Cluster analysis as a Pathway to Overview of Rappahannock Water Quality

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Integrated Trends Assessment Team (ITAT)
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Road Map:

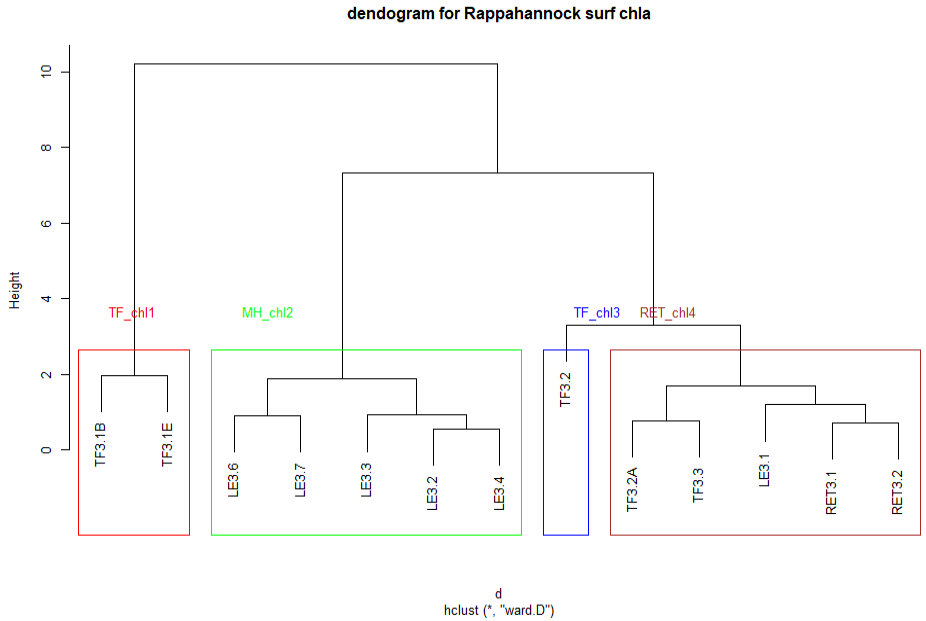
1. Overview of types of Clustering illustrated for Chla.

2. Comparing and Summarizing TN, TP, Chla, Secchi, and DO
Based on cluster of Longitudinal Profiles.

stations included:
TF3.1E TF3.1B TF3.2 TF3.2A TF3.3
RET3.1 RET3.2
LE3.1 LE3.2 LE3.3 LE3.4 LE3.6 LE3.7

1. Cluster analysis grouping items defined by station using patterns over year for mean surf chla observed in the Rappahannock.

The cluster #1 station groupings are primarily discriminated by the mean level of the long term response profile.



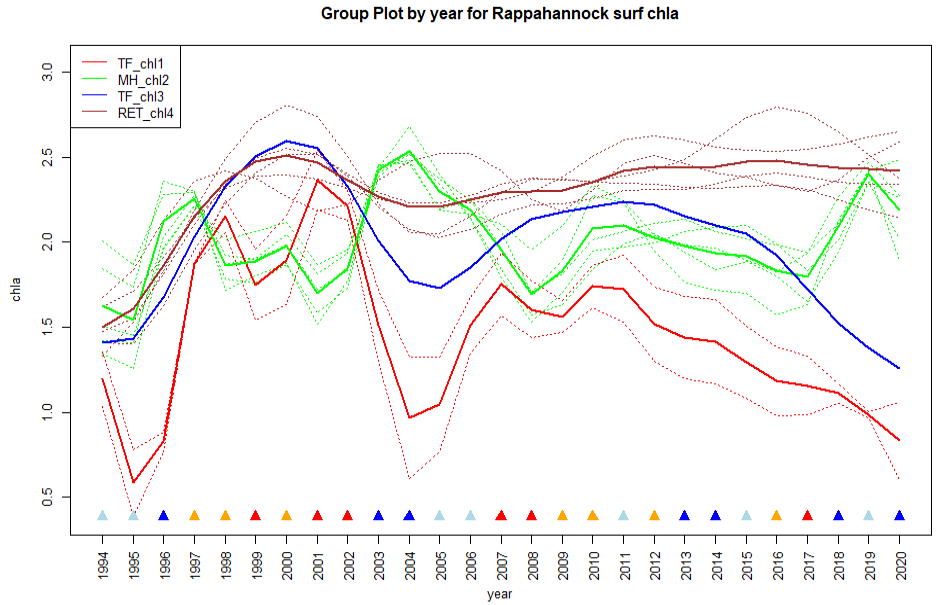


Figure 1.B: Year means plotted with station groups segregated by color. Multiple dash line traces within group show variability among station within groups.

In the upper tidal fresh (red) chlorophyl is low compared to the remainder of the estuary except in drought periods (1997-2002). The tidal fresh (red and blue) shows a negative response to flow. The highest levels of chlorophyll occur in the in the RET and occasionally in the mesohaline in high flow years. Trends will be addressed in cluster #2.

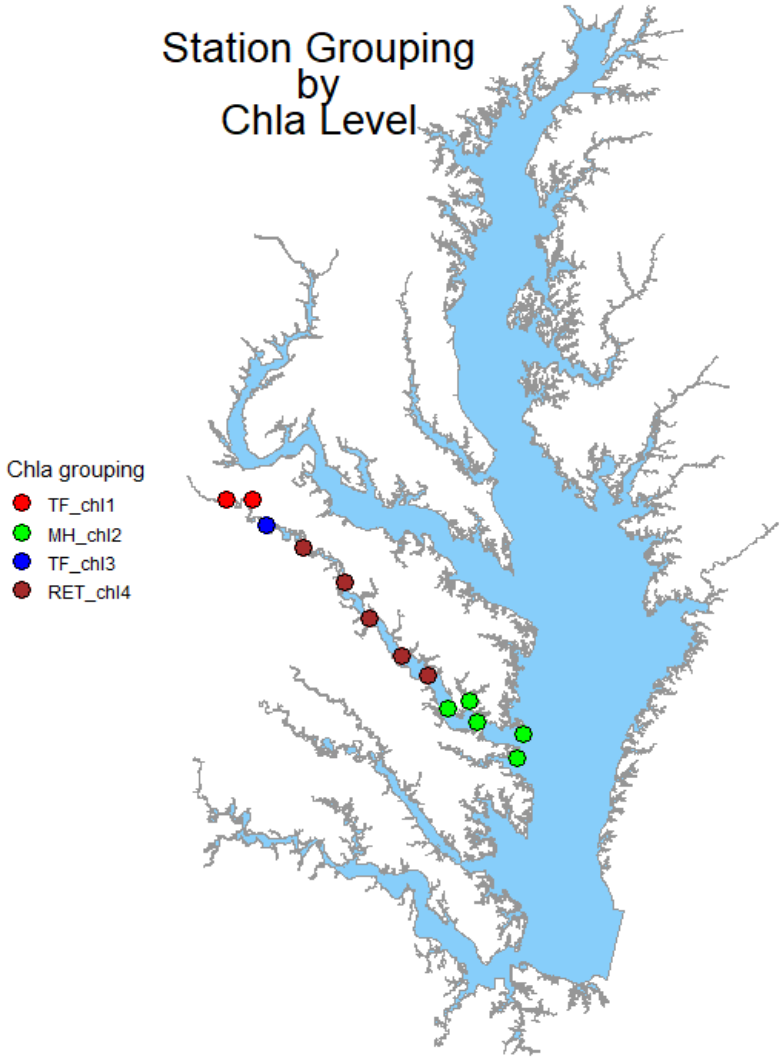
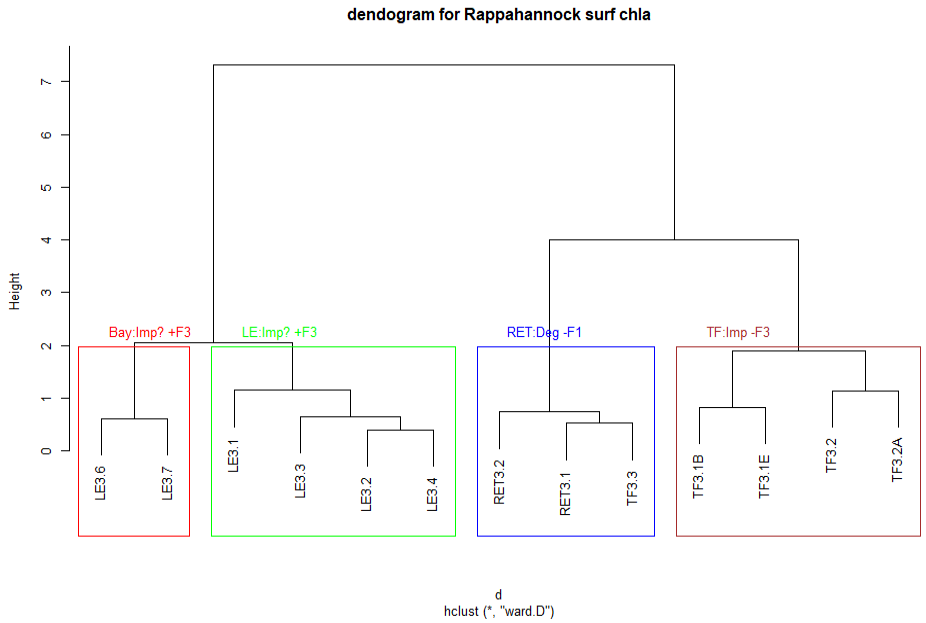
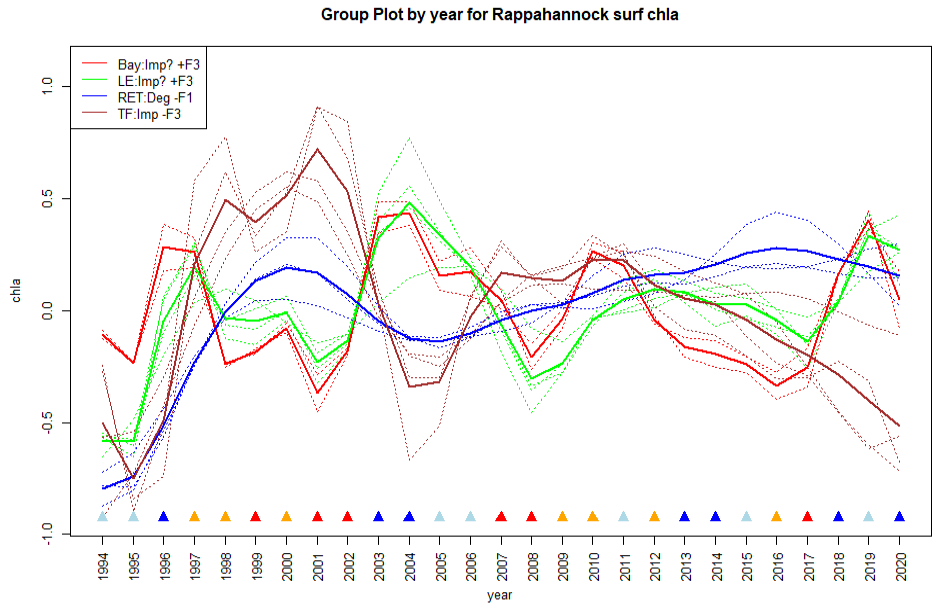


Figure 2: Cluster Map showing station groups by CHLA levels for Rappahannock.

2. Cluster analysis grouping items defined by station using patterns over year for mean-adjusted surf chla observed in the Rappahannock.





Chlorophyll concentrations in upper and lower estuary are opposite. In the tidal fresh chlorophyll is high in low flow years and gets diluted by freshwater input in high flow years. In the lower estuary chlorophyll is higher in high flow years because of the higher nutrient delivery of the increased flow and lower in low flow years because of nutrient limitation. In the tidal fresh (brown) chlorophyll appears to be decreasing since the drought surrounding 2000. On the contrary, in the RET (blue) chlorophyll appears to be increasing over this same period. In the lower estuary (red and green), chlorophyll shows strong responses to flow with little evidence of trend.

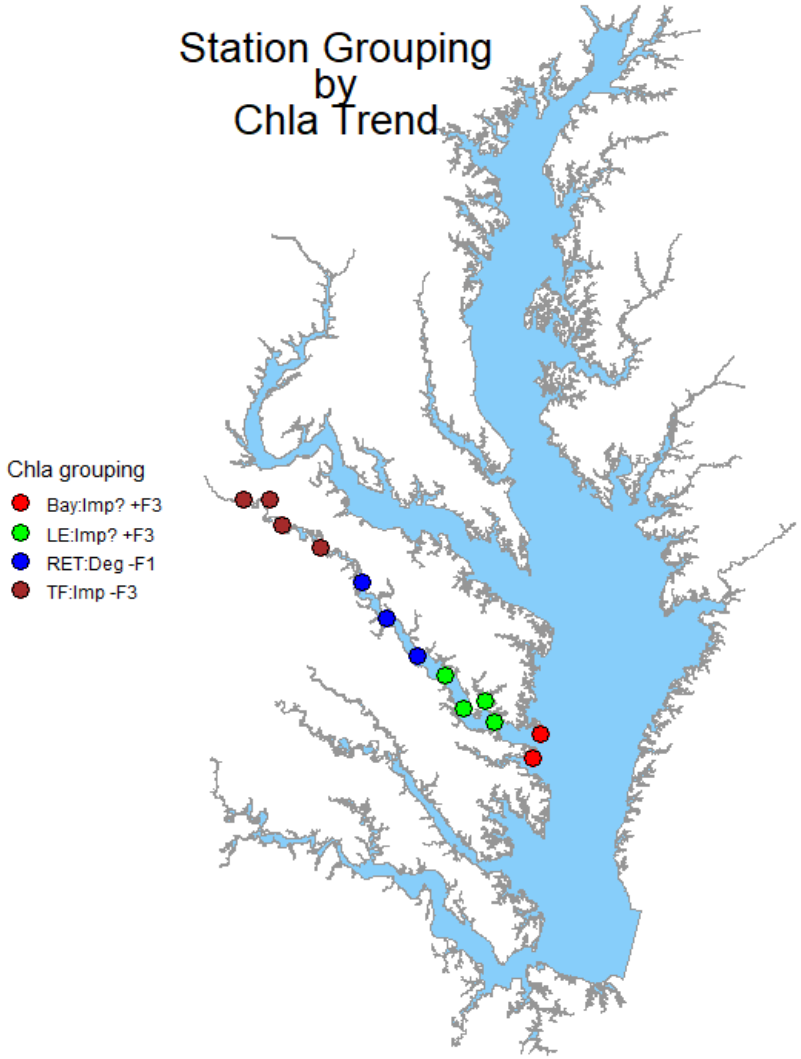
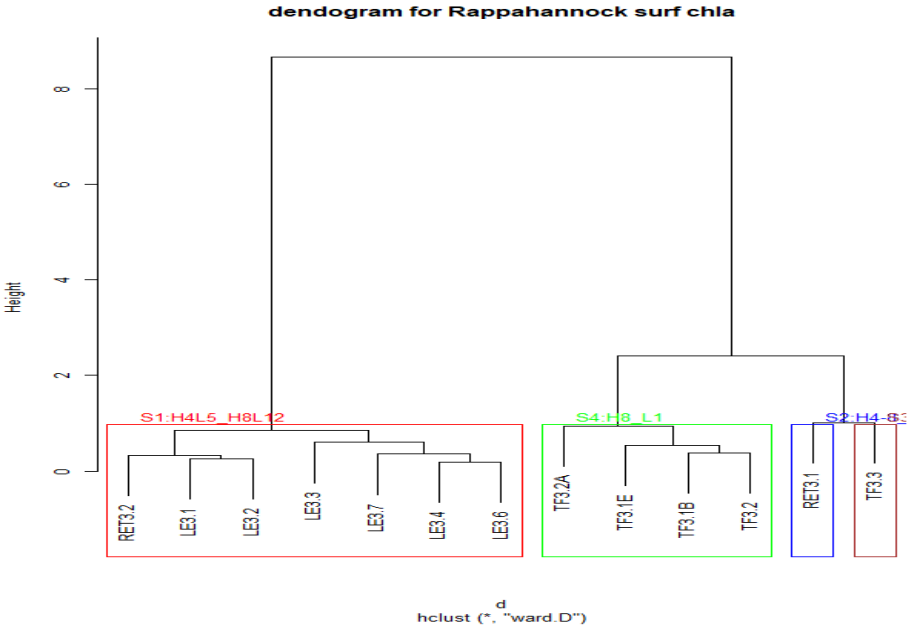


Figure 5: Cluster Map showing station groups by CHLA trend shape for Rappahannock.

3. Cluster analysis grouping items defined by station using patterns over month for mean-adjusted surf chla observed in the Rappahannock. Profiles have been mean adjusted.



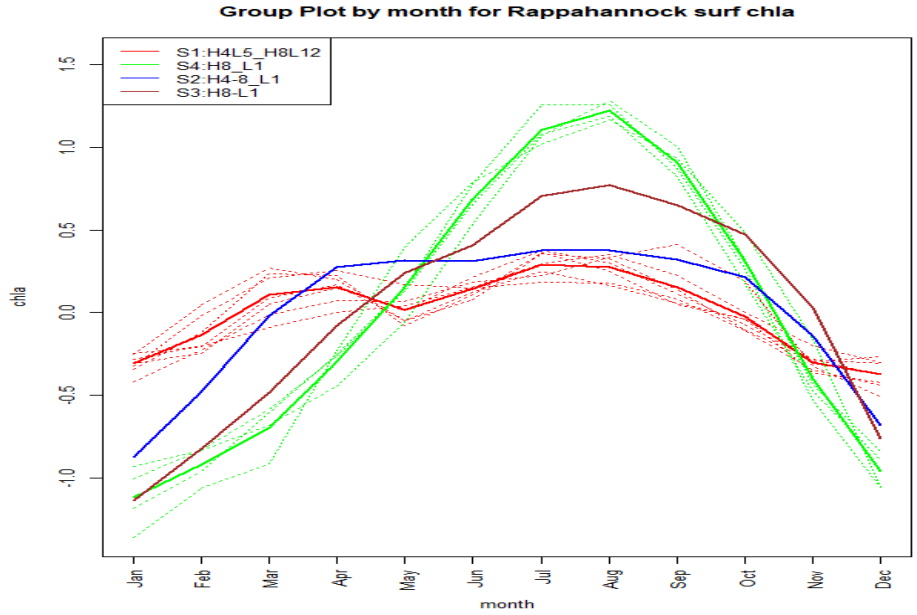


Figure 6.B: Month means plotted with station groups segregated by color. Multiple dash line traces within group show variability among station within groups. Items have been mean adjusted.

In the tidal fresh (green), chlorophyll exhibits a large seasonal amplitude with a zenith in late summer and a nadir in mid-winter. Down estuary in the lower tidal fresh (brown), the seasonal amplitude attenuates. In the RET (blue) there is some evidence of a spring bloom followed by a summer bloom resulting in high chlorophyll from March to October. In the mesohaline (red), the spring bloom is more developed and is followed by a short period of lower chlorophyll in June when there is a transition from larger diatom taxa to green and blue-green taxa. Mesohaline chlorophyll has a second peak in late summer.

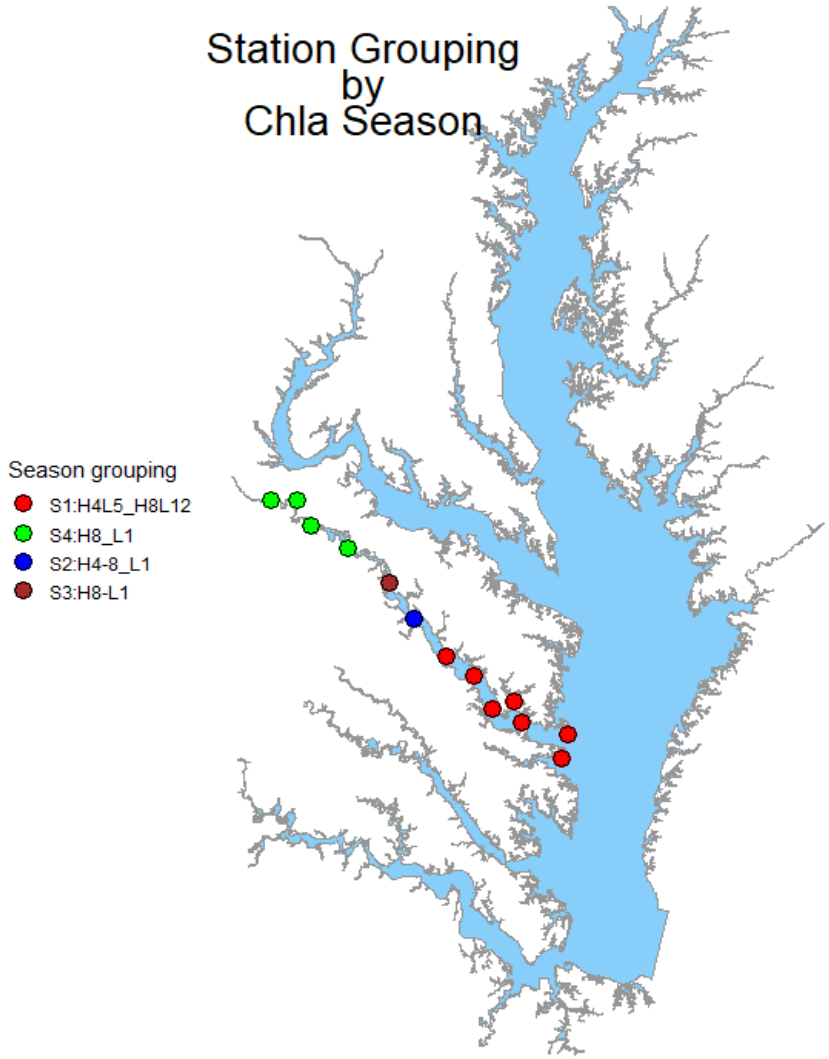
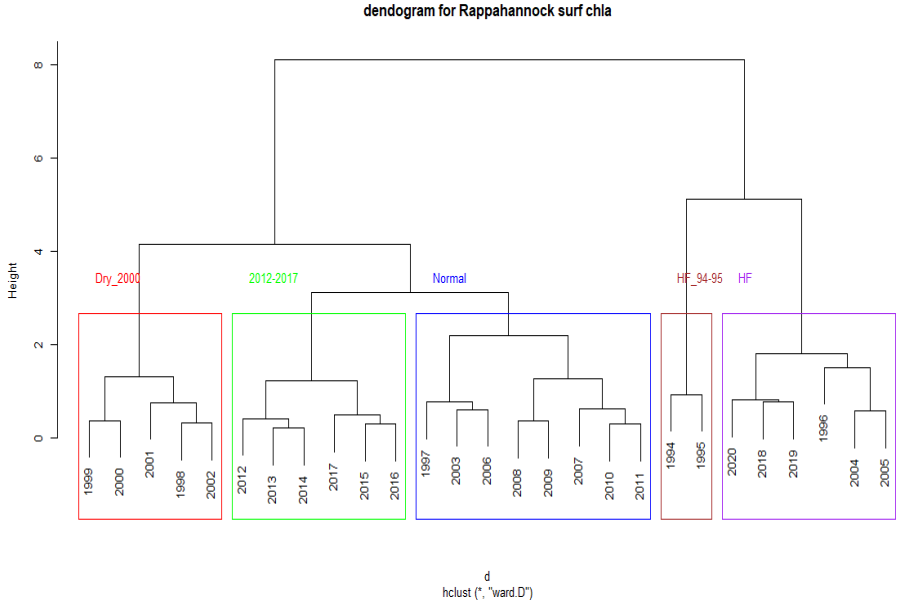
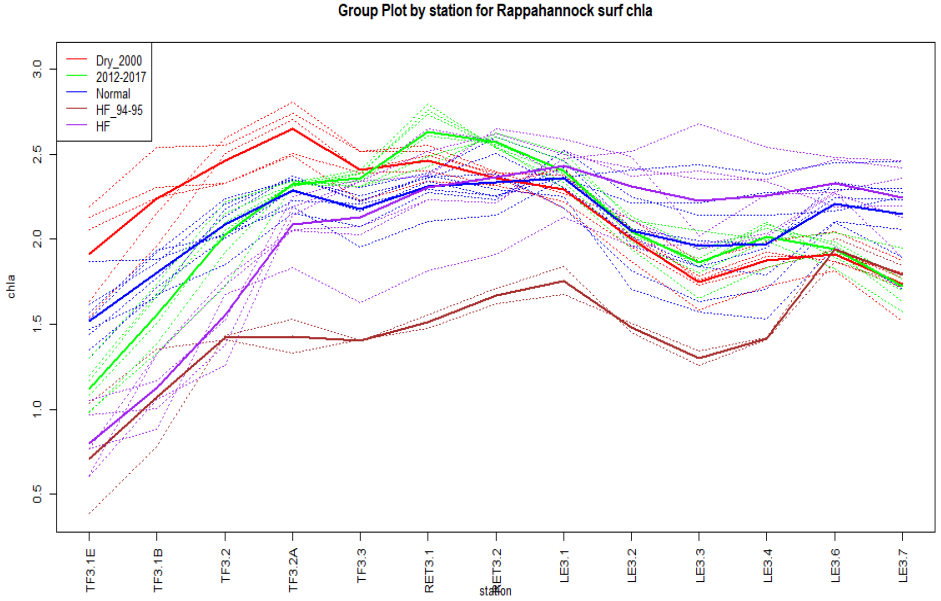


Figure 8: Cluster Map showing station groups by CHLA seasonal shape for Rappahannock.

5. Cluster analysis grouping items defined by year using patterns over station for surf chla observed in the Rappahannock.

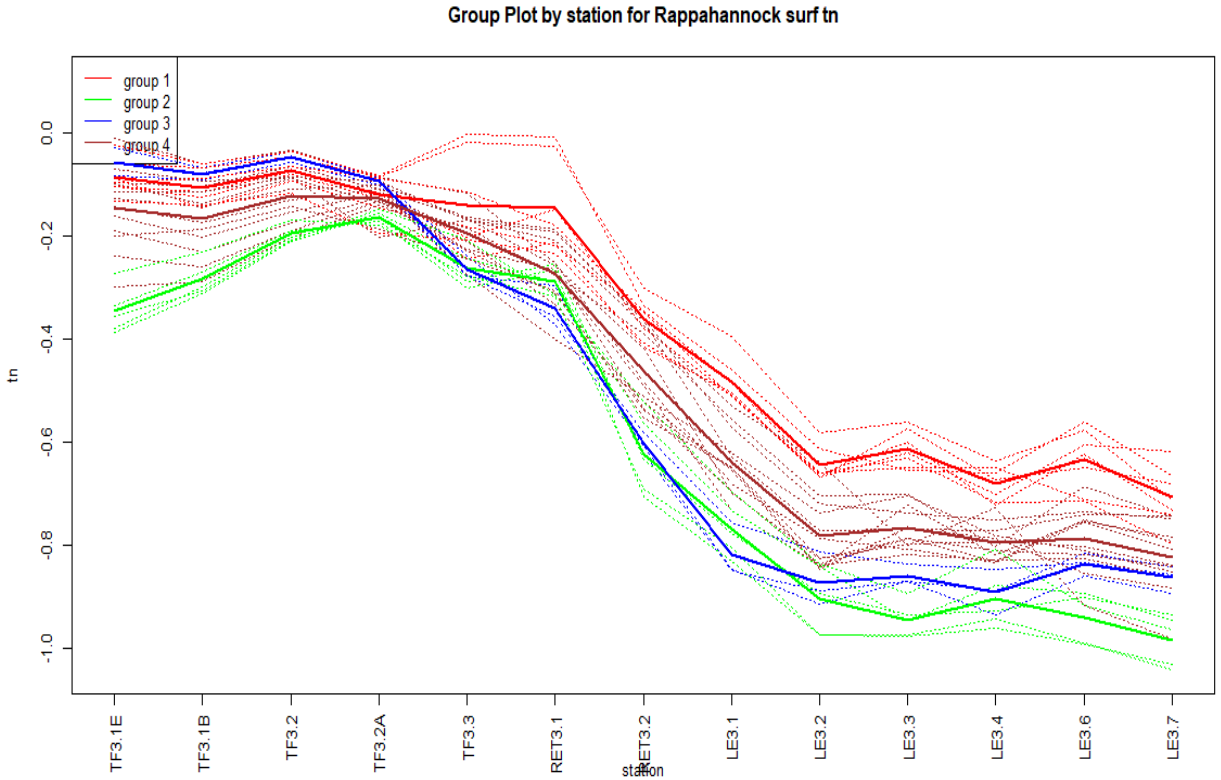




Together the purple and brown groups characterize the chlorophyll profile in the estuary for high flow years. The brown group, which only includes 1994-1995 has a longitudinal pattern that is distinct from the other high flow years in that chlorophyll is lower in the middle portion of the estuary. It is curious that 1996 which is also a high flow year is not part of the brown group. The extended drought years from 1998-2002 are characterized by high chlorophyll in the tidal fresh the longitudinal zenith of chlorophyll being positioned upstream of the location in other years. The blue and green groups together might be classified as 'normal' in that they represent a mixture of flow conditions and have profiles intermediate to high and low flow. The blue and green to differentiate in that the green group has lower chlorophyll in the tidal fresh and higher chlorophyll in the RET. The period represented by green, 2012-2017, is a period when chlorophyll was decreasing in most regions of the estuary except the RET (cluster 2.).

2. Comparing and Summarizing TN, TP, Chla, Secchi, and DO
Based on cluster of Longitudinal Profiles.

Figure 1.



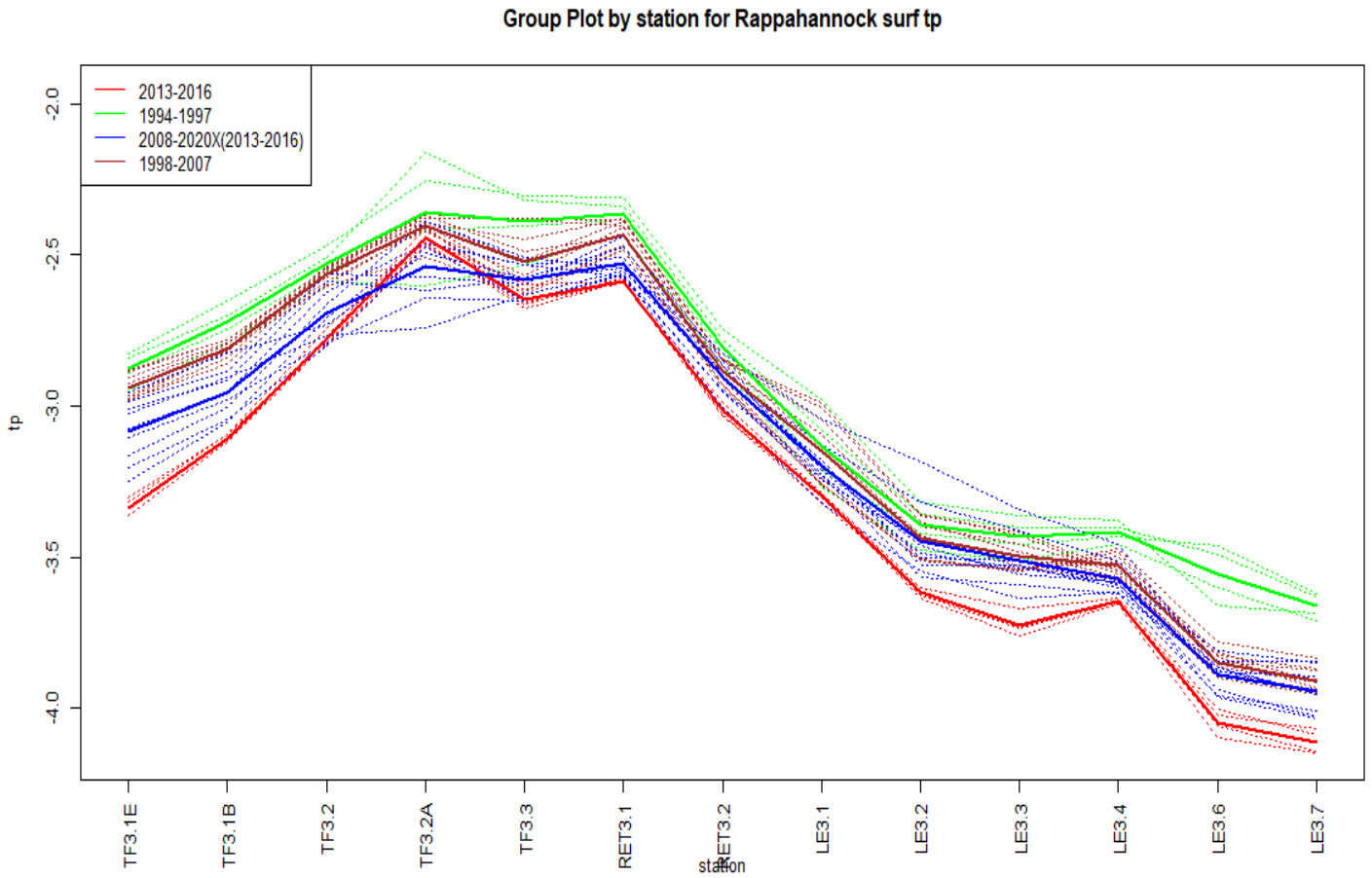
TN Groups:
Green: 2013,2014,2015,2016,2017 flow: 4.4.3.2.1
Blue: 1999, 2000,2001 flow: 1.2.1
Brown: 1995,1998,2002,2006,2007,2008,2009,2010,2011,2012,20018,2020 flow: 3.2.1.3.1.1.2.2.3.2.4.4
Red: 1994,1996,1997,2003,2004,2005,2019 flow: 3.4.2.4.4.3.3

The text above identifies the years in each of the colored groups in the figure. The series of digits in the range 1-4 following the group years gives the flow quartiles for each year where 4 is high flow and 1 is low flow.

The blue group is composed of the extreme drought years of 1999-2001. In these years, TN is high in the tidal fresh but attenuates rapidly moving down estuary. It is curious that the year 2002 is not among this group. In contrast, the red group is composed primarily of high flow years. This group also has high TN in the tidal fresh and the high TN extends further downstream and attenuates less quickly than in low flow years. The green group includes the sequential years 2013-2017. The green profiles show low TN in the tidal fresh and downstream attenuation that is comparable to the drought years in the blue group. This is a period

of decreasing flow; the flow quartiles are 4,4,3,2,1. The profiles of the brown group are intermediate to the blue and red and this group also contains a group of sequential years from 2006 to 20012 with 5 other years. There appears to be some factor that leads to general improvement in TN between the 2005-2012 time period and the 2013-2017 time period. Both groups of years include a range of flow conditions. While flow is clearly a factor in TN concentrations, the improvement between the time periods seems to be due to some other factor.

Figure 2.

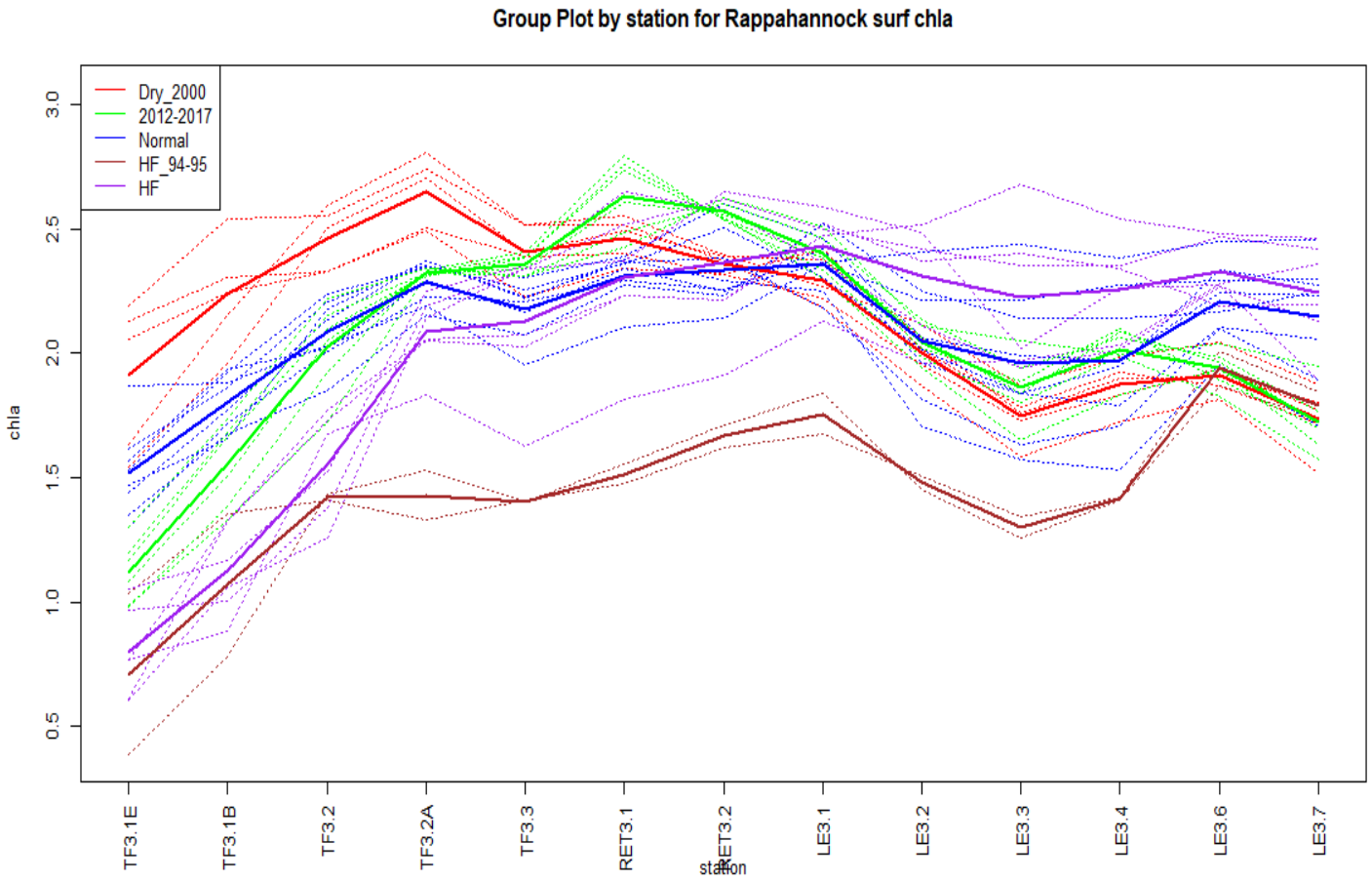


TP Groups:
Red: 2013,2014,2015,2016 flow: 4.4.3.2,
Blue: 2008,2009,2010,2011,2012___2017,2018,2019,2020 flow: 1.2.2.3.2.1.4.3.4
Brown: 1998,1999,2000,2001,2002,2003,2004,2005,2006,2007 flow: 2.1.2.1.1.4.4.3.3.1
Green: 1994,1995,1996,1997 flow: 3.3.4.2

Like for TN, the text above identifies the years in each color group followed by the flow quartiles.

The red group (2013-2016) stands out as a period with low TP for a range of flow conditions. As observed above, this time period coincides with a period of favorable TN. The green group has high TP throughout the estuary and is composed of high flow years early in the period of record. The brown group has lower TP than the green and is the decade from 1998 to 2007 which includes a wide range of flow conditions. The blue group flanks the red group in time. Here again we see a decrease in TP between the 2008-2012 time period and the 2013-2016 time period that does not seem to be explain by a change in the flow regime.

Figure 3.

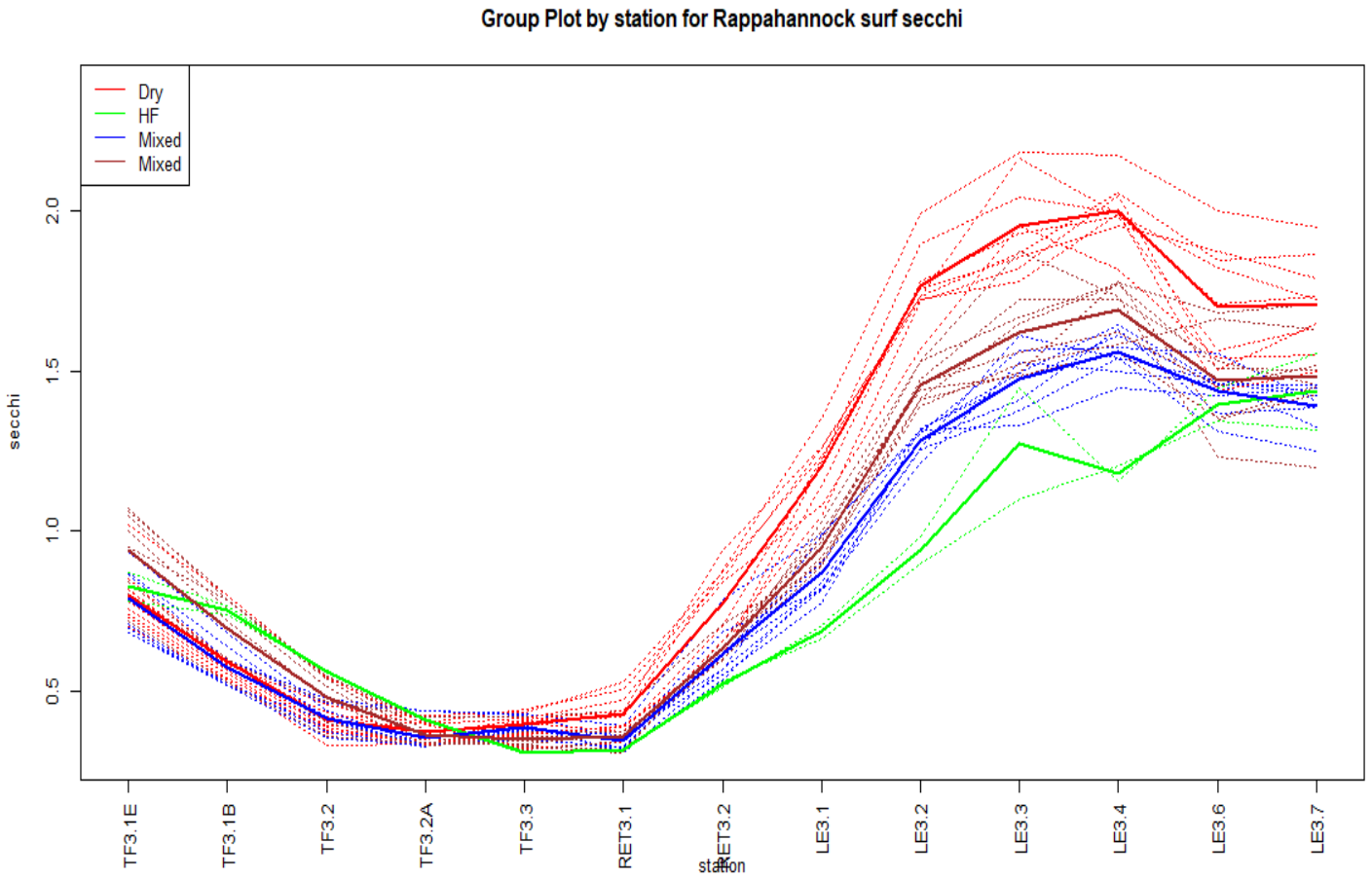


Chla Groups
Brown: 1994,1995 flow: 3.3
Red: 1998,1999,2000,2001,2002 flow: 2.1.2.1.1
Green:2012,2013,2014,2015,2016,2017 flow: 2.4.4.3.2.1
Blue:1997,2003,2006,2007,2008,2009,2010,2011 flow: 2.4.3.1.1.2.2.3
Purple:1996,2004,2005,2018,2019,2020 flow: 4.4.3.4.3.4

The chlorophyll A groups are ordered from lowest (brown) to highest (purple) in the lower estuary. The brown profiles, which show low chlorophyll estuary wide, are 1994 and 1995 and are the first two years of the period of record. These years are above average in flow but not high flow years. It is curious that the

year 1996 is not also in this group. It may be due both 1994 and 1995 achieving a period of below average flow in the spring of each year. The red group which has high chlorophyll in tidal fresh and relatively low chlorophyll in the lower estuary occurs in a low flow half-decade from 1998-2002. In these low flow years, the longitudinal zenith of chlorophyll is positioned upstream of the location in other years. The green profiles occur in the period 2012-2017 which coincides with the favorable periods of TN and TP cited earlier. The green profiles are characterized by the highest Chlorophyll for the period of record in the RET and intermediate Chlorophyll in the tidal fresh and lower estuary. The blue group is mostly composed of the half decade just preceding the green group. Blue is typically higher than green in tidal fresh and lower estuary and lower than green in the RET. Thus, the transition from period 2006-2011 (blue) to 2012 (green) is a period when chlorophyll was decreasing in most regions of the estuary except the RET. The purple profiles are all high flow years and have low chlorophyll in tidal fresh and high chlorophyll in the lower estuary.

Figure 4.

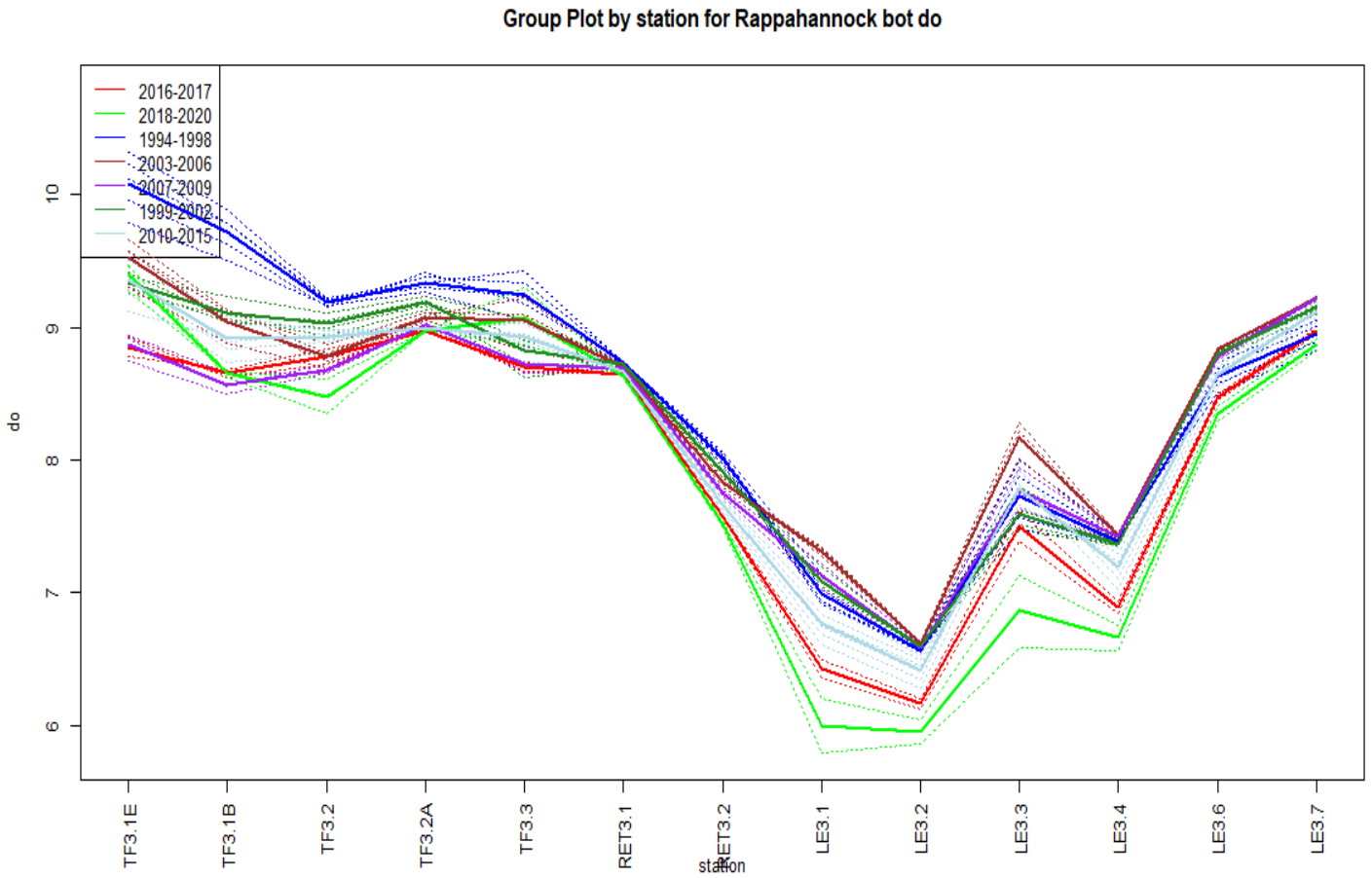


Secchi Groups:
Red:1994,1995,1999,2000,2001,2002,2008,2009,2017 flow:3.3.1.2.1.1.1.2.1
Brown:1998,2007,2010,2013,2014,2015,2016,2018 flow: 2.1.2.4.4.3.2.4
Blue:1996,1997,2003,2004,2005,2006,2011,2012 flow: 4.2.4.4.3.3.3.2
Green: 2019,2020 flow: 3.4

There is little differentiation of clarity in the tidal fresh. In the RET and lower estuary low flow years result in better clarity while high flow years have reduced clarity. It does not appear that the high RET chlorophyll levels for the years 2012-2017 observed above in figure 3 can be explained by improved clarity. Clarity

profiles for the 2012-2017 time period are shown figure 4 in brown or blue and tend toward the lower end of the range in the RET. The brown group is largely composed of years in the interval 2013-2018 while the blue group contains the years 2003-2006 which is a wet period.

Figure 5.



DO Groups:

Brown: 2003, 2004, 2005, 2006 flow: 4.4.3.3
Purple: 2007,2008,2009 flow: 1.1.2
Blue: 1994, 1995, 1996, 1997, 1998 flow: 3.3.4.2.2
DarkGreen: 1999, 2000, 2001, 2002 flow: 1.2.1.1
LightBlue: 2010, 2011, 2012, 2013, 2014, 2015 flow: 2.3.2.4.4.3

Red: 2016,2017 flow: 2.1
Green: 2018, 2019, 2020 flow: 4.3.4

The estuary longitudinal profiles of bottom DO paint a picture of consistent degradation over time. Bottom DO declines are most extreme in the upper tidal fresh and the lower estuary. Remarkably, bottom DO at station RET3.1 changes little over time. In the lower estuary, there is some evidence of improved bottom DO in the high flow years of 2003-2006 (brown), it seems that some factor other than flow is the principal forcing function over time.

The brown group is a high flow group with better DO in the lower estuary while the green group is a high flow group with poor DO in the lower estuary. The red group is low flow, the green group is high flow and DO is poor in the lower estuary for both. This recent period of poor DO in the lower estuary does seem to coincide with poor water clarity and high chlorophyll. Chlorophyll was also high in 2004-2005 and secchi was low in 2004-2005. It seems that something other than Flow, TN, TP, Chlorophyll, and secchi is required to explain the difference between DO in 2004-2005 and 2018-2020.

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