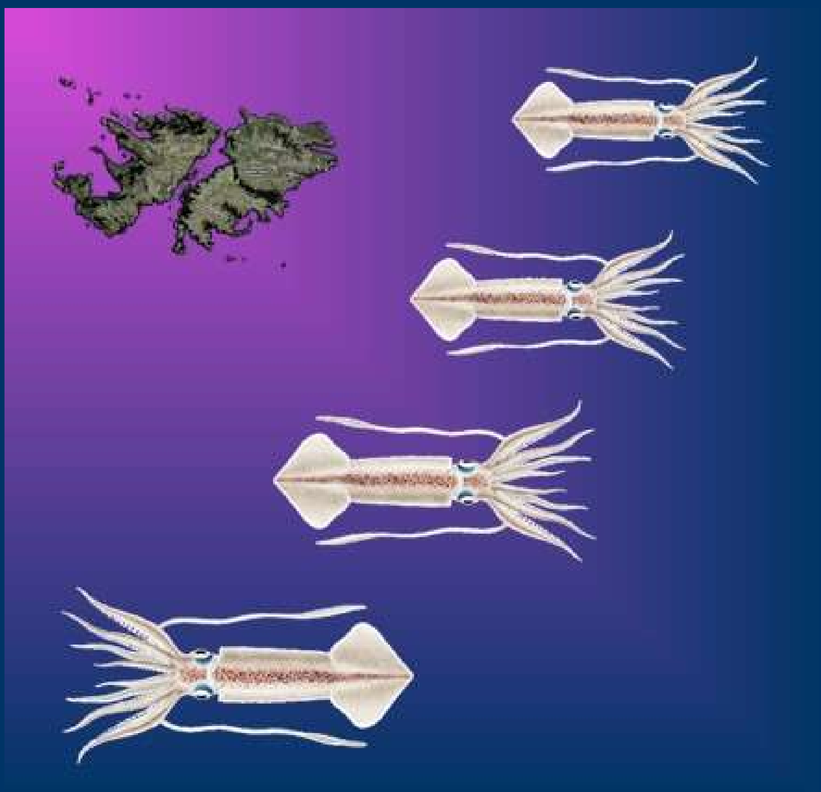
2023 Post-Season 2 Assessment Survey

Falkland calamari

(*Doryteuthis gahi*)



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ZDLO1 – S2 – 2023

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Summary

1) A post-season stock assessment survey for *Doryteuthis gahi* (Falkland calamari) was conducted in the Loligo Box from 31st August to 6th September 2023. Twenty-eight fixed-station scientific trawls were taken during the survey. The scientific catch of the survey was 41.38 tonnes *D. gahi*.
2) An estimate of 13,038 tonnes *D. gahi* (95% confidence interval: 9,421 to 16,837 t) was calculated for the fishing zone by inverse distance weighting. The inferred fishing zone was more restricted than for pre-season surveys, given the off-shore movement of *D. gahi* later in seasons. Of the total, 5,594 tonnes were estimated north of 52 ºS, and 7,444 tonnes were estimated south of 52 ºS. The survey biomass estimates were not significantly different from the season-end biomass estimates by depletion modelling, either north, south, or total.
3) *D. gahi* had significantly greater average mantle lengths and maturities north than south of 52 ºS. Males north: mean mantle length 13.72 cm; mean maturity stage 4.65, south: mantle length 12.52 cm; maturity 4.38. Females north: mantle length 12.97 cm; maturity 3.63, south: mantle length 11.96 cm; maturity 3.25.
4) Thirty-one taxa were identified in the survey catches. *D. gahi* was the largest species group at 37.9% of total catch by weight; which however was a lower percentage than any pre-season survey since 1st season 2018; a season of high medusae abundance. Hake (29.2%) and red cod (27.0%) were the second and third highest survey catches. Biological measurements and samples were taken from *D. gahi*, rock cod, toothfish, red cod, kingclip, southern blue whiting, hake, and several non-commercial species.
5) Results indicate that no further substantial immigration of *D. gahi* into the Loligo Box occurred following emergency closure of the commercial fishery. 2nd season 2023 thus stands as one of the poorest recent calamari fishing seasons, but not inherently unusual as five other 2nd seasons since 2007 have been closed early for biomass conservation.

Introduction

A stock assessment survey for *Doryteuthis gahi* (Falkland calamari – Patagonian longfin squid – colloquially *Loligo*) was carried out by the FIFD on-board the fishing vessel *Argos Pereira* from the 31st August to 6th September 2023; experimental license FK051E23. This survey was conducted following emergency closure of the commercial X-licence fishery, in particular to evaluate whether a further migration of *D. gahi* into the fishing grounds may have occurred over the following 1-2 weeks. Objectives of the survey were to:

1) Estimate the biomass and spatial distribution of *D. gahi* on the fishing grounds following closure of the X-licence fishing season.
2) Opportunistically acquire data to estimate biomass and distribution of other commercial species in the 'Loligo Box', for continued monitoring of those stocks.
3) Collect biological information on *D. gahi*, and other commercial fish species taken in the trawls.

The survey was designed to cover the 'Loligo Box' fishing zone (Arkhipkin et al. 2008, 2013) that extends along the shelf break across the southern and eastern part of the Falkland Islands Interim Conservation Zone. The delineation of the Loligo Box (Figure 1) represents an area of approximately 31,517.9 km^2, subtracting the 3-nautical mile exclusion zone around Beauchêne Island.

This survey is only the second time that an immediate post-season survey has been conducted in the *D. gahi* fishery. The previous occasion was following the 2nd season of 2009, also closed by emergency order because of low biomass (Payá and Winter 2009).

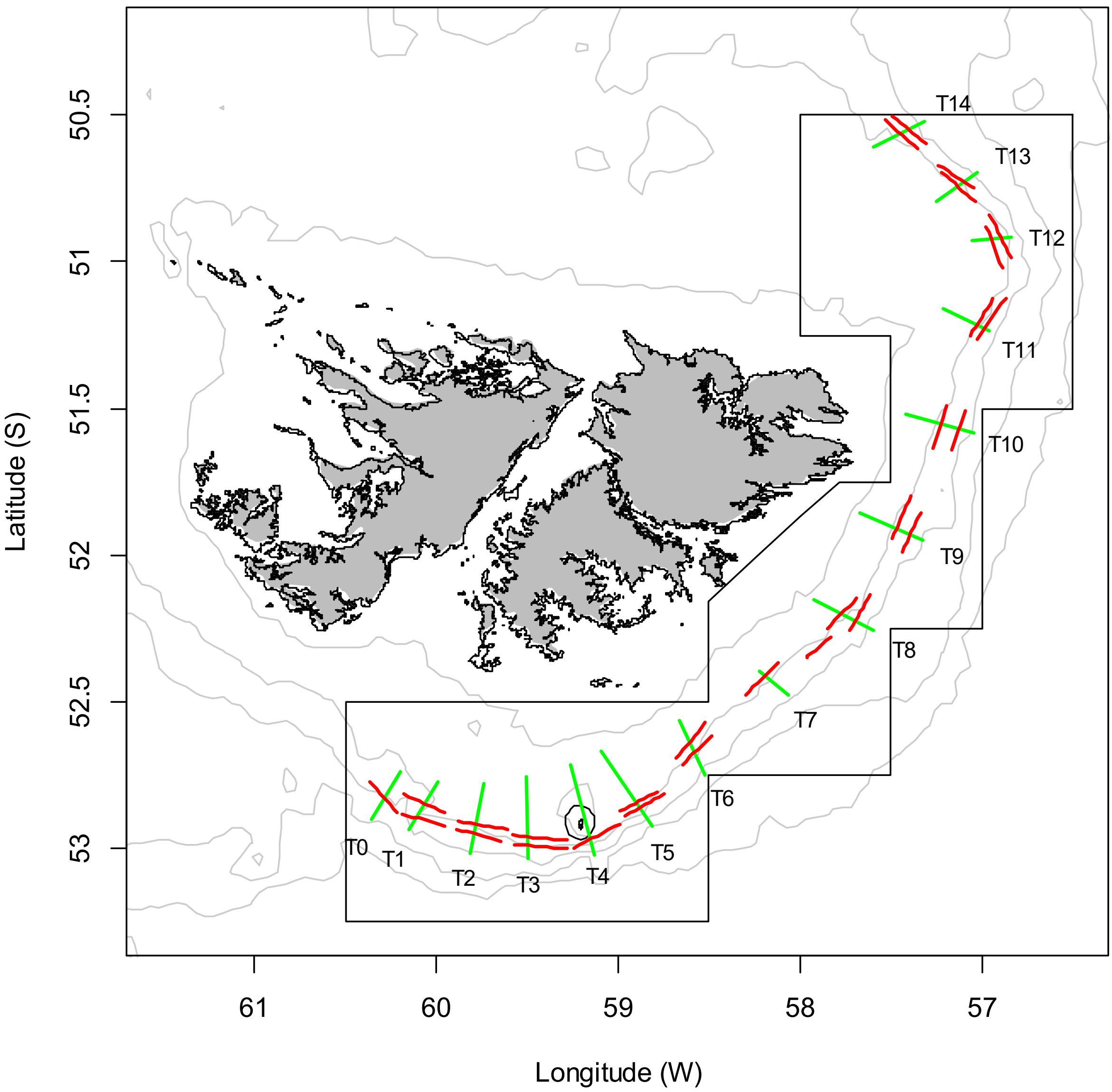

Figure 1. Survey transects (green lines), and fixed-station trawls (red) sampled during the 2nd post-season 2023 survey. Boundaries of the 'Loligo Box' and Beauchêne Island exclusion zone are in black. Isobaths (grey): 100 m, 200 m, 300 m, 400 m, 500 m.

F/V *Argos Pereira* is a Falkland Islands - registered stern trawler of 83.52 m length, 2335 GT, and 3000 main engine BHP. Like all vessels employed for *D. gahi* surveys, *Argos Pereira* operates regularly in the Falkland Islands C- and X-licenced fisheries (including 2nd season 2023), and used its commercial trawl gear for the survey catches.

The following personnel participated in the 2nd post-season 2023 survey:

Aina Amukwaya	lead observer	FIFD
Vedrana Vukasin	observer	MRAG

Methods

Sampling procedures

For this post-season survey (organized at relatively short notice), the regular survey plan was simplified to include just 28 fixed-station trawls located on the 15 transects perpendicular to the shelf break around the Loligo Box (Figure 1). Eleven of the further in-shore fixed-station trawls were disused as *D. gahi* squid occur in deeper water with progressive out-migration during the season (Hatfield and Des Clers 1998). Given the already reduced condition of the stock (e.g., Skeljo and Winter 2023), adaptive-station trawls and optional 'commercial' trawls (after survey hours) were not included in this survey.

The 28 fixed-station trawls were designed to be completed in seven days, at four stations per day. The plan of the survey was to cover each of the 28 stations twice in two successive sweeps of the Loligo Box, to maximize the opportunity of intercepting any possible new immigrations of *D. gahi* over a two-week period. However, the choice was given to the fishing vessel's management that the survey could be ended after the first week if catches were producing a poor cost-benefit outcome.

All trawl tracks were designed for an expected duration of two hours each. All trawls were bottom (demersal) trawls. The standard commercial electronic logbook format was used to record start and end trawl times, start and end GPS latitude, start and end GPS longitude, start and end bottom depth, trawl speed, sea-surface temperature, sea state, and catch (kg) per trawl of *D. gahi*. Acoustic mark scores in 15-minute intervals, as recorded for pre-season surveys (e.g., Chemshirova et al. 2023) were not recorded given the reduced scientific staffing of this post-season survey.

Catch estimation

The catch of every trawl was processed by the factory crew and retained catch weight of *D. gahi*, by size category, was calculated from the number of standard-weight blocks of frozen squid recorded by the factory supervisor. Catch weights of commercially valued fish species were also recorded from the number of blocks of frozen product, but without size categorization. Processed product weights were scaled to whole weights using standard conversion factors (FIG 2016). Total catch composition per trawl, including commercially unvalued species, damaged fish, and undersized fish, was estimated by visual estimation according to FIFD observer protocol. Non-commercial bycatches were added to the factory production weights (as applicable) to give total catch weights of all fish and squid.

Biomass calculation

Biomass density estimates of *D. gahi* per trawl were calculated as catch weight divided by swept area. The calculation of biomass density thus assumes a catchability coefficient = 1, as commonly used in fishery surveys (Somerton et al. 1999)[a]. Swept area equals the product of trawl distance × trawl width, and trawl distance was defined as the distance measurements from the start GPS position to the end GPS position of each trawl. Trawl width was derived from the distance between trawl doors (advised by *Argos Pereira*'s master as an average of 165 m) according to the equation (Seafish 2010):

trawl width = (door distance × footrope length) / (footrope length + bridle + sweep)

[a] Albeit more likely to underestimate than overestimate true density (Harley and Myers 2001); thus conservative.

Measurements of *Argos Pereira'*s trawl, provided by the vessel master, were: footrope = 180 m, sweep = 25 m, bridle = 130 m.

To maintain a computational structure equivalent to pre-season surveys, each trawl track of two hours was still subdivided into 15-minute intervals, but the *D. gahi* trawl catch was simply divided into 8 equal amounts. The algorithm was then applied that *D. gahi* amounts <100 kg were iteratively aggregated by adjacent intervals (if the total *D. gahi* catch in a trawl was <100 kg it was assigned to one interval; the middle one).

Biomass density estimates were extrapolated to the fish stock area using an inverse distance weighting algorithm (Ramos and Winter 2023). Also corresponding to the further off-shore occurrence of *D. gahi* later in a season (Hatfield and Des Clers 1998), the fish stock area was delineated to a restricted contour of 14,578.3 km^2 over the deeper part of the zone, partitioned for analysis into 579 area units of 5×5 km. As for pre-season surveys (e.g., Chemshirova et al. 2023), area units with average depth either <90 m or >400 m (of which there were nine), where calamari trawlers do not work, were assumed for analysis to comprise zero *D. gahi*. Biomass densities from all 579 area units were averaged and multiplied by the total fish stock area for total biomass, as well as separately north and south of 52 ºS; the standard sub-area demarcation (Winter and Arkhipkin 2015).

Uncertainty of the biomass density extrapolation was estimated by hierarchical bootstrapping. For 30,000 iterations a number of survey trawls equivalent to the total number were randomly selected with replacement, and within each selected survey trawl its 15-minute intervals were randomly selected with replacement. The trawl's catch was re-proportioned according to the intervals selected, thus varying the spatial distribution of the catch over that trawl track. When applicable, the aggregation of *D. gahi* amounts <100 kg (see Sampling procedures) was summed to an interval of the trawl also chosen randomly; not necessarily the middle interval. At each of the 30,000 iterations, the inverse distance weighting algorithm was re-calculated over the 5 × 5 km area units.

Biomass distributions for the total fishing area, and north and south sub-areas, were compared with season-end estimates of the in-season depletion models (Skeljo and Winter 2023), as the proportions of randomized season-end MCMC iterations that were either greater or lesser than the proportions of post-season survey iterations.

Biological analyses

Random samples of *D. gahi* (target n = 150, as far as available) were collected from the factory at all trawl stations. Biological analysis at sea included measurements of the dorsal mantle length rounded down to the nearest half-centimetre, sex, and maturity stage scored by inspection of the gonads. Statistical significance of sex ratio departures from 50/50, in total and by station, was evaluated with randomized re-sampling. Statistical significance of differences in mantle length and maturity stage distributions were evaluated with Kruskal-Wallis tests (Kruskal and Wallis 1952). Trends in the time series of mantle lengths from the start of the season (30th July) to the end of the survey (6th September) were evaluated with generalized additive models (GAM).

Some specimens of *D. gahi* were subsampled for statoliths and calculation of the length-weight relationship. Samples for otoliths, length / frequency, and length / weight data were taken opportunistically from other fish species.

Results

Catch rates and distribution

The survey was ended by decision of the vessel's management after one week, due to low *D. gahi* catches. Over that one week, the survey was started in the south-west of the Loligo Box, to avoid bad weather. The survey proceeded from south to northward for the first 5 days, before moving to the furthest stations north on the sixth day, then south again to finish closest to port on the seventh and last day (Table A1). A schedule of 4 scientific trawls per day was maintained every day, resulting in 28 scientific trawls catching 41.38 tonnes *D. gahi*. The mean of 41.38/28 = 1.48 tonnes per trawl is lower than for any 2nd pre-season survey on record (e.g., Chemshirova et al. 2023), although higher than the 2nd post-season survey of 2009 excluding adaptive trawls (Payá and Winter 2009). Areal *D. gahi* catch densities (Figure 2) averaged 0.705 t km^{-2} north of 52º S; very similar to the pre-season survey (Chemshirova et al. 2023), 1.202 t km^{-2} south of 52º S, and 0.988 t km^{-2} combined. Overall, the areal catch density averages were likewise lower than for any 2nd pre-season survey on record.

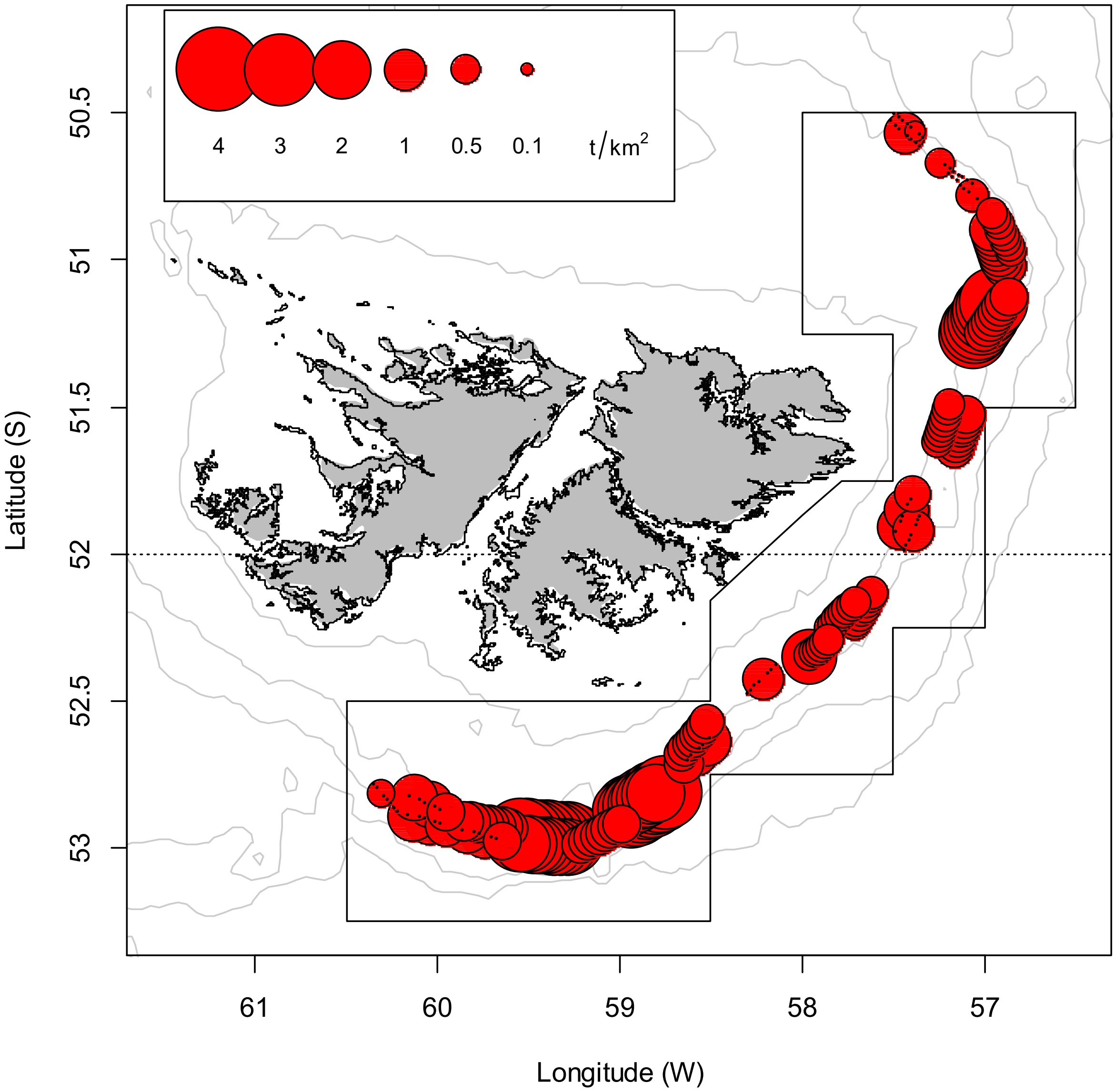

Figure 2. *D. gahi* CPUE (t km^{-2}) of survey trawls per 15-minute trawl interval. Boundaries of the 'Loligo Box' fishing zone are traced in black. Dotted line: 52°S latitude parallel, dividing north and south assessment sub-areas.

Biomass estimation

Total *D. gahi* biomass in the fish stock area was estimated at 13,038 tonnes, with a 95% confidence interval of [9,421 to 16,837 t]. Partition of the estimated biomass was 5,594 tonnes north [2,956 to 7,746 t] vs. 7,444 tonnes south [5,250 to 10,601 t]. Within the north sub-area 50% of *D. gahi* density was aggregated in 41 of 280 5×5 km area units, and 95% of density was aggregated in 157 of the 280 5×5 km area units (Figure 3). Within the south sub-area 50% of *D. gahi* density was aggregated in 51 of 290 5×5 km area units, and 95% of density was aggregated in 189 of the 290 5×5 km area units (Figure 3).

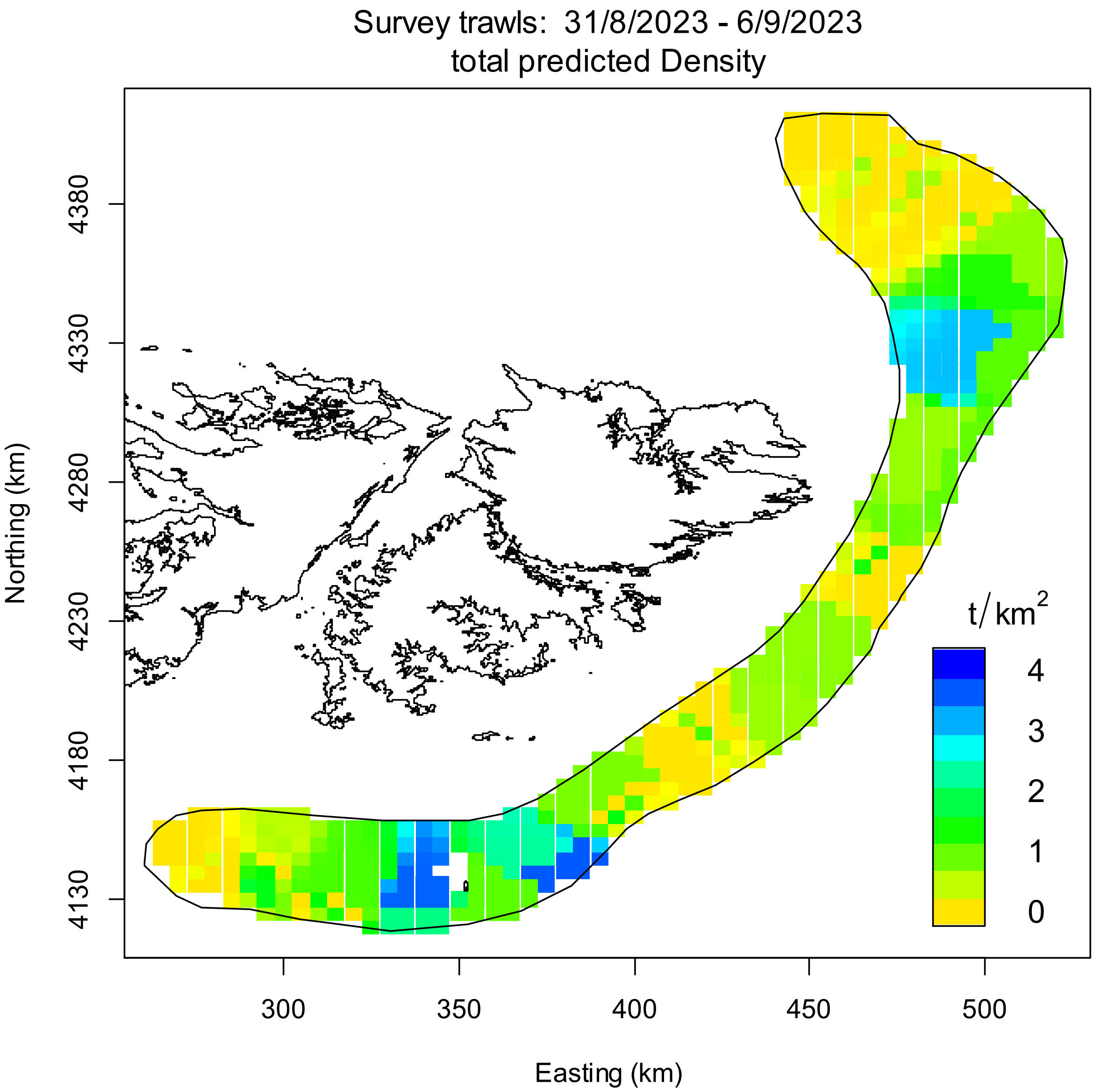

Figure 3. *D. gahi* predicted density estimates per 5 km^2 area units. Blank area units within the perimeter are either <90 or >400 m average depth. Coordinates were converted to WGS 84 projection in UTM sector 21F using the R library rgdal (proj.maptools.org).

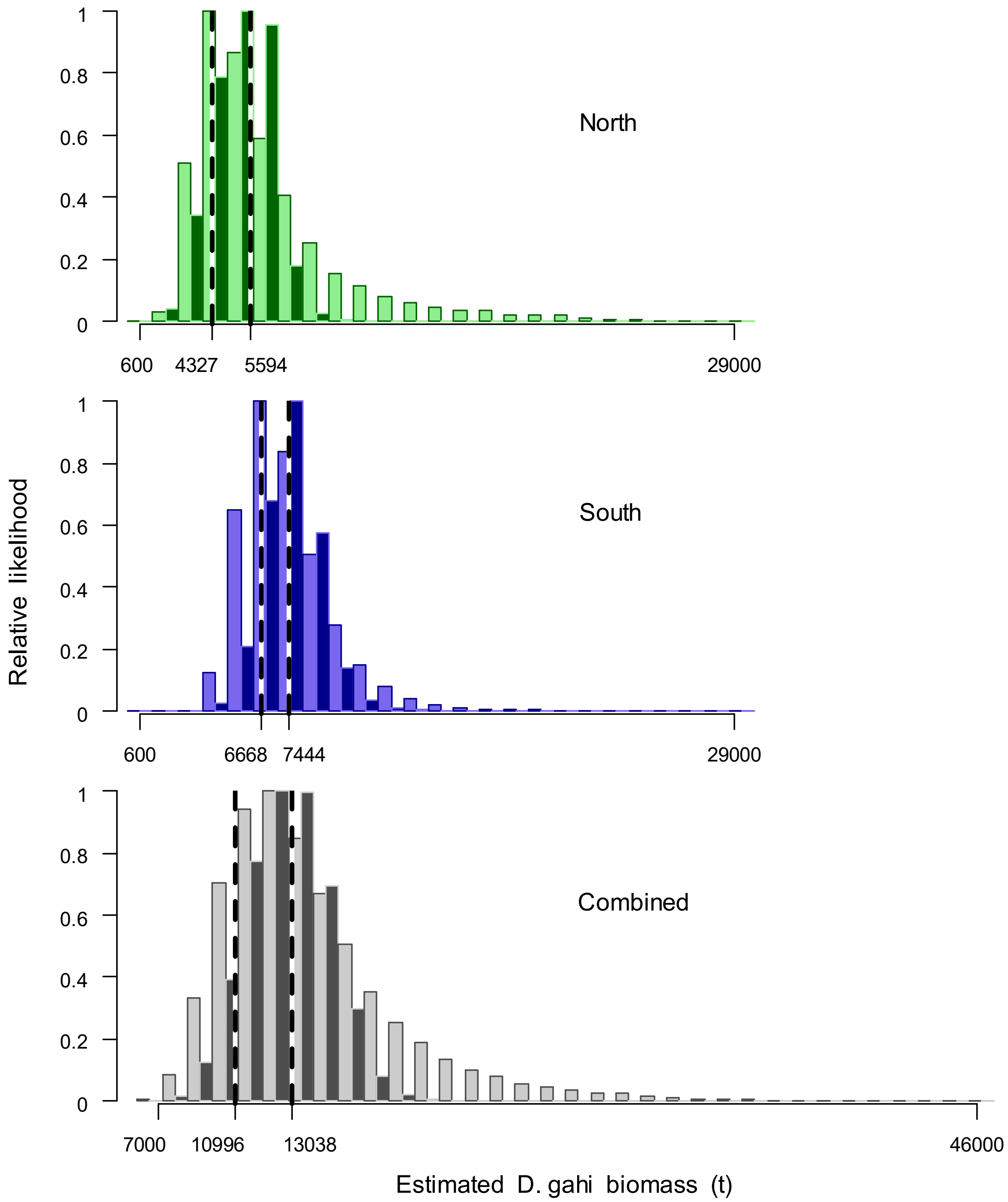

Figure 4. Variability distributions of end-of-season depletion biomass estimates (light shades of green, purple, grey) and post-season survey biomass estimates (dark shades of green, purple, grey). Vertical broken lines: the respective maximum likelihood biomass estimates. End-of-season depletion biomass estimates are comparable to respectively Figures 8-right, 6-right (multiplied by $e^{-M/2}$) and 10 in Skeljo and Winter (2023).

Survey biomass estimates of *D. gahi* were not significantly different from season-end depletion model estimates ($p > 0.10$) for either the total (13038 vs. 10996 t) or north (5594 vs. 4327 t) or south sub-areas (7444 vs. 6668 t) (Figure 4).

Thirty-one taxa were identified in the survey catches. *D. gahi* comprised 37.9% of the total catch weight (Table A2), lower than any pre-season survey percentage since 1st season 2018, which was a season of high medusae abundance (Winter et al. 2018). Seventeen of the 28 survey trawl stations had *D. gahi* as highest catch, the nine deepest survey trawl stations had hake *Merluccius hubbsi* as highest catch, and two stations near the centre of the Loligo Box had red cod *Salilota australis* as highest catch. Over 90% of the survey's total red cod catch was taken at one station; 690 (Table A1).

Biological data

During the survey a total of 4249 *D. gahi* were measured for length and maturity (1812 north, 2541 south), from each of the 28 trawl stations. The total sex ratio was significantly ($p < 0.0001$) majority female. Sixteen individual trawl stations had a significant preponderance of females, and four individual trawl stations had a significant preponderance of males; all four of these stations were within the first two survey days in the south. *D. gahi* typically show sexually segregated distributions (Arkhipkin and Middleton 2002). For both males and females, maturity and mantle length distributions were significantly greater north than south (Table 1, Kruskal-Wallis test, $p < 0.01$).

In the north sub-area, mantle lengths showed a trend of increasing average size over the last three days of the survey (Figure 5). In the south sub-area, mantle lengths initially increased and on the second day of the survey (day 244) reached the highest median value jointly with day 241 at 13 cm. Median mantle length then decreased over the last two days of the survey in the south (Figure 5).

Table 1. *D. gahi* mean maturities and dorsal mantle lengths by sub-area and sex. Maturities scored on a scale of 1 to 6; Lipinski 1979.

Sub-area	Sex	Mean maturity	Mean mantle length (cm)
North	M	4.65	13.72
	F	3.63	12.97
South	M	4.38	12.52
	F	3.25	11.96

545 of the *D. gahi*, and 132 specimens of other species, were sampled for otoliths and/or length weight distributions (Table A3).

Pinniped observations

The 2nd post-season survey 2023 was conducted with seal exclusion devices (SED) in all trawls, to align with compulsory SED use in the commercial X-licence fishery. A total of five South American fur seals *Arctocephalus australis* were observed escaping from the SED just before the net was hauled, on four different trawls, all within the first three days of the survey and south of 52°S latitude.

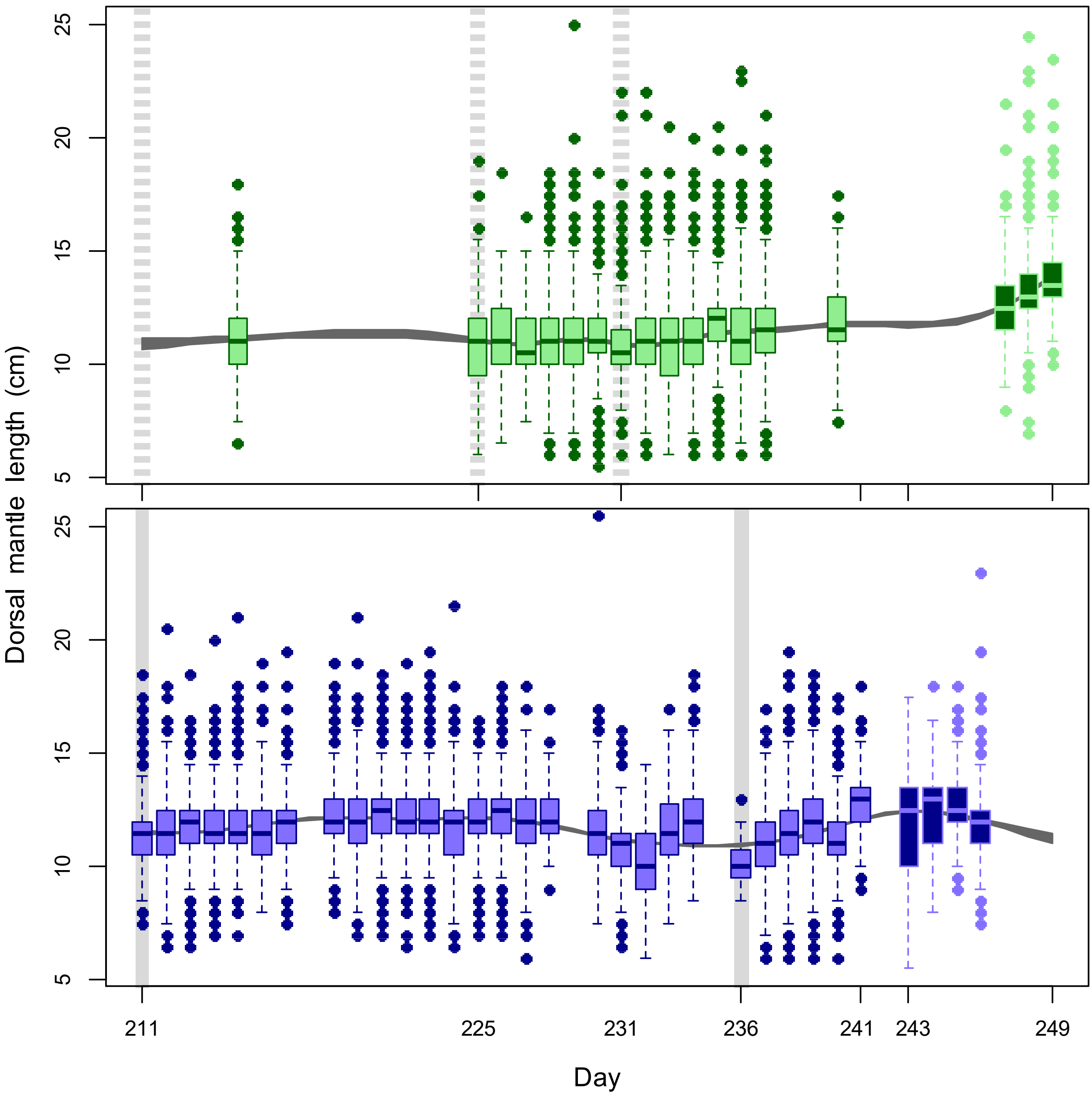

Figure 5. *D. gahi* length-frequency boxplots by day in-season (day 211 to 241, light with dark borders) and post-season (day 243 to 249, dark with light borders). Top panel (green): north-sub-area, bottom panel (purple): south sub-area. For visibility plots are censored to a maximum of 25 cm, thereby excluding 3 lengths north and one length south. Light grey vertical bars: days of in-season immigrations. Dark grey lines: 95% confidence intervals of the GAM trends of dorsal mantle lengths by day.

Conclusions on further *D. gahi* immigration

The absence of any notable increase in catch rates, compared to the last days of the commercial X season, and absence of post-season survey *D. gahi* biomass estimates significantly higher than the season-end biomass estimates, indicates that a substantial further immigration into the fishing zone did not occur during the period of the post-season survey. The slightly decreasing trend in mantle lengths in the south over 3 days showed that some successively smaller, and therefore younger, *D. gahi* were progressively encountered, but this did not correlate with higher catch tonnage.

Immigrations later than the end of August have been recorded in most years since 2007 (the occurrence of in-season immigration was not consistently defined before 2007), but only in two of the six seasons since 2007 that were closed early by order for biomass conservation: 2009 and 2019. The outcome suggests that 2023 has been among the poorest 2nd seasons, but not inherently unusual.

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Appendix

Table A1. Survey stations with total *Doryteuthis gahi* catch. Latitude: °S, longitude: °W.

Transect	Data Station	Date	Start			End			Depth (m)	*D. gahi* (kg)
			Time	Lat	Lon	Time	Lat	Lon		
0	676	31/08/2023	07:10	52.77	60.37	09:10	52.88	60.22	245	91
1	677	31/08/2023	10:05	52.82	60.18	12:05	52.88	59.95	193	710
2	678	31/08/2023	12:55	52.91	59.88	14:55	52.94	59.60	173	1769
3	679	31/08/2023	15:55	52.96	59.58	17:55	52.98	59.28	179	6151
1	680	01/09/2023	07:10	52.88	60.18	09:10	52.92	59.95	230	774
2	681	01/09/2023	10:00	52.94	59.89	12:00	52.98	59.64	234	740
3	682	01/09/2023	12:55	52.99	59.57	14:55	53.00	59.28	232	3586
4	683	01/09/2023	15:50	53.00	59.24	17:50	52.92	58.99	209	1648
5	684	02/09/2023	06:55	52.81	58.78	08:55	52.88	58.99	143	3112
5	685	02/09/2023	09:40	52.89	58.96	11:40	52.81	58.74	190	5196
6	686	02/09/2023	12:50	52.70	58.68	14:50	52.57	58.52	161	1210
6	687	02/09/2023	15:40	52.62	58.48	17:40	52.72	58.64	237	743
8	688	03/09/2023	07:00	52.26	57.73	09:00	52.13	57.61	260	1007
8	689	03/09/2023	09:55	52.15	57.69	11:55	52.25	57.85	202	951
7	[A] 690	03/09/2023	12:50	52.28	57.83	14:25	52.35	57.96	182	740
7	691	03/09/2023	15:35	52.37	58.12	17:35	52.48	58.30	174	218
9	692	04/09/2023	07:00	51.85	57.34	09:00	51.99	57.44	283	201
9	693	04/09/2023	10:00	51.94	57.49	12:00	51.80	57.39	213	689
10	694	04/09/2023	13:10	51.63	57.26	15:10	51.49	57.19	224	965
10	695	04/09/2023	16:05	51.51	57.09	18:05	51.64	57.16	285	1314
14	696	05/09/2023	07:00	50.59	57.31	09:00	50.50	57.49	285	60
14	697	05/09/2023	10:00	50.52	57.53	12:00	50.62	57.35	248	211
13	698	05/09/2023	13:05	50.70	57.22	15:05	50.79	57.04	248	132
13	699	05/09/2023	15:55	50.75	57.04	17:55	50.67	57.24	285	108
11	700	06/09/2023	06:45	51.27	57.03	08:45	51.13	56.87	269	1630
12	701	06/09/2023	09:55	50.99	56.84	11:55	50.84	56.95	241	1100
12	702	06/09/2023	12:55	50.88	56.97	14:55	51.02	56.89	122	1838
11	703	06/09/2023	15:55	51.13	56.94	17:55	51.25	57.06	139	4486

[A]: Trawl stopped early after the net sensors detected a fault, but this turned out to be an exceptionally large catch of red cod.

Table A2. Empirical estimates of survey total catches by species / taxon. Note that sample (kg) refers to all samples brought on board, some of which may subsequently not be included in the FIFD database.

Species Code	Species / Taxon	Total catch (kg)	Total catch (%)	Sample (kg)	Discard (kg)
LOL	*Doryteuthis gahi*	41380	37.9	207	864
HAK	*Merluccius hubbsi*	31878	29.2	0	310
BAC	*Salilota australis*	29490	27.0	266	130
PAR	*Patagonotothen ramsayi*	2771	2.5	15	2771
PTE	*Patagonotothen tessellata*	998	0.9	0	998
CGO	*Cottoperca gobio*	591	0.5	0	591
BLU	*Micromesistius australis*	483	0.4	1	483
TOO	*Dissostichus eleginoides*	236	0.2	56	236
DGH	*Schroederichthys bivius*	231	0.2	6	231
WHI	*Macruronus magellanicus*	175	0.2	0	175

ZYP	*Zygochlamys patagonica*	166	0.2	0	166
MUL	*Eleginops maclovinus*	146	0.1	8	146
GRC	*Macrourus carinatus*	83	0.1	32	83
MED	Medusa sp.	54	<0.1	0	54
ING	*Onykia ingens*	54	<0.1	0	54
RAY	Rajiformes	51	<0.1	0	51
GOC	*Gorgonocephalus chilensis*	50	<0.1	0	50
LIM	*Lithodes murrayi*	49	<0.1	0	49
KIN	*Genypterus blacodes*	48	<0.1	1	48
SAR	*Sprattus fuegensis*	45	<0.1	0	45
RBR	*Bathyraja brachyurops*	37	<0.1	0	37
OCT	Octopus sp.	29	<0.1	0	29
GRF	*Coelorinchus fasciatus*	26	<0.1	0	26
RFL	*Dipturus lamillai*	23	<0.1	0	23
RAL	*Bathyraja albomaculata*	14	<0.1	0	14
EEL	*Iluocoetes*/*Patagolycus* mix	14	<0.1	0	14
RDO	*Amblyraja doellojuradoi*	10	<0.1	0	10
RMC	*Bathyraja macloviana*	8	<0.1	0	8
RGR	*Bathyraja griseocauda*	3	<0.1	0	3
CHE	*Champsocephalus esox*	3	<0.1	0	3
ILL	*Illex argentinus*	2	<0.1	0	2
		109,148		592	7,704

Table A3. Summary of sample numbers by species by sex taken during the survey.

Species		N specimens			
		Lengths		Weights	
		M	F	M	F
Falkland calamari	*Doryteuthis gahi*	1758	2595	218	327
Toothfish	*Dissostichus eleginoides*	37	52	37	52
Common Rock cod	*Patagonotothen ramsayi*	193	108	0	0
Southern Blue Whiting	*Micromesistius australis*	2	0	2	0
Hake	*Merluccius hubbsi*	22	281	0	0
Kingclip	*Genypterus blacodes*	0	2	0	2
Red cod	*Salilota australis*	39	61	0	0
Grenadier	*Macrourus carinatus*	1	14	1	14
Mullet	*Eleginops maclovinus*	2	1	2	1
Catshark	*Schroederichthys bivius*	8	13	8	13