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STANDARDIZED CATCH RATES IN BIOMASS FOR THE NORTH ATLANTIC STOCK OF SWORDFISH (*XIPHIAS GLADIUS*) FROM THE SPANISH SURFACE LONGLINE FLEET FOR THE PERIOD 1986-2011

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SUMMARY

Nominal catch rates of the Spanish surface longline fleet targeting swordfish are provided for a period of 26 years (1986-2011). Standardized catch rates (in number of fish and weight) were also updated using log-normal Generalized Lineal Models (GLM). Factors such as area, quarter, gear, bait as well as the fishing strategy -based on the ratio between both most prevalent and appreciated species by skippers- were used. The models explained the 54% and 55% of the CPUE variability in number and weight, respectively. The results show an overall slightly decreased trend of the standardized CPUE in number and weight up to years 1996 and 1998, respectively, followed by a change of trend afterwards. The standardized mean weights are also provided for the same period.

RÉSUMÉ

Les taux de capture nominale de la flottille palangrière de surface espagnole ciblant l'espadon sont fournis pour une période de 26 ans (1986-2011). Les taux de capture standardisés (en nombre de poissons et en poids) ont également été actualisés à l'aide de modèles linéaires généralisés lognormaux. On a utilisé les facteurs, tels que zone, trimestre, engin, appât ainsi que la stratégie de pêche - sur la base du ratio entre les espèces les plus nombreuses et les plus appréciées par les capitaines. Les modèles ont expliqué 54% et 55% de la variabilité de la CPUE en nombre et en poids, respectivement. Les résultats font apparaître une tendance globale légèrement décroissante de la CPUE standardisée en nombre et en poids jusqu'aux années 1996 et 1998, respectivement, suivie d'un changement de tendance par la suite. Les poids moyens standardisés sont également fournis pour la même période.

RESUMEN

Se presentan tasas de captura nominal del pez espada de la flota española de palangre de superficie en el Atlántico Norte para el período de 26 años (1986-2011). Además, se actualizaron para ese mismo periodo las tasas de captura estandarizadas (en número de peces y en peso) aplicando Modelos Lineales Generalizados (GLM) con una aproximación log-normal similar a la usada en anteriores análisis. Se tuvieron en cuenta los factores área, trimestre, arte, cebo así como la estrategia pesquera basándose en el ratio entre la captura de las dos especies más prevalentes y valoradas por los patrones de pesca (skippers). Los modelos GLM explicaron el 54% y 55% de la variabilidad de la CPUE en número y peso, respectivamente. Los resultados sugieren una tendencia ligeramente descendente de las tasa de captura estandarizadas en número de peces y en peso hasta 1996 y 1998, respectivamente, para producirse posteriormente un cambio de tendencia. El peso medio estandarizado para dicho periodo es también suministrado.

KEY WORDS

Swordfish, CPUE, GLM, longline

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1. Introduction

Catch per unit of effort data from a large number of commercial fleets have been one of the main information used for the assessments of swordfish stocks as an expression of the changes in the abundance throughout time. The type of behavior of this species, its broad geographical distribution jointly with the type of fishing gears regularly used targeting-catching this species makes it difficult to use specific methods and strategies to obtain direct indicators of abundance.

The relative "abundance" estimations obtained from the catch rates of commercial fishing of a given stock is influenced by several factors (e.g. year, area-season and the environmental conditions associated, gear type and style used, operational variables, the fishing strategy, etc). Operational changes and technological advances are particularly difficult to detect, including changes in the target species or in the criteria of the skippers. In order to compensate for these influences, Generalized Linear Models (GLM) (Robson 1966, Gavaris 1980, Kimura 1981) have been recommended and used to standardize CPUE series from commercial longline fleets catching swordfish and other tuna and tuna-like species. Some of the factors are almost impossible to be obtained, such as the criteria of the skipper in order to give priority to one species over another. In such cases indirect factors or proxies could be in some cases a good alternative to be considered. The standardized catch rates of the Atlantic swordfish (*Xiphias gladius*) and of the several shark species have been obtained in recent decades by means of GLM based on data from several commercial fleets (e.g. Anon. 1989, 1991, Hoey *et al*. 1989, 1993, Nakano 1993, Mejuto 1993, 1994, Scott *et al*. 1993, Mejuto and De la Serna 1995, Mejuto *et al*. 1999, 2003, Ortiz *et al*. 2007, Babcock and Skomal 2008, Brown 2008, Cortés 2008, 2009, 2010, Fowler and Campana 2009, Matsunaga 2008, Mourato *et al.* 2007, 2008, Pons and Domingo 2008).

The structure and configuration of the Spanish surface longline fleet targeting swordfish was relative stable during decades of the last century, using the multifilament as the traditional longline style. However, important changes in the fishing strategy of the Spanish fleet were mainly produced during a short period 1998-2001 with the generalized introduction of a new surface longline style. The multifilament style traditionally used was replaced by the imported monofilament type (the American style) in most of the vessels from the end of the last century Descriptions about these changes are available in previous papers (Mejuto *et al*. 1997, 1998, 1999, 2000, 2001, 2002; Mejuto and De la Serna 1995, 1997, 2000, Ramos-Cartelle *et al.* in press). This new style was broadly introduced in most boats of the Spanish fleet fishing in the Atlantic as well as in the Pacific and Indian oceans (García-Cortés *et al.* 2010, Mejuto *et al*. 2011). Additionally, the targeting criteria of the North Atlantic surface longline Spanish fleet was historically based only on swordfish catches. But this strategy has become more diffuse in recent periods, focusing on a combination of swordfish and blue shark as both main and valuable species as was also reported in the case of other surface longline fleets. These changes in the fishing strategy have had an important impact on the swordfish nominal CPUE obtained (Mejuto and De la Serna 2000, Ortiz and Scott 2003, Ortiz *et al.* 2010).

2. Material and methods

The records used were voluntary reports of the Spanish surface longline fleet targeting swordfish in the North Atlantic stock during over the period 1986-2011. Data are mostly records per trip obtained when fish are landed at the different base ports used by the North Atlantic fleet. Other sources of information such as interviews, some scientific observers and aggregated logbook data were used in some cases. These data include information about position, catches, nominal effort (thousands of hooks), nominal CPUE in number of fish and weight (kg round weight) per thousand hooks, representing the activity of this fleet for scientific purposes and were used to build the ICCAT Task II data. Additional information such as the type of gear and bait used is also recorded during landings. More details about the methods can be found in previous papers (Mejuto and De la Serna 2000, Mejuto *et al.* 2000, 2001, 2002). The hypothetical boundary line between both Atlantic stocks was kept at 5ºN latitude as assumed by the ICCAT. The spatial definition used for final runs considered 5 areas (**Figure 1**).

The standardized log-normal CPUE analyses were performed using GLM procedures (*SAS 9.2 ver.*). The models were defined including the 'ratio' effect as an indicator of the target criteria of the skipper on swordfish and/or blue shark during the fishing activity as well as the gear style and bait type used: LOG (CPUE) = u + Y + Q + A + R + G + B+ A*Q + e. Where: u = overall mean, Y= effect year, Q= effect time (quarters), A= effect area, R= effect 'ratio', G= effect gear style, B= bait type, e= logarithm of the normally distributed error term. Three levels of gear styles were defined: 1= traditional multifilament mainline, 3= new monofilament and 9: unknown. Three levels of bait types were considered: 1= mackerel, 6= squid and 9= other types or combinations. The temporal definition corresponding to "quarters" was as follows: Q1 = January- March; Q2 = April-June; Q3 = July-

September; Q4 = October-December. The variable 'ratio' was defined for each available trip record as the percentage of swordfish in weight related to the catches of swordfish and blue shark combined. This 'ratio' might be a good indicator criterion of the skippers (target intensity) belonging to the Spanish surface longline fleet (Mejuto and De la Serna 2000). The records were categorized into ten 'ratio' categories of 10% intervals in order to classify the criteria of the skipper regarding the priority toward these two potentially desirable main species during the trip. CPUE analyses were carried out in number of fish caught and biomass (kg round weight per thousand hooks) for a period of 26 years (1986-2011). The nominal and the standardized CPUE (in kg round weight) were scaled for comparison taking into consideration their respective maximum values. Sensitivity analysis was performed including more interactions inside the model, such as year*quarter and year*area.

The standardized mean weight by year and their confidence intervals was also obtained using the same GLM approach. The methods and specifications were designed to be consistent with previous analyses for updating and comparative purposes.

3. Results and discussion

Figure 1 summarizes the geographical distribution of the 5ºx5º fishing effort of the observations used and the areas defined for the GLM runs for the whole period analyzed 1986-2011. A total of 12,697 trip observations were available for the whole period. The number of observations per spatial-temporal cell may be considered satisfactory for this type of fishery. The available observations cover most of the regular fishing areas of the North Atlantic Spanish surface longline fleet during this period as well as the 76% and 60% of the 5ºx5º North Atlantic stock squares between latitudes 30º-50º N –where most of the international North Atlantic catches are done– and 5º-50º N, respectively.

A summary of the ANOVA results from GLM procedures are in table **1**. The significant models defined explained 54% and 55% of the CPUE variability in number and biomass, respectively. Most of the CPUE variability (Type III SS) may be attributed to the ratio effect as would be expected according to previous finding and secondly to the gear style considering that the effort is expressed in relation to the number of hooks. All gear data belong to styles 1 and 3, except only one record which belongs to style 9. Other factors considered, such as year or area, were also significant and quite important. The area and quarter factors seem to be qualitatively different in terms of explaining the variability of the CPUE in number or weight. Other factors or interactions were also significant but with a minor effect. The impact of some changes on the fishing strategy of the Spanish fleet has already been assessed in recent papers and compared with the results obtained using other approaches (Mejuto and De la Serna 2000, Mejuto *et al*. 2000).

Figures 2 and **3** show a normal standardized residual pattern, the variability *box-plot* and *qq-plots* according to the tests used, for standardized CPUE in number and in biomass, respectively. The fitting of the model does not seem to be biased and residuals are distributed normally. Tables **2** and **3** provide information on estimated parameters, their standard error, CV%, relative CPUE and upper and lower 95% confidence limits, in number and in biomass, respectively.

Figure 4 shows the standardized CPUE in number and weight as well as the standardized mean weight obtained by year and their respective 95% confidence intervals. Both trends of standardized CPUE in number and weight are similar. The analyses show an overall slight decrease of the standardized CPUE in number and weight up to years 1996 or 1997-1998, respectively, followed by a change of trend afterwards. The more positive recruitment scenario observed after 1996 could play an important role in changing these trends after 1996, with an expected years-lag between the overall indicators in number and biomass. Similar conclusions can be achieved when the standardized mean weight trend is interpreted. If the catch rates are assumed to be indices of relative abundance, the results suggest that the biomass of the North Atlantic swordfish have had an overall flat trend since the end of the last century.

The scaled overall nominal catch rates and scaled standardized CPUE of swordfish per year (in kg round weight) are shown in **Figure 5**. The highest values of nominal catch rates were obtained during the most recent period just after 1999 when the monofilament American longline style gear was introduced by most of the boats.

The standardized CPUE trend obtained from the sensitivity analysis including year*quarter interaction did not show any significant difference compared to the base case results. It was not possible to achieve any result including the year*area interaction within the model.

In long-lifespan species, such as the Atlantic, Indian and Pacific swordfish (Mediterranean stock probably excluded), swordfish populations are regularly made up of individuals up to 10+ years of age. Intermediate ages account for the largest part of the available stock biomass. As a result, abrupt changes of the overall biomass and their representative indices should not be expected between consecutive years and the inter-annual fluctuations should be biologically plausible. The age structure of the swordfish population usually softens overall biomass fluctuations even in highly-variable recruitment and/or in high fishing mortality scenarios, as observed in the history of the North Atlantic case (Anon. 2010) or in population simulations. Therefore, biomass trends for the North Atlantic swordfish should tend to be based on multiannual cycles or stages basically depending on the recruitment scenarios -or their phases- and also on the fishing intensity. The standardized CPUE obtained for the analyzed period suggest moderate and biologically plausible changes in the relative biomass index between couples of consecutive years ($CPUE_{yr+1}$ vs. $CPUE_{yr}$), with a mean value of biannual increase of 8.45% (CI95%= ± 2.60) when absolute increments are considered and 0.12% (CI95%: ± 4.26%) when the balance between positive and negative increments are averaged, respectively. Moderate increments in number of fish between couples of consecutive years were also obtained with a mean value of 8.57% (CI95%= ± 2.07) when absolute increments are considered and 0.82% (CI95%: ± 3.9%) when the balance between positive and negative increases are averaged, respectively.

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Table 1. Summary of ANOVAs for each CPUE analysis, in number (upper table) and in biomass (lower table).

North Atl. Spain. LL SWO, CPUE in number of fish
Dependent variable: log (CPUEn)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	57	3629.848257	63.681548	259.75	<.0001
Error	12639	3098.692618	0.245169		
Corrected Total	12696	6728.540875			

R-Square	Coeff. Var.	Root MSE	cpue Mean
0.53947	27.93354	0.495146	1.772584

Source	DF	Type III SS	Mean Square	F Value	Pr > F
yr	25	108.194043	4.327762	17.65	<.0001
qtr	3	106.592610	35.530870	144.92	<.0001
area	4	181.414952	45.353738	184.99	<.0001
gear	2	254.519180	127.259590	519.07	<.0001
bait	2	8.891512	4.445756	18.13	<.0001
ratio	9	1031.291638	114.587960	467.38	<.0001
qtr*area	12	42.787367	3.565614	14.54	<.0001

North Atl. Spain. LL SWO, CPUE in weight
Dependent variable: log (CPUEw)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	57	3386.428433	59.411025	269.07	<.0001
Error	12639	2790.747986	0.220804		
Corrected Total	12696	6177.176419			

R-Square	Coeff. Var.	Root MSE	cpue Mean
0.548216	8.650942	0.469898	5.43176

Source	DF	Type III SS	Mean Square	F Value	Pr > F
yr	25	137.844543	5.513782	24.97	<.0001
qtr	3	144.686689	48.228896	218.42	<.0001
area	4	77.732048	19.433012	88.01	<.0001
gear	2	226.516770	113.258385	512.94	<.0001
bait	2	9.134777	4.567388	20.69	<.0001
ratio	9	1069.460785	118.828976	538.16	<.0001
qtr*area	12	54.227063	4.518922	20.47	<.0001

Table 2. Estimated parameters (lsmean), standard error (stderr), CV%, relative mean CPUE **in number** of swordfish (CPUEn) and upper and lower 95% confidence limits for the Spanish longline fleet in the North Atlantic during the period analyzed 1986-2011.

Year	Lsmean	Stderr.	CV%	UcpueN	Mean CPUEN	LcpueN
1986	1.757	0.167	9.509	8.156	5.878	4.236
1987	1.847	0.168	9.098	8.943	6.433	4.627
1988	1.731	0.168	9.719	7.961	5.725	4.117
1989	1.733	0.168	9.679	7.972	5.738	4.130
1990	1.752	0.167	9.551	8.117	5.847	4.212
1991	1.665	0.167	10.052	7.446	5.363	3.863
1992	1.655	0.167	10.115	7.369	5.308	3.823
1993	1.555	0.168	10.776	6.668	4.801	3.457
1994	1.551	0.167	10.783	6.635	4.781	3.445
1995	1.705	0.167	9.796	7.735	5.576	4.020
1996	1.594	0.166	10.429	6.913	4.991	3.603
1997	1.712	0.167	9.740	7.789	5.618	4.051
1998	1.781	0.167	9.375	8.345	6.017	4.338
1999	1.934	0.167	8.657	9.737	7.013	5.052
2000	2.038	0.168	8.228	10.816	7.786	5.605
2001	1.860	0.169	9.088	9.071	6.513	4.677
2002	1.746	0.167	9.550	8.055	5.810	4.191
2003	1.849	0.167	9.035	8.944	6.446	4.646
2004	1.732	0.167	9.663	7.957	5.732	4.129
2005	1.779	0.168	9.420	8.343	6.007	4.325
2006	1.756	0.168	9.566	8.162	5.872	4.225
2007	1.885	0.168	8.920	9.284	6.678	4.803
2008	1.987	0.168	8.466	10.287	7.398	5.320
2009	1.846	0.168	9.107	8.927	6.421	4.619
2010	1.861	0.168	9.022	9.068	6.525	4.695
2011	1.837	0.168	9.144	8.848	6.366	4.580

Table 3. Estimated parameters (lsmean), standard error (stderr), CV%, relative mean CPUE **in biomass** (CPUEw) of swordfish and upper and lower 95% confidence limits for the Spanish longline fleet in the North Atlantic during the period analyzed 1986-2011.

Year	Lsmean	Stderr.	CV%	UcpueW	Mean CPUEW	LcpueW
1986	5.694	0.159	2.785	410.422	300.780	220.428
1987	5.700	0.160	2.798	413.929	302.799	221.505
1988	5.538	0.160	2.882	351.946	257.396	188.247
1989	5.550	0.159	2.868	355.797	260.433	190.629
1990	5.550	0.159	2.861	355.785	260.621	190.911
1991	5.568	0.159	2.854	361.988	265.125	194.182
1992	5.550	0.159	2.863	355.797	260.588	190.856
1993	5.429	0.159	2.929	315.089	230.721	168.943
1994	5.387	0.159	2.946	302.062	221.322	162.164
1995	5.487	0.158	2.888	333.657	244.573	179.274
1996	5.318	0.158	2.966	281.235	206.445	151.544
1997	5.306	0.158	2.983	278.225	204.030	149.621
1998	5.380	0.158	2.944	299.853	219.818	161.146
1999	5.492	0.159	2.892	335.744	245.912	180.116
2000	5.721	0.159	2.782	422.232	309.084	226.257
2001	5.584	0.160	2.872	369.331	269.711	196.961
2002	5.434	0.158	2.912	316.138	231.849	170.034
2003	5.568	0.159	2.848	362.076	265.347	194.459
2004	5.473	0.159	2.902	329.328	241.226	176.693
2005	5.459	0.159	2.913	324.981	237.947	174.222
2006	5.386	0.159	2.960	302.339	221.205	161.844
2007	5.525	0.160	2.887	347.471	254.164	185.912
2008	5.669	0.160	2.816	401.084	293.320	214.511
2009	5.584	0.160	2.857	368.342	269.448	197.106
2010	5.556	0.159	2.869	358.133	262.046	191.739
2011	5.584	0.159	2.854	368.485	269.608	197.263

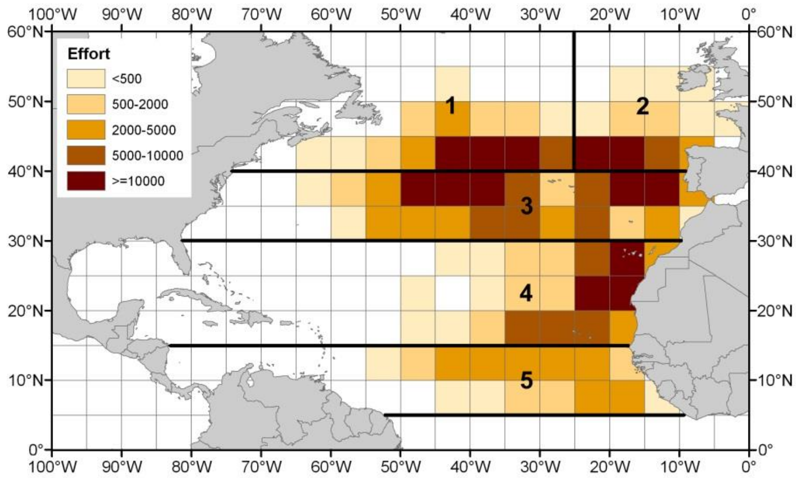

Figure 1. Geographical distribution of the nominal fishing effort (in thousands of hooks) used for the CPUE standardization of the Spanish surface longline fleet in the North Atlantic, during the period 1986-2011 and area definition used for the GLM runs.

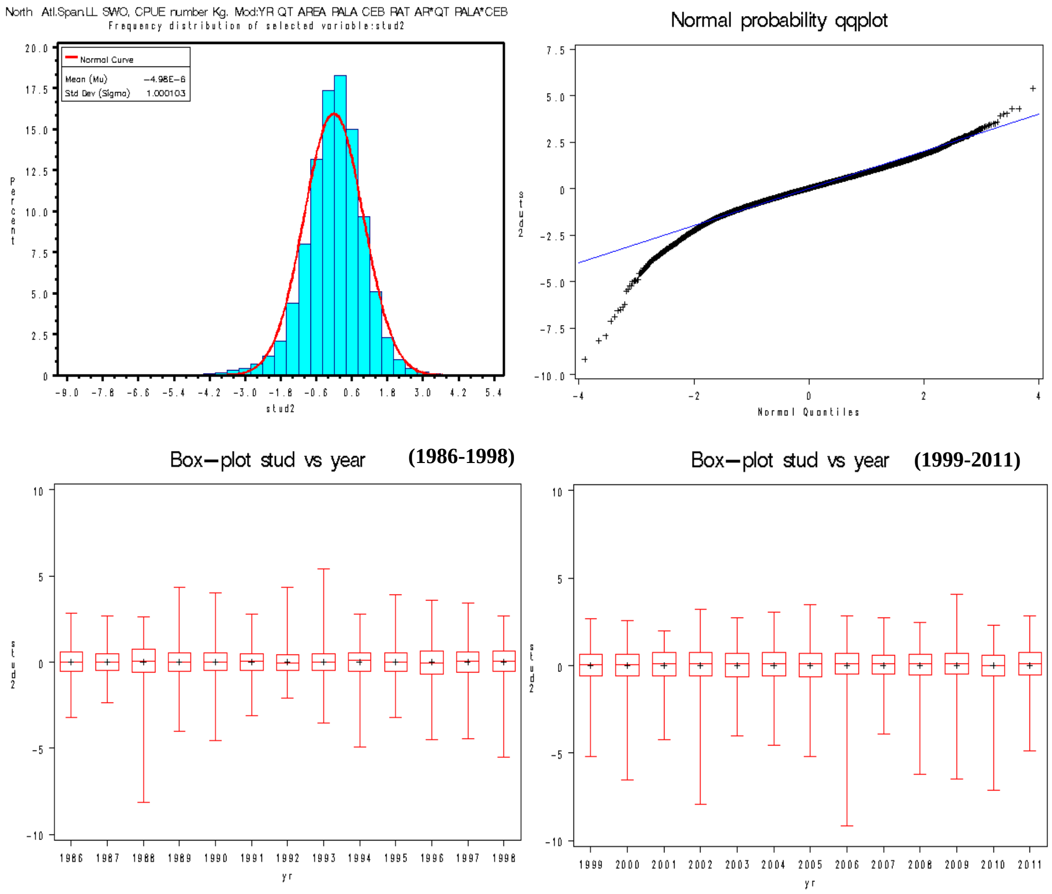

Figure 2. Diagnosis of the GLM runs for standardized CPUE in number of swordfish for North Atlantic: normal fit and frequency distribution of the standardized residuals, years combined and normal probability qq-plot (upper). Variability box-plot of the standardized residuals by year (lower).

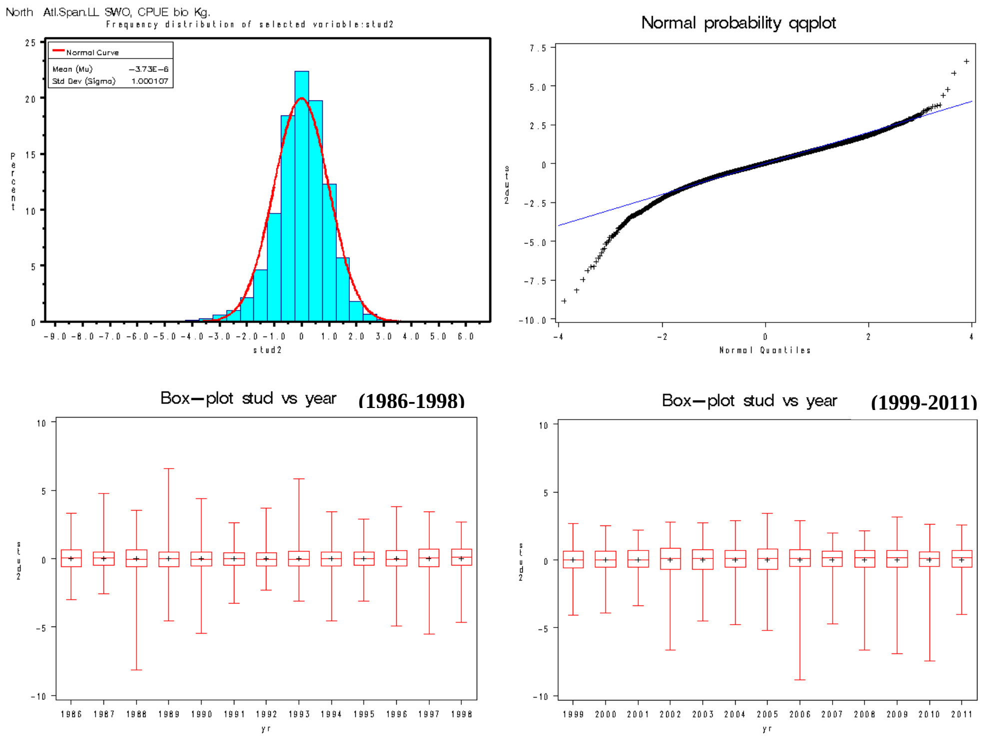

Figure 3. Diagnosis of the GLM runs for standardized CPUE in **biomass** of swordfish for North Atlantic: normal fit and frequency distribution of the standardized residuals, years combined and normal probability qq-plot (upper). Variability box-plot of the standardized residuals by year (lower).

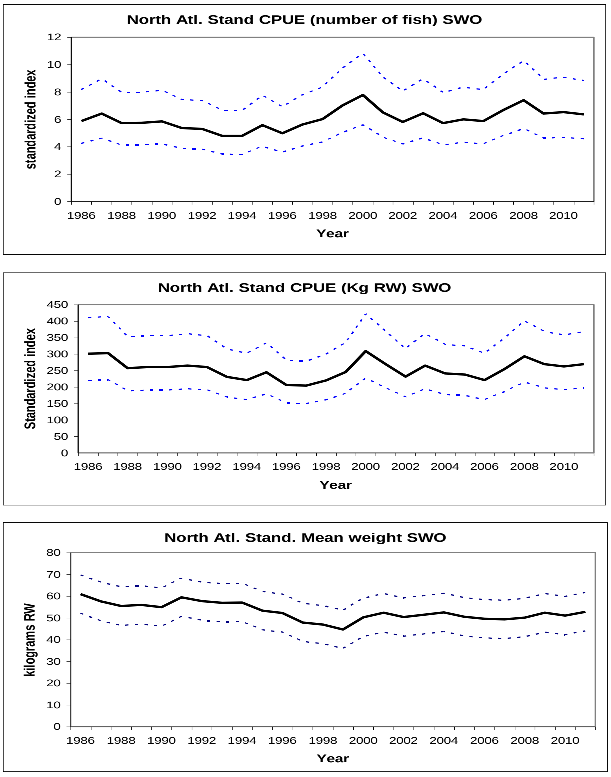

Figure 4. Standardized CPUEs per thousand hooks, in number of fish (upper), in kilograms round weight (medium) and standardized mean round weight in kilograms (lower) of swordfish and their respective confidence intervals (95%) observed in the Spanish surface longline fleet during the period analyzed 1986-2011 in the North Atlantic.

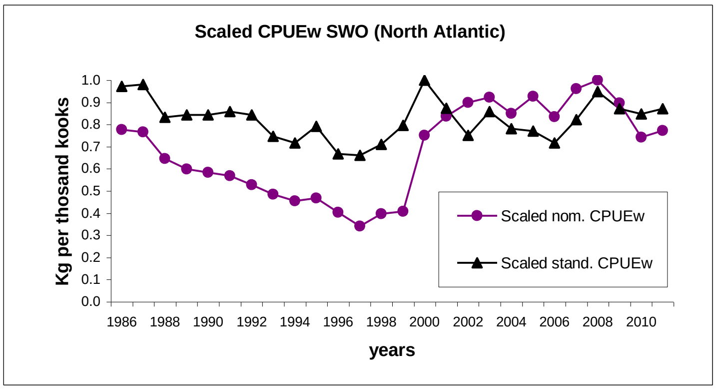

Figure 5. Scaled nominal and standardized CPUE per thousand hooks of swordfish, in kilograms round weight, in the North Atlantic for the period 1986-2011. Both series are scaled from their respective maximum.