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STANDARDIZED CPUE FOR DISTANT-WATER FLEETS TARGETING SOUTH PACIFIC ALBACORE

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1 Introduction

South Pacific albacore are primarily landed at canneries in Pago Pago, American Samoa and Levuka, Fiji. The Van Camp Sea Food Company and Star-Kist Samoa canneries opened in 1954 and 1963, respectively (Otsu and Sumida 1968, Yoshida 1975). The A. Samoa canneries have always been reliant on landings made by foreign flagged vessels and seven Japanese vessels landed albacore in 1954. Vessels from Korea initially landed albacore in 1958 and from Taiwan in 1964. Japan established fishing transshipment bases in Espiritu Santo, Vanuatu in 1958 and Levuka, Fiji in 1963 with the joint venture Pacific Fishing Company Limited (PAFCO). The PAFCO transshipment base was upgraded to a cannery in 1970 (Rajan 2005).

Longline catch and effort series represent the principal indices of relative abundance within the south Pacific albacore MULTIFAN-CL assessment (Langley and Hampton, 2005, 2006); however there have been temporal changes in the catchability of the distant-water longline fisheries. 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 to target yellowfin and bigeye tuna. Previous assessment indices were based on the compilation of nominal 5º-month aggregated data provided by distant-water fishing nations and logsheet data from domestic longline fisheries (Langley and Hampton 2005). The distant-water fleets have very different long term trends in unstandardized CPUE which is not consistent with all fisheries having constant catchability. In the MULTIFAN-CL assessment, catchability was assumed to be constant for Taiwan as this fleet has consistently targeted albacore over a long period using similar operational methods. Catchability for a composite Japan and Korea fleet was allowed to vary as a random walk and MULTIFAN-CL estimates very large changes in catchability for these fisheries (Langley and Hampton 2005).

This paper documents standardized CPUE indices (Hoyle et al. 2007) used in the 2008 assessment (Hoyle et al. 2008). This study developed indices of a distant-water fleets targeting albacore in the south Pacific Ocean (east of 110°W) by analysing an operational level dataset of vessels landing at the two major canneries (Pago Pago and Levuka) in the south Pacific. The approach used to estimate the Generalized Linear Model (GLM) indices is similar to approaches used for yellowfin and bigeye in the Western and Central Pacific Ocean (Langley et al. 2005).

2 Methods

2.1 Data compilation

Catch and effort data were compiled from individual vessels landing in Pago Pago, A. Samoa and Levuka, Fiji. Longline data submitted in Pago Pago were contributed to the National Marine Fisheries Service (NMFS) under a voluntary program of scientific monitoring. SPC Regional Logsheet forms were submitted by longliners landing in Levuka. The NMFS collection of catch and effort data was suspended in 2000, though port-sampling of albacore size data is still ongoing. Duplicate records were removed and only Japan, Korea and Taiwan flags were considered. A total of 1,163 Japan, Korea or Taiwan vessels reported landing fish in Pago Pago or Levuka from 1960 to 2007 (Table 1). These vessels conducted 8,909 trips (Table 2) and 475,019 sets with the Pago Pago dataset representing 95% of the sets. Data were spatially stratified into four regions at 25ºS and 180º for the stock assessment area (south of the equator, 140ºE−250ºW, Figure 1). Previous south Pacific albacore assessments (Langley and Hampton 2005, 2006) considered a four region spatial structure separated at 30ºS and 180º, though a stratification at 25ºS was conducted in this study on the basis of more consistent length-frequency distributions within regions (Langley and Hoyle 2008). Table 3 summaries the number of vessels, trips and sets by fleet for the entire assessment area and four regions.

2.2 Generalized linear models (GLM)

Generalized linear models were implemented in R and indices were calculated by quarter from 1960 to 2007. The dependant variable in the GLMs was the natural logarithm of albacore CPUE with a small constant (0.5) added to the catch. A robust Poisson distribution was also considered with catch as the dependent variable and effort (hooks) as an offset. Each longline set was weighted (1/sqrt(number of sets per trip)) because individual sets within a trip are often highly correlated. One objective of the study was to analyse vessels that consistently participated in the albacore fishery. A criterion was developed for a fleet:region which had 10,000 or more sets to include a vessel if it fished in four quarters or more. All vessels were used if a fleet:region had less than 10,000 sets.

A total of 10 predictors were used in the analysis and a detailed description is provided in Table 4. Predictors included time (year_quarter) as an index of relative abundance, location (latitude and longitude), unique vessel names and oceanographic variables of sea surface temperature and the depth of the 15º isotherm. Four interactions were considered based on location (latitude*longitude) or time and latitude/oceanography. The number of hooks between floats (HBF) is commonly included as an explanatory variable in GLM CPUE standardizations. Mean values of HBF were 8.7, 10.1 and 13.6 within the 1980s, 1990s and 2000; respectively. There was a moderate time-series increase in HBF, but this variable was not included in the GLMs as information was provided on only 21,415 (4.5%) of the sets.

A total of 12 GLMs were conducted as combinations of three fleets and four regions. Models were fit in a stepwise manner and if a significant interaction between month and latitude/oceanography occurred, no other time interactions were considered because of the high correlation between latitude and oceanography. The CPUE index was 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 GLMs for region 2, where the largest effort occurs, were also fit by aggregating fleets and comparing BIC values to the sum of individual fleets.

3 Results

3.1 Comparison of nominal catch, effort and CPUE between data sources

There are substantial spatial differences in catch, effort and CPUE between aggregated 5º-month data and operational level data from albacore targeting vessels (Figures 2−3) though comparisons occurred over different time periods because operational data preceded aggregated data for Korea (c.f. 1963 and 1975) and Taiwan (c.f. 1964 and 1967). Japan and Korea 5º-month data have high longline effort in the tropics reflecting yellowfin and bigeye targeting (Figure 2). The three albacore targeting fleets have a similar spatial area of overlap effort (Figure 3). These albacore fleets have high catches to the north of 20ºS and to the south of 30ºS, which reflects the known seasonal distribution of effort as lower latitudes are primarily fished during the 1st and 4th quarters and higher latitudes in the 2nd and 3rd quarters (Otsu and Sumida 1968, Yoshida 1975).

There is good coherence in nominal CPUE among albacore targeting fleets in comparison to aggregated 5º-month data (Figures 4−5). Nominal CPUE for aggregated 5º-month data in particular has little coherence among fleets and regions (Figure 4). CPUE trends from targeting fleets would be more similar if trends were normalized. Operational data reflect the cessation of targeted effort by Japan and Korea vessels after 1970 and 1990; respectively, whereas aggregated data indicate an increase in overall effort for Japan and Korea especially in region 2.

Operational data allow development of vessel specific trends, such as changes in vessel power. The annual number of sets per trip conducted by individual vessels targeting albacore increased from ~30 in the early 1960s to ~150 in 2000 (Figure 6). The increase in the number of sets per vessel corresponds to shift to a larger geographical area fished especially in the 1960s (Otsu and Sumida 1968) as longline sets occurred further from port. There was a concomitant increase in the number of hooks deployed per set which increased from ~1,300 in the early 1960s to a high of 3,850 in 2003 (Figure 7).

3.2 Generalized linear models (GLM)

A log-normal distribution was preferred to a robust Poisson distribution based on BIC values and model diagnostics. Other distributions (e.g. delta methods) could be considered in additional modelling efforts though performance may not be enhanced as individual longline sets were characterized by few zero catch (3.3%) observations.

Model results are provided in Table 5. Four of the 10 predictors were included in the 12 GLM formulations: the necessary relative abundance (year_quarter), vessel identification and interactions between month and latitude and latitude and longitude. The interaction between month and latitude was usually the 2nd model entry. None of the oceanographic predictors or interactions were included in the final model results. GLM results for region 2 indicated that aggregating fleets was not appropriate based on a comparison of BIC values of GLMs with individual fleets (Table 6).

Figure 8 illustrates a comparison of nominal and standardized year_quarter trends. Only Taiwanese vessels where actively targeting albacore through most of the time-series. The Japan time-series is short (~10 years) while the Korea time-series is of longer duration (~35 years). Standardized CPUE differed from nominal CPUE especially in regions 1 and 2. Standardized CPUE for the Korea fleet in region 2 was substantially higher than nominal CPUE from 1995 to 2000. Likewise standardized CPUE for the Taiwan fleet in regions 1 and 2 were substantially higher than nominal CPUE after 2000. Vessel effects are largely responsible for differences between nominal and standardized CPUE. Mean of year_quarter indices were incorporated into the 2008 albacore assessment (Hoyle et al. 2008.).

Figure 9 illustrates a comparison between current GLM indices and nominal indices used in the 2005 assessment (Langley and Hampton 2005). In general, the current GLM indices for Japan and Korea have less variability than the 2005 indices. The current Taiwan indices are similar to the 2005 indices which is expected as the Taiwan fleet has consistently targeted south Pacific albacore. Taiwan indices for all regions were highest in the 1960s, declined moderately until 1975 with a smaller decline thereafter. Low latitude regions (1 and 2) had high standardized CPUE since 2000 which was not apparent at high latitude regions (3 and 4).

4 Discussion

Previous south Pacific albacore assessments have used nominal CPUE based on aggregated 5°-month distant-water fleets and nominal CPUE from logsheet data of domestic longline fisheries. CPUE indices from Taiwan have been preferentially weighted as more informative given longer fishery participation and the ability to fish over a larger spatial area than domestic fleets. The present study refined the assessment indices by: 1) defining albacore targeting fleets and 2) applying standardization methods, especially with the use of vessel effects. The coherence in nominal and standardized CPUE indices in the present study is encouraging as albacore time-series trends based on aggregated data are often dissimilar between fleets. Defining albacore targeting fleets should prove beneficial in the assessment as catchability can be assumed to be constant. Additional work in developing indices could incorporate logsheet data from Korea vessels fishing and landing in French Polynesia from 1984 to 2001. Operational data would be beneficial in modelling individual vessel behaviour in targeting south Pacific albacore.

This study briefly considered statistical aggregation of fleets and additional modelling could be conducted as aggregating fleets would effectively reduce the numbers of assessment parameters; however, it may not be advisable to aggregate fleets due to their use in the assessment. Size data distributions vary among fleets (Langley and Hoyle 2007), potentially indicating different fishing practices and selectivities. Therefore the stock assessment model may have to separate the fleets and reconsideration should be given to aggregating fleets. Different selectivities among fleets (Hoyle and Langley 2008) also imply different catchabilities for fully selected age-classes. Different selectivities also suggest that there might be differences in the timing and degree of CPUE trends, given that slightly different parts of the population are being harvested. It may be useful to provide CPUE trends for separate fleets, though debatable whether they may be considered as independent abundance indices. To some extent the separate indices experience the same biases, with technological improvements and price signals largely shared amongst fleets. Other types of effects may be more independent, such as trends in the quality and experience of skippers and crew. Finally, the separation or aggregation of fleets has implications for how the CV's are treated within the assessment, for example, separating indices constitutes some lack of independence and the assessment may have to increase the CV of index when multiple indices are being used.

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Table 1. Unique albacore targeting vessels by flag landing in Pago Pago, American Samoa or Levuka, Fiji from 1960 to 2007 by assessment region.

	Region				Total
Fleet	1	2	3	4	
Japan	50	175	27	91	182
Korea	276	370	174	261	380
Taiwan	362	535	128	339	601

Table 2. Number of trips by albacore targeting vessels and flag landing in Pago Pago, American Samoa or Levuka, Fiji from 1960 to 2007. AS=American Samoa, CK=Cook Islands, CN=China, FJ=Fiji, ID=Indonesia, JP=Japan, KR=Korea, NC=New Caledonia, NU=Niue, PA=Palau, TO=Tonga, TW=Taiwan and VU=Vanuatu. Data in bold were used to develop distant-water fleets targeting south Pacific albacore.

Flag	AS	CK	CN	FJ	ID	JP	KR	NC	NU	PA	TO	TW	VU
Return Pago	1674	310	9	0	0	1067	4177	0	1	8	30	3338	167
Return Levuka	0	1	135	256	1	0	6	2	0	0	3	321	37
Total	1674	311	144	256	1	**1067**	**4183**	2	1	8	33	**3659**	204

Table 3. 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	5,120	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	59	0	181	92	0	10,709	4,746
1982	0	85	58	0	141	106	0	8,075	6,270
1983	0	50	19	0	88	25	0	5,407	1,336
1984	0	40	25	0	77	42	0	5,634	2,926
1985	2	47	30	2	106	49	81	7,319	3,028
1986	0	51	51	0	107	106	0	6,718	6,499
1987	0	50	48	0	94	121	0	6,318	7,402
1988	0	48	51	0	98	108	0	5,629	5,973
1989	0	42	31	0	78	48	0	4,228	2,810
1990	0	33	25	0	65	37	0	2,862	2,239
1991	0	11	34	0	12	54	0	787	3,703
1992	0	8	38	0	8	59	0	254	3,824
1993	0	6	47	0	6	99	0	224	5,755
1994	0	8	42	0	8	72	0	301	4,495
1995	0	10	30	0	10	68	0	281	3,873
1996	0	7	23	0	7	37	0	159	2,262
1997	0	5	12	0	6	22	0	217	1,416
1998	0	11	26	0	16	37	0	705	1,930
1999	0	6	14	0	6	15	0	163	912
2000	0	0	6	0	0	8	0	0	468
2001	0	0	11	0	0	13	0	0	592
2002	0	0	15	0	0	17	0	0	1,060
2003	1	0	19	1	0	24	32	0	2,138
2004	1	0	27	5	0	33	59	0	2,344
2005	0	1	12	0	1	16	0	30	1,168
2006	0	0	3	0	0	3	0	0	69
2007	0	0	3	0	0	3	0	0	296

Table 3 (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	9	77	0	180
1965	8	2	6	13	2	6	112	21	78
1966	19	5	37	28	5	37	405	108	990
1967	22	10	57	30	11	57	378	223	1,313
1968	11	3	44	11	3	44	150	23	981
1969	3	20	41	3	26	41	8	521	1,102
1970	3	33	55	3	41	55	20	542	1,706
1971	1	13	46	1	15	46	2	176	1,887
1972	0	15	41	0	16	41	0	399	1,141
1973	0	78	59	0	108	59	0	1,893	1,831
1974	0	92	44	0	125	44	0	2,880	1,455
1975	0	79	30	0	115	30	0	3,040	811
1976	0	62	16	0	91	16	0	2,369	380
1977	0	64	15	0	79	15	0	2,299	379
1978	0	58	5	0	100	5	0	2,667	174
1979	0	48	9	0	74	9	0	1,948	326
1980	0	33	22	0	44	22	0	1,744	678
1981	0	45	21	0	53	21	0	1,854	608
1982	0	38	20	0	50	20	0	1,864	1,375
1983	0	19	4	0	24	4	0	997	138
1984	0	23	5	0	24	5	0	647	475
1985	1	13	5	1	19	5	41	470	303
1986	0	14	13	0	16	13	0	380	373
1987	0	13	25	0	13	25	0	118	1,219
1988	0	16	43	0	17	43	0	389	3,051
1989	0	22	21	0	23	21	0	694	1,029
1990	0	20	6	0	29	6	0	1,327	450
1991	0	5	6	0	5	6	0	117	416
1992	0	0	11	0	0	11	0	0	556
1993	0	2	26	0	2	26	0	59	2,592
1994	0	0	23	0	0	23	0	0	2,321
1995	0	3	21	0	3	21	0	40	2,373
1996	0	3	17	0	3	17	0	66	1,062
1997	0	1	9	0	1	9	0	4	646
1998	0	3	12	0	3	12	0	160	707
1999	0	0	1	0	0	1	0	0	92
2000	0	0	3	0	0	3	0	0	281
2001	0	0	7	0	0	7	0	0	349
2002	0	0	7	0	0	7	0	0	347
2003	1	0	4	1	0	4	16	0	150
2004	1	0	8	3	0	8	32	0	486
2005	0	1	5	0	1	5	0	27	224
2006	0	0	2	0	0	2	0	0	68
2007	0	0	3	0	0	3	0	0	296

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	4,645	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	39	20	0	72	32	0	3,236	1,303
1985	1	46	26	1	92	32	40	4,098	1,389
1986	0	50	46	0	99	85	0	4,126	3,163
1987	0	46	44	0	84	86	0	3,911	2,634
1988	0	45	29	0	91	57	0	3,225	1,154
1989	0	40	18	0	71	27	0	1,594	838
1990	0	29	21	0	47	27	0	1,337	990
1991	0	11	28	0	11	40	0	584	1,868
1992	0	8	29	0	8	39	0	254	868
1993	0	6	29	0	6	44	0	165	1,217
1994	0	8	22	0	8	29	0	301	864
1995	0	10	9	0	10	10	0	241	210
1996	0	5	7	0	5	7	0	93	101
1997	0	5	5	0	6	6	0	213	161
1998	0	9	11	0	14	13	0	545	470
1999	0	6	12	0	6	13	0	163	423
2000	0	0	3	0	0	3	0	0	85
2001	0	0	4	0	0	4	0	0	195
2002	0	0	7	0	0	8	0	0	289
2003	1	0	10	1	0	13	16	0	902
2004	1	0	14	4	0	14	27	0	783
2005	0	1	7	0	1	9	0	3	315
2006	0	0	1	0	0	1	0	0	1
2007	0	0	0	0	0	0	0	0	0

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	3	0	21	3	0	835	168
1985	0	10	0	0	10	0	0	767	0
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	4	0	16	4	0	613	105
1990	0	4	3	0	4	3	0	88	124
1991	0	3	5	0	3	5	0	84	361
1992	0	0	6	0	0	8	0	0	378
1993	0	0	13	0	0	15	0	0	828
1994	0	0	14	0	0	14	0	0	553
1995	0	0	16	0	0	23	0	0	843
1996	0	0	11	0	0	11	0	0	405
1997	0	0	7	0	0	9	0	0	566
1998	0	0	12	0	0	12	0	0	480
1999	0	0	1	0	0	1	0	0	42
2000	0	0	2	0	0	3	0	0	71
2001	0	0	0	0	0	0	0	0	0
2002	0	0	7	0	0	7	0	0	196
2003	0	0	7	0	0	7	0	0	523
2004	0	0	9	0	0	9	0	0	747
2005	0	0	3	0	0	3	0	0	377
2006	0	0	0	0	0	0	0	0	0
2007	0	0	0	0	0	0	0	0	0

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	34	17	0	35	20	0	1,984	1,336
1986	0	29	39	0	31	46	0	1,737	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	15	0	29	17	0	1,327	838
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	32	0	0	2,022
1993	0	0	18	0	0	28	0	0	1,118
1994	0	0	11	0	0	12	0	0	757
1995	0	0	5	0	0	5	0	0	447
1996	0	0	5	0	0	6	0	0	694
1997	0	0	1	0	0	1	0	0	43
1998	0	0	4	0	0	4	0	0	273
1999	0	0	7	0	0	7	0	0	355
2000	0	0	1	0	0	1	0	0	31
2001	0	0	1	0	0	1	0	0	48
2002	0	0	4	0	0	5	0	0	228
2003	0	0	12	0	0	12	0	0	563
2004	0	0	6	0	0	6	0	0	328
2005	0	0	2	0	0	2	0	0	252
2006	0	0	0	0	0	0	0	0	0
2007	0	0	0	0	0	0	0	0	0

Table 4. Predictors used in the analysis of south Pacific albacore catch rate.

Predictor	Abbreviation	Type	Description
Year and quarter	year_quarter	Categorical	Year and quarter of longline set
Latitude	lat.loc	Continuous	Latitude at start of set
Longitude	lon.loc	Continuous	Longitude at start of set
Sea surface temperature	sst	Continuous	Estimated from SODA or GODAS OGCM
Depth of 15ºC isotherm	d15	Continuous	Estimated from SODA or GODAS OGCM
Vessel name	boat_ID	Categorical	Coded from vessel name
Interaction: latitude and longitude	lat5*lon5	Categorical	5º latitude*5º longitude
Interaction: month and SST	month*poly(sst, degree, 3)	Continuous	Month*3rd order polynomial smooth of SST
Interaction: month and depth of 15ºC isotherm	month*poly(d15, degree, 3)	Continuous	Month*3rd order polynomial smooth of 15º isotherm depth
Interaction: month and latitude	month*poly(lat.loc, degree, 3)	Continuous	Month*3rd order polynomial smooth of latitude

Table 5. Model selection results for fleet and region CPUE standardization models using residual deviance and Bayesian information criterion (BIC).

Japan fishery

Region 1, 1,282 sets, Null deviance=760.3

Predictor variable	Residual deviance	d.f.	Percent deviance explained	Deviance per parameter	BIC
Year_quarter	423.1	58	44.3	5.8	4553
Year_quarter lat5*lon5	163.7	27	78.5	7.0	3557

Region 2, 18,642 sets, Null deviance=2996.1

Predictor variable	Residual deviance	d.f.	Percent deviance explained	Deviance per parameter	BIC
Year_quarter	2082.4	48	30.5	19.0	45328
Year_quarter month*latitude	1520.6	44	49.2	16.0	39900
Year_quarter month*latitude lat5*lon5	1403.3	61	53.2	10.4	39004
Year_quarter month*latitude lat5*lon5 boat_ID	1342.4	78	55.2	7.2	38942

Region 3, 687 sets, Null deviance=33.5

Predictor variable	Residual deviance	d.f.	Percent deviance explained	Deviance per parameter	BIC
Year_quarter	22.1	11	34.2	1.0	950
Year_quarter lat5*lon5	16.0	22	52.3	0.5	872

Region 4, 8,819 sets, Null deviance=454.5

Predictor variable	Residual deviance	d.f.	Percent deviance explained	Deviance per parameter	BIC
Year_quarter	392.0	29	13.7	2.2	14000
Year_quarter lat5*lon5	298.9	33	34.2	2.5	11907

Korea fishery

Region 1, 24,779 sets, Null deviance=6887.7

Predictor variable	Residual deviance	d.f.	Percent deviance explained	Deviance per parameter	BIC
Year_quarter	5486.2	96	20.3	14.6	85690
Year_quarter month*latitude	3467.5	44	49.7	24.4	74766
Year_quarter month*latitude lat5*lon5	3148.2	36	54.3	21.2	72737
Year_quarter month*latitude lat5*lon5 boat_ID	2952.8	138	57.1	12.5	72545

Region 2, 143,164 sets, Null deviance=34738.9

Predictor variable	Residual deviance	d.f.	Percent deviance explained	Deviance per parameter	BIC
Year_quarter	23215.0	137	33.2	84.1	442289
Year_quarter month*latitude	15998.1	44	53.9	103.5	389506
Year_quarter month*latitude lat5*lon5	13941.5	80	59.9	79.7	370757
Year_quarter month*latitude lat5*lon5 boat_ID	13182.8	259	62.1	41.5	365820

Region 3, 11,375 sets, Null deviance=780

Predictor variable	Residual deviance	d.f.	Percent deviance explained	Deviance per parameter	BIC
Year_quarter	577.2	62	26.0	3.3	23169
Year_quarter month*latitude	482.3	44	38.2	2.8	21535
Year_quarter month*latitude lat5*lon5	472.5	21	39.4	2.4	21499
Year_quarter month*latitude lat5*lon5 boat_ID	440.3	83	43.5	1.6	21471

Region 4, 41,419 sets, Null deviance=3669.9

Predictor variable	Residual deviance	d.f.	Percent deviance explained	Deviance per parameter	BIC
Year_quarter	2527.8	91	31.1	12.6	91344
Year_quarter month*latitude	2050.3	44	44.1	12.0	83139
Year_quarter month*latitude boat_ID	1947.8	170	46.9	5.6	82823

Taiwan fishery

Region 1, 29,404 sets, Null deviance=4023.8

Predictor variable	Residual deviance	d.f.	Percent deviance explained	Deviance per parameter	BIC
Year_quarter	2986.6	151	25.9	6.9	79820
Year_quarter month*latitude	2351.6	44	41.7	8.6	73244
Year_quarter month*latitude lat5*lon5	2225.6	33	44.8	7.9	71964
Year_quarter month*latitude lat5*lon5 boat_ID	2110.2	145	47.7	5.1	71891

Region 2, 101,955 sets, Null deviance=10612.4

Predictor variable	Residual deviance	d.f.	Percent deviance explained	Deviance per parameter	BIC
Year_quarter	8125.9	156	23.4	15.9	239002
Year_quarter month*latitude	7432.6	44	30.0	15.9	230417
Year_quarter month*latitude boat_ID	6899.1	361	35.0	6.6	226987
Year_quarter month*latitude boat_ID lat5*lon5	6751.7	69	36.4	6.1	225580

Region 3, 9,502 sets, Null deviance=768.6

Predictor variable	Residual deviance	d.f.	Percent deviance explained	Deviance per parameter	BIC
Year_quarter	466.6	85	39.3	3.6	20391
Year_quarter boat_ID	353.2	115	54.0	2.1	18799
Year_quarter boat_ID month*latitude	318.1	37	58.6	1.9	18142
Year_quarter boat_ID month*latitude lat5*lon5	309.0	22	59.8	1.8	18069

Region 4, 33,475 sets, Null deviance=2428.6

Predictor variable	Residual deviance	d.f.	Percent deviance explained	Deviance per parameter	BIC
Year_quarter	1712.4	127	29.5	5.6	70376
Year_quarter boat_ID	1554.1	149	36.0	3.2	68683
Year_quarter boat_ID month*latitude	1371.8	44	43.5	3.3	64964
Year_quarter boat_ID month*latitude lat5*lon5	1344.1	51	44.7	2.9	64812

Table 6. Model comparisons of aggregating albacore targeting fleets and sum of individual fleets. Lower Bayesian information criterion (BIC) indicates better model performance.

Japan fishery	
Region 2, 18,642 sets, Null deviance=2996.1	
Predictor variable	BIC
Year_quarter month*latitude lat5*lon5 boat_ID	38,942
Korea fishery	
Region 2, 143,164 sets, Null deviance=34738.9	
Year_quarter month*latitude lat5*lon5 boat_ID	365,820
Taiwan fishery	
Region 2, 101,955 sets, Null deviance=10612.4	
Year_quarter month*latitude boat_ID lat5*lon5	225,580
Aggregate fisheries	
Japan-Korea fishery	406,245
Korea-Taiwan	611,216
Japan-Taiwan	265,623
Japan-Korea -Taiwan	639,844
Sum of individual fisheries	
Japan-Korea fishery	404,762
Korea-Taiwan	591,400
Japan-Taiwan	264,522
Japan-Korea -Taiwan	630,342

Figure 1. Boundaries of four stock assessment regions for south Pacific albacore and locations (stars) of Pago Pago, American Samoa and Levuka, Fiji canneries.

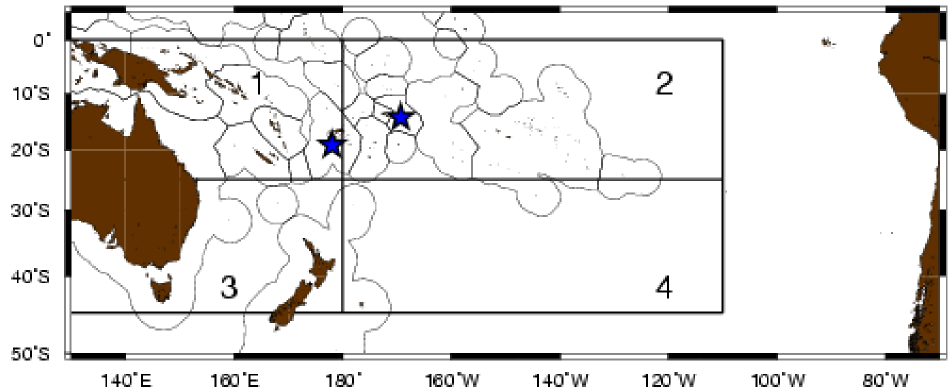

Figure 2. Spatial effort, catch and CPUE for three distant-water fleets based on aggregated 5º-month data.

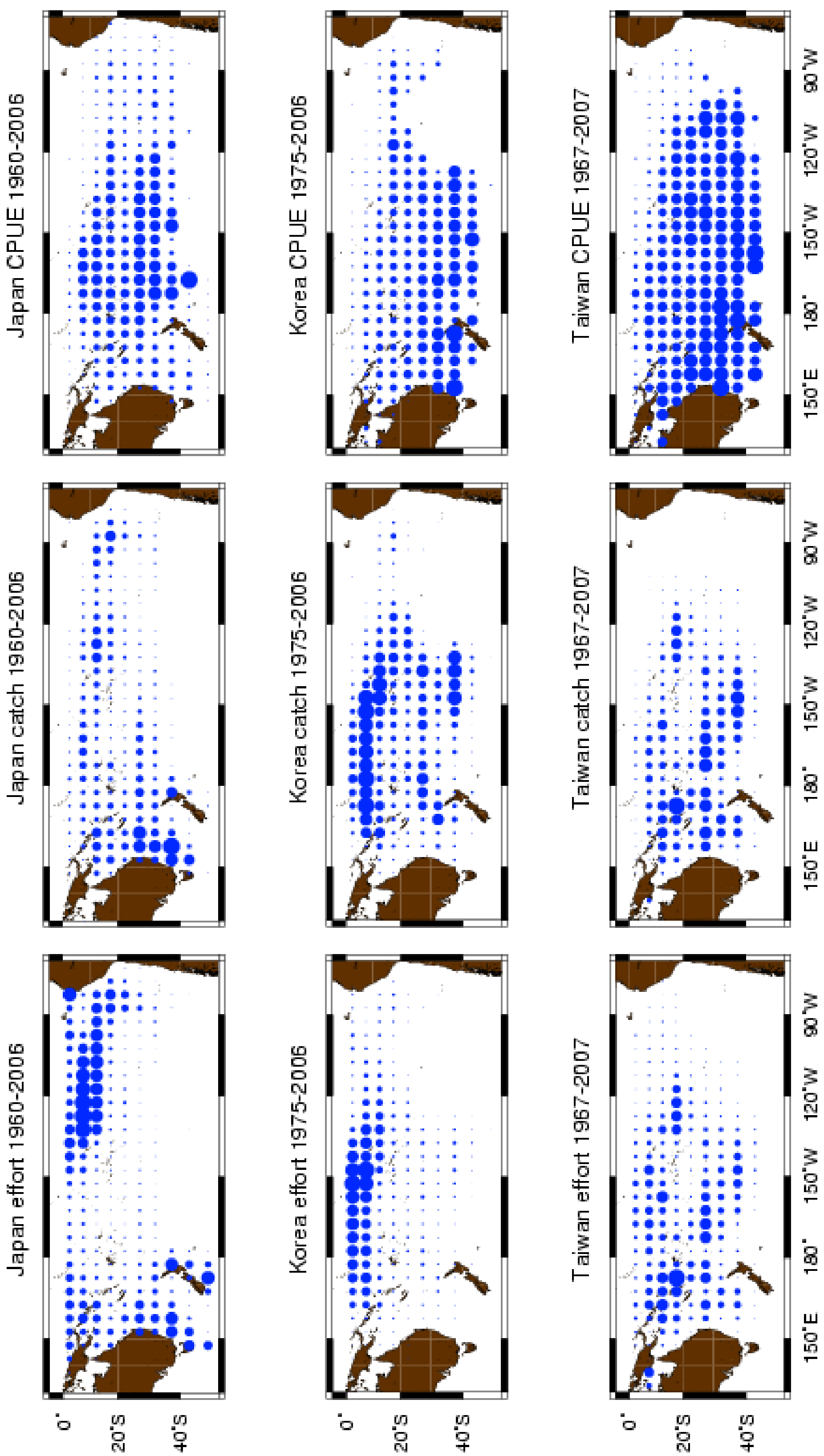

Figure 3. Spatial effort, catch and CPUE for three distant-water fleets targeting albacore based on logsheet data submitted in Pago Pago, American Samoa and Levuka, Fiji.

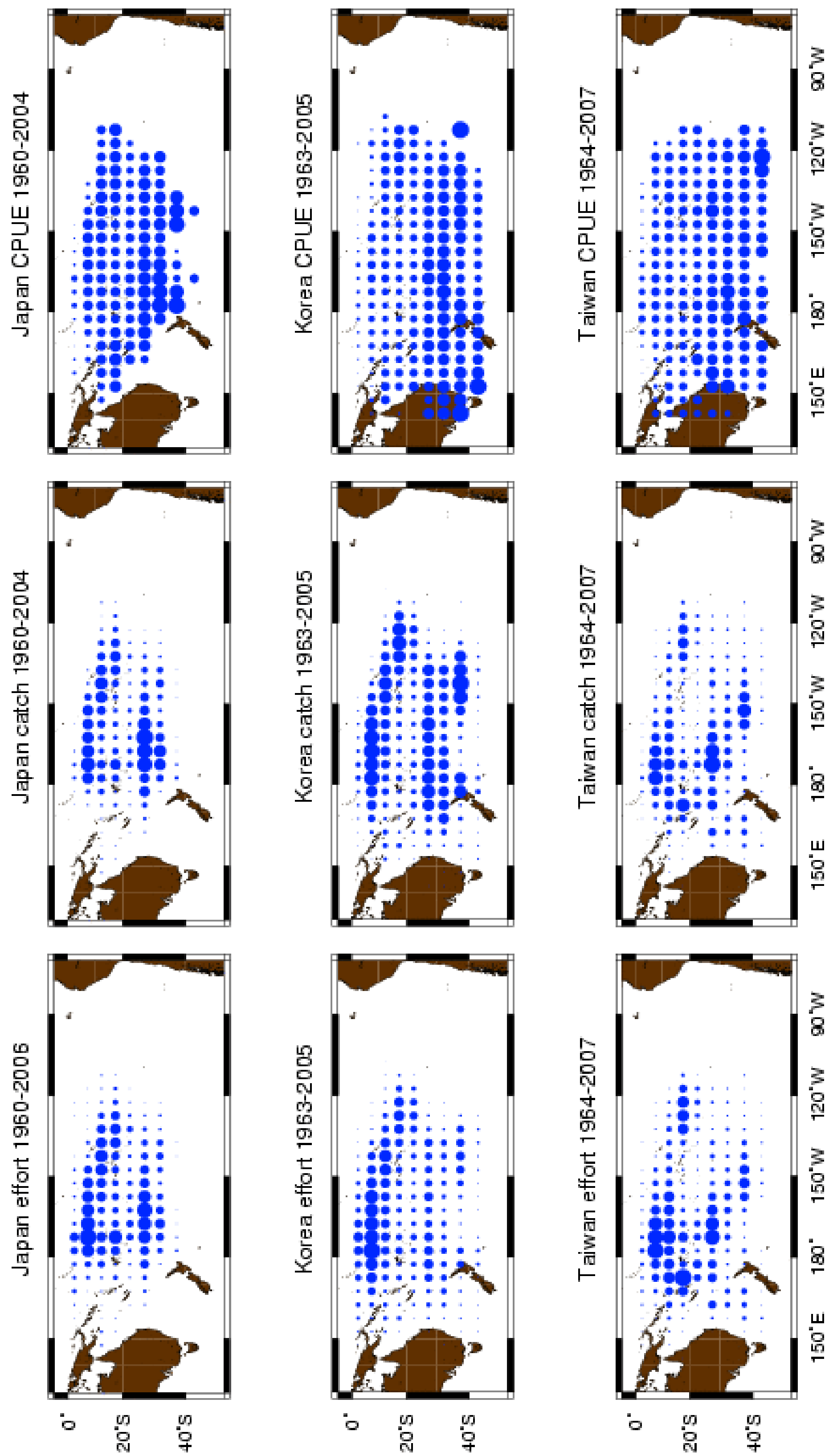

Figure 4. Four region comparison of nominal catch, effort and CPUE for three distant-water fleets and four regions based on aggregated 5º-month data.

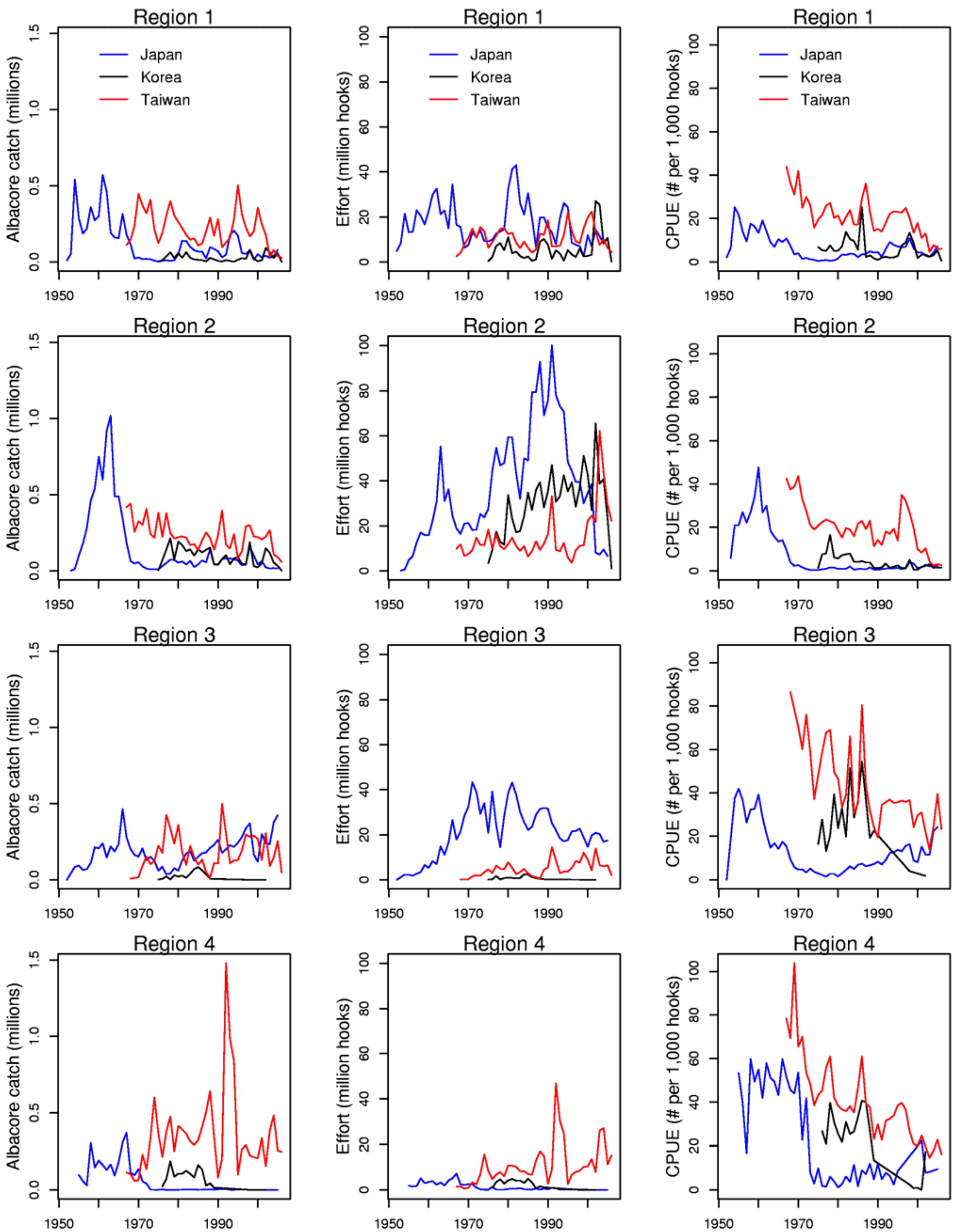

Figure 5. Four region comparison of nominal catch, effort and CPUE for three distant-water fleets targeting albacore based on logsheet data submitted in Pago Pago, American Samoa or Levuka, Fiji.

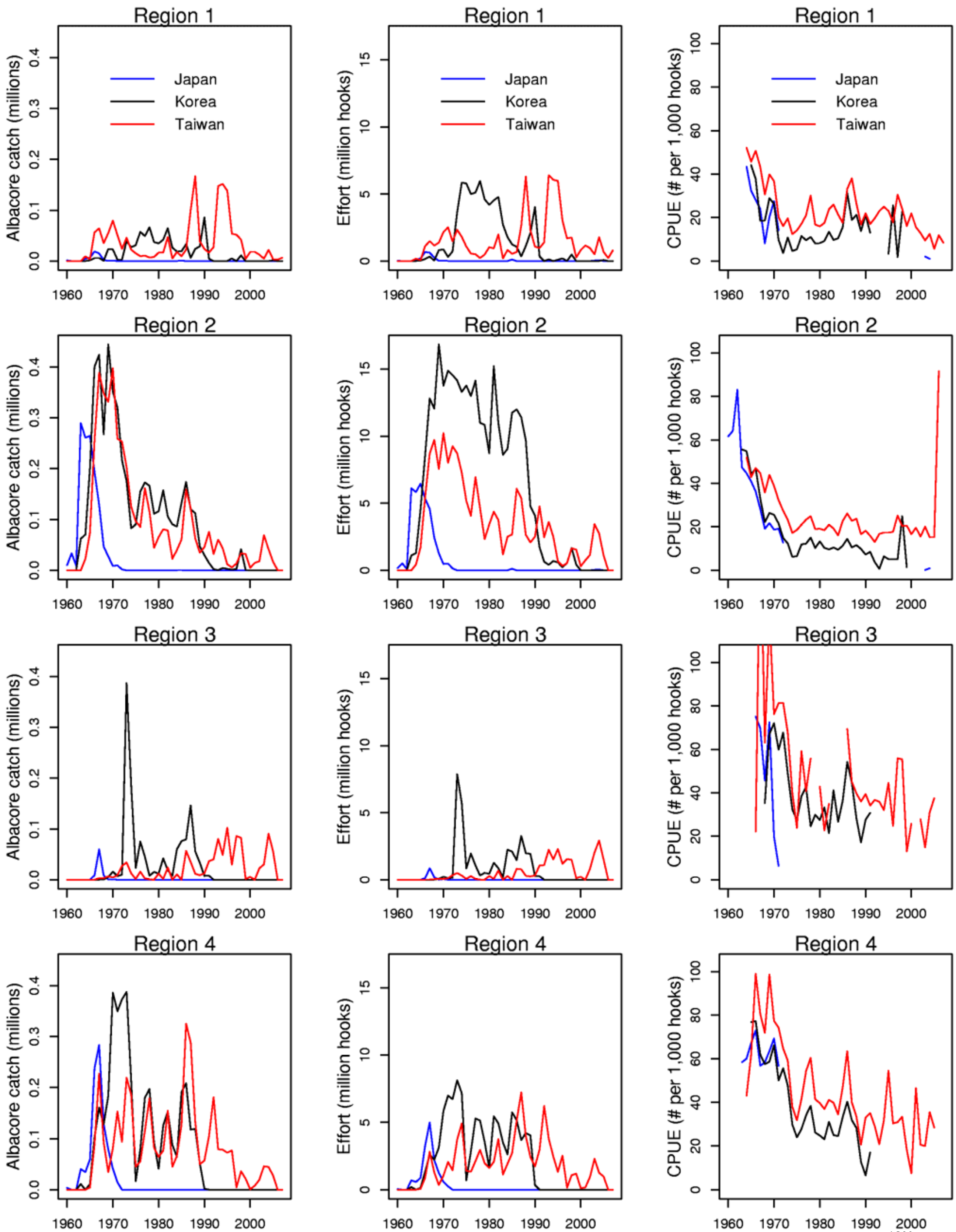

Figure 6. Boxplot of the annual number of sets per trip conducted by individual distant-water vessels targeting albacore.

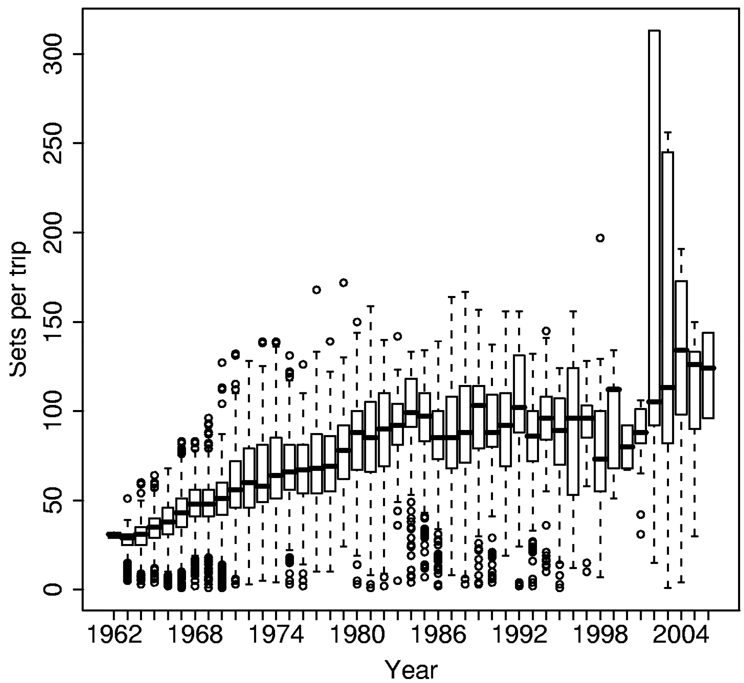

Figure 7. Boxplot of the annual number of hooks per set conducted by individual distant-water vessels targeting albacore.

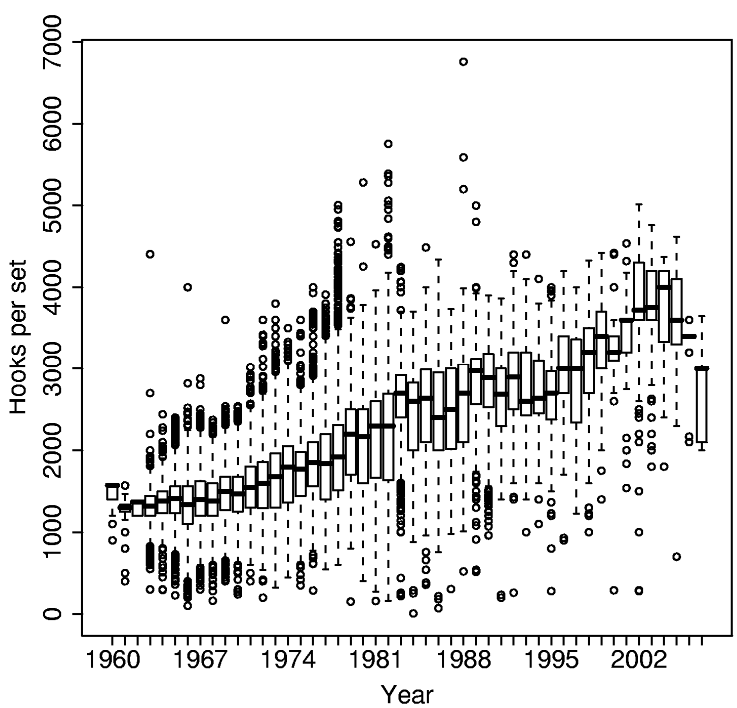

Figure 8. Comparison of normalized year:quarter nominal and standardized CPUE indices.

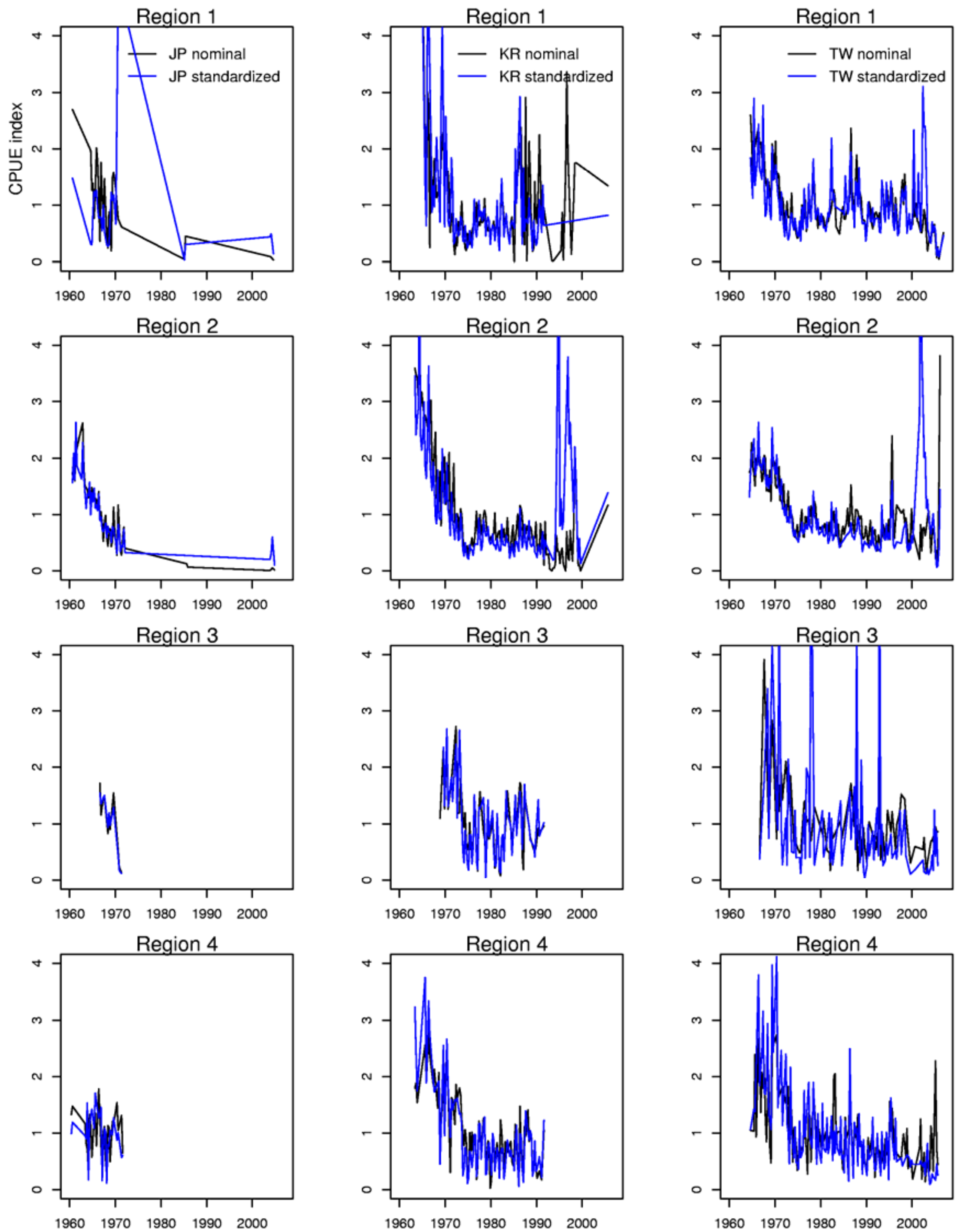

Figure 9. Comparison of normalized year:quarter standardized indices and indices used in the 2005 (Langley and Hampton 2005) south Pacific albacore assessment.