SEDAR65-AW04: Hierarchical Cluster Analysis and Cross-correlations of Selected CPUE Indices for the SEDAR 65 Assessment

Dean Courtney

PW8-RD07

Received: 7/19/2021

This information is distributed solely for the purpose of pre-dissemination peer review. It does not represent and should not be construed to represent any agency determination or policy.

Hierarchical Cluster Analysis and Cross-correlations of Selected CPUE Indices for the SEDAR 65 Assessment

Dean Courtney

SEDAR65-AW04

Received: 3/9/2020

This information is distributed solely for the purpose of pre-dissemination peer review. It does not represent and should not be construed to represent any agency determination or policy.

Please cite this document as:

Courtney, Dean. 2020. Hierarchical Cluster Analysis and Cross-correlations of Selected CPUE Indices for the SEDAR 65 Assessment. SEDAR65-AW04. SEDAR, North Charleston, SC. 29 pp.

SEDAR 65 ASSESSMENT DOCUMENT

Hierarchical Cluster Analysis and Cross-correlations of Selected CPUE Indices for the SEDAR 65 Assessment

Dean Courtney

NOAA Fisheries
Southeast Fisheries Science Center
Panama City Laboratory
3500 Delwood Beach Drive,
Panama City, FL 32408, USA

March 2020

Summary

Hierarchical cluster analysis and cross-correlations of selected CPUE indices were conducted for the SEDAR 65 assessment to identify conflicting information among CPUE indices. Three sets of CPUE indices were recommended by the Index Working Group of the SEDAR 65 Data Workshop (DW) for use in the Atlantic blacktip shark stock assessment: S1 – S10, S1 – S7, and R1 – R3. Time series of residuals for each index from a smooth fit to CPUE data sets S1 – S10 and S1 – S7 identified that S4 consistently increased more rapidly than the other series. Hierarchical cluster analysis and cluster dendrogram groupings for each CPUE data set were sensitive to small sample size and to outliers in some indices. Consequently, CPUE index groupings were based on robust cross-correlations implemented with Spearman's rho and utilized adjusted data sets which removed some CPUE indices with low sample size cross-correlations (n = 2; S4) and removed some years with outliers (2013; S9 and R2). The resulting groupings identified for the adjusted S1 – S10 data set were Group 1 (S3, S1, S8) and Group 2 (S5, S10, S6, S2, S7, S9). Groupings identified for the adjusted S1 – S7 data set were Group 1 (S1, S3) and Group 2 (S6, S7, S2, S5). Groupings identified for the adjusted R1 – R3 data set were Group 1 (R1) and Group 2 (R2, R3).

Because CPUEs with conflicting information were identified, it may be reasonable to assume that the indices reflect alternative hypotheses about states of nature and to run scenarios for single or sets of indices identified that represent a common hypothesis as sensitivity analyses

to the reference case model. However, the groupings identified for the adjusted S1 – S10 data set are suspect because they may have been influenced by highly positively and negatively correlated series with low sample size (n=2), even after adjusting the data set to remove some series with low sample size and to remove outliers. Similarly, the groupings identified for the adjusted R1 – R3 data set were sensitive to removal of the outlier year 2013 from R2. Consequently, the groupings identified for the adjusted S1 – S10 data set and for the adjusted R1 – R3 data set should be interpreted cautiously because they may not be robust to the influence of low sample size and outliers.

Based on results of the analyses conducted here, the following groupings are recommended for sensitivity analyses to the reference case CPUEs (S1-S10): 1) The series S4 versus all other indices in the data set S1 – S10; and 2) the groupings identified for the adjusted S1 – S7, Group 1 (S1, S3) and Group 2 (S6, S7, S2, S5).

Introduction

Hierarchical cluster analysis with Pearson's cross-correlations of catch per unit effort (CPUE) time series was implemented using R scripts developed by the International Commission for the Conservation of Atlantic Tunas (ICCAT). Previous examples of the implementation for sharks are available from a recent Atlantic shortfin mako assessment conducted for ICCAT (Anon. 2017) and a recent sandbar shark assessment conducted through the Southeast Data Assessment and Review process (SEDAR 2017; Courtney 2017).

As noted in the Atlantic shortfin mako assessment (ICCAT 2017): "…it is not uncommon for CPUE indices to contain conflicting information. However, when CPUE indices are conflicting, including them in a single assessment (either explicitly or after combining them into a single index) tends to result in parameter estimates intermediate to what would be obtained from the data sets individually. Schnute and Hilborn (1993) showed the most likely parameter values are usually not intermediate but occur at one of the apparent extremes. Consequently, when CPUEs with conflicting information are identified, an alternative is to assume that indices reflect hypotheses about states of nature and to run scenarios for single or sets of indices that represent a common hypothesis…"

Methods

Ten CPUE indices of relative abundance (**Table 1)** were recommended by the Index Working Group of the SEDAR 65 Data Workshop (DW) for use in the Atlantic blacktip shark stock assessment. The CPUE indices will be entered in the reference case (base) Stock Synthesis model as "survey" time series S1 – S10. Three CPUE indices of age-0 relative abundance (**Table 2)** were recommended by the DW for use in sensitivity analyses within the Atlantic blacktip shark stock assessment. The age-0 CPUE indices will be evaluated in Stock Synthesis model sensitivity analyses as "recruitment" time series R1 – R3. Note that series S8 – S10 (**Table 1**) and series R1 – R3 (**Table 2**) utilize the same data, and, as a result, should not be used together within the same Stock Synthesis model. Consequently, the CPUE data sets S1 – S10, S1 – S7, and R1 – R3 were evaluated separately here.

Analyses used an R script, previously developed by ICCAT. The R script computed the average trend of the combined indices based on a smooth fit (GAM fit to year with series as a factor). Time series of residuals from the smooth fit were evaluated for each index. Pairwise scatter plots were evaluated to identify correlations and high leverage points among indices. A hierarchical cluster analysis (Murtagh and Legendre 2014) was used to group indices based on their Pearson's correlations using the complete agglomeration method.

Following recommendations from a CIE review of a recent sandbar shark assessment[1], the R script was updated here to check for robustness of the cross-correlation and cluster analyses results. Cross-correlation and cluster analyses were adapted to implement Spearman's rho, which is a more robust rank-based measure of association. Cluster analyses for both Pearson's and Spearman's cross-correlations were then implemented on both raw CPUE and on CPUE transformed to the natural log scale.

The CPUE time series data were also adjusted to remove one series which resulted in many cross-correlations with low sample size (n = 2) and to remove outliers. Preliminary results identified several high cross-correlations for the series S4 with low sample size (n = 2), which may have had a large influence on the resulting cluster analyses for the data sets S1 – S10 and S1 – S7. Similarly, a large outlier (year 2013) was identified in series R2 and S9 (based on the same data) which may have had a large influence on the resulting cluster analyses for the data sets S1 – S10 and R1 – R3. Consequently, three adjusted data sets of CPUE indices were also evaluated: S1 – S10 (with S4 removed and with year 2013 removed from S9), S1 – S7 (with S4 removed), and R1 – R3 (with year 2013 removed from R2). This resulted in 6 data sets with four separate cross-correlation and cluster analyses for each data set (**Tables 3** and **4**).

[1] Noel Cadigan. 2017. Center for Independent Experts (CIE) External Independent Peer Review SEDAR 54 HMS Sandbar Shark Assessment Review. December 2017. Southeast Data, Assessment and Review (SEDAR) 4055 Faber Place Drive, Suite 201 North Charleston, SC 29405. Available: http://sedarweb.org/cie-reviewer-report-cadigan-0 (Accessed 3/5/2020).

Results

Because the hierarchical cluster analysis and cluster dendrogram groupings were sensitive to small sample size and to outliers in some indices, CPUE index groupings were based on the adjusted data sets using Spearman's rho cross-correlations (**Tables 3** and **4**). Hierarchical cluster analysis resulted in Group 1 (S3, S1, S8) and Group 2 (S5, S10, S6, S2, S7, S9) for the adjusted S1 – S10 data set; Group 1 (S1, S3) and Group 2 (S6, S7, S2, S5) for the adjusted S1 – S7 data set; and Group 1 (R1) and Group 2 (R2, R3) for the adjusted R1 – R3 data set. Log scale transformation of CPUE did not have an effect on the hierarchical cluster analysis groupings identified using Spearman's rho cross-correlations (**Table 3**), but did change the order of some series within cluster dendrogram groupings (adjusted S1 – S7 data set; **Table 4**). The order of some series within cluster dendrogram groupings (adjusted S1 – S10 data set; **Table 4**) also differed from those within the hierarchical cluster analysis groupings (**Table 3**).

Complete R script output for CPUE analyses of the S1 – S10, S1 – S7, and R1 – R3 data sets are reported in **Appendices A**, **B**, and **C**, respectively. The individual CPUE time series are plotted in **Figures A1**, **B1**, and **C1**, along with smooth fits to each combined CPUE data set. The smooth fits for both the S1 – S10 and S1 – S7 data sets were generally increasing with a slightly slower rate of increase during the years 2005 to 2010. The smooth fit for the R1 – R3 data set had a more variable trend with both increasing and decreasing periods.

Residuals of individual index values to the smooth fits obtained for each data set are provided in **Figures A2**, **B2**, and **C2**. Conflicts between indices can be identified by patterns in the residuals. For example, the residuals of the S4 index to the smooth fits obtained for both the S1 – S10 and S1 – S7 data sets identified a series of negative residuals followed by a series of positive residuals, indicating that the S4 index did not fit the overall trend, and that the S4 index provides evidence of a more rapidly increasing trend in the stock trajectory in recent years than the overall trend. In contrast, the fits of both S8 and R1 (which are based on the same data) to the overall trends identified a series of negative residuals at the end of the time series, providing evidence of a more gradually increasing (or a decreasing) trend in the stock trajectory in recent years compared to the overall trend. Similarly, fits of S3, S5, S9, and R2 to the overall trends identified a series of negative or small positive residuals at the end of the time series, and may also provide evidence of a more gradually increasing (or a decreasing) trend in the stock trajectory in recent years compared to the overall trend.

Correlations between indices are provided in **Figures A3**, **B3**, and **C3**. The lower triangle shows the pairwise scatter plots between indices with a regression line, the upper triangle provides the correlation coefficients, and the diagonal provides the range of observations. A single influential point may cause a strong spurious correlation, so it is important to look at the plots as well as the correlation coefficients. Also, a strong correlation could be found by chance if two series only overlap for a few years.

Hierarchical cluster analyses using a set of dissimilarities and implemented for Spearman's cross-correlations of the adjusted indices (**Table 3**) are provided in **Figures A4**, **B4**, and **C4**. If indices represent the same stock components, then it is reasonable to expect them to be correlated. If indices are not correlated or are negatively correlated, i.e. they show conflicting trends, then this may result in poor fits to the data and bias in the parameter estimates obtained within a stock assessment model. Therefore, the correlations can be used to select groups of indices that represent a common hypothesis about the evolution of the stock (ICCAT 2017).

For the adjusted S1 – S10 data set, the first group included S3, S1, and S8 and was characterized by time-series which were moderately to highly correlated with each other and which had some highly negative correlations with some time-series not included in the group (S1 versus S10, and S8 versus S6). However, the highly negative correlations resulted from low sample size of overlapping years (n = 2; **Table 1**, and **Figure A3**). Consequently, this grouping is suspect because it may be influenced by the highly positively and negatively correlated series with low sample size. The second group included the remaining series, and was characterized by time-series which were both positively and negatively correlated. The corresponding cluster dendrogram for the adjusted S1 – S10 data set is provided in **Figure A5**.

For the adjusted S1 – S7 data set, the first group (S1, S3) was characterized by time-series which were slightly positively correlated with each other and moderately negatively correlated with some of the other time-series (S3 vs S2 and S6). The second group (S6, S7, S2, S5) was characterized by time-series with some small positive correlations with each other (S5 vs S2). The corresponding cluster dendrogram for the adjusted S1 – S7 data set is provided in **Figure B5**.

For the adjusted R1 – R3 data set, the first group (R1) was slightly positively and moderately negatively correlated with the series in the other group. The second group (R2, R3) was moderately positively correlated. However, groupings identified for the adjusted R1 – R3 data set were sensitive to removal of the outlier year 2013 from R2 (**Tables 3** and **4**). Consequently, this grouping is also suspect because it was sensitive to removal of the outlier year 2013 from R2. The corresponding cluster dendrogram for the adjusted R1 – R3 data set is provided in **Figure C5**.

Discussion

Groupings identified for the adjusted S1 – S10 data set are suspect because they may be influenced by highly positively and negatively correlated series with low sample size (n = 2) (**Figures A3** and **A4**, **Table 1**), even after adjusting the data set to remove the series S4 and to remove outliers (year 2013) from series S9. Similarly, groupings identified for the adjusted R1 – R3 data set are also suspect because they were sensitive to removal of the outlier year 2013 from R2 (**Tables 3** and **4**). Consequently, the groupings identified for both the adjusted S1 – S10 data set and the adjusted R1 – R3 data set should be interpreted cautiously. In contrast, groupings identified for the adjusted S1 – S7 data set may be more robust, because they were less affected by CPUE indices with low sample size and outliers.

Acknowledgements

Analyses and figures were adapted from R Markdown code kindly provided by Laurie Kell (ICCAT secretariat). Analyses were conducted in R using FLR and the diags package. FLR provides a set of common methods for reading data into R, plotting and summarizing them (e.g., see: http://www.flr-project.org/).

References

Anon. 2017. Report of the 2017 International Commission for the Conservation of Atlantic Tunas (ICCAT) Shortfin Mako Data Preparatory Meeting (Madrid, Spain 28-31 March, 2017). ICCAT SCRS/2017/002. Collect Vol. Sci. Pap. ICCAT 74(4):1373–1464. Available: https://www.iccat.int/en/pubs_CVSP.html (Accessed 3/5/2020).

Courtney, D. 2017. Example implementation of a hierarchical cluster analysis and cross-correlations of selected CPUE indices for the SEDAR 54 Assessment. SEDAR54-WP-06, September 2017. Southeast Data, Assessment and Review (SEDAR) 4055 Faber Place Drive, Suite 201 North Charleston, SC 29405. Available: http://sedarweb.org/docs/wpapers/S54_WP_06_Cluster_analysis.pdf (Accessed 3/5/2020).

Murtagh F., and P. Legendre. 2014. Wards hierarchical agglomerative clustering method: Which algorithms implement wards criterion? Journal of Classification, 318 31(3): 274–295

Schnute J.T., and R. Hilborn. 1993. Analysis of contradictory data sources in fish stock assessment. Canadian Journal of Fisheries and Aquatic Sciences, 50 (9): 1916-1923.

SEDAR. 2017. SEDAR 54 Stock Assessment Report, HMS sandbar shark. October 2017. Southeast Data, Assessment and Review (SEDAR) 4055 Faber Place Drive, Suite 201 North Charleston, SC 29405. Available: http://sedarweb.org/sedar-54-final-assessment-report-hms-sandbar-shark (Accessed 3/5/2020).

Table 1. Ten CPUE indices of relative abundance were recommended for use in the Atlantic blacktip shark stock assessment by the Index Working Group of the SEDAR 65 Data Workshop (DW). The SEDAR 65 DW report number is identified for each index. The CPUE indices will be entered in Stock Synthesis as "survey" time series S1 – S10.

Year	S1: Shark Bottom Longline Fishery (DW-17)	S2: Shark Research Fishery (DW-17)	S3: VIMS Robust Series (DW-05)	S4: NMFS-NEFSC Bottom Longline (DW-09)	S5: SCDNR SEAMAP LL (DW-11)	S6: SCDNR Red Drum Survey (DW-11)	S7: SCDNR Drumline Survey (DW-21)	S8: COAST-SPAN Longline All-ages (DW-08)	S9: COAST-SPAN Gillnet Long Net All-age (DW-07)	S10: COAST-SPAN Gillnet Short Net Age-0 (DW-10)
1974										
1975										
1976										
1977										
1978										
1979										
1980										
1981										
1982										
1983										
1984										
1985										
1986										
1987										
1988										
1989										
1990			0.026							
1991			0.012							
1992			0.021							
1993										
1994	19.410									
1995	46.050		0.058							
1996	28.030		0.035	0.003		1.227				
1997	2.580		0.069			1.273				
1998	34.630		0.004	0.031		0.458				
1999	93.870		0.218			0.394				
2000	132.340		0.010			1.359				
2001	46.570		0.031	0.013		0.349			0.798	
2002	190.210		0.102			0.589			0.309	
2003	18.290					1.019			0.901	
2004	52.600		0.038	0.031		0.459			0.150	
2005	106.580					0.310		3.023	0.836	
2006	91.350		0.063			1.316		1.522	1.139	0.498
2007	27.480		0.042	0.001	1.721			1.205	0.486	1.493
2008		94.600	0.277		0.838			3.441	0.552	0.301
2009		108.410	0.086	0.026	1.220			1.943	1.072	0.309
2010		69.950	0.082		0.899			2.005	1.056	0.565
2011		74.770	0.051		1.534			1.602	0.726	0.601
2012		176.650	0.031	0.122	1.543			2.690	0.927	1.068
2013		100.090	0.224		2.707		0.166	3.696	3.684	0.827
2014		213.370	0.074		1.766		0.206	1.974	1.277	0.250
2015		144.800	0.028	0.148	1.983		0.174	1.466	0.707	0.540
2016		124.360	0.082		0.974		0.136	1.769	0.607	0.296
2017		266.440	0.092		1.124		0.185	1.585	1.320	0.688
2018		42.130	0.121	0.318	1.464		0.207	1.025	1.420	1.217

Table 2. Three CPUE indices of age-0 recruitment were recommended for use in sensitivity analyses within the Atlantic blacktip shark stock assessment by the Index Working Group of the SEDAR 65 Data Workshop (DW). The SEDAR 65 DW report number is identified for each index. The age-0 CPUE indices will be evaluated in Stock Synthesis as "recruitment" time series R1 – R3. Note that the series R1 – R3 utilize the same data as the series S8 – S10 (**Table 1**). Consequently, they should not be used together within the same stock assessment model, and as a result, they were evaluated separately here.

Year	R1: COAST-SPAN Longline Age-0 (DW-08)	R2 COAST-SPAN Gillnet Long Net Age-0 (DW-07)	R3: COAST-SPAN Gillnet Short Net Age-0 (DW-10)
1974			
1975			
1976			
1977			
1978			
1979			
1980			
1981			
1982			
1983			
1984			
1985			
1986			
1987			
1988			
1989			
1990			
1991			
1992			
1993			
1994			
1995			
1996			
1997			
1998			
1999			
2000			
2001		0.700	
2002		0.223	
2003		0.815	
2004		0.145	
2005	2.819	0.906	
2006	1.413	1.023	0.498
2007	1.214	0.490	1.493
2008	2.883	0.564	0.301
2009	1.882	0.749	0.309
2010	1.753	0.615	0.565
2011	1.597	0.275	0.601
2012	2.656	0.847	1.068
2013	3.440	3.845	0.827
2014	1.892	0.892	0.250
2015	0.897	0.400	0.540
2016	1.670	0.118	0.296
2017	1.607	1.356	0.688
2018	1.031	0.967	1.217

Table 3. Cross-correlations and hierarchical cluster analysis correlation plots (two groupings) were evaluated for six data sets. The three original data sets S1 – S10, S1 – S7, and R1 – R3 were adjusted as follows: S1 – S10 was adjusted to remove S4 and to remove the year 2013 from S9; S1 – S7 was adjusted to remove S4; and R1 – R3 was adjusted to remove the year 2013 from R2. This resulted in 6 data sets with four separate cross-correlations run for each data set (Pearson's and Spearman's correlations with CPUE on the natural and log scale).

		Hierarchical Cluster Analyses (two groupings) by Cross-Correlation Method			
		Pearson's		**Spearman's***	
Data Set		Natural scale	Log scale	**Natural scale***	Log scale
S1 – S10	Group 1	S3, S1, S8	S3, S1, S8	S3, S1, S8	S3, S1, S8
	Group 2	S5,S9,S10,S4,S7,S2,S6	S2,S6,S4,S7,S10,S5,S9	S2,S6,S9,S4,S7,S5,S10	S2,S6,S9,S4,S7,S5,S10
S1 – S10	Group 1	S3,S1,S8	S3,S1,S8	**S3**, **S1**, **S8**	S3,S1,S8
(Adjusted)*	Group 2	S5,S9,S10,S4,S7,S2,S6	S2,S6,S7,S9,S5,S10	**S5**, **S10**, **S6**, **S2**, **S7**, **S9**	S5, S10, S6, S2, S7, S9
S1 – S7	Group 1	S2,S6	S6, S2, S5	S6, S2, S5	S6, S2, S5
	Group 2	S1,S3,S5,S4,S7	S4,S7,S1,S3,	S4,S7,S1,S3	S4,S7,S1,S3
S1 – S7	Group 1	S1, S3	S1, S3	**S1**, **S3**	S1, S3
(Adjusted)*	Group 2	S6, S5,S2,S7	S5, S7 S2, S6	**S6**, **S7**, **S2**, **S5**	S5, S7 S2, S6
R1 – R3	Group 1	R3	R3	R3	R3
	Group 2	R1, R2	R1, R2	R1, R2	R1, R2
R1 – R3	Group 1	R1	R1	**R1**	R1
(Adjusted)*	Group 2	R2, R3	R2, R3	**R2**, **R3**	R2, R3

*Results reported in **Appendices A**, **B**, and **C**.

Table 4. Cluster dendrograms (two groupings) evaluated for six data sets and four separate cross-correlations for each data set (Pearson's and Spearman's correlations with CPUE on the natural and log scale), as described in **Table 3**.

		Cluster Dendrograms (two groupings) by Cross-Correlation Method			
		Pearson's		**Spearman's***	
Data Set		Natural scale	Log scale	**Natural scale***	Log scale
S1 – S10	Group 1	S10,S5,S9,S2,S6	S10,S5,S9,S2,S6	S1, S8	S1, S8
	Group 2	S4,S7,S3,S1,S8	S4,S7,S3,S1,S8	S10,S6,S2,S5,S4,S7,S3,S9	S10,S6,S2,S5,S4,S7,S3,S9
S1–S10	Group 1	S2,S6,S10,S5,S9	S5,S10,S6,S7,S9	**S3**,**S1**,**S8**	S3, S1, S8
(Adjusted)*	Group 2	S4,S7,S3,S1,S8	S2,S3,S1,S8	**S10**, **S2**, **S5**, **S6**, **S7**, **S9**	S10, S2, S5, S6, S7, S9
S1 – S7	Group 1	S5, S2, S6	S6,S2,S5	S6, S2, S5	S6, S2, S5
	Group 2	S1,S3, S4,S7	S3,S1,S4,S7	S3,S1,S4,S7	S3,S1,S4,S7
S1 – S7	Group 1	S1,S3	S1,S3	**S1**, **S3**	S1, S3
(Adjusted)*	Group 2	S6, S5,S2,S7	S5, S7, S2, S6	**S2**, **S5**, **S6**, **S7**	S5, S7, S2, S6,
R1 – R3	Group 1	R3	R3	R3	R3
	Group 2	R1, R2	R1, R2	R1, R2	R1, R2
R1 – R3	Group 1	R1	R1	**R1**	R1
(Adjusted)*	Group 2	R2, R3	R2, R3	**R2**, **R3**	R2, R3

*Results reported in **Appendices A**, **B**, and **C**.

Appendix A. Data set S1 – S10.

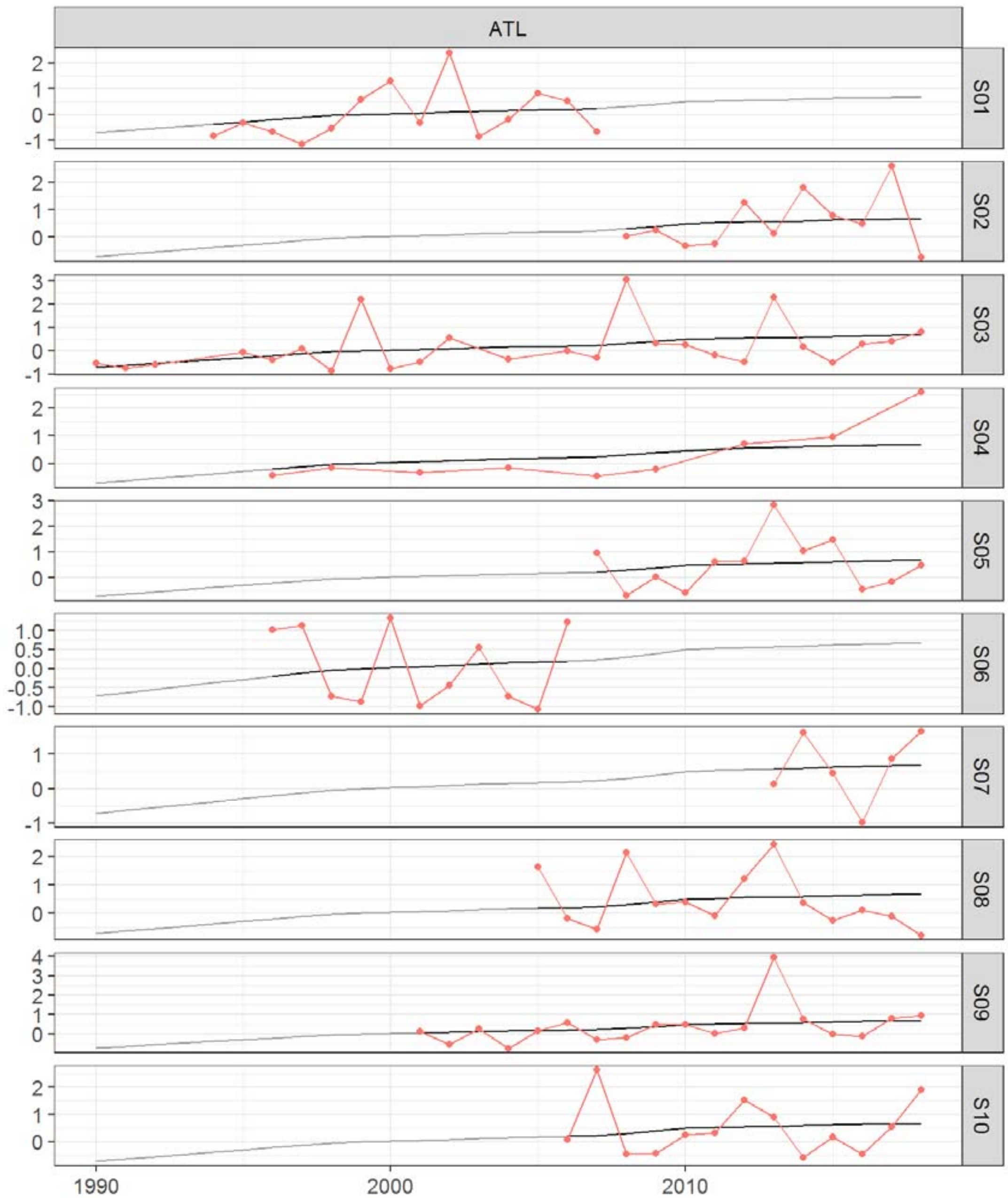

Figure A1. Smooth fit to CPUE indices of relative abundance for the Atlantic (ATL) stock of blacktip sharks (S1 – S10 as defined in **Table 1**). Points are the CPUE indices, continuous black lines are the smoother showing the average trend for the combined ATL region (obtained from a GAM fit to year with series as a factor). X-axis is year, Y-axes are the scaled indices.

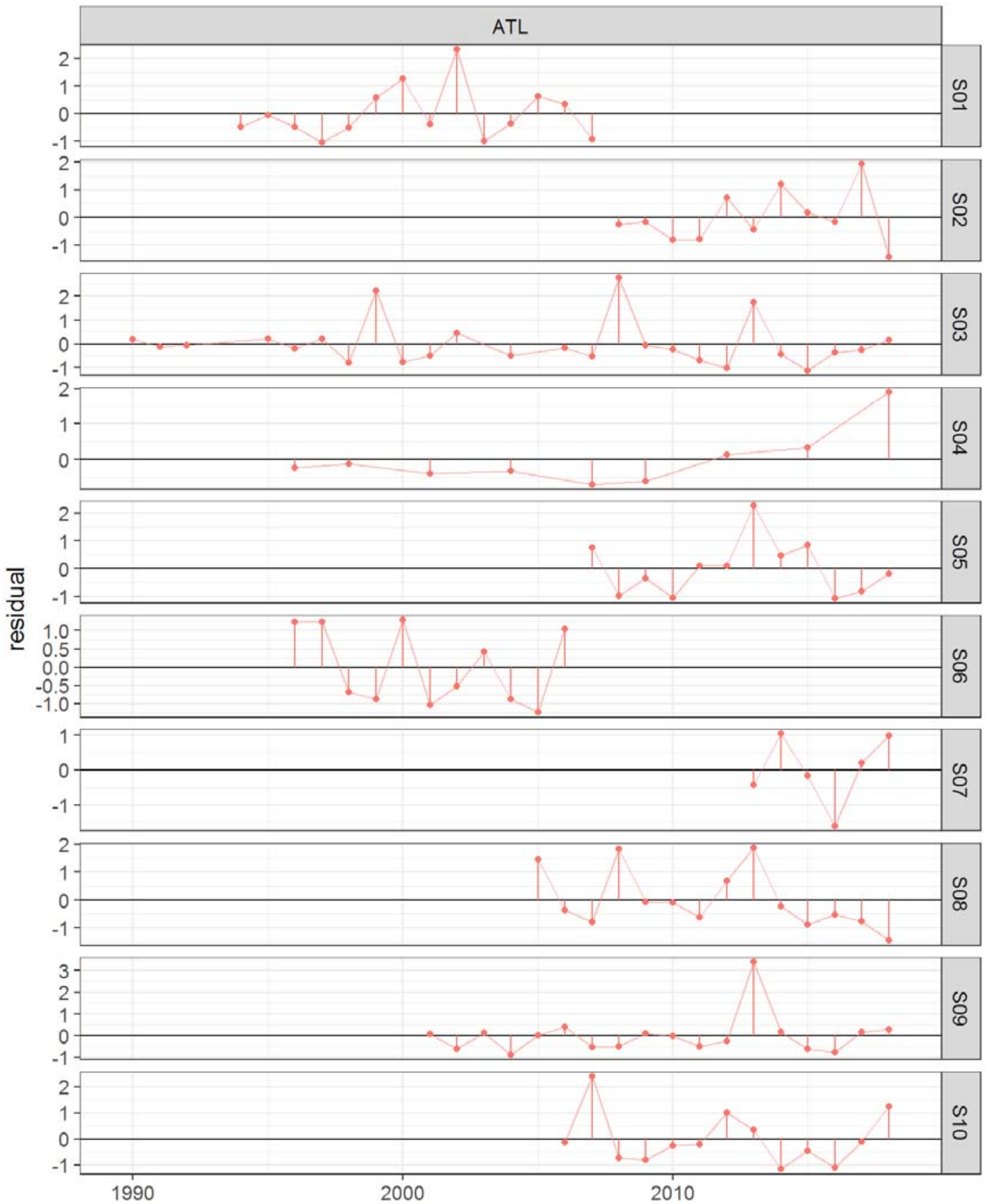

Figure A2. Residuals of the smooth fit to CPUE indices of relative abundance for the Atlantic (ATL) stock of blacktip sharks (S1 – S10 as defined in **Table 1**). Points are residuals of the scaled CPUE indices to the smoothed trend (**Figure A1**). X-axis is year, Y-axes are residuals of the scaled indices.

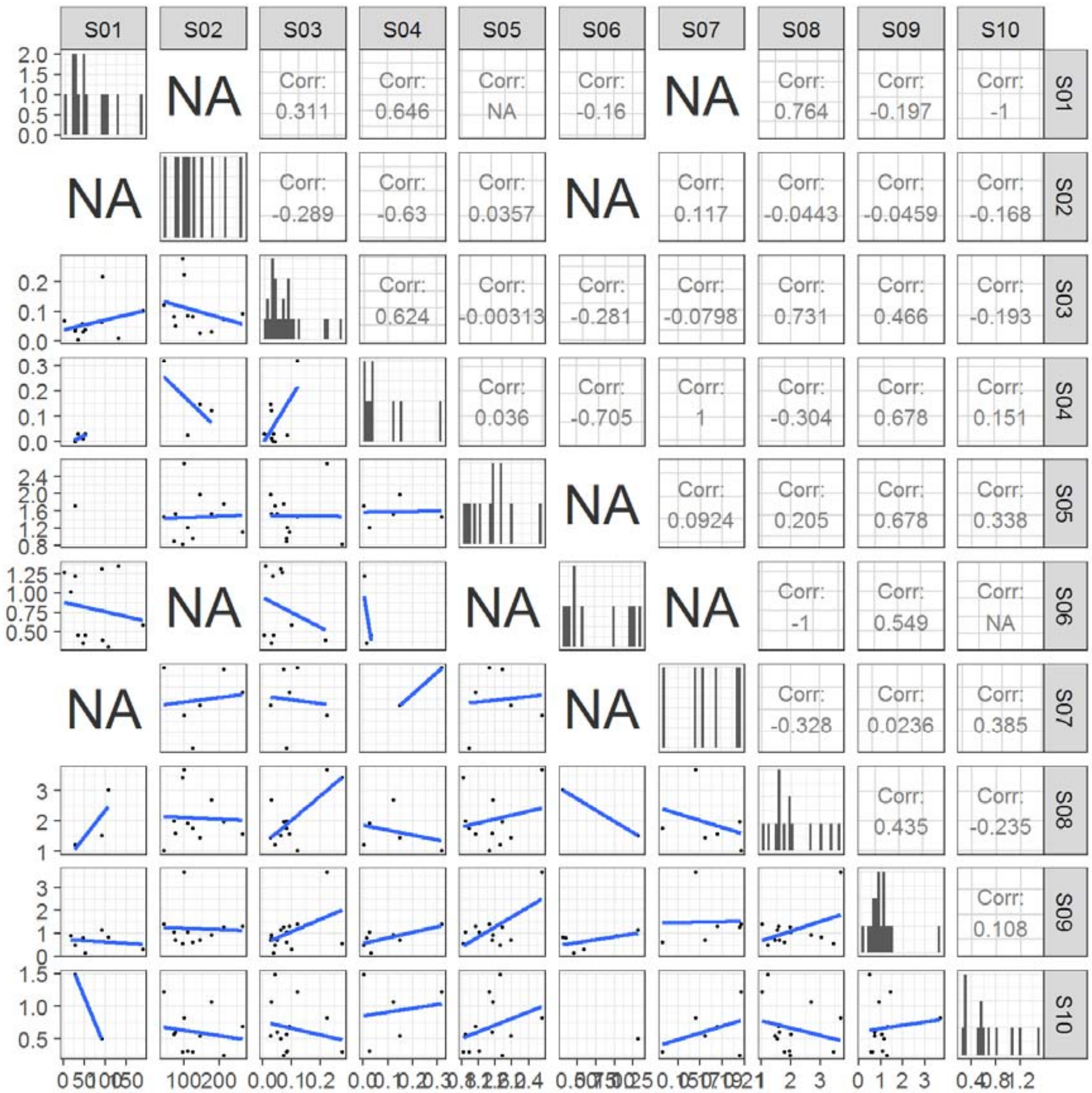

Figure A3. Pairwise scatter plots of CPUE indices of relative abundance for the Atlantic (ATL) stock of blacktip sharks (S1 – S10 as defined in **Table 1** and **Figure A1**). X- and Y-axis are indices.

Data set S1 – S10 (Adjusted); Spearman's cross-correlations of CPUE on natural scale.

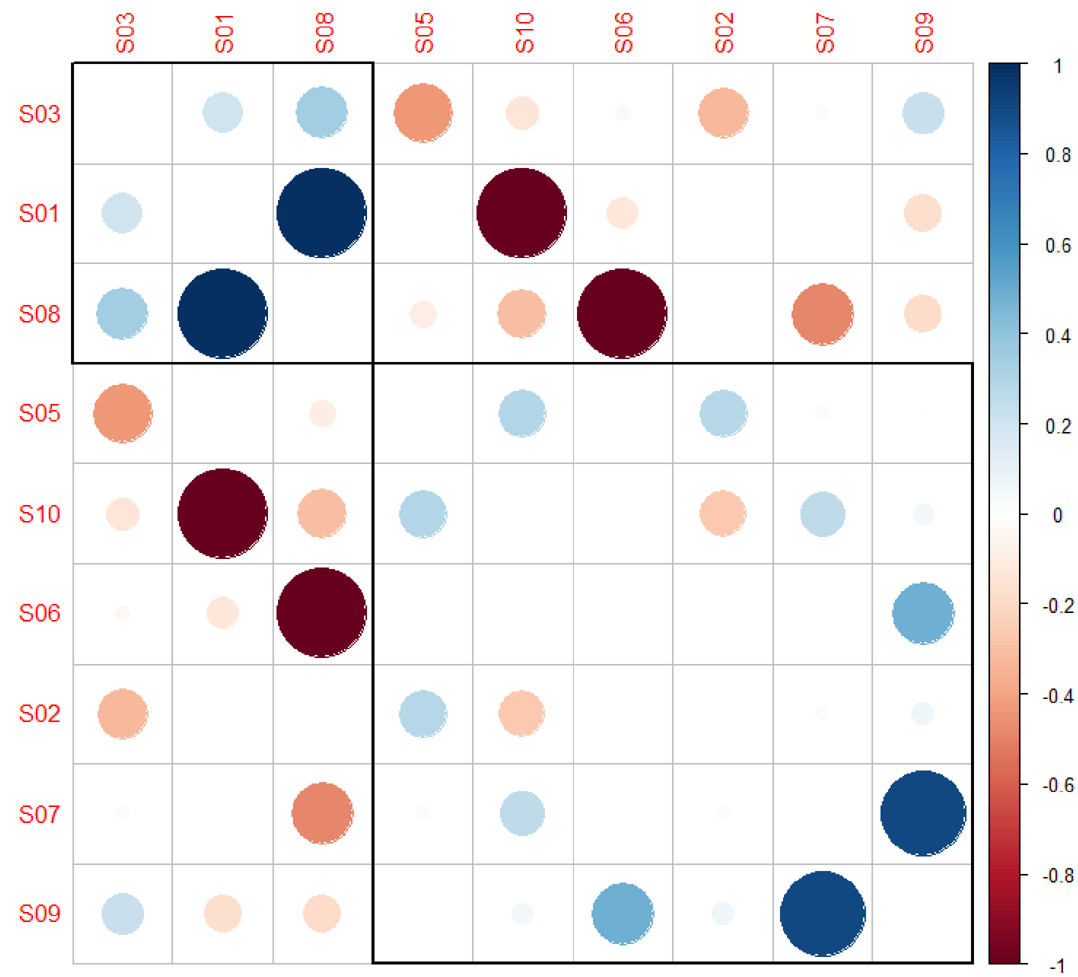

Figure A4. Cross-correlation matrix for adjusted CPUE indices of relative abundance for the Atlantic (ATL) stock of blacktip sharks (S1 – S10 adjusted as described in **Table 3**). Blue indicates positive and red negative correlations. The order of the indices and the rectangular boxes are chosen based on a hierarchical cluster analysis using a set of dissimilarities.

Data set S1 – S10 (Adjusted); Spearman's cross-correlations of CPUE on natural scale.

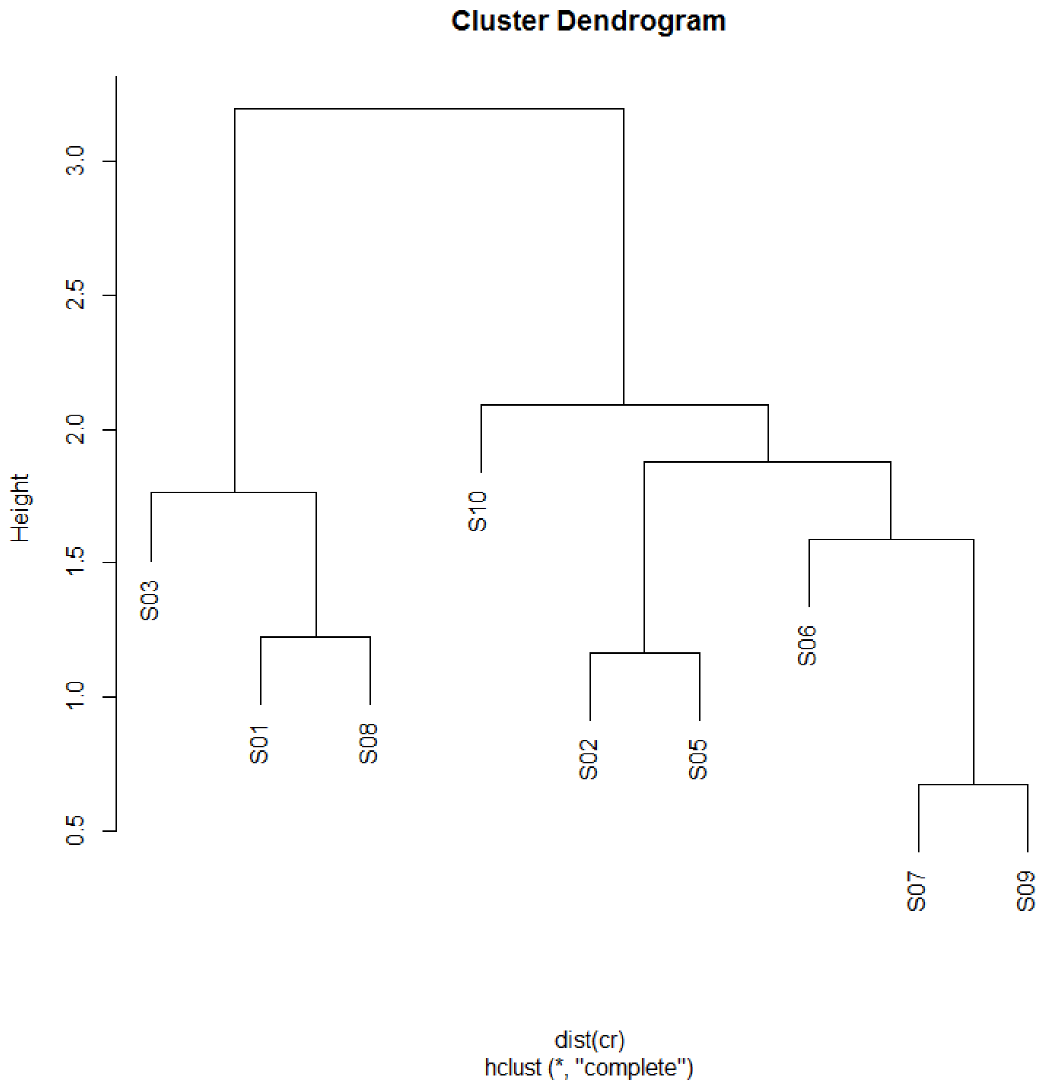

Figure A5. Cluster dendrogram based on the complete agglomeration method using the cross-correlations of adjusted CPUE indices of relative abundance for the Atlantic (ATL) stock of blacktip sharks (S1 – S10 adjusted as described in **Table 4**).

Appendix B. Data set S1 – S7.

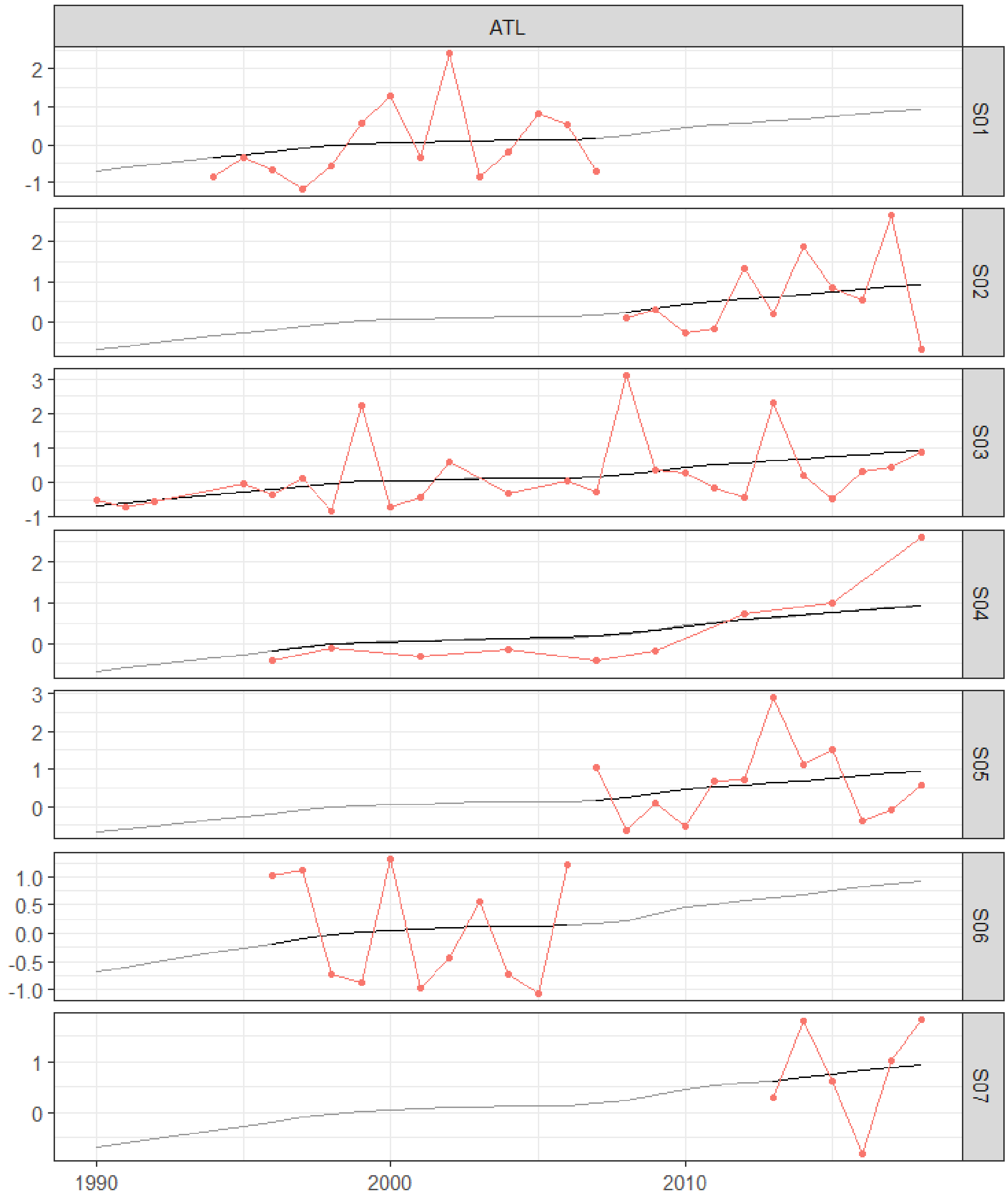

Figure B1. Smooth fit to CPUE indices of relative abundance for the Atlantic (ATL) stock of blacktip sharks (S1 – S7 as defined in **Table 1**). Points are the CPUE indices, continuous black lines are the smoother showing the average trend for the combined ATL region (obtained from a GAM fit to year with series as a factor). X-axis is year, Y-axes are the scaled indices.

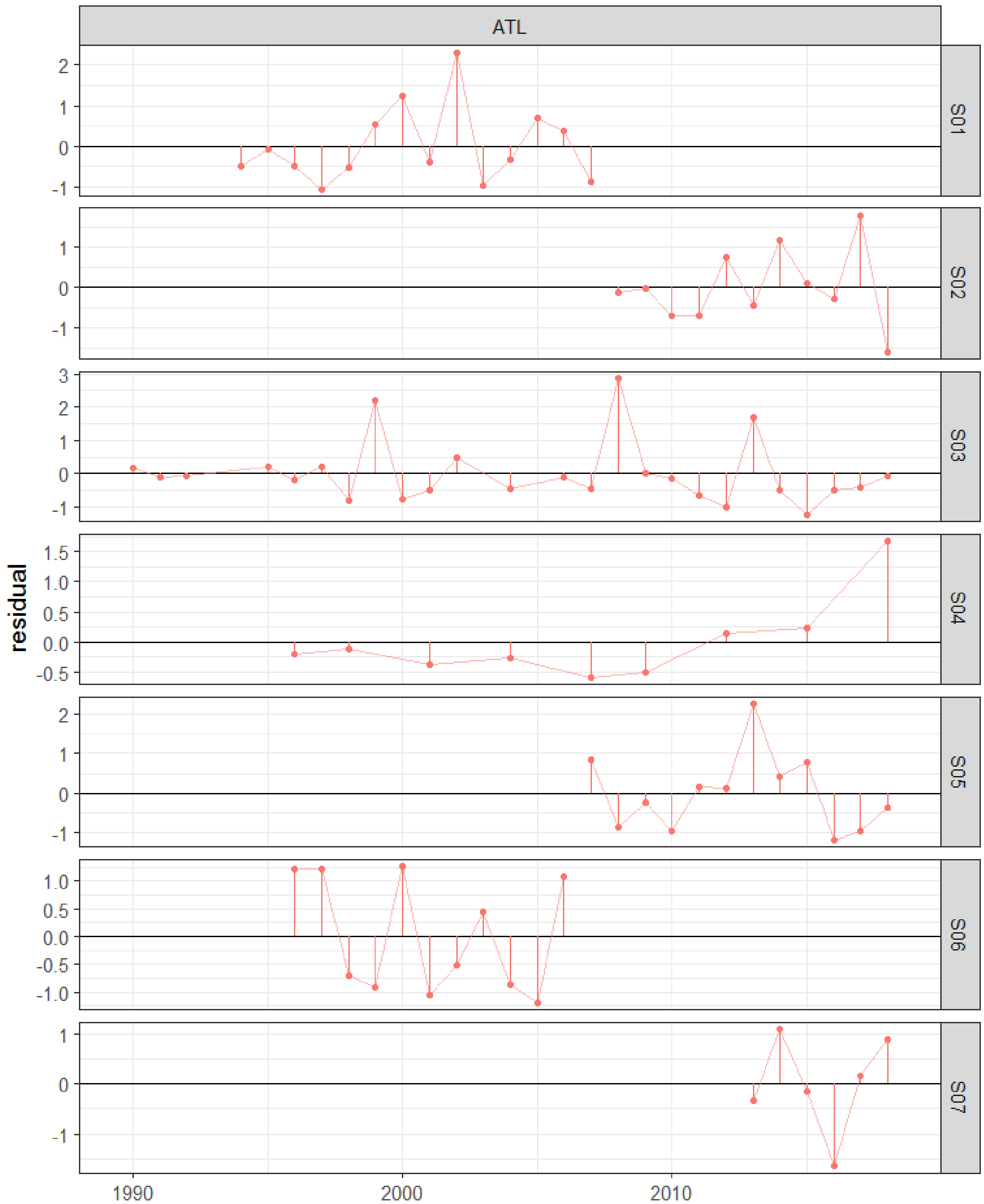

Figure B2. Residuals of the smooth fit to CPUE indices of relative abundance for the Atlantic (ATL) stock of blacktip sharks (S1 – S7 as defined in **Table 1**). Points are residuals of the scaled CPUE indices to the smoothed trend (**Figure B1**). X-axis is year, Y-axes are residuals of the scaled indices.

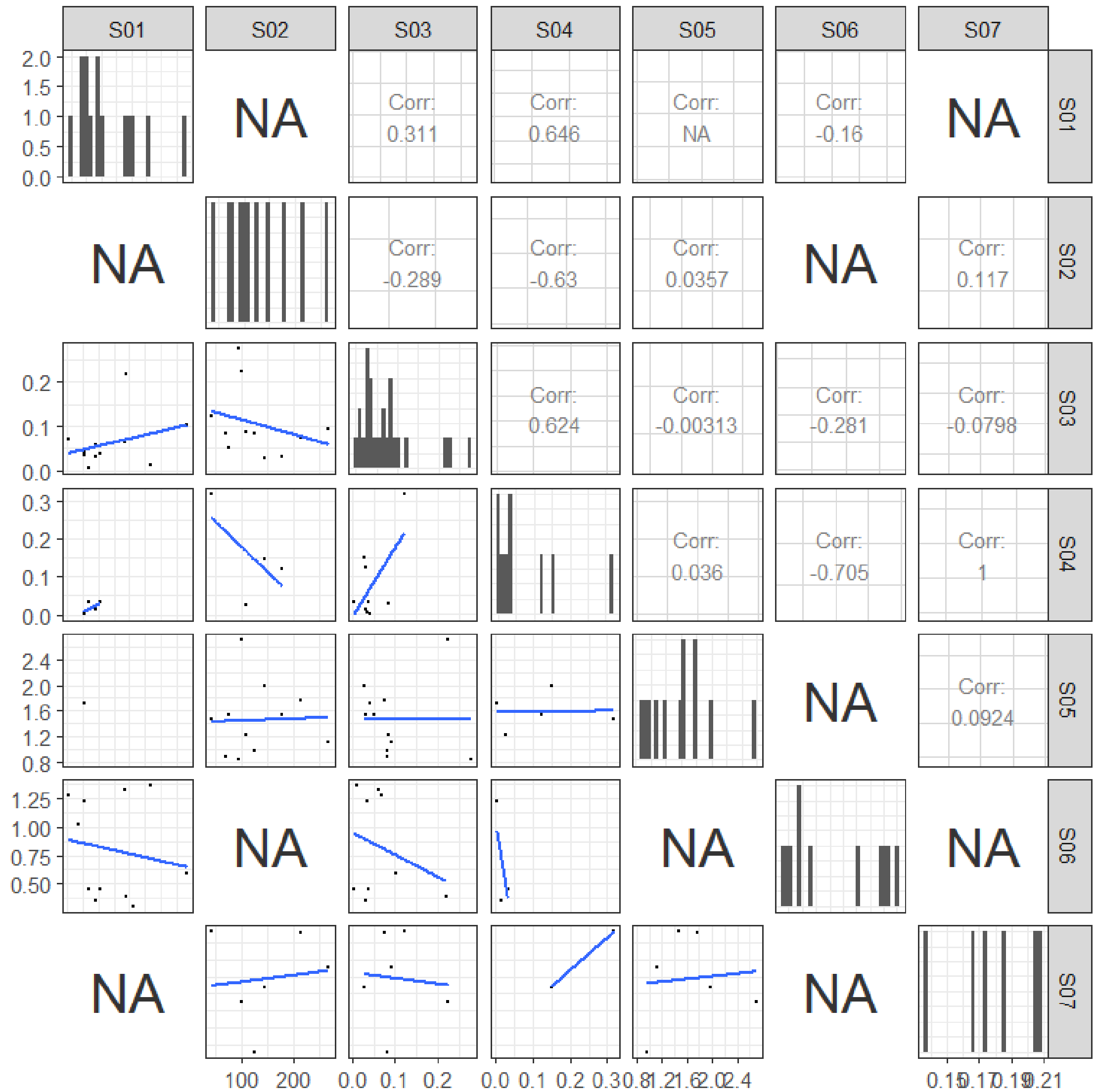

Figure B3. Pairwise scatter plots of CPUE indices of relative abundance for the Atlantic (ATL) stock of blacktip sharks (S1 – S7 as defined in **Table 1** and **Figure B1**). X- and Y-axis are indices.

Data set S1 – S7 (Adjusted); Spearman's cross-correlations of CPUE on natural scale.

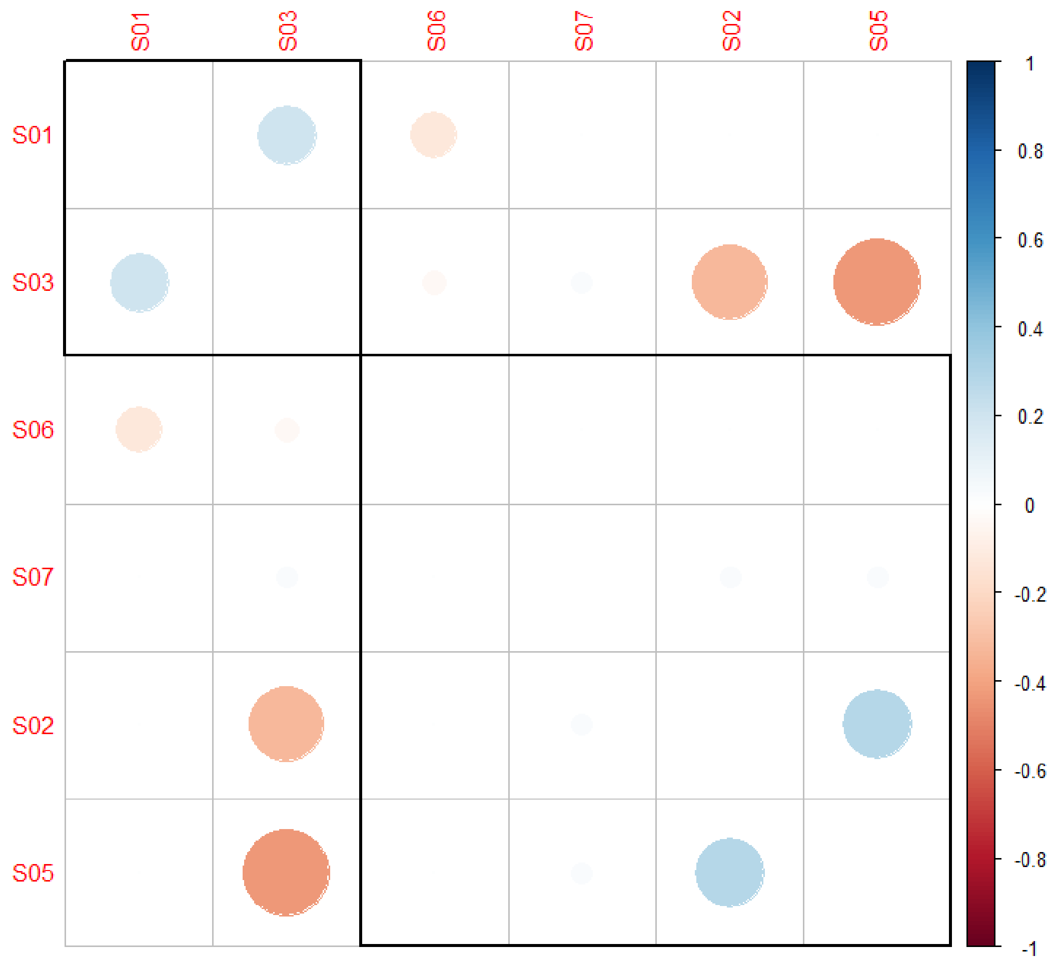

Figure B4. Cross-correlation matrix for adjusted CPUE indices of relative abundance for the Atlantic (ATL) stock of blacktip sharks (S1 – S7 adjusted as described in **Table 3**). Blue indicates positive and red negative correlations. The order of the indices and the rectangular boxes are chosen based on a hierarchical cluster analysis using a set of dissimilarities.

Data set S1 – S7 (Adjusted); Spearman's cross-correlations of CPUE on natural scale.

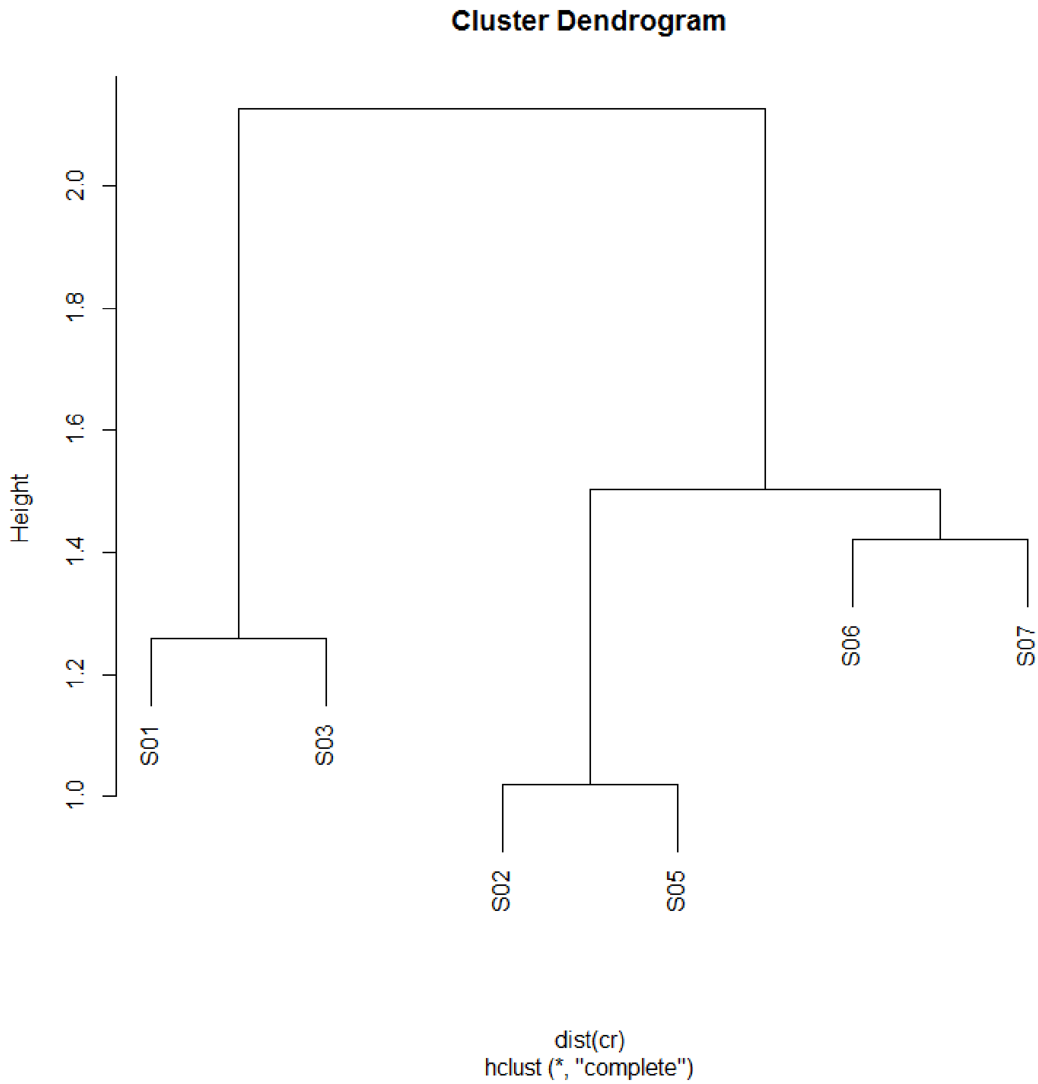

Figure B5. Cluster dendrogram based on the complete agglomeration method using the cross-correlations of adjusted CPUE indices of relative abundance for the Atlantic (ATL) stock of blacktip sharks (S1 – S7 adjusted as described in **Table 4**).

Appendix C. Data set R1 – R3.

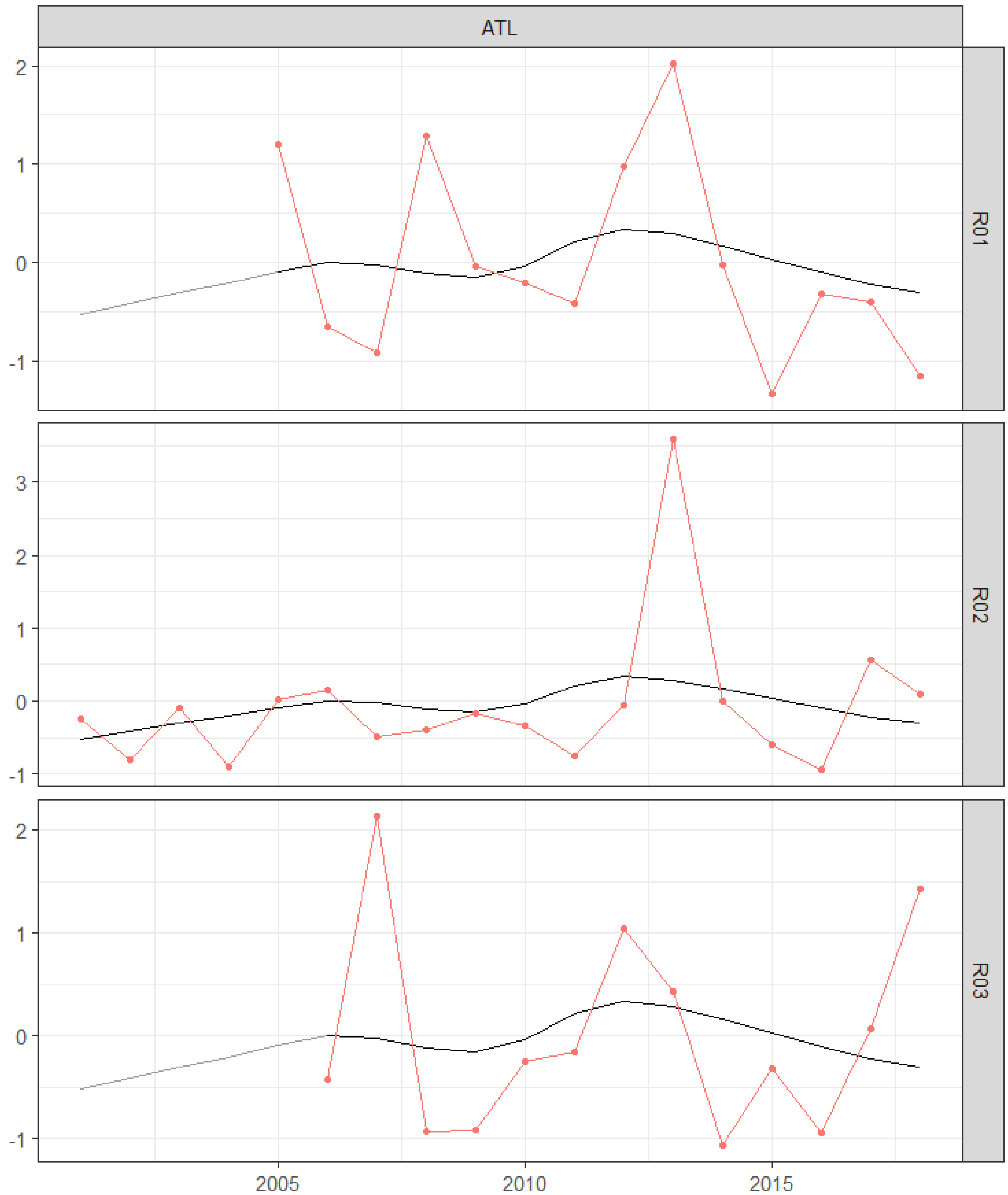

Figure C1. Smooth fit to CPUE indices of relative abundance for the Atlantic (ATL) stock of blacktip sharks (R1 – R3 as defined in **Table 2**). Points are the CPUE indices, continuous black lines are the smoother showing the average trend for the combined ATL region (obtained from a GAM fit to year with series as a factor). X-axis is year, Y-axes are the scaled indices.

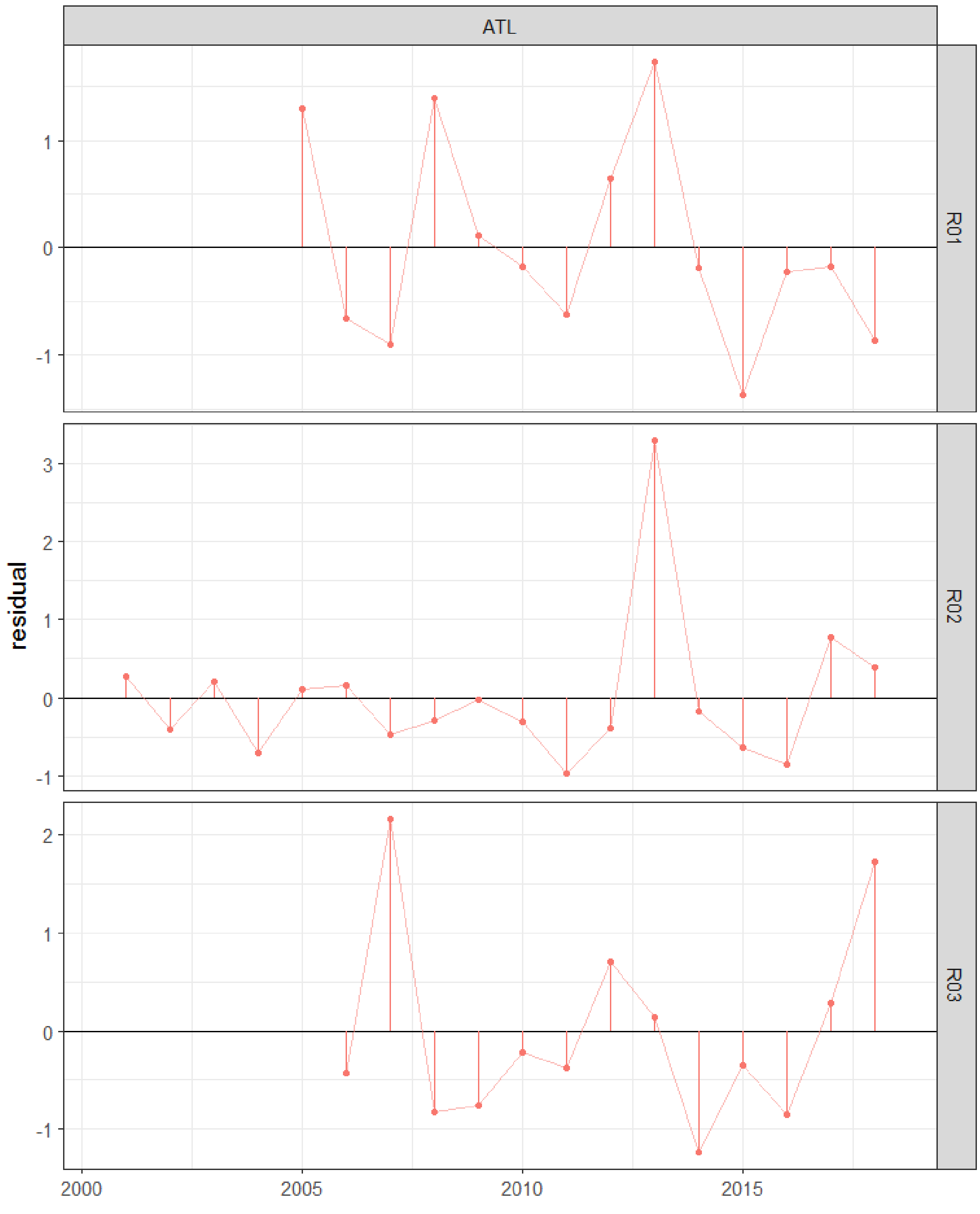

Figure C2. Residuals of the smooth fit to CPUE indices of relative abundance for the Atlantic (ATL) stock of blacktip sharks (R1 – R3 as defined in **Table 2**). Points are residuals of the scaled CPUE indices to the smoothed trend (**Figure C1**). X-axis is year, Y-axes are residuals of the scaled indices.

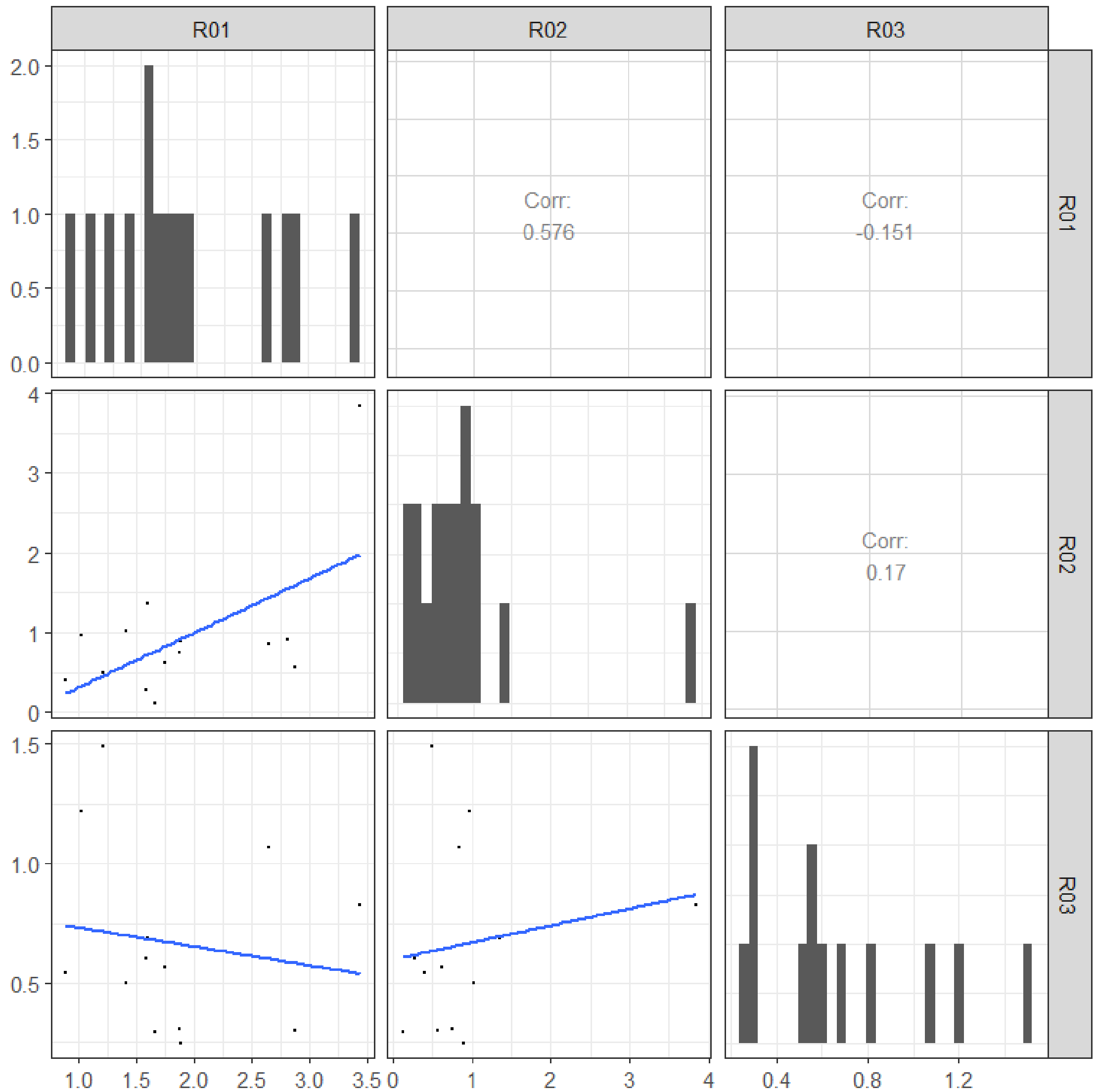

Figure C3. Pairwise scatter plots of CPUE indices of relative abundance for the Atlantic (ATL) stock of blacktip sharks (R1 – R3 as defined in **Table 2** and **Figure C1**). X- and Y-axis are indices.

Data set R1 – R3 (Adjusted); Spearman's cross-correlations of CPUE on natural scale.

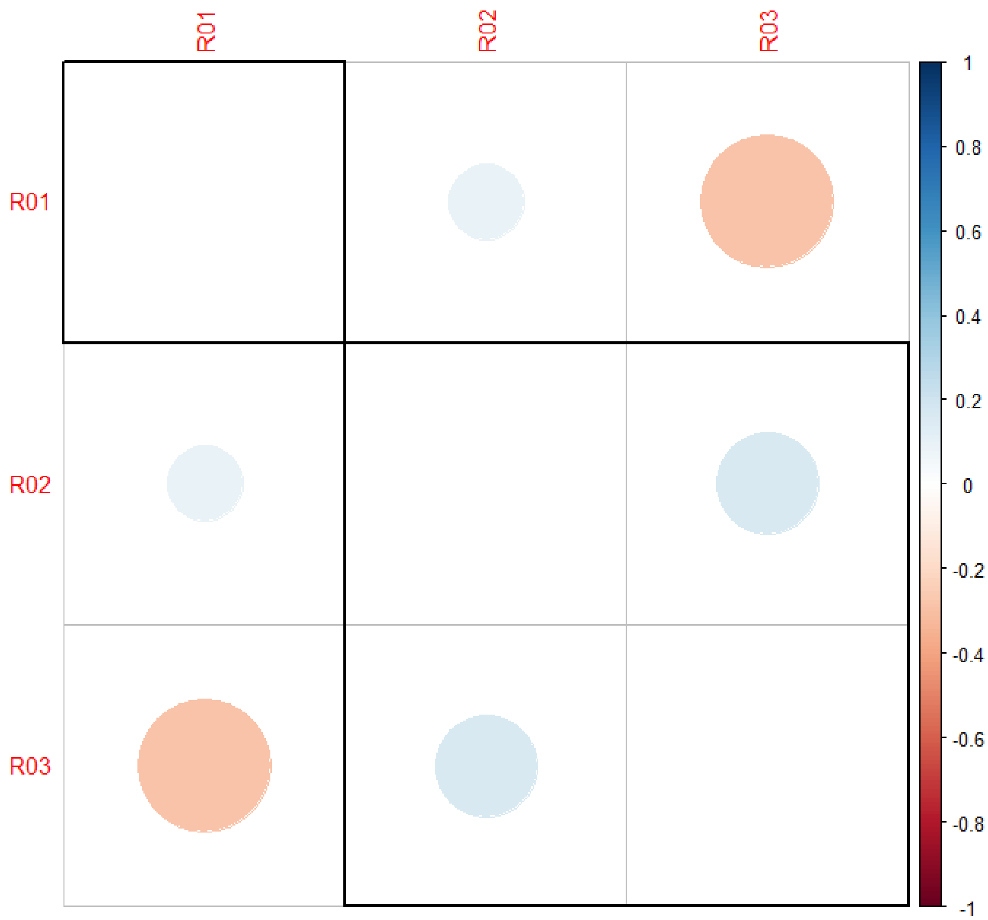

Figure C4. Cross-correlation matrix for adjusted CPUE indices of relative abundance for the Atlantic (ATL) stock of blacktip sharks (R1 – R3; adjusted as described in **Table 3**). Blue indicates positive and red negative correlations. The order of the indices and the rectangular boxes are chosen based on a hierarchical cluster analysis using a set of dissimilarities.

Data set R1 – R3 (Adjusted); Spearman's cross-correlations of CPUE on natural scale.

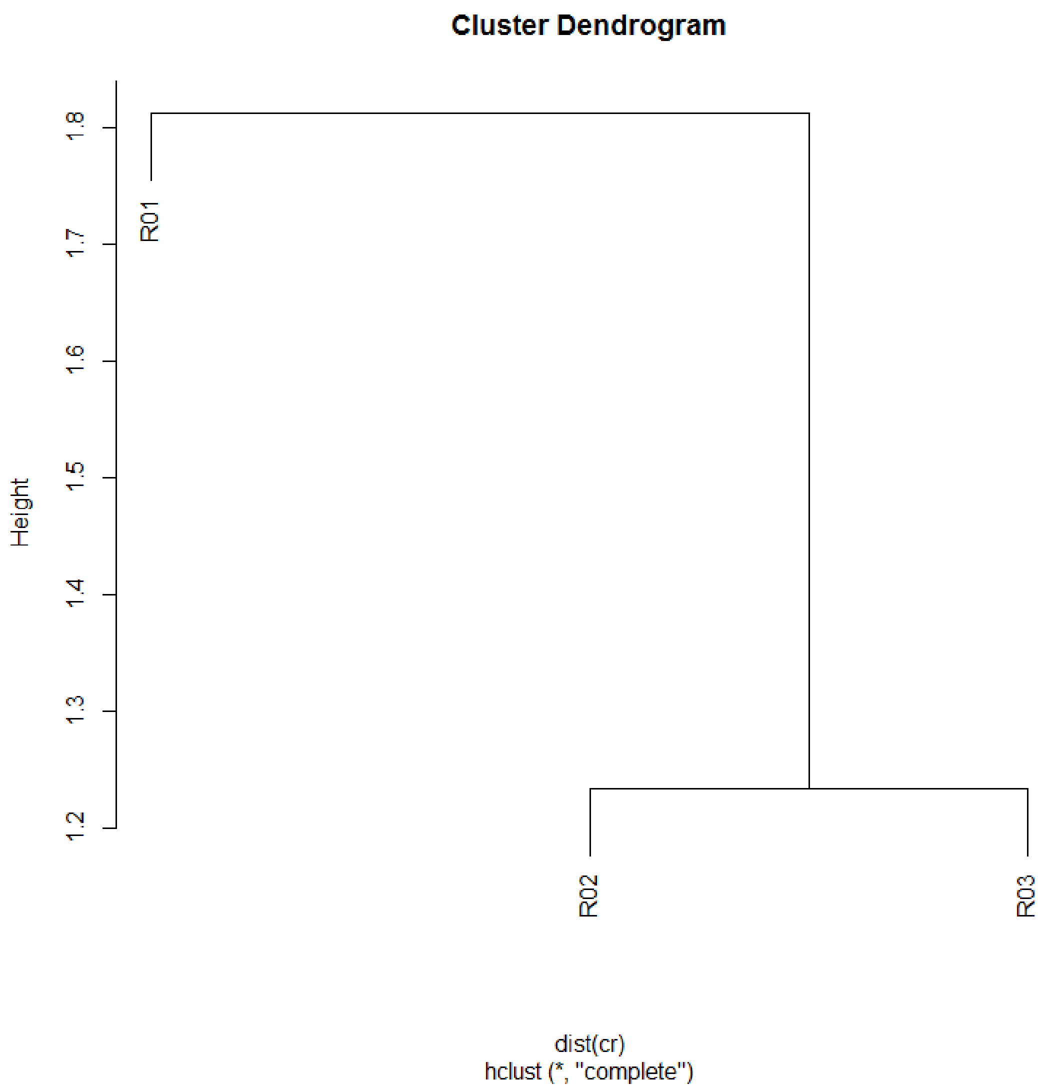

Figure C5. Cluster dendrogram based on the complete agglomeration method using the cross-correlations of adjusted CPUE indices of relative abundance for the Atlantic (ATL) stock of blacktip sharks (R1 – R3, adjusted as described in **Table 4**).