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Standardized CPUE Indices for Greenland Halibut in NAFO Regulatory Area of Divisions 3LMNO Based on Spanish Commercial Catch Rates

by

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Abstract

A standardized CPUE series using a log-linear model for Greenland halibut in NAFO Regulatory Area of Divisions 3LMNO, based on catch and effort data from the Spanish trawl fleet since 1992 is presented. Fixed factors considered in the model were year, month, division, depth stratum and vessel and the interactions included were division*month and division*depth stratum. All of these factors and interactions are statistically significant. The total proportion of variance explained by this model is 46%. The results indicate substantial variability of CPUE over time, with several short periods of increasing and decreasing CPUE. After having reached the lowest value of the series in 2004, standardized CPUE has increased very substantially, reaching a value in 2006 very near the maximum of the entire series.

Introduction

A Spanish Greenland halibut fishery in Divisions 3LM of the NAFO Regulatory Area (NRA) has been performed by bottom trawlers since 1990 (Junquera *et al.* 1992). From about 1993 the activity of this fleet has spread south into Divisions 3N and 3O on the shelf edge, where at present a non-negligible proportion of the effort of this fleet is displayed (Junquera *et al.* 2000). Greenland halibut is the main resource for the Spanish fleet in NRA and Spanish catches have represented more than 40% of the total catches of this stock in recent years.

The objective of this study is to standardize the CPUE series for Greenland halibut in Divisions 3LMNO based on catch and effort data collected by scientific observers travelling on board of vessels of the Spanish trawl fleet. Since Greenland halibut is the target species of this fleet, the standardized CPUE data can be considered as an index of the fishable biomass of this stock.

Material and Methods

1- Catch and effort data.

Catch and effort data from the Spanish Greenland halibut fishery in NRA of Divisions 3LMNO were collected by scientific observers under the national sampling program since 1990. Data were recorded and analyzed on a haul by haul basis. For each haul, CPUE was computed as the catch in kilograms divided by trawling time measured in hours. It was assumed that all hauls at depths of at least 700 m targeted Greenland halibut.

After an examination of the data corresponding to 1990 and 1991, these were found to be unreliable and, consequently, they were not used for further analysis. Years 1992 to 1994 were overrepresented in the dataset, as almost all vessels carried an observer in those years. On the other hand, there are very few observations in 1995 as the fishery operated only for a short period during that year. From 1996 onwards, the sampling program has been working much more regularly, aiming to cover at least (and not much more than) 10% of the yearly effort. Although the level of coverage has varied from year to year, it is assumed that the available data are representative of the fishery. Eight hundred records were selected at random for each of the years 1992 to 1994, in order to make them more comparable with the years 1996 onwards. The total number of records used in the final analysis is 11307.

A histogram of nominal CPUE values is displayed on the left panel of Figure 1. It is clear that the distribution is highly skewed and a logarithmic transformation seems natural. The amount of zero CPUE values in the dataset is very small (less than 0.2%), so the results obtained from the analysis should be rather insensitive to the way these are handled. We opted for adding the value 27 to all the observations, which corresponds to one tenth of the observed mean CPUE. A histogram of the resulting values, transformed to logarithmic scale, is presented on the right panel of Figure 1. Now the distribution is much more symmetric.

2- Method for standardization of CPUE

A linear regression model was applied taking log(27+CPUE) as the response variable. The potential explanatory variables available were year, month, division, depth and vessel and were all treated as factors. We considered 9 depth strata, starting at 700 m. The first 8 strata have a range of 100 m each, and there is a final stratum covering all depths of more than 1500 m.

Figure 2 displays for each of the four divisions, the number of observations available by month (left panel) and by depth stratum (right panel). This indicates that effort concentrates mostly in Division 3L, 3M (in first half of year) and 3N (in second half of year). Effort is very low in Division 3O and there are only 69 observations in this division. All depth strata appear to be similarly covered.

Figure 3 displays the median value of CPUE with respect to the interactions division*month (left panel) and division*depth stratum (right panel). The somewhat strange shape obtained in the right panel for Division 3O should not be emphasized, given the small number of observations in this division.

All two way interactions between factors other than year were considered originally in a big complex model and, due to the very large number of observations (over 11000), all were found to be statistically significant (when tested via F-tests). However, it was also clear that excluding many such interactions from the model did not reduce the quality of the original fit by much and did not alter the results obtained for standardized CPUEs in a significant way. Hence, after much exploring with regards to inclusion and removal of different interactions, we settled on just two interactions: division*month and division*depth stratum.

To summarise the previous discussion, the model used for the final results presented here contains the fixed factors year, month, division, depth stratum and vessel, as well as the interactions division*month and division*depth stratum.

Results

For the model chosen, an analysis of variance is presented in Table 1 and the estimates obtained are in Table 2. It is clear that all variables included in the model are highly significant. The percentage of the variance explained by the model is 46%, which we consider reasonable.

When interpreting the parameter estimates it should be kept in mind that all variables have been treated as factors. Hence, the estimated parameter values refer to the expected difference in the response, log(27+CPUE), under that level of the factor with respect to what would be obtained under the reference level of that same factor (reference levels are year 1992, month January, division 3L, depth stratum of 700 m and a certain vessel).

Due to the interactions present in the model, division*month and division*depth stratum, the results for these variables must be interpreted carefully. As an example, in order to compare Division 3M with Division 3L (which is the reference level), one can not just look at the estimate corresponding to Division 3M (-0.43), as this corresponds just to January and depth stratum of 700 m. If the interest was in comparing Division 3M with 3L in, say, September and depth stratum from 1000 to 1100 m, it would be necessary to add the estimated values of "Division 3M"+"Division 3M*September"+"Division 3M*Depth Stratum 4" = - 0.43 + 0.21 + 0.17 = - 0.05.

As the variable year has not been allowed to interact with any other in the model, the corresponding estimates in Table 2 can be interpreted directly and apply to any division, month, depth stratum or vessel. Hence, the results indicate that all years are significantly worse (when testing at the usual 5% level) than 1992, with the exception of 1996, 2000, 2002 and 2006.

The left panel of Figure 4 displays the residuals plotted *versus* the fitted values, with no clear pattern of residuals. The right panel of the same figure is a Normal QQ plot of the residuals. The QQ plot indicates that the residuals are more dispersed (have wider tails) than would correspond to a Normal distribution, with this effect being a bit more pronounced on the left tail. In other words, the explanatory variables used are not able to capture fully the variability present in the CPUE observed values. Potential ways to improve the model fit in the tails (not pursued here) could be to consider a Student-t instead of a Normal distribution for the error in the log-linear model or to fit a log-linear mixed model (for example, with a separate random effect for each year).

Figure 5 presents the standardized CPUE (transformed back to the original, non-logged scaled), scaled to CPUE in 1992. The graph shows point estimates and 95% confidence limits. According to these results, CPUE has fluctuated through time, with no clear increasing or decreasing trends. Standardized CPUE was particularly low in 2004, but appears to have recovered in the last 2 years, reaching in 2006 a very similar level to that of 1992.

The results obtained here are very similar to those in González *et al.* (2004), which presented a CPUE standardization for the years 1991 to 2003. The very minor differences found must arise from the different range of years considered (here we have analyzed 1992 to 2006) and from the fact that we have now sampled 800 records for each of the years 1992, 1993 and 1994.

References

GONZALEZ, F.; D. GARCIA and H. MURUA (2004).- Standardized CPUE indices for Greenland Halibut in NAFO Divisions 3LMNO based on Spanish commercial catch rates. *NAFO SCR Doc.* 04/**16**.

JUNQUERA, S.; S. IGLESIAS and E. DE CARDENAS (1992).- Spanish fishery of Greenland halibut (*Reinhardtius hippoglossoides*) in 1990- 1991. *NAFO SCR Doc.* 92/**28**.

JUNQUERA, S.; A. VÁZQUEZ and E. DE CÁRDENAS (2000).- Greenland halibut depth variations in catch per unit effort, length composition, mature proportions and associated by-catches in Divisions 3LMNO. *NAFO SCR Doc.* 00/**67**.

Table 1.- **Analysis of Variance Table**

```
Response: lcpueplus27
                     Df  Sum Sq Mean Sq F value    Pr(>F)    
year                 14  455.48   32.53 183.571 < 2.2e-16 ***
division              3   76.90   25.63 144.636 < 2.2e-16 ***
month                11  286.09   26.01 146.750 < 2.2e-16 ***
depth                 8   82.38   10.30  58.100 < 2.2e-16 ***
vessel               56  741.42   13.24  74.704 < 2.2e-16 ***
division:month       33   65.89    2.00  11.266 < 2.2e-16 ***
division:depth       22   48.54    2.21  12.449 < 2.2e-16 ***
Residuals         11159 1977.69    0.18                      
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Table 2.- Parameter estimates from final log-linear model

```
Call:
lm(formula = lcpueplus27 ~ year + division + month + depth +
    vessel + division:month + division:depth)

Residuals:
     Min       1Q   Median       3Q      Max
-2.79094 -0.25307  0.01136  0.25948  2.24523

Coefficients: (2 not defined because of singularities)
                     Estimate Std. Error t value Pr(>|t|)
(Intercept)          6.231689   0.062668  99.440  < 2e-16 ***
year1993            -0.188338   0.025171  -7.482 7.85e-14 ***
year1994            -0.256629   0.025181 -10.191  < 2e-16 ***
year1995            -0.179138   0.054516  -3.286 0.001019 **
year1996             0.039941   0.027534   1.451 0.146928
year1997            -0.064262   0.029190  -2.201 0.027721 *
year1998            -0.295572   0.030133  -9.809  < 2e-16 ***
year1999            -0.385749   0.036859 -10.465  < 2e-16 ***
year2000            -0.046098   0.026353  -1.749 0.080268 .
year2001            -0.135619   0.028832  -4.704 2.58e-06 ***
year2002             0.023816   0.030876   0.771 0.440520
year2003            -0.297470   0.030029  -9.906  < 2e-16 ***
year2004            -0.528084   0.027479 -19.218  < 2e-16 ***
year2005            -0.356906   0.029264 -12.196  < 2e-16 ***
year2006            -0.051988   0.029291  -1.775 0.075946 .
division3M          -0.427129   0.055319  -7.721 1.25e-14 ***
division3N          -0.462469   0.077615  -5.958 2.62e-09 ***
division3O          -1.594691   0.553837  -2.879 0.003993 **
monthFeb            -0.084509   0.028247  -2.992 0.002780 **
monthMar            -0.257590   0.031812  -8.097 6.20e-16 ***
monthApr            -0.173646   0.032241  -5.386 7.36e-08 ***
monthMay            -0.191881   0.030329  -6.327 2.60e-10 ***
monthJun            -0.186623   0.030673  -6.084 1.21e-09 ***
monthJul            -0.274854   0.031541  -8.714  < 2e-16 ***
monthAug            -0.408099   0.030941 -13.189  < 2e-16 ***
monthSep            -0.585478   0.032167 -18.201  < 2e-16 ***
monthOct            -0.711203   0.031110 -22.861  < 2e-16 ***
monthNov            -0.367788   0.028266 -13.011  < 2e-16 ***
monthDec            -0.125381   0.028259  -4.437 9.22e-06 ***
depth2              -0.029155   0.020231  -1.441 0.149583
depth3              -0.056202   0.020723  -2.712 0.006696 **
depth4              -0.043204   0.021230  -2.035 0.041871 *
depth5              -0.017747   0.022372  -0.793 0.427648
depth6               0.014219   0.022908   0.621 0.534803
depth7               0.072573   0.034350   2.113 0.034645 *
depth8               0.150921   0.045898   3.288 0.001012 **
depth9               0.062571   0.098729   0.634 0.526246
vessel2             -0.069873   0.100437  -0.696 0.486633
vessel3             -0.348421   0.089766  -3.881 0.000104 ***
vessel4              0.381375   0.060020   6.354 2.18e-10 ***
vessel5             -0.420609   0.072873  -5.772 8.05e-09 ***
vessel6              0.254053   0.058312   4.357 1.33e-05 ***
vessel7             -0.400154   0.057708  -6.934 4.32e-12 ***
```

vessel8	-0.158457	0.094232	-1.682	0.092684	.
vessel9	-0.204076	0.060184	-3.391	0.000699	***
vessel10	-0.550768	0.077409	-7.115	1.19e-12	***
vessel11	0.088284	0.063053	1.400	0.161490	
vessel12	-0.697825	0.055921	-12.479	< 2e-16	***
vessel13	-0.751576	0.058893	-12.762	< 2e-16	***
vessel14	-0.805472	0.061499	-13.097	< 2e-16	***
vessel15	0.245971	0.218273	1.127	0.259811	
vessel16	-0.232816	0.054228	-4.293	1.78e-05	***
vessel17	-0.242327	0.056938	-4.256	2.10e-05	***
vessel18	0.112629	0.071204	1.582	0.113731	
vessel19	-0.125501	0.056379	-2.226	0.026033	*
vessel20	-0.248543	0.071833	-3.460	0.000542	***
vessel21	-0.029890	0.055504	-0.539	0.590224	
vessel22	-0.193579	0.112938	-1.714	0.086550	.
vessel23	-0.157963	0.057115	-2.766	0.005689	**
vessel24	0.686895	0.068341	10.051	< 2e-16	***
vessel25	-0.261386	0.062796	-4.162	3.17e-05	***
vessel26	-0.597630	0.054031	-11.061	< 2e-16	***
vessel27	0.081637	0.077273	1.056	0.290777	
vessel28	-0.384359	0.077178	-4.980	6.45e-07	***
vessel29	-0.239424	0.130153	-1.840	0.065859	.
vessel30	-0.624947	0.150957	-4.140	3.50e-05	***
vessel31	0.287958	0.141327	2.038	0.041620	*
vessel32	0.184139	0.054763	3.362	0.000775	***
vessel33	-0.279310	0.063132	-4.424	9.77e-06	***
vessel34	-0.324742	0.097997	-3.314	0.000923	***
vessel35	-0.126418	0.103170	-1.225	0.220475	
vessel36	-0.422829	0.064098	-6.597	4.40e-11	***
vessel37	-0.578060	0.061567	-9.389	< 2e-16	***
vessel38	-0.428301	0.074286	-5.766	8.35e-09	***
vessel39	-0.492584	0.085204	-5.781	7.61e-09	***
vessel40	0.089299	0.059038	1.513	0.130415	
vessel41	-0.347829	0.095840	-3.629	0.000285	***
vessel42	0.367013	0.087314	4.203	2.65e-05	***
vessel43	-0.678798	0.074985	-9.052	< 2e-16	***
vessel44	-0.426701	0.066185	-6.447	1.19e-10	***
vessel45	-0.196222	0.060627	-3.237	0.001213	**
vessel46	-0.071145	0.057256	-1.243	0.214054	
vessel47	-0.360830	0.090935	-3.968	7.29e-05	***
vessel48	-0.008916	0.076755	-0.116	0.907524	
vessel49	-0.150898	0.057828	-2.609	0.009081	**
vessel50	-0.135206	0.101820	-1.328	0.184240	
vessel51	-0.290462	0.060948	-4.766	1.91e-06	***
vessel52	0.007208	0.060373	0.119	0.904967	
vessel53	0.075962	0.063099	1.204	0.228676	
vessel54	-0.261708	0.057146	-4.580	4.71e-06	***
vessel55	0.181335	0.054707	3.315	0.000920	***
vessel56	-0.329827	0.066717	-4.944	7.78e-07	***
vessel57	-0.367028	0.055602	-6.601	4.27e-11	***
division3M:monthFeb	0.131887	0.046383	2.843	0.004471	**
division3N:monthFeb	0.196144	0.084972	2.308	0.020999	*
division3O:monthFeb	0.146629	0.547682	0.268	0.788915	
division3M:monthMar	0.206642	0.046256	4.467	8.00e-06	***
division3N:monthMar	0.297965	0.087943	3.388	0.000706	***
division3O:monthMar	0.951723	0.528325	1.801	0.071667	.
division3M:monthApr	0.259049	0.048900	5.298	1.20e-07	***

```
division3N:monthApr  0.514539   0.083583   6.156 7.72e-10 ***
division3O:monthApr  0.878480   0.481630   1.824 0.068183 .
division3M:monthMay  0.138550   0.049673   2.789 0.005293 **
division3N:monthMay  0.495550   0.081927   6.049 1.51e-09 ***
division3O:monthMay  0.735304   0.466965   1.575 0.115367
division3M:monthJun  0.076168   0.053378   1.427 0.153623
division3N:monthJun  0.388020   0.079819   4.861 1.18e-06 ***
division3O:monthJun -0.156223   0.625075  -0.250 0.802648
division3M:monthJul  0.176390   0.057115   3.088 0.002018 **
division3N:monthJul  0.463585   0.079536   5.829 5.74e-09 ***
division3O:monthJul  0.324594   0.463135   0.701 0.483403
division3M:monthAug  0.207023   0.053162   3.894 9.91e-05 ***
division3N:monthAug  0.746797   0.076245   9.795  < 2e-16 ***
division3O:monthAug  1.038345   0.490654   2.116 0.034346 *
division3M:monthSep  0.206887   0.067770   3.053 0.002273 **
division3N:monthSep  0.591492   0.076620   7.720 1.26e-14 ***
division3O:monthSep -0.077970   0.485787  -0.161 0.872488
division3M:monthOct  0.428563   0.056369   7.603 3.13e-14 ***
division3N:monthOct  0.707609   0.075680   9.350  < 2e-16 ***
division3O:monthOct  0.781989   0.580067   1.348 0.177653
division3M:monthNov  0.214437   0.052233   4.105 4.07e-05 ***
division3N:monthNov  0.324854   0.078635   4.131 3.64e-05 ***
division3O:monthNov  0.619937   0.458232   1.353 0.176119
division3M:monthDec  0.272647   0.060238   4.526 6.07e-06 ***
division3N:monthDec  0.288754   0.078936   3.658 0.000255 ***
division3O:monthDec  0.591400   0.458250   1.291 0.196883
division3M:depth2    0.191525   0.047577   4.026 5.72e-05 ***
division3N:depth2   -0.049517   0.043808  -1.130 0.258368
division3O:depth2    0.742253   0.392349   1.892 0.058541 .
division3M:depth3    0.182339   0.045537   4.004 6.26e-05 ***
division3N:depth3   -0.039889   0.042751  -0.933 0.350812
division3O:depth3    0.988172   0.334771   2.952 0.003166 **
division3M:depth4    0.171472   0.044860   3.822 0.000133 ***
division3N:depth4   -0.009340   0.044109  -0.212 0.832310
division3O:depth4    0.952529   0.344968   2.761 0.005768 **
division3M:depth5    0.057555   0.045468   1.266 0.205601
division3N:depth5   -0.001683   0.047277  -0.036 0.971599
division3O:depth5    0.842013   0.360358   2.337 0.019478 *
division3M:depth6   -0.021629   0.049180  -0.440 0.660104
division3N:depth6   -0.003844   0.052474  -0.073 0.941602
division3O:depth6    0.512181   0.357671   1.432 0.152175
division3M:depth7   -0.185609   0.065790  -2.821 0.004793 **
division3N:depth7   -0.016081   0.072364  -0.222 0.824140
division3O:depth7    0.125805   0.469024   0.268 0.788529
division3M:depth8   -0.694239   0.080662  -8.607  < 2e-16 ***
division3N:depth8   -0.198352   0.152682  -1.299 0.193931
division3O:depth8          NA         NA      NA       NA
division3M:depth9   -0.673338   0.120331  -5.596 2.25e-08 ***
division3N:depth9    0.075921   0.182903   0.415 0.678085
division3O:depth9          NA         NA      NA       NA
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.421 on 11159 degrees of freedom
Multiple R-Squared: 0.4704,   Adjusted R-squared: 0.4634
F-statistic: 67.43 on 147 and 11159 DF,  p-value: < 2.2e-16
```

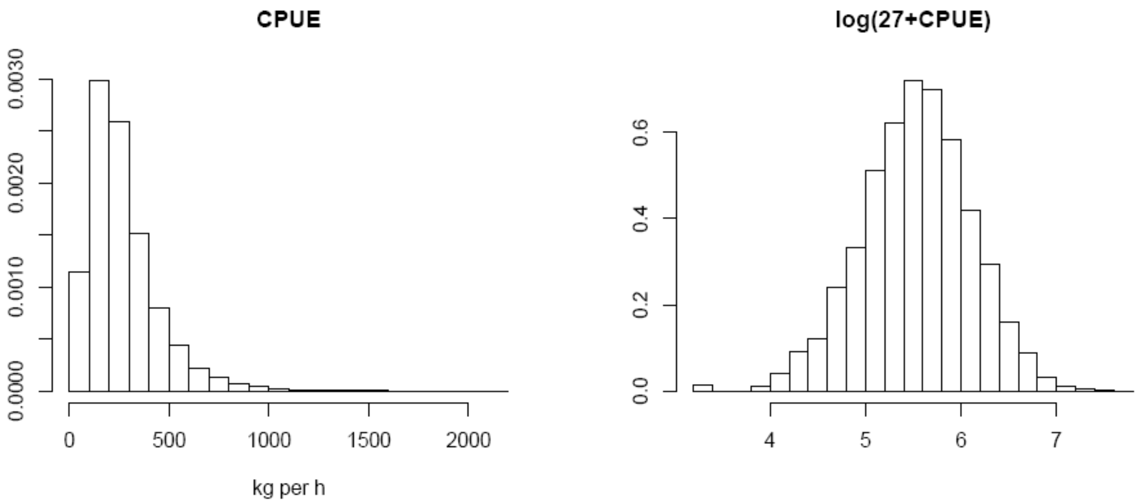

Figure 1.- Histograms of CPUE (left panel) and log-transformed CPUE (right panel) data

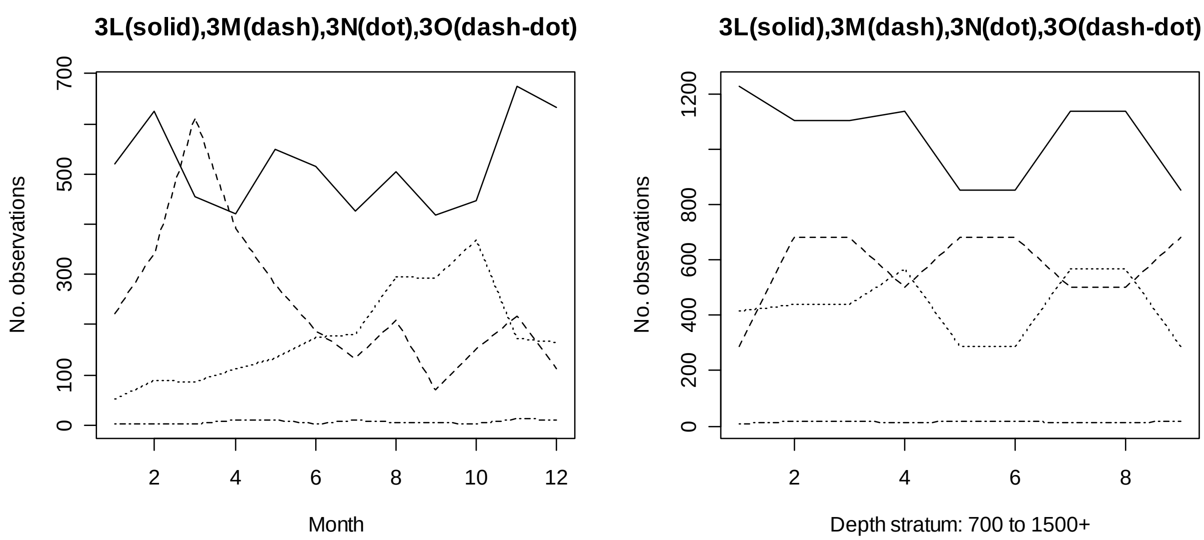

Figure 2.- Number of observations per division, by month (left panel) and depth stratum (right panel)

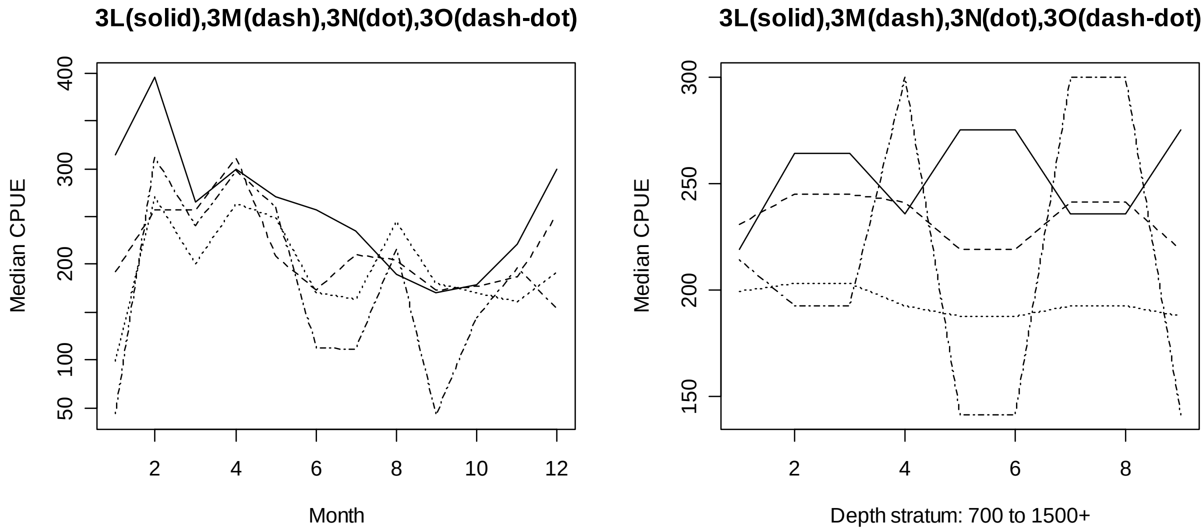

Figure 3.- Interaction plots for division*month (left panel) and division*depth stratum (righ panel)

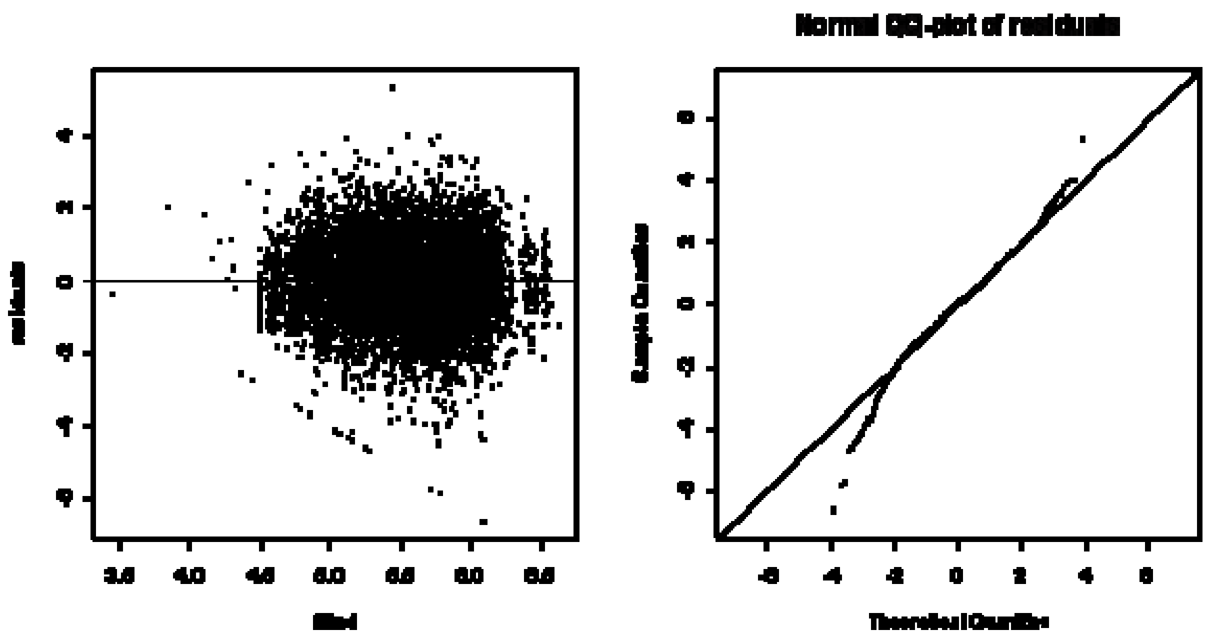

Figure 4.- Residuals *versus* fitted values (left panel) and QQ plot of residuals (right panel)

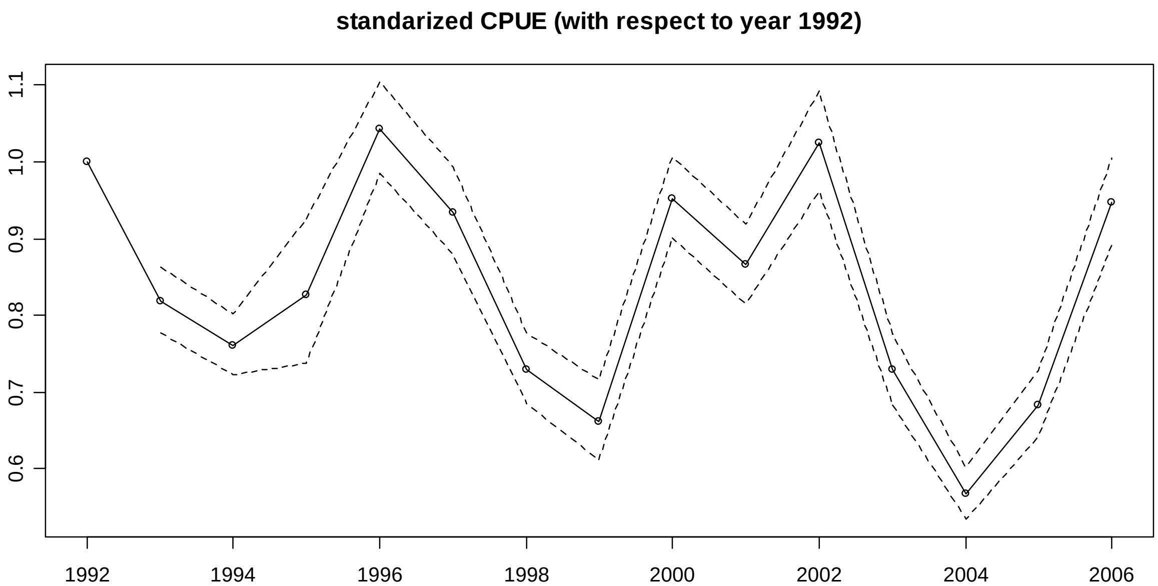

Figure 5.- Standardized CPUE series for Greenland halibut in NRA of Divisions 3LMNO, scaled to CPUE in 1992. Point estimates and 95% confidence limits.