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Estimates of 3Ps Bycatch of Cod in Otter Trawl Fishery

Estimations des prises accessoires de morue dans les pêches au chalut à panneaux de 3Ps

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ABSTRACT

Observer data on bycatch of cod (*Gadus morhua*) in NAFO Subdivision 3Ps in the commercial otter trawl fisheries were collected in the period from 1994 to 2003 by independent observers. A total observed bycatch of 501,901 kg was studied. Sampling was not sufficient to estimate total bycatch for each unit area of 3Ps, therefore only 3Psa, 3Psd, 3Psg and 3Psh were considered in the present study. The average bycatch weight, given as kg per set, was significantly lower in 1994/95. The highest total bycatch was in the witch flounder and redfish fisheries, which accounted for 68% and 13%, respectively. Significant seasonal bycatch variation was identified with the highest bycatch in the winter and lowest in summer. Generalized Linear Models (GLMs) were then used to identify significant factors affecting the 3Ps bycatch cod. The GLMs fitted to the observer data revealed statistically significant factors such as year, season, and areas, and reproduced the total and annual bycatch well. An application of the models to the catch-effort data predicted the total bycatch fairly.

RÉSUMÉ

De 1994 à 2003, des observateurs indépendants ont recueilli des données sur les prises accessoires de morue (*Gadus morhua*) dans les pêches commerciales au chalut à panneaux de la sous-division 3Ps de l'OPANO. Des prises accessoires totales de 501,901 kg ont été étudiées. Comme l'échantillonnage n'était pas suffisant pour estimer les prises accessoires totales dans chaque unité de 3Ps, cette étude n'aborde que les unités 3Psa, 3Psd, 3Psg et 3Psh. Le poids moyen (en kg) des prises accessoires par trait de chalut était significativement plus bas en 1994-1995. Les plus importants niveaux de prises accessoires ont été atteints dans les pêches de la plie grise et du sébaste, qui représentaient respectivement 68 % et 13 %. Les niveaux de prises accessoires fluctuaient significativement selon les saisons : ils étaient les plus élevés en hiver et les plus bas en été. Nous nous sommes servis de modèles linéaires généralisés (MLG) pour cerner les facteurs qui influent significativement sur les prises accessoires de morue dans 3Ps. Les MLG ajustés aux données d'observateurs ont mis en évidence des facteurs statistiquement significatifs, comme l'année, la saison et le secteur, et ont bien reproduit les prises accessoires totales et annuelles. L'application des modèles aux données sur les prises et l'effort a donné une prévision assez bonne du total des prises accessoires.

Introduction

Bycatches refer to the nontarget species caught in the target species fisheries. They are usually discarded or kept depending on the commercial values of the species and sizes. Estimating the extent of bycatch is increasingly important as bycatch in one fishery may include juvenile members of the target species in the same or another fishery, individuals from threatened, endangered, or protected species. Fishing with a bottom trawl often results in the incidental capture of nontarget species, but some fishing practices and locations generate greater amounts of bycatch than others. Identifying significant factors with respect to bycatches is an important step towards estimating the magnitude of the bycatch.

The importance of using independent observers to collect bycatch information has been recognized by the Department of Fisheries and Oceans (DFO) since 1980. In this study, the Newfoundland observer data and catch-effort data were used to examine the distribution of 3Ps (Figure 1) bycatches of cod in otter trawl fisheries. Cod bycatches mainly occurred in otter trawl sets (Chen and Shelton, 2003). The otter trawl fisheries are the largest in the southern Halibut Channel and along the Laurentian Channel and thus have the potential for a high total bycatch (Chen and Shelton, 2003). The observed otter trawl fisheries had total bycatch of 570 tons for the period 1994-2003, which amounted to 75% of total bycatch. The observed witch flounder and redfish fisheries had 68% and 13% of total bycatch, respectively. The observed bycatch is 4%, 9%, 4% and 78% of total bycatch for 3Psa, 3Psd, 3Psg and 3Psh, respectively.

In this study I have used the Newfoundland observer and catch-effort data from the offshore (3Psa, 3Psd, 3Psg and 3Psh) otter trawl fisheries directed at witch founder and redfish for the period 1994-2003 only. For the first time, I applied Generalized Linear Models (GLMs) in NAFO subdiv. 3Ps and sought insights into cod abundance in offshore commercial trawlers from the bycatch perspective. The primary purposes of this study are to use the observer data to determine major factors that affect bycatches of cod, and to estimate total and annual bycatches of cod using GLMs that account for statistically significant factors as in Chen et al (2003), based on Stefansson's Delta-Gamma approach (1996). In the end, significant factors with respect to bycatches, such as year, season, and unit areas, are identified from the statistical models. The models are able to reproduce the total and annual bycatches of cod well. The model parameters were applied to the catch-effort data to estimate total and annual bycatches removed by the offshore commercial trawlers from 1994 to 2003.

Data and Methods

Data sets

Observer data

The Canadian observer program has provided detailed scientific data since 1980, when observers were first deployed on offshore trawlers. Data gathered geo-referenced information on fishing activity (fishing location, depth, gear specification and effort) on a set by set basis. Details of the fishing operation by standard methods were outlined in

Kulka and Firth (1987). Observer estimates of kept cod and discards were round weight (kg). The observer data are the subset of the catch-effort data and are more reliable than the rest of the catch-effort data recorded by the skipper, from whom catching information was generally under-reported (Kulka, 1999).

Catch-effort data
Newfoundland catch-effort data were collected from logbooks and purchase slips and interpreted by Statistics Division of Northwest Atlantic Fisheries Center (NAFC) in Canada. The logbook completed by the skipper during the fishing trip holds information on vessel, fishing gear, fishing area (NAFO unit area) and estimated catches of the landed fish. Fishermen with a vessel with overall length less than 35 feet are exempted from submitting a logbook. In this study only data with logbooks were included.

Bycatch datasets were generated for both observer and catch-effort data by removing the directed cod sets. Presence–absence analysis was considered to reduce the effect of the observer's measurement approach (Kulka and Firth, 1987). Flags distinguishing the observed sets from unobserved sets were added in the catch-effort data. The aim is to identify the bycatch distribution trends in both observed and unobserved sets. However, certain amounts of logbooks had never been sent to Newfoundland Statistics Division. Missing logbooks for observed sets reduce the number of sets for a direct comparison between the catch–effort data and the observer data and for unobserved sets may cause the bycatch estimates to be biased. In this paper, I attempt to estimate the total and annual bycatch for observed and unobserved sets together.

Delta-Gamma models (GLMs)

Delta-Gamma approaches (Stefansson, 1996) were used to identify statistically significant factors that affect bycatches and to estimate total and annual bycatch weights. The selected Newfoundland observer data were analyzed by incorporating zero and non-zero values into a single model. The incorporation is realized by using a model that modifies the delta-distribution approach to fit into the GLM framework and uses maximum likelihood to estimate parameters. The maximum likelihood (ML) estimation reduces to fitting a GLM to 0/1 values and another GLM to the positive bycatch abundance values. All calculations were carried out using SAS (Version 8.1).

The probability of non-zero bycatch sets is modeled using GLMs ((McCullagh and Nelder, 1989) with a binomial distribution and a logit link function as

$$\log(\mathbf{P}/(1-\mathbf{P})) = \mathbf{A}'\ \mathbf{X_1}$$

Where $\mathbf{X_1}$ is a set of the independent variables, **A** is the coefficient to be determined, and **P** is the probability of a non-zero value. For each set the value 0 is recorded if no bycatch is present and value 1 is recorded for non-zero sets to obtain Bernoulli-type 0/1 measurements.

The weight **N** of bycatch cod in 3Ps for the positive sets only is modeled with a gamma distribution and a log link function as

$$\log \mathbf{N} = \mathbf{B}' \mathbf{X_2}$$

Where $\mathbf{X_2}$ is a set of the independent variables and **B** is the coefficients to be determined. The scale parameter is estimated by the ML.

The overall model is an integration of the above two sub-models. With fitted values for the probability (**P**) and the bycatch weight (**N**) of a non-zero set, the predicted bycatch weight (**E**) for a set is given by their product.

$$\mathbf{E} = \mathbf{P}\,\mathbf{N}$$

Establishment of the GLMs

GLMs were used to identify significant factors for bycatch cod in the witch flounder and redfish fisheries. The fisheries in 3Ps have distinct seasons and catch areas. Data from unit areas 3Psa, 3Psd, 3Psg and 3Psh were analyzed because of the limited sampling and bycatch in other areas in the observer data and missing logbooks in the catch-effort data. Besides, aggregation of cod was consistently observed on Burgeo Bank-Hermitage Channel area (3Psd), the Laurentian Channel off the southern end of St. Pierre Bank, as well as adjacent to Halibut Channel, and off southern Green Bank (Figure 1), often encountered during research vessel surveys, and supported an offshore winter fishery in the past (Brattey, 1996). The high fishing activities in offshore and winter made the datasets for analysis highly biased in time and space. In addition, soak time and fishing depth are not compatible between the observer data and the catch-effort data. Model complexity has thus been kept to a minimum, and models analyze only the effect of year, season and areas. For example, data were too sparse to analyze by individual month and instead the models tested for differences between the three periods, January-May (winter), June-August (summer) and September to December (fall), which as far as possible reflects seasonal shifts in the distribution of cod and of fishing effort while keeping reasonable sample sizes. Each combination of year, season and area constitutes a single stratum. To obtain the estimates, it was assumed that each stratum has its own population mean. Figure 2 shows the NAFO Subdiv. 3Ps statistical catch reporting areas. Furthermore, the level of seasonal coverage by the observer is inconsistent during the entire period. In the years for 1997, 1999-2003, observers only appeared on the offshore trawlers in winter or late fall. To avoid biasing the estimates of total bycatch for each stratum, for April, July and August of those years we simply used data of the corresponding months in 1998. Both witch flounder and redfish fisheries which had the high bycatch and high fishing activities were included in the analysis. Observed sets can be classed into two types: on-watches (89%) and off-watches (11%). Only on-watch data was included. The gamma density distribution was used for the positive sets. It can be seen in Figure 3(a, b) that the mean-variance relationship in the data seems to support the use of the gamma distribution.

Results and Discussions

Analysis of the observer and catch-effort data

Observer data
During the period 1994-2003, there were total bycatch cod of 501,901 kg in the witch flounder and redfish fisheries. A total of 1609 on-watch sets were examined, and the cod occurred in 1175 sets (73%) in 3Psa, 3Psd, 3Psg and 3Psh. The overall bycatch is substantial mainly because of a significant number of sets each with bycatch over 20 tons.

The frequency distribution of bycatch per set (kg/set) for the period 1994-2003 including zero sets is shown in Figure 4. About 50% of the sets captured cod within 0-10 kg, of which 55% of sets is zero. Only 7% of sets captured more than 800 kg. For the entire period, the average weight per set for the sets containing the cod is 427 kg. The average weight per set for all sets (including zero bycatch sets) is 312 kg with a median value of only 10 kg. The distribution of the bycatch weight per set is highly skewed to the right, with a substantial proportion of zeros. This heavy tail distribution greatly affects the estimates of not only the mean but also the variance. However, those large values reflect the spatial and temporal distribution of the species which are aggregated and are not outliers that should be discarded (Pennington, 1996).

Catch-effort data
Most of offshore bycatch in the catch-effort data was from witch founder (72%) and redfish (18%) fisheries, consistent with the observer data. Annual bycatches from logbooks for the period of 1994 to 2003 in Table 1 showed total bycatch cod to be 866 tons from a total of 4,492 sets, of which only 1985 sets contained cod. The average bycatch per set and occurrence were significantly lower in the 1994-95 than the rest of the study period. They were almost unchanged from 2001-2003, resulting in a steady increase of the annual total bycatch with the increasing effort. The trend of the frequency distribution of bycatch weight per set from the catch-effort data (Figure 5) is similar to that of the observer data. About 64% of sets bycatch cod within 0-10 kg, of which 69% of sets is zero.

In the offshore, bycatches tended to be higher in late fall (November-December) and winter (January-May) and low during the summer (June-October) (Table 2), with Halibut Channel (3Psh) (Table 3) accounting for most of the offshore bycatches (82%). The similar spatial and temporal trends have been seen in the observed sets except that average weight per set for November-December was very low. Unit area 3Psd was closed to directed cod fishing from 15 November to 15 April since 1998, due to possible mixing of northern Gulf cod into the western portion of the 3Ps stock area (Brattey et al, 2003).

Table 1. Yearly bycatch statistics for both positive and zero sets in witch flounder and redfish fisheries from the catch–effort data, 1994-2003.

Year	Sets	Average bycatch	Total bycatch	Largest set	Presence sets	% occurrence
1994	619	45	28079	2948	160	26%
1995	540	7	3713	1588	61	11%
1996	155	157	24295	1588	123	79%
1997	240	190	45548	5216	131	55%
1998	306	331	101159	12247	178	58%
1999	191	224	42789	10660	65	34%
2000	355	108	38331	6849	167	47%
2001	535	284	152152	14608	272	51%
2002	717	287	205589	16849	385	54%
2003	834	269	224028	18144	443	53%
All	4492		865682		1985	44%

Table 2. Same as Table 1 but for monthly bycatch statistics.

Month	Sets	Average bycatch	Total bycatch	Largest set	Presence sets	% occurrence
Jan	1107	259	286703	16849	547	49%
Feb	735	320	234910	18144	460	63%
Mar	845	231	195162	14608	509	60%
Apr	138	226	31219	8346	78	57%
May	73	256	18706	3856	44	60%
Jun	86	5	402	42	21	24%
Jul	296	13	3708	454	66	22%
Aug	259	19	4852	454	59	23%
Sep	267	6	1694	1361	11	4%
Oct	336	16	5421	1814	31	9%
Nov	295	140	41337	8618	108	37%
Dec	55	756	41570	12247	51	93%
All	4492		865682		1985	44%

Table 3. Same as Table 1 but for unit area bycatch statistics.

Unit	Sets	Average bycatch	Total bycatch	Largest set	Presence sets	% occurrenc e
3Psa	1029	23	24084	1043	322	31%
3Psd	1187	95	112700	12247	524	44%
3Psg	440	46	20259	14608	141	32%
3Psh	1836	386	708639	18144	998	54%
All	4492		865682		1985	44%

GLMs fitted to the observer data

The GLMs analysis of bycatch in the 3Ps offshore trawlers shows that year, season and areas are significant model terms. All the area and season parameters and most of yearly parameters are significantly different from zero at the 5% significance level for both delta and gamma models**.**

Table 4 gives stepwise analysis of variance results for comparing a sequence of Bernoulli models fitted to the observed bycatch data. All effects tested are entered as factors and sequence of factors is in the direction of increasingly detailed splits from year to unit areas. It is seen that the explained variation in Table 4 is not a very large fraction (21%) of the total deviance, indicating that the effects can only somewhat be explained by the model.

Since the data are 0/1 measurements, a χ^2-statistic is used to test for significance. In Table 4, it is seen that the initial (null) deviance of 1876 is reduced by 225 to 1651 by using a model with only a year effect. Although this reduction in deviance is small in relation to the total deviance, it is considerable in comparison to the degrees of freedom (9) expended and therefore it is highly significant. It is seen that a further reduction is obtained by accounting for the difference in the three seasons, but the seasons do not capture all the spatial information, since area is a highly significant addition to the model.

Table 4 Analysis of deviance table for different Bernoulli-based (Delta) generalized linear models fitted to presence/absence of observer bycatch data for 1994-2003.

Model term	Residual d.f.	Residual Deviance	Test d.f.	Change in deviance	p-value
I	1608	1876			
Year	1599	1651	9	225	<0.0001
Year+season	1597	1523	2	128	<0.0001
Year+season+areas	1594	1477	3	46	<0.0001

Table 5. Type III analysis for Bernoulli-based (Delta) generalized linear models fitted to presence/absence of observer bycatch data for 1994-2003.

Model term	Test d.f.	Change in deviance	p-value
Year	9	58	<0.0001
Season	2	133	<0.0001
Area	3	46	<0.0001

The Type III chi-square value for a model variable is twice the difference between the log likelihood for the model with all the model variables included and that with the variable excluded. For example, the chi-square for the `year` variable is twice the difference between the log likelihood for the model with the variables `Intercept`, `year`, `season` and `area` included and the log likelihood for the model with the `year` variable excluded (Table 5). The hypothesis tested in this observer data is the significance of the variable year given that the variables season and area are in the model. In other words, it tests the additional contribution of year in the model.

The values of the Type III likelihood ratio statistics for the year, season and area variables indicate that these factors are highly significant in both delta and gamma models (Table 5 and 6). Relatively speaking, season is more important in the delta model that accounts for the probability of the non-zero sets, while year and area appear to play a more prominent role in the gamma model that accounts for the bycatch weight for the non-zero sets.

Table 6. Type III analysis for gamma-based generalized linear models fitted to the positive bycatch of observed sets, 1994-2003.

Model term	**Test d.f.**	**Change in deviance**	**P**
Year	9	218	<0.0001
season	2	48	<0.0001
area	3	103	<0.0001

Model 1 (Delta model; Figure 6) captures significant interannual variability in the presence (Figure 7) of the observed data, for example, the high cod occurrences in 1998 and low occurrence in 1994-95. The year effect from Model 2 (Gamma model; Figure 8) also reveals strong interannual variability and well reproduces the characteristics of mean weight per set for the positive sets (Figure 7). The model captures the high bycatch in recent three years well.

Table 7 gives annual-mean residuals with standard deviation and 95% confidence levels (CIs). At the 0.05 level of significance, each annual-mean residual is not significantly different from zero. The high residual variance for high bycatch years (1997-1998, 2001-2003) is mainly associated with model-data differences for a few large bycatch sets. Table 8 and Table 9 show the mean residuals for area and season, which are all not significantly from zero at the 5% significance level. The precision of the estimates will improve as sampling coverage increases.

There is strong seasonality and space patterning, with most of the bycatches being taken during the winter and late fall. Unit area 3Psh has high fishing effort and high bycatch variability, and so does the winter season. Note that vessels tried to hit on the spawning or pre-spawning aggregation in Halibut Channel during the winter time (Brattery et al, 2002) for the most recent three years.

Table 7. Annual mean residuals from modeling observer data with standard deviation and 95% CIs.

	N	Lower 95%	Upper 95%		
Year	**Obs**	**CL for Mean**	**CL for Mean**	**Mean**	**Std Dev**
1994	263	-42.35	17.28	-12.54	245.56
1995	148	-38.97	15.52	-11.72	167.7
1996	132	-31.99	48.8	8.41	234.6
1997	100	-91.65	159.32	33.84	632.42
1998	80	-65.11	238.42	86.65	681.98
1999	88	-2.26	70.64	34.19	172.04
2000	118	-50.88	36.23	-7.32	238.92
2001	212	-208.23	357.04	74.41	2087.6
2002	193	-295.58	295.36	-0.11	2081.13
2003	275	-268.57	178.25	-45.16	1881.91

Table 8. Unit area mean residuals from modeling observer data with standard deviation and 95% CIs.

	N	Lower 95%	Upper 95%		
Area	**Obs**	**CL for Mean**	**CL for Mean**	**Mean**	**Std Dev**
3Psa	388	0.06	8.81	4.44	43.86
3Psd	190	-128.54	131.49	1.47	908.52
3Psg	113	-385.63	270.65	-57.49	1760.5
3Psh	918	-85.47	121.13	17.83	1594.82

Table 9. Seasonal mean residuals from modeling observer data with standard deviation and 95% CIs.

	N	Lower 95%	Upper 95%		
Season	**Obs**	**CL for Mean**	**CL for Mean**	**Mean**	**Std Dev**
Fall	360	-9.87	8.8	-0.54	90.07
Summer	285	0.02	10.24	5.13	43.85
Winter	964	-97.41	119.42	11	1715.27

The total bycatch from the observed data is 501,901 kg and that estimated from the combined models is 513,773 kg. The relative discrepancy is only 2%. The annual means for the model-data differences are small compared with the respective annual means from the observed data, suggesting that the model can well reproduce the annual mean bycatches (Figure 10). Nevertheless, large median absolute difference (MAD) for some years suggests large discrepancies for individual sets.

Application of the GLMs to the catch-effort data

The model parameters obtained by fitting the observer data are used to estimate bycatch for the catch-effort data. The total and annual bycatches for offshore trawlers have been predicted, since logbooks are only available for offshore trawlers. Total bycatch weight from the catch-effort data is 865,682 kg, and the estimate from the model parameters is 1,188,427 kg. The model overestimates with a relative discrepancy of 37%. The magnitudes of the annual mean differences and MADs between the model and the data are small relative to the magnitudes of the respective annual means, demonstrating the model's capability of extrapolation in predicting annual mean bycatches from the catch- effort data (Figure 11).

The ML estimates are approximately unbiased, even if there is between-set variability in the bycatch. Part of the total bycatch in each stratum is known exactly (i.e. all bycatch observed during on-watch sampling). The year 2001 has the large MAD and residual mean, which implies that the characteristics in the observer data (Figure 7) did not occur in the catch-effort data (Figure 9).

There are small residual means in estimating the annual total for the catch-effort data except for year 2001 and 2002 (Figure 11). The large discrepancies in these two years are presumably caused by a much more abrupt increase from 2000 to 2001 in the observer data than in the catch-effort data. Individual sets also show wide fluctuations.

The model estimation of the total bycatch for Newfoundland offshore trawlers in 3Ps studied areas gives an average bycatch of about 265 kg per set (including zero sets), or 358 kg per set if zero sets were excluded, comparable to 193 and 436 kg for the former and latter directly calculated from the catch-effort data.

Discussions

Many factors in data sampling, reporting, processing and model establishment can affect the results presented in the preceding subsections. By fixing the time-space stratification and assuming independent incidents of bycatch for all the sets in the area, I may have introduced biases into the analysis. The total bycatch per set in a quota period could be larger due to higher effort and a larger mean size. For some years a few extremely large sets in the observer data might have caused the GLMs to produce an overestimation of bycatch from the catch-effort data. Part of the total bycatch in each area is known exactly (i.e. all bycatch observed during on-watch sampling), so bycatches need to be estimated for the remaining sets (i.e. all off-watches, and all non-sampled trips).

The sampling method might also bias the results, e.g., vessels for sampling were organized by direct contact with skippers. I have assumed that on-watch efficiency is 100%, i.e. that all observable cod taken during on-watches were indeed recorded. Observer estimates used for extrapolation might be inaccurate, and on-watch efficiency may have been somewhat lower. Since I have used the logbooks data to estimate total bycatch, any omissions of logbook would bias my estimates.

Summary

I have examined the Newfoundland observer data and the catch-effort data for the period from 1994 to 2003 for major factors that affect bycatch cod in NAFO Subdiv. 3Ps. Statistically significant factors are then included in the establishment of GLMs based on the observer data. The model that consists of statistically significant factors is used to predict the total and annual bycatches for the catch-effort data.

The examination of the observer data revealed significant temporal and spatial variations and strong effects of directed species on bycatches. The average weight per set for all sets observed (including zero bycatch sets) is 312 kg, with a median of only 10 kg, indicating considerable right skewness. The average weight per set is 427 kg for the sets containing the cod. To develop more efficient estimators of population parameters, the delta-gamma distribution has been chosen to model the bycatch per set for observer data where zero values are treated separately and positive values are assumed to follow a gamma distribution.

The analysis indicated high presence and average bycatch per set for the most recent three years. The bycatch in 1994 almost hugged the bottom as the cod collapsed in 1992 and America plaice was closed in 1993. Since then the bycatch was generally low until 1998. There were also prominent seasonal fluctuations, with bycatch weight highest in winter and lowest in August and September and with fishing activities high in winter and low in fall. Significant spatial patterns of bycatch cod in the areas were evident, with generally high presence and bycatches in 3Psh. Witch flounder and redfish directed fisheries were most vital to the cod bycatch for 1994-2003.

The Delta-Gamma models fitted to the 1994-2003 observer data revealed significant factors such as year, season, and area. The model estimated total bycatch is 513,773 kg, with a relative discrepancy of only 2% to the observed 501,901 kg. The model can also reproduce the annual mean bycatch well. Nevertheless, large discrepancies for individual sets remain. The model predicted total bycatch from the catch-effort data is 1,188,427 kg, 37% larger than 865,682 kg directly from the data.

The present study has demonstrated GLM's ability to reproduce total and annual bycatches for the observer data and to predict the total bycatch for the catch-effort data (both observed and unobserved). Nevertheless the present GLMs are exploratory and have substantial discrepancies in predicting the annual means for the catch-effort data. Further efforts are warranted to refine the models for improved predictive skills.

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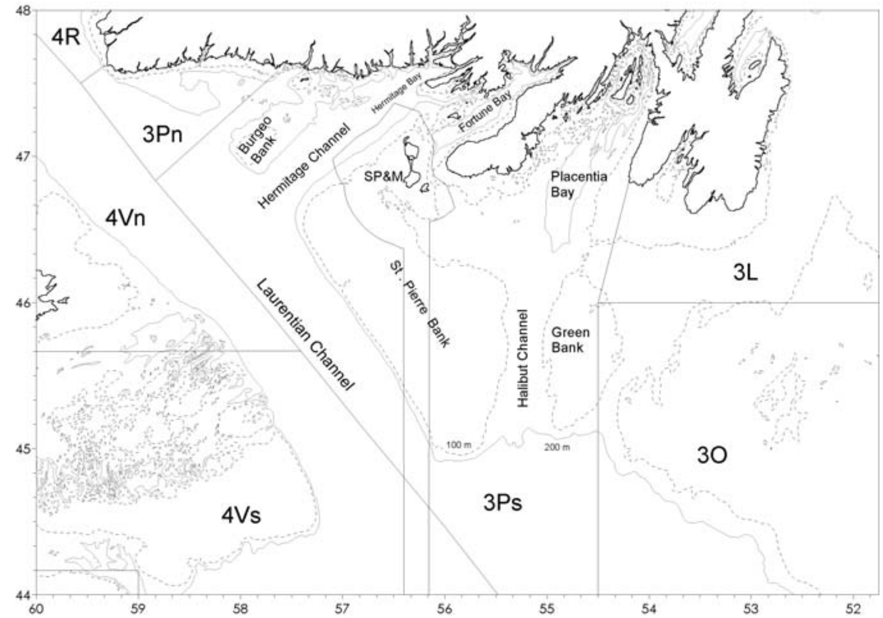


Figure 1. NAFO Subdiv. 3Ps management unit, boundaries of French Economic Zone and main fishing areas.

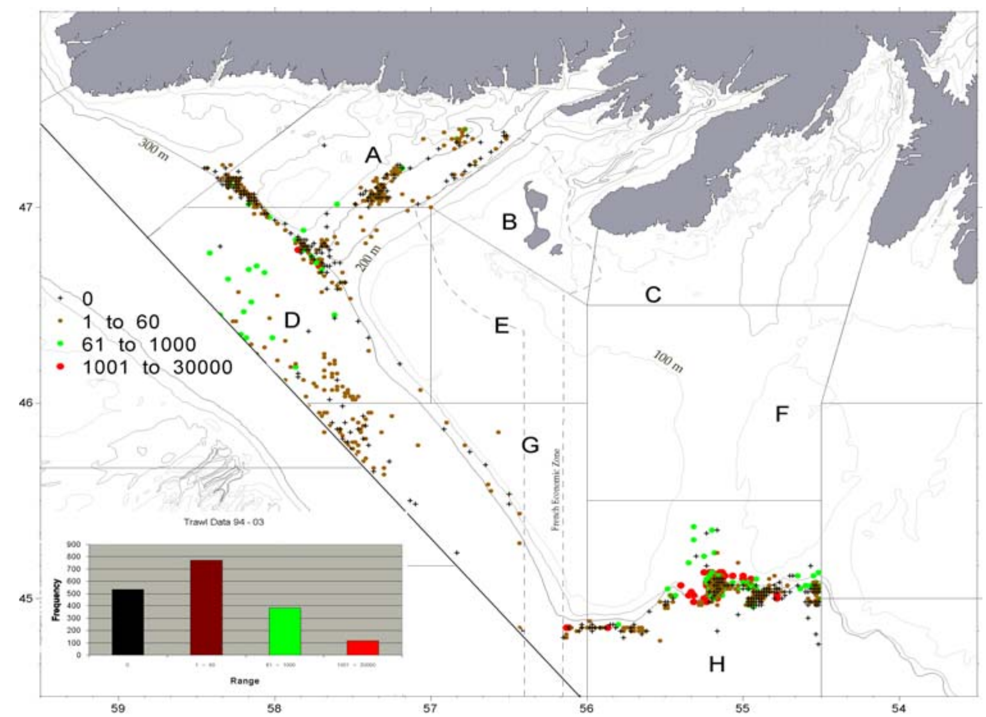
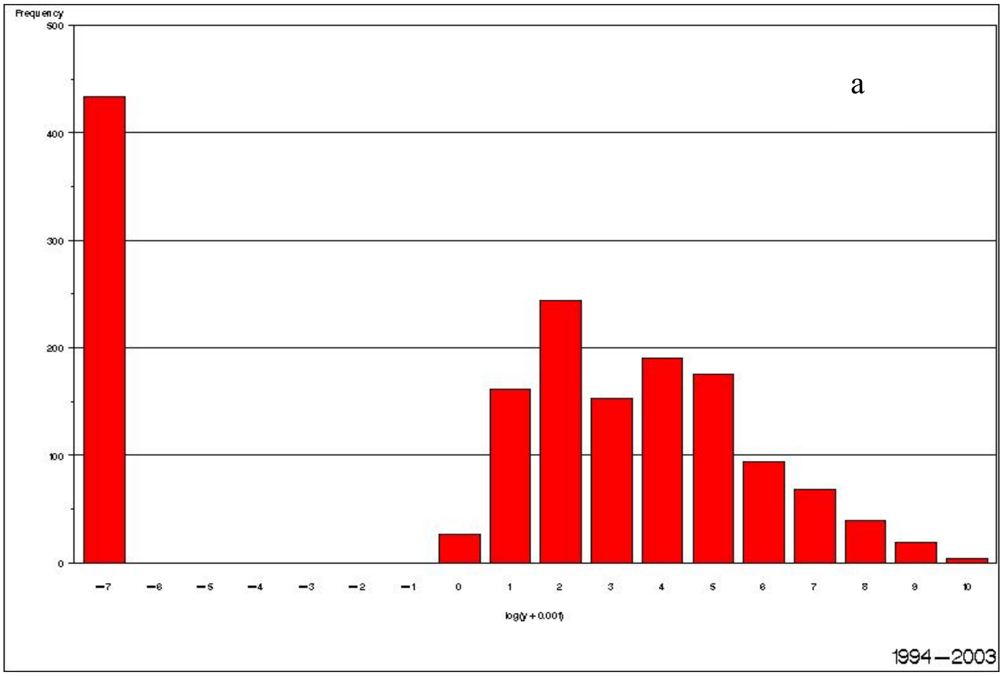


Figure 2. Spatial distribution of observed fishing sets in otter trawl, witch flounder and redfish fisheries, shown as crosses or dots based on weight range (kg/set).



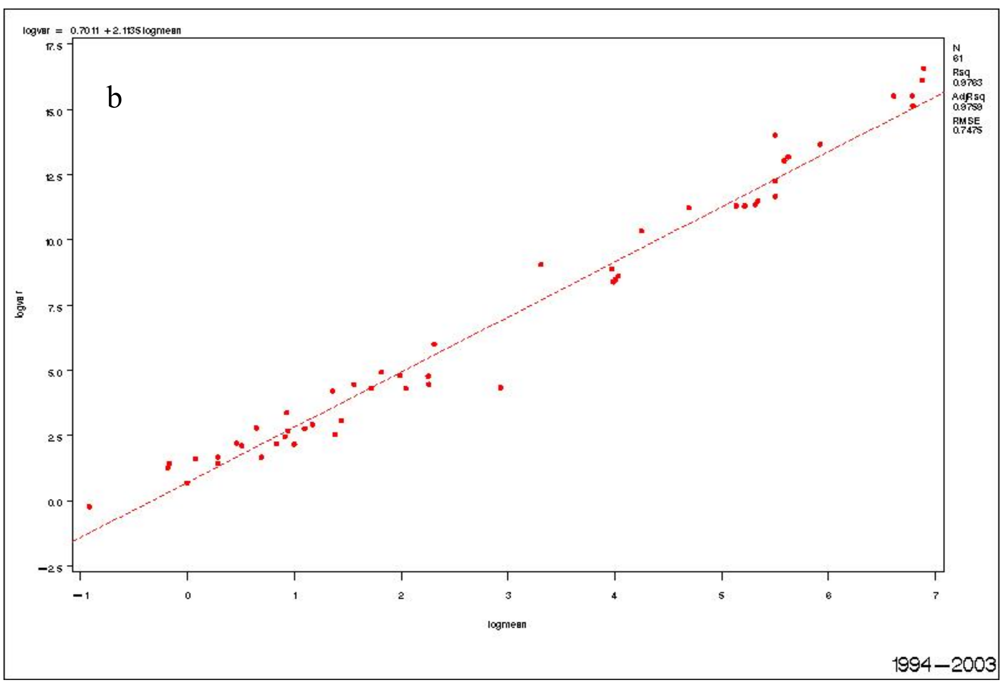


Figure 3. (a)Histogram of logged data values, log(bycatch) for positive sets. (b) Scatterplot of log-variance vs. log-mean for year, depth and duration with regression line. Logvar=0.7011+2.1135*logmean.

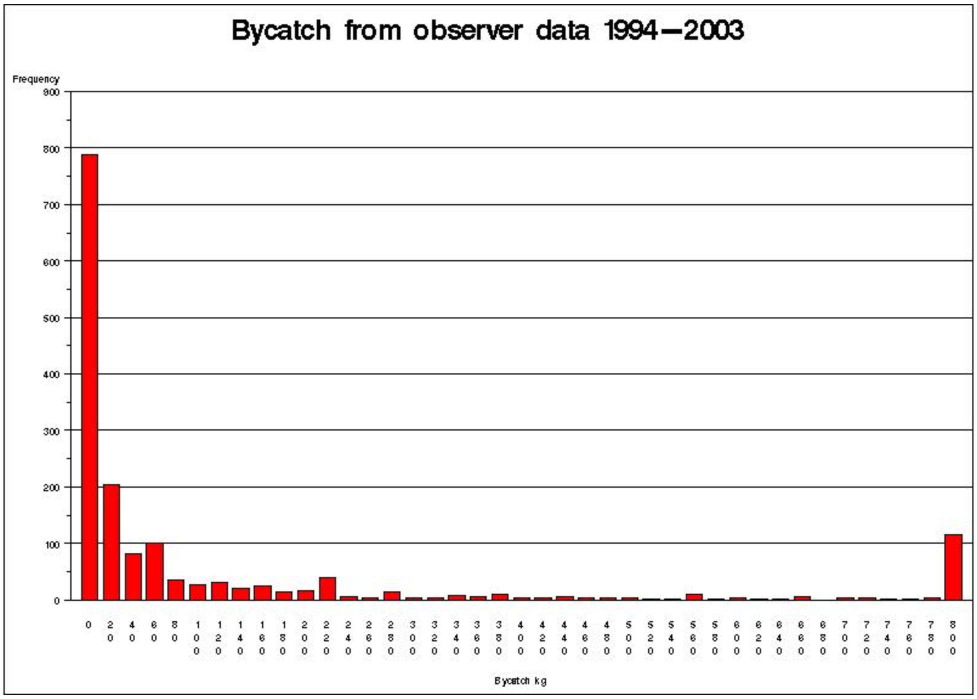


Figure 4. The frequency distribution of observed total bycatches (kg) per set including zero sets in trawler, witch flounder and redfish fisheries, 1994-2003. The last bar includes all the sets of 800 kg or more.

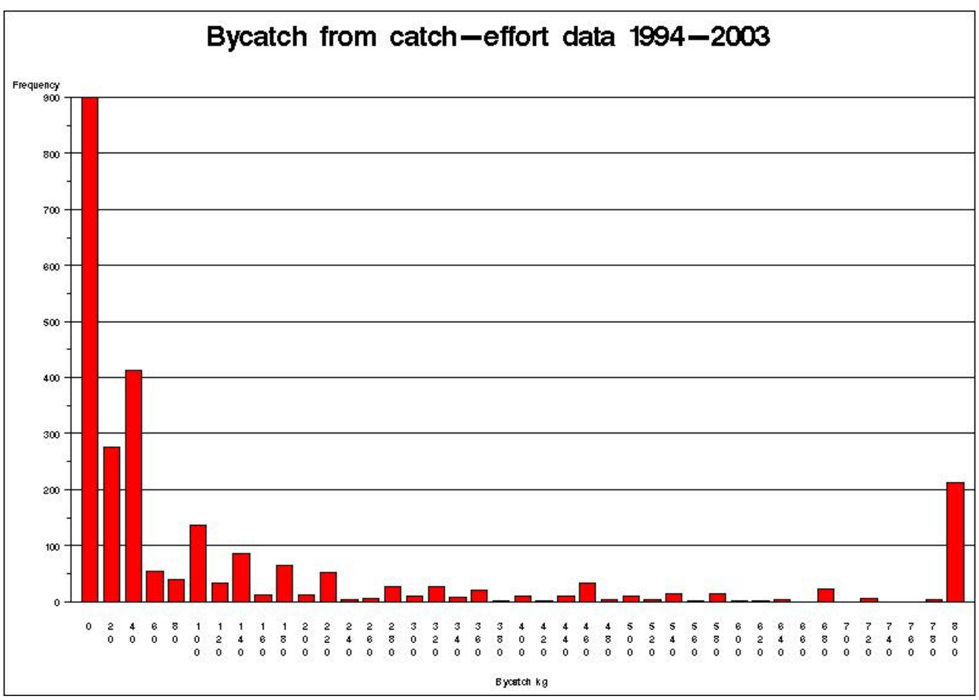


Figure 5. The frequency distribution of the bycatches (kg) per set including the zero sets in trawler, witch flounder and redfish fisheries, 1994-2003. The last bar includes all the sets of 800 kg or more. The frequency of the first bar is 2862

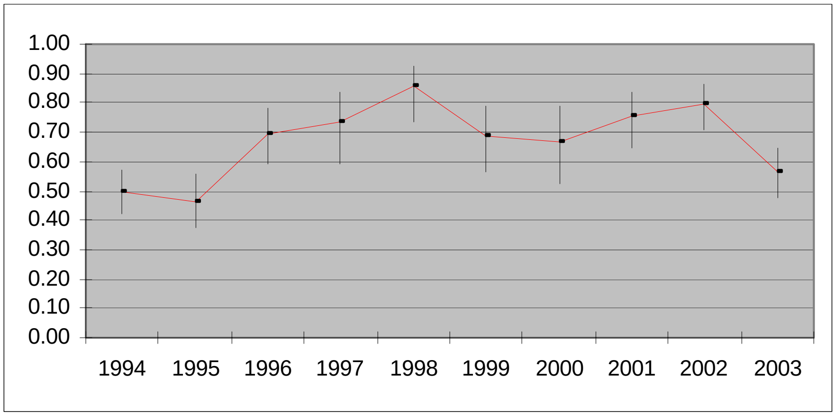


Figure 6. The yearly least squares means and their 95 percent confidence interval for Delta model by fitting into the observer data.

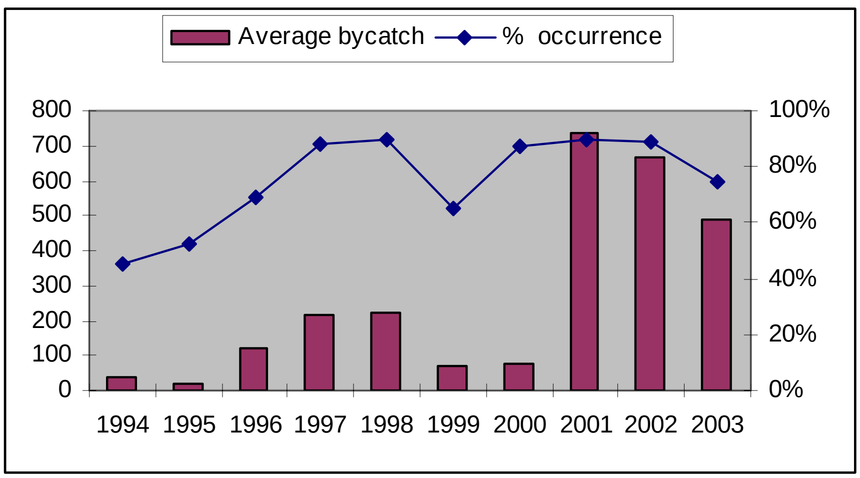


Figure 7. Proportion of observed sets with cod and average weight per set (kg), 1994-2003.

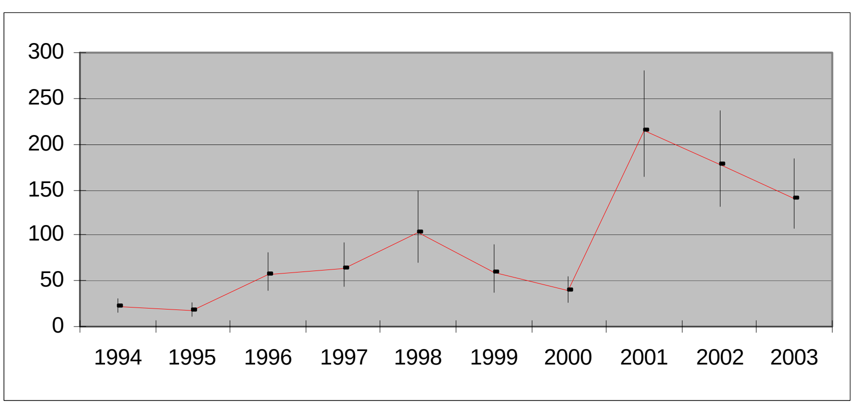


Figure 8. Same as Fig. 6, but for the gamma model for the positive sets only.

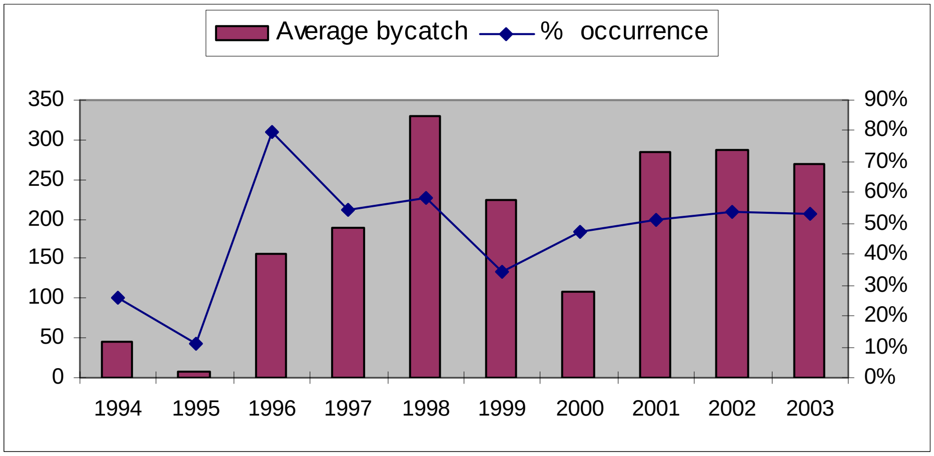


Figure 9. Proportion of sets from logbooks with cod and average weight per set (kg), 1994-2003

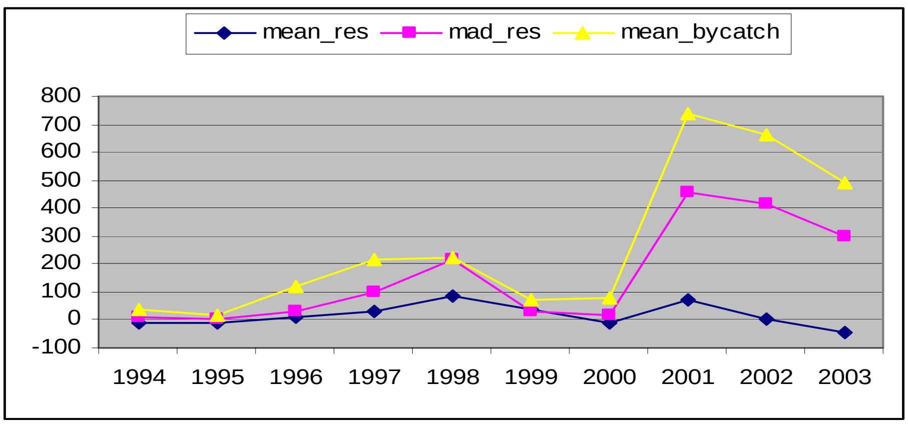


Figure 10: Yearly mean bycatches (kg) per set (triangles) from the observer data, annual mean differences (diamonds, model minus data) and annual MADs (squares) between the model fitting and data.

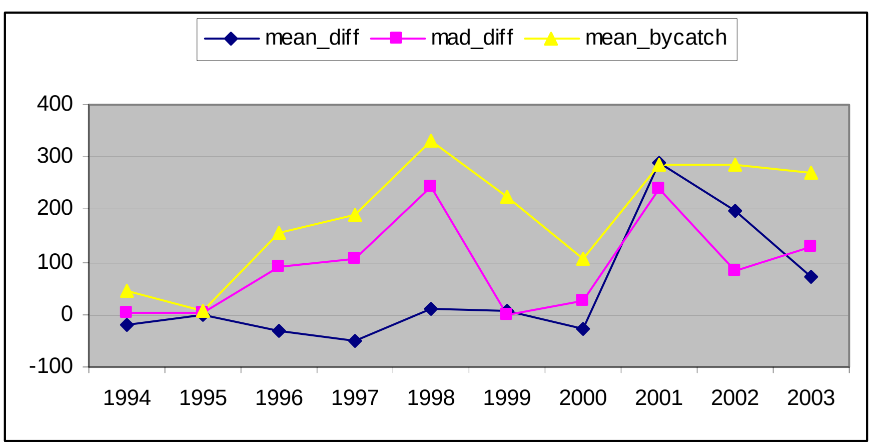


Figure 11. Yearly mean bycatches (kg) per set (triangles) from the catch-effort data, annual mean differences (diamonds, model minus data) and annual MADs (squares) between the model prediction and data.