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STANDARDIZED CATCH RATES FOR THE SWORDFISH (*Xiphias gladius*) CAUGHT BY THE SPANISH LONGLINE IN THE INDIAN OCEAN DURING THE 2001-2012 PERIOD

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ABSTRACT

Standardized catch rates in weight were updated using General Linear Modeling from scientific records of the Spanish surface longline targeting swordfish in the Indian Ocean over the period 2001-2012. The base case run and several sensitivity runs were conducted for comparison with previous analyses. The main factors used for modeling were year, area, time, gear style and ratio. Different area stratifications, time criteria and other factors were considered in 6 tested runs. The models explained up to 53% of the CPUE variability. Base case and sensitivity trials for the whole Indian Ocean have shown similar CPUE trends over time. A first period from 2001 to 2007 with an overall decreasing trend in the standardized CPUE indices was predicted by all models followed by a second recovery period from 2007 to 2010 and a third period exhibiting a stable trend from 2010 to 2012. The analyses restricted to the SW regions are also consistent with each another, suggesting a decrease during the first period, an important increase during the second period and stabilization during the third period, with the most recent year reaching levels similar to those predicted for the initial period of the time series.

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

1. INTRODUCTION

Fishing operations of the Spanish surface longline fleet in the Indian Ocean were started in 1993, when two surface longline vessels surveyed western regions. During the initial period 1993-2000 the observations were mostly obtained from surveys targeting swordfish in new and unknown fishing areas, regularly alternating between the Indian Ocean and other oceans. However after this preliminary period, the Spanish fleet was consolidated in this ocean. Detailed information about the evolution of this fishery in the Indian Ocean is provided in previous papers (García-Cortés and Mejuto 2000, García-Cortés *et al.* 2003, 2004, 2008; Ramos-Cartelle *et al.* 2011).

Catch per unit of effort (CPUE) data from commercial fleets are regularly assumed to be indicators of the relative abundance of the stock in a great number of fisheries targeting large migratory pelagic fish due to the lack of direct indicators. However, this premise should be validated based on the empirical knowledge of the fishery over time, the spatial-temporal coverage in relation to the stock distribution and taking into consideration the limits and risks involved in this assumption. Yearly changes in the predicted biomass indices should also be plausible from a biological point of view of this large-span species (Mejuto *et al.* 1999). The time-area distribution of the fleet and their fishing strategy over time (targeted species, gear configuration, etc.) are also important factors to be considered for said assumption. Consistency in fishing areas over time facilitates this interpretation and increases the reliability of the CPUE information using simpler standardized models (Carruthers *et al.* 2010).

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Recent studies on population genetic structure suggest a single panmictic population of swordfish in the Indian Ocean (Muths *et al.* 2013) and other available information also supports this approach. For this reason, the aim of this document is to update the indicators of relative abundance with the widest possible geographic focus. However, due to the recommendations of the working group, we have also included some alternative analyses assuming more restricted areas for simple comparison with previous studies.

2. MATERIAL AND METHODS

The methodology is based on previous papers and research carried out on the Spanish longline fleet in the Atlantic, Indian and Pacific oceans (Anon. 2010, García-Cortés *et al* 2013, Mejuto & De la Serna 2000, Mejuto *et al.* 2008, Ortiz *et al.* 2007, 2010; Ramos-Cartelle *et al.* 2011). The data used consisted of scientific records voluntarily provided for research developed over the 2001-2012 period. The swordfish nominal CPUE was calculated as kilograms of dressed weight caught per thousand hooks. The ratio factor was defined as the percentage of swordfish with regard to the total catch of both swordfish and blue shark. Taking into account the behavior of Spanish fleet in the Atlantic, this ratio might be a good proxy indicator of possible changes in the target criteria over time (Anon. 2001, García-Cortés *et al.* 2013, Mejuto & De la Serna 2000). Similar approaches are used in other targeted or by-catch fleets as well as in opportunistic-targeting fleets (Anon. 2010). The ratio values were categorized into ten ratio levels of 10% intervals for modeling.

As in previous papers, several sensitivity runs were also tested with the catch of blue shark as a factor (in dressed weight). This factor was categorized into 4 levels based on the thresholds obtained from quartiles of the log normal distribution of the blue shark catch (Ramos-Cartelle *et al.* 2011). Two types of longline styles were categorized: the traditional multifilament gear and the monofilament, so-called 'American style' gear. Several spatial definitions were tested for a comparison with preceding results and updates for previously reported time series: the area stratification used in previous analyses (Mejuto *et al.* 2008, Ramos-Cartelle *et al.* 2011) (figure 1), the four regions as defined by Semba & Nishida (2008) (figure 2), the restricted SW region defined by Semba & Nishida (2008) and also a restricted area 25ºS-35ºS / 30ºE-55ºE. The semester was used in the base case run as a temporal definition and quarters or months were used in other runs when feasible.

The standardized CPUE analyses were done using General Linear Model procedures (SAS 9.2). The model defined as *base case* was: log (CPUE) = u + Y + T + A + R + G + T * A + e, where u= overall mean, Y= effect year, T= effect time, A= effect area, R= effect ratio, G= effect gear, e= logarithm of the normally distributed error term. Records with zero swordfish reported in this target fishery are very scarce -usually less than 1%- so positive catch records were used.

3. RESULTS AND DISCUSSION

A total of 14,397 records (table 1) were available and 6 runs were tested using different models and time-area definitions (table 2). Spatial-temporal limitations are frequently observed in the data from many oceanic longline fleets during access to new fishing area, during the geographical expansion periods or because of shifts to other fishing areas-species. The regrouping or redefinition times-areas is frequently implemented to avoid convergence problems in the GLM caused by too many missing cells or to improve fits (Semba & Nishida 2008, Ichinokawa 2010). However, the most important commercial fishing areas of the Spanish longline fleet targeting swordfish have remained quite constant since 2001. A map of the distributions of observations used for the GLM analyses is provided (figure 3).

A summary of the ANOVA, including R-square, mean square error (root), F statistics and significance level of the model tested and of each factor considered, is provided for each tested run (table 3). The most important factor in CPUE variability (Type III SS) was the ratio factor followed by year factor. CPUE variability is largely attributed to the ratio factor when it is included in the models. Similar findings were described in other fleets catching swordfish in the North and South Atlantic (i.e. Anon. 2001, Chang *et al.* 2007, García-Cortés *et al* 2013, Hazin *et al.* 2007, Mejuto & De la Serna 2000, Mourato *et al.* 2007, Ortiz 2007, 2010; Ortiz *et al.* 2007, 2010; Paul & Neilson 2007, Santos *et al* 2013a, Yokawa 2007) and in the Indian Ocean (Santos *et al.* 2012, 2013b).

The standardized CPUE values by year and their respective confidence interval (95%) for the base case and for the sensitivity runs are shown (tables 4 to 9). Trends over time of the standardized CPUE are also plotted using rescaled values to the highest value obtained in each run (figure 4). A comparison between the different runs using rescaled values is also provided (figure 5). The results and trends obtained for the different models and time-area definitions are very consistent with each other. The predicted CPUE trends are very similar for runs considering the whole Indian Ocean (runs 1, 2, 5 and 6) regardless of the time-area definition and the tested factors. Despite the different definitions, the models used and the diagnosis obtained, the results pointed to almost mimetic trends over time. The highest CPUE value was predicted in the year 2003 for the whole Indian Ocean runs. A decline was predicted until 2007, followed by an increase to more recent years. The standardized CPUE values in recent years are similar to those predicted for the beginning of the time series. The CPUE analyses restricted to the Southwest Indian Ocean were undertaken as a special resource bearing in mind the recommendations from the last Working Party on Billfish (WPB), but this approach focusing restricted areas is probably very weak taking into consideration the broad distribution of the swordfish stock into the Indian Ocean. The results obtained suggest similar trends over time when SW regions are compared. A decline in SW runs was also suggested from 2004 to 2007, followed by an upward trend until 2010 (the highest CPUE value), and showing a stabilization in the most recent years. The normal probability qq-plots (figure 6) and the box-plots of the standardized residual (figure 7) are provided.

As indicated in previous papers, in long-life span species such as the swordfish of the Atlantic, Indian and Pacific (Mediterranean stock excluded), the population is regularly made up of individuals up to ten or more years old. Intermediate ages regularly account for the largest part of the stock population biomass. The population's age structure usually attenuates biomass fluctuations even in highly-variable recruitment scenarios and/or in high fishing mortality situations, as observed in the North Atlantic case (Anon. 2010) or in population simulations. As a result, abrupt changes in the population biomass are not to be expected between consecutive years. Selectivity patterns in oceanic fleets are not usually focused on juvenile fish due to the behaviour of the species and the fishing gears regularly used. Therefore, biomass trends for the swordfish tend to be based on multiannual cycles largely depending on recruitment scenarios or their phases. Standardized CPUE predictions for the analyzed period 2001-2012 for the whole Indian Ocean suggest that biomass changes between consecutive years (CPUEyr+1 vs. CPUEyr) were relatively moderate, with average year-to-year variations between 10% and 16% when their absolute values are considered and between +1% and +2% when the balance between positive and negative increases are considered for the whole period.

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Table 1. Number of observations by year (left) and by area/quarter (right) used for the base case GLM analysis (run 1) for the 2001-2012 period.

Year	N.Obs.
2001	905
2002	1747
2003	1999
2004	1777
2005	1204
2006	2004
2007	1133
2008	1212
2009	803
2010	296
2011	694
2012	623

Area	N.Obs.	Qtr1	Qtr2	Qtr3	Qtr4
51	1826	379	239	772	436
52	2019	651	434	223	711
53	2303	880	481	396	546
54	859	253	44	256	306
55	122	105	0	4	13
57	461	114	24	174	149
58	6807	1112	2659	1796	1240
Total	14397	3494	3881	3621	3401

Table 2. List and details of each run considered: run number, model used, R-squared, relevant comments and area definition used.

Run #	**Model**	**R^2**	**Comments**	**Area definition**
Run1	YR SM AR RT GR SM*AR	0.495	Semester, ratio	Mejuto *et al.* 2008
Run2	YR QT AR RT GR QT*AR	0.537	Quarter, ratio	Semba & Nishida 2008
Run3	YR QT AR RT GR QT*AR	0.457	Quarter, ratio	SW: subareas Semba & Nishida 2008
Run4	YR MN RT GR	0.462	Month, ratio	Area (25-35ºS / 30-55ºE)
Run5	YR SM AR PG GR SM*AR	0.161	Semester, C_BSH	Mejuto *et al.* 2008
Run6	YR QT AR PG GR QT*AR	0.238	Quarter, C_BSH	Semba & Nishida 2008

Model: YR= year, SM=semester, QT= quarter, MN= month, AR= area, RT= ratio, GR= gear, PG= blue shark catch.

Table 3. Summary of the ANOVA for runs 1 to 6 for the period 2001-2012 (see table 2 for details on each run).

Proc. GLM (run 1 base case)

Source	Df	Sum of squares	Mean square	F-value	Pr > F
Source	34	3402.079607	100.061165	413.51	<.0001
Error	14362	3475.347901	0.241982		
Corrected total	14396	6877.427508			

R-squared	Coeff var	Root MSE	cpue1(*) Mean
0.494673	7.911157	0.491917	6.218014

Source	Df	Type III SS	Mean squared	F-value	Pr > F
YR	11	258.791213	23.526474	97.22	<.0001
sem	1	0.098972	0.098972	0.41	0.5225
area	6	207.496216	34.582703	142.91	<.0001
ratio	9	2406.633729	267.403748	1105.06	<.0001
gear	1	195.690956	195.690956	808.7	<.0001
sem*area	6	75.092184	12.515364	51.72	<.0001

Proc. GLM (run 2)

Source	Df	Sum of squares	Mean square	F-value	Pr > F
Source	48	3693.968163	76.95767	346.57	<.0001
Error	14351	3186.688532	0.222053		
Corrected total	14399	6880.656695			

R-squared	Coeff var	Root MSE	cpue1(*) Mean
0.536863	7.578546	0.471225	6.217887

Source	Df	Type III SS	Mean squared	F-value	Pr > F
YR	11	214.445043	19.495004	87.79	<.0001
qtr	3	8.304025	2.768008	12.47	<.0001
area	6	168.597821	28.099637	126.54	<.0001
ratio	9	2114.283611	234.920401	1057.95	<.0001
gear	1	100.819765	100.819765	454.03	<.0001
qtr*area	18	141.469859	7.859437	35.39	<.0001

Proc. GLM (run 3)

Source	Df	Sum of squares	Mean square	F-value	Pr > F
Source	32	1325.450009	41.420313	184.05	<.0001
Error	6984	1571.784732	0.225055		
Corrected total	7016	2897.234741			

R-squared	Coeff var	Root MSE	cpue1(*) Mean
0.457488	7.608983	0.4744	6.234732

Source	Df	Type III SS	Mean squared	F-value	Pr > F
YR	11	120.83255	10.984777	48.81	<.0001
qtr	3	34.949054	11.649685	51.76	<.0001
area	2	6.299162	3.149581	13.99	<.0001
ratio	9	1089.736149	121.081794	538.01	<.0001
gear	1	5.09193	5.09193	22.63	<.0001
qtr*area	6	13.3539	2.22565	9.89	<.0001

Proc. GLM (run 4)

Source	Df	Sum of squares	Mean square	F-value	Pr > F
Source	32	1256.37051	39.261578	181.32	<.0001
Error	6765	1464.823422	0.21653		
Corrected total	6797	2721.193932			

R-squared	Coeff var	Root MSE	cpue1(*) Mean
0.461698	7.45983	0.465328	6.237776

Source	Df	Type III SS	Mean squared	F-value	Pr > F
YR	11	116.974393	10.634036	49.11	<.0001
mon	11	107.38669	9.762426	45.09	<.0001
ratio	9	1013.217742	112.579749	519.93	<.0001
gear	1	5.122933	5.122933	23.66	<.0001

Proc. GLM (run 5)

Source	Df	Sum of squares	Mean square	F-value	Pr > F
Source	28	1106.054771	39.501956	98.34	<.0001
Error	14368	5771.372737	0.401682		
Corrected total	14396	6877.427508			

R-squared	Coeff var	Root MSE	cpue1(*) Mean
0.160824	10.19271	0.633784	6.218014

Source	Df	Type III SS	Mean squared	F-value	Pr > F
YR	11	368.4861801	33.4987436	83.4	<.0001
sem	1	6.6745546	6.6745546	16.62	<.0001
area	6	42.8186049	7.1364341	17.77	<.0001
ratioPG	3	110.6088935	36.8696312	91.79	<.0001
gear	1	291.9678942	291.9678942	726.86	<.0001
sem*area	6	48.5496774	8.0916129	20.14	<.0001

Proc. GLM (run 6)

Source	Df	Sum of squares	Mean square	F-value	Pr > F
Source	42	1636.620494	38.967155	106.68	<.0001
Error	14357	5244.036201	0.36526		
Corrected total	14399	6880.656695			

R-squared	Coeff var	Root MSE	cpue1(*) Mean
0.237858	9.719818	0.604367	6.217887

Source	Df	Type III SS	Mean squared	F-value	Pr > F
YR	11	284.73767	25.8852427	70.87	<.0001
qtr	3	24.5710295	8.1903432	22.42	<.0001
area	6	218.9417402	36.49029	99.9	<.0001
ratioPG	3	56.9359417	18.9786472	51.96	<.0001
gear	1	168.4865348	168.4865348	461.28	<.0001
qtr*area	18	224.9420907	12.4967828	34.21	<.0001

(*) cpue1= log CPUE (kg dressed weight)

Tables 4 to 6. Estimated parameters for **runs 1, 2** and **3,** by year: lsmean, standard error, CV, standardized CPUE and upper and lower 95% confidence limits.

YR	Lsmean	Stderr	CV(%)	Ucpue	**CPUE**	Lcpue
2001	5.077	0.032	0.638	170.9	160.4	150.5
2002	5.032	0.030	0.591	162.6	153.4	144.7
2003	5.172	0.030	0.570	186.8	176.3	166.4
2004	5.009	0.030	0.592	158.7	149.7	141.3
2005	4.883	0.030	0.624	140.2	132.1	124.4
2006	4.754	0.028	0.591	122.6	116.1	109.9
2007	4.709	0.031	0.661	118.0	111.0	104.4
2008	4.898	0.031	0.629	142.4	134.1	126.2
2009	4.905	0.032	0.656	143.8	135.0	126.8
2010	5.110	0.040	0.783	179.3	165.8	153.3
2011	5.053	0.034	0.664	167.2	156.6	146.6
2012	5.060	0.034	0.675	168.6	157.7	147.5

YR	Lsmean	Stderr	CV(%)	Ucpue	**CPUE**	Lcpue
2001	5.197	0.031	0.596	192.1	180.8	170.2
2002	5.144	0.029	0.556	181.4	171.5	162.2
2003	5.277	0.029	0.544	207.3	195.9	185.2
2004	5.089	0.028	0.559	171.6	162.3	153.5
2005	5.130	0.030	0.578	179.2	169.1	159.5
2006	4.981	0.028	0.561	153.8	145.6	137.9
2007	4.808	0.030	0.621	130.0	122.6	115.6
2008	5.034	0.030	0.590	162.8	153.6	144.9
2009	4.992	0.031	0.628	156.7	147.4	138.6
2010	5.222	0.039	0.740	200.0	185.4	171.9
2011	5.210	0.033	0.625	195.2	183.1	171.8
2012	5.222	0.033	0.628	197.7	185.4	173.9

YR	Lsmean	Stderr	CV(%)	Ucpue	**CPUE**	Lcpue
2001	5.351	0.094	1.753	254.5	211.8	176.2
2002	5.239	0.093	1.781	227.2	189.2	157.6
2003	5.341	0.097	1.820	253.8	209.8	173.4
2004	5.394	0.092	1.706	264.7	221.0	184.6
2005	5.336	0.094	1.769	251.1	208.7	173.5
2006	5.185	0.093	1.803	215.4	179.3	149.3
2007	4.960	0.093	1.879	172.0	143.2	119.3
2008	5.205	0.093	1.795	219.8	183.0	152.4
2009	5.241	0.095	1.809	228.4	189.7	157.5
2010	5.432	0.097	1.777	277.5	229.7	190.1
2011	5.430	0.094	1.733	275.7	229.2	190.6
2012	5.401	0.094	1.739	267.7	222.7	185.2

Table 7 to 9. Estimated parameters for **runs 4, 5** and **6,** by year: lsmean, standard error, CV, standardized CPUE and upper and lower 95% confidence limits.

YR	Lsmean	Stderr	CV(%)	Ucpue	**CPUE**	Lcpue
2001	5.370	0.092	1.711	258.5	215.9	180.3
2002	5.241	0.091	1.744	226.8	189.6	158.5
2003	5.375	0.095	1.768	261.3	216.9	180.0
2004	5.372	0.090	1.676	257.8	216.1	181.1
2005	5.331	0.092	1.731	248.7	207.5	173.2
2006	5.144	0.091	1.776	205.9	172.2	143.9
2007	4.981	0.091	1.829	174.9	146.3	122.4
2008	5.200	0.091	1.754	217.7	182.0	152.2
2009	5.234	0.093	1.771	225.9	188.4	157.1
2010	5.442	0.095	1.749	279.5	231.9	192.4
2011	5.423	0.092	1.695	272.4	227.5	190.0
2012	5.394	0.092	1.703	264.6	221.0	184.6

YR	Lsmean	Stderr	CV(%)	Ucpue	**CPUE**	Lcpue
2001	5.425	0.042	0.766	246.6	227.3	209.5
2002	5.411	0.038	0.703	241.4	224.1	208.0
2003	5.514	0.038	0.684	267.4	248.3	230.6
2004	5.321	0.038	0.714	220.6	204.8	190.1
2005	5.174	0.039	0.756	190.9	176.8	163.7
2006	5.026	0.036	0.718	163.6	152.5	142.1
2007	4.997	0.040	0.800	160.1	148.1	136.9
2008	5.187	0.039	0.761	193.5	179.1	165.8
2009	5.144	0.041	0.801	186.0	171.5	158.2
2010	5.461	0.051	0.939	260.7	235.7	213.2
2011	5.282	0.043	0.815	214.2	196.9	181.0
2012	5.393	0.044	0.811	239.7	220.0	201.9

YR	Lsmean	Stderr	CV(%)	Ucpue	**CPUE**	Lcpue
2001	5.428	0.040	0.729	246.3	227.9	210.9
2002	5.413	0.036	0.673	241.1	224.4	209.0
2003	5.528	0.037	0.662	270.6	251.9	234.4
2004	5.331	0.036	0.681	222.0	206.7	192.5
2005	5.362	0.038	0.706	229.8	213.4	198.1
2006	5.161	0.036	0.690	187.1	174.5	162.7
2007	5.012	0.038	0.761	162.0	150.3	139.5
2008	5.243	0.038	0.722	204.0	189.4	175.9
2009	5.173	0.040	0.771	191.0	176.6	163.3
2010	5.515	0.049	0.894	273.9	248.7	225.8
2011	5.335	0.042	0.781	225.3	207.7	191.4
2012	5.469	0.042	0.765	257.7	237.4	218.7

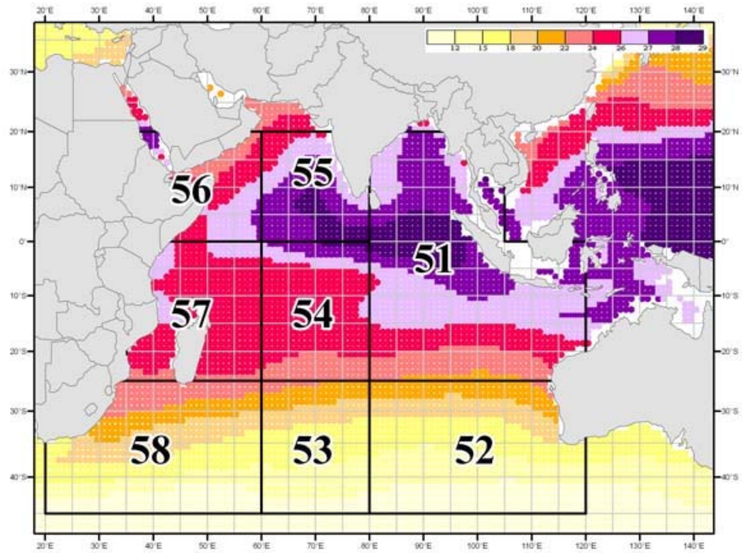

Figure 1. Area stratification (Mejuto *et al*. 2008) used in some GLM runs. In color, temperature at 50 m depth from NOAA (USA).

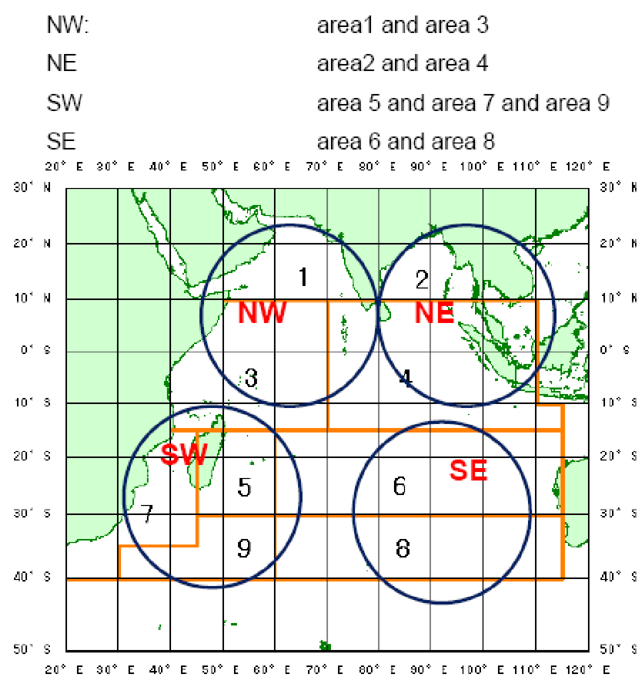

Figure 2. Definition of the sub-areas (Semba & Nishida 2008) considered for some GLM runs.

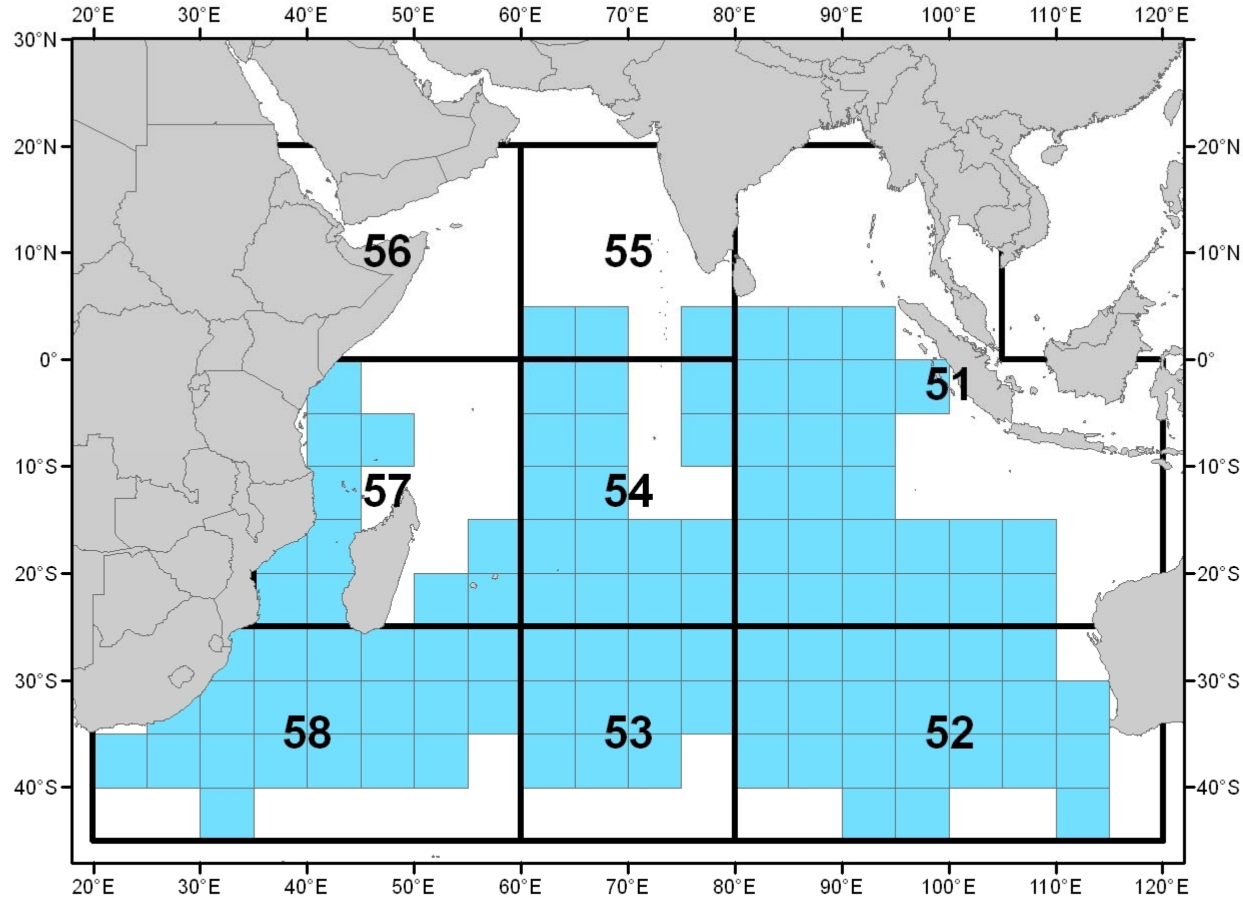

Figure 3. Areas 5ºx5º covered by the fishing observations obtained during the 2001-2012 period and used for the GLM analyses.

Figure 4. Annual changes in the standardized CPUE trends (rescaled values) and 95% confidence intervals obtained for the period 2001-2012 (see details about each run in table 2).

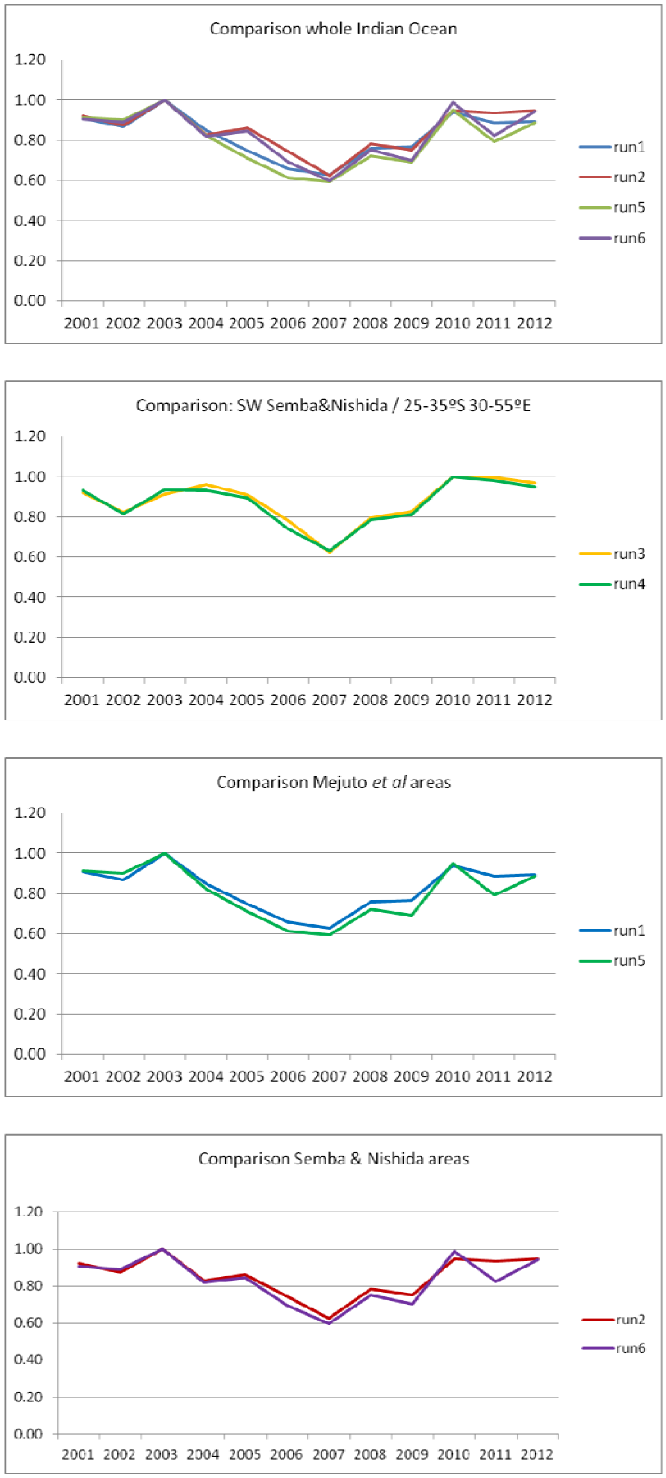

Figure 5. Comparison between scaled standardized CPUE trends obtained (rescaled values) for the different runs-models with equal area definitions or area groups (see details of each run in table 2).

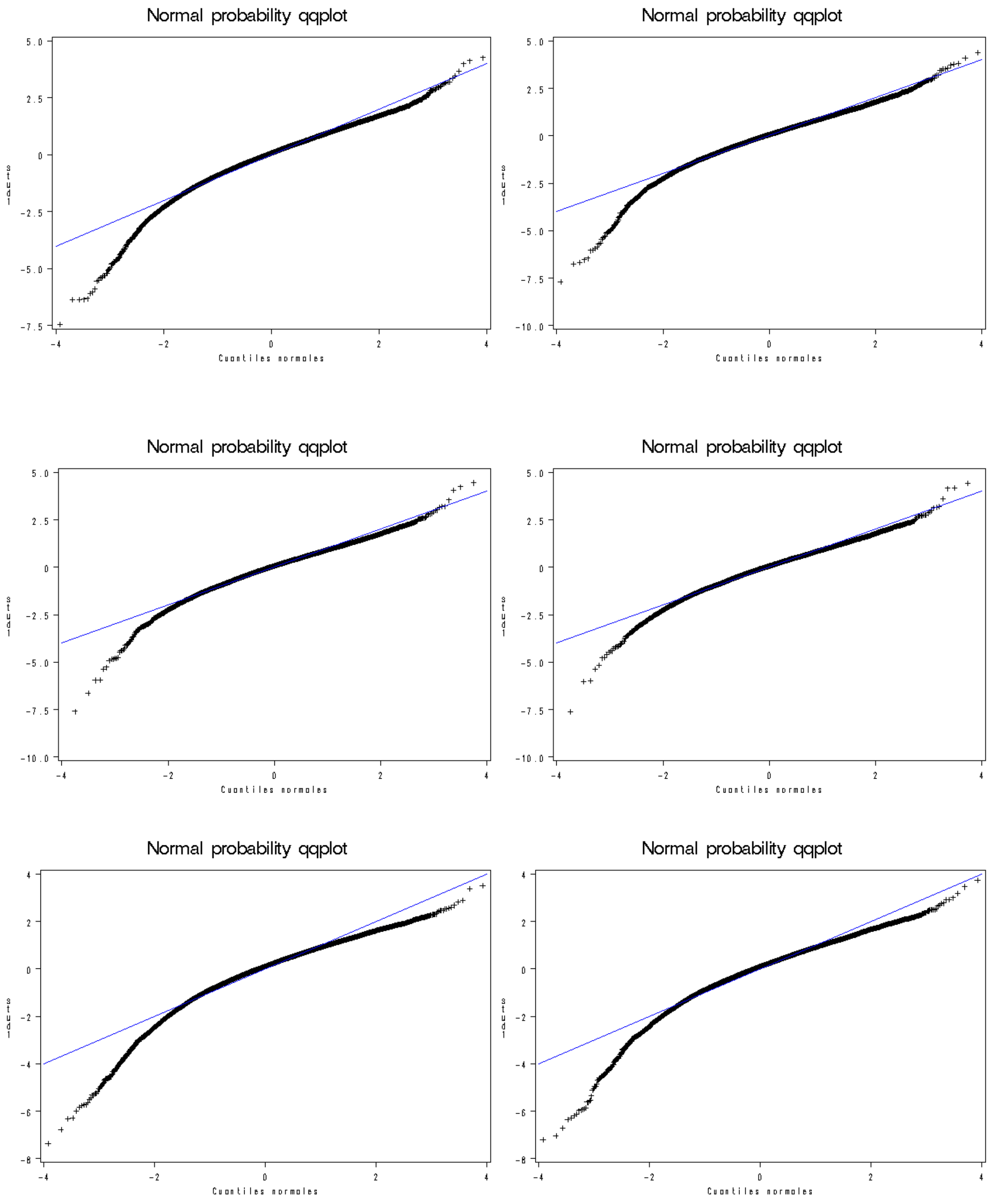

Figure 6. Normal probability *qq*plots for GLM runs 1 to 6. Sequence (left-right) of the plots: runs 1-2, 3-4 and 5-6.

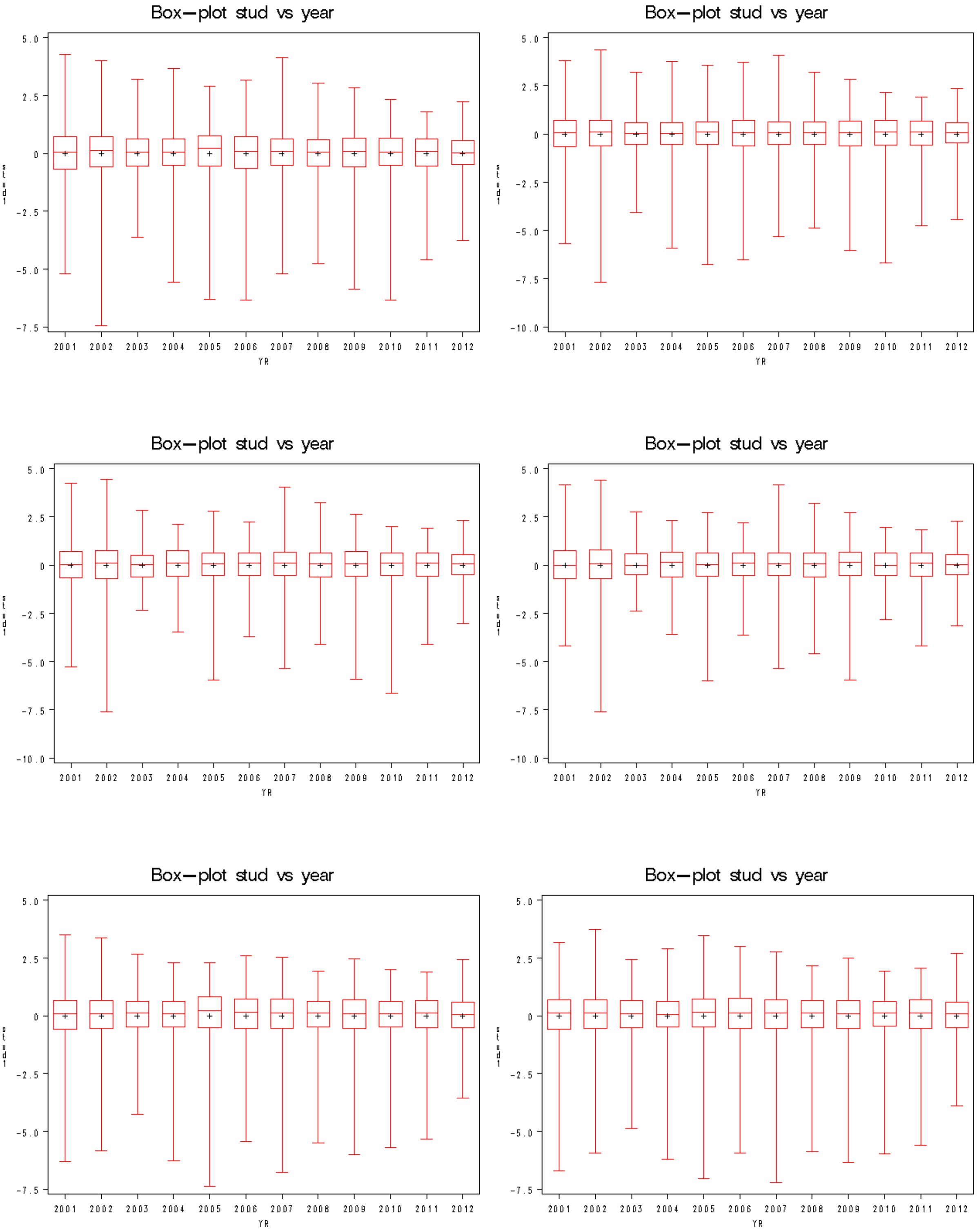

Figure 7. Box plot of the standardized residuals by year for GLM runs 1 to 6. Sequence of the plots (left-right): runs 1-2, 3-4 and 5-6.