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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 Taiwanese longline fishery data to 2015 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 based on the approaches used by the collaborative workshop of longline data and CPUE standardization for bigeye and yellowfin tuna held in April 2016 in Taipei and in July 2016 in Shanghai.

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 and April and July in 2016, several collaborative studies were conducted between national scientists with expertise in Japanese, Taiwanese, and Korean longline fleets, and an independent scientist, Dr. Simon Hoyle. The workshops 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 and Hoyle, 2016).

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 1979-2001, and 2005-2015 was used, which was provided by Overseas Fisheries Development Council (OFDC). From 2013, Taiwanese Fisheries Agency gave an impetus to Taiwanese pelagic longline fishery industry submitting logbook data via E-logbook system. Until 2015, over 80% coverage rate of E-logbook was reached. Therefore, the 2015 data was compiled from E-logbook.

The logbook data in the 2002-2004 period was excluded in this analysis since the period coincides with what is believed to be misreporting of the origins of bigeye catches due to a side effect of fisheries management measures at that time (IOTC, 2015). Data from 2005 to 2015 of this updated data set was the same data set which used in the collaborative work (Hoyle, 2016) held in July 2016 in Shanghai. Data preparation and cleaning were performed by adopting the suggestions made by the collaborative work (IOTC, 2015). Each set was allocated to a bigeye region and a yellowfin region (Figure 1). The region definitions conformed to the 2016 joint work (Hoyle, 2016).

Cluster analysis

We adopted the hierarchical clustering method Ward hclust (IOTC, 2015) to identify effort associated with different fishing strategies. The cluster analysis was performed separately for regions for both bigeye and yellowfin. 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. For this analysis, we aggregated the data by vessel-month to reduce the variability, and therefore reduce misallocation of sets. The assumption is that we believe individual vessels tend to follow a consistent fishing strategy in a month period. More detailed information can be referred to the collaborative work report (IOTC, 2015).

CPUE standardization

CPUE standardization methods adopted the suggestions made from the collaborative work (IOTC, 2015) for Taiwanese fleet to include year-quarter, vessel id, and five by five latitude and longitude grid as main factor. Beside cluster is also included as a main factor in the model. Analyses were conducted separately for each region, and for bigeye and yellowfin. The following model was used:

$$\ln(CPUEs+k) \sim yrqtr+vessid+latlong5+cluster+f(hooks)++\epsilon$$

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() were cubic splines, with 11 degrees of freedom respectively.

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

The recent status of Taiwanese tuna longline fisheries

Data coverage was 72% in 2014 and 80% in 2015 for this analysis. Figure 2 and Figure 3 showed the Taiwanese tuna longline catch composition, effort, nominal bigeye CPUE, and nominal yellowfin CPUE by 5 degree square in the recently two years. Overall speaking, the performance of Taiwanese tuna longline fisheries in 2014 and 2015 was very similar and showed no significant change than previous years. However, compare to 2014, there were relatively higher yellowfin nominal CPUE in some 5x5 grid and yellowfin catch had a higher ratio in species catch composition in 2015.

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 BET region 1 and 2, identified 5 clusters as the number with the most support (Figure 4 and 6), 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 BET region 3, identified 4 clusters as the number with the most support (Figure 8), we found that species composition averaging 87% ‘other’ in one cluster, 83% albacore in another cluster, a mix of bigeye, yellowfin, albacore and swordfish in a third cluster, and a mix of albacore, bigeye,’other’ and southern Bluefin tuna in a forth cluster were identified at the trip level by hcltrip, suggesting that oilfish targeting can represent the majority of the catch (Table 1).

In BET region 4, identified 4 clusters as the number with the most support (Figure 10), we found that species composition averaging 84% albacore in one cluster, a mix of 57% albacore and 25% ‘other’ in another cluster, a mix of bigeye, yellowfin, albacore and swordfish in a third cluster, and a mix of 43% albacore, 35% southern Bluefin tuna and 11% bigeye in a forth cluster, were identified at the trip level by hcltrip (Table 1).

For YFT regions, the outcome of cluster analysis can be referred by Figure 12, 14, 16, 18 and Table 2. And for each cluster in every region, the corresponding fishing strategies were revealed by the various distribution of fishing month, number of hooks between floats, location, number of hooks associated with sets in each cluster (Figure 5, 7, 9, 11, 13, 15, 17 and 19).

Cpue series and comparison with the 2016 collaborative work.

The comparison of the bigeye and yellowfin CPUE indices estimated in this analysis (Table 3) and estimated in the 2016 collaborative work for regions were shown in Figure 20 and 21. There were many approaches to estimate CPUE series in the 2016 collaborative work. We took the one from 1979 and estimated by the model with the vessel effect for our comparison. Except the difference in the data sets, there were two main differences in the process of CPUE standardization. One is low-target clusters were omitted in the 2016 collaborative work versus all clusters were remain in our analysis. The other is delta lognormal model was adopted in the 2016 collaborative work versus lognormal constant generalized linear models was used in this analysis. For both species for the GLMs, model fits were presented by plotting the residual densities and using Q-Q plots (Figure 22 and Figure 23).

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Table 1. For Taiwanese effort in the BET region 1 , 2, 3, and 4, 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
1	1	45.9%	25.4%	16.2%	0.0%	2.7%	0.9%	1.5%	0.2%	0.3%	0.0%	2.0%	4.8%	0.1%
	2	0.8%	45.3%	20.5%	0.0%	14.0%	4.1%	6.1%	0.6%	0.5%	0.0%	2.8%	4.3%	1.1%
	3	1.0%	40.4%	42.4%	0.0%	6.2%	1.1%	2.4%	0.2%	0.3%	0.0%	2.0%	4.0%	0.0%
	4	1.6%	36.4%	18.4%	0.3%	7.2%	1.0%	2.6%	0.1%	2.2%	0.4%	8.9%	20.8%	0.1%
	5	1.1%	62.8%	15.6%	0.0%	7.4%	1.1%	2.3%	0.1%	0.4%	0.0%	2.9%	6.2%	0.0%
2	1	1.2%	75.3%	13.0%	0.0%	4.6%	1.8%	1.8%	0.3%	0.1%	0.0%	0.6%	1.2%	0.0%
	2	74.6%	9.8%	10.5%	0.0%	1.2%	1.1%	0.8%	0.2%	0.1%	0.0%	0.7%	1.0%	0.0%
	3	2.0%	55.2%	8.9%	0.1%	6.9%	1.0%	1.8%	0.6%	0.8%	0.2%	6.8%	15.4%	0.4%
	4	0.4%	32.9%	41.9%	0.0%	4.0%	12.8%	3.3%	1.0%	0.5%	0.1%	2.2%	1.0%	0.0%
	5	2.0%	56.7%	21.8%	0.0%	4.3%	4.2%	4.0%	1.0%	0.6%	0.1%	2.2%	3.0%	0.0%
3	1	82.8%	5.6%	4.8%	0.1%	1.5%	0.2%	0.3%	0.0%	0.1%	0.1%	0.8%	3.2%	0.5%
	2	16.3%	32.0%	17.7%	0.1%	24.7%	1.5%	1.0%	0.2%	0.3%	0.1%	1.9%	3.8%	0.5%
	3	28.9%	17.6%	7.7%	0.8%	6.3%	0.8%	0.6%	0.5%	2.5%	1.9%	11.4%	12.2%	8.8%
	4	5.4%	1.9%	1.1%	0.0%	2.6%	0.0%	0.0%	0.0%	0.0%	0.0%	1.4%	87.4%	0.1%
4	1	83.6%	6.7%	2.8%	0.4%	1.1%	0.6%	0.1%	0.1%	0.1%	0.1%	0.5%	1.5%	2.2%
	2	23.0%	29.6%	17.8%	0.0%	16.7%	1.7%	1.1%	0.4%	1.0%	1.4%	1.8%	3.3%	2.2%
	3	57.1%	5.3%	1.1%	0.0%	1.4%	0.1%	0.0%	0.0%	0.1%	0.0%	2.3%	25.1%	7.5%
	4	42.7%	11.4%	3.1%	0.0%	2.1%	0.2%	0.0%	0.0%	0.2%	0.0%	1.1%	4.3%	34.8%

Table 2. For Taiwanese effort in the YFT 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	2.5%	43.2%	22.0%	0.2%	14.7%	3.3%	4.1%	0.5%	2.2%	0.4%	2.4%	3.7%	0.9%
	2	0.8%	50.0%	14.0%	0.0%	7.5%	1.0%	2.6%	0.1%	0.3%	0.0%	6.5%	17.3%	0.0%
	3	1.1%	59.8%	23.7%	0.0%	7.7%	1.3%	2.2%	0.1%	0.4%	0.1%	1.1%	2.5%	0.0%
	4	0.5%	26.4%	56.7%	0.0%	5.9%	0.9%	1.7%	0.1%	0.3%	0.0%	1.8%	5.8%	0.0%
3	1	80.1%	5.7%	7.5%	0.0%	1.8%	0.3%	0.4%	0.0%	0.1%	0.0%	0.9%	3.0%	0.1%
	2	12.9%	44.0%	18.2%	0.1%	5.1%	1.1%	1.2%	0.2%	0.9%	0.3%	6.7%	8.0%	1.3%
	3	18.3%	24.3%	12.4%	0.0%	36.7%	0.8%	0.6%	0.1%	0.0%	0.0%	2.2%	4.3%	0.3%
	4	4.7%	1.6%	1.1%	0.0%	1.1%	0.0%	0.1%	0.0%	0.0%	0.0%	1.4%	89.7%	0.4%
4	1	87.3%	6.2%	2.6%	0.0%	1.1%	0.3%	0.2%	0.0%	0.1%	0.1%	0.5%	1.0%	0.5%
	2	34.7%	21.2%	9.4%	2.6%	16.4%	1.6%	1.5%	0.6%	1.2%	1.9%	2.7%	4.5%	1.8%
	3	21.6%	42.2%	22.8%	0.1%	5.1%	1.1%	0.6%	0.0%	0.4%	0.1%	0.8%	2.4%	2.8%
	4	56.1%	6.3%	2.8%	0.0%	1.9%	0.1%	0.2%	0.0%	0.1%	0.0%	3.2%	27.4%	1.9%
	5	59.2%	10.1%	2.1%	0.0%	1.8%	0.2%	0.2%	0.0%	0.0%	0.1%	0.9%	5.3%	20.2%
5	1	1.9%	67.7%	14.0%	0.0%	5.4%	1.9%	2.1%	0.4%	0.3%	0.0%	1.9%	4.3%	0.0%
	2	0.8%	44.9%	31.6%	0.1%	4.6%	6.7%	3.8%	1.1%	0.9%	0.3%	2.6%	2.3%	0.4%
	3	73.9%	9.7%	10.5%	0.0%	2.2%	1.0%	0.9%	0.2%	0.1%	0.1%	0.6%	0.8%	0.0%
	4	1.9%	40.6%	9.6%	0.0%	5.9%	0.9%	2.8%	0.3%	0.6%	0.0%	10.6%	26.8%	0.0%

Table 3. Standardized bigeye and yellowfin tuna CPUE indices by regions and year-quarter based on Taiwanese operational data from 1979 to 2015.

Year-Qtr	BET Region 1	BET Region 2	BET Region 3	BET Region 4	Year-Qtr	YFT Region 2	YFT Region 3	YFT Region 4	YFT Region 5
1979.125	0.9928	1.9919			1979.125			1.2417	1.2734
1979.375	1.3141	1.4932	1.9088		1979.375			1.7463	2.0452
1979.625	0.9660	1.1776	3.8756	3.0457	1979.625		0.7378	0.9326	2.1315
1979.875	1.2215	1.3114	0.8058	0.8252	1979.875		2.3781	1.5997	1.5328
1980.125	1.5439	1.3102	1.6812	0.6711	1980.125		0.3456	0.5719	0.6949
1980.375	1.6829	1.2800	1.4960	2.4624	1980.375			0.6785	1.6764
1980.625	2.0491	0.9833	2.5232	1.7021	1980.625		0.2581	0.4262	1.1617
1980.875	1.3639	1.0588	1.0345	1.0949	1980.875		1.7169	0.7884	0.8052
1981.125	0.6602	1.2051	0.6719	0.7275	1981.125		1.1154	0.6353	0.2293
1981.375	0.9546	1.1023	1.3553	1.5334	1981.375			0.9637	1.3419
1981.625	1.4920	1.1294	2.1306	1.1911	1981.625	1.1769	1.0813	1.4075	1.9500
1981.875	0.9893	1.3467	0.7014	0.3925	1981.875	1.4381	4.0447	1.2003	1.7217
1982.125	1.3361	1.1980	0.6231		1982.125	0.9799		0.7196	1.0572
1982.375	2.1726	1.3316	1.7914	1.3191	1982.375	1.2011		0.8004	1.7207
1982.625	1.4259	1.1359	2.3293	1.1822	1982.625	1.0854	0.7739	0.8563	1.6843
1982.875	1.2683	1.4756	0.8423	0.7722	1982.875		3.1441	2.1957	1.4005
1983.125	1.2480	1.0857	0.7700		1983.125	1.0510	1.3648	1.0474	1.1470
1983.375	1.3927	1.2057	1.4401	0.2908	1983.375	0.9991		1.3161	2.3141
1983.625	1.2594	1.1794	2.0480	0.5218	1983.625		1.6487	1.0334	1.7750
1983.875	1.0551	1.0722	0.9224	0.4127	1983.875		3.0955	1.4010	1.3582
1984.125	0.9978	1.3496	0.7666	0.5290	1984.125		2.4222	0.9478	1.3688
1984.375	1.3686	1.2720	1.8251	0.9432	1984.375	0.6879		0.8247	1.9526
1984.625	1.2148	1.0338	3.2173	1.6302	1984.625			0.6874	1.7187
1984.875	1.2442	1.1424	0.8213	0.4573	1984.875		1.5267	1.0173	2.0267
1985.125	1.4992	1.2910	0.7160		1985.125		3.1021	0.9822	1.1921
1985.375	1.1899	1.0505	2.5985		1985.375	0.9391		1.0777	1.6685
1985.625	1.3119	1.0525	2.5810		1985.625	1.5893		0.6049	1.9165
1985.875	1.6471	1.1751	1.0827		1985.875	1.9769	1.9134	1.5501	1.7346
1986.125	0.8970	1.4022	0.8539		1986.125	2.8055		1.1002	1.3975
1986.375	1.2810	1.1060			1986.375	1.7859		1.4683	2.0070
1986.625	1.1278	1.0650	2.7527		1986.625	1.2303		0.7643	1.8561
1986.875	1.2191	1.6210	0.8227	1.3583	1986.875	1.7621	1.6328	1.3241	1.8487
1987.125	0.6958	1.5492			1987.125	2.6597		1.1044	0.9997
1987.375	1.1416	1.2230		1.9286	1987.375	1.5805		1.6225	2.0072
1987.625	0.8823	0.9996	2.3391	2.5960	1987.625	1.1119		0.6086	1.1840
1987.875	0.7624	1.1874	0.8278		1987.875	1.8702	5.5267	1.3953	1.2816
1988.125	1.1050	1.1457			1988.125	1.6169		1.3839	1.5010
1988.375	0.8867	0.9205			1988.375	1.4962		1.1958	1.9590
1988.625	0.7186	1.0328	2.0255	2.4573	1988.625	1.2784		0.6280	1.8028
1988.875	0.7559	1.1149			1988.875	0.9212		0.9522	1.4631
1989.125	0.7322	0.8680			1989.125	0.5845		0.6775	0.5905
1989.375	0.8786	0.9689			1989.375	0.7913		1.5900	0.9992
1989.625	0.7135	0.7000		1.1929	1989.625	1.2110		1.0901	0.9825
1989.875	0.9215	0.7874			1989.875	1.1523		0.6921	0.8672

Year-Qtr	BET Region 1	BET Region 2	BET Region 3	BET Region 4	Year-Qtr	YFT Region 2	YFT Region 3	YFT Region 4	YFT Region 5
1990.125	0.8441	0.9493			1990.125	0.9615		0.2705	1.2439
1990.375	0.9844		0.7877		1990.375	0.9837		1.1262	
1990.625	0.7817	0.7804	1.4546		1990.625	1.0976		0.9360	1.5775
1990.875	0.8025	0.6803	0.9210		1990.875	1.0094		1.0840	0.7991
1991.125	0.6844	0.7648			1991.125	0.6620		0.5491	0.8286
1991.375	0.9523				1991.375	1.0671		1.2329	
1991.625	0.7361		1.5254		1991.625	0.7398	1.1155	1.7452	1.1379
1991.875	0.8707	0.7036			1991.875	0.7796		0.0430	0.6991
1992.125	0.7105				1992.125	0.6415		0.2887	
1992.375	1.0301			0.4701	1992.375	1.3122		1.7924	
1992.625	1.2267		0.5404		1992.625	1.6323	2.3271	2.2365	
1992.875	1.2828	1.5828			1992.875	1.9356		1.5969	2.1222
1993.125	0.8625	1.0688			1993.125	1.1950		1.0422	2.5241
1993.375	1.0626	1.2518	0.9706	0.7789	1993.375	1.2091		1.1511	3.1424
1993.625	0.7307	0.8932	0.9929	0.7028	1993.625	1.1840	0.7701	1.1791	1.5166
1993.875	0.9514	0.9185	0.8337	1.1504	1993.875	0.8653	1.2532	2.0563	1.1271
1994.125	1.1284	1.1437	1.0675	1.1156	1994.125	0.9550	1.6918	1.5252	1.4585
1994.375	1.2089	1.0166	0.9463	1.2273	1994.375	1.1387	3.0107	2.8932	2.0717
1994.625	1.0330	0.7531	0.8105	1.2328	1994.625	2.3915	1.9057	2.1457	0.9078
1994.875	1.0876	0.9114	0.5018		1994.875	1.2837	0.4619	1.5008	0.9011
1995.125	0.8703				1995.125	0.5439	0.9936	1.6851	0.7784
1995.375	0.9947		0.7953		1995.375	0.5615	1.0980	1.9255	
1995.625	0.8699	0.7044	0.6626	1.3896	1995.625	0.7928	1.1236	1.1678	0.5515
1995.875	0.8130	0.9844	0.4420	0.9820	1995.875	1.0337	1.3755	1.4378	0.5191
1996.125	0.7301	1.0229	0.4037	0.9854	1996.125	1.0654	0.9007	1.1518	0.6074
1996.375	1.0690		0.8056	1.1550	1996.375	0.8281	1.0321	1.6528	
1996.625	0.8358	0.8147	0.7865	1.0256	1996.625	0.5205	1.0160	0.7528	0.7124
1996.875	0.7375	0.7110	0.6174		1996.875	0.7085	0.8631	0.9172	0.5342
1997.125	0.8756	1.1490	0.3352		1997.125	0.9847	0.2483	0.3870	0.3337
1997.375	1.4818		1.1490	0.9904	1997.375	0.4361	0.4734	1.1213	
1997.625	0.9960	1.0943	0.9713	0.8527	1997.625	0.8802	0.5955	0.5420	0.7696
1997.875	0.5480	1.0786	0.5758		1997.875	1.4890	1.0571	0.7224	0.6574
1998.125	0.8602		0.3774		1998.125	1.0665	0.5557	0.8479	
1998.375	1.0421		0.7833		1998.375	0.8702	0.7359	1.1596	
1998.625	0.8750	0.8066	0.8924	1.1879	1998.625	0.8895	1.0799	0.9162	0.5603
1998.875	0.8971	0.7721	0.9283		1998.875	1.0247	1.2504	1.8135	0.7775
1999.125	0.8216	0.7528	0.9016		1999.125	0.9264	0.4075	0.8272	0.6732
1999.375	0.9158	0.8924	0.8746	1.0752	1999.375	0.8936	0.5838	1.8444	0.6549
1999.625	0.8978	0.6404	0.8420	1.0270	1999.625	0.8844	0.9477	0.7501	0.7361
1999.875	0.9131	0.7332	0.8398		1999.875	0.7387	0.9516	1.4528	0.6771
2000.125	0.8115	0.8546	1.3342		2000.125	0.7435	1.0021	1.1489	0.6259
2000.375	0.9343	0.6190	1.1899	0.8553	2000.375	0.6913	0.7532	1.5307	0.8514
2000.625	0.9121	0.5458	1.1734	1.0297	2000.625	1.0085	0.5424	0.8392	0.9164
2000.875	0.8924	0.7293	0.6660		2000.875	0.7308	1.0537	1.3867	0.9745
2001.125	0.8853	0.6732	1.2834		2001.125	0.8333	0.9204	0.6815	0.5704
2001.375	1.0066	0.8136	1.0261	1.0181	2001.375	1.0139	1.4759	1.7584	0.6811
2001.625	0.9817	0.9850	0.8907	0.5682	2001.625	1.0491	1.2806	1.4311	0.9615

Year-Qtr	BET Region 1	BET Region 2	BET Region 3	BET Region 4	Year-Qtr	YFT Region 2	YFT Region 3	YFT Region 4	YFT Region 5
2001.875	1.1201	1.1574	0.6807		2001.875	1.1928	1.5947	2.0343	0.8929
2002.125					2002.125				
2002.375					2002.375				
2002.625					2002.625				
2002.875					2002.875				
2003.125					2003.125				
2003.375					2003.375				
2003.625					2003.625				
2003.875					2003.875				
2004.125					2004.125				
2004.375					2004.375				
2004.625					2004.625				
2004.875					2004.875				
2005.125	1.0426	1.1128	0.8404		2005.125	1.1846	2.4262	1.5919	0.9847
2005.375	1.0670		0.6631	0.8215	2005.375	1.4512	1.9990	1.0387	1.3971
2005.625	0.6711	0.8223	1.0258	0.7406	2005.625	0.8455	1.0583	0.9930	0.6027
2005.875	0.5507	0.8093	0.8918		2005.875	1.1791	1.0334	1.0153	0.5431
2006.125	0.9660	1.8261	0.9683		2006.125	1.1544	0.6168	0.5506	0.9673
2006.375	0.8689	1.2664	1.2234	0.8422	2006.375	0.9512	0.3886	1.2127	1.2520
2006.625	0.7122	0.8078	1.1731	1.0590	2006.625	0.4716	0.5058	1.0217	0.7166
2006.875	0.9119	1.0737	0.7696		2006.875	0.8438	0.2412	2.0007	0.6498
2007.125	0.8880	1.2039			2007.125	0.7383	0.6325	0.7225	0.9644
2007.375	0.9214	0.7695	0.5713	0.8986	2007.375	0.6642	0.5731	1.4535	0.7501
2007.625	0.8258	0.7474	0.7232	1.4442	2007.625	0.5803	0.3113	0.9098	0.6377
2007.875	1.1880	1.0575	0.4328		2007.875	0.6589	0.3381	0.2693	0.4796
2008.125	0.6676	0.5996	0.3935		2008.125	0.3940	0.4529	0.3187	0.3146
2008.375	1.0116	0.7348	0.4454	0.7511	2008.375	0.3398	0.5193	0.7138	0.2466
2008.625	0.8819	0.7321	1.0782	0.9520	2008.625	0.6693	0.3302	0.5238	0.3177
2008.875	1.3289	1.3711	0.4036		2008.875	0.4687	0.2952	0.4218	0.3140
2009.125	0.6485	0.7347			2009.125	0.3449	0.3886	0.2753	0.3424
2009.375	0.8001	0.7591	0.6330	0.4107	2009.375	0.3773	0.3847	0.2739	0.3185
2009.625	0.8435	0.7764	0.7732	0.6168	2009.625	0.6874	0.4205	0.3539	0.3766
2009.875	0.9646	0.8978	0.3058		2009.875	0.7329	0.1996	0.4912	0.1982
2010.125	0.6694	0.5652	0.3160		2010.125	0.3723	0.1370	0.4226	0.2104
2010.375	0.8836	0.5401	0.2843	0.5167	2010.375	0.6090	0.5003	0.6687	0.3928
2010.625	0.9996	0.7926	0.6323	0.6682	2010.625	1.0197	0.3709	0.6617	0.3331
2010.875	0.9065	0.8524	0.2718		2010.875	0.9114	0.2257	0.5361	0.2991
2011.125	0.6628	0.6704	0.2522		2011.125	0.5087	0.3306	0.1372	0.3531
2011.375	1.2823	0.8948		0.8916	2011.375	0.9918	0.4247	0.4137	0.5404
2011.625	1.2579	1.0109		1.1501	2011.625	1.6237	0.4374	0.4962	0.7418
2011.875	1.2736	1.3434	0.4844		2011.875	1.6009	0.8413	1.8314	0.6525
2012.125	1.2935	0.9582	0.2206		2012.125	0.8160	0.8044	0.7772	0.4399
2012.375	1.6846				2012.375	0.8668	0.3405	0.4640	0.2748
2012.625	0.9258	0.7334		0.4733	2012.625	0.4874	0.2703	0.2967	0.4648
2012.875	1.1921	0.9979	0.4275		2012.875	0.7627	1.1069	0.9993	0.4330
2013.125	0.6895				2013.125	0.5891	0.3122	0.7050	0.4071
2013.375	0.8505		0.6765	0.7403	2013.375	0.6153	0.3782	0.7438	0.1280

Year-Qtr	BET Region 1	BET Region 2	BET Region 3	BET Region 4	Year-Qtr	YFT Region 2	YFT Region 3	YFT Region 4	YFT Region 5
2013.625	0.6440		0.6542	0.3326	2013.625	0.6396	0.3071	0.3529	0.2522
2013.875	1.1679	1.4783	0.2852		2013.875	0.8450	0.4449	0.1966	0.3544
2014.125	0.4706	0.5678			2014.125	0.8874	0.2956	0.8978	0.1160
2014.375	0.7257		1.0647	0.1999	2014.375	0.8111	0.2734	0.3928	
2014.625	0.7335	0.7229	0.5928	0.7066	2014.625	0.4406	0.2614	0.2145	0.2525
2014.875	1.0032	0.6517	0.4275		2014.875	0.8292	0.1841	0.3120	0.1974
2015.125	0.4236	0.3596			2015.125	0.7775	0.4194	0.0031	0.5960
2015.375	0.7760		0.3133	0.4923	2015.375	1.0195	0.1915	0.3473	
2015.625	0.7099	0.8051	0.6355	0.2339	2015.625	0.6261	0.1852	0.7224	0.3239
2015.875	0.8729	0.8676	0.3840		2015.875	1.1836	0.5639	0.1225	0.4421

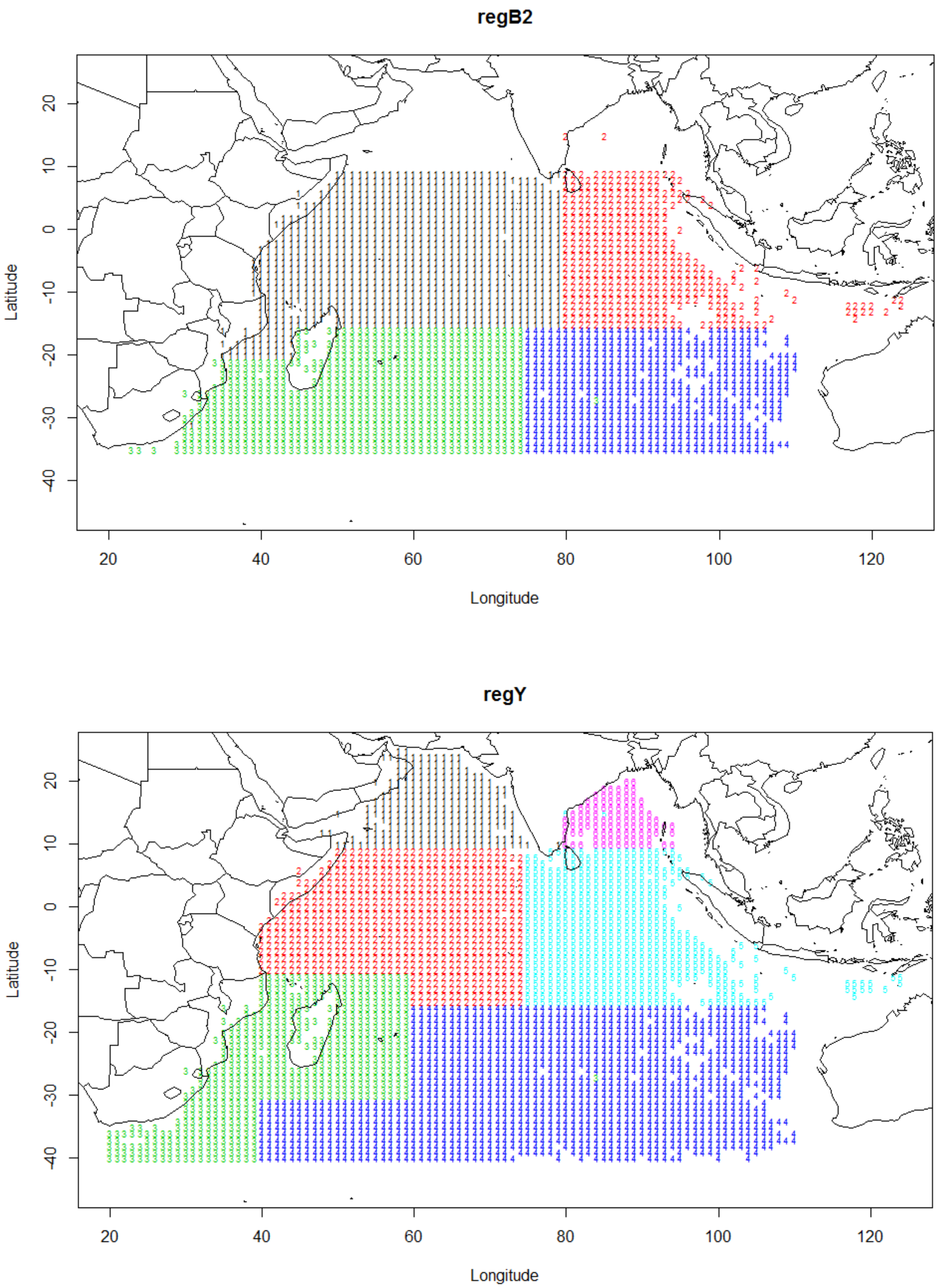


Figure 1. Spatial stratification of the Indian Ocean for this analysis (Holye, 2016).

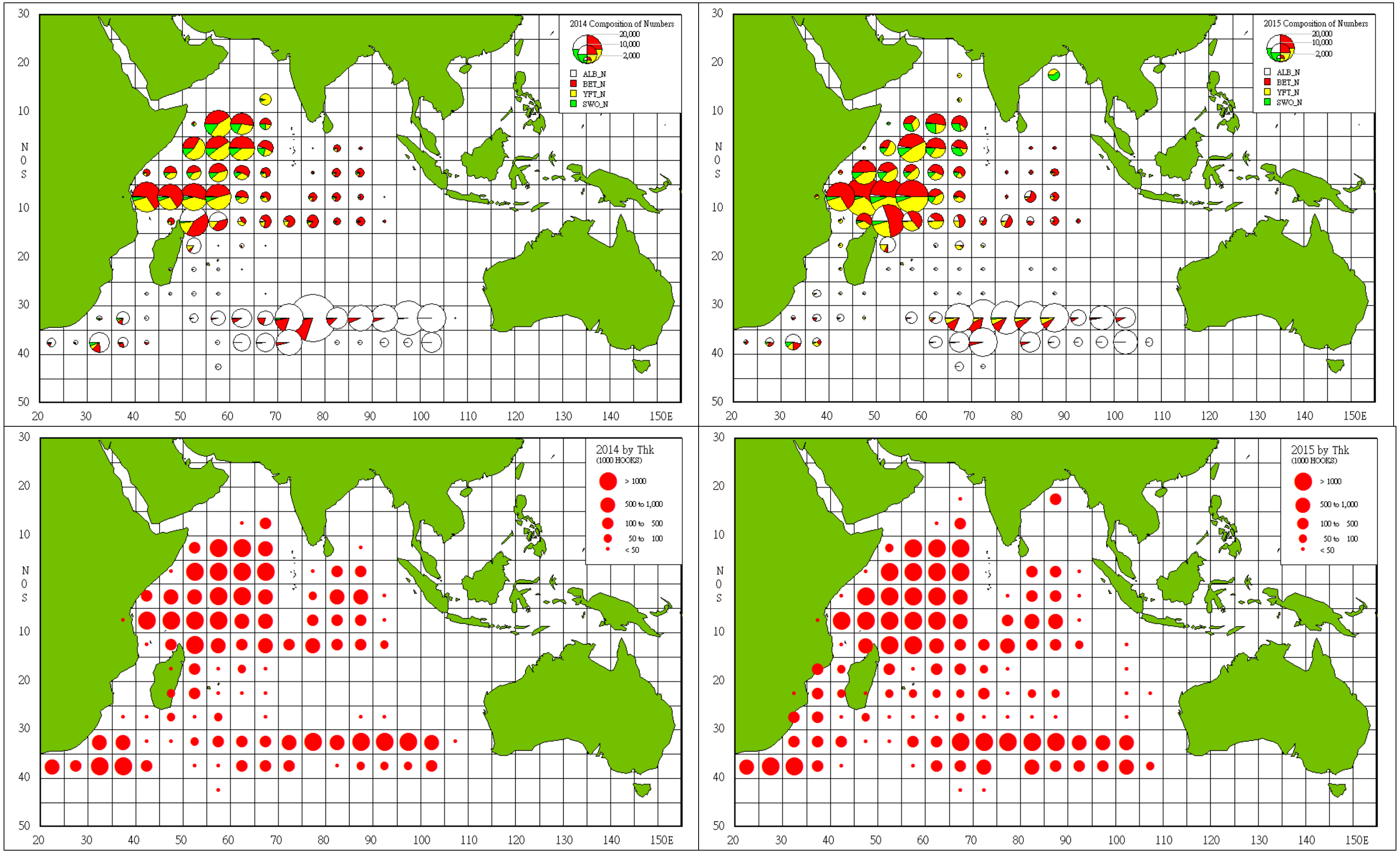

2014 Composition of Numbers
20,000
10,000
2,000
ALB_N
BET_N
YFT_N
SWO_N
2015 Composition of Numbers
2014 by Thk
(1000 HOOKS)
> 1000
500 to 1,000
100 to 500
50 to 100
< 50
2015 by Thk
30
20
10
N
0
S
40
50
60
70
80
90
100
110
120
130
140
150E

Figure 2. Comparison of 2014 and 2015 data used in this analysis. Map of catch composition for 2014 (top_left), for 2015 (top_right), fishing effort by for 2014 (bottom_left), and for 2015 (bottom_right), by 5 degree square.

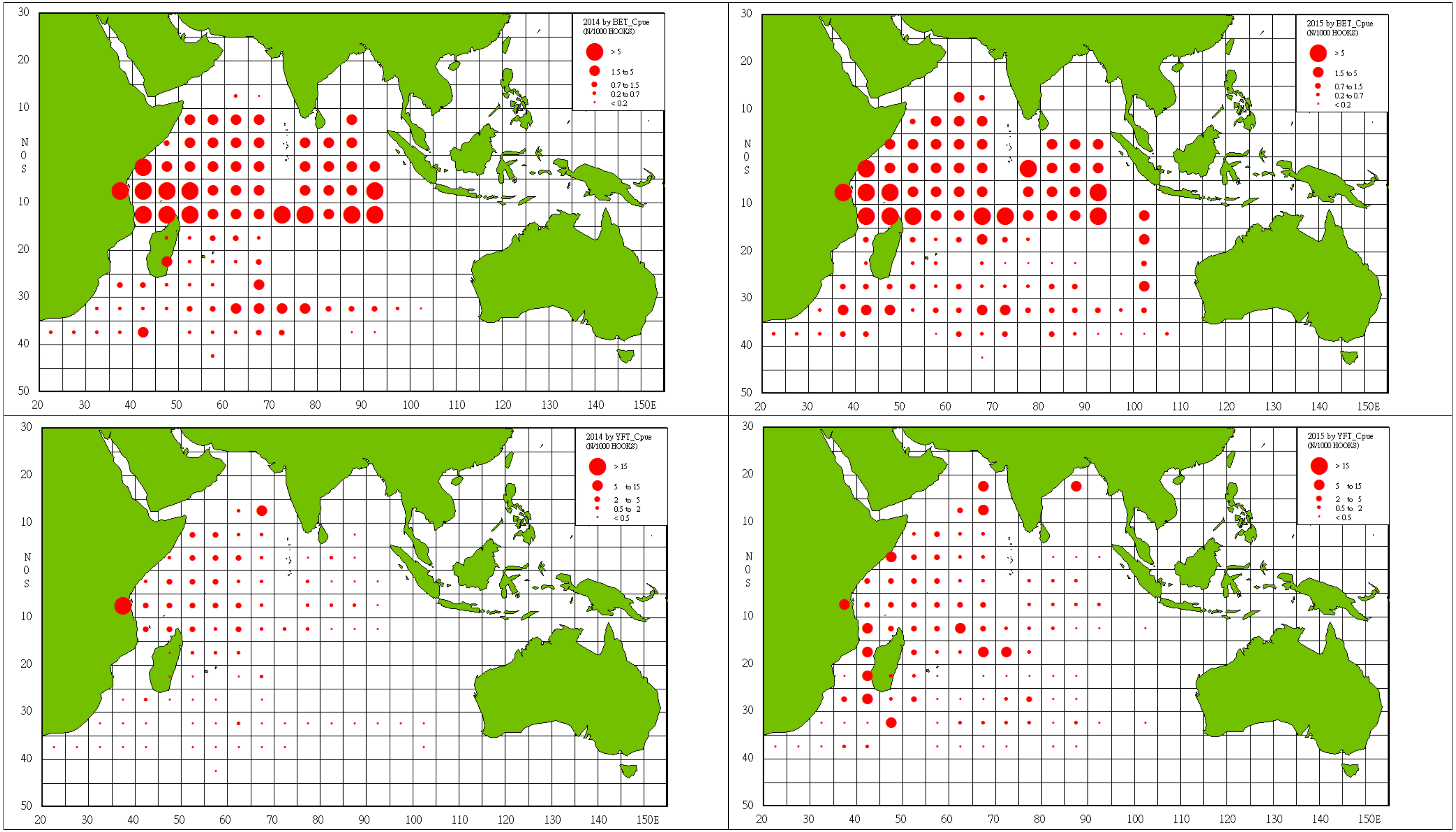

2014 by BET_Cpue
(N/1000 HOOKS)
> 5
1.5 to 5
0.7 to 1.5
0.2 to 0.7
< 0.2
2015 by BET_Cpue
(N/1000 HOOKS)
> 5
1.5 to 5
0.7 to 1.5
0.2 to 0.7
< 0.2
2014 by YFT_Cpue
(N/1000 HOOKS)
> 15
5 to 15
2 to 5
0.5 to 2
< 0.5
2015 by YFT_Cpue
(N/1000 HOOKS)
> 15
5 to 15
2 to 5
0.5 to 2
< 0.5
30
20
10
N
0
S
10
20
30
40
50
20 30 40 50 60 70 80 90 100 110 120 130 140 150E

Figure 3. Comparison of 2014 and 2015 data used in this analysis. Map of nominal bigeye CPUE for 2014 (top_left), for 2015(top_right), nominal yellowfin CPUE for 2014 (bottom_left), for 2015(bottom_right), by 5 degree square.

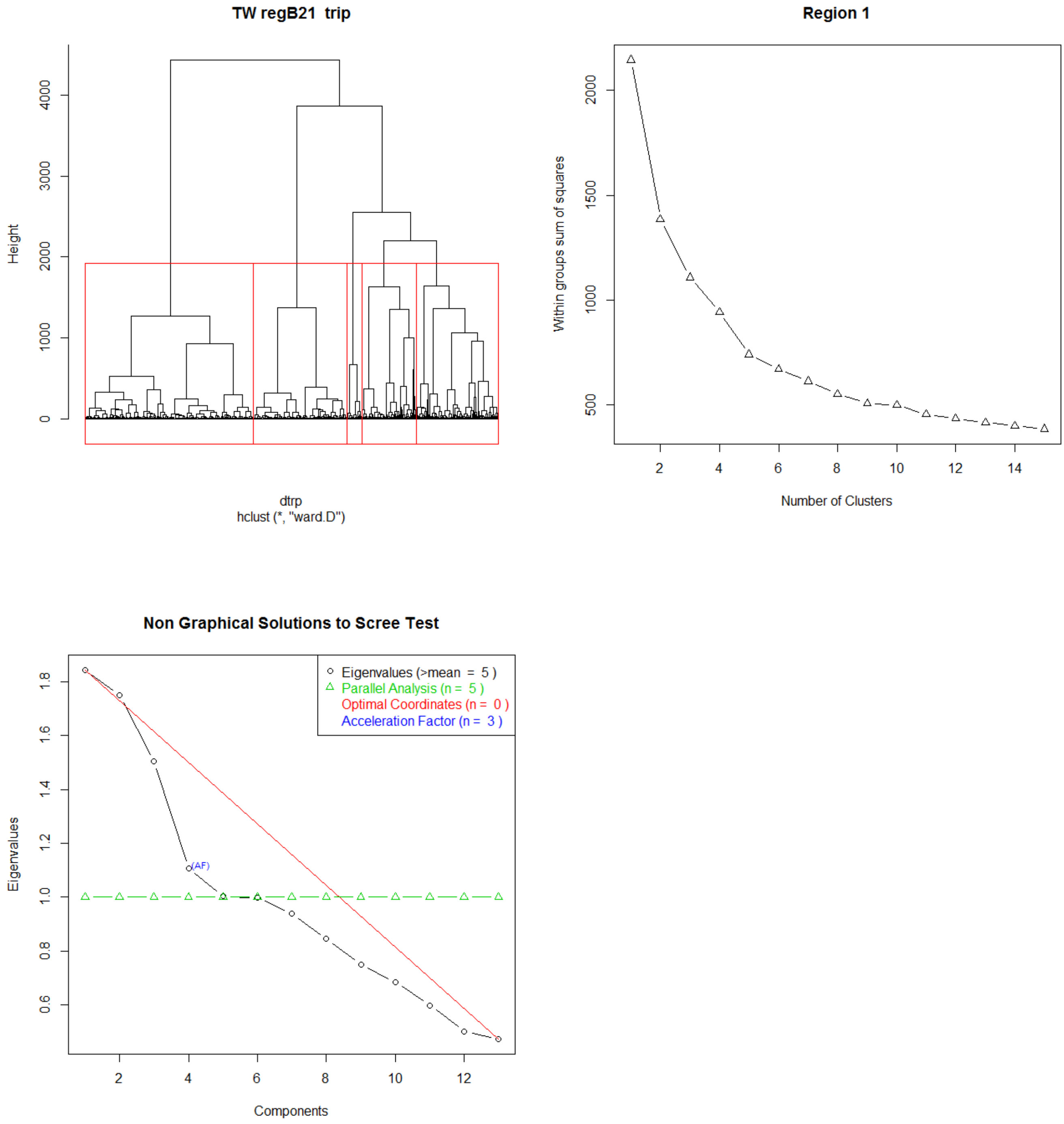
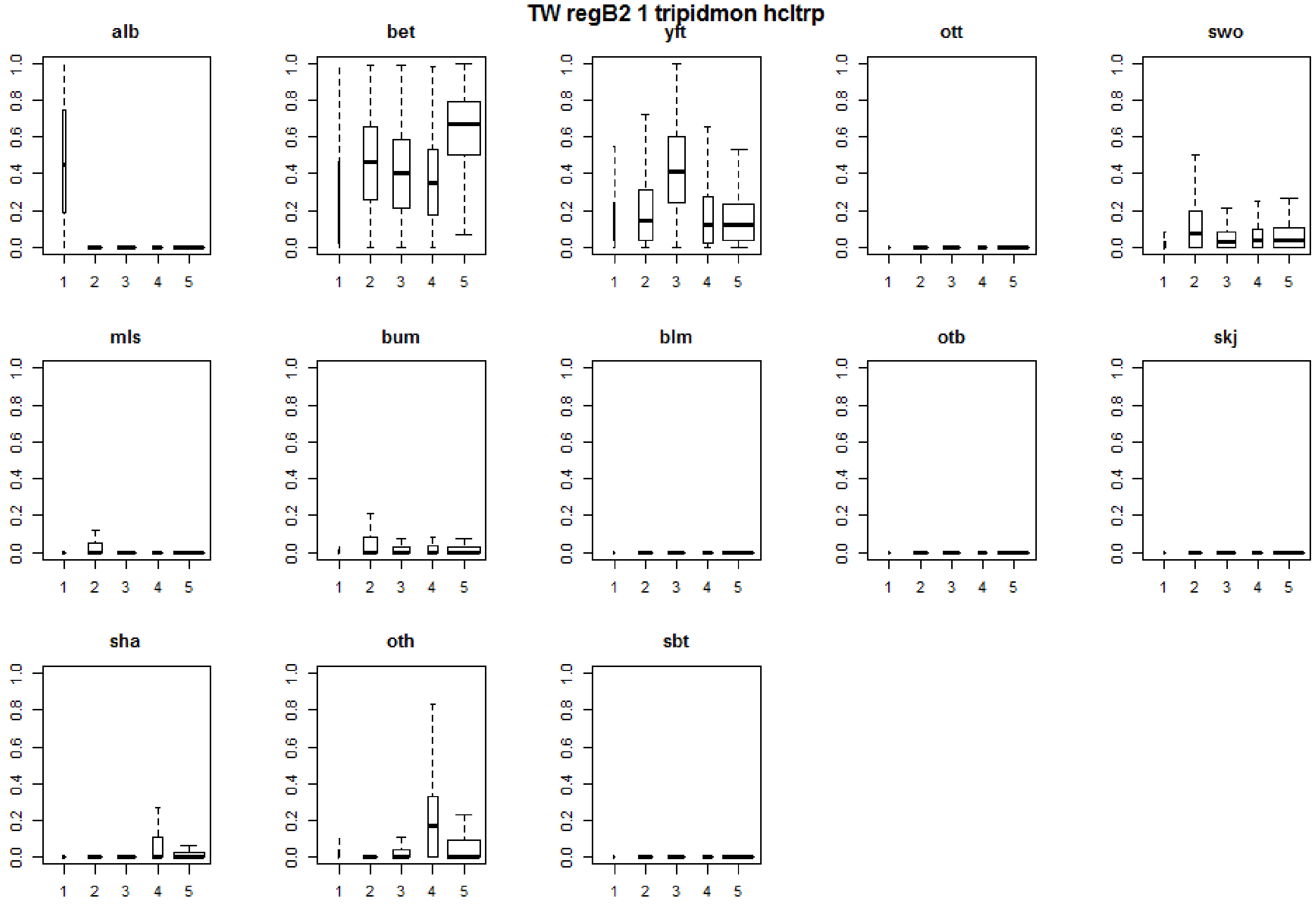


Figure 4. Plots showing analyses to estimate the number of distinct classes of species composition in Taiwanese region 1 of B2. These are based on a hierarchical Ward clustering analysis of trip-level data (top left); within-group sums of squares from kmeans analyses with a range of numbers of clusters (top right); and analyses of the numbers of components to retain from a principal component analysis of trip-level (bottom left) data.


TW regB2 1 tripidmon hcltrp
alb
bet
yft
ott
swo
mls
bum
blm
otb
skj
sha
oth
sbt

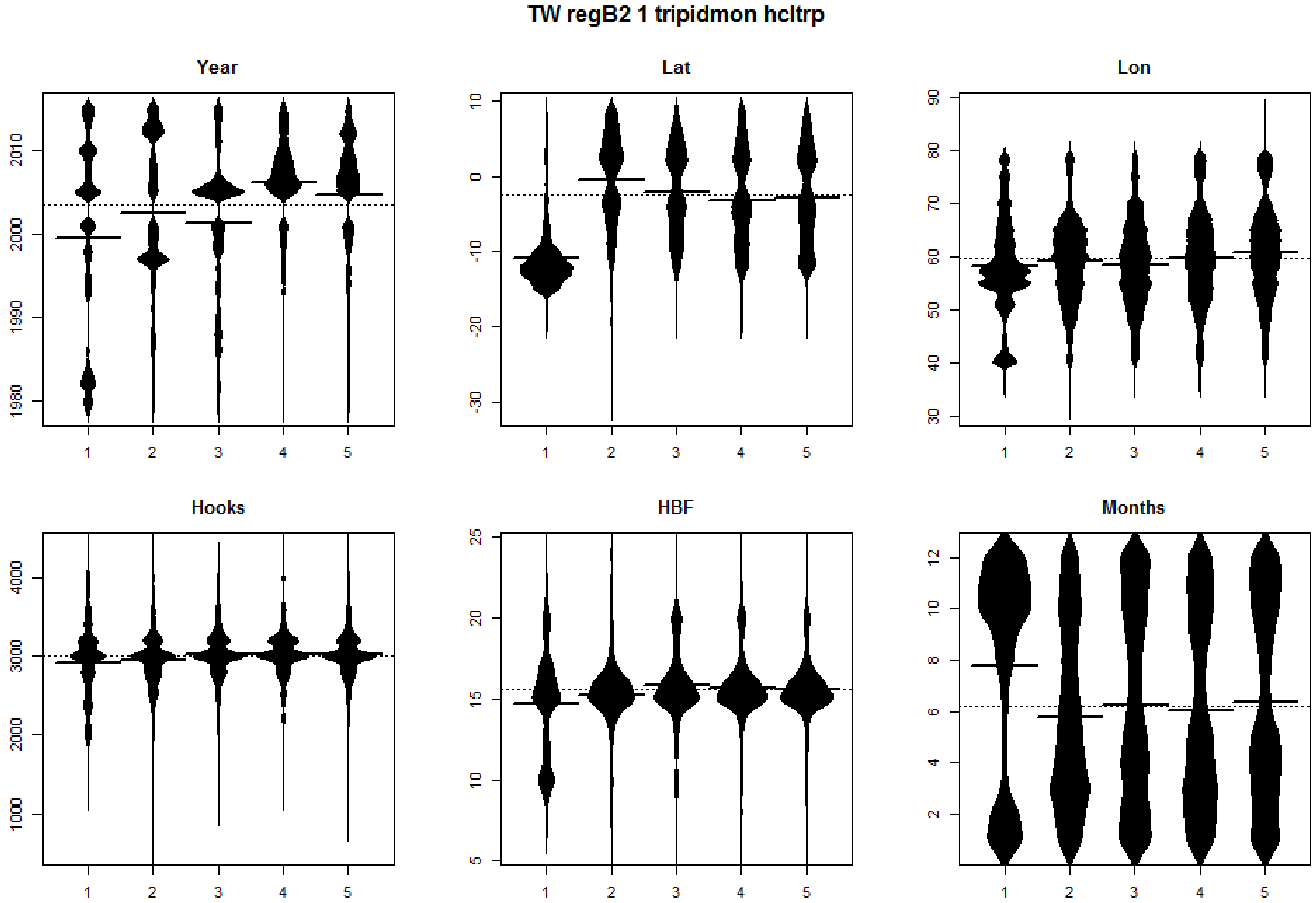

TW regB2 1 tripidmon hcltrp
Year
Lat
Lon
Hooks
HBF
Months

Figure 5. For Taiwanese effort in region 1 of B2 for the period 1979-2015, 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.

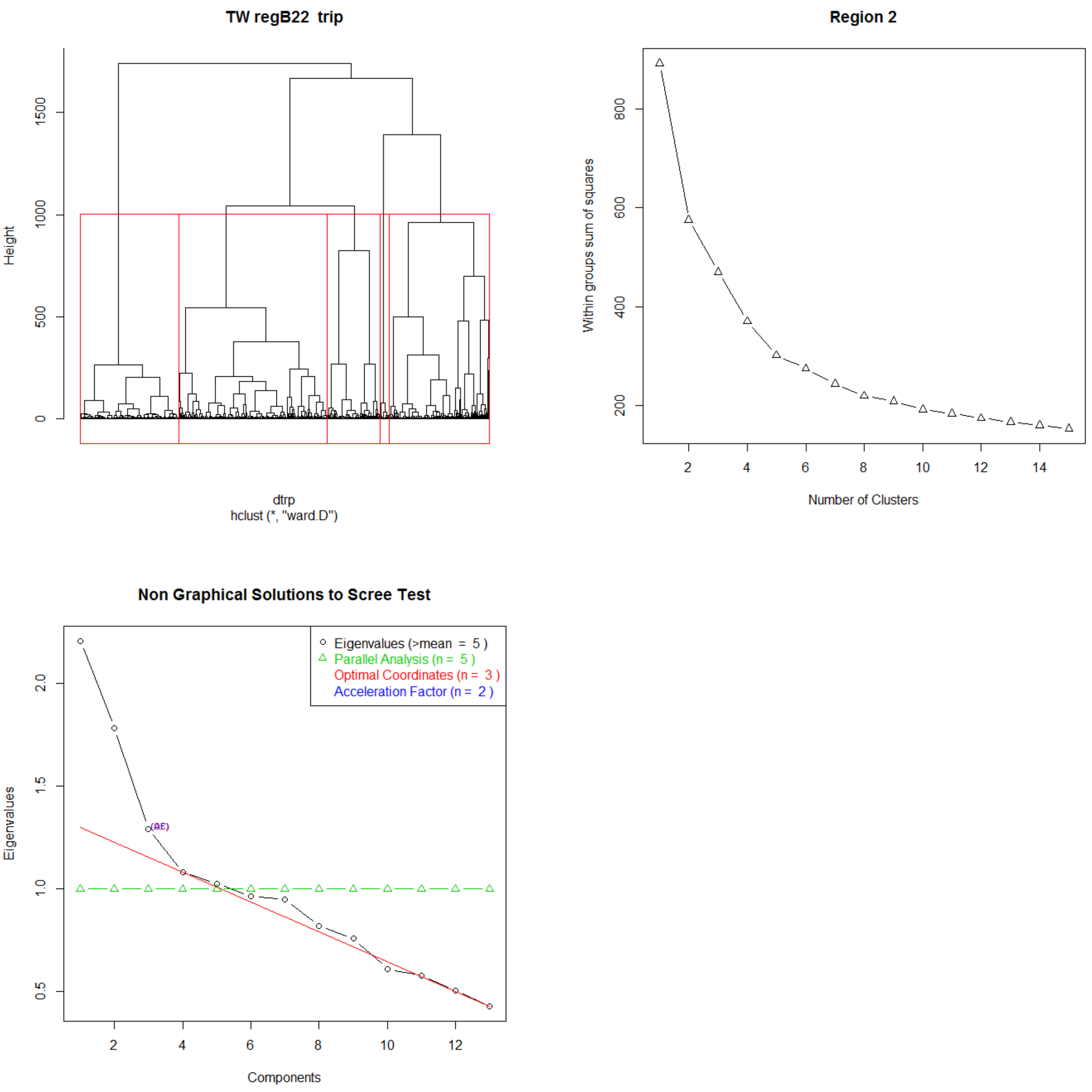
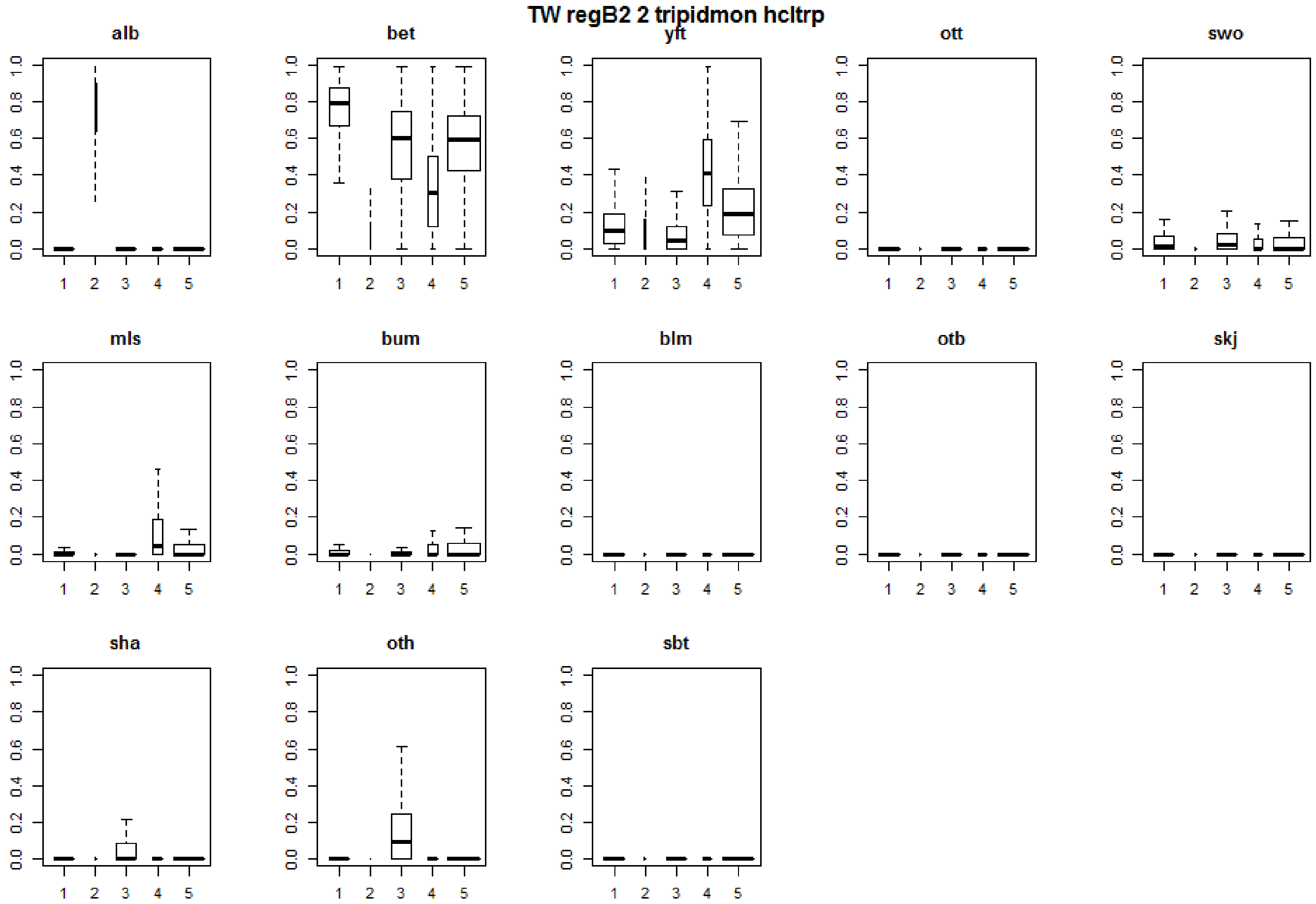


Figure 6. Plots showing analyses to estimate the number of distinct classes of species composition in Taiwanese region 2 of B2. These are based on a hierarchical Ward clustering analysis of trip-level data (top left); within-group sums of squares from kmeans analyses with a range of numbers of clusters (top right); and analyses of the numbers of components to retain from a principal component analysis of trip-level (bottom left) data.


TW regB2 2 tripidmon hcltrp
alb
bet
yft
ott
swo
mls
bum
blm
otb
skj
sha
oth
sbt
0.0
0.2
0.4
0.6
0.8
1.0
1
2
3
4
5

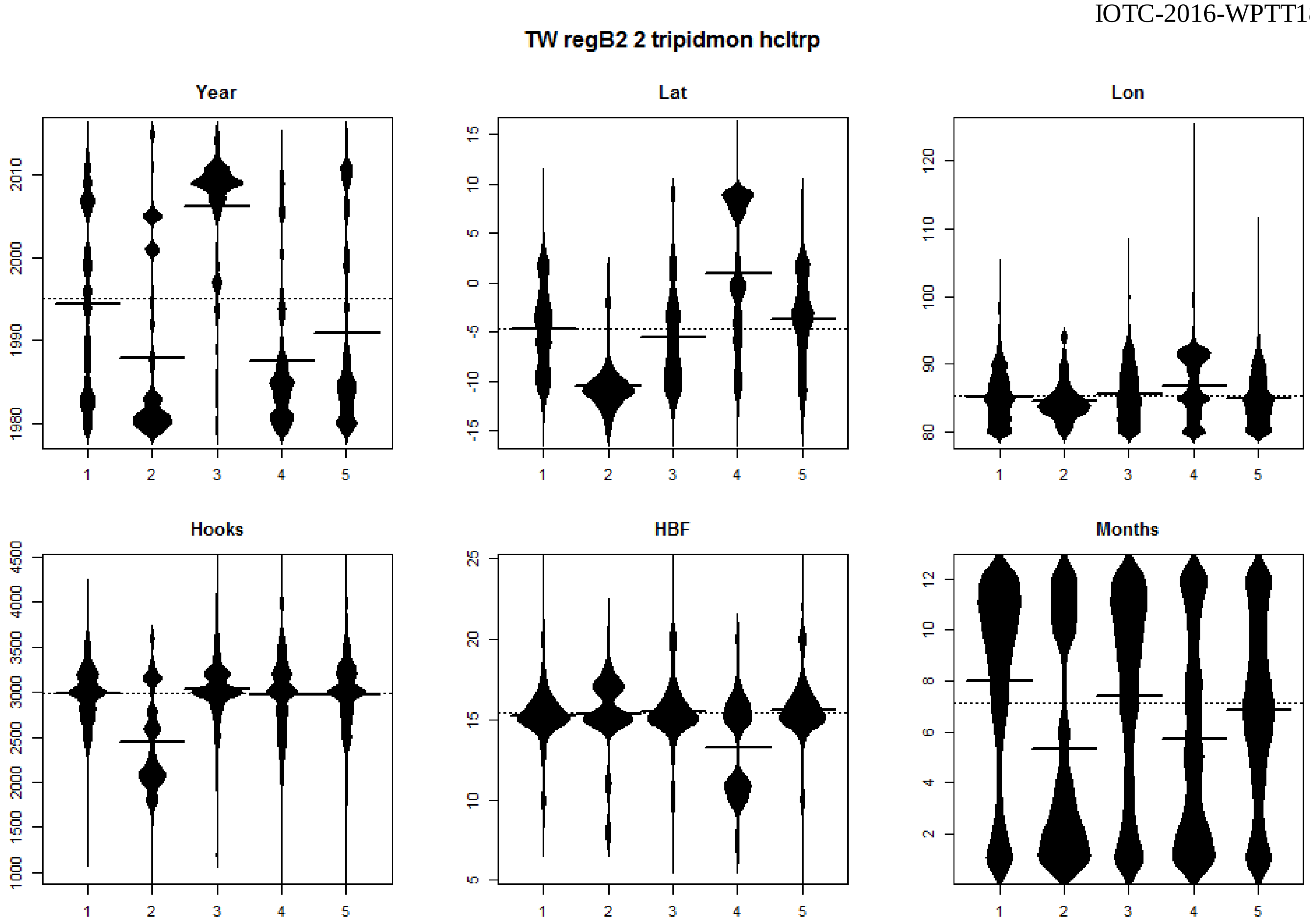


Figure 7. For Taiwanese effort in region 2 of B2 for the period 1979-2015, for each species, boxplot of the proportion of the species in the trip versus the cluster. The widths of the boxes are proportional to the numbers of trips in each cluster (above). Boxplot showing the distributions of variables associated with sets in each hcltrp cluster (below). Clustering was performed using a hierarchical Ward clustering analysis of trip-level data.

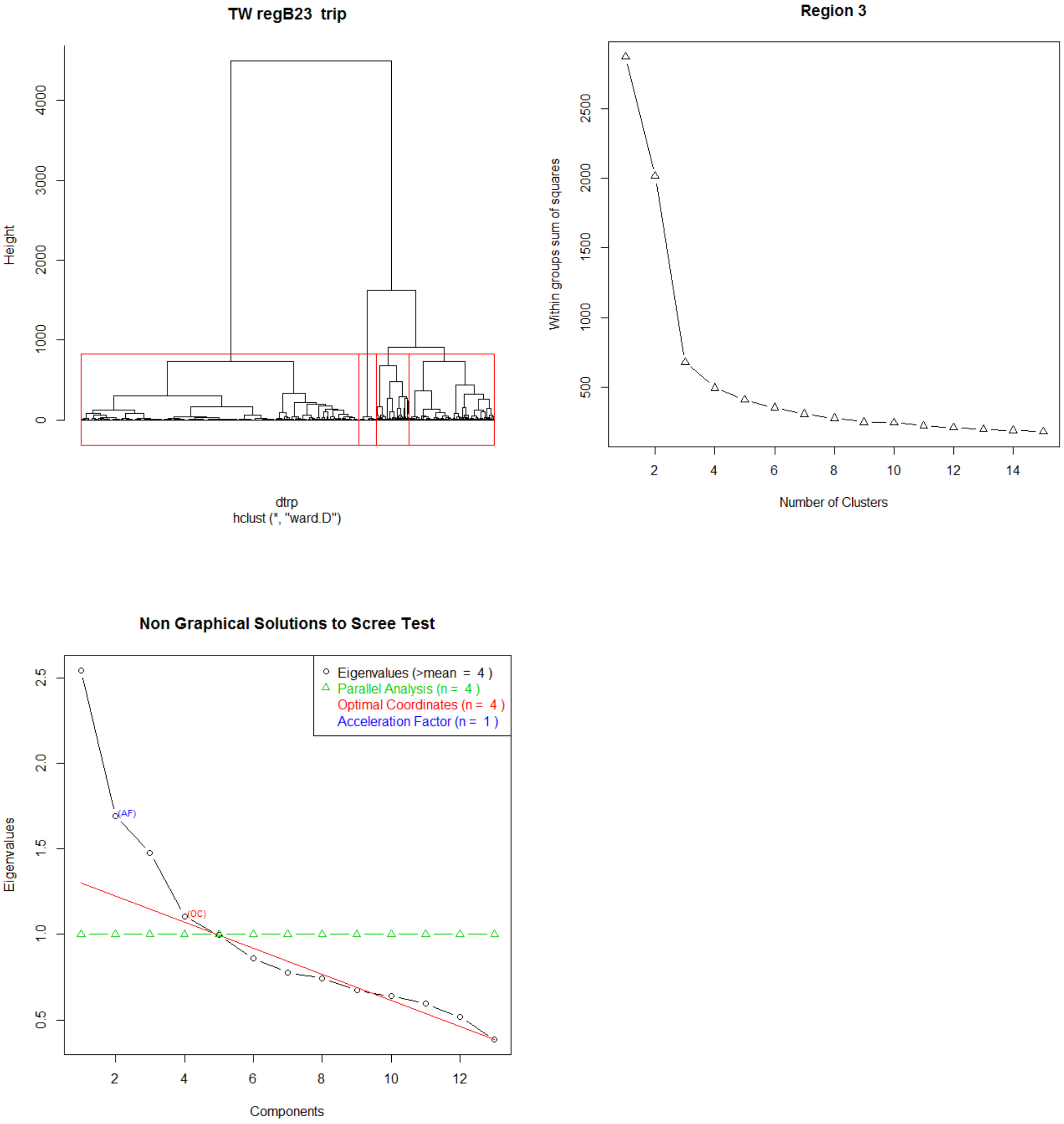
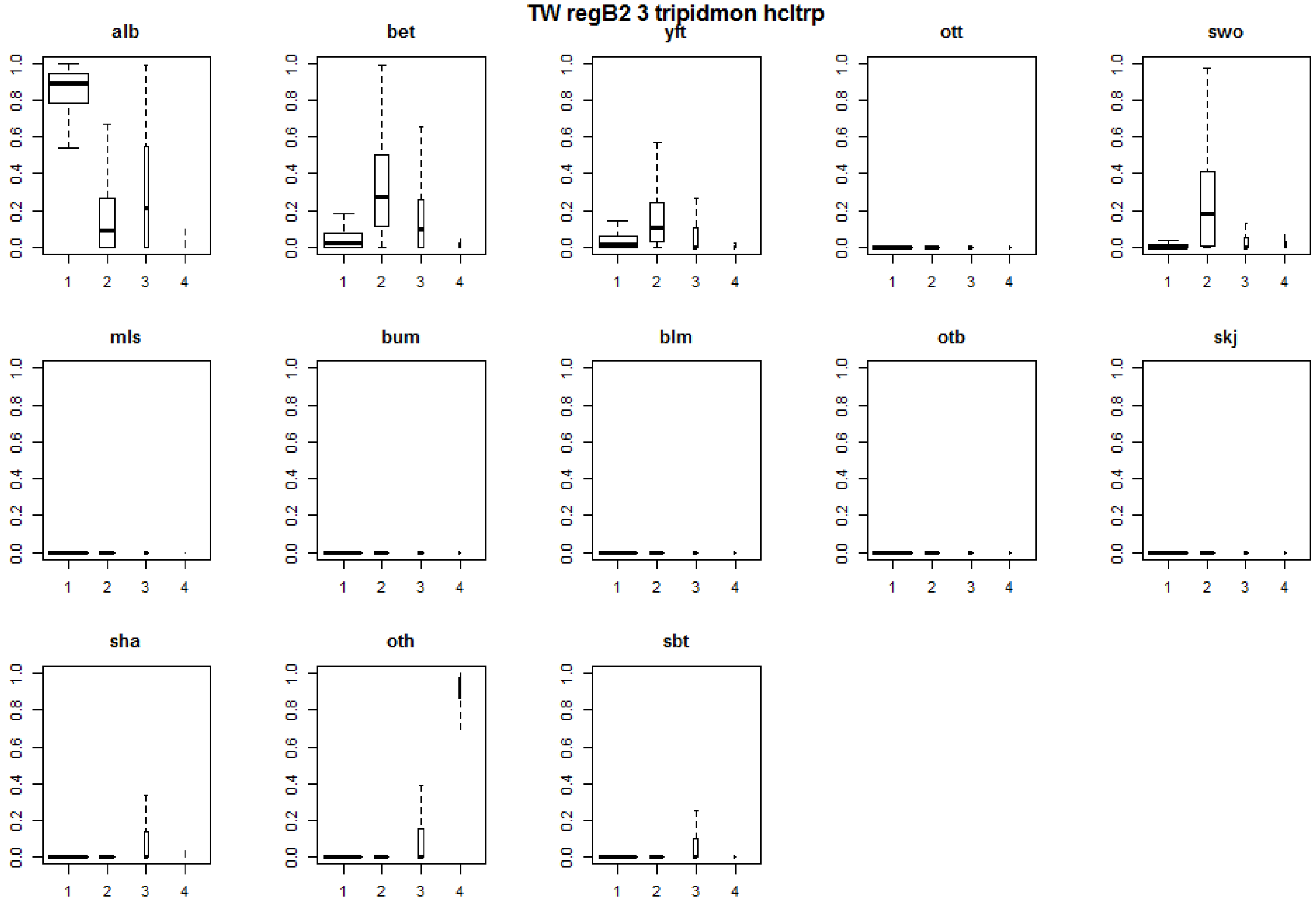


Figure 8. Plots showing analyses to estimate the number of distinct classes of species composition in Taiwanese region 3 of B2. These are based on a hierarchical Ward clustering analysis of trip-level data (top left); within-group sums of squares from kmeans analyses with a range of numbers of clusters (top right); and analyses of the numbers of components to retain from a principal component analysis of trip-level (bottom left) data.



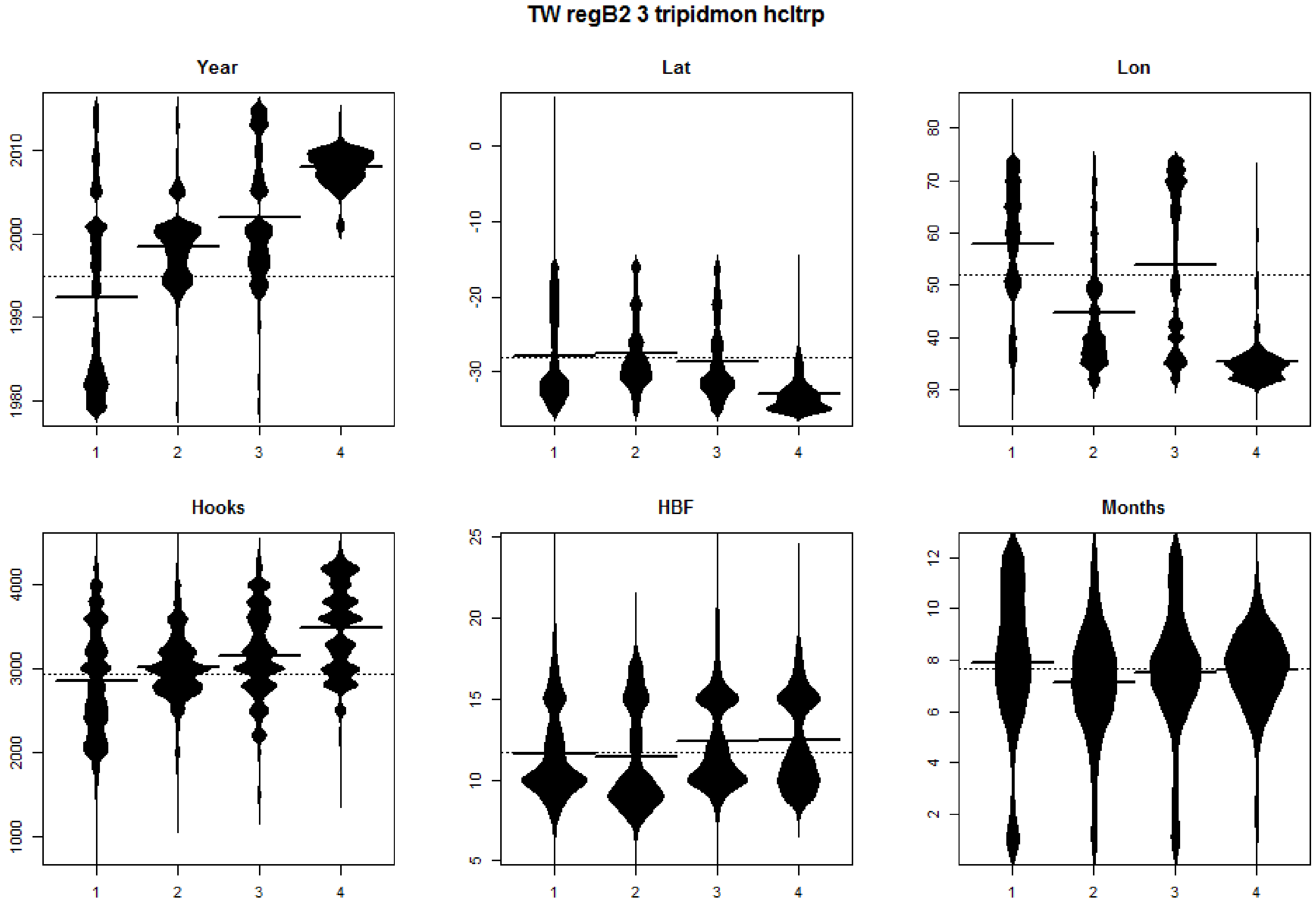


Figure 9. For Taiwanese effort in region 3 of B2 for the period 1979-2015, for each species, boxplot of the

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.

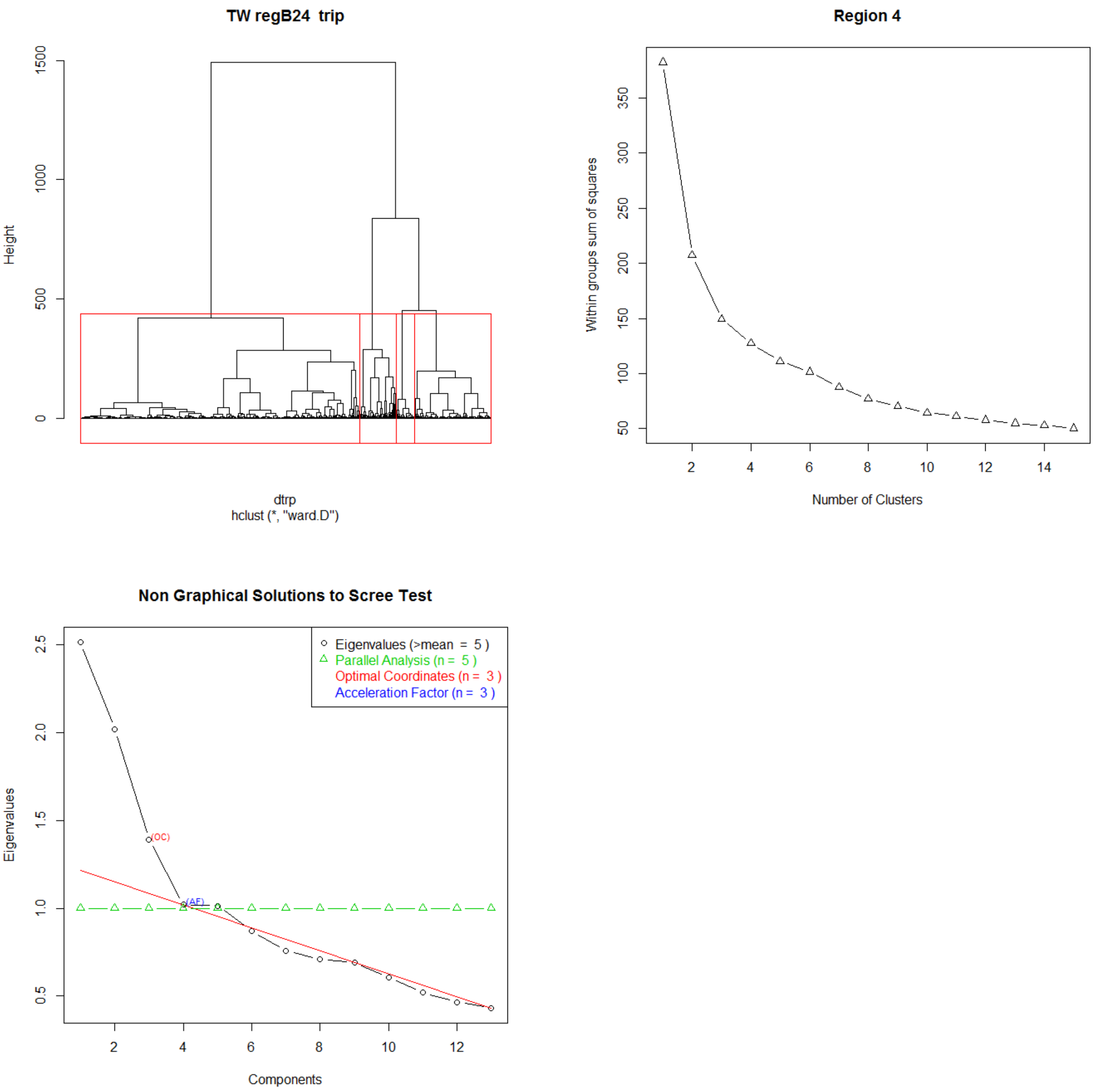
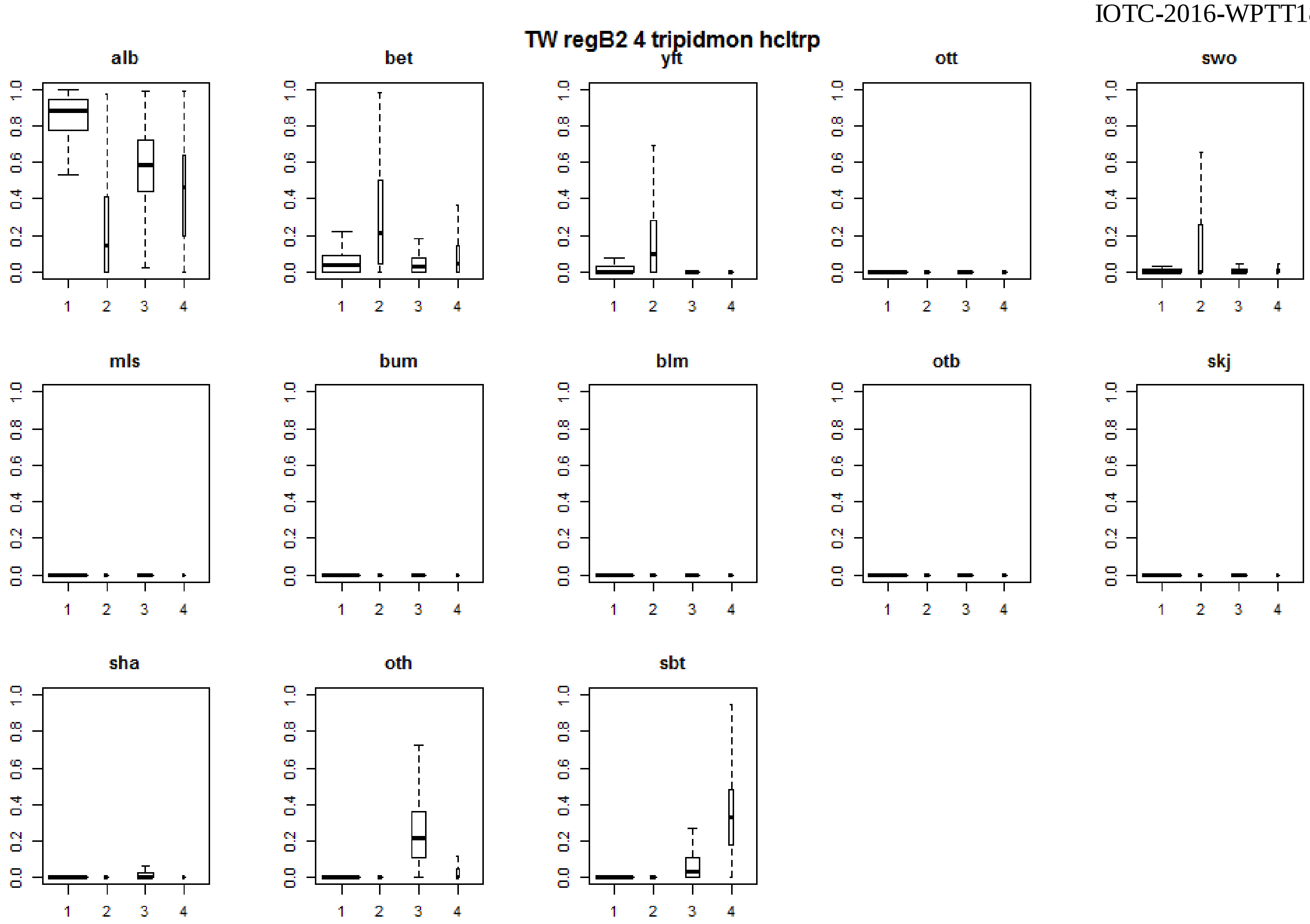


Figure 10. Figure x: Hierarchical clustering trees produced by the hclust function in R, for Taiwanese trip-level data by region. Plots showing analyses to estimate the number of distinct classes of species composition in Taiwanese region 4 of B2. These are based on a hierarchical Ward clustering analysis 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.


TW regB2 4 tripidmon hcltrp
alb
bet
yft
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swo
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bum
blm
otb
skj
sha
oth
sbt

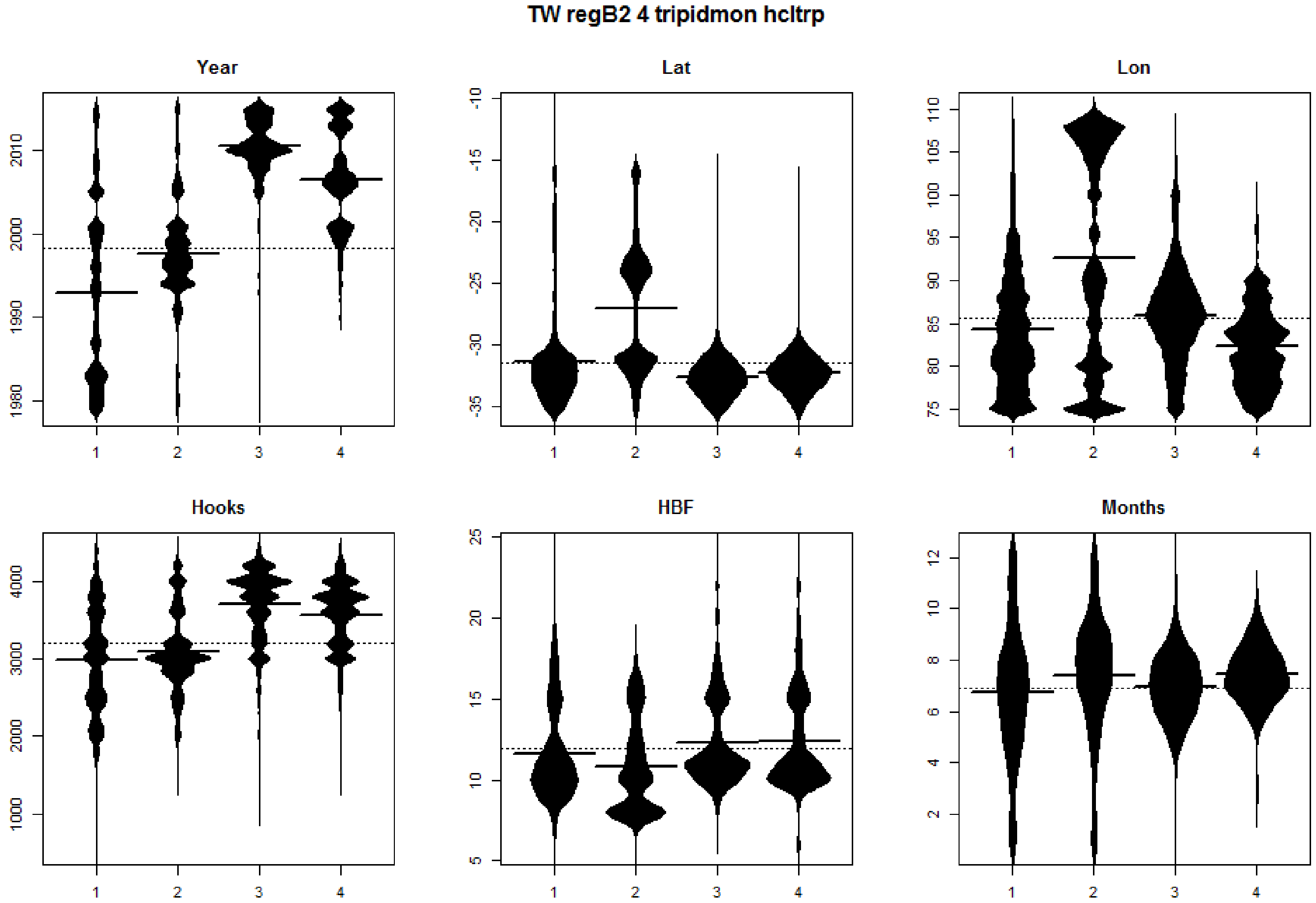

TW regB2 4 tripidmon hcltrp
Year
Lat
Lon
Hooks
HBF
Months

Figure 11. For Taiwanese effort in region 4 of B2 for the period 1979-2015, 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..

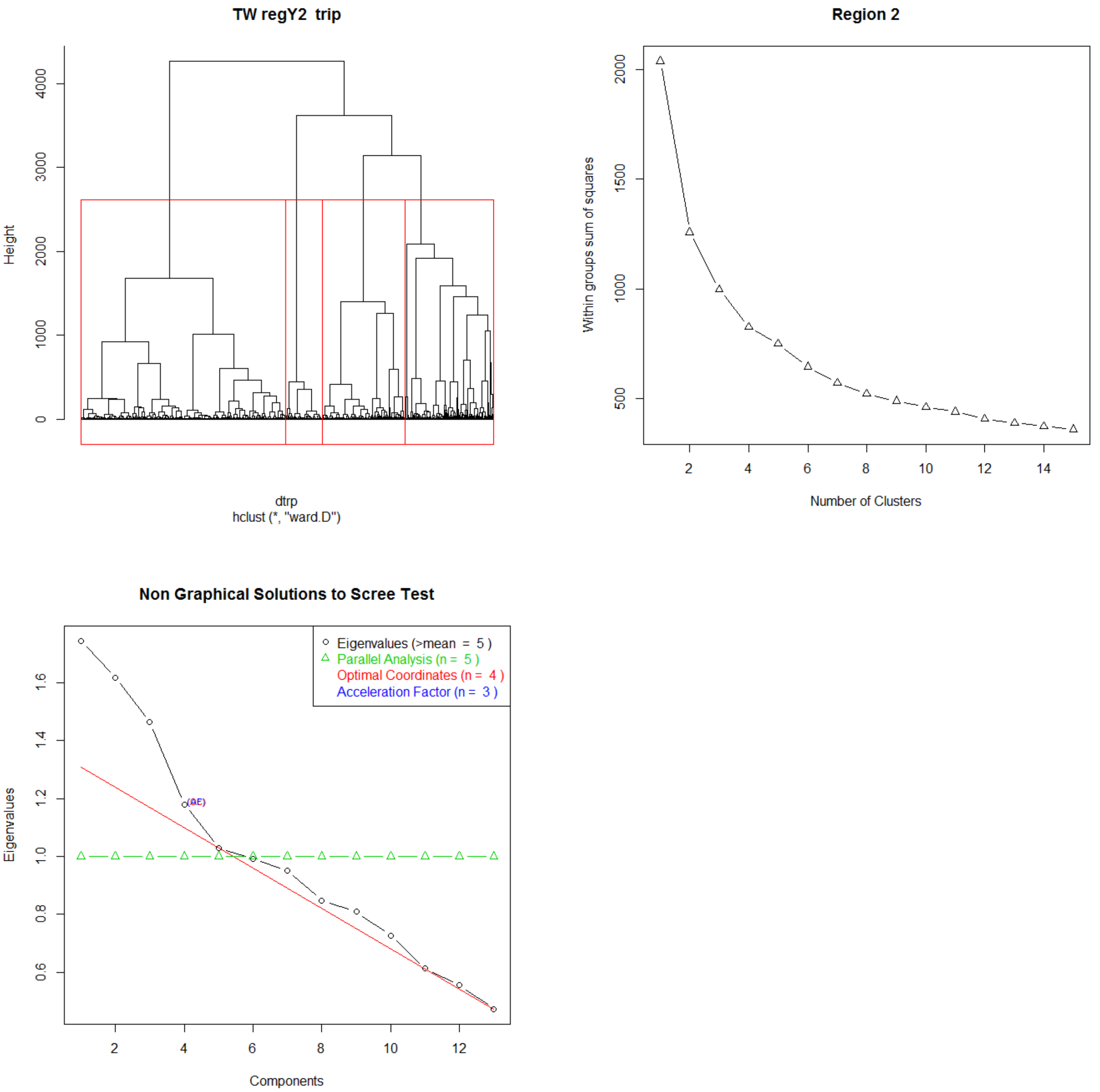
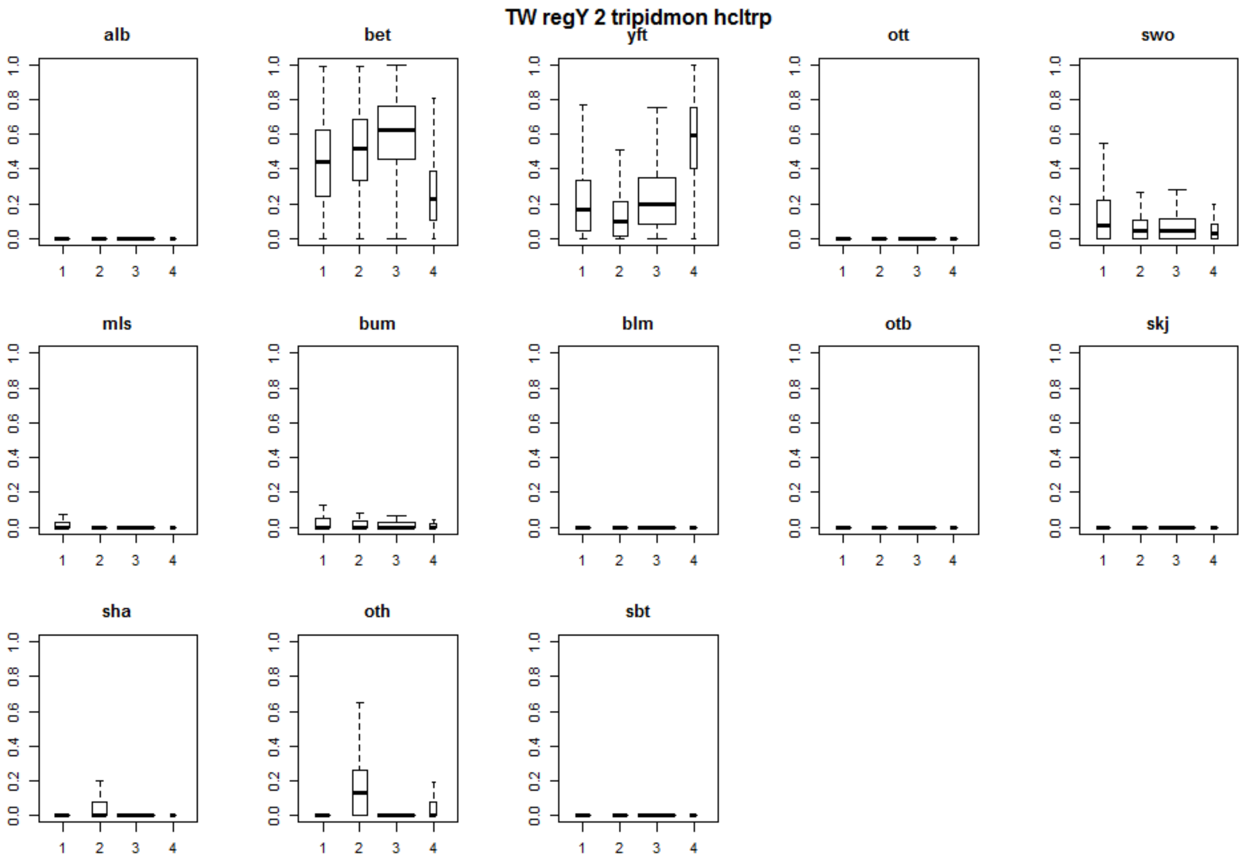


Figure 12. Plots showing analyses to estimate the number of distinct classes of species composition in Taiwanese region 2 of Y. These are based on a hierarchical Ward clustering analysis of trip-level data (top left); within-group sums of squares from kmeans analyses with a range of numbers of clusters (top right); and analyses of the numbers of components to retain from a principal component analysis of trip-level (bottom left) data.



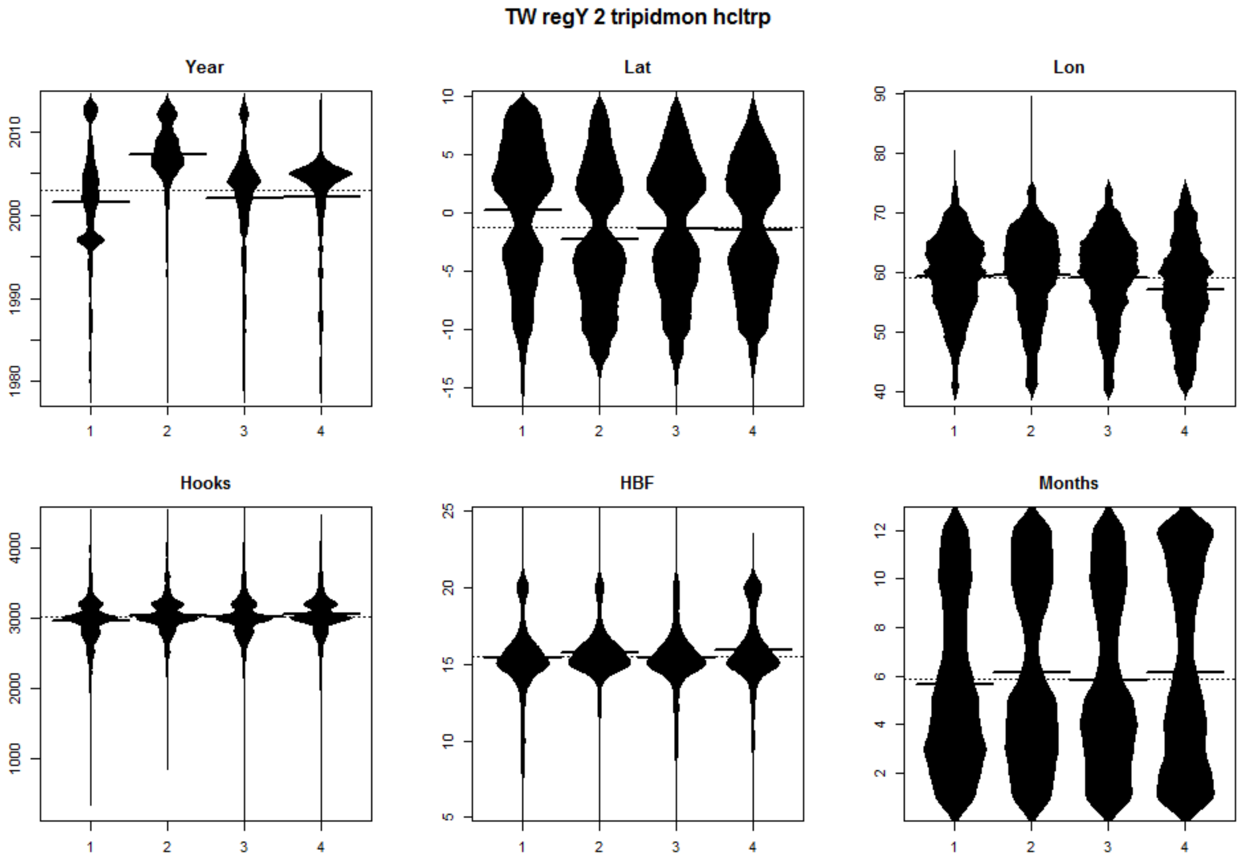


Figure 13. For Taiwanese effort in region 2 of Y for the period 1979-2015, for each species, boxplot of the

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.

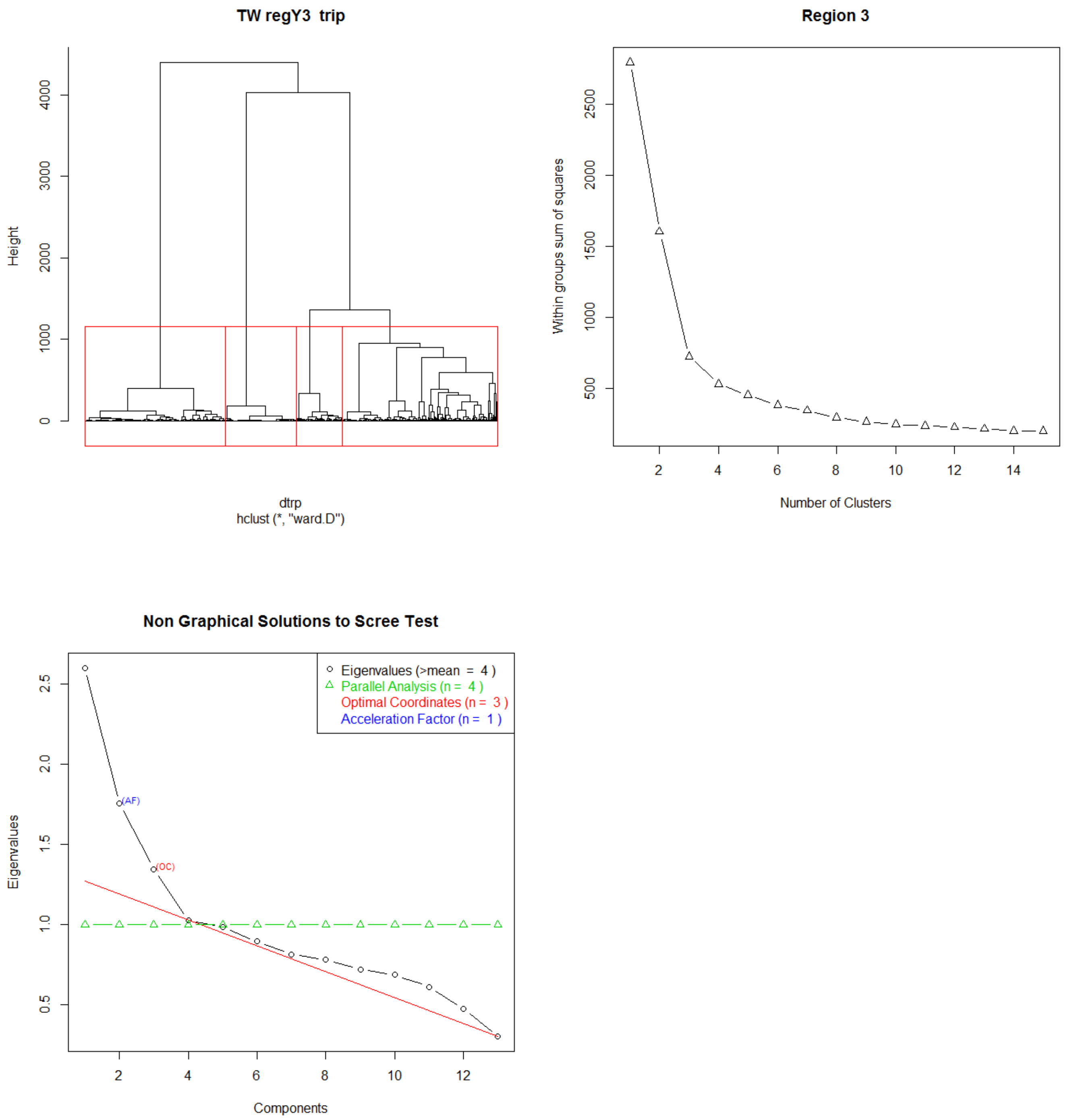
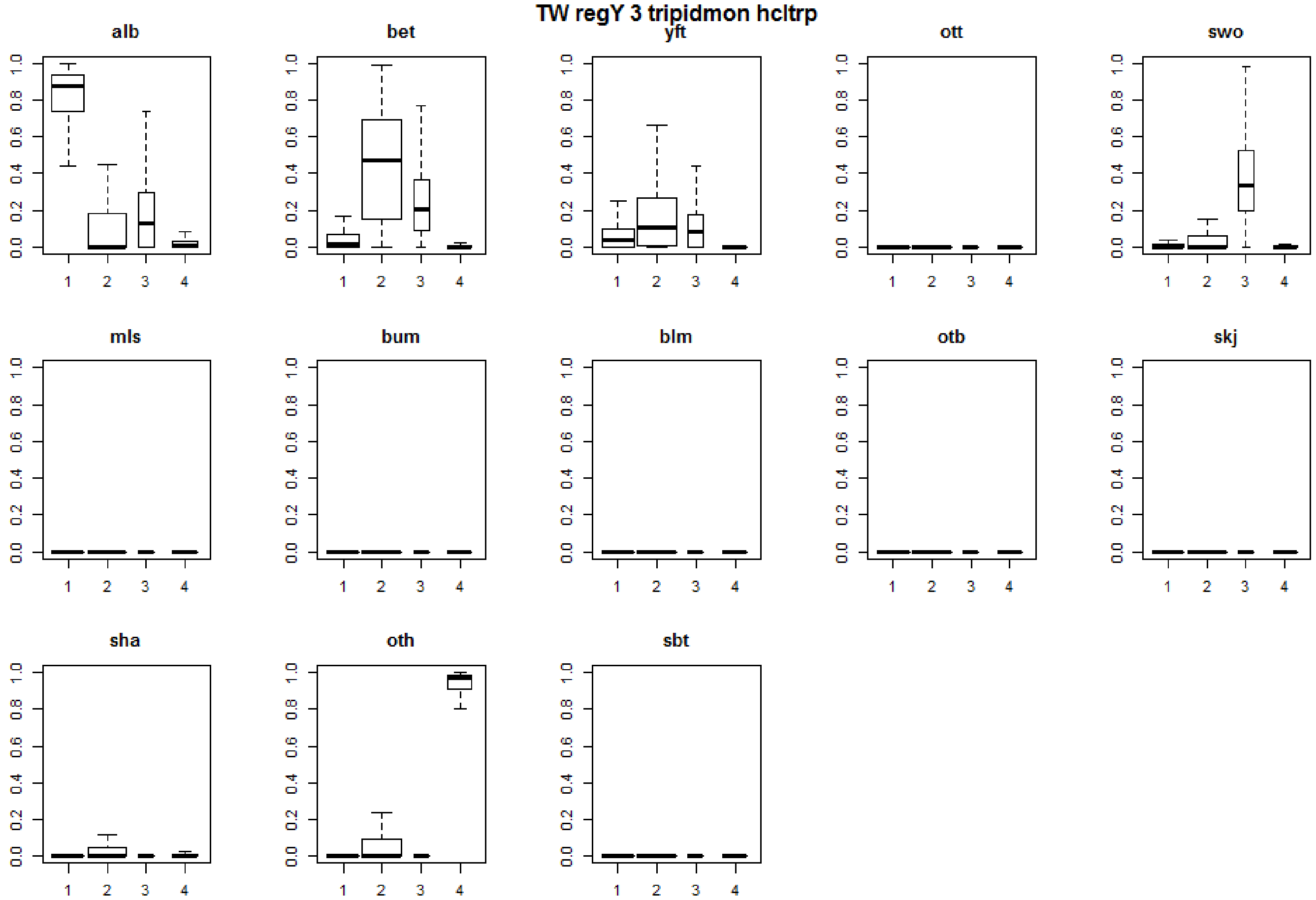


Figure 14. Plots showing analyses to estimate the number of distinct classes of species composition in Taiwanese region 3 of Y. These are based on a hierarchical Ward clustering analysis of trip-level data (top left); within-group sums of squares from kmeans analyses with a range of numbers of clusters (top right); and analyses of the numbers of components to retain from a principal component analysis of trip-level (bottom left) data.



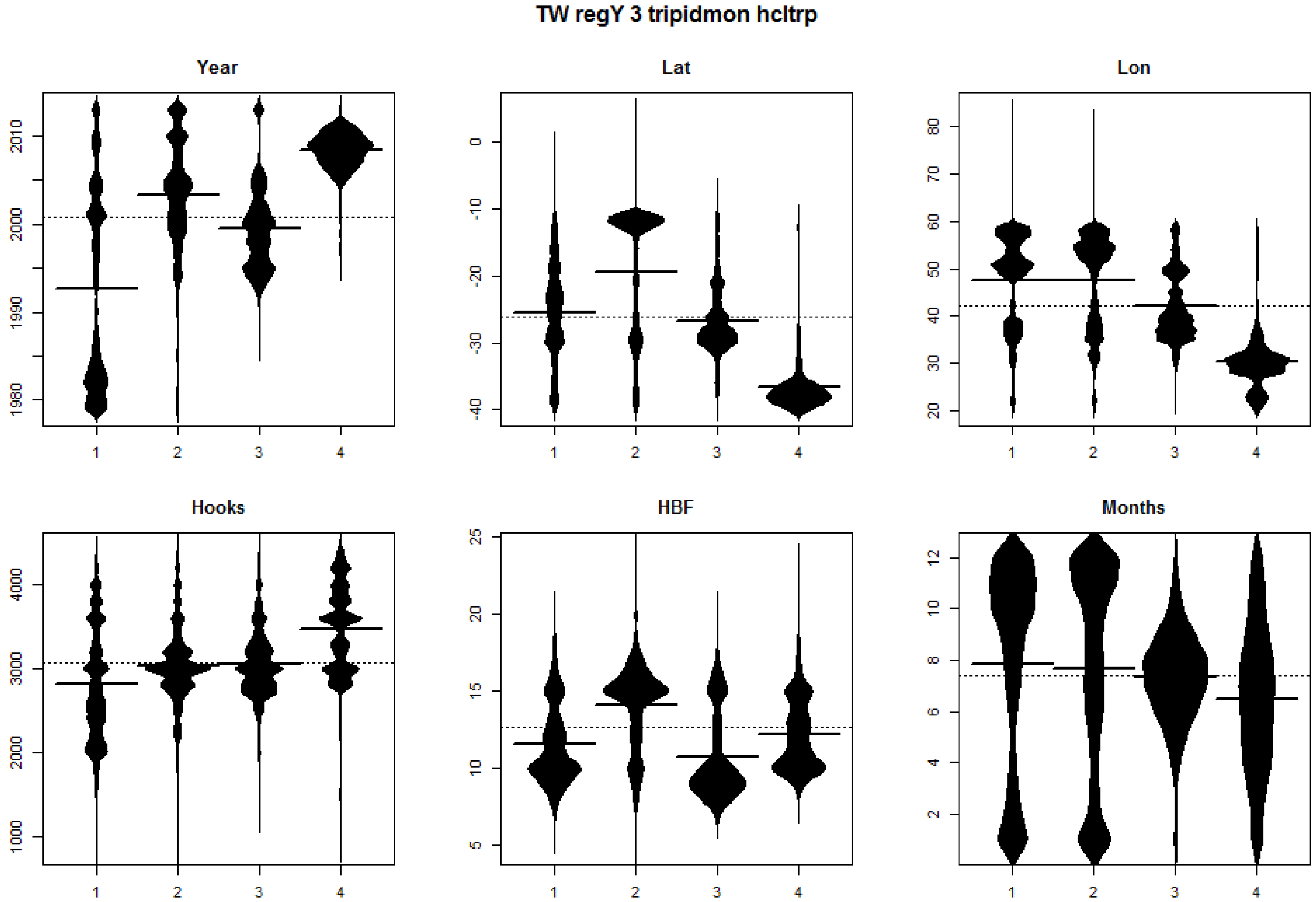


Figure 15. For Taiwanese effort in region 3 of Y for the period 1979-2015, for each species, boxplot of the

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.

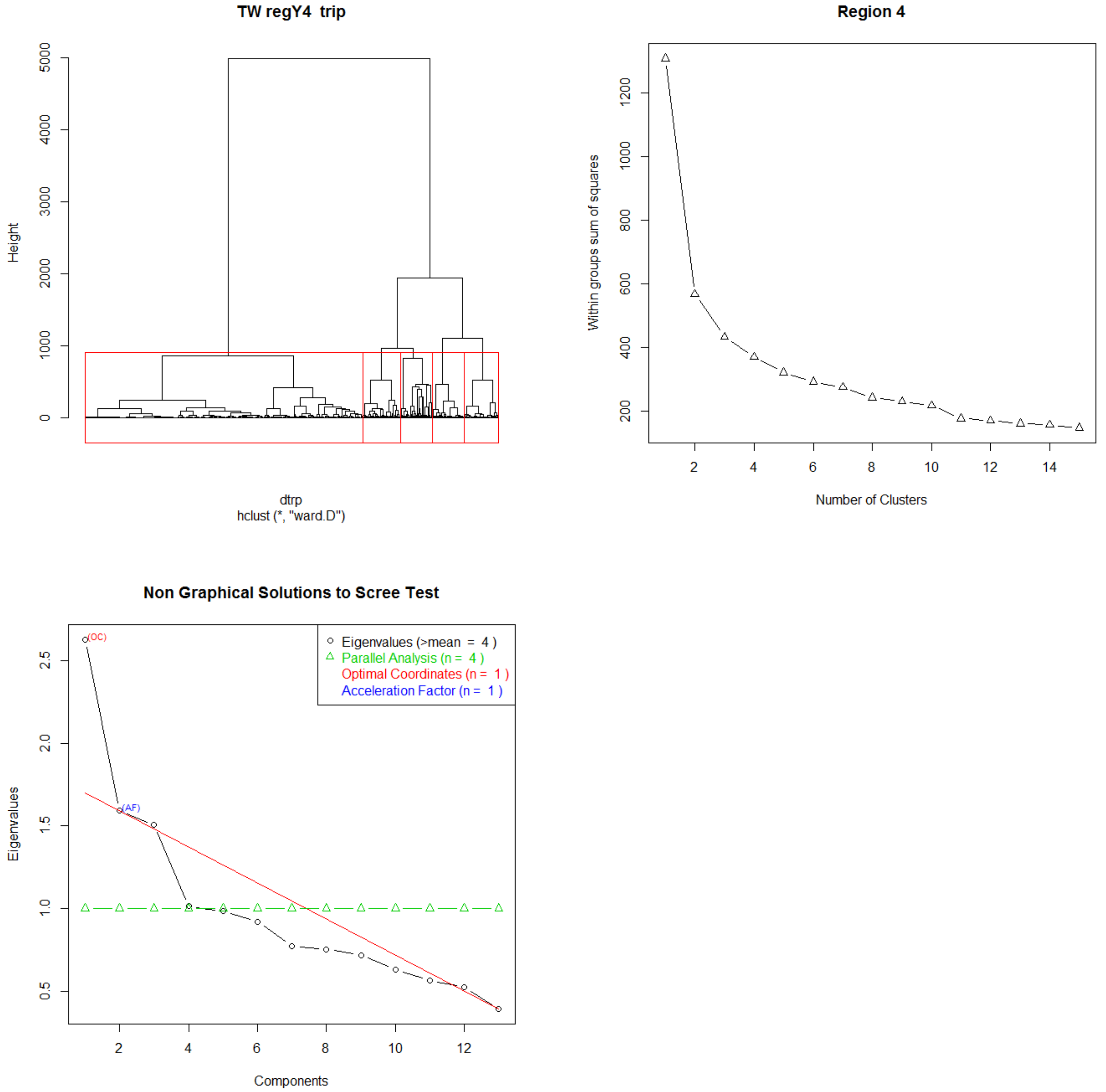
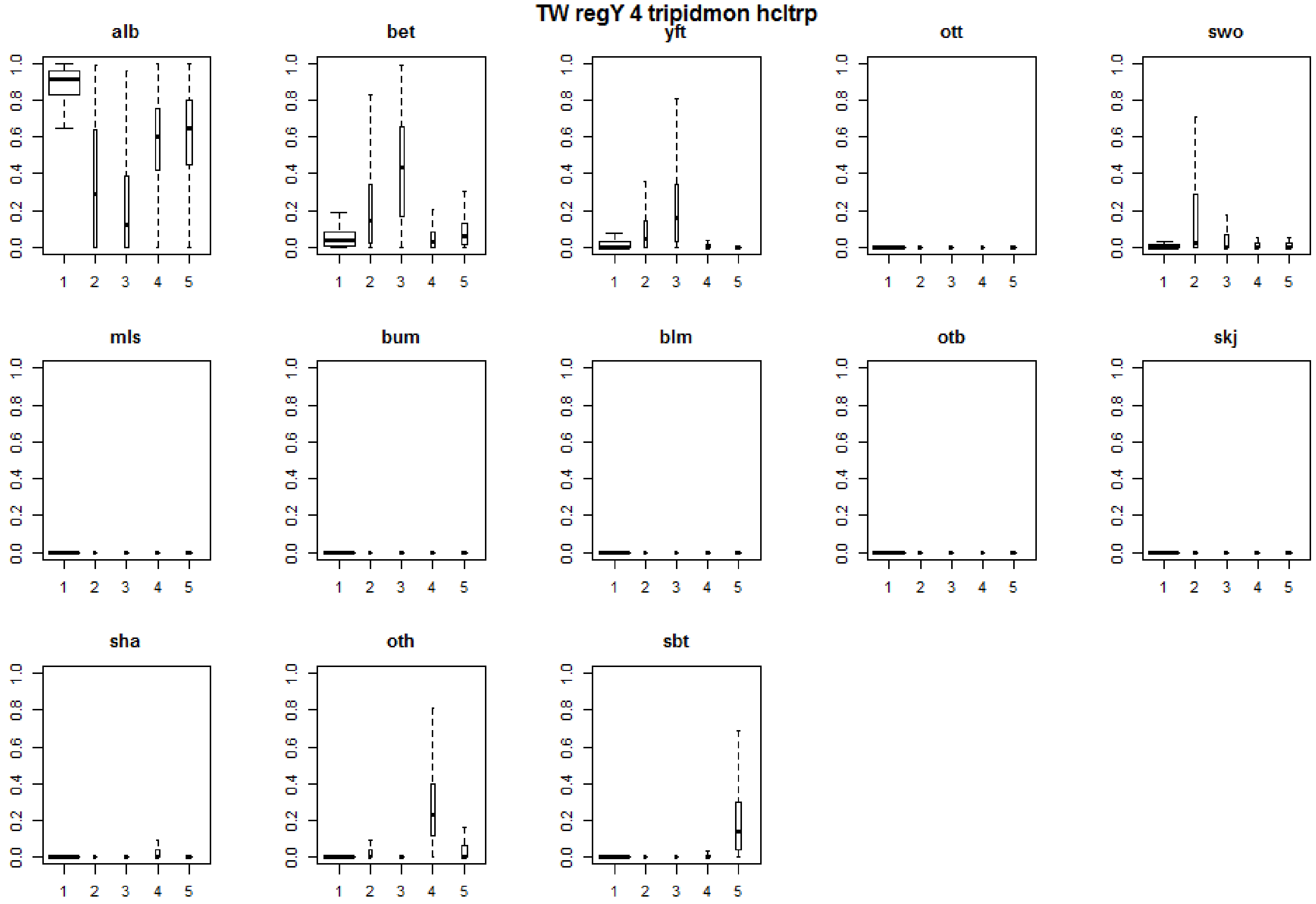


Figure 16. Plots showing analyses to estimate the number of distinct classes of species composition in Taiwanese region 4 of Y. These are based on a hierarchical Ward clustering analysis of trip-level data (top left); within-group sums of squares from kmeans analyses with a range of numbers of clusters (top right); and analyses of the numbers of components to retain from a principal component analysis of trip-level (bottom left) data.



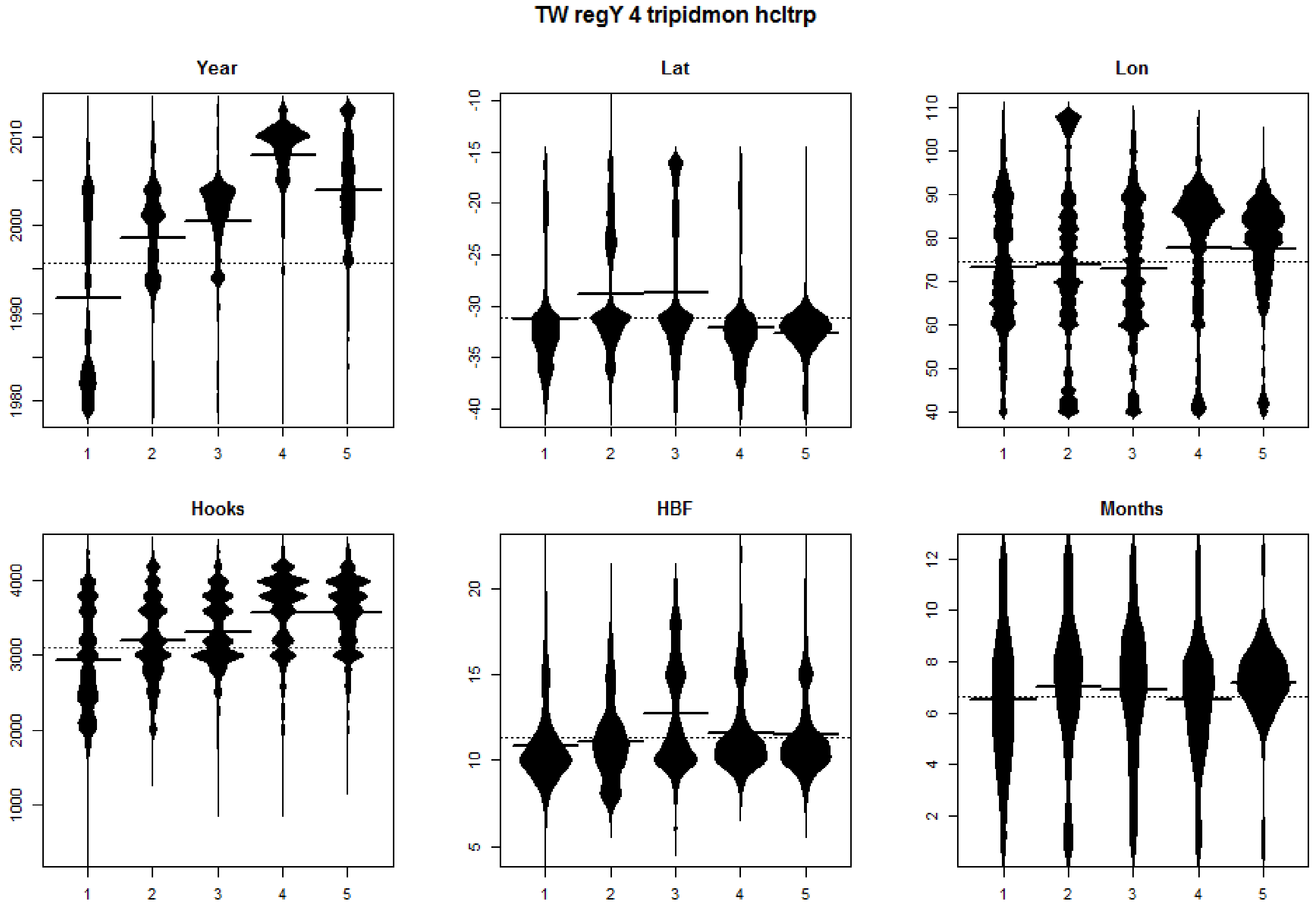


Figure 17. For Taiwanese effort in region 4 of Y for the period 1979-2015, for each species, boxplot of the

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.

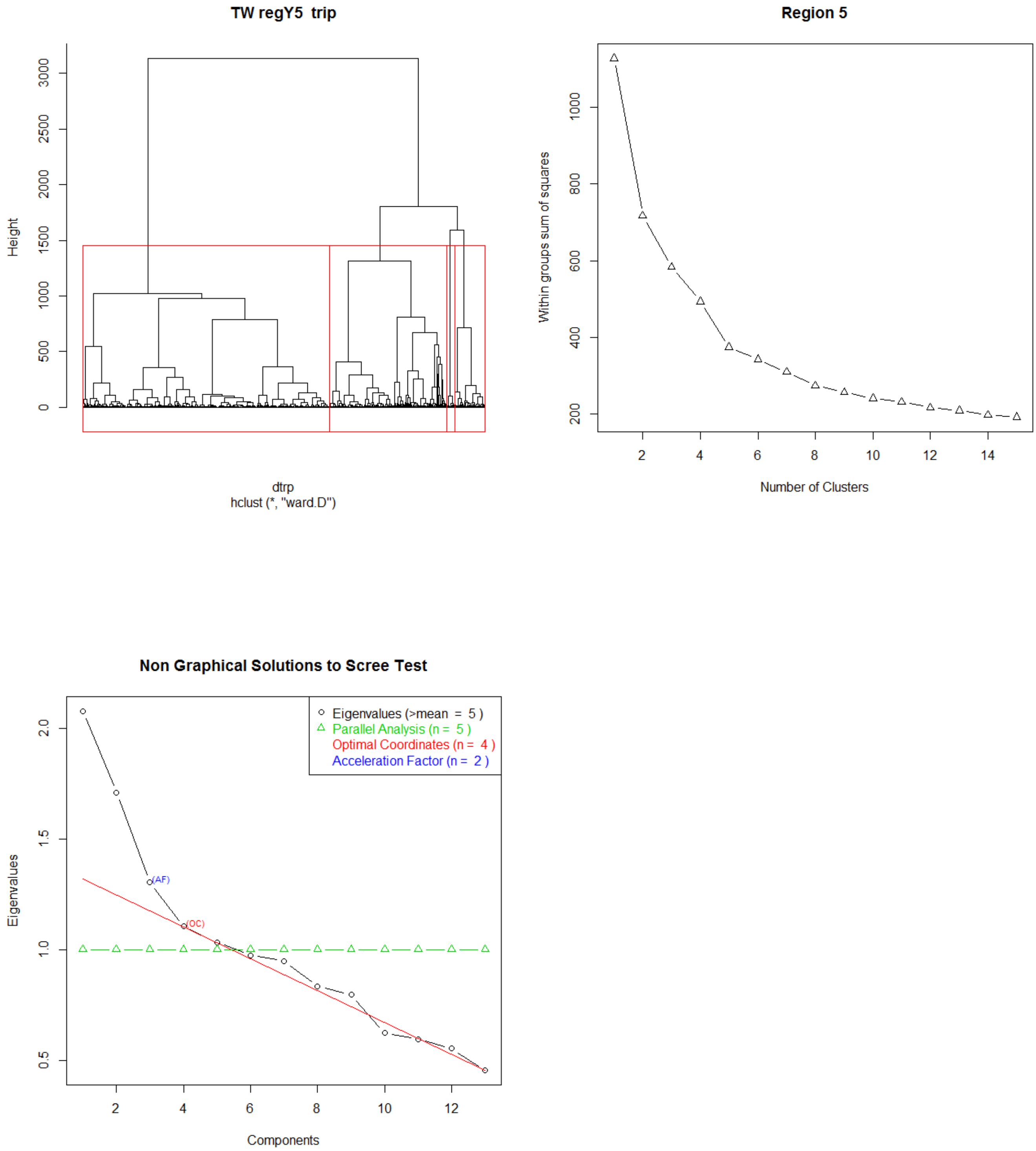
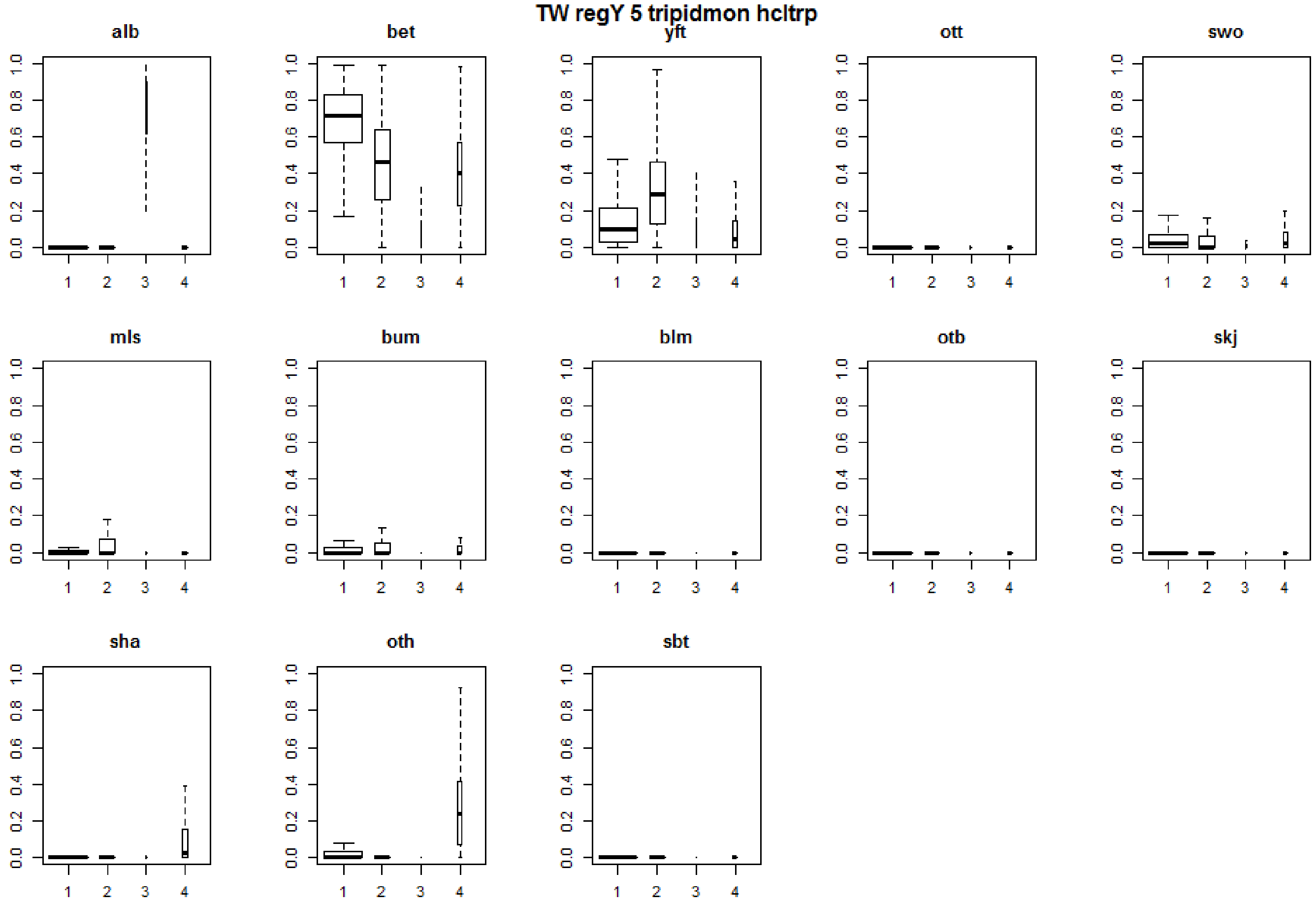


Figure 18. Figure x: Hierarchical clustering trees produced by the hclust function in R, for Taiwanese trip-level data by region. Plots showing analyses to estimate the number of distinct classes of species composition in

Taiwanese region 5 of Y. 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.



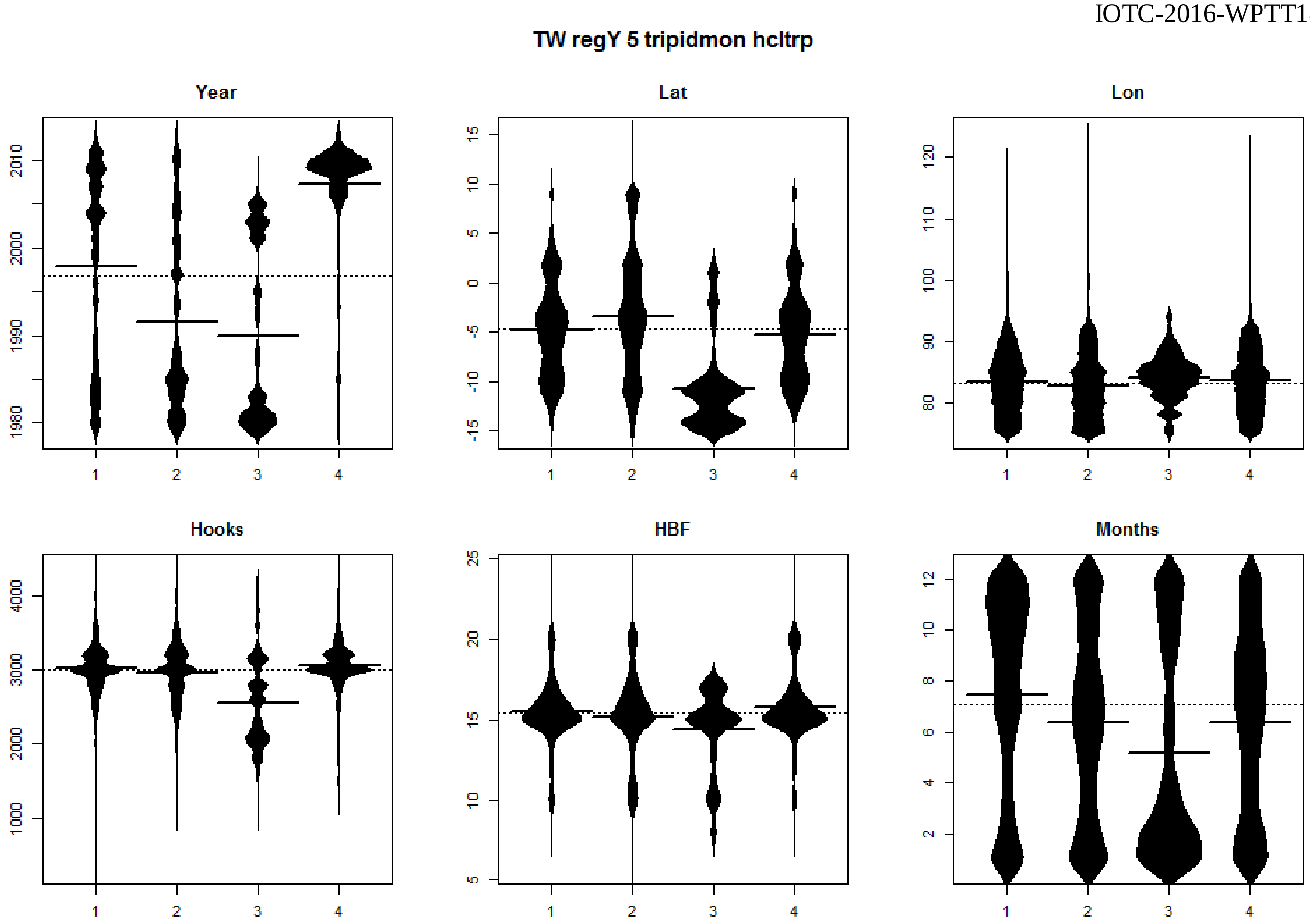


Figure 19. For Taiwanese effort in region 5 of Y for the period 1979-2015, for each species, boxplot of the proportion of the species in the trip versus the cluster. The widths of the boxes are proportional to the numbers of trips in each cluster (above). Boxplot showing the distributions of variables associated with sets in each hcltrp cluster (below). Clustering was performed using a hierarchical Ward clustering analysis of trip-level data..

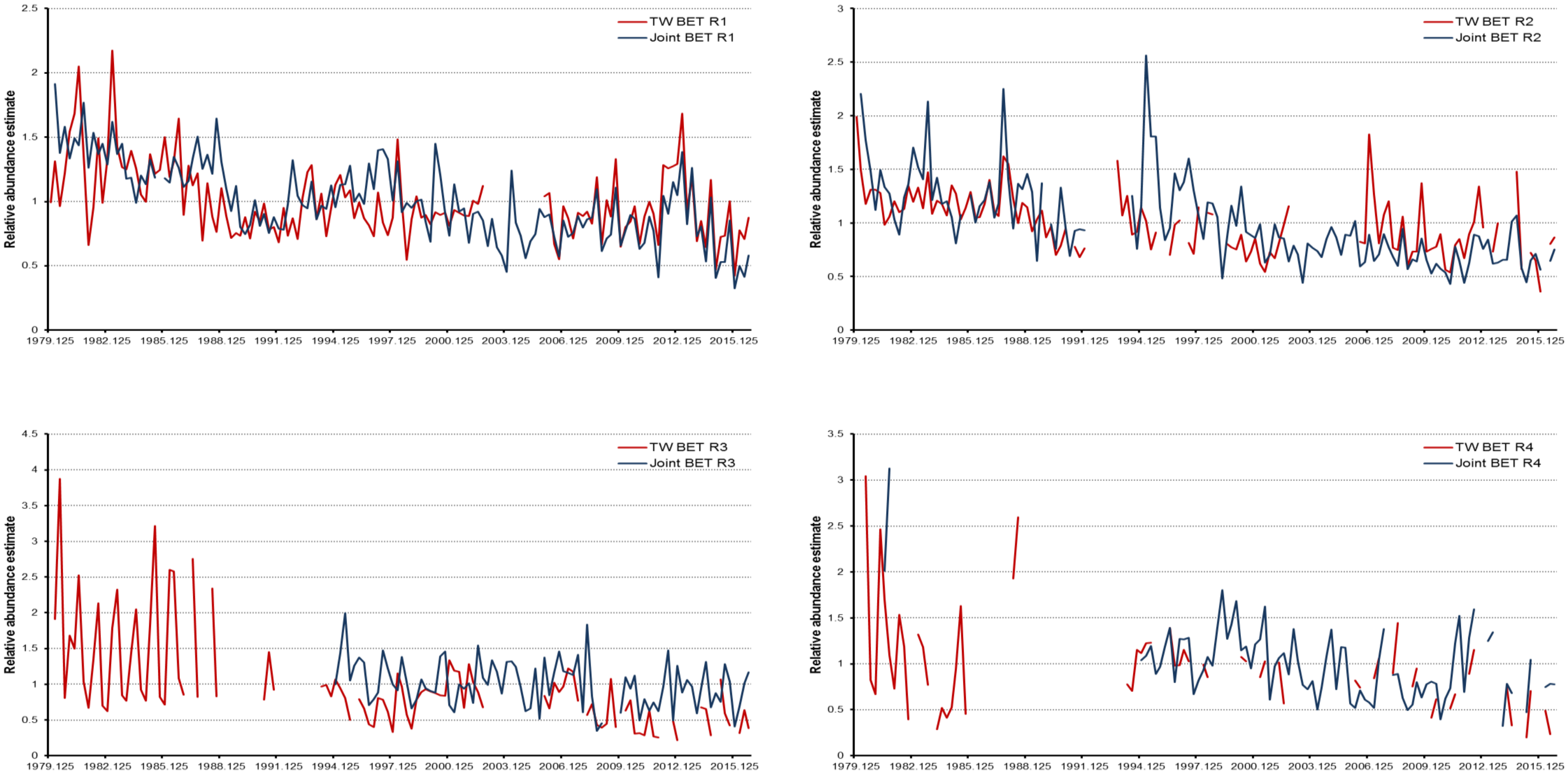


Figure 20. Comparisons of bigeye CPUE time series estimated in this analysis (red) and estimated during the 2016 collaborative project (blue) by regions.

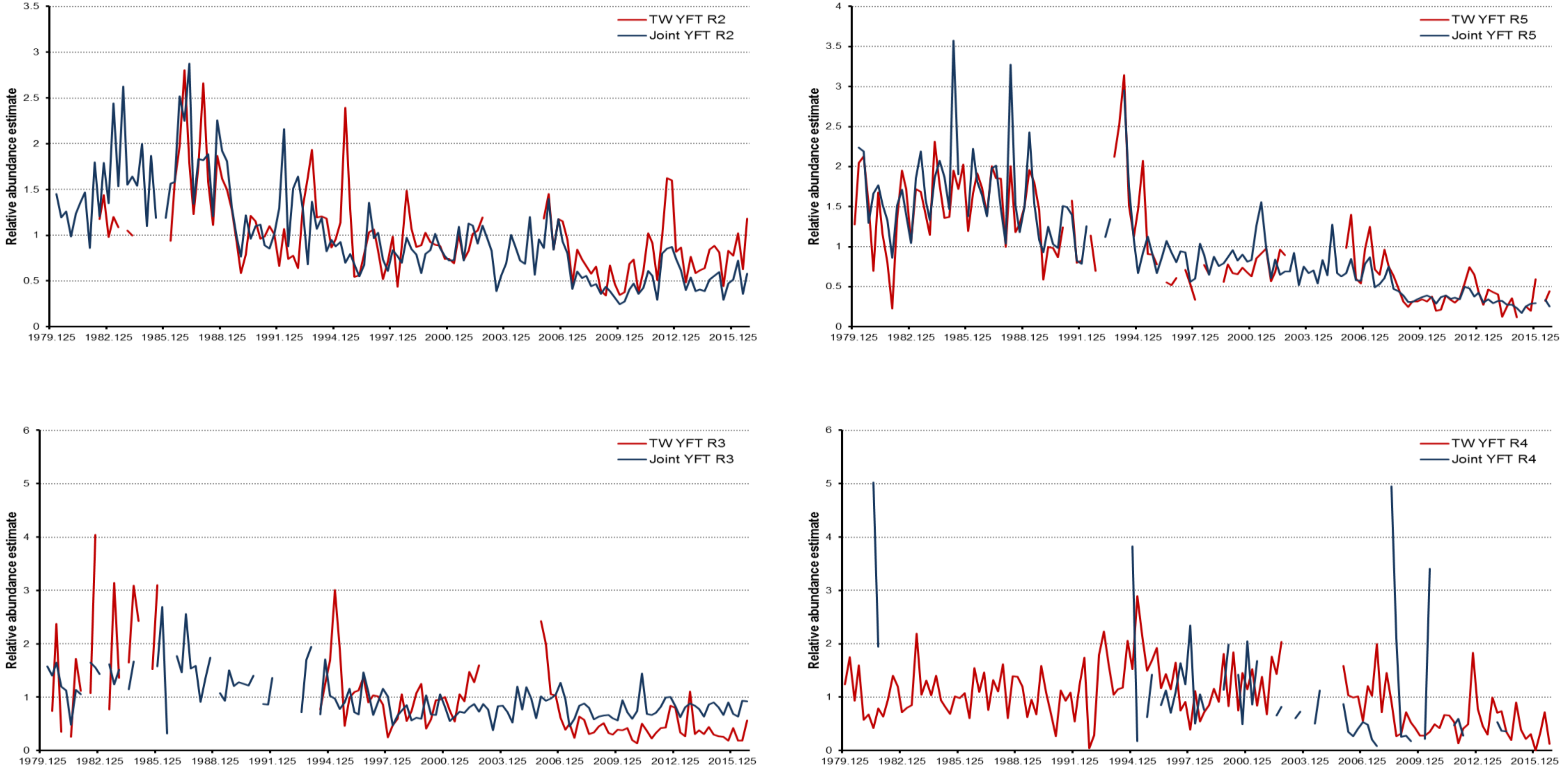


Figure 21. Comparisons of yellowfin CPUE time series estimated in this analysis (red) and estimated during the 2016 collaborative project (blue) by regions.

Region 1 | Region 2 | Region 3 | Region 4

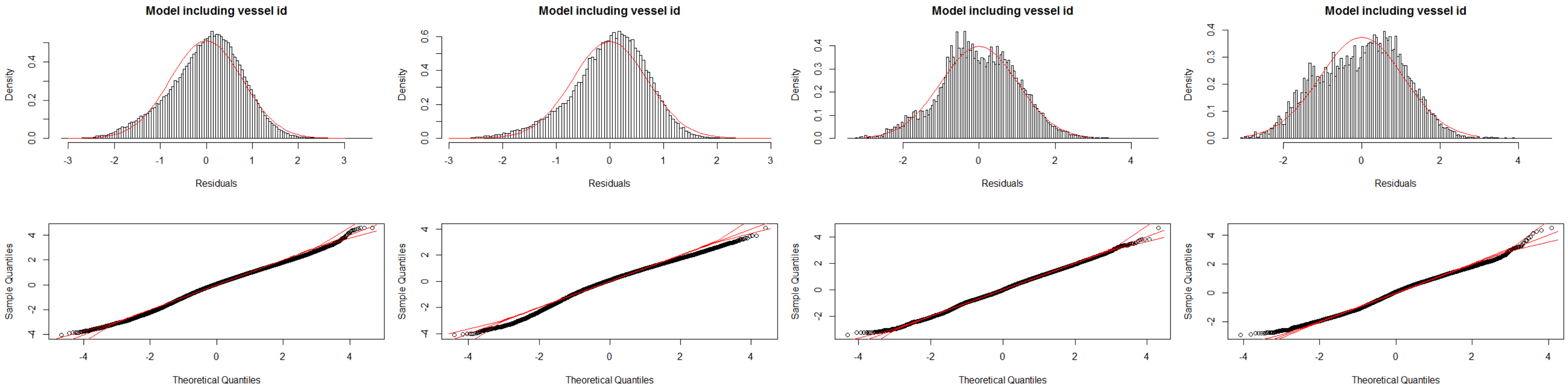


Figure 22. Residual diagnostics (as histogram and QQ plot) on bigeye tuna CPUE indices by region.

Region 2 | Region 3 | Region 4 | Region 5

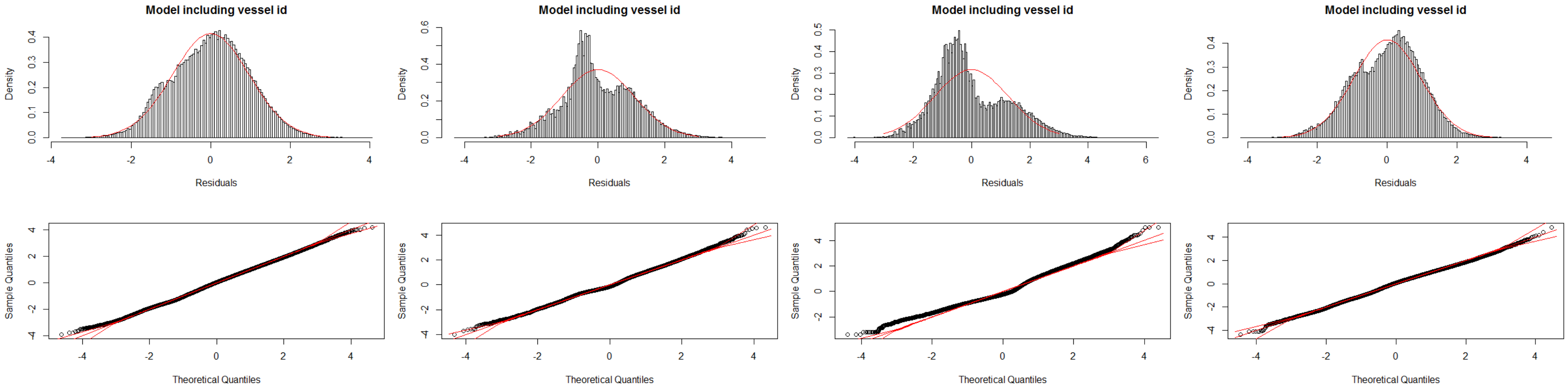


Figure 23. Residual diagnostics (as histogram and QQ plot) on yellowfin tuna CPUE indices by region.