UPDATED STANDARDIZED CATCH RATES IN BIOMASS FOR THE INDIAN STOCK OF BLUE SHARK (*Prionace glauca*) FROM THE SPANISH SURFACE LONGLINE FLEET FOR THE PERIOD 2001-2023

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ABSTRACT

Standardized catch rates per unit of effort (CPUE) were updated for the Indian stock of blue shark (Prionace glauca) using Generalized Linear Models (GLM). A total of 3,189 trips of the Spanish surface longline fleet targeting swordfish, between 2001-2023 period were analyzed. The main factors considered were year, quarter, area, gear and targeting criteria. The base case model explained the 77% of CPUE variability in gutted weight. Most of the variability was explained by the proxy of the targeting criteria. The standardized CPUE showed a stable trend over time, with an increase over the last three years.

Key words: blue shark, CPUE, GLM, abundance, longline

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1. Introduction

Blue shark (*Prionace glauca*) is a highly migratory species of wide ranging in the oceanic-epipelagic ecosystem with very high abundance and a broad geographic distribution in different oceans, regularly found between 50ºN and 50ºS (Compagno 1984).

The Spanish longline fleet targeting swordfish using night setting was developed since 1993 in western areas and later expanded to other areas of the Indian Ocean (Mejuto *et al.* 2006[a]; García-Cortés *et al.* 2008). Important changes in gear configuration took place in the early 2000's in the Spanish fleet when the multifilament style traditionally used was replaced by the American-style monofilament gear (García-Cortés and Mejuto 2000; García-Cortés *et al.* 2003, 2004, 2008; Mejuto *et al.* 2006[a], 2008; Ramos-Cartelle *et al.* 2011).

The geographical distribution of blue shark overlaps with the range of the fishing areas of surface longline fleets targeting tunas and/or swordfish. Blue shark regularly is the most prevalent bycatch shark caught by this and other fleets in all oceans (García-Cortés and Mejuto 2001, 2005; Mejuto and García-Cortés 2005; Mejuto *et al.* 2006[a], 2006[b]; Ramos-Cartelle *et al.* 2008, 2009; Fernández-Costa *et al.* 2015, 2017; Coelho *et al.* 2017).

The target species of Spanish surface longline fleets was traditionally swordfish, but freezing systems introduced since middle of 1980's, changes in the market value of the two most abundant species (swordfish and blue shark) along with other factors, allowing skippers to move towards full retention on board with a combination of both swordfish and blue shark. The impact on the fishing strategy in several longline fleets targeting swordfish has already been described in literature and considered in the recent standardized CPUE analysis of this fleet (e.g. Mejuto and De la Serna 2000, Ramos-Cartelle *et al.* 2011, 2020[a], 2020[b]; Fernández-Costa *et al.* 2014, 2015, 2017).

Catch-per-unit-effort (CPUE) data from fishery-dependent data have traditionally been used as the main source of information in order to obtain the relative index of abundance used in fish stock assessment. In some cases, this index may be considered an indicator of change in abundance over time (Maunder and Punt 2004). The most common method for standardizing catch and effort data from commercial longline fleets is the application of the Generalized Linear Model (GLM) (Robson 1966, Gavaris 1980, Kimura, 1981) which removes the effects of factors other than abundance that bias the index and those standardized CPUEs can be used as annual indices of abundance.

The main objective of this paper is to update the standardized blue shark CPUE index of the Spanish longline fleet previously provided of the Indian Ocean (Fernández-Costa *et al.* 2015, 2017, 2021). Detailed information about this fishery and methods can be found in documents previously cited.

2. Material and methods

The data used in this analysis consisted of trip records voluntarily reported for scientific purposes from the Spanish surface longline fleet targeting swordfish and from the scientific observers onboard in the Indian Ocean during the period 2001-2023.

The methodology used in this paper is based on previous research carried out by the Spanish longline fleet in the Indian Ocean (Mejuto *et al.* 2008, Ramos-Cartelle *et al.* 2011, 2020[a], 2020[b]; Fernández-Costa *et al.* 2014, 2015, 2017, 2021).

The response variable - CPUEw - was measured as biomass (gutted weight in kg) per fishing effort and it was standardized using Generalized Linear Models (GLM).

$$\text{Ln (CPUEw)} = u + Y + Q + A + R + G + A*Q + e$$

where: u = overall mean, Y = *year* effect, Q = *quarter* effect (1: January-March; 2: April-June; 3: July-September; 4: October-December), A = *area* effect (**Figure 1**), R = *ratio* effect defined for each available trip record as an indicator of the target criteria of the skipper expressed as the percentage of swordfish by weight related to the catches in weight of swordfish and blue shark combined, classified in ten categories at 10% intervals (Mejuto and De la

Serna 2000), G = *gear* effect (1: traditional multifilament; 3: American-style monofilament; 9: modified American-style monofilament) and e = logarithm of the normally distributed error term. The symbol * represents the interactions between factors. Standardized residuals by year were plotted.

After analyzing the behavior of the Spanish fleet, it was concluded that the percentage in weight of swordfish landed by trip in relation to the amount of combined swordfish and blue shark landed is the best proxy indicator in this fleet for the skipper targeting criteria to classify trips clearly targeted to swordfish of those trips more diffuses targeted to both species (swordfish and blue shark) (Anon. 2001, Mejuto 2007, Mejuto and De la Serna 2000, Ortiz *et al.* 2010). In this case, the targeting criteria labeled as '*ratio*' variable in the model was defined for each trip as the percentage of swordfish related to both the swordfish and blue shark caught (SWO/(SWO+BSH)). The targeting criteria were categorized in the base case model in ten levels (0.1 quantiles) in order to classify the type of trip into the model (Mejuto 2007, Mejuto and De la Serna 2000). A similar approach to classify the type of trips or sets in multi-specific fisheries is frequently used in the case of other longline fleets where changes for targeting are known but it is diffused or they have changed over time (Carvalho et al. 2010, García-Cortés *et al.* 2016).

Several sensitivity analyses have been performed (**Table 1**). Sensitivity 1 was carried out considering only the trips with the usual American-style monofilament gear (gear=3) with the intention of eliminating possible deviations due to the sporadic changes in the gear that took place on a few trips during last year. To eliminate the blue shark catch on both sides of the equation, Sensitivity 2 and 3 were performed. Sensitivity 4 analysis was carried out applying a finite mixture model –FMM- (Cosgrove *et al.* 2014).

The base case and the sensitivity 1 and 2 runs were carried out using the SAS 9.4 procedures, and in the case of sensitivity 3 and the FMM analyses were carried out using R 4.3.1.

3. Results and discussion

A total of 3,189 trip records were available from the period between 2001 and 2023. The spatial-temporal coverage was appropriate for blue shark catches and the fishing activity of this fleet over time. **Figure 1** shows the areas defined in the Indian Ocean used in the CPUE standardization and a summary of the Spanish longline fleet fishing activity (nominal CPUEw and total effort) during the 2001-2023 period. For GLM convergence reasons, area 56 has been merged with area 57, so finally only 7 areas were considered on the GLM runs.

Table 2 provides the ANOVA summary obtained from the GLM base case analysis, including R-square, mean square error (root), F statistics and significance level, as well as the Type III SS for each factor used.

The base case GLM model explained 77% of the CPUE variability in biomass (gutted weight). As with the case of the previous blue shark CPUE analyses (Mejuto *et al.* 2009, Fernández-Costa 2015, 2017, 2021), the CPUE variability (Type III SS) may be mainly attributed to the targeting criteria (*ratio*). This ratio contributed significantly to explaining most part of the deviance and it is a good approximation of the skipper's criteria for target species per trip in this fleet. The use of these ratios was found to perform best among the different proxy methods simulated and it was considered to be the preferred proxy (Anon. 2001). The *year* variable seems to be also significant, although less important.

Table 3 provides information on estimated base case parameters (Lsmean), their standard error, the percentage of coefficient of variation (CV%), standard CPUE in biomass (gutted weight) and upper and lower 95% confidence limits. **Figure 2** provides distribution of standardized residuals and the normal probability *qq*-plot over the 2001-2023 period. The box-plot of the standardized residuals obtained, by main factor, is shown in **Figure 3**. The fit of the model seems not to be biased and residuals are normally distributed.

The mean CPUE in biomass of gutted weight (CPUEw) and their 95% confidence intervals are plotted in **Figure 4**. The analysis results showed relatively stable trend over the years and showing an increase in the last three years. **Figure 5** shows the comparison between base and sensitivity cases of the all CPUEs scaled to their mean value. Given the results, we believe that the base case best captures all the variability in the data, with the result of the CPUE standardization process being the best approximation of stock abundance.

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Table 1. Description of the base case and sensitivity analyses (u = overall mean, Y = year effect, Q = quarter effect, A = area effect, R = ratio, G=gear effect and e = logarithm of the normally distributed error term).

Model	Formula	Data
Base case - GLM	Ln (CPUEw) = u + Y + Q + A + R + G + A*Q + e	All records
Sensitivity 1 - GLM	Ln (CPUEw) = u + Y + Q + A + R + A*Q + e	Records with gear=3
Sensitivity 2 - GLM	Ln (CPUEw) = u + Y + Q + A + G + A*Q + e	All records
Sensitivity 3 - GLM	Ln (CPUEw) = u + Y + Q + A + Ln (CPUEw_SWO) + G + A*Q + e	All records
Sensitivity 4 - FMM	Ln (CPUEw) = u + Y + Q + A + G + A*Q + e	All records

Table 2. Summary of ANOVA for base case CPUE analysis in biomass (gutted weight) for blue shark in the Indian Ocean: R-square, mean square error (root) and F statistics. Dependent variable: ln (CPUEw).

Indian Ocean. BSH CPUE in gutted weight

Dependent variable: ln (CPUEw)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	60	1385.562216	23.092704	174.37	<.0001
Error	3128	414.254273	0.132434		
Corrected Total	3188	1799.816489			

R-Square	Coef. Var	Root MSE	Cpue1 Mean
0.769835	5.700173	0.363915	6.384283

Source	DF	Tipo III SS	Mean Square	F Value	Pr > F
Year	22	49.5831612	2.2537801	17.02	<.0001
Quarter	3	1.9641882	0.6547294	4.94	0.0020
Area	6	29.8879086	4.9813181	37.61	<.0001
Ratio	9	776.8562681	86.3173631	651.78	<.0001
Gear	2	8.6702708	4.3351354	32.73	<.0001
Quarter*Area	18	15.4427018	0.8579279	6.48	<.0001

Table 3. Estimated parameters (LSMEAN), standard error (STDERR), coefficient of variation (CV%), base case standardized CPUE in biomass of gutted weight (CPUEw) of blue shark and upper and lower 95% confidence limits for the Spanish longline fleet in the Indian Ocean during the period analyzed, 2001-2023.

YEAR	LSMEAN	STDERR	CV%	95%UCPUEw	CPUEw	95%LCPUEw
2001	5.94455	0.066191	6.63	435.491	382.504	335.965
2002	5.87448	0.056905	5.70	398.472	356.417	318.801
2003	5.95793	0.055512	5.56	431.933	387.403	347.464
2004	5.82645	0.056259	5.63	379.291	339.691	304.225
2005	5.70025	0.057546	5.76	335.188	299.436	267.498
2006	5.62091	0.054185	5.42	307.534	276.547	248.683
2007	5.66750	0.059789	5.98	325.863	289.829	257.780
2008	5.75798	0.060549	6.06	357.268	317.288	281.782
2009	5.84913	0.060143	6.02	391.043	347.560	308.912
2010	5.94571	0.068092	6.82	437.682	382.999	335.148
2011	5.88294	0.064742	6.48	408.270	359.616	316.759
2012	5.91392	0.061391	6.14	418.273	370.854	328.811
2013	5.72800	0.059556	5.96	346.024	307.901	273.978
2014	5.60146	0.059448	5.95	304.827	271.300	241.461
2015	5.76377	0.066294	6.64	363.546	319.248	280.348
2016	5.88382	0.069124	6.92	412.276	360.039	314.420
2017	5.83907	0.069701	6.98	394.694	344.294	300.330
2018	5.80041	0.072558	7.27	381.935	331.305	287.386
2019	5.78519	0.065230	6.53	370.616	326.137	286.996
2020	5.67127	0.053804	5.38	323.170	290.825	261.718
2021	5.81623	0.061674	6.17	379.559	336.342	298.046
2022	5.94867	0.061262	6.13	432.948	383.962	340.519
2023	6.05461	0.052468	5.25	472.869	426.658	384.962

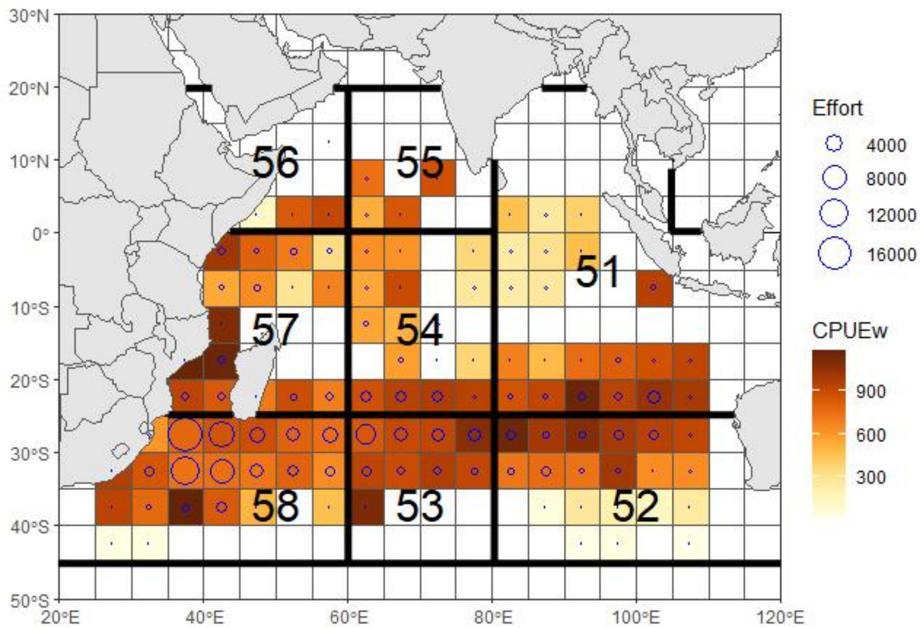

Figure 1. Geographical area definition used in GLM runs for the CPUE standardization of the Spanish surface longline fleet in the Indian Ocean during the period 2001-2023. The color scale represents the nominal CPUEw (gutted weight) per 5ºx5º square and circle scale represents the total effort per 5ºx5º square for all years combined during the 2001-2023 period. For GLM convergence reasons, area 56 has been merged with area 57.

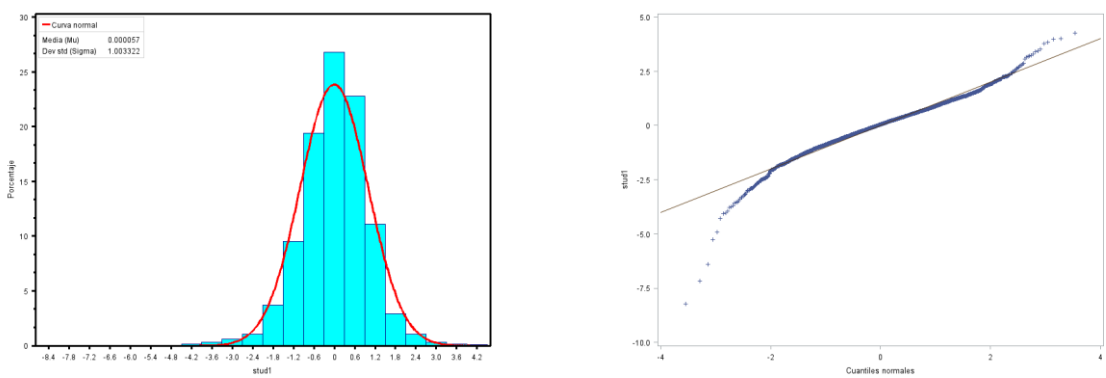

Figure 2. Frequency distribution of the standardized residuals in gutted weight (left) and normal probability *qq*-plots (right), in the Indian Ocean for the 2001-2023 period.

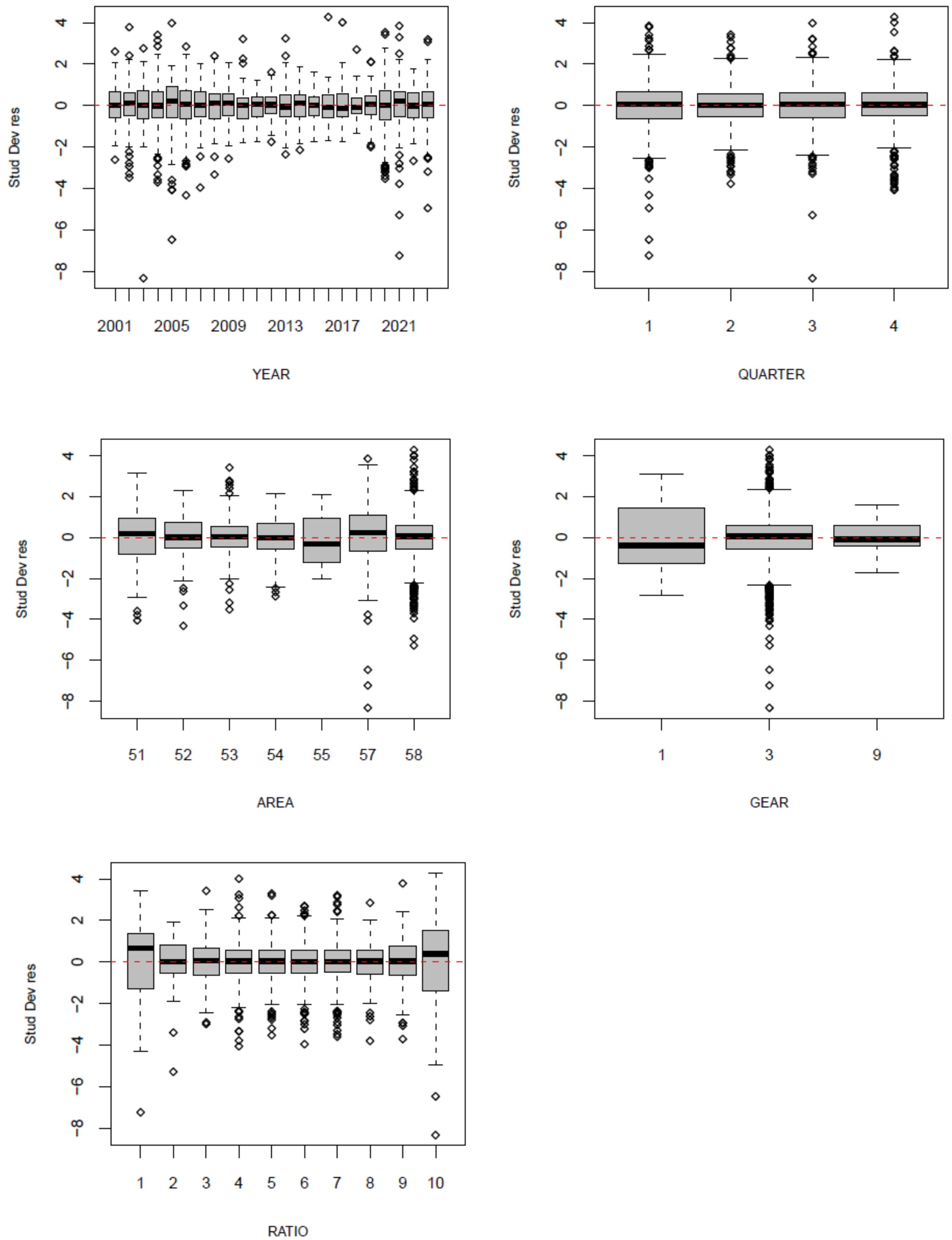

Figure 3. Box-plots of the standardized deviance residuals *versus* explanatory variables, obtained from the GLM analysis in gutted weight for the Indian Ocean stock of the blue shark during the 2001-2023 period.

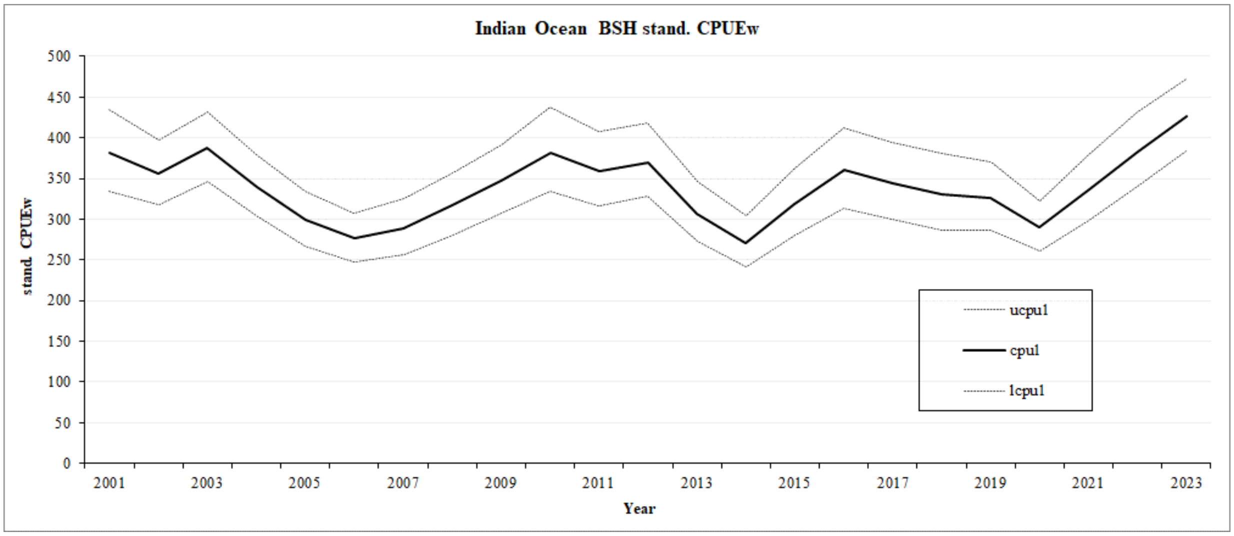

Figure 4. Standardized CPUE in gutted weight by year and confidence intervals (95%) of the Indian Ocean stock of the blue shark during the 2001-2023 period.

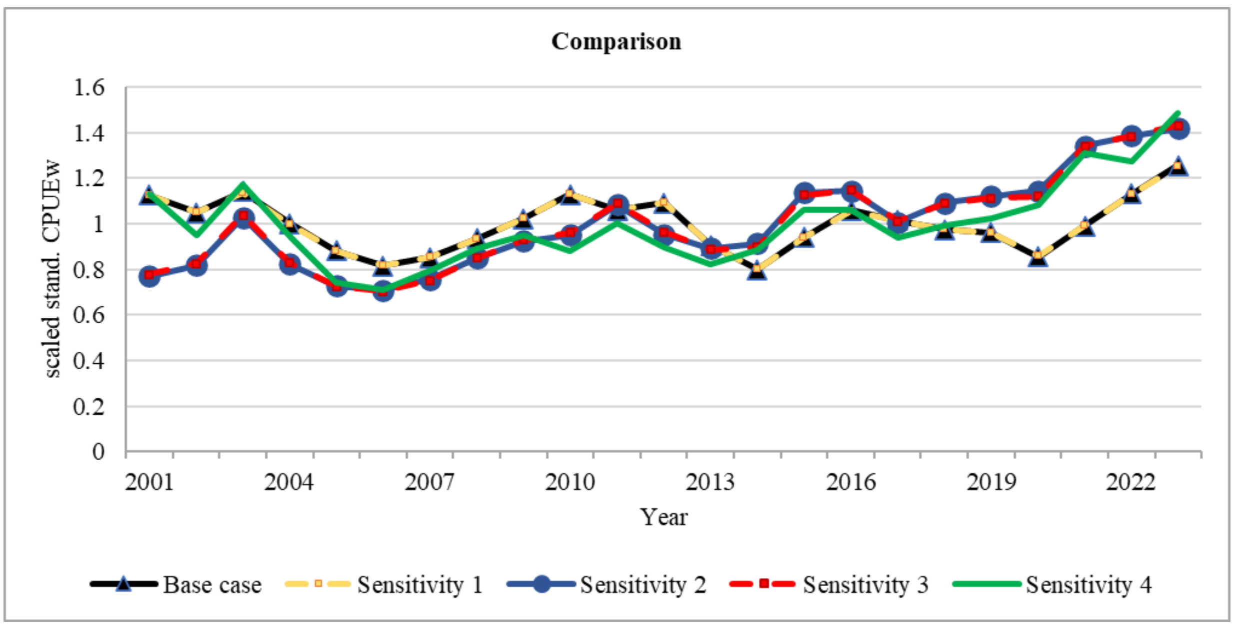

Figure 5. Comparison of trends in standardised CPUE in gutted weight by year: base case *vs* sensitivity analyses. Sensitivity 1: considering only the trips with the usual American-style monofilament gear. Sensitivity 2: GLM formula without the ratio factor. Sensitivity 3: substituting the ratio factor for the swordfish CPUEw. Sensitivity 4: applying a finite mixture model.