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STANDARDIZED BIGEYE TUNA CPUE INDEX OF THE BAITBOAT FISHERY IN DAKAR (2005-2017)

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Summary

Introduction

The tuna baitboat fishery in Dakar (Senegal) has been operating permanently in the area off Senegal since the beginning of the 1950s. Details of the activity of this fleet can be found in Fonteneau & Diouf (1994), Hallier & Delgado de la Molina (2000) and, more recently, in several ICCAT documents (e.g., Pascual-Alayón et al., 2017, 2018). The number of vessels peaked at the end of the 1950s with 85-90 baitboats. Vessel productivity increased in the 1980s when a new technique was developed, the associated-school fishing method, whereas the baitboat maintains a permanent association with the tunas it fish. This method was described for the first time by Fonteneau & Diouf (1994). The Dakar-based fleet currently consists of 14 vessels: six Senegalese-flagged, seven Spanish-flagged, and one French-flagged. Annual catches of skipjack, yellowfin and bigeye are around 15,000 mt.

In this document we have analysed the data corresponding to the seven Spanish flagged baitboat vessels. The activity of this fleet has traditionally taken place in the coastal areas between 14ºN and 21ºN (Figure 1). Their catch is composed mainly by skipjack and, to a lesser extent, by yellowfin and bigeye. In the last 5 years they represented 84%, 10% and 6% of the total catches, respectively. Over the period analysed in this document (2005-2017) the proportion of bigeye has oscillated without tendency between a maximum of 16% in 2006 and a minimum of 3% in 2013; the proportion of bigeye in the last year of this analysis, 2017, was 10%. The annual average catch of bigeye during this period has been 741.8 MT with a standard deviation of 313.8 MT (Figure 2).

The average weight of the three tropical tuna species in the catches of this fleet is around 2-3 kg, 4-10 kg and 6-12 for skipjack, yellowfin and bigeye respectively. They have oscillated around these values without tendency during the last 25 years (Figure 17 of Delgado de Molina, A., et al. 2014).

The Tropical Tuna Workplan adopted by the SCRS in 2017 included the update of standardized bigeye CPUE indices until 2017 for the European baitboat fleet operating in Dakar. In this working document we present the analyses carried out with detailed VMS and logbook data from this fleet for the most recent period for which both sources of information were available.

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Data and methods

Two different sources of information of the fleet activity were available for this period: logbooks and satellite-based Vessel Monitoring System (VMS). They were made available by the "Secretaría General de Pesca Marítima" – Spanish Ministry of Agriculture, Food and Environment. The number of days of activity by vessel, year and month, according to the VMS and logbook data provided are shown in Figure 3.

Since January 2000 all European fishing vessels exceeding 24m in overall length (15m from 2005) have been required to use VMS and to transmit their position at least every two hours. For this study, the Spanish Ministry of Agriculture, Food and Environment has provided 1.3 million records of VMS data, corresponding to 37,486 days of activity of seven Spanish BB vessels for the period 2002-2017.

Skippers of all European Community vessels over 10m length are required to record the retained catch weight (in kg) by species in logbooks on a daily basis. Logbooks available for the present study comprise 19,436 daily observations from seven Spanish BB vessels corresponding to the period 2005-2017. Based on this information, Figure 4 shows the total catch by species by year and by vessel; monthly distribution of the catches of each species is also provided.

Data from logbooks provide detailed information on positive daily catches by vessel. After excluding those records of stay at port using a shapefile[4] containing the main ports, VMS information was used to characterize the activity of the Spanish baitboat fleet to identify among three situations: tuna fishing, bait fishing and en route. The following criteria was followed:

- B=BAIT FISHING: There are catches of bait or the number of days since the departure of the port is less or equal to 2 days.
- R=EN ROUTE: Speed greater than 8 knots or the number of days before arriving to port is less or equal to 1 days or the distance between average daily positions is bigger than 100 miles.
- F=FISHING: There are tuna catches or != (B or R)

Catch rate of bigeye was expressed using the nominal catch per unit effort (CPUE), as catch in weight by fishing day. Those days that were identified as of bait fishing or in transit were not included in the analysis. The variables offered in the CPUE model were Year, Month, Area, Vessel, Vessel speed and Catch of other tuna for each of the observed fishing days.

Other variables that were compiled for the CPUE standardization analysis included some oceanographic variables that could have an effect in the activity of the baitboat fleet (wind speed u,v) and the availability of tuna (sea surface temperature and sea surface elevation) obtained from the Hybrid Coordinate Ocean Model[5]. HYCOM.org provides access to global HYCOM + NCODA based ocean prediction system output. Wind speed (m/s-1) estimates were obtained for each fishing location by the equation: wind speed = $\sqrt{[(\text{meridional wind}^2 + \text{zonal wind}^2)}$.

Finally, nine variables were used in the analysis; they were all treated as categorical: Year (13 levels, 2005-2017), Month (12 levels, 1-12), Area (2 levels, south or north of 17ºN), Vessel (7 levels, 1-7), Vessel daily average speed (3 levels, <1, 1-4. >4 knots),

[4] http://www.naturalearthdata.com/downloads/50m-cultural-vectors/ports-2/
[5] https://hycom.org/hycom/overview

Catch of other tuna (2 levels, 0,1), wind speed (3 levels, =<0.2, 0.2-0.4 and >0.4 m/s), sea surface temperature (4 levels, =<23, 23-25, 25-27, >27 ºC) and sea surface elevation (3 levels, =<-0.22, -0.22 to -0.15, >-0.15 m).

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CPUE was standardized using Generalized Linear Mixed Modelling (GLMM). Because of the significant proportion of sets with zero catch of bigeye tuna [between 58 and 91% on average per year], the standardization method used a delta lognormal model distribution that can take into account zero observations (Lo et al., 1992; Stefansson, 1996; Ortiz and Arocha, 2004; Shono, 2008). The delta model estimates the predicted catch rates as the result of two processes; i) the probability of encounter bigeye tuna in the catch (proportion of positive catch) and, ii) the mean catch rate given that a positive catch has been realized (conditional predicted catch rate) (Lo et al., 1992). Then the estimated catch rates overall are the product of these two processes.

All analyses were conducted using R version 3.4.3 (R Development Core Team, 2012), with the GLMM model performed with the glmer function in the lme4 library (Bates et al., 2013) using maximum likelihood fitting.

All the variables were treated as fixed effects except the variable “Vessel” which was treated as a random effect. In this model, individual vessels were treated as a random effect because the fishing trips made by the same vessel can be thought of as repeated measures in a longitudinal analysis. In the case of a statistically significant interaction between the year factor and any other factor, they were considered as random interactions in the final model.

A step-wise regression procedure was used to determine the set of explanatory factors and interactions that significantly explained the observed variability. For this, deviance analysis tables were created for the proportion of positive observations (e.g., positive sets/total sets), and for the positive catch rates. Final selection of explanatory factors was conditional to: a) the relative percentage of deviance explained by adding the factor in evaluation (normally factors that explained more than 5% were selected), and b) The Chi-square (χ2) significance test. Interactions among factors were also evaluated

Lastly, the selection of the final mixed model was based on the Akaike's Information Criterion (AIC), the Bayesian Information Criterion (BIC), and a Chi-square (χ2) test of the difference between the log-likelihood statistic of two nested model formulations (Littell et al., 1996). Once having a final model selected, the relative indices for the Delta model formulation were calculated as the product of the year effect least square means (LSmeans) from the binomial and the lognormal model components (Ortiz and Arocha, 2004; Punt et al., 2000).

Results and discussion

Tables 1 and 2 present a summary of the deviance analysis for the two processes of the delta lognormal model, lognormal and binomial components, respectively. Those factors and interactions that explained more than 5% of the total deviance were included in the final model. The interactions were incorporated in the GLMM as random variables.

The selected models for the Lognormal and Binomial components were:

- Lognormal: Year, Month, Vessel, Year:Month, Year:Vessel
- Binomial: Year, Month, Year:Month

No significant residual patterns were observed for either the lognormal or the binomial model (Figures 5a-b).

The estimates of the final Delta model, are provided in **Figure 6** and **Table 3**.

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	Df	*Deviance*	*ResidDf*	*ResidDev*	*F*	*Pr(>F)*		*% of total deviance*
NULL			3759	5096.6				
Year	12	169.8	3747	4926.7	16.947	< 2.2e-16	***	3.3%
Month	11	330.6	3736	4596.1	35.995	< 2.2e-16	***	6.5%
Vessel	6	376.7	3730	4219.3	75.183	< 2.2e-16	***	7.4%
Area	1	6.89	3729	4212.4	8.2538	0.0040926	**	0.1%
Vel	2	38.5	3727	4173.9	23.098	1.09E-10	***	0.8%
Other	1	30.8	3726	4143	36.926	1.37E-09	***	0.6%
Wind	2	3.47	3724	4139.5	2.0787	0.125255		0.1%
Temp	3	3.04	3721	4136.5	1.2135	0.3031623		0.1%
Ele	2	1.98	3719	4134.5	1.1853	0.3057732		0.0%
Year:Month	119	611.3	3600	3523.2	6.1509	< 2.2e-16	***	12.0%
Year:Vessel	66	257.6	3534	3265.6	4.6741	< 2.2e-16	***	5.1%
Year:Area	10	24.9	3524	3240.7	2.9848	0.0009411	***	0.5%
Year:Other	12	18.6	3512	3222	1.8595	0.0345716	*	0.4%
Year:Ele	24	37.6	3488	3184.4	1.8773	0.0059847	**	0.7%
Month:Vessel	66	188.6	3422	2995.9	3.4209	< 2.2e-16	***	3.7%
Month:Area	11	21.0	3411	2974.9	2.2847	0.0089011	**	0.4%
Month:Temp	33	75.6	3378	2899.3	2.7417	3.88E-07	***	1.5%
Vessel:Area	6	25.5	3372	2873.8	5.0909	3.26E-05	***	0.5%
Vessel:Other	6	17.2	3366	2856.6	3.4331	0.0022118	**	0.3%
Vessel:Temp	18	29.1	3348	2827.5	1.9386	0.0100286	*	0.6%
Vessel:Ele	12	19.0	3336	2808.4	1.8994	0.0299385	*	0.4%
Area:VEL	2	6.3	3334	2802.2	3.7525	0.0235587	*	0.1%
Area:Wind	2	4.7	3332	2797.4	2.8276	0.0592968	.	0.1%
VEL:Other	2	4.5	3330	2792.9	2.7098	0.066697	.	0.1%
VEL:Ele	4	7.1	3326	2785.9	2.1106	0.0769069	.	0.1%
Other:Wind	2	3.8	3324	2782.1	2.2494	0.1056224		0.1%
Temp:Ele	6	11.1	3318	2771	2.2163	0.0388132	*	0.2%

Table 1. Deviance tables for the lognormal component of the Delta-lognormal model of the 2005-2017 period. Significant (p<0.05) factors and interactions explaining >5% of total deviance are highlighted.

	Df	*Deviance*	*Resid. Df*	*Resid. Dev*	*Pr(>Chi)*		*% of total deviance*
NULL			17189	18060			
Year	12	985.39	17177	17074	< 2.2e-16	***	5.5%
Month	11	937.89	17166	16136	< 2.2e-16	***	5.2%
Vessel	6	116.6	17160	16020	< 2.2e-16	***	0.6%
Area	1	49.88	17159	15970	1.63E-12	***	0.3%
Vel	2	15.45	17157	15954	0.0004415	***	0.1%
Other	1	235.12	17156	15719	< 2.2e-16	***	1.3%
Wind	2	2.83	17154	15717	0.2426463		0.0%
Temp	3	54.58	17151	15662	8.44E-12	***	0.3%
Ele	2	9.24	17149	15653	0.0098598	**	0.0%
Year:Month	131	1778.61	17018	13874	< 2.2e-16	***	9.9%
Year:Vessel	66	566.88	16952	13307	< 2.2e-16	***	3.1%
Year:Area	12	135.83	16940	13172	< 2.2e-16	***	0.7%
Year:Vel	24	64.58	16916	13107	1.40E-05	***	0.4%
Year:Other	12	61.41	16904	13046	1.25E-08	***	0.3%
Year:Temp	36	78.97	16868	12966	4.70E-05	***	0.4%
Year:Ele	24	53.71	16844	12913	0.0004653	***	0.3%
Month:Vessel	66	424.09	16778	12489	< 2.2e-16	***	2.3%
Month:Area	11	73.46	16767	12415	2.68E-11	***	0.4%
Month:Vel	22	46.37	16745	12369	0.0017693	**	0.3%
Month:Other	11	40.29	16734	12329	3.19E-05	***	0.2%
Month:Temp	33	102.37	16701	12226	5.00E-09	***	0.6%
Vessel:Area	6	18.92	16695	12207	0.0042947	**	0.1%
Vessel:Vel	12	21.02	16683	12186	0.0500751	.	0.1%
Vessel:Other	6	54.78	16677	12132	5.13E-10	***	0.3%
Vessel:Ele	12	27.11	16665	12104	0.007462	**	0.2%
Area:Vel	2	5	16663	12099	0.0821182	.	0.0%
Area:Other	1	1.85	16662	12098	0.1735291		0.0%
Vel:Other	2	5.9	16660	12092	0.0522529	.	0.0%
Vel:Temp	6	12.96	16654	12079	0.0437397	*	0.1%
Other:Ele	2	4.64	16652	12074	0.0981714	.	0.0%
Wind:Temp	6	12.97	16646	12061	0.0434676	*	0.1%

Table 2. Deviance tables for the binomial component of the Delta-lognormal model of the 2005-2017 period. Significant (p<0.05) factors and interactions explaining >5% of total deviance are highlighted.

year	*CPUE nominal*	*CPUE standarized*	*CPUE se*
2005	312	51.7	39.8
2006	591	104.1	115.8
2007	757	163.7	181.4
2008	102	6.2	7.1
2009	296	19.4	21.4
2010	347	81.6	88.6
2011	323	48.8	53.1
2012	206	17.6	19.5
2013	104	12.8	14.4
2014	110	7.5	8.4
2015	110	13.6	14.9
2016	255	46.2	50.4
2017	337	46.1	50.5

Table 3. Nominal and standardized baitboat CPUE for the period 2005-2017.

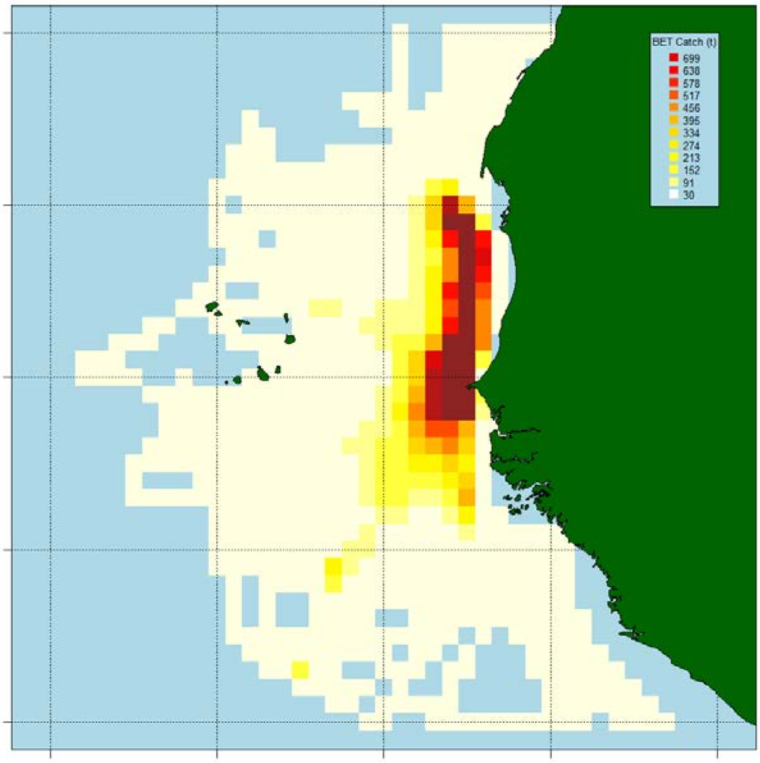


Figure 1. Fishing areas of the Spanish baitboat fleet based in Dakar between 2005 and 2017. This figure shows the total number of days at sea in each 0.5ºx0.5º rectangle by the seven Spanish flag vessels based in Dakar for the period 2005-2017.

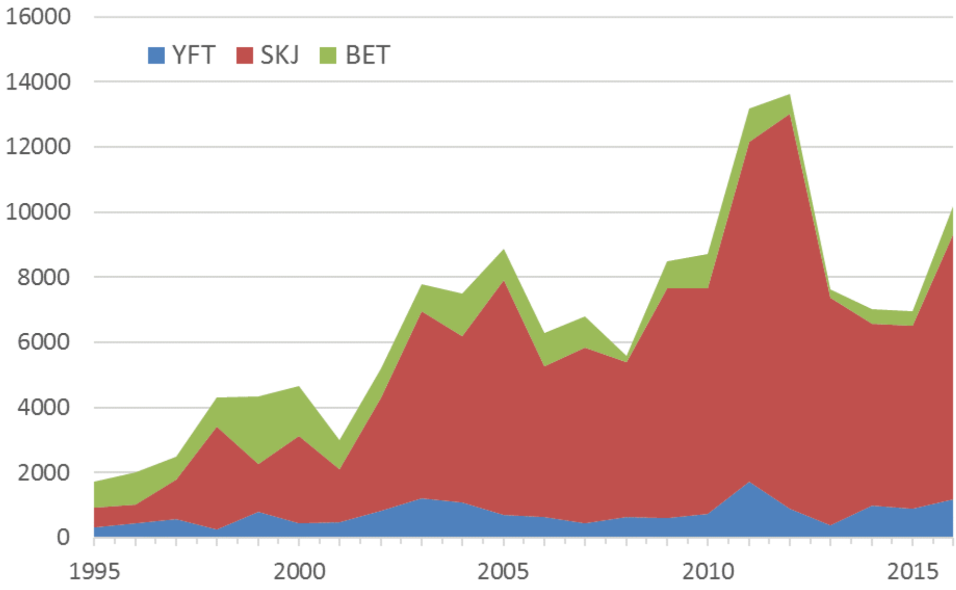


Figure 2. Catches of tropical tunas by the Spanish flag vessels based in Dakar for the period 1995-2017.

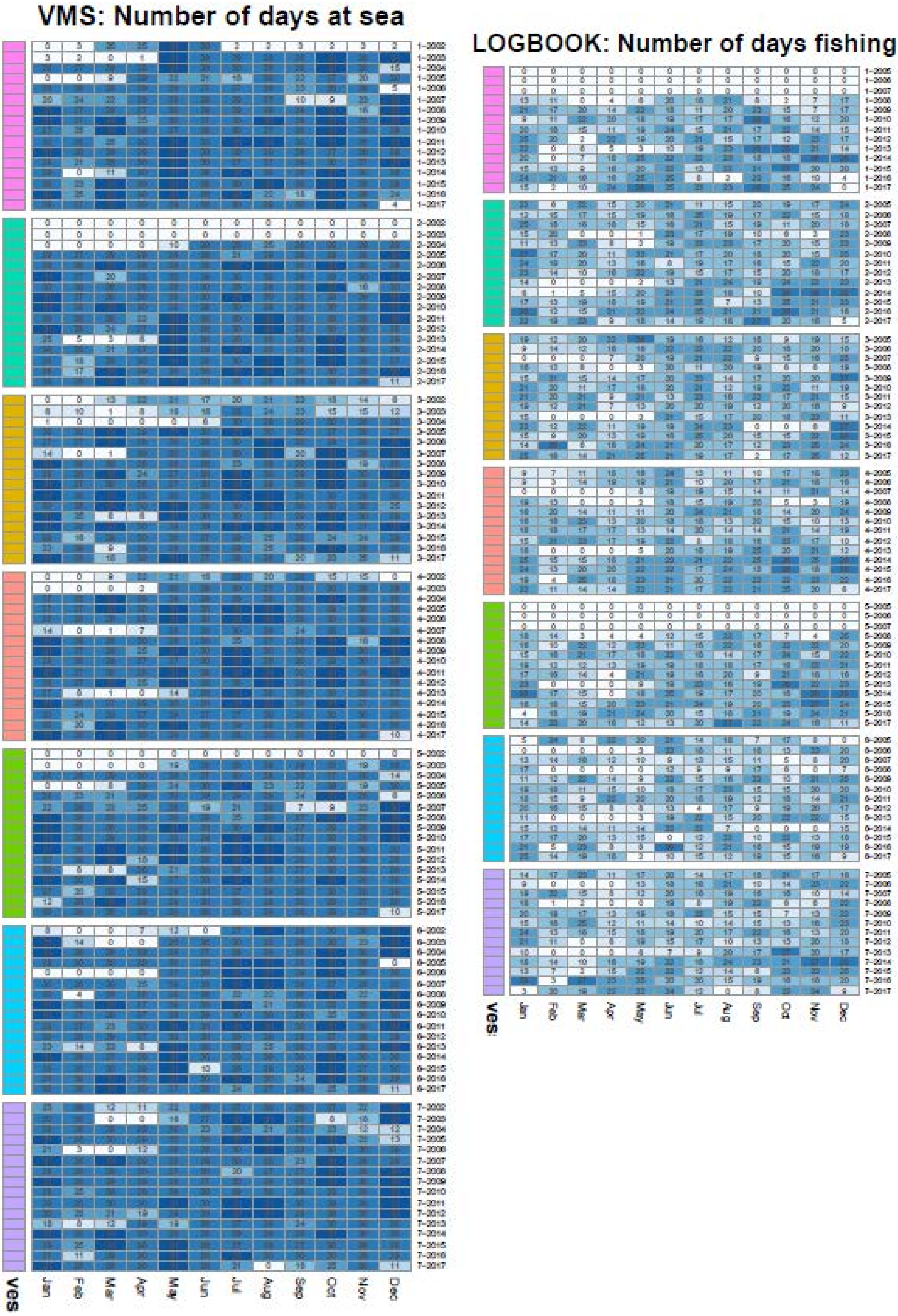
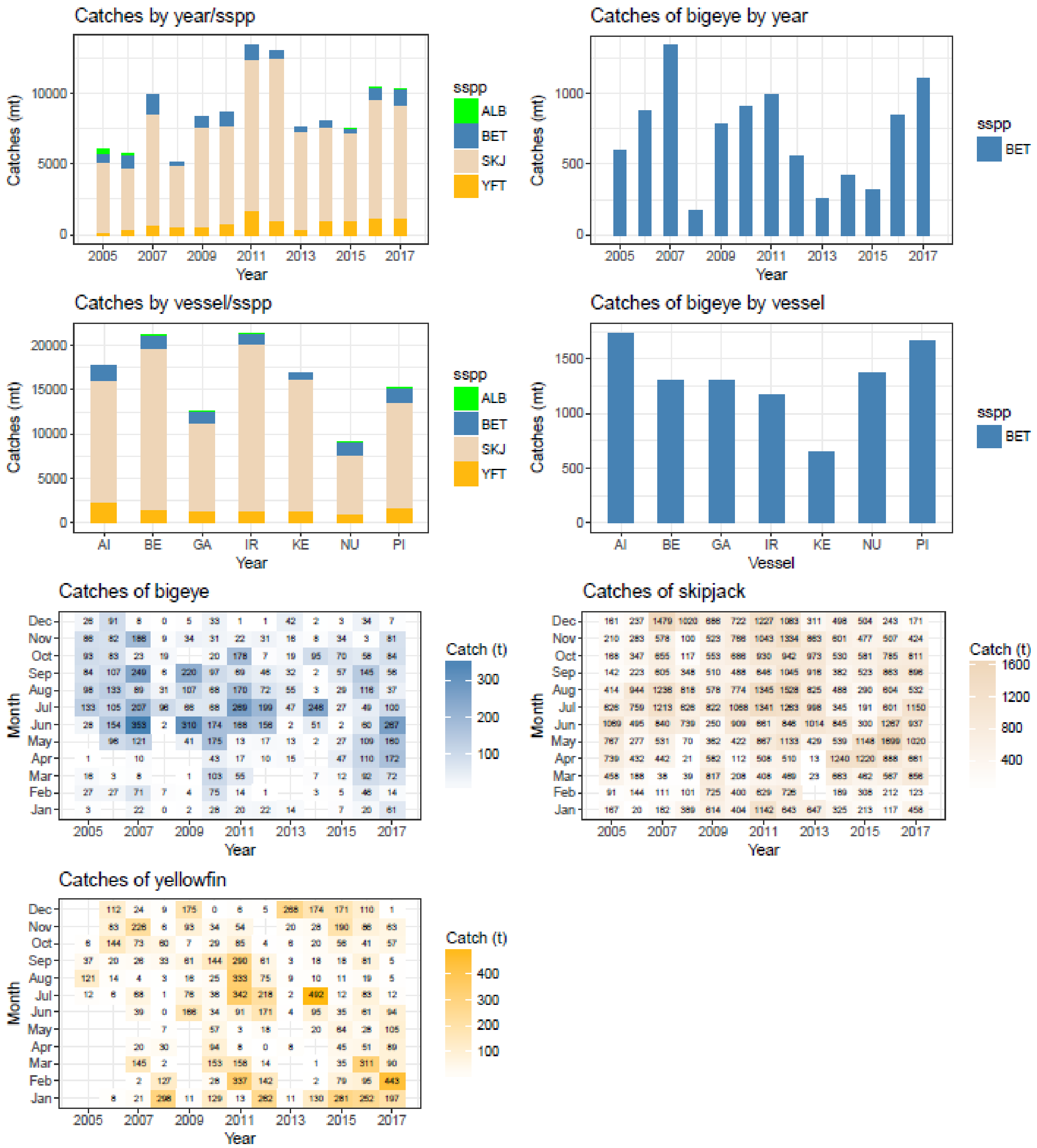
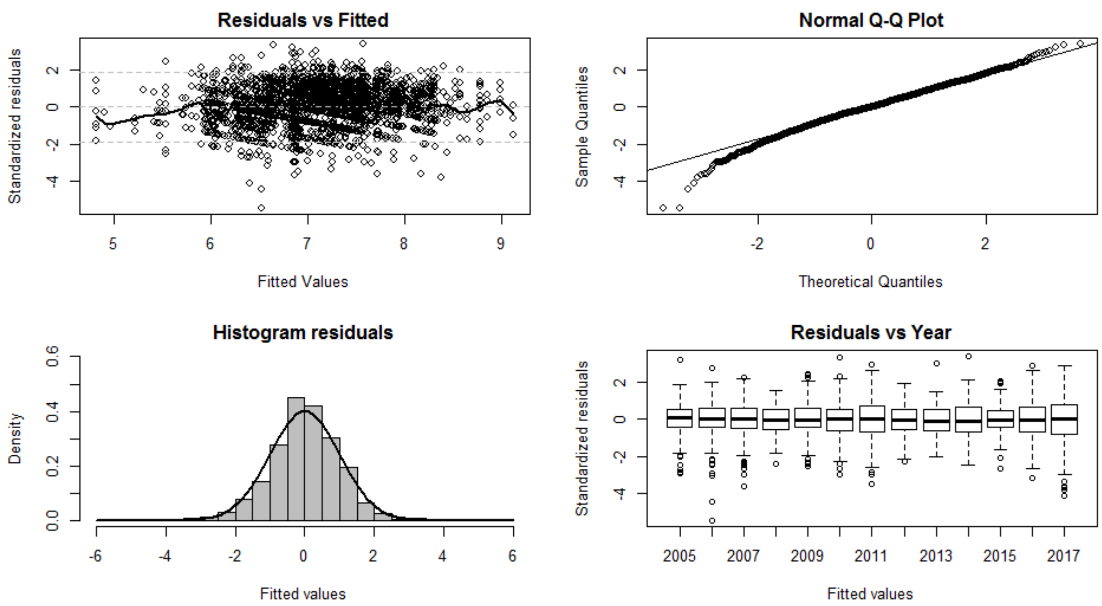


Figure 3. Number of days of activity by vessel, year and month, according to the VMS and logbook data, for the period 2002-2017.

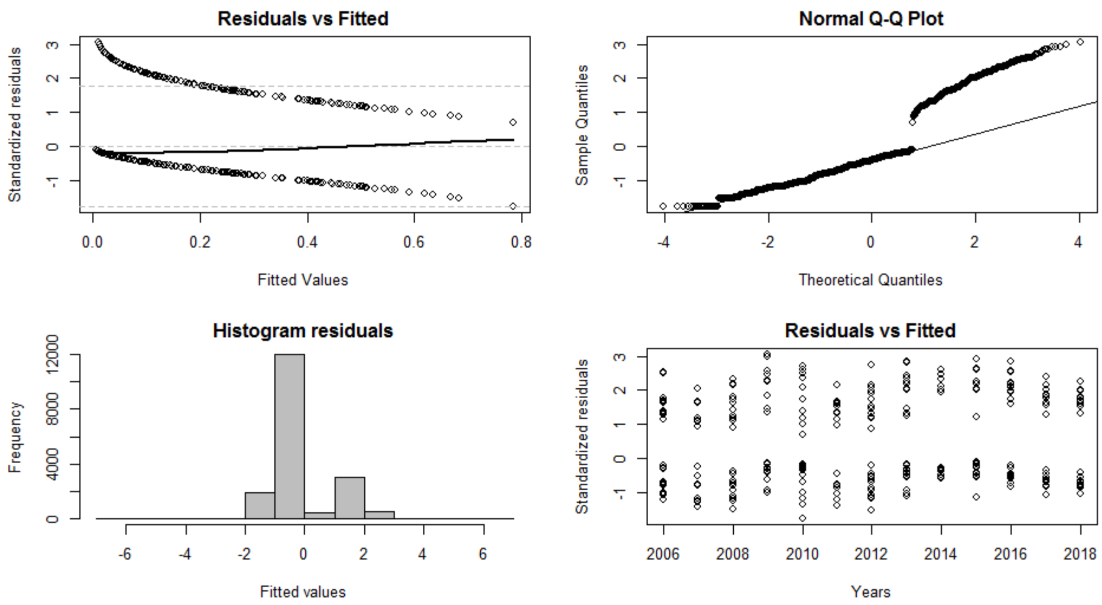


Figures 4a-g. This set of Figures characterize the catch composition from the logbook data for the period 2005-2017. From top to bottom, a) total catch by species and catches of BET by year; b) total catch by species and catches of BET by vessel; and c) catches of BET, SKJ and YFT by month and year.

a - Lognormal component



b - Binomial component



Figures 5a-b. Diagnostics of the binomial (lower panel) and lognormal (upper panel) components of the Delta lognormal model.

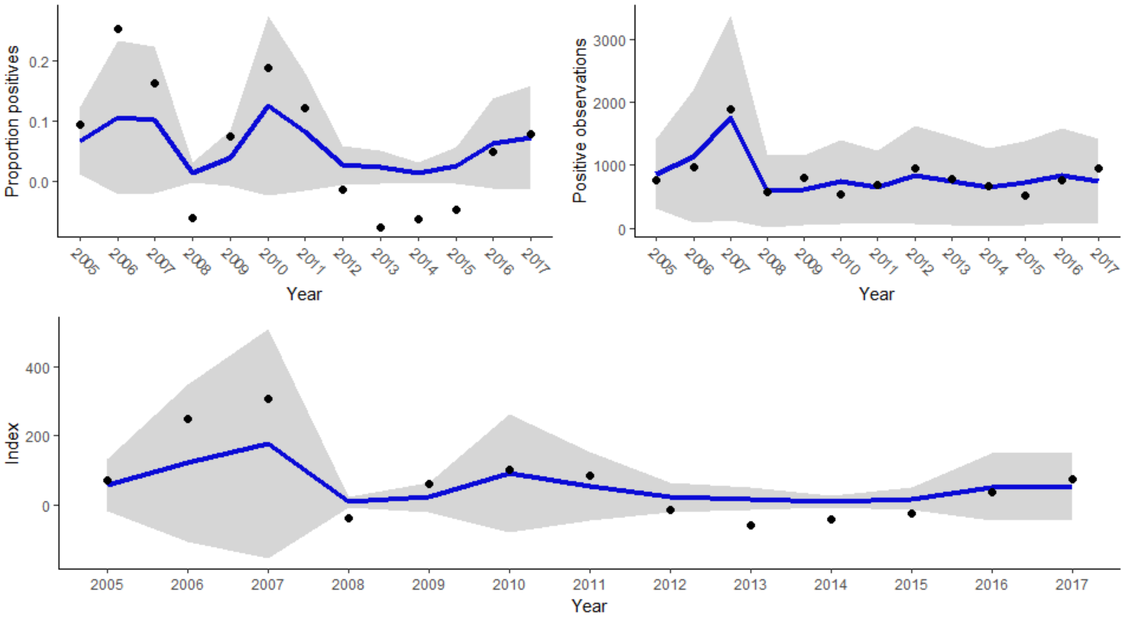


Figure 6. Nominal and standardized CPUE values for the period 2005-2017 for the lognormal and binomial components (top) and delta lognormal (bottom). Upper and lower confidence intervals are also shown.