Received: 8 October 2015

Updated CPUE standardizations for bigeye and yellowfin tuna caught by Taiwanese longline fishery in the Indian Ocean using generalized linear model

Yu-Min Yeh[1] and Shu-Ting Chang[2]

[1]Department of Tourism Management and Master Program of Leisure Environment Management, Nanhua University, 55, Sec. 1, Nanhu Rd. Chung Keng Li, Dalin, Chiayi 62248, Taiwan

[2]Overseas Fisheries Development Council il of the Republic of China, 3F, No, 14, Wenzhou St., Da'an Dist., Taipei 106, Taiwan (R.O.C.)

Abstract

Updated 2012 and 2013 Taiwanese longline fishery data was used in this analysis. Cluster analysis was used to classify longline sets in relation to species composition of the catches to understand whether cluster analysis could identify distinct fishing strategies. Bigeye and Yellowfin tuna CPUE standardization were presented. All analyses were performed by the approaches used by the collaborative workshop of longline data and CPUE standardization for bigeye and yellowfin tuna held in March and April 2015 in Taipei.

Introduction

It has been noted that the CPUE trend of longline fishery for bigeye in the Indian Ocean is considerably different between Taiwan and Japan at WPTT and Scientific committee of IOTC (Anonymous 2013a). Lot of efforts devoted to deal with the issues from various point of views, including data quality, data management system, analytic methods, etc. (Anonymous, 1998; OFDC, 2013; Hoyle S., 2014; Okamoto H., 2014; Yeh, 2014). In March and April 2015 a collaborative study was conducted between national scientists with expertise in Japanese, Taiwanese, and Korean longline fleets, and an independent scientist, Dr. Simon Hoyle. The workshop addressed Terms of Reference covering several important and longstanding issues related to the bigeye and yellowfin tuna CPUE indices in the Indian Ocean, based on data from the Japanese and Taiwanese fleets. Data from the Korean longline fleet were also considered, as a valuable source of independent information (IOTC, 2015).

In this analysis, a framework analysis suggested by the collaborative study was conducted using updated Taiwanese operational data

Materials and methods

In this analysis, operational catch and effort data with 5 degree by 5 degree resolution from the logbooks of Taiwanese longline fishery from 1979-2013 was used, which was provided by

Overseas Fisheries Development Council (OFDC). Updated 2012 and 2013 data relative to the data used in the collaborative work (IOTC, 2015) held in this year was included in this analysis. Data preparation and cleaning were performed by adopting the suggestions made by the collaborative work (IOTC, 2015). Each set was allocated to a yellowfin region (consistent with the definitions in the yellowfin stock assessment, Langley et al. 2012, Figure 1)

Cluster analysis

There were 6 approaches applied to cluster the data in the collaborative work. We adopted one of them, the hierarchical clustering method Ward hclust (IOTC, 2015). Analyses used species composition to group the data. The data were transformed by centering and scaling, so as to reduce the dominance of species with higher average catches. Aggregating the data tends to reduce the variability, and therefore reduce misallocation of sets. For this analysis we aggregated the data by vessel-month, assuming that individual vessels tend to follow a consistent fishing strategy. More detailed information can be referred to the collaborative work report (IOTC, 2015).

CPUE standardization

CPUE standardization methods followed the approaches used by the collaborative work (IOTC,2015) for Taiwanese fleet. Analyses were conducted separately for each region, and for bigeye and yellowfin. Each model was run on a computer with 16GB of memory. The following model was used:

$$\ln(CPUEs+k) \sim yrqtr+vessid+latlong5+f(hooks)+\text{bait1}+\text{bait2}+\text{bait3}+\text{bait4}+\text{bait5}+h(moon)+\epsilon$$

The constant k, added to allow for modeling sets with zero catches of the species of interest, was 10% of the mean CPUE for all sets. The functions f() and h() were cubic splines, with 11 and 4 degrees of freedom respectively. The categorical variables (bait1,bait2, bait3, bait4, and bait5) indicating the use of 5 bait types (Pacific saury, mackerel, squid, milkfish, and other species. The variable ‘moon’ was the lunar illumination on the day of the set.

For the final analyses, data were prepared by selecting operational data by region, for vessels that had fished for 8 quarters in that region. Data in GLM were ‘area-weighted’, with the weights of the sets adjusted so that the total weight per year-quarter in each 5 degree square would sum to 1.

For both species for the GLMs, model fits were examined by plotting the residual densities and using Q-Q plots.

The operational data were standardized using generalized linear models in R. All analyses were basically performed by R source code freely shared by Simon Hoyle in the collaborative work.

Results and Discussions

Updated 2012 and 2013 relative to the data used in the collaborative work

Data coverage was 78% in 2012 and 25% in 2013 for the collaborative analysis. Data coverage was 91% in 2012 and 71% in 2013 for this analysis. Figure 2 and Figure 3 show the difference in information shown in the two data sets. There was minor difference in 2012, but significant difference in 2013.

Output of Cluster analysis

The aims of the cluster analysis were to identify whether cluster analysis could identify distinct fishing strategies in each region; secondly to use the cluster analysis to identify these fishing strategies in the data for each region, and so to better understand the fishing practices.

In region 2 and 5, identified 3 clusters as the number with the most support (Figure 5 ~ 8), However, using cluster analysis to identify bigeye and yellowfin targeting is challenging, since targeting is probably less an either/or strategy than a mixture of variables that shift the species composition one way or the other (Table 1).

In region 3, identified 3 clusters as the number with the most support (Figure 9 ~ 10), we found that species composition averaging 93% 'other' in one cluster, 82% albacore in another cluster, and a mix of bigeye, yellowfin, albacore and swordfish in a third cluster were identified at the trip level by hcltrip, suggesting that oilfish targeting can represent the majority of the catch (Table 1).

In region 4, identified 4 clusters as the number with the most support (Figure 11 ~ 12), we found that species composition averaging 86% albacore in one cluster, a mix of 58% albacore and 26% 'other' in another cluster, a mix of bigeye, yellowfin, albacore and swordfish in a third cluster, and a mix of 52% albacore and 14% bigeye in a forth cluster, were identified at the trip level by hcltrip (Table 1).

Cpue series and comparison with the collaborative work.

We compared the bigeye and yellowfin CPUE indices estimated in this analysis and estimated in the collaborative work for region 2 and region 5 (Figure 12). These indices by species by region were generally very similar except more CPUE values available in recent quarters. (Figure 13).

The bigeye and yellowfin CPUE indices for region 3 and region 4 estimated in this analysis were shown in Figure x.

For both species for the GLMs, model fits were presented by plotting the residual densities and using Q-Q plots (Figure 14 and Figure 15).

References

Anonymous (1998). Critical review of the data collection and processing system of Chinese

Taipei, and revision of statistics for its LL fleet (Taipei, July 1997). SCRS/97/017, ICCAT: 141-204.

Hoyle S. (2014). Spatial considerations in bigeye and yellowfin CPUE from Japanese and Taiwan,China longline fisheries in the Indian Ocean (Hoyle S). Working Party on Tropical Tuna, Indian Ocean Tuna Commission. IOTC–2014–WPTT16–25.

IOTC (2015). Report of the 2nd CPUE Workshop on Longline Fisheries. IOTC–2015–CPUEWS02–R[E]

Indian Ocean. Working Party on Tropical Tuna, Indian Ocean Tuna Commission. IOTC–2014–WPTT16–28.

Langley, A., M. Herrera and J. Million (2012). Stock assessment of yellowfin tuna in the Indian Ocean using MULTIFAN-CL. Working Party on Tropical Tuna, Indian Ocean Tuna Commission. IOTC–2012–WPTT14–38 Rev_1.

Lee, Y.-C. and H.-C. Liu (1996). The tuna statistics procedures of Taiwan longline and gillnet Fisheries in the Indian Ocean." IPTP Collective Volumes(9): 368-369.

Okamoto H (2014). Provisional analysis on comparison of CPUE trend of bigeye and yellowfin tuna between Japanese and Taiwan-China longline fisheries based on whole and shared strata in the Overseas Fisheries Development Council (2013). Data Collection and Processing System of Statistics for the Taiwanese Deep-Sea Longline Fishery. IOTC Working Party on Tropical Tunas (WPTT) 15. San Sebastian, Spain. IOTC–2013–WPTT15–40 Rev_1.

Yeh, Y.-M. (2014). Preliminary analysis of Taiwanese longline fisheries based on operational catch and effort data for bigeye and yellowfin tuna in the Indian Ocean. Working Party on Tropical Tuna, Indian Ocean Tuna Commission. IOTC–2014–WPTT16–42.

Table 1. For Taiwanese effort in the region 2, 3, 4, and 5, average percentage of each species per set, by cluster, as estimated by cluster analysis.

Region	Cluster	Albacore	Bigeye tuna	Yellowfin tuna	Other tuna	Swordfish	Strip marlin	Blue marlin	Black marline	Other billfish	Skipjack	Shark	Other fishes	Southern Bluefin tuna
2	1	2.1%	43.8%	20.7%	0.1%	10.5%	2.5%	3.6%	0.4%	1.6%	0.3%	4.6%	9.1%	0.6%
	2	0.8%	63.3%	17.0%	0.0%	8.7%	1.1%	2.2%	0.1%	0.2%	0.0%	1.3%	5.1%	0.0%
	3	0.9%	37.6%	46.6%	0.0%	6.4%	1.0%	1.7%	0.1%	0.4%	0.0%	1.5%	3.8%	0.0%
3	1	81.7%	4.3%	6.1%	0.0%	1.6%	0.3%	0.4%	0.0%	0.1%	0.0%	0.8%	4.4%	0.1%
	2	14.8%	38.3%	17.3%	0.1%	13.7%	1.0%	1.0%	0.2%	0.7%	0.2%	4.2%	7.5%	0.9%
	3	3.0%	1.0%	0.6%	0.0%	0.7%	0.0%	0.0%	0.0%	0.0%	0.0%	1.1%	93.1%	0.3%
4	1	86.0%	6.9%	2.9%	0.0%	1.2%	0.3%	0.2%	0.0%	0.1%	0.1%	0.5%	1.2%	0.5%
	2	26.2%	32.1%	17.4%	1.4%	11.0%	1.5%	1.1%	0.3%	0.8%	1.1%	2.0%	3.6%	1.4%
	3	58.0%	5.4%	2.1%	0.0%	1.6%	0.1%	0.1%	0.0%	0.1%	0.0%	2.5%	26.1%	3.9%
	4	52.3%	13.9%	3.1%	0.0%	2.6%	0.2%	0.2%	0.0%	0.1%	0.1%	0.9%	3.8%	22.8%
5	1	1.5%	68.7%	15.1%	0.0%	5.1%	2.0%	2.2%	0.4%	0.3%	0.1%	1.4%	3.1%	0.1%
	2	8.5%	42.4%	9.5%	0.2%	4.5%	0.8%	2.3%	0.3%	0.7%	0.3%	9.1%	21.3%	0.0%
	3	0.9%	35.5%	38.1%	0.0%	5.7%	8.9%	4.3%	1.5%	1.0%	0.1%	2.5%	1.4%	0.1%

-

Table 2. Standardized bigeye and yellowfin tuna CPUE indices by regions and year-quarter based on Taiwanese operational data from 1979 to 2013.

Year-Qtr	BET Region 2	BET Region 3	BET Region 4	BET Region 5	Year-Qtr	YFT Region 2	YFT Region 3	YFT Region 4	YFT Region 5
1979.125					1979.125				1.3848
1979.375			2.0028	1.2284	1979.375			0.8399	1.1173
1979.625			2.0541	1.2855	1979.625			0.9657	1.4473
1979.875		1.2449	0.9808	1.3322	1979.875		1.8351	1.3104	1.3674
1980.125		1.6808	1.3250	1.2989	1980.125		1.0187	0.5630	0.9399
1980.375			1.5558	0.9666	1980.375			0.8939	1.4361
1980.625		2.0405	1.5145	1.1741	1980.625		0.4785	0.4737	1.1364
1980.875		1.2394	1.1862	1.0047	1980.875		1.0523	0.5966	0.9092
1981.125		1.3028	1.0311	0.9228	1981.125		1.2319	0.4724	0.6010
1981.375			1.4561	0.8937	1981.375			0.9023	1.2086
1981.625		1.5733	1.3550	1.0991	1981.625		0.7501	0.7593	1.5625
1981.875	1.0392	0.7515	0.6649	1.0395	1981.875	1.8348	2.9174	0.9565	1.8192
1982.125	1.0694		0.6274	0.8854	1982.125	1.1700		0.4513	1.1718
1982.375	2.0767		1.4624	1.1126	1982.375	1.4517		0.7019	1.5088
1982.625	1.2973	1.2826	1.3839	1.0527	1982.625	1.0574	1.1816	0.7791	1.0974
1982.875		1.2419	0.7955	1.3456	1982.875		2.3839	1.2132	1.0486
1983.125	1.0467	1.4386	0.8634	1.1606	1983.125	0.8302	1.7468	0.9407	1.0754
1983.375	1.2724		0.8646	0.9295	1983.375	1.2149		1.0669	2.0697
1983.625		1.1838	1.0352	1.0802	1983.625		1.7975	0.9759	1.6093
1983.875		0.8414	0.7617	1.0782	1983.875		2.5960	1.5207	1.3700
1984.125		1.0496	0.8316	0.9364	1984.125		3.0290	0.9708	1.7357
1984.375	1.4713		1.2018	0.9443	1984.375	1.3739		0.7181	1.6163
1984.625			1.4272	1.0378	1984.625			0.7477	1.7201
1984.875		0.9678	0.6523	1.1013	1984.875		1.6935	0.9583	2.1012
1985.125		1.0661	0.7189	1.2975	1985.125		2.3814	0.8690	1.2919
1985.375	1.2974		1.0603	0.9890	1985.375	1.1682		0.7281	1.9102
1985.625	0.9896		1.1747	1.0219	1985.625	1.2034		0.5775	1.9005
1985.875	1.3157	1.2010	0.8244	1.0356	1985.875	1.5751	1.6014	1.7362	1.4383
1986.125	0.9277		0.7504	1.3063	1986.125	2.7976		0.9892	0.9009
1986.375	1.0325		0.9169	1.1379	1986.375	2.0507		0.8165	1.7117
1986.625	1.0712		1.8492	0.9619	1986.625	1.2847		0.9038	1.6395
1986.875	1.0296	1.1097	0.7541	1.3316	1986.875	2.4175	2.1362	0.9118	1.6178
1987.125	0.7822		0.8978	1.1364	1987.125	1.8561		0.7901	1.0206
1987.375	0.8881		1.1889	1.0955	1987.375	1.3091		1.2476	1.2888
1987.625	0.7317		1.0802	0.9066	1987.625	1.2256		0.7904	0.9272
1987.875	0.8501	1.2405	0.6932	0.9861	1987.875	1.8600	4.4803	0.9723	1.2139
1988.125	0.9146		0.7398	1.1590	1988.125	1.5172		1.1158	1.2599
1988.375	0.6986		1.1060	0.6793	1988.375	1.2617		0.8817	1.8114
1988.625	0.5904		1.2628	0.8633	1988.625	1.4120		0.8252	1.6299
1988.875	0.6225			0.9847	1988.875	1.1336			1.0712
1989.125	0.7625			0.7621	1989.125	0.7067			0.7116
1989.375	0.8842		1.0626	0.7619	1989.375	0.6404		1.3692	0.7635
1989.625	0.7310		0.9486	0.6831	1989.625	1.1781		1.0601	0.8025
1989.875	0.8775			0.9015	1989.875	1.1885			0.8418

Year-Qtr	BET Region 2	BET Region 3	BET Region 4	BET Region 5	Year-Qtr	YFT Region 2	YFT Region 3	YFT Region 4	YFT Region 5
1990.125	0.7803			0.8699	1990.125	1.2349			1.2179
1990.375	0.8473		0.8568		1990.375	0.9509		0.7291	
1990.625	0.8965		0.7426	0.9090	1990.625	1.1930		0.9525	1.3342
1990.875	0.8476			0.9862	1990.875	0.9228			0.7282
1991.125	0.7024			0.9134	1991.125	0.8609			0.7913
1991.375	0.9369		0.5312		1991.375	1.0157		0.7426	
1991.625	0.6245	1.5103	1.4113	0.6387	1991.625	0.8198	0.6511	0.4586	0.9225
1991.875	0.7975			0.8139	1991.875	0.7669			0.6226
1992.125	0.7733				1992.125	0.6092			
1992.375	1.3760		1.0773		1992.375	1.8443		2.2192	
1992.625	1.1750	0.5165	1.8355		1992.625	2.1320	1.3289	3.6068	
1992.875	1.2374			1.2193	1992.875	2.1071			2.2417
1993.125	1.0658			1.1388	1993.125	1.2306			2.2857
1993.375	1.1641		0.7523	0.9443	1993.375	1.2615		0.8438	2.9843
1993.625	0.9729	1.0152	0.7782	0.9501	1993.625	0.8310	0.5298	1.0530	1.5486
1993.875	0.8295	0.9992	0.7409	1.0098	1993.875	0.9064	0.8831	1.3234	1.3012
1994.125	1.0439	0.4577	0.8574	1.0615	1994.125	0.7982	1.3607	0.8962	1.4581
1994.375	1.1043	0.5851	0.8045	1.0560	1994.375	0.9214	1.4682	2.2431	1.9024
1994.625	0.8378	0.9127	0.9415	0.7391	1994.625	1.6363	0.8658	1.4747	0.9084
1994.875	1.0826	0.6850	0.8267	0.9365	1994.875	1.1454	0.4894	1.1091	1.0850
1995.125	0.8149	0.5832	0.6911	1.3022	1995.125	0.4835	0.4945	0.9993	0.8686
1995.375	0.8778	0.8291	0.7529		1995.375	0.4522	0.8477	1.2339	
1995.625	0.8091	0.8527	0.8327	0.7018	1995.625	0.5507	0.5931	0.9424	0.6316
1995.875	0.8490	0.7401	0.6462	0.8798	1995.875	1.0333	0.6425	0.7904	0.6093
1996.125	0.6836	0.6418	0.4785	1.0993	1996.125	0.7951	0.7416	0.6912	0.8066
1996.375	1.0097	0.9887	0.7487		1996.375	0.7451	1.0685	1.0319	
1996.625	0.6964	0.7093	1.0376	0.9235	1996.625	0.4257	0.6892	0.7420	0.6980
1996.875	0.7511	0.6284	0.5337	0.8597	1996.875	0.6885	0.9232	0.5558	0.5874
1997.125	0.7096	0.3208	0.5282	1.1602	1997.125	0.7217	0.4639	0.4455	0.4195
1997.375	0.8169	1.2886	0.8980		1997.375	0.3806	0.4900	0.8062	
1997.625	0.7632	0.8164	1.3523	1.1305	1997.625	0.7445	0.5473	0.6007	0.8596
1997.875	0.6696	0.5548	0.5222	0.9310	1997.875	1.0042	0.7064	0.5967	0.6642
1998.125	0.7752	0.4664	1.0580	1.0638	1998.125	1.0347	0.5595	0.6881	1.3256
1998.375	0.9597	1.0688	1.0803		1998.375	1.0690	0.8751	0.9464	
1998.625	0.8863	0.7535	1.1115	0.8558	1998.625	0.9026	0.8661	0.7711	0.6928
1998.875	0.8982	1.1220	0.6290	0.8744	1998.875	1.0568	1.0664	0.9157	0.6538
1999.125	0.8003	0.7835	0.7090	0.8547	1999.125	0.8736	0.5091	1.0388	0.7064
1999.375	0.9429	0.9319	0.8627	0.9405	1999.375	0.7321	0.8190	1.6242	1.0298
1999.625	0.8464	0.6786	0.8944	0.8364	1999.625	0.8890	0.7505	0.9457	0.8168
1999.875	1.0653	0.6734	1.0606	0.8289	1999.875	0.7836	0.7254	0.9108	0.6873
2000.125	0.8489	0.7674	0.7606	0.8678	2000.125	0.7237	0.4631	1.1136	0.7347
2000.375	0.9493	1.5140	0.5556	0.7708	2000.375	0.7473	0.8103	1.2349	0.8049
2000.625	0.8393	0.8130	0.8059	0.6876	2000.625	0.8107	0.5368	0.8087	0.9590
2000.875	1.0114	0.7665	0.8898	0.7935	2000.875	0.6501	0.7924	1.7720	0.9436
2001.125	0.9235	1.3756	0.6685	0.8456	2001.125	0.7192	1.5468	0.8985	0.7639
2001.375	0.9939	2.9157	0.8025	0.8914	2001.375	0.8736	1.2626	1.3160	0.7273
2001.625	0.9189	1.2056	1.1009	1.0016	2001.625	0.9656	0.8321	1.7960	0.8859

Year-Qtr	BET Region 2	BET Region 3	BET Region 4	BET Region 5	Year-Qtr	YFT Region 2	YFT Region 3	YFT Region 4	YFT Region 5
2001.875	1.0878	1.1495	0.8932	1.0064	2001.875	1.4267	1.1353	2.1598	0.9500
2002.125	1.1259	1.4503	1.5483	0.9363	2002.125	1.0655	1.1643	1.9438	1.3103
2002.375	1.3125	2.1753	1.4036	0.8722	2002.375	0.8483	1.3067	1.0814	0.6883
2002.625	1.2285	1.3659	1.4404	1.1861	2002.625	0.8643	1.3746	0.9881	0.5256
2002.875	1.2161	1.3827	3.1399	1.3968	2002.875	0.7589	1.0569	2.0312	0.7985
2003.125	1.3196	2.0642	2.9362	1.4297	2003.125	0.8192	1.1492	1.9285	0.8216
2003.375	1.6364	2.9366	1.2333	1.2325	2003.375	1.2571	2.5408	1.4158	1.2395
2003.625	1.2206	1.4067	1.6061	1.3334	2003.625	1.1739	1.3696	1.3938	0.8846
2003.875	1.1411	1.1535	1.5880	1.3776	2003.875	1.1635	0.6272	0.8702	0.6003
2004.125	1.2830	1.0575	1.5289	1.6116	2004.125	1.1894	0.7700	1.5953	0.6929
2004.375	1.2958	1.5169	1.2106	1.5724	2004.375	1.4813	0.7509	2.0379	1.1241
2004.625	1.2602	1.4012	2.3146	1.3300	2004.625	0.8229	1.0207	1.1906	0.9978
2004.875	1.3231	1.4359	0.7583	1.0600	2004.875	1.4133	1.2262	0.9734	0.6930
2005.125	1.0690	0.7205	0.5246	1.2299	2005.125	1.3059	1.5693	1.2136	1.0035
2005.375	1.0472	0.7240	0.5738	0.9630	2005.375	1.7063	1.9664	1.3375	1.2232
2005.625	0.7038	0.6154	0.9633	0.6697	2005.625	0.9201	0.8646	1.1886	0.7654
2005.875	0.5619	0.7881	1.6986	0.6888	2005.875	1.6203	0.5940	0.9635	0.5464
2006.125	1.0865	1.2643	1.0025	1.3354	2006.125	1.1563	0.6349	0.7130	1.4531
2006.375	0.7982	1.1120	1.1745	0.9104	2006.375	0.8210	0.5381	1.3335	1.1258
2006.625	0.7536	0.8310	0.9951	0.9420	2006.625	0.5645	0.6368	0.8826	0.9600
2006.875	1.0365	0.6850	2.5054	1.2321	2006.875	0.8442	0.4381	2.4040	0.5885
2007.125	0.9074	0.8837		1.1223	2007.125	0.6456	1.1070		1.0242
2007.375	0.8863	0.6136	0.6322	0.8736	2007.375	0.6211	0.7588	1.3536	0.8056
2007.625	0.8377	0.9816	0.9203	0.8849	2007.625	0.5084	0.4896	0.8351	0.5135
2007.875	1.3537	0.8084	0.7673	1.1217	2007.875	0.5600	0.4353	0.5735	0.5149
2008.125	0.6905	0.6611	0.3525	0.7627	2008.125	0.4373	0.6548	0.4773	0.4359
2008.375	0.9514	0.6662	0.5796	0.9558	2008.375	0.4575	0.5655	0.5672	0.4913
2008.625	0.9307	0.8382	0.6923	0.7982	2008.625	0.6197	0.6346	0.5795	0.4128
2008.875	1.4460	0.7925		1.2175	2008.875	0.4226	0.4199		0.4713
2009.125	0.8056	0.6667	0.2559	0.7628	2009.125	0.3566	0.4584	0.4167	0.5161
2009.375	0.9768	0.4071	0.4577	0.7011	2009.375	0.3743	0.5132	0.3635	0.4178
2009.625	0.9043	0.5985	0.6935	0.8817	2009.625	0.5721	0.4687	0.3342	0.4485
2009.875	0.9643	0.6778	0.4148	0.7904	2009.875	0.6945	0.5371	0.2112	0.3399
2010.125	0.8188	0.5810	0.3011	0.6238	2010.125	0.3855	0.4997	0.5674	0.4005
2010.375	0.9418	0.3858	0.3588	0.5585	2010.375	0.5681	0.7944	0.7081	0.5114
2010.625	1.0154	0.7683	0.7165	0.7923	2010.625	0.6205	0.4660	0.6154	0.4569
2010.875	1.0053	0.7802		0.7635	2010.875	0.7877	0.3744		0.4551
2011.125	0.5505	0.5292	0.2561	0.6850	2011.125	0.5351	0.3190	0.3531	0.3993
2011.375	1.6328	0.2742	0.4444	0.8594	2011.375	0.9011	0.4041	0.6377	0.5690
2011.625	1.2888	0.4782	1.1902	0.9420	2011.625	1.2061	0.7017	0.4012	0.6547
2011.875	1.6040	1.0667		1.3640	2011.875	1.2204	0.8272		0.5958
2012.125	1.5308	0.7986		1.0106	2012.125	0.8759	0.8406		0.5040
2012.375	1.7242	0.5569	0.7220	0.8910	2012.375	0.7191	0.6520	0.3550	0.3371
2012.625	0.9917	1.0599	0.6234	0.8990	2012.625	0.4911	0.5911	0.3192	0.5858
2012.875	1.4137	1.4698		1.0163	2012.875	0.7674	1.0042		0.4565
2013.125	0.8674	0.7941		0.6280	2013.125	0.5016	0.8455		0.5229
2013.375	0.9245	0.4950	0.5279	0.9946	2013.375	0.5110	0.5331	0.6799	0.3186

Year-Qtr	BET Region 2	BET Region 3	BET Region 4	BET Region 5	Year-Qtr	YFT Region 2	YFT Region 3	YFT Region 4	YFT Region 5
2013.625	0.6345	0.5054	0.8346	0.9421	2013.625	0.5254	0.4449	0.3831	0.4110
2013.875	1.3595	0.7580		1.2128	2013.875	0.6895	0.6425		0.4214

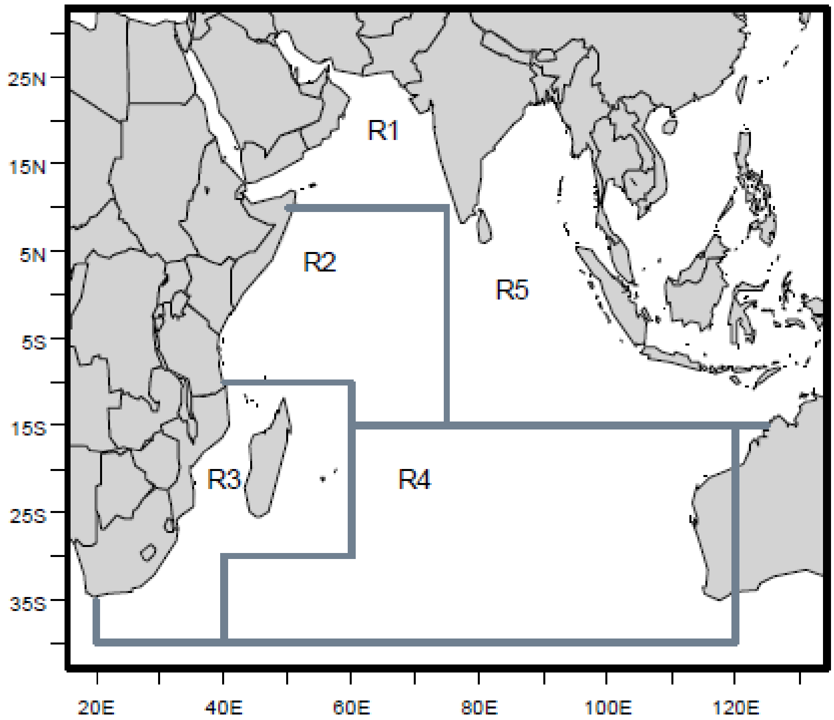


Figure 1. Spatial stratification of the Indian Ocean for this analysis (Langley et al., 2012).

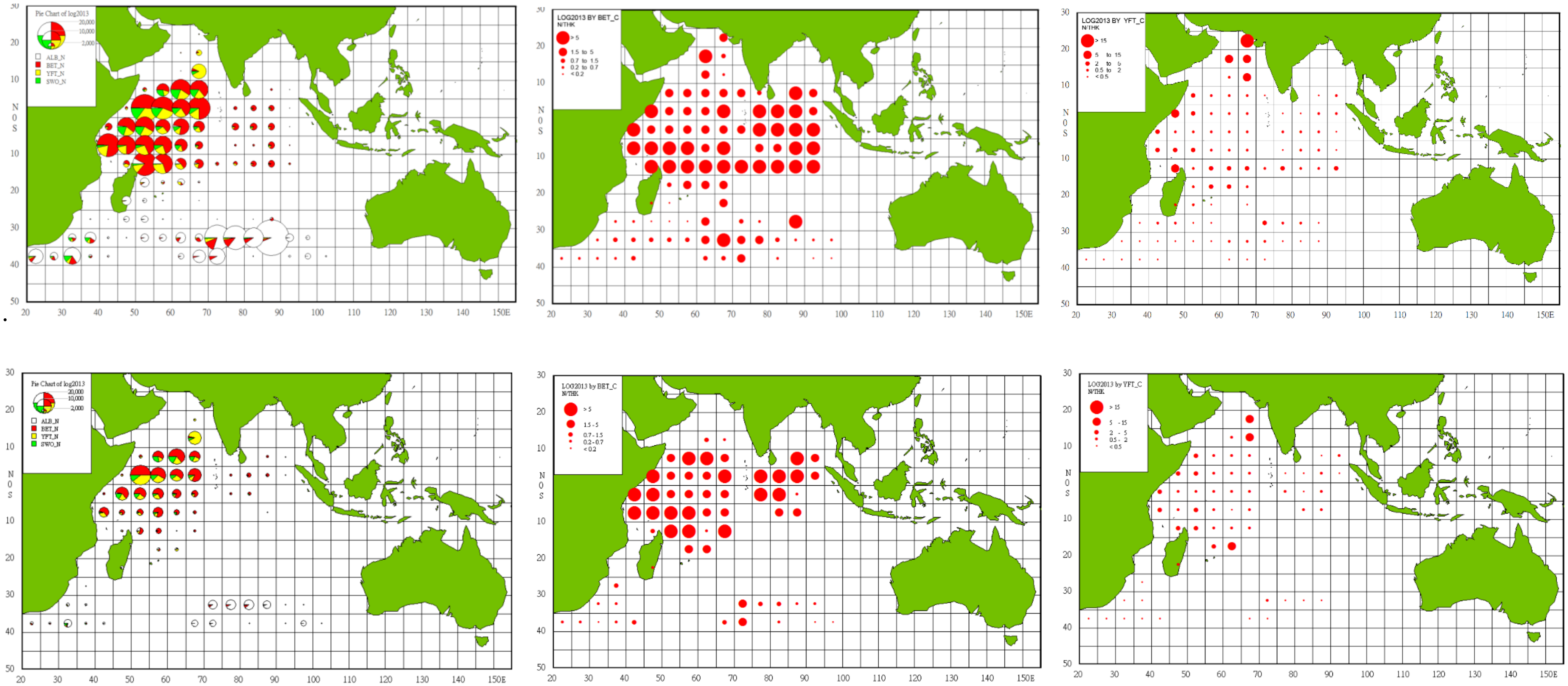


Figure 2.Comparison of 2013 updated data used in this analysis and data used in the collaborative work (below), map of catch composition (left), nominal bigeye CPUE (middle), and nominal yellowfin CPUE (right), by 5 degree square.

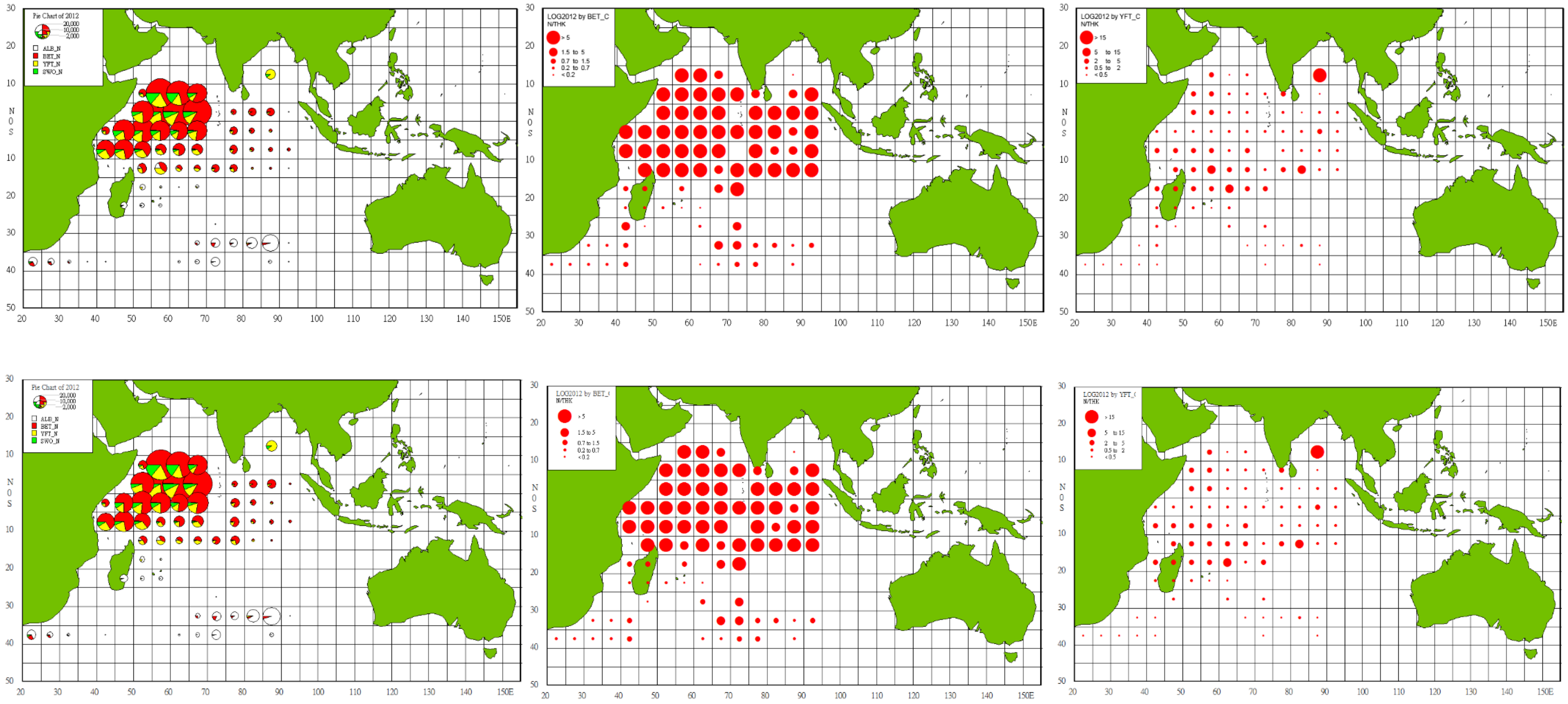


Figure 3.Comparison of 2012 updated data used in this analysis and data used in the collaborative work (below), map of catch composition (left), nominal bigeye CPUE (middle), and nominal yellowfin CPUE (right), by 5 degree square

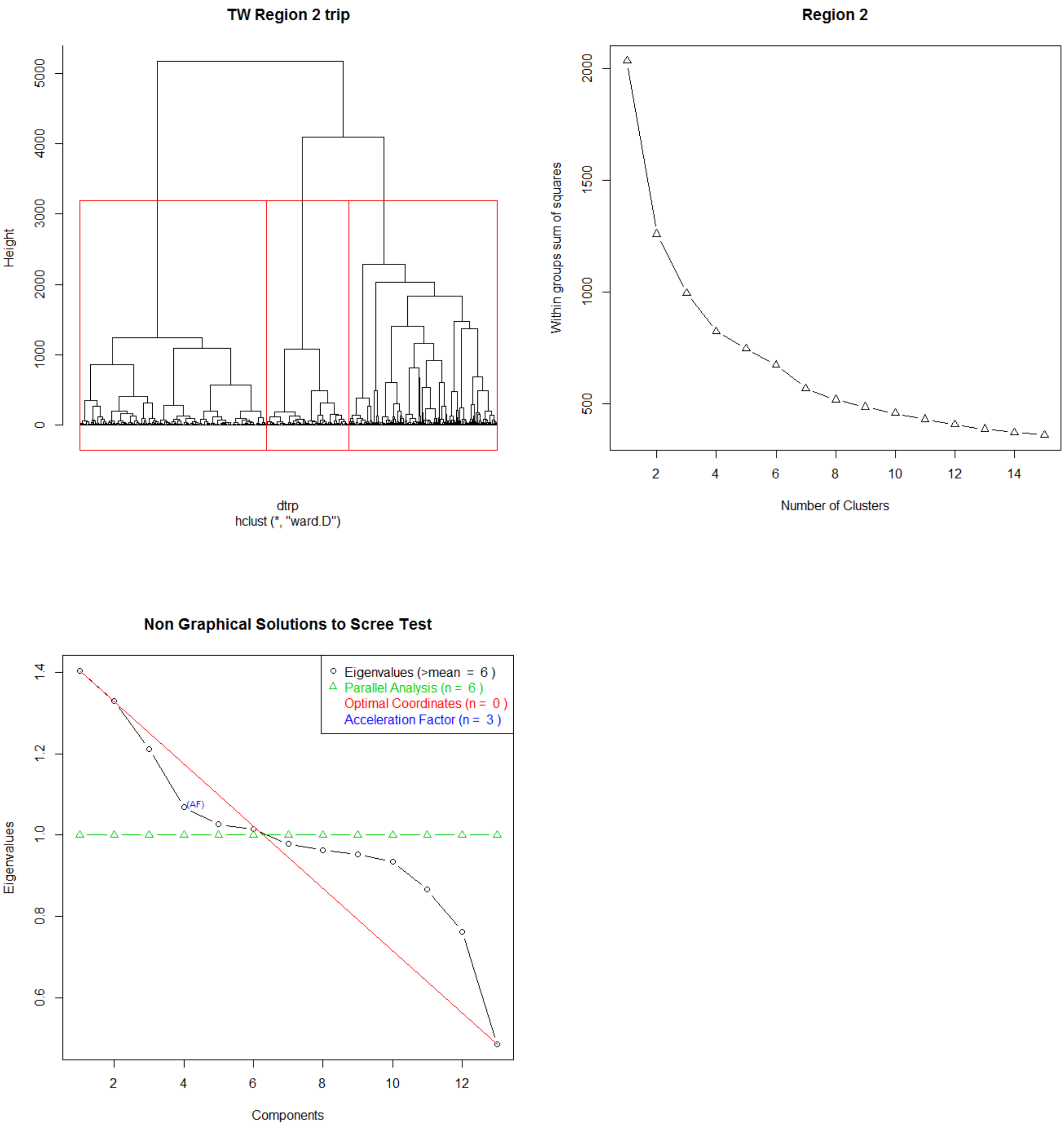


Figure 4: Plots showing analyses to estimate the number of distinct classes of species composition in Taiwanese region 2. These are based on a hierarchical Ward clustering analysis of trip-level data (top left); within-group sums of squares from kmeans analyses with a range of numbers of clusters (top right); and analyses of the numbers of components to retain from a principal component analysis of trip-level (bottom left) data.

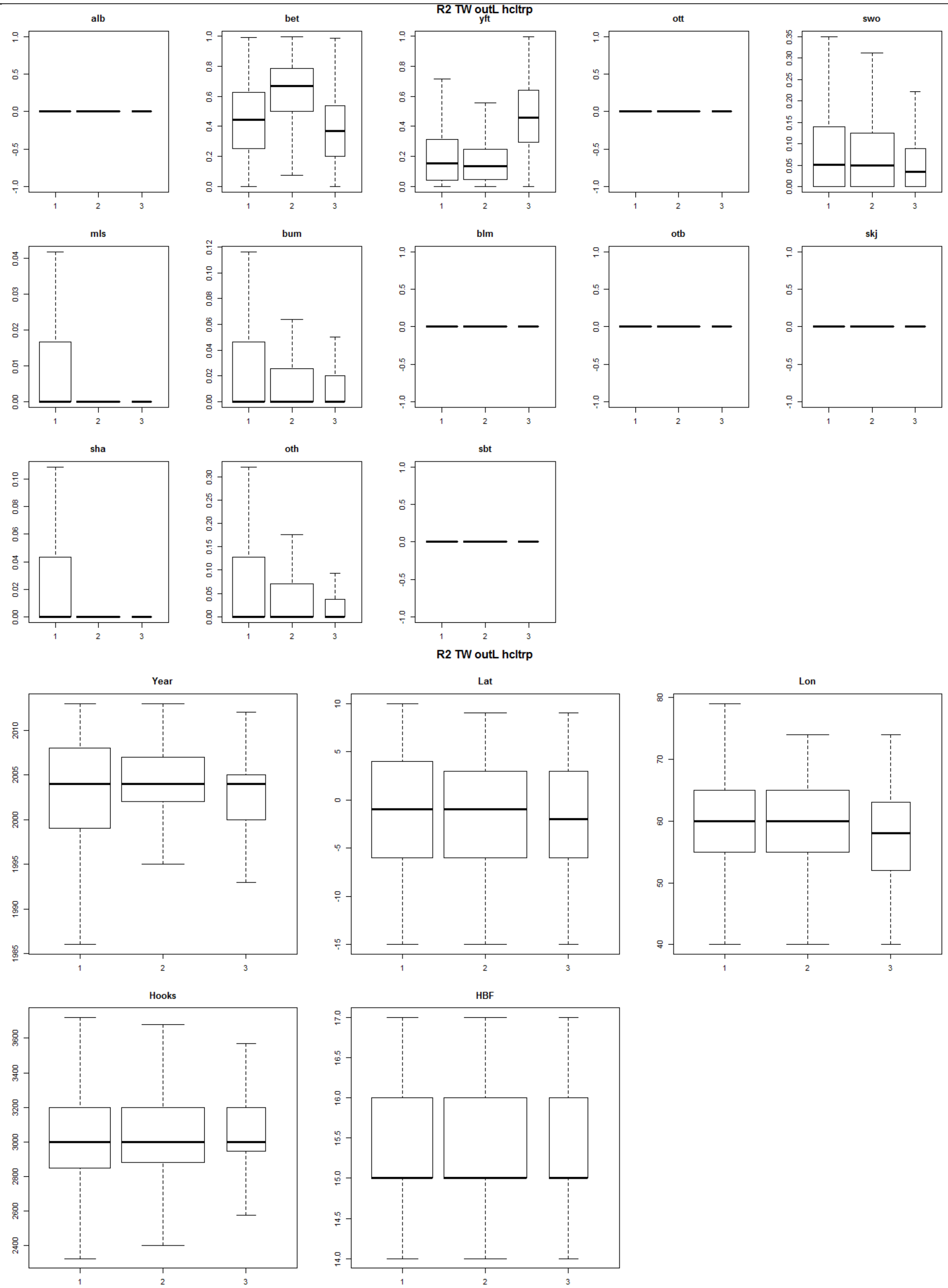


Figure 5. For Taiwanese effort in region 2 for the period 1979-2013, for each species, boxplot of the proportion of the species in the trip versus the cluster. The widths of the boxes are proportional to the numbers of trips in each cluster (above). Boxplot showing the distributions of variables associated with sets in each hcltrp cluster (below).

Clustering was performed using a hierarchical Ward clustering analysis of trip-level data.

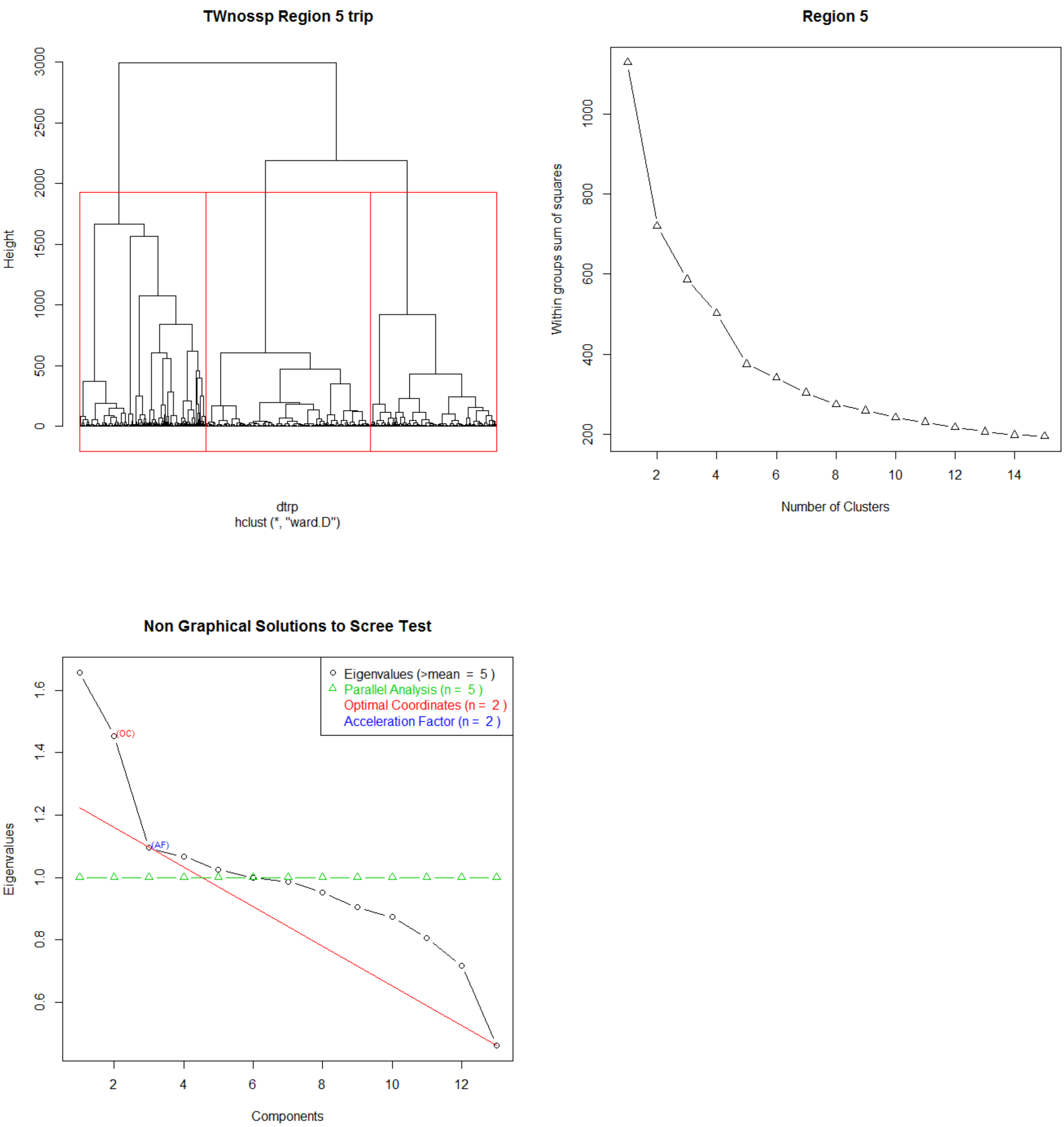
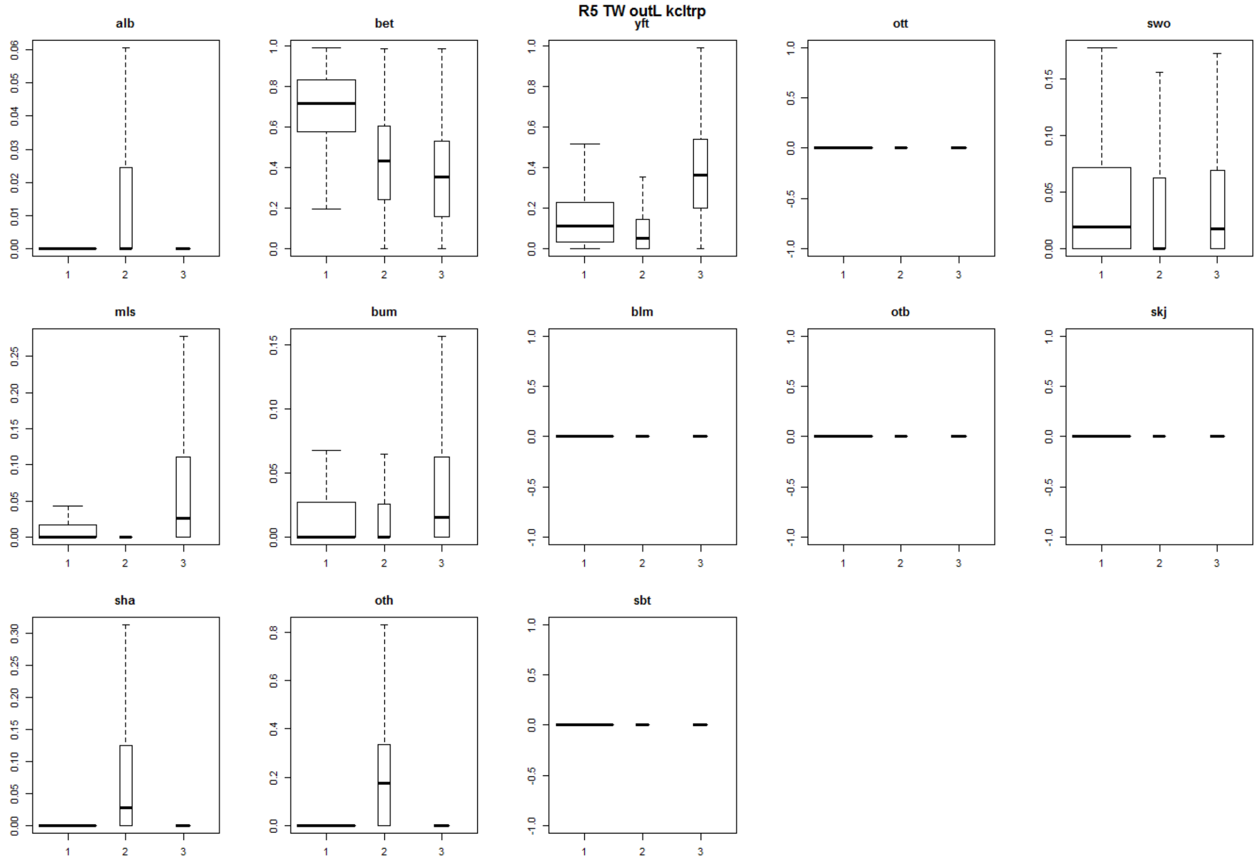


Figure 6: Plots showing analyses to estimate the number of distinct classes of species composition in Taiwanese region 5. These are based on a hierarchical Ward clustering analysis of trip-level data (top left); within-group sums of squares from kmeans analyses with a range of numbers of clusters (top right); and analyses of the numbers of components to retain from a principal component analysis of trip-level (bottom left) data.



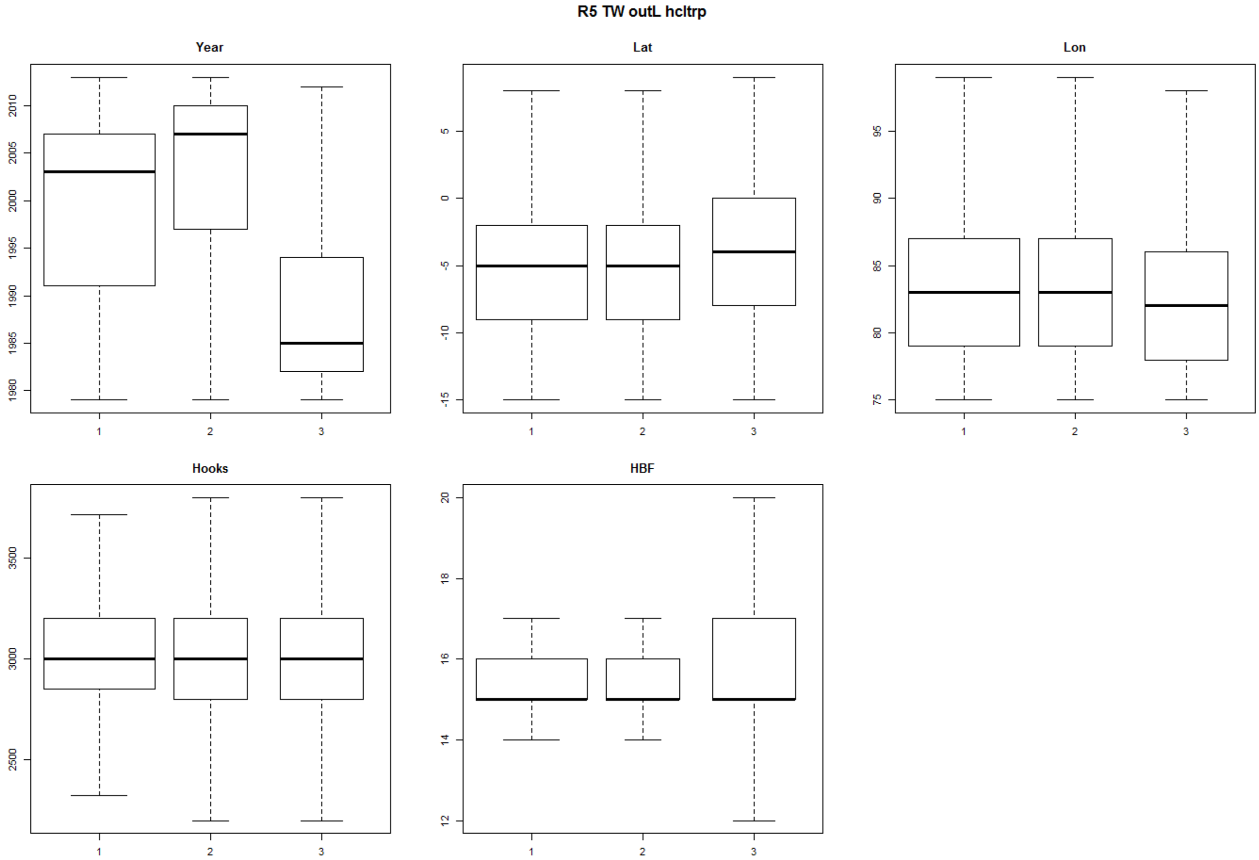


Figure 7. For Taiwanese effort in region 5 for the period 1979-2013, for each species, boxplot of the proportion of

the species in the trip versus the cluster. The widths of the boxes are proportional to the numbers of trips in each cluster (above). Boxplot showing the distributions of variables associated with sets in each hcltrp cluster (below). Clustering was performed using a hierarchical Ward clustering analysis of trip-level data.

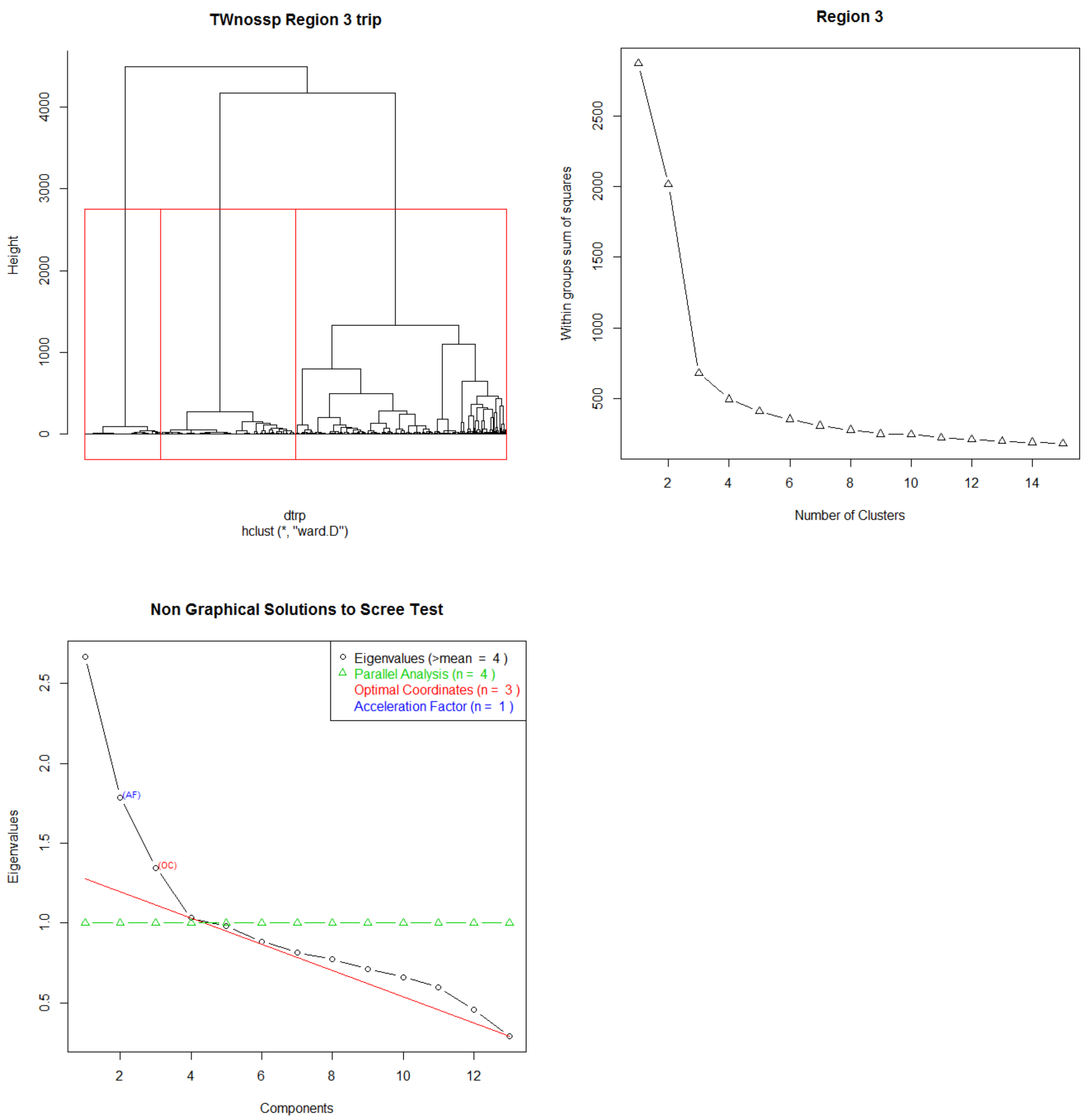


Figure 8: Plots showing analyses to estimate the number of distinct classes of species composition in Taiwanese region 3. These are based on a hierarchical Ward clustering analysis of trip-level data (top left); within-group sums of squares from kmeans analyses with a range of numbers of clusters (top right); and analyses of the numbers of components to retain from a principal component analysis of trip-level (bottom left) data.

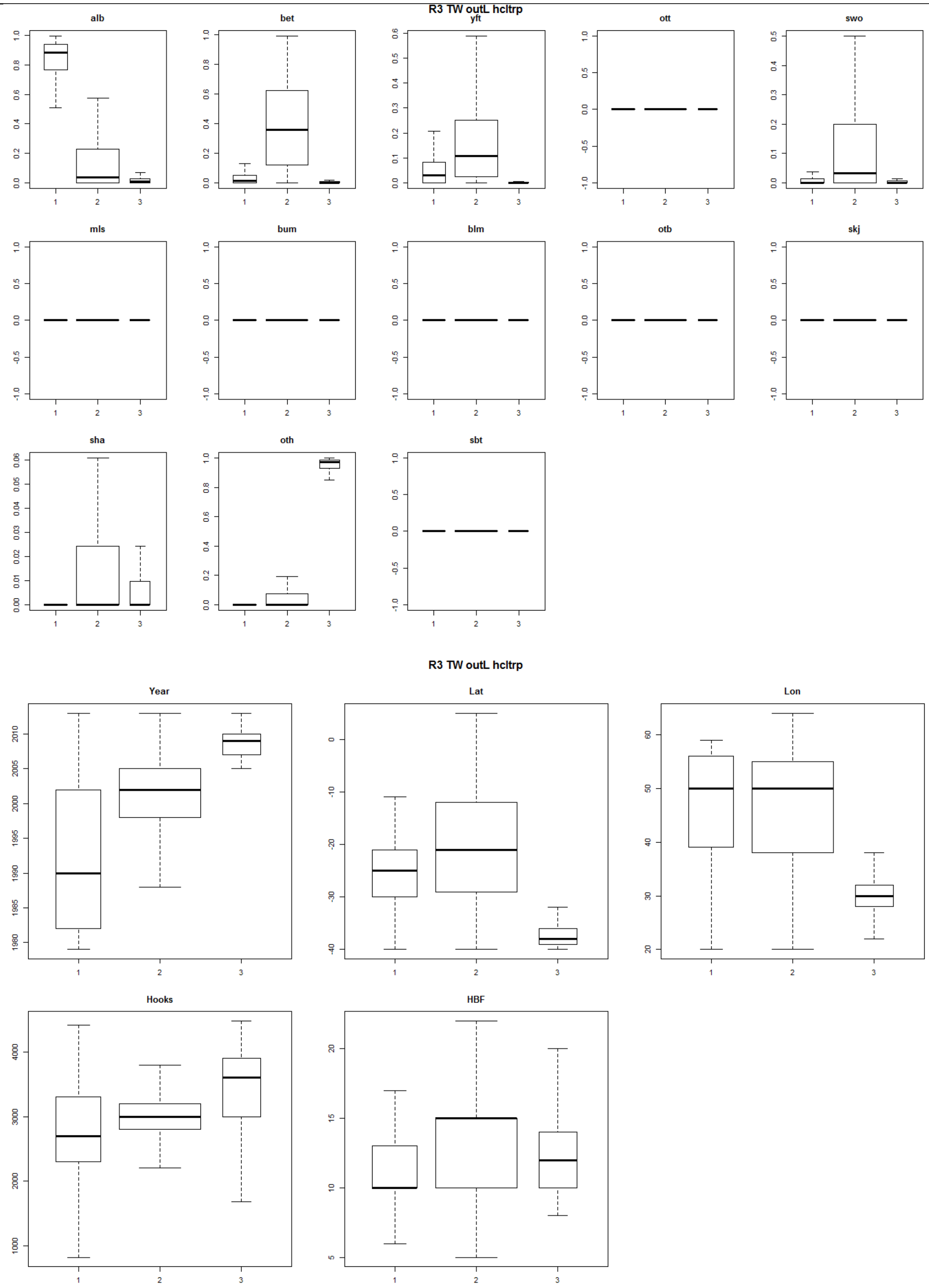


Figure 9. For Taiwanese effort in region 3 for the period 1979-2013, for each species, boxplot of the proportion of the species in the trip versus the cluster. The widths of the boxes are proportional to the numbers of trips in each

cluster (above). Boxplot showing the distributions of variables associated with sets in each hcltrp cluster (below). Clustering was performed using a hierarchical Ward clustering analysis of trip-level data.

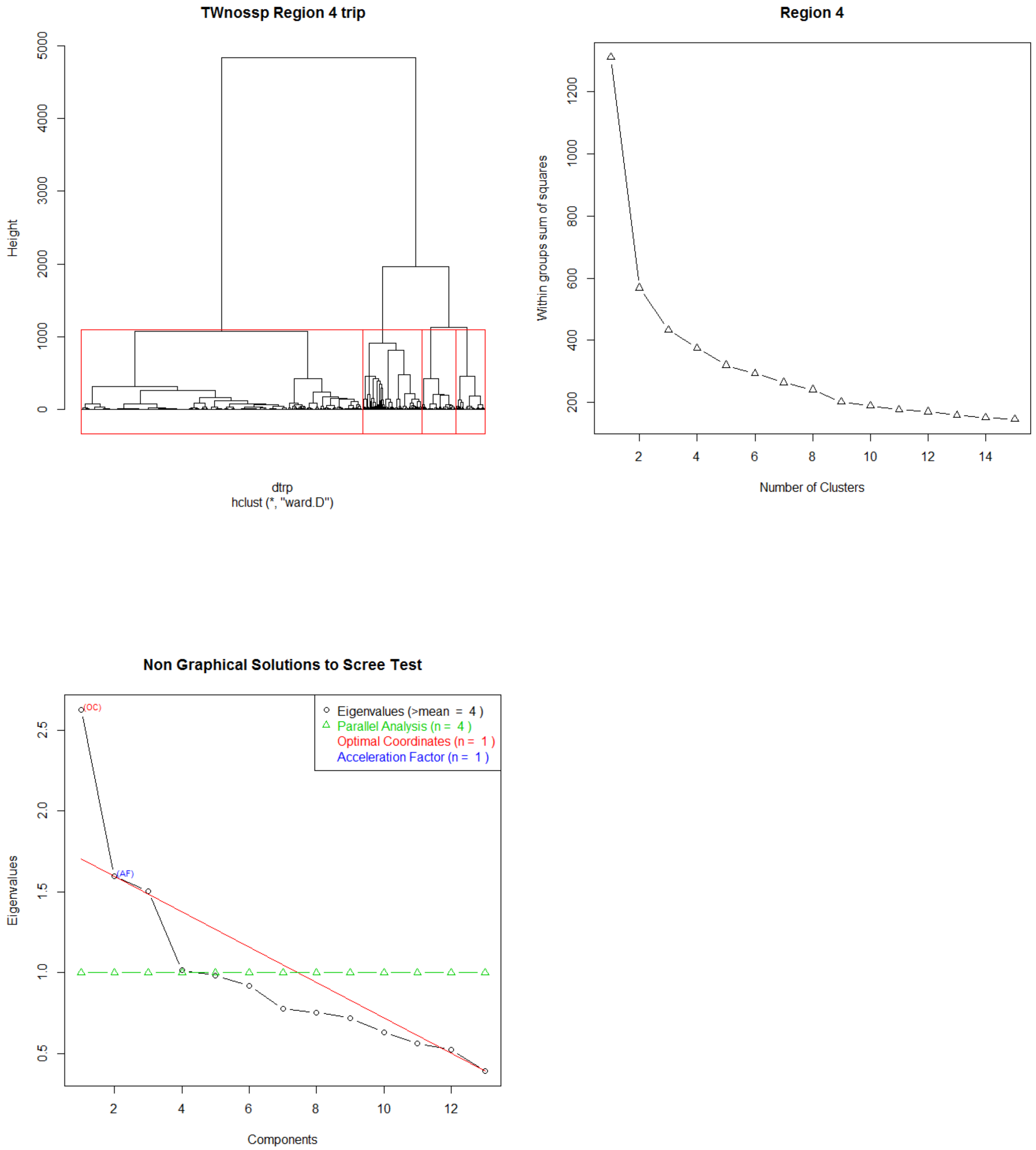
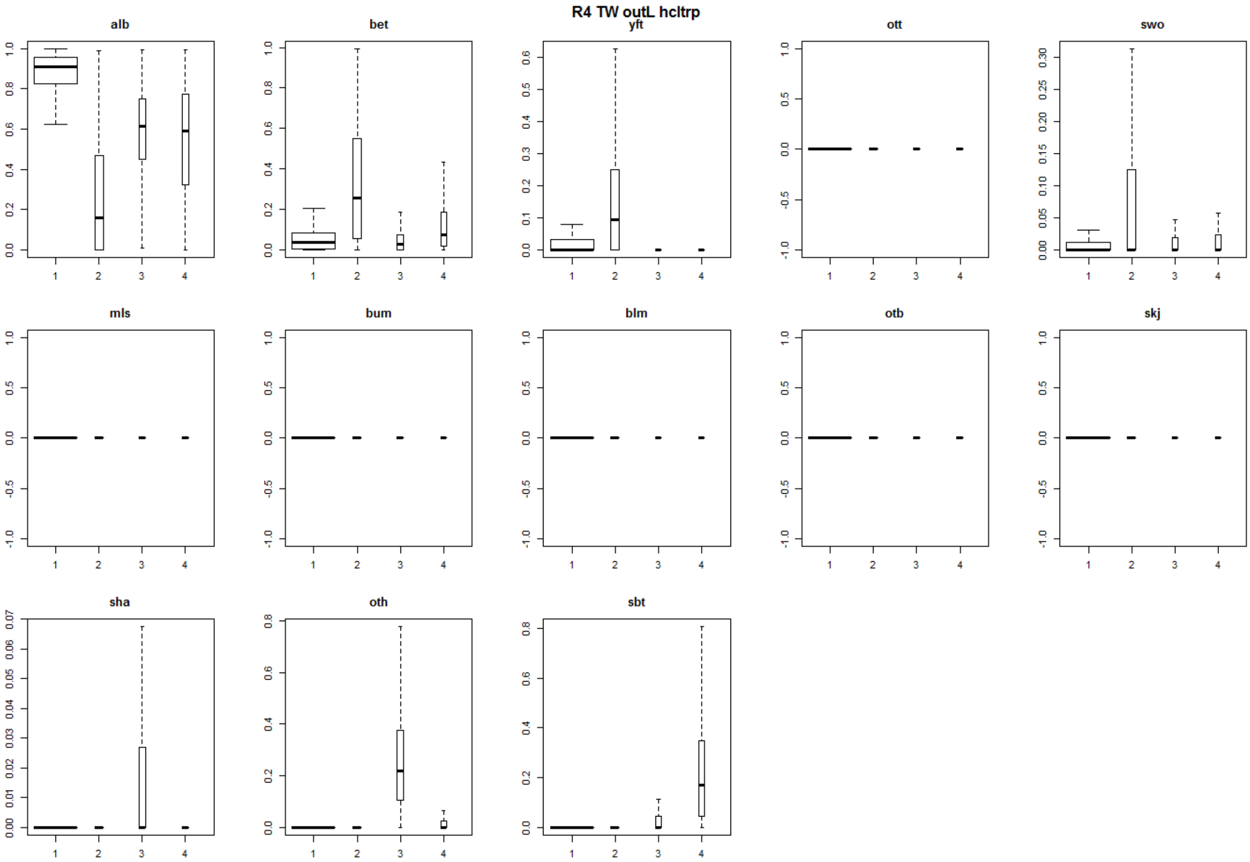


Figure 10: Figure x: Hierarchical clustering trees produced by the hclust function in R, for Taiwanese trip-level data by region. Plots showing analyses to estimate the number of distinct classes of species composition in

Taiwanese region 4. These are based on a hierarchical Ward clustering analysis of trip-level data (top left); within-group sums of squares from kmeans analyses with a range of numbers of clusters (top right); and analyses of the numbers of components to retain from a principal component analysis of trip-level (bottom left) data.



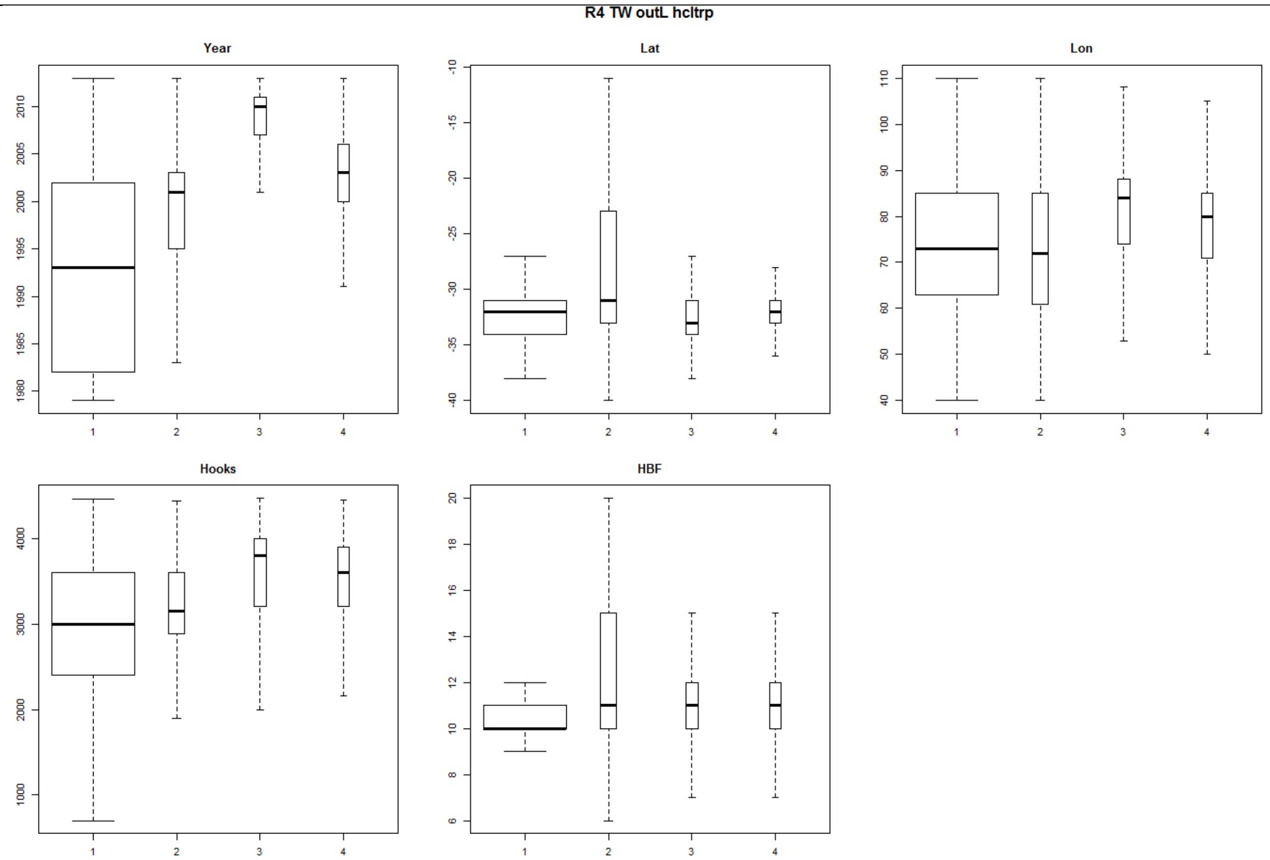


Figure 11. For Taiwanese effort in region 4 for the period 1979-2013, for each species, boxplot of the proportion of the species in the trip versus the cluster. The widths of the boxes are proportional to the numbers of trips in each cluster (above). Boxplot showing the distributions of variables associated with sets in each hcltrp cluster (below). Clustering was performed using a hierarchical Ward clustering analysis of trip-level data..

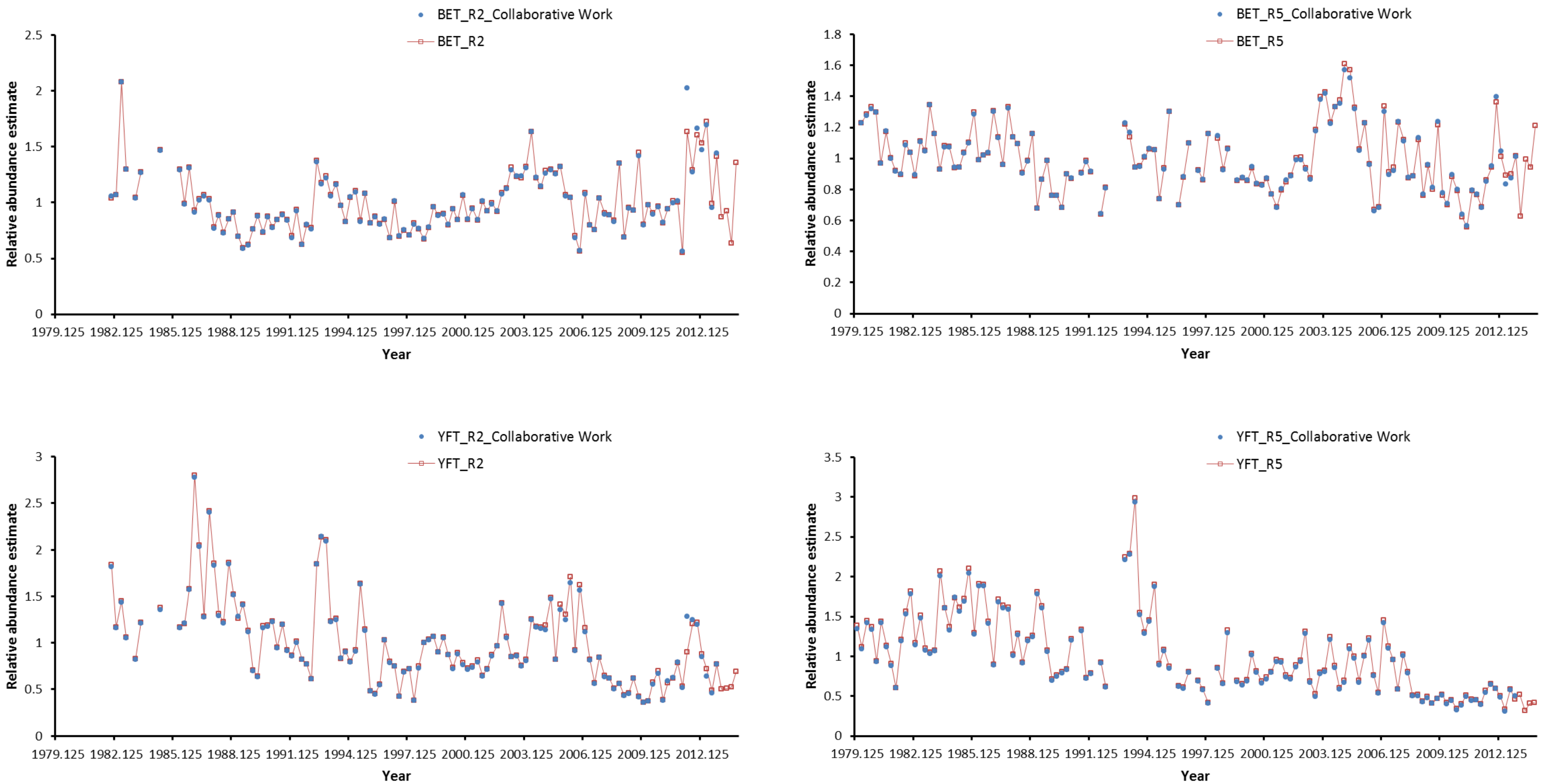


Figure 12: Comparisons of BET and YFT CPUE time series estimated in this analysis with updated 2012 and 2013 data and estimated during the 2015 collaborative project (blue), in region 2 and region 5.

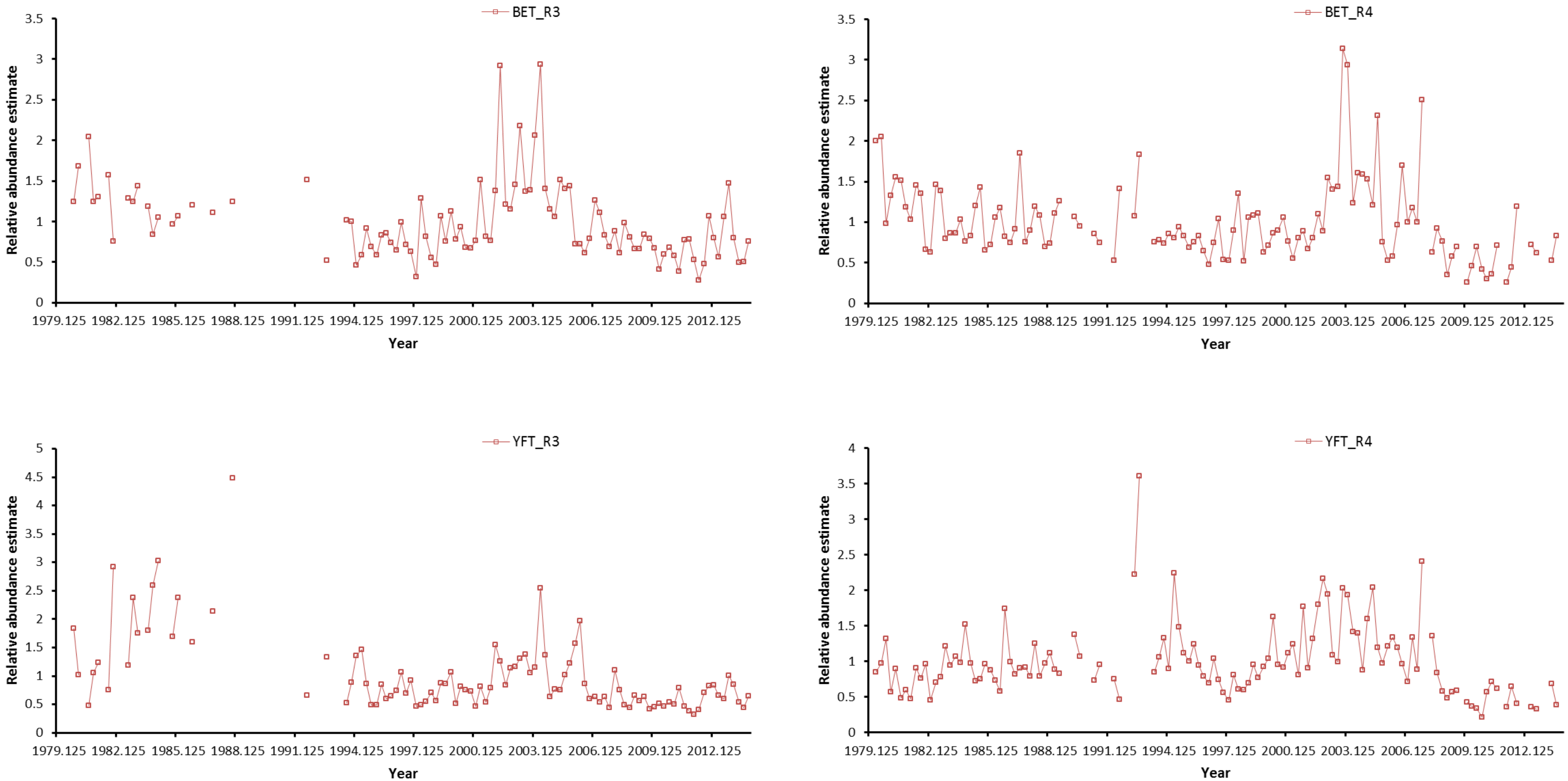


Figure 13: Taiwanese standardized CPUE indices for bigeye and yellowfin in the regions 3 and 4.

Region 2 | Region 3 | Region 4 | Region 5

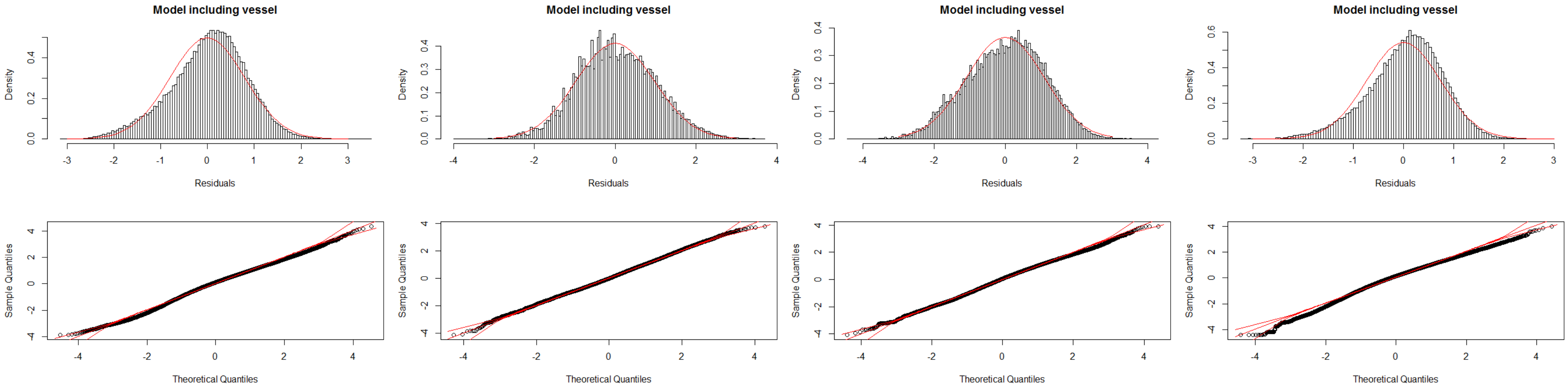


Figure 14. Residual diagnostics (as histogram and QQ plot) on bigeye tuan CPUE indices by region.

Region 2 | Region 3 | Region 4 | Region 5

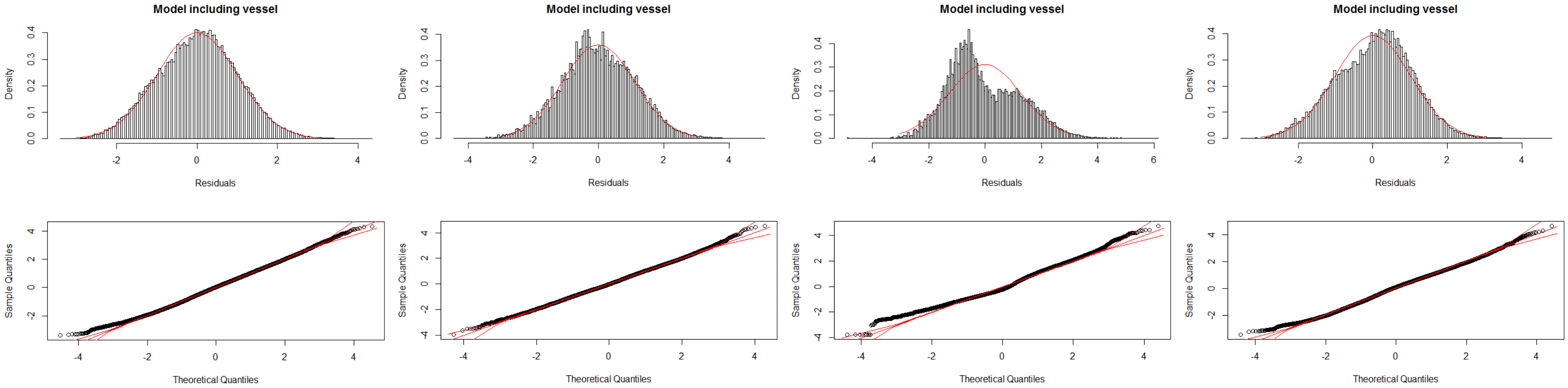


Figure 15. Residual diagnostics (as histogram and QQ plot) on yellowfin tuna CPUE indices by region.