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STANDARDIZED CATCH RATES FOR MEDITERRANEAN SWORDFISH (*XIPHIAS GLADIUS* LINNAEUS, 1758) FROM THE SPANISH LONGLINE FISHERY 1988-2017

J. Ortiz de Urbina[1], S Saber[1], S. García[1], P. Rioja[1], M.J. Gómez-Vives[1], D. Godoy[1], M.J. Meléndez[1], M.A. Puerto[1], D. Macías[1]

SUMMARY

*Standardized relative abundance indices for swordfish (*Xiphias gladius *Linnaeus, 1758) caught by the Spanish surface longline in the western Mediterranean Sea were estimated for the period 1988-2017. Standardized CPUEs were estimated through a General Linear Mixed Modeling (GLMM) approach under a negative binomial (NB) error distribution assumption. The main factors in the standardization analysis were fishing area and time of the year (quarter). The standardized index showed notable annual fluctuations without any definite trend for the period under study*.

RÉSUMÉ

Les indices d'abondance relative standardisés pour l'espadon (Xiphias gladius, *Linnaeus, 1758*) *capturés par la palangre de surface espagnole en Méditerranée occidentale ont été estimés pour la période 1988-2017. Des CPUE standardisées ont été estimées au moyen d'une approche de modélisation linéaire mixte généralisée (GLMM) en postulant une distribution d'erreur binomiale négative. Les principaux facteurs de l'analyse de la standardisation étaient la zone de pêche et la période de l'année (trimestre). L'indice standardisé présentait des fluctuations annuelles notables sans dégager de tendance précise pour la période à l'étude.*

RESUMEN

Se estimaron índices de abundancia relativa estandarizada para el pez espada (Xiphias gladius *Linnaeus, 1758) capturado por la flota de palangre de superficie española en el Mediterráneo occidental para el periodo 1988-2017. Las CPUE estandarizadas se estimaron mediante un enfoque de modelación lineal mixto generalizado (GLMM) bajo un supuesto de distribución de error binomial negativo. Los factores principales en el análisis de estandarización fueron la zona de pesca y el momento del año (trimestre). El índice estandarizado presentaba notables fluctuaciones anuales sin ninguna tendencia definida para el periodo que se estaba estudiando.*

KEYWORDS

Swordfish, Abundance indices, Catch/effort, Generalized Linear Mixed model, Pelagic longline fisheries, Mediterranean Sea

[1] Instituto Español de Oceanografía, Centro Oceanográfico de Málaga, Puerto Pesquero, s/n, 29640 Fuengirola, Málaga, Spain. urbina@ieo.es

1. Introduction

The Spanish longline fleet targeting swordfish in the western Mediterranean operates using several gears which cover a wide range of depths. From the beginning of the fishery until year 2000, the fleet operated by using only a surface gear: the traditional or home based longline (LLHB). About 2000, part of the fleet began to use a weighed gear (*piedras*) and floats (*bolas*), having access to deeper waters, close to the sea bottom. The gear was termed *piedra-bola* or bottom longline (LLPB). After 2002, the fleet began to use the American longline (LLAM): a surface gear that introduced some new elements such as the spool, a thicker main-line, and larger distance between hooks. Finally, in 2007 a semi-pelagic longline (LLSP) that operates in mesopelagic waters began to be used.

A comprehensive description of the Spanish longline fishery directed to swordfish in the Mediterranean Sea, including fishing gears technical characteristics, was previously presented in (de la Serna et al., 2004; García-Barcelona et al., 2010).

Currently the main gears used are LLSP (in summer months), and LLHB (in winter months). In addition, swordfish is also caught seasonally, in small quantities, as a by-catch species on the longline fisheries targeting bluefin tuna and albacore.

Globally, the fishery has remained quite stable regarding total fishing effort. As regards catches, they remained stable for the period between 1988 and 2007, with a tendency to increase since 2008 up to date.

2. Material and Methods

2.1 Data

Data for the analysis were obtained from the Spanish longline fishery targeting swordfish in the western Mediterranean Sea from 1988 to 2017.

As in previous analyses (Mejuto and de la Serna, 1995; Ortiz de Urbina and de la Serna, 1999; Ortiz de Urbina et al., 2004, 2008, 2011, 2015), information on catch by vessel/trip (fishing date, area of the catch, catch in number and fishing effort) was recorded by the Information and Sampling Network of the Spanish Institute of Oceanography (IEO) at the most important landing ports for the aforementioned fleet. Raw data for positive trips (trips with at least one fish) were structured as follows: vessel code, date of landing, landing in number of fish, number of sampled fish, size composition of the catch (Lower Jaw Fork Length- LJFL, 5 cm length-classes), quadrant, area (5 x 5 degrees), number of sets, hooks by set and type of bait. After data cleansing, a total of 28 441 records were available for the analysis.

Following standard criteria, nominal fishing effort by trip was defined as the number of hooks (in thousands of hooks) computed from the number of sets carried out during the trip, and the mean number of hooks by set during the trip.

2.2 Data exclusions

Data inspection basically entailed the elimination of incomplete and erroneus records, such as incorrectly recorded number of fish, number of sets by trip, or erroneously georeferenced sets. Whenever possible, incorrect measurement units were corrected. As a result, approximately one per cent (1 %) of the records available for the period 1988-2017 was eliminated for later analysis.

2.3 Analytical approach

For a response variable recording catch in number of fish, both the Poisson distribution and the negative binomial distribution (NB) describe the probabilities of the occurrence of numbers greater than or equal to 0. Unlike the Poisson distribution, the variance and the mean for the negative binomial are not equivalent. The variance of a negative binomial distribution is a function of its mean and has an additional parameter, the dispersion parameter, Θ or k, which might serve as a proper approach for modeling counts with variability different from its mean.

An exploratory analysis (results not shown in the document) of the available data assuming a Poisson error distribution pointed both to the existence of overdispersion and to statistically significant interactions between *year* and other explanatory factors in the model. Thus, standardized indices of abundance were estimated by a generalized linear mixed modeling (GLMM) approach assuming a negative binomial model (NB), and including the significant interactions year:area and year:quarter as random effects in the model.

The NB generalized linear mixed model was parameterized as a rate model in which the fishing effort (number of hooks) was implemented as an offset, which reflects the total effort by set over which the count response (number of fish) was generated. In fact, the offset is an exposure variable with a coefficient constrained to a value of 1.0 (i.e., enters into the model as a constant). Since the natural logarithm (loge) is the canonical link for the NB model, the offset was logged prior to entry into the estimating algorithm.

The analyses were conducted and the graphs designed by using R statistical software (R Core Team, 2017). Among others, packages MASS (Venables and Ripley, 2002), lme4 (Bates et al., 2015), glmmTMB (Brooks et al., 2017), emmeans (Lenth, 2018), and ggplot2 (Wickham, 2016) were of particular help.

2.4 Model specification

Three previously defined areas (Mejuto and de la Serna, 1995) were implemented to take account of the spatial structure. As regards the temporal definition, it corresponded to the four natural quarters.

The GLMM NB model was de defined as:

number ~ year + quarter + area + quarter:area +
offset(log(effort) +
(1|year:quarter) + (1|year:area)

2.5 Management measures

The Mediterranean swordfish stock is subjected to a multi-annual recovery plan, starting in 2017 and continuing through 2031 (15 years), with the goal of achieving BMSY with at least 60% probability (ICCAT Rec [16-05]).

The recovery plan prescribes, among others, Total Allowable Catches (TACs), capacity limitations, closed fishing season (from 1 October to 30 November and during an additional period of one month between 15 February and 31 March or, alternatively, during the period from 1 January to 31 March each year), minimum size (100 cm LJFL or, in alternative, 11.4 kg of round weight or 10.2 kg of gilled and gutted weight), and technical characteristics of the fishing gear (maximum number of hooks fixed at 2500 hooks, hook size should never be smaller than 7 cm of height, and the length of the pelagic longlines will be of maximum 30 NM -55 km).

3. Results and Discussion

Fishing ground for the Spanish longline fishery targeting swordfish is shown in **Figure 1**.

A total of 28441 fishing sets for the period 1988-2017 were available for analysis. An annual summary of the information available for the analysis (number of sets, fishing effort, nominal catch in number and nominal catch rates) is given in **Table 1.**

Sampling coverage (in terms of annual percentage of weight sampled with respect to total Task I reported to ICCAT) is shown in **Figure 2**. Sampling coverage was around 43 % on average for the period considered (1988-2017), with an increasing trend for the last years of the series.

Figure 3 shows the distribution of factors (month, quarter and area) used in the standardization analysis. Treatment combinations across years were reasonably satisfactory[1].

The estimated parameters for the final NB GLMM model are reported in Section 5. **Table 2** reports type-II and type-III analysis-of-variance results for the final GLMM NB model.

[1] Note here that swordfish fishing in the western Mediterranean from year 2017 on might be influenced by the implementation of ICCAT Mediterranean Swordfish Rebuilding Plan (ICCAT Rec [16-05]).

Factors year, quarter, and the area:quarter interaction were statistically significant ($\alpha = 0:01$). Despite not being statistically significant, according to the principle of marginality and in order to take into account the area:quarter interaction, factor area was included in the model.

Figure 4 shows residual diagnostics for assessing the final NB GLMM model fit. Even though the residual patterns show some departures from distributional assumptions at the tails, generally adequate fit the model.

Table 3 and **Figure 5** report estimated standardized relative abundance indices, standard errors and corresponding coefficients of variation. The standardized index showed notable annual fluctuations without any definite trend for the period under study.

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Table 1. Summary table. Spanish SWO surface longline, western Mediterranean, 1988-2017.

year	sets	effort (hooks 10^{-3})	catchN	cpueN	cpueW (kg)
1988	610	3119.50	31685	15	186.15
1989	50	266.56	1221	6	227.15
1990	69	440.24	2162	6	219.40
1991	862	3965.03	30518	9	125.25
1992	1154	3908.09	32270	10	109.92
1993	1551	5276.10	46439	9	141.51
1994	1898	4998.22	47212	10	159.21
1995	1992	6742.11	57171	10	147.54
1996	1493	4737.84	29776	7	117.12
1997	1111	3281.73	19961	7	122.03
1998	996	3057.96	21643	8	118.46
1999	695	2232.98	13744	7	103.77
2000	29	446.40	2760	6	182.84
2001	944	3203.36	22809	7	113.76
2002	1192	3863.43	38051	13	153.59
2003	799	2635.45	19929	7	121.00
2004	536	1857.40	12531	7	120.68
2005	309	1310.23	9806	7	146.51
2006	240	860.88	8612	10	205.11
2007	218	1139.27	13363	11	188.39
2008	404	1245.16	14217	12	267.12
2009	782	2797.59	20369	7	200.68
2010	795	3120.60	24971	8	212.61
2011	867	3286.54	29135	9	222.13
2012	523	2362.05	20387	10	229.60
2013	1725	8203.32	62677	9	215.74
2014	1916	9055.69	73966	9	255.21
2015	2360	11659.88	86848	8	199.66
2016	2010	9033.85	65266	8	186.65
2017	311	1653.33	12426	8	202.25

Table 2. Type-II (top) and type-III (bottom) analysis-of-variance tables for final GLMM NB model. Spanish SWO surface longline, western Mediterranean, 1988-2017.

	Chisq	Df	Pr(>Chisq)
year	82.82	29	0.0000
quarter	189.49	3	0.0000
area	0.05	2	0.9764
quarter:area	70.85	6	0.0000
(Intercept)	263.92	1	0.0000
year	82.82	29	0.0000
quarter	143.78	3	0.0000
area	1.53	2	0.4645
quarter:area	70.85	6	0.0000

Table 3. Estimated standardized relative abundance indices, standard errors and coefficient of variation. Swordfish catch in number, Spanish surface longline, western Mediterranean, 1988-2017.

Year	lsmean	SE	cv	asymp.LCL	asymp.UCL	nominal
1988	2.46	0.14	0.04	2.19	2.73	2.40
1989	1.40	0.24	0.10	0.93	1.86	1.48
1990	1.53	0.22	0.09	1.11	1.95	1.43
1991	1.99	0.14	0.05	1.72	2.25	1.87
1992	2.11	0.14	0.04	1.84	2.38	2.00
1993	2.11	0.14	0.04	1.84	2.38	1.97
1994	2.34	0.14	0.04	2.08	2.61	2.09
1995	2.18	0.13	0.04	1.91	2.44	2.06
1996	1.79	0.14	0.05	1.53	2.06	1.81
1997	1.75	0.14	0.05	1.48	2.02	1.80
1998	1.96	0.14	0.05	1.69	2.23	1.94
1999	1.73	0.14	0.05	1.46	2.00	1.74
2000	1.54	0.24	0.10	1.08	2.00	1.68
2001	1.82	0.14	0.05	1.53	2.10	1.77
2002	2.43	0.14	0.04	2.16	2.71	2.34
2003	1.97	0.14	0.05	1.69	2.25	1.78
2004	1.63	0.14	0.06	1.35	1.91	1.60
2005	1.85	0.15	0.05	1.56	2.14	1.80
2006	1.96	0.15	0.05	1.66	2.26	1.98
2007	2.24	0.14	0.05	1.96	2.52	2.17
2008	2.16	0.14	0.05	1.89	2.44	2.25
2009	1.60	0.14	0.05	1.33	1.87	1.64
2010	1.71	0.14	0.05	1.43	1.98	1.81
2011	1.83	0.14	0.05	1.56	2.10	1.91
2012	2.13	0.14	0.05	1.86	2.40	2.03
2013	1.89	0.13	0.05	1.62	2.15	1.76
2014	1.92	0.13	0.05	1.65	2.18	1.84
2015	1.92	0.13	0.05	1.66	2.18	1.66
2016	1.93	0.13	0.05	1.67	2.19	1.51
2017	1.86	0.16	0.06	1.54	2.17	1.82

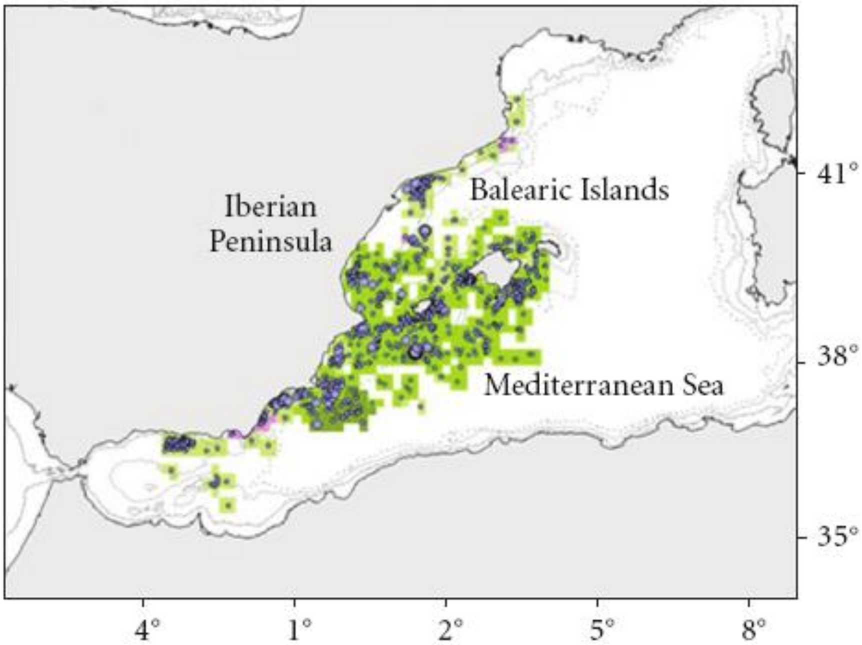

Figure 1. LLHB fishing grounds. Spanish SWO surface longline, western Mediterranean, 1988-2017.

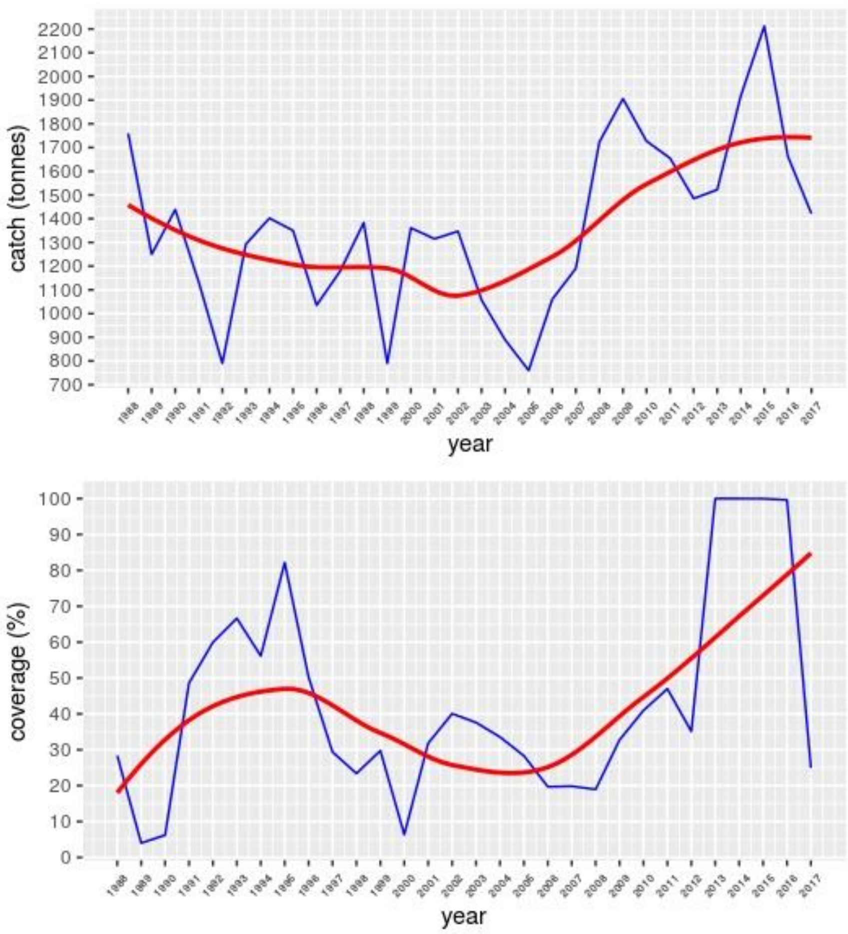

Figure 2. Reported catch (top) and Sampling coverage (bottom). Spanish SWO surface longline, western Mediterranean, 1988-2017 (coverage around 43%, on average, for the period 1988-2017).

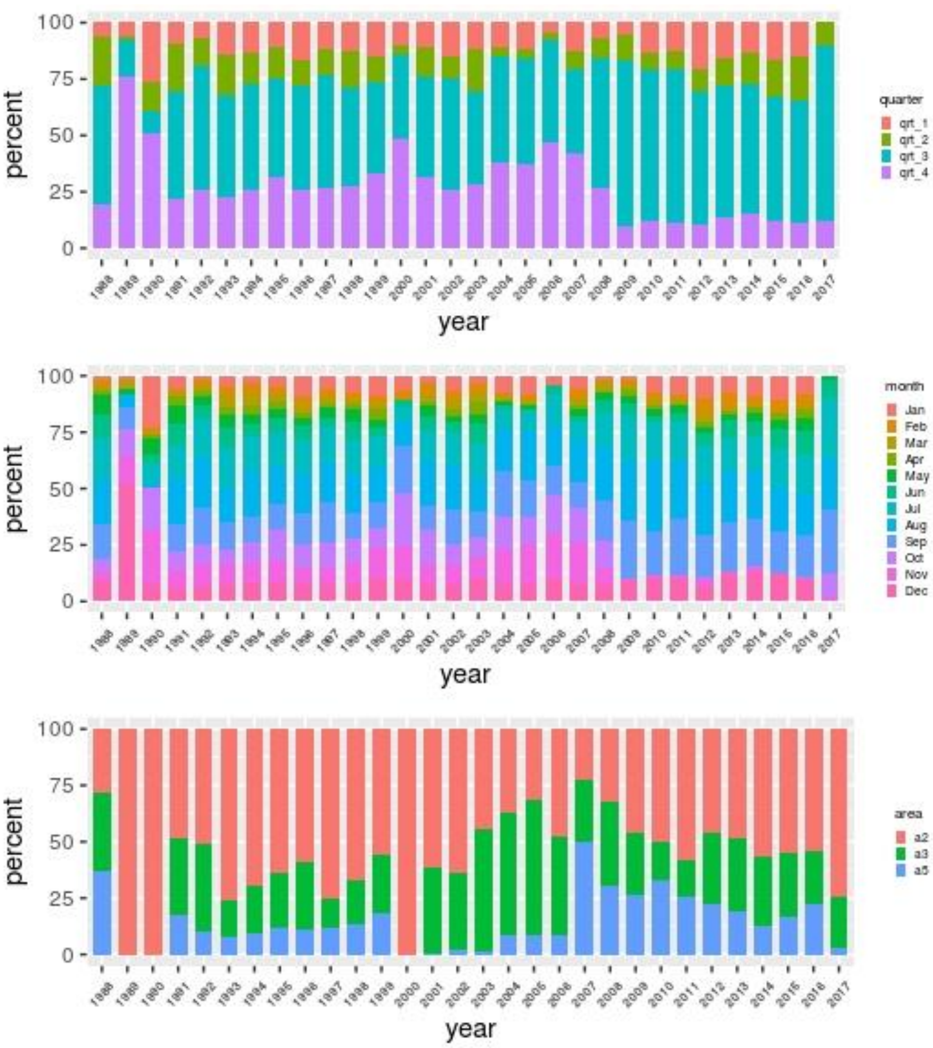

Figure 3. Temporal and spatial distribution of relevant factors in the data analyzed. Spanish SWO surface longline, western Mediterranean, 1988-2017.

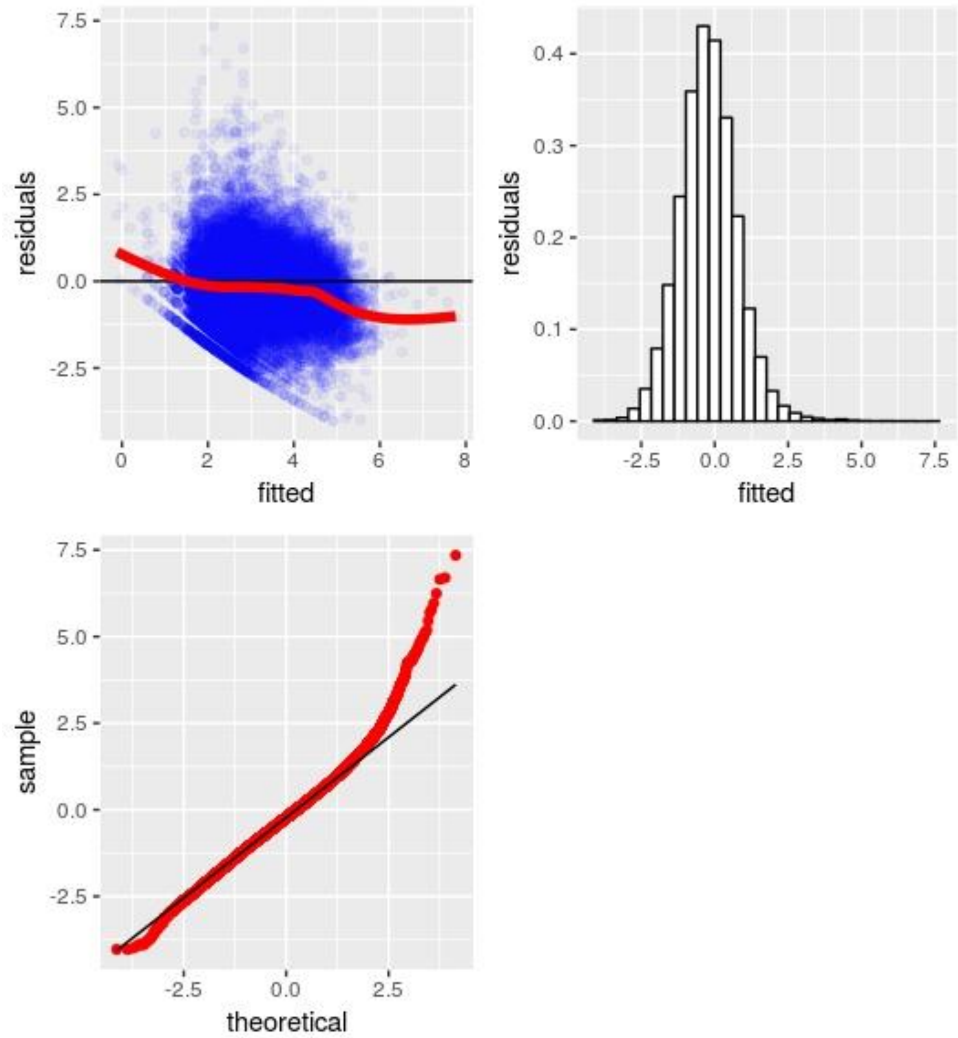

Figure 4. Residuals diagnostics. Spanish SWO surface longline, western Mediterranean, 1988-2017.

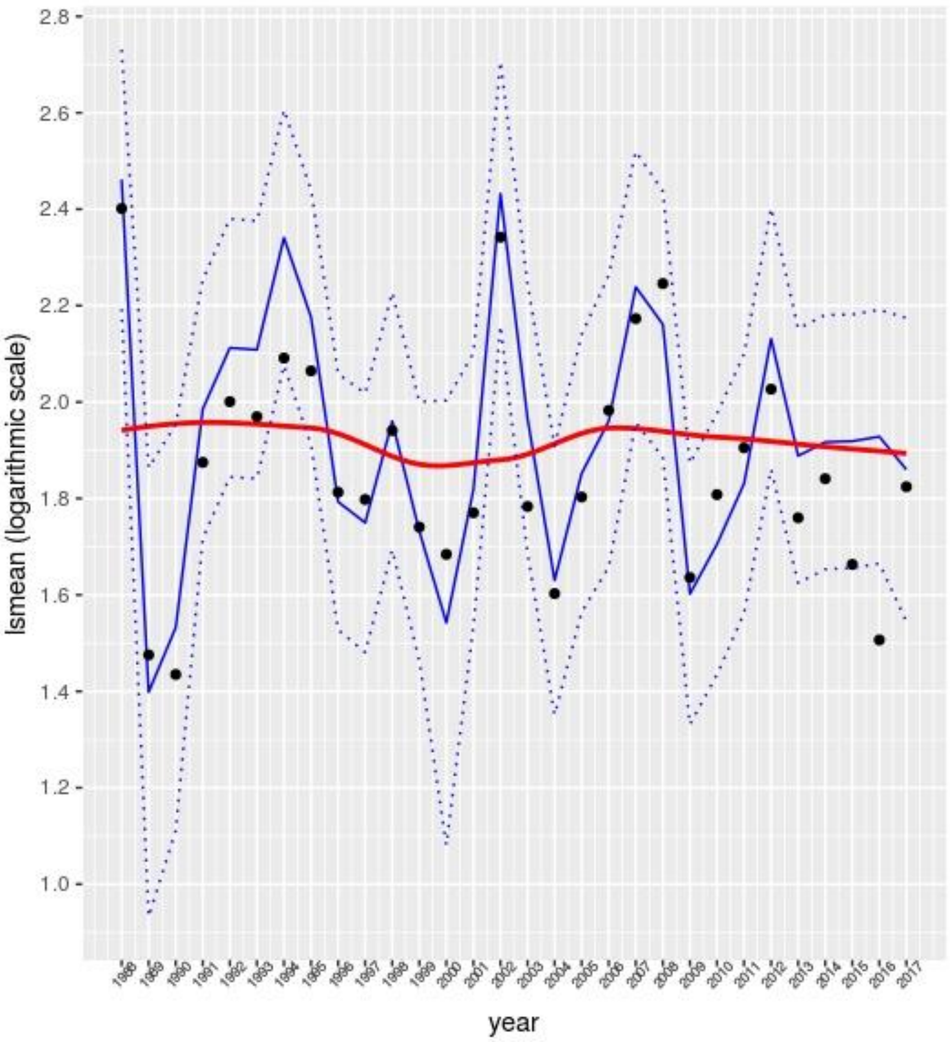

Figure 5. Estimated standardized relative abundance index and corresponding 95% confidence limits (normal approximation). Spanish SWO surface longline, western Mediterranean, 1988-2017 (blue line, standardized CPUE; black dots, nominal CPUE; red line, loess t- *as an aid* to *interpret* CPUE *trend*).

A Summary of estimated parameters for the final GLMM NB model.

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==========================================================================================
Generalized linear mixed model fit      by maximum likelihood (Laplace Approximation) [glmerMod]
Family: Negative Binomial(2.5499)       ( log )
Formula: DESEMBN ~ year + quarter + area + quarter * area + offset(leffort) +
                         (1 | year:quarter) + (1 | year:area)
Data: datuak

     AIC        BIC       logLik     deviance    df.resid
  223844.3   224207.6 -111878.2   223756.3      28397

Scaled residuals:
    Min      1Q  Median      3Q     Max
-1.5708 -0.7056 -0.2173  0.4363 21.1951

==========================================================================================
Random effects:
 Groups       Name          Variance  Std.Dev.
 year:quarter (Intercept)   0.03435   0.1853
 year:area    (Intercept)   0.02726   0.1651
Number of obs: 28441, groups:  year:quarter, 119; year:area, 84

==========================================================================================
Fixed effects:
                        Estimate Std. Error z value  Pr(>|z|)
(Intercept)              2.35438    0.14492  16.246  < 2e-16 ***
year1989                -1.06335    0.27417  -3.878 0.000105 ***
year1990                -0.92955    0.25507  -3.644 0.000268 ***
year1991                -0.47611    0.19377  -2.457 0.014008 *
year1992                -0.34940    0.19362  -1.805 0.071138 .
year1993                -0.35338    0.19354  -1.826 0.067866 .
year1994                -0.12096    0.19266  -0.628 0.530103
year1995                -0.28590    0.19221  -1.487 0.136903
year1996                -0.66880    0.19271  -3.470 0.000520 ***
year1997                -0.71217    0.19391  -3.673 0.000240 ***
year1998                -0.50165    0.19334  -2.595 0.009469 **
year1999                -0.72969    0.19387  -3.764 0.000167 ***
year2000                -0.91951    0.27226  -3.377 0.000732 ***
year2001                -0.64371    0.19927  -3.230 0.001236 **
year2002                -0.02969    0.19590  -0.152 0.879537
year2003                -0.49621    0.19798  -2.506 0.012199 *
year2004                -0.83146    0.19771  -4.205 2.61e-05 ***
year2005                -0.60962    0.20105  -3.032 0.002428 **
year2006                -0.50133    0.20651  -2.428 0.015198 *
year2007                -0.22329    0.19862  -1.124 0.260920
year2008                -0.30067    0.19664  -1.529 0.126261
year2009                -0.85984    0.19472  -4.416 1.01e-05 ***
year2010                -0.75674    0.19459  -3.889 0.000101 ***
year2011                -0.63090    0.19412  -3.250 0.001154 **
year2012                -0.33057    0.19477  -1.697 0.089662 .
year2013                -0.57335    0.19221  -2.983 0.002855 **
year2014                -0.54490    0.19221  -2.835 0.004584 **
year2015                -0.54311    0.19194  -2.830 0.004660 **
year2016                -0.53358    0.19198  -2.779 0.005448 **
year2017                -0.60208    0.21111  -2.852 0.004344 **
quarterqrt_2            -0.18353    0.05766  -3.183 0.001457 **
quarterqrt_3             0.38902    0.05462   7.122 1.07e-12 ***
quarterqrt_4             0.32516    0.05507   5.904 3.54e-09 ***
areaa3                  -0.05320    0.05357  -0.993 0.320731
areaa5                  -0.06538    0.05953  -1.098 0.272085
quarterqrt_2:areaa3      0.04307    0.04007   1.075 0.282371
quarterqrt_3:areaa3      0.03694    0.03118   1.185 0.236092
quarterqrt_4:areaa3      0.11657    0.03482   3.348 0.000814 ***
quarterqrt_2:areaa5 -0.23496    0.05619  -4.182 2.89e-05 ***
quarterqrt_3:areaa5      0.07244    0.04032   1.797 0.072409 .
quarterqrt_4:areaa5      0.13736    0.04520   3.039 0.002374 **
==========================================================================================
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