SCRS/2016/036 Collect. Vol. Sci. Pap. ICCAT, 73(1): 290-317 (2017)

EXPLORATION OF HISTORICAL CHANGES OF TARGET SPECIES FOR JAPANESE LONGLINE IN THE ATLANTIC OCEAN APPLICATION TO STANDARDIZATION OF CPUE OF YELLOWFIN

Keisuke Satoh[1], Takayuki Matsumoto[1]

SUMMARY

Stock assessment results of yellowfin tuna in the Atlantic Ocean using ASPM was reported. The results of this assessment were different between the standardized CPUE group used in the analyses. For the Run01 using standardized CPUE index group called as cluster 1, the spawning biomass ratio (SSB/SSB0) declined to a historically low level of 0.16 at the start of 2002 and then increased with some fluctuation and reached to 0.26 at the beginning of 2014. While the spawning biomass ratio from Run_05 using the standardized CPUE index group cluster 2 came to peak of 0.62 at 1996 and then decreased to 0.26 in 2014. The fishing mortality of purse seine occupied more than 50% to total fishing mortality after 2000 in many years. The recent fishing mortality rates are estimated to be below the level corresponding to MSY, whereas recent spawning biomass are estimated to be almost same of MSY level in the Atlantic Ocean. These interpretations are uncertain and highly sensitive to the assumptions made about the steepness, sigmaR, the type of CAA and natural mortality vector.

RÉSUMÉ

Le présent document fournit les résultats de l'évaluation du stock d'albacore dans l'océan Atlantique à l'aide d'ASPM. Les résultats de cette évaluation étaient différents en fonction du groupe de CPUE standardisées qui était utilisé dans les analyses. Pour le scénario 01 utilisant le groupe d'indice de CPUE standardisée, appelé cluster 1, le ratio de biomasse du stock reproducteur (SSB/SSB0) a chuté à un niveau historiquement faible de 0,16 au début de 2002 et s'est ensuite accru avec quelques fluctuations pour atteindre 0,26 au début de 2014. Le ratio de biomasse du stock reproducteur du scénario 05 utilisant le groupe d'indice de CPUE standardisée (cluster 2) a atteint son apogée en 1996 (0,62), puis a diminué jusqu'à 0,26 en 2014. La mortalité par pêche à la senne représentait plus de 50% de la mortalité par pêche totale après 2000 pendant de nombreuses années. Les récents taux de mortalité par pêche sont estimés être inférieurs au niveau correspondant à la PME, tandis que la récente biomasse reproductrice est estimée se trouver pratiquement identique au niveau de la PME dans l'océan Atlantique. Ces interprétations sont incertaines et très sensibles aux postulats formulés sur la pente à l'origine de la relation stock-recrutement (steepness), sigmaR, le type de CAA et le vecteur de la mortalité naturelle.

RESUMEN

En este documento se presentan los resultados de la evaluación de stock de rabil utilizando ASPM. Los resultados de esta evaluación presentaron diferencias en función del grupo de CPUE estandarizadas utilizado en el análisis. Para el ensayo 1(Run 01) que utilizó el grupo de índice de CPUE estandarizado denominado conglomerado 1, la ratio de biomasa reproductora (SSB/SSB0) descendió hasta un nivel histórico mínimo de 0,16 a comienzos de 2002 y después se incrementó con algunas fluctuaciones y llegó a 0,26 a principios de 2014. Mientras que la ratio de biomasa reproductora para el ensayo 5 (Run_05) que utilizaba el grupo de índice de CPUE estandarizado denominado conglomerado 2 alcanzó un pico de 0,62 en 1996 y después descendió hasta 0,26 en 2014. La mortalidad por pesca del cerco respondió de más del 50% de la mortalidad por pesca total después de 2000 durante varios años. Se estimó que las tasas recientes de mortalidad por pesca se sitúan por debajo del nivel correspondiente a RMS, mientras que la biomasa reproductora reciente se sitúa casi al mismo nivel que el RMS en el Atlántico. Estas interpretaciones son inciertas y muy sensibles a los supuestos realizados con respecto a la inclinación, sigmaR, el tipo de CAA y el vector de mortalidad natural.

KEYWORDS
Atlantic, Yellowfin, Longline, Catch/effort, Target species, Decision tree analysis

[1] National Research Institute of Far Seas Fisheries. 5-7-1 Orido Shimizu, Shizuoka-City, Shizuoka 424-8633, Japan. kstu21-at- affrc.go.jp

1. Introduction

Standardization of catch per unit effort (cpue) is commonly applied to remove the effects of factors that bias cpue as an index of abundance of fish stock. In the previous cpue standardization analyses (Okamoto and Satoh, 2008, Satoh et al., 2012 and Matsumoto and Satoh, 2015) of yellowfin tuna in the Atlantic Ocean, the factors caused the bias are usually fishing location, fishing gear configuration and environmental factors. The catchability of a species can be also affected when a fleet changes its targeting species (Maunder et al., 2006). It is well-known that Japanese longline vessel had changed their target species from albacore to yellowfin and bigeye in the late 1960s or early 1970s in all Ocean (e.g., Suzuki et al., 1977), and the gradual increasing of catch amount of albacore caught by Japanese longline vessel in the Atlantic Ocean had been reported recently (Matsumoto 2014), which might indicate the decreasing importance of bigeye after the early 2000s. The effect of the target species had been considered in the cpue standardization for Taiwanese longline vessel using cluster analysis (Chen and Cheng 2013). The target species for each operation had been successfully detected because the fishing ground of each species is clearly different in latitude for Taiwanese longline fishery. The target species of Japanese longline fishery operated in the North Pacific Ocean was investigated using decision tree analysis (Satoh *et al*., 2013), which can detect the relationship between good albacore catch (albacore dominate set; more than 90% of catch per set in number) and the factors as fishing season, fishing location and longline gear configuration.

The decision tree analysis is the procedure to make a number of groups which have more homogeneity of response variable from the mother population using explanatory variables. In this analysis the response variable is "species name with high cpue", and the explanatory variables are year, month, latitude, longitude and number of hooks between floats. The procedure can split the mother data set into two daughter data sets according to splitting index (the Gini index), which is the difference of the Gini impurity before and after of the splitting. The division occurred at the point with minimum Gini index, which means the maximum homogeneity of response variable. The analysis produces a tree-like diagram composed of root and nodes with combination of number of decision rules (IF-THEN rules using explanatory variables), which are easy to understand visually for the classification.

The aims of this study are, in order to understand deeply the changes of target species of Japanese longline vessel in the Atlantic Ocean, 1) to investigate the relationship between higher CPUE of each species (yellowfin, bigeye and albacore) and fishing season, fishing location and the fishing gear configuration, and 2) to discuss the target effect on the CPUE standardization.

2. Materials and methods

For the first object (to investigate the relationship between higher CPUE and the fishing season, location and gear configuration)

Making data set for decision tree analysis

We select a set which may present target species according to the following ideas. The higher cpue may result from two factors. The first one is the target effect that fisherman select fishing season, fishing location and fishing gear configuration which is appropriate for their target species. The second one is the level of biomass in the fishing season and location. Separating the two effects is essential to investigate the target effect in cpue. We assumed that the biomass is constant in a stratum in a quarter and 5 x 5 degrees rectangle. According to the assumption we can regard that the cpue is only affected by the target effect.

First, we calculate the upper 25% of nominal cpue for each stratum (year, quarter, 5 x 5 degrees in latitude and longitude) of each species (yellowfin, bigeye and albacore) as the indicator of targeting, using set by set (operational) longline catch and effort data. Then, the potential target species (PTS) is assigned for each set when the cpue of the set is larger than the indicator for each species (**Appendix 3**). The "potential" indicates that the assignment of the target species is NOT based on the explicit evidence of target species, such as the data collected by the interviews of fisherman. Only the sets being assigned with PTS are applied for further decision tree analysis. In addition, to avoid variation of results the stratum less than 20 sets was excluded for further analysis, and the sets with the number of PTS were also not used.

Decision tree analysis

The data set for the decision tree analysis is composed of PTS (species names; yellowfin, bigeye and albacore) as response variable, and explanatory variables (year, month, latitude, longitude and number of hooks per basket). The analysis was implemented by rpart package of R (ver. 3.23) (R core team 2015). The number of node was determined by the criteria of the 10-fold cross validation with one SE rule, and also conditioned by the constrain that the minimum number of each node is more than 100 sets to avoid making too deep tree (**Appendix 1**).

In preliminarily analysis, the results of tree analysis using dataset of whole period (1965-2014) indicated that all longline operations with their number of hooks per basket being larger than 10 were assigned into one group regardless of differences in the other factors (**Appendix 4**). The estimated model is not appropriate to estimate the influence of historical changes of target species. Thus, the period was divided into the four sub periods, before 1974, 1975-1989, 1990-2004, and after 2005, and the decision tree model was estimated for each period. The periods are supposed to be corresponding to the period of targeting albacore and transition to other species (before 1974), the period of targeting bigeye (1975-1989), the period of transition (1990-2004), the period of increasing proportion of albacore and yellowfin (after 2005). The results of the decision tree analysis are presented as the percentage of three tuna species (yellowfin, bigeye and albacore) for each node. The node is classified by the explanatory variables (period, year, month latitude, longitude and number of hooks per basket). For example, the proportions by species in a node of 70%, 20% and 10% for yellowfin, bigeye and albacore, respectively, are implemented as the effort in this node are expected to target yellowfin, bigeye and albacore according to the proportion (70, 20 and 10%).

The second object (influence of the PTS in the CPUE standardization）

The longline fishery catch and effort data set and standardization procedures are compatible to those of SCRS/2016/035 (Japanese longline cpue for yellowfin tuna (*Thunnus albacares*) in the Atlantic Ocean standardized using GLM up to 2014).

First, the PTS for each node was assigned for each stratum (year, month, 5 x 5 degrees in latitude and longitude) using the developed tree models. Then, the cpue standardization was conducted. Next, the standardized cpues with and without PTS were compared.

Results and discussion

Historical changes of effort and catch composition

The historical highest effort of Japanese longline vessel in the Atlantic Ocean is recorded in 1996 (**Figure 1**) and then the number of hooks have decreased with some fluctuations. The species composition of catch indicated that the ratio of bigeye decreased since around 2005 in all sub area (**Figure 2**). The geographical distribution of dominant species, which was defined as the species with highest catch number in a stratum (quarter and 1 x 1 degree) for each period (1991-2000 and 2005-2014), indicated large differences of the dominant species in a stratum between the two periods (**Figure 3**). In coastal area of west side of African continent yellowfin dominated in the later period instead of bigeye in the earlier period. After around 2005 yellowfin have become more important for Japanese longline fishery. These results suggest that the target species of Japanese longline fishery in the Atlantic Ocean had probably changed and it is important to classify the target species of the longline operation in the process of cpue standardization especially after around 2005.

Dataset for the decision tree analysis

The PTS was estimated for 27% (21.0-34.5%) of effort in average from 1965 to 2014 of total annual amount of number of hooks (**Table 1**). The percentage of the number of hooks in a stratum with multiple PTS (yellowfin + bigeye, yellowfin + albacore, bigeye + albacore and all three species) to total number of hooks was 5.2% (3.0-9.2%) in average from 1965 to 2014. The quite low percentage of the multiple PTS shows that high cpue occurred simultaneously in a low probability. Thus the criteria of the upper 25% cpue is appropriate for detecting potential target species. The number of yellowfin caught in the strata of the yellowfin PTS to total number of annual catch number of yellowfin was 45.5% (37.8-52.2%) in average from 1965 to 2014 (**Table 2**). The percentage was higher than that of effort (27%) because of the higher cpue.

Decision tree analysis

The four tree diagrams for each period showed that the location (latitude and longitude) played vital role for the classification, and then month and the number of hooks per basket. The "year" factor did not work in the models (**Figure 4**). The results of the classification are presented as the percentage of each species, thus the percentage of yellowfin was considered as the explanatory variables of the further cpue standardization process. Some example of geographical distributions of PTS (percentage of yellowfin, bigeye and albacore) showed in **Figure 5**.

The influence of the PTS in the CPUE standardization

The final models with the PTS as explanatory variables (model PTS) and without PTS (model without PTS, described in SCRS/2016/035) were identical except for the PTS (percentage of yellowfin) in the model PTS. The F value of the PTS was quite large, which suggested the PTS was most influential factor. (**Table 3**). Comparison of the trend of the two standardized cpues showed that the lower standardized cpue of the model PTS was observed from 1971 to 1979, and 2005 to 2014 (**Figure 6**). If the species is targeted, fisherman should select suitable fishing season, fishing location and gear configuration for the species, therefore the apparent cpue is assumed to increase even if the abundance is constant. The two periods coincided with the periods with higher species composition in **Figure 2.** In the earlier period, the target species had changed from albacore to yellowfin and bigeye, and in the later period yellowfin and albacore have become important. Therefore, the PTS variable (effect of target species) seemed to work well in the cpue standardization process. The statistical significance among periods (**Appendix Figure 3** in SCRS/2016/035) was observed in the Model PTS (**Figure 7;** Number; $F_{(3, 46)} = 26.26$, $P< 0.001$), however the indices between the period 1992-2005 and after 2006 was not significantly different (post hoc HSD test, $P < 0.6973$), so the relatively high index after 2005 in the model without PTS is probably overestimate one.

References

Chiee-Young Chen, Fei-Chi Cheng. 2013. Development of Taiwanese albacore-targeting longline fisheries in the North Pacific Ocean, 1995-2010 ISC/13/ALBWG/16.

Okamoto, H. and K. Satoh. 2008. Japanese longline CPUE for yellowfin tuna (*Thunnus albacares*) in the Atlantic Ocean standardized using GLM up to 2006. SCRS/2008/108; Collect. Vol. Sci. Pap. ICCAT, 64(3): 960-976

R Core Team (2015). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Matsumoto, T. 2014. Review of the Japanese longline fishery and its albacore catch in the Atlantic Ocean SCRS/2013/062; Collect. Vol. Sci. Pap. ICCAT, 70(3): 1139-1153.

Matsumoto, T., and K. Satoh. 2015. Japanese longline CPUE for yellowfin tuna (*Thunnus albacares*) in the Atlantic Ocean standardized using GLM up to 2013. SCRS/2014/081; Collect. Vol. Sci. Pap. ICCAT, 71(1): 275-287.

Maunder, M. N., Sibert, J. R. Fonteneau, A., Hampton, J., Kleiber, P., and Harley, S. J. 2006. Interpreting catch per unit effort data to assess the status of individual stocks and communities. ICES Journal of Marine Science, 63: 1373-1385.

Satoh, K., H. Okamoto, and H. Ijima. 2012. Japanese longline CPUE for yellowfin tuna (*Thunnus albacares*) in the Atlantic Ocean using GLM up to 2010. SCRS/2011/128; Collect. Vol. Sci. Pap. ICCAT, 68(2): 818-834.

Satoh, K., H. Kiyofuji, H. Ijima, and H. Okamoto. 2013. Proposed Japanese fishery definition for albacore stock assessment in the North Pacific Ocean. ISC/13/ALBWG-03/05.

Suzuki, Z., Warashina, Y., and Kishida, M. 1977. The comparison of catches by regular and deep tuna longline gears in the western and central equatorial Pacific. Bulletin of the Far Seas Fisheries Research Laboratory, 15: 51-89.

Myers, R. A., and Worm, B. 2003. Rapid worldwide depletion of predatory fish communities. Nature, 423: 280-283.

Table 1. **Effort.** Annual number of hooks (x1000) and its percentage with PTS (potential target species), without PTS and multiple PTS to total number of with for the decision tree analysis.

	with PTS			without PTS (not specified)	multiple PTS					total	percentage		
	YFT	BET	ALB		total	ALB+YFT	ALB+BET+YFT	ALB+BET	BET+YFT		with PTS	without PTS	multiple PTS
1965	8,238	9,660	7,901	44,324	7,139	1,974	717	2,237	2,211	77,263	33.4%	57.4%	9.2%
1966	3,724	4,679	4,884	23,226	3,212	765	257	1,266	924	39,725	33.4%	58.5%	8.1%
1967	3,330	3,856	3,224	17,214	2,516	879	207	814	616	30,139	34.5%	57.1%	8.3%
1968	1,931	2,706	2,156	14,022	1,744	433	144	630	538	22,559	30.1%	62.2%	7.7%
1969	2,187	2,299	1,621	12,328	1,658	518	133	590	418	20,092	30.4%	61.4%	8.3%
1970	2,158	2,954	3,297	18,510	1,413	325	107	622	359	28,332	29.7%	65.3%	5.0%
1971	3,310	6,284	4,062	28,065	2,891	787	167	1,311	625	44,612	30.6%	62.9%	6.5%
1972	1,894	4,094	2,471	20,654	1,550	241	75	718	516	30,662	27.6%	67.4%	5.1%
1973	1,447	3,577	1,555	15,614	1,245	186	69	712	278	23,438	28.1%	66.6%	5.3%
1974	898	3,985	2,950	19,658	1,288	141	27	986	135	28,778	27.2%	68.3%	4.5%
1975	2,481	6,509	2,490	30,684	1,700	90	24	1,195	390	43,864	26.2%	70.0%	3.9%
1976	1,861	3,251	1,998	21,087	1,433	190	40	979	224	29,630	24.0%	71.2%	4.8%
1977	765	2,677	1,075	16,188	758	70	26	523	139	21,463	21.0%	75.4%	3.5%
1978	1,179	3,355	1,132	16,096	880	112	19	520	229	22,642	25.0%	71.1%	3.9%
1979	1,864	5,142	2,057	23,025	1,608	152	57	922	478	33,696	26.9%	68.3%	4.8%
1980	2,877	8,891	2,589	33,296	2,087	256	82	1,131	618	49,739	28.9%	66.9%	4.2%
1981	4,116	9,350	4,289	38,595	3,355	494	236	1,507	1,117	59,705	29.7%	64.6%	5.6%
1982	5,709	11,384	2,811	44,787	3,967	493	224	1,327	1,923	68,658	29.0%	65.2%	5.8%
1983	2,233	6,575	1,903	28,398	1,693	174	85	657	777	40,802	26.3%	69.6%	4.1%
1984	3,889	8,398	1,859	37,397	2,712	246	117	805	1,544	54,254	26.1%	68.9%	5.0%
1985	4,660	9,775	2,438	40,782	3,743	538	229	1,198	1,778	61,398	27.5%	66.4%	6.1%
1986	3,258	7,278	2,209	32,058	2,815	518	244	901	1,152	47,617	26.8%	67.3%	5.9%
1987	3,054	5,421	1,741	25,087	2,547	366	278	711	1,192	37,849	27.0%	66.3%	6.7%
1988	5,040	9,123	1,827	39,443	4,077	523	449	857	2,248	59,509	26.9%	66.3%	6.9%
1989	7,087	12,754	2,980	50,065	5,706	961	552	1,455	2,738	78,593	29.0%	63.7%	7.3%
1990	7,530	13,624	3,358	53,319	5,630	903	474	1,258	2,996	83,460	29.4%	63.9%	6.7%
1991	5,757	12,238	3,763	53,607	4,980	938	481	1,259	2,302	80,345	27.1%	66.7%	6.2%
1992	4,490	11,970	2,799	54,416	3,691	517	255	981	1,938	77,365	24.9%	70.3%	4.8%
1993	6,603	14,719	2,704	60,376	4,853	496	361	1,095	2,901	89,256	26.9%	67.6%	5.4%
1994	6,752	14,549	2,447	58,758	4,529	575	322	1,162	2,470	87,035	27.3%	67.5%	5.2%
1995	6,753	14,297	1,514	62,789	3,520	350	128	590	2,452	88,874	25.4%	70.7%	4.0%
1996	7,739	16,589	2,044	74,299	4,346	396	191	1,013	2,746	105,017	25.1%	70.7%	4.1%
1997	5,668	14,975	1,669	68,708	3,259	394	153	586	2,126	94,280	23.7%	72.9%	3.5%
1998	5,481	13,691	1,524	63,482	2,602	295	103	546	1,658	86,780	23.8%	73.2%	3.0%
1999	4,569	10,570	2,106	55,488	2,595	287	138	768	1,402	75,328	22.9%	73.7%	3.4%
2000	4,741	11,683	2,480	57,203	2,851	393	194	630	1,635	78,958	23.9%	72.4%	3.6%
2001	3,115	9,521	2,415	48,112	2,178	296	121	752	1,008	65,341	23.0%	73.6%	3.3%
2002	2,870	7,912	2,052	43,382	1,781	172	41	541	1,027	57,996	22.1%	74.8%	3.1%
2003	3,937	10,016	2,239	56,787	2,876	487	240	627	1,523	75,855	21.3%	74.9%	3.8%
2004	5,824	11,159	3,395	59,126	3,180	425	113	701	1,942	82,684	24.6%	71.5%	3.8%
2005	3,994	9,230	3,881	53,088	2,445	501	95	694	1,154	72,637	23.5%	73.1%	3.4%
2006	4,522	8,948	2,693	45,012	2,649	368	208	429	1,643	63,823	25.3%	70.5%	4.2%
2007	5,080	9,221	963	43,302	1,934	219	88	218	1,409	60,499	25.2%	71.6%	3.2%
2008	6,005	10,786	1,938	51,538	2,671	355	95	507	1,715	72,938	25.7%	70.7%	3.7%
2009	5,539	10,736	1,574	44,186	2,358	328	127	714	1,189	64,393	27.7%	68.6%	3.7%
2010	5,271	10,749	1,558	44,482	3,280	375	195	1,256	1,454	65,340	26.9%	68.1%	5.0%
2011	5,249	9,408	1,840	39,530	3,143	494	247	844	1,558	59,171	27.9%	66.8%	5.3%
2012	5,065	9,390	2,545	37,777	3,944	828	338	1,138	1,640	58,720	28.9%	64.3%	6.7%
2013	4,324	7,536	2,903	29,070	3,831	873	292	1,083	1,583	47,664	31.0%	61.0%	8.0%
2014	3,752	7,556	1,977	27,563	2,821	603	238	797	1,184	43,670	30.4%	63.1%	6.5%
										average (1965-2014)	27.0%	67.8%	5.2%

Table 2. **Catch**. Annual number of **yellowfin** (x1000) and its percentage with PTS (potential target species), without PTS and multiple PTS to total number of with for the decision tree analysis.

	with PTS YFT	with PTS BET	with PTS ALB	without PTS	multiple PTS total	multiple PTS ALB+YFT	multiple PTS ALB+BET+YFT	multiple PTS ALB+BET	multiple PTS BET+YFT	total	percentage with PTS	percentage without PTS	percentage multiple PTS
1965	203	70	36	277	120	40	16	13	52	707	43.8%	39.2%	17.0%
1966	84	25	15	123	49	15	7	7	20	296	42.0%	41.5%	16.5%
1967	102	33	19	140	56	24	7	6	20	350	43.9%	40.0%	16.1%
1968	54	19	9	104	30	9	3	3	14	216	37.8%	48.2%	14.0%
1969	48	16	10	80	28	13	2	3	10	182	40.5%	44.2%	15.3%
1970	51	9	4	82	14	5	2	1	6	160	40.0%	51.4%	8.5%
1971	74	10	9	101	33	19	3	2	9	227	41.1%	44.4%	14.5%
1972	35	6	4	56	13	6	1	1	5	114	39.4%	49.0%	11.6%
1973	29	4	2	36	8	3	1	1	4	80	45.1%	44.4%	10.4%
1974	23	4	3	37	8	4	1	1	3	75	40.2%	49.0%	10.9%
1975	37	5	1	42	5	1	0	0	3	91	48.5%	45.7%	5.8%
1976	39	4	3	46	11	4	1	1	5	104	45.0%	44.6%	10.3%
1977	14	2	1	21	3	1	0	0	1	41	39.6%	52.5%	7.9%
1978	20	3	1	21	8	4	0	1	3	54	45.7%	39.5%	14.8%
1979	22	5	2	22	11	3	1	1	6	63	47.5%	35.1%	17.4%
1980	28	7	2	24	9	3	1	1	5	69	52.2%	35.4%	12.4%
1981	42	8	3	34	16	5	1	1	8	103	51.1%	33.0%	15.9%
1982	41	13	3	45	19	4	2	1	12	122	47.0%	37.1%	15.8%
1983	15	5	1	20	7	1	0	0	4	48	43.9%	42.5%	13.6%
1984	25	8	1	33	15	2	1	1	11	82	41.6%	40.6%	17.8%
1985	39	10	2	45	20	4	1	1	14	116	44.1%	38.8%	17.1%
1986	26	7	2	32	13	4	2	1	6	80	44.4%	39.8%	15.7%
1987	26	7	2	30	17	4	3	1	9	82	42.6%	36.5%	20.9%
1988	45	13	3	48	31	5	5	2	18	140	43.5%	34.6%	21.9%
1989	64	17	5	56	37	9	5	3	19	177	47.9%	31.4%	20.7%
1990	46	14	3	49	26	6	3	2	16	138	45.9%	35.2%	18.9%
1991	31	10	3	37	25	7	4	1	13	106	41.1%	35.2%	23.7%
1992	19	6	1	24	12	3	1	1	8	63	42.6%	38.0%	19.4%
1993	27	9	1	30	15	2	1	1	11	82	45.7%	36.3%	18.0%
1994	39	10	2	36	19	4	2	1	12	105	48.1%	34.2%	17.7%
1995	44	13	2	45	17	2	1	1	14	120	48.5%	37.2%	14.4%
1996	43	13	1	43	18	3	1	1	14	119	48.3%	36.5%	15.2%
1997	34	9	1	36	13	2	0	0	11	92	47.1%	38.4%	14.5%
1998	50	11	1	45	15	2	1	1	11	122	51.1%	36.9%	12.0%
1999	28	7	1	33	10	2	1	0	7	79	45.7%	41.3%	13.0%
2000	36	8	3	38	17	3	2	1	11	102	45.8%	37.3%	16.9%
2001	20	6	1	27	9	3	1	0	5	63	42.1%	43.7%	14.3%
2002	16	4	1	20	7	1	0	0	5	48	44.3%	41.1%	14.6%
2003	24	6	2	30	12	3	1	0	8	73	43.6%	40.2%	16.2%
2004	49	10	3	47	15	3	1	1	11	124	49.5%	38.0%	12.5%
2005	29	7	2	34	10	3	1	1	6	82	46.2%	41.8%	12.1%
2006	38	8	2	36	13	2	1	0	9	96	49.4%	37.4%	13.2%
2007	82	22	1	80	21	1	0	0	19	206	50.9%	38.9%	10.2%
2008	64	13	1	60	17	2	0	0	14	155	50.6%	38.6%	10.7%
2009	57	11	2	52	14	4	1	1	8	136	51.6%	38.2%	10.2%
2010	53	11	3	50	20	3	2	1	13	136	49.0%	36.6%	14.5%
2011	56	10	5	52	25	5	3	2	15	149	47.9%	35.0%	17.1%
2012	57	14	4	59	30	8	4	2	16	165	45.6%	36.0%	18.4%
2013	40	10	4	41	20	5	2	2	11	115	46.8%	35.6%	17.6%
2014	33	9	2	33	12	3	1	1	7	91	49.7%	37.0%	13.4%
										average (1965-2014)	45.5%	39.7%	14.8%

Table 3. ANOVA table for annual CPUE in number with PTS_yellowfin (potential target species effect for yellowfin) variable (left) and without the PTS_yellowfin variables standardized by log-normal error structured model.

Number with PTS
Year
1965-2014

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	760	25900.8	34.08	38.50	<.0001	0.43
Error	38994	34514.4	0.89			CV =
Corrected Total	39754	60415.2				665.34
year	49	723.1	14.8	16.7	<.0001	
month	11	115.5	10.5	11.9	<.0001	
area	2	116.4	58.2	65.7	<.0001	
CNHPB	4	121.4	30.3	34.3	<.0001	
sst	1	81.7	81.7	92.3	<.0001	
sst2	1	106.6	106.6	120.5	<.0001	
sst3	1	146.2	146.2	165.2	<.0001	
main	1	0.0	0.0	0.0	0.913	
bran	1	18.5	18.5	20.9	<.0001	
PTS_yellowfin	1	894.7	894.7	1010.9	<.0001	
year*area	98	1076.3	11.0	12.4	<.0001	
year*month	539	2275.3	4.2	4.8	<.0001	
area*month	22	256.5	11.7	13.2	<.0001	
area*CNHPB	8	46.7	5.8	6.6	<.0001	
sst*month	11	115.2	10.5	11.8	<.0001	
sst*area	2	181.5	90.8	102.5	<.0001	
sst*CNHPB	4	191.3	47.8	54.0	<.0001	
main*CNHPB	4	154.4	38.6	43.6	<.0001	
bran*CNHBF						

Number without PTS (updated index; SCRS/2016/035)
Year
1965-2014

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square=
Model	759	25006.1	32.95	36.28	<.0001	0.41
Error	38995	35409.1	0.91			CV =
Corrected Total	39754	60415.2				673.90
year	49	725.6	14.8	16.3	<.0001	
month	11	120.3	10.9	12.0	<.0001	
area	2	111.8	55.9	61.5	<.0001	
CNHBF	4	159.7	39.9	44.0	<.0001	
sst	1	75.7	75.7	83.4	<.0001	
sst2	1	100.5	100.5	110.7	<.0001	
sst3	1	143.8	143.8	158.3	<.0001	
main	1	0.2	0.2	0.2	0.633	
bran	1	21.8	21.8	24.0	<.0001	
year*area	98	1261.9	12.9	14.2	<.0001	
year*month	539	2265.4	4.2	4.6	<.0001	
area*month	22	323.9	14.7	16.2	<.0001	
area*CNHBF	8	67.7	8.5	9.3	<.0001	
sst*month	11	118.0	10.7	11.8	<.0001	
sst*area	2	202.7	101.4	111.6	<.0001	
sst*CNHBF	4	259.0	64.7	71.3	<.0001	
main*CNHBF	4	151.1	37.8	41.6	<.0001	
bran*CNHBF						

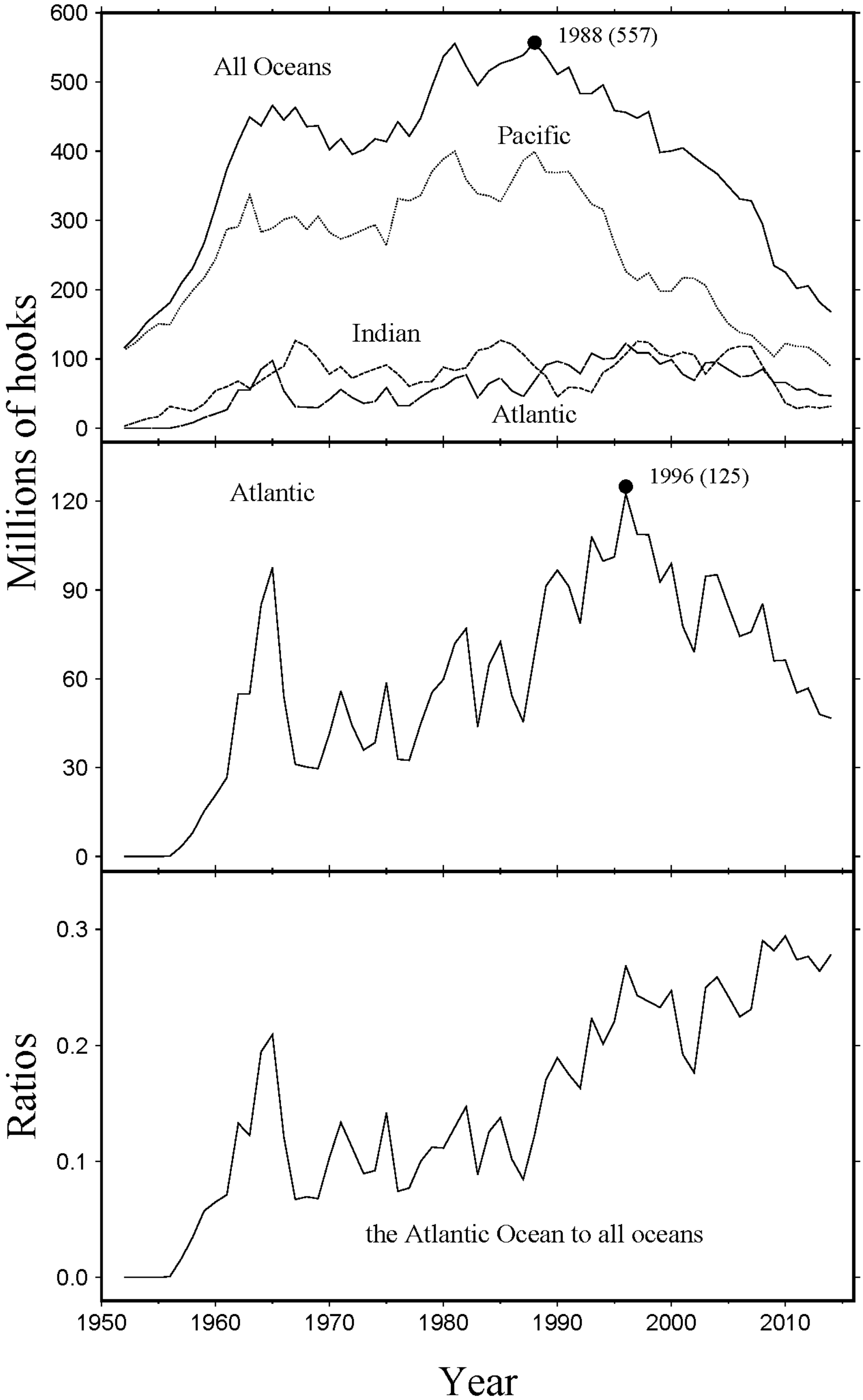


Figure 1. Historical changes of number of hooks of Japanese longline vessel by Ocean (upper), in the Atlantic Ocean (middle) and the ratio of number of hooks of the Atlantic Ocean to total number of hooks in all Ocean (bottom).

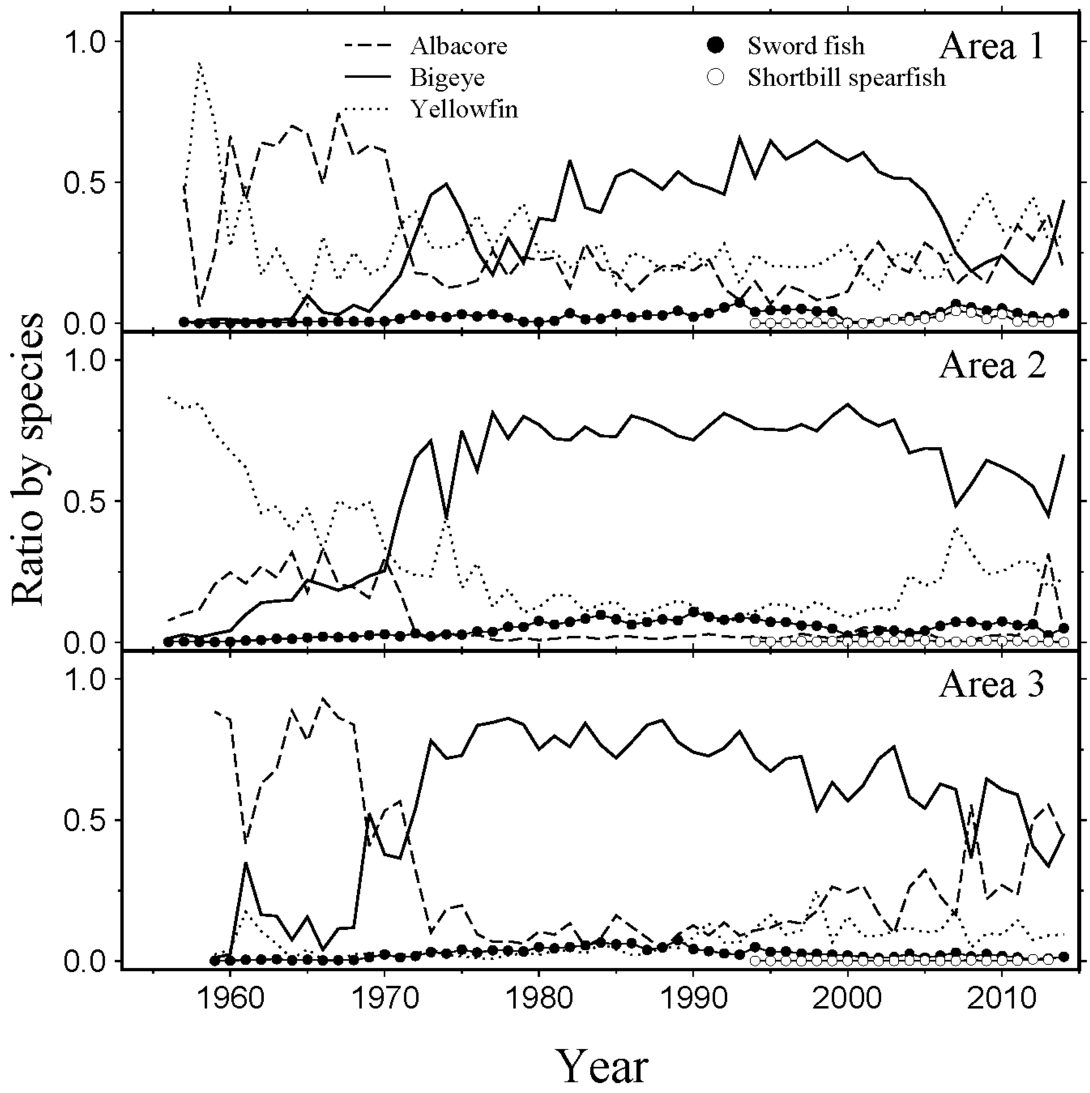


Figure 2. Historical changes of ratio of number of fish by tuna and billfish species caught by Japanese longline vessel in the Atlantic Ocean by area, which is used for the last assessment and defined in SCRS/2016/035 and figures 3 in this study.

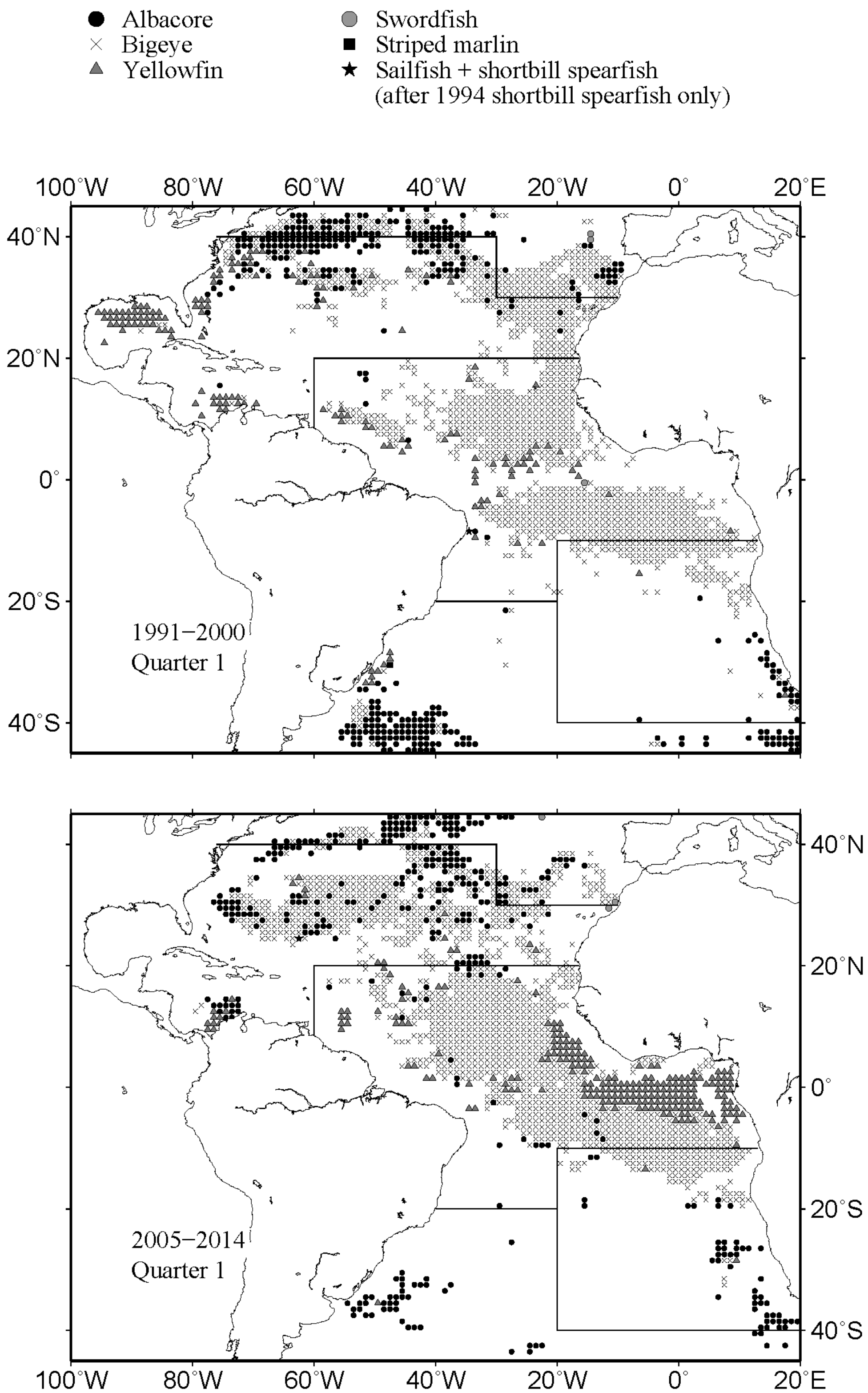


Figure 3. Geographical distribution of dominant species by quarter and 1 x 1 degree (latitude and longitude) caught by Japanese longline vessel in the Atlantic Ocean for two periods, 1991-2000 (upper) and 2005-2014(bottom). The dominant species is defined as the species with highest catch number in a stratum (quarter and 1 x 1 degree) in during each period.

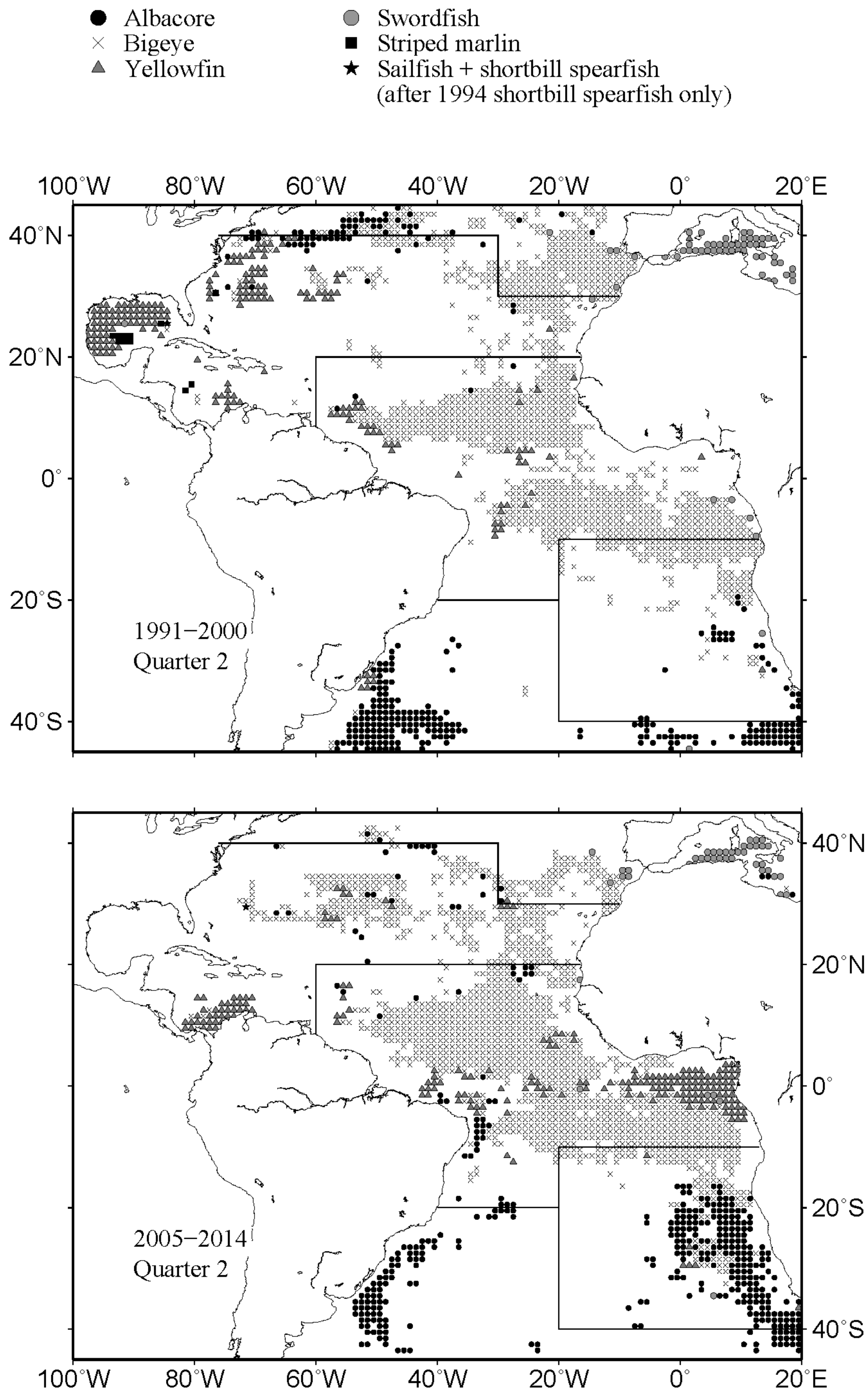


Figure 3. (continue) Qurter 2.

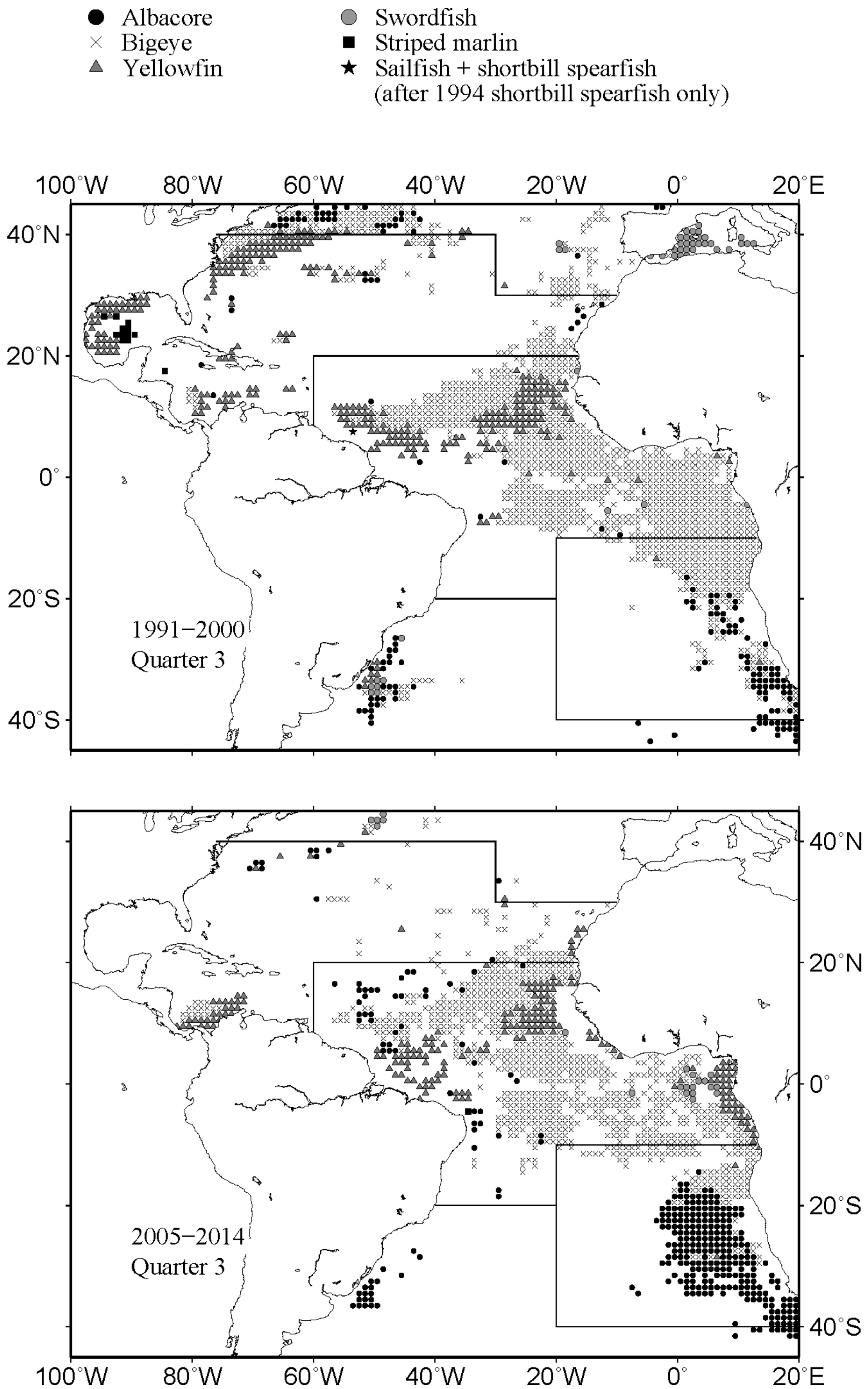


Figure 3. (continue) Qurter 3.

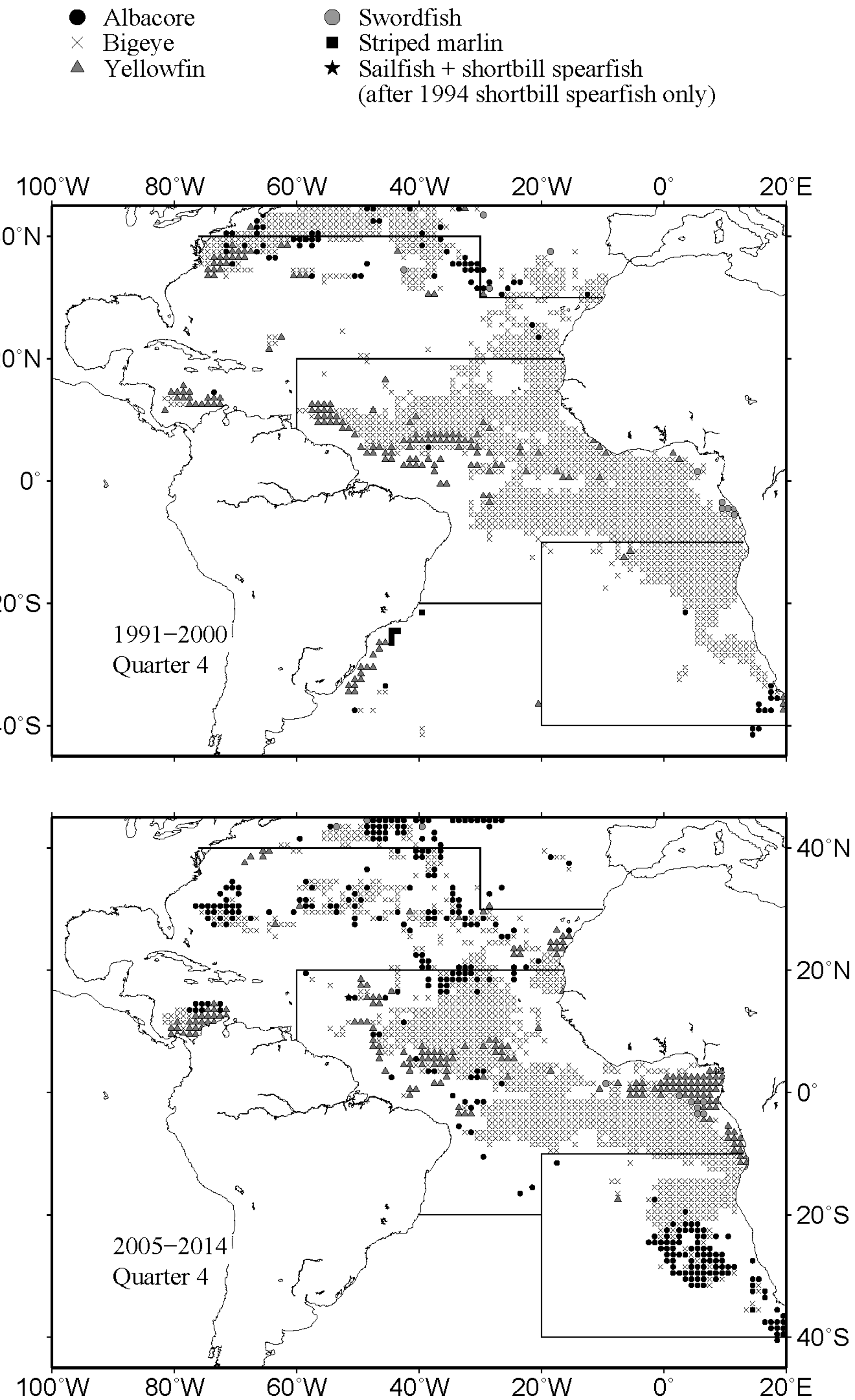


Figure 3. (continue) Qurter 4.

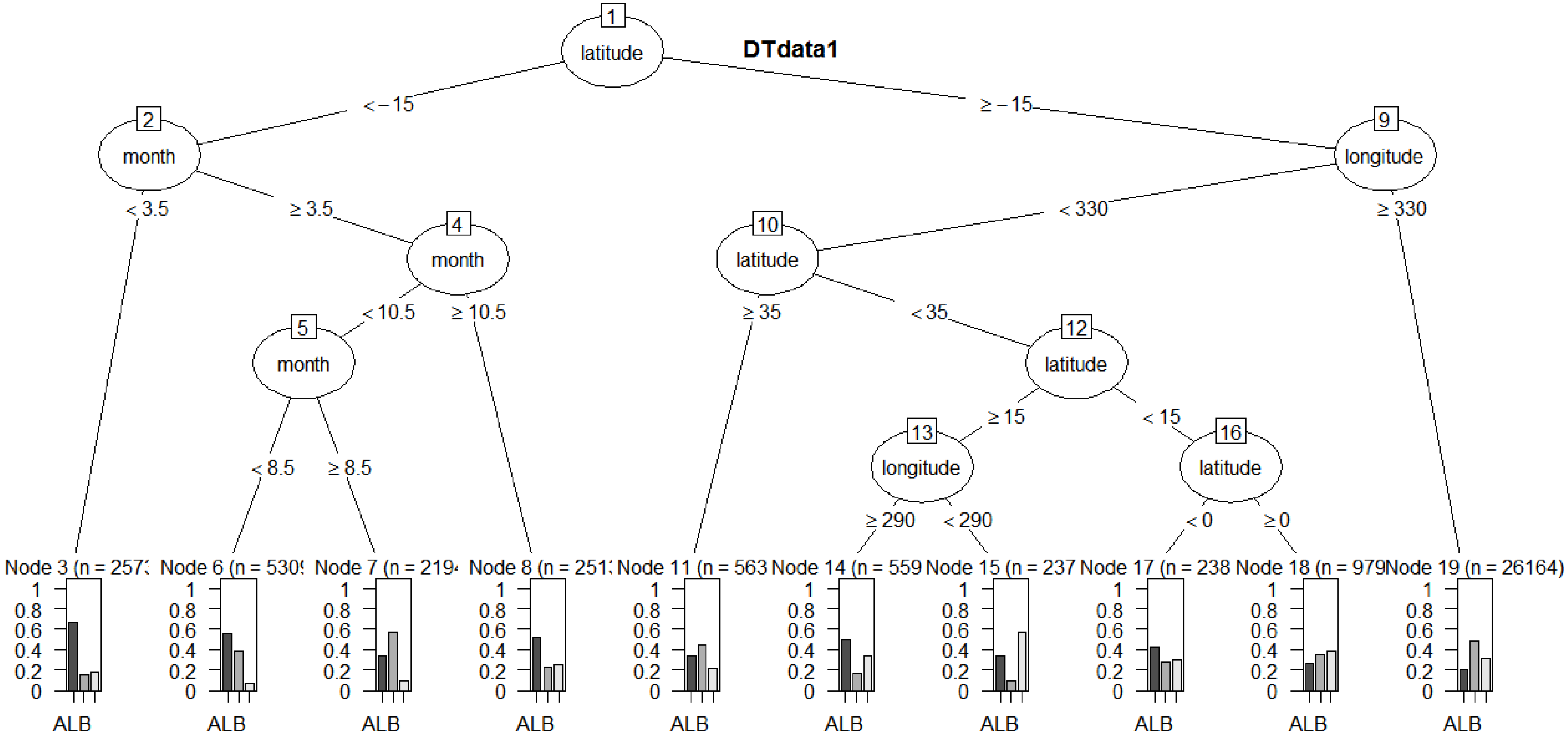


Figure 4. **Before 1974**. Decision tree for relationship between high CPUE for each species and fishing location (latitude and longitude), fishing month, number of hooks per basket (NHPB) and fishing. The analyses were conducted for each period (before 1974, 1975-1989, 1990-2004, after 2005). The high CPUE was defined as the upper 25 % in stratum of quarter and 5x5 degrees (longitude and latitude) for each year. The numbers in the small rectangle in the figure are identification of nod during the making tree process. The histograms in the very bottom of the figure present the ratio of each species (albacore, bigeye and yellowfin from the left) for each nod. The "n" over each histogram presents number of operation for each nod.

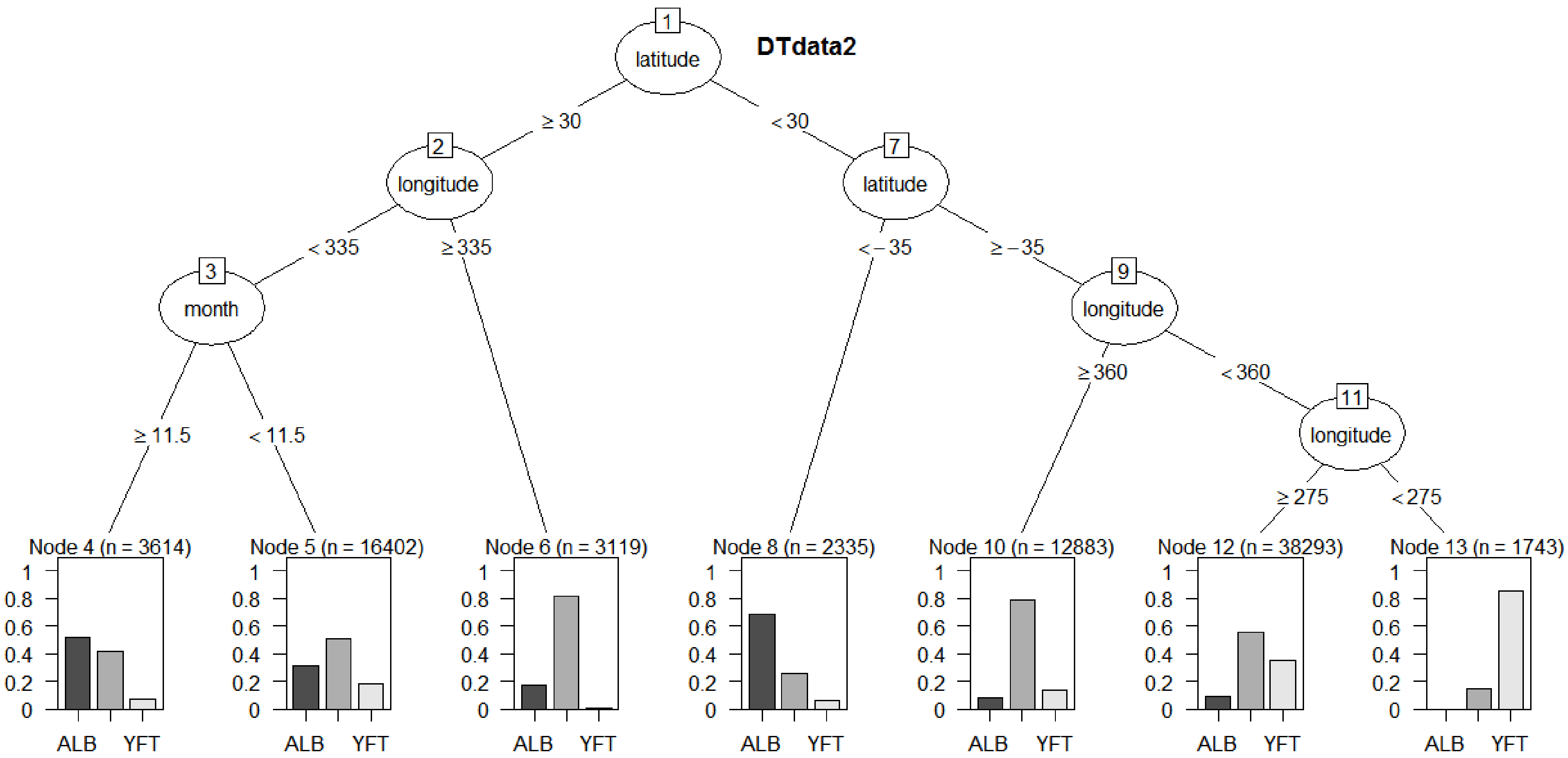


Figure 4. (continue) from 1975 to 1989.

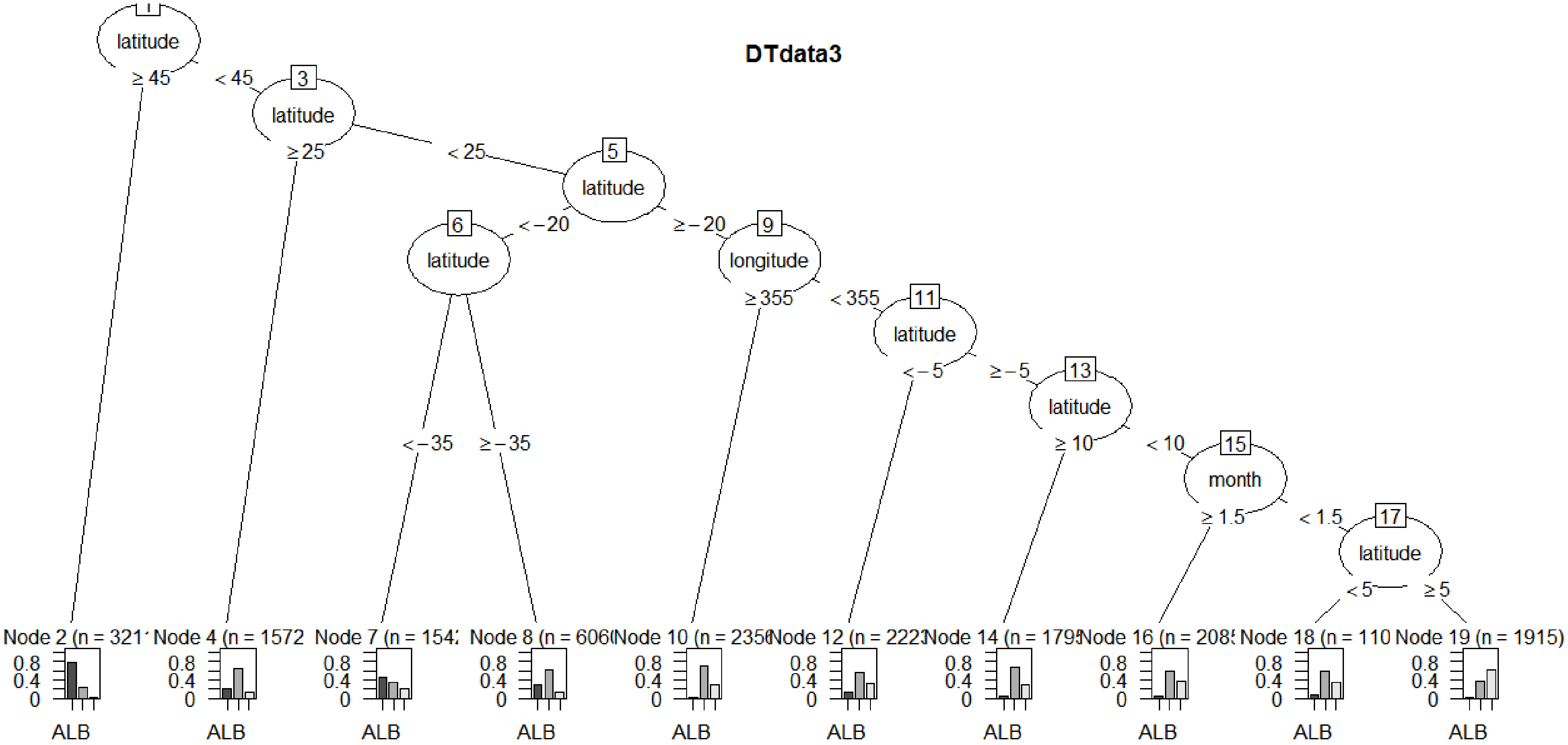


Figure 4. (continue) from 1990 to 2004.

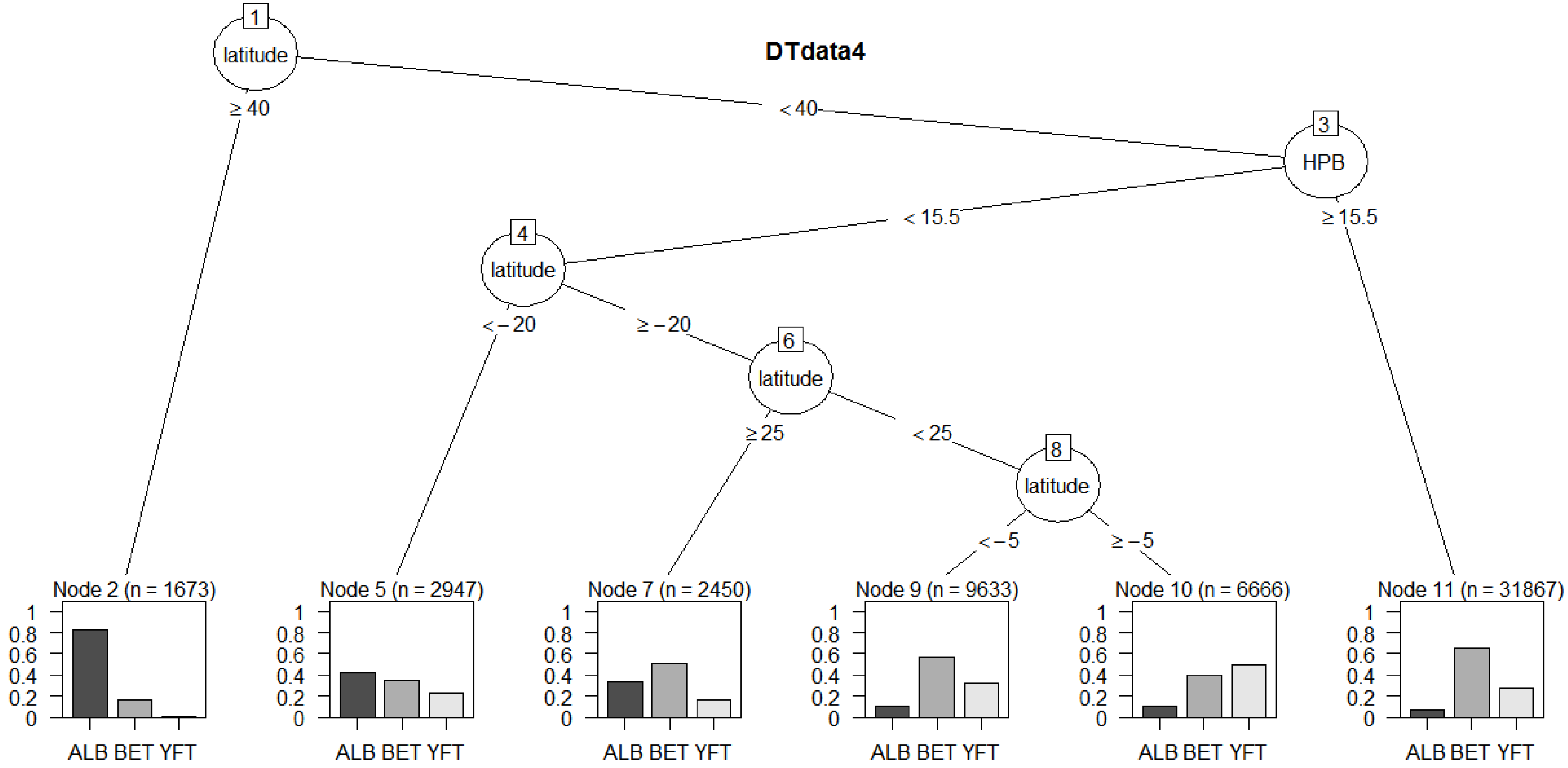


Figure 4. (continue) from 2005 to 2014.

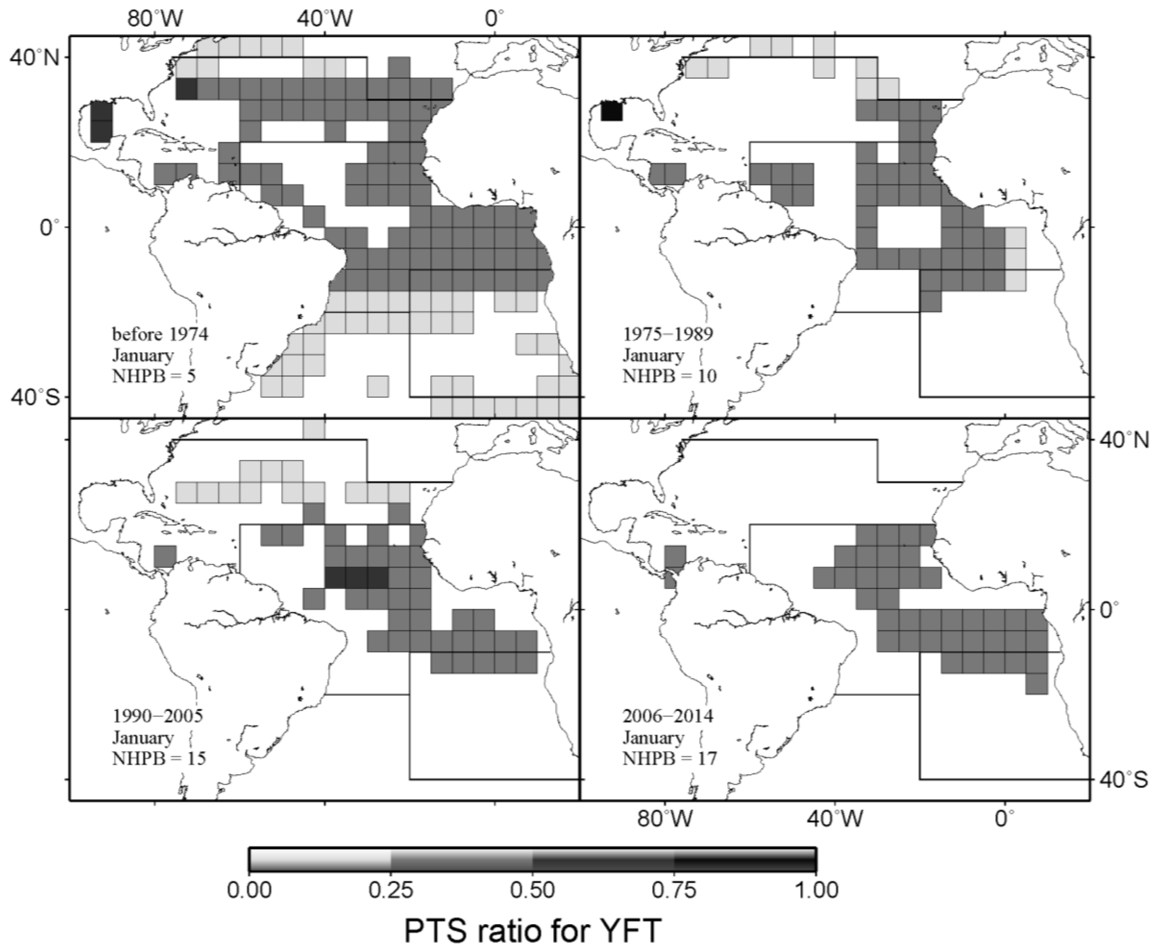


Figure 5. **Yellowfin**. Example of geographical PTS (potential target species) ratio for three species (yellowfin, bigeye and albacore) by period, month, number of hooks per basket (NHPB). For example the high PTS ratio of yellowfin tuna mora than 0.75 is observed in the equatrical area for the period from 1990 to 2005, which indicate that during this period mora than 75 % of fishing effort in this equatorical area targeted on yellowfin.

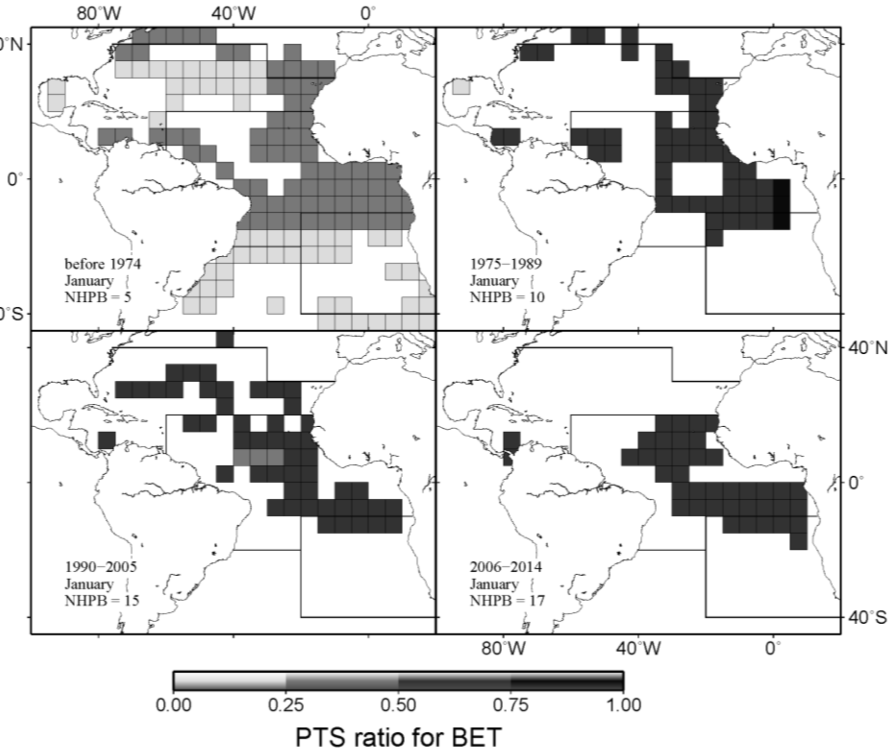


Figure 5.(Continue) **Bigeye.**

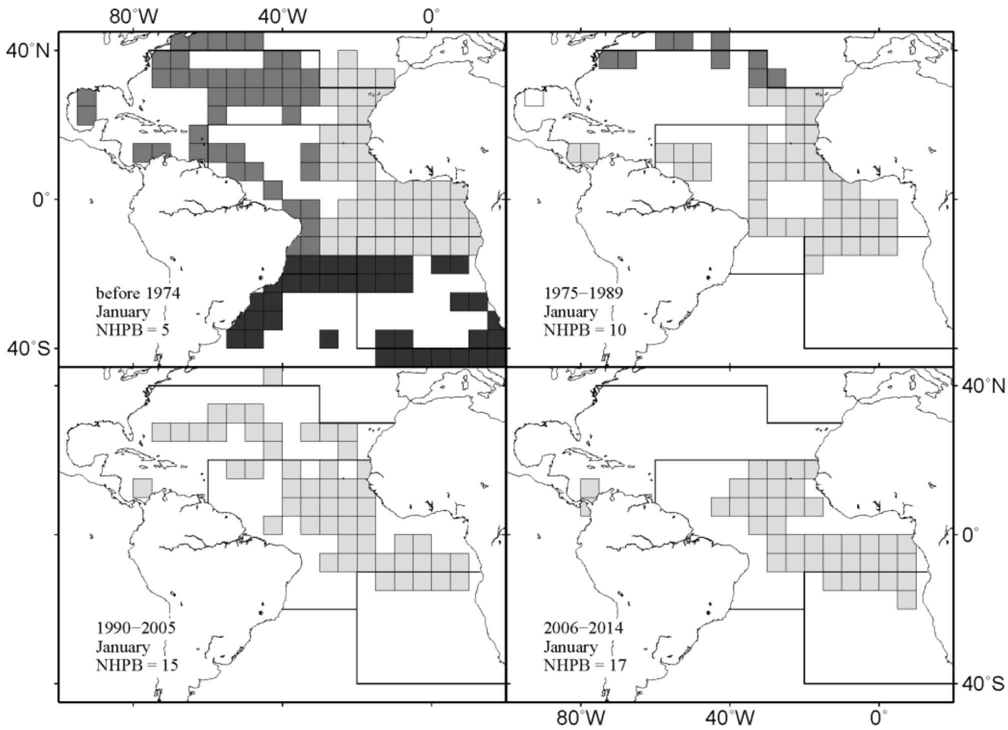


Figure 5.(Continue) **Albacore.**

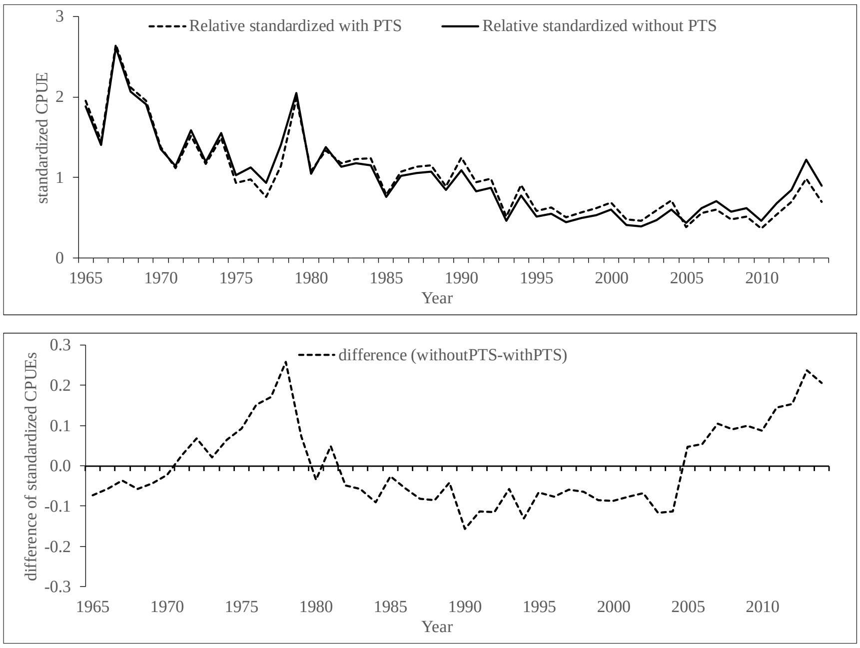


Figure 6. Comparison between annual standardized CPUEs (upper panel) estimated by the GLM model with PTS_yellowfin (potential target species effect for yellowfin) variable (dashed line) and without the PTS variable (solid line) in relative scale in which the average from 1965 (1970) to 2014 is 1.0. The annual differences of the two indices in the upper panel is presented in the bottom panel.

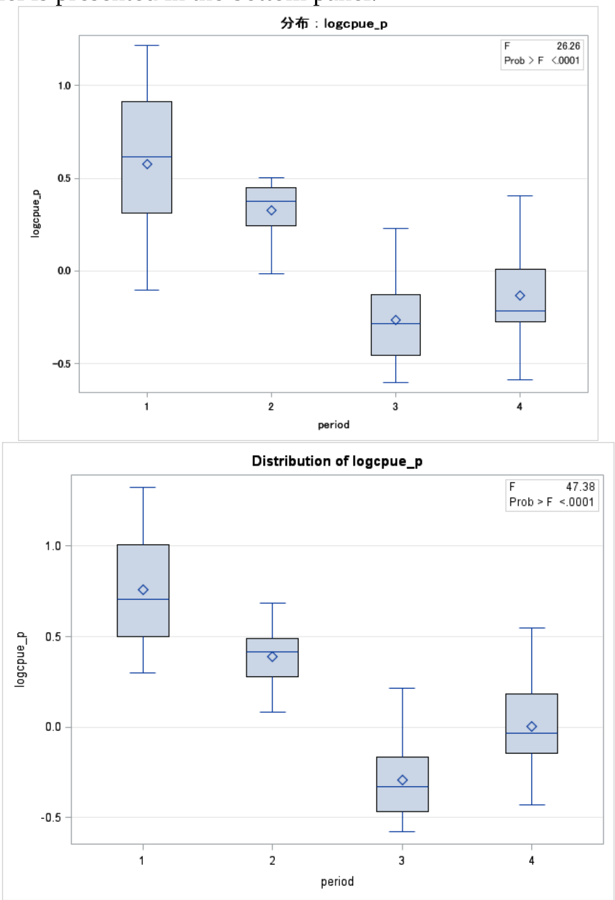


Figure 7. Differences of distribution of average standardized annual CPUE (natural log transformed real scale) in number of yellowfin tuna caught by Japanese longline in the Atlantic Ocean among periods (before 1979, 1980-1991, 1992-2005 and after 2006) for containing target effect (model PTS; upper) and no target effect (model without PTS; bottom, from Appendix Fig. 3 in SCRS/2016/035).

Appendix 1 R code for decision tree analysis in this study.

```
#(1)
   #library(rpart)
   library(rpart)
   library(partykit)
   library(rpart.plot)
# vector of data files
files <- c('DTdata1')

for (file.name in files) {
       file1 <- read.fwf(file=file.name, width=c(4,1,2,5,5,2,3,1), header=F)    # Reading data file
# file format
# odatey (operation year), quarter, odatem (operation month), X(longitude), Y(latitude), HPB (number of hooks per basket), PTS (potential target species; name of species), period (1=-1974, 2=1975-1989, 3=1990-2004, 4=2005-2014)

#(2)
   xxall <- file1[,c(1,2,3,4,5,6,7,8)]
   xx1 <- xxall[,1]
   xx2 <- xxall[,2]
   xx3 <- xxall[,3]
   xx4 <- xxall[,4]
   xx5 <- xxall[,5]
   xx6 <- xxall[,6]
   xx7 <- xxall[,7]
   xx8 <- xxall[,8]
   data1 <- data.frame(year=xx1, quarter=xx2, month=xx3, longitude=xx4, latitude=xx5, HPB=xx6, PTS=xx7, period=xx8)
#(3)
   par(mfrow = c(1, 1))
#(4) decision tree analysis
   gc()
   gc()
   set.seed(1299)
   rpart.out1 <- rpart(formula = PTS ~ year + month + longitude + latitude + HPB, data=data1, method="class", xval=10, minbucket=1700, cp=0.0041)

# detect appropriate cp from relationship between number of nod and cp
   printcp(rpart.out1)
# detect appropriate cp from relationship between number of size of branch and cp
   plotcp(rpart.out1)

   plot(as.party(rpart.out1),cex=0.1)

   title(file.name)
   out1.file <- paste(file.name, 'outall.txt', sep = '')    # output of node
   capture.output(print(rpart.out1), file = out1.file)
   data.file <- paste(file.name, 'sum.txt', sep = '')    # output of summary
   summary(rpart.out1, cp=0.001, digits=5, data.file, path=TRUE)
   out2.file <- paste(file.name, 'path.txt', sep = '')    # output of path (path to the last node "IF-THEN" rule)
   capture.output(path.rpart(rpart.out1, node=c(1:300)), file = out2.file)
}
```

Appendix 2. Model PTS. Nominal and standardize CPUE in number (number of fish per 1000 hooks) in real scale and relative scale in which the average from 1965 to 2014 is 1.0. The point in real scale is calculated by exp (lsmean)-mean/10, the upper is calculated as exp (lsmean+1.96*standard error)-mean/10, the lower is calculated by exp (lsmean-1.96 standard error)-mean/10. The lsmean is least square means of "year effect". These values are conditioned by the area effect as mentioned in the text.

CPUE in number (Model PTS)

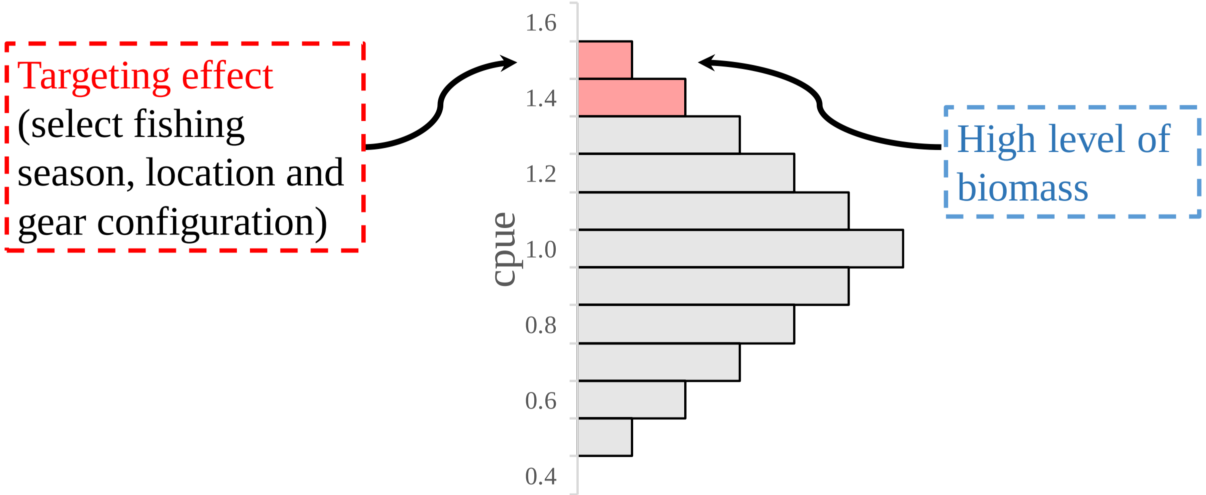
Year	nominal		standardized			
	real scale	relative scale	real scale			relative scale
			upper	point	lower	
1965	10.174	3.106	3.168	2.649	2.211	1.958
1966	7.853	2.397	2.445	1.974	1.587	1.459
1967	12.709	3.880	4.441	3.591	2.899	2.655
1968	10.459	3.193	3.577	2.872	2.299	2.123
1969	9.793	2.990	3.342	2.643	2.083	1.954
1970	7.741	2.363	2.353	1.862	1.465	1.376
1971	6.566	2.005	1.881	1.514	1.211	1.119
1972	4.619	1.410	2.663	2.057	1.578	1.521
1973	4.161	1.270	2.127	1.583	1.164	1.171
1974	5.631	1.719	2.928	2.013	1.372	1.488
1975	3.133	0.957	1.600	1.265	0.990	0.935
1976	5.203	1.588	1.749	1.323	0.989	0.978
1977	2.732	0.834	1.392	1.027	0.743	0.759
1978	3.209	0.980	2.033	1.546	1.163	1.143
1979	2.851	0.870	3.469	2.674	2.049	1.977
1980	1.954	0.597	1.808	1.464	1.179	1.082
1981	2.594	0.792	2.151	1.803	1.505	1.333
1982	2.250	0.687	1.942	1.598	1.311	1.181
1983	1.688	0.515	2.153	1.667	1.281	1.232
1984	2.148	0.656	2.087	1.680	1.347	1.242
1985	2.320	0.708	1.300	1.065	0.868	0.787
1986	1.660	0.507	1.828	1.453	1.148	1.074
1987	2.214	0.676	1.898	1.534	1.234	1.134
1988	2.215	0.676	1.906	1.563	1.277	1.156
1989	2.155	0.658	1.423	1.199	1.006	0.886

Appendix 2. (continue)

Year	CPUE in number					
	nominal		standardized			
	real scale	relative scale	real scale			relative scale
			upper	point	lower	
1990	1.938	0.592	2.062	1.684	1.371	1.245
1991	1.374	0.419	1.572	1.270	1.022	0.939
1992	1.012	0.309	1.685	1.331	1.046	0.984
1993	1.078	0.329	0.883	0.700	0.550	0.518
1994	1.279	0.390	1.602	1.232	0.947	0.911
1995	1.645	0.502	0.951	0.791	0.655	0.585
1996	1.421	0.434	1.000	0.849	0.717	0.628
1997	1.280	0.391	0.810	0.681	0.568	0.503
1998	1.929	0.589	0.896	0.762	0.644	0.563
1999	1.415	0.432	1.003	0.838	0.696	0.620
2000	1.577	0.481	1.096	0.932	0.789	0.689
2001	1.268	0.387	0.790	0.654	0.537	0.484
2002	1.133	0.346	0.773	0.629	0.506	0.465
2003	1.271	0.388	0.951	0.798	0.665	0.590
2004	1.924	0.587	1.145	0.972	0.820	0.718
2005	1.548	0.473	0.642	0.523	0.422	0.387
2006	1.808	0.552	0.919	0.759	0.622	0.561
2007	4.157	1.269	1.073	0.813	0.611	0.601
2008	2.588	0.790	0.839	0.652	0.500	0.482
2009	2.284	0.697	0.894	0.701	0.542	0.518
2010	2.112	0.645	0.640	0.501	0.385	0.371
2011	2.237	0.683	0.952	0.727	0.548	0.537
2012	2.752	0.840	1.218	0.943	0.724	0.697
2013	2.507	0.765	1.902	1.329	0.927	0.983
2014	2.214	0.676	1.434	0.942	0.615	0.697

Appendix 3. Schematic diagram of making data set for decision tree analysis in this study.

The higher cpue may result from two factors. The first one is the target effect that fisherman select fishing season, fishing location and fishing gear configuration which is appropriate for their target species. The second one is the level of biomass in the fishing season and location.

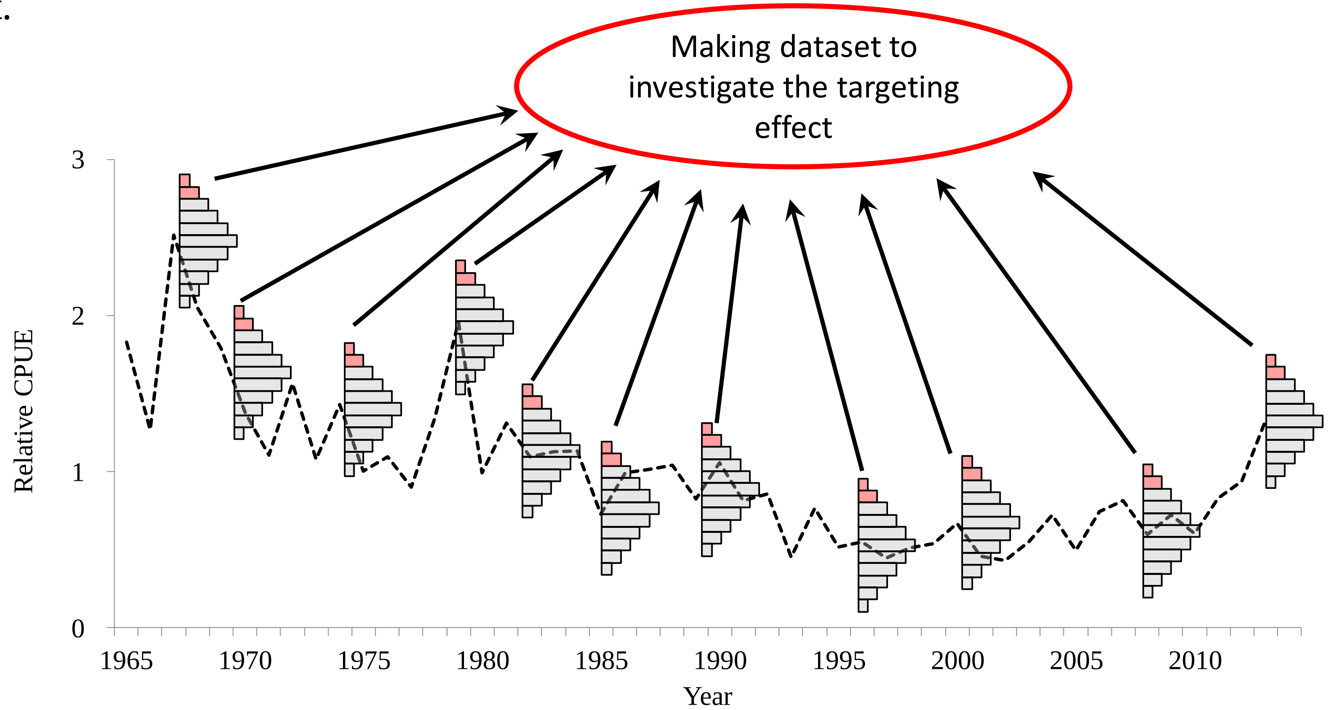


Separating the two factors (targeting, biomass) is essential to investigate the target effect in cpue.

Appendix 3. (continue)

We simply assumed that the biomass is constant in a stratum.

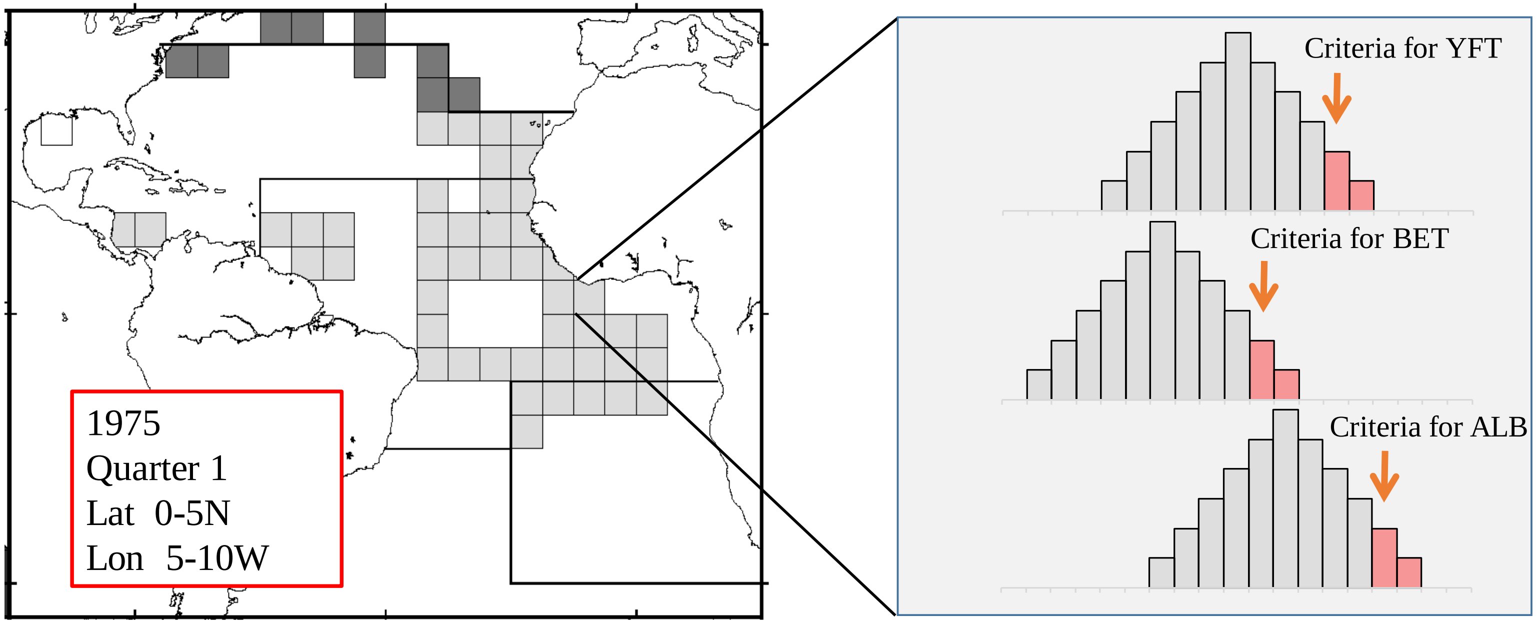
According to the assumption we can regard that the cpue is only affected by the target effect.



Actually the stratum is a year, quarter and 5 x 5 degrees rectangle

Appendix 3. (continue)

First, we calculate the upper 25% of nominal cpue for each stratum (year, quarter, 5 x 5 degrees in latitude and longitude) of each species (yellowfin, bigeye and albacore) as the criteria of targeting, using set by set (operational) longline catch and effort data.



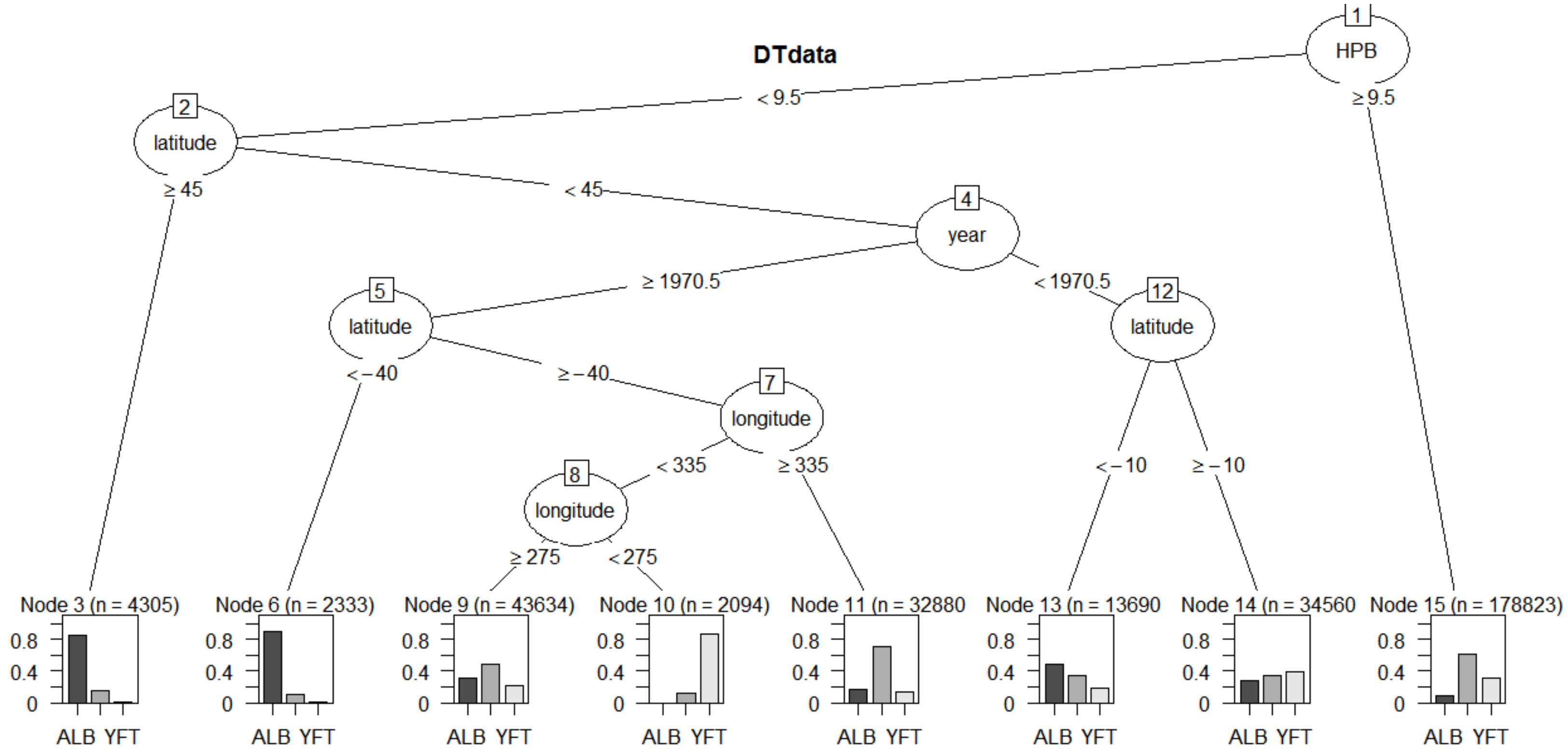
Appendix 3. (continue)

- Then, using the criteria, the potential target species (PTS) is assigned for all set (set by set (operational) data) when the cpue of the set is larger than the criteria for each species.

- "Potential" indicates that the assignment of the target species is NOT based on the explicit evidence of target species, such as the results of interviews of fisherman.

- Only the sets being assigned with PTS are applied for further decision tree analysis.

- In addition, to avoid variation the stratum less than 20 sets were excluded for further analysis, and the sets with a number of PTS were also not used.



Appendix 4. **Preliminary analysis fore whole period (1965-2014).** Decision tree for relationship between high CPUE for each species and fishing location (latitude and longitude), fishing month, number of hooks per basket (NHPB) and fishing. The analyses were conducted for whole period (1965-2014). The high CPUE was defined as the upper 25 % in stratum of quarter and 5x5 degrees (longitude and latitude) for each year. The numbers in the small rectangle in the figure are identification of nod during the making tree process. The histograms in the very bottom of the figure present the ratio of each species (albacore, bigeye and yellowfin from the left) for each nod. The “n” over each histogram presents number of operation for each nod.