15	0.66	0.49	0.0031
EEL	*Iluocetes fimbriatus*	1.14	0.01	1.13	0.0031
XXX	*Unidentified molluscs*	0.86	0	0.86	0.0023
ZYP	*Zygochlamys patagonica*	0.2	0	0.2	0.0005
ICA	*Icichthys australis*	0.16	0.16	0	0.0004
BRP	*Brachiopod spp.*	0.06	0.06	0	0.0002
	Total Catch Area1	***37321***	***10806***	***9105***	***100***

Table 3.2 Catch composition, sample, and discard weights for Area 2.

Area2

Species	Latin name	Catch (kg)	Sample (kg)	Discard (kg)	Catch Proportion (%)
HAK	*Merluccius hubbsi*	32111.4	1853.26	0	37.3879
MED	*Medusae sp.*	11939.71	0	11939.71	13.9016
ILL	*Illex argentinus*	9593.62	3118.77	528.75	11.1700
KIN	*Genypterus blacodes*	9400.01	3899.4	20	10.9446
PAR	*Patagonotothen ramsayi*	6455.72	1448.79	1545.22	7.5165
RBR	*Bathyraja brachyurops*	5090.07	5090.07	503.93	5.9265
RAL	*Bathyraja albomaculata*	3682.04	3682.04	107.2	4.2871
LOL	*Doryteuthis gahi*	1564.275	481.91	499.36	1.8213
RGR	*Bathyraja griseocauda*	1082.93	1082.93	0	1.2609
BUT	*Stromateus brasiliensis*	803.85	0	803.85	0.9359
RFL	*Raja flavirostris*	688.53	688.53	66.78	0.8017
RMC	*Bathyraja macloviana*	669.72	669.72	669.72	0.7798
DGS	*Squalus acanthias*	480.84	0	480.84	0.5599
WHI	*Macruronus magellanicus*	443.32	401.35	443.32	0.5162
BAC	*Salilota australis*	303.79	240.95	67.19	0.3537
RMU	*Bathyraja multispinis*	280.06	280.06	0	0.3261
SHT	*Mixed invertebrates*	214.839	0	214.839	0.2501
RPX	*Psammobatis sp.*	209.13	1.76	209.13	0.2435
RDO	*Raja doellojuradoi*	179.65	171.47	179.65	0.2092
ING	*Onykia ingens*	176.15	69.97	106.87	0.2051
CGO	*Cottoperca gobio*	148.78	0	148.78	0.1732
RSC	*Bathyraja scaphiops*	85.86	85.86	5.19	0.1000
TOO	*Dissostichus eleginoides*	74.59	70.21	0.69	0.0868
RBZ	*Bathyraja cousseauae*	56.49	56.49	3.11	0.0658
SPN	*Porifera*	42.89	0.72	42.07	0.0499
RTR	*Raja trachyderma*	32	32	0	0.0373
POR	*Lamna nasus*	23	23	0	0.0268
BLU	*Micromesistius australis*	17.01	0	17.01	0.0198
AUL	*Austrolycus laticinctus*	8.19	5.76	2.43	0.0095
DGH	*Schroederichthys bivius*	7.69	0	7.69	0.0090
NEM	*Neophrynichthys marmoratus*	5.32	0	5.32	0.0062
RED	*Sebastes oculatus*	4.42	0	4.42	0.0051
MUE	*Muusoctopus eureka*	4.06	4.06	0	0.0047
PAT	*Merluccius australis*	3.97	0	0	0.0046
COP	*Congiopodus peruvianus*	1.28	0.27	0	0.0015
RDA	*Dipturus argentinensis*	0.9	0.9	0	0.0010
EEL	*Iluocetes fimbriatus*	0.5	0	0.5	0.0006
MLA	*Muusoctopus longibrachus akambei*	0.44	0.44	0	0.0005
	Total Catch Area2	***85887***	***23461***	***18624***	***100***

A



B

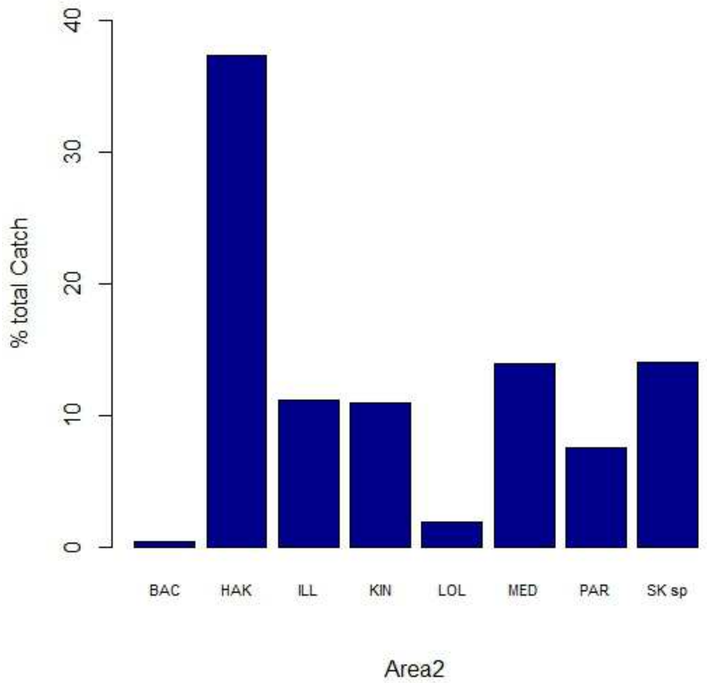
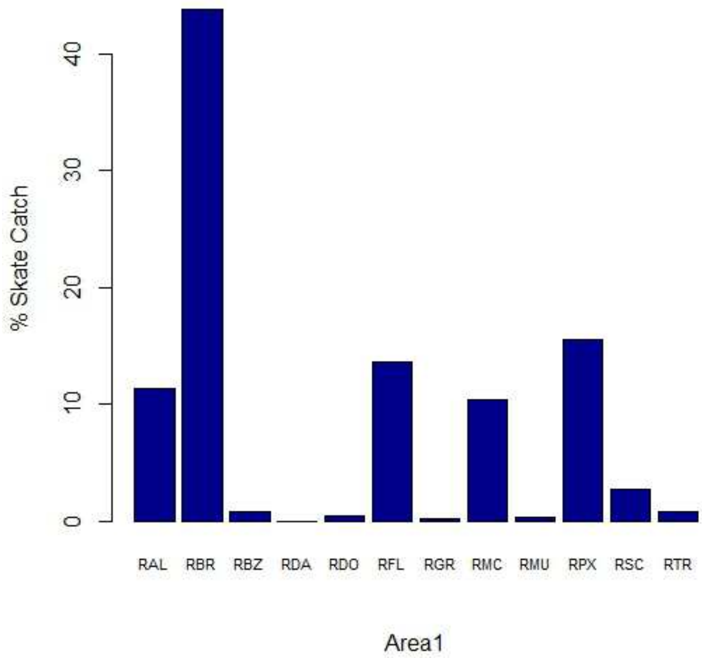


Figure 3.1 Percent contributions to total catch weight for commercial species (BAC (*S. australis),* HAK (*M. hubbsi*), ILL (*I. argentinus*), KIN (*G. blacodes*), LOL (*D. gahi*) and PAR (*P. ramsayi*)) as well as medusae species (MED) and skates species (SK sp.), together representing 97% of total catch in (A) Area1 and (B) Area2.

A



B

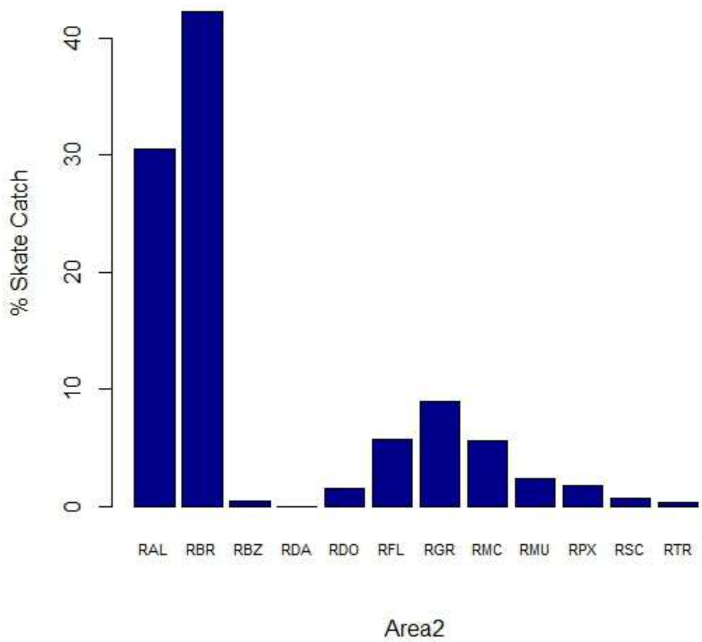


Figure 3.2 Skates species composition as percent contribution (by weight) to total skate catch in (A) Area1 and (B) Area2.

In contrast, Fig 3.3b shows that on a species' relative abundance basis (CPUE), Areas 1 and 2 are better differentiated, where the 2-d plot represents 64% of the overall pattern, and site scores show more discrete clusters compared to species occurrence data. These results show that catch diversity varies between Areas more in terms of relative species abundance than composition. Area 1 is characterised by comparatively larger catches of *Sebastes oculatus* (RED), *Merluccius australis* (PAT), *Dissostichus eleginoides* (TOO), and *Salilota australis* (BAC). Conversely, Area 2 is characterised by comparatively larger catches of and *Merluccius australis* (PAR), *Illex argentinus* (ILL), *Merluccius hubbsi* (HAK), *Stromateus brasiliensis* (BUT), and pooled skate species (RAY). Noteworthy is the particularly high catch of *Genypterus blacodes* (KIN) in Area 1 (station 998), and a higher than average *G. blacodes* catch in Area 2 (station 986), as noted by the large positive site scores on PC2 axis. Based on these data, any further analyses should be done on Areas 1 and 2 separately.

Within Areas 1 and 2, mesh size treatments had little effect on overall catch diversity (Figure 3.4). Station scores tend to overlap, i.e. there is little or no clustering of stations among mesh treatments. Observed pattern in the PCA analyses is driven primarily by extreme values, for example the high *Genypterus blacodes* (KIN) catch at Station 998 (extreme negative value PC1 axis, Figure 3.4a), or the very low overall catch at Station 965 (extreme positive value PC1 axis Figure 3.4a).

3.1.2. Mesh size and skate species catch composition.

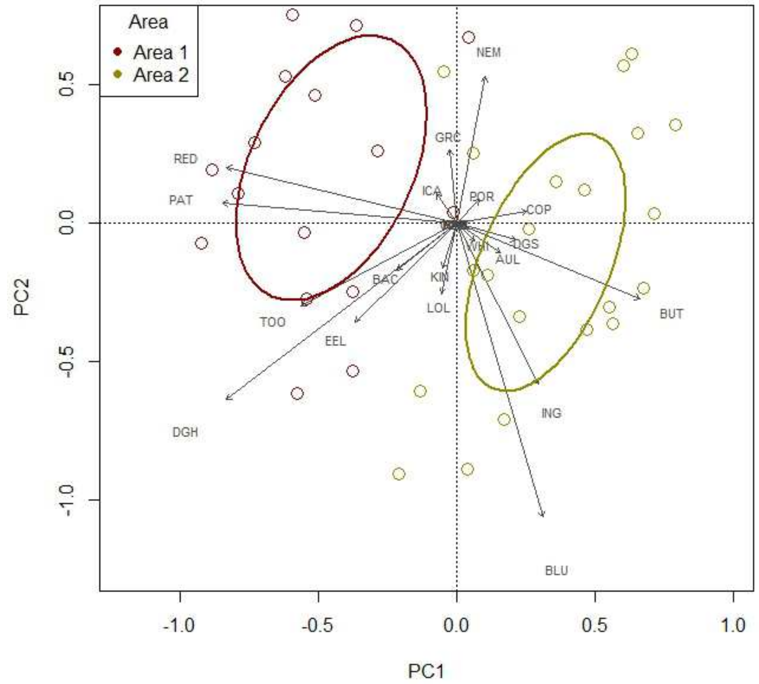
Catch diversity analysis for skates was carried out after removal of *Psammobatis spp.* (RPX) from the dataset. These constitute a species complex where species within the complex are likely to have different ecologies, meaning that any differences in RPX in the analyses would be confounded. Also removed from the analysis was *Dipturus argentinensis* (RDA) (1 individual) and *Raja trachyderma* (RTR) (2 individuals) as they are deep water species, and thus an exceptional occurrence at the depths we conducted the surveys.

Skate catch diversity varied between Areas 1 and 2 more in terms of species abundances (CPUE) than the presence or absence of species in the catch, similar to total catch composition. Within Areas 1 and 2, no differences in skate species caught among different mesh sizes were detected (Figure 3.5), either in terms of species caught or their relative abundances.

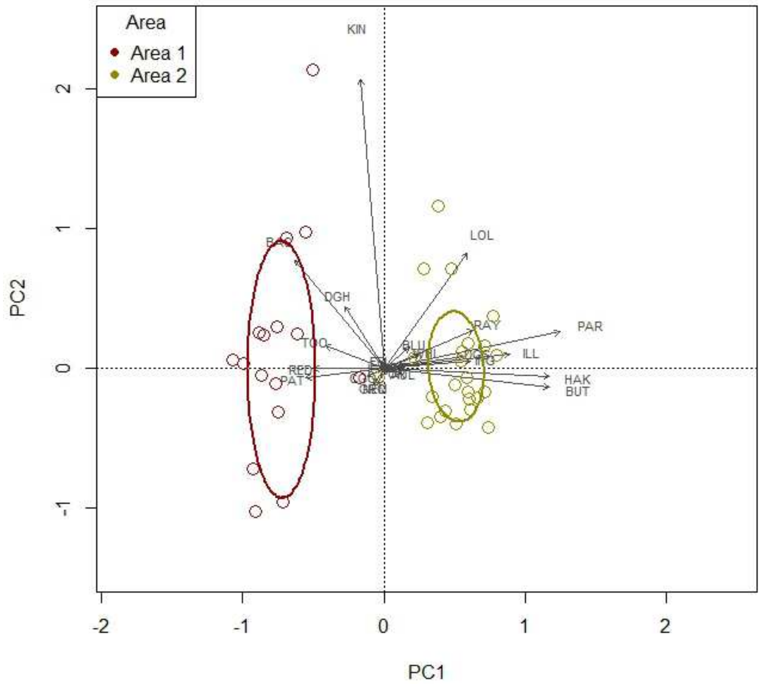
3.1.3 Catch composition summary

Diversity of total catch composition and diversity of skate catch varied with respect to species abundance, but not presence of absence of species. Mesh size had no effect on catch diversity in either location. Differences in catch diversity observed between locations are likely due to factors correlated to gradients in temperature along the Argentine Drift current, decreasing towards the south-east as it approaches the eastern branch of the Falkland Current (see section 3.3 Oceanography).

A

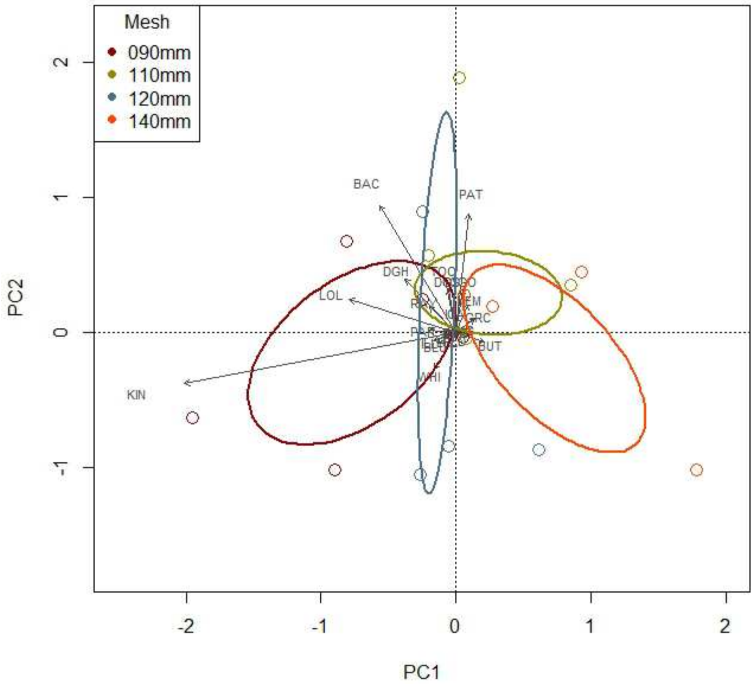


B



Figures 3.3 Principal component analyses of total species composition per catch, using presence/absence transformed data (A), and 4^{th} root transformed data (B). Clusters are indicated by the standard deviations (ellipsoids) of centroid (means) of station scores. Arrows (species scores) indicate the most influential species describing the pattern between Areas.

A



B

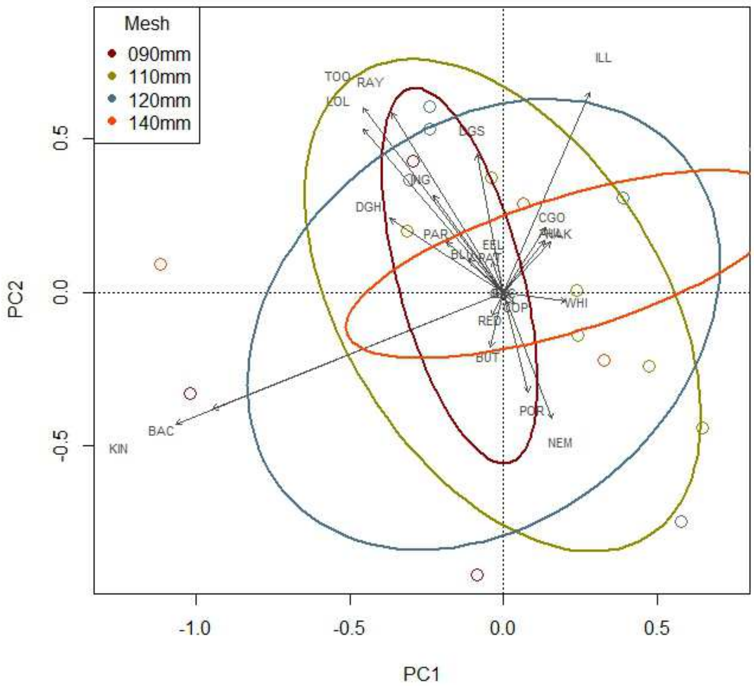
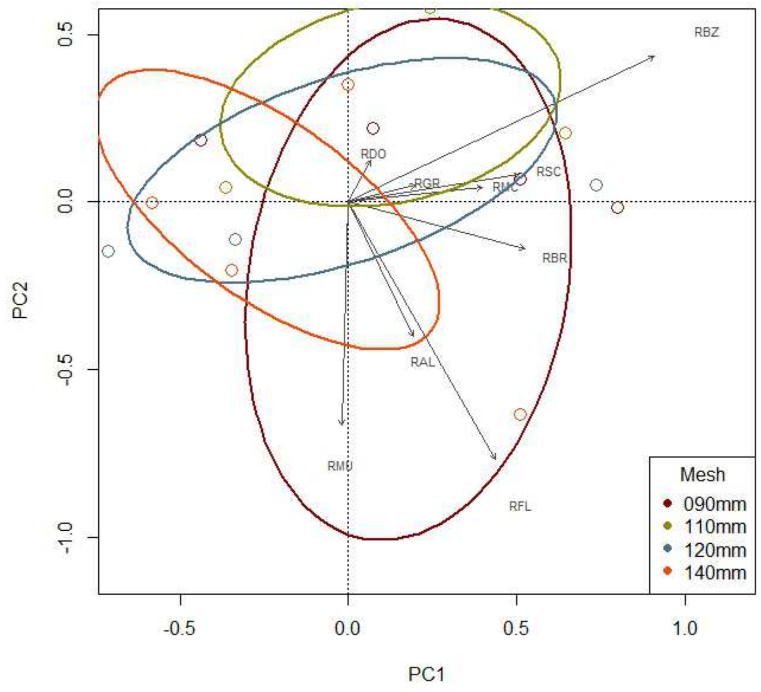


Figure 3.4 PCA of mesh size effects in Area 1 (A) and Area 2 (B) on total species abundance per catch. All data were 4th root transformed before analysis. Clusters are indicated by the standard deviations (ellipsoids) of centroid (means) of station scores. Arrows (species scores) indicate the most influential species describing the pattern between mesh size treatments.

A



B

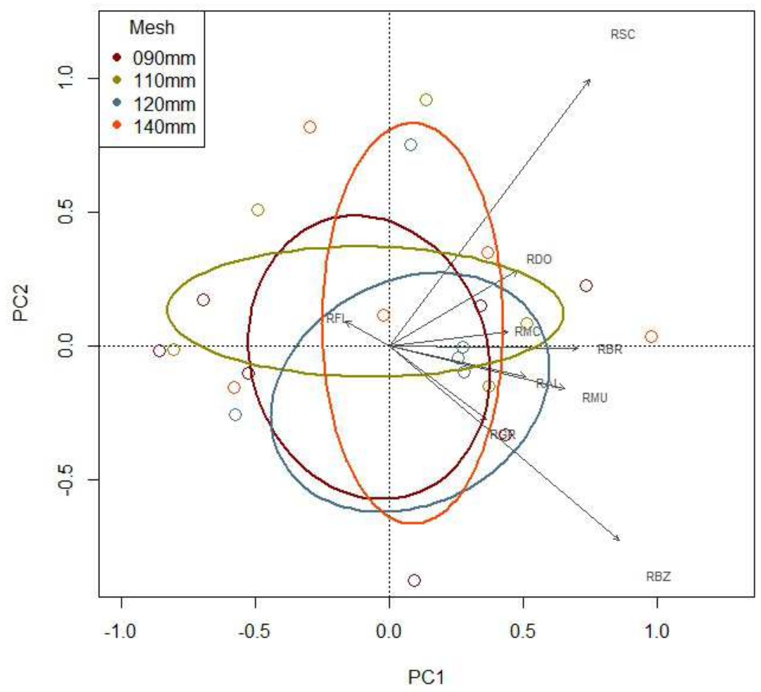


Figure 3.5 PCA of mesh size effects in Area 1 (A) and Area 2 (B) on skate species abundance per catch. All data were 4th root transformed before analysis. Clusters are indicated by the standard deviations (ellipsoids) of centroid (means) of station scores. Arrows (species scores) indicate the most influential species describing the pattern between mesh size treatments.

3.2. Fishery efficiency

3.2.1. Trawl Catch

Mesh size versus trawl catch

Trends in total and average catch weight by mesh size and area are shown in Figure 3.6a. Sampling day within area and mesh size explained 33% of the variation in catch weight among trawls during the survey (Table 3.3). Area accounted for most (64%) of the variance. These results underline the importance of spatial and daily variation affecting fishery efficiency in FICZ/FOCZ.

Table 3.3 Outputs from variance components analysis for species Catch per Unit Effort (CPUE (kg hr-1)) vs. mesh size, area within mesh size, and day within area and mesh size.

	% of Explained Variance			
	Mesh	Area:Mesh	Day:Area:Mesh	Residual
Total (Trawl Catch)	0.8	63.6	32.7	3.0
Finfish				
M. hubbsi	0.1	88.8	10.6	0.5
G. blacodes	17.2	16.5	0.0	66.2
P. ramsayi	0.0	92.2	7.7	0.1
Squid				
I. argentinus	4.3	71.3	7.9	16.5
D. gahi	20.6	0.0	0.0	79.4
Skates				
B. brachyurops	0.0	46.8	53.1	0.0

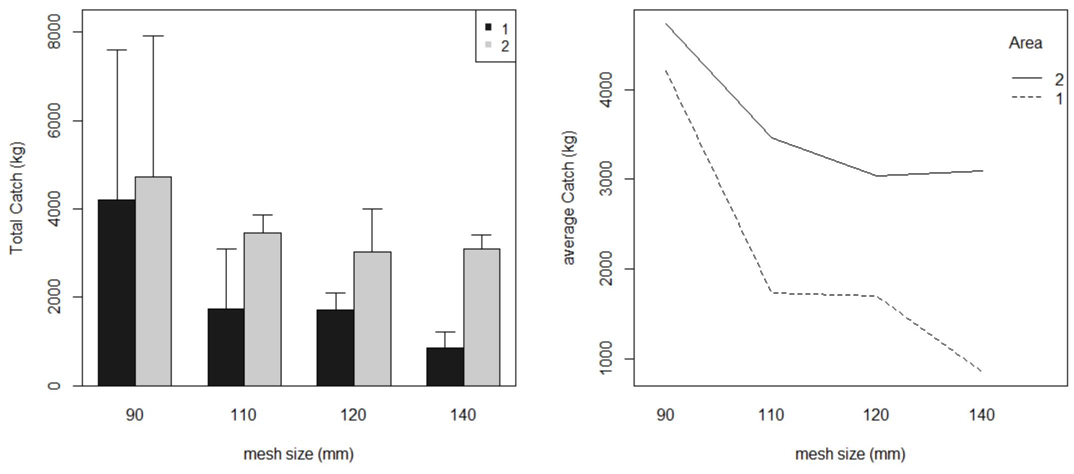
Mesh size effects were similar and significant in Area1 and Area2, with the larger mesh (140 mm) codend yielding lower mean catch weights (Figure 3.6a). Sampling day had a significant influence on trawl catch in Area2 (Table 3.4.). In both areas, catch data were best fitted by including trawl depth as a continuous, random effect explaining 96% (Area1) and 77% (Area2) of the variation in catch weight within mesh size treatments.

3.2.2. *Patagonotothen ramsayi* (Patagonian rock cod)

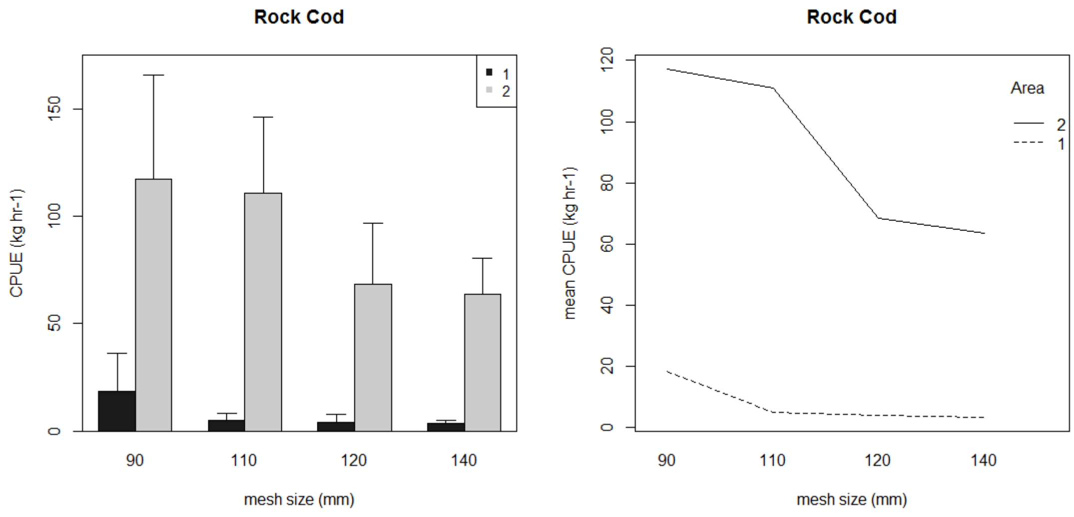
Mesh size and CPUE

Changes in mean rock cod CPUE with increasing mesh size are shown by area in Figure 3.6b. Area within mesh size explained almost all (92%) variation in rock cod CPUE while day within area accounted for most of the remaining variance (Table 3.3). The relative abundance of rock cod was very low in Area1 (average CPUE of 8.2 kg hr^{-1}). Consequently, mesh size effects on fishery efficiency were assessed using data from Area2 only.

A



B



C

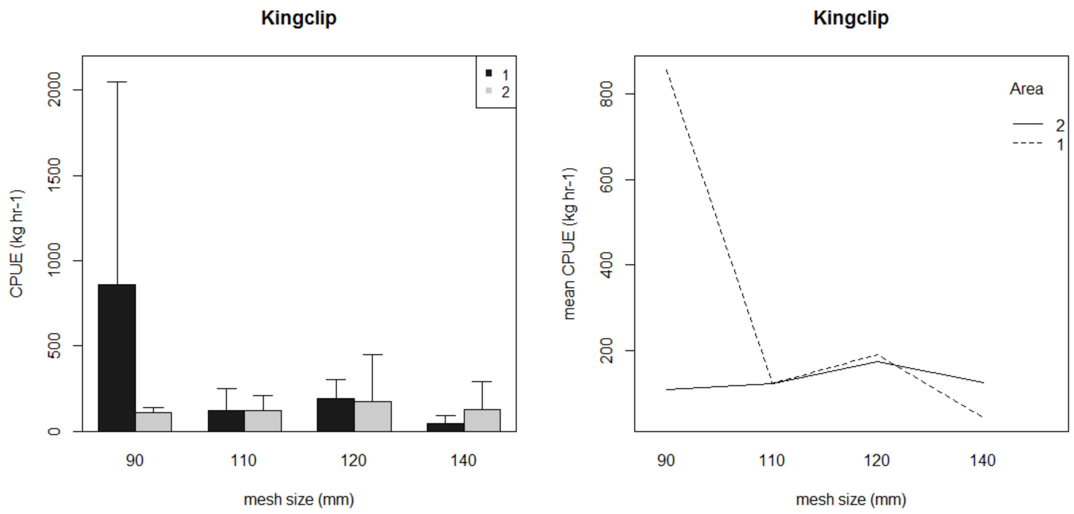
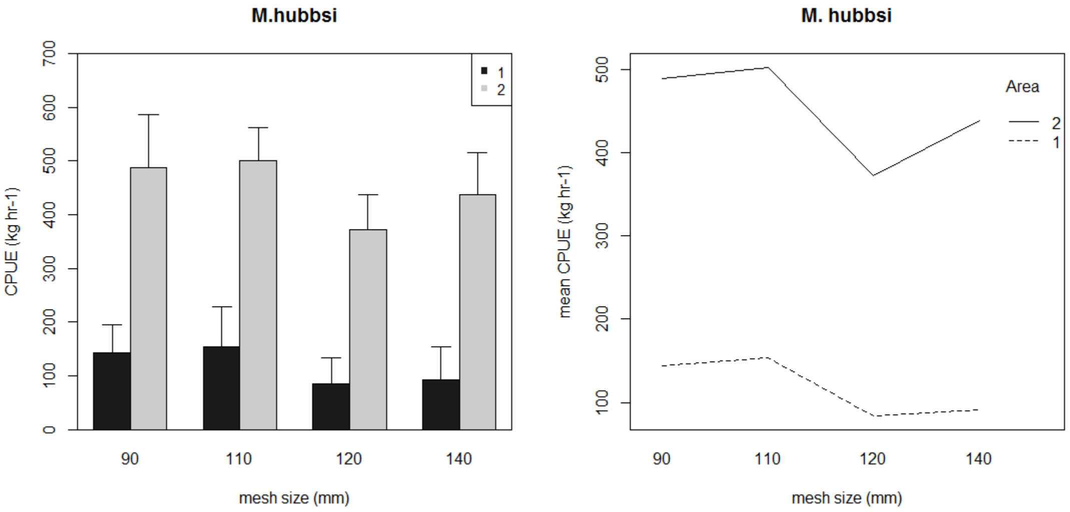
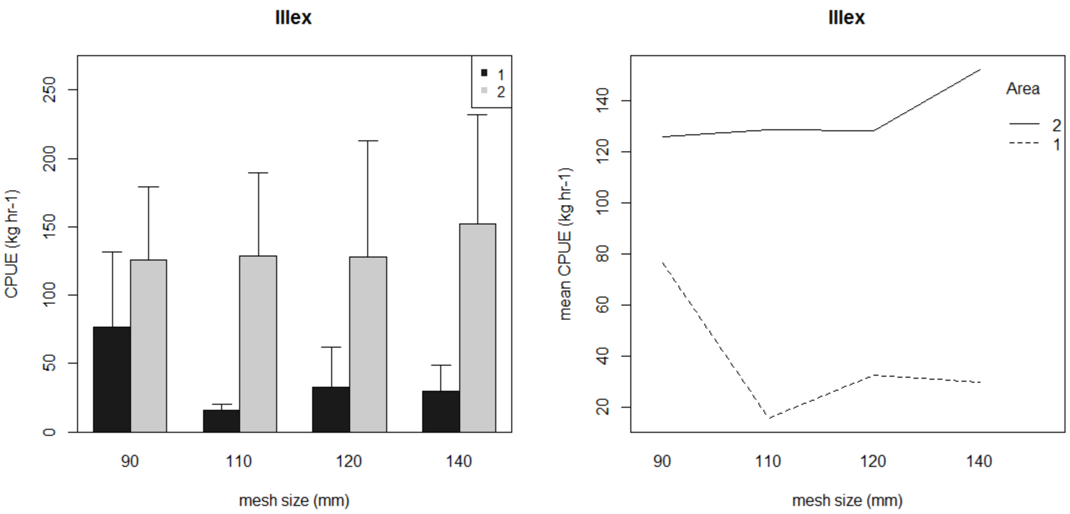


Figure 3.6 Interaction plots for trawl catch (A) and species CPUE (B-G) by mesh size and area (error bars on barplots correspond to ±1 standard deviation).

D



E



F

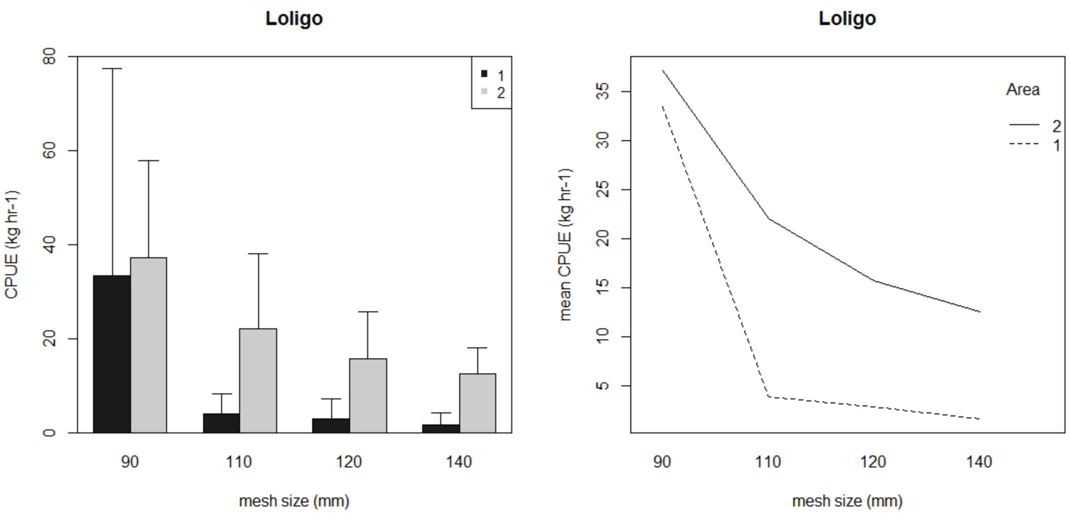
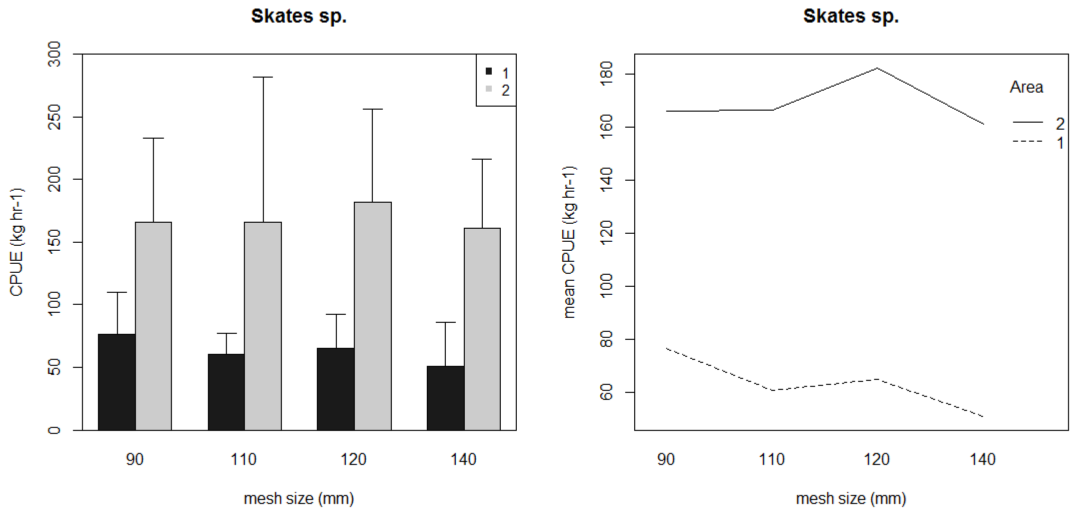


Figure 3.6 (continued).

G



H

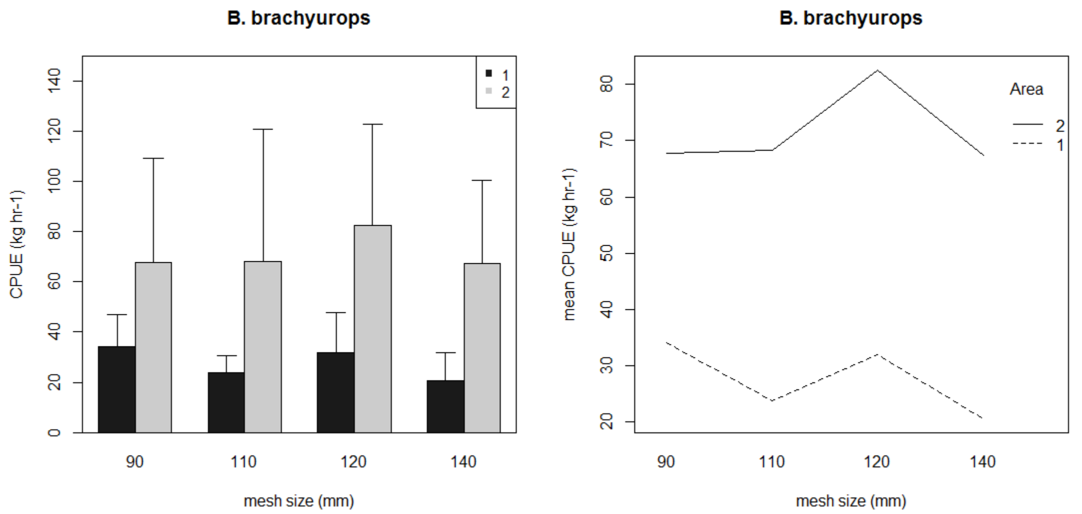


Figure 3.6 (continued).

Average rock cod CPUE in Area2 was equivalent to 90 kg per hour (range 30-173 kg hr^{-1} among trawls). Mesh size had a significant effect on catches of rock cod with lower mean CPUE in 120 mm and 140 mm mesh codends (Figure 3.6b). A GLMM using mesh size and time of day as fixed effects and sampling day as a random factor provided a better fit for rock cod CPUE (Table 3.4). Time of day had a significant influence with higher mean CPUE in midday and afternoon trawls relative to morning trawls. Day-to-day variability explained 37% of random variation within treatments.

Table 3.4 Summary of fixed and random effects (where applicable) on trawl catch and species-specific CPUE and proportions of commercial-size individuals relative to total catch (CSF). For fixed effects, 'x' indicates a significant effect at α=0.05. For random effects, 'x' indicates presence of random effect contributing to reduce residual variance within treatments.

			Fixe effects				Random effects				
Species	Area	Response variable	Mesh	Day	TofDay	Depth	Day	TofDay	Depth	procedure	error structure
all	1	Trawl Catch	x						x	GLMM	gaussian
	2	Trawl Catch	x	x					x	GLMM	gaussian
Rock Cod	2	CPUE	x		x		x			GLMM	gaussian
	2	CSF	x	x	x				x	GLMM	binomial
Kingclip	1	CPUE	x							GLM	gaussian
	2	CPUE								GLM	gaussian
	1	CSF	x						x	GLMM	binomial
	2	CSF	x	x	x				x	GLMM	binomial
Hake	1	CPUE	x						x	GLMM	gaussian
	2	CPUE	x							GLM	gaussian
	2	CSF	x						x	GLMM	binomial
Illex	1	CPUE	x		x				x	GLMM	gaussian
	2	CPUE							x	GLMM	gaussian
Loligo	1	CPUE	x				x			GLMM	gaussian
	2	CPUE							x	GLMM	gaussian
RBR	1	CPUE	x			x		x		GLMM	gaussian
	2	CPUE		x				x		GLMM	gaussian
	2	CSF	x	x	x				x	GLMM	binomial

Mesh size and catch composition by length/weight

Rock cod sample size was too small in Area 1 (mean of 48 fish per trawl) for length frequency analyses, which were only examined for rock cod from Area2, where sample sizes ranged 200-242 fish per trawl.

Rock cod length ranged 13-42 cm. Fitted length frequency distributions by mesh size are shown in Figure 3.7. Modal length increased with mesh size from 24 cm in the 90 mm mesh to 27 cm (110 mm), 29 cm (120 mm) and 30 cm (140 mm).

A 25 cm threshold was used to distinguish between commercial size (> 25 cm) and commonly discarded (≤ 25 cm) rock cod. Proportions of commercial size fish in the catch increased with mesh size, from a mean of 50% (in 90 mm) to 65% (110 mm), 70% (120 mm) and 75% (140 mm) (Figure 3.8). The 90 mm mesh codend yielded significantly lower numbers of commercial size rock cod in comparison with larger mesh sizes. Catch proportion data were fitted using mesh size, day and time of day as fixed effects and trawl depth as a random predictor explaining variation within treatments. Day and time of day were significant covariates, underlining the importance of day-to-day and within-day variations in length-class availability to the fishery.

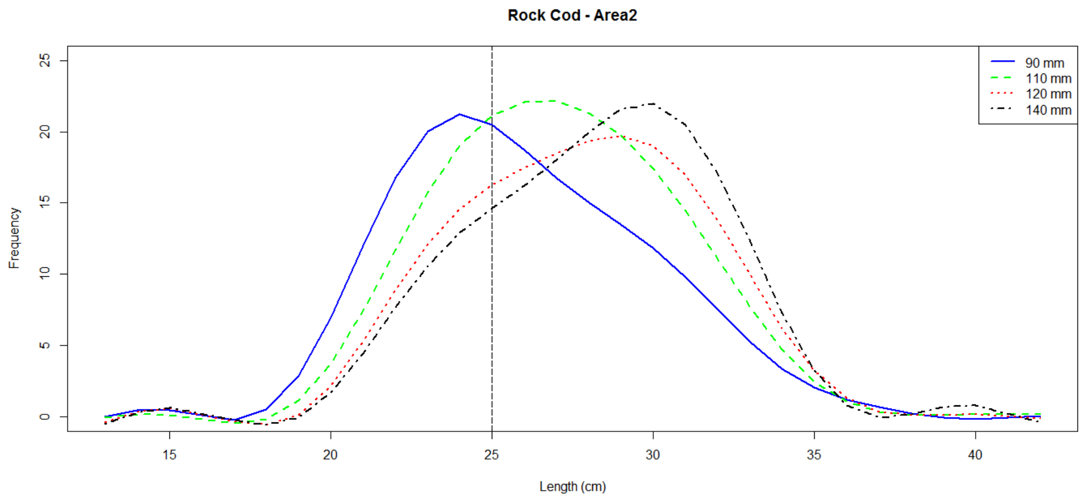


Figure 3.7 Fitted length frequency distributions by mesh size for rock cod in Area2. Dashed vertical line indicates 25 cm threshold for commercial-size (> 25 cm) versus commonly discarded (<25 cm) rock cod.

Fitted numbers of rock cod per 1-cm length classes were converted to weights using the power length-weight function shown in Figure 3.9. Estimated catch weights standardized for individual trawl catch demonstrate a significant decrease in discard weight with increasing mesh size (Figure 3.10a). The 90 mm mesh codend yielded significantly higher discard weights relative to larger mesh codends, as well as a greater variability. Estimated process weights were statistically similar among mesh sizes (Figure 10b).

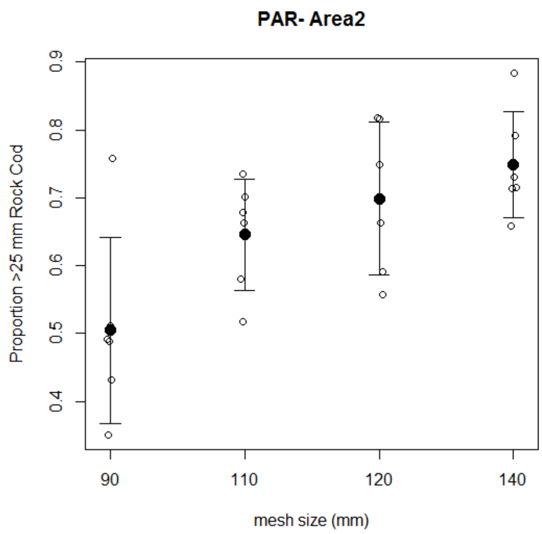


Figure 3.8 Fitted proportions of commercial-size (>25 cm) rock cod in the catch among codend mesh sizes. Dark circles and error bars are means ± sd. Empty circles are trawl-specific values.

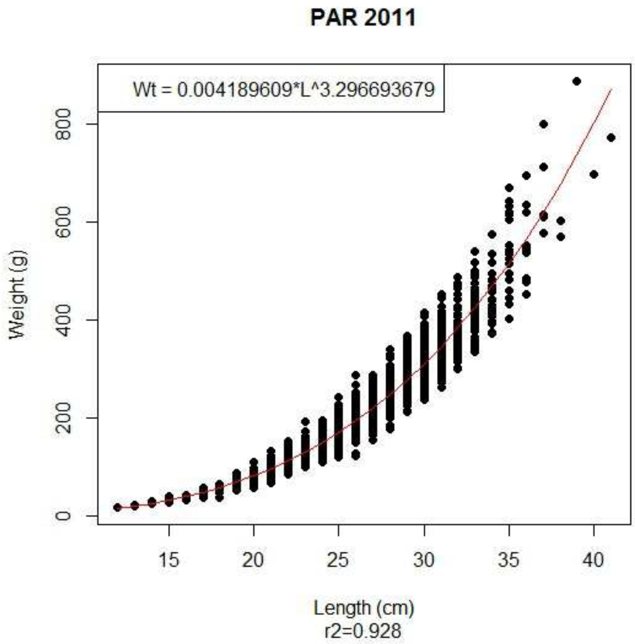


Figure 3.9 Power length-weight function estimated using random Length-Weight samples for rock cod collected in FICZ/FOCZ throughout 2011.

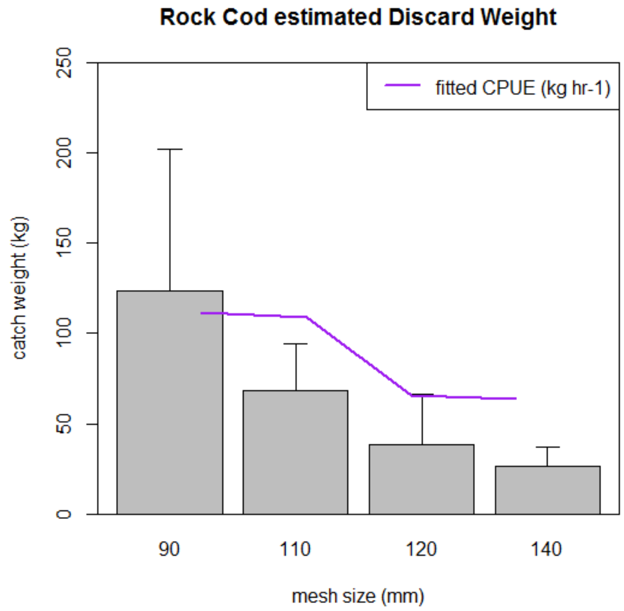
Mesh size versus probability of retention at length

Retention probability curves for rock cod were fitted within the 21-35 cm size range, corresponding to those length classes having sample sizes ≥10 specimens in all mesh sizes. Fitted curves demonstrate an increasing probability of retention of commercial-size (>25 cm) rock cod with increasing mesh size (Figure 3.11), with full retention of < 25 cm specimens in the 90 mm mesh codend and full retention of >28 cm specimens in the 140 mm mesh. First length of 50% retention (p2) increased from 18 cm (in 90 mm mesh) to 21 cm (110 mm and 120 mm) and 23 cm (140 mm).

Rock cod summary

Larger codend mesh sizes (120 mm and 140 mm) reduced rock cod CPUE by nearly half relative to the 90 mm mesh currently used in the finfish fishery. Estimated catch composition by weight however suggested that this decrease in catch corresponded to a statistically significant decrease in discard weight, without significant changes in estimated process weight. This was corroborated by the observation of increasing proportions of commercial-size rock cod in the catch, as well as increasing probabilities of retention of larger rock cod with increasing codend mesh sizes. Overall, the results indicate that fishery efficiency for rock cod is maintained in larger codend mesh sizes, as lower catch weights are offset by larger numbers of commercial-size fish and fewer discards. However since the present survey was not conducted in areas of high-rock cod density similar to those usually targeted by the finfish fleet, it is recommended that another survey be conducted in high-density areas in order to confirm the observed trends.

A



B

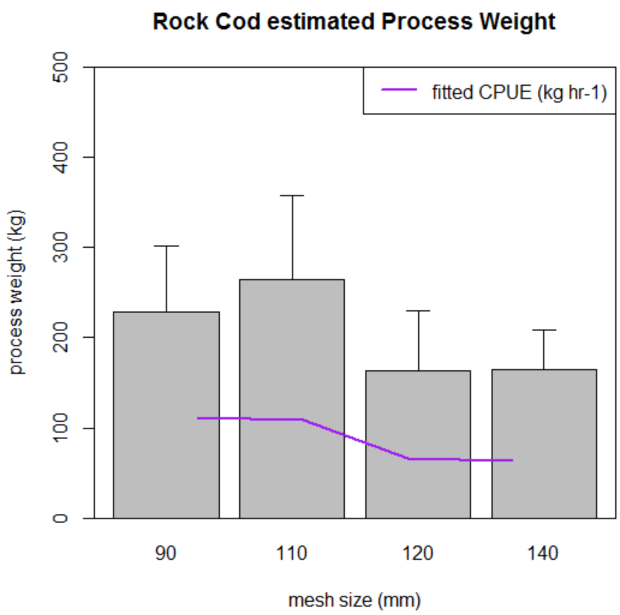


Figure 3.10 Average (a) discard and (b) process weight for rock cod among mesh sizes in Area2, as estimated from fitted length frequency distributions (Figure 3.7) and power length-weight function (Figure 3.9). Purple lines show fitted mean rock cod CPUE by mesh size in Area2 (Figure 3.6).

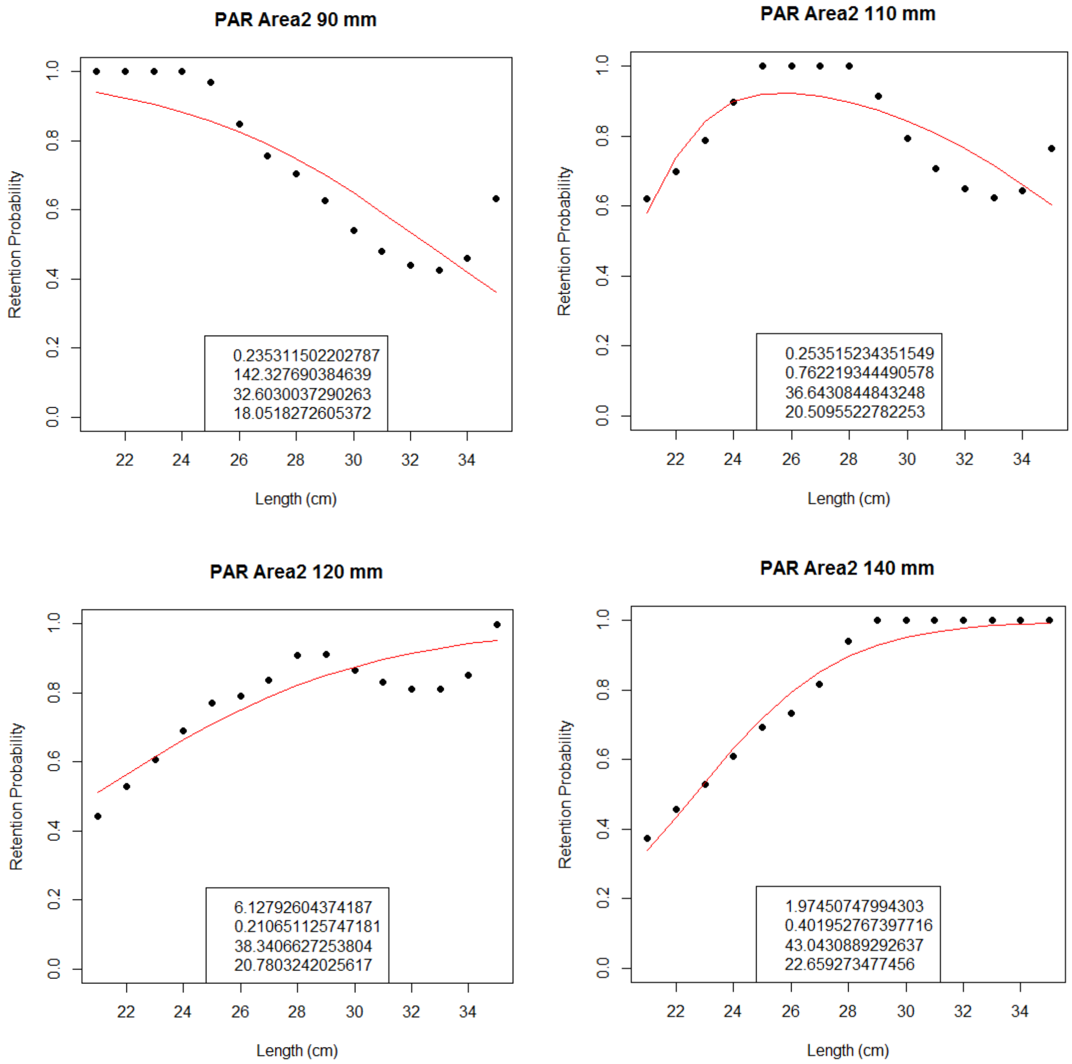


Figure 3.11 Fitted retention probability at length among codend mesh sizes for 21-35 cm rock cod from Area2. Black dots are observed retention probabilities maximized over area. Red lines are fitted probability curves using the double-logistic equation. Numbers in bottom square are fitted parameters values (from top to bottom): s1, s2, p1 and p2. p1 and p2 correspond to largest and smallest lengths of 50% retention, respectively.

3.2.3. *Genypterus blacodes* (kingclip)

Mesh size versus CPUE

Area effects explained only 17% of the variance in kingclip CPUE by mesh size (Table 3.3). Sampling day within area and mesh size had no measurable influence. Area differences in mean CPUE were important in the smaller mesh (90 mm) codend but comparatively small in larger mesh sizes (Figure 3.6c).

The relative abundance of kingclip was higher in Area1 with an average of 331 kg per hour (range 0-2950 kg hr^{-1} among trawls) compared to 132 kg per hour (range 37-728 kg hr^{-1} among trawls) in Area2. This difference was partly explained by a single large trawl catch of kingclip (> 8 tonnes) in Area1. In both areas, variation in kingclip CPUE was independent from sampling day, time of day and trawling depth (Table 3.4). Codend mesh sizes did not affect kingclip CPUE in Area2 while larger mesh trials (140 mm) on average yielded lower CPUE in Area1 (Figure 3.6c). Depending on area, CPUE variability was most important in the smaller 90 mm mesh (Area1) or in larger mesh (≥ 110 mm) codends (Area2) (Figure 3.6c). These results suggest that other, area-specific factors besides mesh size, day, time of day and trawling depth, determine trawl catches of kingclip.

Mesh size versus catch composition by length/weight

Kingclip samples sizes for length frequencies ranged 45-121 specimens per trawl in Area1 and 61-111 specimens in Area2. Station 967 in Area1 was removed from analyses as only 10 kingclip were caught and sampled for length in this trawl. Smaller sample sizes (< 70 fish) were generally observed in 140 mm mesh trials in both areas.

A broad range of sizes characterized the species. Kingclip length ranged 47-106 cm in Area1 and 42-119 cm in Area2. Fitted length frequency distributions by mesh size are shown in Figure 3.12. Modal length increased with codend mesh size, in Area1 from 64-65 cm (in 90 mm and 110 mm) to 72-75 cm (in 120 mm and 140 mm) and in Area2 from 59 cm (90 mm), 63 cm (110 mm), 67 cm (120 mm) to 72 cm (140 mm).

A 70 cm threshold corresponding to length at minimum commercial HGT weight (600 g) was used to investigate mesh size effects on proportions of commercial-size (or higher commercial value) kingclip in the catch. Proportions of >70 cm fish increased with codend mesh size, from 28-33% in 90 mm to 46-61% in 120 mm and 65-73% in 140 mm, depending on area (Figure 3.13). Both 120 mm and 140 mm mesh yielded significantly higher means in Area1. In Area2, only in the larger mesh (140 mm) codend was statistically different. In both areas, trawl depth explained random variation in catch proportions within mesh size. Day and time of day had a significant influence on numbers of >70 cm kingclip in the catch only in Area1, indicating area-specific differences in length-class availability to the fishery.

Fitted length frequencies were converted to weights using the power length-weight function shown in Figure 3.14. Converted weights were used to estimate HGT-process weights and total weights of < 70 cm fish in individual trawls. Average HGT-process weights were statistically similar among mesh sizes in both areas (Figure 3.15a). Area-specific trends differed however, with greater variability and a tendency for higher HGT-process weight in smaller (90 mm) mesh trials in Area1 and the converse in Area2 (greater variability and a tendency for higher process weights in larger mesh sizes) (Figure 3.15a). These results again indicate important spatial differences in the size composition of kingclip aggregations. However where larger-size kingclip are relatively abundant (as in Area2), larger mesh codends appear to yield greater HGT-process weights. Notwithstanding differences in length-class abundance, a reduction in catch weights of smaller-size (< 70 cm) kingclip with increasing mesh size was observed in both areas (Figure 3.15b). This pattern was significant in Area2, with 140 mm mesh trials on average yielding lower catch weights of < 70 cm kingclip (Figure 3.15b).

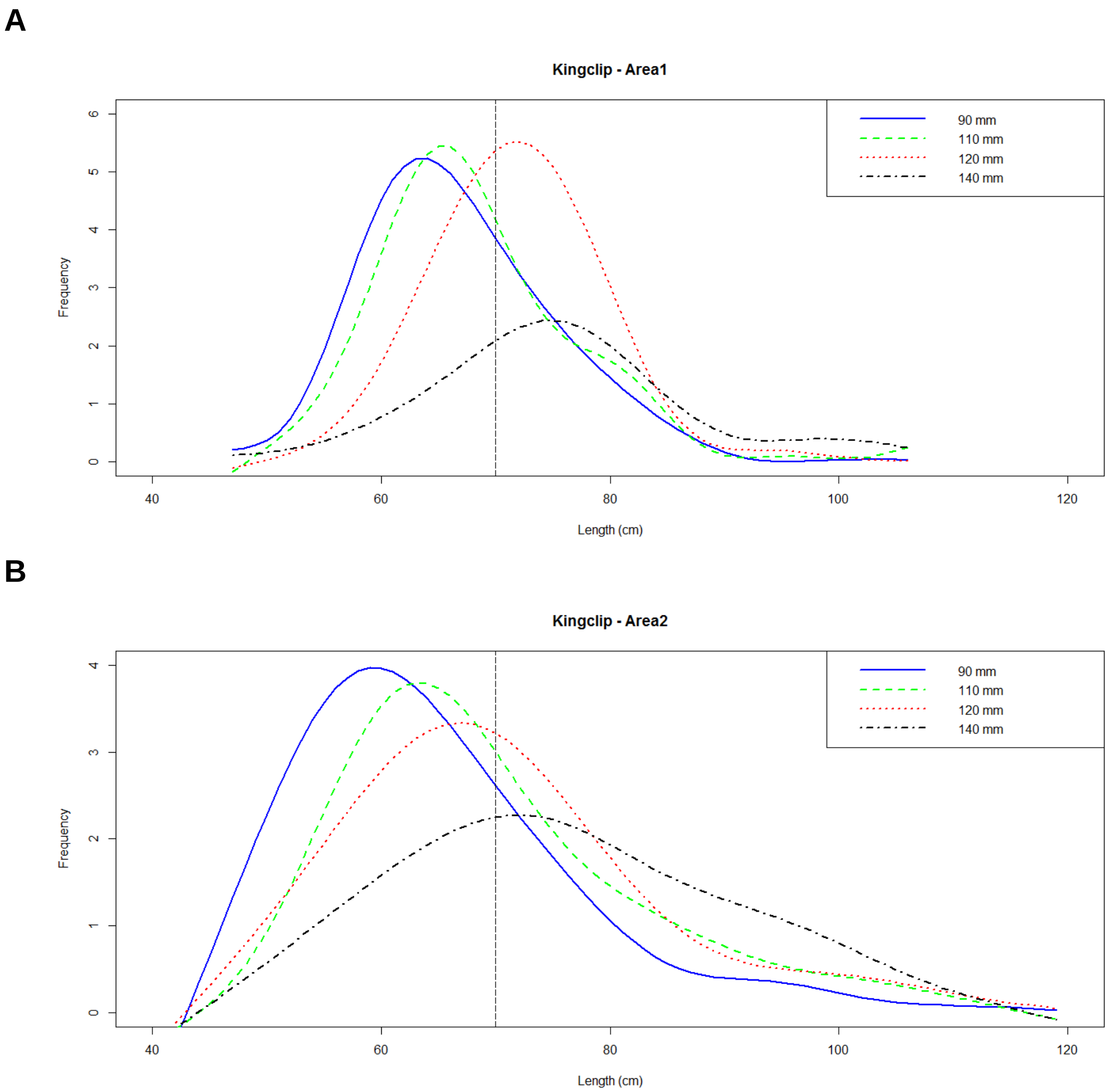


Figure 3.12 Fitted length frequency distributions by mesh size for kingclip from (a) Area1 and b) Area2. Dashed vertical lines indicate the 70 cm threshold for commercial (HGT) size kingclip (≥ 70 cm).

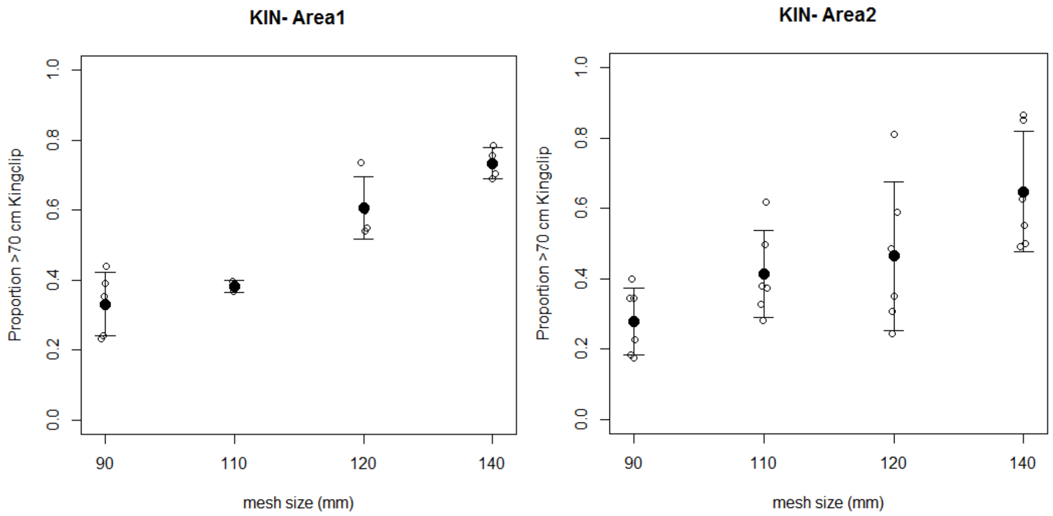


Figure 3.13 Fitted proportions of HGT-size (≥70 cm) kingclip in the catch among codend mesh sizes. Dark circles and error bars are means ± sd. Empty circles are trawl-specific values.

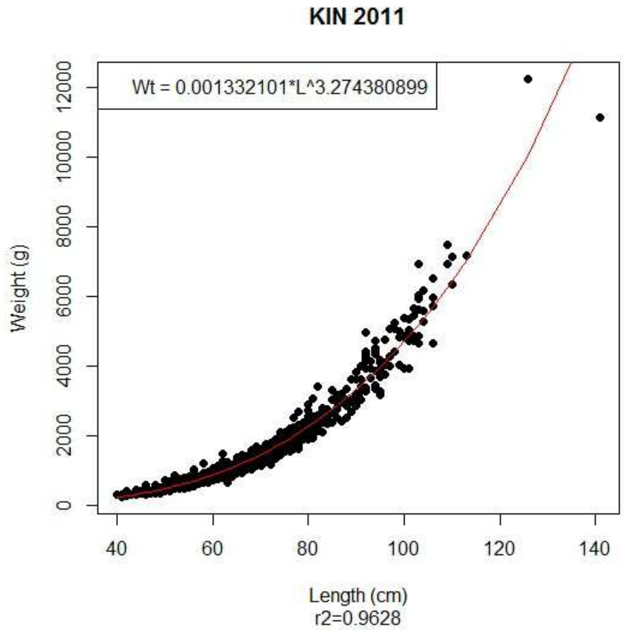


Figure 3.14 Power length-weight function for kingclip, estimated using random length-weight samples collected in FICZ/FOCZ throughout 2011.

Mesh size versus probability of retention at length

Retention probabilities were fitted for 57-81 cm kingclip from Area1 and 50-91 cm kingclip from Area2, corresponding to the size range within which sample sizes per length class were ≥ 20 specimens across mesh sizes. Sample sizes per length intervals were especially small (generally < 10 specimens) in 110 mm and 140 mm mesh trials in Area1. Fitted retention probability at length for such mesh sizes should thus be regarded with caution.

In both areas, the results suggest decreasing retention probabilities for smaller (< 60 cm) kingclip in larger mesh sizes relative to the 90 mm mesh which is fully selective for smaller fish (Figure 3.16). First length of 50% retention increased with mesh size, from an unrealistic 5-6 cm in 90 mm mesh trials to 53-62 cm in 120 mm and 62-75 cm in 140 mm. The 110 mm mesh in both areas appeared to be more selective of kingclip of intermediate-sizes (i.e. 60-70 cm). A similar pattern was observed in 120 mm mesh in Area2, where retention probabilities peaked in 65-85 cm fish. In contrast, kingclip ≥ 69 cm were fully retained by the 120 mm mesh in Area1. The 140 mm mesh was highly selective for larger kingclip, with full retention at 78 cm in Area2.

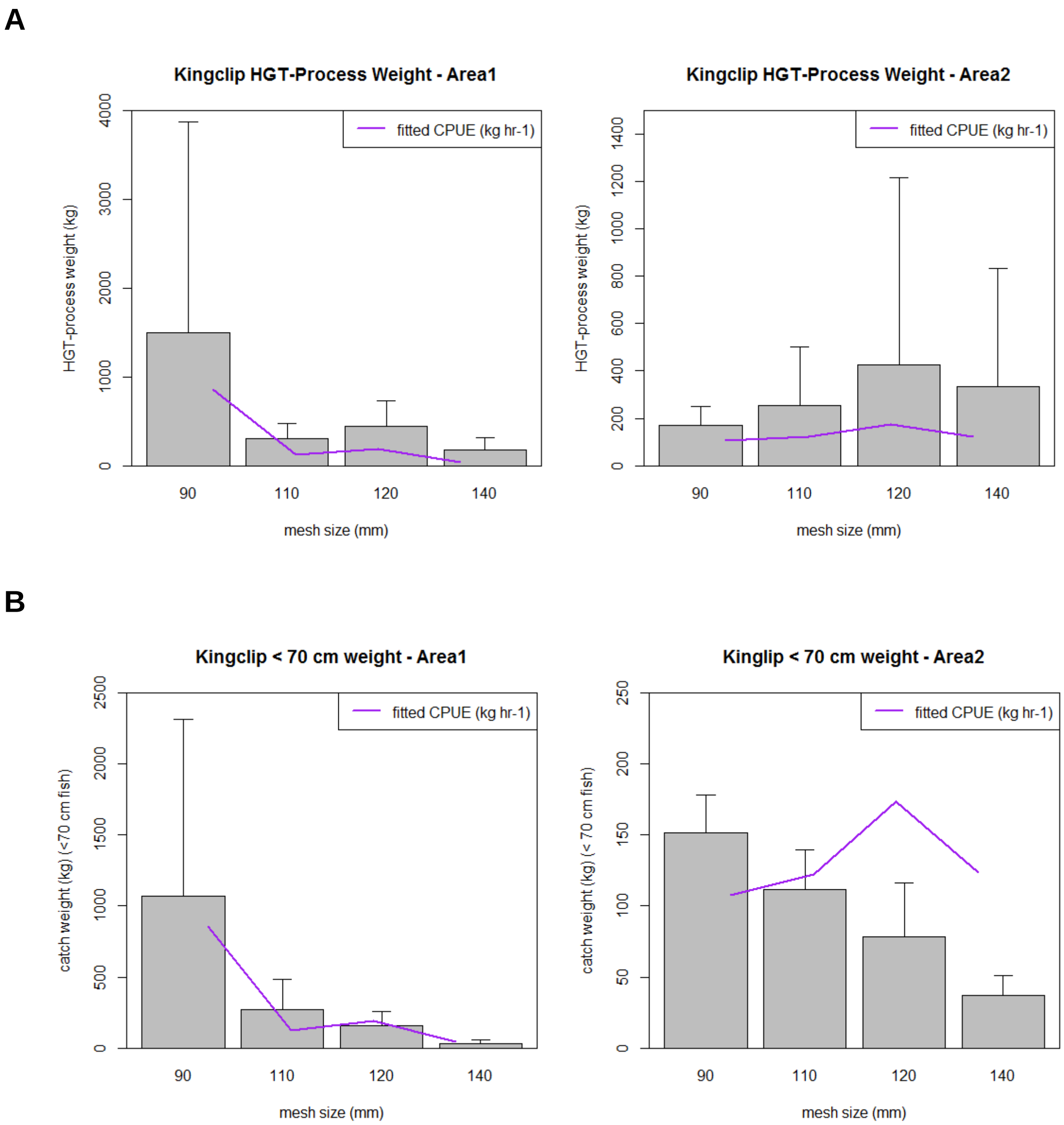


Figure 3.15 Average (a) HGT-process weight and (b) < 70 cm fish catch weight for kingclip among mesh sizes in the sampling areas, as estimated from fitted length frequency distributions (Figure 3.12) and power length-weight function (Figure 3.14). Purple lines correspond to average kingclip CPUE by mesh size (Figure 3.6c).

Kingclip summary

The results underlined the variable character of fishery efficiency for kingclip, both in terms of catch weight and size composition. Mesh size did not explain variation in kingclip CPUE during the survey. The only exception to this was a reduction in mean CPUE in the 140 mm mesh in Area1, which was not independent from important day-to-day variations in size composition of the catch. Increasing codend mesh sizes increased numbers of HGT-size kingclip in the catch by a factor of 2 (in 120 mm and 140 mm mesh) and reduced catch weights and retention probabilities of smaller (< 70 cm) individuals below the 50% maturity threshold (see kingclip maturity ogive in Appendix 1). Larger codend mesh sizes therefore can be expected to improve fishery efficiency for kingclip whilst contributing to ensure fishery sustainability in the long term.

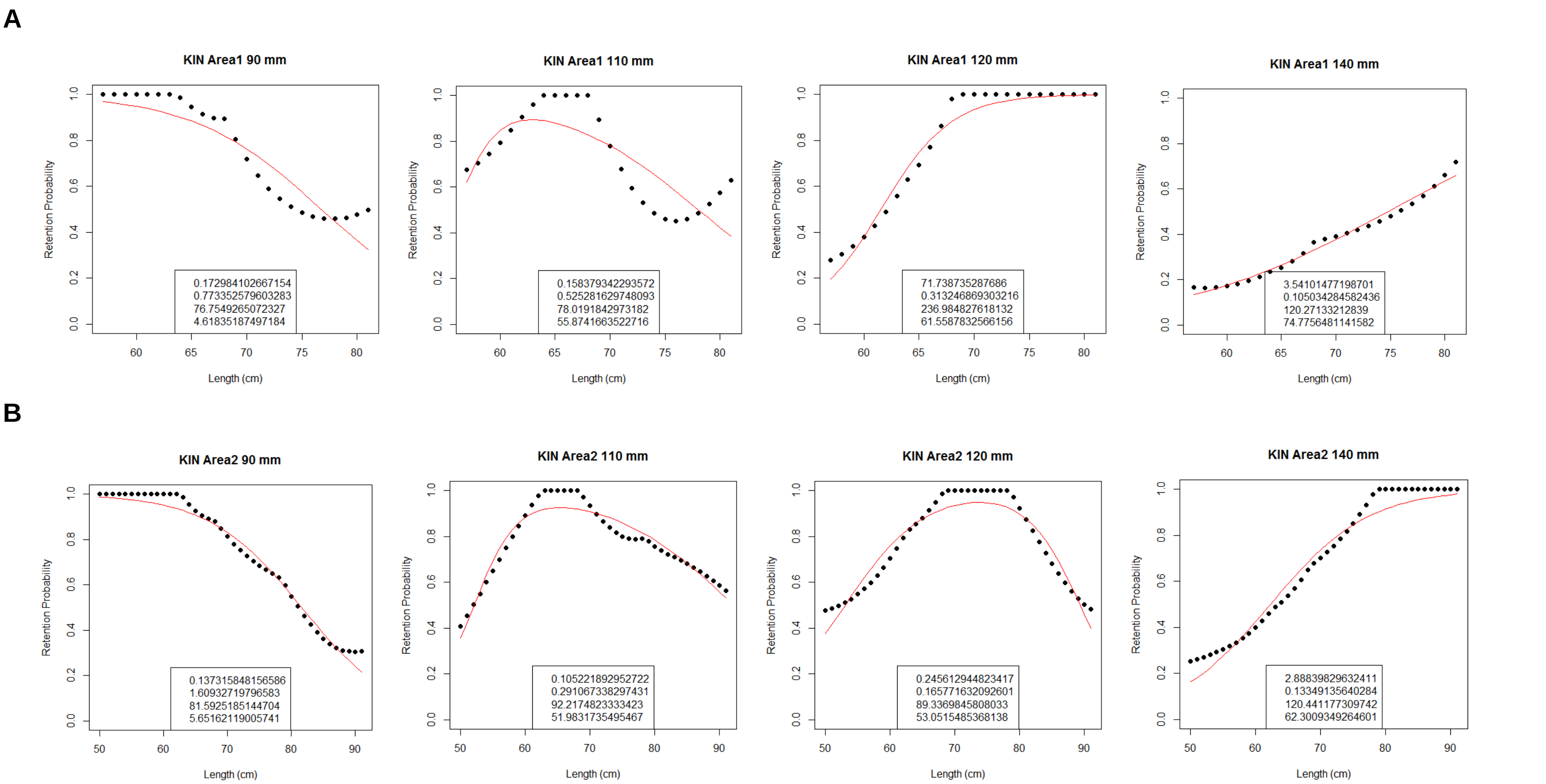


Figure 3.16 Retention probability at length among mesh sizes for (a) 57-81 cm kingclip from Area1 and (b) 50-91 cm kingclip from Area2. Black dots are observed retention probabilities maximized over area. Red lines are fitted probability curves using the double-logistic equation. Numbers in bottom square are fitted parameters values (from top to bottom): s1, s2, p1 and p2. p1 and p2 correspond to largest and smallest lengths of 50% retention, respectively.

3.2.4 *Merluccius hubbsi* (common hake)

Mesh size versus CPUE

Different aggregations of the common hake stock were encountered between the study areas. In Area1, hake catches consisted primarily of larger females migrating further east into the Falkland zone (mean length = 62 ± 9 cm; ratio of male to female = 0.005). In Area2, hake catches comprised a mixture of male and female of generally smaller sizes (mean length = 47 ± 7 cm; male to female ratio =0.33). As a result, area explained a large proportion (89%) of the variance in the species CPUE within mesh sizes (Table 3.3).

Hake relative abundance was higher in Area2 (average CPUE of 450 kg per hour - range 268-598 kg hr^{-1} among trawls) relative to Area1 (mean 116 kg hr^{-1} – range 38-222 kg hr^{-1}) (Figure 3.6d). Trends in average CPUE with increasing mesh size were similar between areas (Figure 3.6d). Mesh size effects were significant and corresponded to a reduction in mean CPUE in 120 mm and 140 mm mesh in Area1 and in the 120 mm mesh only in Area2 (Figure 3.6d). In both areas, hake catches were independent from sampling day and time of day effects (Table 3.4). Trawling depth explained 37% of random variation within mesh size treatments in Area1, but had no measurable influence in Area2.

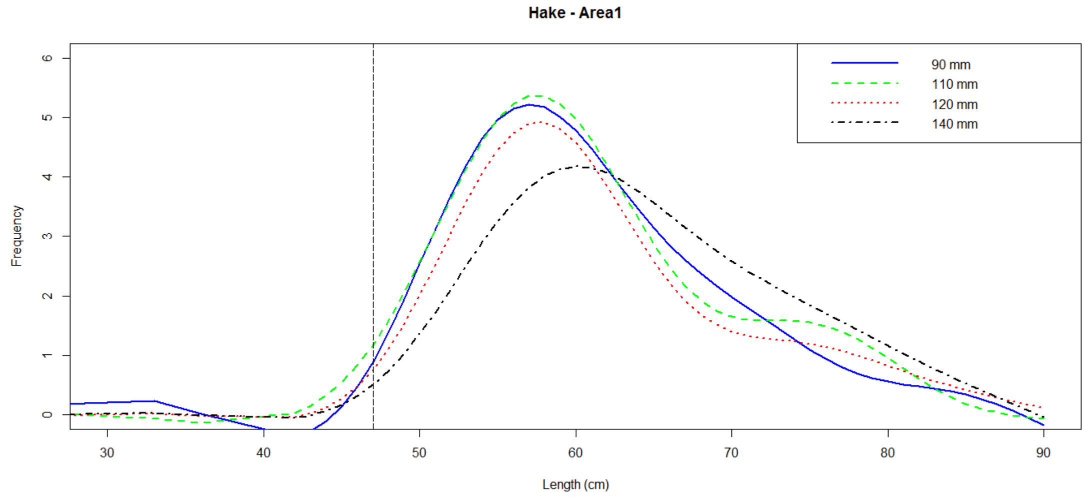
Mesh size versus catch composition by length/weight

Between 61-108 and 100-123 hakes were sampled for length in trawls from Area1 and Area2, respectively. Size range was similar between areas (27-90 cm in Area1 and 27-83 cm in Area2), however the catch in Area1 was by comparison clearly dominated by larger fish (> 50 cm) (Figure 3.16). Modal length showed only limited increase with increasing mesh size, ranging 57-60 cm between 90 mm and 140 mm mesh in Area1, and 44-46 cm in Area2.

A 47 cm threshold corresponding to length at minimum commercial HGT weight (760 g) was used to compare proportions of commercial-size hake in the catch among mesh sizes. In Area1, 97% to 100% of hake catches among trawls were HGT-size fish (Figure 3.16a). In Area2, numbers of HGT-size hake in the catch were significantly higher (> 40%) in 110 mm and 140 mm mesh trials. Proportions of HGT-size hake varied little within mesh size treatments and this variation was partly explained by trawling depth. Day and time of day had no measurable effects (Figure 3.17).

Fitted length frequencies from Area2 were converted to weights using the length-weight function shown in Figure 3.18. Estimated catch composition by weight revealed a significant reduction in average catch weights of smaller (< 47 cm) hake with increasing mesh size but no significant change in HGT-process weights (Figure 3.19). These results suggest that reductions in hake CPUE in larger mesh trials are in part related to a decrease in catches of smaller-size hake.

A



B

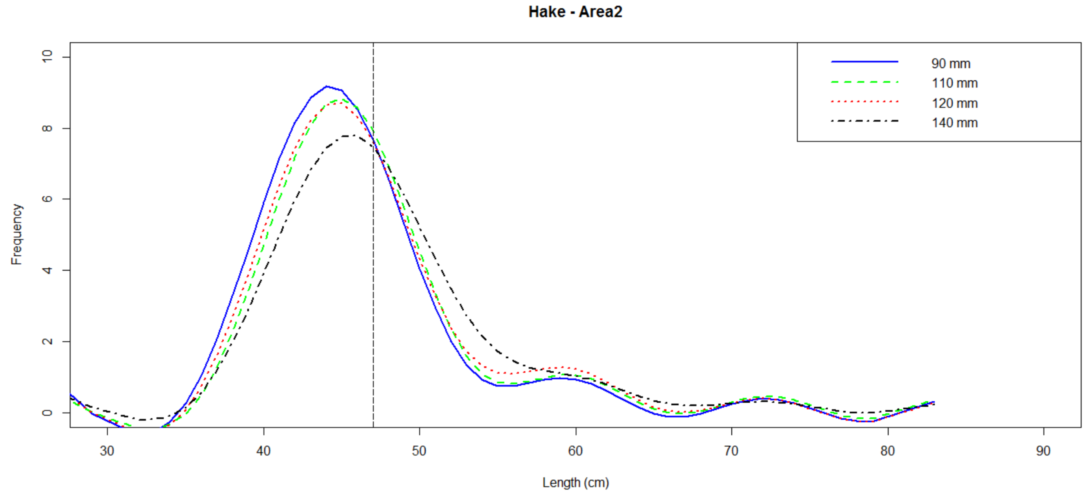


Figure 3.16 Fitted length frequency distributions by mesh size for common hake in (a) Area1 and b) Area2. Dashed vertical lines indicate the 47 cm threshold for commercial (HGT) size hake (≥ 47 cm).

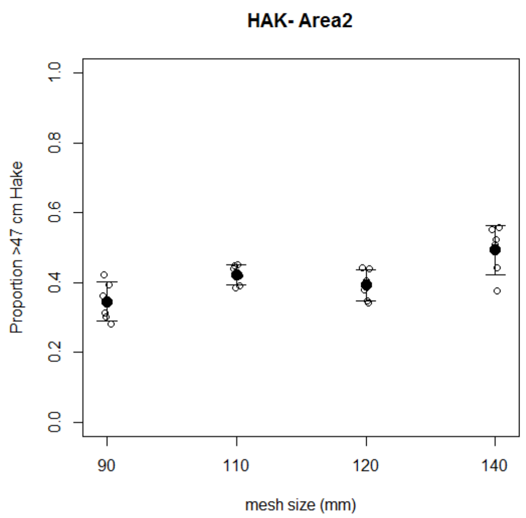


Figure 3.17 Proportions of HGT-size (≥ 47 cm) hake in the catch among codend mesh sizes in Area2. Dark circles and error bars are means ± sd. Empty circles are trawl-specific values.

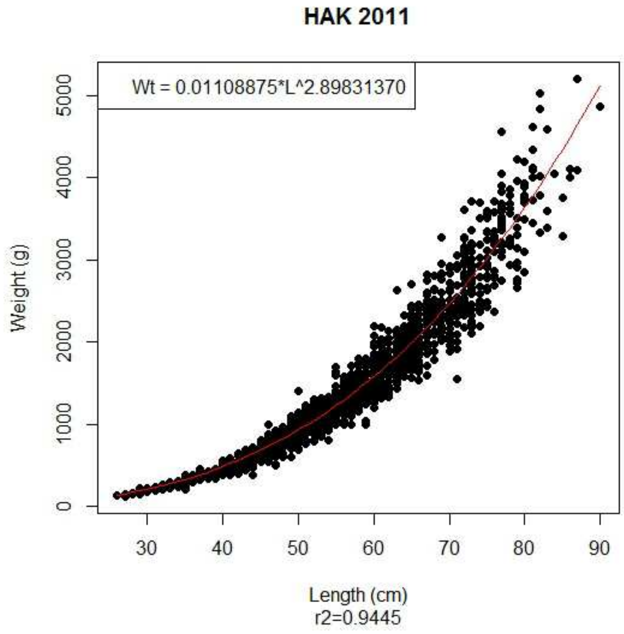


Figure 3.18 Power length-weight function for hake, estimated using random length-weight samples collected in FICZ/FOCZ throughout 2011.

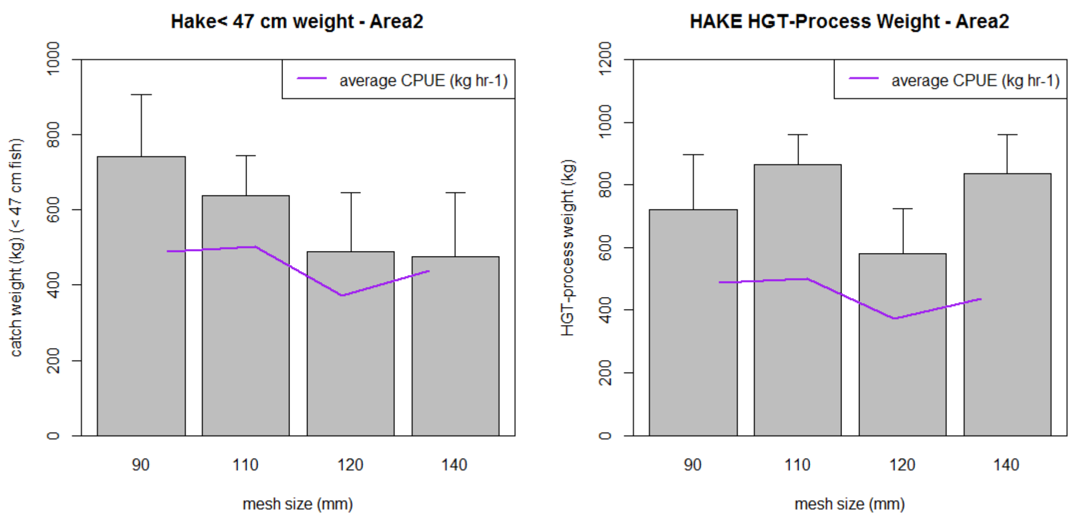


Figure 3.19 Average catch weight for small (< 47 cm) and HGT-size (≥ 47 cm) hake among mesh sizes in Area2, as estimated from fitted length frequency distributions (Figure 3.16b) and a length-weight function (Figure 3.18). Purple lines correspond to average hake CPUE by mesh size in Area2 (Figure 3.6d).

Mesh size versus probability of retention at length

Retention probability curves were fitted for 49-79 cm hake from Area1 and 38-58 cm hake from Area2, corresponding to size ranges within which sample sizes in 1-cm length intervals were ≥ 20 specimens across mesh sizes. The smaller (90 mm) and larger (140 mm) mesh codends were clearly more selective of smaller and larger-size hake, respectively. Estimated lengths of 50% retention reflected area differences in stock composition, with all hakes up to 77 cm and 57 cm having a 50% probability of being retained in the 90 mm mesh codend in Area1 and Area2, respectively. In contrast, only hakes larger than 50 cm (Area1) and 37 cm (Area2) had a 50% probability of being retained in the larger mesh (140 mm) codend. Intermediate mesh sizes showed variable selectivity between areas. Where larger hakes were more abundant (Area1), the 110 mm mesh remained highly selective of smaller length classes (first length of 50% retention = 10 cm) while the 120 mm mesh was less likely to retain hakes smaller than 46 cm (Figure 3.20a). The reverse was observed in Area2, where the 120 mm mesh codend showed higher probabilities of retaining a broader range of hake sizes. Overall, the results suggest that only the larger mesh (140 mm) codend may effectively reduce probabilities of catching smaller-size hake while maximizing retention probabilities of larger (i.e. HGT-size) hake, notwithstanding spatial differences in stock composition within FICZ/FOCZ.

Hake summary

Mesh size effects on fishery efficiency for hake varied with spatial differences in stock composition. Fishery efficiency (as CPUE) was generally higher in an area where hake aggregations comprised a broad range of sizes dominated by smaller (< 50 cm) individuals. In this context, larger codend mesh sizes generally improved fishery efficiency, as indicated by increasing numbers of HGT-size hake, lower catch weights of smaller (< 47 cm) hake and higher retention probabilities of larger fish in 120 mm and 140 mm mesh trials. Where hake aggregations were instead dominated by larger (>50 cm) females (Area1), larger (≥ 120 mm) mesh sizes caused a reduction in fishery efficiency as CPUE. Based on these findings, a 120 mm mesh codend would represent a fair compromise for hake, enhancing fishery efficiency in some areas whilst reducing catches of smaller hakes below the 50% maturity threshold (see Hake maturity ogive in Appendix 2).

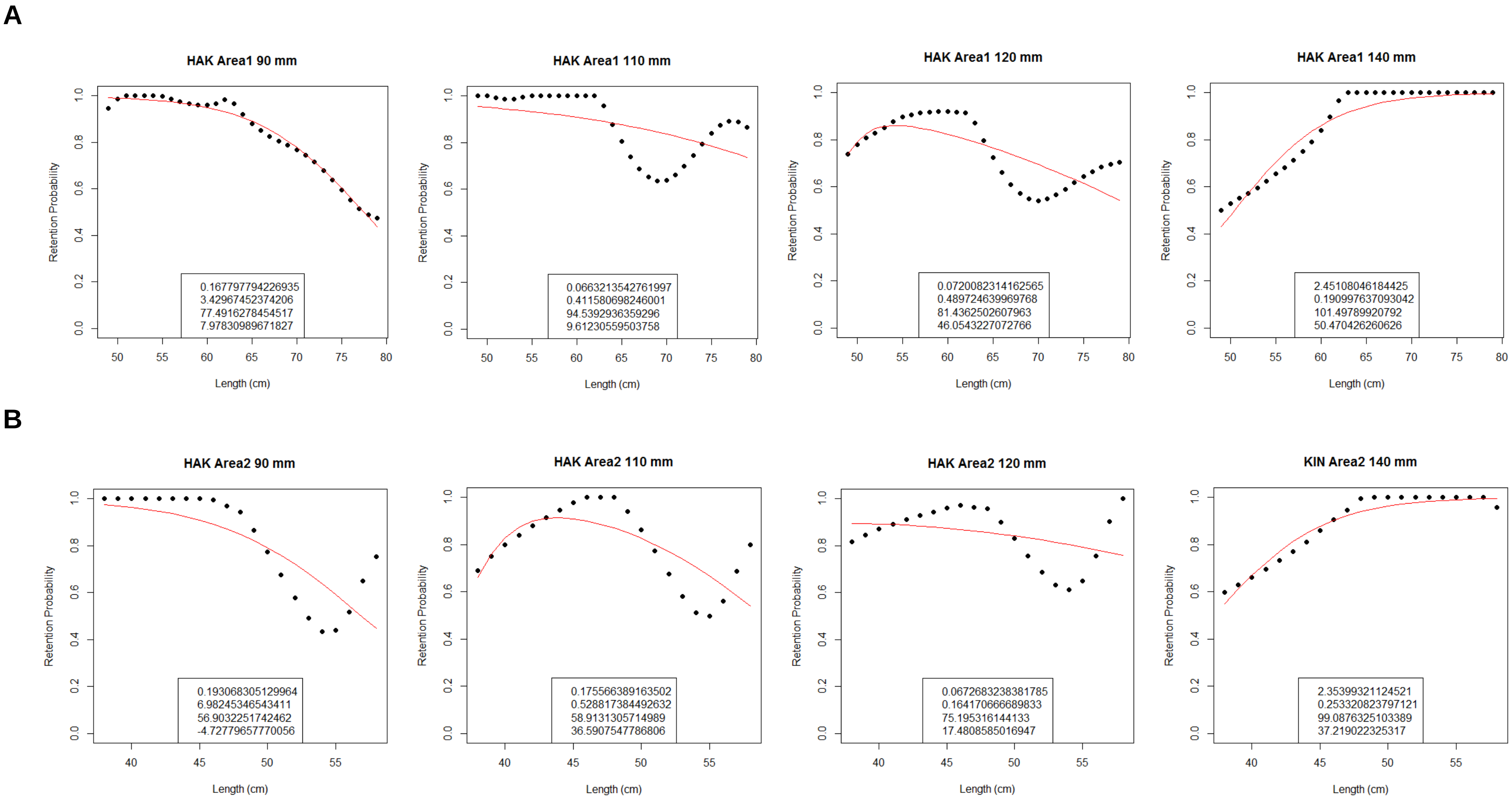


Figure 3.20 Retention probability at length among mesh sizes for (a) 49-79 cm hake from Area1 and (b) 38-58 cm hake from Area2. Black dots are observed retention probabilities as maximized over area. Red lines are fitted probability curves using the double-logistic equation. Numbers in bottom square are fitted parameters values (from top to bottom): s1, s2, p1 and p2. p1 and p2 correspond to largest and smallest lengths of 50% retention, respectively.

3.2.5 *Illex argentinus* (*Illex* squid)

Mesh size and CPUE

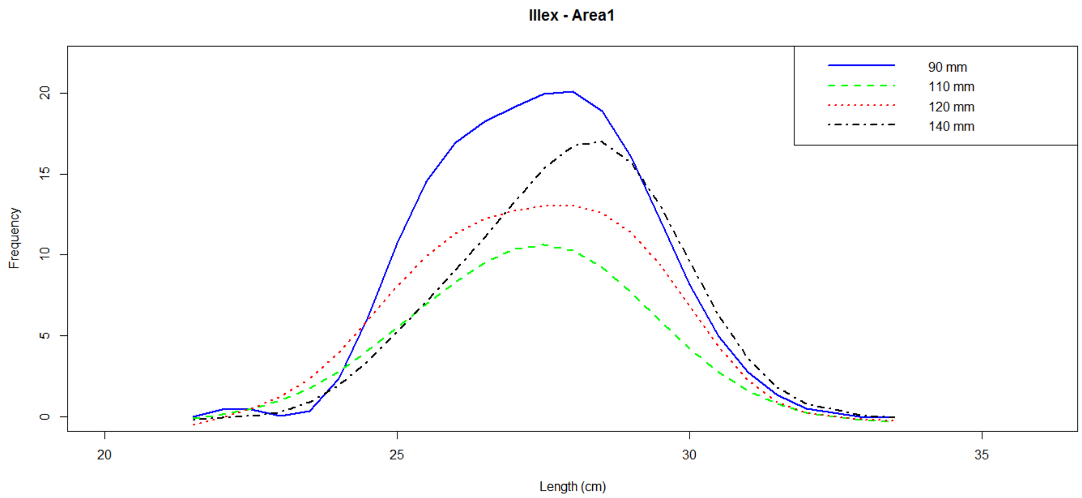
Trends in *Illex* CPUE with increasing codend mesh sizes differed between areas (Figure 3.6e). Area within mesh size accounted for 71% of the variance in *Illex* CPUE during the survey (Table 3.3). *Illex* relative abundance was low in Area1 with an average of 42 kg hr^{-1} (range 11-171 kg hr^{-1} among trawls) and about three times higher in Area2 (mean 134 kg hr^{-1}, range 33-281 kg hr^{-1} among trawls).

In Area1, *Illex* CPUE varied with mesh size and time of day with comparatively higher CPUE in morning trawls (Table 3.4). The 90 mm mesh codend yielded greater *Illex* CPUE and a greater variability in catch in Area1 (Figure 3.6e). In contrast, there were no effects of codend mesh sizes on CPUE in Area2, where larger mesh sizes (≥ 120 mm) yielded greater variability in catch and higher CPUE generally occurred in larger mesh (140 mm) trials (Figure 3.6e). Trawling depth explained 87% (Area1) and 32% (Area2) of random variation in *Illex* CPUE within mesh size treatments.

Mesh size and catch composition by length

Illex sample sizes for mantle length ranged 51-206 individuals per trawl in Area1 and 111-214 in Area2. Fitted mantle length frequency distributions by mesh size differed between areas, reflecting spatial differences in sex composition (Figure 3.21). The average ratio of male to female was 0.40 in Area1 and close to 1 (0.97) in Area2. This explained the bimodal length frequency distribution in Area2, with male length peaking at 27.5 cm and female length peaking at 31-32 cm (Figure 3.21b).

A



B

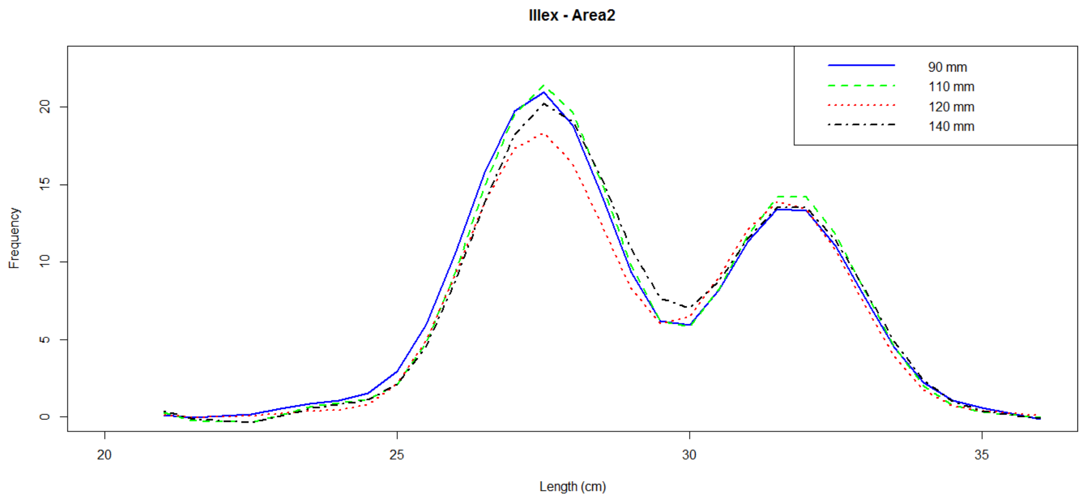


Figure 3.21 Fitted length frequency distributions by mesh size for *Illex* in (a) Area1 and (b) Area2.

Mesh size and probability of retention at length

Retention probabilities were fitted for 24-31 cm *Illex* from Area1 and 24.5-34 cm *Illex* from Area2, corresponding to size ranges within which sample sizes per 0.5-cm mantle length intervals were ≥ 35 specimens across mesh sizes.

In both areas, retention probabilities were generally constant across *Illex* sizes, suggesting the gear was not size-selective between 24-34 cm mantle length (Figure 3.22). Only in the 140 mm mesh codend in Area1 did retention probabilities increase with *Illex* size. Full retention occurred at 29 cm mantle length – a decrease relative to the standard 90 mm mesh codend (Figure 3.22a). At all lengths, retention probabilities were generally lower in intermediate mesh sizes (110 mm and 120 mm) in Area1. In Area2, fitted retention curves were similar among mesh sizes and across length intervals (Figure 3.22b). These results suggest that *Illex* abundance/availability, more than gear selectivity, determined the amount and size composition of the catch in Area2.

Illex summary

The impact of mesh size on fishery efficiency for *Illex* varied between areas and associated differences in relative abundance and stock composition. Mesh size effects were mainly evident in Area1 where *Illex* relative abundance was low and encountered aggregations were dominated by maturing, migrating females. Effects included a reduction in CPUE and in retention probabilities in larger mesh sizes relative to the standard 90 mm mesh. In contrast, no mesh size effects were evidenced in Area2 where *Illex* was more abundant and the stock comprised a mixture of mature males and maturing and mature females. Results from length frequencies and fitted retention probabilities indicated limited size-selection for *Illex* by the trawl gear. In view of this, increasing codend mesh sizes can be expected to have limited impacts on fishery efficiency for *Illex*, depending on area, aggregation density and stock composition.

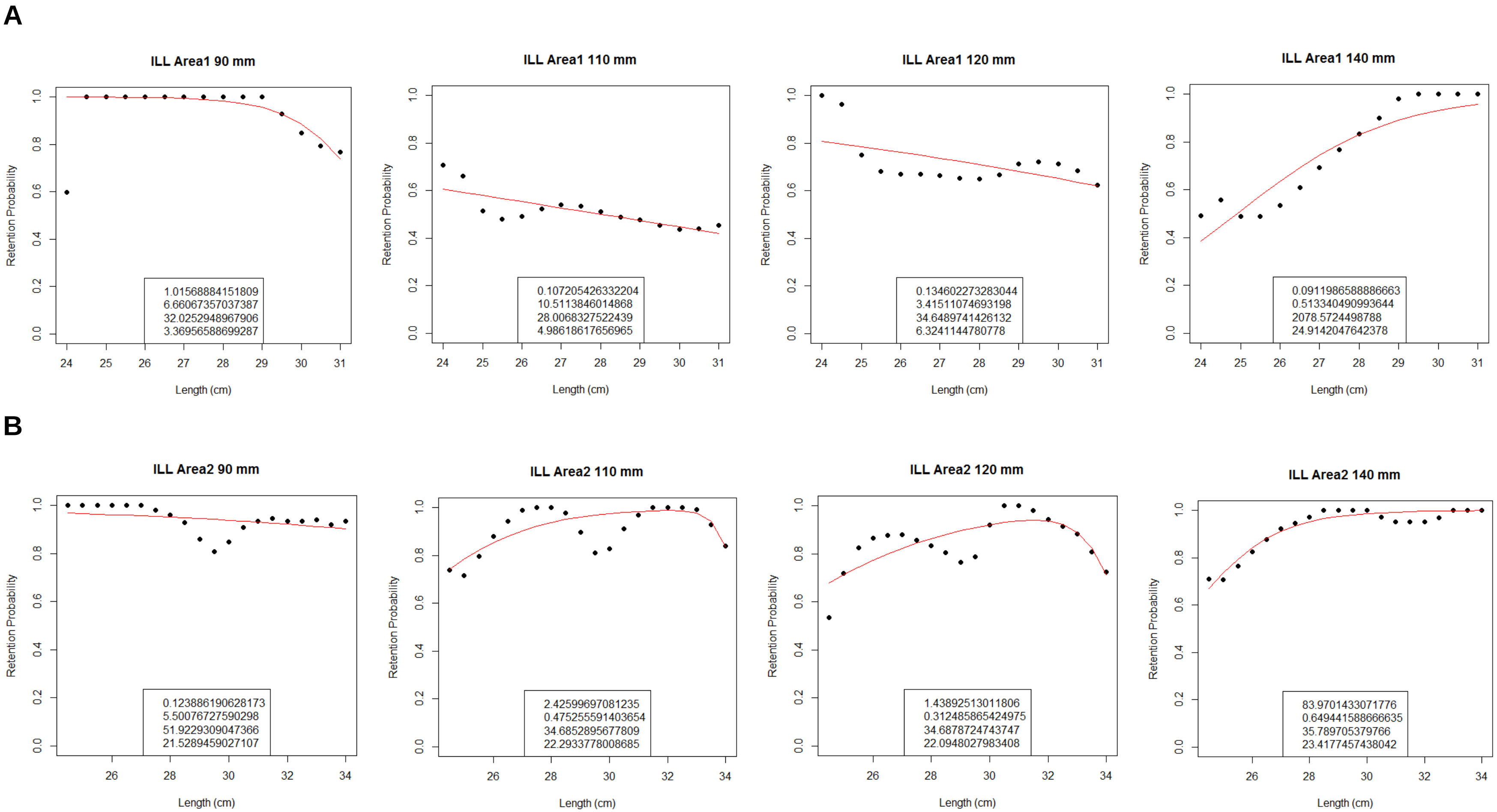


Figure 3.22 Retention probability at mantle length among mesh sizes for (a) 24-31 cm *Illex* from Area1 and (b) 24.5-34 cm *Illex* from Area2. Black dots are observed retention probabilities as maximized over area. Red lines are fitted probability curves using the double-logistic equation. Numbers in bottom square are fitted parameters values (from top to bottom): s1, s2, p1 and p2. p1 and p2 correspond to largest and smallest lengths of 50% retention, respectively.

3.2.6 *Doryteuthis gahi* (*Loligo* squid)

Mesh size and CPUE

Average *Loligo* CPUE decreased with increasing mesh size (Figure 3.6f). Area and sampling day did not contribute to explain variation in CPUE within mesh size treatments (Table 3.3). Area had a significant influence on mean CPUE however, so mesh size effects were still assessed separately for Area1 and Area2. Relative abundance varied from a mean of 12 kg per hour (range 1-111 kg hr^{-1}) and 22 kg per hour (range 3-62 kg hr^{-1}) in Area1 and Area2, respectively.

Mesh size effects were significant in Area1 and corresponded to higher mean *Loligo* CPUE in the 90 mm mesh (Figure 3.6f). The same pattern was observed in Area2 where larger mesh sizes (120 mm and 140 mm) yielded comparatively lower mean CPUEs. Area2 differences however were only significant at α=0.10 level, rather than α=0.05. Sampling day and trawling depth each explained 30% of random variation in *Loligo* CPUE within mesh size treatments in Area1 and Area2, respectively (Table 3.4).

Mesh size and catch composition by length

Loligo samples sizes for length frequencies ranged 88-214 specimens among trawls in Area1 and 78-295 in Area2. A broad range of *Loligo* sizes were encountered during the survey, ranging 8-33 cm and 6-37 cm mantle length in Area1 and Area2, respectively. Smaller size *Loligo* (< 15 cm mantle length) were comparatively more abundant in Area1 (Figure 3.23). Modal mantle length remained relatively constant at 13-13.5 cm among mesh sizes in Area1 and between 16.5-17.5 cm in Area2.

Mesh size and probability of retention at length

Retention probability curves were fitted for *Loligo* from Area2, where sample sizes of ≥ 20 specimens per 0.5 cm length intervals were available for a broader range of *Loligo* sizes (7-32 cm) than Area1 (10-19.5 cm).

The probability of retaining < 20 cm mantle length *Loligo* was clearly reduced in larger mesh sizes (120 mm and 140 mm) relative to 90 mm and 110 mm mesh (Figure 3.24). This would explain a reduction in fishery efficiency in larger mesh trials as 10-20 cm *Loligo* were the dominant length classes during the survey (Figure 3.23).

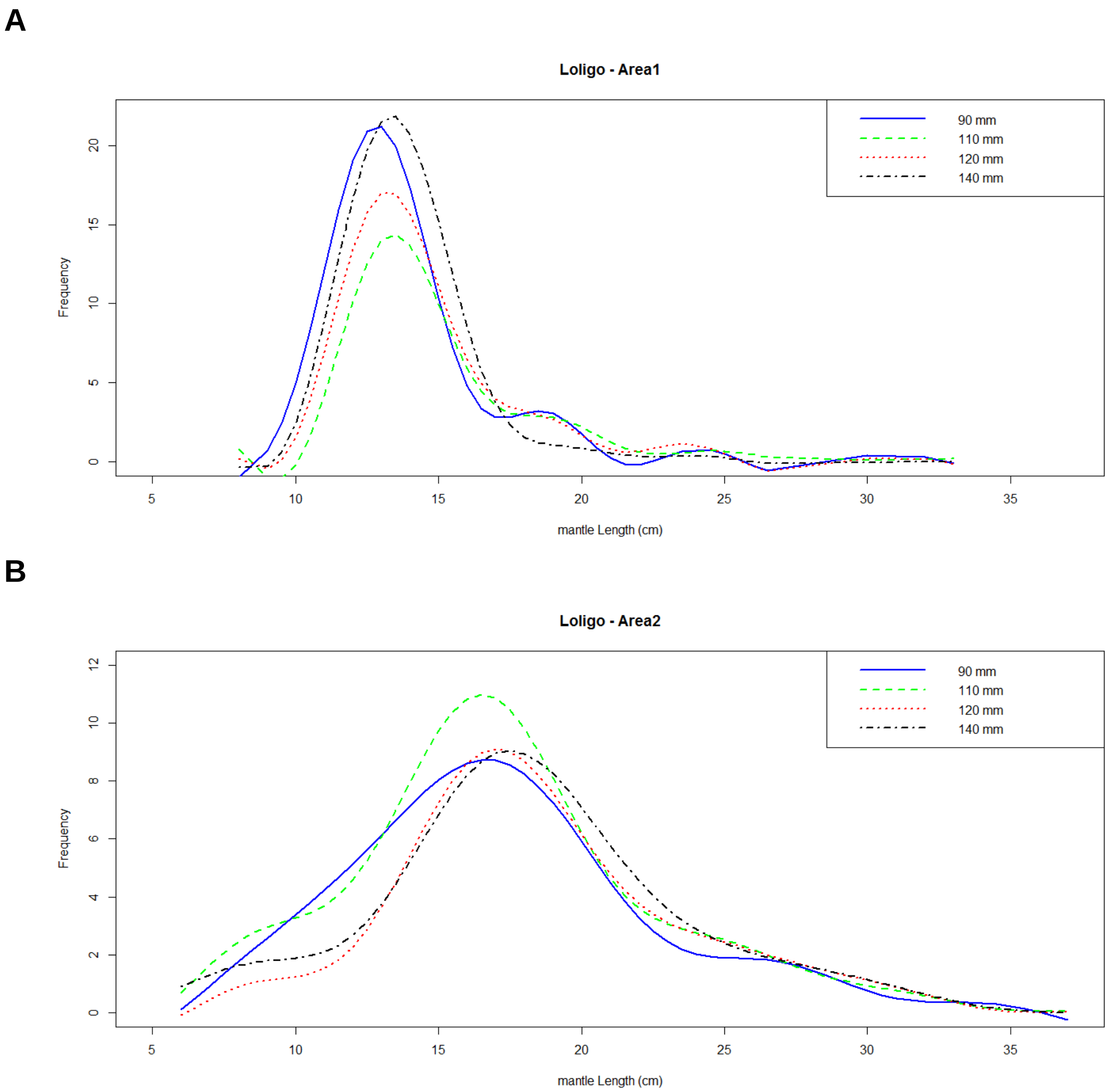


Figure 3.23 Fitted mantle length frequency distributions by mesh size for *Loligo* in (a) Area1 and b) Area2.

Loligo *summary*

Larger codend mesh sizes can be expected to reduce fishery efficiency for *Loligo* in terms of CPUE, as larger mesh codends are less effective at retaining *Loligo* from dominant length classes (10-20 cm).

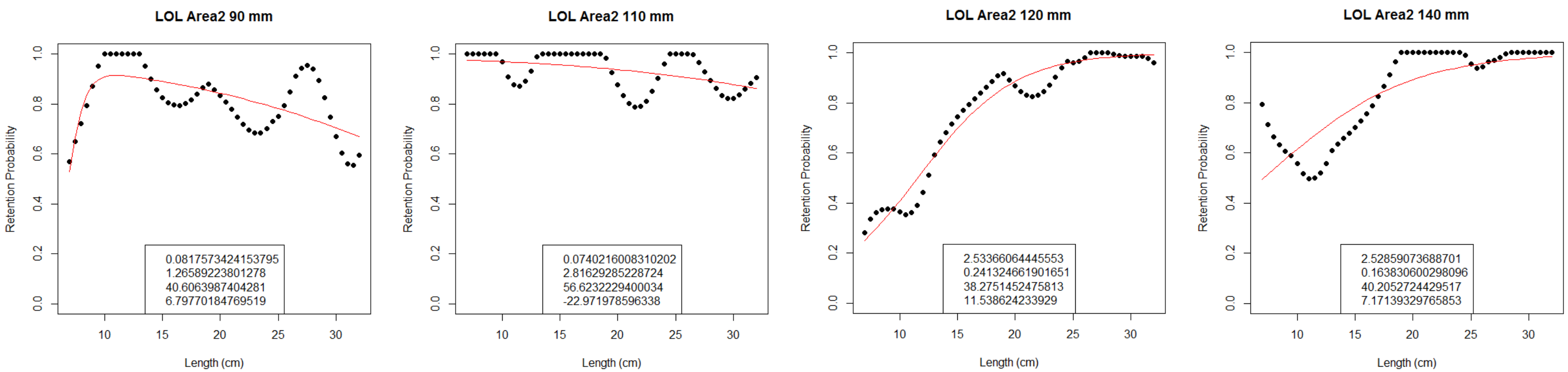


Figure 3.24 Retention probability at mantle length among mesh sizes for 7-32 cm *Loligo* from Area2. Black dots are observed retention probabilities as maximized over area. Red lines are fitted probability curves using the double-logistic equation. Numbers in bottom square are fitted parameters values (from top to bottom): s1, s2, p1 and p2. p1 and p2 correspond to largest and smallest lengths of 50% retention, respectively.

3.2.7 Rajidae sp. (Skates)

Mesh size and CPUE

Trends in *B. brachyurops* (RBR) CPUE with increasing mesh size were similar to those observed for all skates combined, thus supporting the use of RBR as indicator species (Figure 3.6g & 3.6h). Area within mesh size explained 47% of the variance in RBR CPUE during the survey (Table 3.3). Day within area and mesh size explained a similar amount (53%). RBR relative abundance was higher in Area2, with an average of 71 kg per hour (range 15-158 kg hr^{-1} among trawls) compared to 28 kg per hour in Area1 (range 10-50 kg hr^{-1}).

Skate CPUE in Area1 varied with mesh size and trawling depth, with time of day explaining a small proportion of random variation within treatments (Table 3.4). The larger mesh (140 mm) codend yielded lower mean RBR CPUEs in Area1 (Figure 3.6g). In Area2, codend mesh sizes had no effect on CPUE. Skate catches were instead determined by day effects, with CPUE increasing almost linearly over time.

Mesh size and catch composition by disk width/weight

Fewer than 50 RBR specimens were sampled for disk width in half the trawls from Area1. These sample sizes were considered too small for meaningful comparisons and length frequency information was evaluated only for RBR from Area2. Samples sizes per trawl in Area2 ranged 59 - 339 specimens after two trawls with small sample sizes (27 and 42 specimens) were removed from analyses.

A broad range of RBR sizes were harvested during the survey (8-80 cm disk width). Modal disk width ranged 40-43 cm and showed no directional trend with increasing codend mesh sizes (Figure 3.25). Similarly, fitted disk width frequency distributions did not differ among mesh sizes (14-64 cm range).

A threshold of 30 cm disk width corresponding to the minimum size at which skates are retained for commercial purposes was defined based on FIFD staff observations. Proportions of commercial size (≥ 30 cm disk width) RBR relative to total catch in Area2 varied with mesh size, day and time of day, while trawling depth explained random variation within treatments. The 120 mm and 140 mm mesh yielded higher mean proportions of commercial-size RBR (≥ 85%) relative to smaller mesh codends (Figure 3.26). Variability in numbers of commercial-size skates in the catch was also reduced in larger mesh sizes compared to smaller mesh sizes (Figure 3.26).

Fitted disk width frequency distributions were converted to weights using the power function shown in Figure 3.27. Converted weights were used to estimate process and discard weights (sum of RBR catch weights above and below the 30 cm threshold standardized for trawl catch) for mesh size comparisons. Mesh size had no significant effect on estimated discard and retained weights, although discard weights were generally lower and less variable in larger mesh sizes (120 mm and 140 mm mesh) (Figure 3.28).

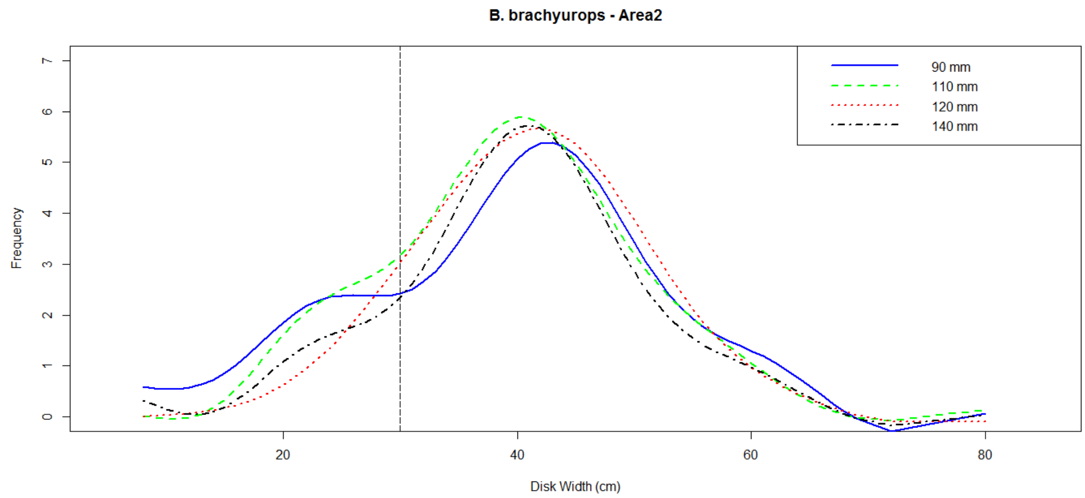


Figure 3.25 Fitted disk width frequency distributions by mesh size for *B. brachyurops* (RBR) from Area2. Dashed vertical line corresponds to a 30 cm threshold for commercial-size Skates (≥ 30 cm).

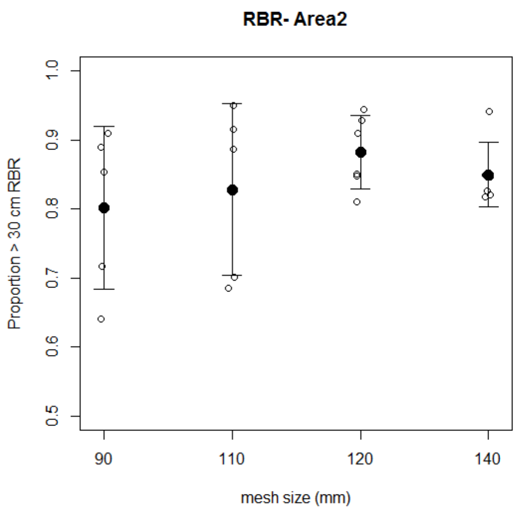


Figure 3.26 Proportions of commercial-size (≥ 30 cm disk width) RBR in the catch among mesh sizes in Area2. Dark circles and error bars are means ± sd. Empty circles are trawl-specific values.

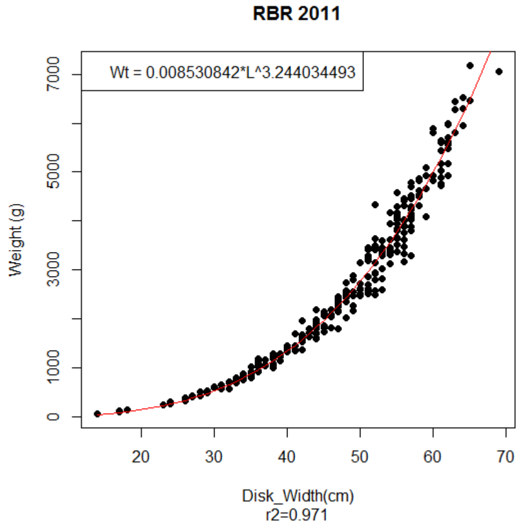


Figure 3.27 Disk width-weight function for *B. brachyurops* estimated from random samples collected in FICZ/FOCZ throughout 2011.

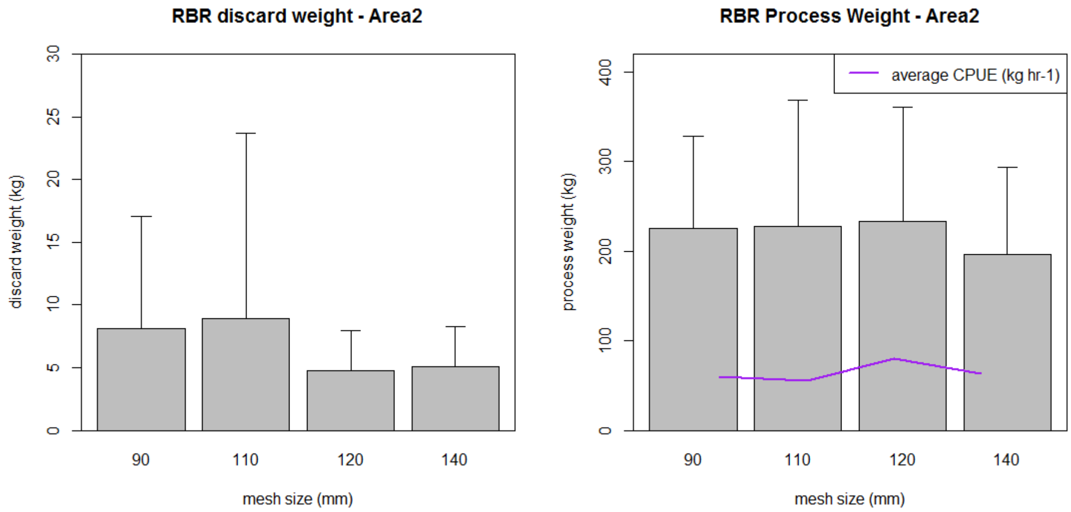


Figure 3.28 Average discards and retained weight among mesh sizes for RBR from Area2, as estimated using fitted length frequency distributions (Figure 3.25) and a 30-cm disk width threshold for discard/commercial-size skates (Figure 3.27). The purple line corresponds to average RBR CPUE by mesh size in Area2 (Figure 3.6h)

Mesh size and probability of retention at length

Retention probability curves were fitted for 19-61 cm disk width RBR from Area2, corresponding to the size range with ≥ 20 specimens per 1-cm interval across mesh sizes (Figure 3.29). The results indicate limited size-selectivity for skates in smaller (90 mm and 110 mm) mesh sizes. A reduction in retention probabilities for smaller (< 30 cm) RBR was visible in larger mesh codends (120 mm and 140 mm). The 120 mm mesh was most effective at retaining commercial size (30-55 cm) skates in mesh size trials from Area2.

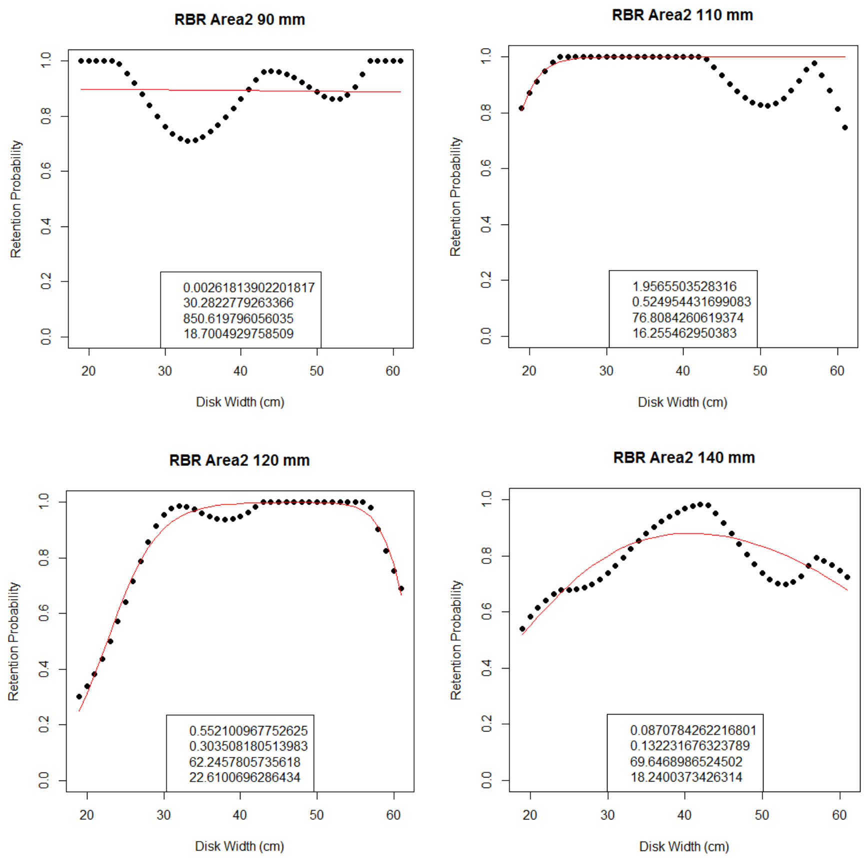


Figure 3.29. Retention probability at disk width among mesh sizes for 19-61 cm *B. brachyurops* (RBR) from Area2. Black dots are observed retention probabilities as maximized over area. Red lines are fitted probability curves using the double-logistic equation. Numbers in bottom square are fitted parameters values (from top to bottom): s1, s2, p1 and p2. p1 and p2 correspond to largest and smallest lengths of 50% retention, respectively.

Skates summary

Impacts of varying codend mesh sizes on fishery efficiency for skates were generally limited within the size range considered (90-140 mm mesh) and as evaluated using RBR as indicator species. The results indicated that the larger mesh size (140 mm) may reduce RBR CPUE depending on area and day-to-day variability in relative abundance. Larger mesh sizes however yielded higher numbers of commercial-size skates in the catch and reduced probabilities of retaining skates below the commercial size threshold (30 cm disk width). This was supported by generally lower and less variable discard weights in larger mesh sizes.

Considering the low productivity of skates stocks and increasing skates bycatch in finfish fisheries in FICZ/FOCZ (FIG 2012), it is recommended that development of measures minimising catches/discards of small skates be set as a high priority. The results presented herein suggest that an increase in codend mesh size to 120 mm in finfish fisheries will serve as improvement over the 90 mm mesh. However it is recommended that even larger mesh sizes be tested for use in skates/rays (F-licence) fishery.

3.3 Oceanography

Oceanographic data were collected at eight oceanographic stations. These stations were sampled either once every two days if the vessel was working along the same track, or at arrival to a new position (Fig. 3.30).

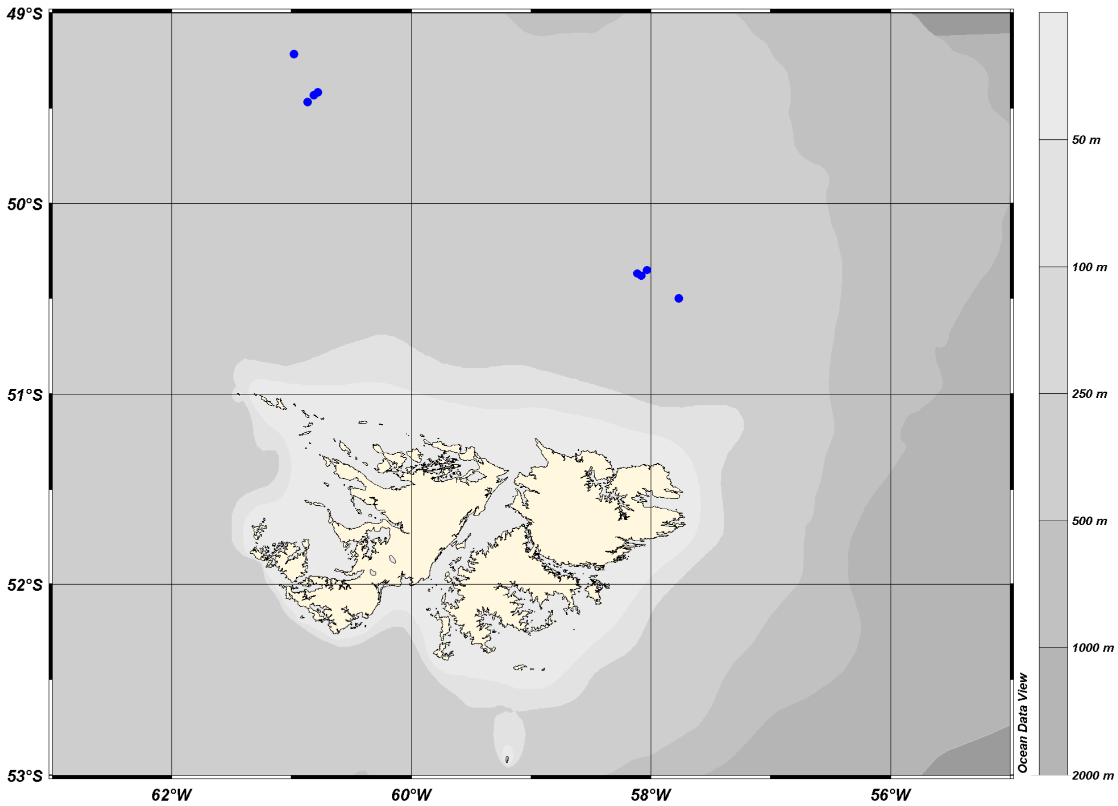


Figure 3.30 Oceanographic stations for ZDLT1-04-2012

Bottom temperatures varied from 5.57 – 7.25 ºC in Area 1, and 7.22 to 7.43 ºC in Area 2. Respective values of salinity were 33.86-33.88‰ and 33.76-33.80‰.

At the surface, temperatures varied from 7.86-8.38 °C in Area 1, and 8.65 to 9.24°C in Area 2. Respective values of salinity were 33.77-33.80‰ and 33.71-33.72‰.

Temperature and salinity profiles are summarised in Figure 3.31. Generally waters in the more eastern stations were slightly colder and more saline (i.e. higher density). These differences suggest differing water masses between Areas, with Area 1 being closer to the southern proximity of the Falkland Current mainstream.

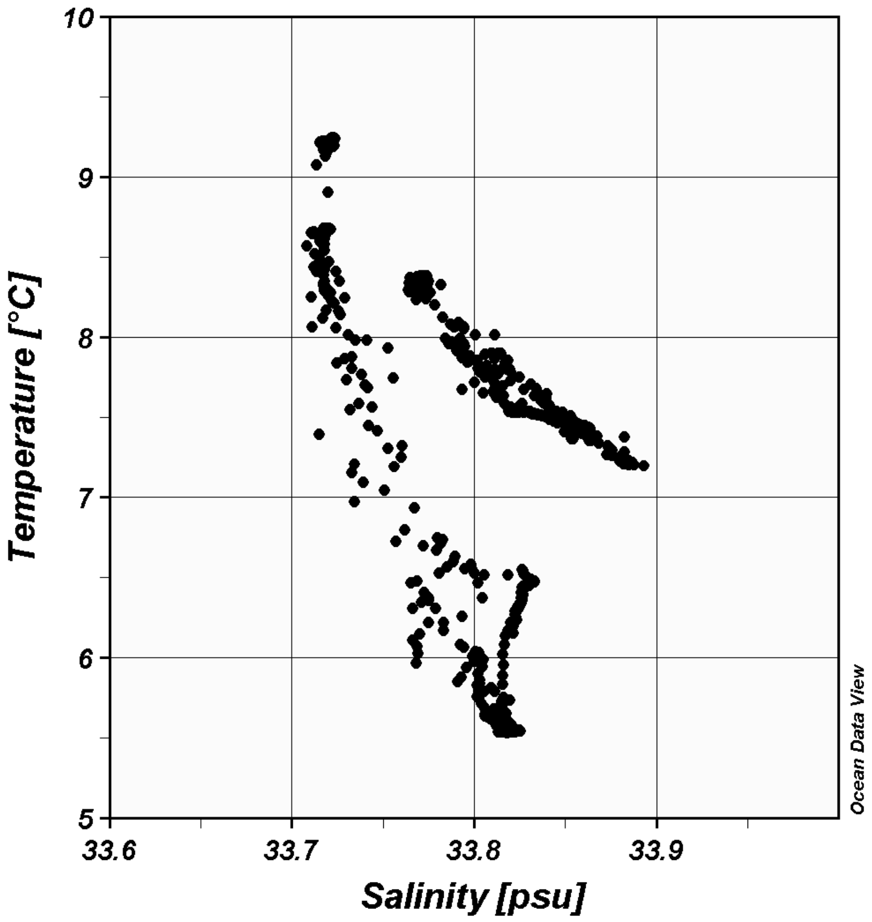


Figure 3.31 T-S curves throughout the water column on the Falkland shelf in April 2012 in the nothwestern area (left “cloud” of dots) and in the eastern area (right “cloud” of dots)

4.0 Conclusions and Recommendations

The 2nd codend mesh size research cruise confirmed that larger mesh sizes (120 mm and 140 mm) effectively increase retention probabilities for commercial-size rock cod while decreasing numbers of smaller size fish (rock cod, kingclip, hake) and skates in the catch. Results demonstrate a reduction in average catch weight in the larger (140 mm) mesh codend that corresponds to a reduction in catches of either discard-size or vulnerable-size (i.e. immature) specimens, as opposed to a reduction in process weights. Differences in species catch composition between areas were independent from mesh size effects.

Increasing the minimum codend mesh size to 120 mm in finfish fisheries can therefore be expected to maintain or improve fishery efficiency for finfish, have limited impacts on fishery efficiency for *Illex* (depending on area and stock abundance), have no effect on catch composition by species, and contribute to enhance fishery sustainability for finfish and skates in the long-term.

It is recommended that a third mesh size experiment be conducted in areas of high rock cod density mimicking recent year's behaviour of the finfish fleet, in order to confirm these findings prior to final recommendation and implementation of management measures.

References

Arkhipkin A, Brickle P, Laptikhovsky V (In Review) Links between marine fauna and oceanic fronts on the Patagonian Shelf break and slope. Deep-sea Research.

Bolker B M (2008) Ecological Models and Data in R. Princeton University Press, Princeton, New Jersey. 396 pp.

Bolker B M, Brooks M E, Clark C J, Geange S W, Poulsen J R, Stevens M H S and White J-S (2008) Generalized linear mixed models: a practical guide for ecology and evolution. Trends in Ecology and Evolution 24:127-135.

Brickle P and Winter A (2011) Scientific Report, Fisheries Cruise ZDLT1-11-2011. Stanley, Fisheries Department, Directorate of Natural Resources, Falkland Islands Government.

Crawley M J (2007) The R Book. John Wiley and Sons Ltd, Sussex, England. 942 pp.

Falkland Islands Government (2012) Fisheries Department Fisheries Statistics. Vol 16, 2002-2011:72pp. Stanley, FIG Fisheries Department.

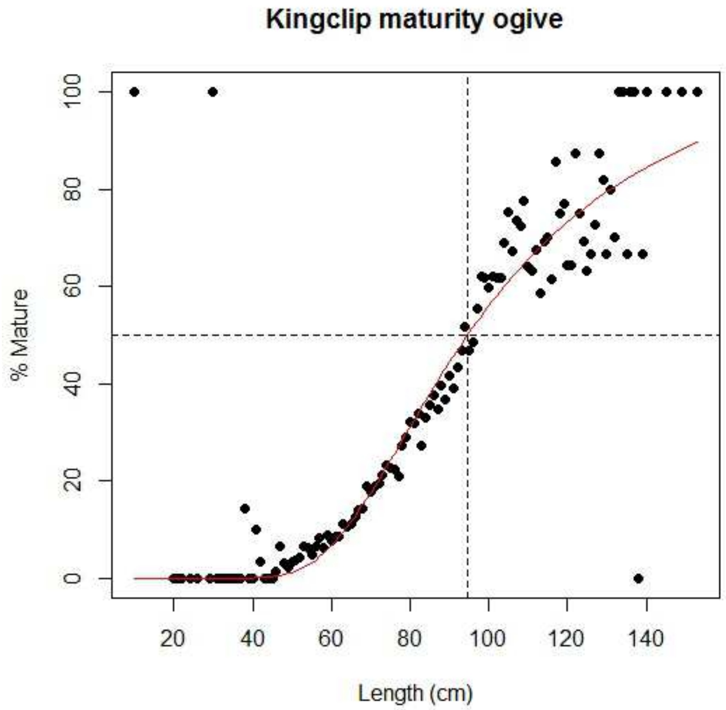
Quinn II TJ and Deriso, RB (1999) Quantitative fish dynamics. Biological Resource Management Series. Oxford University Press: New York. XV, 542 pp.

R Development Core Team (2012). R: A language and environment for statistical computing. R Foundation for Statistical Computing,Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org/.

Schlitzer R. 2009. Ocean Data View. Ver. 3.4.3. http://odv.awi.de

Appendix 1

Kingclip maturity at length as approximated using available data in the FIFD biological database (‘R’ and ‘S’ samples only). Sexual maturity here corresponded to maturity stage III and above. Dashed lines intersection indicates length of 50% maturity.



Appendix 2

Hake (*M. hubbsi*) maturity at length as approximated using available data in the FIFD biological database ('R' and 'S' samples only). Sexual maturity here corresponded to maturity stage III and above. Dashed lines intersection indicates length of 50% maturity.