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2017 年のミナミマグロのコア船データおよび CPUE の更新

Update of the core vessel data and CPUE for southern bluefin tuna in 2017

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要旨

本文書は、CCSBT の管理方式に用いられるミナミマグロの資源指数であるコア船 CPUE についてまとめたものである。データ準備、GLM を用いた CPUE 標準化、エリア重み付けについて記述する。データは 2016 年までに更新した。2016 年の指数は、ベース GLM モデルによる W0.8 及び W0.5 において、この 10 年間の平均より高く、高かった 2015 年よりは低下した。

Summary

This paper summarizes the core vessel CPUE which is an abundance index of southern bluefin tuna used for the Management Procedure in CCSBT. It describes data preparation, CPUE standardization using GLM and area weighting. The data were updated up to 2016. The index values in 2016, W0.8 and W0.5 by the base GLM model, are higher than the average in the last 10 years, however, lower than those in 2015 which increased largely.

Introduction

Stock management of southern bluefin tuna *Thunnus maccoyii* in CCSBT entered a new era with the agreement and implementation of Management Procedure (MP) in 2011. The adapted MP in CCSBT determines TAC by the pre-specified rule using longline CPUE and aerial survey index, so that those indices should be evaluated with high transparency. However, because shot-by-shot data for Japanese longline is critically important intellectual property for fishermen, Japanese government is not able to open it for CCSBT scientists. Therefore, we describe the data preparation and indices made in detail in the present paper and try to ensure transparency and evaluation.

Data preparation

The dataset used was made from shot-by-shot records of Japanese longline from Japan (1986-2016), from Australia (RTMP data; 1989-2005) and from New Zealand (Joint venture; 1990-2015). New Zealand joint venture with Japanese longline vessels was not carried in 2016. Data from Japan were based on logbook data, except that RTMP data were used for the most recent years if logbook data were not yet available and RTMP data of the vessel were available. Note that data of operations especially for non-SBT targeting will be added to the dataset one or two years later after logbook data become available.

Dataset was limited within CCSBT statistical areas between Area 4 and Area 9 and months between April and September. Because of the absence of New Zealand chartered Japanese vessels, data in Area 5 and Are 6 were scarce. Data in Area 5 and Area 6 were combined to Area 4 and Area 7, respectively (Itoh 2017). CPUE was defined as the number of SBT for age 4 and older caught per 1000 hooks. Proportion of age 4+ by 5x5 degree square and month was calculated from the CCSBT catch-at-age database including catch-at-age data made by Japan for 2015 and 2016.

Vessels which caught a large number of SBT (called “core vessels”) were selected with x (top rank of SBT catch in a year) = 56 and y (number of years in the top ranks) = 3. A subset of vessels with a total data records of 184,955 was extracted from entire vessels (Table 1). The number of core vessels chosen ranged from 35 to 105 in each year.

For reference, the number of area operated in terms of 5x5-degree / month, 1x1-degree / month and the number of 1x1-degree squares in 5x5-degree square are shown in Fig. 1 for all operations and operations with positive SBT (age 4+) catch.

Following corrections were made to the dataset before CPUE standardization: deleted records for operations in south of 50 degree South; and deleted records for operations with extremely high CPUE (>120) as outliers. The shot-by-shot data were aggregated into 5x5 degrees and month. Aggregated data with little effort (< 10,000 hooks) were deleted.

CPUE standardization

CPUE were standardized with GLM using SAS (version 9.4). Small constant of 0.2, 10% of nominal CPUE, was added into CPUE for age 4+ before log transformation (Nishida and Tsuji 1998).

Base series:

$$log(CPUE+0.2) = Intercept + Year + Month + Area + Lat5 + BET\_CPUE + YFT\_CPUE + (Month*Area) + (Year*Lat5) + (Year*Area) + Error,$$

Two additional CPUE series were made for monitoring purpose of the status of the stock and MP implementation.

Monitoring series 1 (Reduced base model):

$$log(CPUE+0.2) = Intercept + Year + Month + Area + Lat5 + BET\_CPUE + YFT\_CPUE + (Month*Area) + Error,$$

Monitoring series 2: Same procedure as applied in Base series, but the data used were prepared at the shot-by-shot daily level rather than the aggregated 5x5-degree/month level.

Estimated parameter values for Base case are shown in Table 2. ANOVA statistics for the three cases are shown in Table 3. Standardized CPUE (ls-mean) and QQ plots of residuals are shown in Fig.2 and Fig. 3.

AIC and BIC were calculated for the base model and the reduced base model which are nested models each other. The base model is selected in terms of AIC, but not in BIC (Table 4).

Area weighted standardized CPUE

With the estimated parameters obtained from CPUE standardization by GLM, the Constant Square (CS) and Variable Square (VS) abundance indices were computed by the following equations:

$$CS_{4+,y} = \sum_m \sum_a \sum_l (AI_{CS})_{(1969\text{-}present)}[\exp(Intercept + Year + Month + Area + Lat5 + BET\_CPUE + YFT\_CPUE + (Month*Area) + (Year*Lat5) + (Year*Area) + \sigma^2/2) - 0.2]$$

$$VS_{4+,y} = \sum_m \sum_a \sum_l (AI_{VS})_{ymal}[\exp(Intercept + Year + Month + Area + Lat5 + BET\_CPUE + YFT\_CPUE + (Month*Area) + (Year*Lat5) +$$

$(Year*Area) + \sigma^2/2) - 0.2]$

where

$CS_{4+,y}$	is the CS abundance index for age 4+ and y-th year,
$VS_{4+,y}$	is the VS abundance index for age 4+ and y-th year,
$(AI_{CS})_{(1969\text{-}present)}$	is the area index of the CS model for the period 1969-present,
$(AI_{VS})_{ymal}$	is the area index of the VS model for y-th year, m-th month, a-th SBT statistical area, and l-th latitude,
σ	is the mean square error in the GLM analyses,

Then, w0.5 and w0.8 (B-ratio and geostat proxies) were calculated using the equation below.

$$I_{y,a} = wCS_{y,a} + (1-w)VS_{y,a}$$

The area weighted CPUE value in the most recent year (2016), which was mainly from RTMP and targeting on SBT, was corrected from the average ratio of CPUEs between RTMP and Logbook data of recent three years according to the agreement in the CPUE web-meeting held in March 2010. The constant was 0.946, the average in three years (0.790 in 2013 and 1.0180 in 2014, and 1.0297 in 2015 of ratio Logbook based CPUE in W0.8 / RTMP based CPUE in W0.8 in the core vessel dataset[1]).

The area weighted CPUE series between 1986 and 2016 were calibrated to the historical time series since 1969 based on the agreed method (SAG9 Report in 2008, attachment 5) derived from GLM model using data from all vessels described in Nishida and Tsuji (1998). At the 3rd OMMP Technical meeting held in Seattle in 2010, it was agreed that the pre-1986 series used in MP implementation will be fixed at the values estimated based on data to 2008 only. Calibration would thus in future always be based upon the 1986-2008 points of this series.

Calculated area weighted standardized CPUE are shown in Table 5 and Fig. 4. The relative index values of W0.8 in 2016 with the base GLM model (1.150) is high as 141% of the previous 10 years mean (0.816). That of W0.5 in 2016 (0.858) is high as 142% of the previous 10 years mean (0.606).

The trends of the indices among GLM models (Base vs Reduced Base) were similar to each other but different since 2010. Differences in the two GLM models were interaction terms of *Year*Lat5 and Year*Area* which were included in Base but not

[1] In order to prevent luck of data for interaction terms, the threshold to be deleted for the little effort was lowered to 1000 instead of 10,000.

included in Reduced Base. Nominal CPUE by year and latitude in five degrees are shown in Fig. 5. Year trends were different by latitude, such as nominal CPUE since 2010 were much higher than in the 1990s in 40S and 45S, but similar in 35S except 2015. Nominal CPUE by year and Area are shown in Fig. 6. Year trends were different by Area, such as nominal CPUE since 2010 were much higher than in the 1990s in Area 7 and Area 9, but similar or lower in other Areas. These different trends were taken accounted in the Base model, but not in Reduced Base model, and may be resulted in the differences in the indices.

Reference

Itoh, T. 2017. Examination of influence of absence of data from New Zealand chartered Japanese longline vessels on the core vessel CPUE and proposal of its solution. CCSBT/CPUE/1706/04.

Nishida, T., and S. Tsuji. 1998. Estimation of abundance indices of southern bluefin tuna (*Thunnus maccoyii*) based on the coarse scale Japanese longline fisheries data (1969-97). CCSBT/SC/9807/13.27.

Table 1. Number of records in the dataset used.

Year	All vessels Japan	All vessels Australia	All vessels New Zealand	All vessels Total	Core vessel Total	Core vessel Vessel number
1986	27,005			27,005	4,068	35
1987	26,759			26,759	4,804	41
1988	24,418			24,418	5,353	49
1989	24,315	1,156		25,471	6,897	63
1990	19,899	504	475	20,878	6,546	73
1991	18,316	1,204	460	19,980	7,165	73
1992	17,233	1,717	499	19,449	7,102	86
1993	14,797	2,001	486	17,284	6,851	83
1994	12,610	1,394	268	14,272	6,227	92
1995	12,804	800	373	13,977	6,456	97
1996	14,854			14,854	7,057	97
1997	16,322		379	16,701	7,832	93
1998	16,310		310	16,620	8,338	106
1999	14,414		306	14,720	8,103	99
2000	11,746		265	12,011	7,282	98
2001	14,075		198	14,273	7,915	101
2002	10,721		228	10,949	6,310	91
2003	11,563		294	11,857	6,538	90
2004	13,101		349	13,450	8,523	94
2005	13,848		198	14,046	8,822	95
2006	9,124		183	9,307	6,521	86
2007	5,540		387	5,927	4,473	80
2008	6,815		167	6,982	5,279	89
2009	5,016		231	5,247	4,418	74
2010	4,102		144	4,246	3,627	66
2011	4,757		151	4,908	3,982	65
2012	4,432		163	4,595	3,731	72
2013	4,157		148	4,305	3,482	70
2014	4,727		186	4,913	3,526	67
2015	5,050		181	5,231	3,687	67
2016	5,704			5,704	4,040	65
Total	394,534	8,776	7,029	410,339	184,955	

Data are from Area 4-9 and month 4-9.

Table 2. Estimated parameter values in GLM Base model

Parameter	Estimate	Biased	StdErr	tValue	Probt
Intercept	1.43753	1	0.71112	2.02	0.043
Year 1986	−0.88660	1	0.77738	−1.14	0.254
Year 1987	−0.28523	1	0.76571	−0.37	0.710
Year 1988	−0.50739	1	0.73399	−0.69	0.489
Year 1989	−0.80745	1	0.75640	−1.07	0.286
Year 1990	−0.58316	1	0.72798	−0.80	0.423
Year 1991	−1.19566	1	0.76250	−1.57	0.117
Year 1992	−0.87745	1	0.78800	−1.11	0.266
Year 1993	−0.21892	1	0.76971	−0.28	0.776
Year 1994	−0.81303	1	0.81952	−0.99	0.321
Year 1995	−0.97141	1	0.81704	−1.19	0.235
Year 1996	−0.66194	1	0.78540	−0.84	0.399
Year 1997	−0.82039	1	0.77708	−1.06	0.291
Year 1998	−0.34810	1	0.76783	−0.45	0.650
Year 1999	−0.51703	1	0.77222	−0.67	0.503
Year 2000	−1.07457	1	0.80046	−1.34	0.180
Year 2001	−0.34984	1	0.75974	−0.46	0.645
Year 2002	−0.00064	1	0.79913	0.00	0.999
Year 2003	−0.35458	1	0.83531	−0.42	0.671
Year 2004	−0.56068	1	0.79754	−0.70	0.482
Year 2005	−0.44584	1	0.78283	−0.57	0.569
Year 2006	−0.79979	1	0.85151	−0.94	0.348
Year 2007	−1.85820	1	0.90603	−2.05	0.040
Year 2008	−0.38067	1	0.75926	−0.50	0.616
Year 2009	−0.62570	1	0.91111	−0.69	0.492
Year 2010	−0.20653	1	1.04014	−0.20	0.843
Year 2011	−0.29103	1	0.79249	−0.37	0.714
Year 2012	0.31421	1	0.83690	0.38	0.707
Year 2013	0.33018	1	0.87761	0.38	0.707
Year 2014	0.30960	1	0.87858	0.35	0.725
Year 2015	0.22613	1	0.87886	0.26	0.797
Year 2016	0	1			
Month 4	−0.39158	1	0.09156	−4.28	<.0001
Month 5	−0.17424	1	0.08583	−2.03	0.043
Month 6	−0.07286	1	0.08517	−0.86	0.392
Month 7	0.18234	1	0.08405	2.17	0.030
Month 8	0.23733	1	0.08874	2.67	0.008
Month 9	0	1			
Area 4	−0.22741	1	0.33614	−0.68	0.499
Area 7	−0.35137	1	0.38451	−0.91	0.361
Area 8	−1.01464	1	0.28220	−3.60	0.000
Area 9	0	1			
Lat5 30	−2.01591	1	0.80926	−2.49	0.013
Lat5 35	0.29735	1	0.73234	0.41	0.685
Lat5 40	0.44977	1	0.72065	0.62	0.533
Lat5 45	0	1			
BETcpue5	−0.14261	0	0.01004	−14.20	<.0001
YFTcpue5	−0.07474	0	0.00508	−14.73	<.0001
Month*Area 4 4	−1.45352	1	0.16234	−8.95	<.0001
Month*Area 4 7	0.78119	1	0.22507	3.47	0.001
Month*Area 4 8	−1.25168	1	0.19178	−6.53	<.0001
Month*Area 4 9	0	1			
Month*Area 5 4	−0.76189	1	0.15599	−4.88	<.0001
Month*Area 5 7	0.66237	1	0.21829	3.03	0.002
Month*Area 5 8	−0.88547	1	0.18385	−4.82	<.0001
Month*Area 5 9	0	1			
Month*Area 6 4	−0.59872	1	0.14815	−4.04	<.0001
Month*Area 6 7	0.54841	1	0.21989	2.49	0.013
Month*Area 6 8	−0.40261	1	0.19079	−2.11	0.035
Month*Area 6 9	0	1			
Month*Area 7 4	−0.41960	1	0.14323	−2.93	0.003
Month*Area 7 7	0.34408	1	0.23388	1.47	0.141
Month*Area 7 8	0.00530	1	0.13631	0.04	0.969
Month*Area 7 9	0	1			
Month*Area 8 4	−0.45364	1	0.14952	−3.03	0.002
Month*Area 8 7	−0.10697	1	0.35686	−0.30	0.764
Month*Area 8 8	0.08311	1	0.12525	0.66	0.507
Month*Area 8 9	0	1			
Month*Area 9 4	0	1			
Month*Area 9 7	0	1			
Month*Area 9 8	0	1			
Month*Area 9 9	0	1			
Year*Lat5 1986 30	1.24096	1	0.94502	1.31	0.189
Year*Lat5 1986 35	0.33123	1	0.80583	0.41	0.681
Year*Lat5 1986 40	−0.23930	1	0.78343	−0.31	0.760
Year*Lat5 1986 45	0	1			
Year*Lat5 1987 30	0.57334	1	0.93882	0.61	0.541
Year*Lat5 1987 35	−0.45096	1	0.79832	−0.56	0.572
Year*Lat5 1987 40	−0.49875	1	0.77017	−0.65	0.517
Year*Lat5 1987 45	0	1			
Year*Lat5 1988 30	1.42948	1	0.89077	1.60	0.109
Year*Lat5 1988 35	−0.10825	1	0.77006	−0.14	0.888
Year*Lat5 1988 40	−0.46253	1	0.74799	−0.62	0.536
Year*Lat5 1988 45	0	1			
Year*Lat5 1989 30	1.27149	1	0.93335	1.36	0.173
Year*Lat5 1989 35	−0.17286	1	0.79505	−0.22	0.828
Year*Lat5 1989 40	−0.37138	1	0.76592	−0.48	0.628
Year*Lat5 1989 45	0	1			
Year*Lat5 1990 30	0.45902	1	0.89530	0.51	0.608
Year*Lat5 1990 35	−0.70063	1	0.77502	−0.90	0.366
Year*Lat5 1990 40	−0.57068	1	0.74294	−0.77	0.443
Year*Lat5 1990 45	0	1			
Year*Lat5 1991 30	1.51351	1	0.90174	1.68	0.093
Year*Lat5 1991 35	−0.02773	1	0.79337	−0.03	0.972
Year*Lat5 1991 40	0.03139	1	0.76853	0.04	0.967
Year*Lat5 1991 45	0	1			
Year*Lat5 1992 30	1.23697	1	0.92140	1.34	0.180
Year*Lat5 1992 35	−0.11339	1	0.81752	−0.14	0.890
Year*Lat5 1992 40	−0.15697	1	0.79395	−0.20	0.843
Year*Lat5 1992 45	0	1			
Year*Lat5 1993 30	0.31517	1	0.90862	0.35	0.729
Year*Lat5 1993 35	−1.31783	1	0.80205	−1.64	0.101
Year*Lat5 1993 40	−0.27649	1	0.78026	−0.35	0.723
Year*Lat5 1993 45	0	1			
Year*Lat5 1994 30	0.41199	1	0.96417	0.43	0.669
Year*Lat5 1994 35	−0.78555	1	0.85017	−0.92	0.356
Year*Lat5 1994 40	−0.00222	1	0.82093	0.00	0.998
Year*Lat5 1994 45	0	1			
Year*Lat5 1995 30	1.38967	1	0.95533	1.45	0.146
Year*Lat5 1995 35	−0.26061	1	0.84505	−0.31	0.758
Year*Lat5 1995 40	0.25180	1	0.81970	0.31	0.759
Year*Lat5 1995 45	0	1			
Year*Lat5 1996 30	0.64996	1	0.92485	0.70	0.482
Year*Lat5 1996 35	−0.99229	1	0.81736	−1.21	0.225
Year*Lat5 1996 40	−0.31222	1	0.79331	−0.39	0.694
Year*Lat5 1996 45	0	1			
Year*Lat5 1997 30	0.30968	1	0.92534	0.33	0.738
Year*Lat5 1997 35	−0.50973	1	0.80681	−0.63	0.528
Year*Lat5 1997 40	−0.29447	1	0.78026	−0.38	0.706
Year*Lat5 1997 45	0	1			
Year*Lat5 1998 30	0.46909	1	0.90516	0.52	0.604
Year*Lat5 1998 35	−0.66547	1	0.79950	−0.83	0.405
Year*Lat5 1998 40	−0.59211	1	0.77818	−0.76	0.447
Year*Lat5 1998 45	0	1			
Year*Lat5 1999 30	0.04548	1	0.93204	0.05	0.961
Year*Lat5 1999 35	−0.68993	1	0.80373	−0.86	0.391
Year*Lat5 1999 40	−0.42216	1	0.78041	−0.54	0.589
Year*Lat5 1999 45	0	1			
Year*Lat5 2000 30	0.12702	1	0.95371	0.13	0.894
Year*Lat5 2000 35	−0.35667	1	0.83002	−0.43	0.667
Year*Lat5 2000 40	0.04341	1	0.80425	0.05	0.957
Year*Lat5 2000 45	0	1			
Year*Lat5 2001 30	0.30156	1	0.91555	0.33	0.742
Year*Lat5 2001 35	−0.77727	1	0.79677	−0.98	0.329
Year*Lat5 2001 40	−0.38312	1	0.76904	−0.50	0.618
Year*Lat5 2001 45	0	1			
Year*Lat5 2002 30	0.43986	1	1.01337	0.43	0.664
Year*Lat5 2002 35	−0.14879	1	0.87400	−0.17	0.865
Year*Lat5 2002 40	−0.36946	1	0.81262	−0.45	0.649
Year*Lat5 2002 45	0	1			
Year*Lat5 2003 30	0.22530	1	0.99673	0.23	0.821
Year*Lat5 2003 35	−0.16717	1	0.88199	−0.19	0.850
Year*Lat5 2003 40	−0.43911	1	0.84617	−0.52	0.604
Year*Lat5 2003 45	0	1			
Year*Lat5 2004 30	0.59430	1	0.94419	0.63	0.529
Year*Lat5 2004 35	−0.09533	1	0.82580	−0.12	0.908
Year*Lat5 2004 40	−0.54676	1	0.80389	−0.68	0.497
Year*Lat5 2004 45	0	1			
Year*Lat5 2005 30	0.79191	1	0.93343	0.85	0.396
Year*Lat5 2005 35	−0.35099	1	0.81288	−0.43	0.666
Year*Lat5 2005 40	−0.80441	1	0.79762	−1.01	0.313
Year*Lat5 2005 45	0	1			
Year*Lat5 2006 30	−0.07707	1	1.00696	−0.08	0.939
Year*Lat5 2006 35	−0.75501	1	0.88026	−0.86	0.391
Year*Lat5 2006 40	−0.84412	1	0.85610	−0.99	0.324
Year*Lat5 2006 45	0	1			
Year*Lat5 2007 30	1.56577	1	1.03325	1.52	0.130
Year*Lat5 2007 35	0.36268	1	0.93330	0.39	0.698
Year*Lat5 2007 40	0.08290	1	0.90628	0.09	0.927
Year*Lat5 2007 45	0	1			
Year*Lat5 2008 30	−0.74334	1	0.91979	−0.81	0.419
Year*Lat5 2008 35	−1.35334	1	0.79305	−1.71	0.088
Year*Lat5 2008 40	−0.74285	1	0.77750	−0.96	0.339
Year*Lat5 2008 45	0	1			
Year*Lat5 2009 30	−0.82934	1	1.04243	−0.80	0.426
Year*Lat5 2009 35	−0.58213	1	0.93970	−0.62	0.536
Year*Lat5 2009 40	−0.21359	1	0.91255	−0.23	0.815
Year*Lat5 2009 45	0	1			
Year*Lat5 2010 30	−0.69631	1	1.16170	−0.60	0.549
Year*Lat5 2010 35	−0.98658	1	1.06358	−0.93	0.354
Year*Lat5 2010 40	−0.33395	1	1.03980	−0.32	0.748
Year*Lat5 2010 45	0	1			
Year*Lat5 2011 30	0.07016	1	0.94978	0.07	0.941
Year*Lat5 2011 35	−0.51493	1	0.82835	−0.62	0.534
Year*Lat5 2011 40	−0.20190	1	0.81243	−0.25	0.804
Year*Lat5 2011 45	0	1			
Year*Lat5 2012 30	0.70873	1	0.97465	0.73	0.467
Year*Lat5 2012 35	−0.67781	1	0.86925	−0.78	0.436
Year*Lat5 2012 40	−0.68391	1	0.84645	−0.81	0.419
Year*Lat5 2012 45	0	1			
Year*Lat5 2013 30	0.03822	1	1.03995	0.04	0.971
Year*Lat5 2013 35	−0.89998	1	0.91144	−0.99	0.324
Year*Lat5 2013 40	−0.66952	1	0.88952	−0.75	0.452
Year*Lat5 2013 45	0	1			
Year*Lat5 2014 30	−0.25725	1	1.02627	−0.25	0.802
Year*Lat5 2014 35	−0.85388	1	0.91575	−0.93	0.351
Year*Lat5 2014 40	−0.37875	1	0.89087	−0.43	0.671
Year*Lat5 2014 45	0	1			
Year*Lat5 2015 30	−0.66285	1	1.03612	−0.64	0.522
Year*Lat5 2015 35	−0.70502	1	0.91158	−0.77	0.439
Year*Lat5 2015 40	0.06778	1	0.89092	0.08	0.939
Year*Lat5 2015 45	0	1			
Year*Lat5 2016 30	0	1			
Year*Lat5 2016 35	0	1			
Year*Lat5 2016 40	0	1			
Year*Lat5 2016 45	0	1			
Year*Area 1986 4	0.30165	1	0.45727	0.66	0.510
Year*Area 1986 7	0.01371	1	0.41466	0.03	0.974
Year*Area 1986 8	0.36684	1	0.32757	1.12	0.263
Year*Area 1986 9	0	1			
Year*Area 1987 4	0.23052	1	0.45496	0.51	0.612
Year*Area 1987 7	−0.49511	1	0.39240	−1.26	0.207
Year*Area 1987 8	0.31062	1	0.32527	0.95	0.340
Year*Area 1987 9	0	1			
Year*Area 1988 4	−0.69022	1	0.41376	−1.67	0.095
Year*Area 1988 7	−0.57867	1	0.36866	−1.57	0.117
Year*Area 1988 8	0.16737	1	0.32965	0.51	0.612
Year*Area 1988 9	0	1			
Year*Area 1989 4	0.34048	1	0.42265	0.81	0.421
Year*Area 1989 7	−0.23642	1	0.37727	−0.63	0.531
Year*Area 1989 8	0.46537	1	0.31964	1.46	0.146
Year*Area 1989 9	0	1			
Year*Area 1990 4	0.76246	1	0.42186	1.81	0.071
Year*Area 1990 7	−0.10782	1	0.36446	−0.30	0.767
Year*Area 1990 8	0.92122	1	0.34566	2.67	0.008
Year*Area 1990 9	0	1			
Year*Area 1991 4	0.67495	1	0.38230	1.77	0.078
Year*Area 1991 7	−0.35297	1	0.37476	−0.94	0.346
Year*Area 1991 8	0.69058	1	0.33506	2.06	0.039
Year*Area 1991 9	0	1			

Table 2 (cont.)

Parameter	Estimate	Biased	StdErr	tValue	Probt
Year*Area 1992 4	0.43349	1	0.38716	1.12	0.263
Year*Area 1992 7	−0.03581	1	0.37606	−0.10	0.924
Year*Area 1992 8	0.60548	1	0.32706	1.85	0.064
Year*Area 1992 9	0	1			
Year*Area 1993 4	1.25481	1	0.38647	3.25	0.001
Year*Area 1993 7	−0.58114	1	0.38073	−1.53	0.127
Year*Area 1993 8	1.12714	1	0.33633	3.35	0.001
Year*Area 1993 9	0	1			
Year*Area 1994 4	1.15969	1	0.42568	2.72	0.007
Year*Area 1994 7	0.32306	1	0.44096	0.73	0.464
Year*Area 1994 8	1.52141	1	0.35176	4.33	<.0001
Year*Area 1994 9	0	1			
Year*Area 1995 4	0.65611	1	0.41017	1.60	0.110
Year*Area 1995 7	0.34784	1	0.38380	0.91	0.365
Year*Area 1995 8	1.19287	1	0.33404	3.57	0.000
Year*Area 1995 9	0	1			
Year*Area 1996 4	1.04234	1	0.39592	2.63	0.009
Year*Area 1996 7	0.04779	1	0.38759	0.12	0.902
Year*Area 1996 8	1.45776	1	0.39514	3.69	0.000
Year*Area 1996 9	0	1			
Year*Area 1997 4	1.23150	1	0.39644	3.11	0.002
Year*Area 1997 7	0.11435	1	0.39007	0.29	0.769
Year*Area 1997 8	0.88749	1	0.37643	2.36	0.019
Year*Area 1997 9	0	1			
Year*Area 1998 4	0.28926	1	0.37572	0.77	0.441
Year*Area 1998 7	−0.33873	1	0.39165	−0.86	0.387
Year*Area 1998 8	0.81989	1	0.33510	2.45	0.015
Year*Area 1998 9	0	1			
Year*Area 1999 4	0.72311	1	0.39215	1.84	0.065
Year*Area 1999 7	−0.12029	1	0.38513	−0.31	0.755
Year*Area 1999 8	0.93285	1	0.32799	2.84	0.005
Year*Area 1999 9	0	1			
Year*Area 2000 4	1.10455	1	0.39922	2.77	0.006
Year*Area 2000 7	−0.10598	1	0.37983	−0.28	0.780
Year*Area 2000 8	1.36014	1	0.37867	3.59	0.000
Year*Area 2000 9	0	1			
Year*Area 2001 4	0.54196	1	0.40207	1.35	0.178
Year*Area 2001 7	−0.32699	1	0.37395	−0.87	0.382
Year*Area 2001 8	0.76120	1	0.36420	2.09	0.037
Year*Area 2001 9	0	1			
Year*Area 2002 4	−0.14270	1	0.49182	−0.29	0.772
Year*Area 2002 7	−0.50183	1	0.40622	−1.24	0.217
Year*Area 2002 8	−0.03643	1	0.37973	−0.10	0.924
Year*Area 2002 9	0	1			
Year*Area 2003 4	0.57290	1	0.45871	1.25	0.212
Year*Area 2003 7	−0.74483	1	0.41787	−1.78	0.075
Year*Area 2003 8	0.50141	1	0.43408	1.16	0.248
Year*Area 2003 9	0	1			
Year*Area 2004 4	0.55234	1	0.40935	1.35	0.177
Year*Area 2004 7	−0.42243	1	0.40731	−1.04	0.300
Year*Area 2004 8	1.23422	1	0.33714	3.66	0.000
Year*Area 2004 9	0	1			
Year*Area 2005 4	0.02466	1	0.40148	0.06	0.951
Year*Area 2005 7	−0.63495	1	0.43230	−1.47	0.142
Year*Area 2005 8	1.20025	1	0.35320	3.40	0.001
Year*Area 2005 9	0	1			
Year*Area 2006 4	0.98301	1	0.40607	2.42	0.016
Year*Area 2006 7	−0.01739	1	0.40242	−0.04	0.966
Year*Area 2006 8	1.40877	1	0.35197	4.00	<.0001
Year*Area 2006 9	0	1			
Year*Area 2007 4	0.62617	1	0.40141	1.56	0.119
Year*Area 2007 7	0.14632	1	0.41576	0.35	0.725
Year*Area 2007 8	1.02380	1	0.34301	2.98	0.003
Year*Area 2007 9	0	1			
Year*Area 2008 4	1.83715	1	0.42232	4.35	<.0001
Year*Area 2008 7	0.41831	1	0.41645	1.00	0.315
Year*Area 2008 8	1.15806	1	0.33338	3.47	0.001
Year*Area 2008 9	0	1			
Year*Area 2009 4	1.84261	1	0.41117	4.48	<.0001
Year*Area 2009 7	0.48925	1	0.42728	1.15	0.252
Year*Area 2009 8	0.68078	1	0.35568	1.91	0.056
Year*Area 2009 9	0	1			
Year*Area 2010 4	1.00858	1	0.41893	2.41	0.016
Year*Area 2010 7	0.57254	1	0.43163	1.33	0.185
Year*Area 2010 8	1.26612	1	0.35283	3.59	0.000
Year*Area 2010 9	0	1			
Year*Area 2011 4	0.48631	1	0.43906	1.11	0.268
Year*Area 2011 7	0.38364	1	0.42276	0.91	0.364
Year*Area 2011 8	0.68181	1	0.34769	1.96	0.050
Year*Area 2011 9	0	1			
Year*Area 2012 4	−0.97255	1	0.41122	−2.37	0.018
Year*Area 2012 7	0.37448	1	0.42789	0.88	0.382
Year*Area 2012 8	0.22522	1	0.35352	0.64	0.524
Year*Area 2012 9	0	1			
Year*Area 2013 4	−0.16598	1	0.47493	−0.35	0.727
Year*Area 2013 7	0.05665	1	0.43137	0.13	0.896
Year*Area 2013 8	0.58220	1	0.34951	1.67	0.096
Year*Area 2013 9	0	1			
Year*Area 2014 4	−0.12263	1	0.42965	−0.29	0.775
Year*Area 2014 7	0.06180	1	0.43956	0.14	0.888
Year*Area 2014 8	0.48082	1	0.36588	1.31	0.189
Year*Area 2014 9	0	1			
Year*Area 2015 4	0.69514	1	0.45325	1.53	0.125
Year*Area 2015 7	−0.26161	1	0.44228	−0.59	0.554
Year*Area 2015 8	0.47039	1	0.35866	1.31	0.190
Year*Area 2015 9	0	1			
Year*Area 2016 4	0	1			
Year*Area 2016 7	0	1			
Year*Area 2016 8	0	1			
Year*Area 2016 9	0	1			

Table 3. ANOVA statistics

Base

HypothesisType	Source	DF	SS	MS	FValue	ProbF
2	Year	30	193.108	6.437	12.92	<.0001
2	Month	5	203.855	40.771	81.82	<.0001
2	Area	3	66.580	22.193	44.54	<.0001
2	Lat5	3	235.324	78.441	157.41	<.0001
2	BETcpue5	1	100.473	100.473	201.62	<.0001
2	YFTcpue5	1	108.057	108.057	216.84	<.0001
2	Month*Area	15	109.743	7.316	14.68	<.0001
2	Year*Lat5	90	128.982	1.433	2.88	<.0001
2	Year*Area	90	149.388	1.660	3.33	<.0001

HypothesisType	Source	DF	SS	MS	FValue	ProbF
3	Year	30	51.934	1.731	3.47	<.0001
3	Month	5	154.809	30.962	62.13	<.0001
3	Area	3	66.517	22.172	44.49	<.0001
3	Lat5	3	260.366	86.789	174.16	<.0001
3	BETcpue5	1	100.473	100.473	201.62	<.0001
3	YFTcpue5	1	108.057	108.057	216.84	<.0001
3	Month*Area	15	109.743	7.316	14.68	<.0001
3	Year*Lat5	90	128.982	1.433	2.88	<.0001
3	Year*Area	90	149.388	1.660	3.33	<.0001

RedB

HypothesisType	Source	DF	SS	MS	FValue	ProbF
2	Year	30	193.108	6.437	11.12	<.0001
2	Month	5	237.247	47.449	81.97	<.0001
2	Area	3	84.650	28.217	48.75	<.0001
2	Lat5	3	282.699	94.233	162.79	<.0001
2	BETcpue5	1	189.921	189.921	328.09	<.0001
2	YFTcpue5	1	112.469	112.469	194.29	<.0001
2	Month*Area	15	126.040	8.403	14.52	<.0001

HypothesisType	Source	DF	SS	MS	FValue	ProbF
3	Year	30	193.108	6.437	11.12	<.0001
3	Month	5	174.214	34.843	60.19	<.0001
3	Area	3	101.897	33.966	58.68	<.0001
3	Lat5	3	282.699	94.233	162.79	<.0001
3	BETcpue5	1	189.921	189.921	328.09	<.0001
3	YFTcpue5	1	112.469	112.469	194.29	<.0001
3	Month*Area	15	126.040	8.403	14.52	<.0001

BaseSxS

HypothesisType	Source	DF	SS	MS	FValue	ProbF
2	Year	30	7658.947	255.298	334.23	<.0001
2	Month	5	4428.434	885.687	1159.51	<.0001
2	Area	3	456.932	152.311	199.4	<.0001
2	Lat5	3	7858.329	2619.443	3429.27	<.0001
2	BETcpue	1	4272.501	4272.501	5593.39	<.0001
2	YFTcpue	1	4313.324	4313.324	5646.84	<.0001
2	Month*Area	15	6133.269	408.885	535.3	<.0001
2	Year*Lat5	90	9646.838	107.187	140.33	<.0001
2	Year*Area	90	9108.653	101.207	132.5	<.0001

HypothesisType	Source	DF	SS	MS	FValue	ProbF
3	Year	30	1516.069	50.536	66.16	<.0001
3	Month	5	4330.759	866.152	1133.93	<.0001
3	Area	3	1975.691	658.564	862.17	<.0001
3	Lat5	3	8266.157	2755.386	3607.24	<.0001
3	BETcpue	1	4272.501	4272.501	5593.39	<.0001
3	YFTcpue	1	4313.324	4313.324	5646.84	<.0001
3	Month*Area	15	6133.269	408.885	535.3	<.0001
3	Year*Lat5	90	9646.838	107.187	140.33	<.0001
3	Year*Area	90	9108.653	101.207	132.5	<.0001

Table 4. AIC and BIC of Base case model and reduced base case

Model	AIC	BIC
Base	7,311	8,770
Reduced Base	7,635	7,996

Table 5. Area weighted standardized CPUE

Year	Base w08	Base w05	Reduced Base w08	Reduced Base w05	Base with SxS w08	Base with SxS w05
1969	2.2841	2.4934	2.2841	2.4934	2.2841	2.4934
1970	2.2268	2.4169	2.2268	2.4169	2.2268	2.4169
1971	2.0654	2.2054	2.0654	2.2054	2.0654	2.2054
1972	2.1669	2.2273	2.1669	2.2273	2.1669	2.2273
1973	1.8263	1.9271	1.8263	1.9271	1.8263	1.9271
1974	1.8989	1.9710	1.8989	1.9710	1.8989	1.9710
1975	1.4556	1.4974	1.4556	1.4974	1.4556	1.4974
1976	1.8715	1.9279	1.8715	1.9279	1.8715	1.9279
1977	1.6556	1.6850	1.6556	1.6850	1.6556	1.6850
1978	1.4300	1.3820	1.4300	1.3820	1.4300	1.3820
1979	1.1472	1.2558	1.1472	1.2558	1.1472	1.2558
1980	1.3862	1.3852	1.3862	1.3852	1.3862	1.3852
1981	1.3103	1.2917	1.3103	1.2917	1.3103	1.2917
1982	1.0285	1.0220	1.0285	1.0220	1.0285	1.0220
1983	1.0103	1.0228	1.0103	1.0228	1.0103	1.0228
1984	1.0261	1.0603	1.0261	1.0603	1.0261	1.0603
1985	0.8578	0.8861	0.8578	0.8861	0.8578	0.8861
1986	0.6343	0.6673	0.6472	0.6838	0.6479	0.6793
1987	0.6435	0.6682	0.6657	0.6851	0.6469	0.6695
1988	0.5425	0.5573	0.5236	0.5273	0.5785	0.5877
1989	0.5072	0.5341	0.5107	0.5337	0.5389	0.5588
1990	0.5342	0.5287	0.5868	0.5715	0.4822	0.4813
1991	0.4414	0.4511	0.5058	0.5047	0.4299	0.4431
1992	0.5458	0.5378	0.6082	0.5862	0.5102	0.5061
1993	0.7269	0.6645	0.6978	0.6343	0.7052	0.6638
1994	0.6995	0.5861	0.5844	0.4925	0.7078	0.5988
1995	0.7337	0.6579	0.7366	0.6575	0.7995	0.6985
1996	0.5976	0.5371	0.5590	0.5169	0.6274	0.5678
1997	0.5181	0.4697	0.5481	0.4963	0.4950	0.4541
1998	0.5595	0.5428	0.5784	0.5539	0.5301	0.5098
1999	0.5675	0.5441	0.5799	0.5545	0.5413	0.5193
2000	0.5394	0.4786	0.5224	0.4635	0.5261	0.4750
2001	0.6032	0.5609	0.6111	0.5619	0.5880	0.5458
2002	0.9195	0.7580	0.8222	0.6805	0.8608	0.7098
2003	0.6672	0.5555	0.6868	0.5667	0.6262	0.5322
2004	0.6315	0.5714	0.6670	0.5944	0.6352	0.5648
2005	0.5114	0.4707	0.5288	0.4785	0.6497	0.5748
2006	0.3772	0.3295	0.3554	0.3224	0.3746	0.3293

Table 5. (cont.)

Year	Base w08	Base w05	Reduced Base w08	Reduced Base w05	Base with SxS w08	Base with SxS w05
2007	0.2714	0.2304	0.3216	0.2645	0.3042	0.2594
2008	0.5798	0.4411	0.5047	0.4122	0.5467	0.4137
2009	0.7153	0.5486	0.6178	0.4869	0.6371	0.4837
2010	0.9585	0.6785	0.6334	0.4694	1.0278	0.7132
2011	0.8603	0.6341	0.6969	0.5215	0.8332	0.5963
2012	1.0491	0.7660	0.7216	0.5322	0.9642	0.7045
2013	0.9026	0.6438	0.7392	0.5314	1.0689	0.7523
2014	1.1112	0.8066	0.7955	0.5797	1.0144	0.7221
2015	1.3304	0.9812	1.0881	0.7893	1.3983	1.0075
2016	1.1497	0.8579	1.0169	0.7467	0.8945	0.6667

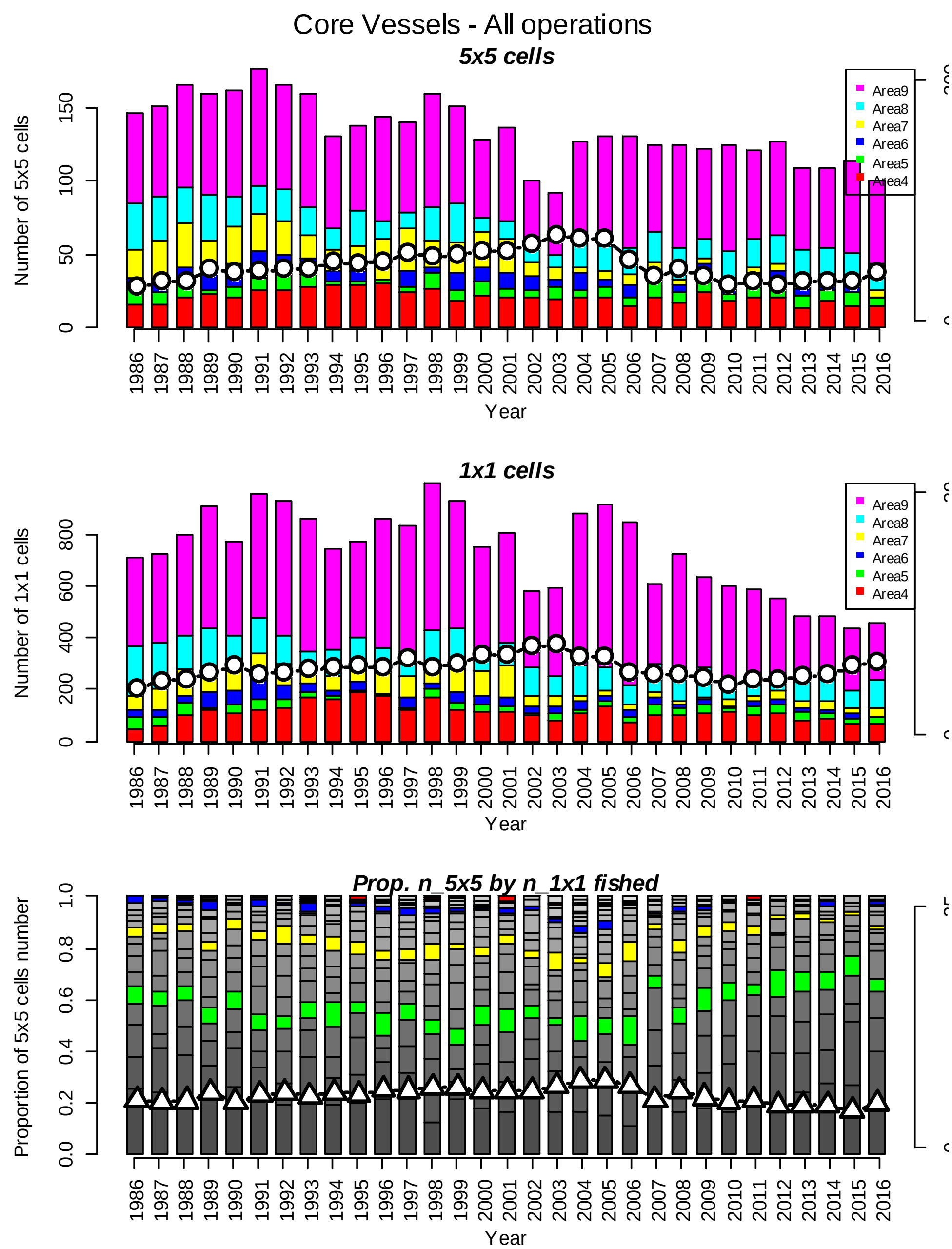


Figure 1a. Number of cells in the core vessel for all operations.

(Top panel) Bar represents the number of 5x5 degrees square and month (cell) where fishing operated by CCSBT statistical area and refer to left side y-axis. Line with circle plot represents the mean annual number of operations per cell and refer to right side y-axis. (Middle panel) Bar represents the number of 1x1 degree square and month (cell) where fishing operated by CCSBT statistical area and refer to left side y-axis. Line with circle plot represents the mean annual number of operations per cell and refer to right side y-axis. (Bottom panel) Composition of frequency for the number of 1x1 degree square and month cells operated in a 5x5 degree squares and month cell. Refer to left side y-axis. The grey band is one of 25 cells and that at top is 25 of 25 cells, and every five is colored. Line with triangle represents the mean number of 1x1 month cells operated in a 5x5 month cell and refer to right side y-axis.

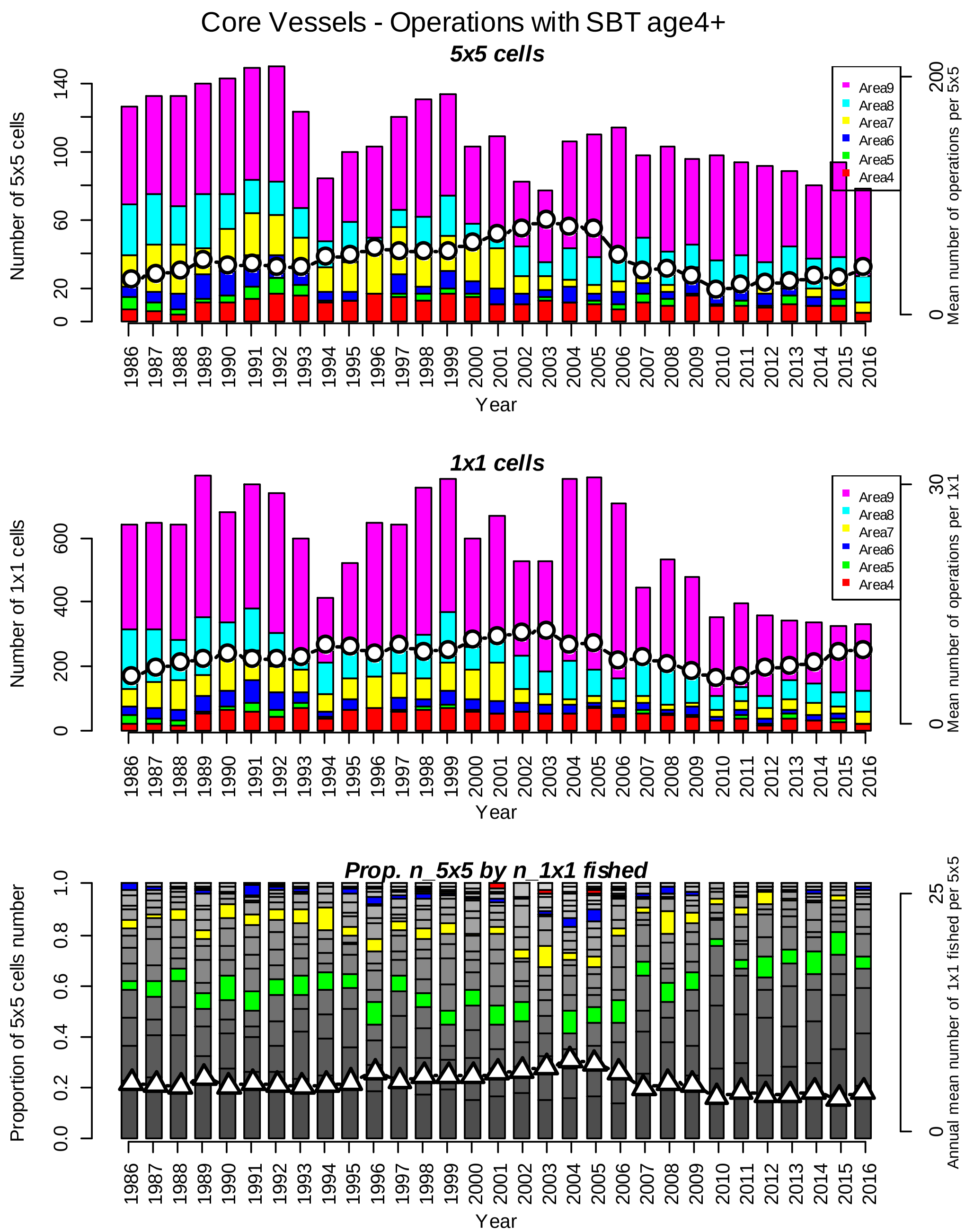


Figure 1b. Number of cells in the core vessel for SBT 4+ catch positive. See explanation in Fig. 1a.

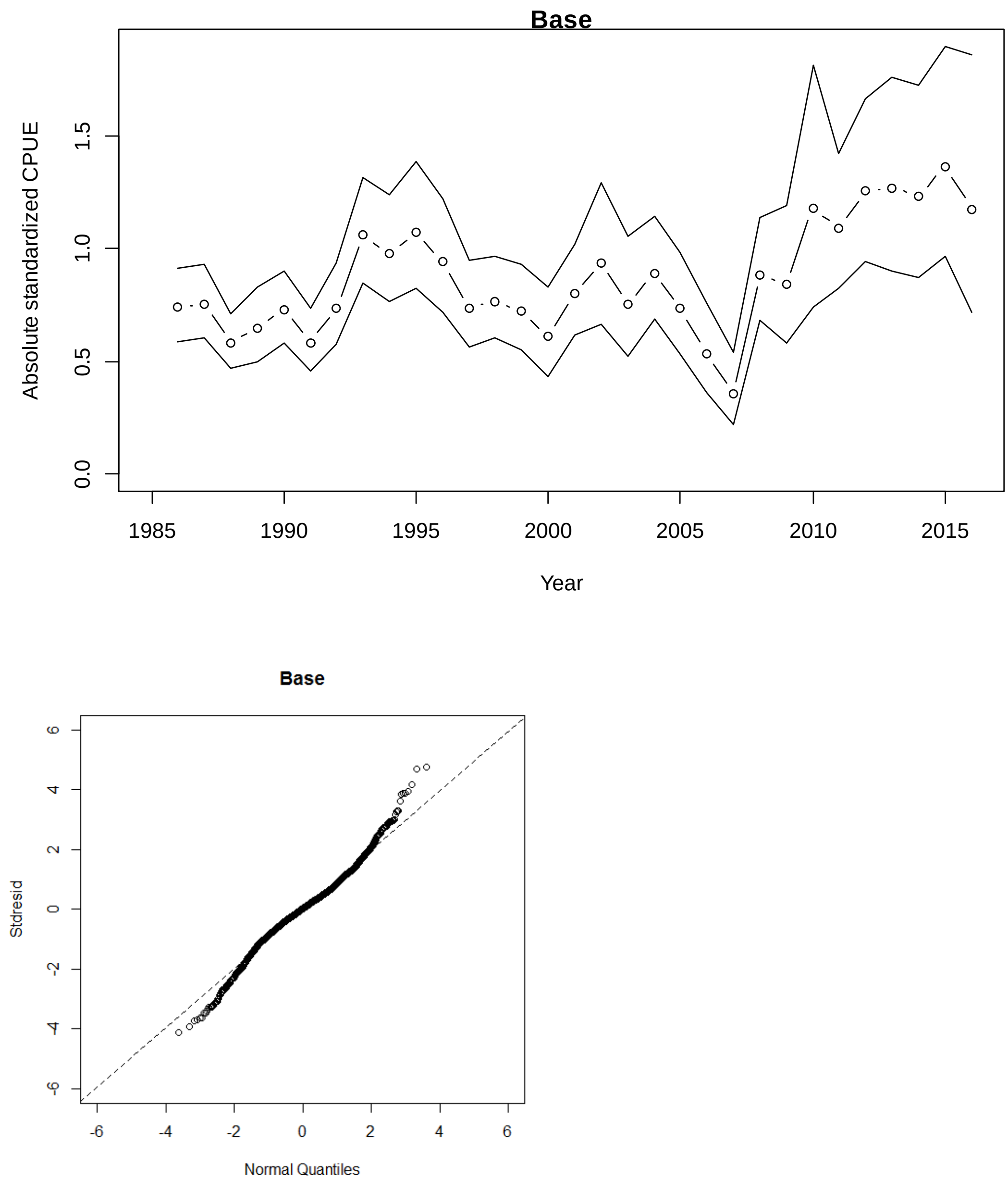


Fig 2. Standardized CPUE (ls-mean with 95% confidence interval) of the core vessel data (upper panel) and its QQ plot of residual (lower panel) for Base case.

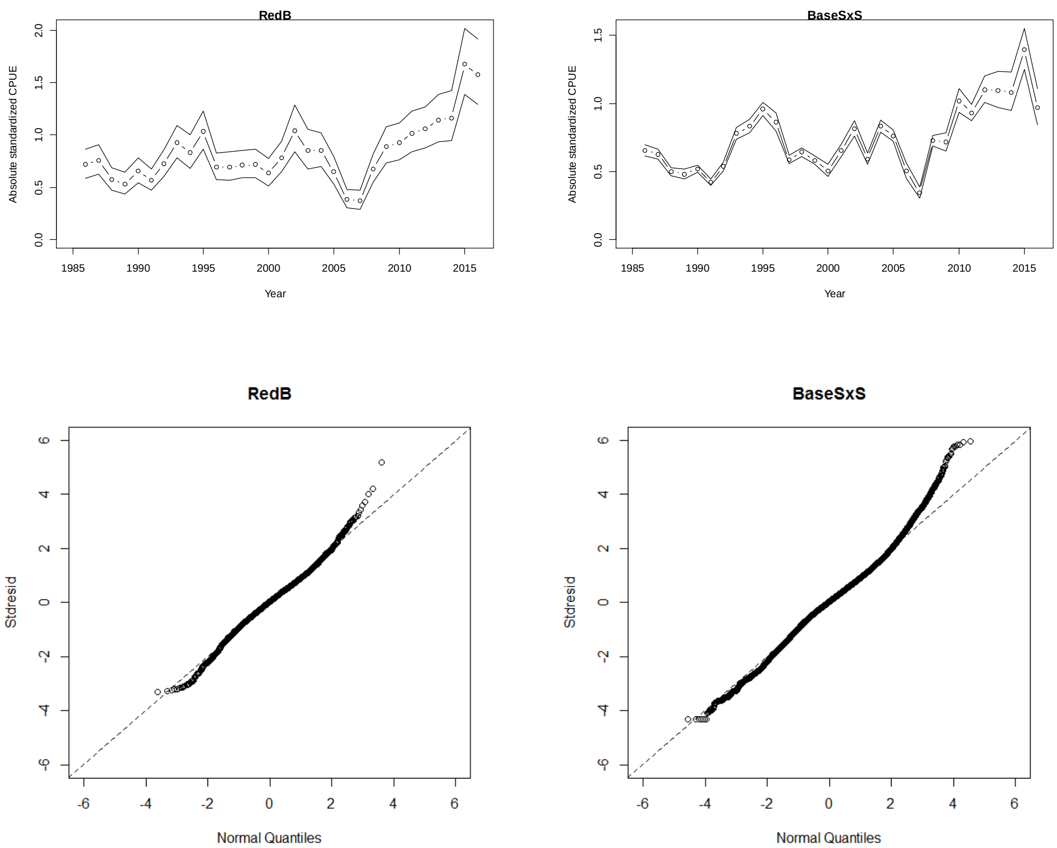
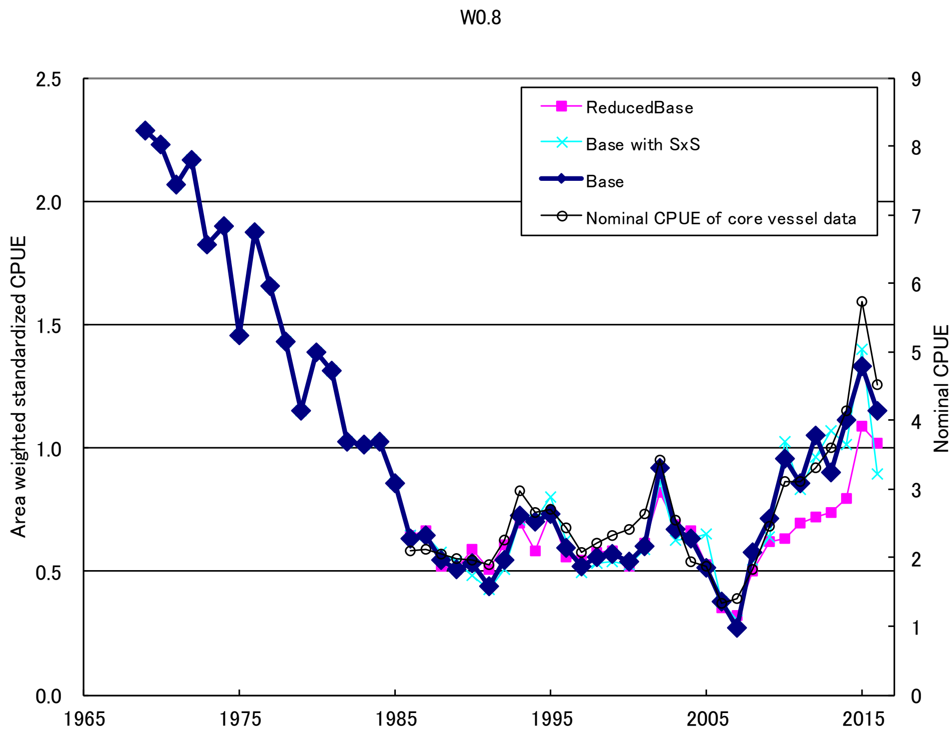


Fig 3. Standardized CPUE (ls-mean with 95% confidence interval) of the core vessel data (upper panel) and its QQ plot of residual (lower panel) for monitoring series. Left panels for reduced base case and right panels for shot-by-shot data with base case GLM model.



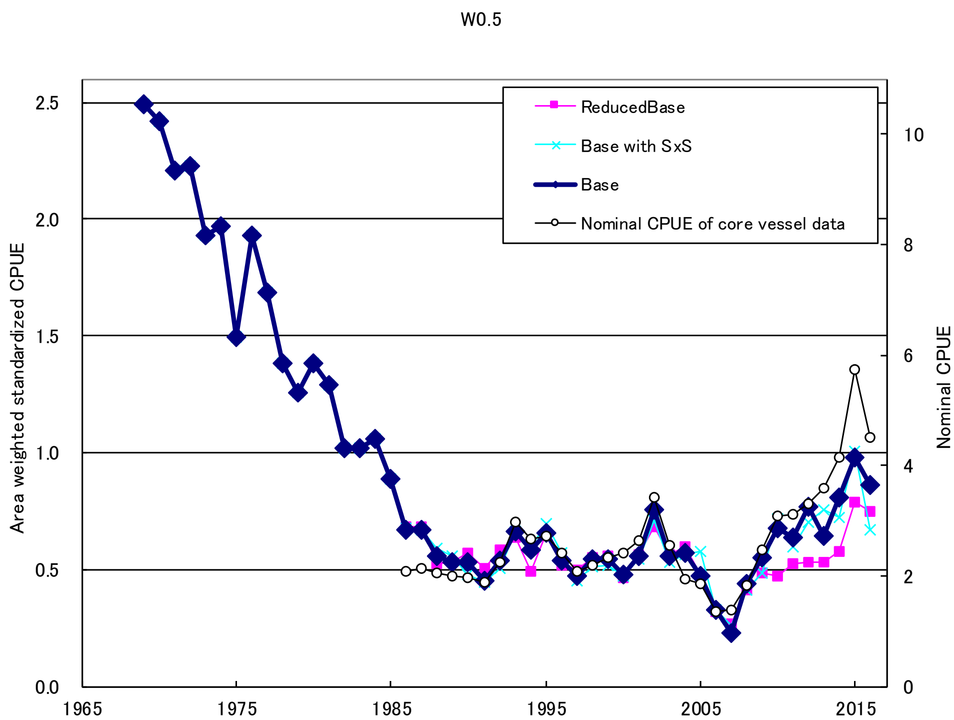


Fig 4. Area weighed standardized CPUEs. Nominal CPUE of the core vessels is also shown.

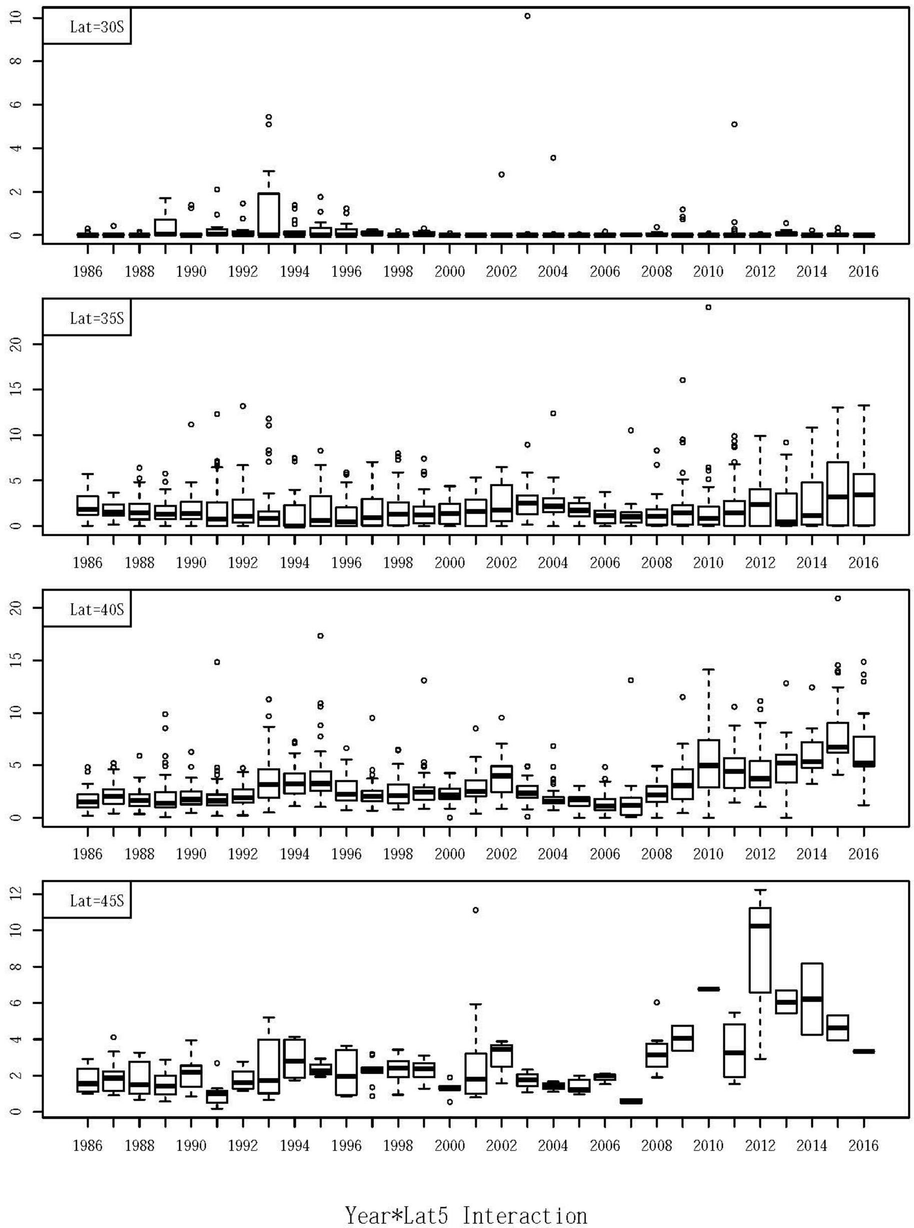


Fig 5. Nominal CPUE by year and latitude to evaluate whether year*latitude interaction should be included in the GLM model

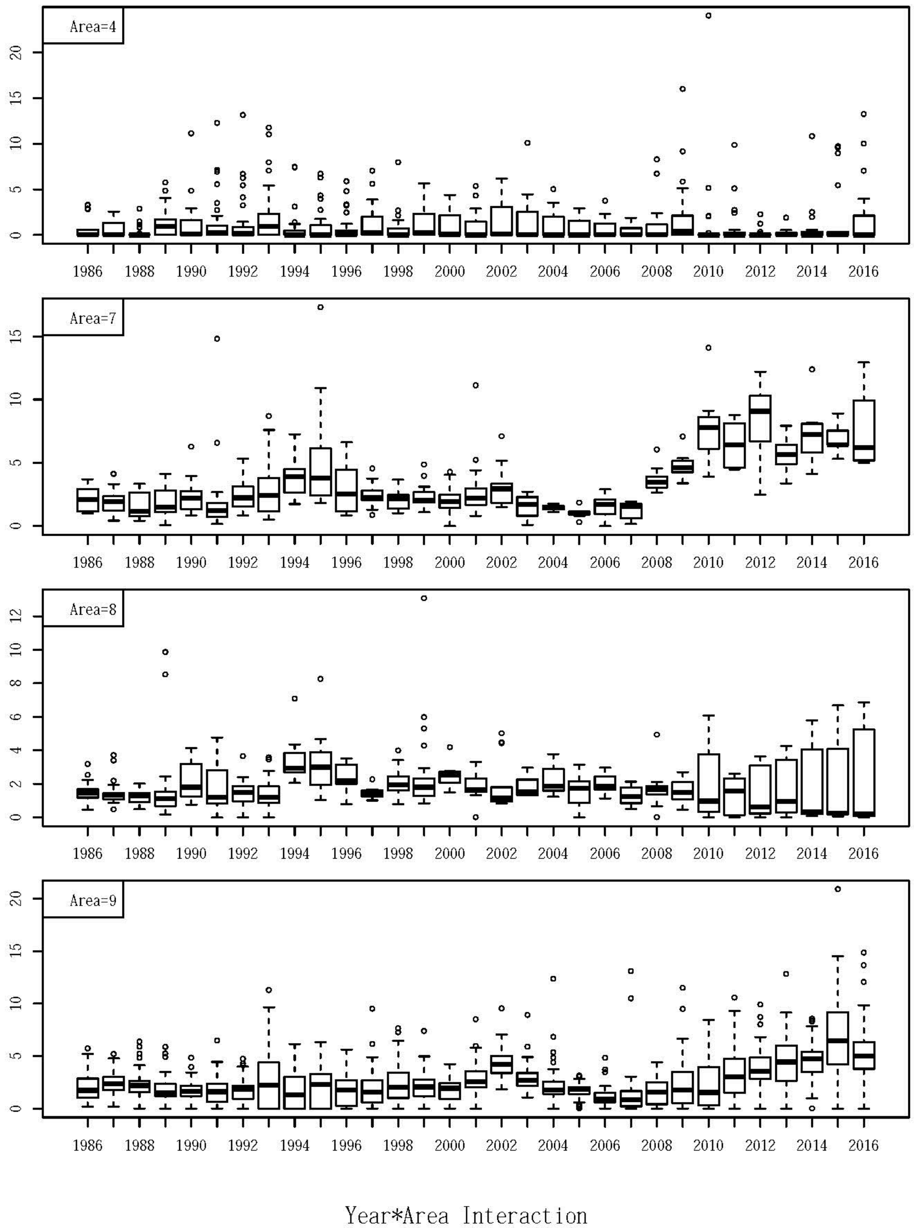


Fig 6. Nominal CPUE by year and Area to evaluate whether year*Area interaction should be included in the GLM model