2019 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 2019

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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 2018 年にまで更新した。2018 年の指数は、ベース GLM モデルによる W0.8 及び W0.5 においてこの 10 年間の平均より高い水準にある。

Summary

This paper summarizes the core vessel CPUE which is an abundance index of southern bluefin tuna used in the Management Procedure of CCSBT. It explains data preparation, CPUE standardization using GLM, and area weighting. The data were updated up to 2018. The index values in 2018, in W0.8 and W0.5 by the base GLM model, are higher than the average over the past 10 years.

Introduction

The stock management of southern bluefin tuna *Thunnus maccoyii* in CCSBT entered a new era with the agreement and implementation of the Management Procedure (MP) in 2011. The adapted MP in CCSBT determines TAC by the pre-specified rule using longline CPUE and aerial survey index, so that those indices should be evaluated with high transparency. 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 (1986-2018), Australia (RTMP data; 1989-2005), and New Zealand (Joint venture; 1990-2015). New Zealand joint venture with Japanese longline vessels was not implemented since 2016. The data from Japan were based on the logbook data, except that RTMP data were used for the most recent years if logbook data were not yet available and RTMP data of the vessel were available. Note that data of operations especially for non-SBT targeting will be added to the dataset one or two years later when logbook data become available.

The dataset was limited to the CCSBT statistical areas between Area 4 and Area 9 and months between April and September. Because there was no Japanese vessel chartered in New Zealand since 2016, data in Area 5 and Are 6 were scarce. It was agreed in the CPUE group that the data in Area 5 and Area 6 should be combined in 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 and month was calculated from the CCSBT catch-at-age database which added catch-at-age data made by Japan this year for 2017 and 2018.

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 193,164 were extracted from entire vessels (Table 1). The number of core vessels chosen ranged from 35 to 108 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 (2018), 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 2018 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 2018 using the base GLM model (2.270) is high as 174% of the average (1.088) in the past 10 years. That of W0.5 in 2018 (1.558) is high as 164% of the average (0.794) 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 shown in Fig. 5. The year trends were different by latitude, such as nominal CPUE since 2010 were much higher than in the 1990s in 40S and 45S. The nominal CPUE by year

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

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. An index for monitoring purpose was made according to the agreement in 2018 at OMMP9 which using the Base GLM model but delete Area 7 (Fig. 7, Table 6).

Sensitivity analysis

A sharp increase was seen in the series from 2017 to 2018. It had already seen in the ls-mean of standardized CPUE (Fig. 2) and exaggerated in the area weighted standardized CPUE (Fig. 4). The reason of the increase was explored in two sensitivity tests for CPUE ls-mean and area weighted index, respectively. The first test considered various dataset. The main core vessel dataset was chosen from the whole dataset by condition of *x* (top rank of SBT catch in a year) = 56 and *y* (number of years in the top ranks) = 3 ("Base dataset"). We made datasets of x=51 ("dataset small") and x=61 ("dataset large"). We also made dataset of x=56 but all the data in 2018 were included ("dataset extra large"). We also used the whole dataset prepared for the core vessel dataset ("dataset all").

In the second case of sensitivity analysis, we considered various model of glm. From the base model of glm, we deleted interaction terms of Year*Area, Year*Lat5, or Month*Area (called "delYearArea", "delYearLat5", "delMonthArea", respectively), or main terms of Month, Area, Lat5, BET_CPUE or YFT_CPUE (called "delMonth", "delArea", "delLat5", "delBET", or "delYFT", respectively). When we delete the main term, relevant interactions were also eliminated.

In the ls-mean of CPUE in different datasets, no significant change was observed that relating the sharp increase in 2018 (Fig .8). In the ls-mean of CPUE in different glm models, some variation among models were observed but the values in 2018 were not so high (Fig. 9). In the area weighted CPUE indices in different datasets, sharp increase was observed in the constant square hypothesis (hence observed also in W0.8 and W0.5 in some degree), but little difference among datasets (Fig. 10). In the area weighted CPUE indices in different glm models, significant change was observed. Comparing to the "Base case", delArea, delLat5, delYearLat5, and delYearArea produced moderate increase from 2017 to 2018. That of delYFT was higher than Base case in 2018. Therefore, it was found that the core vessel area weighted CPUE index was sensitive to the glm model chosen, while less sensitive to datasets.

Further data exploration suggested that 40S in Area 8 was responsible for the sharp increase in 2018 and any specific month was not responsible (Fig. 12). No operations were given in 40S (40S-44S) in Area 8 in recent years (2016-2018) but has a large area weighting in Constant square hypothesis (e.g. weighting value of 96 in 35S and 126 in

40S in August of Area 8) because fishing operation conducted in many one-degree square areas in 40S in historically.

OMMP10 may need some CPUE series for robustness tests. We propose a series of delete Area 8 named “delA8” (using the parameter values from the Base GLM model and area weighting of Area 8 changed to be zero) and a series of delete 40S in Area 8 named “delete 840” (using the parameter values from the Base GLM model and area weighting of 40S in Area 8 changed to be zero) for discussion (Fig. 7, Table 6).

Reference

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

Table 1. Number of records in the dataset used.

Year	All vessels Japan	All vessels Australia	All vessels New Zealand	All vessels Total	Core vessel Total	Core vessel Vessel number
1986	27,005	0	0	27,005	4,068	35
1987	26,759	0	0	26,759	4,804	41
1988	24,418	0	0	24,418	5,353	49
1989	24,315	1,156	0	25,471	6,897	63
1990	19,899	504	475	20,878	6,562	74
1991	18,316	1,204	460	19,980	7,209	74
1992	17,233	1,717	499	19,449	7,213	87
1993	14,797	2,001	486	17,284	6,952	84
1994	12,610	1,394	268	14,272	6,346	93
1995	12,804	800	373	13,977	6,456	97
1996	14,854	0	0	14,854	7,269	99
1997	16,322	0	379	16,701	7,951	95
1998	16,310	0	310	16,620	8,486	108
1999	14,414	0	306	14,720	8,225	101
2000	11,746	0	265	12,011	7,265	98
2001	14,075	0	198	14,273	8,097	103
2002	10,721	0	228	10,949	6,434	93
2003	11,563	0	294	11,857	6,739	93
2004	13,098	0	349	13,447	8,678	96
2005	13,848	0	198	14,046	8,978	97
2006	9,124	0	183	9,307	6,494	87
2007	5,381	0	387	5,768	4,480	82
2008	6,388	0	167	6,555	5,122	90
2009	4,492	0	231	4,723	4,009	72
2010	3,442	0	144	3,586	3,059	64
2011	4,110	0	151	4,261	3,445	62
2012	4,214	0	163	4,377	3,695	73
2013	3,842	0	148	3,990	3,191	67
2014	4,609	0	186	4,795	3,687	71
2015	4,933	0	181	5,114	3,944	71
2016	5,571	0	0	5,571	4,354	69
2017	4,633	0	0	4,633	3,660	67
2018	5,038	0	0	5,038	4,042	66
Total	400,884	8,776	7,029	416,689	193,164	

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		2.1717	1	0.5122	4.24	<.0001
Year	1986	−1.5322	1	0.6019	−2.55	0.011
Year	1987	−0.9081	1	0.5862	−1.55	0.122
Year	1988	−1.1467	1	0.5433	−2.11	0.035
Year	1989	−1.4406	1	0.5732	−2.51	0.012
Year	1990	−1.2312	1	0.5355	−2.30	0.022
Year	1991	−1.8313	1	0.5825	−3.14	0.002
Year	1992	−1.5531	1	0.5960	−2.61	0.009
Year	1993	−0.8668	1	0.5900	−1.47	0.142
Year	1994	−1.4619	1	0.6572	−2.22	0.026
Year	1995	−1.6077	1	0.6539	−2.46	0.014
Year	1996	−1.3107	1	0.6133	−2.14	0.033
Year	1997	−1.4566	1	0.6024	−2.42	0.016
Year	1998	−0.9947	1	0.5905	−1.68	0.092
Year	1999	−1.1528	1	0.5958	−1.93	0.053
Year	2000	−1.7108	1	0.6329	−2.70	0.007
Year	2001	−1.0372	1	0.5798	−1.79	0.074
Year	2002	−0.6470	1	0.6320	−1.02	0.306
Year	2003	−0.9786	1	0.6768	−1.45	0.148
Year	2004	−1.1383	1	0.6290	−1.81	0.070
Year	2005	−1.0283	1	0.6105	−1.68	0.092
Year	2006	−1.4464	1	0.6973	−2.07	0.038
Year	2007	−2.5188	1	0.7615	−3.31	0.001
Year	2008	−1.0057	1	0.5786	−1.74	0.082
Year	2009	−1.1035	1	0.7693	−1.43	0.152
Year	2010	−0.7855	1	0.9204	−0.85	0.394
Year	2011	−0.8531	1	0.6009	−1.42	0.156
Year	2012	−0.2081	1	0.6788	−0.31	0.759
Year	2013	−0.3712	1	0.7290	−0.51	0.611
Year	2014	−0.2943	1	0.7302	−0.40	0.687
Year	2015	−0.4077	1	0.7305	−0.56	0.577
Year	2016	−0.6634	1	0.8743	−0.76	0.448
Year	2017	−0.0261	1	0.7127	−0.04	0.971
Year	2018	0.0000	1			
Month	4	−0.4782	1	0.0944	−5.06	<.0001
Month	5	−0.2451	1	0.0891	−2.75	0.006
Month	6	−0.1813	1	0.0884	−2.05	0.040
Month	7	0.0710	1	0.0873	0.81	0.416
Month	8	0.1797	1	0.0915	1.96	0.050
Month	9	0.0000	1			
Area	4	2.4730	1	0.6081	4.07	<.0001
Area	7	−0.7147	1	0.3834	−1.86	0.062
Area	8	1.3596	1	0.5726	2.37	0.018
Area	9	0.0000	1			
Lat5	30	−5.4844	1	0.8285	−6.62	<.0001
Lat5	35	−2.3696	1	0.7148	−3.32	0.001
Lat5	40	0.0601	1	0.5211	0.12	0.908
Lat5	45	0.0000	1			
BETcpue5		−0.1463	0	0.0103	−14.25	<.0001
YFTcpue5		−0.0753	0	0.0065	−11.54	<.0001
Month*Area	4 4	−1.3698	1	0.1601	−8.56	<.0001
Month*Area	4 7	0.8470	1	0.2276	3.72	0.000
Month*Area	4 8	−1.3538	1	0.1815	−7.46	<.0001
Month*Area	4 9	0.0000	1			
Month*Area	5 4	−0.6557	1	0.1537	−4.27	<.0001
Month*Area	5 7	0.7272	1	0.2211	3.29	0.001
Month*Area	5 8	−1.1114	1	0.1784	−6.23	<.0001
Month*Area	5 9	0.0000	1			
Month*Area	6 4	−0.4859	1	0.1451	−3.35	0.001
Month*Area	6 7	0.6500	1	0.2225	2.92	0.004
Month*Area	6 8	−0.4372	1	0.1930	−2.27	0.024
Month*Area	6 9	0.0000	1			
Month*Area	7 4	−0.2953	1	0.1409	−2.10	0.036
Month*Area	7 7	0.4644	1	0.2367	1.96	0.050
Month*Area	7 8	0.0825	1	0.1396	0.59	0.555
Month*Area	7 9	0.0000	1			
Month*Area	8 4	−0.3805	1	0.1476	−2.58	0.010
Month*Area	8 7	−0.0307	1	0.3436	−0.09	0.929
Month*Area	8 8	0.0993	1	0.1278	0.78	0.437
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	4.7112	1	0.9628	4.89	<.0001
Year*Lat5	1986 35	2.9865	1	0.7910	3.78	0.000
Year*Lat5	1986 40	0.1489	1	0.6064	0.25	0.806
Year*Lat5	1986 45	0.0000	1			
Year*Lat5	1987 30	4.0105	1	0.9568	4.19	<.0001
Year*Lat5	1987 35	2.1762	1	0.7833	2.78	0.006
Year*Lat5	1987 40	−0.1300	1	0.5888	−0.22	0.825
Year*Lat5	1987 45	0.0000	1			
Year*Lat5	1988 30	4.8850	1	0.9087	5.38	<.0001
Year*Lat5	1988 35	2.5379	1	0.7535	3.37	0.001
Year*Lat5	1988 40	−0.0803	1	0.5587	−0.14	0.886
Year*Lat5	1988 45	0.0000	1			
Year*Lat5	1989 30	4.7131	1	0.9512	4.95	<.0001
Year*Lat5	1989 35	2.4663	1	0.7795	3.16	0.002
Year*Lat5	1989 40	0.0058	1	0.5826	0.01	0.992
Year*Lat5	1989 45	0.0000	1			
Year*Lat5	1990 30	3.9471	1	0.9136	4.32	<.0001
Year*Lat5	1990 35	1.9722	1	0.7592	2.60	0.009
Year*Lat5	1990 40	−0.1755	1	0.5520	−0.32	0.751
Year*Lat5	1990 45	0.0000	1			
Year*Lat5	1991 30	4.9628	1	0.9198	5.40	<.0001
Year*Lat5	1991 35	2.6218	1	0.7782	3.37	0.001
Year*Lat5	1991 40	0.4152	1	0.5866	0.71	0.479
Year*Lat5	1991 45	0.0000	1			
Year*Lat5	1992 30	4.7425	1	0.9264	5.12	<.0001
Year*Lat5	1992 35	2.5767	1	0.7880	3.27	0.001
Year*Lat5	1992 40	0.2618	1	0.6006	0.44	0.663
Year*Lat5	1992 45	0.0000	1			
Year*Lat5	1993 30	3.8128	1	0.9261	4.12	<.0001
Year*Lat5	1993 35	1.3620	1	0.7863	1.73	0.083
Year*Lat5	1993 40	0.1113	1	0.6007	0.19	0.853
Year*Lat5	1993 45	0.0000	1			
Year*Lat5	1994 30	3.4501	1	0.9759	3.54	0.000
Year*Lat5	1994 35	1.9091	1	0.8366	2.28	0.023
Year*Lat5	1994 40	0.3832	1	0.6548	0.59	0.558
Year*Lat5	1994 45	0.0000	1			
Year*Lat5	1995 30	4.8684	1	0.9733	5.00	<.0001
Year*Lat5	1995 35	2.4081	1	0.8316	2.90	0.004
Year*Lat5	1995 40	0.6383	1	0.6533	0.98	0.329
Year*Lat5	1995 45	0.0000	1			
Year*Lat5	1996 30	4.1791	1	0.9412	4.44	<.0001
Year*Lat5	1996 35	1.6790	1	0.8031	2.09	0.037
Year*Lat5	1996 40	0.0870	1	0.6191	0.14	0.888
Year*Lat5	1996 45	0.0000	1			
Year*Lat5	1997 30	4.0427	1	0.9379	4.31	<.0001
Year*Lat5	1997 35	2.1479	1	0.7921	2.71	0.007
Year*Lat5	1997 40	0.0925	1	0.6021	0.15	0.878
Year*Lat5	1997 45	0.0000	1			
Year*Lat5	1998 30	3.9395	1	0.9242	4.26	<.0001
Year*Lat5	1998 35	2.0007	1	0.7850	2.55	0.011
Year*Lat5	1998 40	−0.2041	1	0.5996	−0.34	0.734
Year*Lat5	1998 45	0.0000	1			
Year*Lat5	1999 30	3.4486	1	0.9455	3.65	0.000
Year*Lat5	1999 35	1.9366	1	0.7887	2.46	0.014
Year*Lat5	1999 40	−0.0477	1	0.6023	−0.08	0.937
Year*Lat5	1999 45	0.0000	1			
Year*Lat5	2000 30	3.6017	1	0.9719	3.71	0.000
Year*Lat5	2000 35	2.2997	1	0.8162	2.82	0.005
Year*Lat5	2000 40	0.4276	1	0.6333	0.68	0.500
Year*Lat5	2000 45	0.0000	1			
Year*Lat5	2001 30	3.8541	1	0.9341	4.13	<.0001
Year*Lat5	2001 35	1.9435	1	0.7820	2.49	0.013
Year*Lat5	2001 40	0.0347	1	0.5874	0.06	0.953
Year*Lat5	2001 45	0.0000	1			
Year*Lat5	2002 30	4.0218	1	1.0397	3.87	0.000
Year*Lat5	2002 35	2.6374	1	0.8708	3.03	0.003
Year*Lat5	2002 40	0.0324	1	0.6448	0.05	0.960
Year*Lat5	2002 45	0.0000	1			
Year*Lat5	2003 30	3.6865	1	1.0151	3.63	0.000
Year*Lat5	2003 35	2.4845	1	0.8700	2.86	0.004
Year*Lat5	2003 40	−0.0576	1	0.6865	−0.08	0.933
Year*Lat5	2003 45	0.0000	1			
Year*Lat5	2004 30	4.1769	1	0.9608	4.35	<.0001
Year*Lat5	2004 35	2.5001	1	0.8118	3.08	0.002
Year*Lat5	2004 40	−0.2128	1	0.6328	−0.34	0.737
Year*Lat5	2004 45	0.0000	1			
Year*Lat5	2005 30	4.2427	1	0.9518	4.46	<.0001
Year*Lat5	2005 35	2.2300	1	0.7987	2.79	0.005
Year*Lat5	2005 40	−0.4742	1	0.6254	−0.76	0.448
Year*Lat5	2005 45	0.0000	1			
Year*Lat5	2006 30	3.3705	1	1.0253	3.29	0.001
Year*Lat5	2006 35	1.8856	1	0.8681	2.17	0.030
Year*Lat5	2006 40	−0.4566	1	0.6991	−0.65	0.514
Year*Lat5	2006 45	0.0000	1			
Year*Lat5	2007 30	5.1856	1	1.0508	4.93	<.0001
Year*Lat5	2007 35	3.2970	1	0.9219	3.58	0.000
Year*Lat5	2007 40	0.6377	1	0.7607	0.84	0.402
Year*Lat5	2007 45	0.0000	1			
Year*Lat5	2008 30	2.7411	1	0.9391	2.92	0.004
Year*Lat5	2008 35	1.4359	1	0.7791	1.84	0.065
Year*Lat5	2008 40	−0.2900	1	0.5996	−0.48	0.629
Year*Lat5	2008 45	0.0000	1			
Year*Lat5	2009 30	2.8032	1	1.0660	2.63	0.009
Year*Lat5	2009 35	2.2375	1	0.9335	2.40	0.017
Year*Lat5	2009 40	0.1882	1	0.7683	0.25	0.807
Year*Lat5	2009 45	0.0000	1			
Year*Lat5	2010 30	2.8823	1	1.1801	2.44	0.015
Year*Lat5	2010 35	1.8017	1	1.0564	1.71	0.088
Year*Lat5	2010 40	0.0532	1	0.9182	0.06	0.954
Year*Lat5	2010 45	0.0000	1			
Year*Lat5	2011 30	3.7053	1	0.9574	3.87	0.000
Year*Lat5	2011 35	2.3074	1	0.8012	2.88	0.004
Year*Lat5	2011 40	0.2149	1	0.6253	0.34	0.731
Year*Lat5	2011 45	0.0000	1			
Year*Lat5	2012 30	4.2900	1	0.9939	4.32	<.0001
Year*Lat5	2012 35	2.0965	1	0.8574	2.45	0.015
Year*Lat5	2012 40	−0.2781	1	0.6882	−0.40	0.686
Year*Lat5	2012 45	0.0000	1			
Year*Lat5	2013 30	4.0606	1	1.0675	3.80	0.000
Year*Lat5	2013 35	2.3126	1	0.9110	2.54	0.011
Year*Lat5	2013 40	−0.0912	1	0.7408	−0.12	0.902
Year*Lat5	2013 45	0.0000	1			
Year*Lat5	2014 30	3.2939	1	1.0514	3.13	0.002
Year*Lat5	2014 35	2.1985	1	0.9126	2.41	0.016
Year*Lat5	2014 40	0.0540	1	0.7422	0.07	0.942
Year*Lat5	2014 45	0.0000	1			
Year*Lat5	2015 30	3.1827	1	1.0477	3.04	0.002
Year*Lat5	2015 35	1.9078	1	0.9027	2.11	0.035
Year*Lat5	2015 40	0.4477	1	0.7423	0.60	0.547
Year*Lat5	2015 45	0.0000	1			
Year*Lat5	2016 30	3.4029	1	1.1577	2.94	0.003
Year*Lat5	2016 35	2.5552	1	1.0294	2.48	0.013
Year*Lat5	2016 40	0.4084	1	0.8952	0.46	0.648
Year*Lat5	2016 45	0.0000	1			
Year*Lat5	2017 30	1.9025	1	1.0687	1.78	0.075
Year*Lat5	2017 35	0.8363	1	0.9284	0.90	0.368
Year*Lat5	2017 40	0.0290	1	0.7364	0.04	0.969
Year*Lat5	2017 45	0.0000	1			
Year*Lat5	2018 30	0.0000	1			
Year*Lat5	2018 35	0.0000	1			
Year*Lat5	2018 40	0.0000	1			
Year*Lat5	2018 45	0.0000	1			
Year*Area	1986 4	−2.4850	1	0.6860	−3.62	0.000
Year*Area	1986 7	0.2988	1	0.4135	0.72	0.470
Year*Area	1986 8	−2.0598	1	0.5981	−3.44	0.001
Year*Area	1986 9	0.0000	1			
Year*Area	1987 4	−2.5488	1	0.6844	−3.72	0.000
Year*Area	1987 7	−0.2230	1	0.3908	−0.57	0.568
Year*Area	1987 8	−2.1111	1	0.5968	−3.54	0.000
Year*Area	1987 9	0.0000	1			
Year*Area	1988 4	−3.4760	1	0.6574	−5.29	<.0001
Year*Area	1988 7	−0.2988	1	0.3665	−0.82	0.415
Year*Area	1988 8	−2.2670	1	0.5989	−3.79	0.000
Year*Area	1988 9	0.0000	1			
Year*Area	1989 4	−2.4421	1	0.6633	−3.68	0.000
Year*Area	1989 7	0.0408	1	0.3751	0.11	0.913

Table 2. (cont.)

Parameter	Estimate	Biased	StdErr	tValue	Probt
Year*Area 1989 8	−1.9659	1	0.5933	−3.31	0.001
Year*Area 1989 9	0.0000	1			
Year*Area 1990 4	−2.0401	1	0.6624	−3.08	0.002
Year*Area 1990 7	0.1800	1	0.3622	0.50	0.619
Year*Area 1990 8	−1.5078	1	0.6084	−2.48	0.013
Year*Area 1990 9	0.0000	1			
Year*Area 1991 4	−2.1027	1	0.6374	−3.30	0.001
Year*Area 1991 7	−0.0794	1	0.3727	−0.21	0.831
Year*Area 1991 8	−1.7540	1	0.6016	−2.92	0.004
Year*Area 1991 9	0.0000	1			
Year*Area 1992 4	−2.3648	1	0.6399	−3.70	0.000
Year*Area 1992 7	0.2165	1	0.3708	0.58	0.559
Year*Area 1992 8	−1.8083	1	0.5969	−3.03	0.003
Year*Area 1992 9	0.0000	1			
Year*Area 1993 4	−1.5556	1	0.6395	−2.43	0.015
Year*Area 1993 7	−0.2981	1	0.3788	−0.79	0.431
Year*Area 1993 8	−1.2693	1	0.6023	−2.11	0.035
Year*Area 1993 9	0.0000	1			
Year*Area 1994 4	−1.2012	1	0.6547	−1.83	0.067
Year*Area 1994 7	0.6073	1	0.4399	1.38	0.168
Year*Area 1994 8	−0.8537	1	0.6086	−1.40	0.161
Year*Area 1994 9	0.0000	1			
Year*Area 1995 4	−2.1542	1	0.6547	−3.29	0.001
Year*Area 1995 7	0.6231	1	0.3818	1.63	0.103
Year*Area 1995 8	−1.2512	1	0.6015	−2.08	0.038
Year*Area 1995 9	0.0000	1			
Year*Area 1996 4	−1.8256	1	0.6431	−2.84	0.005
Year*Area 1996 7	0.3177	1	0.3853	0.82	0.410
Year*Area 1996 8	−1.0085	1	0.6374	−1.58	0.114
Year*Area 1996 9	0.0000	1			
Year*Area 1997 4	−1.7768	1	0.6413	−2.77	0.006
Year*Area 1997 7	0.3906	1	0.3882	1.01	0.314
Year*Area 1997 8	−1.5791	1	0.6259	−2.52	0.012
Year*Area 1997 9	0.0000	1			
Year*Area 1998 4	−2.5006	1	0.6337	−3.95	<.0001
Year*Area 1998 7	−0.0513	1	0.3898	−0.13	0.895
Year*Area 1998 8	−1.6200	1	0.6019	−2.69	0.007
Year*Area 1998 9	0.0000	1			
Year*Area 1999 4	−2.0573	1	0.6434	−3.20	0.001
Year*Area 1999 7	0.1584	1	0.3832	0.41	0.679
Year*Area 1999 8	−1.5114	1	0.5977	−2.53	0.012
Year*Area 1999 9	0.0000	1			
Year*Area 2000 4	−1.6922	1	0.6481	−2.61	0.009
Year*Area 2000 7	0.1742	1	0.3777	0.46	0.645
Year*Area 2000 8	−1.0964	1	0.6275	−1.75	0.081
Year*Area 2000 9	0.0000	1			
Year*Area 2001 4	−2.2759	1	0.6499	−3.50	0.001
Year*Area 2001 7	−0.0217	1	0.3717	−0.06	0.953
Year*Area 2001 8	−1.7051	1	0.6185	−2.76	0.006
Year*Area 2001 9	0.0000	1			
Year*Area 2002 4	−3.0583	1	0.7203	−4.25	<.0001
Year*Area 2002 7	−0.2301	1	0.4043	−0.57	0.569
Year*Area 2002 8	−2.7839	1	0.6432	−4.33	<.0001
Year*Area 2002 9	0.0000	1			
Year*Area 2003 4	−2.2285	1	0.6875	−3.24	0.001
Year*Area 2003 7	−0.4792	1	0.4161	−1.15	0.250
Year*Area 2003 8	−1.9701	1	0.6632	−2.97	0.003
Year*Area 2003 9	0.0000	1			
Year*Area 2004 4	−2.2832	1	0.6548	−3.49	0.001
Year*Area 2004 7	−0.1735	1	0.4058	−0.43	0.669
Year*Area 2004 8	−1.1688	1	0.6042	−1.93	0.053
Year*Area 2004 9	0.0000	1			
Year*Area 2005 4	−2.8036	1	0.6498	−4.31	<.0001
Year*Area 2005 7	−0.3640	1	0.4314	−0.84	0.399
Year*Area 2005 8	−1.1093	1	0.6142	−1.81	0.071
Year*Area 2005 9	0.0000	1			
Year*Area 2006 4	−1.7849	1	0.6527	−2.73	0.006
Year*Area 2006 7	0.2692	1	0.4010	0.67	0.502
Year*Area 2006 8	−0.9996	1	0.6147	−1.63	0.104
Year*Area 2006 9	0.0000	1			
Year*Area 2007 4	−2.2165	1	0.6505	−3.41	0.001
Year*Area 2007 7	0.3869	1	0.4105	0.94	0.346
Year*Area 2007 8	−1.5767	1	0.6057	−2.60	0.009
Year*Area 2007 9	0.0000	1			
Year*Area 2008 4	−0.9643	1	0.6647	−1.45	0.147
Year*Area 2008 7	0.7532	1	0.4161	1.81	0.070
Year*Area 2008 8	−1.3701	1	0.6024	−2.27	0.023
Year*Area 2008 9	0.0000	1			
Year*Area 2009 4	−1.2569	1	0.6629	−1.90	0.058
Year*Area 2009 7	0.6055	1	0.4264	1.42	0.156
Year*Area 2009 8	−1.8543	1	0.6187	−3.00	0.003
Year*Area 2009 9	0.0000	1			
Year*Area 2010 4	−1.9616	1	0.6610	−2.97	0.003
Year*Area 2010 7	0.7903	1	0.4298	1.84	0.066
Year*Area 2010 8	−1.2062	1	0.6140	−1.96	0.050
Year*Area 2010 9	0.0000	1			
Year*Area 2011 4	−2.5536	1	0.6770	−3.77	0.000
Year*Area 2011 7	0.5634	1	0.4201	1.34	0.180
Year*Area 2011 8	−1.8519	1	0.6130	−3.02	0.003
Year*Area 2011 9	0.0000	1			
Year*Area 2012 4	−3.9977	1	0.6568	−6.09	<.0001
Year*Area 2012 7	0.5247	1	0.4270	1.23	0.219
Year*Area 2012 8	−2.3686	1	0.6140	−3.86	0.000
Year*Area 2012 9	0.0000	1			
Year*Area 2013 4	−3.4537	1	0.7112	−4.86	<.0001
Year*Area 2013 7	0.2321	1	0.4314	0.54	0.591
Year*Area 2013 8	−2.0934	1	0.6282	−3.33	0.001
Year*Area 2013 9	0.0000	1			
Year*Area 2014 4	−3.0519	1	0.6782	−4.50	<.0001
Year*Area 2014 7	0.2740	1	0.4387	0.62	0.532
Year*Area 2014 8	−2.1445	1	0.6329	−3.39	0.001
Year*Area 2014 9	0.0000	1			
Year*Area 2015 4	−2.4266	1	0.6770	−3.58	0.000
Year*Area 2015 7	0.0153	1	0.4415	0.03	0.972
Year*Area 2015 8	−1.9354	1	0.6177	−3.13	0.002
Year*Area 2015 9	0.0000	1			
Year*Area 2016 4	−2.5797	1	0.6809	−3.79	0.000
Year*Area 2016 7	0.3419	1	0.4535	0.75	0.451
Year*Area 2016 8	−2.0511	1	0.6309	−3.25	0.001
Year*Area 2016 9	0.0000	1			
Year*Area 2017 4	−1.8587	1	0.7218	−2.58	0.010
Year*Area 2017 7	−0.0065	1	0.4510	−0.01	0.989
Year*Area 2017 8	−1.6263	1	0.6833	−2.38	0.017
Year*Area 2017 9	0.0000	1			
Year*Area 2018 4	0.0000	1			
Year*Area 2018 7	0.0000	1			
Year*Area 2018 8	0.0000	1			
Year*Area 2018 9	0.0000	1			

Table 3. ANOVA statistics

Base

HypothesisType	Source	DF	SS	MS	FValue	ProbF
2	Year	32	258.445	8.076	15.93	<.0001
2	Month	5	228.381	45.676	90.11	<.0001
2	Area	3	91.336	30.445	60.06	<.0001
2	Lat5	3	259.786	86.595	170.83	<.0001
2	BETcpue5	1	102.999	102.999	203.19	<.0001
2	YFTcpue5	1	67.522	67.522	133.2	<.0001
2	Month*Area	15	127.923	8.528	16.82	<.0001
2	Year*Lat5	96	152.172	1.585	3.13	<.0001
2	Year*Area	96	160.258	1.669	3.29	<.0001
HypothesisType	Source	DF	SS	MS	FValue	ProbF
3	Year	32	65.143	2.036	4.02	<.0001
3	Month	5	186.486	37.297	73.58	<.0001
3	Area	3	80.106	26.702	52.68	<.0001
3	Lat5	3	301.229	100.410	198.08	<.0001
3	BETcpue5	1	102.999	102.999	203.19	<.0001
3	YFTcpue5	1	67.522	67.522	133.2	<.0001
3	Month*Area	15	127.923	8.528	16.82	<.0001
3	Year*Lat5	96	152.172	1.585	3.13	<.0001
3	Year*Area	96	160.258	1.669	3.29	<.0001

RedB

HypothesisType	Source	DF	SS	MS	FValue	ProbF
2	Year	32	258.445	8.076	13.45	<.0001
2	Month	5	273.733	54.747	91.19	<.0001
2	Area	3	121.069	40.356	67.22	<.0001
2	Lat5	3	313.265	104.422	173.93	<.0001
2	BETcpue5	1	201.004	201.004	334.8	<.0001
2	YFTcpue5	1	69.697	69.697	116.09	<.0001
2	Month*Area	15	148.296	9.886	16.47	<.0001
HypothesisType	Source	DF	SS	MS	FValue	ProbF
3	Year	32	258.445	8.076	13.45	<.0001
3	Month	5	208.854	41.771	69.57	<.0001
3	Area	3	151.948	50.649	84.36	<.0001
3	Lat5	3	313.265	104.422	173.93	<.0001
3	BETcpue5	1	201.004	201.004	334.8	<.0001
3	YFTcpue5	1	69.697	69.697	116.09	<.0001
3	Month*Area	15	148.296	9.886	16.47	<.0001

BaseSxS

HypothesisType	Source	DF	SS	MS	FValue	ProbF
2	Year	32	13202.969	412.593	552.39	<.0001
2	Month	5	4918.462	983.692	1316.99	<.0001
2	Area	3	999.244	333.081	445.94	<.0001
2	Lat5	3	7807.050	2602.350	3484.1	<.0001
2	BETcpue	1	4346.211	4346.211	5818.83	<.0001
2	YFTcpue	1	3277.903	3277.903	4388.55	<.0001
2	Month*Area	15	7252.792	483.519	647.35	<.0001
2	Year*Lat5	96	8919.528	92.912	124.39	<.0001
2	Year*Area	96	10812.246	112.628	150.79	<.0001
HypothesisType	Source	DF	SS	MS	FValue	ProbF
3	Year	32	1789.085	55.909	74.85	<.0001
3	Month	5	5163.839	1032.768	1382.7	<.0001
3	Area	3	2252.772	750.924	1005.36	<.0001
3	Lat5	3	8008.204	2669.401	3573.87	<.0001
3	BETcpue	1	4346.211	4346.211	5818.83	<.0001
3	YFTcpue	1	3277.903	3277.903	4388.55	<.0001
3	Month*Area	15	7252.792	483.519	647.35	<.0001
3	Year*Lat5	96	8919.528	92.912	124.39	<.0001
3	Year*Area	96	10812.246	112.628	150.79	<.0001

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

Model	AIC	BIC
Base	7,644	9,198
Reduced Base	8,042	8,417

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	0.6272	0.6625	0.6421	0.6798	0.6427	0.6761
1987	0.6378	0.6644	0.6599	0.6803	0.6414	0.6660
1988	0.5355	0.5523	0.5180	0.5231	0.5729	0.5840
1989	0.5007	0.5294	0.5026	0.5266	0.5335	0.5547
1990	0.5318	0.5273	0.5828	0.5681	0.4793	0.4798
1991	0.4364	0.4476	0.5009	0.5009	0.4275	0.4423
1992	0.5345	0.5291	0.5959	0.5764	0.5023	0.5007
1993	0.7232	0.6627	0.6936	0.6326	0.7024	0.6643
1994	0.7271	0.6111	0.6163	0.5208	0.7176	0.6092
1995	0.7256	0.6535	0.7328	0.6557	0.7842	0.6884
1996	0.5817	0.5262	0.5458	0.5063	0.6157	0.5603
1997	0.4967	0.4513	0.5341	0.4845	0.4818	0.4422
1998	0.5506	0.5355	0.5713	0.5484	0.5218	0.5025
1999	0.5545	0.5338	0.5625	0.5400	0.5309	0.5112
2000	0.5305	0.4732	0.5182	0.4608	0.5210	0.4719
2001	0.5871	0.5478	0.6003	0.5526	0.5752	0.5354
2002	0.9304	0.7613	0.8038	0.6661	0.8705	0.7170
2003	0.6649	0.5545	0.6879	0.5685	0.6191	0.5273
2004	0.6342	0.5733	0.6793	0.6061	0.6480	0.5747
2005	0.5209	0.4760	0.5257	0.4771	0.6663	0.5840
2006	0.3719	0.3260	0.3454	0.3154	0.3731	0.3280

Table 5. (cont.)

Year	Base w08	Base w05	Reduced Base w08	Reduced Base w05	Base with SxS w08	Base with SxS w05
2007	0.3181	0.2691	0.3711	0.3021	0.3396	0.2869
2008	0.6311	0.4746	0.5621	0.4506	0.5857	0.4357
2009	0.8306	0.6309	0.7878	0.6051	0.7207	0.5450
2010	1.0083	0.7178	0.7193	0.5309	0.9789	0.6938
2011	0.9576	0.7109	0.8076	0.6014	0.9691	0.7242
2012	1.1461	0.8354	0.7989	0.5839	1.0650	0.7776
2013	1.1013	0.7802	0.9262	0.6550	1.0914	0.7827
2014	1.2753	0.9263	0.9675	0.6998	1.0610	0.7646
2015	1.3266	0.9721	1.0647	0.7668	1.3731	0.9980
2016	1.2929	0.9436	1.1055	0.7985	1.0937	0.7967
2017	1.3067	0.9505	0.9143	0.6482	1.4533	1.0250
2018	2.2699	1.5575	1.3576	0.9817	2.4613	1.6450

Table 6. Other area weighted standardized CPUE series

Year	del A7 w08	del A7 w05	del A8 w08	del A8 w05	del840 w08	del840 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	0.6139	0.6507	0.6547	0.6560	0.6590	0.6755
1987	0.6445	0.6512	0.6674	0.6683	0.6546	0.6603
1988	0.5669	0.5773	0.5722	0.5725	0.5625	0.5655

Table 6. (cont.)

	del A7	del A7	del A8	del A8	del840	del840
Year	w08	w05	w08	w05	w08	w05
1989	0.5048	0.5308	0.5254	0.5387	0.5141	0.5251
1990	0.5041	0.4837	0.5340	0.5234	0.5304	0.5165
1991	0.4541	0.4523	0.4470	0.4553	0.4420	0.4509
1992	0.5181	0.5134	0.5599	0.5533	0.5519	0.5450
1993	0.7725	0.6973	0.6879	0.6514	0.6681	0.6297
1994	0.6655	0.5628	0.6372	0.5258	0.6472	0.5401
1995	0.6210	0.5575	0.6942	0.6288	0.6960	0.6364
1996	0.5544	0.5039	0.5351	0.5063	0.5392	0.5056
1997	0.4535	0.4150	0.5148	0.4738	0.5050	0.4621
1998	0.5524	0.5450	0.5551	0.5527	0.5556	0.5462
1999	0.5301	0.5195	0.5546	0.5440	0.5496	0.5329
2000	0.5431	0.4743	0.4871	0.4496	0.4953	0.4511
2001	0.5710	0.5263	0.6094	0.5779	0.5907	0.5583
2002	0.9948	0.8040	1.0726	0.8639	1.0201	0.8259
2003	0.7645	0.6323	0.7065	0.5844	0.7026	0.5868
2004	0.7146	0.6527	0.5680	0.5260	0.6289	0.5778
2005	0.5946	0.5497	0.4551	0.4416	0.5133	0.4838
2006	0.3761	0.3435	0.3399	0.3050	0.3606	0.3185
2007	0.3266	0.2834	0.3173	0.2598	0.3268	0.2729
2008	0.5113	0.4161	0.6568	0.4840	0.6389	0.4757
2009	0.7486	0.5965	0.9069	0.6743	0.8778	0.6669
2010	0.8085	0.6014	1.0021	0.7184	0.9918	0.7150
2011	0.8186	0.6303	1.0340	0.7678	1.0010	0.7461
2012	0.8987	0.6839	1.3087	0.9460	1.2438	0.9044
2013	1.0276	0.7386	1.1992	0.8396	1.1711	0.8296
2014	1.1558	0.8514	1.4014	1.0121	1.3542	0.9877
2015	1.2970	0.9613	1.4101	1.0426	1.3477	1.0000
2016	1.2132	0.9032	1.4103	1.0246	1.3657	1.0022
2017	1.2484	0.9242	1.3391	0.9978	1.2748	0.9485
2018	2.5332	1.7174	1.4489	1.1122	1.4942	1.1301

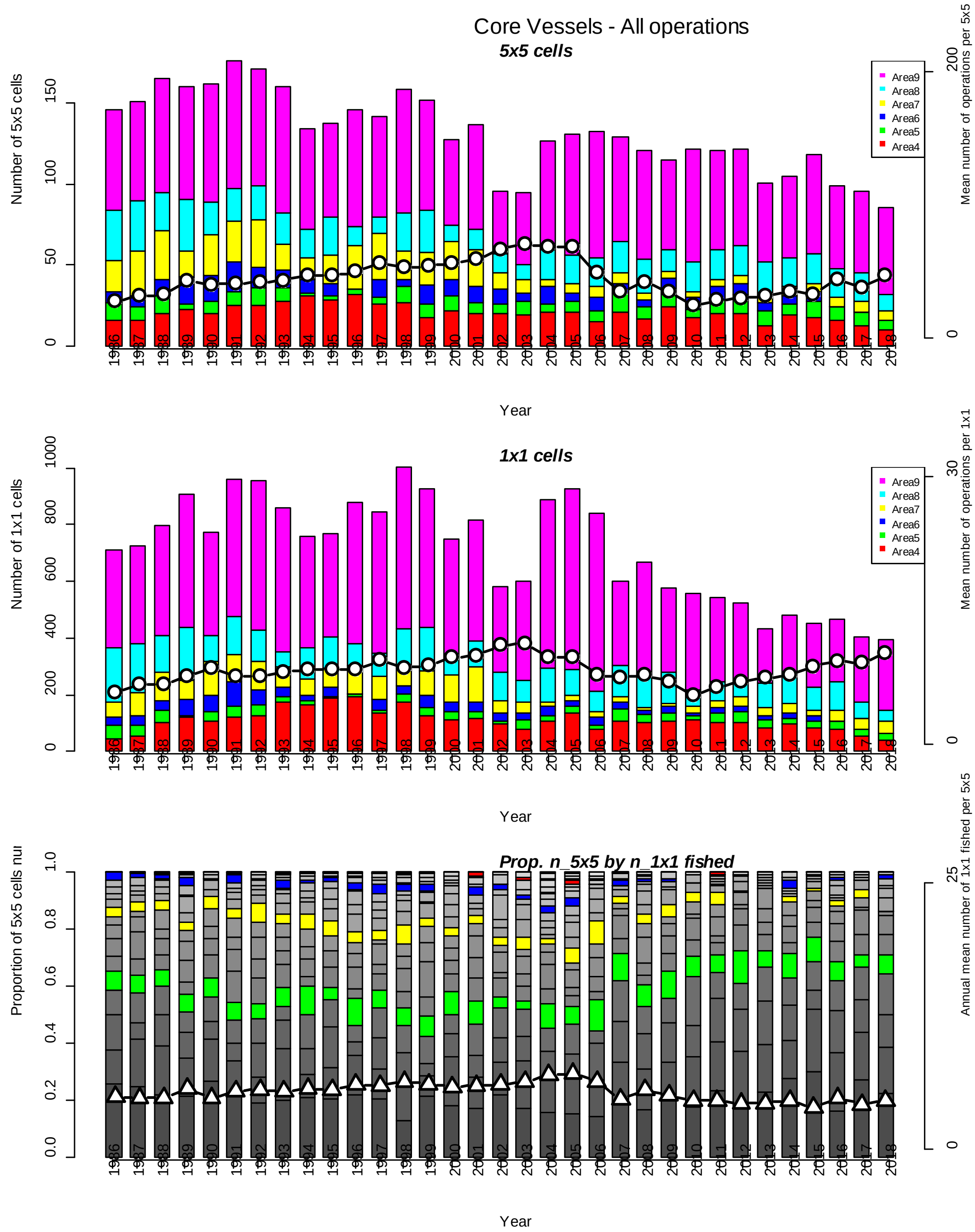


Fig. 1a. Number of cells in the core vessel for <u>all operations</u>.

(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.

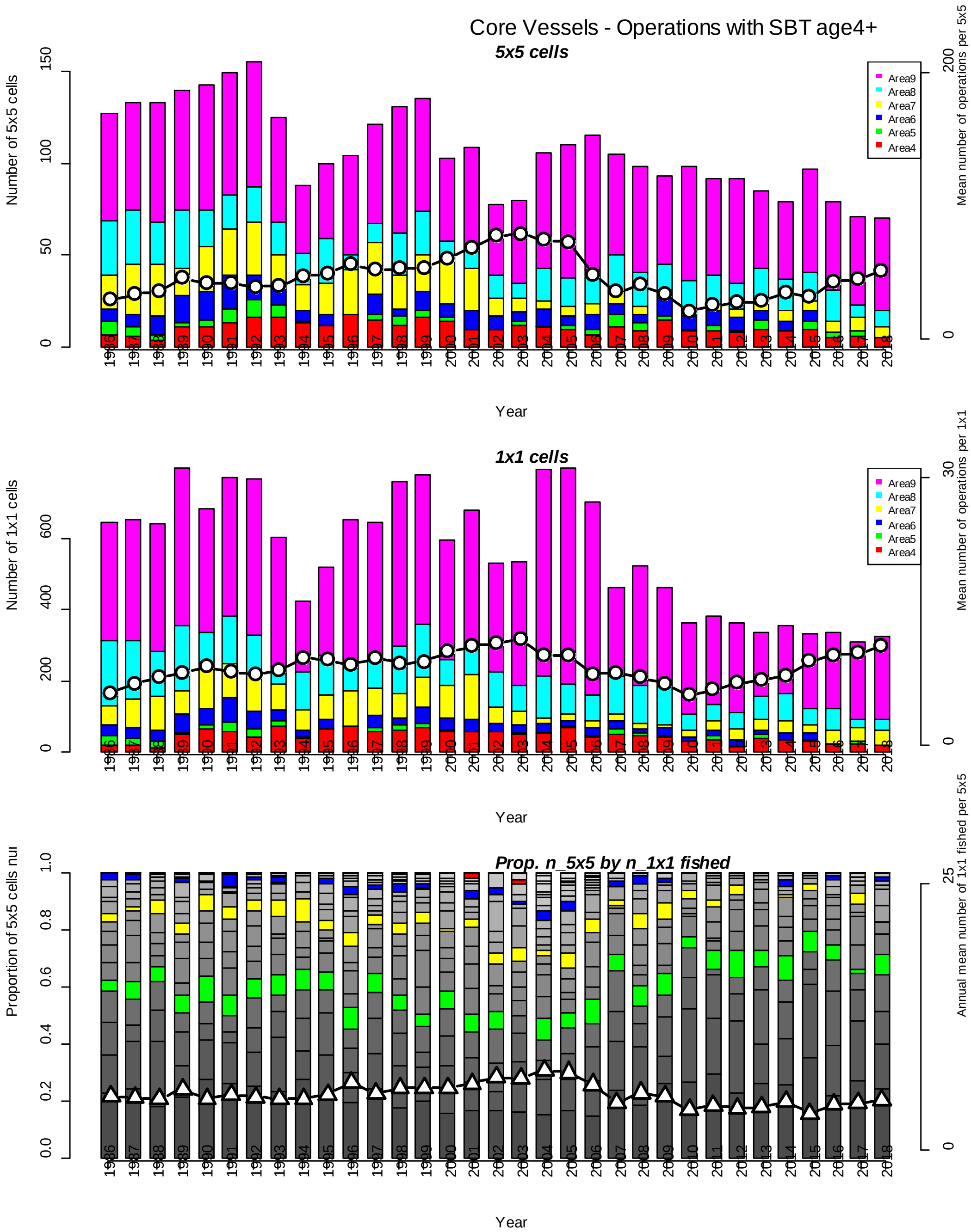
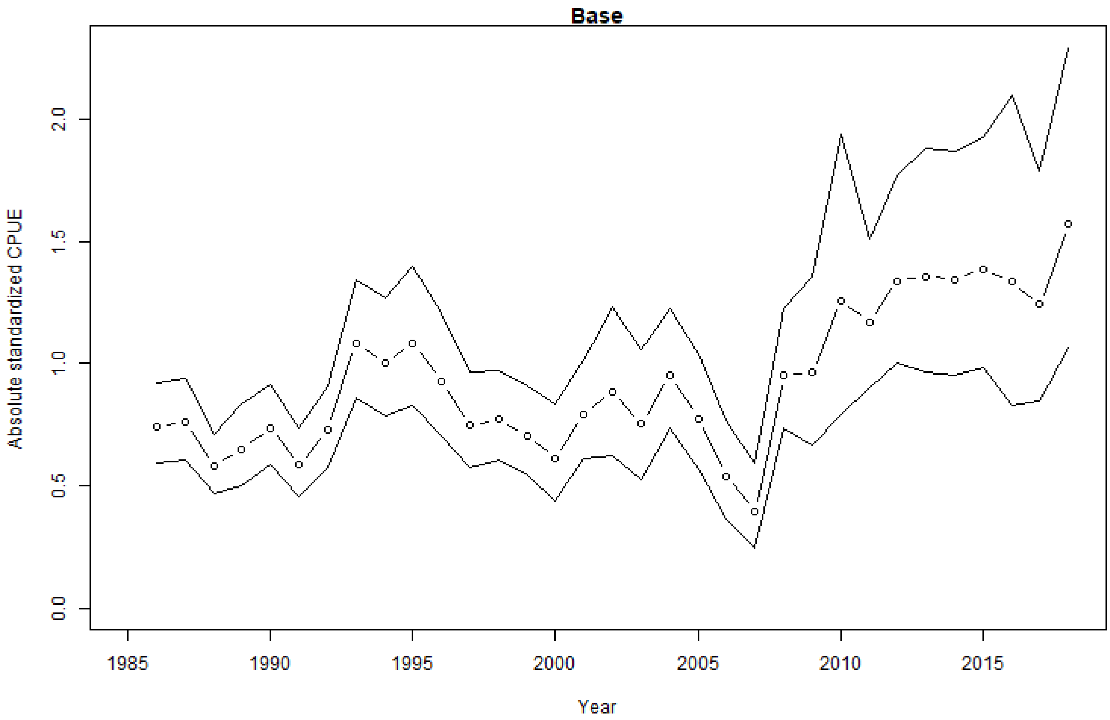


Fig. 1b. Number of cells in the core vessel for SBT 4+ catch positive. See explanation in Fig. 1a.



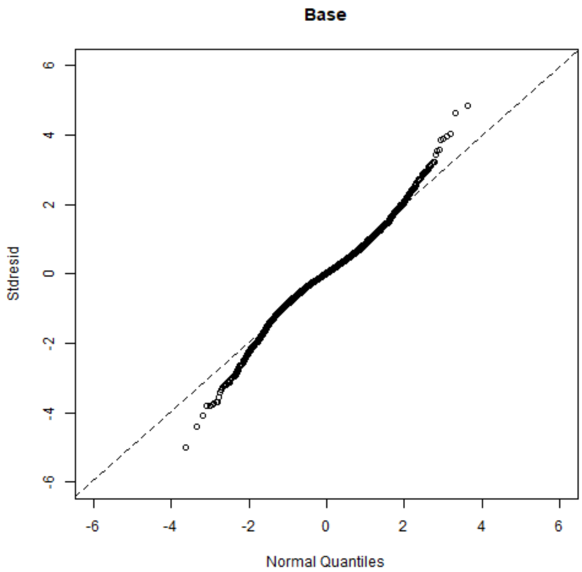


Fig. 2. Standardized CPUE (ls-mean with 95% confidence interval) of the core vessel data (upper panel) and its QQ plot of residual (lower panel) for Base case.

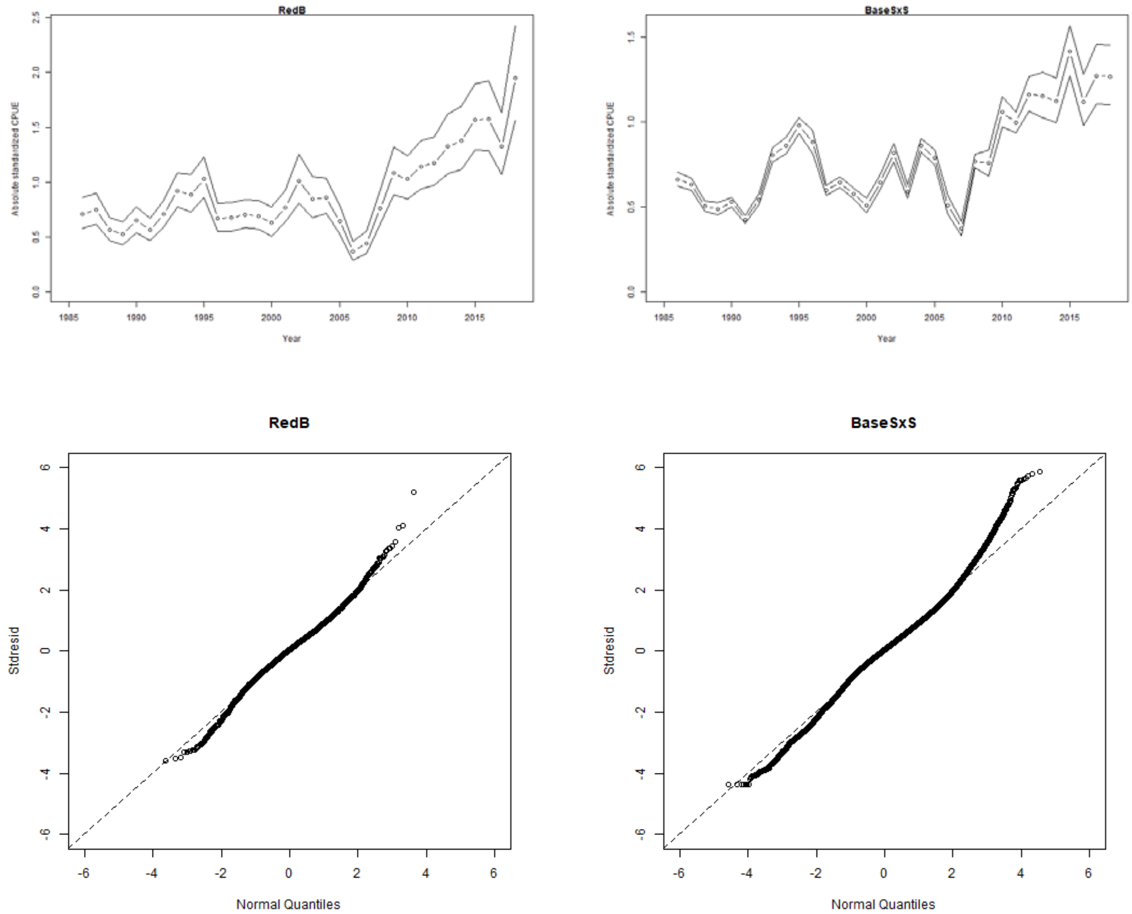
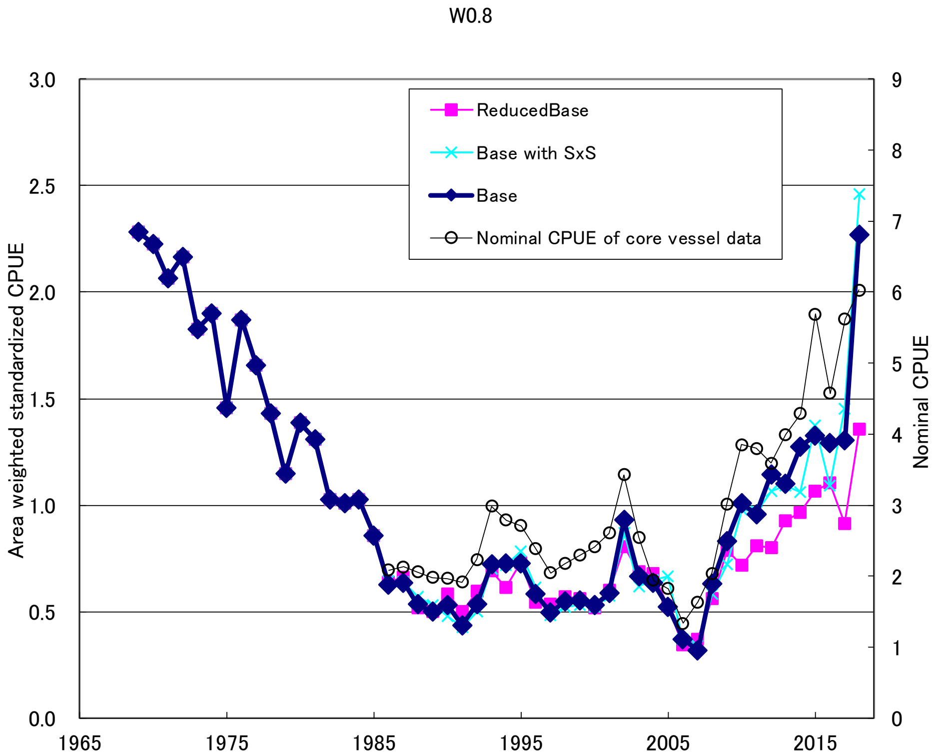


Fig. 3. Standardized CPUE (ls-mean with 95% confidence interval) of the core vessel data (upper panel) and its QQ plot of residual (lower panel) for monitoring series. Left panels for reduced base case and right panels for shot-by-shot data with base case GLM model.



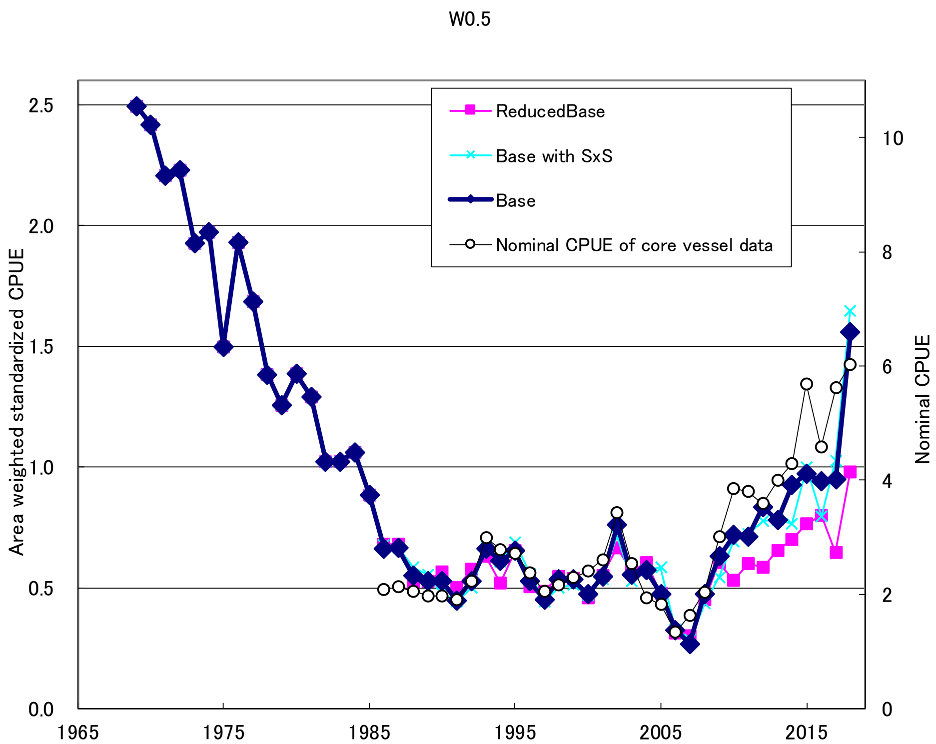


Fig. 4. Area weighed standardized CPUEs. Nominal CPUE of the core vessels is also shown.

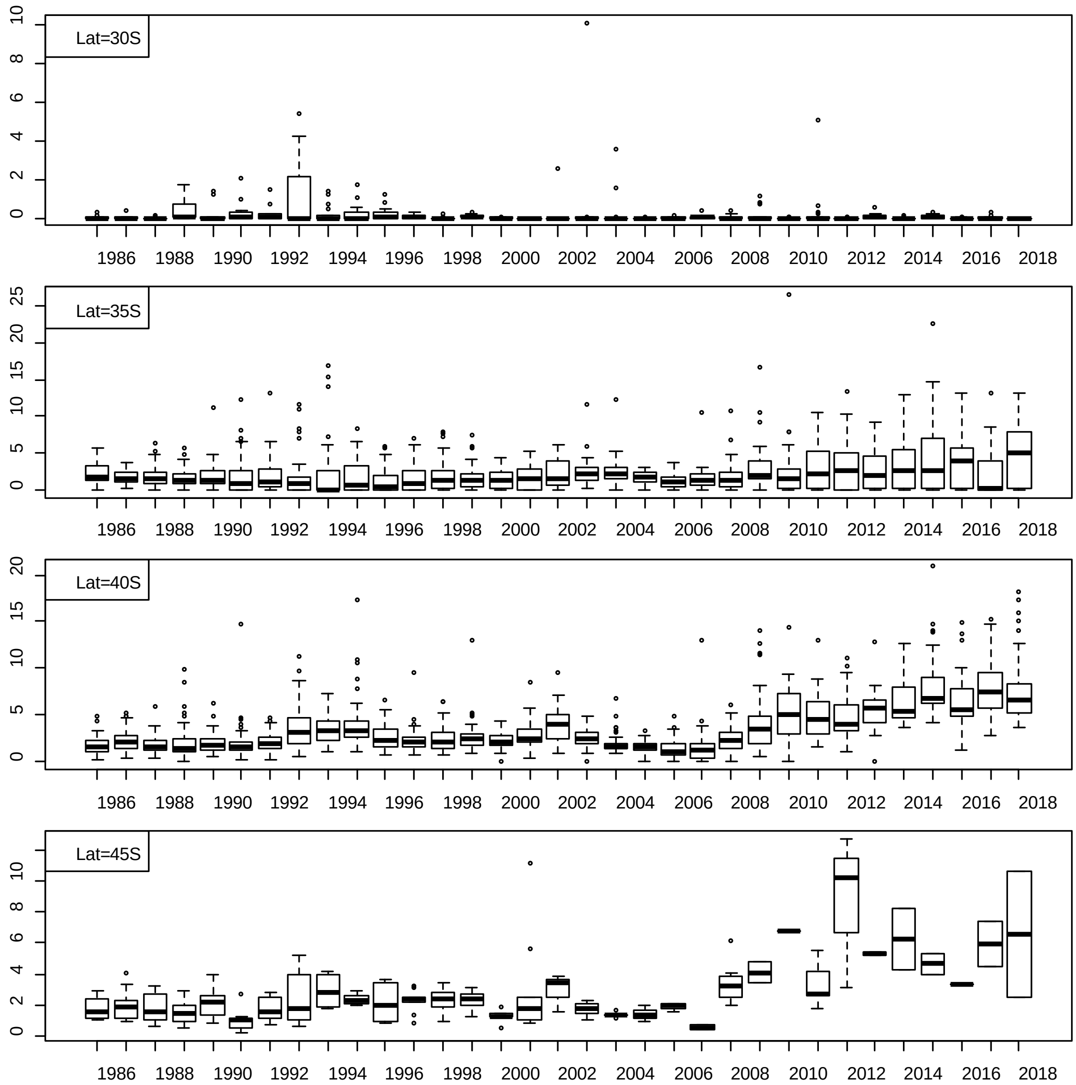


Fig. 5. Nominal CPUE by year and latitude to evaluate whether year*latitude interaction should be included in the GLM model

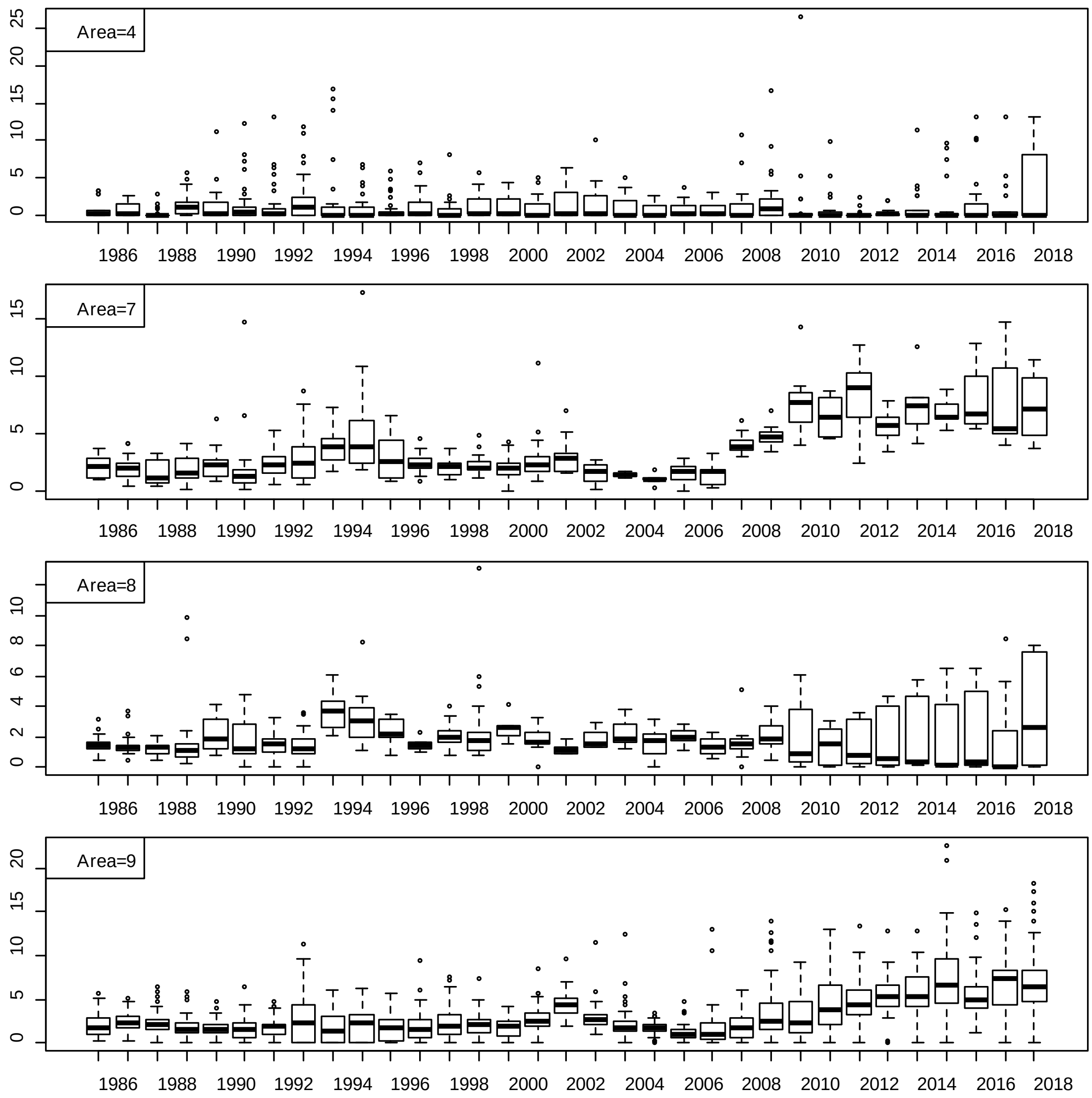
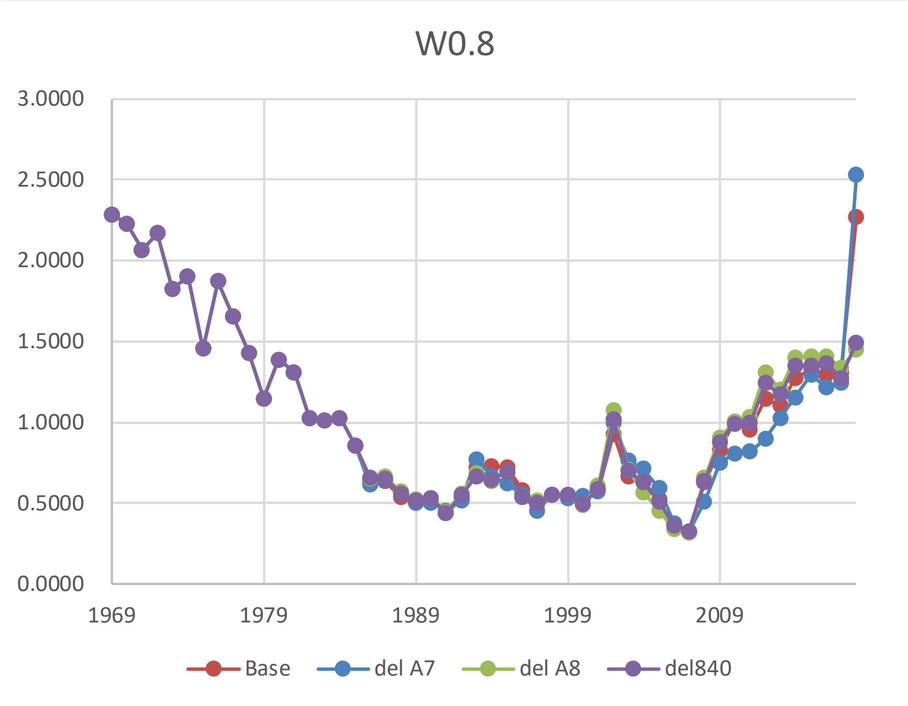


Fig. 6. Nominal CPUE by year and Area to evaluate whether year*Area interaction should be included in the GLM model



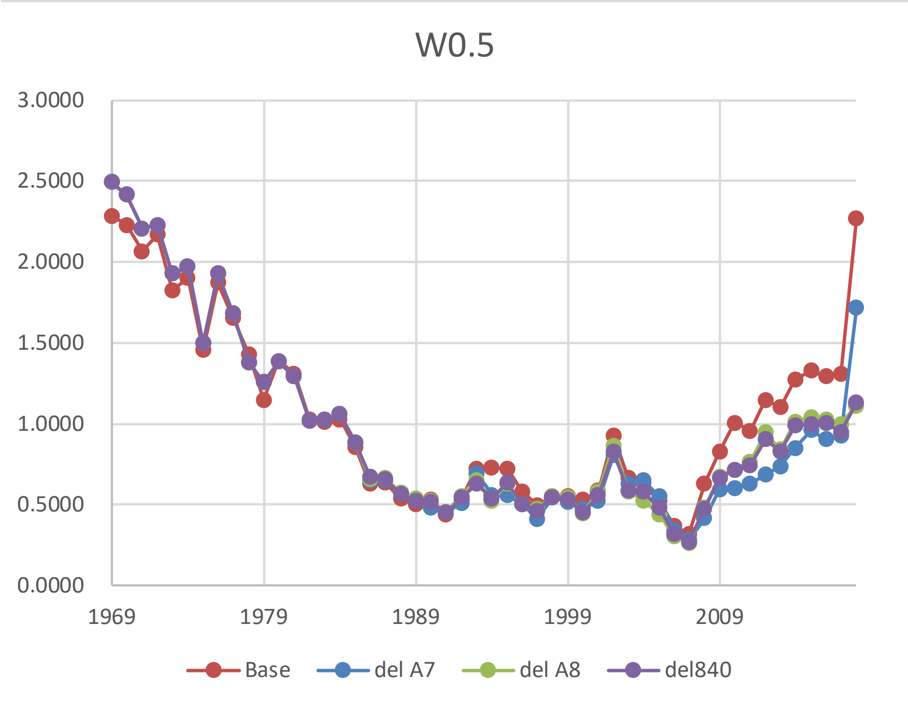


Fig. 7. Area weighted CPUE indices of the Base and delete area 7, delete area 8, and delete 40S in Area 8 (del840) which are the candidate for the robustness tests.

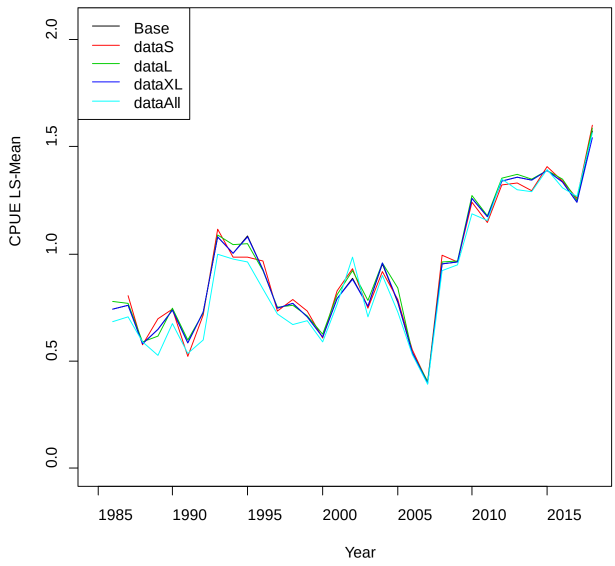


Fig. 8. Sensitivity test of ls-mean of CPUE in various datasets.

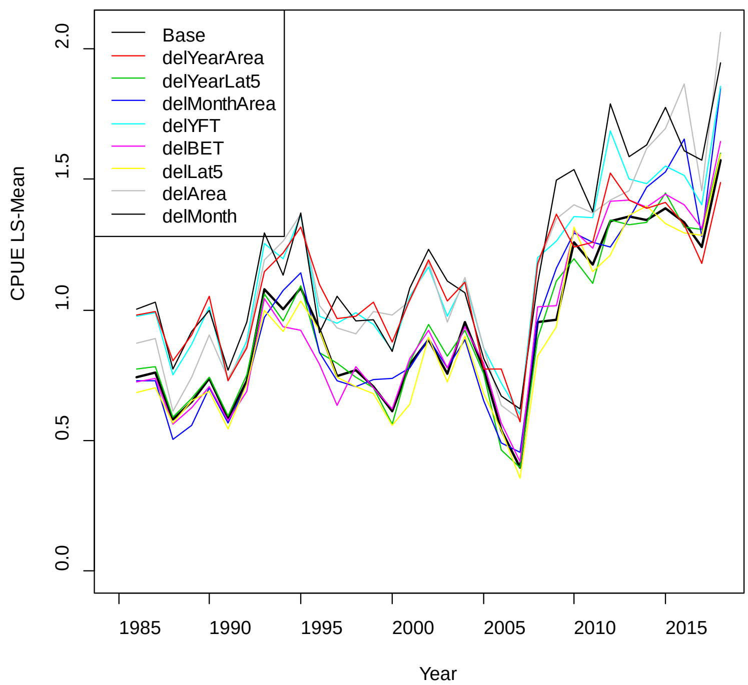


Fig. 9. Sensitivity test of ls-mean of CPUE in various glm models.

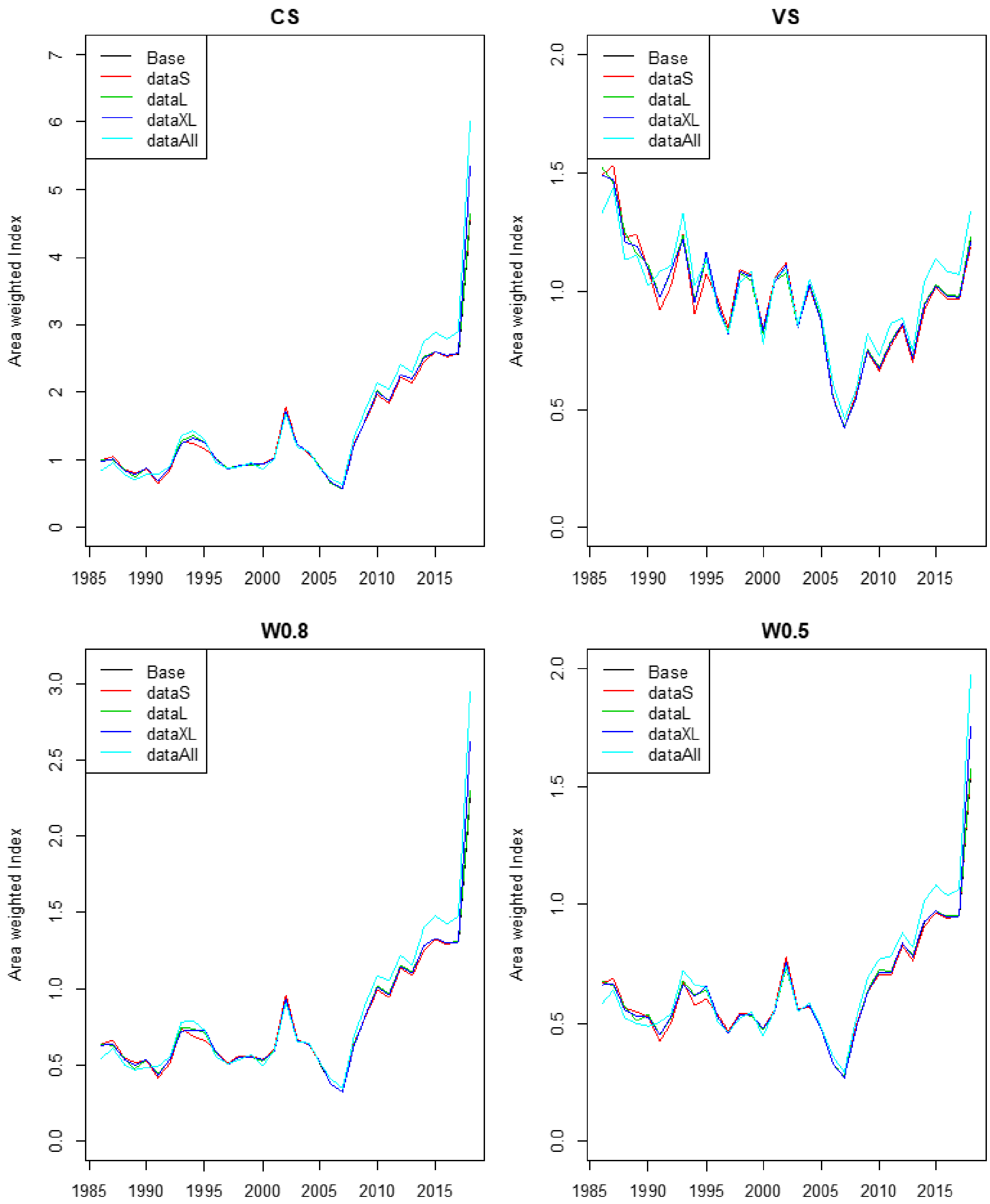


Fig. 10. Sensitivity test of the area weighted CPUE indices in various datasets.

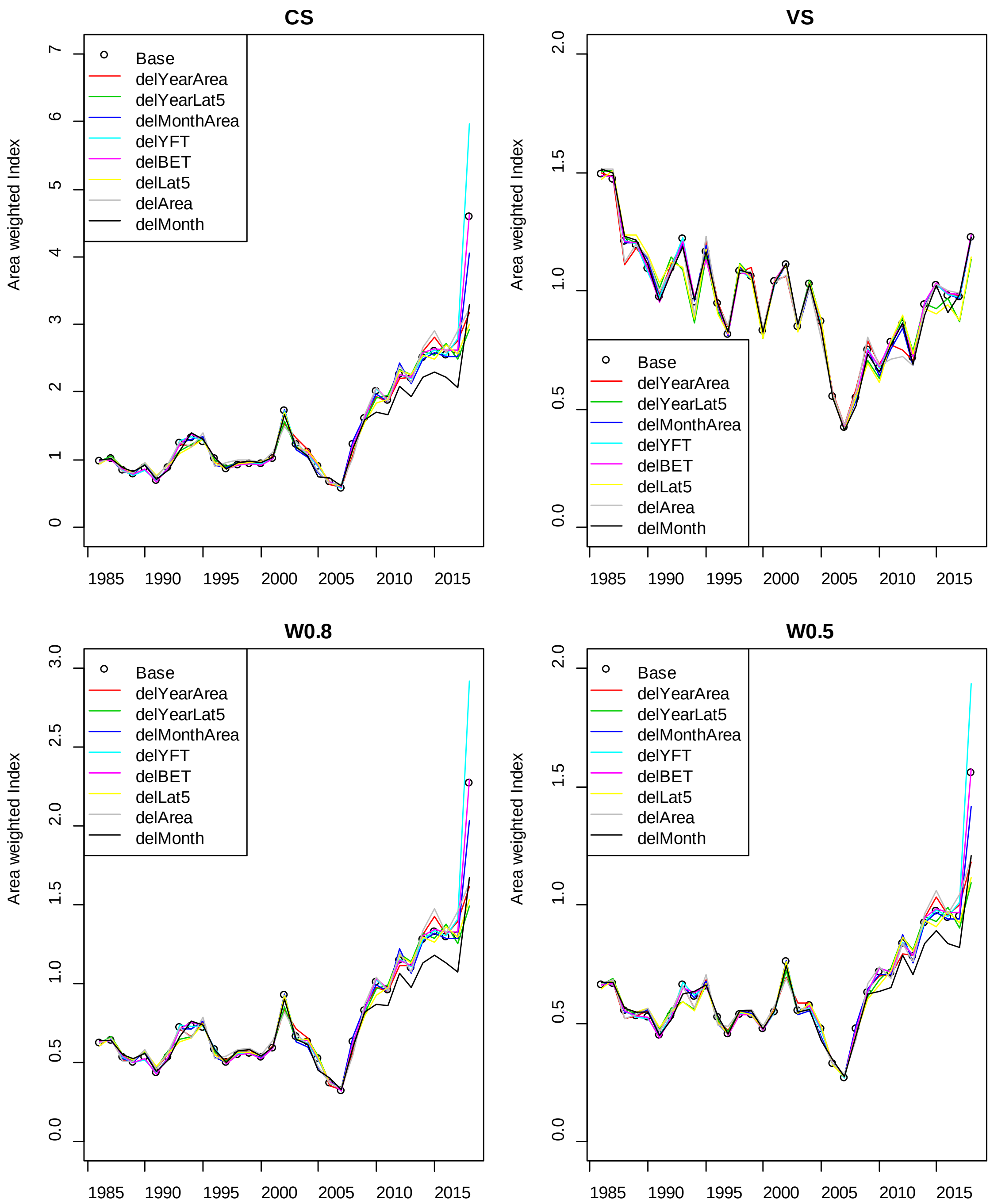


Fig. 11. Sensitivity test of the area weighted CPUE indices in various glm models.

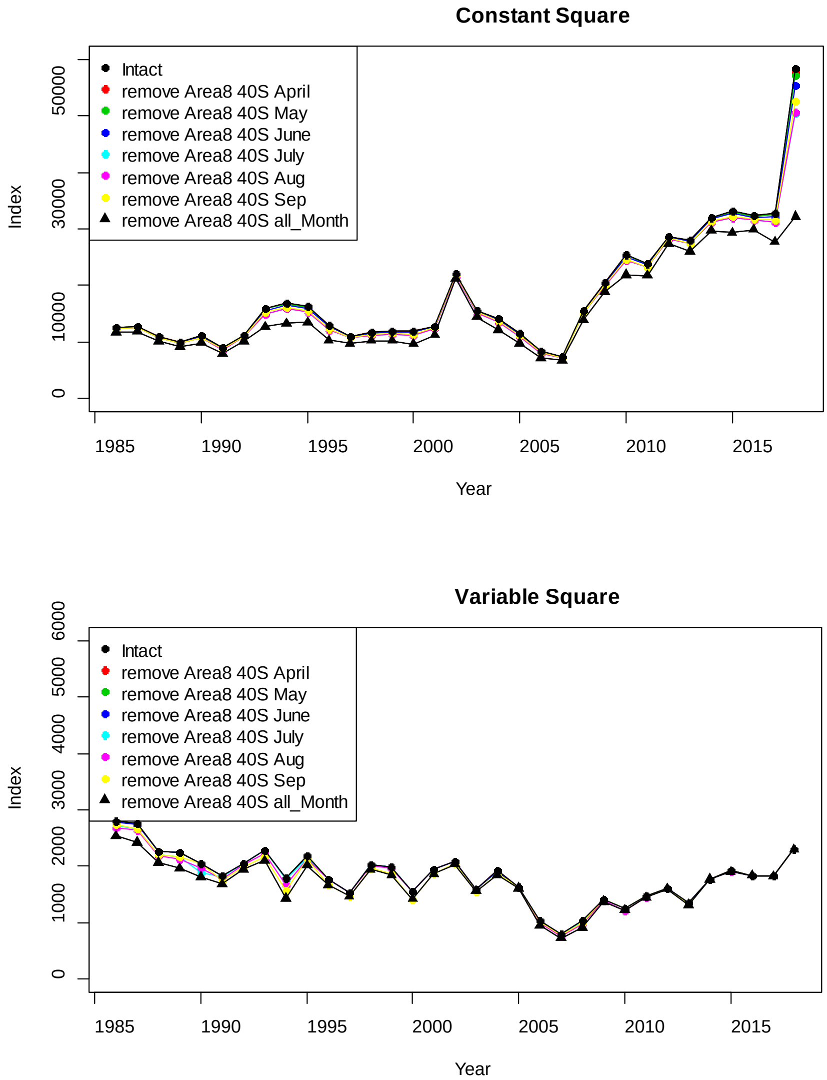


Fig. 12. Area weighted CPUE indices that change along with some data removal.

Note that a line with triangle represent 40S in Area 8 is responsible for the sharp increase in 2018 in Constant square hypothesis (upper panel), because removing the data produce a moderate increase. No change has occurred in Variable Square hypothesis because no weighting factor exists in 40S of Area 8 in 2018 due to no operation conducted there (lower panel). The calculation was based on the parameters from the Base CPUE standardization and just change the weighting factor (i.e. area weighting change to be zero in 40S of Area 8).