2021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 work of the core vessel data and CPUE for southern bluefin tuna in 2021

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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並びに2020年に検討したGLMMとGAM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2020年にまで更新した。2020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, as well as GLMM and GAM used in the 2020 ESC, and area weightings. The data were updated up to 2020. The index values in 2020, 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 (SBT) *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 have been explaining data preparation and indices in detail in papers every year (e.g. Itoh and Takahashi 2020), and try to ensure transparency and evaluation. This is the updated paper for ESC in 2021.

Data preparation

The dataset used was created from shot-by-shot records of Japanese longline fishing from Japan (1986-2020), Australia (RTMP data; 1989-2005), and New Zealand (Joint venture; 1990-2015). New Zealand joint venture with Japanese longline vessels was ceased in 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 in the recent years. 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 2020.

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 197,906 were extracted from entire vessels (Table 1). The number of core vessels chosen ranged from 34 to 105 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 by generalized linier model (GLM) using R (version 4.0.5). Small constant of 0.2, which was 10% of the nominal CPUE, was added to CPUE of age 4+ before log transformation to prevent log(0) (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,*

where year, month, area, lat5 were treated as factors. glm function of R was used.

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.

Furthermore, two series developed in the ESC 2020 were updated. One is generalized linier mixed model (GLMM) where year-area interaction was used as a random effect term. The other is generalized additive model (GAM) which was called gam11. The gam11 was used for the stock assessment of SBT in the ESC 2020 (Anon. 2020).

GLMM model:

*log(CPUE+0.2) = Intercept + Year + Month + Area + Lat5 + BET_CPUE + YFT_CPUE + (Month*Area) + (Year*Lat5) + (1|Year*Area) + Error,*

where (1|Year*Area) is the random term. The aggregated dataset in 5x5, month was used. lmer function in lme4 package was used.

GAM model (gam 11):

log(CPUE +0.2) = Intercept + Year + te(Lon, Lat) +te(Lon, Month) = te(Year, Lat) +

te(Year, Month) + te(Lat, Lon, Month) + te(Lat, Lon, Year) + s(BET=CPUE) + s(YFT_CPUE) + Error,

where it is described by R code as follows.

```
modgam11 <- gam(log(cpue +0.2) ~ yf + te(Lon, Lat, k = c(40,4)) +
                te(Month, Lat, k = c(6,4)) +te(Lon, Month, k = c(10, 5)) +
                te(Year, Lat, k = c(20, 4)) + te(Year, Month, k = c(20, 5)) +
                te(Lat, Lon, Month, k = c(4,15, 6)) +
                te(Lat, Lon, Year, k = c(4,10, 9)) + s(BETcpue) + s(YFTcpue),
                data = data, gamma = 2)
```

The shot-by-shot dataset was used for GAM.

Estimated parameter values for Base case are shown in Table 2. The ANOVA statistics for the three GLM 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 of GLMs and GLMM where used the same dataset. 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, predict values were calculated for a test dataset. The test dataset were constructed by all combination of strata (year (1986 to the most recent year) x month (4-9) x area (4, 7, 8, 9) x lat5 (-30, -35, -40, -45). CPUE of bigeye tuna (or yellowfin tuna) used in the test data was a mean CPUE of bigeye tuna in all records. Same test dataset was used for GLMs and GLMM, while that used for GAM was different because it had longitude strata instead of area strata. Note that records in the test dataset used were only those corresponds with the strata in area weighting (i.e. eliminate records in strata where no fishing operation have been done).

Area weightings were applied to the test dataset in two ways; the Constant Square (CS) and Variable Square (VS) abundance indices by the following equations:

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

$$VS_{4+,y} = \sum_m \sum_a \sum_l (AI_{VS})_{ymal}[\exp(\mathit{Intercept} + \mathit{Year} + \mathit{Month} + \mathit{Area} + \mathit{Lat5} + \mathit{BET\_CPUE} + \mathit{YFT\_CPUE} + (\mathit{Month}*\mathit{Area}) + (\mathit{Year}*\mathit{Lat5}) + (\mathit{Year}*\mathit{Area}) + \sigma^2/2) - 0.2]$$

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. Note that w0.9 and w0.6 were used in GAM11.

$$w0.8_y = 0.8 \times \frac{CS_{4+,y}}{mean\left(CS_{4+,y}\right)} + 0.2 \times \frac{VS_{4+,y}}{mean\left(VS_{4+,y}\right)}$$

$$w0.5_y = 0.5 \times \frac{CS_{4+,y}}{mean\left(CS_{4+,y}\right)} + 0.5 \times \frac{VS_{4+,y}}{mean\left(VS_{4+,y}\right)}$$

The area weighted CPUE value in the latest year (2020), 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 2020 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 2020 using the base GLM model (2.646) is high as 207% of the average (1.28)0 in the past 10 years. That of W0.5 in 2020 (1.795) is high as 201% of the average (0.893) in the past 10 years.

The trends of the indices between the GLM model (Base vs Reduced Base) are similar to each other but different since 2010 (Fig. 4). The indices by Reduced Base is moderately increased while that by Base increased sharply. The differences between the two GLM models were interaction terms of *Year*Lat5* and *Year*Area* which were included in Base but not included in Reduced Base. The indices of Base by shot-by-shot dataset jump in 2019 while drop in 2020 to the same level in 2018.

[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.

Compare to the indices by Base in GLM that jump in 2018 and 2020, the indices by GLMM are similar until 2017 and show moderate increase since 2018 (Fig. 5). Those by GAM11 are similar until 2010 and show earlier increase which reaches a peak in 2015, and show slight decrease up to 2020.

Reference

Anonymous (2020) Report of the twenty fifth meeting of the Scientific Committee, CCSBT. 7 Sep. 2020, Online. 142pp.

Itoh, T., and N. Takahashi. 2020. Update of the core vessel data and CPUE for southern bluefin tuna in 2020. CCSBT-OMMP/2006/11.

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.

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	3,954	34
1987	26,759	0	0	26,759	4,671	40
1988	24,418	0	0	24,418	5,296	48
1989	24,315	1,156	0	25,471	6,804	62
1990	20,076	504	475	21,055	6,655	72
1991	18,424	1,204	460	20,088	7,187	72
1992	17,233	1,717	499	19,449	7,059	85
1993	14,976	2,001	486	17,463	6,904	82
1994	12,665	1,394	268	14,327	6,153	91
1995	12,973	800	373	14,146	6,431	96
1996	14,854	0	0	14,854	6,980	96
1997	16,398	0	379	16,777	7,863	92
1998	16,450	0	310	16,760	8,347	105
1999	14,494	0	306	14,800	8,103	98
2000	11,746	0	265	12,011	7,230	96
2001	14,109	0	198	14,307	7,849	100
2002	10,768	0	228	10,996	6,335	91
2003	11,634	0	294	11,928	6,723	92
2004	13,104	0	349	13,453	8,589	95
2005	13,848	0	198	14,046	8,783	95
2006	9,124	0	183	9,307	6,365	85
2007	5,431	0	387	5,818	4,484	81
2008	6,356	0	167	6,523	4,923	87
2009	4,522	0	231	4,753	4,039	72
2010	3,573	0	144	3,717	3,181	62
2011	4,262	0	151	4,413	3,557	62
2012	4,367	0	163	4,530	3,820	72
2013	3,830	0	148	3,978	3,141	66
2014	4,605	0	186	4,791	3,683	71
2015	4,933	0	181	5,114	3,944	71
2016	5,571	0	0	5,571	4,468	71
2017	4,625	0	0	4,625	3,752	69
2018	5,038	0	0	5,038	4,177	68
2019	3,992	0	0	3,992	3,285	66
2020	3,999	0	0	3,999	3,171	56
Total	410,477	8,776	7,029	426,282	197,906	

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)	-2.0078	0.2197	-9.14	0.000
year1987	-0.1397	0.2866	-0.49	0.626
year1988	-0.4177	0.2726	-1.53	0.126
year1989	0.1515	0.3351	0.45	0.651
year1990	0.0042	0.2884	0.01	0.988
year1991	0.3416	0.2770	1.23	0.218
year1992	0.1412	0.2656	0.53	0.595
year1993	0.6902	0.2697	2.56	0.011
year1994	0.1019	0.2629	0.39	0.698
year1995	0.4157	0.2705	1.54	0.125
year1996	0.3720	0.2637	1.41	0.158
year1997	0.0641	0.2950	0.22	0.828
year1998	-0.2391	0.2770	-0.86	0.388
year1999	-0.3875	0.3360	-1.15	0.249
year2000	-0.4796	0.3218	-1.49	0.136
year2001	-0.1391	0.2956	-0.47	0.638
year2002	-0.3319	0.3757	-0.88	0.377
year2003	-0.2012	0.2875	-0.70	0.484
year2004	-0.0532	0.2874	-0.19	0.853
year2005	-0.2629	0.3029	-0.87	0.385
year2006	-0.5278	0.3354	-1.57	0.116
year2007	-0.2974	0.2773	-1.07	0.284
year2008	0.0838	0.2784	0.30	0.763
year2009	-0.2300	0.2821	-0.82	0.415
year2010	-0.5370	0.2827	-1.90	0.058
year2011	-0.3790	0.2601	-1.46	0.145
year2012	-0.5909	0.2601	-2.27	0.023
year2013	-0.4284	0.2739	-1.56	0.118
year2014	-0.7150	0.2890	-2.47	0.013
year2015	-0.3320	0.2769	-1.20	0.231
year2016	-0.5095	0.2876	-1.77	0.077
year2017	-0.6482	0.2880	-2.25	0.024
year2018	-0.6633	0.3357	-1.98	0.048
year2019	-0.8740	0.3757	-2.33	0.020
year2020	-0.7482	0.3534	-2.12	0.034
month5	1.0090	0.1014	9.95	0.000
month6	1.1558	0.0941	12.29	0.000
month7	1.5887	0.0940	16.90	0.000
month8	1.6382	0.1057	15.50	0.000
month9	1.8340	0.1324	13.85	0.000
area7	1.7961	0.4116	4.36	0.000
area8	-0.7124	0.3685	-1.93	0.053
area9	1.4101	0.3436	4.10	0.000
lat535	1.4100	0.3529	4.00	0.000
lat540	0.9941	0.3949	2.52	0.012
lat545	0.7899	0.4870	1.62	0.105
cpue.bet	-0.1436	0.0101	-14.23	0.000
cpue.yft	-0.0731	0.0064	-11.39	0.000
month5_area7	-0.8787	0.1300	-6.76	0.000
month6_area7	-1.0217	0.1307	-7.82	0.000
month7_area7	-1.4197	0.1593	-8.91	0.000
month8_area7	-1.8630	0.3202	-5.82	0.000
month9_area7	-2.1911	0.2440	-8.98	0.000
month5_area8	-0.5479	0.1924	-2.85	0.004
month6_area8	0.1228	0.2074	0.59	0.554
month7_area8	0.4237	0.1854	2.29	0.022
month8_area8	0.5082	0.1801	2.82	0.005
month9_area8	0.0477	0.1977	0.24	0.809
month5_area9	-0.8070	0.1179	-6.84	0.000
month6_area9	-0.8767	0.1119	-7.83	0.000
month7_area9	-1.0812	0.1127	-9.59	0.000
month8_area9	-1.0472	0.1282	-8.17	0.000
month9_area9	-1.4016	0.1575	-8.90	0.000
year1987_lat535	-0.0927	0.4962	-0.19	0.852
year1988_lat535	-0.6509	0.4539	-1.43	0.152
year1989_lat535	-0.5286	0.4933	-1.07	0.284
year1990_lat535	-0.2710	0.4538	-0.60	0.550
year1991_lat535	-0.6403	0.4328	-1.48	0.139
year1992_lat535	-0.4611	0.4307	-1.07	0.284
year1993_lat535	-0.7209	0.4327	-1.67	0.096
year1994_lat535	-0.3000	0.4618	-0.65	0.516
year1995_lat535	-0.7447	0.4520	-1.65	0.100
year1996_lat535	-0.7513	0.4392	-1.71	0.087
year1997_lat535	0.0907	0.4592	0.20	0.843
year1998_lat535	-0.2333	0.4301	-0.54	0.588
year1999_lat535	0.1582	0.4772	0.33	0.740
year2000_lat535	0.4001	0.4737	0.84	0.398
year2001_lat535	-0.1919	0.4553	-0.42	0.673
year2002_lat535	0.2901	0.5185	0.56	0.576
year2003_lat535	0.5008	0.4690	1.07	0.286
year2004_lat535	0.1531	0.4628	0.33	0.741
year2005_lat535	-0.2858	0.4632	-0.62	0.537
year2006_lat535	0.2075	0.4939	0.42	0.674
year2007_lat535	-0.3328	0.4481	-0.74	0.458
year2008_lat535	0.2648	0.4702	0.56	0.573
year2009_lat535	1.1128	0.4603	2.42	0.016
year2010_lat535	0.5822	0.4737	1.23	0.219
year2011_lat535	0.2811	0.4711	0.60	0.551
year2012_lat535	-0.5070	0.4476	-1.13	0.257
year2013_lat535	-0.0792	0.5072	-0.16	0.876
year2014_lat535	0.5789	0.4701	1.23	0.218
year2015_lat535	0.4153	0.4790	0.87	0.386
year2016_lat535	0.7595	0.4761	1.60	0.111
year2017_lat535	0.5392	0.4766	1.13	0.258
year2018_lat535	1.6011	0.5420	2.95	0.003
year2019_lat535	1.7104	0.5537	3.09	0.002
year2020_lat535	1.2432	0.5382	2.31	0.021
year1987_lat540	0.4370	0.5543	0.79	0.431
year1988_lat540	-0.4299	0.5151	-0.83	0.404
year1989_lat540	-0.1503	0.5541	-0.27	0.786

Parameter	Estimate	StdErr	tValue	Probt
year1990_	0.4188	0.5276	0.79	0.427
year1991_	-0.0005	0.4918	0.00	0.999
year1992_	0.0544	0.4905	0.11	0.912
year1993_	0.8761	0.4937	1.77	0.076
year1994_	1.0607	0.5245	2.02	0.043
year1995_	0.3410	0.5130	0.66	0.506
year1996_	0.5144	0.5029	1.02	0.306
year1997_	0.8866	0.5221	1.70	0.090
year1998_	0.4172	0.4905	0.85	0.395
year1999_	1.0035	0.5343	1.88	0.060
year2000_	1.3696	0.5363	2.55	0.011
year2001_	0.7691	0.5211	1.48	0.140
year2002_	0.5065	0.6378	0.79	0.427
year2003_	0.7923	0.5598	1.42	0.157
year2004_	0.2907	0.5221	0.56	0.578
year2005_	-0.1359	0.5241	-0.26	0.795
year2006_	0.7005	0.5483	1.28	0.201
year2007_	-0.1702	0.5127	-0.33	0.740
year2008_	1.4516	0.5303	2.74	0.006
year2009_	1.9432	0.5328	3.65	0.000
year2010_	1.7195	0.5377	3.20	0.001
year2011_	1.0512	0.5455	1.93	0.054
year2012_	-0.0577	0.5165	-0.11	0.911
year2013_	0.3723	0.5913	0.63	0.529
year2014_	1.3555	0.5686	2.38	0.017
year2015_	1.8083	0.5513	3.28	0.001
year2016_	1.4580	0.5645	2.58	0.010
year2017_	2.6944	0.6121	4.40	0.000
year2018_	4.4437	0.7667	5.80	0.000
year2019_	4.5805	0.7193	6.37	0.000
year2020_	3.6169	0.6751	5.36	0.000
year1987_	0.7106	0.6761	1.05	0.293
year1988_	-0.2092	0.6112	-0.34	0.732
year1989_	-0.0105	0.6704	-0.02	0.987
year1990_	0.7412	0.6186	1.20	0.231
year1991_	-0.2706	0.6242	-0.43	0.665
year1992_	-0.0301	0.6537	-0.05	0.963
year1993_	0.9089	0.6361	1.43	0.153
year1994_	0.8239	0.7132	1.16	0.248
year1995_	-0.1535	0.7010	-0.22	0.827
year1996_	0.5797	0.6616	0.88	0.381
year1997_	0.9427	0.6610	1.43	0.154
year1998_	0.7646	0.6318	1.21	0.226
year1999_	1.1868	0.6688	1.77	0.076
year2000_	1.0954	0.6977	1.57	0.116
year2001_	0.9167	0.6455	1.42	0.156
year2002_	0.6270	0.7881	0.80	0.426
year2003_	0.9929	0.7541	1.32	0.188
year2004_	0.6565	0.6851	0.96	0.338
year2005_	0.4796	0.6708	0.71	0.475
year2006_	1.3088	0.7683	1.70	0.089
year2007_	-0.5522	0.8011	-0.69	0.491
year2008_	1.9629	0.6528	3.01	0.003
year2009_	1.9060	0.8204	2.32	0.020
year2010_	1.8129	0.9610	1.89	0.059
year2011_	1.0402	0.6793	1.53	0.126
year2012_	0.3928	0.7285	0.54	0.590
year2013_	0.6836	0.8244	0.83	0.407
year2014_	1.4918	0.8039	1.86	0.064
year2015_	1.5087	0.7981	1.89	0.059
year2016_	1.2666	0.9343	1.36	0.175
year2017_	2.8399	0.8274	3.43	0.001
year2018_	4.5896	0.9482	4.84	0.000
year2019_	4.8083	1.0366	4.64	0.000
year2020_	4.1015	0.8786	4.67	0.000
year1987_	-0.4701	0.5531	-0.85	0.395
year1988_	0.4133	0.5051	0.82	0.413
year1989_	-0.3029	0.5190	-0.58	0.560
year1990_	-0.5651	0.5127	-1.10	0.270
year1991_	-0.7483	0.4851	-1.54	0.123
year1992_	-0.1560	0.4907	-0.32	0.751
year1993_	-1.5347	0.4984	-3.08	0.002
year1994_	-0.5530	0.5709	-0.97	0.333
year1995_	-0.0161	0.5118	-0.03	0.975
year1996_	-0.7058	0.5111	-1.38	0.167
year1997_	-0.8383	0.5101	-1.64	0.100
year1998_	-0.3415	0.4980	-0.69	0.493
year1999_	-0.5603	0.4993	-1.12	0.262
year2000_	-0.9115	0.4998	-1.82	0.068
year2001_	-0.5710	0.5042	-1.13	0.258
year2002_	0.0725	0.6001	0.12	0.904
year2003_	-1.0173	0.5659	-1.80	0.072
year2004_	-0.6746	0.5331	-1.27	0.206
year2005_	-0.3749	0.5482	-0.68	0.494
year2006_	-0.7218	0.5294	-1.36	0.173
year2007_	-0.0346	0.5312	-0.07	0.948
year2008_	-1.1112	0.5536	-2.01	0.045
year2009_	-0.9433	0.5591	-1.69	0.092
year2010_	-0.0404	0.5640	-0.07	0.943
year2011_	0.3325	0.5735	0.58	0.562
year2012_	1.7762	0.5548	3.20	0.001
year2013_	0.9026	0.6197	1.46	0.145
year2014_	0.4683	0.5903	0.79	0.428
year2015_	-0.3369	0.5898	-0.57	0.568
year2016_	0.1529	0.6040	0.25	0.800
year2017_	-1.0239	0.6493	-1.58	0.115
year2018_	-2.7453	0.7780	-3.53	0.000
year2019_	-2.6707	0.7102	-3.76	0.000
year2020_	-1.6628	0.6692	-2.48	0.013
year1987_	-0.0069	0.4738	-0.01	0.988

Parameter	Estimate	StdErr	tValue	Probt
year1988_	0.7973	0.4383	1.82	0.069
year1989_	0.0415	0.4402	0.09	0.925
year1990_	0.1145	0.4466	0.26	0.798
year1991_	-0.0687	0.4190	-0.16	0.870
year1992_	0.1338	0.4162	0.32	0.748
year1993_	-0.1494	0.4222	-0.35	0.723
year1994_	0.2819	0.4701	0.60	0.549
year1995_	0.4729	0.4364	1.08	0.279
year1996_	0.3242	0.4791	0.68	0.499
year1997_	-0.4555	0.4671	-0.98	0.330
year1998_	0.4531	0.4135	1.10	0.273
year1999_	0.1101	0.4158	0.26	0.791
year2000_	0.1645	0.4646	0.35	0.723
year2001_	0.1112	0.4496	0.25	0.805
year2002_	-0.1504	0.4743	-0.32	0.751
year2003_	-0.1696	0.5069	-0.33	0.738
year2004_	0.6877	0.4513	1.52	0.128
year2005_	1.2560	0.4528	2.77	0.006
year2006_	0.3652	0.4612	0.79	0.428
year2007_	0.3956	0.4387	0.90	0.367
year2008_	-0.7198	0.4581	-1.57	0.116
year2009_	-1.2022	0.4470	-2.69	0.007
year2010_	0.3455	0.4674	0.74	0.460
year2011_	0.2628	0.4637	0.57	0.571
year2012_	1.1764	0.4475	2.63	0.009
year2013_	0.9497	0.4961	1.91	0.056
year2014_	0.5035	0.4497	1.12	0.263
year2015_	0.1037	0.4690	0.22	0.825
year2016_	0.2766	0.4545	0.61	0.543
year2017_	-0.0719	0.4717	-0.15	0.879
year2018_	-0.3124	0.5235	-0.60	0.551
year2019_	-0.2862	0.5166	-0.55	0.580
year2020_	0.9907	0.5043	1.96	0.050
year1987_	0.0446	0.4628	0.10	0.923
year1988_	1.0054	0.4243	2.37	0.018
year1989_	-0.0525	0.4321	-0.12	0.903
year1990_	-0.4502	0.4321	-1.04	0.298
year1991_	-0.3738	0.3926	-0.95	0.341
year1992_	-0.1127	0.3988	-0.28	0.778
year1993_	-0.9454	0.3985	-2.37	0.018
year1994_	-0.8459	0.4360	-1.94	0.052
year1995_	-0.3483	0.4195	-0.83	0.407
year1996_	-0.7222	0.4077	-1.77	0.077
year1997_	-0.9284	0.4083	-2.27	0.023
year1998_	0.0157	0.3877	0.04	0.968
year1999_	-0.4187	0.4053	-1.03	0.302
year2000_	-0.7861	0.4110	-1.91	0.056
year2001_	-0.2288	0.4137	-0.55	0.580
year2002_	0.5850	0.5133	1.14	0.254
year2003_	-0.2374	0.4678	-0.51	0.612
year2004_	-0.1973	0.4201	-0.47	0.639
year2005_	0.2908	0.4124	0.71	0.481
year2006_	-0.6819	0.4180	-1.63	0.103
year2007_	-0.1669	0.4137	-0.40	0.687
year2008_	-1.5268	0.4351	-3.51	0.000
year2009_	-1.3919	0.4329	-3.21	0.001
year2010_	-0.5811	0.4319	-1.35	0.179
year2011_	-0.0481	0.4540	-0.11	0.916
year2012_	1.4032	0.4237	3.31	0.001
year2013_	0.8730	0.5034	1.73	0.083
year2014_	0.4131	0.4564	0.91	0.365
year2015_	-0.0683	0.4550	-0.15	0.881
year2016_	0.1115	0.4604	0.24	0.809
year2017_	-0.7020	0.5206	-1.35	0.178
year2018_	-2.4254	0.6756	-3.59	0.000
year2019_	-2.3754	0.5963	-3.98	0.000
year2020_	-1.9242	0.5609	-3.43	0.001

Table 3. ANOVA statistics

Base	**Type_2**			
name	Sum Sq	Df	F value	Pr(>F)
year	294.77	34	17.633	4.178E-95
month	220.32	5	89.621	1.272E-88
area	77.36	3	52.451	4.143E-33
lat5	277.23	3	187.955	1.746E-112
cpue.bet	99.52	1	202.424	1.272E-44
cpue.yft	63.81	1	129.776	1.630E-29
month:area	135.80	15	18.413	7.100E-48
year:lat5	188.56	102	3.760	8.974E-32
year:area	184.49	102	3.679	1.399E-30
Residuals	1,615.61	3,286		

Base	**Type_3**			
name	Sum Sq	Df	F value	Pr(>F)
(Intercept)	44.49	1	90.486	3.481E-21
year	74.19	34	4.438	3.234E-16
month	190.54	5	77.507	4.901E-77
area	51.44	3	34.876	3.495E-22
lat5	342.65	3	232.305	1.089E-136
cpue.bet	99.52	1	202.424	1.272E-44
cpue.yft	63.81	1	129.776	1.630E-29
month:area	135.80	15	18.413	7.100E-48
year:lat5	188.56	102	3.760	8.974E-32
year:area	184.49	102	3.679	1.39867E-30
Residuals	1,615.61	3,286		

RedB	**Type_2**			
name	Sum Sq	Df	F value	Pr(>F)
year	294.77	34	14.630	1.479E-77
month	260.55	5	87.935	2.477E-87
area	107.63	3	60.539	3.779E-38
lat5	334.83	3	188.339	3.382E-113
cpue.bet	186.17	1	314.154	2.243E-67
cpue.yft	65.66	1	110.809	1.566E-25
month:area	157.55	15	17.725	5.151E-46
Residuals	2,068.16	3,490		

RedB	**Type_3**			
name	Sum Sq	Df	F value	Pr(>F)
(Intercept)	56.05	1	94.590	4.454E-22
year	294.77	34	14.630	1.479E-77
month	201.14	5	67.885	6.716E-68
area	140.24	3	78.886	2.261E-49
lat5	334.83	3	188.339	3.382E-113
cpue.bet	186.17	1	314.154	2.243E-67
cpue.yft	65.66	1	110.809	1.566E-25
month:area	157.55	15	17.725	5.151E-46
Residuals	2,068.16	3,490		

BaseSS	**Type_2**			
name	Sum Sq	Df	F value	Pr(>F)
year	17,558.37	34	706.288	0.000E+00
month	4,800.23	5	1,313.012	0.000E+00
area	895.37	3	408.187	2.254E-264
lat5	8,109.47	3	3,696.985	0.000E+00
cpue.bet	4,138.19	1	5,659.610	0.000E+00
cpue.yft	3,100.79	1	4,240.812	0.000E+00
month:area	7,718.11	15	703.714	0.000E+00
year:lat5	9,898.05	102	132.717	0.000E+00
year:area	11,000.50	102	147.499	0.000E+00
Residuals	144,928	198,211		

BaseSS	**Type_3**			
name	Sum Sq	Df	F value	Pr(>F)
(Intercept)	48.07	1	65.744	5.163E-16
year	1,902.58	34	76.532	0.000E+00
month	5,280.11	5	1,444.273	0.000E+00
area	1,303.30	3	594.157	0.000E+00
lat5	9,012.24	3	4,108.543	0.000E+00
cpue.bet	4,138.19	1	5,659.610	0.000E+00
cpue.yft	3,100.79	1	4,240.812	0.000E+00
month:area	7,718.11	15	703.714	0.000E+00
year:lat5	9,898.05	102	132.717	0.000E+00
year:area	11,000.50	102	147.499	0.000E+00
Residuals	144,928	198,211		

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

Method	Model	AIC	BIC
GLM	Base	7,819	9,474
GLM	Reduced Base	8,288	8,684
GLMM	Random=Year_Area	8,209	9,240

Table 5. Area weighted standardized CPUE

	Base	Base	Reduced Base	Reduced Base	Base SxS	Base SxS	GLMM	GLMM	GAM	GAM
Year	w08	w05	w08	w05	w08	w05	w08	w05	w09	w06
1969	2.2841	2.4934	2.2841	2.4934	2.2841	2.4934	2.2841	2.4934	2.2144	2.4236
1970	2.2268	2.4169	2.2268	2.4169	2.2268	2.4169	2.2268	2.4169	2.1635	2.3535
1971	2.0654	2.2054	2.0654	2.2054	2.0654	2.2054	2.0654	2.2054	2.0188	2.1588
1972	2.1669	2.2273	2.1669	2.2273	2.1669	2.2273	2.1669	2.2273	2.1468	2.2072
1973	1.8263	1.9271	1.8263	1.9271	1.8263	1.9271	1.8263	1.9271	1.7927	1.8935
1974	1.8989	1.9710	1.8989	1.9710	1.8989	1.9710	1.8989	1.9710	1.8749	1.9469
1975	1.4556	1.4974	1.4556	1.4974	1.4556	1.4974	1.4556	1.4974	1.4416	1.4835
1976	1.8715	1.9279	1.8715	1.9279	1.8715	1.9279	1.8715	1.9279	1.8527	1.9091
1977	1.6556	1.6850	1.6556	1.6850	1.6556	1.6850	1.6556	1.6850	1.6458	1.6752
1978	1.4300	1.3820	1.4300	1.3820	1.4300	1.3820	1.4300	1.3820	1.4460	1.3980
1979	1.1472	1.2558	1.1472	1.2558	1.1472	1.2558	1.1472	1.2558	1.1111	1.2196
1980	1.3862	1.3852	1.3862	1.3852	1.3862	1.3852	1.3862	1.3852	1.3865	1.3856
1981	1.3103	1.2917	1.3103	1.2917	1.3103	1.2917	1.3103	1.2917	1.3165	1.2979
1982	1.0285	1.0220	1.0285	1.0220	1.0285	1.0220	1.0285	1.0220	1.0307	1.0242
1983	1.0103	1.0228	1.0103	1.0228	1.0103	1.0228	1.0103	1.0228	1.0061	1.0186
1984	1.0261	1.0603	1.0261	1.0603	1.0261	1.0603	1.0261	1.0603	1.0147	1.0489
1985	0.8578	0.8861	0.8578	0.8861	0.8578	0.8861	0.8578	0.8861	0.8484	0.8767
1986	0.6526	0.6840	0.6395	0.6715	0.6563	0.6873	0.6517	0.6827	0.6194	0.6350
1987	0.6546	0.6780	0.6584	0.6766	0.6591	0.6823	0.6586	0.6802	0.6266	0.6346
1988	0.5482	0.5647	0.5106	0.5146	0.5855	0.5974	0.5396	0.5531	0.5048	0.5028
1989	0.5041	0.5306	0.4908	0.5114	0.5354	0.5560	0.5109	0.5358	0.4581	0.4686
1990	0.5137	0.5043	0.5550	0.5363	0.4753	0.4718	0.5261	0.5137	0.5208	0.5003
1991	0.4500	0.4576	0.5007	0.4966	0.4293	0.4412	0.4617	0.4672	0.4642	0.4545
1992	0.5553	0.5499	0.6060	0.5871	0.5106	0.5092	0.5639	0.5558	0.5506	0.5349
1993	0.7297	0.6692	0.7302	0.6746	0.7037	0.6653	0.7249	0.6662	0.7386	0.6868
1994	0.6918	0.5908	0.6410	0.5618	0.6927	0.5919	0.6893	0.5894	0.7001	0.6067
1995	0.7549	0.6813	0.7935	0.7149	0.7847	0.6896	0.7628	0.6876	0.8163	0.7369
1996	0.5823	0.5240	0.5630	0.5175	0.6193	0.5627	0.5777	0.5222	0.6517	0.5982
1997	0.5272	0.4830	0.5624	0.5143	0.5000	0.4620	0.5379	0.4912	0.6050	0.5518
1998	0.5785	0.5650	0.5981	0.5766	0.5381	0.5199	0.5858	0.5698	0.6481	0.6218
1999	0.5767	0.5488	0.5914	0.5602	0.5471	0.5234	0.5872	0.5567	0.6287	0.5966
2000	0.5180	0.4608	0.5139	0.4565	0.5137	0.4645	0.5173	0.4608	0.5678	0.5097
2001	0.6085	0.5570	0.6246	0.5652	0.6014	0.5534	0.6158	0.5614	0.6787	0.6211
2002	0.8725	0.7052	0.7443	0.6125	0.8384	0.6854	0.7933	0.6522	0.8256	0.6975
2003	0.6236	0.5146	0.6389	0.5236	0.6027	0.5094	0.6341	0.5197	0.7158	0.6039
2004	0.6515	0.5942	0.6697	0.5981	0.6574	0.5851	0.6564	0.5963	0.6229	0.5840
2005	0.5424	0.4992	0.5393	0.4891	0.6863	0.6049	0.5393	0.4950	0.5037	0.4773

Table 5. (cont.)

Year	Base w08	Base w05	Reduced Base w08	Reduced Base w05	Base SxS w08	Base SxS w05	GLMM w08	GLMM w05	GAM w09	GAM w06
2006	0.3649	0.3211	0.3429	0.3126	0.3739	0.3301	0.3688	0.3250	0.3535	0.3299
2007	0.2773	0.2292	0.3160	0.2520	0.3030	0.2502	0.2853	0.2350	0.3251	0.2671
2008	0.5740	0.4303	0.5219	0.4191	0.5385	0.3998	0.5640	0.4255	0.5628	0.4591
2009	0.7243	0.5343	0.6807	0.5150	0.6423	0.4726	0.7096	0.5258	0.8512	0.6604
2010	0.9508	0.6697	0.6874	0.5076	0.9390	0.6569	0.9342	0.6609	0.9324	0.7227
2011	0.8732	0.6357	0.7379	0.5466	0.9011	0.6602	0.8484	0.6201	1.0022	0.7747
2012	1.0634	0.7603	0.7461	0.5422	0.9973	0.7140	0.9810	0.7028	1.0895	0.8305
2013	1.0010	0.6972	0.8397	0.5887	1.0250	0.7256	0.9661	0.6750	1.3253	0.9863
2014	1.1591	0.8217	0.8806	0.6272	1.0151	0.7170	1.1360	0.8064	1.5122	1.1328
2015	1.2742	0.9133	1.0333	0.7326	1.3533	0.9653	1.2761	0.9124	1.8589	1.3981
2016	1.1783	0.8507	1.0211	0.7325	1.0588	0.7658	1.1492	0.8317	1.7870	1.3565
2017	1.2231	0.8799	0.8565	0.6058	1.4476	1.0111	1.2208	0.8770	1.5097	1.1476
2018	2.0725	1.3759	1.2316	0.8529	2.3484	1.5283	1.4559	1.0172	1.7455	1.3194
2019	2.0091	1.3274	1.1784	0.8115	3.3062	2.1012	1.4525	1.0036	1.6289	1.2226
2020	2.6460	1.7949	1.0861	0.7990	2.0534	1.4316	1.5856	1.1344	1.5748	1.2369

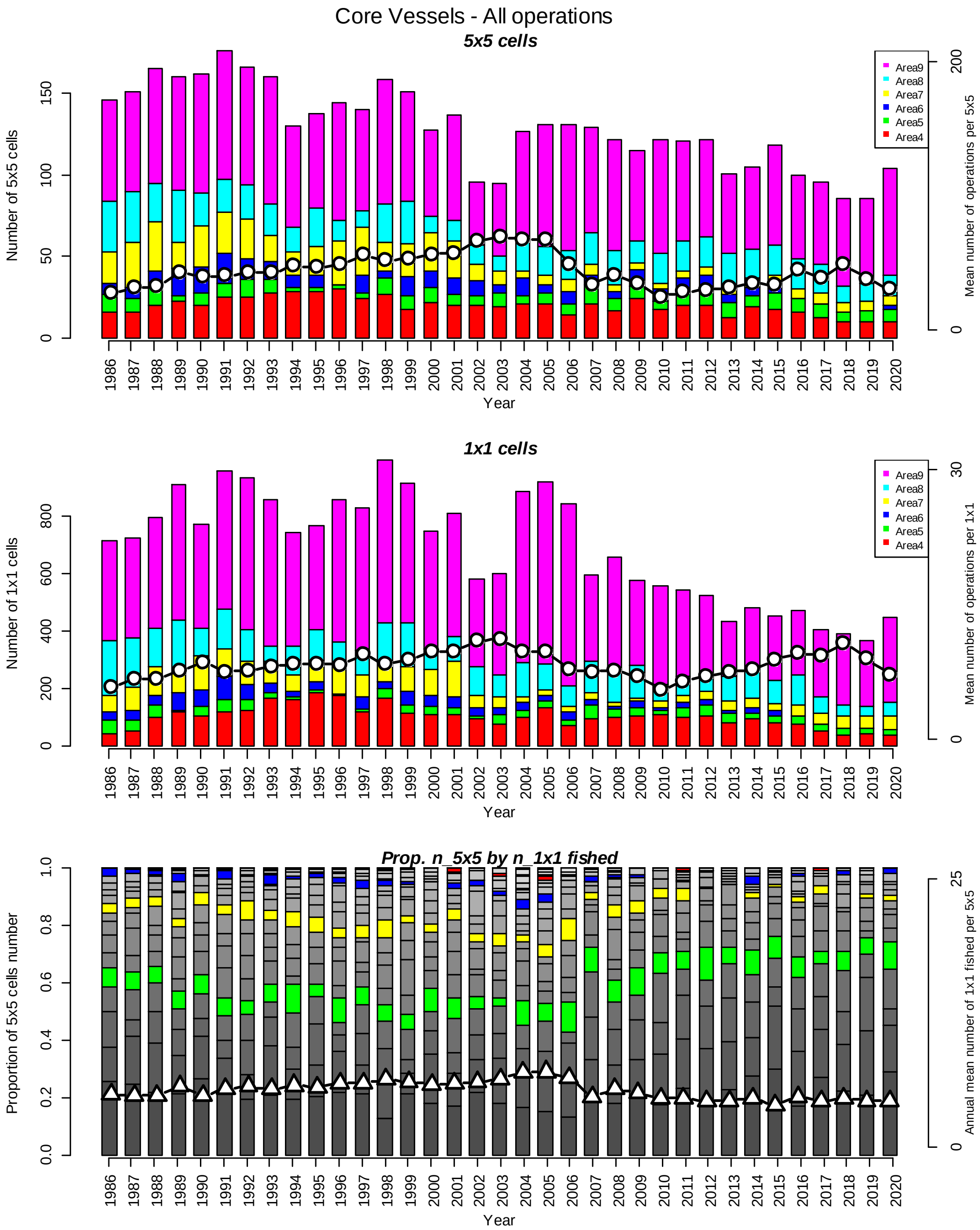


Fig. 1a. Number of cells in the core vessel for <u>all operations</u>.

(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.

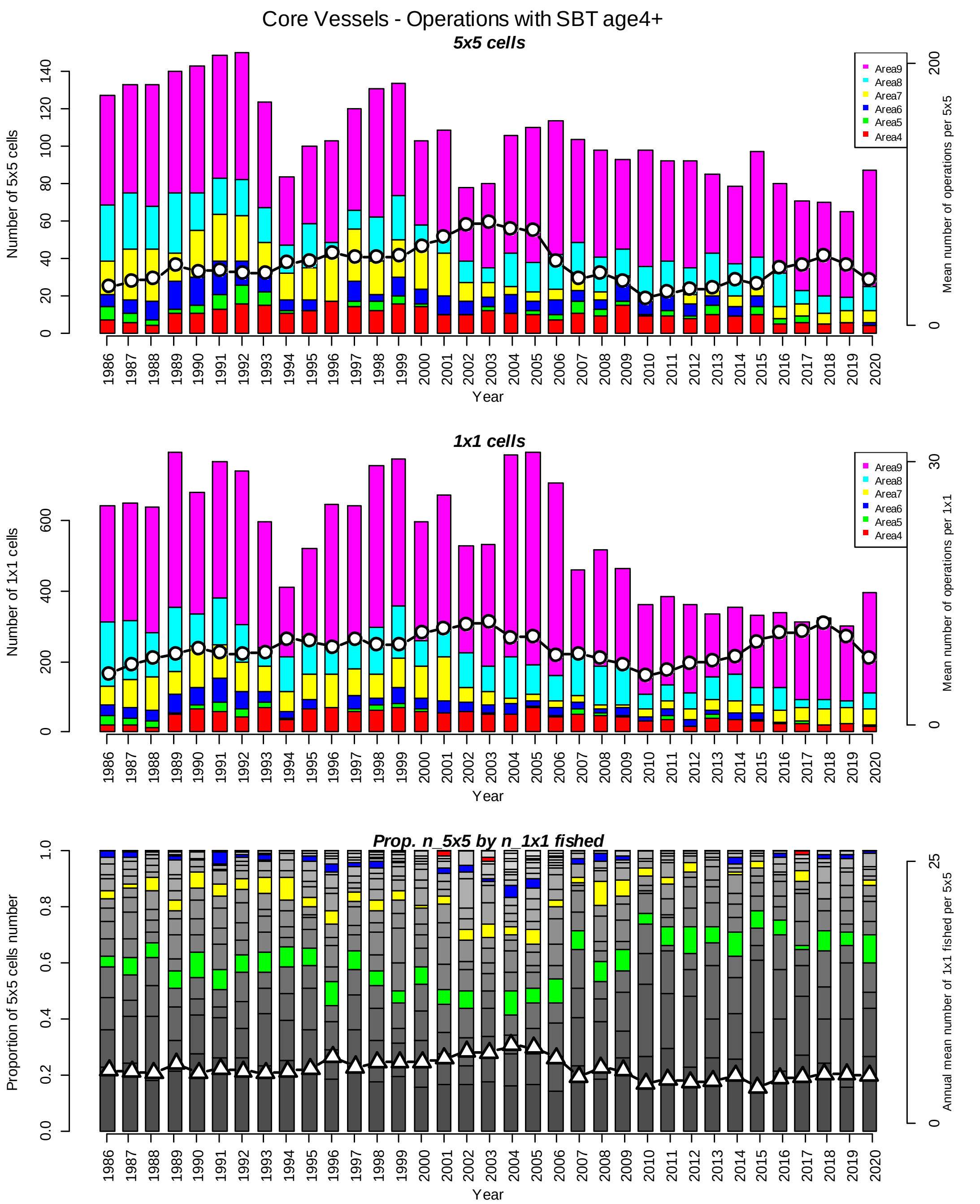
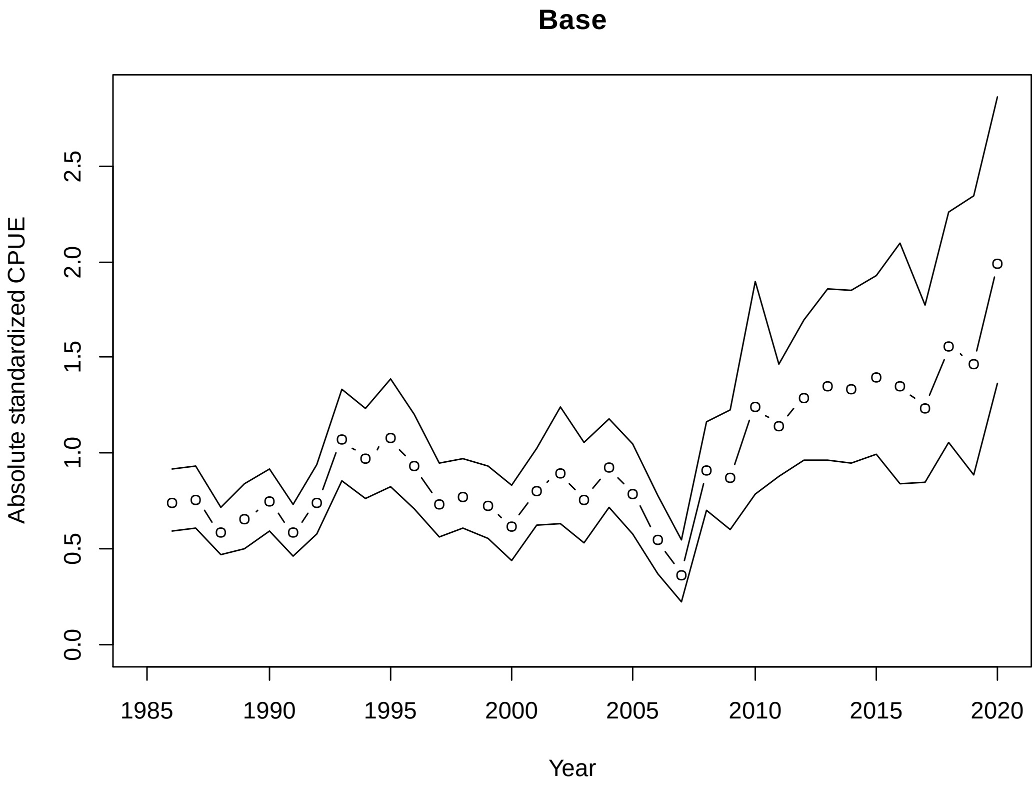


Fig. 1b. Number of cells in the core vessel for <u>SBT 4+ catch positive</u>. See explanation in Fig. 1a.



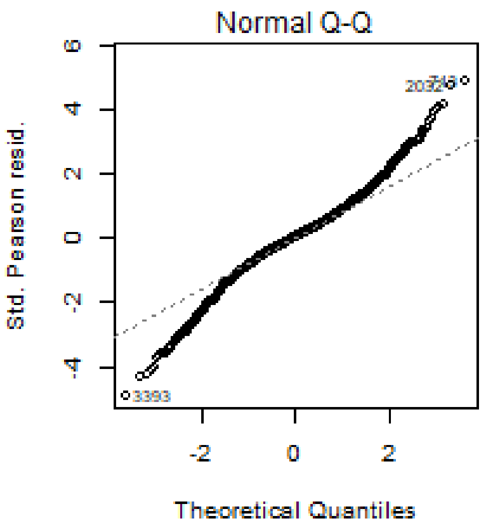


Fig. 2. Standardized CPUE (ls-mean with 95% confidence interval) of the core vessel data (upper panel) and its QQ plot of residual (lower panel) for Base case.

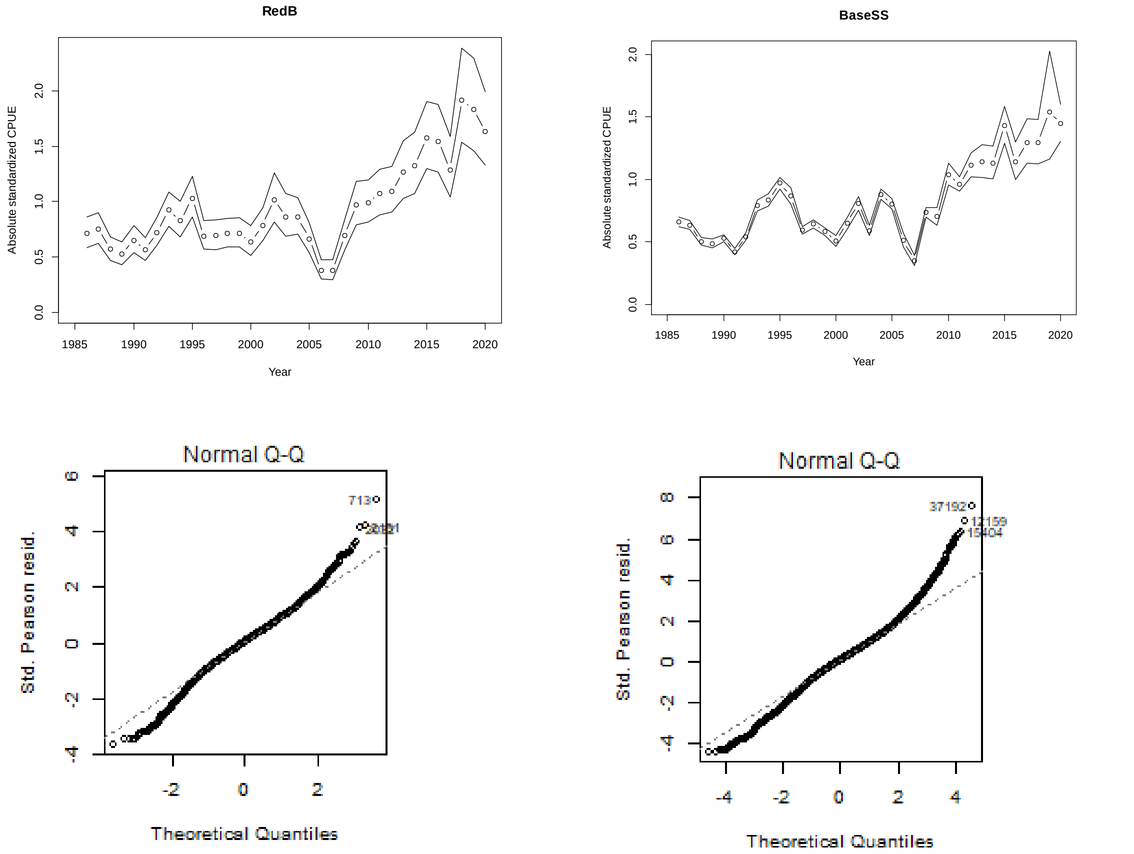
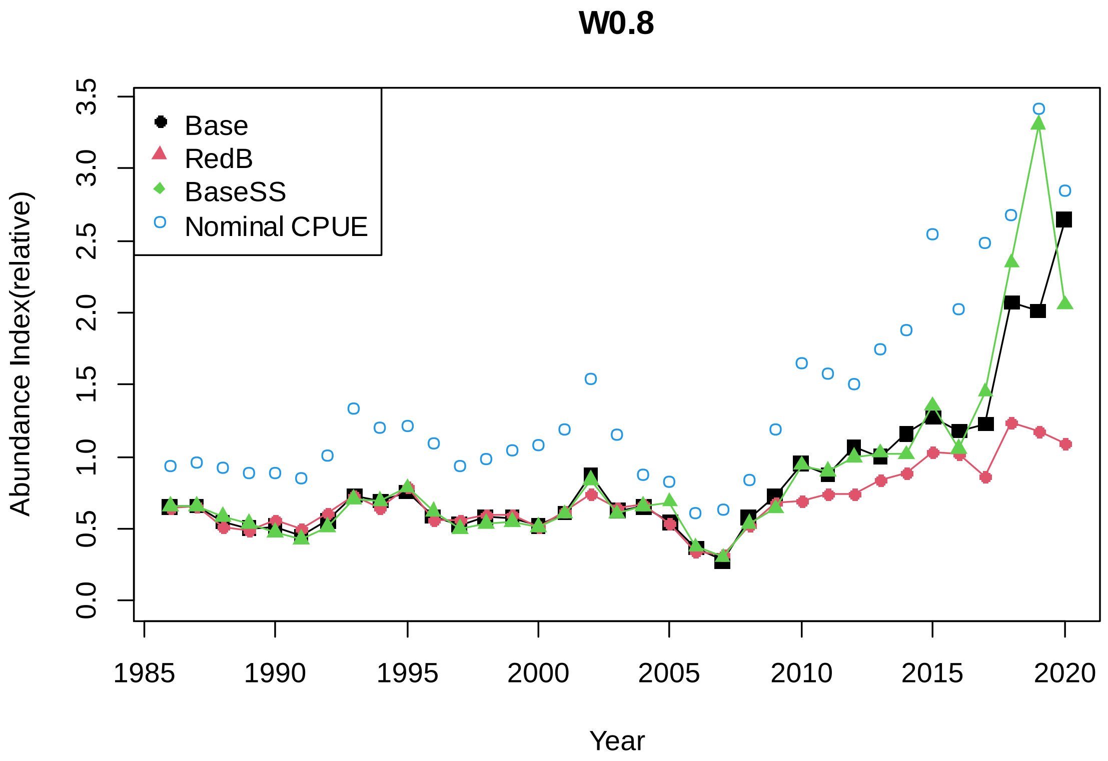


Fig. 3. Standardized CPUE (ls-mean with 95% confidence interval) of the core vessel data (upper panel) and its QQ plot of residual (lower panel) for monitoring series. Left panels for reduced base case and right panels for shot-by-shot data with base case GLM model.



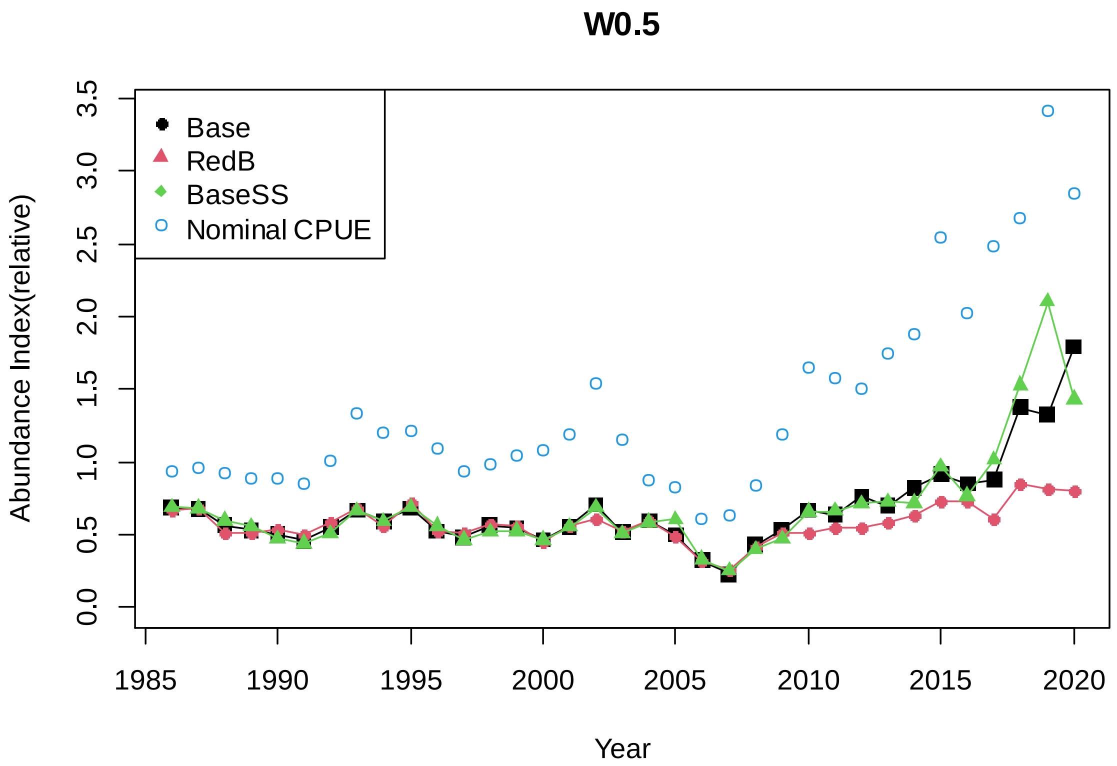
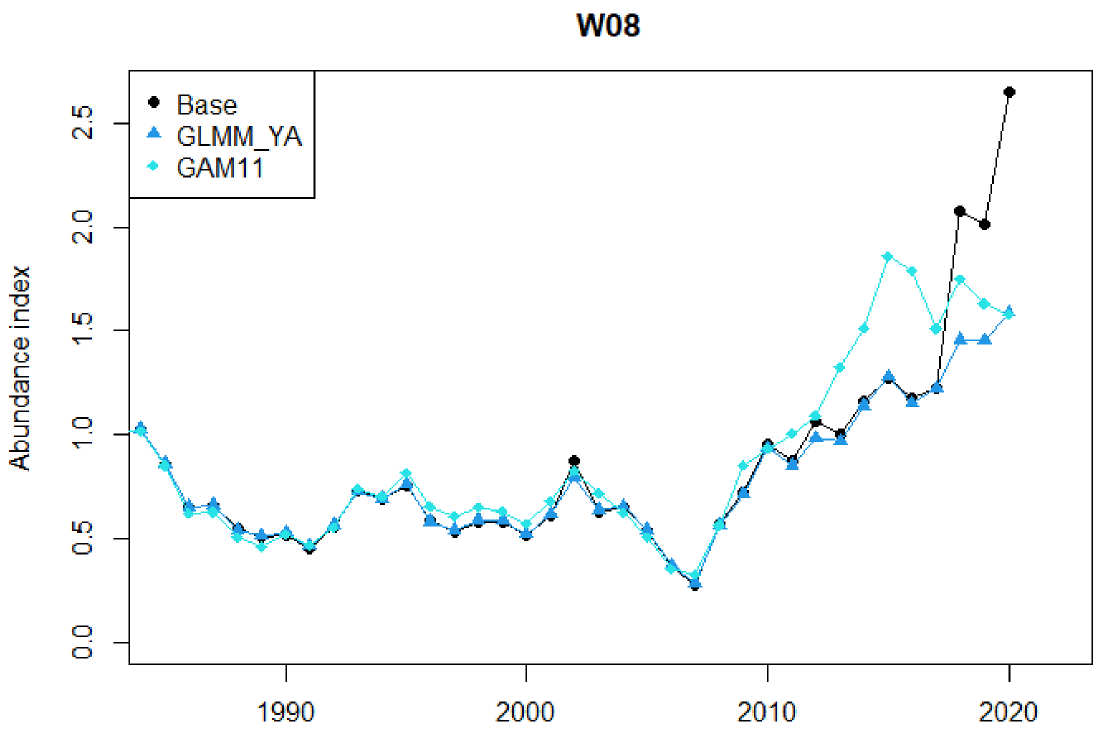


Fig. 4. Area weighed standardized CPUE from three GLMs. Nominal CPUE of the core vessels is also shown.



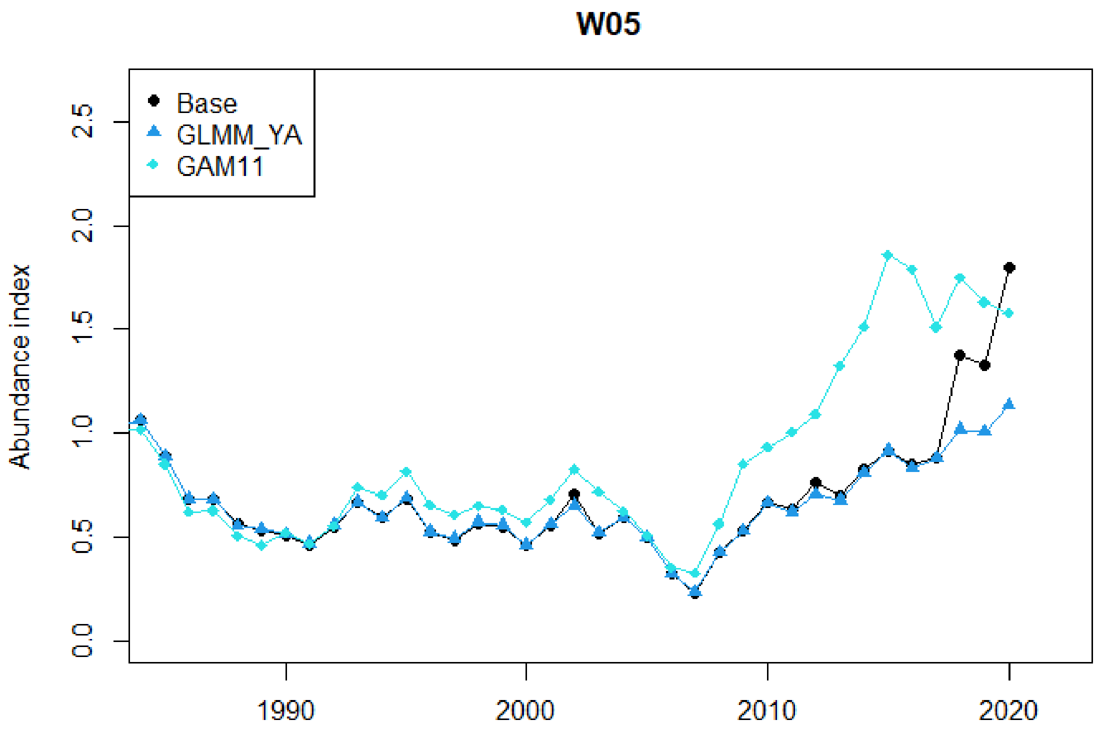


Fig. 5. Area weighed standardized CPUE series from GLM (Base), GLMM and GMA. In GAM11, the index is for W0.9 in the upper panel and W0.6 in the lower panel.