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STANDARDIZED CPUE FOR SAILFISH CAUGHT BY THE JAPANESE TUNA LONGLINE FISHERY IN THE ATLANTIC OCEAN FROM 1994 TO 2014

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SUMMARY

Standardized CPUEs for Sailfish caught by Japanese tuna longline fishery in the western and eastern Atlantic Ocean were estimated using logbook data during 1994-2014. Delta lognormal model was used to standardize the nominal CPUEs. Annual changes in the standardized CPUEs for the western Atlantic stock showed a large fluctuation. The time series had a slight decreasing trend from 1994 to 2007 and after that the time series had sharply increased and maintained at higher values. Annual changes in the standardized CPUEs for the eastern Atlantic stock were considerably stable. The time series had a slight decreasing trend during 1994 and 2001, while the time series showed an increasing trend since then. The 95 % confidence intervals were not wide for the western and eastern Atlantic sailfish stocks. These results suggest that the current adult stock level of sailfish in the western and eastern Atlantic increased in recent years compared with those in the 1990s and 2000s.

RÉSUMÉ

Les CPUE standardisées des voiliers capturés par les palangriers thoniers japonais dans l'océan Atlantique Ouest et Est ont été estimées à l'aide des données des carnets de pêche pendant la période 1994-2014. Un modèle delta lognormal a été utilisé pour standardiser les CPUE nominales. Les changements annuels dans les CPUE standardisées pour le stock de l'Atlantique Ouest ont montré une grande fluctuation. La série temporelle dégageait une légère tendance décroissante de 1994 à 2007, après quoi la série temporelle a brusquement augmenté et s'est maintenue à des valeurs plus élevées. Les changements annuels des CPUE standardisées pour le stock de l'Atlantique Est étaient considérablement stables. Les séries temporelles dégageaient une légère tendance à la baisse entre 1994 et 2001 ; depuis lors, elles dégagent une tendance à la hausse. Les intervalles de confiance de 95 % n'étaient pas larges pour les stocks de voiliers de l'Atlantique Ouest et Est. Ces résultats suggèrent que le niveau actuel du stock de voiliers adultes dans l'Atlantique Ouest et Est a augmenté au cours de ces dernières années par rapport au niveau des années 90 et 2000.

RESUMEN

Se estimaron las CPUE estandarizadas para el pez vela capturado por la pesquería atunera de palangre japonés en el Atlántico oriental y occidental utilizando los datos de los cuadernos de pesca del periodo 1994-2014. Se usó un modelo delta lognormal para estandarizar las CPUE nominales. Los cambios anuales en las CPUE estandarizadas para el stock del Atlántico occidental mostraban una fuerte fluctuación. La serie temporal tenía una tendencia ligeramente descendente desde 1994 hasta 2007 y después de eso, la serie temporal aumentó bruscamente y se mantuvo en niveles más elevados. Los cambios anuales en las CPUE estandarizadas para el stock del Atlántico oriental eran considerablemente estables. La serie temporal presentaba una tendencia ligeramente descendente entre 1994 y 2001, mientras que, tras dicho periodo, mostraba una tendencia ascendente. Los intervalos de confianza del 95% no eran amplios para los stocks de pez vela del Atlántico oriental y occidental. Estos resultados sugieren que el nivel actual del stock adulto de pez vela en el Atlántico oriental y occidental ha aumentado en años recientes en comparación con los niveles de los 90 y los 2000.

KEYWORDS

Atlantic Ocean, Sailfish, Istiophorus, Japanese Longline, CPUE

1. Introduction

Catch per unit of effort (CPUE) of sailfish (*Istiophorus*) caught by Japanese longline fishery in the eastern and western Atlantic Ocean were standardized using both generalized linear model (GLM) based on the delta-lognormal model and habitat model (Yokawa and Takeuchi, 2002). They used the logbook data only from the coastal areas at some specific quarters in the tropical regions, because high catch ratio of sailfish was mainly observed in coastal area of Venezuela in 2nd and 3rd quarters and tropical areas in off Brazil and off Africa in 4th quarter (Yokawa and Takeuchi, 2002). In addition, they assumed that the vertical distribution pattern of sailfish was the same as the ones for Pacific blue marlin (Hinton and Nakano, 1998) because there was no information about the vertical distribution pattern of sailfish (Yokawa and Takeuchi, 2002). In general, the CPUE series generated using the habitat model showed more optimistic trend than the series produced using the GLM approach, and the CPUE series generated using the vertical distribution patterns of swordfish for sailfish was quite similar to the one obtained by GLM (Anon, 2002). Yokawa and Takeuchi (2002) concluded that the standardized CPUEs estimated from the GLM shall be considered to be biased because the results of GLM approach with the data in off Africa was similar to the one of habitat model with the use of the swordfish vertical distribution pattern that was applied as sailfish one. However, there was no clear description which standardization approach is better for the sailfish stocks. In the 2009 stock assessment, CPUE series of Japanese longline fishery were not provided by Japanese delegation.

The objective of this working document paper is to provide the standardized CPUE of sailfish in the eastern and western Atlantic Ocean during 1994 and 2014. We used only delta-lognormal model because there is no information about the vertical distribution pattern of sailfish in the Atlantic Ocean. In addition, we used the data collected from wider ranges of the distributional areas than hotspots of sailfish catch to avoid the effect of the hyper-stability: i.e. the CPUE remains high while the abundance declines (Hilborn and Walters, 1992).

2. Material and methods

2.1 Data source

Set-by-set logbook data from Japanese offshore and distant water longline fishery in the Atlantic Ocean are used to standardize CPUEs for 1994-2014. The logbook data contain, for each set operation, information on latitude and longitude by 1×1 degree, temporal information (year, month, and day), catch in number of tunas, billfishes and sharks species, gear configurations such as a hooks between float (HBF) and so on. The logbook data of sailfish have been collected and compiled by the National Research Institute of Far Seas Fisheries since 1994. The logbook records before 1994 contain only species combined catch numbers of sailfish and spearfish. Therefore, we used only the logbook data after 1993 to standardize the CPUEs of sailfish. We chose the logbook data which includes only tropical and subtropical regions between 20 S ° and 20 N ° where main distributional area of sailfish (**Figure 1**) and we removed the outlier of data as well.

2.2 CPUE standardization

We used GLMtree (Ichinokawa and Broziak 2010) to separate statistically the operational areas into several reasonable regions for the CPUE standardization (**Figures 1 and A1**). Numbers of hooks between floats (hbf) were simply classified into shallower sets gear (hbf < 15) and deeper sets gear (14 < hbf) based on the gear configuration of the Japanese longliner in the tropical regions, where they generally target the bigeye tuna using the deep-set and sometimes changes their set to target the yellowfin tuna (**Figure A2**). Four seasons (quarters (qt) 1 to 4) were defined as follows: qt1 was from January to March; qt2 was from April to June; qt3 was from July to September; and qt4 was from October to December. CPUEs (number of sailfish caught per 1,000 hooks) of western and eastern Atlantic sailfish were standardized using delta-lognormal model (Lo et al, 1992) not only to deal with the excess zero catches (**Figures A3 and A4**) but also to eliminate the biases arising from the non-systematic operation of longline fishery and the distributional changes of the species over the time. We assumed that a binomial error distribution for the proportion of positive sets, and lognormal distribution for the positive catches. Five factors were treated as main effects: year, qt, area, and hbf. In addition to main effects, first order interactions between each main effects were included in the lognormal model. Higher order interactions were not included to avoid over-parameterization. A stepwise approach (Analysis of deviance table and backward elimination from the full model with AIC) was used to identify the variables with a significant impact on the standardized CPUEs. The distribution of the residuals and the regression diagnostics were used to verify the assumptions of the lognormal distributions and the goodness of the fits. The estimates were weighted by relative area to all operational areas (area1: 0.699, area2: 0.300, area3: 0.815, area4: 0.075, area5: 0.109), where the number of hooks was positive, because the interaction terms between year and area were included in the models. The 95% confidence interval (CI) and coefficient variation (CV) of standardized CPUE for each year were estimated using a bootstrap (1000 random samples of set by set data with replacement).

3. Results

Deviance table (Type III) of binomial model and lognormal models were shown in **Table 1**. For binomial model, all explanatory variables were significant (P < 0.01) for western and eastern stocks. For lognormal model, two interaction terms (qt*hbf, area*hbf) were not significant (P > 0.1) for western stock and we eliminated those interaction terms from the model. On the other hand, full model was selected for eastern stock (P < 0.01). The same model structures as those chose in the first step (i.e. analysis of deviance tables) were selected using the backward elimination approaches based on AIC for both of the western and eastern stocks (**Table 2**). The Pearson residuals for the lognormal model showed a reasonable distribution for the western stock, whereas the distribution of eastern stock was slightly skewed toward the negative values (**Figure 2**).

The general trends of positive catch ratio were similar between nominal and standardized CPUEs for the both western and eastern stocks (**Figures 3a and b**). The annual changes in the positive catch ratios were largely fluctuated for the western stock (**Figure 3a**), whereas those were stable for the eastern stock (**Figure 3b**). The positive catch ratio of western stock had sharply increased after 2007 and maintained at higher catch ratio (23.7% on average from 2008 to 2014). The annual trends of positive catch ratio for eastern stock had slightly decreased until 2001 and after that those ratios showed a slight increasing trend. Annual changes in the standardized CPUEs of positive catch showed a slight decreasing trend for the western stock, while those of the eastern stock had a slight increasing trend (**Figures 3c and d**).The levels of the standardized CPUEs were higher than those of the nominal CPUEs for both stocks. Annual changes in the standardized (combined) CPUEs for the western stock showed a large fluctuation (**Figure 3e**). The time series had a slight decreasing trend from 1994 to 2007 and after that the time series had sharply increased and maintained at higher values. Annual changes in the standardized CPUEs for the eastern Atlantic stock were considerably stable (**Figure 3f**). The time series had a slight decreasing trend during 1994 and 2001, while the time series showed an increasing trend since then. The 95 % confidence intervals were not wide for the western and eastern stocks throughout the periods of standardization. The summary table of the outputs were shown in **Table 3**.

The details of other diagnostics such as goodness of fit were shown in **Figures A5 and A6**.The GLM analyses were carried out using an R package (R core Team, 2013).

4. Discussions

Our results suggest that the current adult stock size of sailfish in the western and eastern Atlantic Ocean increased in recent years compared with those in the 1990s and 2000s. These results were fundamentally obtained from that catch number of sailfish in both stocks had increased in the middle of 2000s, while the fishing effort (number of hooks) were more or less stable (**Figure A7**). High nominal CPUE of sailfish were observed in area 1 and 4, in particular since 2008 (**Figure A8**). The nominal CPUEs were remarkably high in the area 1 throughout the four quarters and in the area 4 except for qt 3 (**Figure A9**). Annual changes of the nominal CPUEs for both stocks were largely changed by quarters (**Figure A10**). Nominal CPUEs of shallow set gear was higher than those of deep-set in the western Atlantic Ocean, while nominal CPUEs of both shallow-set and deep-set gears were high in the eastern Atlantic Ocean (**Figure A11**). Sailfish is known to be distributed mainly in the surface layer in the western Atlantic Ocean (Yokawa and Saito, 2004). However, the latter results showed that the sailfish might stay in the deep water where the hooks of the regular longline gear cover between 50 and 250 m (Suzuki et al., 1977). Recent several study on the electronic tags exhibited diel oscillations in its vertical diving behaviour and sailfish dove to depths deeper than 100 m (Kerstetter et al., 2011; Chiang et al., 2013; Mourato et al., 2014). Therefore, it is possible to catch the sailfish using the deep set gear.

Hotspots of sailfish were observed in tropical areas in off Brazil and off Africa regardless of the year as well as quarter (**Figures A12 and A13**). Spatial distribution of the nominal CPUEs showed that the positive catch of sailfish was observed in the tropical and sub-tropical areas between 20 S ° and 20 N ° (**Figure 1**). These results support that it is better to use the data in a wide range of tropical and sub-tropical areas than the use of the hotspots areas. In addition, we showed the spatial distributions of catch in number and efforts (number of hooks) by year and quarter (**Figures A14-17**).

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Table 1. Deviance table (Type III).

1-a Deviance table of binomial model for western Atlantic sailfish

Explanatory variables	LR Chisq	Df	Pr(>Chisq)
year	2127.35	20	< 0.001
quarter	422.87	3	< 0.001
area	66.35	1	< 0.001
hbf	1425.46	1	< 0.001

1-b Deviance table of binomial model for eastern Atlantic sailfish

Explanatory variables	LR Chisq	Df	Pr(>Chisq)
year	4696.5	20	< 0.001
quarter	738.5	3	< 0.001
area	2937.4	2	< 0.001
hbf	552.7	1	< 0.001

1-c Deviance table of lognormal model for western Atlantic sailfish

Explanatory variables	LR Chisq	Df	Pr(>Chisq)
year	373.23	20	< 0.001
quarter	77.66	3	< 0.001
area	0.86	1	**0.354**
hbf	14.79	1	< 0.001
year:area	69.93	20	< 0.001
quarter:area	26.27	3	< 0.001
quarter:hbf	6.22	3	**0.102**
area:hbf	0.4	1	**0.528**

1-d Deviance table of lognormal model for eastern Atlantic sailfish

Explanatory variables	LR Chisq	Df	Pr(>Chisq)
year	377.01	20	< 0.001
quarter	35.13	3	< 0.001
area	8.04	2	**0.018**
hbf	0.04	1	**0.851**
year:quarter	1080.46	60	< 0.001
year:area	324.23	40	< 0.001
year:hbf	266.39	20	< 0.001
quarter:area	155.75	6	< 0.001
quarter:hbf	15.33	3	0.0016
area:hbf	24.03	2	0.007

Table 2. Summary tables of the backward elimination approach.

2-a Summary of the binomial model for the western Atlantic sailfish.

Removed factor	Df	Deviance	AIC
none		26304	26356
area	1	26370	26420
quarter	3	26727	26773
hbf	1	27729	27779
year	20	28431	28443

2-b Summary of the binomial model for the eastern Atlantic sailfish.

Removed factor	Df	Deviance	AIC
none		142998	143052
hbf	1	143551	143603
quarter	3	143737	143785
area	2	145936	145986
year	20	147695	147709

2-c Summary of the lognormal model for the western Atlantic sailfish.

Removed factor	Df	Deviance	AIC
none		2699	11106
quarter:area	3	2717.8	11134
year:area	20	2737.2	11135
hbf	1	2731.3	11162

2-d Summary of the lognormal model for the eastern Atlantic sailfish.

Removed factor	Df	Deviance	AIC
none		11657	47532
quarter:hbf	3	11666	47542
area:hbf	2	11670	47553
year:area	6	11744	47677
quarter:area	20	11806	47759
year:hbf	40	11838	47777
year:quarter	60	12262	48474

Table 3. Summary tables of yearly changes in the nominal and standardized CPUEs (catch number / number of 1000 hooks) and the coefficient of variations (CV) for the positive catch ratio derived from binomial model, CPUE of positive catch part derived from the log-normal model, and the combined CPUE derived from the combine the both parts for the western Atlantic sailfish (a) and for the eastern Atlantic sailfish (b).

Table 3a.

Year	Positive catch ratio			CPUE of positive catch			Combined CPUE		
	Nominal	Standardized	CV	Nominal	Standardized	CV	Nominal	Standardized	CV
1994	0.065	0.095	0.073	0.677	0.832	0.080	0.044	0.079	0.108
1995	0.031	0.040	0.141	0.866	0.712	0.213	0.027	0.029	0.246
1996	0.043	0.051	0.099	1.054	1.038	0.118	0.045	0.053	0.155
1997	0.105	0.115	0.056	1.372	1.106	0.053	0.144	0.127	0.076
1998	0.057	0.082	0.105	0.778	0.912	0.078	0.044	0.075	0.130
1999	0.123	0.153	0.070	1.081	0.990	0.046	0.133	0.152	0.083
2000	0.103	0.104	0.074	1.127	0.897	0.043	0.116	0.094	0.085
2001	0.026	0.022	0.138	0.970	0.784	0.074	0.025	0.017	0.157
2002	0.040	0.064	0.127	0.620	0.738	0.084	0.025	0.047	0.151
2003	0.091	0.133	0.064	0.748	0.739	0.051	0.068	0.098	0.081
2004	0.042	0.061	0.092	0.659	0.752	0.107	0.027	0.046	0.143
2005	0.071	0.113	0.078	2.099	1.041	0.074	0.149	0.118	0.108
2006	0.052	0.090	0.141	1.055	0.917	0.104	0.055	0.082	0.168
2007	0.021	0.026	0.205	0.527	0.669	0.132	0.011	0.017	0.235
2008	0.193	0.258	0.039	1.104	0.883	0.035	0.213	0.227	0.053
2009	0.194	0.256	0.036	1.261	0.871	0.036	0.245	0.223	0.050
2010	0.214	0.267	0.035	0.959	0.799	0.037	0.205	0.213	0.051
2011	0.245	0.315	0.036	1.279	0.863	0.040	0.313	0.272	0.053
2012	0.134	0.162	0.049	0.898	0.754	0.042	0.121	0.122	0.066
2013	0.103	0.139	0.073	0.845	0.755	0.048	0.087	0.105	0.088
2014	0.210	0.261	0.058	1.228	0.899	0.045	0.257	0.234	0.073

Table 3b.

Year	*Positive catch ratio*			*CPUE of positive catch*			*Combined CPUE*		
	Nominal	*Standardized*	*CV*	*Nominal*	*Standardized*	*CV*	*Nominal*	*Standardized*	*CV*
1994	0.044	0.056	0.033	0.808	0.830	0.047	0.035	0.046	0.056
1995	0.046	0.057	0.032	0.872	0.844	0.045	0.040	0.048	0.055
1996	0.037	0.045	0.033	0.915	0.885	0.110	0.034	0.040	0.112
1997	0.027	0.034	0.042	0.706	0.821	0.085	0.019	0.028	0.093
1998	0.037	0.047	0.040	1.035	0.825	0.052	0.039	0.038	0.065
1999	0.028	0.035	0.048	0.684	0.818	0.087	0.019	0.029	0.100
2000	0.036	0.044	0.041	0.773	0.836	0.091	0.028	0.037	0.100
2001	0.014	0.018	0.081	0.584	0.705	0.188	0.008	0.013	0.203
2002	0.027	0.032	0.061	1.293	0.904	0.100	0.035	0.029	0.120
2003	0.035	0.042	0.046	0.841	0.840	0.076	0.030	0.035	0.089
2004	0.062	0.079	0.035	1.297	0.916	0.115	0.081	0.072	0.118
2005	0.079	0.095	0.036	0.951	0.822	0.062	0.075	0.078	0.073
2006	0.074	0.073	0.033	0.954	0.849	0.036	0.070	0.062	0.050
2007	0.118	0.101	0.026	1.054	0.930	0.040	0.124	0.094	0.048
2008	0.144	0.131	0.021	1.210	0.883	0.033	0.174	0.115	0.039
2009	0.091	0.091	0.027	0.912	0.786	0.034	0.083	0.071	0.043
2010	0.079	0.082	0.030	1.173	0.886	0.030	0.092	0.073	0.042
2011	0.134	0.145	0.023	0.999	0.840	0.029	0.134	0.122	0.037
2012	0.113	0.118	0.024	1.394	0.883	0.028	0.158	0.104	0.037
2013	0.104	0.129	0.028	0.904	0.878	0.040	0.094	0.114	0.049
2014	0.070	0.087	0.035	1.002	0.869	0.047	0.070	0.076	0.057

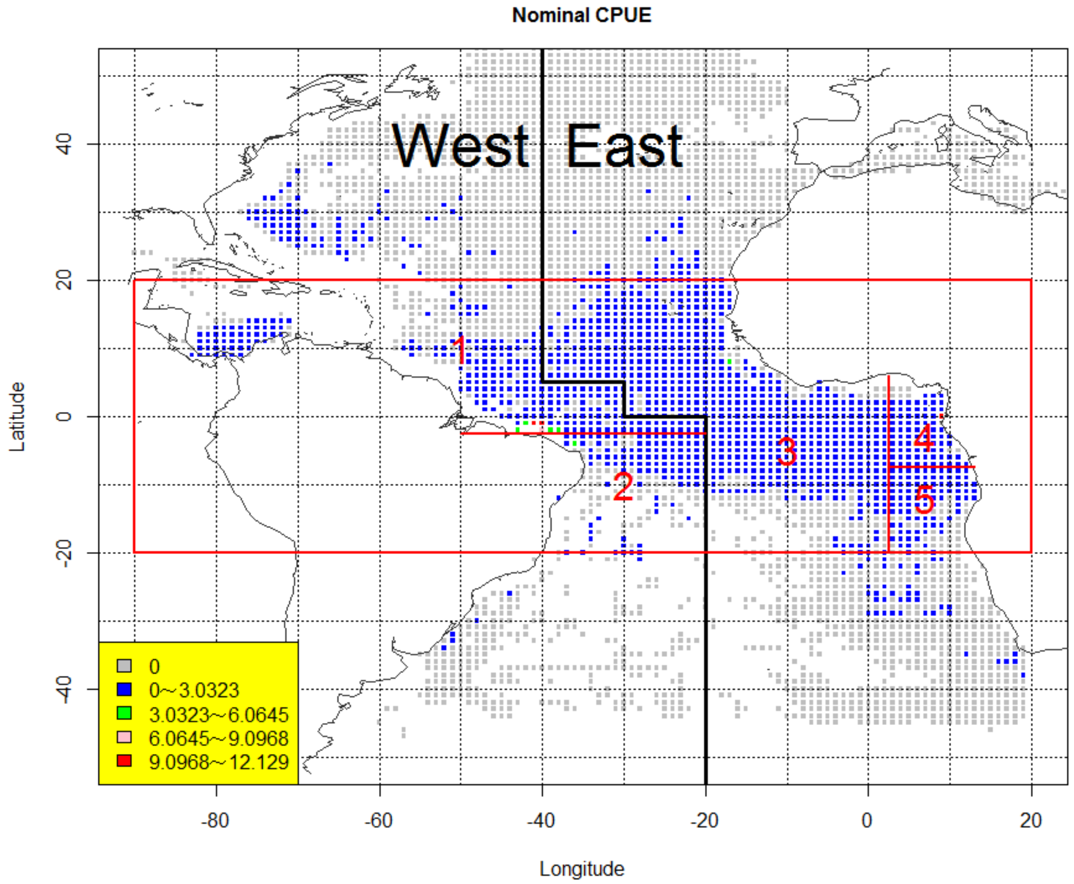


Figure 1. Spatial distribution of nominal CPUEs (catch number / number of hooks (x1000)) based on the data combined from 1994 to 2014, and area stratification of the Atlantic Ocean based on the GLMtree. The tropical area was separated into five areas. The numerals from 1 to 5 denotes the given number of each area.

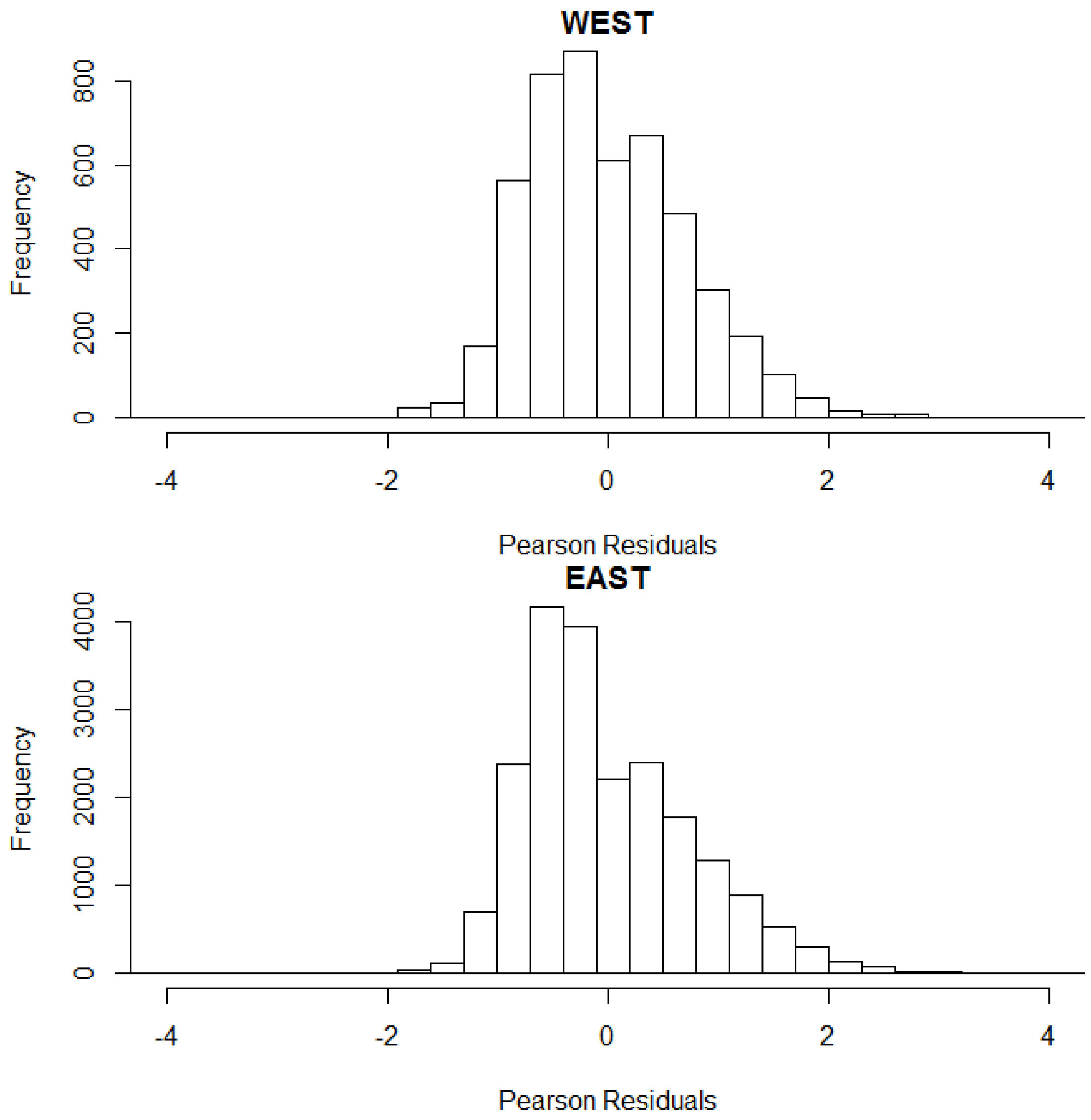


Figure 2. Pearson residuals of the lognormal model for the data in the western and eastern Atlantic sailfish.

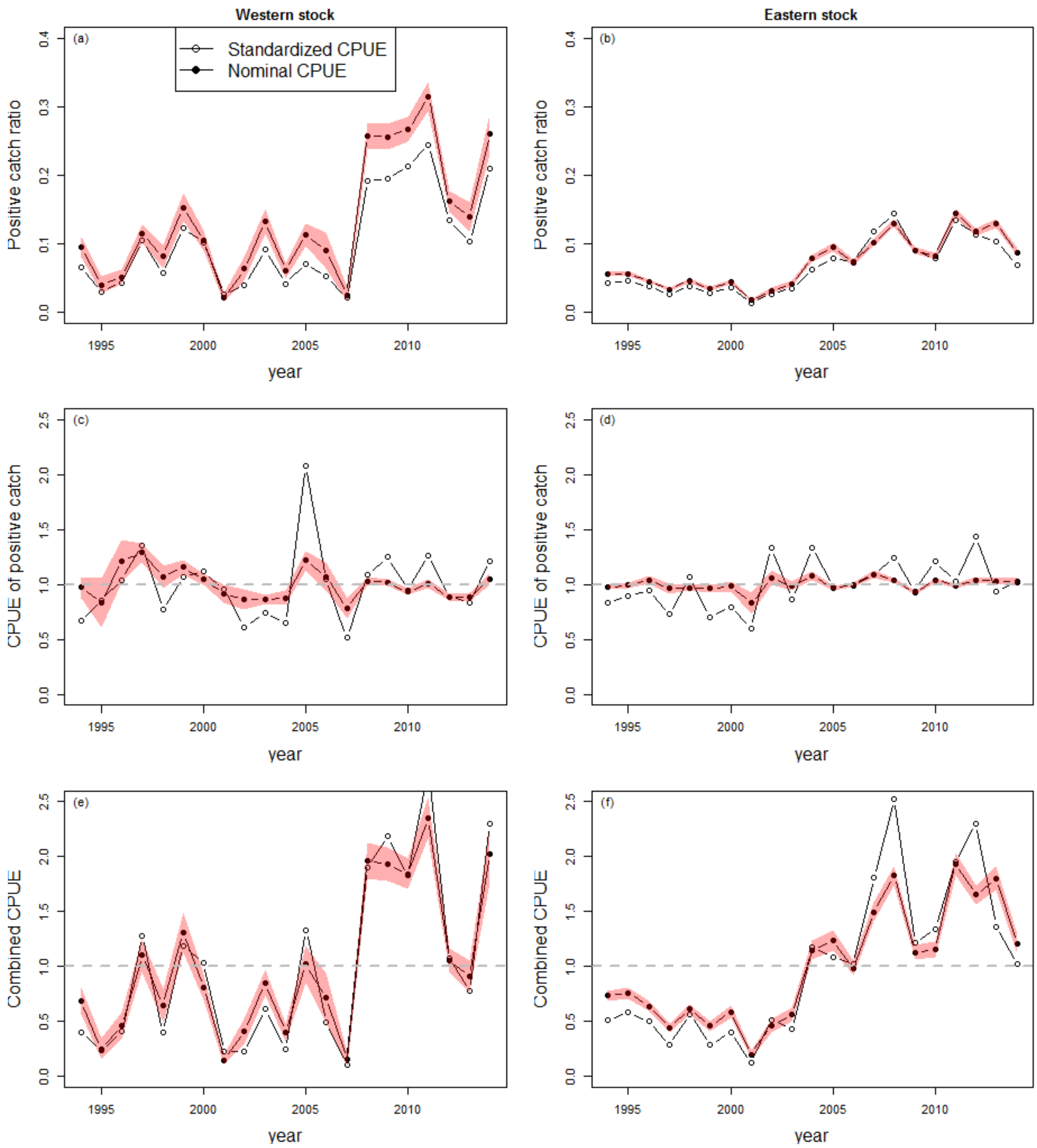


Figure 3. Nominal and standardized CPUEs estimated by binomial model (catch ratio), lognormal model (relative to mean value), and combined model (relative to mean value) with 95% confidence intervals for the western (left figure) and eastern (right figure) stocks from 1994 to 2014.

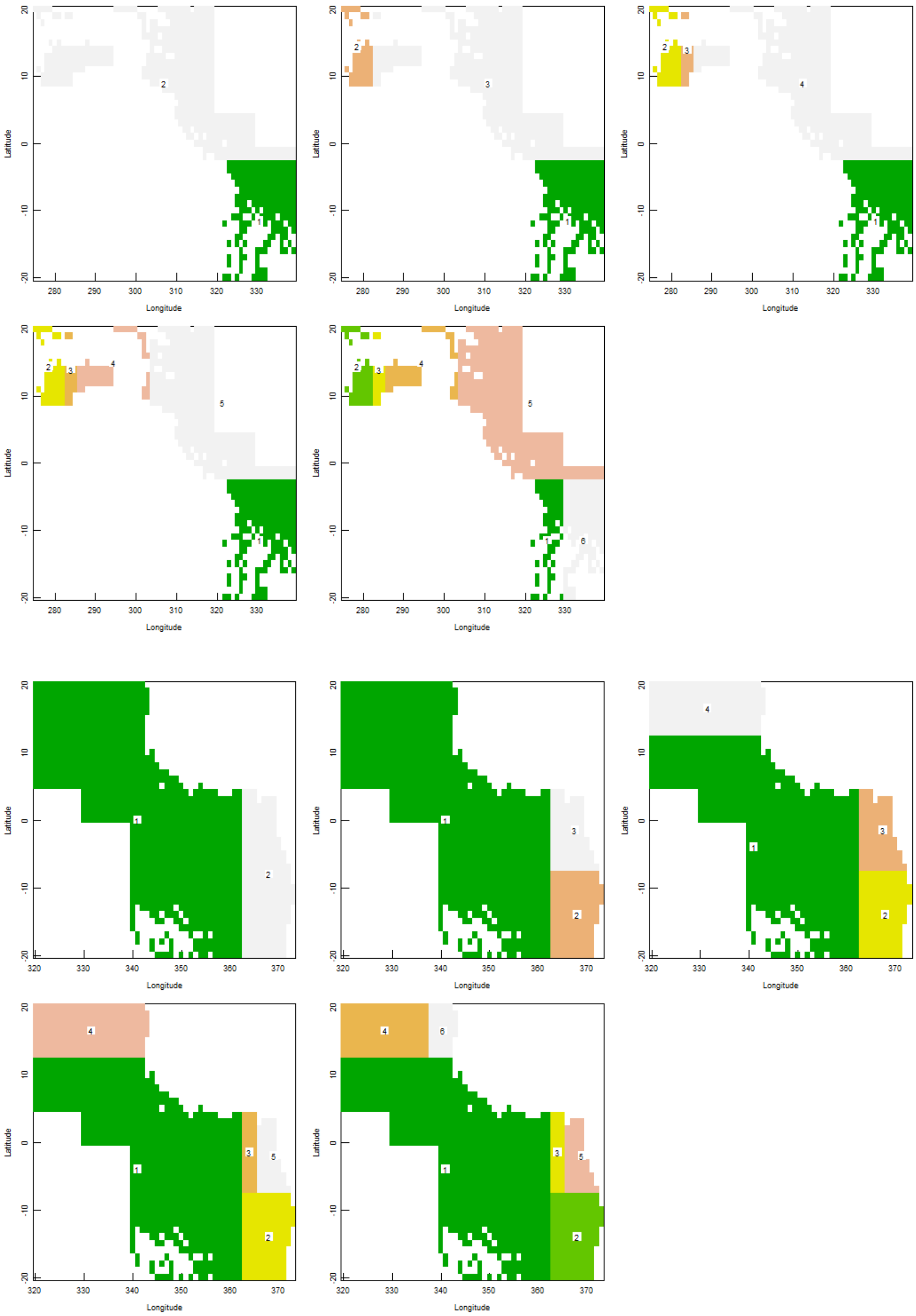


Figure A1. Area stratifications estimated from the GLM trees for western (upper figure) and eastern (lower figure) Atlantic sailfish. In consideration of the interaction terms of the GLM approach, we arbitrarily chose the small number of areas and applied the area stratification to both western and eastern stocks (See **Figure 1**).

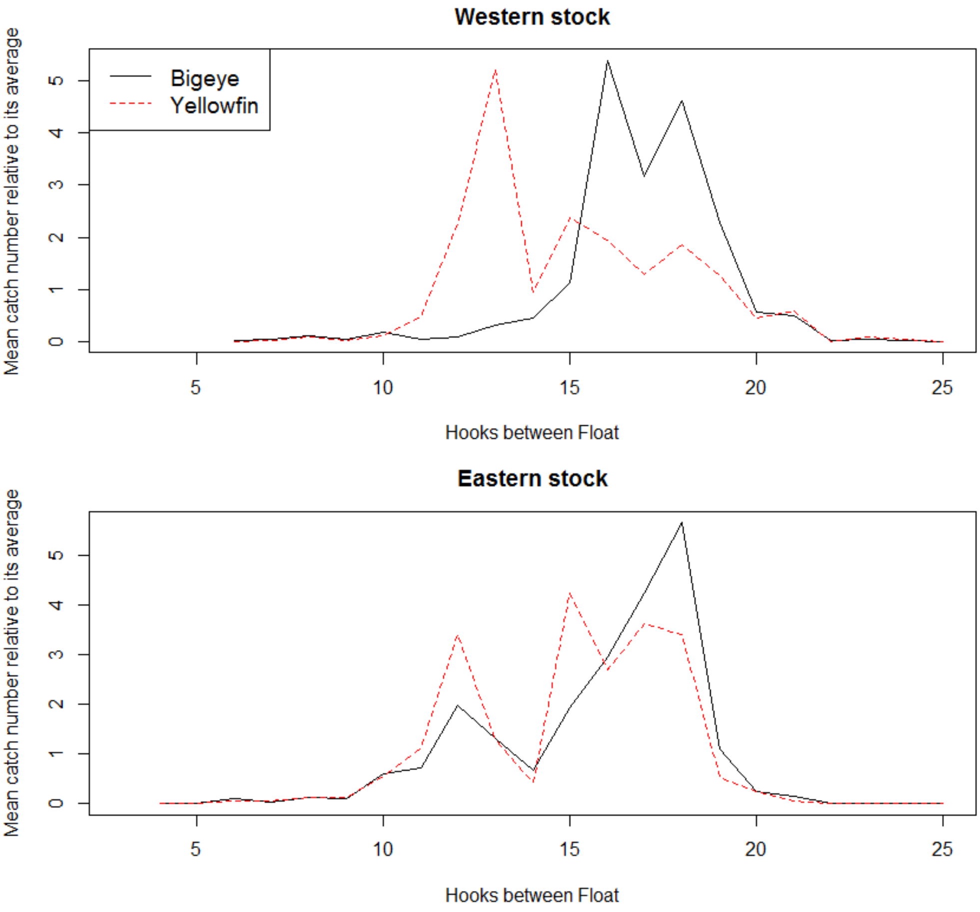


Figure A2. Mean catch number of tropical tunas (bigeye tuna and yellowfin tuna) relative to its average against hooks between float (HBF) for western and eastern stock.

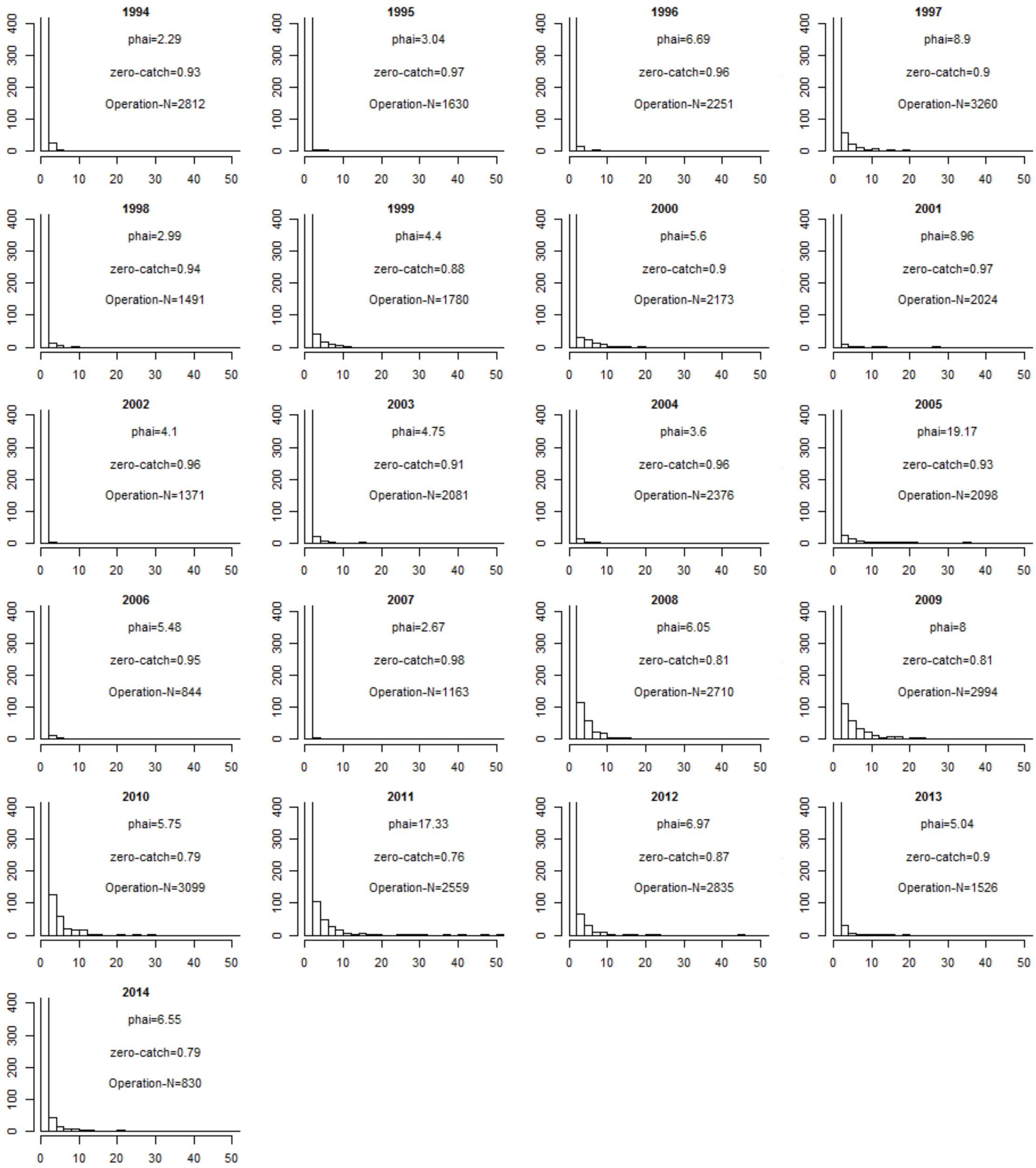


Figure A3. Frequency distribution of catch number by year for the western Atlantic sailfish stock.

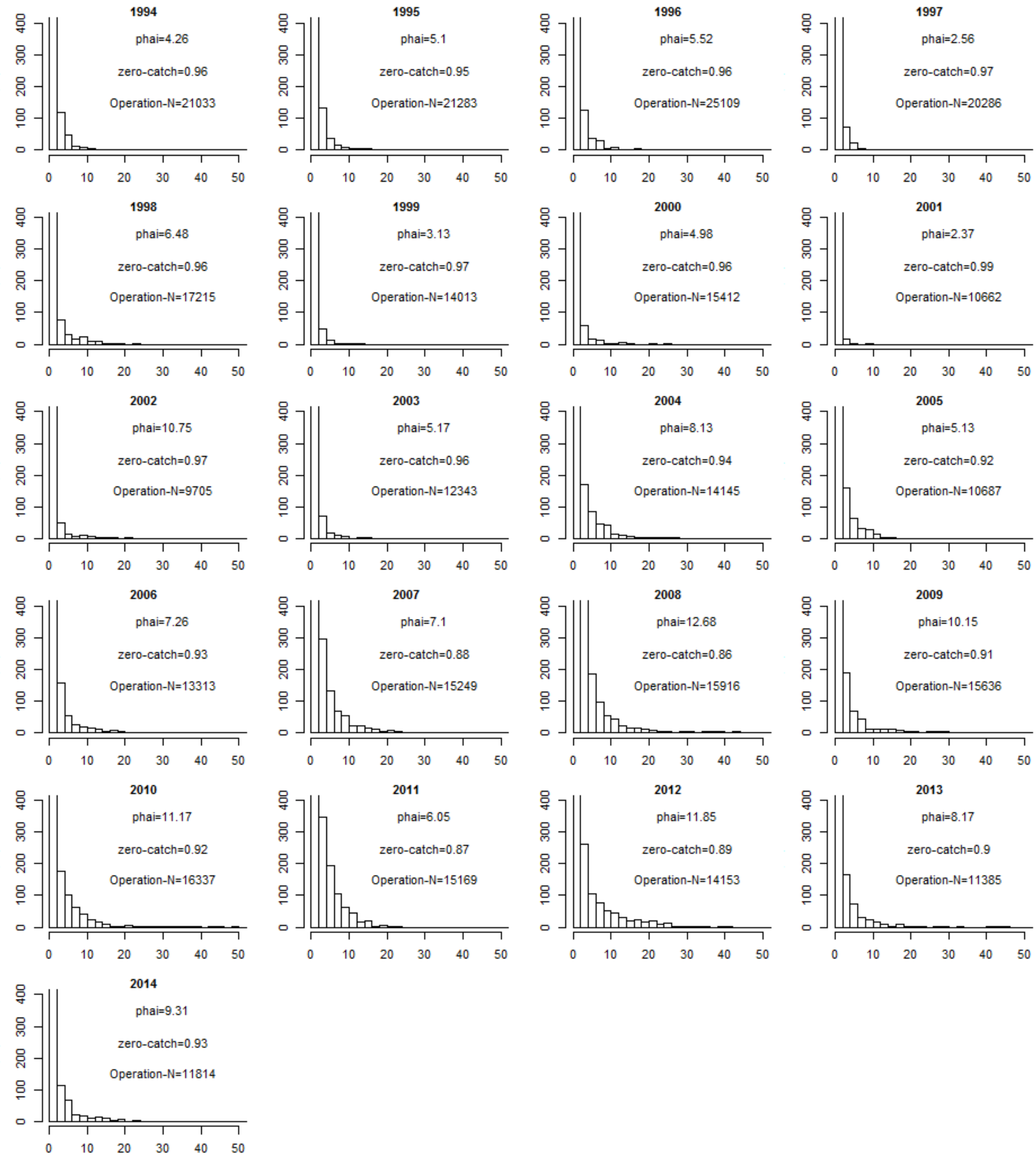


Figure A4. Frequency distribution of catch number by year for the western Atlantic sailfish stock.

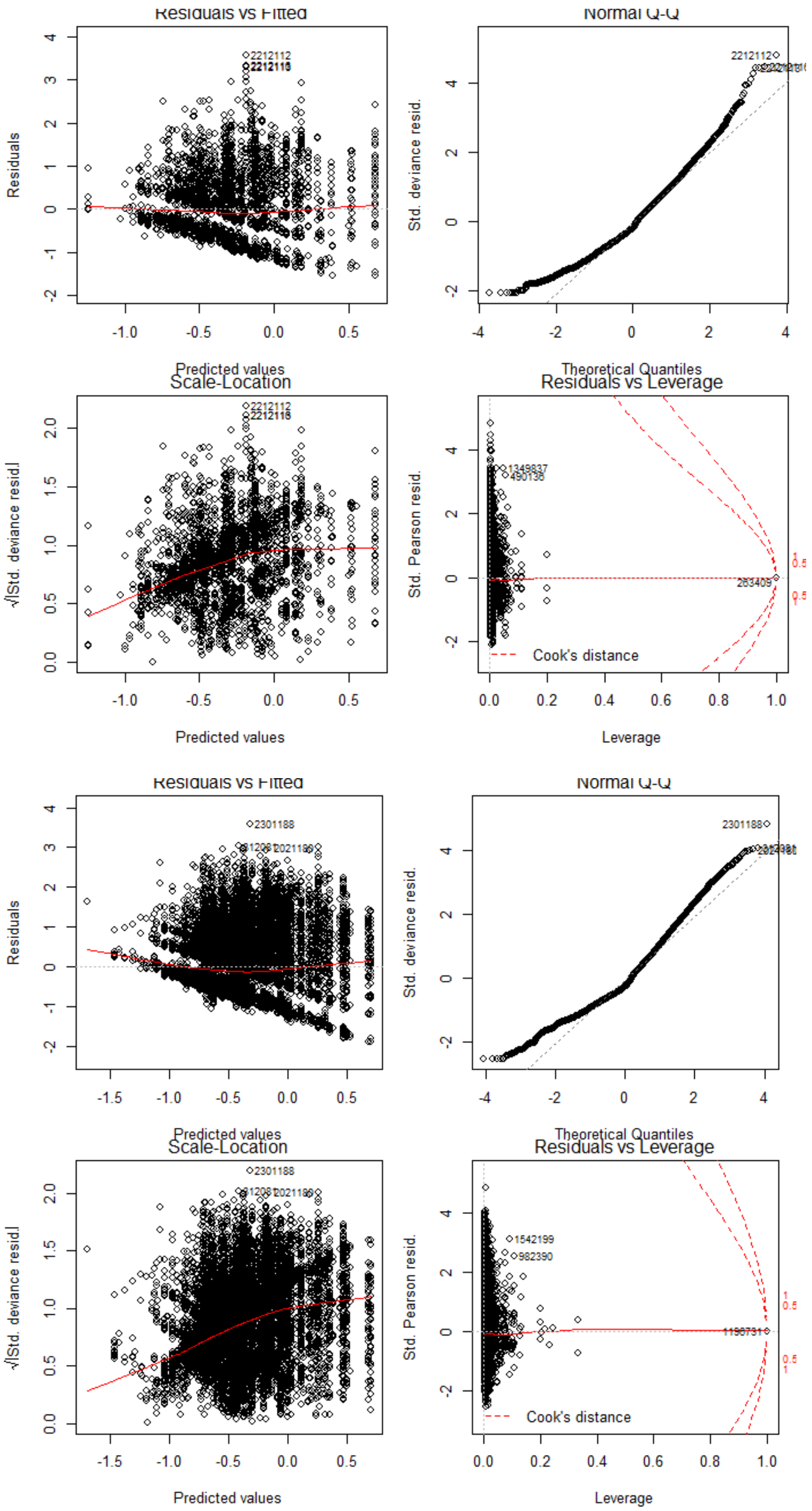


Figure A5. Diagnostics of the goodness of the fits for the lognormal model of the western (upper four figure) and eastern (lower four figures) stocks.

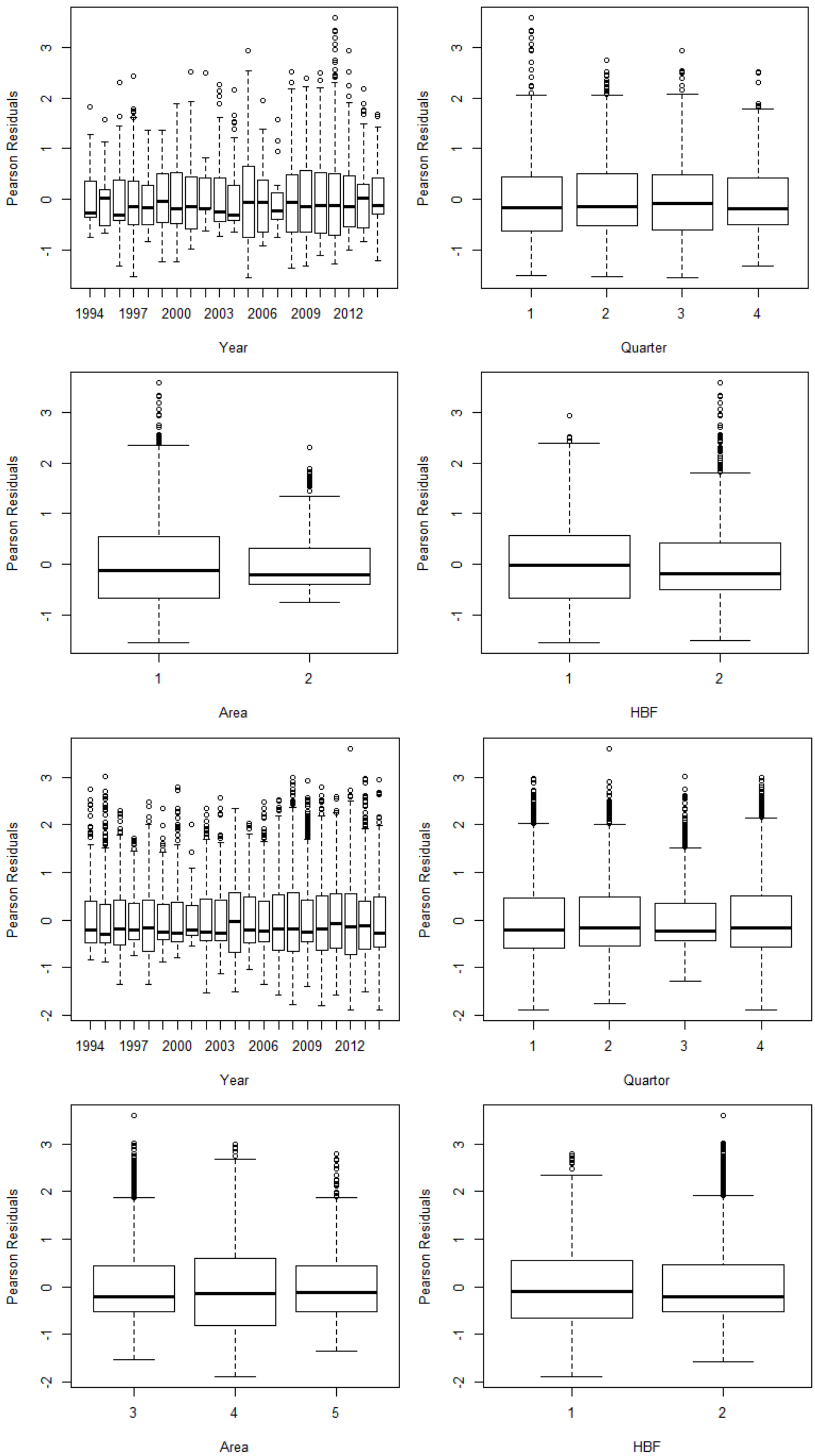


Figure A6. Pearson residuals against each main factors for the lognormal model of the western (upper four figure) and eastern (lower four figures) stocks.

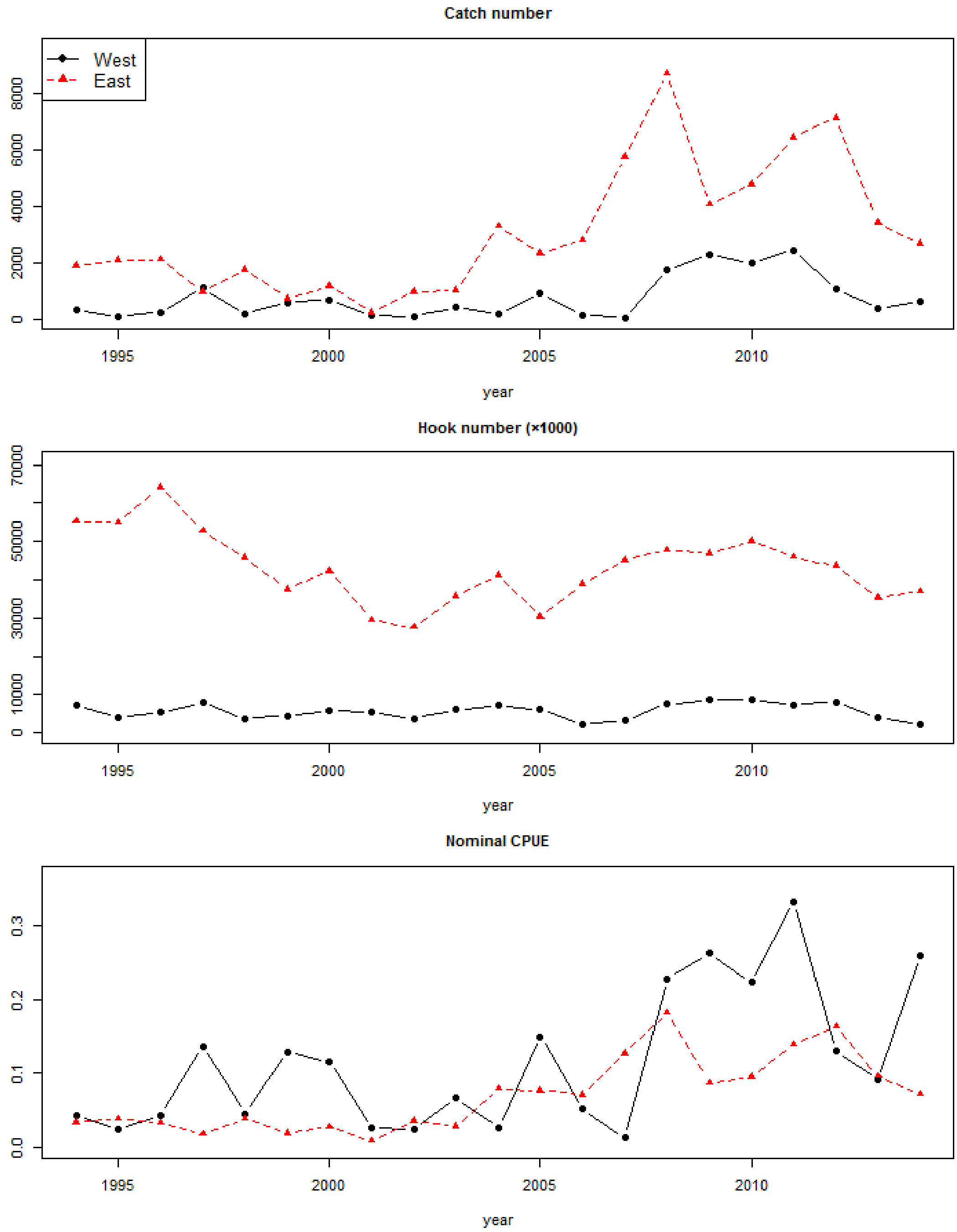


Figure A7. Annual changes of the reported catch in number of sailfish, reported number of hooks (x 1000) and nominal CPUE.

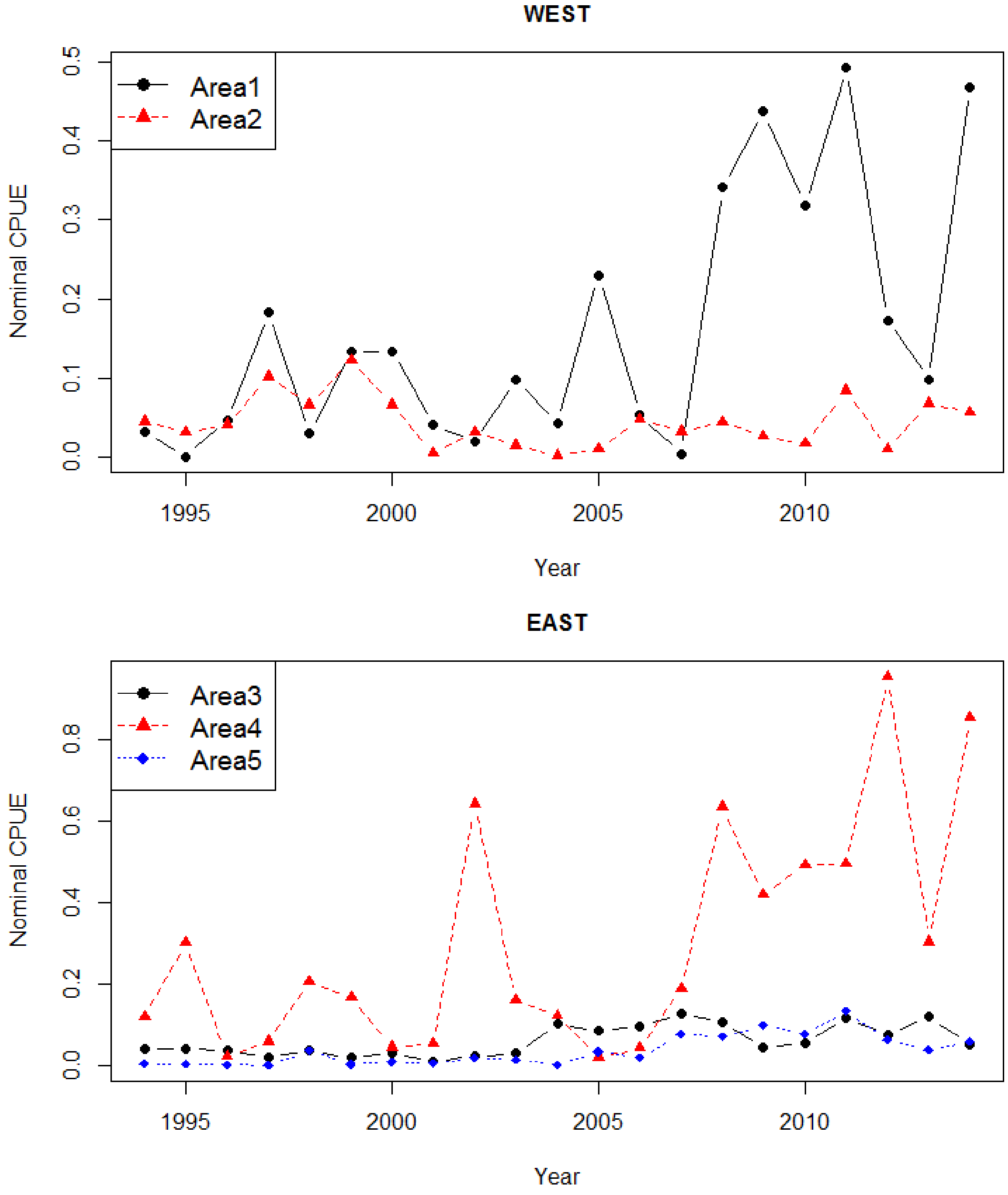


Figure A8. Annual changes of the nominal CPUE by areas.

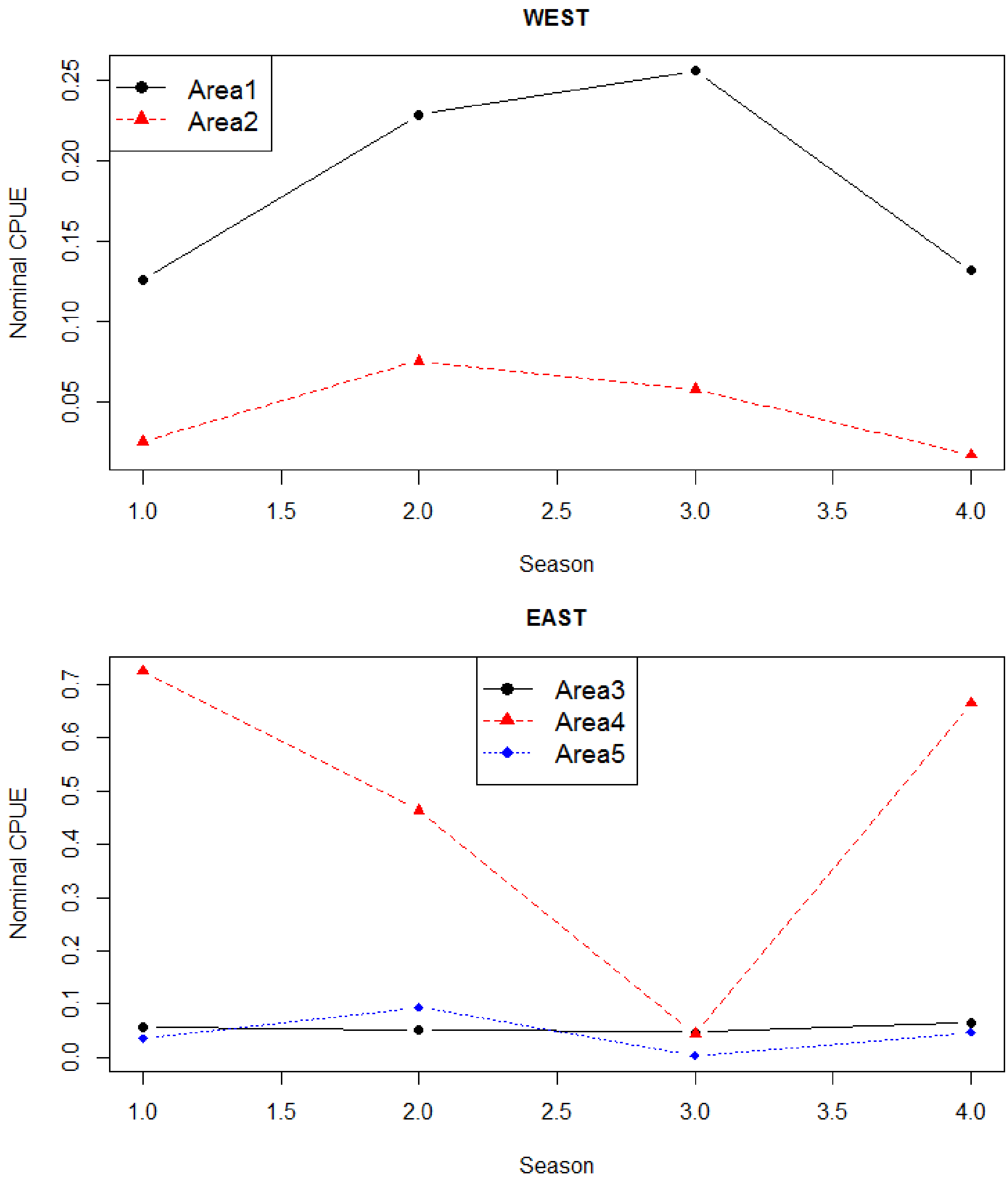
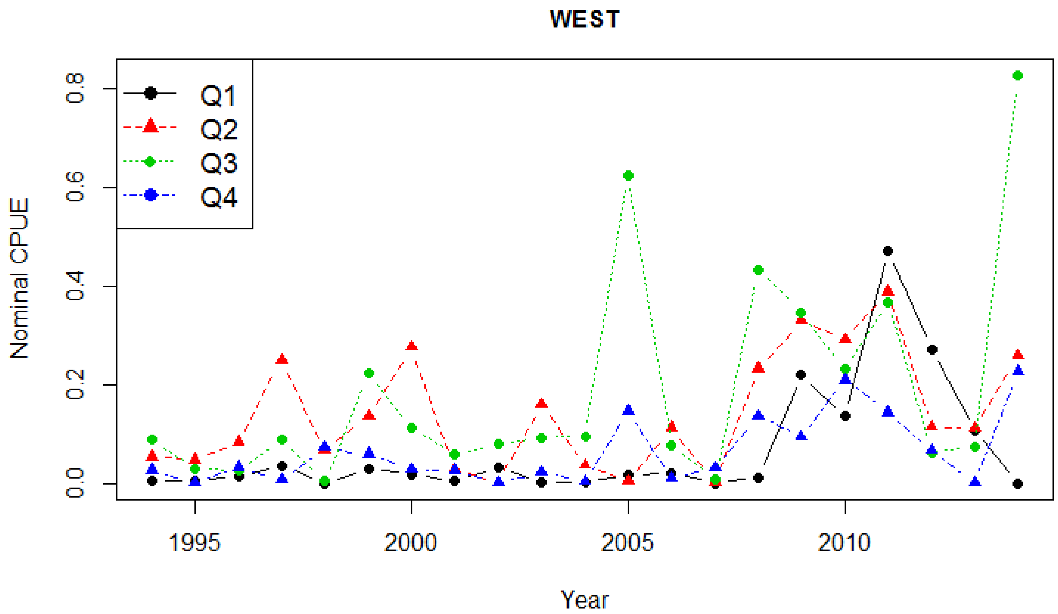


Figure A9. Seasonal changes of the nominal CPUE by areas.



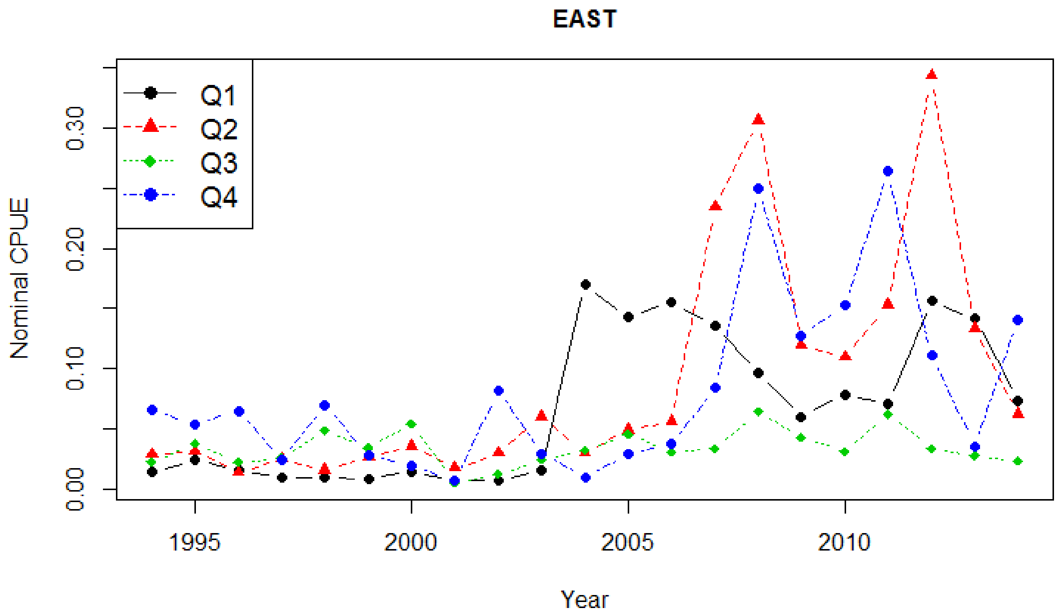


Figure A10. Annual changes of the nominal CPUE by quarter.

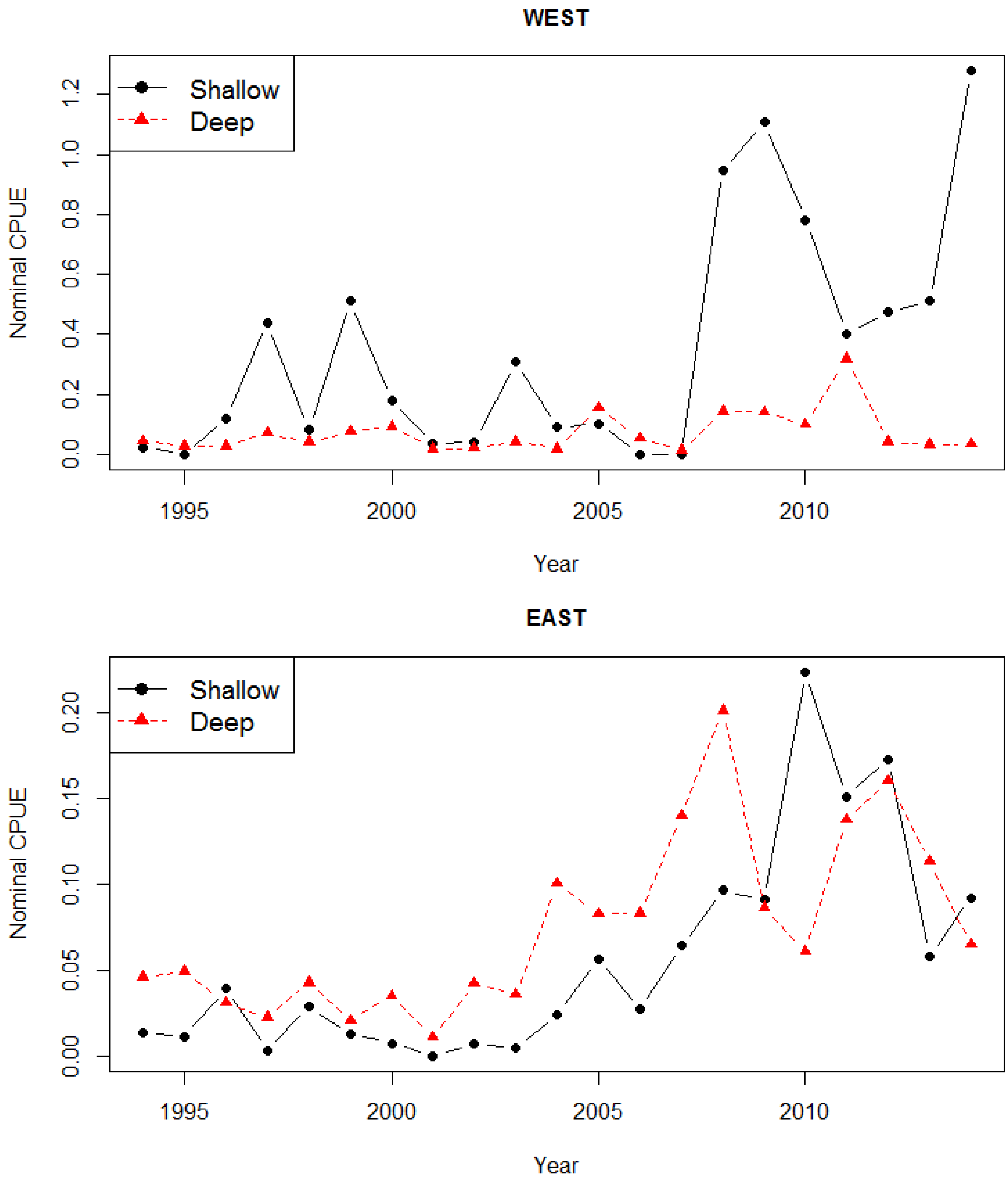


Figure A11. Annual changes of the nominal CPUE by depth. Shallow-set denotes the hbf is less than 15 and deep-set denotes the hbf is more than

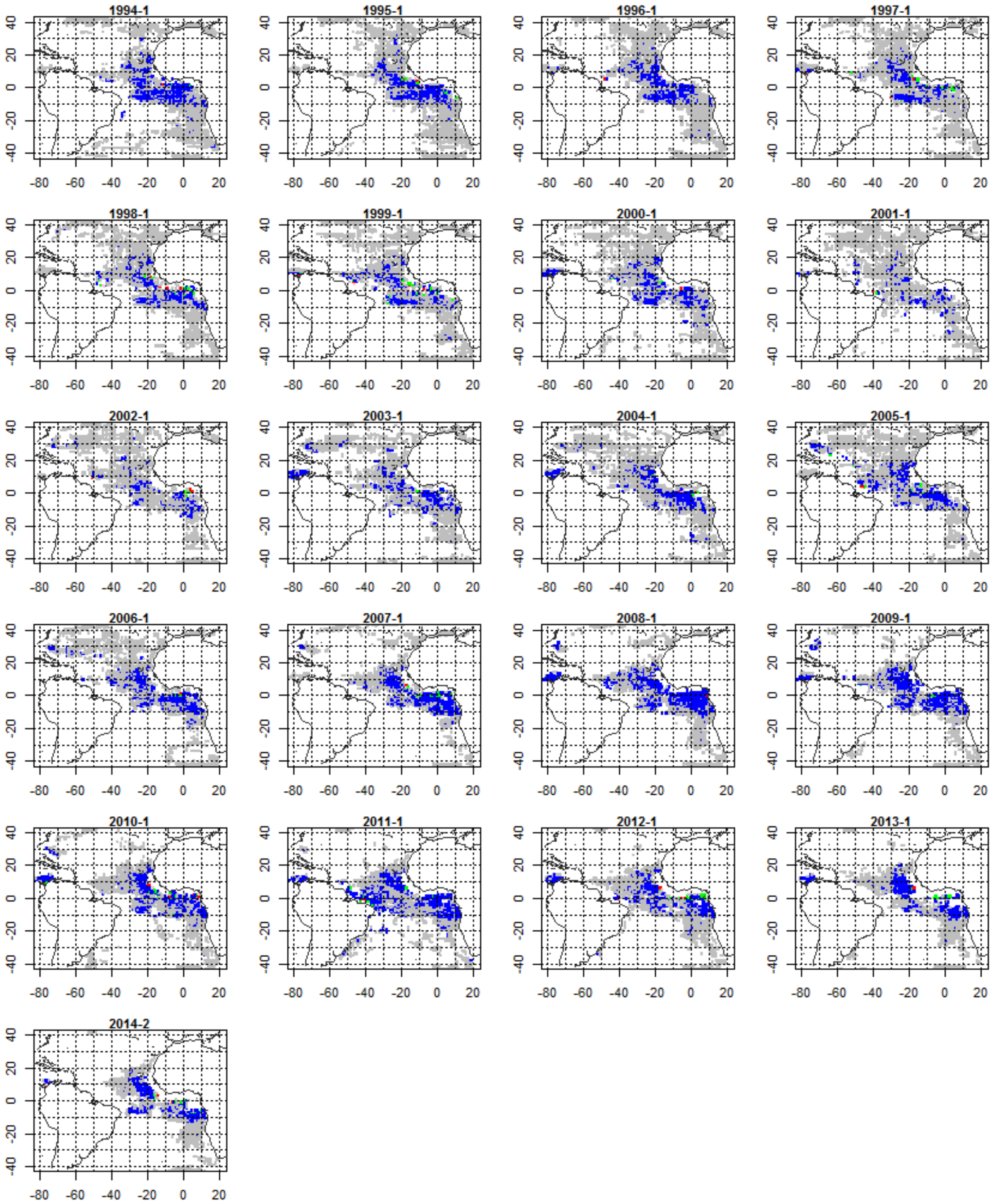


Figure A12. Spatial distribution of nominal CPUEs by years. The CPUEs are higher in the order of red, pink, green, blue and grey denotes zero.

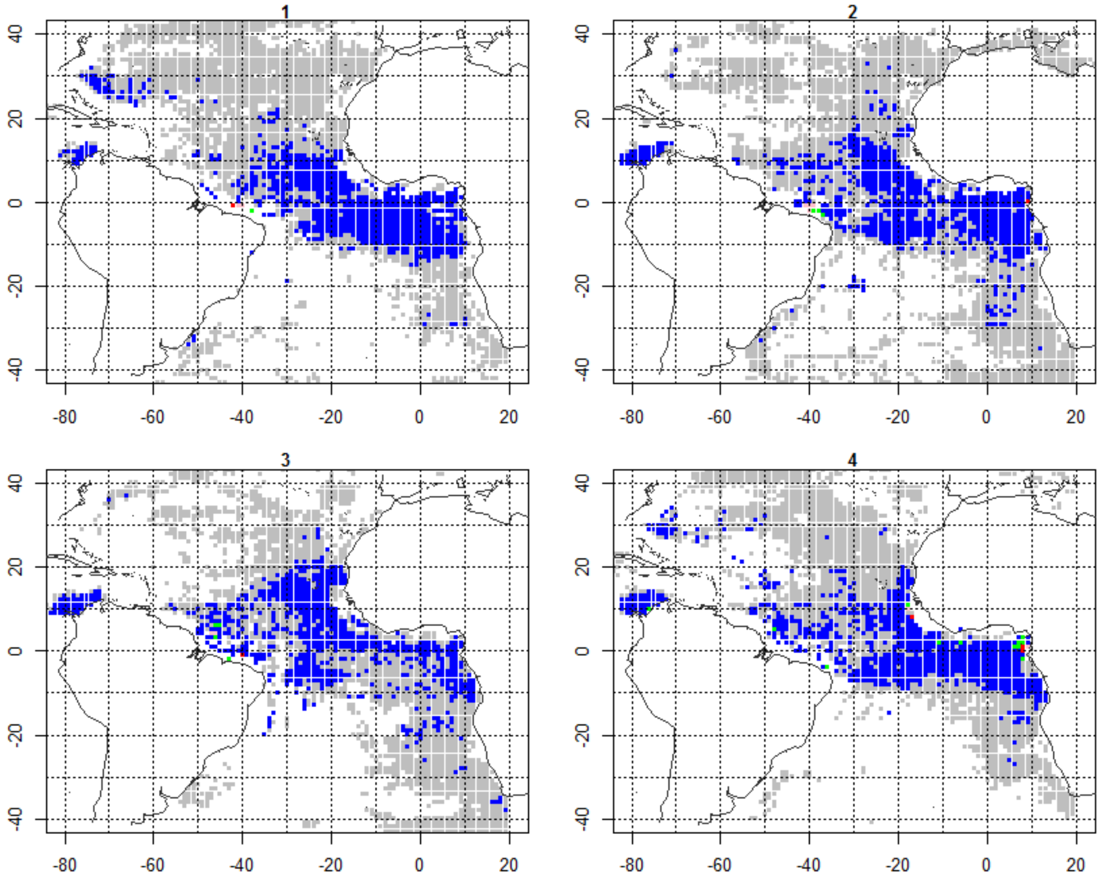


Figure A13. Spatial distribution of nominal CPUEs by quarter. The CPUE is higher in the order of red, pink, green, blue and grey denotes zero.

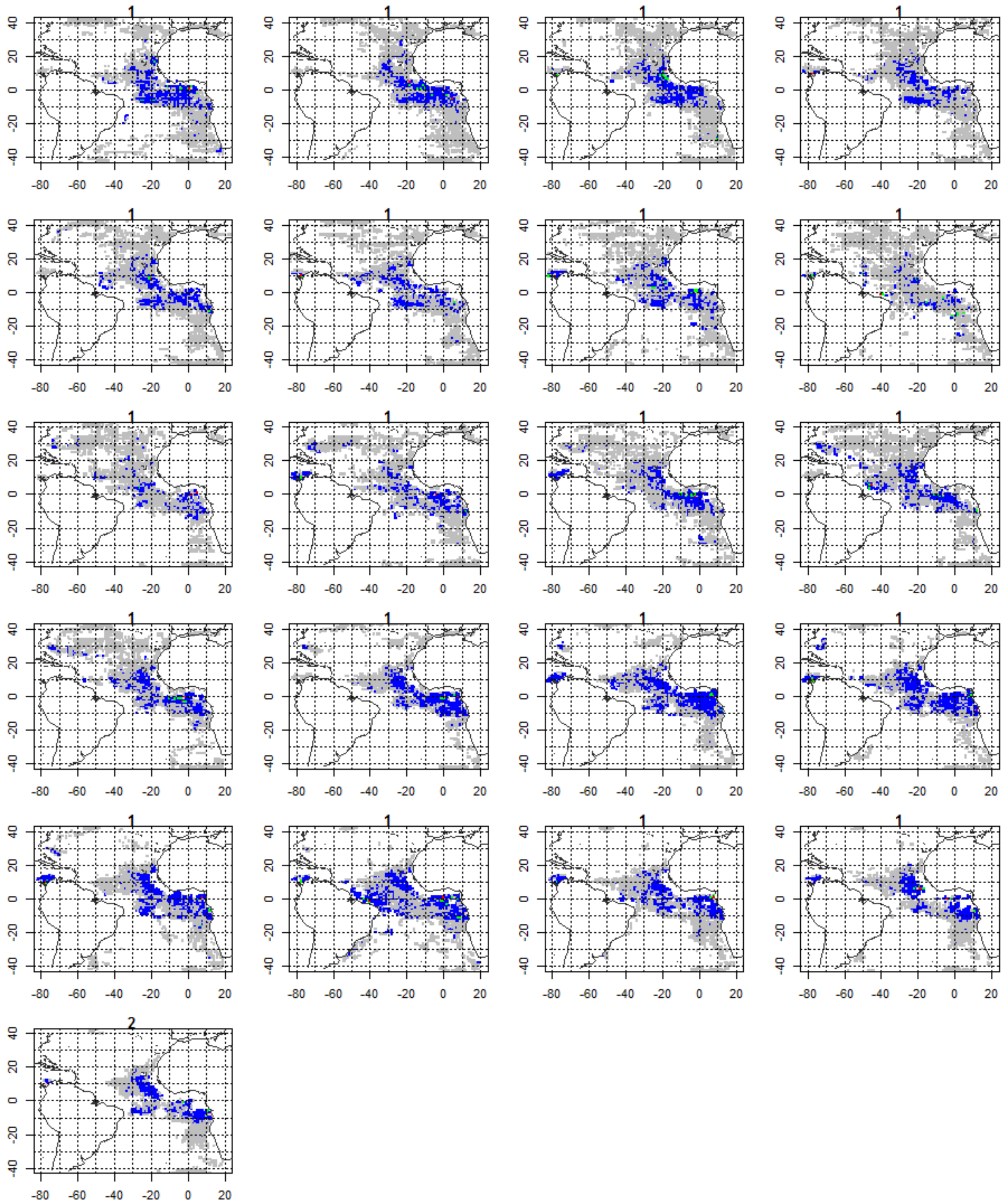


Figure A14. Spatial distribution of catch in number by years. The catch is higher in the order of red, pink, green, blue and grey denotes zero.

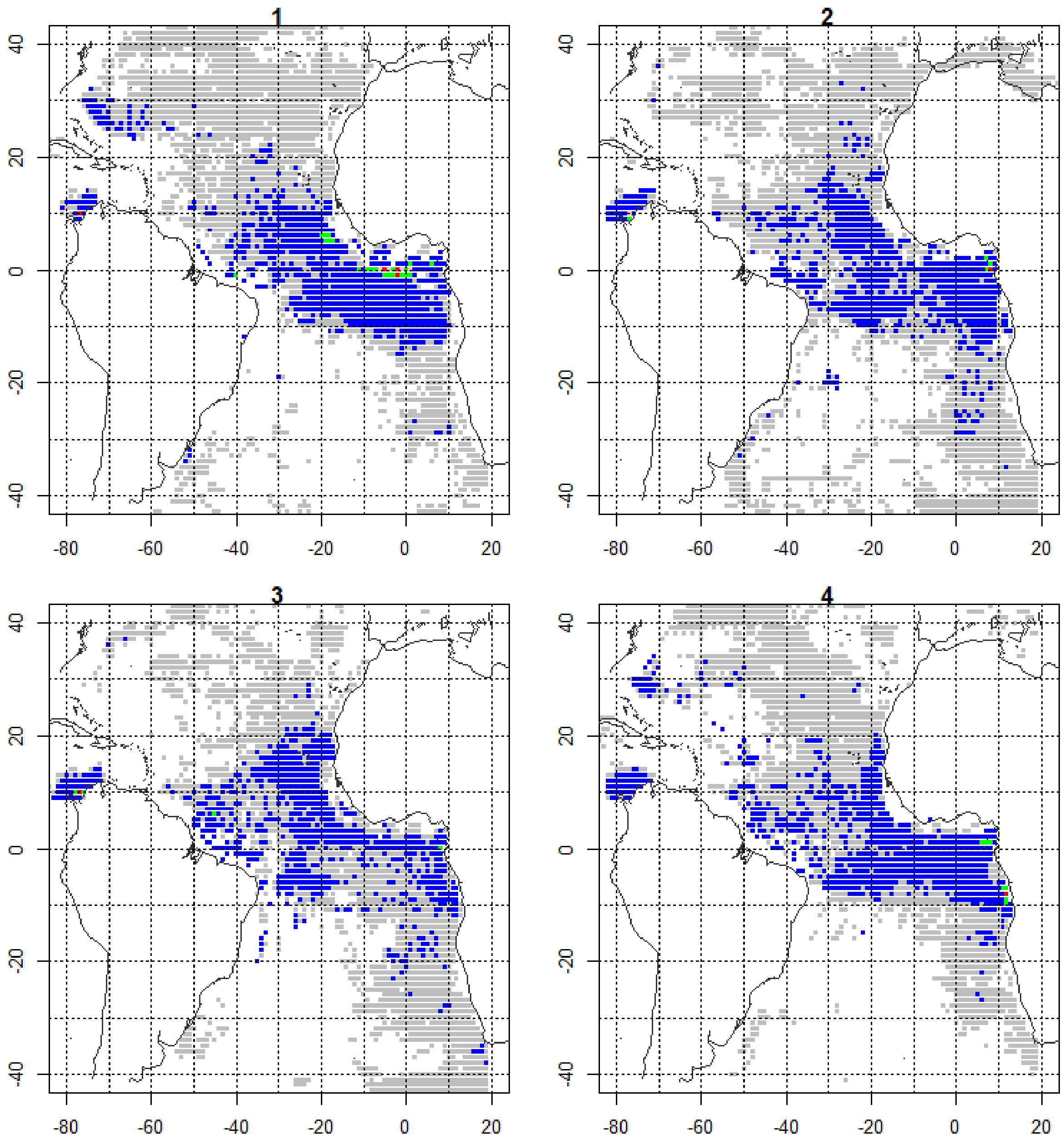


Figure A15. Spatial distribution of catch in number by quarter. The catch is higher in the order of red, pink, green, blue and grey denotes zero.

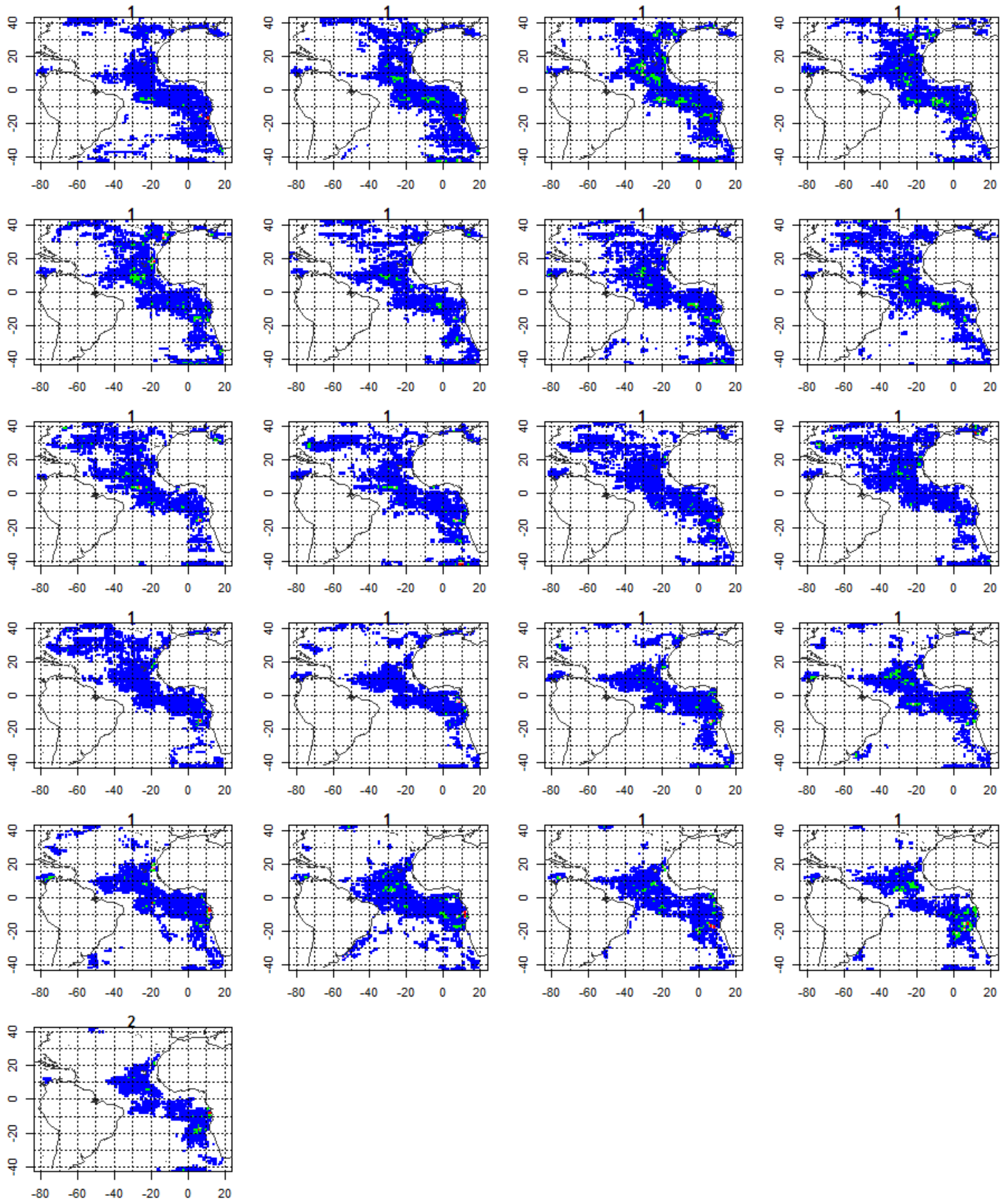


Figure A16. Spatial distribution of effort (number of hooks) by years. The effort is higher in the order of red, pink, green, blue and grey denotes zero.

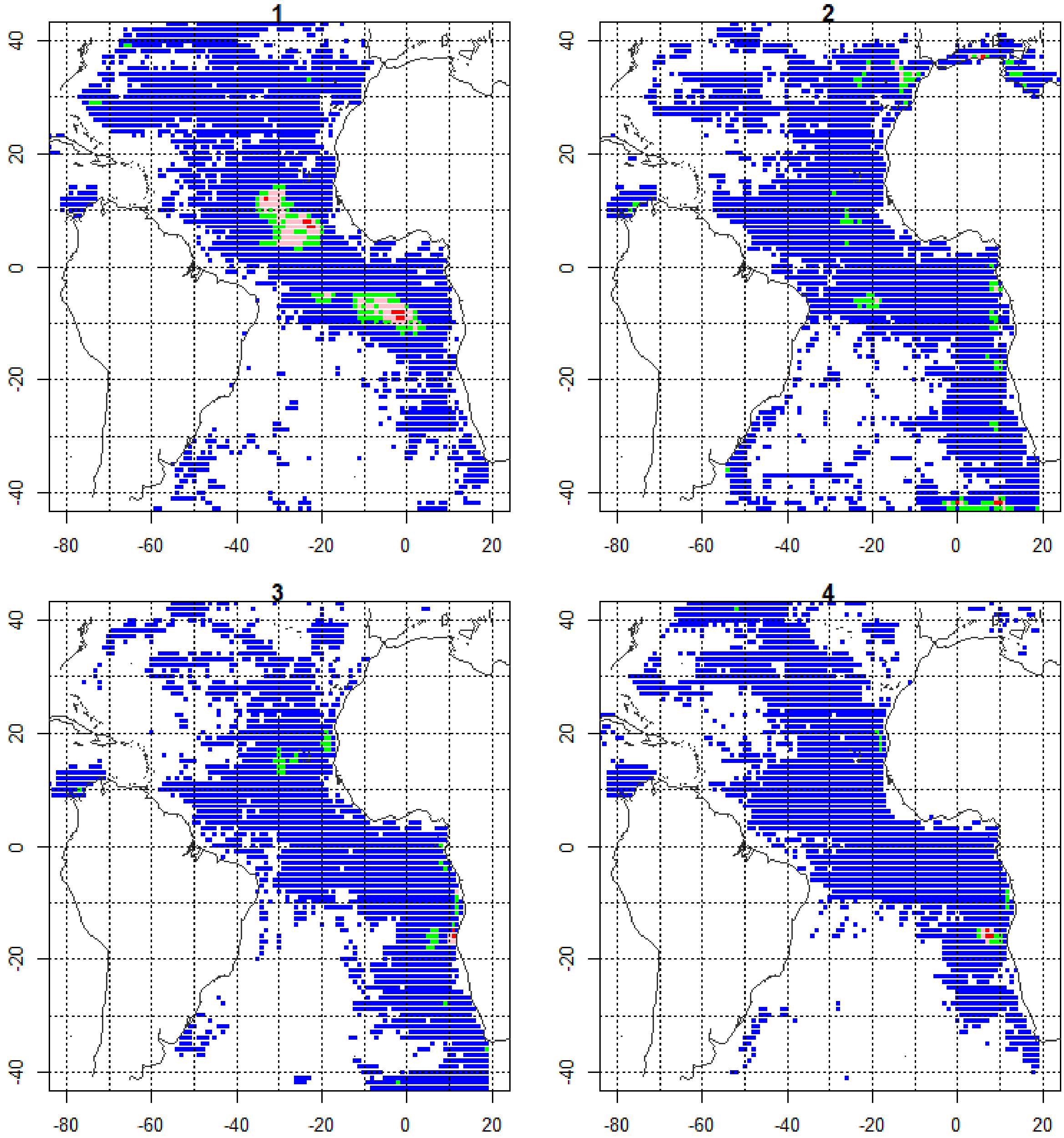


Figure A17. Spatial distribution of effort (number of hooks) by quarter. The effort is higher in the order of red, pink, green, blue and grey denotes zero.