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2022 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 2022

伊藤智幸・高橋紀夫

Tomoyuki ITOH and Norio TAKAHASHI

水産研究・教育機構　水産資源研究所

Fisheries Resources Institute,

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 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 2021 年にまで更新した。2021 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 年間の平均と同じ水準であった。

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 2021. The index values in 2021, in W0.8 and W0.5 by the base GLM model, are at the same level as 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 2022. A new CPUE index is being developed for CCSBT (Itoh 2022), but the previous series of CPUE indexes has also been updated for comparison.

Data preparation

The dataset used was created from shot-by-shot records of Japanese longline fishing from Japan (1986-2021), 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 2021.

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 203,333 were extracted from entire vessels (Table 1). The number of core vessels chosen ranged from 35 to 107 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 4.1.2). 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:

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

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

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

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

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

The area weighted CPUE value in the latest year (2021), 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 2021 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 2021 using the base GLM model (1.289) is about the same as 97% of the average (1.322) for the past 10 years. That of W0.5 in 2021 (0.932) is as same as the average (0.936) for 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 and decreased largely. 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

[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.

dataset jump in 2018 while drop in 2021.

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 change since 2018 (Fig. 5). Those by GAM11 are similar until 2010 and show earlier increase which reaches a peak in 2015, and show decrease up to 2021.

Reference

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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	4,068	35
1987	26,759	0	0	26,759	4,804	41
1988	24,418	0	0	24,418	5,353	49
1989	25,471	1,156	0	25,471	6,897	63
1990	20,878	504	475	21,055	6,546	73
1991	19,980	1,204	460	20,088	7,165	73
1992	19,449	1,717	499	19,449	7,102	86
1993	17,284	2,001	486	17,463	6,851	83
1994	14,272	1,394	268	14,327	6,227	92
1995	13,977	800	373	14,146	6,456	97
1996	14,854	0	0	14,854	7,057	97
1997	16,701	0	379	16,777	7,832	93
1998	16,620	0	310	16,760	8,390	107
1999	14,720	0	306	14,800	8,290	101
2000	12,011	0	265	12,011	7,315	99
2001	14,273	0	198	14,307	8,028	103
2002	10,949	0	228	10,996	6,543	94
2003	11,857	0	294	11,928	6,742	93
2004	13,447	0	349	13,453	8,686	97
2005	14,046	0	198	14,046	8,992	97
2006	9,307	0	183	9,307	6,562	87
2007	5,768	0	387	5,818	4,495	84
2008	6,555	0	167	6,523	5,054	91
2009	4,723	0	231	4,753	4,093	74
2010	3,586	0	144	3,717	3,116	66
2011	4,261	0	151	4,413	3,496	64
2012	4,377	0	163	4,530	3,767	75
2013	3,990	0	148	3,978	3,334	69
2014	4,795	0	186	4,791	3,853	74
2015	5,114	0	181	5,114	4,135	74
2016	5,571	0	0	5,571	4,635	74
2017	4,633	0	0	4,625	3,881	72
2018	5,038	0	0	5,038	4,301	71
2019	3,960	0	0	3,960	3,382	68
2020	4,000	0	0	4,000	3,270	59
2021	3,870	0	0	3,870	2,615	48
Total	428,519	8,776	7,029	430,121	203,333	

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)	-2.0028	0.2210	-9.06	0.000
year1987	-0.1409	0.2888	-0.49	0.626
year1988	-0.4235	0.2747	-1.54	0.123
year1989	0.1445	0.3376	0.43	0.669
year1990	0.0030	0.2906	0.01	0.992
year1991	0.3366	0.2791	1.21	0.228
year1992	0.1372	0.2676	0.51	0.608
year1993	0.6838	0.2717	2.52	0.012
year1994	0.0949	0.2649	0.36	0.720
year1995	0.4171	0.2726	1.53	0.126
year1996	0.3747	0.2657	1.41	0.158
year1997	0.0647	0.2972	0.22	0.828
year1998	-0.2443	0.2791	-0.88	0.381
year1999	-0.3975	0.3386	-1.17	0.241
year2000	-0.4861	0.3243	-1.50	0.134
year2001	-0.1366	0.2978	-0.46	0.647
year2002	-0.3454	0.3786	-0.91	0.362
year2003	-0.2075	0.2896	-0.72	0.474
year2004	-0.0524	0.2896	-0.18	0.856
year2005	-0.2638	0.3052	-0.86	0.387
year2006	-0.5387	0.3380	-1.59	0.111
year2007	-0.3017	0.2794	-1.08	0.280
year2008	0.0844	0.2805	0.30	0.764
year2009	-0.2401	0.2843	-0.84	0.398
year2010	-0.5497	0.2848	-1.93	0.054
year2011	-0.3919	0.2621	-1.50	0.135
year2012	-0.6011	0.2620	-2.29	0.022
year2013	-0.4418	0.2759	-1.60	0.109
year2014	-0.7286	0.2911	-2.50	0.012
year2015	-0.3394	0.2790	-1.22	0.224
year2016	-0.5182	0.2898	-1.79	0.074
year2017	-0.6615	0.2902	-2.28	0.023
year2018	-0.6753	0.3382	-2.00	0.046
year2019	-0.8876	0.3785	-2.34	0.019
year2020	-0.7616	0.3561	-2.14	0.033
year2021	-0.1036	0.4092	-0.25	0.800
month5	1.0153	0.1016	9.99	0.000
month6	1.1713	0.0938	12.49	0.000
month7	1.6011	0.0938	17.06	0.000
month8	1.6576	0.1057	15.68	0.000
month9	1.8604	0.1330	13.99	0.000
area7	1.8322	0.4137	4.43	0.000
area8	-0.7577	0.3683	-2.06	0.040
area9	1.4914	0.3450	4.32	0.000
lat535	1.3952	0.3556	3.92	0.000
lat540	0.9215	0.3963	2.32	0.020
lat545	0.7450	0.4902	1.52	0.129
cpue.bet	-0.1471	0.0101	-14.56	0.000
cpue.yft	-0.0750	0.0065	-11.63	0.000
month5_area7	-0.8673	0.1300	-6.67	0.000
month6_area7	-1.0131	0.1300	-7.79	0.000
month7_area7	-1.4150	0.1596	-8.87	0.000
month8_area7	-1.8682	0.3221	-5.80	0.000
month9_area7	-2.2291	0.2453	-9.09	0.000
month5_area8	-0.6134	0.1884	-3.26	0.001
month6_area8	0.1348	0.2011	0.67	0.503
month7_area8	0.3976	0.1796	2.21	0.027
month8_area8	0.5392	0.1776	3.04	0.002
month9_area8	0.0264	0.1961	0.13	0.893
month5_area9	-0.8491	0.1177	-7.21	0.000
month6_area9	-0.9308	0.1112	-8.37	0.000
month7_area9	-1.1267	0.1123	-10.03	0.000
month8_area9	-1.0938	0.1277	-8.57	0.000
month9_area9	-1.4472	0.1577	-9.18	0.000
year1987_lat535	-0.0942	0.5000	-0.19	0.851
year1988_lat535	-0.6401	0.4573	-1.40	0.162
year1989_lat535	-0.5208	0.4970	-1.05	0.295
year1990_lat535	-0.2690	0.4572	-0.59	0.556
year1991_lat535	-0.6346	0.4361	-1.46	0.146
year1992_lat535	-0.4575	0.4340	-1.05	0.292
year1993_lat535	-0.7127	0.4360	-1.63	0.102
year1994_lat535	-0.2876	0.4653	-0.62	0.537
year1995_lat535	-0.7434	0.4555	-1.63	0.103
year1996_lat535	-0.7492	0.4425	-1.69	0.091
year1997_lat535	0.0940	0.4626	0.20	0.839
year1998_lat535	-0.2220	0.4334	-0.51	0.608
year1999_lat535	0.1676	0.4808	0.35	0.727
year2000_lat535	0.4105	0.4773	0.86	0.390
year2001_lat535	-0.2009	0.4587	-0.44	0.662
year2002_lat535	0.2852	0.5225	0.55	0.585
year2003_lat535	0.4971	0.4725	1.05	0.293
year2004_lat535	0.2022	0.4663	0.43	0.665
year2005_lat535	-0.2514	0.4668	-0.54	0.590
year2006_lat535	0.2197	0.4977	0.44	0.659
year2007_lat535	-0.3262	0.4515	-0.72	0.470
year2008_lat535	0.2711	0.4738	0.57	0.567
year2009_lat535	1.1275	0.4638	2.43	0.015
year2010_lat535	0.6005	0.4773	1.26	0.208
year2011_lat535	0.3012	0.4747	0.63	0.526
year2012_lat535	-0.4901	0.4509	-1.09	0.277
year2013_lat535	-0.0593	0.5110	-0.12	0.908
year2014_lat535	0.5936	0.4737	1.25	0.210
year2015_lat535	0.4253	0.4827	0.88	0.378
year2016_lat535	0.7706	0.4797	1.61	0.108
year2017_lat535	0.5551	0.4802	1.16	0.248
year2018_lat535	1.6113	0.5462	2.95	0.003
year2019_lat535	1.7231	0.5579	3.09	0.002
year2020_lat535	1.2584	0.5423	2.32	0.020
year2021_lat535	1.4272	0.6126	2.33	0.020
year1987_lat540	0.4866	0.5575	0.87	0.383
year1988_lat540	-0.3777	0.5176	-0.73	0.466
year1989_lat540	-0.0490	0.5570	-0.09	0.930
year1990_lat540	0.4663	0.5301	0.88	0.379
year1991_lat540	0.0527	0.4944	0.11	0.915
year1992_lat540	0.1040	0.4931	0.21	0.833
year1993_lat540	0.8849	0.4957	1.79	0.074
year1994_lat540	1.1147	0.5270	2.12	0.034
year1995_lat540	0.3255	0.5148	0.63	0.527
year1996_lat540	0.5365	0.5051	1.06	0.288
year1997_lat540	0.9422	0.5249	1.80	0.073
year1998_lat540	0.4828	0.4930	0.98	0.327
year1999_lat540	1.0587	0.5372	1.97	0.049
year2000_lat540	1.4128	0.5377	2.63	0.009
year2001_lat540	0.8109	0.5239	1.55	0.122
year2002_lat540	0.6935	0.6265	1.11	0.268
year2003_lat540	0.8576	0.5603	1.53	0.126
year2004_lat540	0.3965	0.5249	0.76	0.450
year2005_lat540	-0.0465	0.5269	-0.09	0.930
year2006_lat540	0.7350	0.5504	1.34	0.182
year2007_lat540	-0.1072	0.5155	-0.21	0.835
year2008_lat540	1.4958	0.5332	2.81	0.005
year2009_lat540	1.9510	0.5339	3.65	0.000
year2010_lat540	1.7851	0.5406	3.30	0.001
year2011_lat540	1.1206	0.5485	2.04	0.041
year2012_lat540	0.0037	0.5163	0.01	0.994
year2013_lat540	0.4007	0.5865	0.68	0.494
year2014_lat540	1.4273	0.5719	2.50	0.013
year2015_lat540	1.8710	0.5544	3.37	0.001
year2016_lat540	1.5207	0.5677	2.68	0.007
year2017_lat540	2.7530	0.6158	4.47	0.000
year2018_lat540	4.5111	0.7718	5.85	0.000
year2019_lat540	3.8336	0.6761	5.67	0.000
year2020_lat540	3.2146	0.6594	4.87	0.000
year2021_lat540	2.8457	0.6986	4.07	0.000
year1987_lat545	0.7318	0.6807	1.07	0.282
year1988_lat545	-0.1849	0.6154	-0.30	0.764
year1989_lat545	0.0662	0.6751	0.10	0.922
year1990_lat545	0.7609	0.6227	1.22	0.222
year1991_lat545	-0.2423	0.6286	-0.39	0.700
year1992_lat545	-0.0062	0.6583	-0.01	0.992
year1993_lat545	0.8905	0.6403	1.39	0.164
year1994_lat545	0.8535	0.7180	1.19	0.235
year1995_lat545	-0.1911	0.7054	-0.27	0.787
year1996_lat545	0.5827	0.6660	0.87	0.382
year1997_lat545	0.9738	0.6657	1.46	0.144
year1998_lat545	0.8043	0.6362	1.26	0.206
year1999_lat545	1.2120	0.6735	1.80	0.072
year2000_lat545	1.1000	0.6988	1.57	0.116
year2001_lat545	0.9601	0.6501	1.48	0.140
year2002_lat545	0.7862	0.7823	1.01	0.315
year2003_lat545	1.0733	0.7581	1.42	0.157
year2004_lat545	0.7425	0.6896	1.08	0.282
year2005_lat545	0.5610	0.6754	0.83	0.406
year2006_lat545	1.3233	0.7731	1.71	0.087
year2007_lat545	-0.5031	0.8069	-0.62	0.533
year2008_lat545	1.9893	0.6574	3.03	0.002
year2009_lat545	1.8811	0.8252	2.28	0.023
year2010_lat545	1.8479	0.9681	1.91	0.056
year2011_lat545	1.0898	0.6841	1.59	0.111
year2012_lat545	0.4337	0.7323	0.59	0.554
year2013_lat545	0.6951	0.8261	0.84	0.400
year2014_lat545	1.5384	0.8097	1.90	0.058
year2015_lat545	1.5472	0.8039	1.92	0.054
year2016_lat545	1.3134	0.9412	1.40	0.163
year2017_lat545	2.8605	0.8334	3.43	0.001
year2018_lat545	4.6023	0.9552	4.82	0.000
year2019_lat545	4.0741	1.0125	4.02	0.000
year2020_lat545	3.7116	0.8721	4.26	0.000
year2021_lat545	3.0966	1.0316	3.00	0.003
year1987_area7	-0.4984	0.5566	-0.90	0.371
year1988_area7	0.3855	0.5081	0.76	0.448
year1989_area7	-0.3795	0.5222	-0.73	0.467
year1990_area7	-0.5928	0.5156	-1.15	0.250
year1991_area7	-0.7817	0.4881	-1.60	0.109
year1992_area7	-0.1879	0.4938	-0.38	0.704
year1993_area7	-1.5238	0.5010	-3.04	0.002
year1994_area7	-0.5896	0.5742	-1.03	0.305
year1995_area7	0.0089	0.5142	0.02	0.986
year1996_area7	-0.7169	0.5139	-1.39	0.163
year1997_area7	-0.8787	0.5133	-1.71	0.087
year1998_area7	-0.3852	0.5012	-0.77	0.442
year1999_area7	-0.5812	0.5025	-1.16	0.247
year2000_area7	-0.9129	0.4979	-1.83	0.067
year2001_area7	-0.6254	0.5074	-1.23	0.218
year2002_area7	-0.0858	0.5881	-0.15	0.884
year2003_area7	-1.1171	0.5677	-1.97	0.049
year2004_area7	-0.7630	0.5364	-1.42	0.155
year2005_area7	-0.4426	0.5518	-0.80	0.423
year2006_area7	-0.7334	0.5317	-1.38	0.168
year2007_area7	-0.0756	0.5347	-0.14	0.888
year2008_area7	-1.1371	0.5573	-2.04	0.041
year2009_area7	-0.9222	0.5611	-1.64	0.100
year2010_area7	-0.0766	0.5677	-0.13	0.893
year2011_area7	0.2916	0.5773	0.51	0.613
year2012_area7	1.7426	0.5560	3.13	0.002
year2013_area7	0.9028	0.6162	1.47	0.143
year2014_area7	0.4265	0.5943	0.72	0.473
year2015_area7	-0.3748	0.5937	-0.63	0.528
year2016_area7	0.1165	0.6081	0.19	0.848
year2017_area7	-1.0512	0.6538	-1.61	0.108
year2018_area7	-2.7831	0.7835	-3.55	0.000
year2019_area7	-1.8928	0.6665	-2.84	0.005
year2020_area7	-1.2299	0.6536	-1.88	0.060
year2021_area7	-1.6103	0.6519	-2.47	0.014
year1987_area8	0.0406	0.4766	0.09	0.932
year1988_area8	0.8259	0.4401	1.88	0.061
year1989_area8	0.1284	0.4424	0.29	0.772
year1990_area8	0.1585	0.4480	0.35	0.723
year1991_area8	-0.0287	0.4212	-0.07	0.946
year1992_area8	0.1756	0.4183	0.42	0.675
year1993_area8	-0.1543	0.4227	-0.37	0.715
year1994_area8	0.3225	0.4708	0.69	0.493
year1995_area8	0.4419	0.4373	1.01	0.312
year1996_area8	0.2327	0.4744	0.49	0.624
year1997_area8	-0.4065	0.4696	-0.87	0.387
year1998_area8	0.4943	0.4156	1.19	0.234
year1999_area8	0.1497	0.4180	0.36	0.720
year2000_area8	0.2134	0.4666	0.46	0.647
year2001_area8	0.1539	0.4520	0.34	0.733
year2002_area8	0.0749	0.4661	0.16	0.872
year2003_area8	-0.2271	0.5021	-0.45	0.651
year2004_area8	0.6923	0.4535	1.53	0.127
year2005_area8	1.2950	0.4546	2.85	0.004
year2006_area8	0.2564	0.4519	0.57	0.570
year2007_area8	0.4345	0.4411	0.98	0.325
year2008_area8	-0.6358	0.4607	-1.38	0.168
year2009_area8	-1.2309	0.4477	-2.75	0.006
year2010_area8	0.3903	0.4625	0.84	0.399
year2011_area8	0.2995	0.4659	0.64	0.520
year2012_area8	1.2522	0.4453	2.81	0.005
year2013_area8	0.9856	0.4953	1.99	0.047
year2014_area8	0.5329	0.4483	1.19	0.235
year2015_area8	0.2340	0.4712	0.50	0.620
year2016_area8	0.2953	0.4563	0.65	0.518
year2017_area8	0.0478	0.4684	0.10	0.919
year2018_area8	-0.3992	0.5199	-0.77	0.443
year2019_area8	-0.2424	0.5193	-0.47	0.641
year2020_area8	0.8136	0.5016	1.62	0.105
year2021_area8	-1.3705	0.5277	-2.60	0.009
year1987_area9	0.0103	0.4657	0.02	0.982
year1988_area9	0.9706	0.4267	2.27	0.023
year1989_area9	-0.1230	0.4346	-0.28	0.777
year1990_area9	-0.4826	0.4343	-1.11	0.267
year1991_area9	-0.4045	0.3948	-1.02	0.306
year1992_area9	-0.1453	0.4012	-0.36	0.717
year1993_area9	-0.9528	0.4006	-2.38	0.017
year1994_area9	-0.8671	0.4385	-1.98	0.048
year1995_area9	-0.3416	0.4217	-0.81	0.418
year1996_area9	-0.7405	0.4099	-1.81	0.071
year1997_area9	-0.9623	0.4107	-2.34	0.019
year1998_area9	-0.0223	0.3899	-0.06	0.954
year1999_area9	-0.4466	0.4076	-1.10	0.273
year2000_area9	-0.8077	0.4127	-1.96	0.050
year2001_area9	-0.2535	0.4161	-0.61	0.542
year2002_area9	0.4412	0.4996	0.88	0.377
year2003_area9	-0.2729	0.4686	-0.58	0.560
year2004_area9	-0.2796	0.4226	-0.66	0.508
year2005_area9	0.2247	0.4147	0.54	0.588
year2006_area9	-0.6989	0.4200	-1.66	0.096
year2007_area9	-0.2060	0.4161	-0.50	0.621
year2008_area9	-1.5617	0.4377	-3.57	0.000
year2009_area9	-1.3968	0.4346	-3.21	0.001
year2010_area9	-0.6219	0.4345	-1.43	0.152
year2011_area9	-0.0920	0.4568	-0.20	0.840
year2012_area9	1.3626	0.4252	3.20	0.001
year2013_area9	0.8599	0.5017	1.71	0.087
year2014_area9	0.3723	0.4592	0.81	0.418
year2015_area9	-0.1092	0.4578	-0.24	0.811
year2016_area9	0.0678	0.4633	0.15	0.884
year2017_area9	-0.7328	0.5239	-1.40	0.162
year2018_area9	-2.46745	0.680271	-3.62715	0.000291
year2019_area9	-1.63398	0.542229	-3.01345	0.002602
year2020_area9	-1.5252	0.544457	-2.80132	0.005118
year2021_area9	-1.5937	0.5578	-2.86	0.004

Table 3. ANOVA statistics

Base	**Type_2**			
name	Sum Sq	Df	F value	Pr(>F)
year	324.98	35	18.601	1.048E-103
month	233.63	5	93.607	1.427E-92
area	93.41	3	62.374	3.010E-39
lat5	284.76	3	190.158	5.813E-114
cpue.bet	105.80	1	211.947	1.286E-46
cpue.yft	67.50	1	135.223	1.121E-30
month:area	152.01	15	20.302	2.371E-53
year:lat5	185.89	105	3.547	1.926E-29
year:area	183.19	105	3.495	1.130E-28
Residuals	1,690.20	3,386		
Base	**Type_3**			
name	Sum Sq	Df	F value	Pr(>F)
(Intercept)	47.50	1	95.151	3.447E-22
year	76.41	35	4.374	2.915E-16
month	202.39	5	81.091	1.284E-80
area	76.84	3	51.312	1.992E-32
lat5	350.59	3	234.113	4.964E-138
cpue.bet	105.80	1	211.947	1.286E-46
cpue.yft	67.50	1	135.223	1.121E-30
month:area	152.01	15	20.302	2.371E-53
year:lat5	185.89	105	3.547	1.926E-29
year:area	183.19	105	3.495	1.12997E-28
Residuals	1,690.20	3,386		

RedB	**Type_2**			
name	Sum Sq	Df	F value	Pr(>F)
year	324.98	35	15.564	1.423E-85
month	273.75	5	91.776	3.642E-91
area	129.67	3	72.457	1.698E-45
lat5	345.04	3	192.795	6.166E-116
cpue.bet	191.18	1	320.467	1.013E-68
cpue.yft	68.62	1	115.029	1.939E-26
month:area	176.63	15	19.739	7.144E-52
Residuals	2,145.23	3,596		
RedB	**Type_3**			
name	Sum Sq	Df	F value	Pr(>F)
(Intercept)	60.06	1	100.678	2.191E-23
year	324.98	35	15.564	1.423E-85
month	210.18	5	70.463	1.600E-70
area	172.97	3	96.647	3.696E-60
lat5	345.04	3	192.795	6.166E-116
cpue.bet	191.18	1	320.467	1.013E-68
cpue.yft	68.62	1	115.029	1.939E-26
month:area	176.63	15	19.739	7.144E-52
Residuals	2,145.23	3,596		

BaseSS	**Type_2**			
name	Sum Sq	Df	F value	Pr(>F)
year	20,240.12	35	792.830	0.000E+00
month	5,357.72	5	1,469.080	0.000E+00
area	936.58	3	428.016	3.204E-277
lat5	8,406.69	3	3,841.835	0.000E+00
cpue.bet	4,165.97	1	5,711.520	0.000E+00
cpue.yft	3,124.15	1	4,283.189	0.000E+00
month:area	9,254.54	15	845.860	0.000E+00
year:lat5	9,940.89	105	129.799	0.000E+00
year:area	11,325.54	105	147.878	0.000E+00
Residuals	148,110	203,058		
BaseSS	**Type_3**			
name	Sum Sq	Df	F value	Pr(>F)
(Intercept)	55.49	1	76.078	2.747E-18
year	2,072.87	35	81.197	0.000E+00
month	5,796.77	5	1,589.466	0.000E+00
area	1,739.00	3	794.719	0.000E+00
lat5	9,333.20	3	4,265.250	0.000E+00
cpue.bet	4,165.97	1	5,711.520	0.000E+00
cpue.yft	3,124.15	1	4,283.189	0.000E+00
month:area	9,254.54	15	845.860	0.000E+00
year:lat5	9,940.89	105	129.799	0.000E+00
year:area	11,325.54	105	147.878	0.000E+00
Residuals	148,110	203,058		

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

Method	Model	AIC	BIC
GLM	Base	8,109	9,815
GLM	Reduced Base	8,561	8,965
GLMM	Random=Year_Area	8,492	9,553

Table 5. Area weighted standardized CPUE

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
1969	2.2841	2.4934	2.2841	2.4934	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	2.2268	2.4169	2.2268	2.4169
1971	2.0654	2.2054	2.0654	2.2054	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	2.1669	2.2273	2.1669	2.2273
1973	1.8263	1.9271	1.8263	1.9271	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	1.8989	1.9710	1.8989	1.9710
1975	1.4556	1.4974	1.4556	1.4974	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	1.8715	1.9279	1.8715	1.9279
1977	1.6556	1.6850	1.6556	1.6850	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	1.4300	1.3820	1.4300	1.3820
1979	1.1472	1.2558	1.1472	1.2558	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	1.3862	1.3852	1.3862	1.3852
1981	1.3103	1.2917	1.3103	1.2917	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	1.0285	1.0220	1.0285	1.0220
1983	1.0103	1.0228	1.0103	1.0228	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	1.0261	1.0603	1.0261	1.0603
1985	0.8578	0.8861	0.8578	0.8861	0.8578	0.8861	0.8578	0.8861	0.8578	0.8861
1986	0.6563	0.6848	0.6174	0.6482	0.6568	0.6868	0.6153	0.6308	0.6563	0.6848
1987	0.6569	0.6799	0.6604	0.6785	0.6590	0.6818	0.6440	0.6547	0.6569	0.6799
1988	0.5506	0.5666	0.5075	0.5114	0.5858	0.5971	0.5050	0.5055	0.5506	0.5666
1989	0.5095	0.5362	0.5010	0.5221	0.5361	0.5561	0.4718	0.4869	0.5095	0.5362
1990	0.5163	0.5057	0.5539	0.5355	0.4755	0.4717	0.5096	0.4936	0.5163	0.5057
1991	0.4529	0.4600	0.5009	0.4971	0.4280	0.4403	0.4653	0.4593	0.4529	0.4600
1992	0.5579	0.5521	0.6062	0.5881	0.5105	0.5092	0.5447	0.5327	0.5579	0.5521
1993	0.7127	0.6562	0.7273	0.6727	0.7024	0.6650	0.7132	0.6643	0.7127	0.6562
1994	0.6964	0.5945	0.6494	0.5692	0.6897	0.5901	0.6751	0.5768	0.6964	0.5945
1995	0.7401	0.6690	0.7865	0.7085	0.7835	0.6886	0.7774	0.6992	0.7401	0.6690
1996	0.5639	0.5097	0.5613	0.5158	0.6191	0.5624	0.6347	0.5827	0.5639	0.5097
1997	0.5327	0.4866	0.5634	0.5152	0.4996	0.4616	0.5869	0.5331	0.5327	0.4866
1998	0.5830	0.5680	0.6000	0.5782	0.5380	0.5197	0.6420	0.6166	0.5830	0.5680
1999	0.5785	0.5480	0.5909	0.5584	0.5430	0.5186	0.6111	0.5800	0.5785	0.5480
2000	0.5227	0.4639	0.5160	0.4582	0.5120	0.4634	0.5448	0.4865	0.5227	0.4639
2001	0.6078	0.5551	0.6209	0.5616	0.5938	0.5463	0.6538	0.5976	0.6078	0.5551
2002	0.8625	0.7022	0.7502	0.6166	0.8323	0.6817	0.8034	0.6597	0.8625	0.7022
2003	0.6131	0.5051	0.6242	0.5109	0.5919	0.5013	0.6683	0.5499	0.6131	0.5051
2004	0.6635	0.6024	0.6794	0.6060	0.6712	0.5946	0.6255	0.5904	0.6635	0.6024
2005	0.5545	0.5074	0.5466	0.4954	0.7032	0.6165	0.5036	0.4779	0.5545	0.5074

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	0.3528	0.3118	0.3414	0.3111	0.3719	0.3284	0.3450	0.3202	0.3528	0.3118
2007	0.2824	0.2356	0.3190	0.2574	0.3052	0.2546	0.2951	0.2374	0.2824	0.2356
2008	0.5855	0.4417	0.5288	0.4265	0.5439	0.4071	0.5168	0.4067	0.5855	0.4417
2009	0.7280	0.5462	0.6712	0.5133	0.6497	0.4867	0.7333	0.5487	0.7280	0.5462
2010	0.9596	0.6822	0.6958	0.5169	0.9616	0.6781	0.8369	0.6189	0.9596	0.6822
2011	0.8827	0.6501	0.7423	0.5544	0.9145	0.6786	0.9067	0.6711	0.8827	0.6501
2012	1.0820	0.7851	0.7489	0.5500	1.0156	0.7384	0.9658	0.7042	1.0820	0.7851
2013	1.0114	0.7092	0.8410	0.5934	1.0405	0.7416	1.1631	0.8123	1.0114	0.7092
2014	1.1676	0.8368	0.8874	0.6374	1.0320	0.7372	1.3303	0.9420	1.1676	0.8368
2015	1.2992	0.9415	1.0565	0.7574	1.3744	0.9925	1.6601	1.1824	1.2992	0.9415
2016	1.1776	0.8490	1.0179	0.7301	1.0637	0.7687	1.5566	1.1168	1.1776	0.8490
2017	1.2351	0.8820	0.8615	0.6038	1.4643	1.0177	1.3147	0.9444	1.2351	0.8820
2018	1.9521	1.3214	1.2134	0.8579	2.3378	1.5406	1.4823	1.0828	1.9521	1.3214
2019	1.5309	1.0714	1.1863	0.8369	2.0916	1.4264	1.3753	0.9994	1.5309	1.0714
2020	1.8838	1.3169	1.1053	0.8284	2.0414	1.4217	1.3630	1.0509	1.8838	1.3169
2021	1.2890	0.9323	1.1404	0.8141	1.5733	1.1318	1.2727	0.9217	1.2890	0.9323

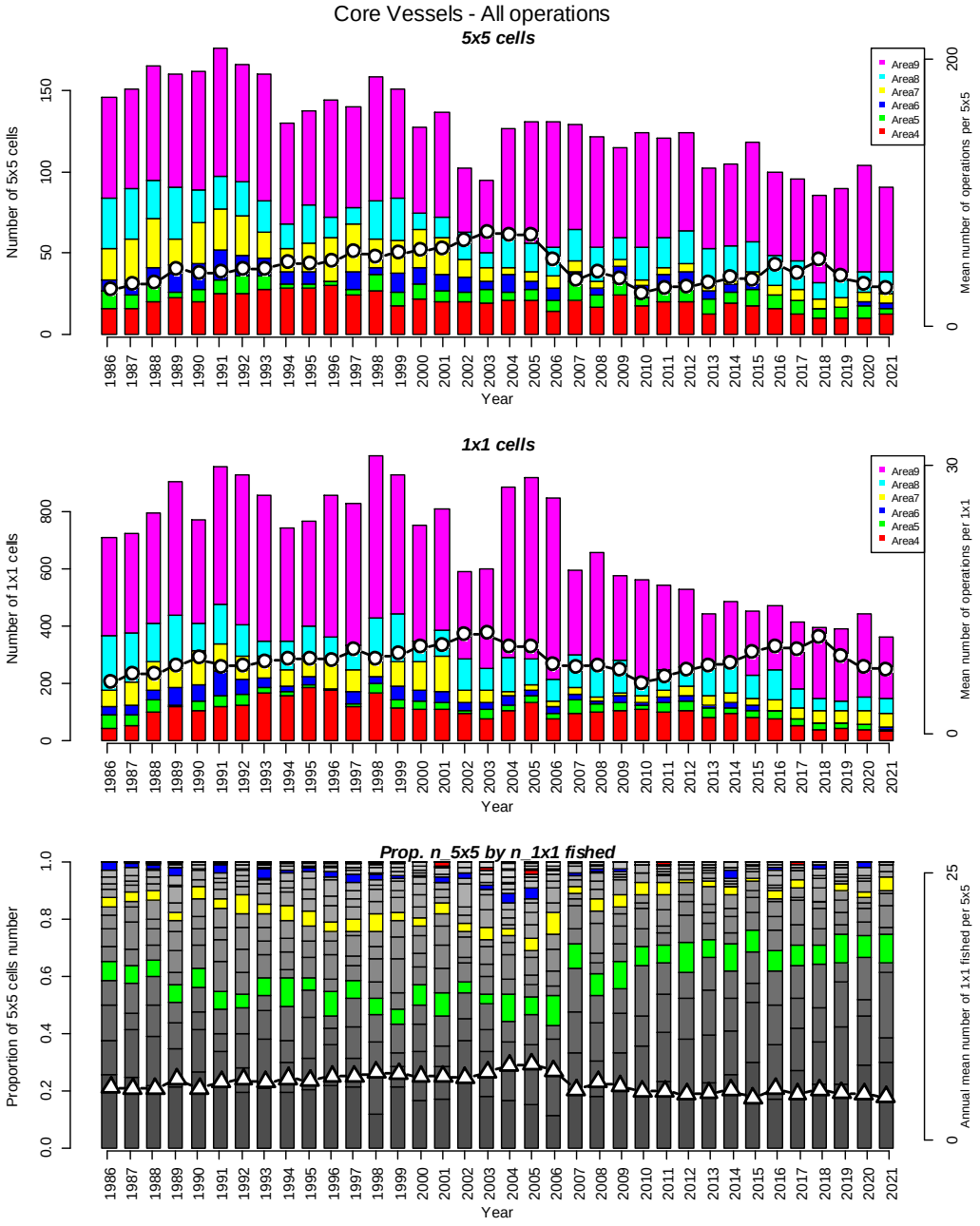


Fig. 1a. Number of cells in the core vessel for all operations.

(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.

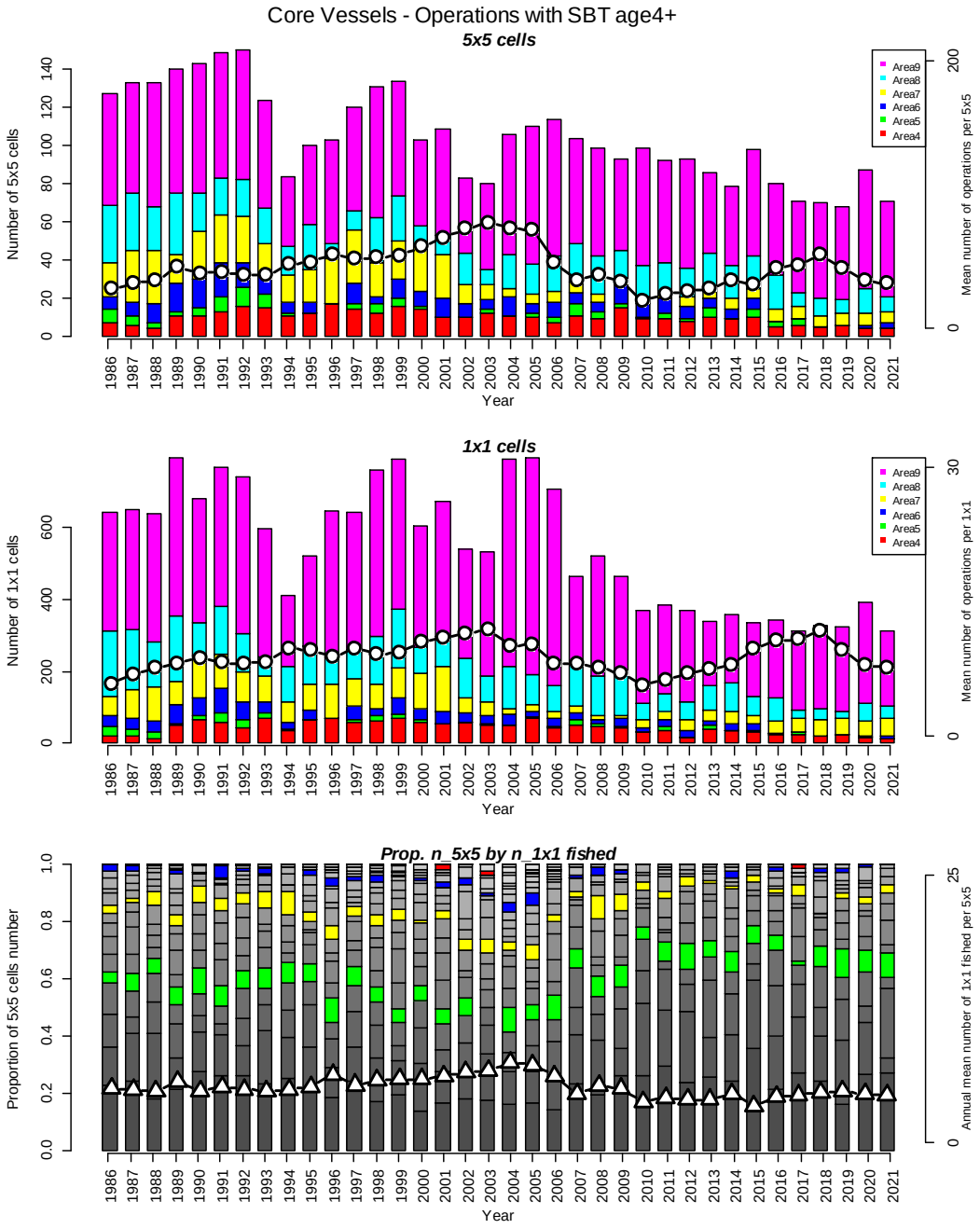


Fig. 1b. Number of cells in the core vessel for SBT 4+ catch positive. See explanation in Fig. 1a.

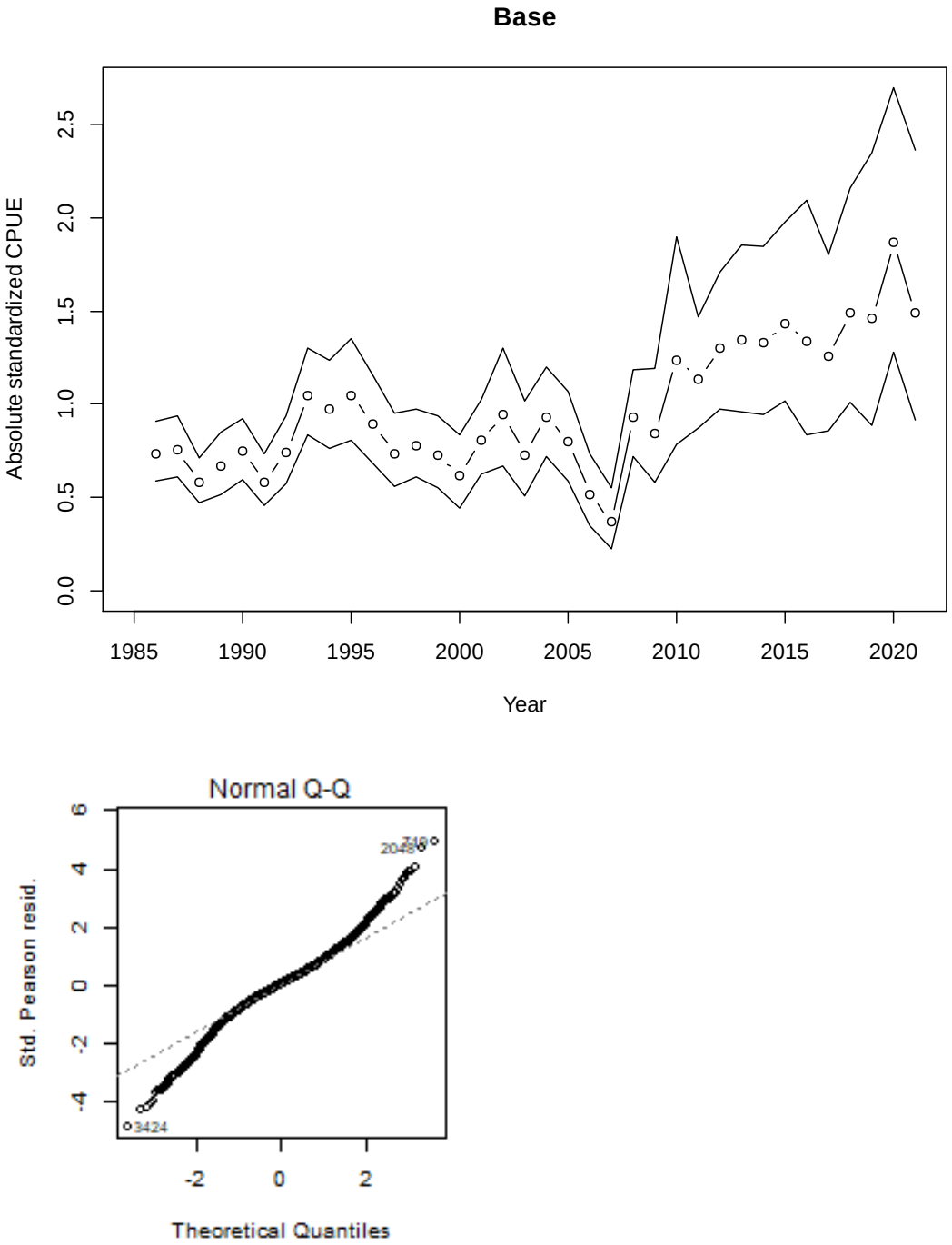


Fig. 2. Standardized CPUE (ls-mean with 95% confidence interval) of the core vessel data (upper panel) and its QQ plot of residual (lower panel) for Base case.

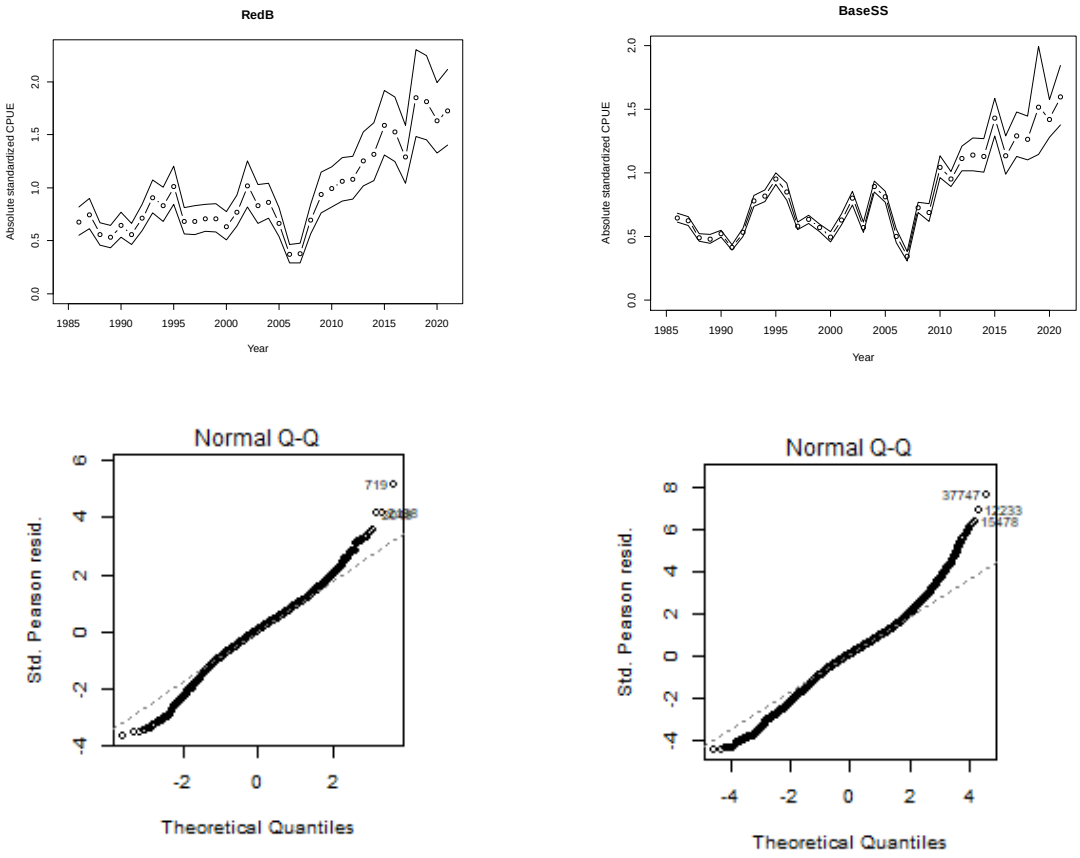
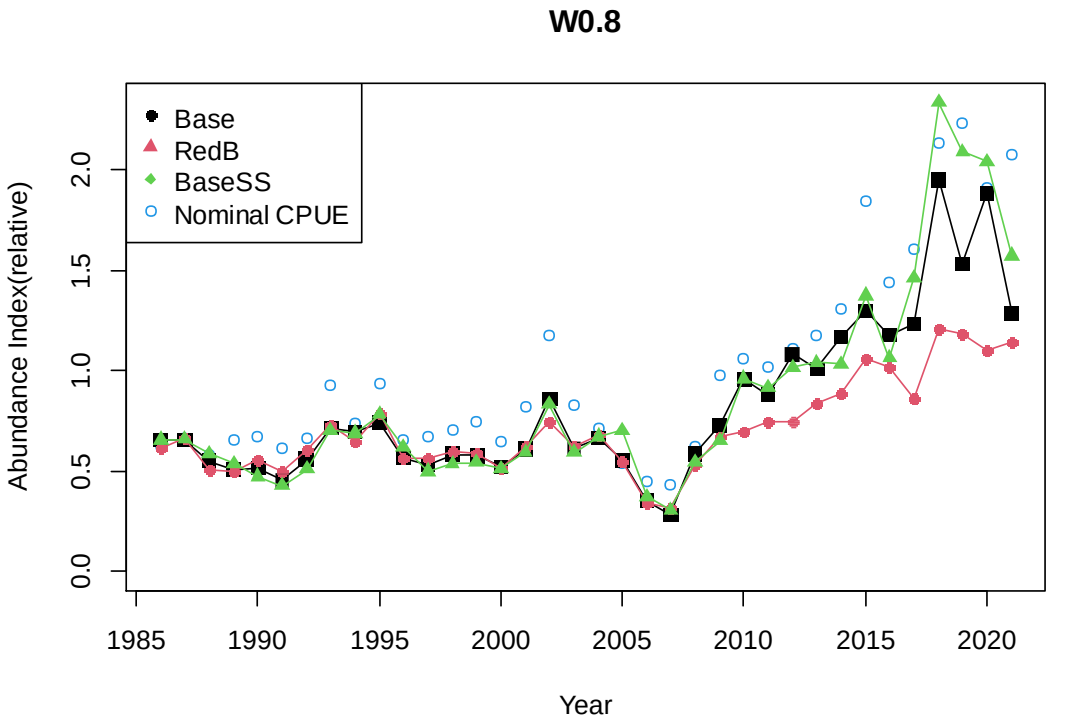


Fig. 3. Standardized CPUE (ls-mean with 95% confidence interval) of the core vessel data (upper panel) and its QQ plot of residual (lower panel) for monitoring series. Left panels for reduced base case and right panels for shot-by-shot data with base case GLM model.



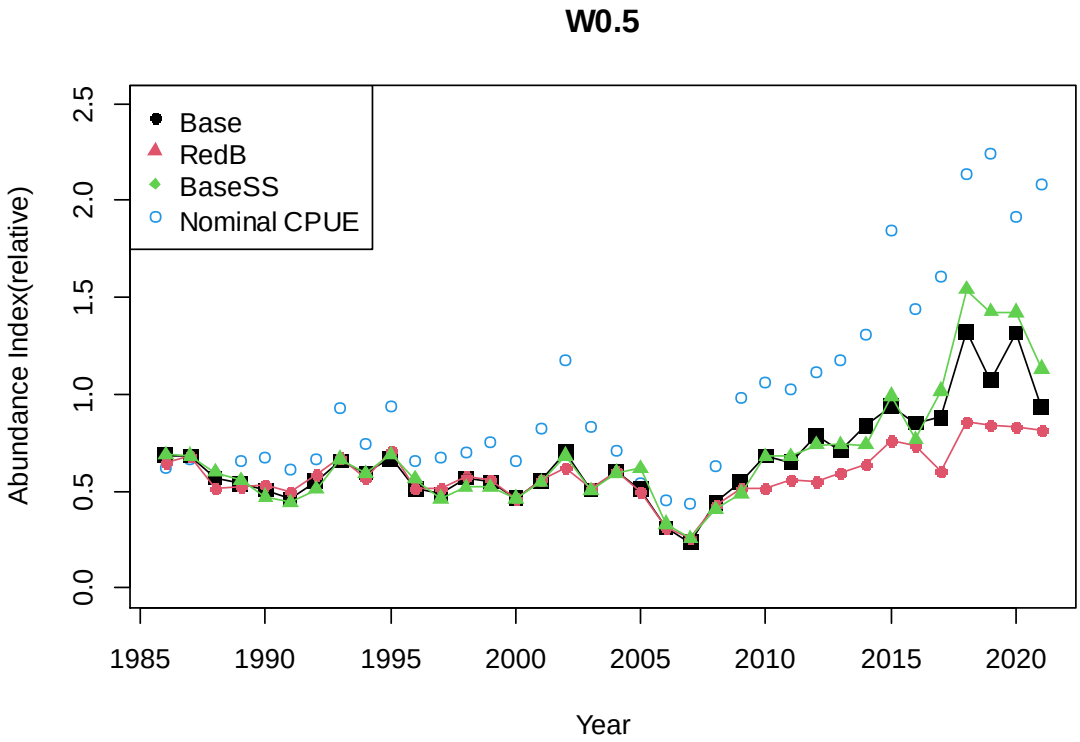


Fig. 4. Area weighed standardized CPUE from three GLMs. Nominal CPUE of the core vessels is also shown.

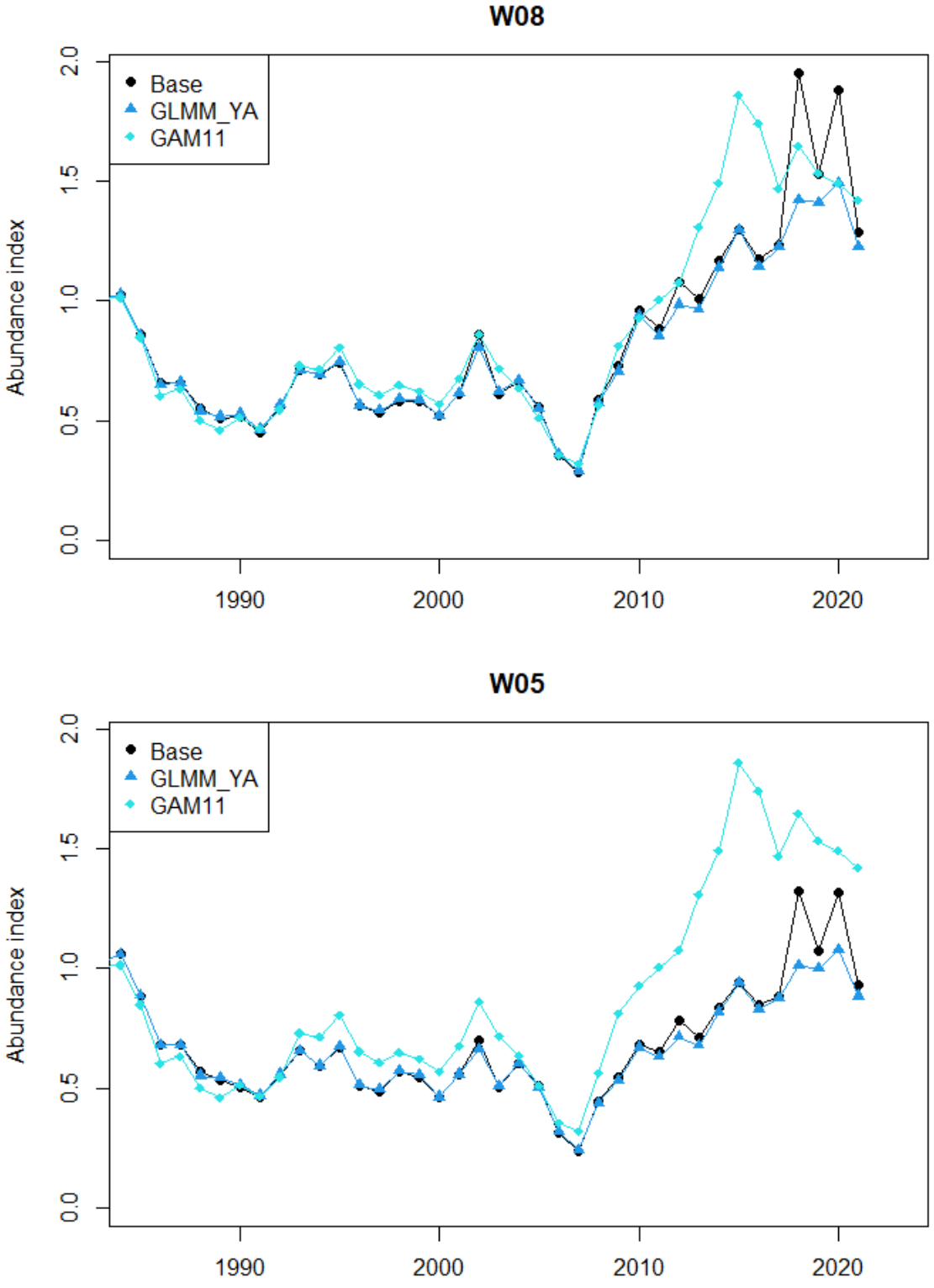


Fig. 5. Area weighed standardized CPUE series from GLM (Base), GLMM and GMA. In GAM11, the index is for W0.9 in the upper panel and W0.6 in the lower panel.