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Northwest Atlantic Fisheries Organization

Serial No. N2701

NAFO SCR DOC. 96/28

SCIENTIFIC COUNCIL MEETING - JUNE 1996

Report on the Comparative Fishing Trial Between the *Gadus Atlantica* and *Teleost*

by

William G. Warren
Science Branch, Department of Fisheries and Oceans
P. O. Box 5667, St. John's, Newfoundland, Canada A1C 5X1

SUMMARY

Equations are developed for converting catches at length, of five major groundfish species, obtained by the *Gadus Atlantica* using 30 minute tows with Engel 145 High Lift otter trawl to *Teleost* equivalents (15 minute tows with the Campelen 1800 shrimp trawl). Paired tows were employed and criteria developed for determining whether one vessel fished on a aggregation essentially missed by the other vessel; such pairs were omitted from the final analysis. Bootstrap distributions were used for estimating the precision of the conversions. Because the Campelen 1800 is more efficient at catching small fish than the Engel 145 and because of the current scarcity of larger fish, extrapolation in either direction beyond the ranges indicated cannot be justified.

Introduction

In 1995 the *Teleost* replaced the *Gadus Atlantica* as a research vessel for the Newfoundland Region of the Department of Fisheries and Oceans. The change in vessel was accompanied by a change in the net used for trawl surveys of groundfish; specifically, the Engel 145 High Lift otter trawl was replaced by the Campelen 1800 shrimp trawl. The latter is known to be more efficient in catching the smaller fish. To maintain the continuity of the time series of the groundfish research trawl surveys, a comparative fishing exercise was undertaken early in 1995 to derive factors by which the catches prior to 1995, carried out by the *Gadus Atlantica* with the Engel net, could be converted to values equivalent to what would have been obtained by the *Teleost* with the Campelen net.

The exercise was carried out by having the vessels make paired tows. The objective in so doing was to reduce one source of variation in order to focus on the difference between vessel/net combinations *per se.* In general, the vessels fished at the same time along parallel courses, although the length of tow for the *Teleost* was 15 minutes (the new standard) while that for the *Gadus Atlantica* was 30 minutes (the old standard). The vessel speeds were 3.0 and 3.5 knots respectively. The ships remained as close as safety considerations permitted. The procedure differed somewhat in areas where the sea bottom sloped too much for parallel tows to be at effectively the same depth. In this circumstance one vessel followed the other (with the order being alternated) while ensuring that there was no overlap in the areas trawled. The numbers of fish caught were recorded by 1 cm. length classes for each of five species, namely Atlantic cod (*Gadus morhua*), American plaice (*Hippoglossoides platessoides*), Greenland halibut commonly known as turbot (*Reinharditus hippoglossoides*), witch flounder (*Glyptocephalus cynoglossus*) and redfish (*Sebastes mentella*). A total of 285 successful paired tows, spread over three trips, was accomplished in February-March 1995.

Methodology

It was immediately obvious from a scanning of the data that any conversion would have to be length based. Plots of the logarithm of the ratio of the number caught by the *Teleost* to the number caught by the *Gadus Atlantica* against fish length revealed, for each of the five species, a seemingly steeply declining almost linear trend, with a tendency to flatten out at the longest lengths. Specifically, the ratio fell from values in the range of 20-60, depending on species, to something approaching 1/2, which, allowing for the difference in trawling times, would correspond to roughly equal efficiency.

Something of a departure of the above occurred for redfish. Here the ratio declined to a minimum of 0.7 at length 25 cm., then rapidly increased to a peak of 2.0 at 31 cm., before gradually falling to values < 1.0. An examination of the data revealed one obvious instance where, in spite of the effort made to have the vessels fish on equivalent fish densities, it was clear that the *Teleost* had fished on an extremely dense aggregation that was, in effect, entirely missed by the *Gadus Atlantica.* Further examination of the data suggested that this, although by far the most graphic, was not a unique happening. It should, perhaps, not have been unexpected for redfish, which is known, at times, to occur in relatively small, highly dense clusters.

This prompted the quest for an objective criterion for determining which pairs should be regarded as outliers and omitted from, or at least downweighted in, the analysis.

For any of the paired trawls and a particular length class, there are four possibilities.

(1) The catch for each vessel is zero. If this occurs over all length classes, it seems likely that fish of the species in question were not present in the region of this pair of sets. Such pairs are noninformative and thus excluded from further consideration. Catches of other species will, of course, not necessarily be zero.

(2) The catch for the *Gadus Atlantica* is zero but that for the *Teleost* non-zero. This could arise because of the greater efficiency of the Campelen net on the *Teleost,* particularly with the shorter length classes, or because the *Teleost* fished on an aggregation largely missed by the *Gadus Atlantica.* In the latter case, one would expect this pattern to occur over several length classes.

(3) The catch for the *Teleost* is zero but that for the *Gadus Atlantica* non-zero. This would likely arise again over several length classes, if the *Gadus Altantica* fished on an aggregation largely missed by the *Teleost.* With fish present, it would be possible for the *Gadus Atlantica* to catch one or a few fish of, in particular, a longer length class, while the *Teleost* caught none of that class.

(4) Both vessels have non-zero catches.

For the last-mentioned case, one can form, for each trawl pair, the ratio of the number caught by the *Teleost* to the number caught by the *Gadus Atlantica.* Recall that this is being done for a particular length class. Plots on normal probability paper of the empirical cumulative distribution of the logarithms of these ratios, taken over all pairs within this category (and length class) show most points falling on, more or less, straight lines, with occassional outliers at the upper end. Not much should be read into a single outlier but, if there are outliers associated with the same trawl pair for a sufficient number of length classes, this may be taken as evidence that the *Teleost* fished on an aggregation more or less missed by the *Gadus Atlantica.* The procedure given by Aitkin and Wilson (1980) was used to identify outliers of this kind in each length class.

There may also be information in case (2) to assist in the identification of outliers. With the *Gadus Atlantica* catch as zero, it seems reasonable to suppose that the *Teleost* catch, apart from outliers, would follow a Poisson distribution. This means that one must also consider the cases where the *Teleost* catch (for the particular length class) is also zero. However the number of zero *Teleost* catches, in general, exceeds the number that would be expected on the basis of the non-zero frequencies. The zero *Teleost* catches are of two types. Some arise because there are no fish of that length class in the region of the trawl pair. Recall that, while trawl pairs with zero catch over *all* length classes have been eliminated, there will remain trawl pairs where fish are present over a range of lengths, but not over all lengths. The remaining zeros arise from the chance of a zero catch although fish of that length are present in the region of the trawl. These would be, so to speak, the real Poisson zeros.

To deal with the above situation, we introduce the "mixed delta Poisson" distribution. We define

$$P(Y < 0) = 0$$
$$P(Y = 0) = \delta + (1 - \delta)f(0)$$
$$P(Y = i) = (1 - \delta)f(i), \quad i > 0$$

This is structurally the same as the delta (lognormal) distribution (Aitchison and Brown 1957, see also Pennington 1983) but with the lognormal density replaced by the Poisson density $f(i) = \lambda^i e^{-\lambda}/i!$. To accomodate the possibility of outliers, we the replace the Poisson by a mixture of Poissons, i.e. $f(i) = \pi f_1(i) + (1 - \pi)f_2(i)$ where $f_j(i) = \lambda_j e^{-\lambda_j}/i!$. (The idea can be extended to multiple mixtures; then $f(i) = \sum_j^k \pi_j f_j(i)$, $k > 2$ with $\sum_j^k \pi_j = 1$). With n_0 as the observed number of zeros in a sample of size n ($n = n_0 + n_1$), the likelihood of the sample can be written

$$L = [\delta + (1 - \delta)f(0)]^{n_0} \prod^{n_1} (1 - \delta)f(i)$$

The parameter estimates are then obtained by finding those values that maximize L (or, equivalently, $\log L$). The probability that observation i comes from population (distribution) 1 is

$$P(1|i) = \pi f_1(i)/[\pi f_1(i) + (1 - \pi)f_2(i)] = \pi f_1(i)/f(i) = 1 - P(2|i)$$

Details are given in Warren (in prep.)

The above has considered the detection of cases where the *Teleost* fished on aggregations essentially missed by the *Gadus Atlantica*. It is equally likely that the *Gadus Atlantica* could fish on aggregations essentially missed by the *Teleost*. To detect such cases we follow the above procedure but with the ratio replaced by the number caught by the *Gadus Atlantica* to the number caught by the *Teleost* and the information from case (3) replacing that from case (2).

The procedure is illustrated in the Appendix.

Results

For redfish, for the 250 trawl pairs in which fish were caught by one or both vessels, application of the criterion outlined above identified three trawl pairs where the *Teleost* clearly appeared to have fished on an aggregation missed by the *Gadus Atlantica* and five trawl pairs where the *Gadus Atlantica* fished on an aggregation missed by the *Teleost*. With these 8 pairs removed from the data, the trend of the logarithm of the ratio (*Teleost* counts/*Gadus Atlantica* counts) was in concordance with that observed for the other species. It transpired that the outlying, and therefore removed, *Gadus Atlantica* counts came mainly from the 20-30 cm length classes, whereas those from the *Teleost* came mainly from the 30-40 cm. classes.

A few outliers were identified for American plaice, turbot and witch flounder, however, these were such that their removal had an almost imperceptible effect of the trend of the ratios with length class. Accordingly, these pairs were not eliminated in calculating the estimates that follow.

For Atlantic cod, however, the removal of six trawl pairs (out of 242) in four of which the *Teleost* apparently fished on aggregations missed by the *Gadus Atlantica* and *vice versa* for the other two, did result in a noticeable change in the trend. Before the removal of these pairs, the flattening of of the trend with the longer length classes was less marked than with the other species. The removal of these six pairs resulted in the curvature of the trend being more in concordance with the others. Further, initially, the trend seemed to fall well below 0.5, whereas with the removal of these pairs, it appears to be tending towards 0.5. This comes about from the outlying and therefore removed *Gadus Atlantica* counts belonging more to the longer length classes. It is believed that the removal of the six pairs is appropriate in generating the final estimates. This is also supported by the numerical aspects presented below.

There was no *a priori* information as to the functional form, if any, of the relationship between the ratio of the numbers caught (y) and their length (x). After a certain amount of trial and error, a relationship of the form

$$y = ax^b e^{cx}$$

fitted as

$$\log(y) = \log(a) + b\log(x) + cx$$

was found to provide an excellent tracking of the data for all five species. It is noted that the above has a minimum $(= a(-b/c)^b e^{-b})$ when $x = -b/c$. The consequences of this will be discussed below.

Fitting was by weighted least squares. The weights were taken as the number of trawls going into the estimate of the ratio for a length class. Note that the ratio was obtained as the total catch (of a particular length class) by the *Teleost* to the total catch (of the same length class) by the *Gadus Atlantica*, and not as the mean of the ratios. However, as described above, the distribution of the individual ratios was used to detect and eliminate outliers.

Because of the greater ability of the Campelen net to catch small fish, there are lower limits to the lengths that can be used in fitting. These limits are determined by the catches made by the Engel net (on the *Gadus Atlantica*) and vary by species. For the data collected they are 16, 7, 11, 10 and 9 cm. for cod, plaice, turbot, witch flounder and redfish, respectively. Not surprisingly, the sample ratios at lengths slightly greater than these limits are relatively widely scattered, albeit somewhat equally, about the trend suggested by the main body of the data.

Similarly, because of the scarcity of large fish, the ratios for the longest length classes are also somewhat widely scattered. Accordingly, for each species, an upper limit on length was chosen, somewhat subjectively, on the grounds that the ratios at greater lengths, other than 0 or ∞, (often stemming from just one or two fish) were not sufficiently representative to justify their inclusion. Indeed, above the limits chosen there were very few instances where the *Teleost* and *Gadus Atlantica* both caught fish of the same length class. These could possibly have been "binned" and thus included in the fitting. We decided against this because, particularly in the case of Atlantic cod, the bin widths would have had to have been substantial and, with the potential curvature of the relationship, the ratios so obtained might not be strictly representative of the assigned length and also would receive very little weight.

Occasionally, within the range of lengths utilized, there was a length class for which one or the other of the *Teleost* or *Gadus Atlantica* catches was zero. The ratios, then being either infinte or zero, were omitted from the calculations. Specific results follow.

1. Atlantic cod: The upper length limit was taken as 93 cm. although there were a few fish up to 131 cm. The least squares fit (with the 6 pairs judged to be outliers removed) is (Fig. 1)

$$\log(y) = 10.857058 + 0.0030710x - 2.654115\log(x)$$

The fit without the outliers removed is (Fig. 1a)

$$\log(y) = 9.6126328 - 0.030838x - 1.936764\log(x)$$

Note that the first equation as a minumum at $x \approx 864$, well outside the range of the data whereas in the second equation y continues to decrease as x increases. Indeed, at $x = 90$, y has dropped to

0.15, whereas the ratio based on all fish of length > 93 cm. (not included in the fit) is 0.42. This latter is in much better agreement with the first equation. Since there were no fish > 93 cm in any of the outlying pairs, the first equation appears as the more realistic.

2. American plaice: The upper length limit was initially taken as 51 cm. This led to

$$\log(y) = 9.7101373 - 0.032971x - 2.272111 \log(x)$$

As this also is a decreasing function of x, the upper limit was extended to 61 cm. This led to (Fig. 2)

$$\log(y) = 11.740705 + 0.0103355x - 3.256100 \log(x)$$

which has a minimum at $x \approx 315$, again well outside the range of the data. Up to about 40 cm length there is effectively no difference between the predicted ratios. For lengths > 40 cm., the somewhat greater values predicted by the second equation are felt to be the more appropriate.

3. Turbot: The upper length limit was taken as 63 cm. This led to (Fig. 3)

$$\log(y) = 14.123825 + 0.0910797x - 4.850857 \log(x)$$

There is a minimum ($y = 0.7347$) when $x \approx 53.26$, i.e. within the range of the data. It seems unreasonable to have y increasing for $x > 53.26$. It is therefore suggested that the above equation be used for $x \leq 53.26$ and $y = 0.7347$ for all $x > 53.26$.

4. Witch flounder: The upper length limit was taken as 58 cm. This led to (Fig. 4)

$$\log(y) = 13.234150 + 0.0367427x - 3.949935 \log(x)$$

which has a minimum at $x \approx 108$.

5. Redfish: The upper length limit was taken as 47 cm. The fit, with the 8 pairs judged to be outliers, removed is (Fig. 5)

$$\log(y) = 6.7580137 + 0.006839x - 1.927210 \log(x)$$

There is a minimum at $x \approx 282$, i.e well outside the range of the data. As noted above, failure to remove at least some of the pairs judged to be outliers leads to a relationship that clearly seems unreasonable (Fig 5a).

Precision

The precision of the above estimated relationships was determined by bootstrapping methods. Specifically bootstrap distributions covering the length range of the particular species were generated by resampling (with replacement) at the set pair level and, exactly as with the basic data, a function of the form

$$\log(y) = a + b\log(x) + cx$$

was fitted by weighted least squares. For each species, 1000 bootstrap samples were generated. The same length range as with the basic data was used and, in the case of cod and redfish, the same paired tows omitted as outliers. To keep the amount of output within reasonable bounds, evaluation was carried out at 5 cm length intervals

For convenience of presentation, the estimated 1st, 2.5th, 5th, 10th, 25th, 50th (median), 75th, 90th, 95th, 97.5th and 99th precentiles of the bootstrap distribution are presented below.

The 90% confidence intervals are illustrated in Figs. 6-10. It can be seen that, over the main body of the data, i.e. lengths from 25 to 75 cm for cod and from 15 to 45 cm for other species, the resulting confidence intervals are, perhaps, acceptably small. As one moves outside these ranges the confidence intervals will widen rapidly, and extrapolation outside the range of the data would be inadvisable.

Discussion

At the low end of the length range, the lack of precision may not be a significant problem, especially for biomass. However, when the focus is on numbers at length (or age) and the intent is the conversion of past *Gadus Atlantica* counts to equivalent *Teleost* counts, this cannot be accomplished when, as with small fish, the *Gadus Atlantica* counts are zero. It would seem that conversion will have to be limited to lengths above a critical value (possibly different for each species).

There may, however, be a significant problem at the upper end of the length range since, in the past, there appear to have been more larger fish in the population then today. The present scarcity of large fish prohibits the determination of reasonably precise conversion factors for such fish. (At this end, a small error in the conversion factor corresponds to considerably more biomass than an error at the other end). For redfish, we can justifiably flatten the estimated relationship to 0.7346 at c. 53 cm (although the 0.7346 might be a little high given the 0.5 ratio of towing times). Likewise flattening the relationships for the other species at their minima might seem a reasonable strategy, however, these minima occur at impossibly large lengths and are perhaps lower than what might be anticipated on the basis of the tow length, unless the Campelen is distinctly less effective at catching these larger fish than is the Engel. It may be that, given the shorter tow time and lower tow speed, big fish are able to escape the Campelen but not the Engel. The difficulty is that, while the parameters of the relationship can be adjusted to give a different extrapolation with negligible change in tracking the main body of the data, information is lacking on what the extrapolation should be.

Finally, it might be conjectured that the discrepanies between the *Teleost* and *Gadus Atlantica* judged to be outliers were the result of gear failure on one vessel rather than one vessel fishing on a aggregation that was missed by the other. However, in the case of the former one would expect to see the discrepancy for a specific pair to occur for all species. This, in general, is not the situation; either way, the omission of these pairs would be justified.

Acknowledgements

Thanks are due to W. Brodie, chairman of the Comparative Fishing Working Group, and to all members of the Groundfish Division who participated in the collection and preparation of the data.

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1. Atlantic Cod.

	Percentile										
Length	1	2.5	5	10	25	50	75	90	95	97.5	99
10	25.6	34.1	39.4	50.0	74.1	114	184	276	386	479	586
15	16.4	19.7	21.4	24.4	31.0	40.2	54.0	68.4	86.1	95.3	109
20	11.1	12.4	13.2	14.1	16.5	19.4	23.0	27.1	29.9	32.6	36.2
25	7.70	8.22	8.46	9.07	9.86	10.9	12.1	13.5	14.3	15.0	16.3
30	5.34	5.57	5.76	5.97	6.39	6.83	7.39	7.90	8.31	8.59	8.87
35	3.69	3.81	3.96	4.07	4.33	4.61	4.95	5.27	5.49	5.60	5.80
40	2.54	2.67	2.76	2.88	3.07	3.29	3.55	3.78	3.94	4.03	4.23
45	1.87	1.94	2.01	2.11	2.26	2.44	2.67	2.85	2.96	3.08	3.21
50	1.40	1.46	1.51	1.59	1.72	1.88	2.06	2.21	2.33	2.42	2.50
55	1.07	1.12	1.17	1 23	1.34	1.48	1.63	1.76	1.87	1.94	2.02
60	0.893	0.878	0.916	0.972	1.08	1.19	1.32	1.43	1.53	1.60	1.69
65	0.668	0.697	0.732	0.778	0.872	0.976	1.09	1.21	1.28	1.36	1.44
70	0.534	0.551	0.589	0.632	0.715	0.812	0.934	1.03	1.09	1.16	1.25
75	0.420	0.447	0.479	0.514	0.597	0.683	0.789	0.897	0.964	1.03	1.17
80	0.330	0.358	0.386	0.423	0.496	0.588	0.685	0.792	0.871	0.929	1.06
85	0.261	0.289	0.313	0.355	0.418	0.506	0.607	0.719	0.792	0.862	0.986
90	0.208	0.231	0.256	0.297	0.354	0.436	0.538	0.660	0.733	0.814	0.961
95	0.169	0.185	0.212	0.244	0.301	0.382	0.486	0.612	0.687	0.784	0.901
100	0.134	0.148	0.176	0.203	0.258	0.337	0.442	0.577	0.660	0.762	0.893
105	0.108	0.121	0.142	0.169	0.223	0.299	0.405	0.558	0.636	0.766	0.901
110	0.085	0.099	0.116	0.142	0.193	0.267	0.376	0.532	0.629	0.731	0.918
115	0.069	0.080	0.096	0.121	0.167	0.239	0.351	0.508	0.621	0.754	0.944
120	0.056	0.065	0.079	0.102	0.145	0.216	0.330	0.496	0.619	0.777	0.978
125	0.044	0.054	0.066	0.086	0.124	0.197	0.311	0.484	0.616	0.825	1.02
130	0.033	0.043	0.055	0.075	0.109	0.180	0.296	0.469	0.622	0.864	1.08

2. American Plaice.

	Percentile										
Length	1	2.5	5	10	25	50	75	90	95	97.5	99
10	39.5	43.2	47.5	51.2	61.4	74.3	90.0	110	120	138	146
15	16.6	17.3	17.9	18.7	20.0	21.7	23.6	25.5	26.7	27.4	28.5
20	7.73	7.93	8.09	8.28	8.64	9.97	9.52	9.99	10.3	10.5	10.8
25	3.93	4.01	4.08	4.20	4.39	4.60	4.87	5.12	5.26	5.41	5.54
30	2.23	2.29	2.35	2.40	2.53	2.66	2.82	2.95	3.05	3.13	3.22
35	1.37	1.43	1.46	1.50	1.58	1.67	1.77	1.87	1.93	1.99	2.05
40	0.873	0.915	0.942	0.979	1.04	1.12	1.20	1.29	1.34	1.38	1.48
45	0.547	0.585	0.616	0.654	0.712	0.789	0.869	0.949	1.01	1.06	1.12
50	0.334	0.378	0.406	0.442	0.501	0.573	0.663	0.746	0.807	0.854	0.915
55	0.216	0.246	0.271	0.300	0.362	0.431	0.523	0.612	0.680	0.739	0.805
60	0.138	0.161	0.183	0.209	0.264	0.334	0.424	0.523	0.592	0.645	0,742
65	0.090	0.108	0.125	0.149	0.196	0.265	0.356	0.457	0.527	0.600	0.731
70	0.051	0.072	0.087	0.105	0.150	0.214	0.304	0.411	0.496	0.585	0.748

3. Greenland Halibut/Turbot.

Length	Percentile										
	1	2.5	5	10	25	50	75	90	95	97.5	99
10	20.4	22.2	25.1	27.6	33.1	40.8	51.6	65.6	80.2	91.6	101
15	6.91	7.37	7.62	8.11	8.90	9.89	11.0	12.4	13.5	14.4	15.3
20	3.21	3.32	3.44	3.57	3.80	4.05	4.33	4.59	4.75	4.88	5.08
25	1.83	1.87	1.93	1.99	2.09	2.20	2.33	2.46	2.53	2.58	2.65
30	1.21	1.24	1.26	1.31	1.37	1.44	1.53	1.61	1.66	1.70	1.74
35	0.917	0.934	0.955	0.983	1.03	1.08	1.13	1.19	1.22	1.25	1.27
40	0.759	0.776	0.794	0.811	0.845	0.884	0.921	0.962	0.983	0.998	1.02
45	0.653	0.680	0.697	0.712	0.741	0.776	0.813	0.847	0.861	0.880	0.902
50	0.583	0.606	0.623	0.642	0.679	0.720	0.767	0.818	0.840	0.856	0.880
55	0.530	0.549	0.571	0.594	0.641	0.699	0.767	0.841	0.883	0.905	0.935
60	0.484	0.503	0.532	0.560	0.625	0.703	0.803	0.911	0.977	1.02	1.06
65	0.439	0.474	0.505	0.544	0.626	0.733	0.868	1.03	1.13	1.20	1.30
70	0.417	0.447	0.486	0.538	0.640	0.781	0.975	1.21	1.35	1.44	1.66

4. Witch Flounder.

Length	Percentile										
	1	2.5	5	10	25	50	75	90	95	97.5	99
10	50.1	55.8	62.5	71.2	88.7	114	154	206	240	272	314
15	16.4	17.1	18.3	19.3	21.5	24.4	27.9	31.7	34.3	36.8	39.1
20	7.11	7.34	7.56	7.79	8.22	8.70	9.24	9.84	10.2	10.5	11.0
25	3.66	3.74	3.80	3.88	4.01	4.15	4.33	4.47	4.58	4.71	4.85
30	2.12	2.17	2.20	2.24	2.32	2.40	2.49	2.57	2.62	2.67	2.72
35	1.39	1.42	1.45	1.47	1.52	1.57	1.62	1.67	1.70	1.74	1.76
40	1.00	1.02	1.04	1.06	1.09	1.13	1.17	1.21	1.23	1.25	1.28
45	0.739	0.761	0.779	0.797	0.834	0.871	0.917	0.962	0.991	1.01	1.03
50	0.549	0.580	0.602	0.621	0.664	0.717	0.773	0.816	0.859	0.888	0.923
55	0.416	0.441	0.471	0.498	0.548	0.614	0.686	0.758	0.797	0.847	0.890
60	0.317	0.349	0.374	0.411	0.470	0.545	0.639	0.728	0.789	0.846	0.922

5. Redfish.

Length	Percentile										
	1	2.5	5	10	25	50	75	90	95	97.5	99
5	10.4	12.9	15.4	19.3	29.8	49.9	85.4	139	191	270	363
10	7.39	7.94	8.42	9.07	10.6	12.4	14.8	17.8	20.0	22.0	25.4
15	3.87	4.12	4.30	4.53	4.98	5.58	6.35	7.11	7.55	8.06	8.49
20	2.11	2.22	2.35	2.52	2.84	3.20	3.76	4.13	4.32	4.47	4.63
25	1.42	1.51	1.58	1.68	1.88	2.10	2.45	2.66	2.76	2.83	2.91
30	1.13	1.18	1.23	1.29	1.39	1.52	1.67	1.78	1.84	1.88	1.94
35	0.989	1.01	1.03	1.06	1.10	1.15	1.21	1.25	1.29	1.32	1.35
40	0.714	0.738	0.768	0.799	0.854	0.916	0.976	1.04	1.09	1.13	1.17
45	0.467	0.500	0.530	0.566	0.644	0.750	0.863	0.982	1.08	1.16	1.25
50	0.308	0.342	0.361	0.397	0.491	0.633	0.756	0.983	1.14	1.26	1.41

Fig. 1 (cod)

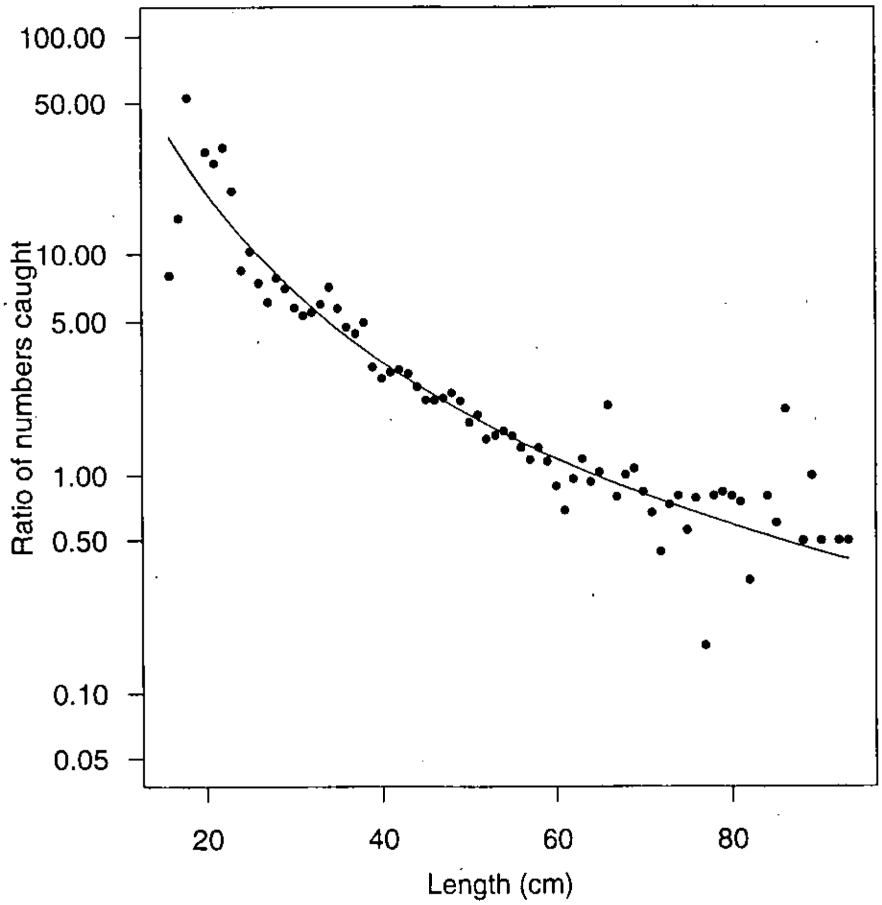


Fig. 1a (cod)

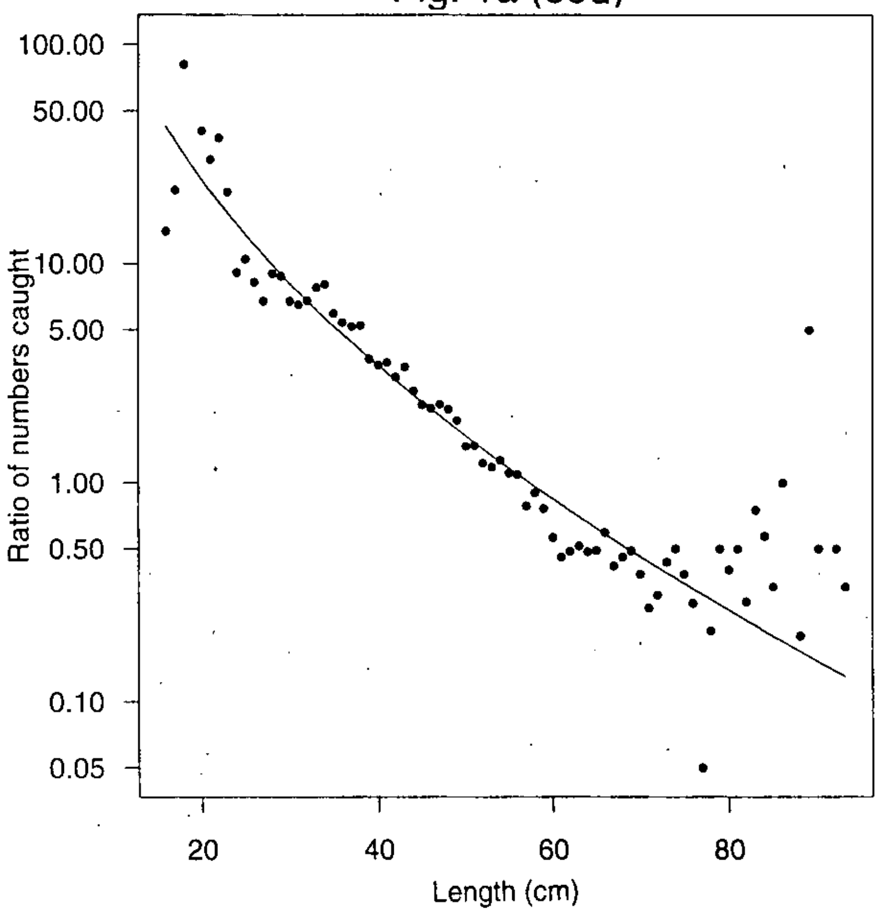


Fig. 2 (plaice)

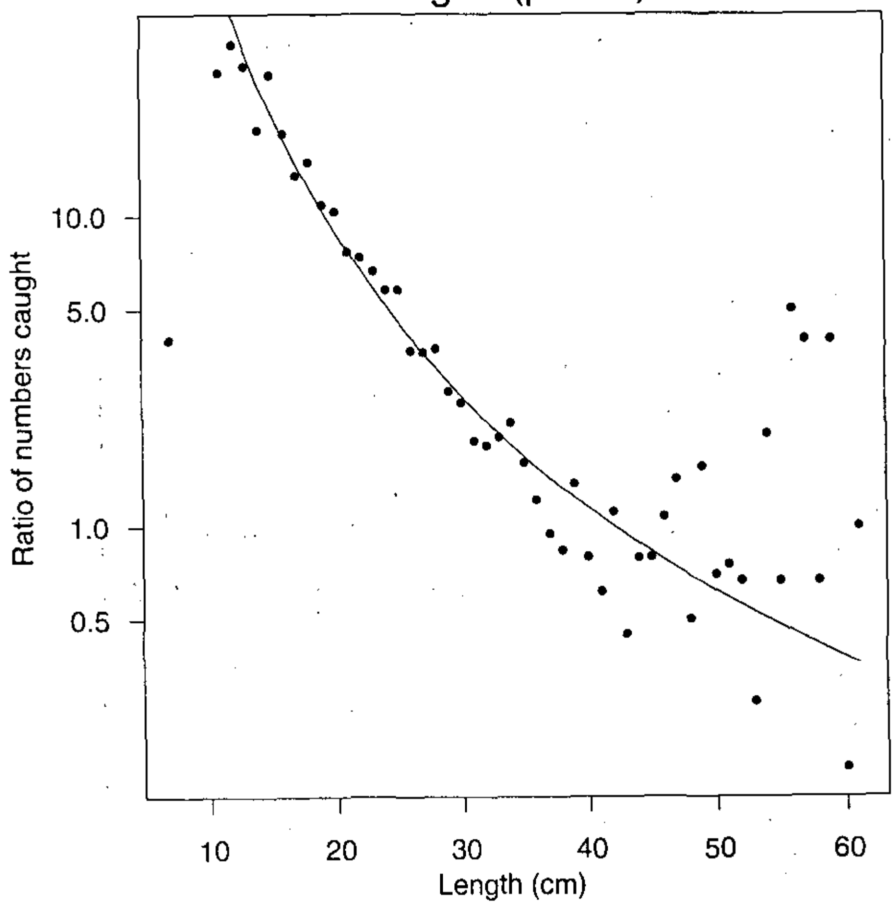


Fig. 3 (turbot)

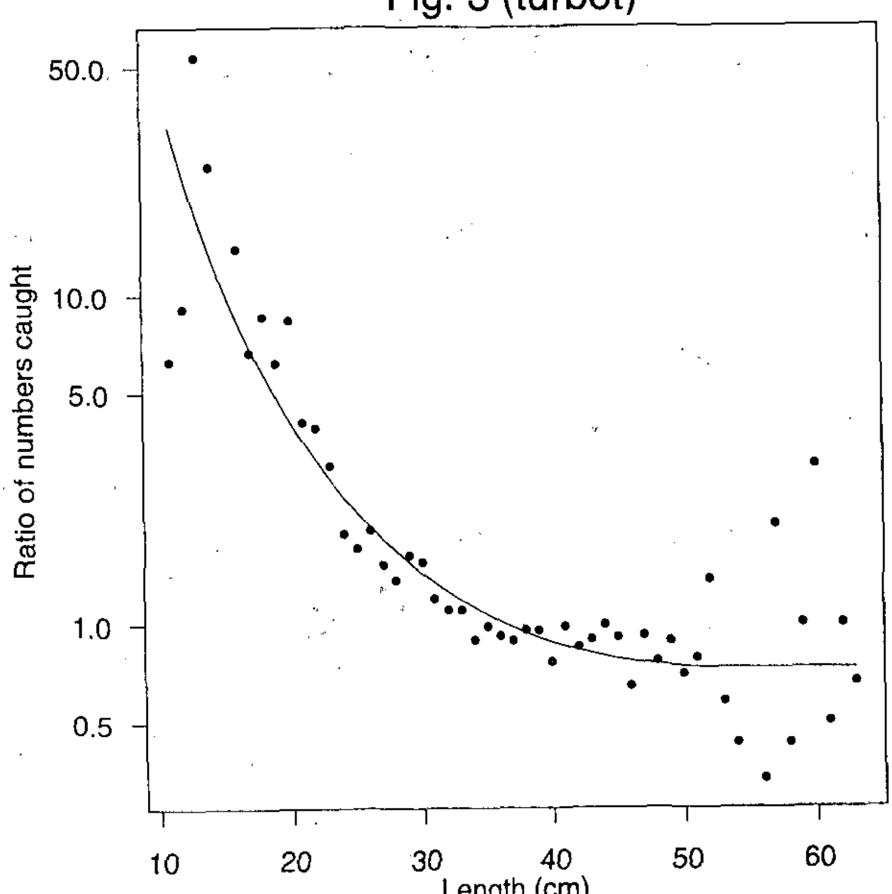


Fig. 4 (witch flounder)

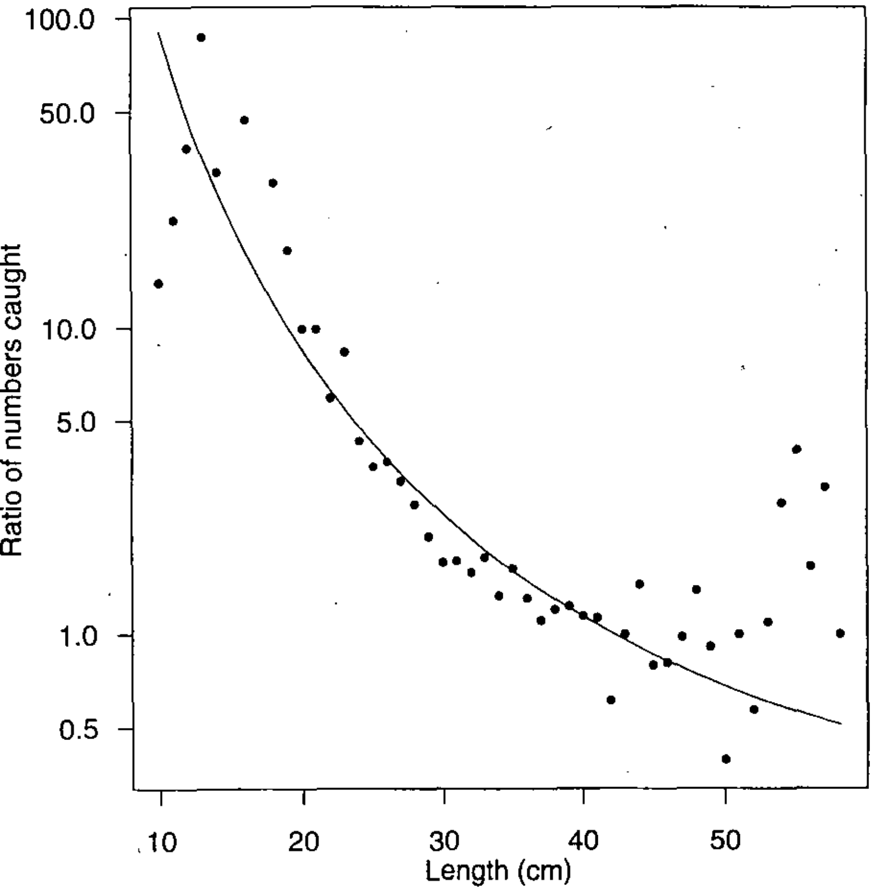


Fig. 5 (redfish)

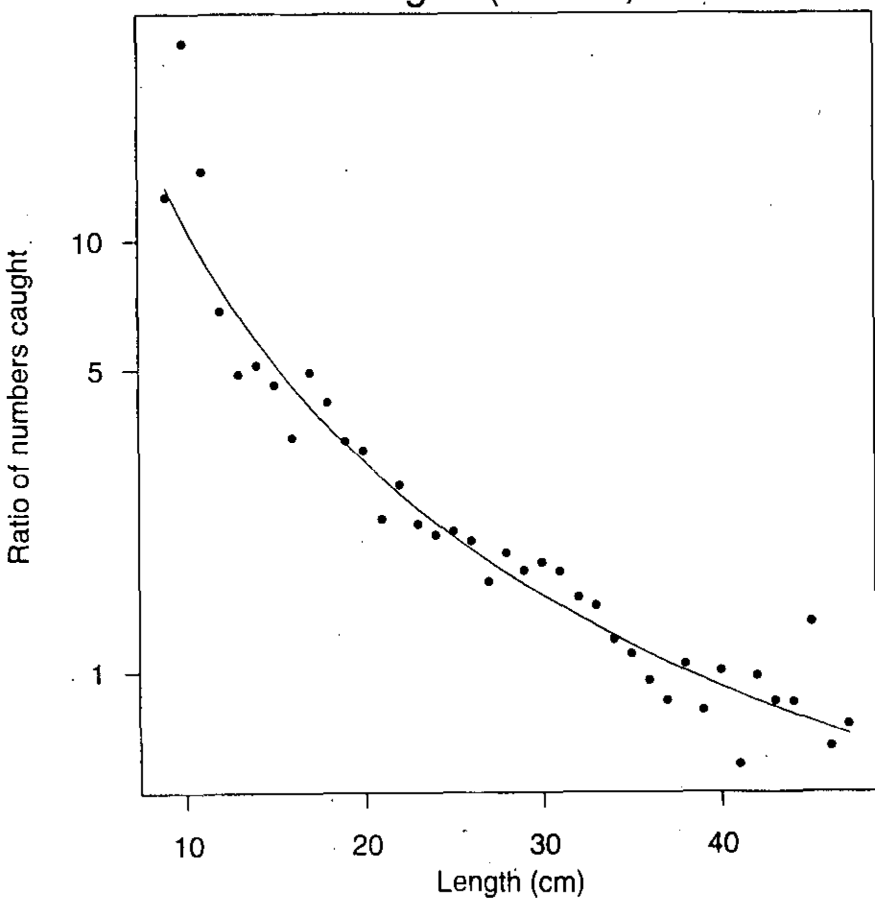
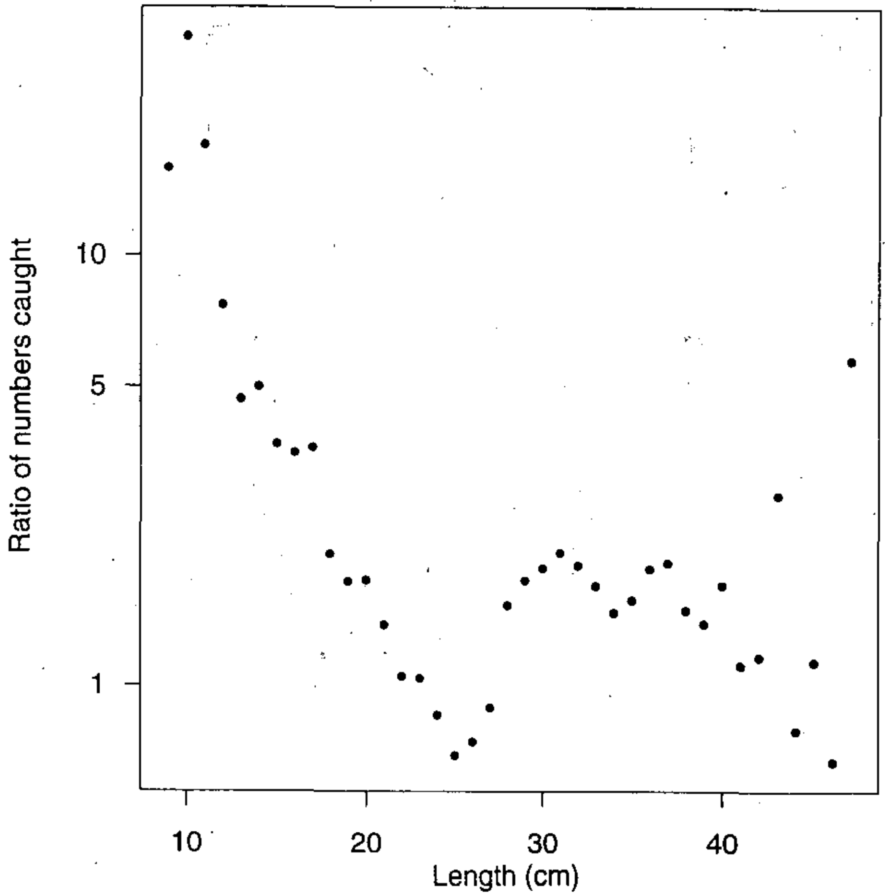
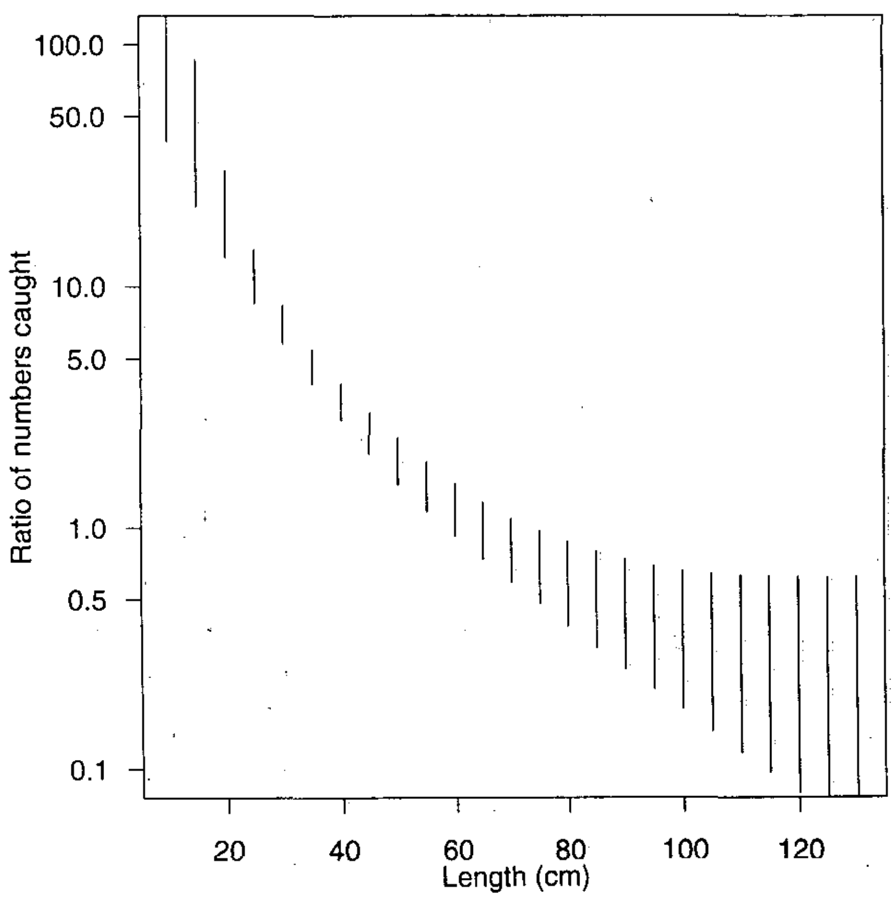
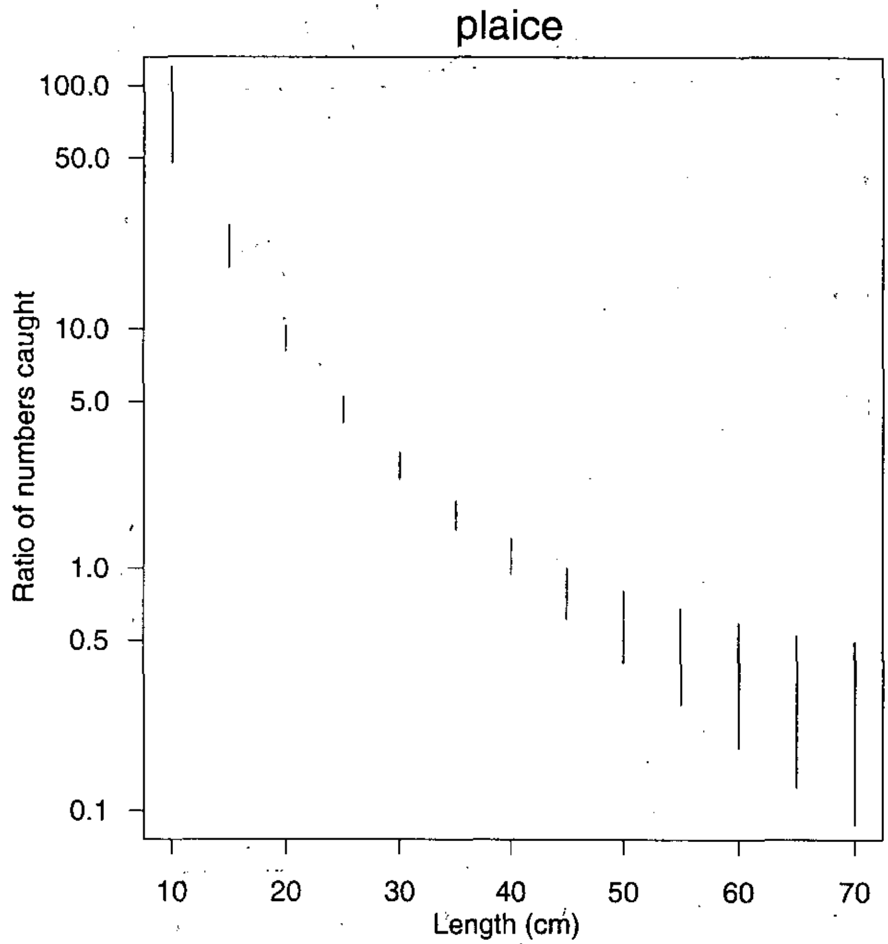


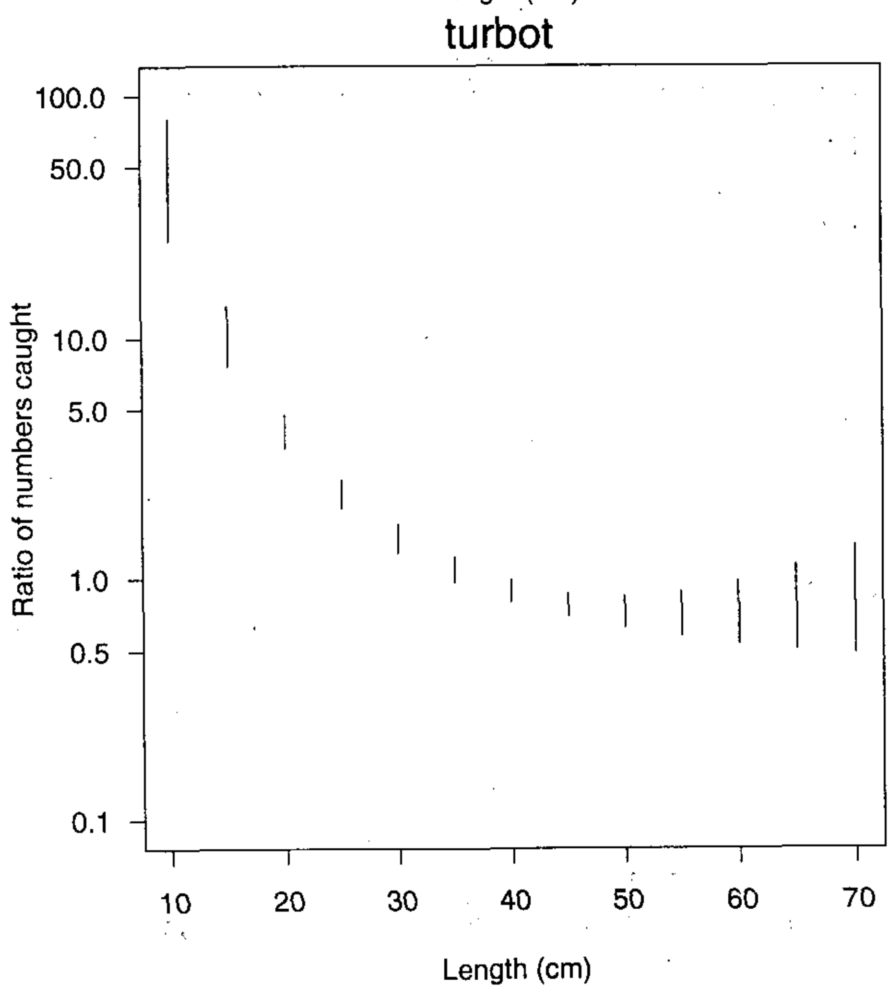
Fig. 5a (redfish)

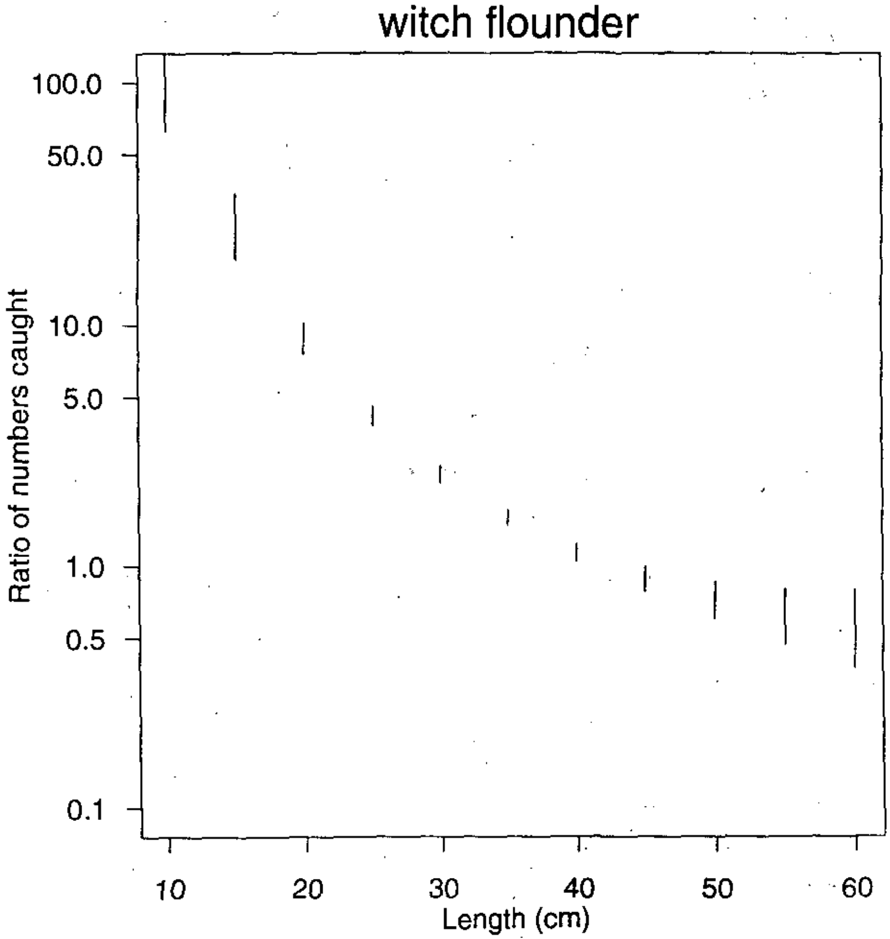


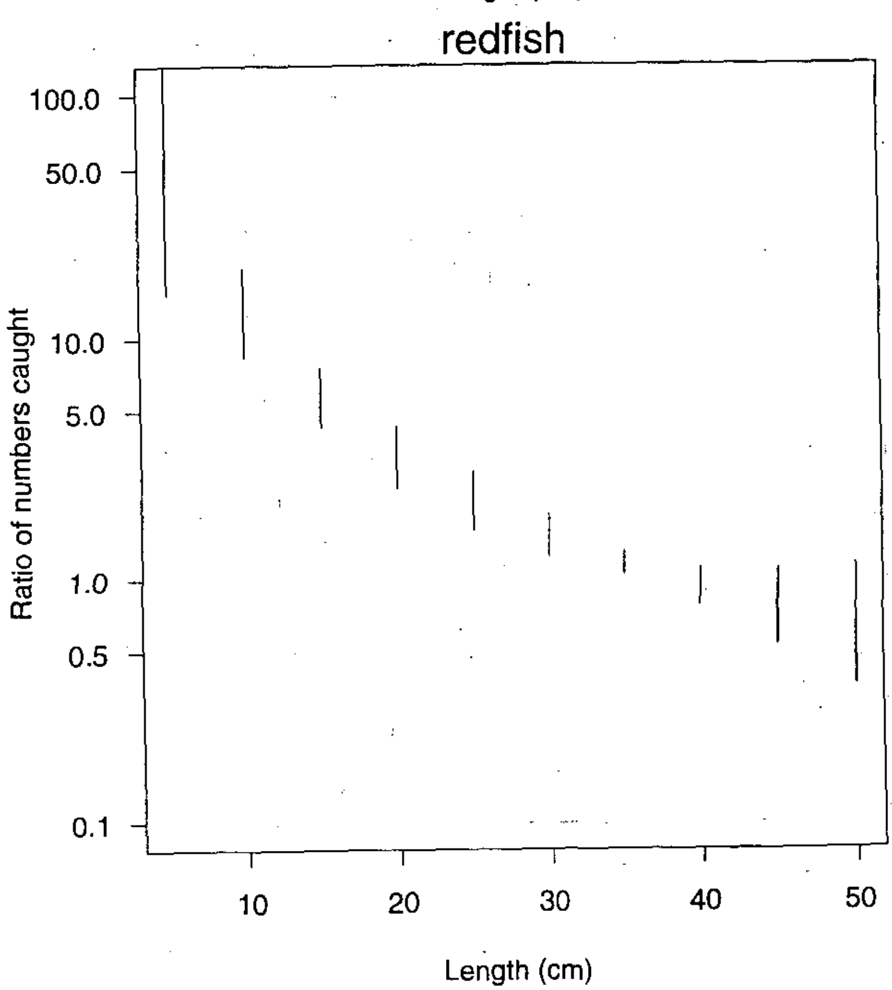
cod




plaice
100.0
50.0
10.0
5.0
1.0
0.5
0.1
Ratio of numbers caught
10
20
30
40
50
60
70
Length (cm)


turbot
100.0
50.0
10.0
5.0
1.0
0.5
0.1
Ratio of numbers caught
10
20
30
40
50
60
70
Length (cm)


witch flounder
Ratio of numbers caught
100.0
50.0
10.0
5.0
1.0
0.5
0.1
10
20
30
40
50
60
Length (cm)


redfish
Ratio of numbers caught
100.0
50.0
10.0
5.0
1.0
0.5
0.1
10
20
30
40
50
Length (cm)

APPENDIX

We here illustrate the outlier detection method, firstly the use of the mixed delta Poisson distribution. We consider a subset of the Altantic cod data, namely those trawls in which the *Gadus Atlantica* had zero catch in length classes 16-25 cm. Table A.1 gives the frequencies of corresponding catches by the *Teleost*. For catches above 10 the number caught, rather than the frequency, is given.

Table A.1
Number caught by *Teleost* given *Gadus Atlantica* caught zero

Length	0	1	2	3	4	5	6	7	8	9	10	
16	229	8	2	-	-	-	-	-	-	-	-	12*
17	221	11	2	2	1	-	-	-	-	-	-	21*
18	222	9	3	1	2	1	1	1	-	-	-	28*
19	211	18	7	2	1	-	1	-	1	-	1	23*
20	216	11	4	7	-	1	-	-	-	-	-	17*
21	198	21	5	6	2	1	1	2	-	-	-	19*
22	189	29	11	4	1	1	-	2	-	1	-	15, 15*
23	188	26	8	6	3	1	2	1	2	-	1	17*
24	181	21	10	6	3	3	2	1	-	-	-	11, 11
25	170	33	5	6	5	1	2	2	1	1	-	13, 17

All numbers in the final column, with the exception of the 11's for length 24 cm and the 13 for length 25 cm, test as outliers. Of these, those marked * are associated with trawl 3-105. In addition, the Aitkin and Wilson procedure also identifies trawl 3-105 as an outlier for length 24 cm (the *Teleost* and *Gadus Atlantica* catch for this length and trawl pair each being > 0). Overall, in 9 or 41% of the 22 length classes for which the *Teleost* and/or *Gadus Atlantica* caught Atlantic cod, the number caught by the *Teleost* in set pair 3-105 tested as outliers. Accordingly, for this set pair, the *Teleost* was judged to have fished on an aggregation largely missed by the *Gadus Atlantica* and the set pair was omitted from the final analysis.

As a second, somewhat different, example, we consider the catches of Altantic cod in length classes 57-69 cm. In Table A.2 we give the ratio of the number caught in trawl 3-005 by the *Gadus Atlantica* to the number caught by the *Teleost*.

Table A.2

Length	57	58	59	60	61	62	63	64	65	66	67	68	69
Ratio	16	13	-	26	-	10	4	4	*	14	*	-	10

The Aitkin and Wilson procedure indicates that all ratios in Table 2, other than the two 4's, are indicative of outliers. In addition, for the lengths marked *, the *Teleost* catch is zero. The distribution of *Gadus Atlantica* catches, given a zero *Teleost* catch, for these lengths are as in Table A.3

Table A.3

Length 65 cm		Length 67 cm	
Number	Frequency	Number	Frequency
0	213	0	218
1	5	1	10
2	4	2	1
.	.	3	1
.	.	.	.
.	.	12	1
16	1	.	.

Both the 16 fish of length 65 cm and the 12 fish of length 67 cm come from trawl pair 3-005 and are judged as outliers by the mixed delta Poisson. Overall, by one procedure of the other, in 15, or 31%, of the 48 length classes for which the *Teleost* and/or the *Gadus Atlantica* caught Atlantic cod, the number caught by the *Gadus Atlantica* in set pair 3-005 tested as outliers. Accordingly, for this set pair, the *Gadus Atlantica* was judged to have fished on an aggregation largely missed by the *Teleost* and the set pair was omitted from the final analysis.

The proportion of length classes for which a member of a set pair was judged as an outlier reach a high of 20 out of 22 (91%) in the case of redfish and set pair 3-014. In general, proportions in excess of 25% were judged as being sufficient to warrant the omission of a set pair.