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STANDARDIZED CATCH RATES IN BIOMASS FOR THE SWORDFISH (*Xiphias gladius*) CAUGHT BY THE SPANISH LONGLINE FLEET IN THE INDIAN OCEAN FOR THE PERIOD 1993-2007.

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ABSTRACT

Preliminary standardized catch rates in biomass were obtained using General Linear Modeling (GLM) procedures from sets carried out by the Spanish surface longline fleet targeting swordfish in the Indian Ocean over two independent periods, 1993-2000 and 2001-2007. The factors used for modeling were year, area, semester/quarter, gear and ratio between swordfish and blue shark catches. The models explained 24% and 51% of the CPUE variability for the first and the second period, respectively. As in the case of the Atlantic and Pacific swordfish, an important part of the CPUE variability was attributed to the ratio between the two most prevalent species in the catch. Other significant, although less important factors, were also identified. The different sensitivity trials have shown similar trends over time. The conclusions on the standardized CPUE suggest a 'learning' and erratic trend over the first period of activity of the Spanish fleet and a decreasing trend during the second period.

Key words: swordfish, CPUE, GLM, longline, Spanish fleet.

1. INTRODUCTION.

The Spanish fishery on swordfish (*Xiphias gladius*) began in the Mediterranean Sea and the Atlantic Ocean centuries ago. However, activities in the Indian Ocean are still recent, since they began in 1993 when two surface longline vessels undertook a prospective survey for this species. In 1994, three more vessels joined these surveys. In the following three years, one or two vessels continued with their trips in the Indian Ocean, alternating between this fishery and the activities in the Atlantic Ocean on a seasonal basis. Between 1998 and 2000, the number of vessels rose to eight and nine units. In the beginning, these vessels also alternated between the Indian Ocean and the fisheries in other oceans.

Catch per unit of effort data from commercial fleets are frequently used as abundance indicators in a great number of fisheries targeting large pelagic fish. The CPUE obtained by commercial fleets has become a reliable indicator of abundance for most large pelagic species due to the lack of direct indicators of abundance, especially when the available data from the fishery covers broad areas. However, this interpretation may not necessarily be assumed 'a priori'. The CPUE indicators must be evaluated case by case, based on the empirical knowledge of the fishery, the spatial-temporal coverage in relation to the stock distribution and taking into consideration the limits and risks involved in this assumption (Mejuto *et al*. 1999).

The consistency in the fishing patterns of the fleets over time facilitates the interpretation of these indices. Important changes in the fishing strategy of the Spanish surface longline fleet in the Atlantic areas have been reported in recent years (Mejuto *et al*. 1997; Mejuto & De la Serna 1997; Mejuto *et al*. 1998; Mejuto

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et al. 1999) and similar events have been observed in the Indian Ocean (García-Cortés & Mejuto 2000; García-Cortés *et al.* 2003, 2004; Mejuto *et al.* 2006). However, the access to fishing areas in the Indian is more recent. The fishery started in 1993 and used the traditional multifilament Spanish longline gear, although the monofilament "American style" was largely introduced in 2001. The Spanish surface longline fleet targeting swordfish has historically used the traditional gear with a similar number of hooks per basket, since the fishing activity only covers the surface layers, usually above 50 m depth, with night sets. Other longline activities carried out by vessels flying other flags, targeting mostly tunas or having mixed or more diffuse fishing strategies, may change the number of hooks per basket (or between buoys) according to the depth of the gear and/or to the hours of fishing, the targeted species, the respective local abundance of the different species or even the economic worth of the species on the priority international markets. In such cases, the number of hooks per basket or between buoys, as well as other elements or proxies, could help in CPUE standardization in order to indirectly identify target species and fishing strategies, explaining in some cases the discrepancies detected between apparently similar longline styles (Saito & Yokawa 2001, 2003; Nishida & Wang 2006; Okamoto *et al*. 2001; Wang *et al.* 2006). In the last case, the interpretation of CPUE data as abundance indices becomes even more difficult.

The Generalized Linear Modeling technique (GLM) (Robson 1966; Gavaris 1980; Kimura 1981) is used to estimate standardized catch rates based on data from commercial fleets with unbalanced spatial and temporal activity. The standardized catch rates of the Atlantic swordfish were routinely obtained in recent decades by means of GLM based on data from commercial fleets, some of which targeted this species (Hoey *et al*. 1989; Anonymous 1989, 1991; Hoey *et al*. 1993; Nakano 1993; Mejuto 1993; Scott *et al*. 1993; Mejuto 1994; Mejuto & de la Serna 1995, Mejuto *et al*. 1999; Ortiz *et al*. 2007). This has become a basic routine task in the assessment of stocks in accordance with the scientific dynamics of the ICCAT and other RFOs. As previously indicated, the activity of the Spanish fleet in the Indian regions has been carried out since 1993 and it was mostly restricted to western regions (García-Cortés *et al.* 2008). This has limited the historical and geographical overview. Its progressive geographical expansion towards new areas has resulted in an increase in the number of observations by spatial-temporal cell, including the recently accessed Southeastern regions.

2. MATERIAL AND METHODS.

The methodology used in this paper is based on previous research carried out on the Spanish longline fleet in the Atlantic and Pacific Oceans and used in the CPUE analysis of the Spanish and other Atlantic longline fleets (Mejuto & De la Serna 2000; Ortiz 2007). The data used consisted of scientific records obtained in research projects covering the 1993-2007 period (data of 2007 are preliminary). Nominal effort was defined by thousands of hooks set. The overall swordfish nominal CPUE was calculated as kilograms of dressed weight caught per thousand hooks. The data for catches of blue shark in dressed weight were also considered for modeling. The variable 'ratio' was defined for each available set as the percentage of swordfish related to both the swordfish and blue shark caught. After analyzing the behavior of the Spanish fleet in different oceans, it was concluded that this ratio might be a good proxy indicator of target intensity, mainly and clearly directed towards swordfish vs. a more diffuse fishing strategy aimed at the two main caught species combined (Mejuto & De la Serna 2000; Anonymous 2001). In this case, these ratio values were categorized into ten 'ratio' levels of 10% intervals for modeling. A similar approach is frequently used for other longline fleets where the criteria for target species are diffuse.

As previously indicated, two types of longline gears were categorized; the Spanish traditional multifilament gear and the monofilament or 'American style' gear. The use of the traditional surface longline gear of the Spanish fleet remained relatively constant over decades in terms of general structure and configuration (Rey *et al*. 1988; Hoey *et al*. 1988). There have been some technological improvements in this traditional fishing gear over this period. The most common improvements had to do with the introduction of new elements to facilitate handling, setting out and hauling back the fishing gear and also tended to allow for a greater number of hooks per set, which were appropriately considered as nominal effort in the analysis. However, in 2001, the monofilament units or the so-called “American style” gears were largely introduced in most fishing areas of the Indian ocean. The transition between both periods was fast and with a minor overlapping period. That is why the CPUE analysis was split into two different historical periods (1993-2000 and 2001-2007).

The standardized log (CPUE) analyses were done using the GLM procedure (*SAS 9.1*). The spatial definition for GLM runs the considered areas: 51, 52, 53, 54, 55, 56, 57 and 58, (figure 1). Since the sampling in areas 56 and 57 was scarce, both areas were combined as 57 in the final runs. Several temporal definitions were tested in the different runs. The ‘semester‘ division was initially used: SEM=1 from January to June and SEM=2 from July to December.

The model defined as ‘base case’ or run1 includes ‘year’, ‘semester’, ‘area’, ‘ratio’ and ‘gear’ as main factors, as well as the ‘semester*area’ interaction: LOG (CPUE) = u + Y + S + A + R +G + S * A + e. Where, u= overall mean, Y= effect year, S= effect semester, A= effect area, R= effect ratio, G= effect gear, e= logarithm of the normally distributed error term. As in the case of several fleets operating in the Atlantic and Pacific oceans, the ‘ratio’ was considered an proxy indicator of ‘target intensity’ or fishing criteria of the skipper during the fishing activity.

Some ‘sensitivity analyses’ or run2 were also tested using main factors and ‘quarters’, where: Q1 = January, February, March; Q2 = April, May, June; Q3 = July, August, September; Q4 = October, November, December. The main effects considered in this run were: ‘year’, ‘quarter’, ‘area’, ‘ratio’ and ‘gear’: LOG (CPUE) = u + Y + Q + A + R +G + e. It was not possible to include the interaction A*Q, because of the limitations in spatial-time coverage over time. Over the 1993-2007 period, the fishing activity did not take place in several areas-months due to the scarce activity at the beginning of the time series and the large expansion of the new fishing areas in a few years. A summary of the expansion areas of the Spanish fleet was previously provided (figure 2).

3. RESULTS AND DISCUSSION

The number of set records available was 1,952 for the first period (1993-2000) and 10,311 for the second period (2001-2007). Spatial-temporal limitations were often observed in the data obtained from most of the oceanic longline fleets, especially during the access to new fishing areas, the geographical expansion periods or the shifts to other fishing areas. Four areas were sampled during the first period (1993-2000): 53, 54, 57 and 58. For the second period (2001-2007) a total of seven areas were sampled. Two time definitions were tested for each year period (tables 1 and 2). The ANOVA summary, including R-square, mean square error (root), F statistics and significance level, is also provided for each period considered (tables 3 and 4).

The models tested for the period 1993-2000 explained 24% of the CPUE variability. The CPUE variability (Type III SS) may be mainly attributed to the year and, secondly, to the ratio factor. The area factor was also significant, although less important. During this period, only the traditional gear was used by the fleet.

The models tested for the second period (2001-2007) explained 51% of the CPUE variability. The CPUE variability (Type III SS) may be largely attributed to the ‘ratio’ factor, as it was also observed in the Atlantic and Pacific oceans. The factors ‘year’, ‘area’ and ‘gear’ as well as the interaction ‘semester*area’ are also significant but relatively less important. The 'semester' factor was not considered significant neither for this period nor for the first one.

The CPUE trends by year for the 'base case' and their respective confidence interval (95%) are shown in Figure 3. The low number of observations and the prospecting strategy of the fleet during the first fishing period have caused a more erratic trend and broader confidence intervals. However, the trend is more consistent and the confidence intervals are narrower when the observations and the area coverage are increased. Additionally, the observations during the first period are usually obtained from survey trips of the Spanish fleet searching for the target species in new fishing areas. After this preliminary period, the Spanish fleet was consolidated in this ocean and was expanded geographically. Figure 4 shows the standardized residual pattern and the normal probability plots for each period considered in both analyses.

The sensitivity runs using main effects and including 'quarter' suggest that the last factor is significant, although not powerful enough to largely explain the CPUE variability of this data set. The results and trends obtained are consistent with the 'base case' runs. The rescaled standardized CPUEs obtained for both periods in the base case and in the sensitivity runs are shown in Figure 5. Additional research on the CPUE standardization of the Indian Ocean data is needed.

The great significance of the 'ratio' factor among the main species retained onboard was described in the most important oceanic longline fleets fishing in the North and South Atlantic areas. Besides, these ratios have been used for modeling according to their respective fishing patterns (Chang *et al*. 2007; Hazin *et al*. 2007; Mejuto & De la Serna 2000; Mourato *et al*. 2007; Ortiz 2007; Ortiz *et al,* 2007; Paul & Neilson 2007; Yokawa 2007). Of the different proxy methods simulated, the use of catch ratios was found to perform best, on average, and remains the preferred proxy, although this method may not necessarily provide the best performance in all cases (Anonymous 2001). The inclusion of this factor in the modeling has improved the fit levels and the interpretation of CPUE as an abundance index when slight changes in the fishing strategy or other skipper's factors are detected related with species preference. The importance of the ratio versus other factors in the Spanish longline fleet fishing in the Atlantic was previously described and explained based on micro-scale area shifts among trips-sets and the respective local prevalence of the two most prevalent species in the catch. These species frequently overlap in their areas of distribution, but their respective maximum of local abundance are probably not coincident, or even their maximum are mutually exclusive. The low CPUEs of swordfish were regularly observed in the Atlantic associated with high rates of blue shark bycatch. In contrast, high swordfish CPUEs were typically related to lower rates of blue shark bycatch. This assumption is not surprising since in different Atlantic areas and fleets, fishermen have frequently reported that the optimal CPUEs of swordfish and blue shark rarely coincide in space and time. This may be due to different reasons, such as the spatial-temporal exclusion between the maximum of two species and/or the different ranges of optimum temperatures sought by each of them for their respective biological processes in the epipelagic system (Mejuto & De la Serna 2000).

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Table 1. Number of observations per cell used in the GLM analysis for the period 1993-2000. Areas (53, 54, 57, 58), semesters (1,2), years (1993-2000) and ratio (1-10).

FREQ area/sem

YR=1993

Freq	1	2	Total
53	0	0	0
54	0	2	2
57	0	232	232
58	0	0	0
Total	0	234	234

YR=1994

Freq	1	2	Total
53	0	0	0
54	2	0	2
57	669	0	669
58	109	96	205
Total	780	96	876

Table 1 (cont.)

YR=1995

Freq	1	2	Total
53	0	0	0
54	0	0	0
57	0	0	0
58	15	0	15
Total	15	0	15

YR=1996

Freq	1	2	Total
53	0	0	0
54	2	0	2
57	3	0	3
58	24	0	24
Total	29	0	29

YR=1998

Freq	1	2	Total
53	6	0	6
54	0	0	0
57	8	0	8
58	208	159	367
Total	222	159	381

YR=1999

Freq	1	2	Total
53	28	12	40
54	0	149	149
57	0	0	0
58	83	103	186
Total	111	264	375

Table 1 (cont.)

YR=2000

Freq	1	2	Total
53	11	0	11
54	8	0	8
57	0	0	0
58	23	0	23
Total	42	0	42

FREQ YR/ratio

Freq	1	2	3	4	5	Total
1993	0	0	0	0	2	234
1994	0	3	7	7	10	876
1995	0	0	0	3	3	15
1996	0	0	3	2	4	29
1998	0	4	13	27	31	381
1999	3	17	23	44	48	375
2000	0	0	0	5	9	42
Total	3	24	46	88	107	1952

Freq	6	7	8	9	10	Total
1993	2	0	11	19	200	234
1994	36	56	83	109	565	876
1995	5	4	0	0	0	15
1996	3	8	3	3	3	29
1998	26	41	31	35	173	381
1999	59	40	41	31	69	375
2000	5	12	3	4	4	42
Total	136	161	172	201	1014	1952

Table 2. Number of observations per cell used in the GLM analysis for the period 2001-2007. Areas (51, 52, 53, 54, 55, 57, 58), semesters (1-2) and year-ratio (1-10).

FREQ area/sem

YR=2001

Freq	1	2	Total
51	0	0	0
52	0	0	0
53	4	53	57
54	0	10	10
55	0	0	0
57	0	170	170
58	202	466	668
Total	206	699	905

YR=2002

Freq	1	2	Total
51	0	37	37
52	0	88	88
53	202	415	617
54	4	93	97
55	0	0	0
57	53	60	113
58	418	377	795
Total	677	1070	1747

Table 2. (cont.)

FREQ area/sem

YR=2003

Freq	1	2	Total
51	29	431	460
52	179	445	624
53	439	71	510
54	16	97	113
55	0	0	0
57	61	3	64
58	166	62	228
Total	890	1109	1999

YR=2004

Freq	1	2	Total
51	165	313	478
52	379	114	493
53	214	152	366
54	15	105	120
55	0	0	0
57	0	4	4
58	100	214	314
Total	873	902	1775

Table 2. (cont.)

FREQ area/sem

YR=2005

Freq	1	2	Total
51	53	184	237
52	175	83	258
53	104	0	104
54	50	60	110
55	0	11	11
57	0	7	7
58	256	221	477
Total	638	566	1204

YR=2006

Freq	1	2	Total
51	321	105	426
52	286	38	324
53	77	59	136
54	201	13	214
55	105	0	105
57	3	0	3
58	501	294	795
Total	1494	509	2003

Table 2. (cont.)

FREQ area/sem

YR=2007

Freq	1	2	Total
51	0	0	0
52	0	0	0
53	42	3	45
54	2	0	2
55	0	0	0
57	6	0	6
58	586	39	625
Total	636	42	678

FREQ YR/ratio

YR Freq	ratio 1	2	3	4	5	Total
2001	5	9	10	31	52	905
2002	8	21	29	52	100	1747
2003	25	75	86	120	159	1999
2004	51	85	89	84	94	1775
2005	32	38	52	66	80	1204
2006	42	71	93	114	182	2003
2007	8	18	33	57	75	678
Total	171	317	392	524	742	10311

Table 2. (cont.)

FREQ YR/ratio

YR / Freq	ratio 6	7	8	9	10	Total
2001	69	101	125	194	309	905
2002	164	212	336	393	432	1747
2003	200	295	329	458	252	1999
2004	153	210	291	396	322	1775
2005	120	183	201	195	237	1204
2006	214	289	314	328	356	2003
2007	75	103	117	120	72	678
Total	995	1393	1713	2084	1980	10311

Table 3. Summary of the ANOVA 'base case' results for the period 1993-2000. The model includes the following factors: year, semester, area, ratio, gear, semester *area.

Proc. GLM. INDIAN LL SWO, CPUE bio Kg. Mod: YR SEM AR RAT SEM*AR
Variable dependiente: log cpue

Fuente	DF	Suma de cuadrados	Cuadrado de la media	F-Valor	Pr > F
Model	22	187.6262818	8.5284674	27.49	<.0001
Error	1929	598.3676141	0.3101958		
Total corrected	1951	785.9938958			

R-cuadrado	Coef Var	Raiz MSE	cpue Media
0.238712	9.747375	0.556952	5.713869

Fuente	DF	Tipo III SS	Cuadrado de la media	F-Valor	Pr > F
YR	6	68.02285249	11.33714208	36.55	<.0001
sem	1	0.55984613	0.55984613	1.80	0.1793
area	3	3.29167866	1.09722622	3.54	0.0142
ratio	9	61.68334913	6.85370546	22.09	<.0001
sem*area	3	1.72039587	0.57346529	1.85	0.1363

Table 4. Summary of the ANOVA 'base case' results for the period 2001-2007. The model includes the following factors: year, semester, area, ratio, gear, semester *area.

Proc. GLM. INDIAN LL SWO, CPUE bio Kg. Mod: YR SEM AR RAT GR SEM*AR
Variable dependiente: log cpue

Fuente	DF	Suma de cuadrados	Cuadrado de la media	F-Valor	Pr > F
Model	29	2745.296303	94.665390	370.24	<.0001
Error	10281	2628.737349	0.255689		
Total corrected	10310	5374.033652			

R-cuadrado	Coef Var	Raiz MSE	cpue Media
0.510845	8.131449	0.505657	6.218534

Fuente	DF	Tipo III SS	Cuadrado de la media	F-Valor	Pr > F
YR	6	225.665625	37.610937	147.10	<.0001
sem	1	0.000506	0.000506	0.00	0.9645
area	6	183.633827	30.605638	119.70	<.0001
ratio	9	1786.171462	198.463496	776.19	<.0001
gear	1	192.503097	192.503097	752.88	<.0001
sem*area	6	81.753355	13.625559	53.29	<.0001

Table 5. Estimated parameters (base case run 1), standard error, relative CPUE and upper and lower 95% confidence limits. Regions 53, 54, 57 and 58, years 1993-2000.

Proc. GLM. INDIAN LL SWO, CPUE bio Kg. Mod: YR SEM AR RAT SEM*AR

YR	LSMEAN	STDERR	ucpu	cpu	lcpu
1993	5.30759	0.35135	427.504	214.716	107.842
1994	5.90880	0.08038	432.492	369.454	315.604
1995	5.88160	0.16350	500.410	363.204	263.618
1996	5.28934	0.12625	255.893	199.798	155.999
1998	5.46672	0.07860	276.957	237.416	203.520
1999	5.10106	0.07098	189.181	164.610	143.230
2000	5.28940	0.11156	248.210	199.462	160.287

Table 6. Estimated parameters (base case run 1), standard error, relative CPUE and upper and lower 95% confidence limits. Areas 51, 52, 53, 54, 55, 57 and 58, years 2001-2007.

Proc. GLM. INDIAN LL SWO, CPUE bio Kg. Mod: YR SEM AR RAT GR SEM*AR

YR	LSMEAN	STDERR	ucpu	cpu	lcpu
2001	5.10045	0.034329	175.621	164.193	153.509
2002	5.04743	0.031396	165.580	155.698	146.406
2003	5.19008	0.031219	190.901	179.570	168.912
2004	5.03049	0.031315	162.773	153.083	143.970
2005	4.89489	0.031965	142.317	133.674	125.556
2006	4.76211	0.029801	124.084	117.044	110.404
2007	4.62781	0.035817	109.800	102.356	95.417

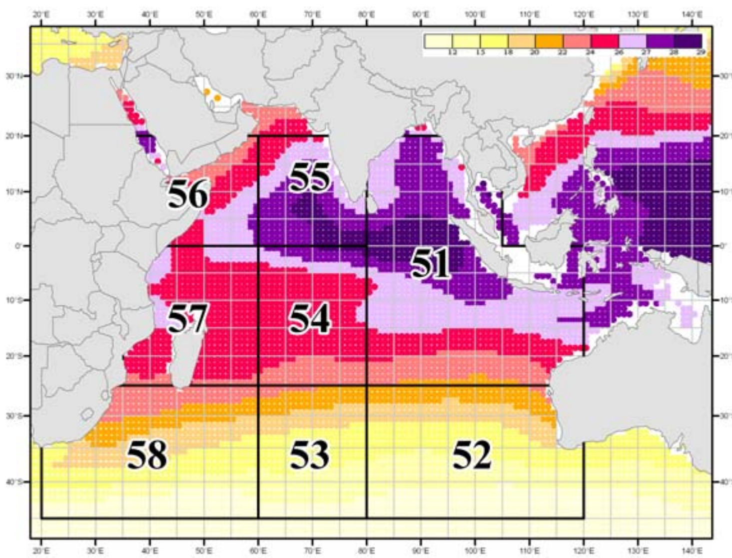

Figure 1. Definition of all the Indian areas used for the GLM analysis and temperature at 50 m deep, as reported in the NOAA web page.

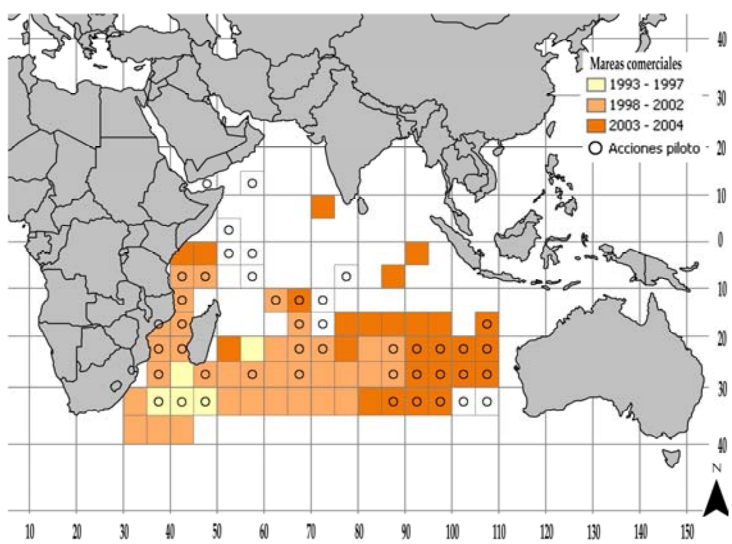

Figure 2. Summary of the 5ºx5º squares accessed by the Spanish surface longline fleet from 1993 to 2004, grouped by four-year periods. The circles indicate the areas where the commercial vessels of the surface longline fleet carried out experimental survey activities (from Mejuto *et al*. 2006)

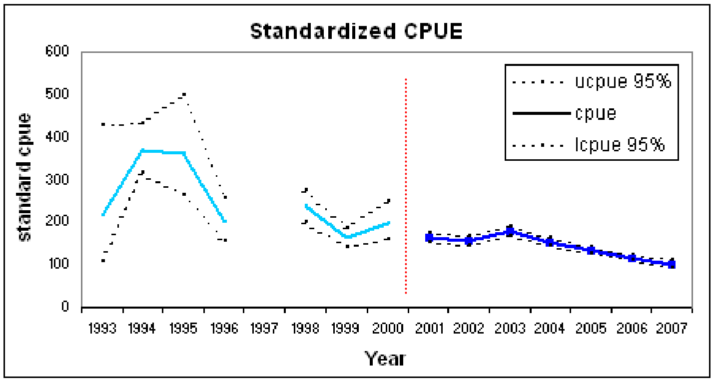

Figure 3. Annual change in the standardized catch rates in weight and 95% confidence intervals obtained for the independent periods 1993-2000 and 2001-2007 (continuity should not be considered between trends of both time periods).

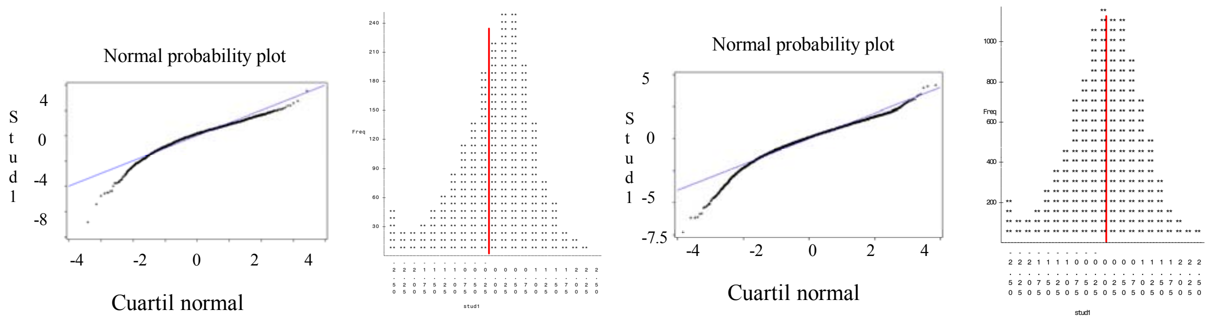

Figure 4. Q-Q plots and standardized residuals for the period 1993-2000 (left panels) and for the period 2001-2007 (right panels).

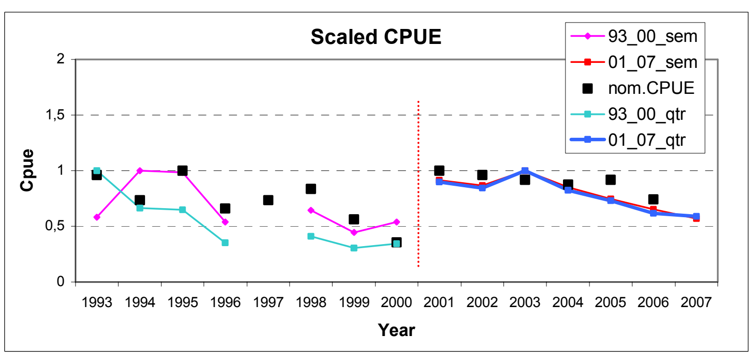

Figure 5. Annual change in the standardized catch rates in weight for the two periods 1993-2000 and 2001-2007, by semesters (run1) and quarters (run2), and overall nominal CPUE by year. (Continuity should not be considered between trends of both time periods).