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2020年のミナミマグロのコア船データおよびCPUEの更新作業

Update of the core vessel data and CPUE for southern bluefin tuna in 2020

伊藤智幸[1]・高橋紀夫[2]

Tomoyuki ITOH[1] and Norio TAKAHASHI[2]

1: 国立研究開発法人水産研究・教育機構　国際水産資源研究所

2: 国立研究開発法人水産研究・教育機構　中央水産研究所

1: National Research Institute of Far Seas Fisheries,
Japan Fisheries Research and Education Agency

2: National Research Institute of Fisheries Science,
Japan Fisheries Research and Education Agency

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2019年にまで更新した。2019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年間の平均より高い水準にある。

Summary

This paper summarizes the core vessel CPUE which is an abundance index of southern bluefin tuna used in the Management Procedure of CCSBT. It explains data preparation, CPUE standardization using GLM, and area weighting. The data were updated up to 2019. The index values in 2019, in W0.8 and W0.5 by the base GLM model, are higher than the average over the past 10 years.

Introduction

The stock management of southern bluefin tuna *Thunnus maccoyii* in CCSBT entered a new era with the agreement and implementation of the 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. The MP was reconstructed in 2019 and changed to include data of longline CPUE, gene tagging, POP and HSP. In terms of longline CPUE, however, because the shot-by-shot data of Japanese longline is critically important intellectual property for fishermen, Japanese government is not able to open it to CCSBT scientists. Therefore, we explain data preparation and indices in detail in this paper, and try to ensure transparency and evaluation. Consideration on the extremely high CPUE in 2018 was given in another document (CCSBT-OMMP/2006/12).

Data preparation

The dataset used was created from shot-by-shot records of Japanese longline from Japan (1986-2019), Australia (RTMP data; 1989-2005), and New Zealand (Joint venture; 1990-2015). New Zealand joint venture with Japanese longline vessels was not implemented since 2016. The data from Japan were based on the 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 when logbook data become available.

The dataset was limited to the CCSBT statistical areas between Area 4 and Area 9 and months between April and September. Because there was no Japanese vessel chartered in New Zealand since 2016, data in Area 5 and Are 6 were scarce. It was agreed in the CPUE group that the data in Area 5 and Area 6 should be combined into Area 4 and Area 7, respectively.

CPUE was defined as the number of SBT for age 4 and older (age 4+) caught per 1000 hooks. Proportion of age 4+ by 5x5 degree square in longitude and latitude and month was calculated from the CCSBT catch-at-age database which added catch-at-age data made by Japan this year for 2018 and 2019.

Vessels which caught a large number of SBT (called “core vessels”) were selected with a rule of 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 195,134 were extracted from entire vessels (Table 1). The number of core vessels chosen ranged from 35 to 106 each year.

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

The following modifications were made to the dataset before CPUE standardization: deleted the records of the 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 by 5x5 degrees in the month. Aggregated data of little effort (< 10,000 hooks) had been deleted.

CPUE standardization

CPUE were standardized in GLM using R (version 3.6.1). Small constant of 0.2, which was 10% of the nominal CPUE, was added to CPUE of 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, not the aggregated 5x5-degree/month level.

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

AIC and BIC were calculated for the base model and the reduced base model nested with each other. The base model is selected from the viewpoint of AIC, but not from BIC (Table 4).

Area weighted standardized CPUE

Using 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 latest year (2019), which was mainly from RTMP data and targeting on SBT, was corrected from the average ratio of CPUEs between RTMP and Logbook data over the recent three years according to the agreement in the CPUE web-meeting held in March 2010. The constant was set as 1.0 because the average value over three years exceeds 1.0 (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 2019 were calibrated to the historical time series since 1969 based on the agreed method (SAG9 Report in 2008, attachment 5) derived from the GLM model using data of 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 value 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 CPUEs are shown in Table 5 and Fig. 4. The relative index values of W0.8 in 2019 using the base GLM model (1.743) is high as 144% of the average (1.210) in the past 10 years. That of W0.5 in 2019 (1.202) is high as 140% of the average (0.858) in the past 10 years.

The trends of the indices between the GLM model (Base vs Reduced Base) were similar to each other but different since 2010. The differences between the two GLM models

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

were interaction terms of *Year*Lat5* and *Year*Area* which were included in Base but not included in Reduced Base. The nominal CPUE by year and latitude in five degrees are shown in Fig. 5. The year trends were different by latitude, such as nominal CPUE since 2010 were much higher than in the 1990s in 40S and 45S. The nominal CPUE by year and Area are shown in Fig. 6. The 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 into account in the Base model, but not in Reduced Base model. As a result, differences in the indices may occur.

Reference

Itoh, T. 2020. Examination of an extremely high value of the core vessel CPUE in 2018 for southern bluefin tuna. CCSBT-OMMP/2006/12.

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	0	0	27,005	4,068	35
1987	26,759	0	0	26,759	4,804	41
1988	24,418	0	0	24,418	5,353	49
1989	24,315	1,156	0	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	0	0	14,854	7,057	97
1997	16,322	0	379	16,701	7,832	93
1998	16,310	0	310	16,620	8,338	106
1999	14,414	0	306	14,720	8,061	99
2000	11,746	0	265	12,011	7,258	97
2001	14,075	0	198	14,273	7,910	101
2002	10,721	0	228	10,949	6,394	92
2003	11,563	0	294	11,857	6,652	92
2004	13,098	0	349	13,447	8,583	95
2005	13,848	0	198	14,046	8,879	96
2006	9,124	0	183	9,307	6,486	86
2007	5,381	0	387	5,768	4,445	82
2008	6,388	0	167	6,555	5,014	89
2009	4,492	0	231	4,723	4,009	72
2010	3,442	0	144	3,586	3,059	64
2011	4,110	0	151	4,261	3,445	62
2012	4,214	0	163	4,377	3,695	73
2013	3,842	0	148	3,990	3,191	67
2014	4,609	0	186	4,795	3,687	71
2015	4,933	0	181	5,114	3,944	71
2016	5,571	0	0	5,571	4,468	71
2017	4,633	0	0	4,633	3,760	69
2018	5,038	0	0	5,038	4,177	68
2019	3,960	0	0	3,960	3,321	66
Total	404,844	8,776	7,029	420,649	195,134	

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

Table 2. Estimated parameter values in GLM Base model

Parameter	Estimate	StdErr	tValue	Probt
(Intercept)	-1.9938	0.2207	-9.04	0.000
year1987	-0.1387	0.2878	-0.48	0.630
year1988	-0.4184	0.2737	-1.53	0.126
year1989	0.1517	0.3365	0.45	0.652
year1990	0.0001	0.2896	0.00	1.000
year1991	0.3373	0.2782	1.21	0.225
year1992	0.1383	0.2667	0.52	0.604
year1993	0.6895	0.2708	2.55	0.011
year1994	0.1004	0.2640	0.38	0.704
year1995	0.4136	0.2716	1.52	0.128
year1996	0.3701	0.2647	1.40	0.162
year1997	0.0629	0.2962	0.21	0.832
year1998	-0.2408	0.2781	-0.87	0.387
year1999	-0.3903	0.3374	-1.16	0.247
year2000	-0.4825	0.3232	-1.49	0.136
year2001	-0.1432	0.2969	-0.48	0.630
year2002	-0.3363	0.3773	-0.89	0.373
year2003	-0.2018	0.2886	-0.70	0.485
year2004	-0.0571	0.2886	-0.20	0.843
year2005	-0.2671	0.3042	-0.88	0.380
year2006	-0.5325	0.3368	-1.58	0.114
year2007	-0.3020	0.2784	-1.08	0.278
year2008	0.0783	0.2796	0.28	0.779
year2009	-0.2321	0.2833	-0.82	0.413
year2010	-0.5408	0.2838	-1.91	0.057
year2011	-0.3800	0.2612	-1.46	0.146
year2012	-0.5924	0.2611	-2.27	0.023
year2013	-0.4333	0.2750	-1.58	0.115
year2014	-0.7199	0.2902	-2.48	0.013
year2015	-0.3322	0.2780	-1.19	0.232
year2016	-0.5143	0.2888	-1.78	0.075
year2017	-0.6526	0.2892	-2.26	0.024
year2018	-0.6687	0.3371	-1.98	0.047
year2019	-0.8784	0.3772	-2.33	0.020
month5	0.9696	0.1025	9.46	0.000
month6	1.1502	0.0952	12.08	0.000
month7	1.5783	0.0948	16.64	0.000
month8	1.6265	0.1064	15.28	0.000
month9	1.8225	0.1333	13.68	0.000
area7	1.7896	0.4134	4.33	0.000
area8	-0.7260	0.3711	-1.96	0.051
area9	1.3871	0.3453	4.02	0.000
lat535	1.4090	0.3544	3.98	0.000
lat540	0.9981	0.3965	2.52	0.012
lat545	0.7906	0.4890	1.62	0.106
cpue.bet	-0.1436	0.0102	-14.14	0.000
cpue.yft	-0.0731	0.0064	-11.35	0.000
month5_area7	-0.8502	0.1315	-6.47	0.000
month6_area7	-1.0329	0.1323	-7.81	0.000
month7_area7	-1.4202	0.1604	-8.85	0.000
month8_area7	-1.8630	0.3217	-5.79	0.000
month9_area7	-2.1890	0.2453	-8.92	0.000
month5_area8	-0.5041	0.1944	-2.59	0.010
month6_area8	0.0915	0.2154	0.43	0.671
month7_area8	0.4388	0.1886	2.33	0.020
month8_area8	0.5198	0.1831	2.84	0.005
month9_area8	0.0530	0.2006	0.26	0.792
month5_area9	-0.7681	0.1196	-6.42	0.000
month6_area9	-0.8664	0.1137	-7.62	0.000
month7_area9	-1.0595	0.1141	-9.28	0.000
month8_area9	-1.0147	0.1296	-7.83	0.000
month9_area9	-1.3815	0.1586	-8.71	0.000
year1987_lat535	-0.0985	0.4983	-0.20	0.843
year1988_lat535	-0.6464	0.4558	-1.42	0.156
year1989_lat535	-0.5304	0.4953	-1.07	0.284
year1990_lat535	-0.2661	0.4556	-0.58	0.559
year1991_lat535	-0.6360	0.4346	-1.46	0.143
year1992_lat535	-0.4527	0.4325	-1.05	0.295
year1993_lat535	-0.7203	0.4345	-1.66	0.097
year1994_lat535	-0.2995	0.4637	-0.65	0.518
year1995_lat535	-0.7429	0.4539	-1.64	0.102
year1996_lat535	-0.7452	0.4410	-1.69	0.091
year1997_lat535	0.0899	0.4610	0.19	0.845
year1998_lat535	-0.2327	0.4319	-0.54	0.590
year1999_lat535	0.1598	0.4792	0.33	0.739
year2000_lat535	0.4031	0.4756	0.85	0.397
year2001_lat535	-0.1894	0.4572	-0.41	0.679
year2002_lat535	0.2935	0.5207	0.56	0.573
year2003_lat535	0.5018	0.4709	1.07	0.287
year2004_lat535	0.1573	0.4647	0.34	0.735
year2005_lat535	-0.2823	0.4651	-0.61	0.544
year2006_lat535	0.2113	0.4960	0.43	0.670
year2007_lat535	-0.3269	0.4499	-0.73	0.468
year2008_lat535	0.2711	0.4722	0.57	0.566
year2009_lat535	1.1135	0.4622	2.41	0.016
year2010_lat535	0.5898	0.4757	1.24	0.215
year2011_lat535	0.2876	0.4731	0.61	0.543
year2012_lat535	-0.5036	0.4494	-1.12	0.263
year2013_lat535	-0.0694	0.5093	-0.14	0.892
year2014_lat535	0.5875	0.4721	1.24	0.213
year2015_lat535	0.4232	0.4810	0.88	0.379
year2016_lat535	0.7653	0.4781	1.60	0.110
year2017_lat535	0.5445	0.4785	1.14	0.255
year2018_lat535	1.6929	0.5443	3.11	0.002
year2019_lat535	1.7798	0.5560	3.20	0.001
year1987_lat540	0.4337	0.5566	0.78	0.436
year1988_lat540	-0.4271	0.5172	-0.83	0.409
year1989_lat540	-0.1527	0.5563	-0.27	0.784
year1990_lat540	0.4254	0.5298	0.80	0.422
year1991_lat540	0.0031	0.4938	0.01	0.995
year1992_lat540	0.0633	0.4925	0.13	0.898
year1993_lat540	0.8761	0.4957	1.77	0.077
year1994_lat540	1.0601	0.5267	2.01	0.044
year1995_lat540	0.3414	0.5151	0.66	0.507
year1996_lat540	0.5175	0.5050	1.02	0.306
year1997_lat540	0.8838	0.5242	1.69	0.092
year1998_lat540	0.4155	0.4925	0.84	0.399
year1999_lat540	1.0036	0.5365	1.87	0.061
year2000_lat540	1.3718	0.5385	2.55	0.011
year2001_lat540	0.7707	0.5233	1.47	0.141
year2002_lat540	0.5063	0.6404	0.79	0.429
year2003_lat540	0.7912	0.5621	1.41	0.159
year2004_lat540	0.2956	0.5243	0.56	0.573
year2005_lat540	-0.1345	0.5262	-0.26	0.798
year2006_lat540	0.7006	0.5506	1.27	0.203
year2007_lat540	-0.1647	0.5148	-0.32	0.749
year2008_lat540	1.4560	0.5325	2.73	0.006
year2009_lat540	1.9442	0.5350	3.63	0.000
year2010_lat540	1.7255	0.5399	3.20	0.001
year2011_lat540	1.0564	0.5478	1.93	0.054
year2012_lat540	-0.0547	0.5186	-0.11	0.916
year2013_lat540	0.3776	0.5938	0.64	0.525
year2014_lat540	1.3627	0.5710	2.39	0.017
year2015_lat540	1.8158	0.5536	3.28	0.001
year2016_lat540	1.4642	0.5668	2.58	0.010
year2017_lat540	2.6975	0.6146	4.39	0.000
year2018_lat540	4.5426	0.7699	5.90	0.000
year2019_lat540	3.8076	0.6746	5.64	0.000
year1987_lat545	0.7119	0.6789	1.05	0.294
year1988_lat545	-0.2031	0.6137	-0.33	0.741
year1989_lat545	-0.0143	0.6732	-0.02	0.983
year1990_lat545	0.7515	0.6211	1.21	0.226
year1991_lat545	-0.2663	0.6267	-0.42	0.671
year1992_lat545	-0.0193	0.6564	-0.03	0.976
year1993_lat545	0.9106	0.6387	1.43	0.154
year1994_lat545	0.8244	0.7161	1.15	0.250
year1995_lat545	-0.1510	0.7039	-0.21	0.830
year1996_lat545	0.5859	0.6644	0.88	0.378
year1997_lat545	0.9403	0.6638	1.42	0.157
year1998_lat545	0.7661	0.6344	1.21	0.227
year1999_lat545	1.1882	0.6715	1.77	0.077
year2000_lat545	1.0954	0.7005	1.56	0.118
year2001_lat545	0.9175	0.6482	1.42	0.157
year2002_lat545	0.6313	0.7914	0.80	0.425
year2003_lat545	0.9917	0.7572	1.31	0.190
year2004_lat545	0.6656	0.6879	0.97	0.333
year2005_lat545	0.4815	0.6736	0.71	0.475
year2006_lat545	1.3077	0.7714	1.70	0.090
year2007_lat545	-0.5528	0.8044	-0.69	0.492
year2008_lat545	1.9699	0.6555	3.01	0.003
year2009_lat545	1.9130	0.8238	2.32	0.020
year2010_lat545	1.8236	0.9650	1.89	0.059
year2011_lat545	1.0526	0.6821	1.54	0.123
year2012_lat545	0.3988	0.7315	0.55	0.586
year2013_lat545	0.6936	0.8278	0.84	0.402
year2014_lat545	1.5023	0.8072	1.86	0.063
year2015_lat545	1.5207	0.8014	1.90	0.058
year2016_lat545	1.2804	0.9382	1.36	0.172
year2017_lat545	2.8510	0.8308	3.43	0.001
year2018_lat545	4.6814	0.9521	4.92	0.000
year2019_lat545	4.2687	1.0092	4.23	0.000
year1987_area7	-0.4706	0.5553	-0.85	0.397
year1988_area7	0.4091	0.5071	0.81	0.420
year1989_area7	-0.3021	0.5211	-0.58	0.562
year1990_area7	-0.5707	0.5148	-1.11	0.268
year1991_area7	-0.7474	0.4871	-1.53	0.125
year1992_area7	-0.1620	0.4927	-0.33	0.742
year1993_area7	-1.5332	0.5004	-3.06	0.002
year1994_area7	-0.5481	0.5732	-0.96	0.339
year1995_area7	-0.0151	0.5139	-0.03	0.977
year1996_area7	-0.7062	0.5132	-1.38	0.169
year1997_area7	-0.8349	0.5122	-1.63	0.103
year1998_area7	-0.3401	0.5001	-0.68	0.497
year1999_area7	-0.5595	0.5014	-1.12	0.265
year2000_area7	-0.9125	0.5019	-1.82	0.069
year2001_area7	-0.5707	0.5063	-1.13	0.260
year2002_area7	0.0739	0.6026	0.12	0.902
year2003_area7	-1.0166	0.5683	-1.79	0.074
year2004_area7	-0.6782	0.5353	-1.27	0.205
year2005_area7	-0.3761	0.5505	-0.68	0.495
year2006_area7	-0.7169	0.5316	-1.35	0.178
year2007_area7	-0.0376	0.5334	-0.07	0.944
year2008_area7	-1.1148	0.5559	-2.01	0.045
year2009_area7	-0.9454	0.5614	-1.68	0.092
year2010_area7	-0.0446	0.5663	-0.08	0.937
year2011_area7	0.3262	0.5758	0.57	0.571
year2012_area7	1.7711	0.5571	3.18	0.001
year2013_area7	0.9001	0.6222	1.45	0.148
year2014_area7	0.4640	0.5927	0.78	0.434
year2015_area7	-0.3474	0.5922	-0.59	0.558
year2016_area7	0.1492	0.6065	0.25	0.806
year2017_area7	-1.0249	0.6520	-1.57	0.116
year2018_area7	-2.7720	0.7812	-3.55	0.000
year2019_area7	-1.8737	0.6647	-2.82	0.005
year1987_area8	-0.0005	0.4758	0.00	0.999
year1988_area8	0.7935	0.4401	1.80	0.071
year1989_area8	0.0432	0.4421	0.10	0.922
year1990_area8	0.1071	0.4485	0.24	0.811
year1991_area8	-0.0672	0.4208	-0.16	0.873
year1992_area8	0.1292	0.4180	0.31	0.757
year1993_area8	-0.1438	0.4239	-0.34	0.734
year1994_area8	0.2857	0.4720	0.61	0.545
year1995_area8	0.4757	0.4382	1.09	0.278
year1996_area8	0.3258	0.4812	0.68	0.498
year1997_area8	-0.4484	0.4691	-0.96	0.339
year1998_area8	0.4555	0.4152	1.10	0.273
year1999_area8	0.1117	0.4175	0.27	0.789
year2000_area8	0.1686	0.4666	0.36	0.718
year2001_area8	0.1171	0.4515	0.26	0.795
year2002_area8	-0.1434	0.4763	-0.30	0.763
year2003_area8	-0.1643	0.5090	-0.32	0.747
year2004_area8	0.6939	0.4532	1.53	0.126
year2005_area8	1.2601	0.4547	2.77	0.006
year2006_area8	0.3679	0.4631	0.79	0.427
year2007_area8	0.3933	0.4405	0.89	0.372
year2008_area8	-0.7219	0.4600	-1.57	0.117
year2009_area8	-1.2010	0.4489	-2.68	0.008
year2010_area8	0.3472	0.4694	0.74	0.460
year2011_area8	0.2600	0.4657	0.56	0.577
year2012_area8	1.1793	0.4494	2.62	0.009
year2013_area8	0.9471	0.4983	1.90	0.057
year2014_area8	0.5074	0.4517	1.12	0.261
year2015_area8	0.0896	0.4711	0.19	0.849
year2016_area8	0.2140	0.4615	0.46	0.643
year2017_area8	-0.0767	0.4737	-0.16	0.871
year2018_area8	-0.4028	0.5257	-0.77	0.444
year2019_area8	-0.3345	0.5188	-0.64	0.519
year1987_area9	0.0485	0.4647	0.10	0.917
year1988_area9	1.0025	0.4261	2.35	0.019
year1989_area9	-0.0508	0.4339	-0.12	0.907
year1990_area9	-0.4512	0.4339	-1.04	0.298
year1991_area9	-0.3731	0.3942	-0.95	0.344
year1992_area9	-0.1167	0.4005	-0.29	0.771
year1993_area9	-0.9427	0.4002	-2.36	0.019
year1994_area9	-0.8429	0.4378	-1.93	0.054
year1995_area9	-0.3441	0.4213	-0.82	0.414
year1996_area9	-0.7236	0.4093	-1.77	0.077
year1997_area9	-0.9245	0.4100	-2.26	0.024
year1998_area9	0.0189	0.3893	0.05	0.961
year1999_area9	-0.4167	0.4070	-1.02	0.306
year2000_area9	-0.7857	0.4127	-1.90	0.057
year2001_area9	-0.2263	0.4154	-0.54	0.586
year2002_area9	0.5900	0.5154	1.14	0.252
year2003_area9	-0.2354	0.4698	-0.50	0.616
year2004_area9	-0.1985	0.4219	-0.47	0.638
year2005_area9	0.2925	0.4141	0.71	0.480
year2006_area9	-0.6799	0.4198	-1.62	0.105
year2007_area9	-0.1675	0.4154	-0.40	0.687
year2008_area9	-1.5266	0.4369	-3.49	0.000
year2009_area9	-1.3925	0.4347	-3.20	0.001
year2010_area9	-0.5822	0.4337	-1.34	0.180
year2011_area9	-0.0524	0.4558	-0.12	0.908
year2012_area9	1.4033	0.4255	3.30	0.001
year2013_area9	0.8716	0.5055	1.72	0.085
year2014_area9	0.4123	0.4582	0.90	0.368
year2015_area9	-0.0752	0.4569	-0.16	0.869
year2016_area9	0.1114	0.4623	0.24	0.810
year2017_area9	-0.7001	0.5227	-1.34	0.181
year2018_area9	-2.5030	0.6784	-3.69	0.000
year2019_area9	-1.5673	0.5409	-2.90	0.004

Table 3. ANOVA statistics

Base	**Type_2**			
name	Sum Sq	Df	F value	Pr(>F)
year	277.38	33	16.957	1.424E-88
month	219.56	5	88.587	1.572E-87
area	83.30	3	56.014	2.733E-35
lat5	264.68	3	177.986	8.978E-107
cpue.bet	99.18	1	200.077	4.097E-44
cpue.yft	63.82	1	128.749	2.749E-29
month:area	131.43	15	17.677	9.991E-46
year:lat5	170.22	99	3.469	8.398E-27
year:area	163.21	99	3.326	8.136E-25
Residuals	1,596.13	3,220		

Base	**Type_3**			
name	Sum Sq	Df	F value	Pr(>F)
(Intercept)	38.64	1	77.950	1.702E-18
year	65.98	33	4.033	1.250E-13
month	185.75	5	74.945	1.753E-74
area	71.76	3	48.255	1.686E-30
lat5	317.82	3	213.719	1.993E-126
cpue.bet	99.18	1	200.077	4.097E-44
cpue.yft	63.82	1	128.749	2.749E-29
month:area	131.43	15	17.677	9.991E-46
year:lat5	170.22	99	3.469	8.398E-27
year:area	163.21	99	3.326	8.1358E-25
Residuals	1,596.13	3,220		

RedB	**Type_2**			
name	Sum Sq	Df	F value	Pr(>F)
year	277.38	33	14.227	4.935E-73
month	262.27	5	88.786	4.865E-88
area	114.07	3	64.359	1.780E-40
lat5	322.16	3	181.762	2.392E-109
cpue.bet	186.56	1	315.773	1.218E-67
cpue.yft	66.72	1	112.927	5.668E-26
month:area	152.55	15	17.213	1.663E-44
Residuals	2,019.35	3,418		

RedB	**Type_3**			
name	Sum Sq	Df	F value	Pr(>F)
(Intercept)	49.52	1	83.826	9.069E-20
year	277.38	33	14.227	4.935E-73
month	201.44	5	68.193	3.902E-68
area	145.87	3	82.303	2.076E-51
lat5	322.16	3	181.762	2.392E-109
cpue.bet	186.56	1	315.773	1.218E-67
cpue.yft	66.72	1	112.927	5.668E-26
month:area	152.55	15	17.213	1.663E-44
Residuals	2,019.35	3,418		

BaseSS	**Type_2**			
name	Sum Sq	Df	F value	Pr(>F)
year	15,696.91	33	647.545	0.000E+00
month	4,736.56	5	1,289.623	0.000E+00
area	894.24	3	405.789	8.275E-263
lat5	7,875.51	3	3,573.777	0.000E+00
cpue.bet	4,148.48	1	5,647.538	0.000E+00
cpue.yft	3,104.24	1	4,225.961	0.000E+00
month:area	7,431.35	15	674.445	0.000E+00
year:lat5	9,606.65	99	132.101	0.000E+00
year:area	10,641.50	99	146.331	0.000E+00
Residuals	143,146.79	194,873		

BaseSS	**Type_3**			
name	Sum Sq	Df	F value	Pr(>F)
(Intercept)	31.15	1	42.403	7.446E-11
year	1,756.88	33	72.477	0.000E+00
month	5,107.32	5	1,390.571	0.000E+00
area	1,835.33	3	832.842	0.000E+00
lat5	8,471.79	3	3,844.360	0.000E+00
cpue.bet	4,148.48	1	5,647.538	0.000E+00
cpue.yft	3,104.24	1	4,225.961	0.000E+00
month:area	7,431.35	15	674.445	0.000E+00
year:lat5	9,606.65	99	132.101	0.000E+00
year:area	10,641.50	99	146.331	0.000E+00
Residuals	143,146.79	194,873		

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

Model	AIC	BIC
Base	7,685	9,292
Reduced Base	8,108	8,496

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
1970		2.2268	2.4169	2.2268	2.4169	2.2268
1971		2.0654	2.2054	2.0654	2.2054	2.0654
1972		2.1669	2.2273	2.1669	2.2273	2.1669
1973		1.8263	1.9271	1.8263	1.9271	1.8263
1974		1.8989	1.9710	1.8989	1.9710	1.8989
1975		1.4556	1.4974	1.4556	1.4974	1.4556
1976		1.8715	1.9279	1.8715	1.9279	1.8715
1977		1.6556	1.6850	1.6556	1.6850	1.6556
1978		1.4300	1.3820	1.4300	1.3820	1.4300
1979		1.1472	1.2558	1.1472	1.2558	1.1472
1980		1.3862	1.3852	1.3862	1.3852	1.3862
1981		1.3103	1.2917	1.3103	1.2917	1.3103
1982		1.0285	1.0220	1.0285	1.0220	1.0285
1983		1.0103	1.0228	1.0103	1.0228	1.0103
1984		1.0261	1.0603	1.0261	1.0603	1.0261
1985		0.8578	0.8861	0.8578	0.8861	0.8578
1986	2.089	0.631	0.666	0.646	0.684	0.645
1987	2.132	0.6433	0.6692	0.6640	0.6848	0.6452
1988	2.059	0.5402	0.5561	0.5216	0.5264	0.5757
1989	1.983	0.5047	0.5330	0.5064	0.5305	0.5358
1990	1.963	0.5341	0.5294	0.5843	0.5700	0.4806
1991	1.895	0.4385	0.4492	0.5037	0.5036	0.4274
1992	2.251	0.5426	0.5361	0.6068	0.5865	0.5065
1993	2.970	0.7279	0.6664	0.6979	0.6363	0.7024
1994	2.667	0.6890	0.5803	0.5832	0.4926	0.6982
1995	2.715	0.7298	0.6569	0.7376	0.6593	0.7871
1996	2.426	0.5882	0.5318	0.5578	0.5166	0.6185
1997	2.083	0.5143	0.4679	0.5478	0.4966	0.4908
1998	2.204	0.5574	0.5421	0.5790	0.5551	0.5291
1999	2.321	0.5653	0.5449	0.5785	0.5551	0.5405
2000	2.413	0.5337	0.4760	0.5233	0.4649	0.5243
2001	2.644	0.6009	0.5596	0.6122	0.5629	0.5892
2002	3.441	0.9388	0.7660	0.8047	0.6676	0.8739
2003	2.564	0.6715	0.5596	0.6935	0.5734	0.6301
2004	1.962	0.6386	0.5774	0.6751	0.6011	0.6557
2005	1.851	0.5287	0.4823	0.5352	0.4842	0.6773
2006	1.350	0.3747	0.3284	0.3524	0.3203	0.3748

Table 5. (cont.)

Year	Base w08	Base w05	Reduced Base w08	Reduced Base w05	Base with SxS w08	Base with SxS w05
2007	1.407	0.2796	0.2327	0.3264	0.2616	0.3019
2008	1.879	0.5793	0.4309	0.5147	0.4093	0.5427
2009	2.644	0.7507	0.5543	0.7040	0.5334	0.6574
2010	3.676	0.9866	0.6920	0.6925	0.5073	0.9597
2011	3.510	0.9013	0.6544	0.7559	0.5572	0.9132
2012	3.360	1.0718	0.7624	0.7447	0.5377	0.9979
2013	3.890	1.0466	0.7317	0.8822	0.6192	1.0520
2014	4.185	1.2125	0.8654	0.9254	0.6625	1.0386
2015	5.651	1.3216	0.9527	1.0575	0.7518	1.3692
2016	4.497	1.2336	0.8977	1.0639	0.7678	1.0863
2017	5.523	1.2996	0.9429	0.8875	0.6330	1.4698
2018	6.054	2.2809	1.5246	1.3388	0.9373	2.4142
2019	7.780	1.7429	1.2017	1.3438	0.9322	2.2160

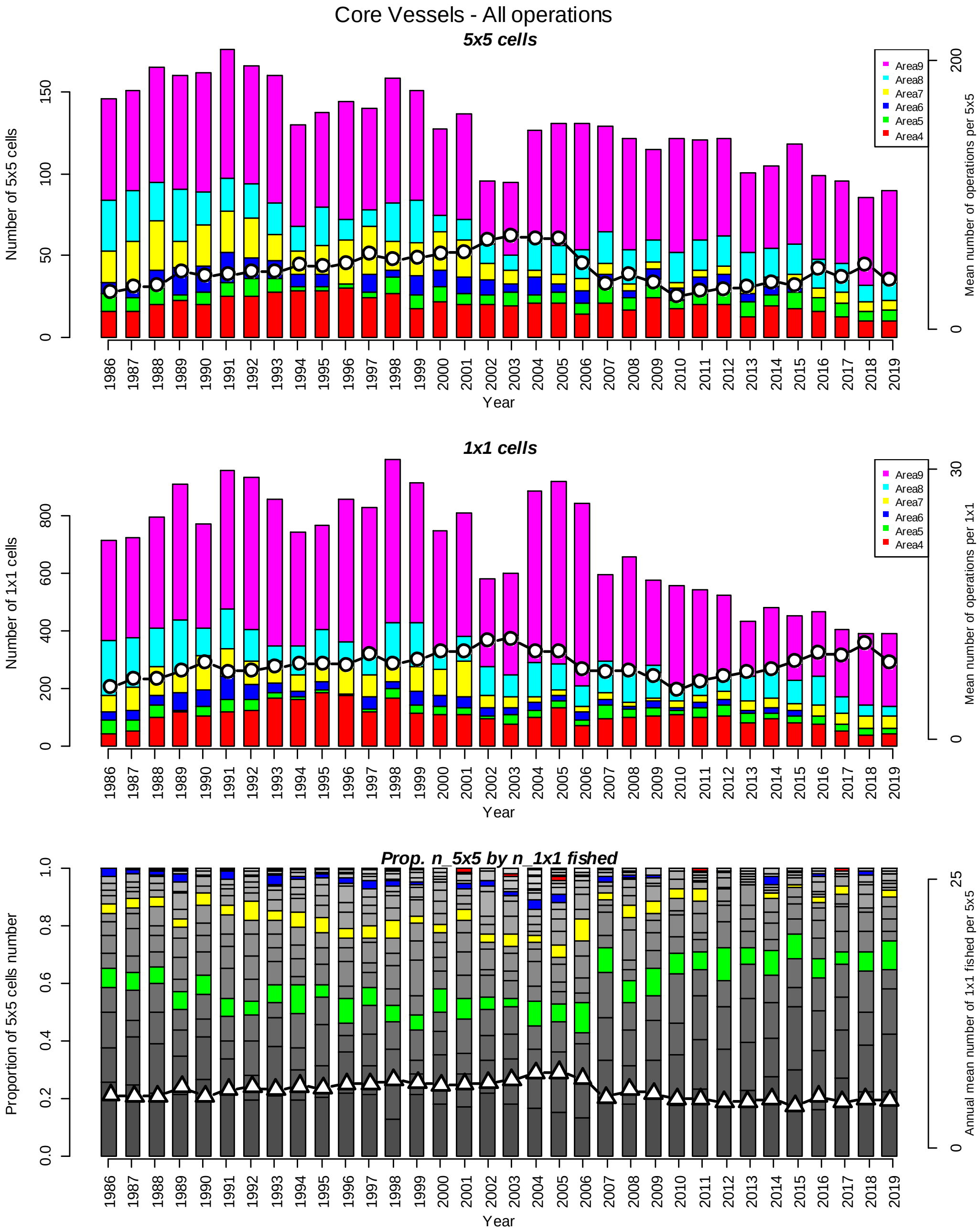
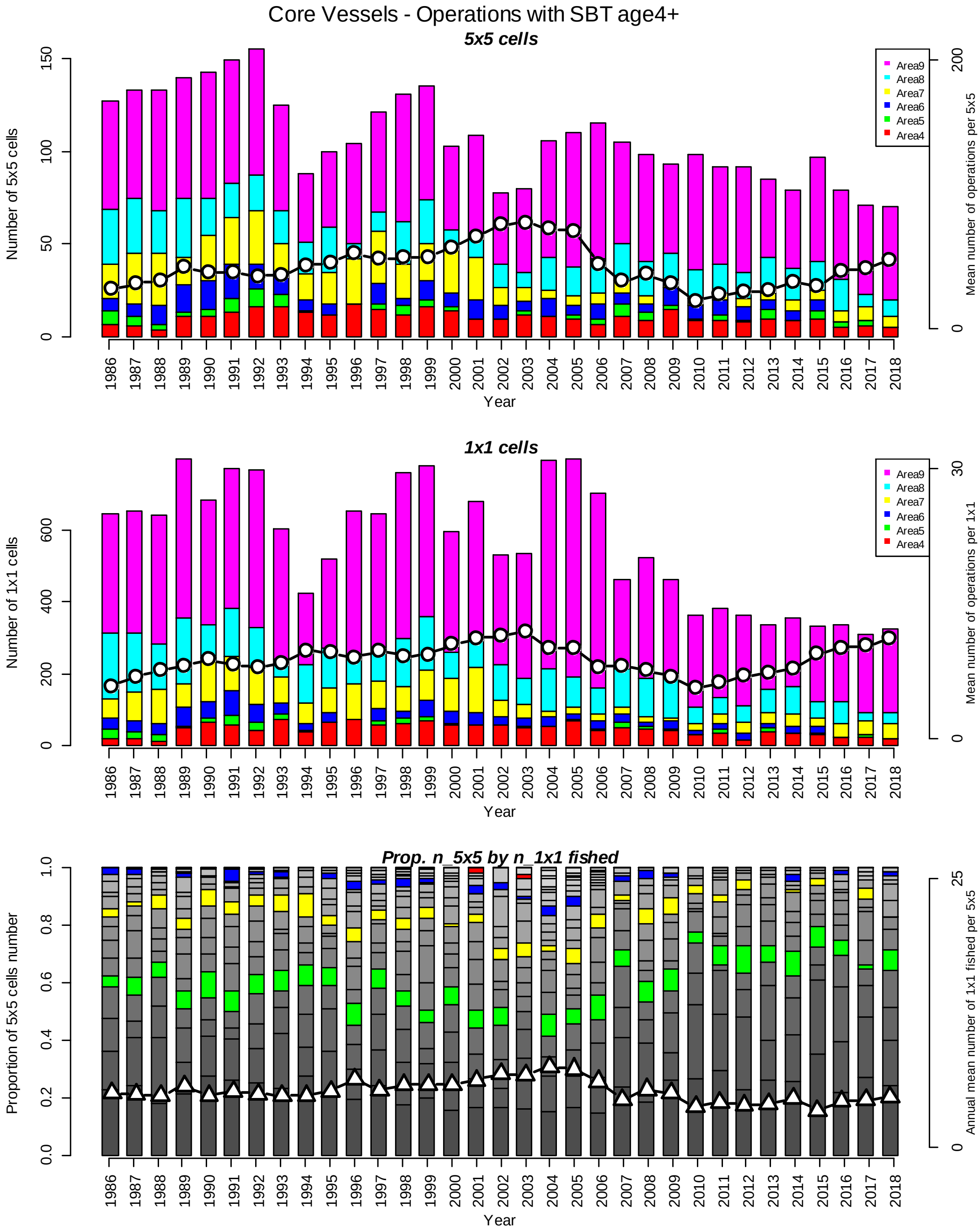


Fig. 1a. Number of cells in the core vessel for <u>all operations</u>.

(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.


Core Vessels - Operations with SBT age4+
5x5 cells
Number of 5x5 cells
Mean number of operations per 5x5
Area9
Area8
Area7
Area6
Area5
Area4
Year
1x1 cells
Number of 1x1 cells
Mean number of operations per 1x1
Prop. n_5x5 by n_1x1 fished
Proportion of 5x5 cells number
Annual mean number of 1x1 fished per 5x5

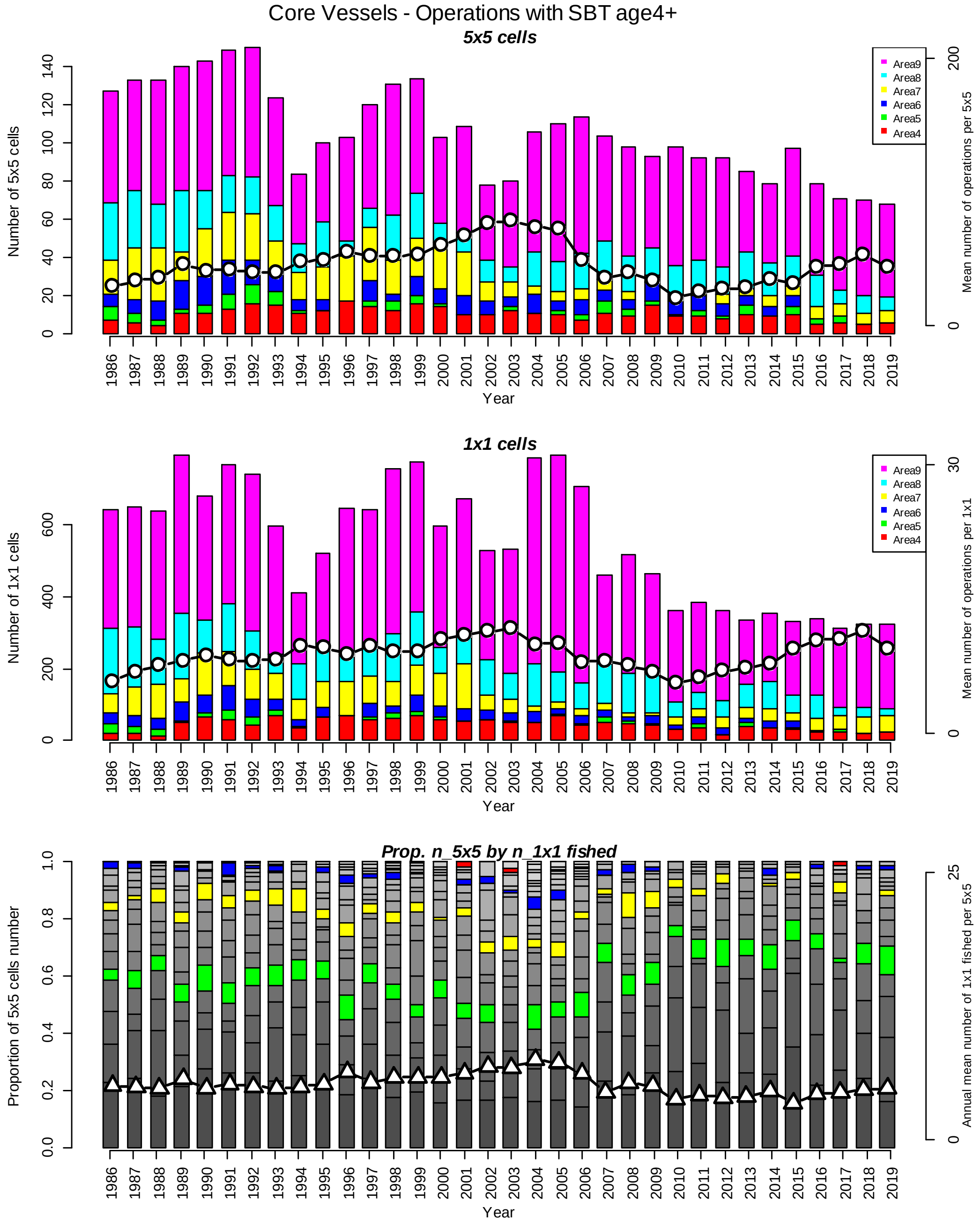


Fig. 1b. Number of cells in the core vessel for SBT 4+ catch positive. See explanation in Fig. 1a.

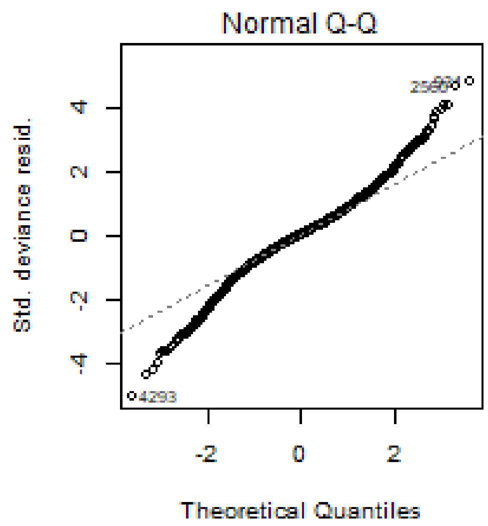


Fig. 2. Standardized CPUE (ls-mean with 95% confidence interval) of the core vessel data (upper panel) and its QQ plot of residual (lower panel) for Base case.

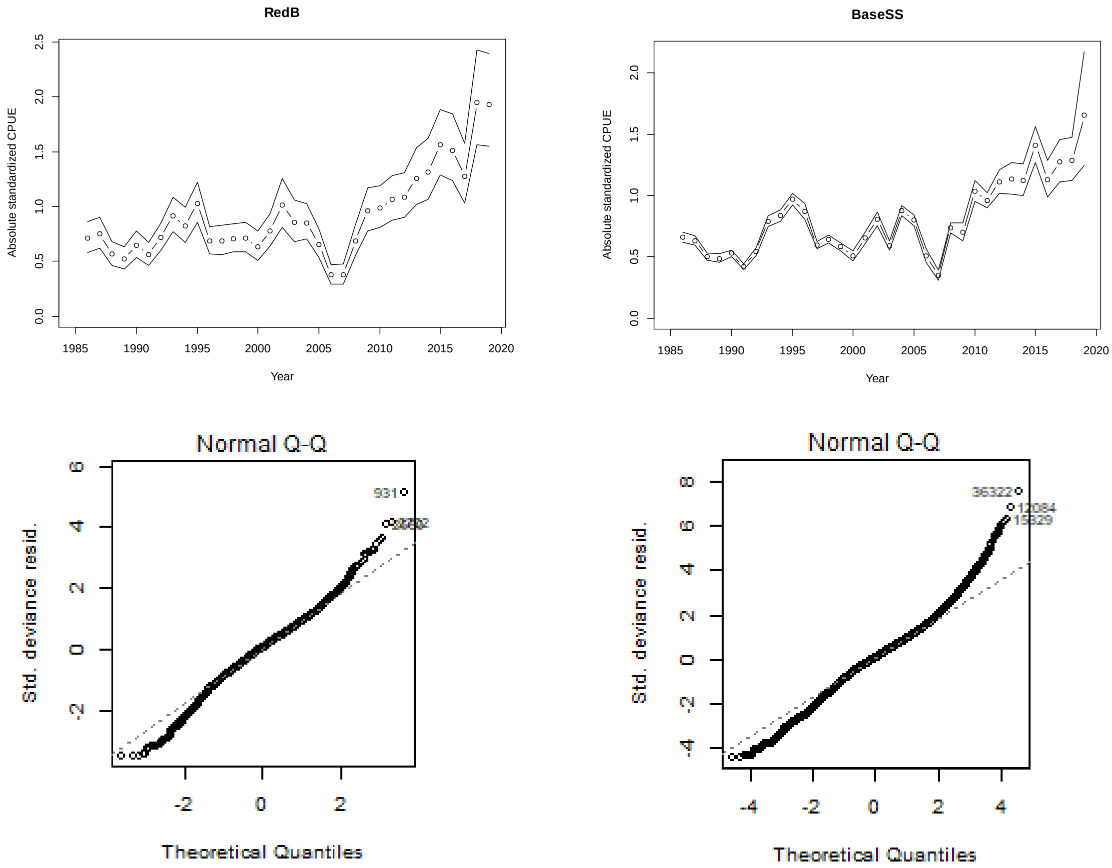
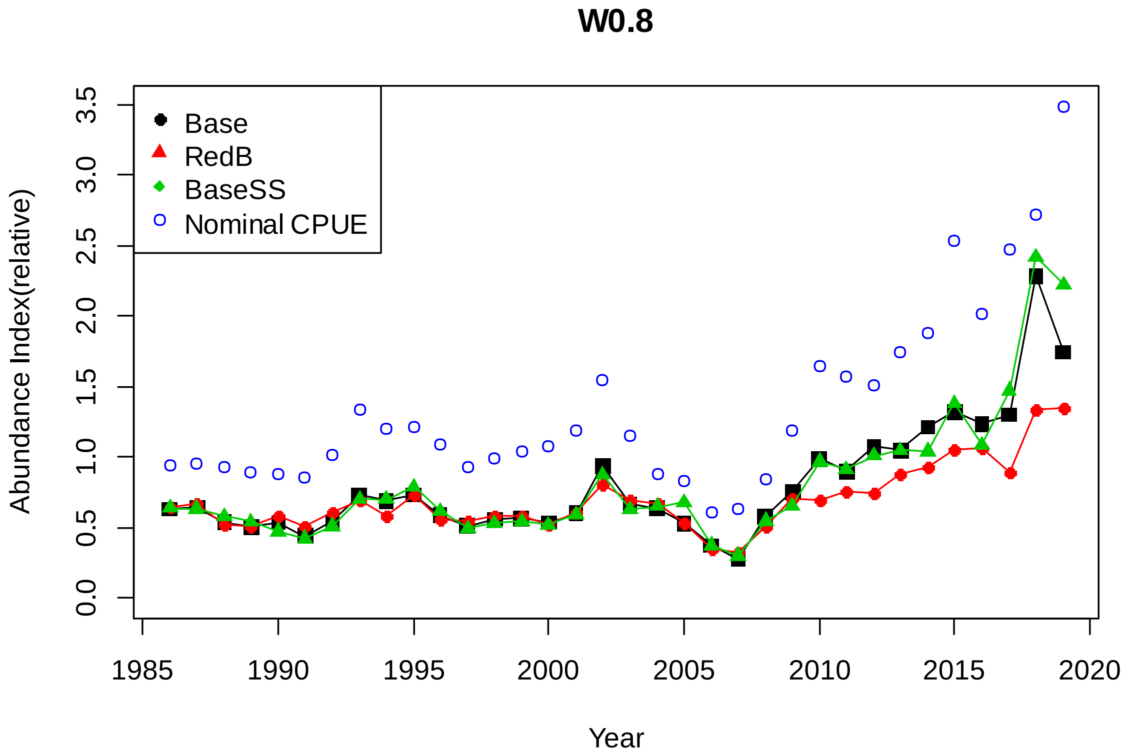


Fig. 3. Standardized CPUE (ls-mean with 95% confidence interval) of the core vessel data (upper panel) and its QQ plot of residual (lower panel) for monitoring series. Left panels for reduced base case and right panels for shot-by-shot data with base case GLM model.



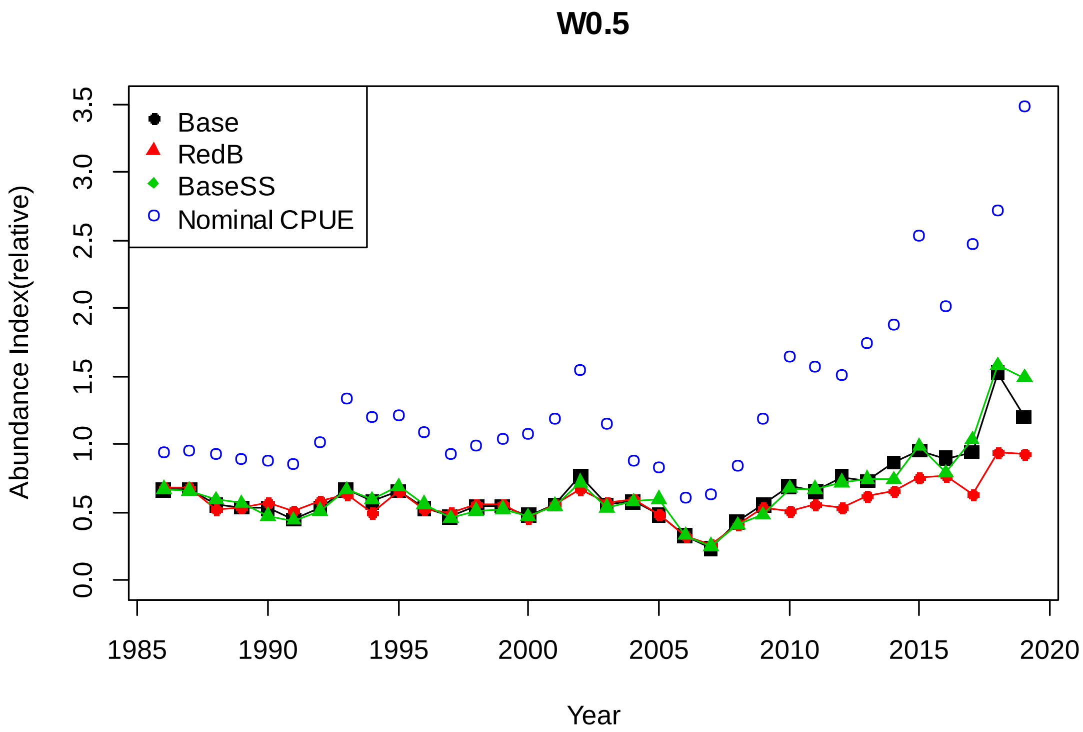


Fig. 4. Area weighed standardized CPUEs. Nominal CPUE of the core vessels is also shown.

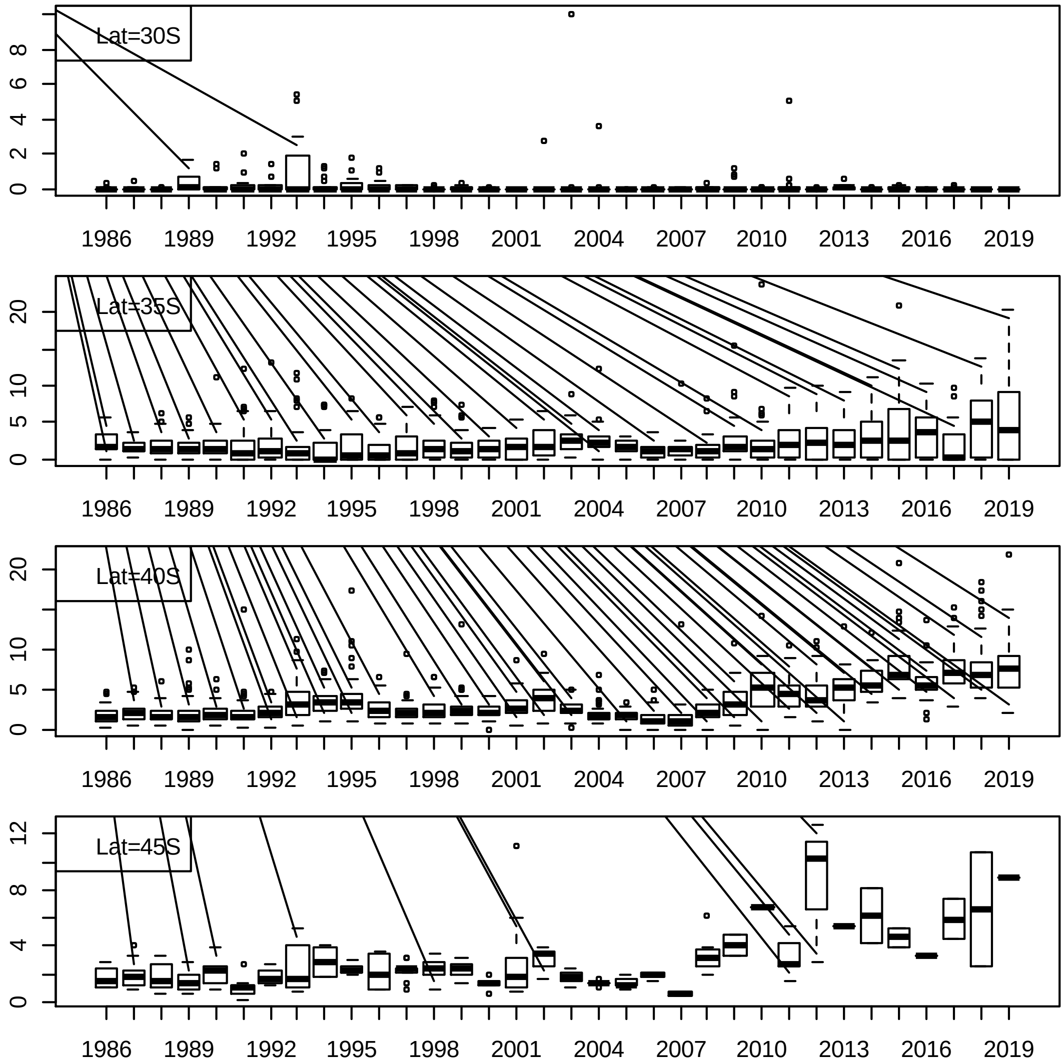


Fig. 5. Nominal CPUE by year and latitude to evaluate whether year*latitude interaction should be included in the GLM model

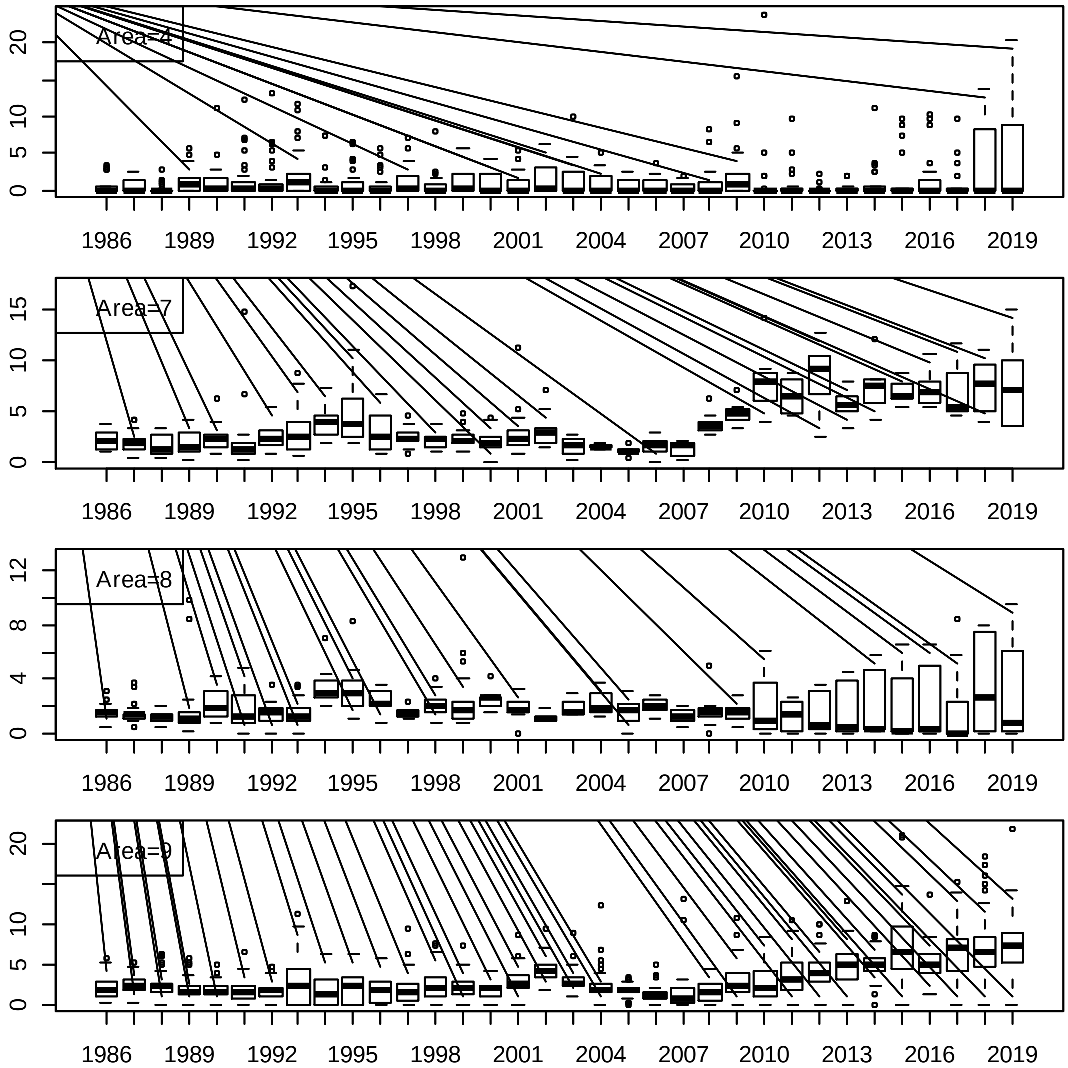


Fig. 6. Nominal CPUE by year and Area to evaluate whether year*Area interaction should be included in the GLM model