DATA EXPLORATION AND CPUE STANDARDIZATION FOR THE KOREAN SOUTHERN BLUEFIN TUNA LONGLINE FISHERY (1996-2015)

Simon Hoyle[1], Sung Il Lee[2] and Doo Nam Kim[2]

ABSTRACT

In this study we standardized southern bluefin tuna, *Thunnus maccoyii* (SBT) CPUE from Korean tuna longline fisheries (1996-2015) using Generalized Linear Models (GLM) with operational data. The data used for the GLMs were catch (number), effort (number of hooks), number of hooks between floats (HBF), fishing location (5° cell), and vessel identifier by year, quarter, and area. We explored CPUE by area, and identified two separate areas in which Korean vessels have targeted SBT. SBT CPUE was standardized for each of these areas. Explanatory variables for the GLM analyses were year, month, vessel identifier, 5° cell, and number of hooks. GLM results for the whole area suggested that location, year, and month effects were the most important factors affecting the nominal CPUE. The standardized CPUEs for both areas decreased until the mid-2000s and have shown an increasing trend since that time.

INTRODUCTION

Korean tuna longline fisheries began targeting southern bluefin tuna, *Thunnus maccoyii* (SBT) in the CCSBT convention area in 1991 (Kim et al., 2015), although SBT were reported as bycatch before this time, starting in 1972. The catch was initially low but increased to 1,320 mt in 1996, peaked at 1,796 mt in 1998, and thereafter decreased to below 200 mt in the mid-2000s. In 2008, the catch increased again to 1,134 mt and thereafter fluctuated in a range of 705-1,117 mt due to the national catch limit. The catch in 2014 was 1044 mt (Fig. 1).

Korean tuna longline vessels fishing for SBT have mainly operated in two locations to the south of 35°S either between 10°E-50°E (within statistical area 9) or between 90°E-120°E (within statistical area 8) (Figure 2). Effort has focused on western areas (statistical area 9) from March to July/August and shifted to the east (statistical area 8) from July/August until December (Figures 3 and 4). In general, there has been more fishing effort in the west.

In this study, we first explored the data in order to better understand the fisheries, and then standardized the CPUE data of Korean tuna longline fisheries (1996-2015) using Generalized Linear Models (GLM) to obtain a proxy for the abundance index.

[1] Hoyle Consulting, Nelson, New Zealand, simon.hoyle@gmail.com
[2] National Institute of Fisheries Science, Busan, Rep. of Korea, k.sungillee@gmail.com

DATA AND METHODS

Catch and effort data were selected with the criterion that when a vessel reported the capture of at least one 1 SBT in a month, all effort for the vessel-month was included.

The fields reported in the operational (set by set) data were catch (number), effort (number of hooks), HBF (number of hooks between floats), vessel id, location to 1° cell of latitude and longitude, date, and catch in numbers of southern bluefin tuna (SBT), bigeye (BET), yellowfin (YFT), albacore (ALB), swordfish (SWO), black marlin (BLM), blue marlin (BUM), striped marlin (MLS), sailfish (SFA), skipjack (SKJ), sharks (SHA), and other species (OTH).

Dates were converted to months and quarters, and to identify moon phase. Spatial positions were classified into 5° cells, and CCSBT statistical areas.

For CPUE standardization, data were cleaned by removing sets in which HBF was less than 9 or greater than 12. Sets with fewer than 1000 hooks were removed from the dataset.

Data were plotted to explore trends in total catch through time; the spatial and seasonal distributions of effort; and patterns in operational characteristics such as HBF and hooks per set. We examined patterns through time and among species in both the nominal catch rates and by year-quarter and statistical area, and compared them with patterns in the proportions of sets with no catch of each species. We plotted maps of the species composition through time, to identify possible changes in fishing behaviour or population composition.

To further explore changes in the fishery and identify periods of change, we plotted the participation of vessels in the fleet, sorted first by the start date and then by the end date of participation in the fishery.

Several approaches were used to explore changes in effort distribution and concentration through time. For each statistical area and for each year, we plotted the numbers of 5°x5° and 1°x1° cells fished and the average number of operations per fished cell. We defined two separate core SBT fishing areas: with statistical areas 9 in the west from March-October, and statistical area 8 in the east from July-December.

Indices of fishing effort concentration were also calculated, including the Gini coefficient (Gini, 1912) and Gulland's index of concentration (Gulland, 1956). The Gini coefficient is best known as an indicator of wealth concentration, but can be used to measure aggregation of any quantity. We use it to estimate the spatial aggregation of the catch of each species, and effort, in each region. A higher Gini coefficient indicates that more of the catch (or effort) is being taken from fewer spatial cells. We estimated values separately for each year, where the values y_i are catches or effort per 5° x 5° cell, ranked from lowest to highest, and including zeroes for unfished cells. Cell areas are assumed to be uniform.

$$Gini = \frac{2\sum_{i=1}^{n} i y_i}{n\sum_{i=1}^{n} y_i} - \frac{n+1}{n}$$

Gulland's index of concentration measures the extent to which a fleet has concentrated its fishing effort in areas with higher than average catch rates (Harley, 2009). The weighted version of the index is calculated as follows, where y_i is the catch in the ith stratum, e_i is the effort in the ith stratum, and N is the number of exploited strata. from year to year depending on both the distribution of the effort, and the distribution of the catch rates. If effort is evenly distributed with respect to catch rate then the index will average 1, whereas it will be higher than 1 if effort is preferentially targeted to areas with higher than average catch rate (Hoyle, 2014).

$$Gulland = \frac{\sum_{i=1}^{n} y_i}{\sum_{i=1}^{n} e_i} \cdot \frac{1}{\sum_{i=1}^{N} \frac{y_i}{e_i N}}$$

This index varies from year to year depending on both the distribution of the effort, and the distribution of the catch rates. If effort is evenly distributed with respect to catch rate then the index will average 1, whereas it will be higher than 1 if effort is preferentially targeted to areas with higher than average catch rate.

Given the spatial and seasonal separation of fishing in these two areas, and potentially different size distributions, we standardized data separately for each area.

Data from the period 1996-2015 were used in CPUE standardizations. Data prior to 1996 were not used in this study as they included insufficient reliable data from vessels targeting SBT.

CPUE standardization methods generally followed the approaches used by Hoyle and Okamoto (2011) and Hoyle et al. (2015), with some modifications. Parts of the methods text below are the same as these articles. R code is also used from examples presented in Hoyle *et al*. (2014).

GLM analyses

The operational data were standardized using generalized linear models in R 3.2.1 (R Core Team, 2014). Analyses were conducted separately for each of the two core areas. Data were prepared by selecting operational data for vessels that had made at least 100 sets, for years in which there had been at least 100 sets, and for 5° cells in which there had been at least 200 sets.

Analyses were carried out using generalized linear models that assumed a lognormal distribution with an added constant. The following model, which we call the lognormal constant GLM, was used:

$$\ln(CPUE_s + k) \sim year + vessid + latlong + \lambda(hooks) + g(month) + h(moon) \qquad (1)$$

The constant *k*, added to allow for modelling sets with zero catches of the species of interest, was 10% of the mean CPUE for all sets. The functions λ, *g* and *h* were cubic splines with 10, 4, and 4 degrees of freedom respectively. The number of hooks was included in the model to allow for possible hook saturation or other factors associated with hooks per set. The variable *moon* was the lunar illumination on the date of the set. The variables *year*, *vessid*, and *latlong* (5° latitude-longitude cell) were fitted as categorical variables.

Data in the lognormal constant GLM were 'area-weighted', with the weights of the sets adjusted so that the total weight per year-quarter in each 5° cell would sum to 1. This method was based on the approach identified using simulation by Punsly (1987) and Campbell (2004), that for set *j* in area *i* and year-qtr *t*, the weighting function that gave the least average bias was: $w_{ijt} = \frac{log(h_{ijt}+1)}{\sum_{j=1}^{n} \log(h_{ijt}+1)}$. Given the relatively low variation in number of hooks between sets in a stratum, we simplified this to $w_{ijt} = \frac{h_{ijt}}{\sum_{j=1}^{n} h_{ijt}}$.

Model fits were examined by plotting the residual densities and using Q-Q plots.

The effects of covariates were examined in exploratory analyses by using the package influ (Bentley *et al.*, 2011) to show the influence of each covariate.

Changes in catchability through time were investigated by fitting to the operational data both with and without a term for individual vessel.

The two models were designated respectively the 'base model' and the 'vessel-effects model'. Abundance indices were calculated for each model, and normalized to average 1. The indices estimated for each year-quarter were compared by dividing the base model by the vessel effects model, plotting the time series of ratios, and fitting a log-linear regression. The slope of the regression represented the average annual compounding rate of change in fishing power attributable to changes in the vessel identities; i.e. the introduction of new vessels and retirement of old vessels. Gradients are shown on the figures, together with confidence intervals.

Indices of abundance were obtained by running the lognormal constant GLM model with the standard settings, including vessel effects. Time effects were obtained by predicting the expected catch rate for each year, for (across all years) the vessel, month and cell with the most sets, lunar illumination of 0.5, and the median number of hooks. The uncertainty associated with the year effect was used as the measure of uncertainty. Indices were normalised by dividing through by the mean of the year effects, giving relative CPUE with mean of 1.

RESULTS AND DISCUSSION

Data exploration

The great majority of effort employed between 9 and 12 HBF (Figure 5), and the majority of HBF outside this range came from north of 35S, outside the main SBT targeting area. The number of hooks per set averaged less than 3000 in the period from 1990-95, but since that time has been relatively consistent, averaging a little over 3000 hooks per set (Figure 6).

Mean catch rates by species in the southern statistical areas 7, 8, and 9 are highest for southern bluefin tuna until the mid-2000s. After this time in area 9 SBT catch rates decrease and other species increase, some higher catch rates of albacore catch rates increase, particularly albacore. However, in the most recent year the SBT catch rates are again higher than other species (Figure 7). Similarly, the proportion of sets reported with zero SBT catches was low through most of the time series in the southern areas 7 to 9 (Figure 8), but area 9 shows an increase in the proportion of zeroes from 2004 to 2010. The majority of sets reported no yellowfin catch, and the same applied to bigeye and albacore. However, in area 9 the proportion of sets with zero albacore catches increased in the late 2000's, and there was a decrease in the proportions of zero albacore catches from about 2000-2010. There may have been some albacore targeting in area 9 during this period.

In the northern statistical areas 13 and 1, the tropical bigeye and yellowfin tunas dominate with the highest catch rates, along with albacore. Southern bluefin tuna catch rates are low throughout the time series, despite being inflated due to the selection of data only from vessels that report at least one SBT in the month. The existence of zero SBT catch rates is likely due to vessels being included due to reporting SBT catch during the month in a different statistical area, though some may be due to effort with SBT catch being removed during the cleaning process. The majority of sets in these areas catch no SBT (Figure 8), and there are few sets with zero catches of bigeye or yellowfin, while intermediate numbers of sets report no albacore catch. Given the low rate of SBT capture in the northern areas, misreporting, species misidentification, and data errors may be a concern, and could explain a significant proportion of the observed catches.

Statistical areas 14 and 2 in the Indian Ocean are at temperate latitudes between 20S and 35S. Highest catch rates are for yellowfin and (more recently) albacore in the western area 14, and bigeye and albacore in eastern area 2. Since the mid-2000s albacore catch rates have increased markedly and particularly in area 2, suggesting a trend towards targeting this species. Catch rates of SBT have been relatively low throughout the period, consistent with a high proportion of zero SBT sets, suggesting little or no deliberate targeting of SBT by the Korean fleet in these statistical areas.

The proportions of zero catches for both sharks and other species reduced substantially between 1990 and 2014, particularly in southern areas 8 and 9. Sharks and other species have always been caught in most sets, so this change may be entirely due to increased reporting rather than increased catches, linked to stronger requirements to report catches of bycatch species.

We mapped the species composition of catch (proportion of SBT in the catch of all species) south of 30S by 5-year period (Figure 10). The proportion of SBT in the catch was high in all periods, increasing further south, but declined steadily in all areas after 2000. This partly reflects targeting of other species, but also reflects increased reporting of sharks and other species. In the post-2010 period there is little SBT taken in statistical area 8 north of about 37S, whereas a high proportion of the catch in this area is albacore (Figure 11). It is apparent from Figures 12 and 13 that this spatially differentiated targeting in area 8 also has a temporal aspect, with albacore targeting April-July, and SBT targeting July-December. In area 9 to the west, there is less spatial or temporal separation of SBT and ALB catch, with both species caught in the months March-October (Figures 12 and 13).

Relatively few vessels participate in the fishery (Figure 14), with about half of the total number reporting their first participation before 2000. Arrival of new vessels has been slow but steady. A number of vessels stopped participating in 2009.

The total number of major (5° x 5° x month) cells fished has been variable from year to year (Figure 15), but has declined considerably since the peak year in 2008. Over the same period, effort has become more concentrated with more operations per cell. This increasing concentration is also apparent at the minor (1° x 1° x month) cell level (Figure 16). However, the distribution of effort within major cells has not concentrated significantly, with similar numbers of minor cells per major cell on average. In the period since 2008 the timing of effort in areas 8 and 9 has changed, gradually moving earlier in the year, though with different timing peaks in each area (Table 3).

Gulland's index of concentration indicates whether effort is concentrated in areas of high or low catch rate for a species, but estimates can be variable and uncertain where sample sizes are small. Plots for SBT in areas 8 and 9 suggest that effort is generally higher in areas with higher SBT catch rate, since most points are above 1 (Figure 17). The results for bigeye and yellowfin are considerably more variable, possibly reflecting the lower catch rates.

Gini coefficients are widely used in many fields to measure the distribution of quantity – with uniform to very uneven distributions represented by low to high Gini coefficients. Estimates for regions 8 and 9 and for SBT, bigeye and albacore tuna, and for effort, show similar patterns, with increasing concentration through time.

CPUE standardization

The data selection process aimed to identify effort targeted mostly at southern bluefin tuna, by selecting area 9 data from March-October and area 8 data from July-December. However, this approach was not entirely successful, as indicated by the higher proportions of zero catches in area 9 between 2004 and 2010 (Figure 19).

Table 1 shows the results of dropping each variable from the lognormal constant GLMs. These results suggest that all explanatory variables were statistically significant, with the year, location, and month effects the largest factors affecting the nominal CPUE. It is common in CPUE standardizations for all variables to be statistically significant. However, lack of independence is to be expected in observational fisheries data, and tends to result in overestimation of statistical significance.

Comparison of standardized and unstandardized CPUE series shows them to be quite similar (Figure 20). The largest change is for the area 8 indices in the most recent year, where the standardized indices are much lower than the nominal.

The influence plots (Figures 21-25) showed the patterns of the parameter estimates at the top of each plot, and the influence of each parameter on the year effect on the right side of each plot. Note that the influence scales (bottom right) differ among plots. The influences of all variables are summarised in Figure 26.

Vessel effects (Figure 21) were quite variable, with a few vessels having significantly lower SBT catch rates. On average, the influence of vessel effects raised the average catchability at the end of the time series in both areas, but the low number of vessels resulted in significant variability.

Spatial effects (Figure 22) showed significant variation in catch rates, with more variation in area 9 than area 8. In area 9 there was a strong trend through time towards fishing in areas with lower average catch rates, particularly in the last two years. This trend has contributed to the higher catch abundance indices in 2014 and 2015. It would be useful to explore whether the areas of highest catch rate have moved through time. However, this may be difficult to determine since fishing activity is currently very concentrated spatially.

The effects of the number of hooks per set on catch rates (Figure 23) were difficult to interpret. In eastern area 8 there were relatively small differences by hook number across the range of data with most hooks, and minimal influence on year effects. In area 9 there were larger differences, and apparently a significant influence on the year effects, with catchability averaging about 5% above the mean in 2012-15. Sets with more than about 3150 hooks tended to catch more SBT than sets with fewer hooks. This may reflect a mixture of targeting methods in area 9, with different fishing methods using different numbers of hooks. In area 9 there were more sets with fewer hooks between 2004 and 2007, a period during which there were more zero SBT sets than at most other times.

The effect of month was strong in both the eastern and western areas (Figure 24). In both areas the highest catch rates were obtained in July and August. The seasonality of fishing effort changed through time, with the model suggesting that mean catchability in area 8 was over 10% higher than the average in 2014-15, and almost 20% below average in area 9 in 2010-11 and 2013-15.

Catch rates appeared to vary moderately with lunar illumination (Figure 25). Longline catch rates of other pelagic fish such as bigeye tuna are known to be affected by moon phase (Poisson et al., 2010). The patterns we observed differed between the two areas, and may be artefacts of lack of independence in the data. Fishing effort is distributed relatively evenly across all phases of the moon, so moon phase has almost no influence on the year effects.

The combined effects of the influence plots suggest that a number of factors are reducing the 2015 index below the nominal level, including the effects of vessel and fishing location, but particularly month (Figure 26).

Like the abundance indices, the influence estimates are conditional on the model, which assumes that there are no interactions between the different effects. However, interactions may be expected, such as variation between years in the timing and location of higher catch rates, due to environmental variation affecting tuna movements. The small sample sizes limit the ability to model interaction terms, and there was limited time available to explore alternative models, but this would be worthwhile in future analyses.

Diagnostic frequency distributions and QQ-plots (Figure 27) suggest that the data fitted the GLM adequately.

Patterns in the indices (Figure 28) differ somewhat between east and west. Both sets of indices decreased until the mid-2000s, and subsequently increased, particularly in the last few years. Lack of data prevents the estimation for eastern area 8 from 2003-2007 (Table 2). The presence of more zero SBT catches in area 9 from 2004-2010 suggests that the data during that period may include more effort targeted at other species. Such ‘contamination’ of the effort would tend to bias the indices low, and this is a period when the indices are the lowest in the time series. It would therefore be useful to separate sets with different fishing strategies. Applying cluster analysis to separate the effort is recommended for future analyses.

The ratios of analyses with and without vessel effects suggest increasing fishing power in area 8 by approximately 0.5% per year. Estimates for area 9 are not statistically significant and are very uncertain, possibly because the data include a mixture of fishing strategies. Trends in fishing power estimated this way represent the effects of changes in the fleet composition. They do not account for changes in fishing power caused by vessels that stay in the fishery and change their equipment or their fishing behaviour.

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TABLES

Table 1: Degrees of freedom, Deviance, and delta AIC results from lognormal (CPUE + k) GLMs for statistical areas 8 and 9.

	Stat area 9			Stat area 8		
	Df	Deviance	ΔAIC	Df	Deviance	ΔAIC
<none>		123.7	0		38.5	0
Year	19	142.5	1702	15	44.5	1225
Latlong	16	136.4	1164	10	40.3	364
ns(hooks, 10)	10	126.0	209	10	38.7	29
Vessid	22	133.1	856	19	39.5	190
ns(month, df = 4	4	136.0	1159	4	40.4	410
ns(moon, df = 4)	4	124.0	24	4	39.2	152

Table 2: Lognormal constant indices for statistical areas 9 and 8.

Year	Stat area 9	CV	Stat area 8	CV
1995	NA	NA	0.96	0.03
1996	1.22	0.04	1.14	0.04
1997	0.92	0.03	0.77	0.02
1998	0.89	0.03	0.84	0.02
1999	1.01	0.03	0.71	0.02
2000	0.80	0.03	0.72	0.02
2001	1.00	0.03	0.82	0.03
2002	0.97	0.03	0.50	0.03
2003	0.78	0.04	NA	NA
2004	0.44	0.03	NA	NA
2005	0.24	0.05	NA	NA
2006	0.60	0.04	NA	NA
2007	0.50	0.03	NA	NA
2008	1.01	0.03	1.14	0.02
2009	0.85	0.03	0.75	0.03
2010	0.77	0.04	0.83	0.02
2011	1.45	0.05	1.10	0.02
2012	1.44	0.03	1.23	0.03
2013	1.28	0.05	1.70	0.04
2014	2.33	0.06	1.73	0.05
2015	1.50	0.07	1.06	0.05

Table 3: Numbers of operations per year, month and area. %10Y, %5Y, and %2015 denote the proportions of each area-month to the 10 year (2006-2015), 5 year (2011-2015), and 2015 totals, respectively. Where the %2015 is 3% larger or 3% smaller than the %5Y it is marked with grey shading or an outline, respectively.

		Year															
Area	**Month**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**%10Y**	**%5Y**	**%2015**
2	3	0	0	0	0	0	0	0	0	1	0	0	0	0	0.0%	0.0%	0.0%
	4	0	0	0	0	0	0	0	0	30	1	0	4	0	0.3%	0.6%	0.0%
	5	0	0	0	0	0	0	0	7	8	0	0	23	0	0.3%	0.6%	0.0%
	6	0	0	3	0	0	17	0	14	26	8	72	49	0	1.6%	2.8%	0.0%
	7	0	0	22	0	0	30	0	27	48	19	91	46	45	2.6%	4.6%	5.7%
	8	0	0	17	0	0	19	0	0	0	0	0	0	0	0.2%	0.0%	0.0%
	9	5	0	0	0	0	0	6	25	0	0	2	9	5	0.4%	0.3%	0.6%
	10	0	0	0	0	0	0	3	24	0	4	0	0	0	0.3%	0.1%	0.0%
	11	0	0	0	0	0	7	0	12	0	0	0	0	0	0.2%	0.0%	0.0%
8	1	0	0	0	0	0	0	4	0	0	0	0	0	0	0.0%	0.0%	0.0%
	3	0	0	0	0	0	0	0	0	8	0	0	0	0	0.1%	0.1%	0.0%
	4	0	0	3	0	0	0	0	0	23	27	0	44	0	0.8%	1.7%	0.0%
	5	0	0	0	0	0	0	0	20	71	30	115	33	0	2.2%	4.6%	0.0%
	6	0	0	0	0	0	0	0	12	51	3	4	4	0	0.6%	1.1%	0.0%
	7	0	0	0	0	0	46	19	10	60	0	16	8	11	1.4%	1.7%	1.4%
	8	18	0	0	0	0	132	181	167	185	115	143	168	115	10.1%	13.3%	14.5%
	9	8	0	0	0	0	189	214	166	179	191	130	95	106	10.6%	12.8%	13.4%
	10	0	0	0	0	0	252	180	79	207	139	103	0	0	8.0%	8.2%	0.0%
	11	0	0	0	0	0	169	165	73	190	0	23	0	0	5.2%	3.9%	0.0%
	12	0	0	0	0	0	98	36	0	75	0	0	0	0	1.7%	1.4%	0.0%
9	3	15	62	5	0	64	6	19	0	0	87	0	0	0	1.5%	1.6%	0.0%
	4	44	103	20	6	127	76	258	172	72	125	97	136	122	9.9%	10.1%	15.4%
	5	44	69	9	18	130	189	329	173	86	130	115	168	194	12.8%	12.7%	24.4%
	6	55	63	3	5	125	198	297	138	65	156	105	152	137	11.5%	11.3%	17.3%
	7	41	45	34	34	169	144	186	69	17	122	22	83	30	7.3%	5.0%	3.8%
	8	43	75	21	133	138	71	60	2	0	0	0	0	0	3.4%	0.0%	0.0%
	9	22	71	24	41	154	0	8	0	0	0	0	0	0	1.7%	0.0%	0.0%
	10	0	119	0	17	142	2	0	0	0	0	0	0	0	1.3%	0.0%	0.0%
	11	0	44	0	0	1	0	0	0	0	0	0	0	0	0.0%	0.0%	0.0%
14	3	0	0	0	0	20	0	41	0	0	15	0	0	0	0.6%	0.3%	0.0%
	4	0	4	0	13	0	0	7	0	0	0	0	0	29	0.4%	0.5%	3.7%
	5	0	0	8	0	0	0	0	0	0	0	0	0	0	0.0%	0.0%	0.0%
	6	0	16	84	22	0	2	16	37	0	0	0	0	0	0.6%	0.0%	0.0%
	7	0	68	79	87	16	0	30	13	0	0	11	0	0	1.3%	0.2%	0.0%
	8	0	4	14	8	20	0	0	0	0	0	0	0	0	0.2%	0.0%	0.0%
	9	0	21	39	9	1	4	5	0	0	0	0	1	0	0.2%	0.0%	0.0%
	10	0	13	0	3	7	1	0	0	0	6	0	0	0	0.1%	0.1%	0.0%
	11	0	5	0	0	34	16	0	0	0	0	2	0	0	0.4%	0.0%	0.0%
	12	0	0	0	0	0	2	1	0	12	0	0	0	0	0.1%	0.2%	0.0%
Total	277	295	782	385	396	1148	1670	2065	1240	1414	1178	1051	1023	794	100.0%	100.0%	100.0%

FIGURES

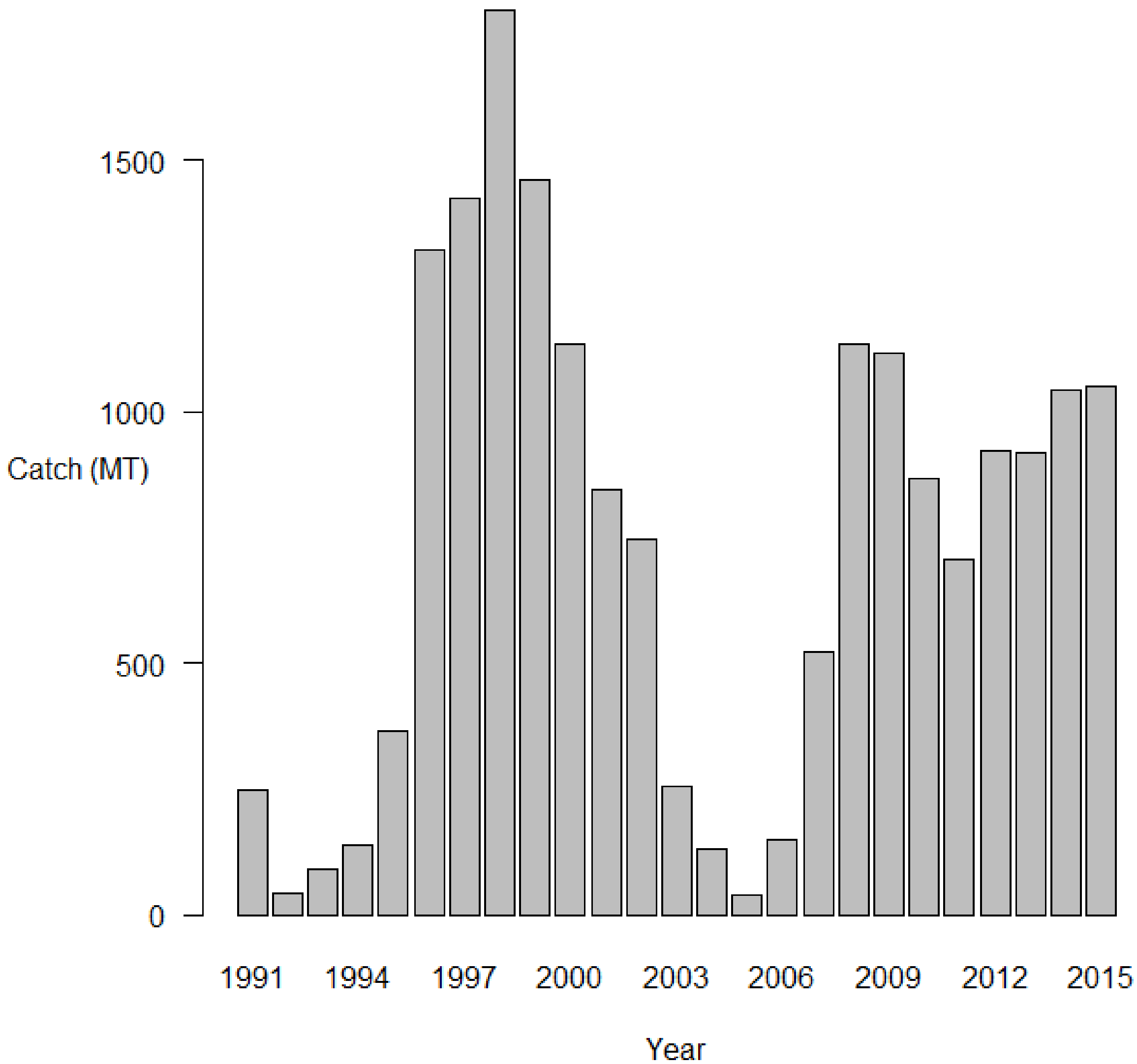

Figure 1: The annual Korean SBT catches in the CCSBT convention area, 1991 - 2015.

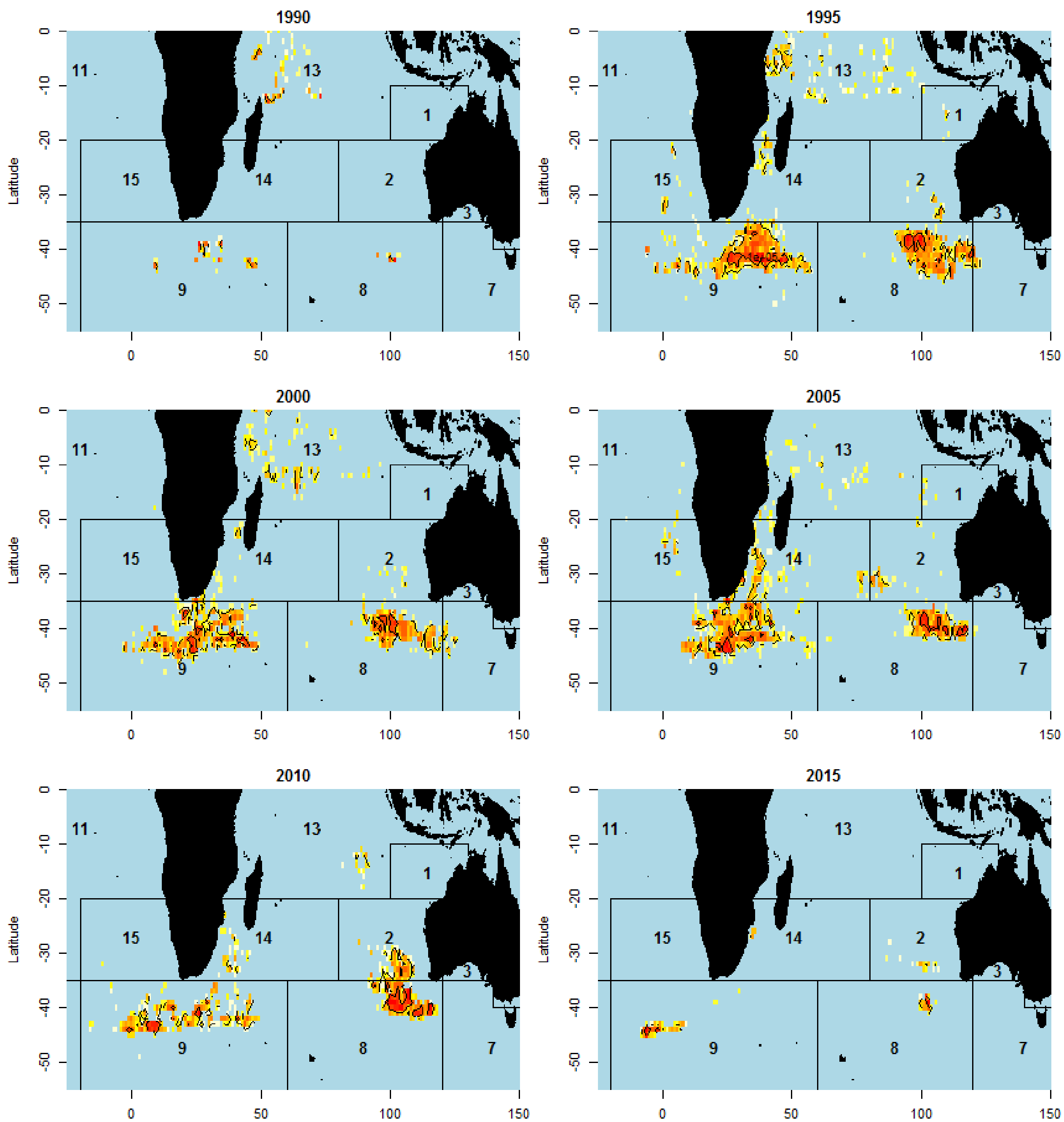

Figure 2: Map showing the core areas of Korean tuna longline vessels fishing for SBT, aggregated by 5 year period. Red colour indicates higher fishing effort, in numbers of hooks.

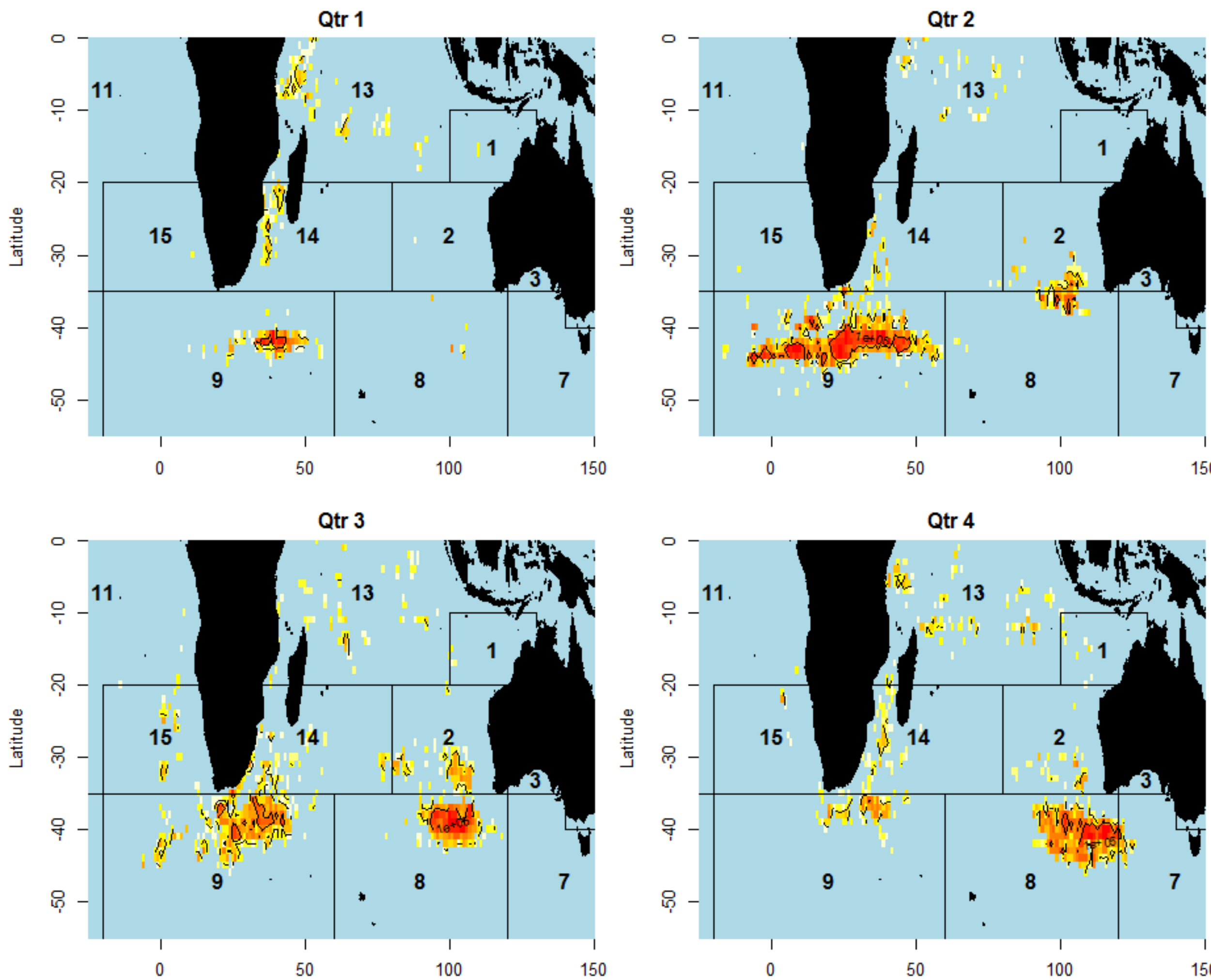

Figure 3: Map showing the core areas of Korean tuna longline vessels fishing for SBT, by quarter. Red colour indicates higher fishing effort, in numbers of hooks. Data are aggregated across the period 1994-2014.

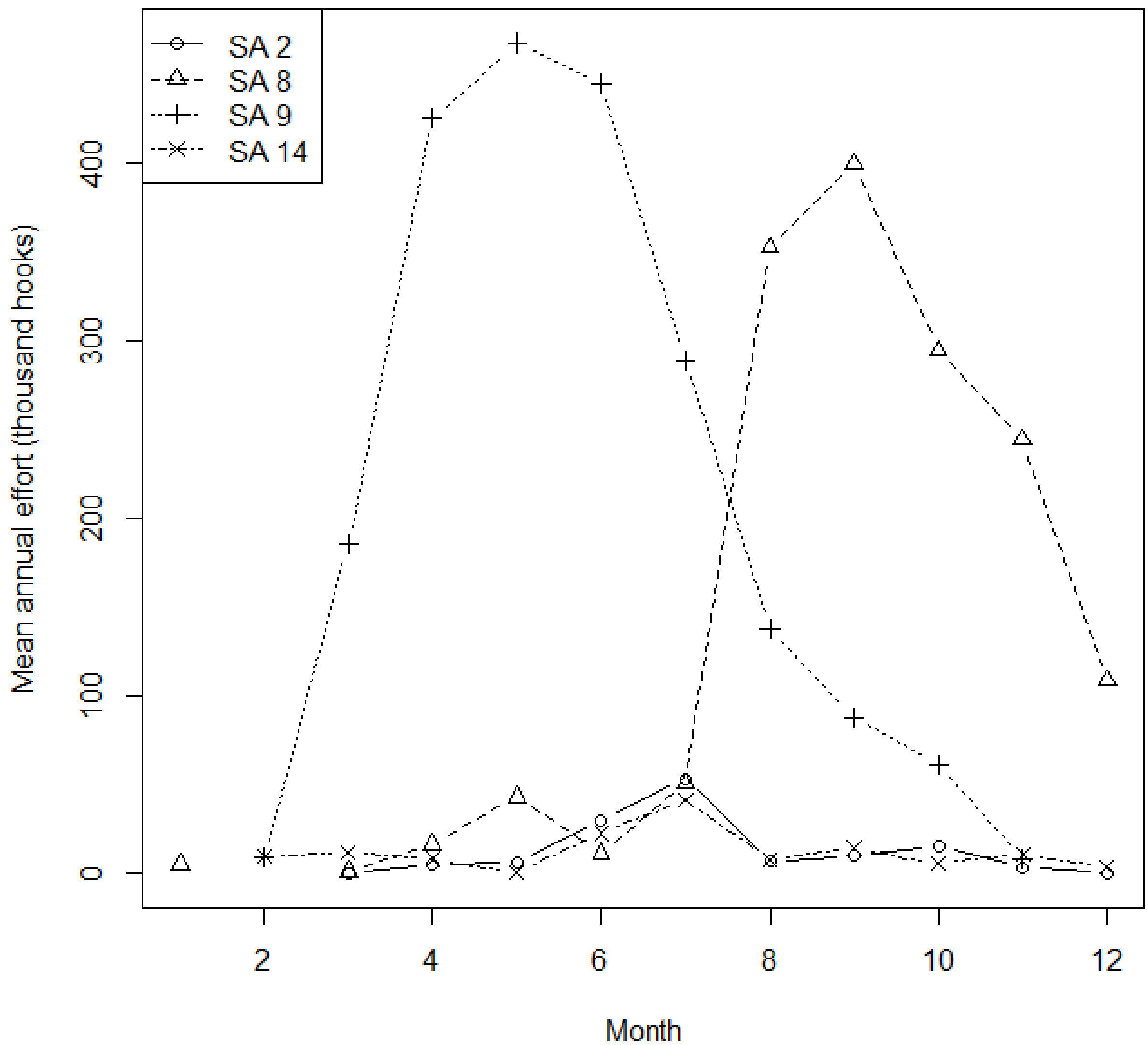

Figure 4: Mean annual effort in thousands of hooks, by month and statistical area.

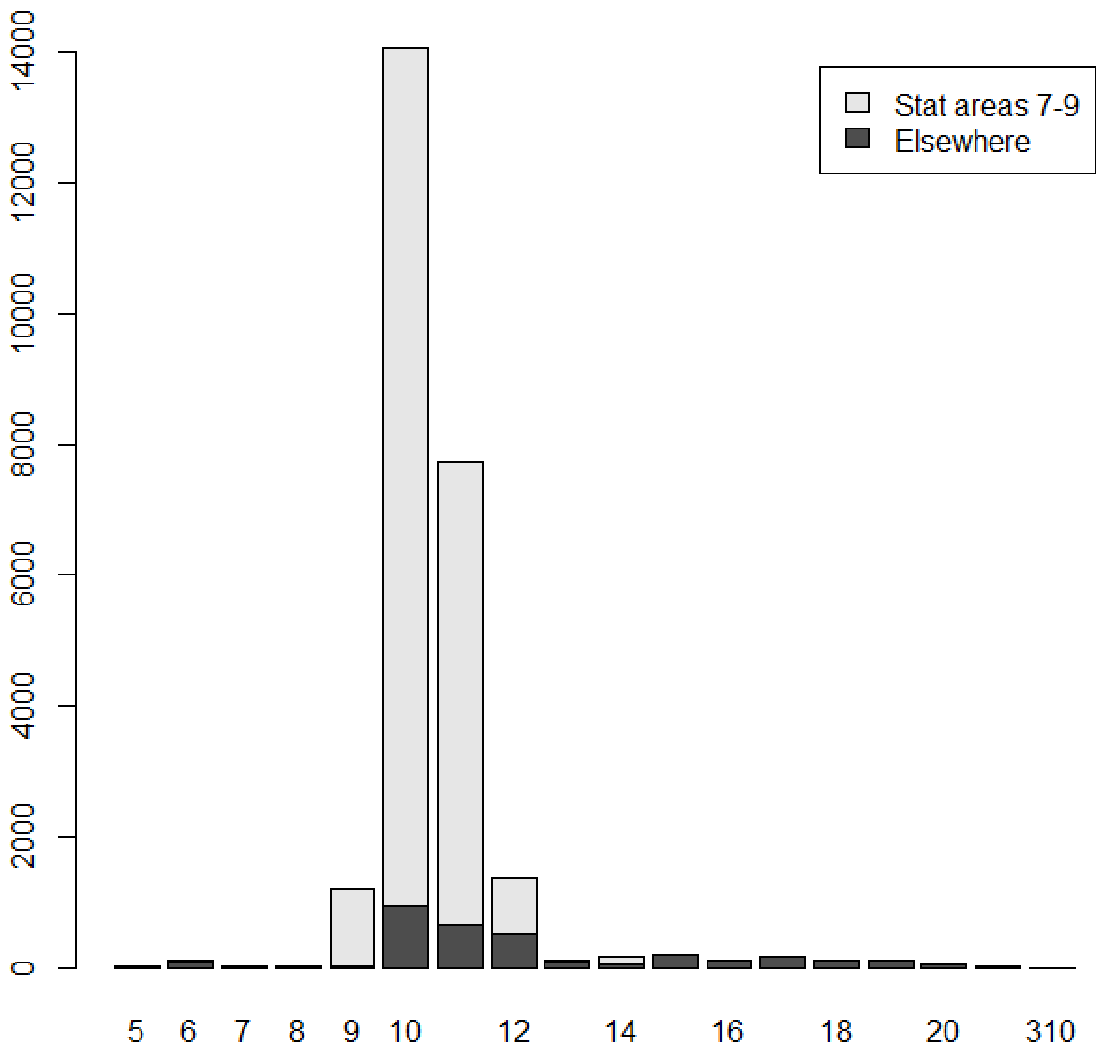

Figure 5: Frequency table of HBF for the main fishing ground with the lighter shade for statistical areas 7-9, and the darker shade for other areas.

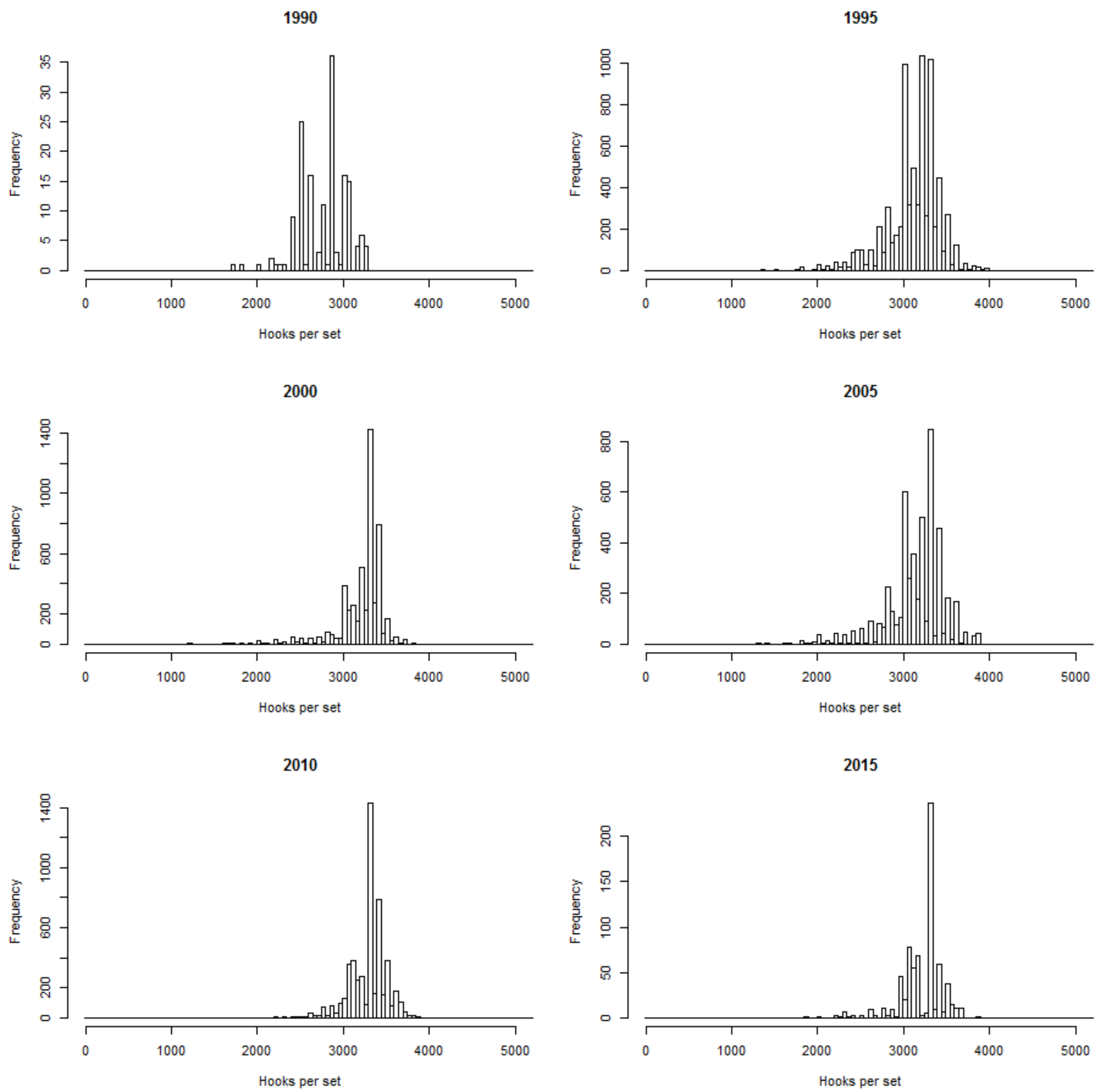

Figure 6: Distribution of hooks per set per 5 year period, for sets in the SBT-targeting areas south of 35S.

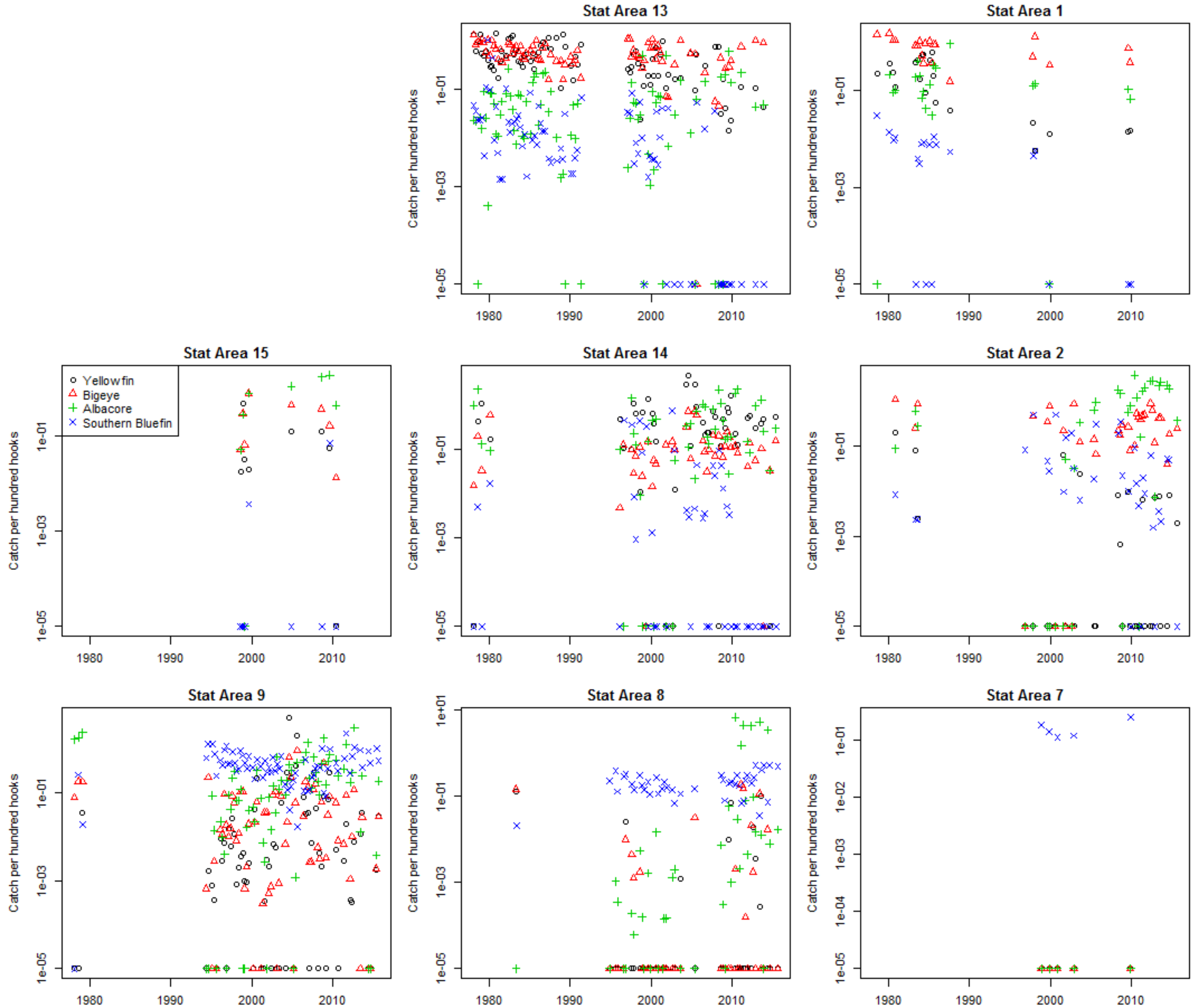

Figure 7: Mean catch per hundred hooks by year-qtr, species, and statistical area, plotted on a log scale, for yellowfin, bigeye, albacore, and southern bluefin tuna. Each CPUE has 1E-5 added so that zero catches appear on the log scale.

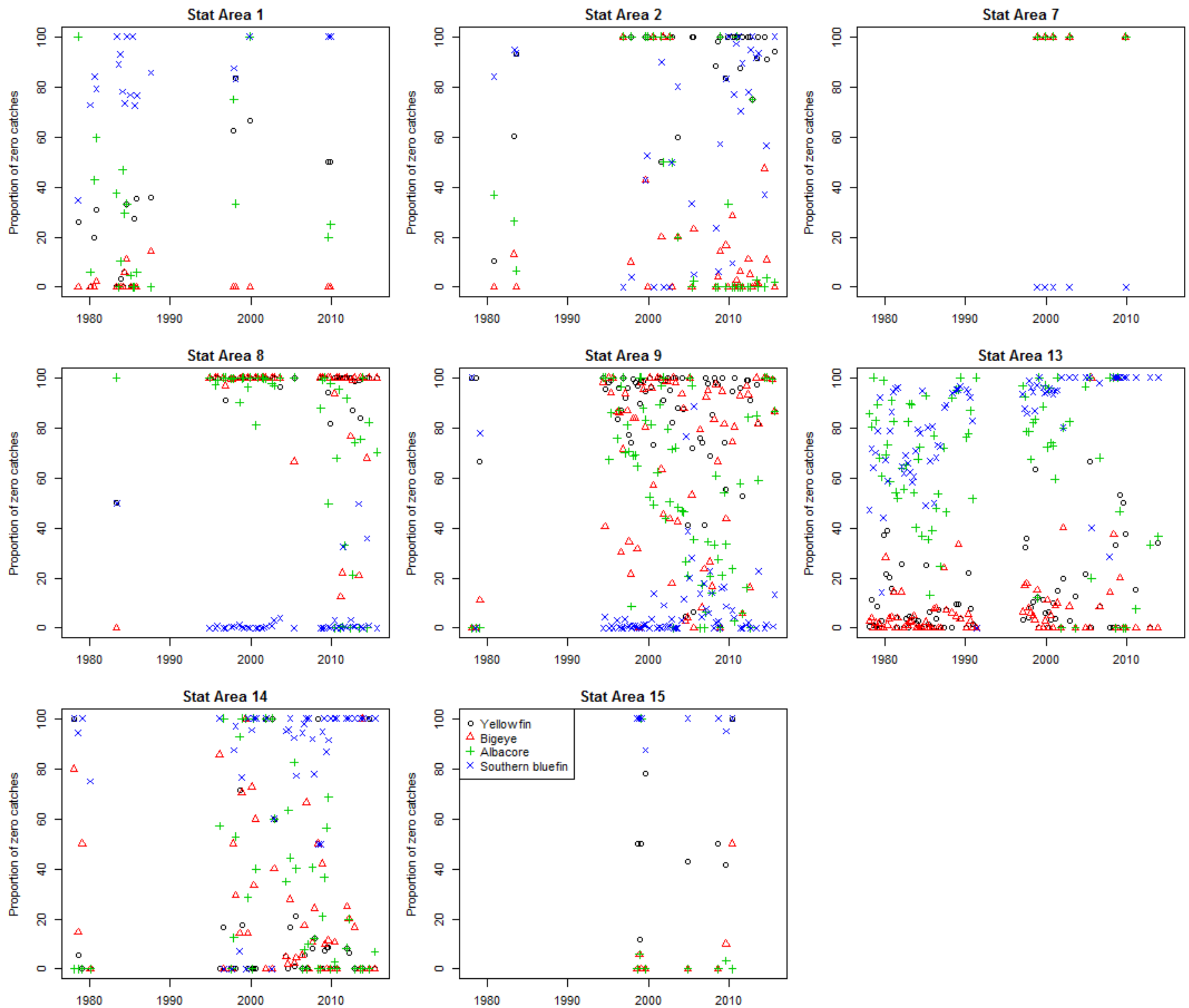

Figure 8: Proportion of zero catches per set by year-qtr, species, and statistical area, for yellowfin, bigeye, albacore, and southern bluefin tuna.

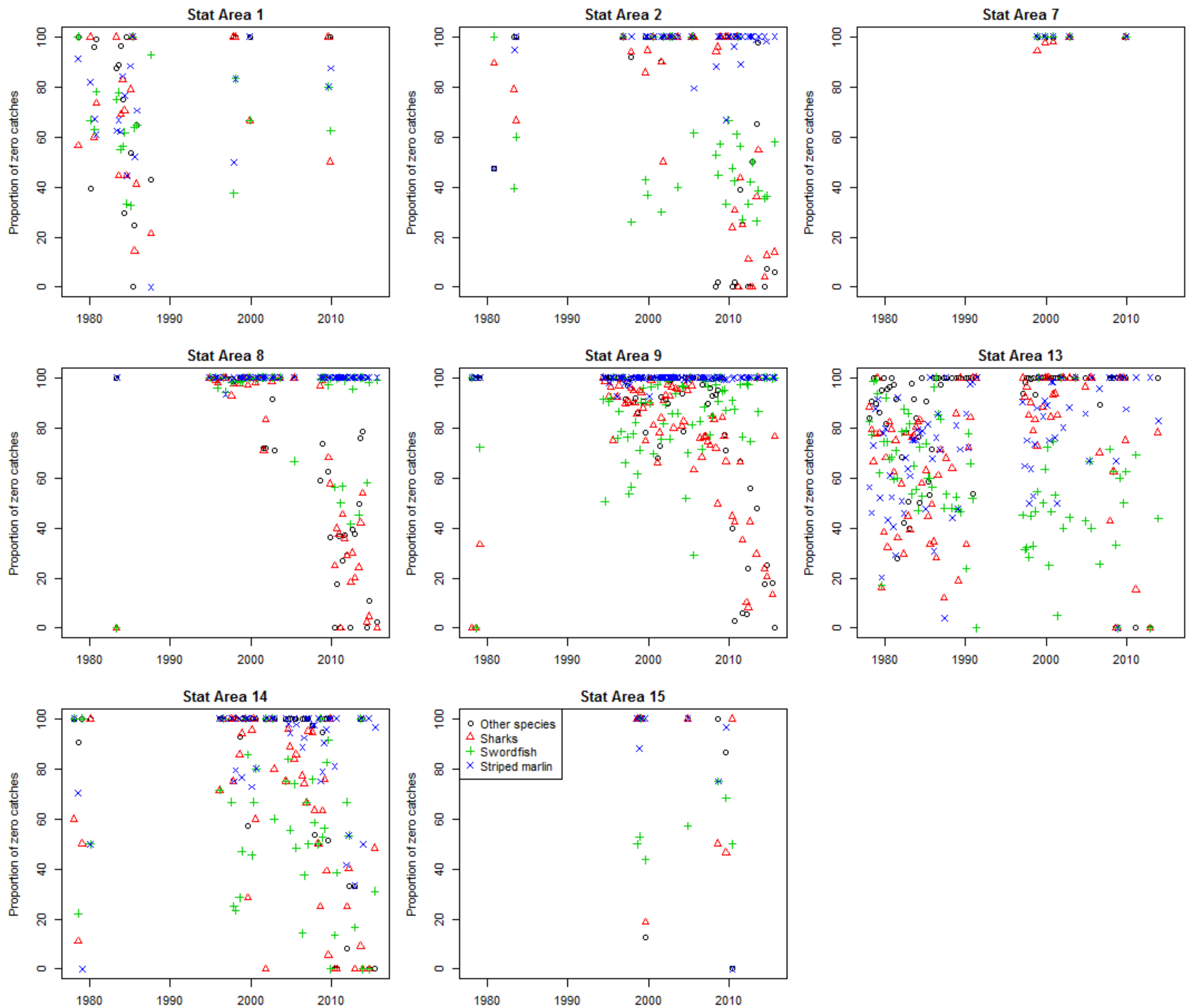

Figure 9: Proportion of zero catches per set by year-qtr, species, and statistical area for sharks, swordfish, striped marlin, and species not otherwise recorded (i.e. everything other than SBT, BET, YFT, ALB, SWO, BLM, BUM, MLS, SFA, SKJ, and SHA).

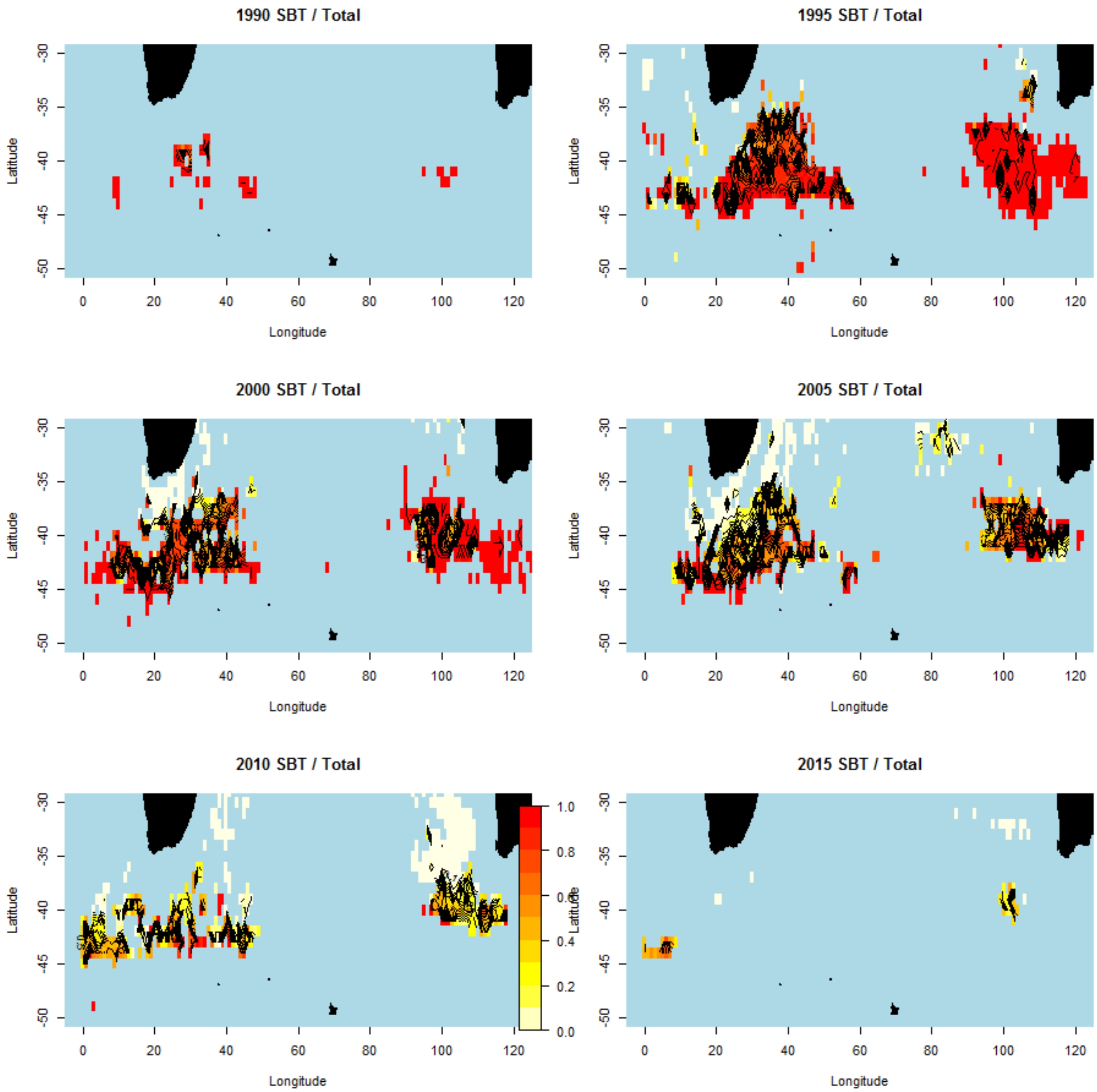

Figure 10: Proportion southern bluefin tuna (SBT) in the total reported catch in numbers by 1° cell, aggregated over 5 years within the period 1990-2014. Red colour indicates a higher proportion of SBT.

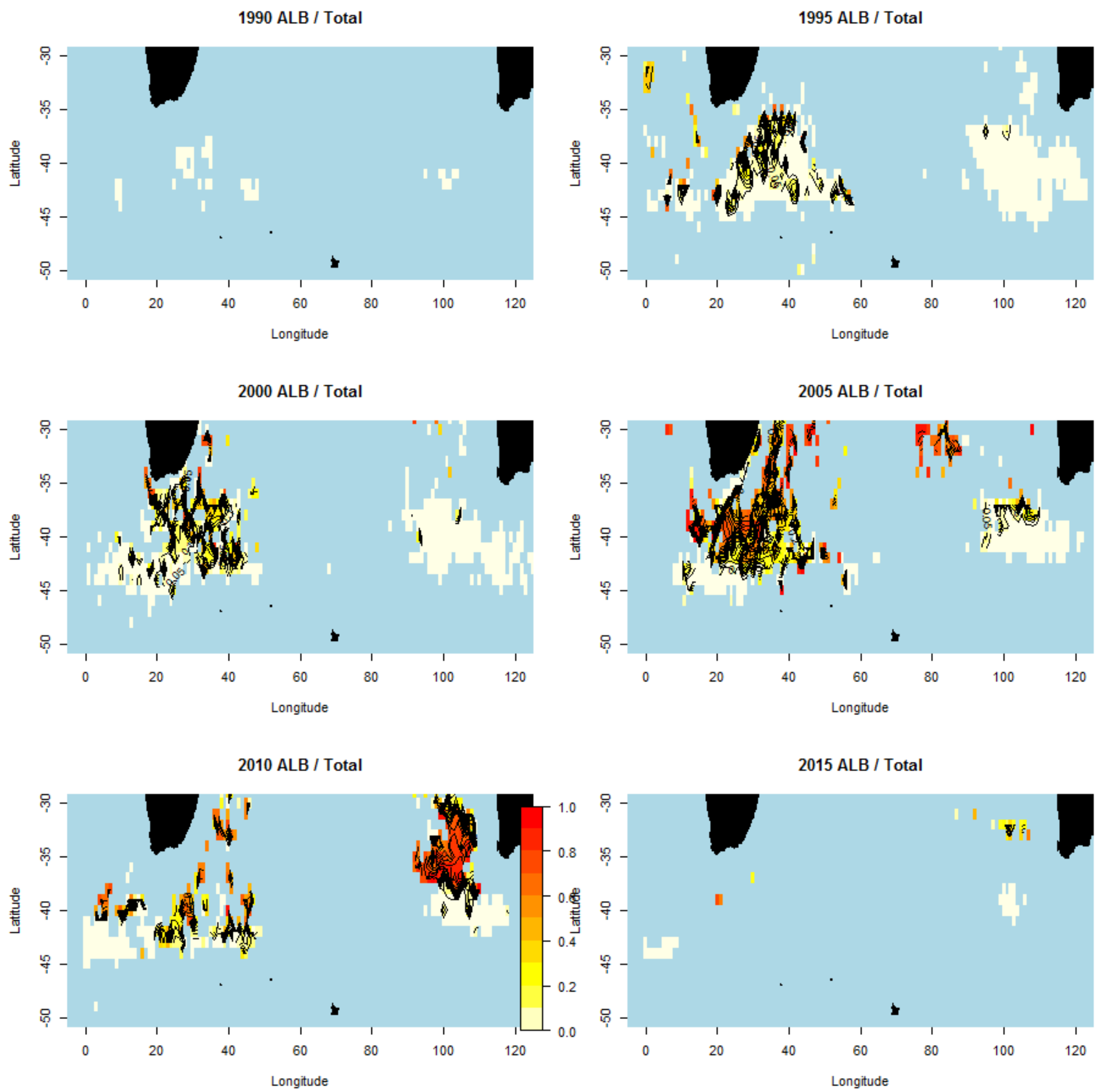

Figure 11: Proportion albacore (ALB) in the total reported catch in numbers by 1° cell, aggregated over 5 years within the period 1990-2014. Red colour indicates a higher proportion of ALB.

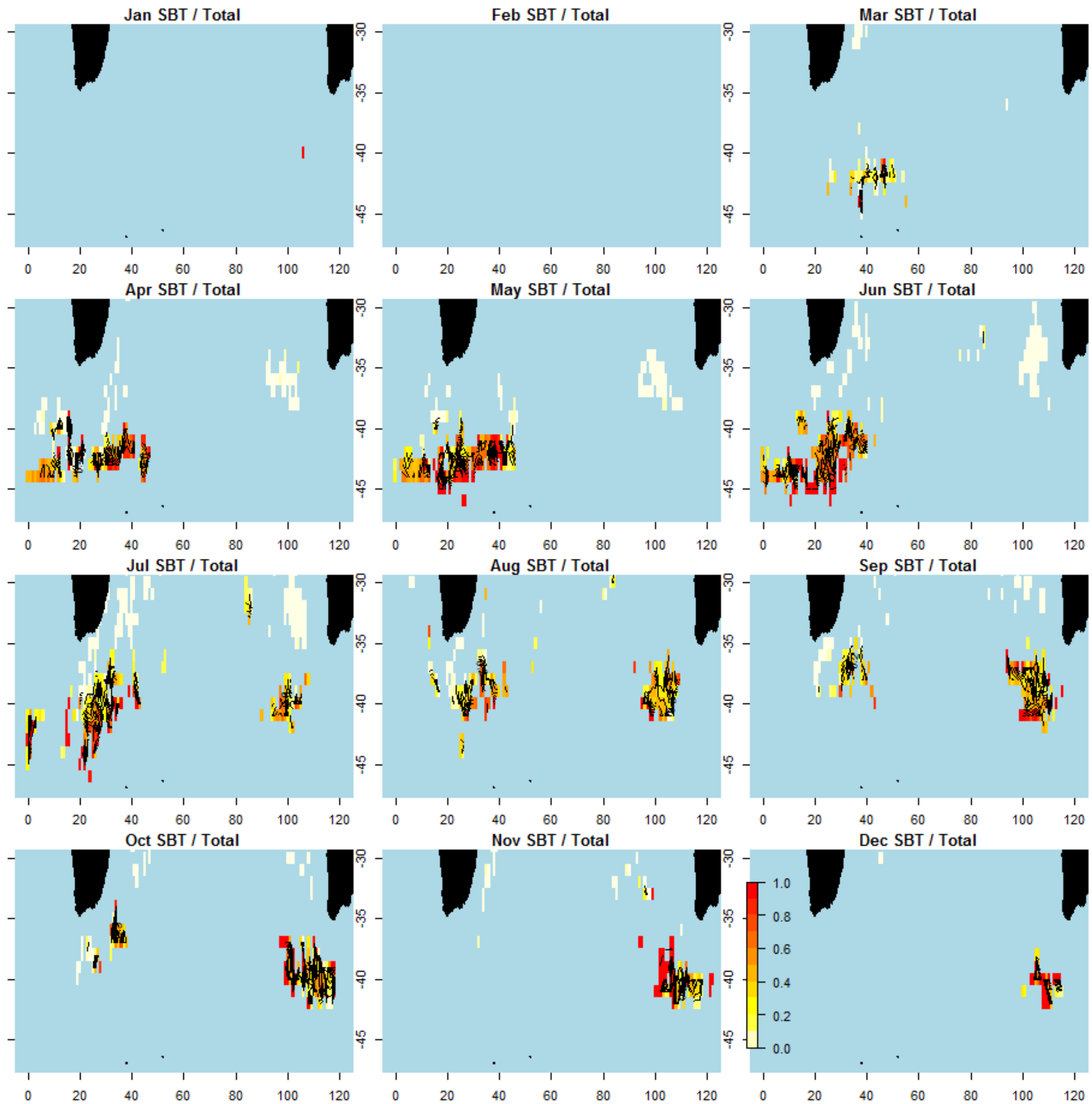

Figure 12: Proportion southern bluefin tuna (SBT) in the total reported catch in numbers by 1° cell, by month, aggregated over the period 2005-2014. Red colour indicates a higher proportion of SBT.

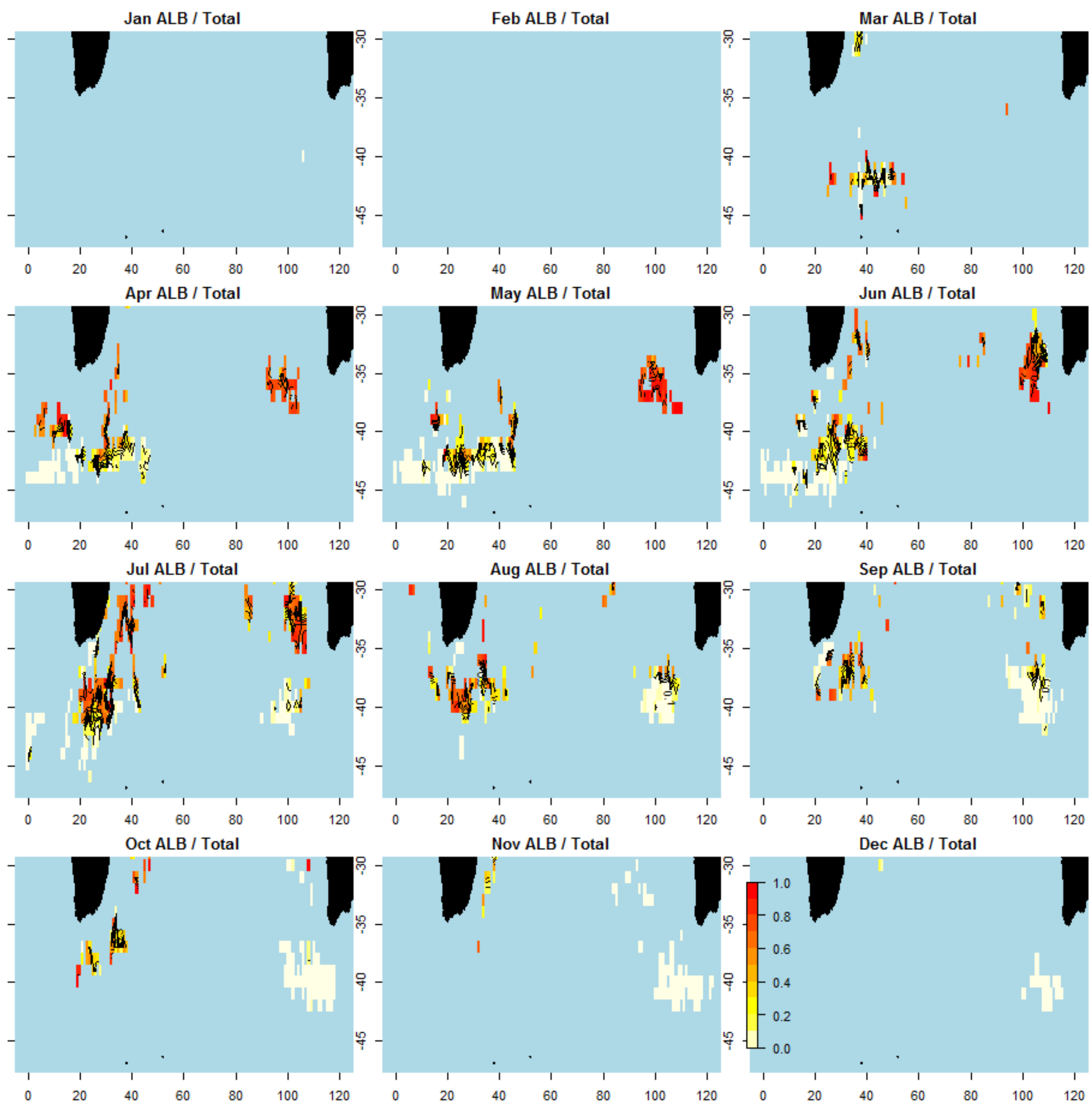

Figure 13: Proportion albacore (ALB) in the total reported catch in numbers by 1° cell, by month, aggregated over the period 2005-2014. Red colour indicates a higher proportion of ALB.

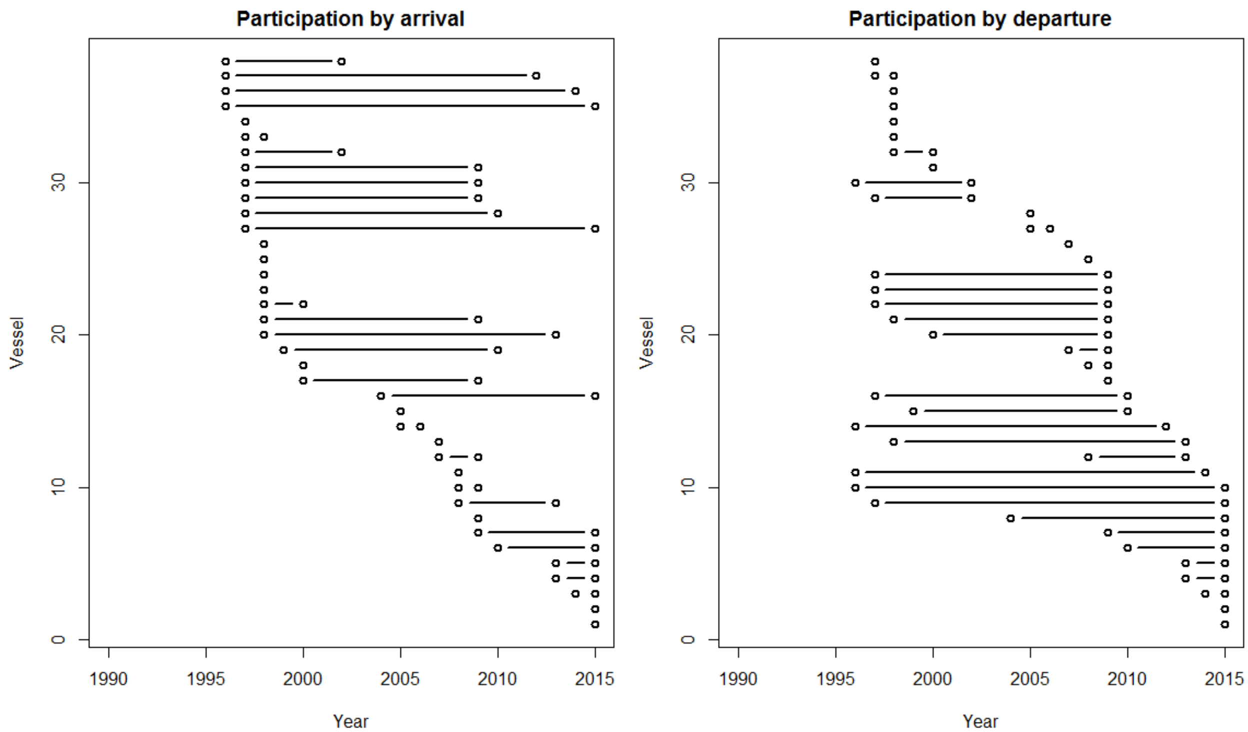

Figure 14: Plots of participation by vessel and year. Each row represents a vessel, sorted by the first year of participation, except for the top right plot which is sorted by the final year.

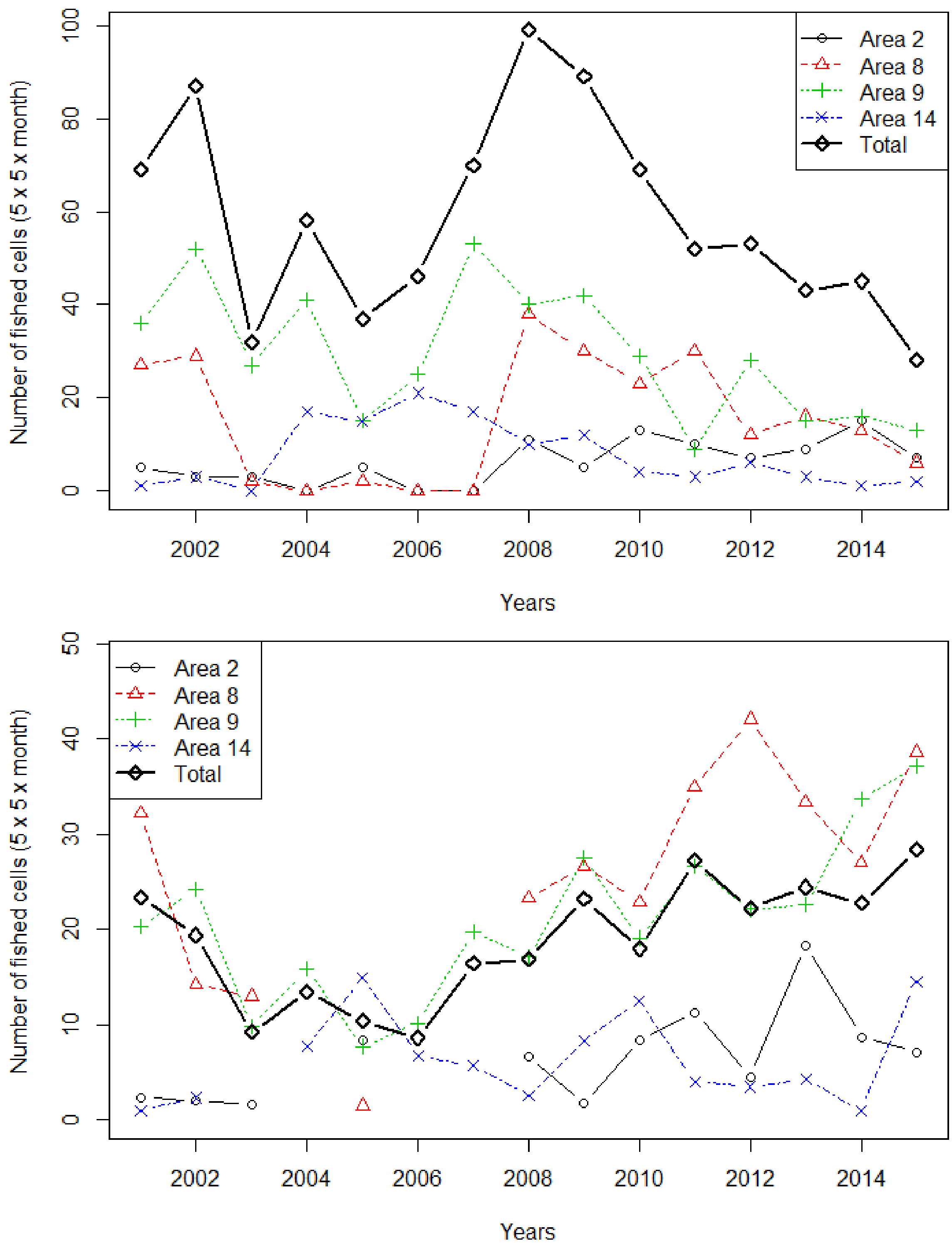

Figure 15: For fishing since 2000 in areas 2, 8, 9, and 14, the number of cells (5° latitude by 5° longitude by month) fished (above) and the number of longline operations per cell (below).

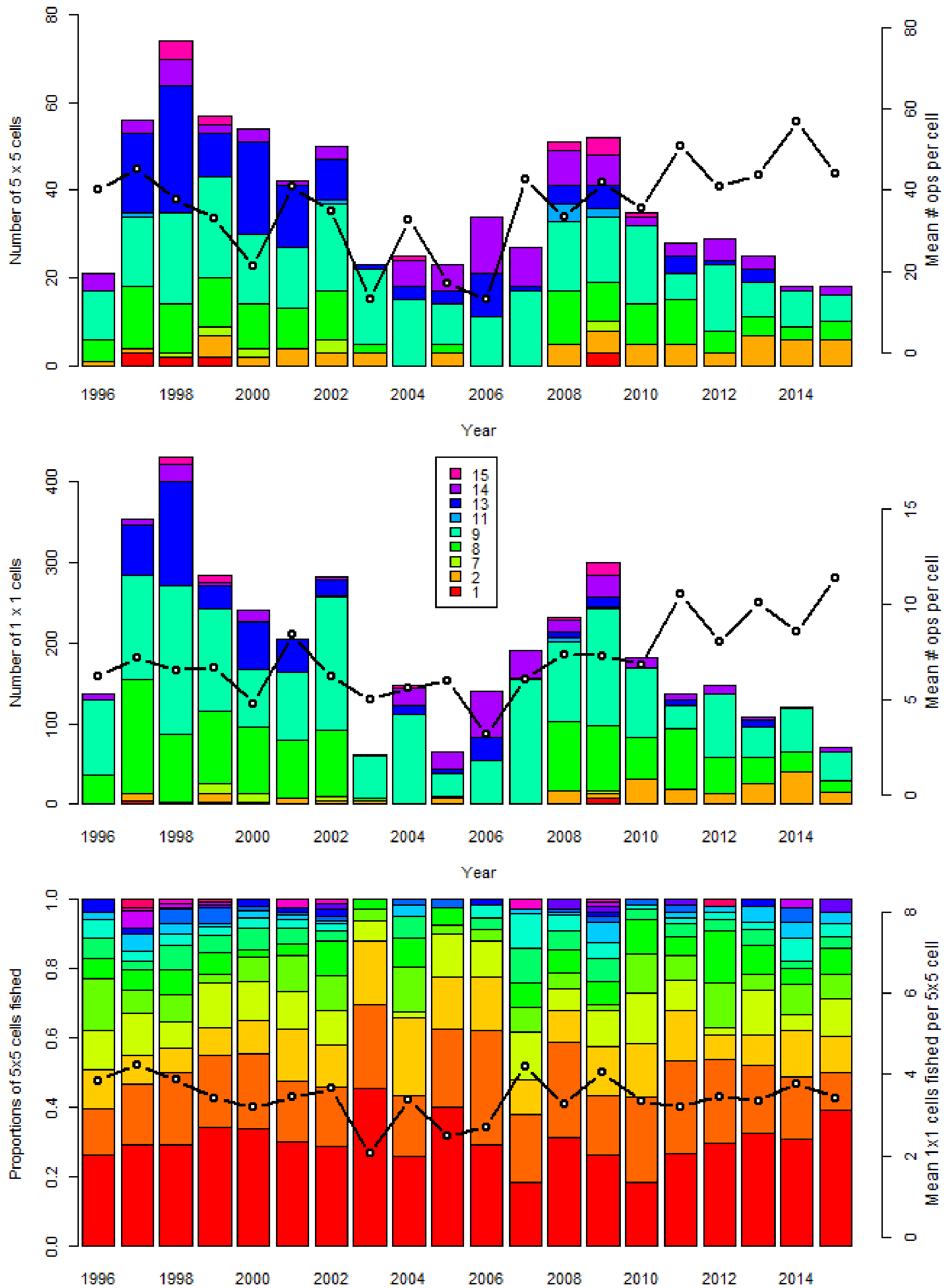

Figure 16: (Upper) Bars represent the number of major cells (5x5° by month) fished by CCSBT statistical area and year, see left y-axis. The line represents the mean annual operations per cell, see right y-axis. (Middle) As for upper plot, but with minor cells (1x1° by month) instead of major cells. (Lower) Relative distribution of fished major cells by the proportion of the cell fished, measured as the number of minor cells fished within each major cell (see left y-axis). The lowest (red) and highest (purple) bands represent major cells in which, respectively, 1 and 15 of the 25 minor cells were fished. The line represents the mean number of minor cells fished per major cell by year, see right y-axis.

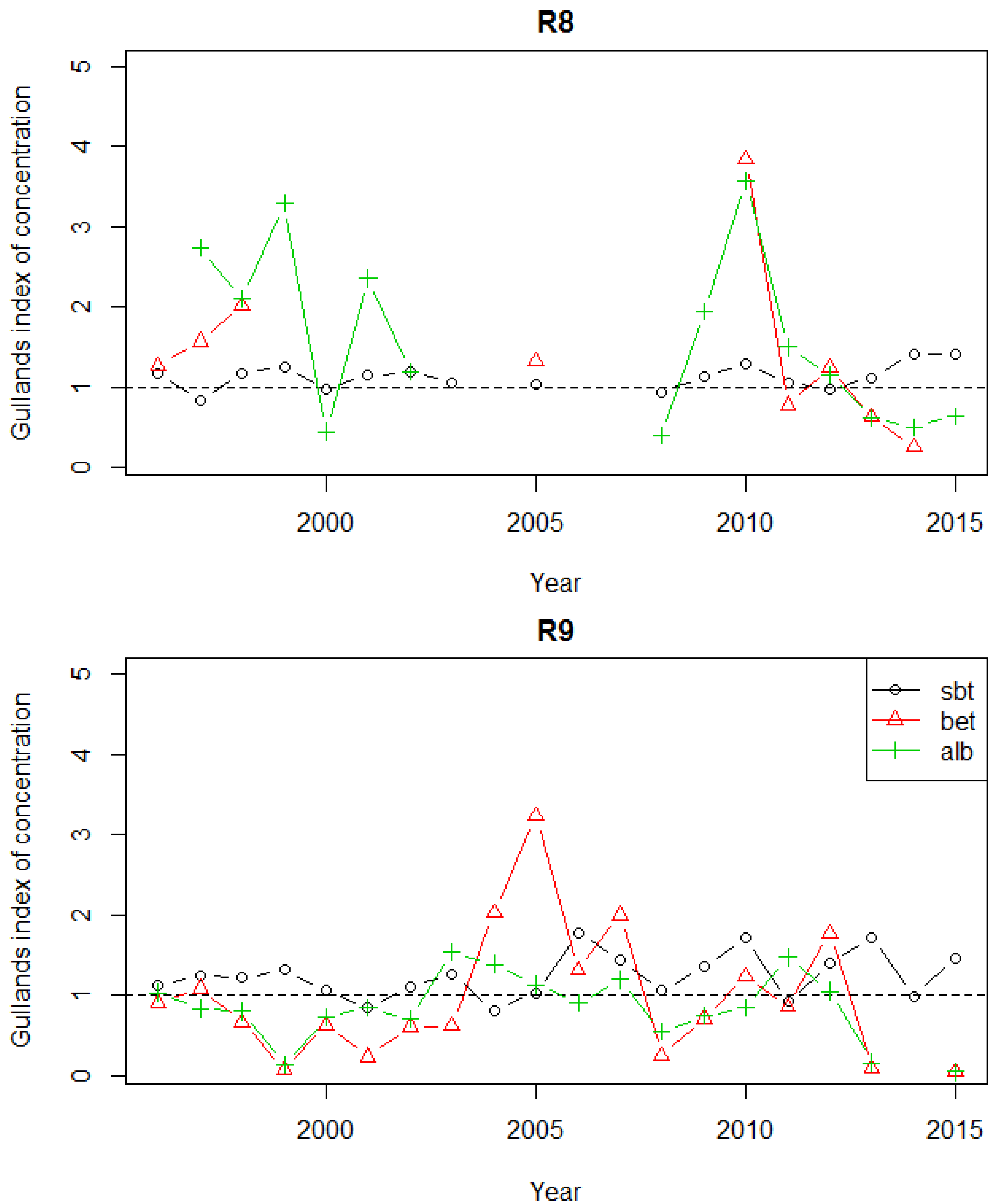

Figure 17: Gulland's indices of concentration estimated annually for southern bluefin tuna, bigeye tuna, and albacore tuna, in statistical areas 8 and 9.

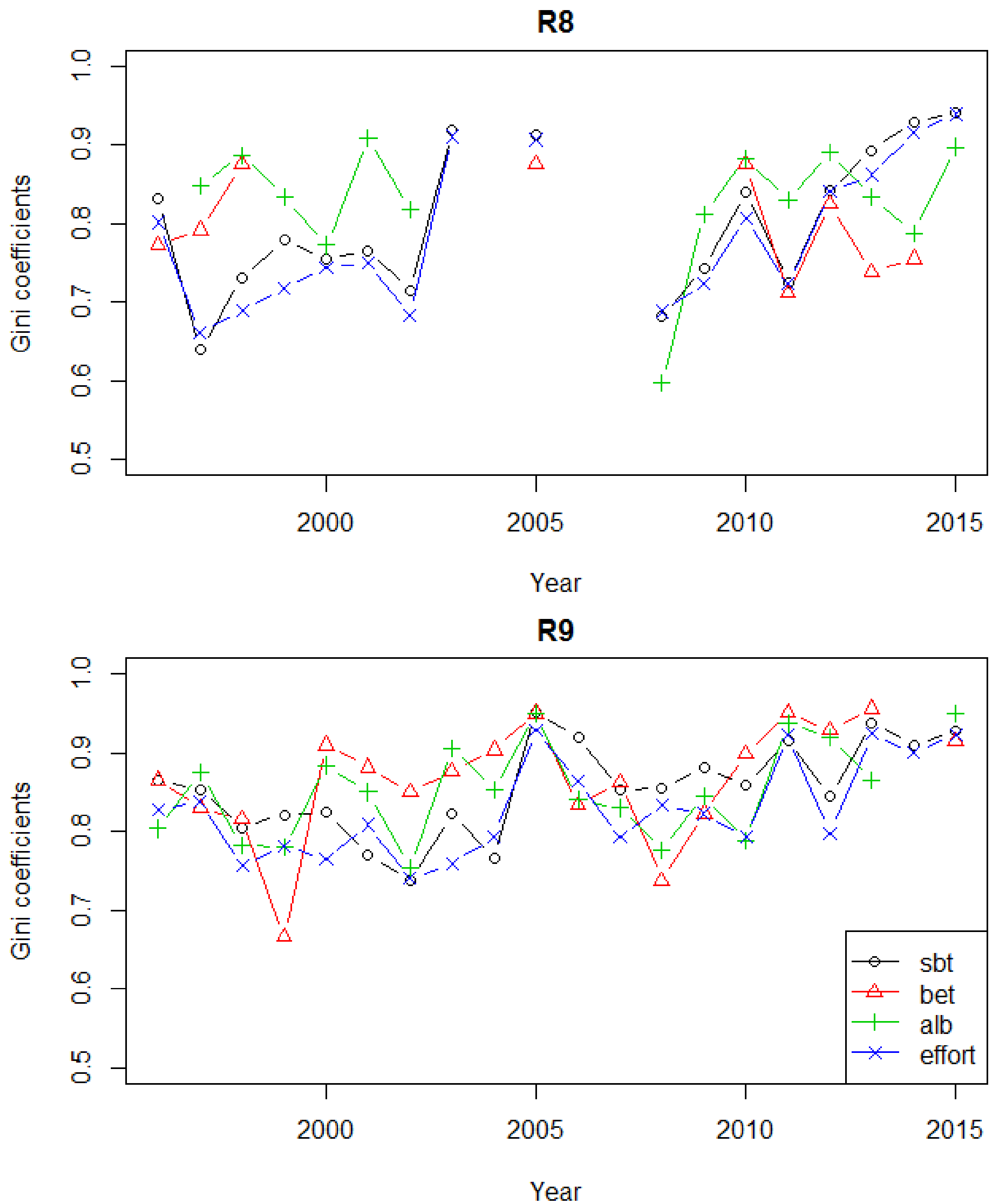

Figure 18: Gini coefficients estimated annually for southern bluefin tuna, bigeye tuna, albacore tuna, and fishing effort in statistical areas 8 and 9

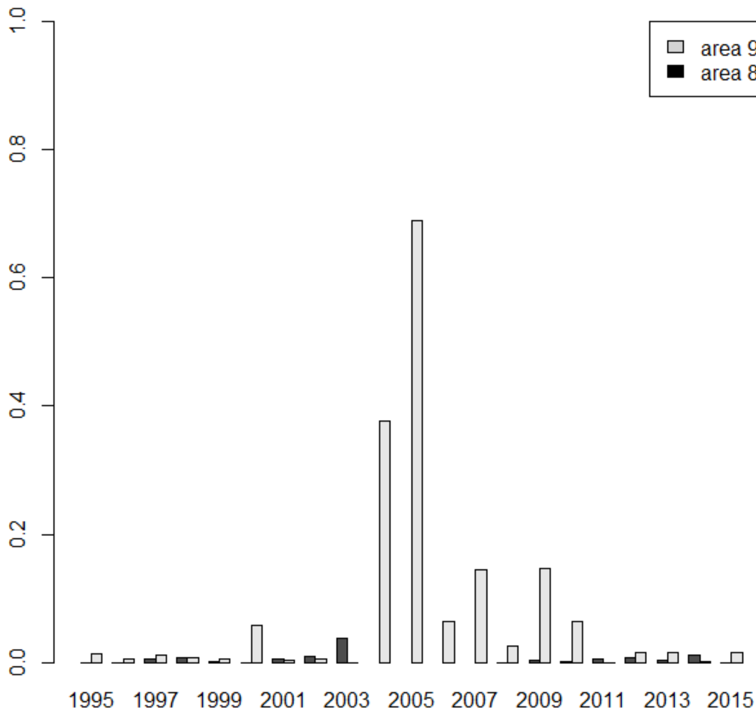

Figure 19: Proportions of sets with zero catches of SBT by year and statistical area, in the data used in the standardization models.

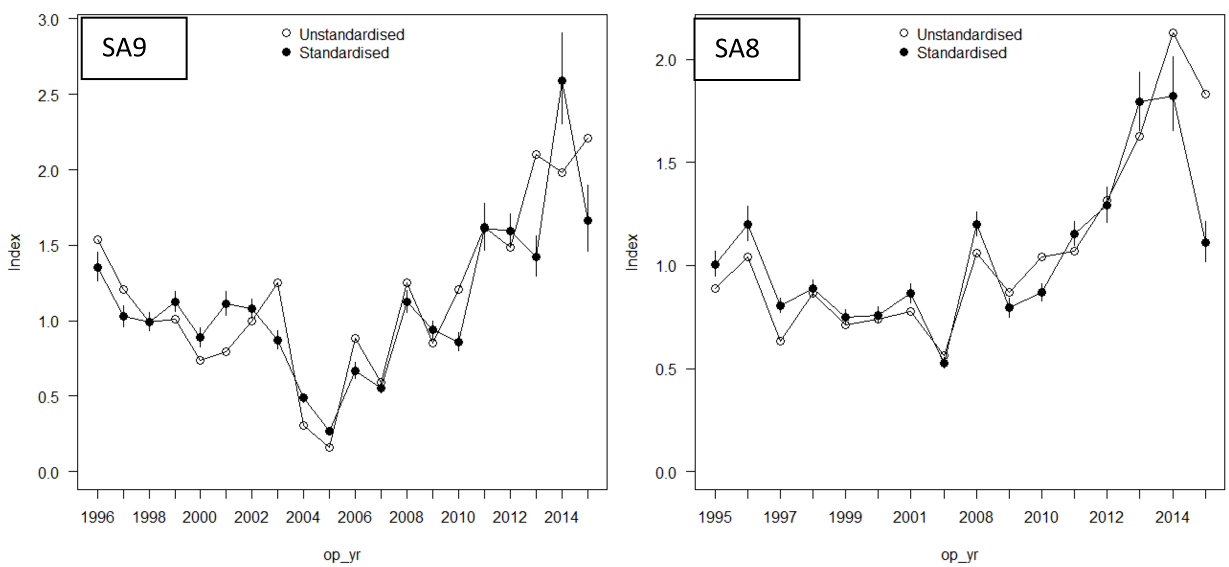

Figure 20: Unstandardized and standardized CPUE indices for statistical areas 9 (left) and 8 (right), based on lognormal GLMs with an added constant.

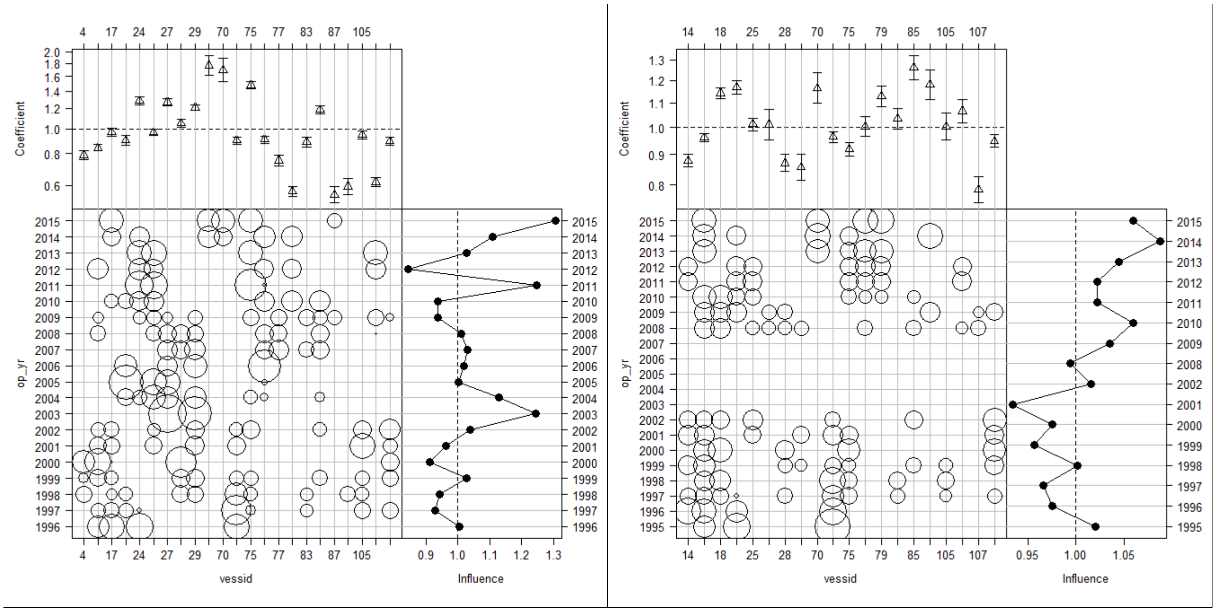

Figure 21: Influence plots for vessel effects for areas 9 (left) and 8 (right).

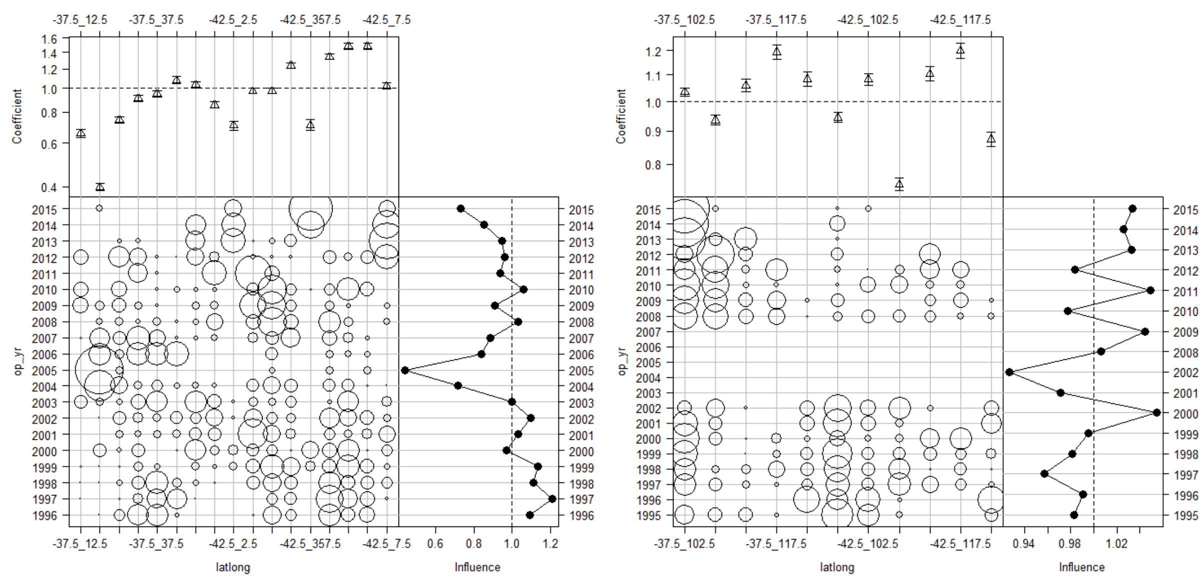

Figure 22: Influence plots for spatial latlong effects for statistical areas 9 (left) and 8 (right).

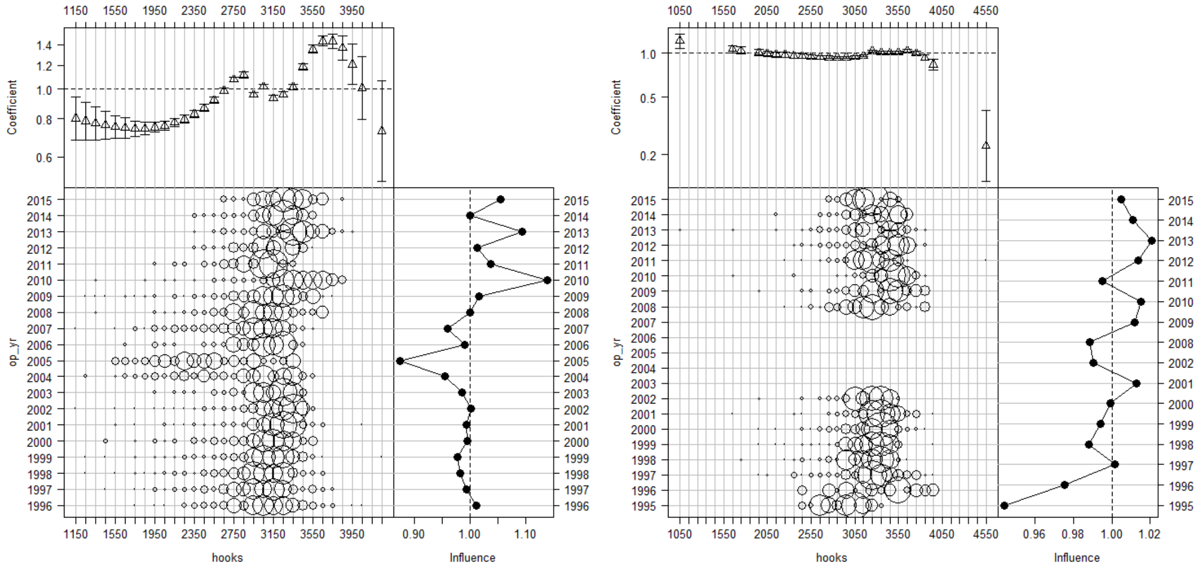

Figure 23: Influence plots for the effects of numbers of hooks for statistical areas 9 (left) and 8 (right).

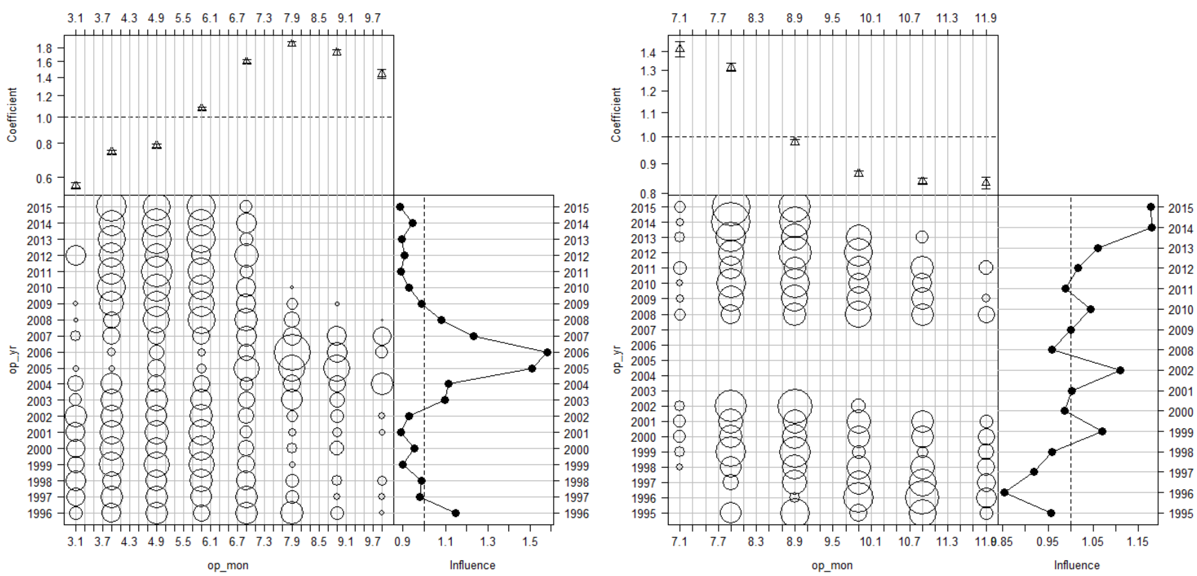

Figure 24: Influence plots for month effects for statistical areas 9 (left) and 8 (right).

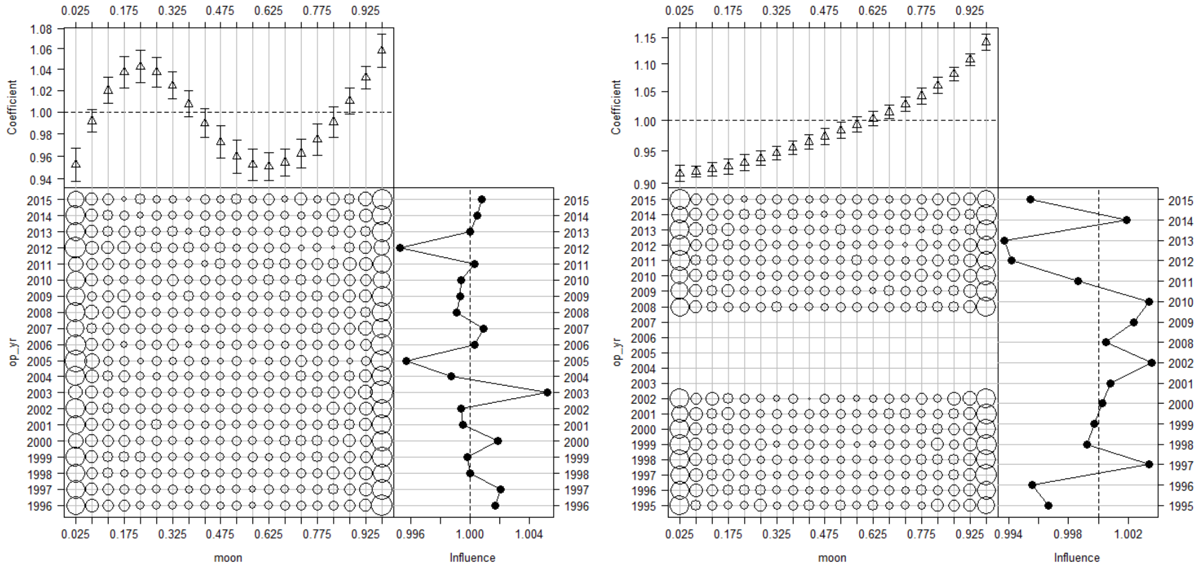

Figure 25: Influence plots for lunar illumination effects for statistical areas 9 (left) and 8 (right).

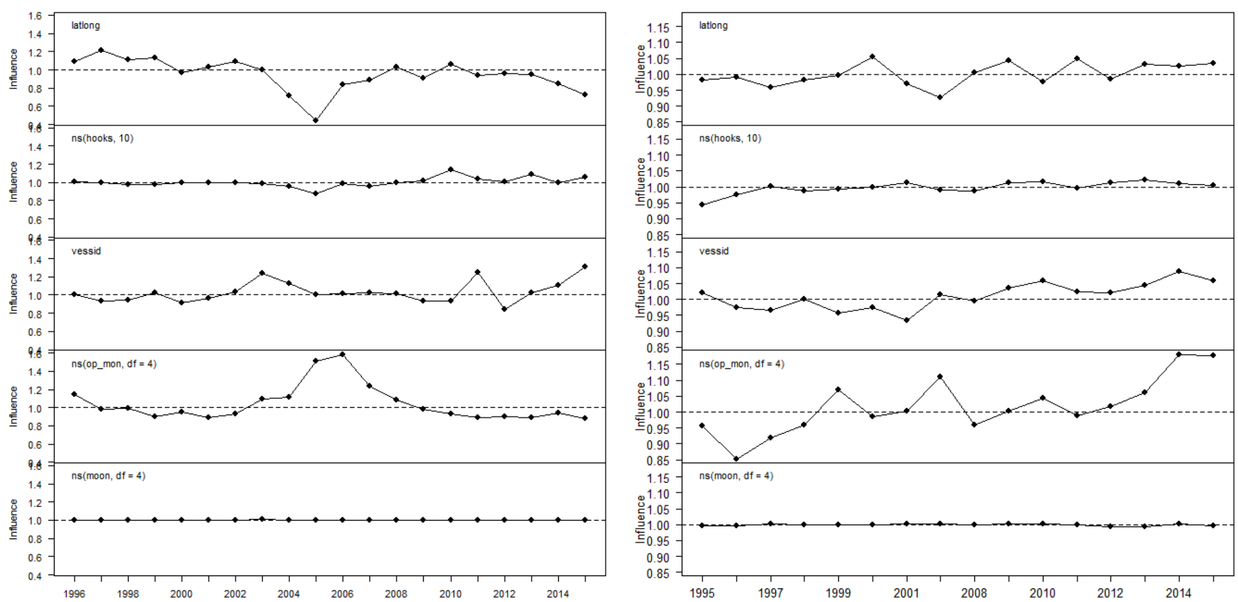

Figure 26: Compilation of influence plots for statistical areas 9 (left) and 8 (right).

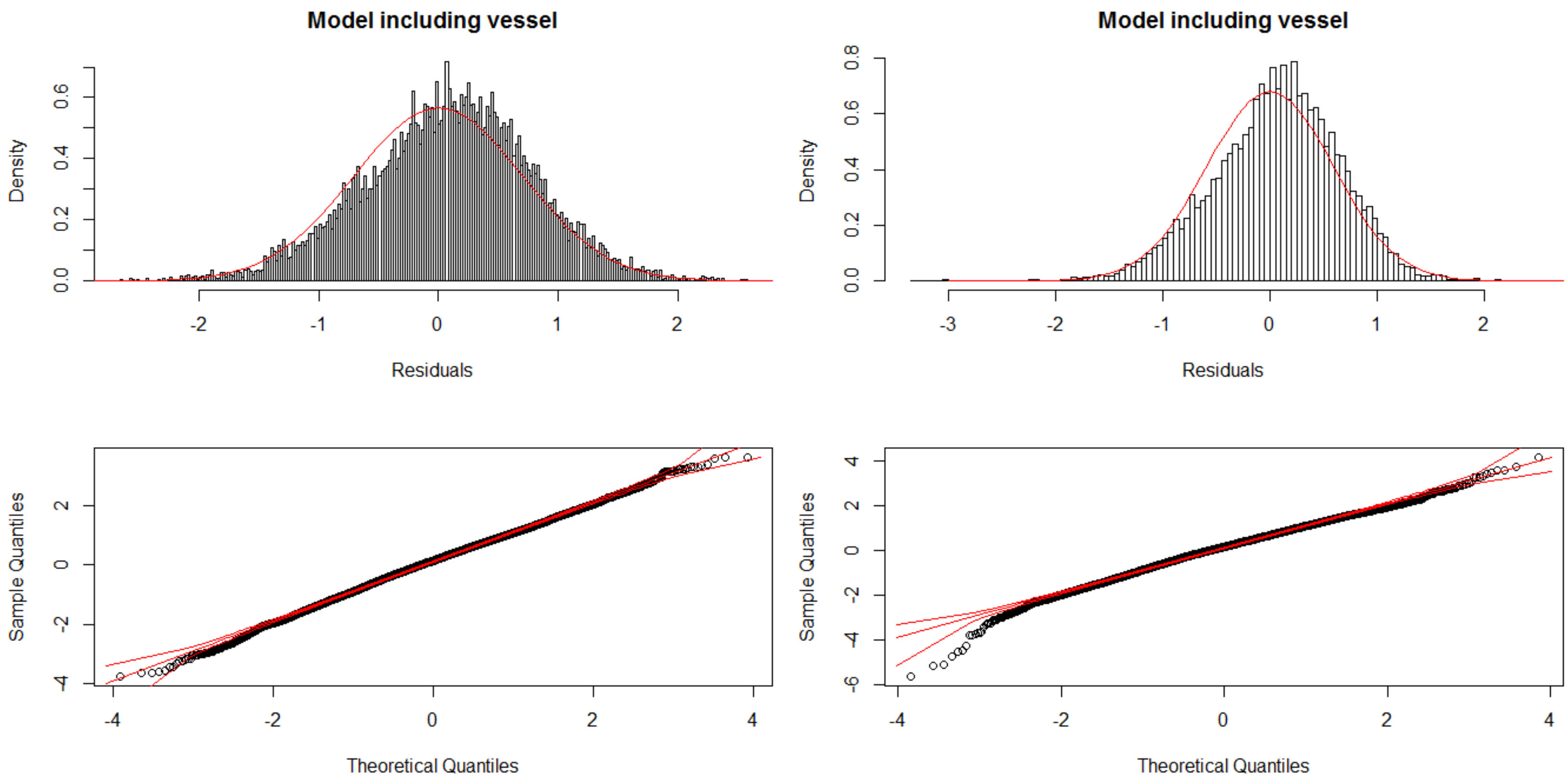

Figure 27: Frequency distributions of the standardized residuals (above) and Q-Q plots of standardized residuals for lognormal constant GLM analyses of statistical areas 9 (left) and 8 (right).

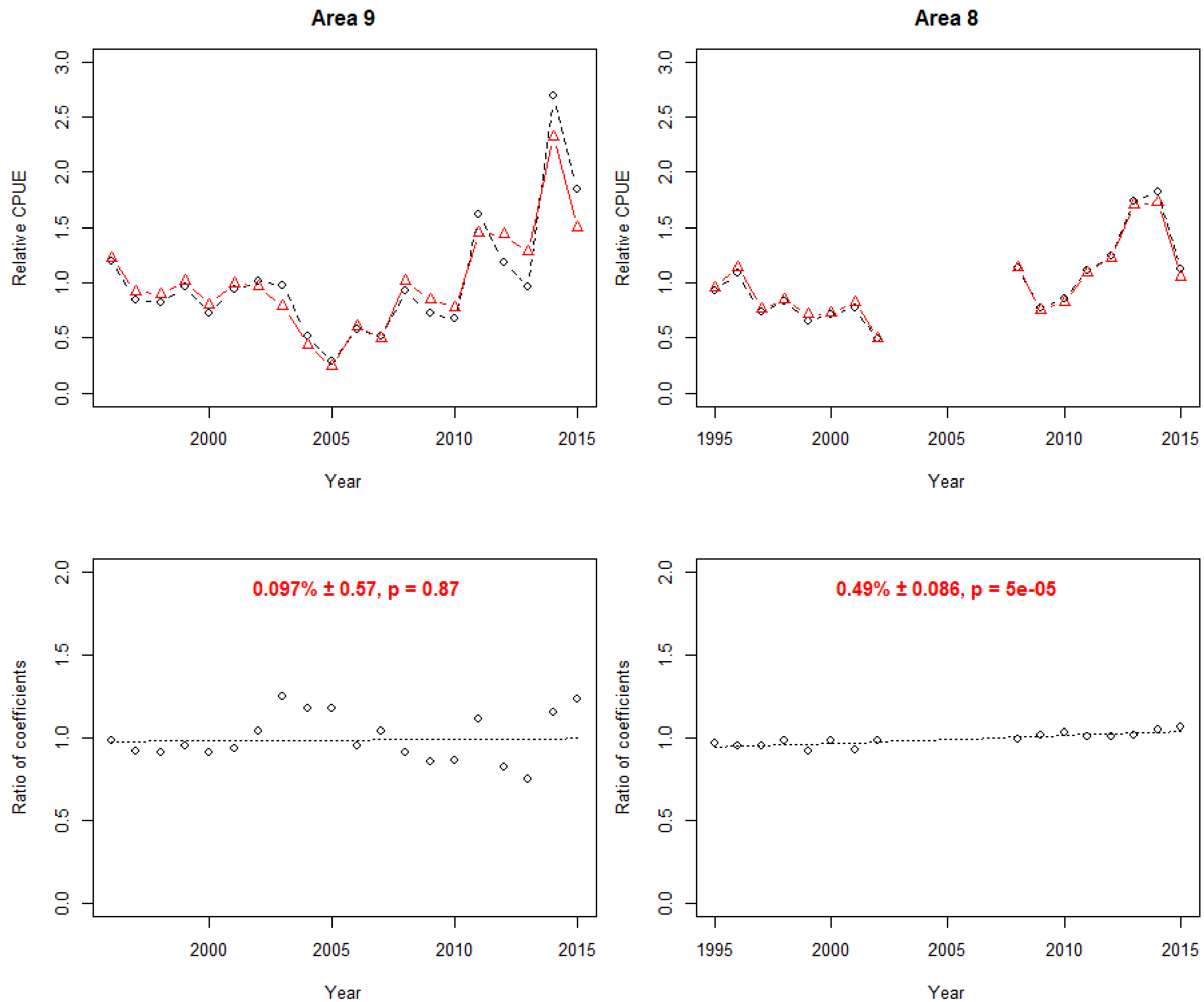

Figure 28: Plots of annual indices of abundance resulting from standardization of SBT CPUE for statistical areas 9 (left) and 8 (right) using lognormal constant models, fitted either with (red triangles) or without (black circles) vessel effects. The lower plots show the ratio of the two sets of indices, with a log-linear trend fitted. The numbers indicate the annual rate of change in the ratio.