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Trends in Spanish catch rates for Northern European hake *Merluccius merluccius* (L., 1758): Standardizing trawler and longliner fleets in ICES subarea VII

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ABSTRACT

Standardization of catch per unit effort (cpue) series using a generalized linear model (GLM) for Northern European hake *Merluccius merluccius* (L., 1758) in International Council for the Exploration of the Sea (ICES) subarea VII, based on catch and effort data from the Spanish trawler and longliner fleets from 1986 to 2000, are presented. Data were collected from trawler and longliner fleets targeting hake off the Spanish ports of La Coruña, Burela, and Celeiro. Main factors in the models created include a factor for engine Horse Power, to adjust for characteristics that determine fishing power; Year and Month factors for La Coruña's trawler fleet; and the factors Month, Year, Vessel, and Fishing Days for the Spanish longliner fleet as a whole. Moreover, both models indicate that interactions between the Year and Month factors also had a significant impact on hake catch rates. The total proportions of variance explained by these models were 55 % for La Coruña's trawler fleet, and about 48 % for Spanish longliner fleet. The results showed similar patterns comparing nominal and standardized catch rates.

Keywords: Standardization, cpue, Generalized Linear Model, European hake; trawler fleet, longliner fleet, ICES subarea VII.

RESUMEN

Análisis de las tasas de captura de la merluza europea* Merluccius merluccius *(L., 1758) del* stock *norte: estandarización del esfuerzo de las flotas españolas arrastreras y palangreras que faenan en la subárea VII del CIEM

Se muestra la aplicación de un modelo lineal generalizado (GLM) para la estandarización de la captura por unidad de esfuerzo (cpue) de la merluza europea Merluccius merluccius *(L., 1758) del* stock *norte en la subárea VII del Consejo Internacional para la Exploración del Mar (CIEM) durante el periodo 1986-2000. Los datos de esfuerzo y captura proceden de las flotas de arrastre y de palangre de los puertos de A Coruña, Burela y Celeiro (en el noroeste de España) dirigidas a la pesca de merluza del* stock *norte. En el modelo para la flota arrastrera del puerto de A Coruña se incluyeron los factores año, mes y categoría del barco, que relacionan la potencia del motor con su poder de pesca, y en el modelo para la flota palangrera de los puertos de A Coruña, Burela y Celeiro se incluyeron los factores año, mes, barco y días de pesca. Ambos modelos reflejan interacciones significativas entre los factores año-mes; así, el 55 % de la variación total observada se explica con el modelo para la flota arrastrera del puerto de A Coruña, y el 48 % se explica con el modelo para la flota palangrera. Las dos tipificaciones demuestran, así mismo, tendencias interanuales similares en las tasas de capturas estandarizadas y nominales.*

Palabras clave: *Estandarización, cpue, modelo lineal generalizado, merluza europea, flota arrastrera, flota palangrera, subárea VII del CIEM.*

INTRODUCTION

Catch Per Unit Effort (cpue) data from commercial fishing vessels have traditionally been used as a relative index of fish stock abundance (Large, 1992; Goñi, Álvarez and Adlerstein, 1999). The utility of indices of abundance based on catch and effort data can be improved by standardizing them; that is, removing from the data any variation due to effects other than fish abundance (Punt *et al*., 2000). This process is often referred to as catch-effort standardization.

Traditionally, the European hake *Merluccius merluccius* (L., 1758) has been a target species for the Spanish fleet and/or a valuable incidental catch, owing to its high price on European fish markets (Casey and Pereiro, 1995).

The main Northern European hake commercial fishing grounds are found in International Council for the Exploration of the Sea (ICES) subarea VII. The Spanish ports of Burela, Celeiro and La Coruña are amongst the most important trawler and longliner fleets targeting Northern European hake in this area.

The Generalized Linear Model (GLM) is generally used to analyse and standardise catch rates, because this approach makes it possible to identify the factors that influence catch rates and calculation of standardized abundance indices through the year factor (O'Brien and Kell, 1996). GLM technique provides a very powerful, consistent method for examining the effects of vessel differences and area differences to determine time trends in cpue (Hilborn and Walters, 1992). The present study applied a GLM to develop standardized cpue.

MATERIALS AND METHODS

The catch and effort data used in our analysis came from records of trip landings per vessel of the trawler and longliner fleets based at La Coruña port (1986-2000) and longliner fleets at the ports of Burela and Celeiro (1994-2000), all operating in ICES subarea VII. Data on trip landings were obtained from fish markets, with the exception of data from La Coruña port in the period covering 1998-2000, which come from the sampling network of the Instituto Español de Oceanografía (IEO).

Each individual record contains information on the vessel, date, species, landing and number of fishing days. Vessels were identified and their technical characteristics (gross registered tonnage, width, length, and horse power) were also recorded.

A GLM was fitted to hake *M. merluccius* landings for trawler and longliner Spanish fleets that operated in ICES subarea VII from 1986 to 2000.

Traditionally, it was assumed that the modelled catch rate (cpue) is a log-normal distribution (Beverton and Holt, 1957). An undesirable consequence of using the logarithm of the catch rates is needed to accommodate any zero catch rate observations. An usual practice is to add a small constant to the calculated catch rate for all observations. The value of this constant in this study was equal to 1.

Trawler data

Data used were landings per vessel of La Coruña's trawler fleet that operated in ICES subarea VII from 1986 to 2000. La Coruña's trawler fleet is the most important Spanish trawler fleet targeting European hake. In this fleet, fishing pattern and vessel technical characteristics have remained stable over the course of the period 1994-2000 (table I). This fleet has an average gross registered tonnage (grt) of 238 and an average horse power (HP) of 843. Raw data were a total of 8 872 records; from these raw data, records of vessels with only sporadic trips during this period, or without information on vessels' technical characteristics, were

Table I. Summary of number of vessels, number of fishing trips (observations), and vessels' technical characteristics, average by year from La Coruña's trawler fleet in ICES subarea VII

Year	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Vessels	55	54	56	56	56	51	40	27	26	23	20	18	18	14	14
Observations	755	874	930	870	912	797	530	441	423	379	328	319	89	48	75
HP mean	827	836	849	844	861	867	863	878	888	920	905	910	932	854	959
trb mean	234	234	234	234	234	234	234	234	234	234	234	234	234	234	234

removed (11 %). Records indicating zero hake landings were also removed (2 %), to avoid the problem of undefined logarithms.

Most of the fishing trips lasted 1 day and therefore for the purpose of the analysis it was assumed that one trip was one fishing day and cpue was calculated as hake catch per day (fishing trip) expressed in hake kg/day.

The final working data set included a total of 7 770 records (trips) made by 56 trawler vessels (table I). In trawler fleet analysis, cpue were calculated as the ratio of recorded landings of hake to the number of fishing days, and log-transformed under the assumption that catch rate is a log-normal distribution. Inclusion in the analysis of all technical characteristics of vessels as explanatory variables was not appropriate, because they showed a high correlation (colinearity). Therefore, we used only information on HP to classify the trawler fleet into 9 main categories (HP cat.) according to their fishing power (table II).

Longliner data

Data used included landings per vessel of La Coruña's longliner fleet from 1986 to 2000, and those of the Burela and Celeiro longliner fleets from 1994-2000, which operated in ICES subarea VII. These fleets are the most important Spanish longliner fleets targeting European hake. During the period covering 1994-2000, most longliner vessels that in previous years were landing at La Coruña port had moved to Burela and Celeiro.

Raw data consisted of a total of 7 845 records; from these raw data, records of vessels with only sporadic trips during this period, or without information on vessels' technical characteristics, were removed. Records containing zero hake landings, or a proportion of hake landings that was too small (i.e., hake not a target species) were also removed. Additionally, records from La Coruña's longliner fleet in the period from 1998 to 2000 were removed, because they did not contain fishing days by trip.

The final working data set included a total of 7 070 records (trips) made by 71 longliner vessels with an average grt of 197 and an average HP of 693 (table III). In longliner fleet analysis, cpue were calculated as the ratio of recorded hake landings by trip, and log-transformed under the assumption that catch rate is a log-normal variable.

For the present study, we modelled standardized indices of relative abundance of European hake, assuming that the errors in the dependent variable follow a Gaussian distribution. We used a Gaussian GLM model to adjust the cpue trend of hake, with identity as a link function (McCullag and Nelder, 1989), using statistics package S-Plus 2000. A stepwise regression procedure was used to determine the set of factors and interactions that significantly explained the most variability with the least number of estimated parameters. Deviance tables show the percentage of deviance explained by each factor. The difference in deviance between two consecutive factors follows a chi-squared (χ^2) distribution with the degrees of freedom (df) equal to the number of additional parameters estimated minus one (McCullag and Nelder, 1989). A p-value based on the χ^2 test statistic was used to evaluate the significance of each additional factor in the model (Ortiz,

Table II. Summary of vessel category classification of La Coruña's trawler fleet based on Horse Power (HP cat.)

HP category	400	500	600	700	800	900	1 000	1 100	1 200
HP	<500	500-599	600-699	700-799	800-899	900-999	1 000-1 099	1 100-1 199	≥1 200
Vessels	2	7	6	4	10	11	7	3	6
Observations	273	1 003	649	407	1 479	1 395	1 028	462	1 074

Table III. Summary of number of vessels, number of fishing trips (observations), and vessels' technical characteristics, average by year from the Spanish longliner fleet in ICES subarea VII

Year	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Vessels	32	27	27	29	27	25	22	19	63	61	68	69	53	47	44
Observations	244	254	262	284	256	229	206	200	776	705	977	844	618	626	589
HP mean	763	759	758	757	770	804	826	834	671	713	705	697	695	697	684
trb mean	207	206	204	201	203	206	207	212	198	199	200	198	196	195	194

Turner and Brown, 1999; Ortiz, Legault and Ehrhardt, 2000). The total deviance explained should be interpreted only as an indicator of the goodness of a fit between the observed data and the assumed model. The impact of each explanatory factor is summarized by the percentage of the deviance explained. The final selection of explanatory factors was conditional to the relative percent of deviance explained by adding the factor.

Annual abundance indices were obtained from adjusted means of the year factor, adjusted for the GLM's statistically significant factors.

RESULTS AND DISCUSSION

As expected, the frequency distributions of the hake cpue for each fleet are skewed, with a few extremely large catches (figure 1 and figure 2).

The main factors considered in the analysis for La Coruña's trawler fleet data were year, month and HP cat. The interactions for the main factors were also considered. Analysis for La Coruña's trawler fleet showed that the factors year, month, HP cat., and interaction between month and year factors (month * year) were statistically significant on both analysis of deviance and anova (table IV and table V). The selected final model was as follows:

$$\ln\,(\text{cpue}) \sim \text{year} + \text{month} + \text{HP cat.} + \text{month} * \text{year}$$

The final model explained 55 % of the overall deviance. The HP cat. factor explained 25 % of the total variability accounted for by the final model. The considerable amount of variation explained in the final model by the HP cat. Factor could reflect the differences in fishing power between vessels.

The distribution of the standardized residuals did not appear to differ much from those expected under the normal distribution (figure 3). The normal probability plot shows slight divergences for tails (figure 3). However, the standardized residuals conform adequately to the normal distribution.

Nominal and standardized annual indices of abundance for La Coruña trawlers in ICES subarea

Table IV. Deviance analysis table of explanatory variables in the Gaussian GLM model for *M. merluccius* catch rates from La Coruña's trawler fleet in ICES subarea VII. Percent of total deviance refers to the deviance explained by the full model. (Df): degrees of freedom; (Residual dev.): residual deviance; (% total dev.): percent of total deviance explained by each factor; (p): significance level of the χ^2 statistic for each factor (i.e., whether the addition of an additional factor is significant)

	Df	Residual dev.	Change in dev.	% total dev.	p
Null		5 818			
Year	14	5 102	717	12	<0.001
Month	11	4 340	762	13	<0.001
HP cat.	7	2 888	1 452	25	<0.001
Month * year	144	2 639	249	4	<0.001
Total			3 180	54	

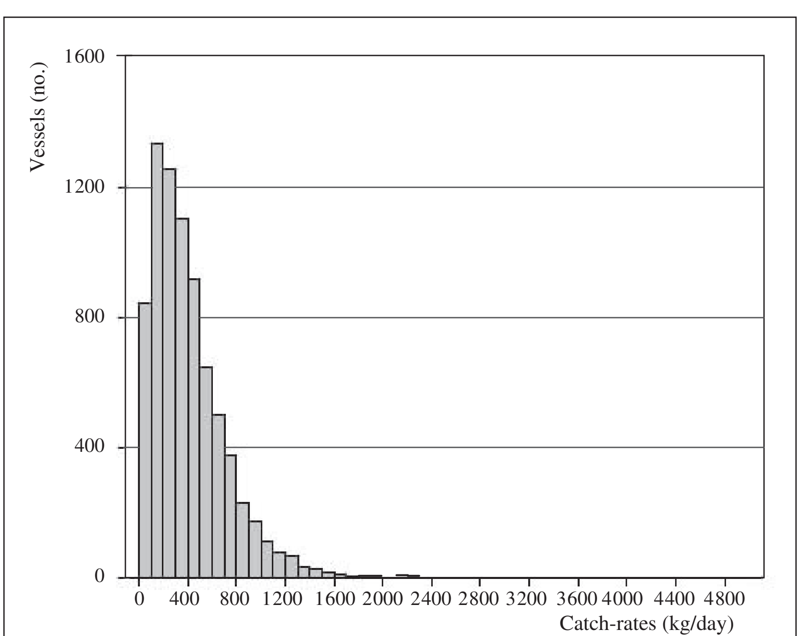

Figure 1. Frequency distribution of European hake catch-rates of the vessels of La Coruña's trawler fleet in 1986-2000

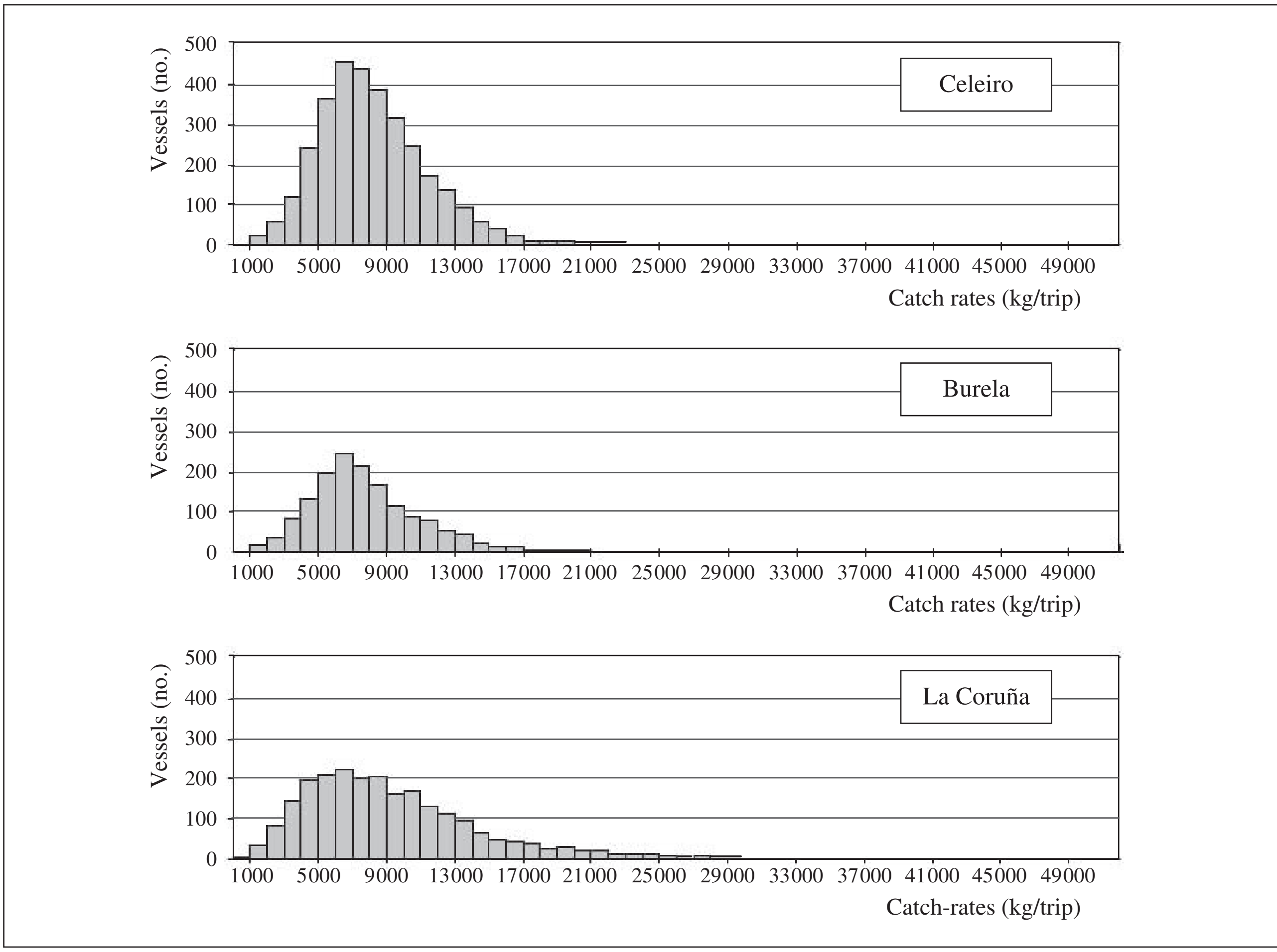

Figure 2. Frequency distribution of European hake catch-rates of the vessels of La Coruña's, Burela and Celeiro longliner fleets in 1986-2000

VII are shown in table VI and figure 4. Both indices show similar trends over the time series.

On the other hand, in the analysis for the Spanish longliner fleet data, the main factors were: year, month, fishing days and vessel. The interactions for the main factors were also considered. The deviance and anova tables show that factors year, month, fishing days, vessel and interaction be-

Table V. Analysis of variance (anova) of standardized cpue using GLM method for *M. merluccius* from La Coruña's trawler fleet in ICES subarea VII. (Df): degrees of freedom; (Sum of sq.): sum of squares; (F): F-test value; (p): significance level of the F-test for each factor

	Df	Sum of sq.	Mean of sq.	F	p
Year	14	675	48.2	146.2	0
Month	11	413	37.5	113.8	0
HP cat.	8	1 580	197.5	598.7	0
Month * year	144	252	1.8	5.3	0
Residuals	7 592	2 505	0.3		

Table VI. Nominal and standardized catch rates series (ln kg/day) for *M. merluccius* from La Coruña's trawler fleet in ICES subarea VII. (se): standard error

La Coruña's trawlers in ICES subarea VII			
	Nominal Index	GLM	
		Index	se
1985	6		
1986	5.9	5.3	0.02
1987	6.5	6.0	0.02
1988	6.2	5.7	0.02
1989	6.2	5.7	0.02
1990	6.0	5.4	0.02
1991	5.8	5.2	0.02
1992	6.3	5.8	0.03
1993	6.1	5.6	0.03
1994	6.3	5.8	0.03
1995	6.7	6.2	0.03
1996	6.5	6.1	0.03
1997	6.1	5.6	0.03
1998	6.4	6.0	0.10
1999	6.6	6.1	0.09
2000	7.1	6.5	0.07

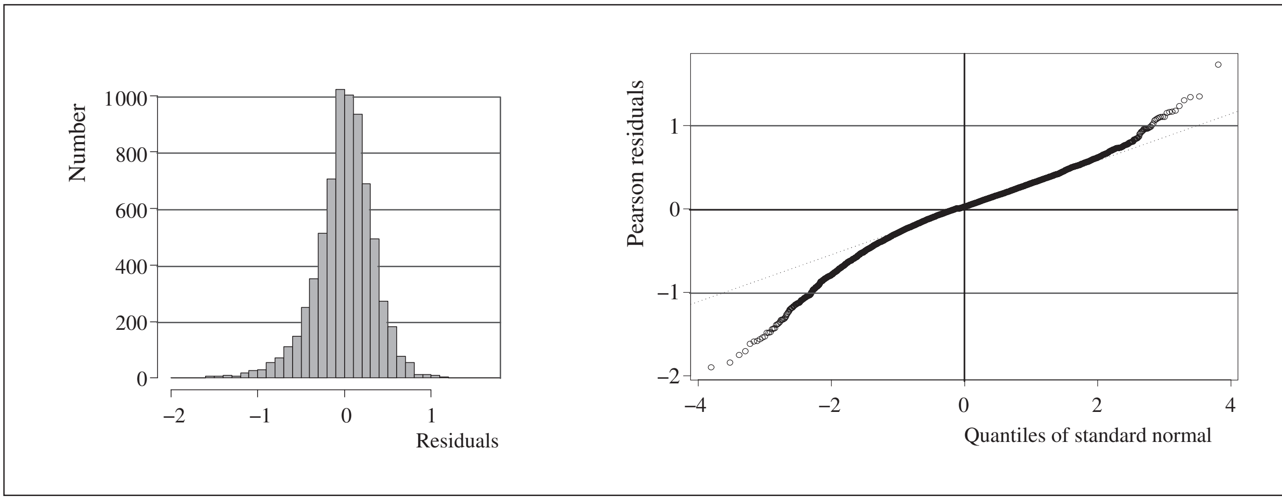

Figure 3. Distributions of the standardized residuals and the normal probability plots for the standardization model fitted to the catch and effort data of La Coruña's trawler fleet in the period from 1986 to 2000

Table VII. Deviance analysis table of explanatory variables in the Gaussian GLM model for *M. merluccius* catch rates from the Spanish longliner fleet in ICES subarea VII. Percent of total deviance refers to the deviance explained by the full model. (Df): degrees of freedom; (Residual dev.): residual deviance; (% total dev.): percent of total deviance explained by each factor; (p): significance level of the χ^2 statistic for each factor (i.e., whether the addition of an additional factor is significant)

Source	Df	Residual dev.	Change in dev.	% total dev.	p
Null		1 581			
Year	14	1 369	212	13.4	<0.001
Month	11	1 113	256	16.2	<0.001
Fishing days	23	1 062	51	3.3	<0.001
Vessel	70	998	64	4.1	<0.001
Month * year	154	827	170	10.8	< 0.001
Total			53	47.8	

tween month and year factors (month * year) were statistically significant (table VII and table VIII). The final model was as follows:

$$\ln\ (\text{cpue}) \sim \text{year} + \text{month} + \text{fishing days} + \\ + \text{vessel} + \text{month} * \text{year}$$

The deviance table shows that the final model explained 48 % of the overall deviance. Factor month explained 16 % total variability. Figure 5 shows standardized residual plots and QQ-plots for the final model that confirms the model adequacy.

Table VIII. Analysis of variance (anova) of standardized cpue using GLM method for *M. merluccius* from the Spanish longliner fleet in ICES subarea VII. (Df): degrees of freedom; (Sum of sq.): sum of squares; (F): F-test value; (p): significance level of the F-test for each factor

	Df	Sum of sq.	Mean sq.	F	p
Year	14	190	13.6	112.7	0
Month	11	232	21.1	175.5	0
Fishing days	189	67	0.4	3.0	0
Vessel	70	65	0.9	7.7	0
Month * year	154	164	1.1	8.9	0
Residuals	6 631	799	0.1		

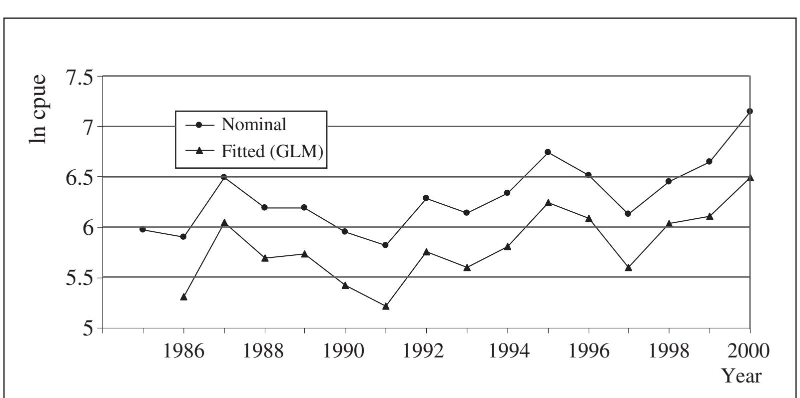

Figure 4. Trends of standardized and nominal catch rates of European hake (ln kg/day) from La Coruña trawler fleet in ICES subarea VII in 1986-2000

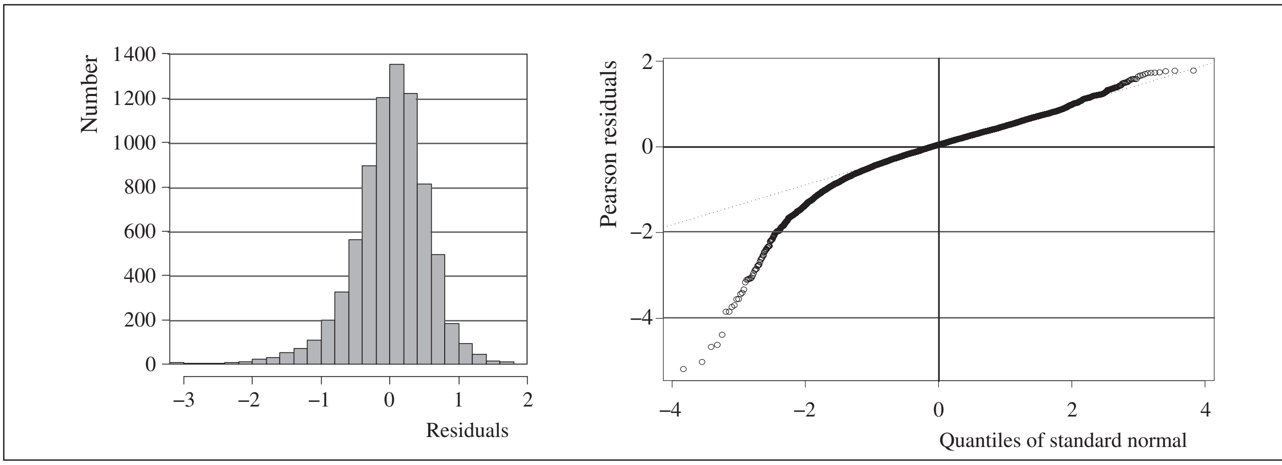

Figure 5. Distributions of the standardized residuals and the normal probability plots for the standardization model fitted to the catch and effort data of the Spanish longliner fleet in the period from 1986 to 2000

The variability explained by factor Month reflects the differences in hake catches that are mainly due to seasonality.

Nominal and standardized annual indices of abundance for the Spanish longliner fleet in ICES subarea VII are shown in table IX and figure 6. Both indices show analogous trajectory trends over the time series.

CONCLUSIONS

The results of the present study indicate that analysis on catch-rates series in both trawler and longliner Spanish fleets showed similar patterns when nominal and standardized catch rates were compared. Moreover, these trends are similar to ICES stock assessment reports (ICES, 2001). These similar trends can be explained as being a consequence of the constant composition of fleet and were no changes in fishing pattern for La Coruña trawler fleet and the Spanish longliner fleet during this period.

Table IX. Nominal and standardized catch rates series (ln kg/trip) for *M. merluccius* from the Spanish longliner fleet in ICES subarea VII. (se): standard error

Spanish longliners in ICES subarea VII			
	Nominal Index	GLM	
		Index	se
1986	9.1	8.8	0.04
1987	8.9	8.6	0.03
1988	9.2	8.9	0.03
1989	9.1	8.7	0.03
1990	8.9	8.7	0.03
1991	9.0	8.7	0.03
1992	9.3	9.0	0.03
1993	9.5	9.2	0.04
1994	9.0	8.7	0.03
1995	9.3	9.1	0.03
1996	9.3	9.2	0.02
1997	9.0	8.8	0.03
1998	8.9	8.7	0.03
1999	9.0	8.9	0.03
2000	9.2	9.0	0.03

Cpue is a reliable index of population density only if the assumptions regarding gear and spatial

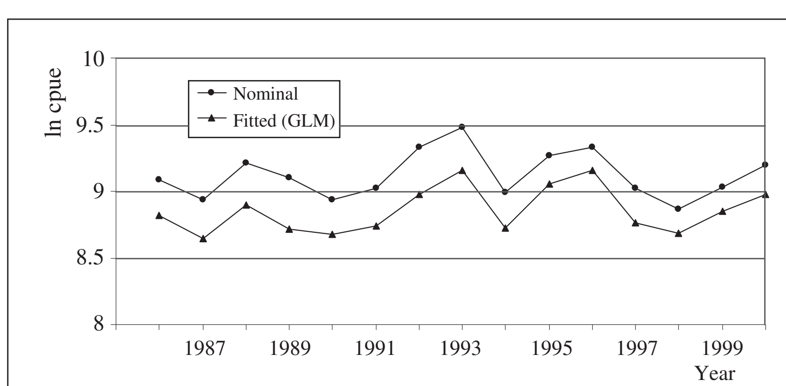

Figure 6. Trends of standardized and nominal catch rates for European hake (ln kg/trip) from Spanish Longliner fleet in ICES subarea VII in 1986-2000

and temporal distributions of fish and fishing effort are met (Beverton and Holt, 1957).

A critical assumption in these models is that geographic factors should be used. The yields of commercial fishing correspond to a non-random sampling, closely linked to the spatial and temporal structure of the resource, which does not respect the basic conditions of sampling theory, since fishermen normally operated in areas with high fish densities. Spatial distribution usually has more influence on cpue than vessels' technical characteristics and unexplained noise. It should be noted that there are many situations in which the assumption that catch rate is proportional to abundance is violated, even though the data have been standardized to remove the impact of known factors (Hilborn and Walters, 1992).

Further applications of these modelling approaches is the study of area effects on catch rates of different fleets sharing the same resource, and the inclusion of spatial factors.

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