CCSBT-OMMP/1806/08
(OMMP Agenda Item 2)

2018 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 2018

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要旨

本文書は、CCSBT の管理方式に用いられるミナミマグロの資源指数であるコア船 CPUE についてまとめたものである。データ準備、GLM を用いた CPUE 標準化、エリア重み付けについて記述する。データは 2017 年にまで更新した。2017 年の指数は、ベース GLM モデルによる W0.8 及び W0.5 において、この 10 年間の平均より高く、近年 3 年間は高い水準にある。

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 2017. The index values in 2017, in W0.8 and W0.5 by the base GLM model, are higher than the average over the past 10 years, and those are high in recent three 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. 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.

Data preparation

The dataset used was created from shot-by-shot records of Japanese longline from Japan (1986-2017), Australia (RTMP data; 1989-2005), and New Zealand (Joint venture; 1990-2015). New Zealand joint venture with Japanese longline vessels was not implemented 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 insufficient. The data in Area 5 and Area 6 were combined in Area 4 and Area 7, respectively (Itoh 2017). Since we found that NZ and South African joint venture ships were mistakenly included in past catch data in Japan, we created a dataset excluding duplication in 2018 (Itoh 2018). In this data analysis, the newly created data set is used.

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 and month was calculated from the CCSBT catch-at-age database which added catch-at-age data made by Japan this year for 2016 and 2017.

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 185,284 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 area 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 SAS (version 9.4). 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 in 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 (2017), 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 2017 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 2017 using the base GLM model (1.294) is high as 137% of the average (0.945) in the past 10 years. That of W0.5 in 2017 (0.927) is high as 134% of the average (0.691) 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 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

[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.

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, but it was similar in 35S except 2015. 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. 2017. Examination of influence of absence of data from New Zealand chartered Japanese longline vessels on the core vessel CPUE and proposal of its solution. CCSBT/CPUE/1706/04.

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

Itoh, T. 2018. Proposal for revision of the historical data of Japanese SBT fishery between 2007 and 2015. CCSBT-ESC/1809/xx.

Table 1. Number of records in the dataset used.

Year	All vessels Japan	All vessels Australia	All vessels New Zealand	All vessels Total	Core vessel Total	Core vessel Vessel number
1986	27,005			27,005	4,068	35
1987	26,759			26,759	4,804	41
1988	24,418			24,418	5,353	49
1989	24,315	1,156		25,471	6,897	63
1990	19,899	504	475	20,878	6,546	73
1991	18,316	1,204	460	19,980	7,165	73
1992	17,233	1,717	499	19,449	7,102	86
1993	14,797	2,001	486	17,284	6,851	83
1994	12,610	1,394	268	14,272	6,227	92
1995	12,804	800	373	13,977	6,456	97
1996	14,854			14,854	7,057	97
1997	16,322		379	16,701	7,832	93
1998	16,310		310	16,620	8,338	106
1999	14,414		306	14,720	7,984	98
2000	11,746		265	12,011	7,258	97
2001	14,075		198	14,273	7,882	100
2002	10,721		228	10,949	6,251	90
2003	11,563		294	11,857	6,538	90
2004	13,098		349	13,447	8,419	93
2005	13,848		198	14,046	8,709	94
2006	9,124		183	9,307	6,445	85
2007	5,381		387	5,768	4,274	79
2008	6,388		167	6,555	4,921	87
2009	4,492		231	4,723	3,899	70
2010	3,442		144	3,586	2,971	62
2011	4,110		151	4,261	3,334	60
2012	4,214		163	4,377	3,589	71
2013	3,842		148	3,990	3,094	65
2014	4,609		186	4,795	3,548	69
2015	4,933		181	5,114	3,776	68
2016	5,571			5,571	4,175	66
2017	4,633				3,521	64
Total	395,846	8,776	7,029	407,018	185,284	

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

Table 2. Estimated parameter values in GLM Base model

Parameter			Estimate	Biased	StdErr	tValue	Probt
Intercept			2.1164	1	0.5057	4.19	<.0001
Year	1986		−1.5037	1	0.5946	−2.53	0.012
Year	1987		−0.8956	1	0.5792	−1.55	0.122
Year	1988		−1.1223	1	0.5366	−2.09	0.037
Year	1989		−1.4201	1	0.5666	−2.51	0.012
Year	1990		−1.2052	1	0.5287	−2.28	0.023
Year	1991		−1.8108	1	0.5752	−3.15	0.002
Year	1992		−1.4978	1	0.6083	−2.46	0.014
Year	1993		−0.8373	1	0.5837	−1.43	0.152
Year	1994		−1.4310	1	0.6491	−2.20	0.028
Year	1995		−1.5913	1	0.6459	−2.46	0.014
Year	1996		−1.2807	1	0.6058	−2.11	0.035
Year	1997		−1.4333	1	0.5947	−2.41	0.016
Year	1998		−0.9667	1	0.5828	−1.66	0.097
Year	1999		−1.1267	1	0.5883	−1.92	0.056
Year	2000		−1.6886	1	0.6249	−2.70	0.007
Year	2001		−0.9682	1	0.5721	−1.69	0.091
Year	2002		−0.6320	1	0.6237	−1.01	0.311
Year	2003		−0.9631	1	0.6688	−1.44	0.150
Year	2004		−1.1246	1	0.6211	−1.81	0.070
Year	2005		−1.0321	1	0.6024	−1.71	0.087
Year	2006		−1.4179	1	0.6889	−2.06	0.040
Year	2007		−2.5381	1	0.7549	−3.36	0.001
Year	2008		−0.9877	1	0.5712	−1.73	0.084
Year	2009		−1.2240	1	0.7607	−1.61	0.108
Year	2010		−0.7873	1	0.9104	−0.86	0.387
Year	2011		−0.9180	1	0.6149	−1.49	0.136
Year	2012		−0.2979	1	0.6706	−0.44	0.657
Year	2013		−0.2638	1	0.7206	−0.37	0.714
Year	2014		−0.3026	1	0.7217	−0.42	0.675
Year	2015		−0.3924	1	0.7221	−0.54	0.587
Year	2016		−0.6407	1	0.8639	−0.74	0.458
Year	2017		0.0000	1			
Month	4		−0.4523	1	0.0942	−4.80	<.0001
Month	5		−0.2125	1	0.0886	−2.40	0.017
Month	6		−0.1460	1	0.0878	−1.66	0.097
Month	7		0.1002	1	0.0868	1.15	0.248
Month	8		0.1740	1	0.0908	1.92	0.056
Month	9		0.0000	1			
Area	4		0.6299	1	0.4192	1.50	0.133
Area	7		−0.7102	1	0.3826	−1.86	0.064
Area	8		−0.3147	1	0.3987	−0.79	0.430
Area	9		0.0000	1			
Lat5	30		−3.5727	1	0.6751	−5.29	<.0001
Lat5	35		−1.5318	1	0.5925	−2.59	0.010
Lat5	40		0.0961	1	0.5170	0.19	0.853
Lat5	45		0.0000	1			
BETcpue5			−0.1430	0	0.0102	−14.04	<.0001
YFTcpue5			−0.0733	0	0.0065	−11.36	<.0001
Month*Area	4	4	−1.3741	1	0.1597	−8.60	<.0001
Month*Area	4	7	0.8354	1	0.2258	3.70	0.000
Month*Area	4	8	−1.2851	1	0.1887	−6.81	<.0001
Month*Area	4	9	0.0000	1			
Month*Area	5	4	−0.6599	1	0.1530	−4.31	<.0001
Month*Area	5	7	0.6942	1	0.2191	3.17	0.002
Month*Area	5	8	−1.0332	1	0.1804	−5.73	<.0001
Month*Area	5	9	0.0000	1			
Month*Area	6	4	−0.5197	1	0.1445	−3.60	0.000
Month*Area	6	7	0.6274	1	0.2206	2.84	0.005
Month*Area	6	8	−0.4026	1	0.1924	−2.09	0.037
Month*Area	6	9	0.0000	1			
Month*Area	7	4	−0.3413	1	0.1400	−2.44	0.015
Month*Area	7	7	0.4250	1	0.2346	1.81	0.070
Month*Area	7	8	0.0644	1	0.1389	0.46	0.643
Month*Area	7	9	0.0000	1			
Month*Area	8	4	−0.3699	1	0.1465	−2.53	0.012
Month*Area	8	7	−0.0443	1	0.3569	−0.12	0.901
Month*Area	8	8	0.1204	1	0.1277	0.94	0.346
Month*Area	8	9	0.0000	1			
Month*Area	9	4	0.0000	1			
Month*Area	9	7	0.0000	1			
Month*Area	9	8	0.0000	1			
Month*Area	9	9	0.0000	1			
Year*Lat5	1986	30	2.7849	1	0.8318	3.35	0.001
Year*Lat5	1986	35	2.1512	1	0.6808	3.16	0.002
Year*Lat5	1986	40	0.1119	1	0.6013	0.19	0.852
Year*Lat5	1986	45	0.0000	1			
Year*Lat5	1987	30	2.0945	1	0.8251	2.54	0.011
Year*Lat5	1987	35	1.3591	1	0.6720	2.02	0.043
Year*Lat5	1987	40	−0.1539	1	0.5839	−0.26	0.792
Year*Lat5	1987	45	0.0000	1			
Year*Lat5	1988	30	2.9815	1	0.7700	3.87	0.000
Year*Lat5	1988	35	1.7072	1	0.6379	2.68	0.008
Year*Lat5	1988	40	−0.1123	1	0.5543	−0.20	0.839
Year*Lat5	1988	45	0.0000	1			
Year*Lat5	1989	30	2.8073	1	0.8187	3.43	0.001
Year*Lat5	1989	35	1.6426	1	0.6677	2.46	0.014
Year*Lat5	1989	40	−0.0228	1	0.5780	−0.04	0.969
Year*Lat5	1989	45	0.0000	1			
Year*Lat5	1990	30	2.0307	1	0.7758	2.62	0.009
Year*Lat5	1990	35	1.1366	1	0.6442	1.76	0.078
Year*Lat5	1990	40	−0.2137	1	0.5475	−0.39	0.696
Year*Lat5	1990	45	0.0000	1			
Year*Lat5	1991	30	3.0562	1	0.7829	3.90	<.0001
Year*Lat5	1991	35	1.7881	1	0.6663	2.68	0.007
Year*Lat5	1991	40	0.3827	1	0.5817	0.66	0.511
Year*Lat5	1991	45	0.0000	1			
Year*Lat5	1992	30	2.7925	1	0.8052	3.47	0.001
Year*Lat5	1992	35	1.7105	1	0.6944	2.46	0.014
Year*Lat5	1992	40	0.1941	1	0.6148	0.32	0.752
Year*Lat5	1992	45	0.0000	1			
Year*Lat5	1993	30	1.8631	1	0.7903	2.36	0.019
Year*Lat5	1993	35	0.5091	1	0.6756	0.75	0.451
Year*Lat5	1993	40	0.0726	1	0.5963	0.12	0.903
Year*Lat5	1993	45	0.0000	1			
Year*Lat5	1994	30	1.9636	1	0.8547	2.30	0.022
Year*Lat5	1994	35	1.0343	1	0.7330	1.41	0.158
Year*Lat5	1994	40	0.3499	1	0.6492	0.54	0.590
Year*Lat5	1994	45	0.0000	1			
Year*Lat5	1995	30	2.9371	1	0.8443	3.48	0.001
Year*Lat5	1995	35	1.5626	1	0.7269	2.15	0.032
Year*Lat5	1995	40	0.6048	1	0.6476	0.93	0.350
Year*Lat5	1995	45	0.0000	1			
Year*Lat5	1996	30	2.2053	1	0.8099	2.72	0.007
Year*Lat5	1996	35	0.8313	1	0.6950	1.20	0.232
Year*Lat5	1996	40	0.0449	1	0.6141	0.07	0.942
Year*Lat5	1996	45	0.0000	1			
Year*Lat5	1997	30	1.8500	1	0.8099	2.28	0.022
Year*Lat5	1997	35	1.3083	1	0.6823	1.92	0.055
Year*Lat5	1997	40	0.0562	1	0.5971	0.09	0.925
Year*Lat5	1997	45	0.0000	1			
Year*Lat5	1998	30	2.0237	1	0.7878	2.57	0.010
Year*Lat5	1998	35	1.1604	1	0.6740	1.72	0.085
Year*Lat5	1998	40	−0.2384	1	0.5945	−0.40	0.688
Year*Lat5	1998	45	0.0000	1			
Year*Lat5	1999	30	1.5912	1	0.8175	1.95	0.052
Year*Lat5	1999	35	1.1227	1	0.6783	1.66	0.098
Year*Lat5	1999	40	−0.0712	1	0.5973	−0.12	0.905
Year*Lat5	1999	45	0.0000	1			
Year*Lat5	2000	30	1.6930	1	0.8417	2.01	0.044
Year*Lat5	2000	35	1.4694	1	0.7095	2.07	0.038
Year*Lat5	2000	40	0.3928	1	0.6280	0.63	0.532
Year*Lat5	2000	45	0.0000	1			
Year*Lat5	2001	30	1.8684	1	0.7995	2.34	0.020
Year*Lat5	2001	35	1.0525	1	0.6706	1.57	0.117
Year*Lat5	2001	40	−0.0285	1	0.5825	−0.05	0.961
Year*Lat5	2001	45	0.0000	1			
Year*Lat5	2002	30	2.1517	1	0.9177	2.34	0.019
Year*Lat5	2002	35	1.8192	1	0.7704	2.36	0.018
Year*Lat5	2002	40	−0.0085	1	0.6389	−0.01	0.989
Year*Lat5	2002	45	0.0000	1			
Year*Lat5	2003	30	1.7922	1	0.8903	2.01	0.044
Year*Lat5	2003	35	1.6658	1	0.7696	2.16	0.031
Year*Lat5	2003	40	−0.0933	1	0.6807	−0.14	0.891
Year*Lat5	2003	45	0.0000	1			
Year*Lat5	2004	30	2.1471	1	0.8317	2.58	0.010
Year*Lat5	2004	35	1.6777	1	0.7045	2.38	0.017
Year*Lat5	2004	40	−0.2414	1	0.6275	−0.38	0.701
Year*Lat5	2004	45	0.0000	1			
Year*Lat5	2005	30	2.3446	1	0.8198	2.86	0.004
Year*Lat5	2005	35	1.4351	1	0.6896	2.08	0.038
Year*Lat5	2005	40	−0.4767	1	0.6197	−0.77	0.442
Year*Lat5	2005	45	0.0000	1			
Year*Lat5	2006	30	1.4807	1	0.9020	1.64	0.101
Year*Lat5	2006	35	1.0650	1	0.7676	1.39	0.165
Year*Lat5	2006	40	−0.4924	1	0.6930	−0.71	0.477
Year*Lat5	2006	45	0.0000	1			
Year*Lat5	2007	30	3.3052	1	0.9323	3.55	0.000
Year*Lat5	2007	35	2.3545	1	0.8289	2.84	0.005
Year*Lat5	2007	40	0.5130	1	0.7539	0.68	0.496
Year*Lat5	2007	45	0.0000	1			
Year*Lat5	2008	30	0.8191	1	0.8046	1.02	0.309
Year*Lat5	2008	35	0.4658	1	0.6667	0.70	0.485
Year*Lat5	2008	40	−0.3987	1	0.5943	−0.67	0.502
Year*Lat5	2008	45	0.0000	1			
Year*Lat5	2009	30	0.8785	1	0.9467	0.93	0.354
Year*Lat5	2009	35	1.3671	1	0.8392	1.63	0.103
Year*Lat5	2009	40	0.1344	1	0.7614	0.18	0.860
Year*Lat5	2009	45	0.0000	1			
Year*Lat5	2010	30	0.9432	1	1.0715	0.88	0.379
Year*Lat5	2010	35	0.9073	1	0.9717	0.93	0.351
Year*Lat5	2010	40	0.0078	1	0.9097	0.01	0.993
Year*Lat5	2010	45	0.0000	1			
Year*Lat5	2011	30	1.7617	1	0.8408	2.10	0.036
Year*Lat5	2011	35	1.4260	1	0.7111	2.01	0.045
Year*Lat5	2011	40	0.1600	1	0.6391	0.25	0.802
Year*Lat5	2011	45	0.0000	1			
Year*Lat5	2012	30	2.3710	1	0.8666	2.74	0.006
Year*Lat5	2012	35	1.2423	1	0.7554	1.64	0.100
Year*Lat5	2012	40	−0.3308	1	0.6817	−0.49	0.628
Year*Lat5	2012	45	0.0000	1			
Year*Lat5	2013	30	1.9671	1	0.9489	2.07	0.038
Year*Lat5	2013	35	1.2754	1	0.8149	1.56	0.118
Year*Lat5	2013	40	−0.3059	1	0.7342	−0.42	0.677
Year*Lat5	2013	45	0.0000	1			
Year*Lat5	2014	30	1.2669	1	0.9312	1.36	0.174
Year*Lat5	2014	35	1.2304	1	0.8166	1.51	0.132
Year*Lat5	2014	40	−0.0343	1	0.7356	−0.05	0.963
Year*Lat5	2014	45	0.0000	1			
Year*Lat5	2015	30	1.2731	1	0.9270	1.37	0.170
Year*Lat5	2015	35	1.0632	1	0.8057	1.32	0.187
Year*Lat5	2015	40	0.4080	1	0.7356	0.55	0.579
Year*Lat5	2015	45	0.0000	1			
Year*Lat5	2016	30	1.5097	1	1.0470	1.44	0.149
Year*Lat5	2016	35	1.7350	1	0.9428	1.84	0.066
Year*Lat5	2016	40	0.3787	1	0.8859	0.43	0.669
Year*Lat5	2016	45	0.0000	1			
Year*Lat5	2017	30	0.0000	1			
Year*Lat5	2017	35	0.0000	1			
Year*Lat5	2017	40	0.0000	1			
Year*Lat5	2017	45	0.0000	1			
Year*Area	1986	4	−0.6253	1	0.5233	−1.19	0.232
Year*Area	1986	7	0.3146	1	0.4122	0.76	0.446
Year*Area	1986	8	−0.3707	1	0.4313	−0.86	0.390
Year*Area	1986	9	0.0000	1			
Year*Area	1987	4	−0.6820	1	0.5214	−1.31	0.191
Year*Area	1987	7	−0.1981	1	0.3900	−0.51	0.611
Year*Area	1987	8	−0.4242	1	0.4294	−0.99	0.323
Year*Area	1987	9	0.0000	1			
Year*Area	1988	4	−1.6233	1	0.4858	−3.34	0.001
Year*Area	1988	7	−0.2791	1	0.3661	−0.76	0.446
Year*Area	1988	8	−0.5747	1	0.4330	−1.33	0.185
Year*Area	1988	9	0.0000	1			
Year*Area	1989	4	−0.5800	1	0.4934	−1.18	0.240
Year*Area	1989	7	0.0628	1	0.3747	0.17	0.867
Year*Area	1989	8	−0.2765	1	0.4252	−0.65	0.516
Year*Area	1989	9	0.0000	1			
Year*Area	1990	4	−0.1748	1	0.4922	−0.36	0.723
Year*Area	1990	7	0.1951	1	0.3619	0.54	0.590
Year*Area	1990	8	0.1832	1	0.4453	0.41	0.681

Table 2. (cont.)

Parameter		Estimate	Biased	StdErr	tValue	Probt
Year*Area	1990 9	0.0000	1			
Year*Area	1991 4	−0.2517	1	0.4596	−0.55	0.584
Year*Area	1991 7	−0.0541	1	0.3722	−0.15	0.884
Year*Area	1991 8	−0.0551	1	0.4368	−0.13	0.900
Year*Area	1991 9	0.0000	1			
Year*Area	1992 4	−0.5007	1	0.4630	−1.08	0.280
Year*Area	1992 7	0.2688	1	0.3736	0.72	0.472
Year*Area	1992 8	−0.1293	1	0.4306	−0.30	0.764
Year*Area	1992 9	0.0000	1			
Year*Area	1993 4	0.3223	1	0.4625	0.70	0.486
Year*Area	1993 7	−0.2773	1	0.3783	−0.73	0.464
Year*Area	1993 8	0.4066	1	0.4366	0.93	0.352
Year*Area	1993 9	0.0000	1			
Year*Area	1994 4	0.2245	1	0.4960	0.45	0.651
Year*Area	1994 7	0.6204	1	0.4384	1.42	0.157
Year*Area	1994 8	0.7736	1	0.4494	1.72	0.085
Year*Area	1994 9	0.0000	1			
Year*Area	1995 4	−0.2752	1	0.4829	−0.57	0.569
Year*Area	1995 7	0.6511	1	0.3812	1.71	0.088
Year*Area	1995 8	0.4545	1	0.4358	1.04	0.297
Year*Area	1995 9	0.0000	1			
Year*Area	1996 4	0.1022	1	0.4703	0.22	0.828
Year*Area	1996 7	0.3449	1	0.3849	0.90	0.370
Year*Area	1996 8	0.6993	1	0.4845	1.44	0.149
Year*Area	1996 9	0.0000	1			
Year*Area	1997 4	0.3020	1	0.4708	0.64	0.521
Year*Area	1997 7	0.4122	1	0.3874	1.06	0.287
Year*Area	1997 8	0.1281	1	0.4695	0.27	0.785
Year*Area	1997 9	0.0000	1			
Year*Area	1998 4	−0.6431	1	0.4537	−1.42	0.156
Year*Area	1998 7	−0.0374	1	0.3890	−0.10	0.924
Year*Area	1998 8	0.0746	1	0.4368	0.17	0.865
Year*Area	1998 9	0.0000	1			
Year*Area	1999 4	−0.2027	1	0.4665	−0.43	0.664
Year*Area	1999 7	0.1746	1	0.3824	0.46	0.648
Year*Area	1999 8	0.1783	1	0.4311	0.41	0.679
Year*Area	1999 9	0.0000	1			
Year*Area	2000 4	0.1654	1	0.4732	0.35	0.727
Year*Area	2000 7	0.1945	1	0.3771	0.52	0.606
Year*Area	2000 8	0.6070	1	0.4713	1.29	0.198
Year*Area	2000 9	0.0000	1			
Year*Area	2001 4	−0.3928	1	0.4755	−0.83	0.409
Year*Area	2001 7	−0.0236	1	0.3712	−0.06	0.949
Year*Area	2001 8	0.0024	1	0.4596	0.01	0.996
Year*Area	2001 9	0.0000	1			
Year*Area	2002 4	−1.2051	1	0.5658	−2.13	0.033
Year*Area	2002 7	−0.1935	1	0.4036	−0.48	0.632
Year*Area	2002 8	−1.0846	1	0.4918	−2.21	0.028
Year*Area	2002 9	0.0000	1			
Year*Area	2003 4	−0.3771	1	0.5246	−0.72	0.472
Year*Area	2003 7	−0.4486	1	0.4152	−1.08	0.280
Year*Area	2003 8	−0.2690	1	0.5171	−0.52	0.603
Year*Area	2003 9	0.0000	1			
Year*Area	2004 4	−0.4273	1	0.4817	−0.89	0.375
Year*Area	2004 7	−0.1459	1	0.4047	−0.36	0.718
Year*Area	2004 8	0.5124	1	0.4370	1.17	0.241
Year*Area	2004 9	0.0000	1			
Year*Area	2005 4	−0.9285	1	0.4750	−1.95	0.051
Year*Area	2005 7	−0.3447	1	0.4298	−0.80	0.423
Year*Area	2005 8	0.5305	1	0.4478	1.18	0.236
Year*Area	2005 9	0.0000	1			
Year*Area	2006 4	0.0576	1	0.4789	0.12	0.904
Year*Area	2006 7	0.2871	1	0.3999	0.72	0.473
Year*Area	2006 8	0.6921	1	0.4538	1.52	0.127
Year*Area	2006 9	0.0000	1			
Year*Area	2007 4	−0.4181	1	0.4783	−0.87	0.382
Year*Area	2007 7	0.4429	1	0.4133	1.07	0.284
Year*Area	2007 8	0.2237	1	0.4440	0.50	0.614
Year*Area	2007 9	0.0000	1			
Year*Area	2008 4	0.8971	1	0.4941	1.82	0.070
Year*Area	2008 7	0.7267	1	0.4148	1.75	0.080
Year*Area	2008 8	0.4289	1	0.4357	0.98	0.325
Year*Area	2008 9	0.0000	1			
Year*Area	2009 4	0.7657	1	0.4926	1.55	0.120
Year*Area	2009 7	0.7773	1	0.4249	1.83	0.067
Year*Area	2009 8	−0.1708	1	0.4593	−0.37	0.710
Year*Area	2009 9	0.0000	1			
Year*Area	2010 4	−0.0425	1	0.4909	−0.09	0.931
Year*Area	2010 7	0.8433	1	0.4283	1.97	0.049
Year*Area	2010 8	0.4982	1	0.4485	1.11	0.267
Year*Area	2010 9	0.0000	1			
Year*Area	2011 4	−0.5700	1	0.5116	−1.11	0.265
Year*Area	2011 7	0.6898	1	0.4203	1.64	0.101
Year*Area	2011 8	−0.1023	1	0.4494	−0.23	0.820
Year*Area	2011 9	0.0000	1			
Year*Area	2012 4	−2.0127	1	0.4845	−4.15	<.0001
Year*Area	2012 7	0.6774	1	0.4256	1.59	0.112
Year*Area	2012 8	−0.5770	1	0.4510	−1.28	0.201
Year*Area	2012 9	0.0000	1			
Year*Area	2013 4	−1.4860	1	0.5556	−2.67	0.008
Year*Area	2013 7	0.3250	1	0.4298	0.76	0.450
Year*Area	2013 8	−0.3829	1	0.4736	−0.81	0.419
Year*Area	2013 9	0.0000	1			
Year*Area	2014 4	−1.0334	1	0.5135	−2.01	0.044
Year*Area	2014 7	0.3667	1	0.4371	0.84	0.402
Year*Area	2014 8	−0.4452	1	0.4769	−0.93	0.351
Year*Area	2014 9	0.0000	1			
Year*Area	2015 4	−0.5592	1	0.5120	−1.09	0.275
Year*Area	2015 7	0.0544	1	0.4398	0.12	0.902
Year*Area	2015 8	−0.2781	1	0.4577	−0.61	0.544
Year*Area	2015 9	0.0000	1			
Year*Area	2016 4	−0.7333	1	0.5163	−1.42	0.156
Year*Area	2016 7	0.3517	1	0.4516	0.78	0.436
Year*Area	2016 8	−0.4645	1	0.4730	−0.98	0.326
Year*Area	2016 9	0.0000	1			
Year*Area	2017 4	0.0000	1			
Year*Area	2017 7	0.0000	1			
Year*Area	2017 8	0.0000	1			
Year*Area	2017 9	0.0000	1			

Table 3. ANOVA statistics

Base

HypothesisType	Source	DF	SS	MS	FValue	ProbF
2	Year	31	207.201	6.684	13.45	<.0001
2	Month	5	203.569	40.714	81.95	<.0001
2	Area	3	80.512	26.837	54.02	<.0001
2	Lat5	3	239.139	79.713	160.44	<.0001
2	BETcpue5	1	97.898	97.898	197.05	<.0001
2	YFTcpue5	1	64.064	64.064	128.95	<.0001
2	Month*Area	15	116.071	7.738	15.58	<.0001
2	Year*Lat5	93	136.271	1.465	2.95	<.0001
2	Year*Area	93	151.627	1.630	3.28	<.0001
HypothesisType	Source	DF	SS	MS	FValue	ProbF
3	Year	31	55.977	1.806	3.63	<.0001
3	Month	5	162.537	32.507	65.43	<.0001
3	Area	3	84.441	28.147	56.65	<.0001
3	Lat5	3	267.012	89.004	179.14	<.0001
3	BETcpue5	1	97.898	97.898	197.05	<.0001
3	YFTcpue5	1	64.064	64.064	128.95	<.0001
3	Month*Area	15	116.071	7.738	15.58	<.0001
3	Year*Lat5	93	136.271	1.465	2.95	<.0001
3	Year*Area	93	151.627	1.630	3.28	<.0001

RedB

HypothesisType	Source	DF	SS	MS	FValue	ProbF
2	Year	31	207.201	6.684	11.41	<.0001
2	Month	5	246.099	49.220	83.99	<.0001
2	Area	3	105.427	35.142	59.97	<.0001
2	Lat5	3	291.246	97.082	165.67	<.0001
2	BETcpue5	1	189.006	189.006	322.54	<.0001
2	YFTcpue5	1	66.362	66.362	113.25	<.0001
2	Month*Area	15	135.257	9.017	15.39	<.0001
HypothesisType	Source	DF	SS	MS	FValue	ProbF
3	Year	31	207.201	6.684	11.41	<.0001
3	Month	5	185.577	37.115	63.34	<.0001
3	Area	3	131.177	43.726	74.62	<.0001
3	Lat5	3	291.246	97.082	165.67	<.0001
3	BETcpue5	1	189.006	189.006	322.54	<.0001
3	YFTcpue5	1	66.362	66.362	113.25	<.0001
3	Month*Area	15	135.257	9.017	15.39	<.0001

BaseSxS

HypothesisType	Source	DF	SS	MS	FValue	ProbF
2	Year	31	10232.152	330.069	445.43	<.0001
2	Month	5	4249.251	849.850	1146.87	<.0001
2	Area	3	897.994	299.331	403.95	<.0001
2	Lat5	3	6993.434	2331.145	3145.88	<.0001
2	BETcpue	1	4119.754	4119.754	5559.61	<.0001
2	YFTcpue	1	3060.575	3060.575	4130.25	<.0001
2	Month*Area	15	6443.904	429.594	579.74	<.0001
2	Year*Lat5	93	8336.724	89.642	120.97	<.0001
2	Year*Area	93	9979.090	107.302	144.8	<.0001
HypothesisType	Source	DF	SS	MS	FValue	ProbF
3	Year	31	1619.052	52.227	70.48	<.0001
3	Month	5	4473.614	894.723	1207.43	<.0001
3	Area	3	2645.666	881.889	1190.11	<.0001
3	Lat5	3	6848.620	2282.873	3080.74	<.0001
3	BETcpue	1	4119.754	4119.754	5559.61	<.0001
3	YFTcpue	1	3060.575	3060.575	4130.25	<.0001
3	Month*Area	15	6443.904	429.594	579.74	<.0001
3	Year*Lat5	93	8336.724	89.642	120.97	<.0001
3	Year*Area	93	9979.090	107.302	144.8	<.0001

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

Model	AIC	BIC
Base	7,379	8,883
Reduced Base	7,753	8,120

Table 5. Area weighted standardized CPUE

Year	Base w08	Base w05	Reduced Base w08	Reduced Base w05	Base with SxS w08	Base with SxS w05
1969	2.2841	2.4934	2.2841	2.4934	2.2841	2.4934
1970	2.2268	2.4169	2.2268	2.4169	2.2268	2.4169
1971	2.0654	2.2054	2.0654	2.2054	2.0654	2.2054
1972	2.1669	2.2273	2.1669	2.2273	2.1669	2.2273
1973	1.8263	1.9271	1.8263	1.9271	1.8263	1.9271
1974	1.8989	1.9710	1.8989	1.9710	1.8989	1.9710
1975	1.4556	1.4974	1.4556	1.4974	1.4556	1.4974
1976	1.8715	1.9279	1.8715	1.9279	1.8715	1.9279
1977	1.6556	1.6850	1.6556	1.6850	1.6556	1.6850
1978	1.4300	1.3820	1.4300	1.3820	1.4300	1.3820
1979	1.1472	1.2558	1.1472	1.2558	1.1472	1.2558
1980	1.3862	1.3852	1.3862	1.3852	1.3862	1.3852
1981	1.3103	1.2917	1.3103	1.2917	1.3103	1.2917
1982	1.0285	1.0220	1.0285	1.0220	1.0285	1.0220
1983	1.0103	1.0228	1.0103	1.0228	1.0103	1.0228
1984	1.0261	1.0603	1.0261	1.0603	1.0261	1.0603
1985	0.8578	0.8861	0.8578	0.8861	0.8578	0.8861
1986	0.6321	0.6664	0.6470	0.6839	0.6470	0.6794
1987	0.6424	0.6684	0.6648	0.6849	0.6462	0.6697
1988	0.5400	0.5558	0.5219	0.5261	0.5779	0.5878
1989	0.5056	0.5336	0.5086	0.5321	0.5377	0.5578
1990	0.5342	0.5293	0.5858	0.5710	0.4810	0.4806
1991	0.4390	0.4496	0.5044	0.5038	0.4281	0.4420
1992	0.5434	0.5363	0.6065	0.5856	0.5084	0.5055
1993	0.7262	0.6649	0.6972	0.6351	0.7019	0.6627
1994	0.6927	0.5823	0.5805	0.4902	0.7015	0.5946
1995	0.7306	0.6571	0.7348	0.6572	0.7913	0.6931
1996	0.5919	0.5339	0.5563	0.5152	0.6239	0.5659
1997	0.5156	0.4686	0.5464	0.4956	0.4928	0.4524
1998	0.5570	0.5416	0.5780	0.5543	0.5292	0.5096
1999	0.5659	0.5440	0.5789	0.5543	0.5417	0.5208
2000	0.5360	0.4771	0.5234	0.4649	0.5249	0.4746
2001	0.6009	0.5597	0.6121	0.5632	0.5904	0.5489
2002	0.9327	0.7620	0.8050	0.6668	0.8583	0.7073
2003	0.6677	0.5561	0.6906	0.5704	0.6265	0.5323
2004	0.6366	0.5754	0.6736	0.5999	0.6431	0.5714
2005	0.5203	0.4767	0.5334	0.4829	0.6646	0.5854
2006	0.3774	0.3301	0.3520	0.3202	0.3760	0.3305

Table 5. (cont.)

Year	Base w08	Base w05	Reduced Base w08	Reduced Base w05	Base with SxS w08	Base with SxS w05
2007	0.2809	0.2364	0.3336	0.2710	0.3109	0.2609
2008	0.5829	0.4373	0.5174	0.4140	0.5489	0.4094
2009	0.7584	0.5708	0.7060	0.5414	0.6704	0.5029
2010	0.9888	0.7015	0.6937	0.5112	0.9805	0.6909
2011	0.9049	0.6673	0.7577	0.5637	0.9317	0.6940
2012	1.0812	0.7829	0.7490	0.5469	1.0046	0.7291
2013	1.0542	0.7422	0.8717	0.6162	1.0563	0.7548
2014	1.1948	0.8650	0.9021	0.6523	1.0397	0.7468
2015	1.3153	0.9635	1.0598	0.7626	1.3636	0.9913
2016	1.2867	0.9397	1.1017	0.7952	1.0900	0.7943
2017	1.2937	0.9268	0.9060	0.6355	1.4253	0.9923

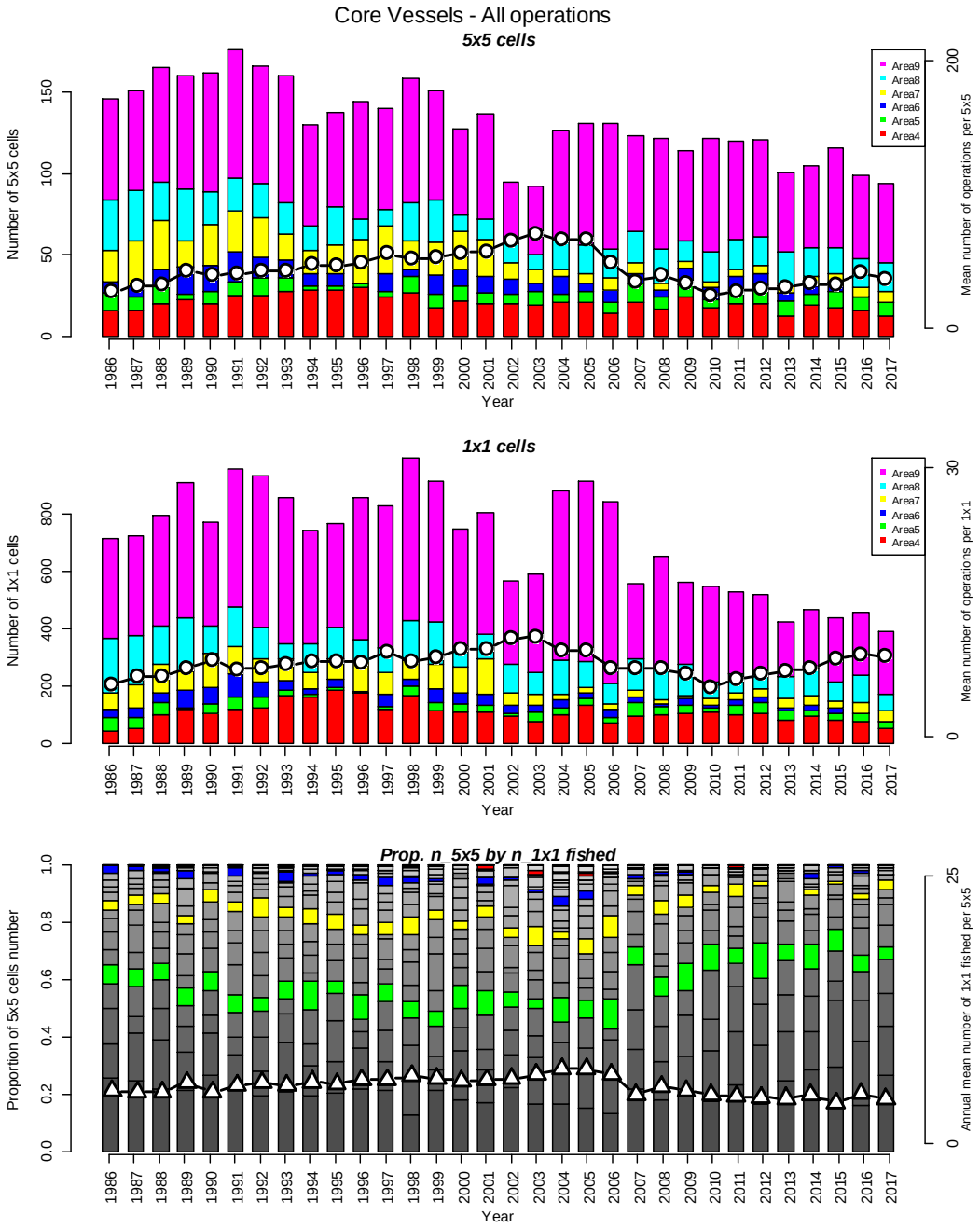


Fig. 1a. Number of cells in the core vessel for all operations.

(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.

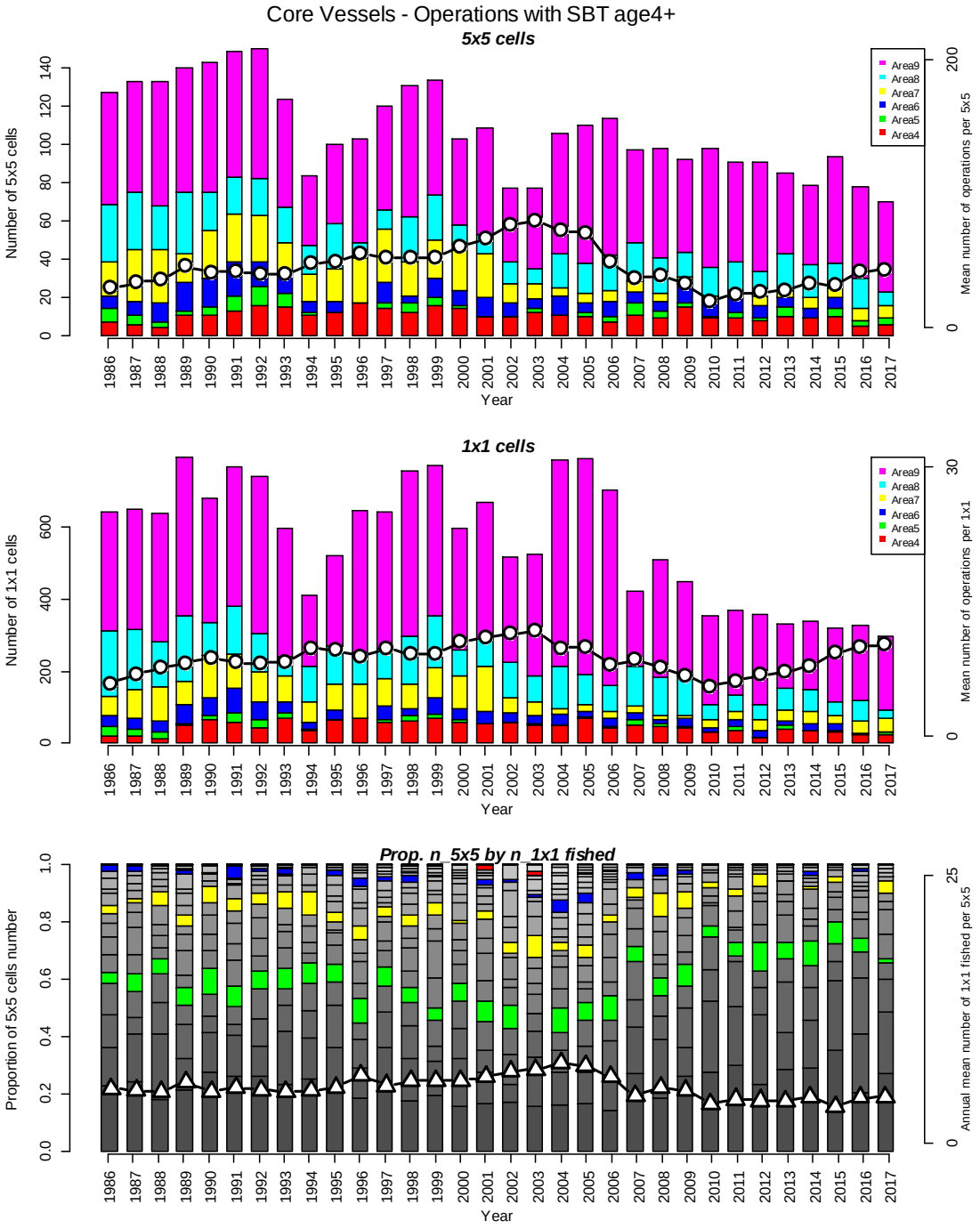
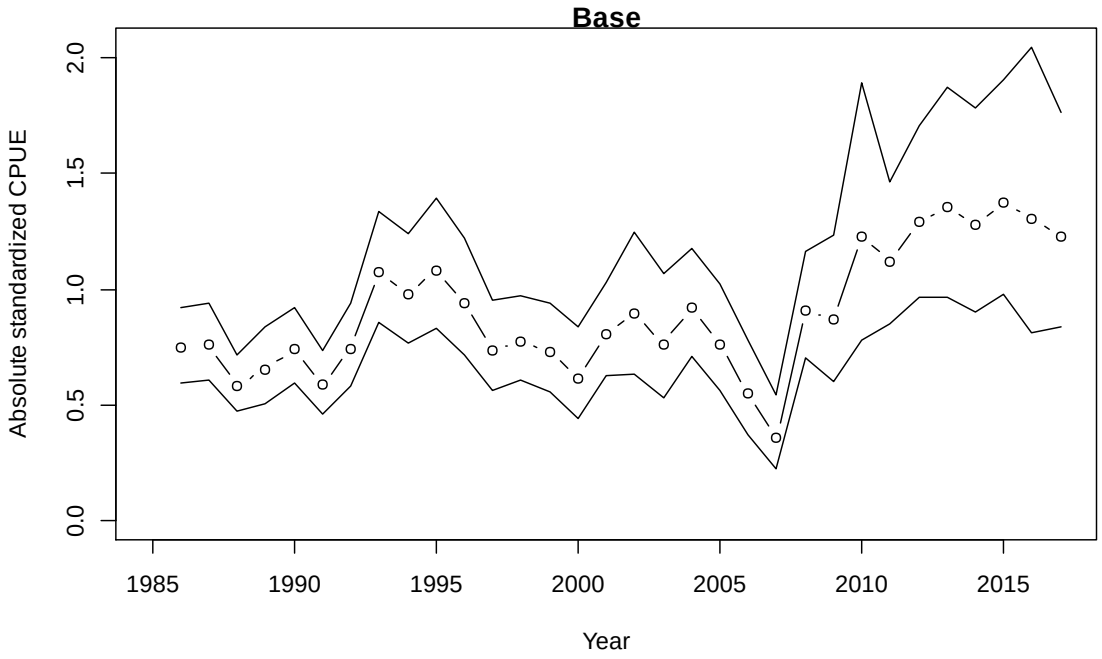


Fig. 1b. Number of cells in the core vessel for SBT 4+ catch positive. See explanation in Fig. 1a.



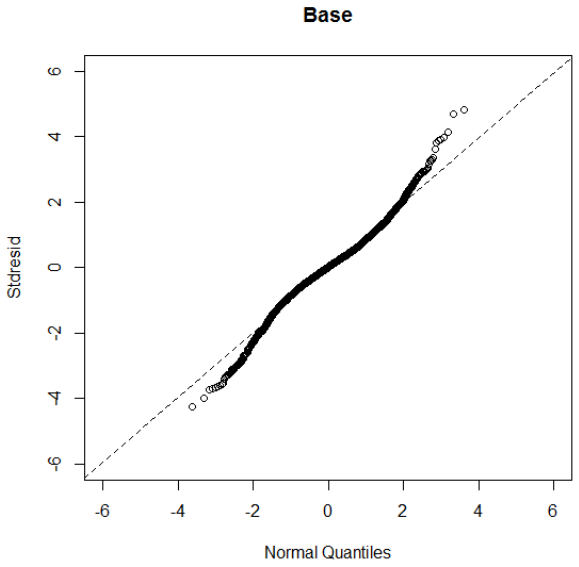


Fig. 2. Standardized CPUE (ls-mean with 95% confidence interval) of the core vessel data (upper panel) and its QQ plot of residual (lower panel) for Base case.

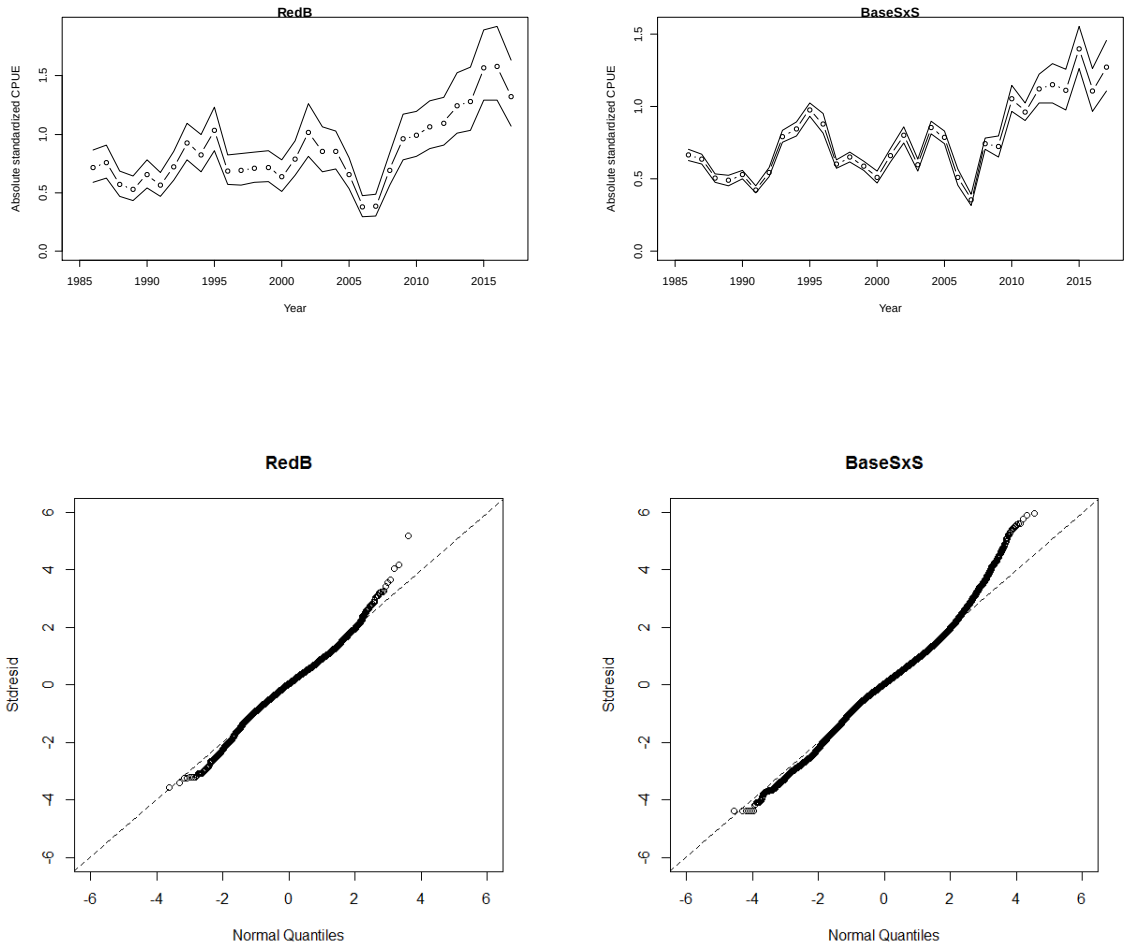


Fig. 3. Standardized CPUE (ls-mean with 95% confidence interval) of the core vessel data (upper panel) and its QQ plot of residual (lower panel) for monitoring series. Left panels for reduced base case and right panels for shot-by-shot data with base case GLM model.

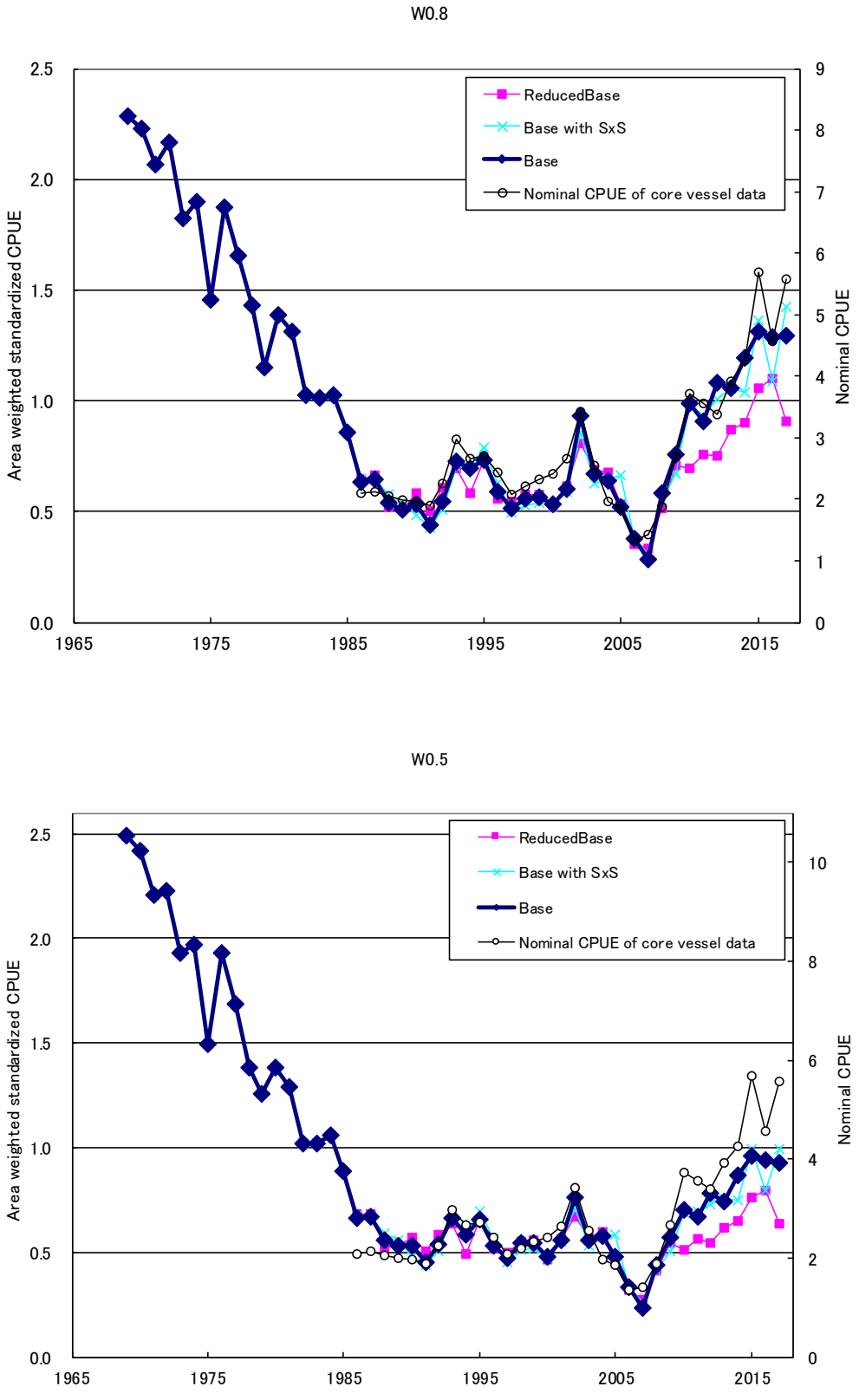


Fig. 4. Area weighed standardized CPUEs. Nominal CPUE of the core vessels is also shown.

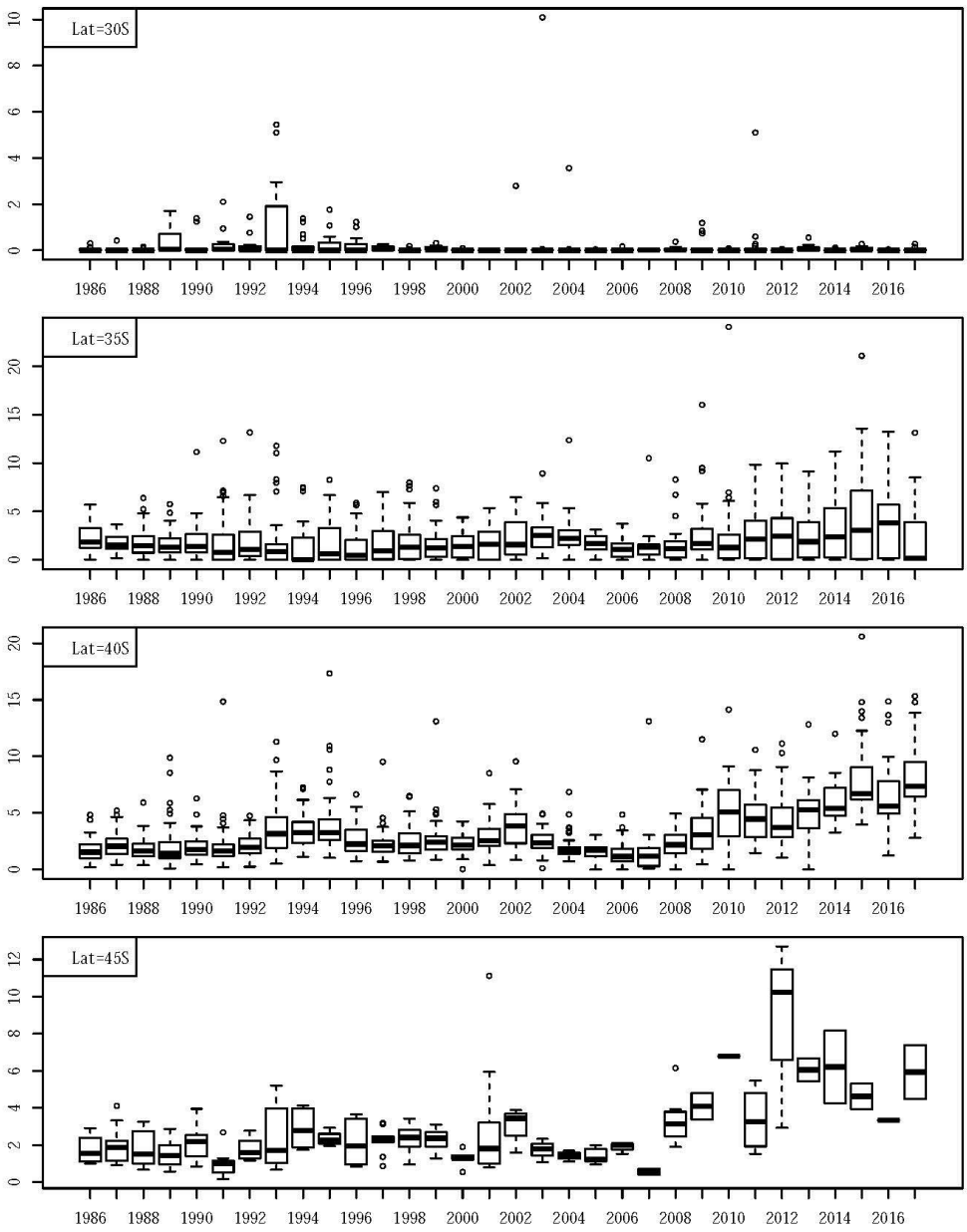


Fig. 5. Nominal CPUE by year and latitude to evaluate whether year*latitude interaction should be included in the GLM model

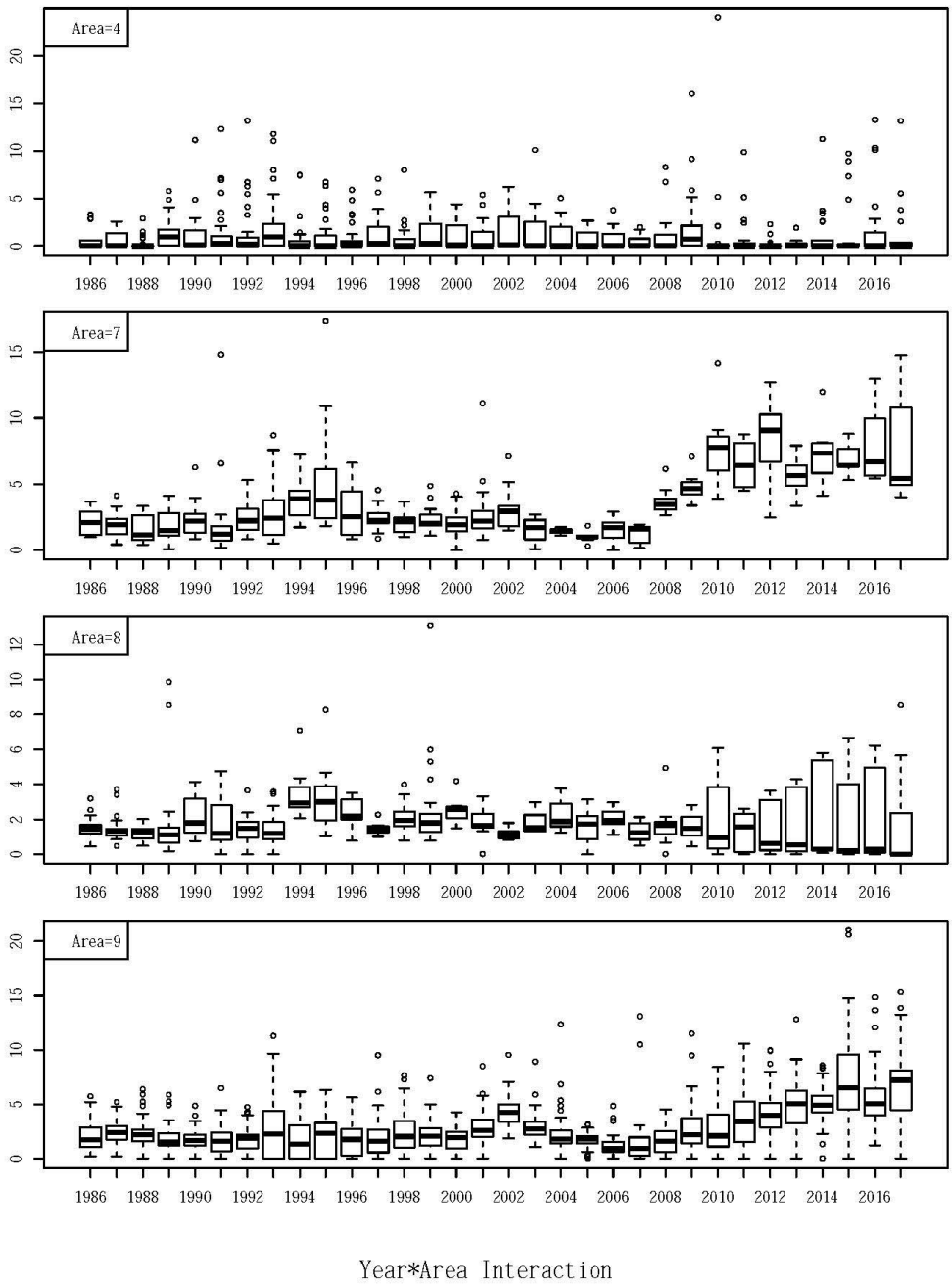


Fig. 6. Nominal CPUE by year and Area to evaluate whether year*Area interaction should be included in the GLM model

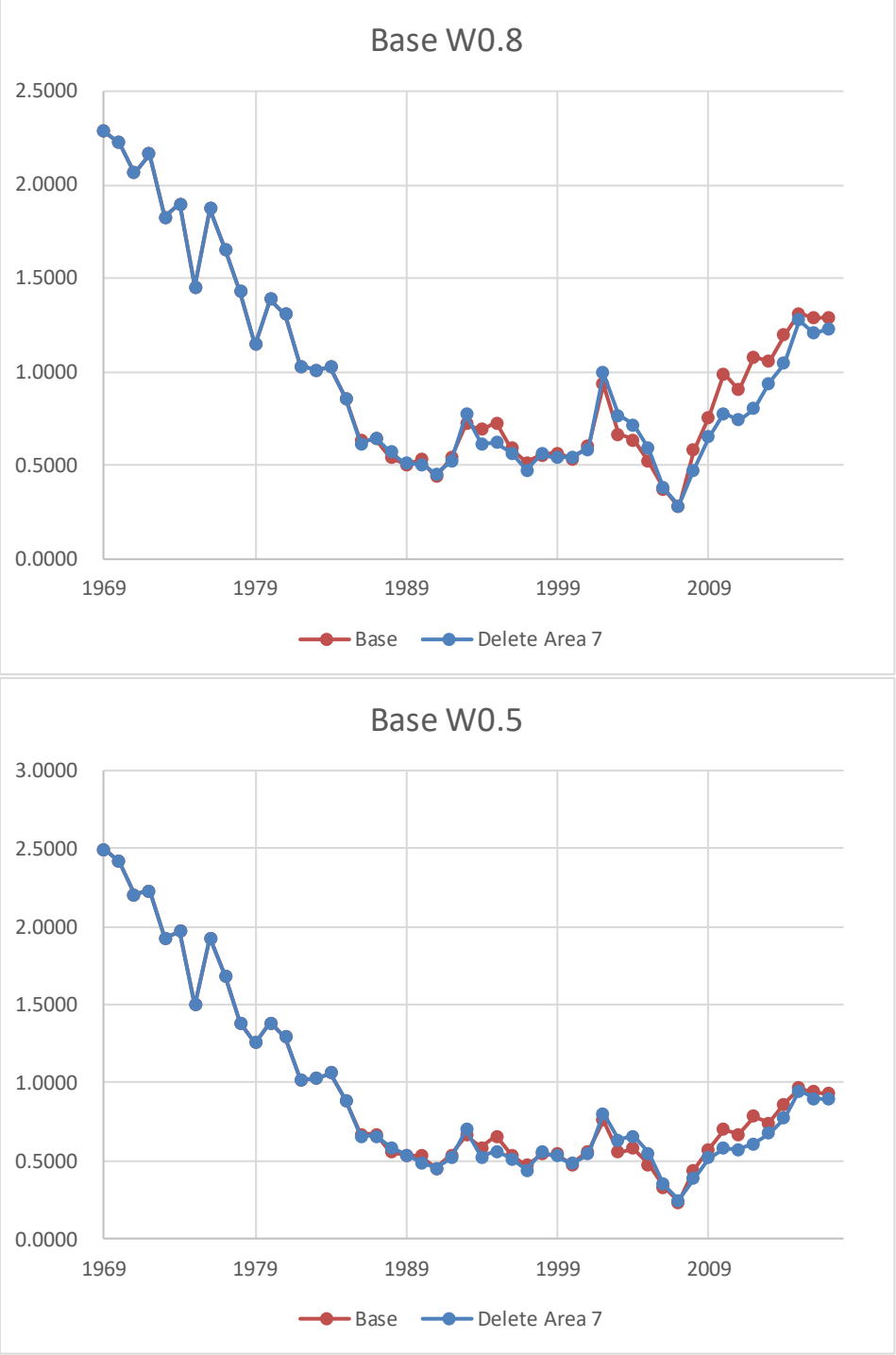


Fig. 7. Area weighted CPUE indices of the Base and the delete area 7, which will be used for the robustness tests.