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STANDARDIZED CPUE FOR DISTANT–WATER FLEETS TARGETING SOUTH PACIFIC ALBACORE[1]

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1 Introduction

Longline catch and effort series represent the principal indices of relative abundance within the south Pacific albacore MULTIFAN-CL assessment. However, there have been temporal changes in the catchability of the distant-water longline fisheries, some of which are associated with changes in the species targeted. For example, since 1975 the entire Japan distant-water fleet and a large portion of the Korea fleet have changed the geographic area fished and the configuration of the longline gear by increasing the number of hooks between floats, in order to target yellowfin and bigeye tuna.

Assessment indices in the 2005 MULTIFAN-CL assessment (Langley and Hampton 2005) were based on the compilation of nominal 5º-month aggregated data provided by distant-water fishing nations and logsheet data from domestic longline fisheries. The distant-water fleets have very different long term trends in unstandardized CPUE, that are not consistent with all fisheries having constant catchability. In the 2005 assessment, catchability was assumed to be constant for Taiwan as this fleet has consistently targeted albacore over a long period, using operational methods that have been assumed to be similar. Catchability for a composite Japan and Korea fleet was allowed to vary as a random walk, and the resulting catchability estimates show large temporal changes for these fisheries (Langley and Hampton 2005).

Assessment indices in the 2008 MULTIFAN-CL assessment (Hoyle et al. 2008) were based upon a new standardized CPUE index (Bigelow and Hoyle 2008) developed for distant-water fleets targeting south Pacific albacore (east of 110°W) by analysing an operational level dataset (logsheet data) of vessels landing at the two major canneries (Pago Pago, American Samoa and Levuka, Fiji). Data were spatially stratified into four regions at 25ºS and 180º, and standardized using 12 (3 fleet and 4 regions) Generalized Linear Models (GLMs). There were substantial spatial differences in effort, catch, and CPUE between the aggregated 5º-month data previously used in the assessment (2005) and the operational level data from albacore targeting vessels developed in 2008. In contrast with the aggregated data, there was good coherence in nominal operational-level CPUE among the fleets assumed to be targeting albacore. This was believed to be because the operational data was largely targeted at albacore, whereas the aggregated data included substantial yellowfin and bigeye-targeted effort. The assessment assumed that catchability was constant over time for all distant water longline fisheries (Japan, Korea, and Taiwan fleets).

While the CPUE standardization using operational level data represented an improvement in constructing relative abundance indices for south Pacific albacore, there was concern that some Taiwan vessels since the late 1990's had changed targeting from albacore to bigeye tuna. This targeting change was accompanied by a spatial change in the fishery, the use of deeper longline gear, and much higher catch rates of bigeye tuna. Taiwan indices for the low latitude regions (1 and 2) have declined since 2001 and had an earlier decline at high latitude regions (3 and 4, Bigelow and Hoyle 2008). If the indices constructed in 2008 included bigeye targeted effort then the resulting south Pacific albacore indices may have been biased downwards.

With the aim of removing this bias in targeting, we used cluster analysis to separate these data according to the target species. The species being targeted by a set can be difficult to identify if it is not recorded explicitly. In some cases operational characteristics of the set, such as hooks between floats (HBF), can be used. In this case, however, few operational characteristics were available for the whole time series. Cluster analysis was applied to the species composition.

The objective of this study was to: 1) incorporate operational data into the CPUE analysis in addition to data provided vessels landing at the canneries (Pago Pago and Levuka), 2) statistically disaggregate albacore and bigeye tuna targeting operations and 3) apply traditional GLMs to the albacore targeted fishery to estimate relative abundance indices for assessment.

2 Methods

2.1 Data compilation

Catch in numbers of fish by species and effort data were compiled from individual distant-water vessels (Japan, Korea, Taiwan) submitting operational logsheet data of longline activity in the south Pacific. A total of 1,398 vessels reported landing fish from 1960 to 2007 (Table 1). These vessels conducted 9,588 trips and 532,262 longline sets (Table 2). Eighty-three percent of the longline data were submitted in Pago Pago, A. Samoa under a voluntary program of scientific monitoring by the US National Marine Fisheries Service (NMFS). The remaining 17% of these data were submitted on SPC Regional Logsheet forms and provided mainly by Fiji (7.7%), French Polynesia (3.7%) and Vanuatu (3.0%). Duplicate records were removed.

2.1 Cluster analysis of longline targeting

There is evidence of bigeye targeting by some vessels in the Taiwan fleet since at least 1999 (Figure 1). The HBF metric is commonly included as an explanatory variable in GLM CPUE standardizations to characterize longline catchability given different longline targeting. The HBF field was only included on 26,555 (5.0%) of the longline sets and therefore could not be used to disaggregate species targeting.

A cluster analysis was conducted to disaggregate species targeting in the absence of operational data on HBF. Two clustering routines were performed in R (version 2.7.2 for Linux) based on the proportion of albacore, yellow and bigeye tuna for each longline set or trip. The proportion of various ‘other’ species was not incorporated as the species composition is probably only valid for the three tuna species (P. Williams, SPC personal communication). A Ward Hierarchical clustering (hclust) or agglomerative approach was initially performed on the Taiwan dataset (238,617 sets and 4,091 trips) to produce a dendrogram or cluster tree. A dendrogram is informative to determine the appropriate number of clusters (species targeting) represented in the data. Since the species proportion may change through time due to changes in overall population abundance of individual species, it is important to choose a temporal period that is not sensitive to large changes in abundance. A time-period of three years was initially chosen to produce the cluster trees. Clustering can be conducted on species proportion at a longline set or trip level. Clustering was conducted on trip as clustering on each set was computationally too time consuming. In the final analysis, the three year period was expanded to nine years and two periods, 1990−1998 and 1999−2007, were used to depict the number of clusters. An additional clustering (clara) routine was used to partition the dataset into appropriate clusters as determined by the dendrogram. The clara routine was used due to its ability to run on large datasets. Partitioning was applied at both the longline set and trip level for comparison. Longline sets that caught zero tuna (0.8% of the sets) were removed from the cluster analysis as zero proportions were uninformative in the cluster analysis.

2.2 Generalized linear models (GLM)

Data were spatially stratified into four regions at 25ºS and 180º for the stock assessment area (south of the equator, 140ºE−250ºW) as used in the 2008 CPUE standardization and assessment (Bigelow and Hoyle 2008, Hoyle et al. 2008). The GLM was fitted to the entire Japan and Korea time-series and the albacore cluster for Taiwan. Ten predictors were considered in the CPUE standardization in 2008, and four predictors were statistically selected. These four predictors (year_quarter, vessel identification and interactions between month and latitude, and latitude and longitude) were considered in the present study, with no oceanographic predictors due to their inferior results in the 2008 standardization. The dependent variable in the GLMs was the natural logarithm of albacore CPUE with a small constant (0.5) added to the catch. Each longline set was weighted by (1/sqrt(number of sets per trip)), because individual sets within a trip are often highly correlated. Similar to the 2008 standardization, a criterion was used for each fleet:region which had 10,000 or more sets to include only vessels that had fished in four or more quarters. All vessels were used if a fleet:region had less than 10,000 sets. A total of 12 GLMs were conducted as combinations of three fleets and four regions. The CPUE index was comprised of the exponentiated year_quarter coefficients from the fleet and region-specific GLM. Model selection was based on the Bayesian Information Criteria (BIC, Schwarz 1978). Alternative models such as delta-GLMs are appropriate with high zero catches in the dataset, but were not considered due to the low percentage of zero catches for each fleet (Japan 1.4%, Korea 9.2% and Taiwan 0.5%).

3 Results

3.1 Nominal catch, effort and CPUE

Figure 2 illustrates a regional comparison of nominal catch, effort and CPUE for three distant-water fleets based on logsheet data submitted. The Japan time-series is short (~10 years) while the Korea time-series is of longer duration (~35 years). Only Taiwanese vessels were active throughout most of the time-series. There was little difference in nominal CPUE before 2000 for all logsheet data from Taiwan in comparison to a subset of vessels landed in Pago Pago and Levuka (Figure 3). There were differences between datasets in region 1 since 2006 and in region 2 from 2000 to 2003.

3.2 Cluster analysis of longline targeting

Dendrograms indicated two and three clusters for the Taiwan fleet for periods 1990−1998 and 1999−2007, respectively (Figure 4). There were two clusters dominated by albacore and albacore/yellowfin in each period. The distinction between these clusters relates to the seasonality in catch rates. The albacore dominated cluster occurs on a larger spatial scale typically during the 2^{nd} and 3^{rd} quarters, whereas the albacore/yellowfin cluster occurs in the subtropics during the 1^{st} and 4^{th} quarters when the yellowfin proportion increased (Figure 5). From 1999 to 2007 there was evidence of a third cluster (Figure 4) dominated by bigeye tuna that was not apparent before 1999.

Individual longline sets and trips were partitioned into two clusters for 1990−1998 and three clusters since 1999. Species proportions were similar for the albacore and albacore/yellowfin clusters during each time period (Table 3) and these two clusters were combined as an albacore cluster for subsequent analyses. The albacore clusters based on longline set or trip had higher CPUE from 2004 to 2006 in comparison to using all Taiwan data, though there was little difference in CPUE by clustering on set or trip (Figure 6). A decision was made to conduct the south Pacific albacore GLMs with clustering results applied to longline set, due to a spatial analysis of individual vessel movements that indicated both albacore and bigeye tuna targeting within the same trip (not illustrated due to confidentiality). A total of 2,308 longline sets targeted bigeye tuna and were removed from the 1999−2007 time-series.

While the HBF information is largely incomplete, there was evidence that the cluster partitioning reflected target types. The mean estimates for HBF corresponding to the albacore, albacore/yellowfin and bigeye clusters were 12.0, 12.3 and 16.2, respectively. A higher HBF for the bigeye fishery is indicative of the operational behavior of the fleet which has deeper gear compared to an albacore fishery.

3.3 Generalized linear models (GLM)

Model results of the step-wise GLM analysis are provided in Table 4. Differences between nominal and standardized indices are more apparent in the low latitude regions (1 and 2) than at higher latitudes (3 and 4). Region 2 has the largest amount of albacore longline effort and standardized CPUE was higher for the Korea fleet in the mid-1990s than nominal values (Figure 7). Conversely, standardized CPUE was lower for the Taiwan fleet since 2000. Vessel effects are largely responsible for differences between nominal and standardized CPUE. Residuals were normally distributed in each of the 12 GLMs (Figure 8). The mean of year_quarter indices and their standard deviations were incorporated into the 2009 albacore assessment (Hoyle et al. 2009).

Figure 9 illustrates a comparison between current GLM indices and standardized indices used in the 2008 assessment (Hoyle et al. 2008). The standardized CPUE index from the current study is higher for Taiwan in region 1 since 2002 due to the inclusion of additional logsheet data and the removal of bigeye targeted effort. Additional data have improved the Taiwan index in region 3 since 1999, and effectively removed the unrealistically high CPUE values in region 2 for Korea (1995−2000) and Taiwan (2001−2004) evident in the 2008 standardization.

A comparison between the standardized Taiwan indices and nominal CPUE of various domestic Pacific Islands fleets indicates similar trends in the subtropical regions 1 and 2 (Figure 10). In both regions there is evidence in most domestic fisheries of a CPUE decline in 2002 or 2003. In region 1 in the west, Fiji and New Caledonia fisheries had similar CPUE since 2002 with depressed CPUE from 2003 to 2005. The Taiwan CPUE is coherent with the Fiji and New Caledonia since 2002. There are more precipitous declines in domestic fisheries in region 2 (Independent and American Samoa, Tonga and French Polynesia) since 2002. There has been a marginal CPUE increase in these Polynesian fisheries, though CPUE remains depressed in domestic fisheries at southern latitudes in region 2 (Tonga and French Polynesia). The Taiwan CPUE in region 2 also declined since 2002, though the decline was not as dramatic as in Tonga and French Polynesia perhaps due to Taiwan vessels having a larger spatial range then vessels in the domestic fisheries.

4 Discussion

South Pacific albacore is the only WCPFC species that is assessed with standardized CPUE indices constructed with operational data. These operational data include identification of individual vessels which in the GLM framework implicitly accounts for a certain amount of change in fishing power and consistent activity through time. The current standardization benefited from the use of operational data of distant-water vessels in addition to vessels landing at the canneries (Pago Pago and Levuka). There is evidence that some Taiwan vessels have targeted bigeye tuna at least since 1999 and this longline activity should be removed from the south Pacific albacore time-series. Taiwan trips in the last decade may contain longline sets targeting exclusively bigeye or albacore tuna or a small proportion contain mixed target types within a trip. The use of cluster analysis appeared appropriate to disaggregate targeting and there was little sensitivity if clustering was conducted at the trip or set level.

The time-series among distant-water fleets was coherent. There was a rapid decline from the early 1960s until 1975 followed by a slower decline thereafter. In the 1990s, there was an increase in standardized CPUE in the west (regions 1 and 3) which was not evident in the east (regions 2 and 4). There was a decline in standardized CPUE for the Taiwan distant-water fleet since 2000 that also occurred in most domestic Pacific Island fisheries. Similar to the 1990s, domestic fisheries in the eastern region (2 and 4) of the assessment area experienced the largest decline in CPUE since 2000. The decline in south Pacific albacore CPUE since 2002 remains in the standardized time-series for Taiwan though the decline is not as dramatic as in the 2008 standardized indices. The depressed CPUE since 2002 results from a decline in population abundance and/or a yet unexplained change in south Pacific availability that affected the Taiwan fleet and domestic Pacific Island fleets.

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6 References

Bigelow, K. and S. Hoyle. 2008. Standardized CPUE for distant-water fleets targeting south Pacific albacore. Working Paper ME-WP3. 4th Regular Session of the WCPFC Scientific Committee, Port Moresby, Papua New Guinea, 11−22 August, 2008.

Hoyle, S.D., Langley, A.D., and J. Hampton. 2008. Stock assessment of albacore tuna in the south Pacific Ocean. Working Paper SA-WP8. 4th Regular Session of the WCPFC Scientific Committee, Port Moresby, Papua New Guinea, 11−22 August, 2008.

Hoyle, S. and N. Davies. 2009. Stock assessment of albacore tuna in the South Pacific Ocean. Working Paper SA-WP6. 5th Regular Session of the WCPFC Scientific Committee, Vila, Vanuatu, 10−21 August, 2009.

Langley, A. and J. Hampton. 2005. Stock assessment of albacore tuna in the South Pacific Ocean. Working Paper SA-WP3. 1st Regular Session of the WCPFC Scientific Committee, Noumea, 8−19 August, 2005.

Table 1. Unique vessels by flag and region used in the cluster analysis and CPUE standardization from 1960 to 2007.

Fleet	Region				Total
	1	2	3	4	
Japan	50	175	27	91	182
Korea	281	493	174	262	503
Taiwan	431	593	170	388	713

Table 2. Annual number of vessels, trips and sets by fleet for the entire assessment area and four regions. All regions.

	Vessels			Trips			Sets		
Year	Japan	Korea	Taiwan	Japan	Korea	Taiwan	Japan	Korea	Taiwan
1960	2	0	0	2	0	0	159	0	0
1961	7	0	0	7	0	0	396	0	0
1962	1	0	0	3	0	0	83	0	0
1963	80	9	0	213	34	0	5,121	1,053	0
1964	74	18	11	191	33	27	4,575	954	592
1965	63	26	21	178	107	70	4,870	3,450	1,784
1966	65	55	75	199	193	273	5,765	7,111	7,203
1967	57	68	132	202	253	375	6,642	10,104	11,233
1968	37	82	110	87	217	282	3,180	9,189	10,300
1969	14	74	74	44	307	220	1,483	12,828	7,772
1970	7	78	112	22	314	288	672	12,370	11,009
1971	4	90	106	14	282	242	484	12,595	10,201
1972	2	89	103	3	253	225	81	11,923	10,001
1973	0	147	129	0	359	249	0	17,522	11,893
1974	0	154	119	0	363	226	0	16,142	10,636
1975	0	121	70	0	242	125	0	10,995	5,529
1976	0	95	59	0	225	84	0	11,105	4,326
1977	0	112	72	0	228	137	0	11,902	6,986
1978	0	94	55	0	206	96	0	10,011	5,408
1979	0	87	36	0	161	55	0	8,257	3,195
1980	0	71	47	0	104	74	0	6,066	4,138
1981	0	96	60	0	181	93	0	10,709	4,824
1982	0	85	58	0	141	107	0	8,075	6,294
1983	0	50	32	0	88	40	0	5,407	2,030
1984	0	42	48	0	79	92	0	5,648	6,870
1985	2	61	46	2	132	83	81	8,005	5,406
1986	0	79	53	0	161	112	0	8,080	6,630
1987	0	77	48	0	130	121	0	7,677	7,402
1988	0	63	51	0	119	112	0	6,455	6,175
1989	0	55	35	0	101	56	0	4,548	3,092
1990	0	49	27	0	88	39	0	3,628	2,279
1991	0	28	36	0	36	59	0	2,133	4,025
1992	0	28	43	0	29	69	0	1,284	4,304
1993	0	23	52	0	23	119	0	712	7,056
1994	0	19	44	0	21	85	0	685	4,832
1995	0	12	33	0	13	78	0	526	4,315
1996	0	20	29	0	22	70	0	1,570	4,350
1997	0	27	21	0	37	48	0	2,243	2,995
1998	0	50	31	0	62	47	0	1,901	2,625
1999	0	56	29	0	68	35	0	3,606	2,446
2000	0	43	36	0	49	59	0	3,196	3,455
2001	0	2	37	0	2	52	0	173	2,292
2002	0	0	63	0	0	108	0	0	6,661
2003	1	0	65	1	0	100	32	0	6,293
2004	1	0	42	5	0	59	59	0	4,121
2005	0	3	22	0	3	29	0	104	2,291
2006	0	2	15	0	2	22	0	20	1,220
2007	0	0	22	0	0	44	0	0	2,128

Table 2 (con't). Annual number of vessels, trips and sets by fleet for the entire assessment area and four regions. Region 1.

	Vessels			Trips			Sets		
Year	Japan	Korea	Taiwan	Japan	Korea	Taiwan	Japan	Korea	Taiwan
1960	1	0	0	1	0	0	14	0	0
1961	0	0	0	0	0	0	0	0	0
1962	0	0	0	0	0	0	0	0	0
1963	0	0	0	0	0	0	0	0	0
1964	7	0	9	8	0	13	77	0	180
1965	8	2	6	13	2	9	112	21	78
1966	19	5	37	28	5	63	405	108	990
1967	22	10	57	30	11	86	378	223	1,313
1968	11	3	44	11	3	53	150	23	981
1969	3	20	41	3	26	59	8	521	1,102
1970	3	33	55	3	41	76	20	542	1,706
1971	1	13	46	1	15	57	2	176	1,887
1972	0	15	41	0	16	51	0	399	1,141
1973	0	78	59	0	108	76	0	1,893	1,831
1974	0	92	44	0	125	56	0	2,880	1,455
1975	0	79	30	0	115	41	0	3,040	811
1976	0	62	16	0	91	18	0	2,369	380
1977	0	64	15	0	79	17	0	2,299	379
1978	0	58	5	0	100	6	0	2,667	174
1979	0	48	9	0	74	10	0	1,948	326
1980	0	33	22	0	44	25	0	1,744	678
1981	0	45	22	0	53	22	0	1,854	686
1982	0	38	20	0	50	33	0	1,864	1,399
1983	0	19	17	0	24	19	0	997	832
1984	0	23	28	0	24	57	0	647	3,032
1985	1	13	19	1	19	34	41	470	1,680
1986	0	14	16	0	16	19	0	380	504
1987	0	13	25	0	13	37	0	118	1,219
1988	0	16	43	0	17	74	0	389	3,253
1989	0	22	25	0	23	35	0	694	1,252
1990	0	20	7	0	29	9	0	1,327	463
1991	0	5	7	0	5	12	0	117	539
1992	0	0	15	0	0	21	0	0	877
1993	0	2	29	0	2	61	0	59	3,009
1994	0	0	24	0	0	49	0	0	2,566
1995	0	4	24	0	4	61	0	51	2,708
1996	0	3	25	0	3	59	0	101	2,404
1997	0	3	17	0	4	35	0	75	1,396
1998	0	4	18	0	4	24	0	161	879
1999	0	0	11	0	0	15	0	0	757
2000	0	2	31	0	2	43	0	26	1,962
2001	0	0	25	0	0	34	0	0	1,460
2002	0	0	29	0	0	53	0	0	1,874
2003	1	0	20	1	0	41	16	0	890
2004	1	0	15	3	0	28	32	0	1,221
2005	0	1	9	0	1	9	0	27	462
2006	0	0	12	0	0	19	0	0	956
2007	0	0	14	0	0	32	0	0	1,280

Table 3 (con't). Annual number of vessels, trips and sets by fleet for the entire assessment area and four regions. Region 2.

	Vessels			Trips			Sets		
Year	Japan	Korea	Taiwan	Japan	Korea	Taiwan	Japan	Korea	Taiwan
1960	2	0	0	2	0	0	113	0	0
1961	7	0	0	7	0	0	396	0	0
1962	1	0	0	3	0	0	83	0	0
1963	78	9	0	205	34	0	4,646	914	0
1964	73	18	10	188	33	23	4,128	954	409
1965	63	26	21	170	106	67	4,231	3,319	1,648
1966	62	55	74	152	184	249	3,366	6,207	5,441
1967	54	68	128	136	244	334	2,840	8,478	7,627
1968	34	81	108	65	208	267	1,604	7,878	8,269
1969	14	74	72	36	294	213	764	10,496	6,345
1970	6	78	110	14	266	282	273	8,415	8,476
1971	4	89	105	11	251	230	311	8,562	6,719
1972	2	86	101	3	218	219	81	7,982	7,599
1973	0	129	125	0	263	223	0	7,602	7,142
1974	0	146	107	0	267	183	0	6,992	5,763
1975	0	113	69	0	220	119	0	7,170	3,860
1976	0	92	57	0	200	78	0	6,366	3,030
1977	0	105	71	0	202	127	0	6,617	5,135
1978	0	92	53	0	185	86	0	4,935	3,342
1979	0	84	32	0	144	47	0	4,660	1,665
1980	0	68	41	0	95	62	0	3,490	2,317
1981	0	92	50	0	167	76	0	6,154	2,849
1982	0	72	40	0	118	68	0	4,148	2,348
1983	0	49	13	0	83	16	0	3,092	647
1984	0	41	20	0	74	32	0	3,250	1,303
1985	1	60	26	1	118	32	40	4,766	1,389
1986	0	78	46	0	153	85	0	5,487	3,163
1987	0	73	44	0	120	86	0	5,270	2,634
1988	0	60	29	0	112	57	0	4,051	1,154
1989	0	53	18	0	94	27	0	1,914	838
1990	0	45	21	0	70	27	0	2,103	990
1991	0	28	28	0	35	40	0	1,930	1,868
1992	0	28	30	0	29	40	0	1,284	925
1993	0	23	32	0	23	53	0	653	1,643
1994	0	19	26	0	21	36	0	685	955
1995	0	12	11	0	13	13	0	475	299
1996	0	18	9	0	20	12	0	1,469	239
1997	0	26	11	0	35	12	0	2,168	282
1998	0	48	14	0	59	17	0	1,740	523
1999	0	56	16	0	68	18	0	3,606	795
2000	0	43	10	0	49	11	0	3,169	413
2001	0	2	14	0	2	14	0	173	542
2002	0	0	34	0	0	46	0	0	1,952
2003	1	0	31	1	0	41	16	0	2,536
2004	1	0	24	4	0	24	27	0	1,308
2005	0	3	12	0	3	14	0	77	567
2006	0	2	3	0	2	3	0	20	258
2007	0	0	8	0	0	9	0	0	548

Table 3 (con't). Annual number of vessels, trips and sets by fleet for the entire assessment area and four regions. Region 3.

	Vessels			Trips			Sets		
Year	Japan	Korea	Taiwan	Japan	Korea	Taiwan	Japan	Korea	Taiwan
1960	0	0	0	0	0	0	0	0	0
1961	0	0	0	0	0	0	0	0	0
1962	0	0	0	0	0	0	0	0	0
1963	0	0	0	0	0	0	0	0	0
1964	0	0	0	0	0	0	0	0	0
1965	0	0	0	0	0	0	0	0	0
1966	6	0	1	6	0	1	62	0	1
1967	18	0	1	19	0	1	491	0	16
1968	4	1	3	4	1	3	102	7	38
1969	1	5	1	1	5	1	3	46	40
1970	2	14	2	2	15	3	28	133	40
1971	1	5	2	1	5	3	1	73	72
1972	0	7	5	0	7	6	0	82	221
1973	0	71	11	0	116	11	0	4,068	339
1974	0	83	9	0	132	9	0	2,805	193
1975	0	17	5	0	20	5	0	425	30
1976	0	39	4	0	48	4	0	990	166
1977	0	18	2	0	18	2	0	471	52
1978	0	12	1	0	12	1	0	142	9
1979	0	7	0	0	7	0	0	216	0
1980	0	4	3	0	4	3	0	170	171
1981	0	13	3	0	15	3	0	478	42
1982	0	9	8	0	10	10	0	269	468
1983	0	2	0	0	2	0	0	72	0
1984	0	20	22	0	21	22	0	835	1,555
1985	0	10	11	0	10	11	0	767	1,001
1986	0	6	10	0	6	10	0	475	444
1987	0	14	15	0	14	16	0	1,096	353
1988	0	11	9	0	11	10	0	652	123
1989	0	16	5	0	16	5	0	613	107
1990	0	4	4	0	4	4	0	88	151
1991	0	3	8	0	3	9	0	84	560
1992	0	0	8	0	0	10	0	0	455
1993	0	0	16	0	0	18	0	0	964
1994	0	0	14	0	0	14	0	0	554
1995	0	0	16	0	0	24	0	0	791
1996	0	0	16	0	0	23	0	0	847
1997	0	0	13	0	0	19	0	0	1,271
1998	0	0	16	0	0	16	0	0	889
1999	0	0	6	0	0	6	0	0	230
2000	0	0	11	0	0	13	0	0	733
2001	0	0	2	0	0	2	0	0	52
2002	0	0	18	0	0	19	0	0	936
2003	0	0	17	0	0	19	0	0	1,054
2004	0	0	11	0	0	11	0	0	940
2005	0	0	6	0	0	6	0	0	633
2006	0	0	1	0	0	1	0	0	6
2007	0	0	4	0	0	5	0	0	48

Table 3 (con't). Annual number of vessels, trips and sets by fleet for the entire assessment area and four regions. Region 4.

	Vessels			Trips			Sets		
Year	Japan	Korea	Taiwan	Japan	Korea	Taiwan	Japan	Korea	Taiwan
1960	1	0	0	1	0	0	32	0	0
1961	0	0	0	0	0	0	0	0	0
1962	0	0	0	0	0	0	0	0	0
1963	27	3	0	29	6	0	475	139	0
1964	17	0	1	21	0	1	370	0	3
1965	24	7	3	30	8	3	527	110	58
1966	38	15	29	69	21	38	1,932	796	771
1967	47	27	54	100	36	76	2,933	1,403	2,277
1968	20	33	33	33	40	37	1,324	1,281	1,012
1969	11	45	12	20	59	12	708	1,765	285
1970	6	57	24	11	88	27	351	3,280	787
1971	4	67	37	6	90	38	170	3,784	1,523
1972	0	70	25	0	83	26	0	3,460	1,040
1973	0	98	44	0	135	49	0	3,959	2,581
1974	0	92	53	0	134	60	0	3,465	3,225
1975	0	24	16	0	26	20	0	360	828
1976	0	48	14	0	62	14	0	1,380	750
1977	0	59	24	0	70	24	0	2,515	1,420
1978	0	46	26	0	55	33	0	2,267	1,883
1979	0	28	17	0	28	18	0	1,433	1,204
1980	0	15	15	0	16	15	0	662	972
1981	0	54	18	0	63	19	0	2,223	1,247
1982	0	43	28	0	47	33	0	1,794	2,079
1983	0	21	6	0	22	7	0	1,246	551
1984	0	19	15	0	19	17	0	916	980
1985	0	35	17	0	36	20	0	2,002	1,336
1986	0	30	39	0	32	46	0	1,738	2,519
1987	0	30	37	0	30	53	0	1,193	3,196
1988	0	25	22	0	29	24	0	1,363	1,645
1989	0	28	17	0	29	19	0	1,327	895
1990	0	11	10	0	11	10	0	110	675
1991	0	2	18	0	2	20	0	2	1,058
1992	0	0	22	0	0	33	0	0	2,047
1993	0	0	18	0	0	32	0	0	1,440
1994	0	0	11	0	0	12	0	0	757
1995	0	0	5	0	0	5	0	0	517
1996	0	0	7	0	0	9	0	0	860
1997	0	0	3	0	0	3	0	0	46
1998	0	0	5	0	0	6	0	0	334
1999	0	0	11	0	0	11	0	0	664
2000	0	1	7	0	1	9	0	1	347
2001	0	0	5	0	0	9	0	0	238
2002	0	0	30	0	0	35	0	0	1,899
2003	0	0	31	0	0	31	0	0	1,813
2004	0	0	9	0	0	10	0	0	652
2005	0	0	6	0	0	7	0	0	629
2006	0	0	0	0	0	0	0	0	0
2007	0	0	6	0	0	7	0	0	252

Table 3. Cluster partitioning of species proportions within the Taiwan longline fishery based on individual sets during 1990−1998 and 1999−2007.

	Species percentages (BET:YFT:ALB)	Species percentages (BET:YFT:ALB)	Species percentages (BET:YFT:ALB)
1990−1998	0.5:1.0:98.5 Albacore cluster	5.4:16.1:78.5 Albacore/Yellowfin cluster	No Bigeye/Yellowfin cluster
1999−2007	0.7:0.8:94.5 Albacore cluster	5.8:17.5:76.7 Albacore/Yellowfin cluster	46.4:35.6:18.0 Bigeye/Yellowfin cluster

Table 4. Model selection results for fleet and region CPUE standardization models using residual deviance and Bayesian information criterion (BIC).

Japan fishery

Region 1, 1,255 sets, Null deviance=728.6

Predictor variable	Residual deviance	d.f.	Percent deviance explained	Deviance per parameter	BIC
Year_quarter	419.4	27	42.4	11.5	4562
Year_quarter lat5*lon5	158.5	27	78.2	21.1	3533

Region 2, 18,646 sets, Null deviance=2938.9

Predictor variable	Residual deviance	d.f.	Percent deviance explained	Deviance per parameter	BIC
Year_quarter	2078.6	47	29.3	18.3	45363
Year_quarter month*latitude	1517.6	44	48.4	32.3	39931
Year_quarter month*latitude lat5*lon5	1399.6	61	52.4	25.2	39021
Year_quarter month*latitude lat5*lon5 boat_ID	1338.6	88	54.5	18.2	38957

Region 3, 687 sets, Null deviance=33.5

Predictor variable	Residual deviance	d.f.	Percent deviance explained	Deviance per parameter	BIC
Year_quarter	22.0	10	34.3	1.2	950
Year_quarter boat_ID	16.0	22	52.2	0.8	872

Region 4, 8,822 sets, Null deviance=454.2

Predictor variable	Residual deviance	d.f.	Percent deviance explained	Deviance per parameter	BIC
Year_quarter	391.8	28	13.8	2.2	14003
Year_quarter mont*latitude	300.3	33	33.9	4.7	11957

Korea fishery

Region 1, 25032.7 sets, Null deviance=6925.8

Predictor variable	Residual deviance	d.f.	Percent deviance explained	Deviance per parameter	BIC
Year_quarter	5518.9	96	20.3	14.7	86523
Year_quarter lat5*lon5	3520.8	39	49.2	87.3	75666
Year_quarter lat5*lon5 month*latitude	3162.7	44	54.3	85.5	73427
Year_quarter lat5*lon5 month*latitude boat_ID	2968.3	139	57.1	28.5	73247

Region 2, 160,966 sets, Null deviance=51972.8

Predictor variable	Residual deviance	d.f.	Percent deviance explained	Deviance per parameter	BIC
Year_quarter	23215.0	156	55.3	184.3	513494
Year_quarter month*latitude	15998.1	44	69.2	817.6	459573
Year_quarter month*latitude lat5*lon5	13941.5	82	73.2	463.8	433784
Year_quarter month*latitude lat5*lon5 boat_ID	13182.8	341	74.6	113.8	423881

Region 3, 11,666 sets, Null deviance=805.3

Predictor variable	Residual deviance	d.f.	Percent deviance explained	Deviance per parameter	BIC
Year_quarter	577.2	62	28.3	3.7	23929
Year_quarter month*latitude	482.3	44	40.1	7.3	22193
Year_quarter month*latitude lat5*lon5	472.5	32	41.3	10.4	22171

Region 4, 41,642 sets, Null deviance=3671.3

Predictor variable	Residual deviance	d.f.	Percent deviance explained	Deviance per parameter	BIC
Year_quarter	2532.7	90	31.0	12.7	91795
Year_quarter month*latitude	2053.4	44	44.1	36.8	83527
Year_quarter month*latitude boat_ID	1950.8	170	46.9	10.1	83199

Taiwan fishery

Region 1, 45,883 sets, Null deviance=5429.9

Predictor variable	Residual deviance	d.f.	Percent deviance explained	Deviance per parameter	BIC
Year_quarter	4194.0	164	22.8	7.5	120853
Year_quarter lat5*lon5	3507.9	39	35.4	49.3	113074
Year_quarter lat5*lon5 boat_ID	3201.9	209	41.0	10.7	111151
Year_quarter lat5*lon5 boat_ID month*latitude	3073.8	44	43.4	53.5	109750

Region 2, 107,530 sets, Null deviance=10588.3

Predictor variable	Residual deviance	d.f.	Percent deviance explained	Deviance per parameter	BIC
Year_quarter	8235.1	165	22.2	14.3	249508
Year_quarter month*latitude	7670.3	44	27.6	66.3	242377
Year_quarter month*latitude boat_ID	7040.1	413	33.5	8.6	237933
Year_quarter month*latitude boat_ID lat5*lon5	6876.7	73	35.1	50.8	236252

Region 3, 16,547 sets, Null deviance=1169.6

Predictor variable	Residual deviance	d.f.	Percent deviance explained	Deviance per parameter	BIC
Year_quarter	833.9	100	28.7	3.4	36019
Year_quarter boat_ID	626.0	156	46.5	3.5	32790
Year_quarter boat_ID lat5*lon5	606.8	24	48.1	23.5	32507

Region 4, 39,159 sets, Null deviance=3039.0

Predictor variable	Residual deviance	d.f.	Percent deviance explained	Deviance per parameter	BIC
Year_quarter	2199.7	137	27.6	6.1	86767
Year_quarter month*latitude	1948.3	44	35.9	24.8	82481
Year_quarter month*latitude boat_ID	1662.0	203	45.3	6.8	78403
Year_quarter month*latitude boat_ID lat5*lon5	1631.3	54	46.3	26.1	78244

Figure 1. Boxplots of annual bigeye catch rates by the Taiwan fleet through time for region 2 (top) and post-1998 catch rates by vessels in region 2 (bottom).

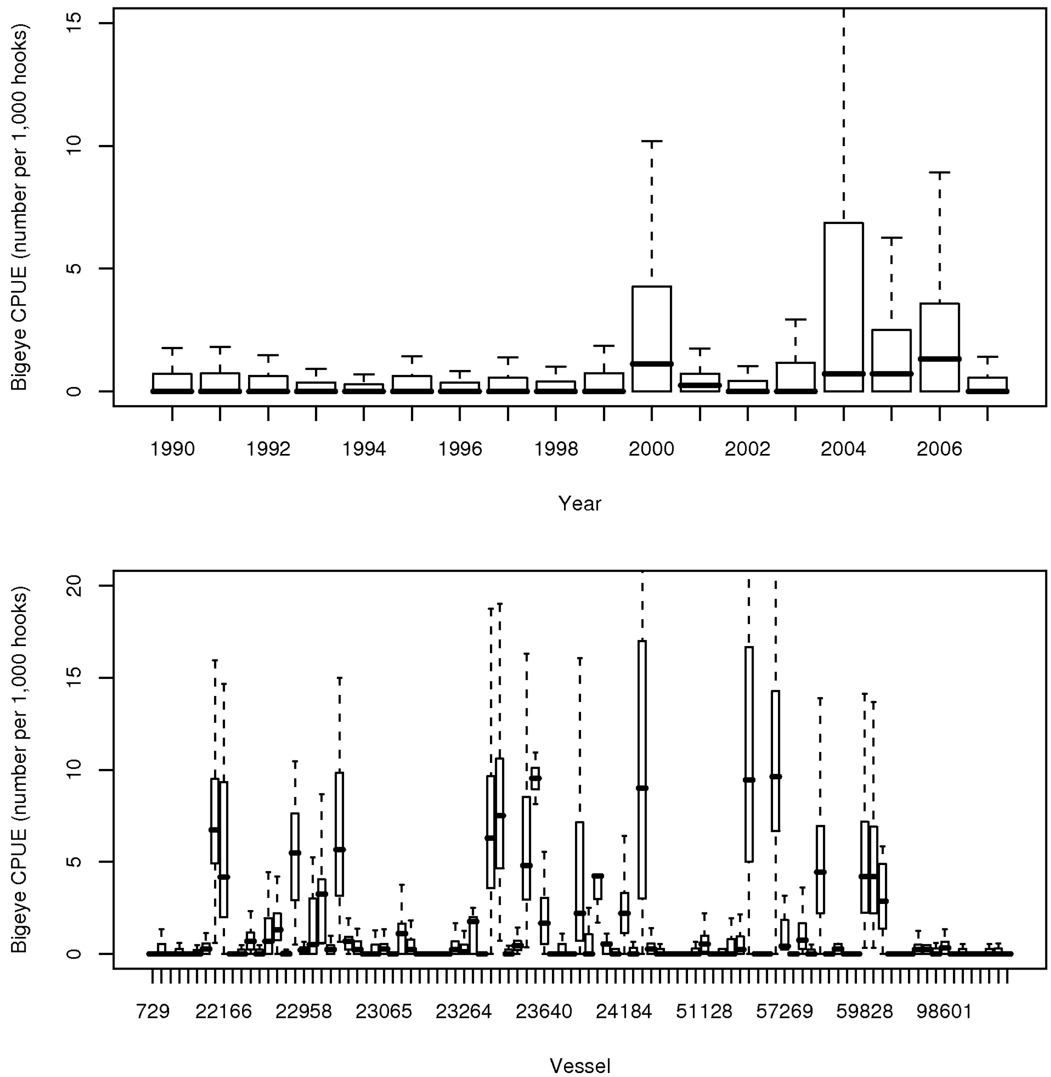

Figure 2. Four region comparison of nominal catch, effort and CPUE for three distant-water fleets based on logsheet data submitted.

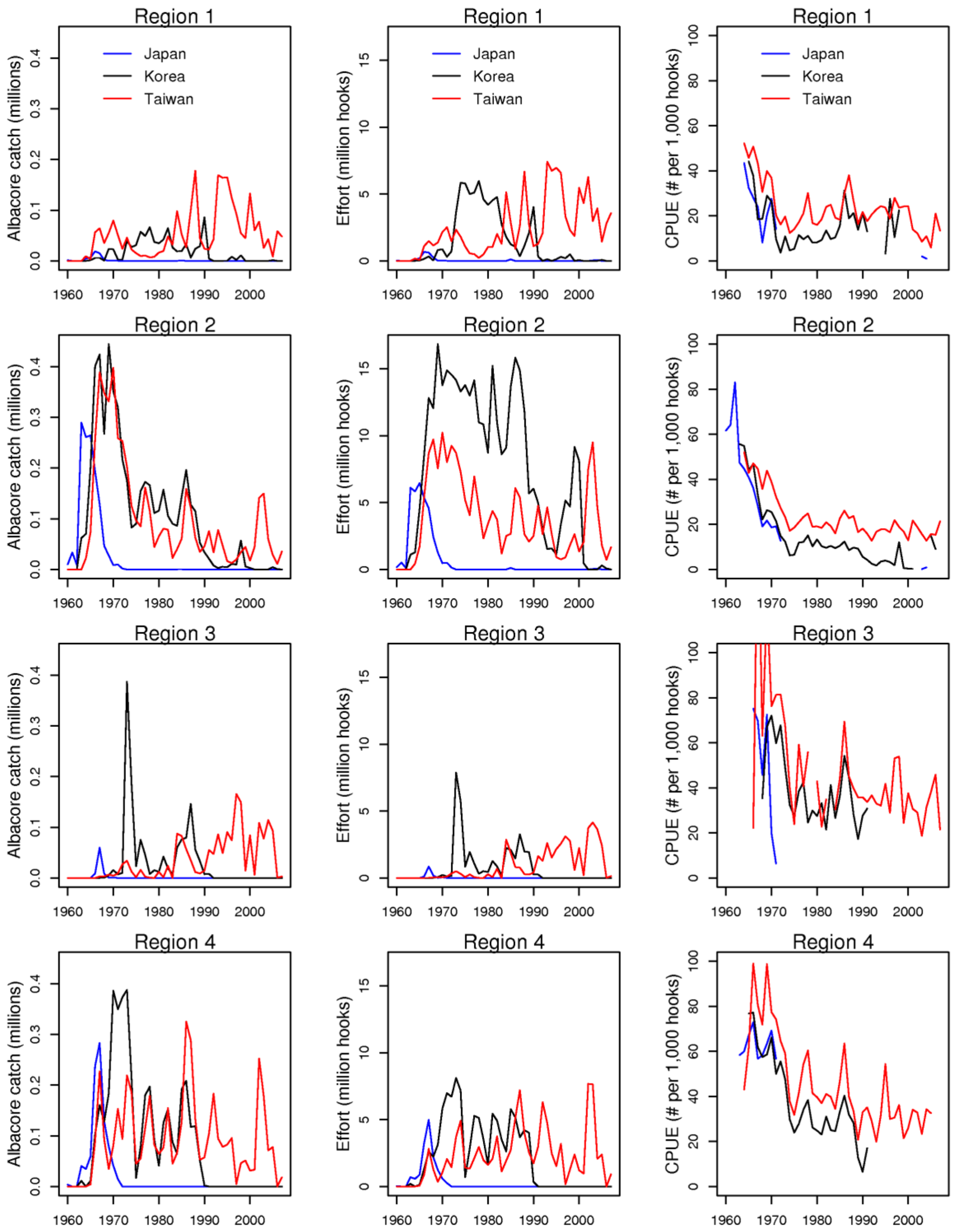

Figure 3. Comparison of quarterly nominal CPUE time-series from all Taiwan logsheet data versus logsheets from Pago Pago, American Samoa and Levuka, Fiji.

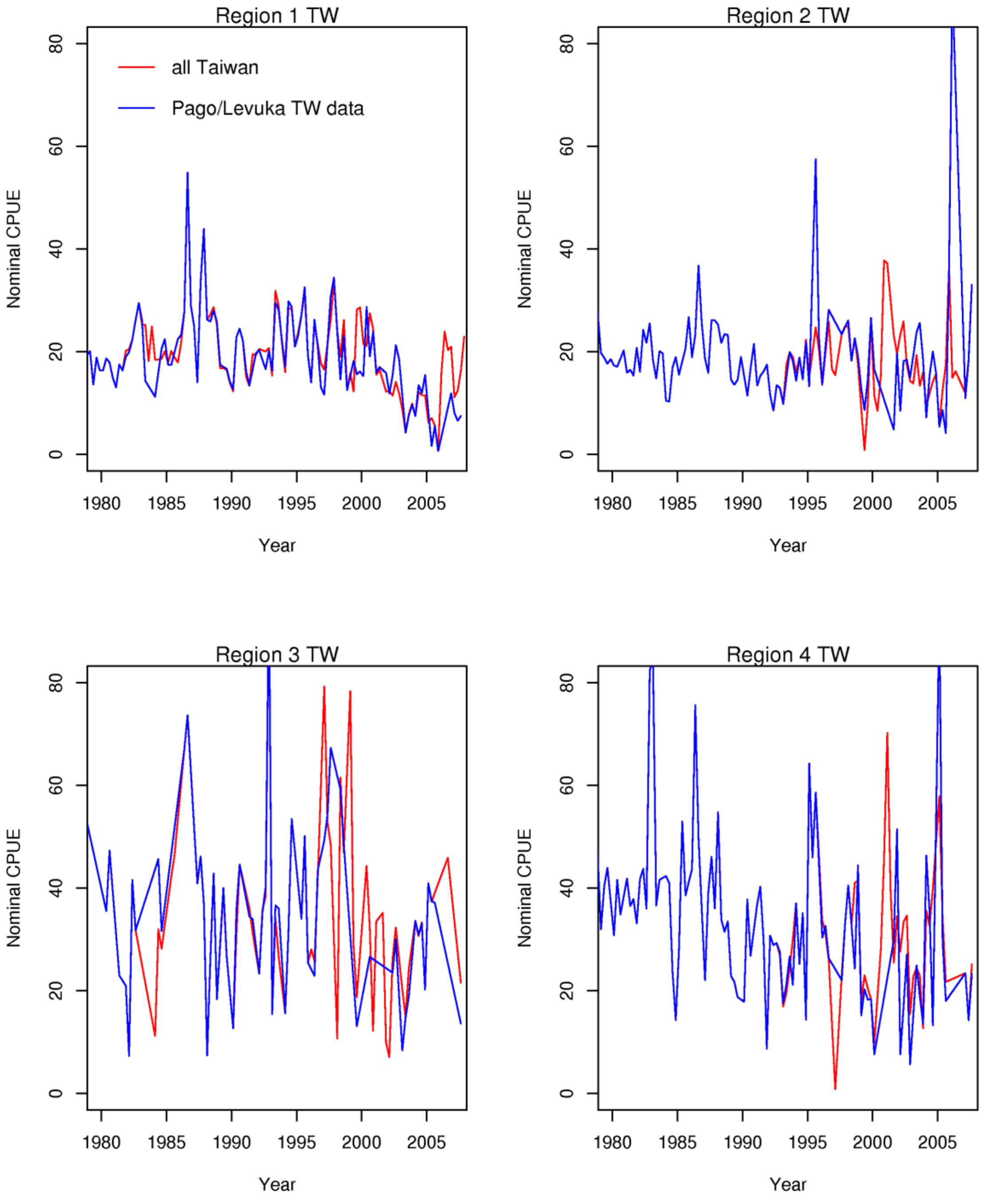

Figure 4. Dendrogram of agglomerative clustering based on the catch proportion of three tuna species (south Pacific albacore, yellowfin and bigeye tuna) per longline trip. Two clusters from 1990 to 1998 are illustrated (left) and three clusters from 1999 to 2007 (right).

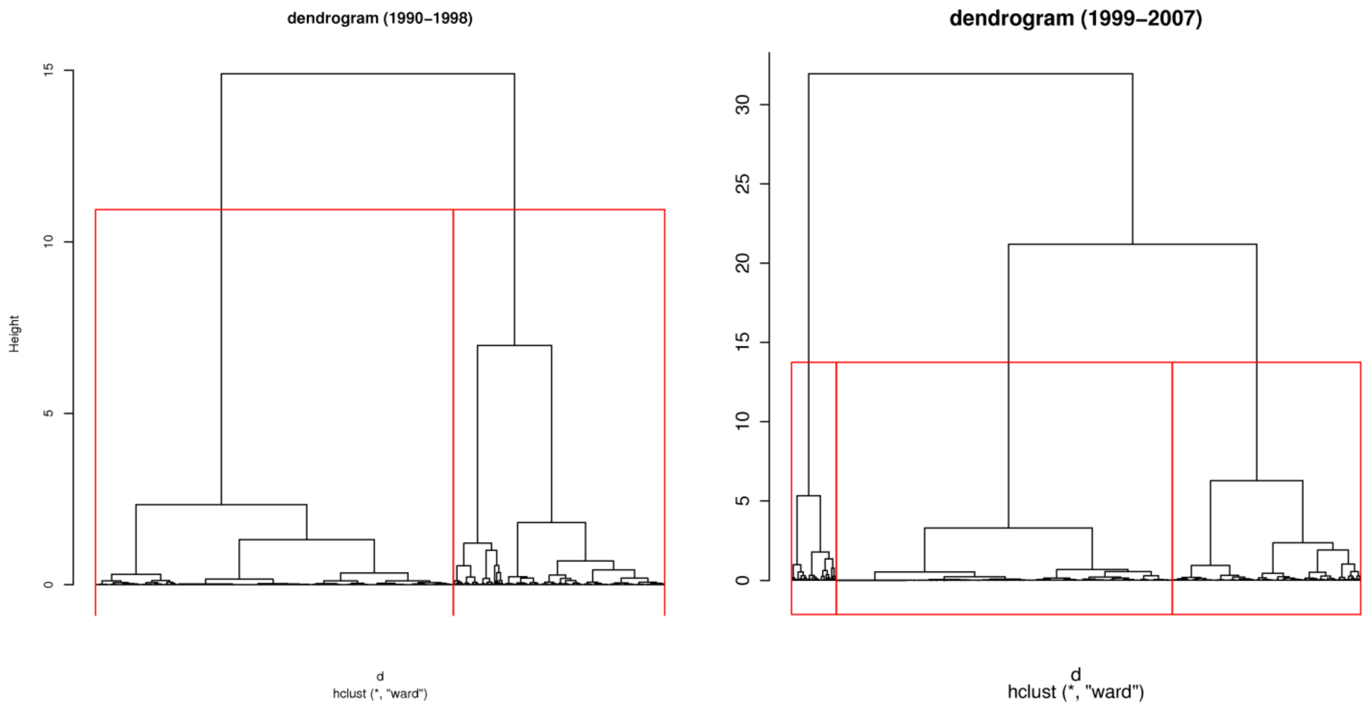

Figure 5. Spatial distribution of fishing effort for three clusters (south Pacific albacore, south Pacific albacore and yellowfin and bigeye tuna) from 1999 to 2007.

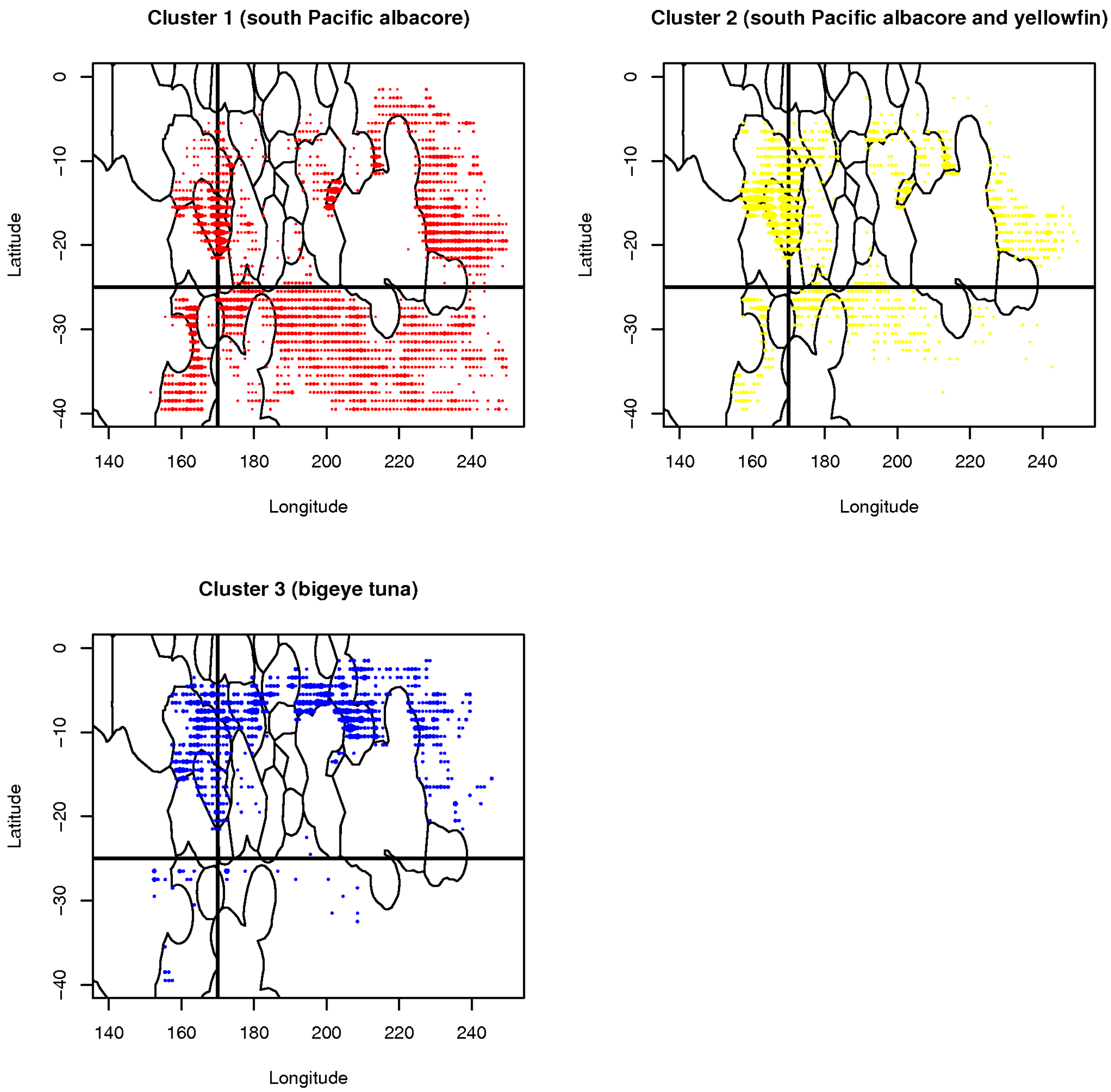

Figure 6. Comparison of quarterly nominal CPUE time-series from all Taiwan logsheet data and by conducting a cluster analysis on longline trip and set.

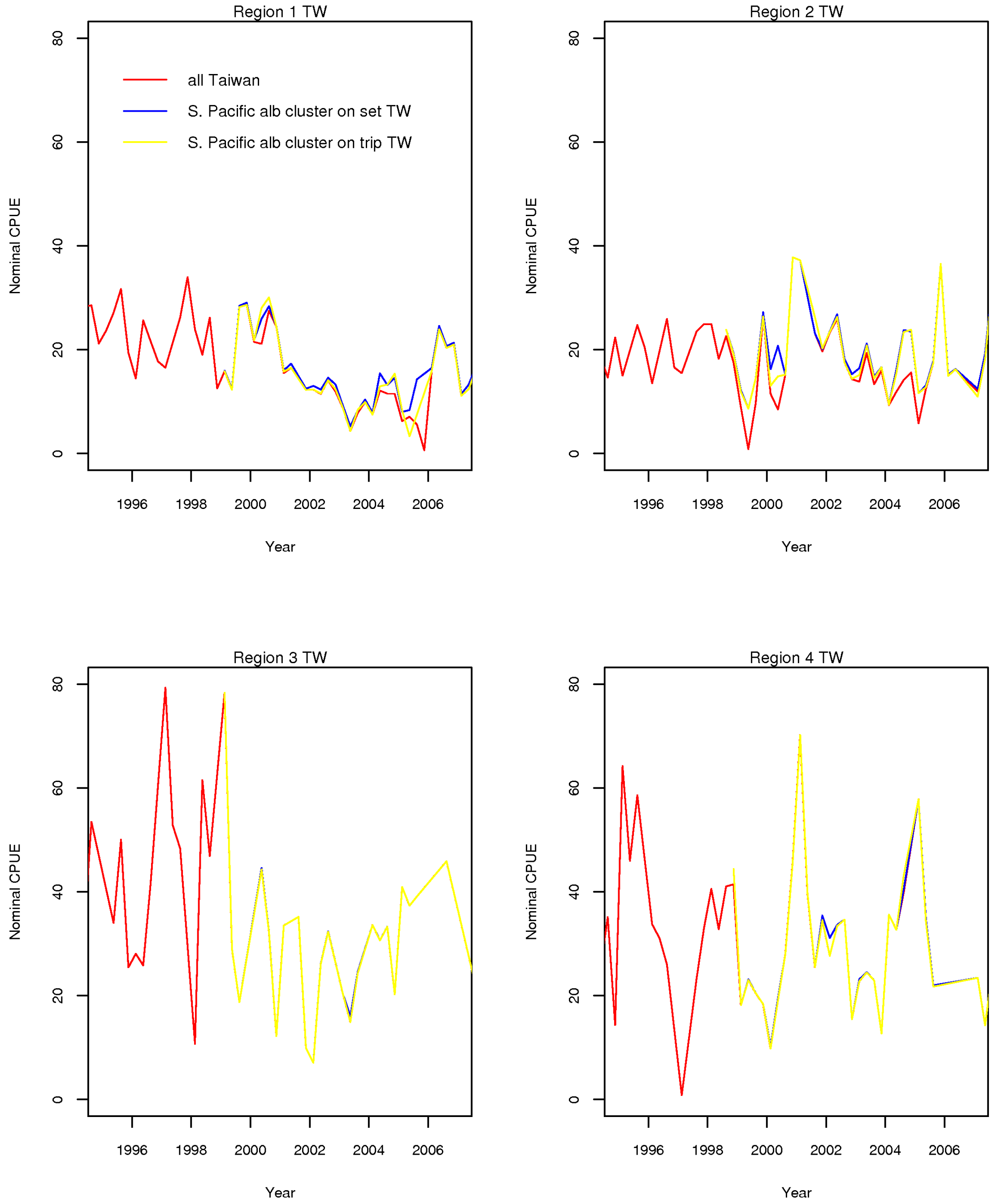

Figure 7. Comparison of normalized year:quarter nominal and standardized CPUE indices for three distant-water longline fleets.

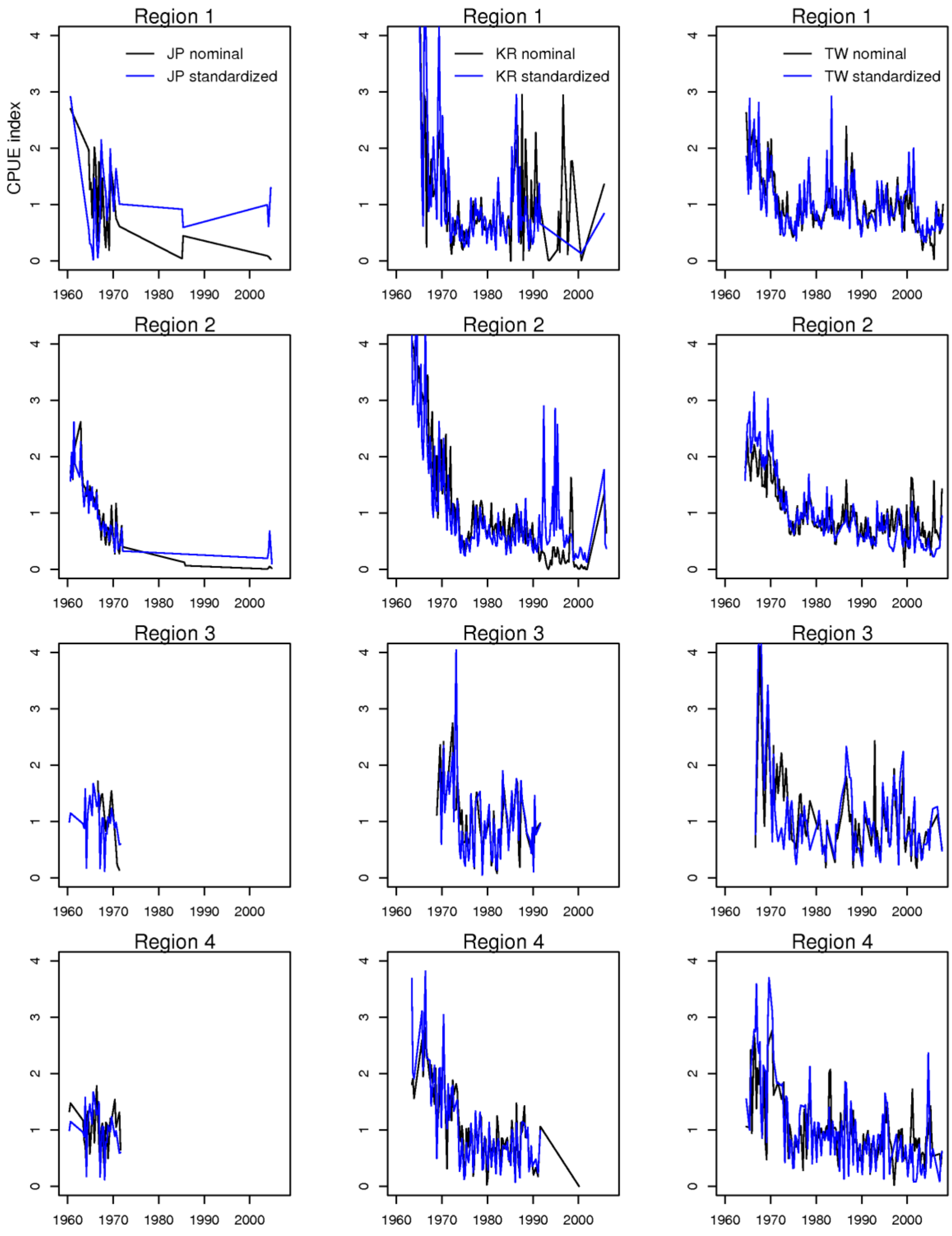

Figure 8. Diagnostics for Generalized Linear Model fits for standardization of south Pacific albacore CPUE for the Taiwan distant-water fleet.

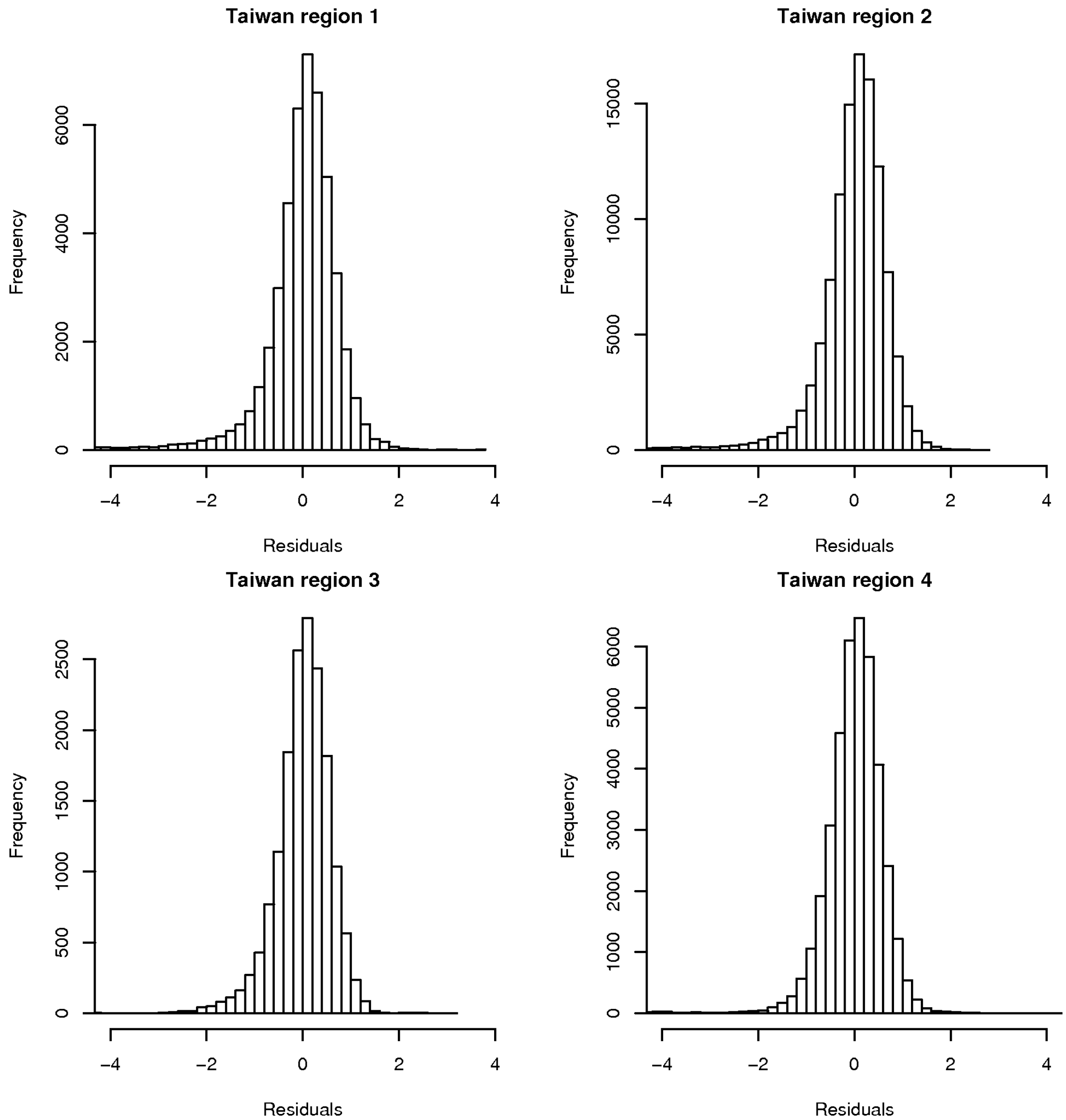

Figure 9. Comparison of standardized CPUE for south Pacific albacore from 2008 (Bigelow and Hoyle 2008) and 2009.

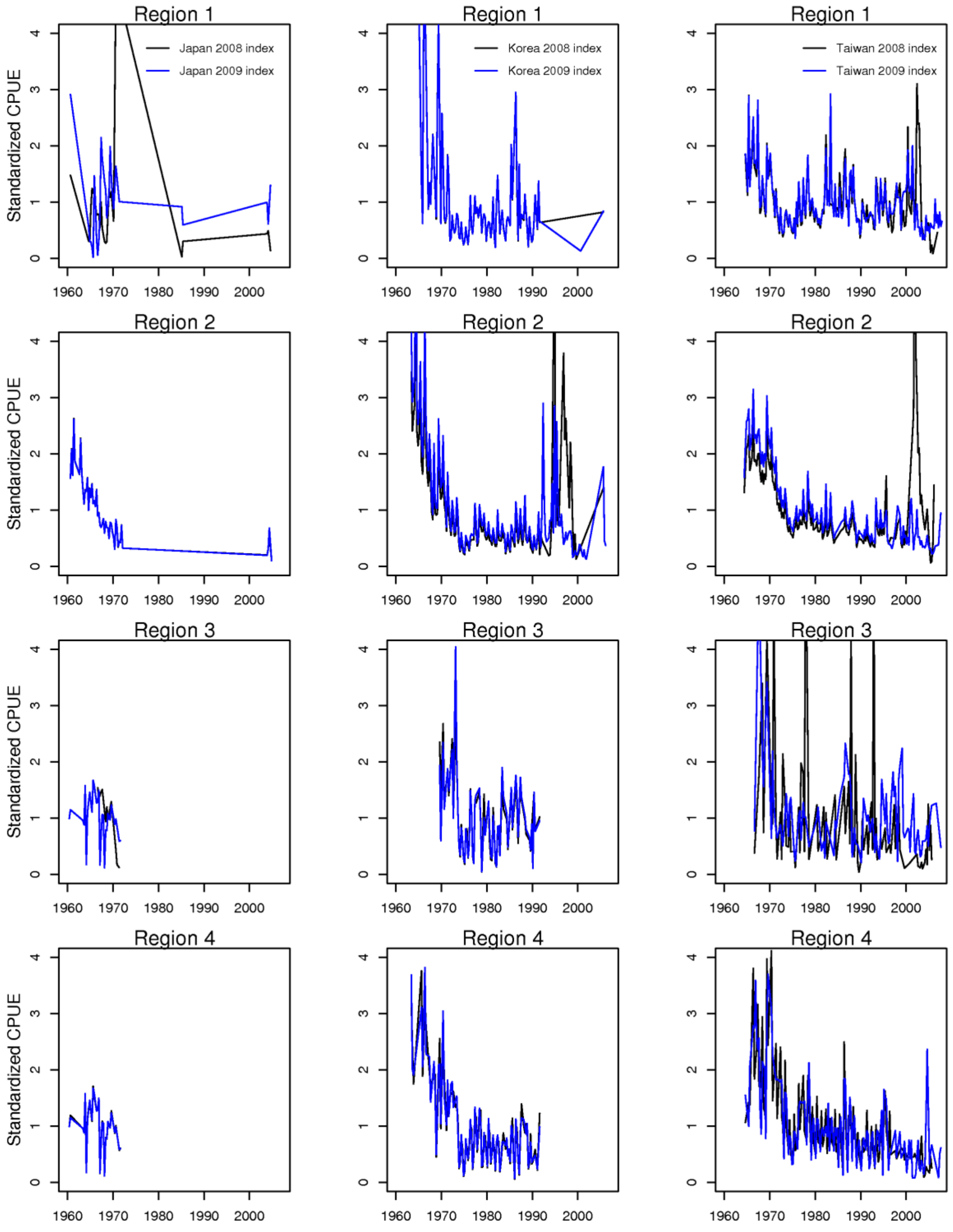

Figure 10. Comparison of nominal CPUE for fleets operating in various Pacific Islands and standardized CPUE for the Taiwan distant-water fleet.