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## **The Effects of Chlorophyll and Water Temperature on Harmful Algal Bloom Species off the Southern Coast of California**

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### **Abstract**

*Harmful algal blooms are dense aggregates of algae that negatively impact local economies, marine or freshwater ecosystems, and/or public health. Some HABs produce toxins that cause various illnesses that harm both humans and marine wildlife such as Diarrheic Shellfish Poisoning, Paralytic Shellfish Poisoning and Amnesic Shellfish Poisoning. While it is known that HABs persist when nutrients and water temperature combine to create the optimal environmental conditions for their propagation, there are many questions surrounding exactly what these conditions are and how they are reached. Therefore, the focus of this project as part of the NASA Student Airborne Research Program was to look at the effects of chlorophyll and water temperature on 6 different HAB species along the California Coast from San Diego to Monterey Bay. In this study, it is shown using time series and cluster analysis indicate both positive and negative correlations of water temperature with respect to HAB species, but only positive correlations between chlorophyll and HAB species. Correlations of chlorophyll indicate satellite imagery can be used to map HABs initially but not predict them. Results are consistent with previous attempts to model distribution of HAB species (e.g. Pseudo-Nitzschia) in California Coastal waters, as they indicate that a strong regional component is involved in doing so. This demonstrates the need for a more integrative approach to HAB forecasting along the California Coast that takes into account not just temperature and chlorophyll measurements, but also differences in water chemistry and other environmental conditions between sampling stations that result from differences in coastal topography, river discharge, coastal bathymetry, and meteorological parameters.*

*This work has been supported by the NASA Student Airborne Research Program (SARP) and the National Suborbital Education and Research Center of University of North Dakota*

### **Introduction**

The purpose of this project is to look at possible effects that can either cause or indicate the presence of Harmful Algal Blooms (HABs) along the coast of California. There are six major HAB species along the coast: Alexandrium, Akashiwo Sanguinea, Dinophysis, Lingulodinium Polyedrum, Prorocentrum and the most prominent Pseudo-Nitzschia; this project examined the effects of chlorophyll and sea surface temperature on these different HAB species off the Southern Coast of California from Monterey Bay to San Diego. Using in-situ data collected from eight different locations along the coast by the Southern California Ocean Observing System (SCOOS)

over a six year time span allows for an in-depth look into the relationship between sea surface temperature, chlorophyll, and HABs

### **Review of Literature**

HABS have a major impact on marine ecosystems, public health, and the local economy. Species like Pseudo-Nitzschia excrete a potent neurotoxin called Domoic Acid (DA) that has been known to cause severe illness and even death in marine wildlife and humans. Other HAB species such as Alexandrium and Dinophysis produce toxins that cause Paralytic Shellfish Poisoning (PSP) and Diarrhetic Shellfish Poisoning (DSP) respectively. HABs such as Akashiwo Sanguinea, Lingulodinium, and Prorocentrum cause what are known as “red tides” this is where the population of these HAB species becomes so dense, they discolor the water a reddish-brown color and deplete the oxygen in the water causing harm to the marine life present. Since HABs have such a major effect in the ecosystem and public health, oceanographers and other experts are conducting extensive research to understand the cause of HABs and attempt to predict their blooms.

Recently it has been generally agreed upon that HABs are increasing in occurrence, and intensity since the early 2000s. The cause is still unknown, but research is being conducted to look at recent changes in climate and the variability the climate has on HABs. Some changes in the conditions such as sea surface temperature, global atmospheric concentrations of carbon dioxide and other gases have increased, and human caused pollution could have an impact on the HAB species. (Moore) More extensive research needs to be conducted before any conclusions can be drawn.

The other concern for researchers, is once knowing that HABs are present in a specific area, how far do the HABs spread? There is no accepted way to map HABs to get a large-scale view of the bloom along the coast. Recent discussion about using satellite imagery of chlorophyll can be used to map HABs along the coast (Kudela). The only concern is that sometimes when

chlorophyll is present, HABs are not. There needs to be further research in this area to see how the presence of chlorophyll could indicate HABs and how satellites can be used.

The most extensive research has been conducted on the HAB species *Pseudo-Nitzschia* off the coast of California in the Santa Barbara Channel. Extensive in-situ data was collected and a 15 year time series was used to analyze the trends in DA concentration indicating the presence of *Pseudo-Nitzschia*. A model was designed to map *Pseudo-Nitzschia* along the coast of California from Monterey Bay to San Diego (Anderson). Results were inconclusive and showed regional variability needed to be taken into account in order to model HABs

## **Methodology**

HAB species concentration, chlorophyll content, and sea surface temperature was collected from the SCOOS database from 2008 to 2014. Time series analysis using MATLAB allowed for a first order glance to see if there are any correlations between chlorophyll, sea surface temperature, and HAB species concentration. Once graphed, time series indicated possible correlations with chlorophyll, sea surface temperature and the HAB species. Kendall's Tau correlations were applied to the data to show how strong the data actually correlates.

Kendall's Tau ranks the highest data point value a 1 and ranks the rest of the data points in order to the smallest value. The other dataset that is compared, also gets ranked from 1 being the largest value to the smallest value in the dataset. Once this is done, each adjusted dataset is matched. If more data points match based on their rank, the stronger the correlation value becomes.

Kendall's Tau showed overall, how strongly the data correlates, now Cluster Analysis can be applied to the data to show how similar the data is over the Southern Coast of California. Cluster analysis breaks down the data based on region and illustrates how similar the data is in each regions and then compares the different regions. The regions for this project, are Monterey Bay, Santa Barbara Channel, and the southern data points by San Diego.

### Data Analysis/Results

Time series analysis shows there are first order correlations between HAB species and chlorophyll and sea surface temperature. Figure 1 shows that there are three distinguished peaks in the HAB time series that are circled in the top graph and there are three corresponding points that are circled in the sea surface temperature and chlorophyll graph. This time series indicates that there could be correlations between chlorophyll and sea surface temperature to the six HAB species. A more in depth analysis will need to be done using Kendall's Tau correlations.

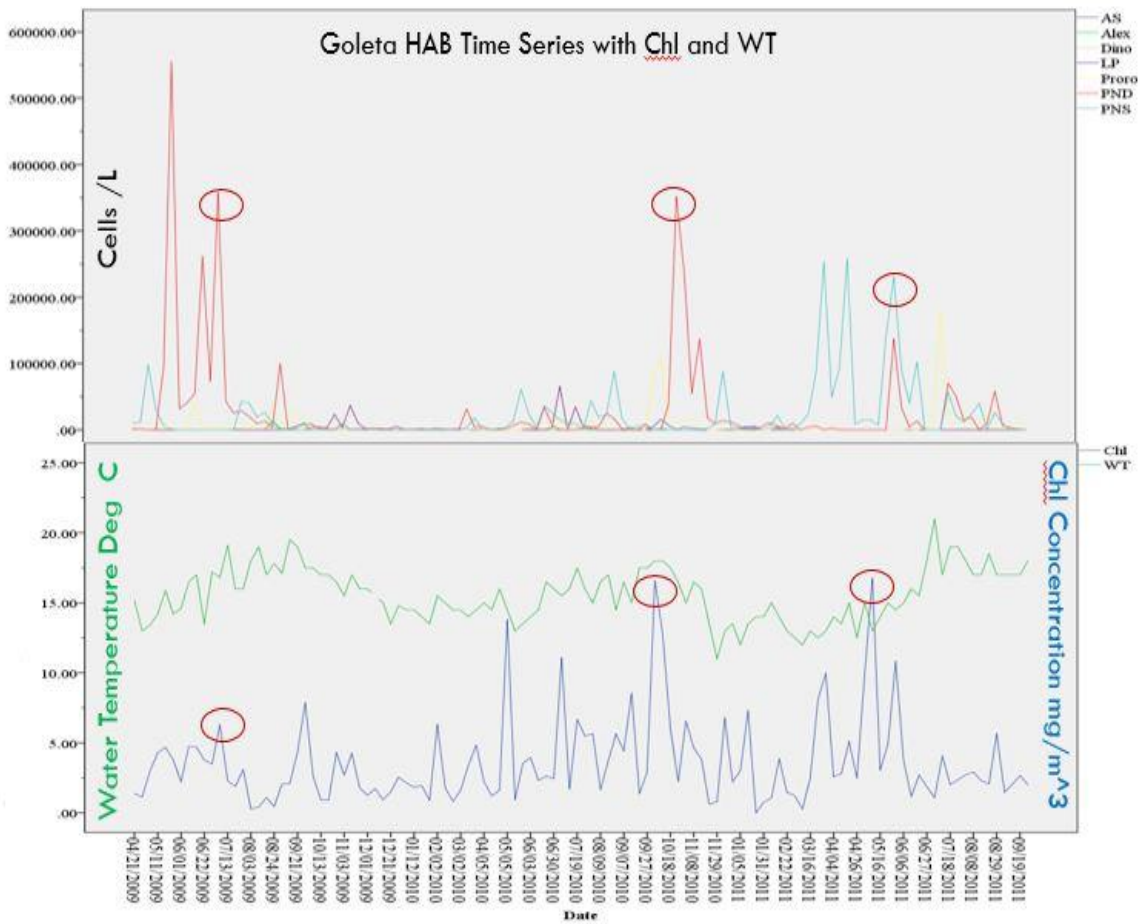


Figure 1: Time Series of Six HAB species and Chlorophyll and Sea Surface Temperature

Kendall’s Tau correlations show that there is a strong positive correlation between chlorophyll and the different HAB species while there is both strong positive and negative correlations between sea surface temperature and the HAB species. This indicates that satellite imagery of chlorophyll can be used for an initial glance to map the HAB species and understand their trajectories in the area.

Table 1 describes the strength and how much the data correlates. The highlighted values in green indicate a strong positive correlation, the highlighted colors in yellow show a positive correlation, orange shows a negative correlation in the data, and red shows a strong negative correlation in the data. It is shown that there is a majority of green highlighted values in the chlorophyll column. This indicates satellite imagery of chlorophyll could be used for a first order map of HABs.

Table 1: Kendall’s Tau Correlations: Green indicates strong positive correlations, yellow indicates positive correlations, orange indicates negative correlations, and red indicates strong negative correlations

Akashiwo Sanguinea	Alexandrium		Dinophysis		Lingulodinium		Prorocentrum		Pseudo-Nitzschia Delicatissima		Pseudo-Nitzschia Seriata			
	SST	Chl	SST	Chl	SST	Chl	SST	Chl	SST	Chl	SST	Chl		
Cal Poly	0.2	0.174	0.201	0.093	0.236	0.157	0.135	0.12	0.243	0.248	0.176	0.2	0.133	0.223
Goleta	0.022	0.108	0.242	0.081	0.104	0.089	-0.037	-0.012	0.516	0.147	0.077	0.025	-0.187	0.051
Monterey	0.07	0.16	0.073	0.114	0.211	0.089	0.123	0.055	0.2455	0.05	0.133	0.508	0.078	0.553
Newport	-0.182	0.116	-0.063	0.108	-0.048	0.068	0.103	0.114	0.019	0.284	-0.012	0.136	-0.198	0.263
Santa Cruz	NaN	NaN	0.59	0.125	0.092	0.228	NaN	NaN	NaN	NaN	NaN	NaN	-0.045	0.194
Santa Monica	0.077	0.083	-0.026	0.078	-0.152	0.248	-0.03	0.215	0.01	0.229	-0.008	0.077	0.108	-0.021
Scripps	-0.22	0.21	-0.182	0.164	-0.12	0.341	-0.069	0.362	0.015	0.184	-0.078	0.184	-0.243	0.248
Stearns	0.065	0.098	0.083	0.132	0.17	0.23	0.15	0.083	0.33	0.259	-0.052	0.024	-0.064	0.028

The rest of the table illustrates that sea surface temperature both positively and negatively correlates with the different HAB species. This illustrates that there is variability in the HAB species and the sea surface temperature and further research needs to be done to look at how much sea surface temperature affects HABs.

After Kendall's Tau correlations Cluster Analysis is applied to the data and outputs a dendrogram that describes how similar the data in each region is compared to other regions. This was done over each year from 2008 to 2014 for each dataset to compare the different HAB species to chlorophyll and sea surface temperature. Figure 2 is the dendrogram for the HAB species along the coast of CA for the year 2011 and Figure 3 shows the dendrogram for the sea surface temperature and chlorophyll for 2011.

Dendrograms can be read by looking at the vertical bars and seeing how close they are to the left-hand side of the graph and how they connect to the horizontal bars. The closer the vertical bar are to the left-hand side the more similar the regions are, and if it is connected to horizontal bars, there is some similarity in the regions.

Figure 2 shows there is little similarity in between the regions, only showing small similarity between Goleta and Santa Monica piers which is circled in Figure 3. Even though Goleta and Santa Monica are on opposite ends of the Santa Barbara Channel, they show a little similarity, but everywhere else is not. This shows that there is regional variability in the HAB species during the 2011 year. The rest of the vertical lines are not connected and are closer to the right hand side of the dendrogram which indicates there is little regional similarity between Newport, Stearns, Cal Poly and Scripps. Overall, this lack of similarity between the regions shows HAB species vary along the California coast



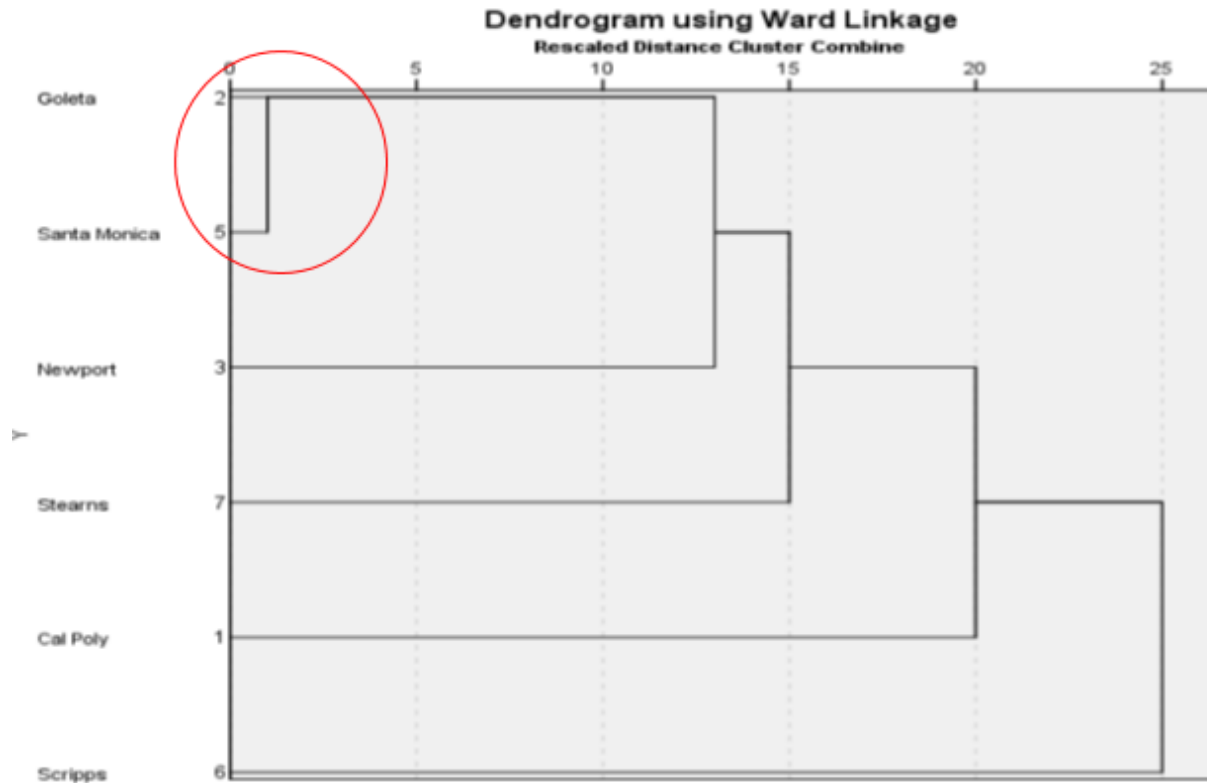


Figure 2: Non-similarity between the HAB species over the Southern Coast of California during 2011

Figure 3 shows there is similarity between Goleta and Stearns within the Santa Barbara Channel while there is similarity between Santa Monica, Newport and Scripps which is below the Santa Barbara Channel. Now comparing Santa Barbara to the lower three locations, they are not similar at all, and this is illustrated by the vertical bar that is connected the two regions together. If that bar was closer, for example in the 10 – 15 range, the regions would be similar. This shows, even though some of the regions have their own local similarities, compared to other regions, they demonstrate variability.

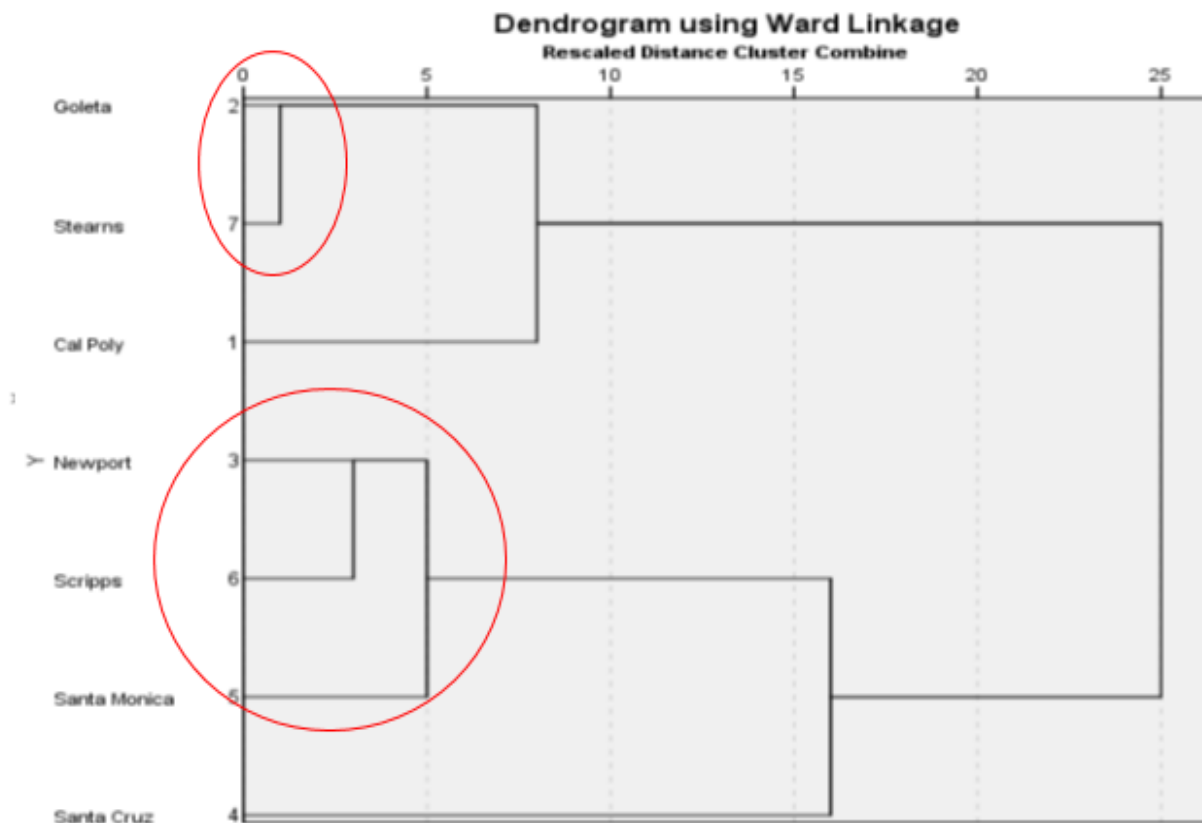


Figure 3: Similarity in sea surface temperature and chlorophyll by region over the Southern Coast of California during 2011

Figures 2 and 3 illustrate that there is regional variability between the HAB species along the coast between Monterey Bay and San Diego. Moving forward to 2012, the results show there is a difference between 2011 and 2012 which is illustrated in Figures 4 and 5.

Figure 4 shows there is some similarity along the coast of California between the different HAB species. The similarities occur between Santa Monica, Scripps, and Cal Poly, while there is even a little bit of similarity with Monterey. This shows that compared to 2011 the HAB species can change drastically, since there is more regional similarity between the HAB species in 2012.

Figure 4: Similarities in HAB species off the Southern Coast of California during 2012

Figure 5 shows there is very little similarity between sea surface temperature and chlorophyll content during the 2012 year. This varies greatly compared to 2011. This change indicates there is variability between the regions over the years.

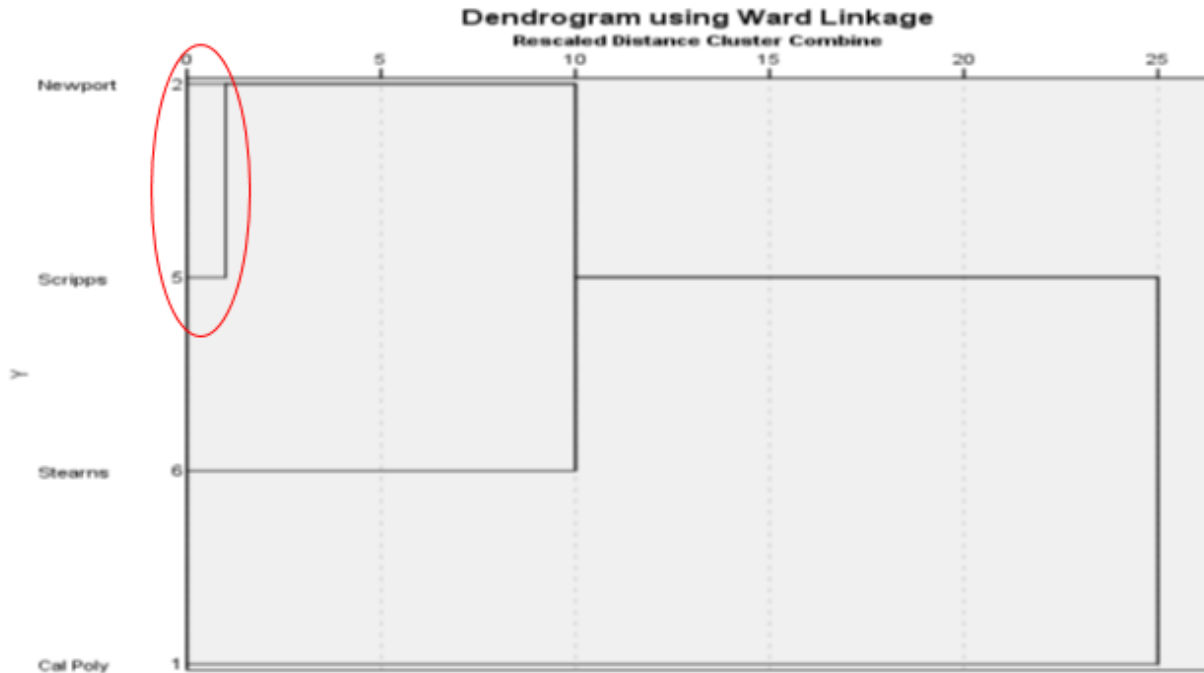


Figure 5: Non-similarities in sea surface temperature and chlorophyll during 2012

The rest of the dendrograms can be found in Appendix B. These results coincide with Clarissa Anderson's model (Appendix A) which attempt to model HAB species along the Southern Coast of California. Her results indicate a model that maps the Southern Coast of California in its entirety is too complex and will not work. There are too many variables that need to be taken into account and there is too much regional variability along the coast. More than just chlorophyll and sea surface temperature need to be taken into account even though chlorophyll has a positive correlation. Anderson suggests a breakdown of regions along the Southern Coast of California from Monterey to Point of Conception, Santa Barbara Channel, Santa Monica Basin, and Orange County/ San Diego region. It is suggested to develop models that are localized for each region that takes into account localized conditions and develop a model to map HAB species.

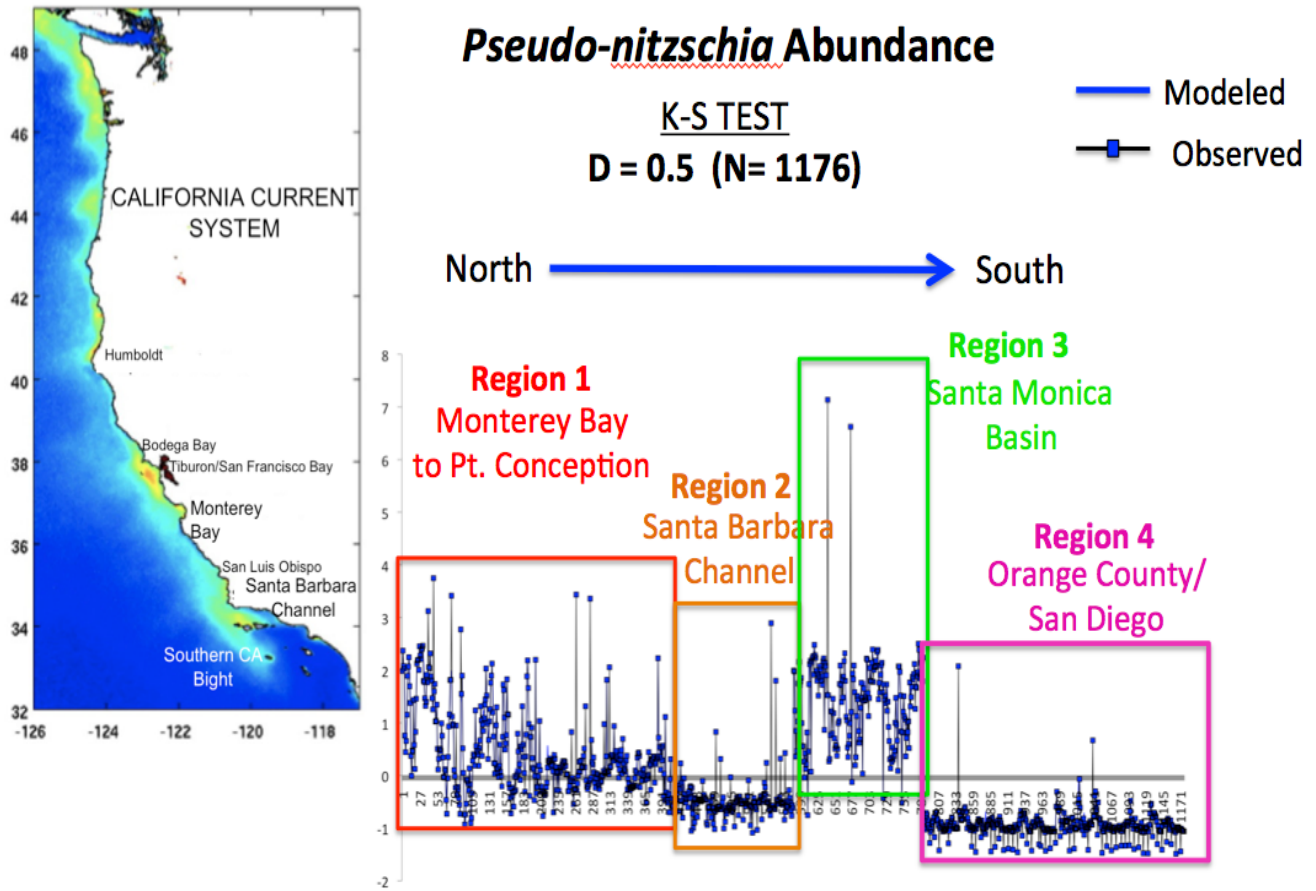
## **Conclusion**

In order to understand Harmful Algal Bloom species, more extensive research needs to be conducted. Very little is still known about these environmental threats. This project demonstrates that satellite imagery of chlorophyll can be used as a first order glance to map HAB species and to gain an initial understanding of the surface area covered by HABs. Also, there needs to be a more in depth look before HABs can be forecasted using a model. Sea surface temperature and chlorophyll are not enough to determine how HABs form even when chlorophyll indicates HABs a majority of the time. Water chemistry, localized environmental conditions, coastal topography, possible river discharge, coastal bathymetry, and meteorological parameters need to be taken into account. In order to model HABs along the coast of California, localized conditions need to be considered and models should be developed regionally instead of a one-size-fits all model for the entire coast of California. Further research can be conducted that looks into more localized conditions in a specific region to understand and forecast HABs.

## Appendix

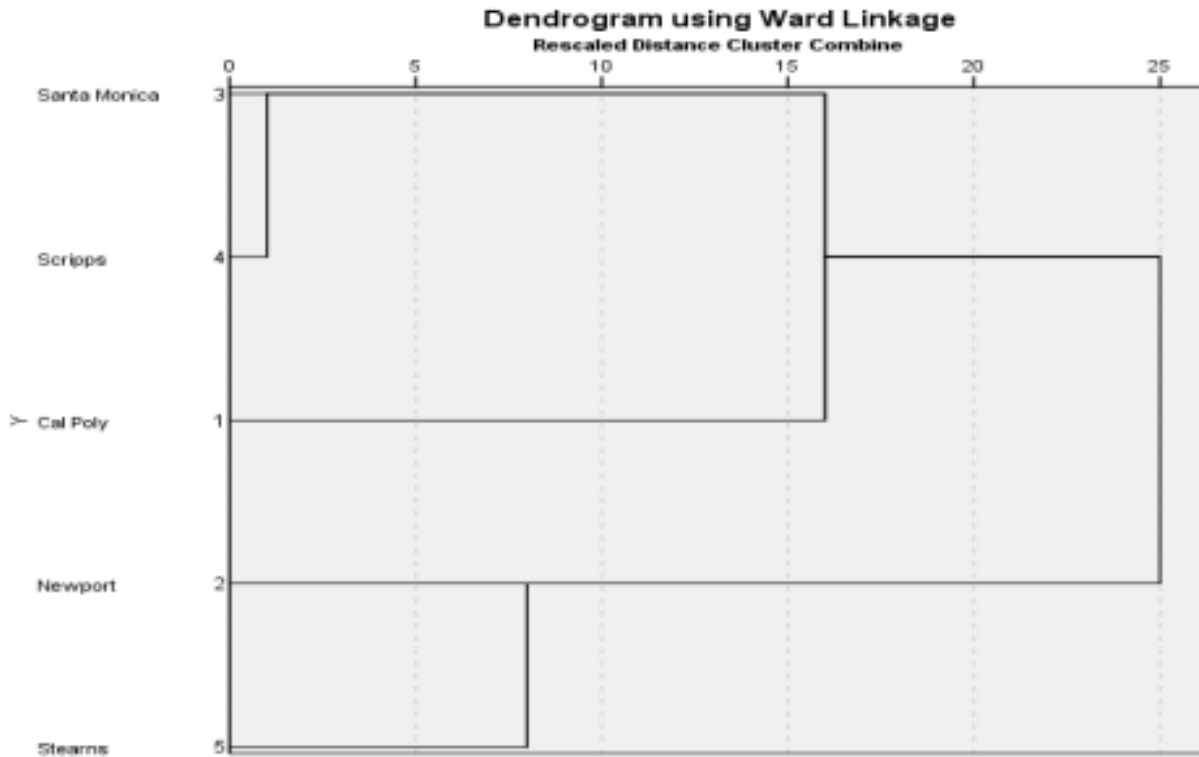
### Appendix A: Anderson Model

Regional Variation in Model Range from N to S California...  
*suggests that we need regionally varying thresholds*

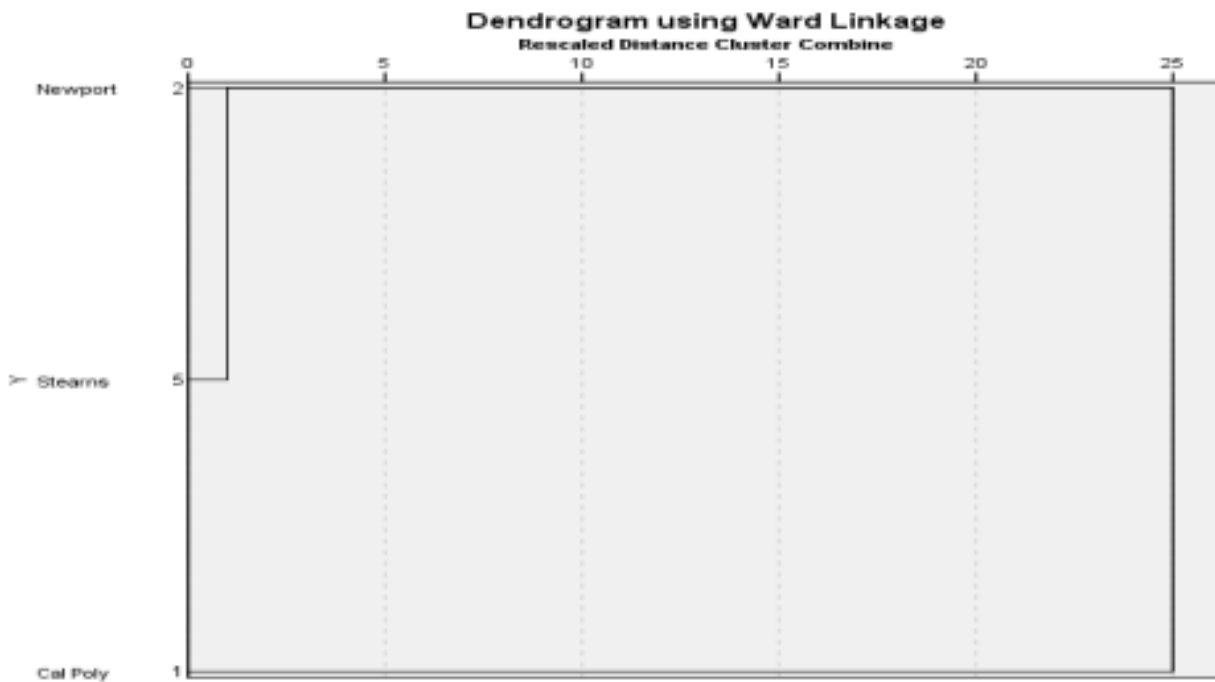


(Anderson)

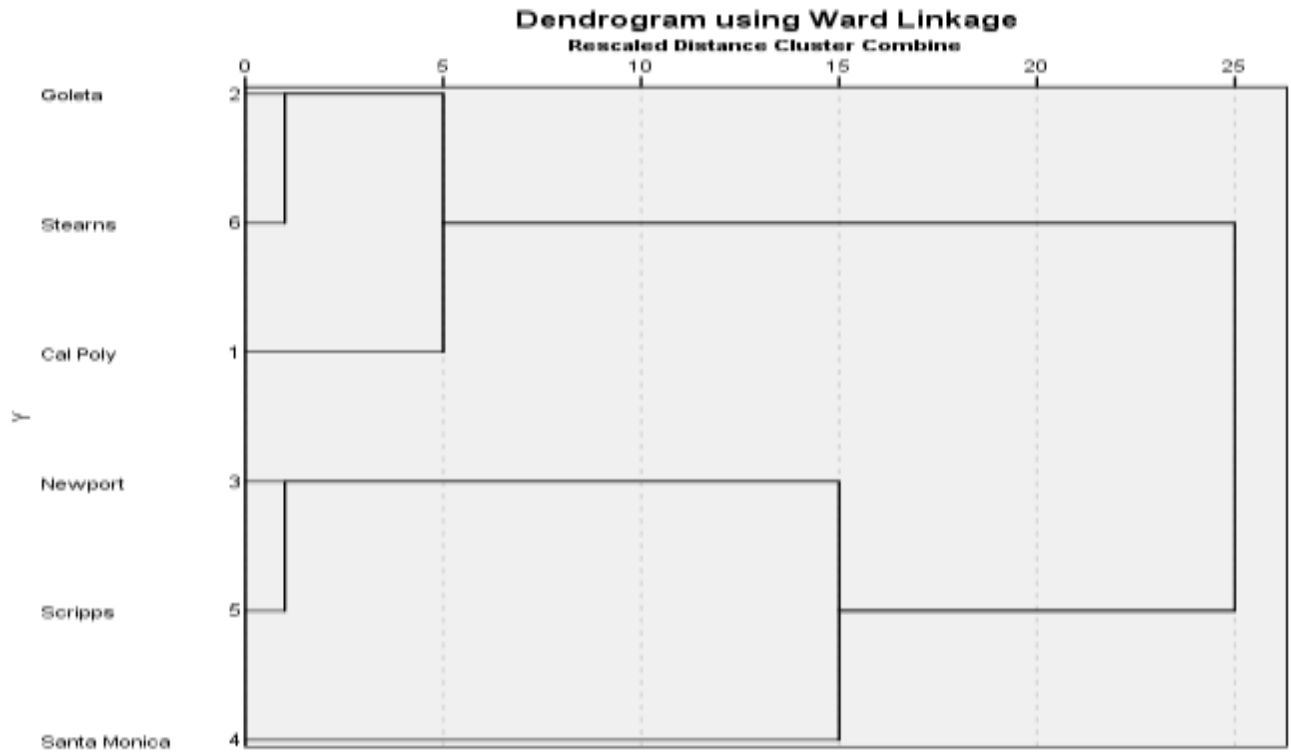
**Appendix B: Dendrograms from 2008 to 2014**  
2008 HAB Species



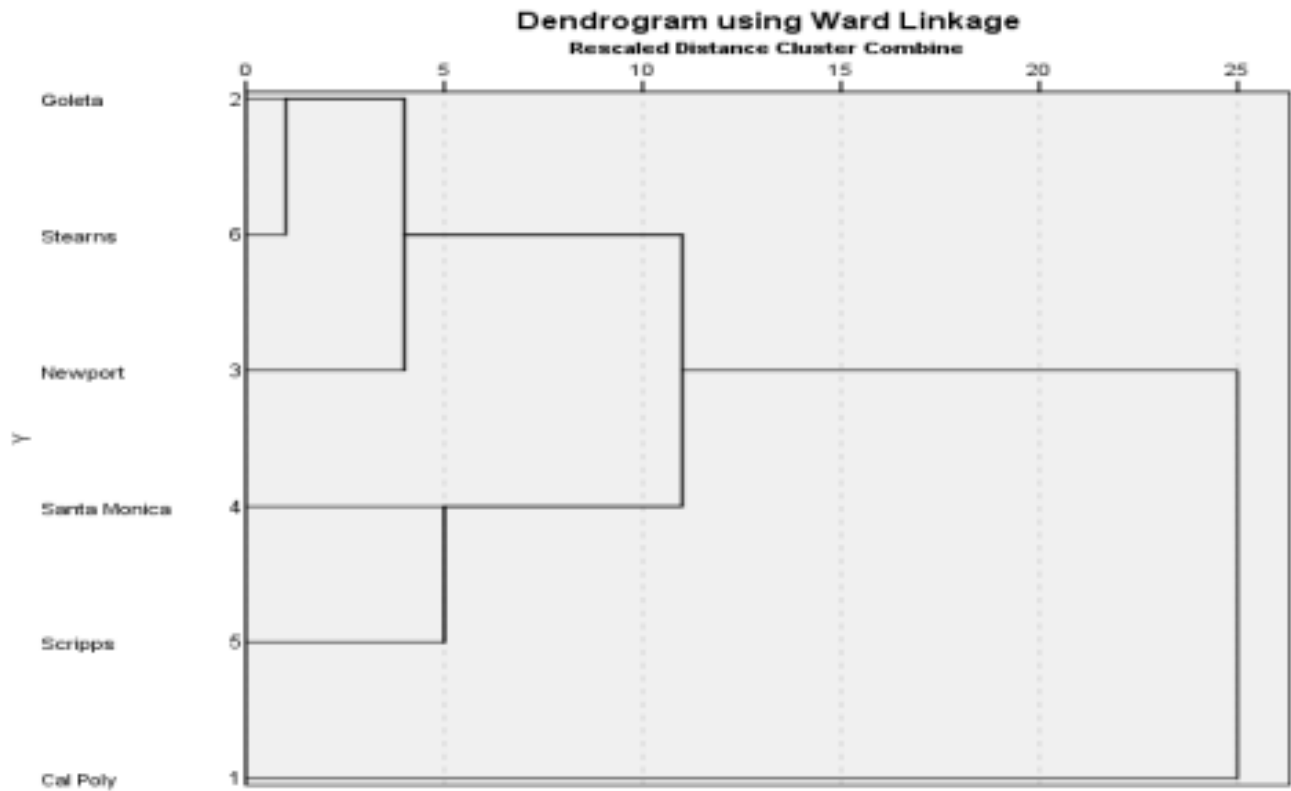
2008 Sea Surface Temperature and Chlorophyll



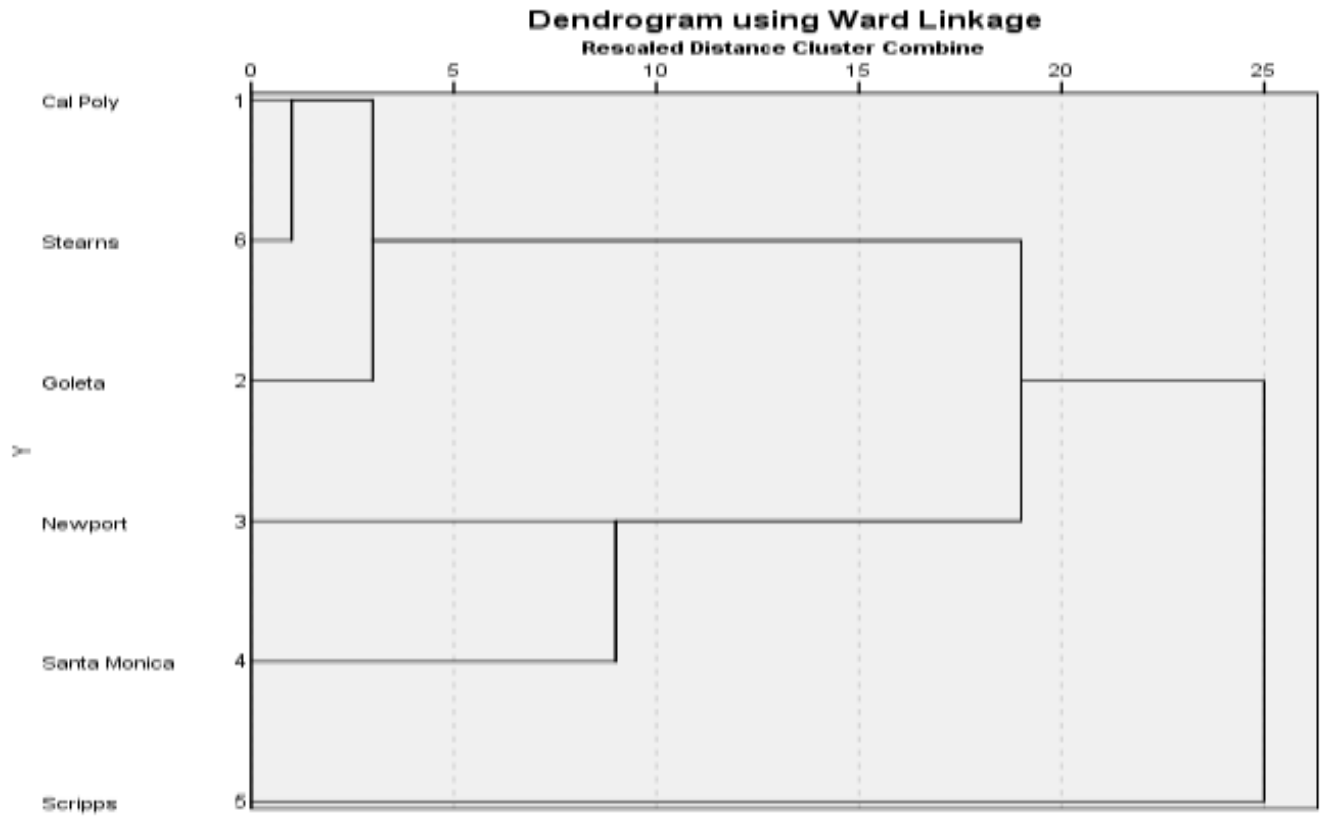
### 2009 HAB Species



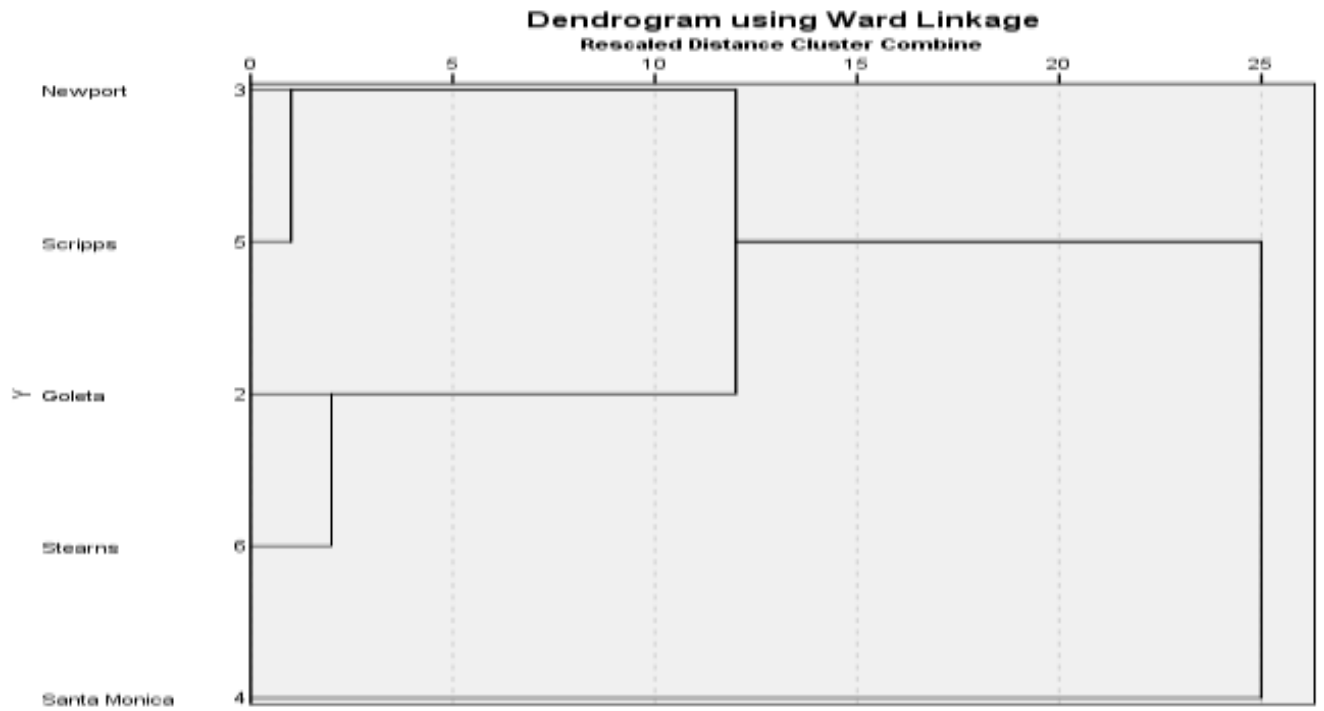
### 2009 Sea Surface Temperature and Chlorophyll



2010 HAB Species

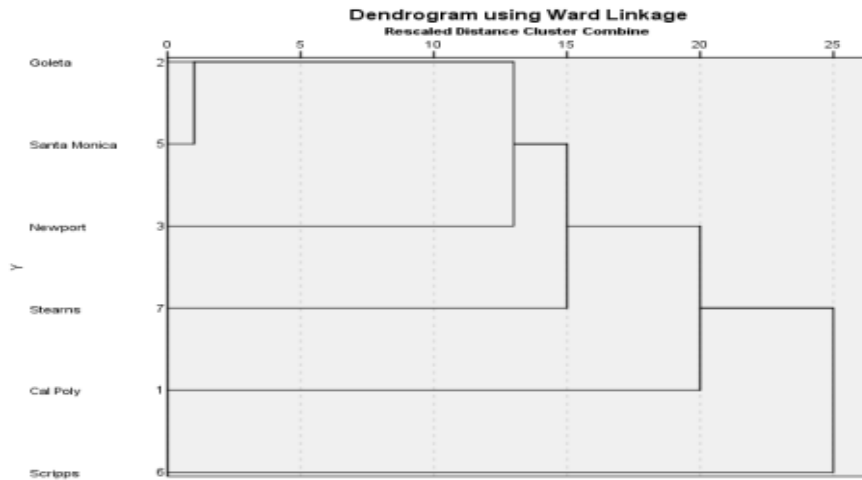


2010 Sea Surface Temperature and Chlorophyll

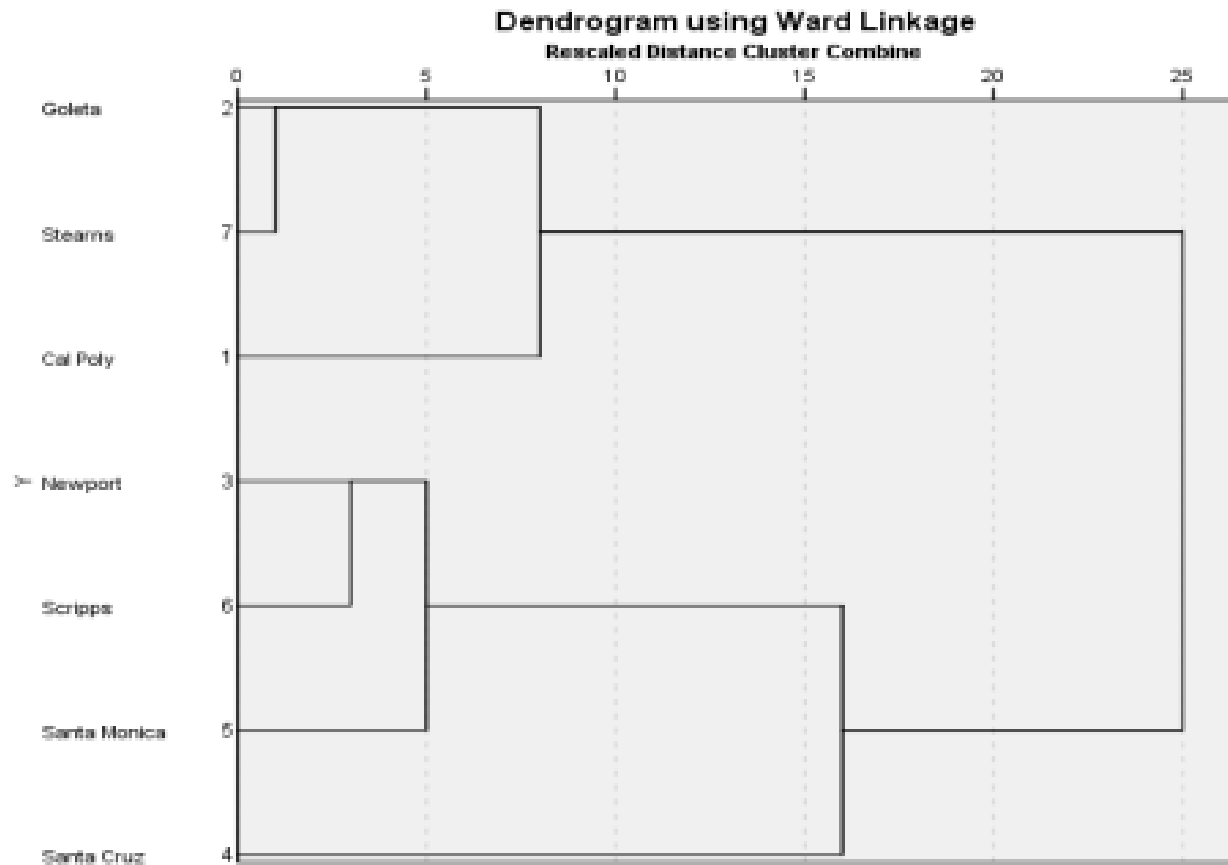




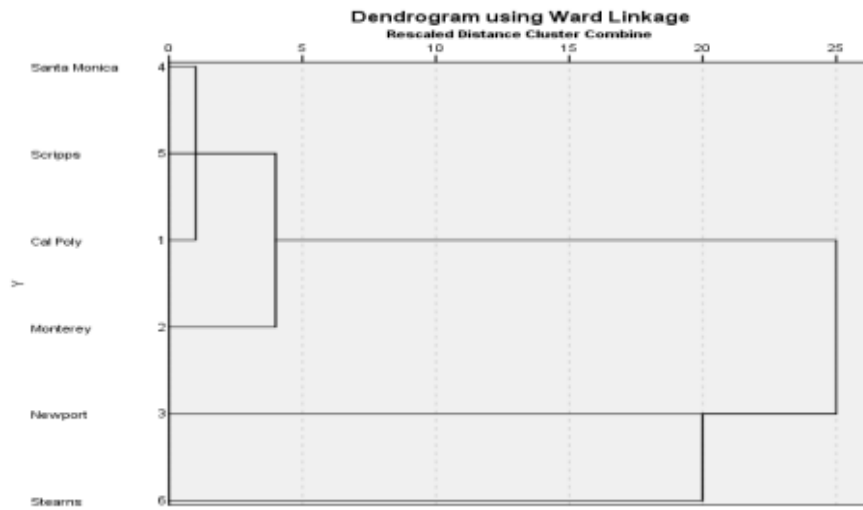
### 2011 HAB Species



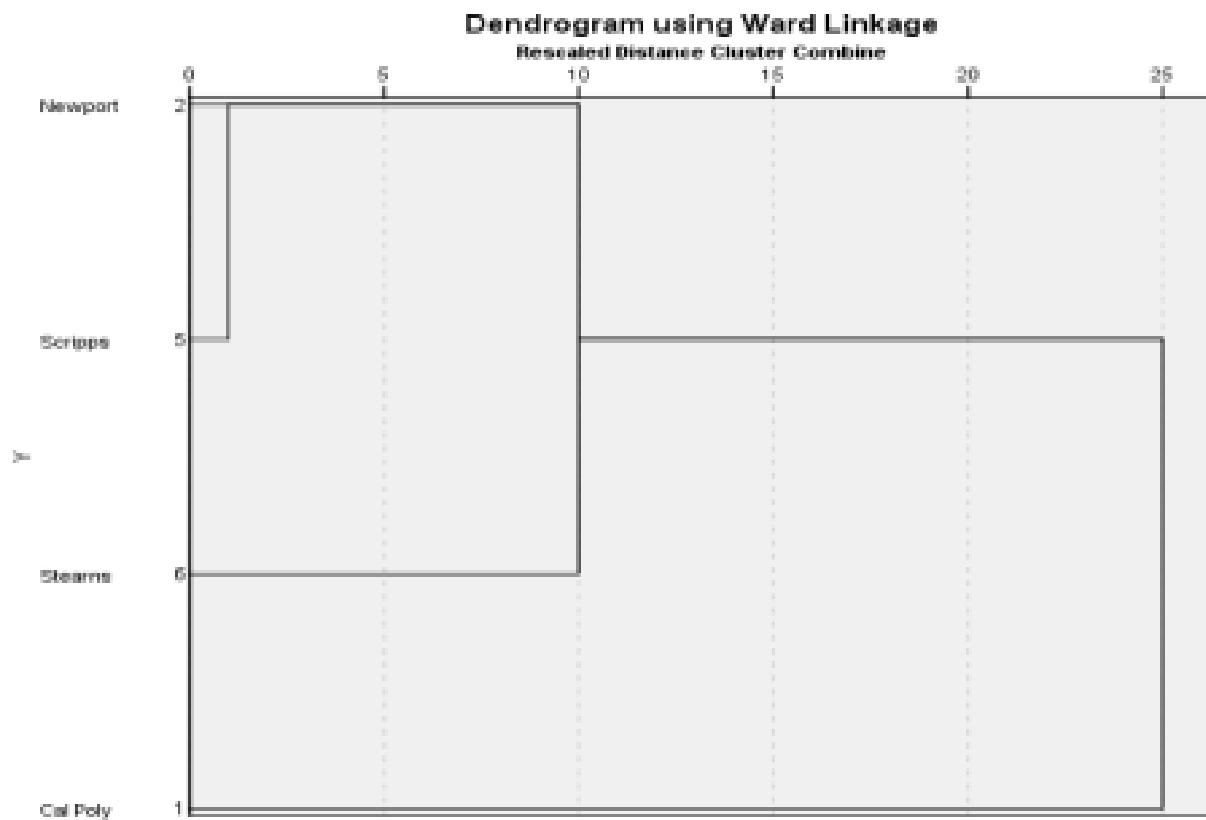
### 2011 Sea Surface Temperature and Chlorophyll



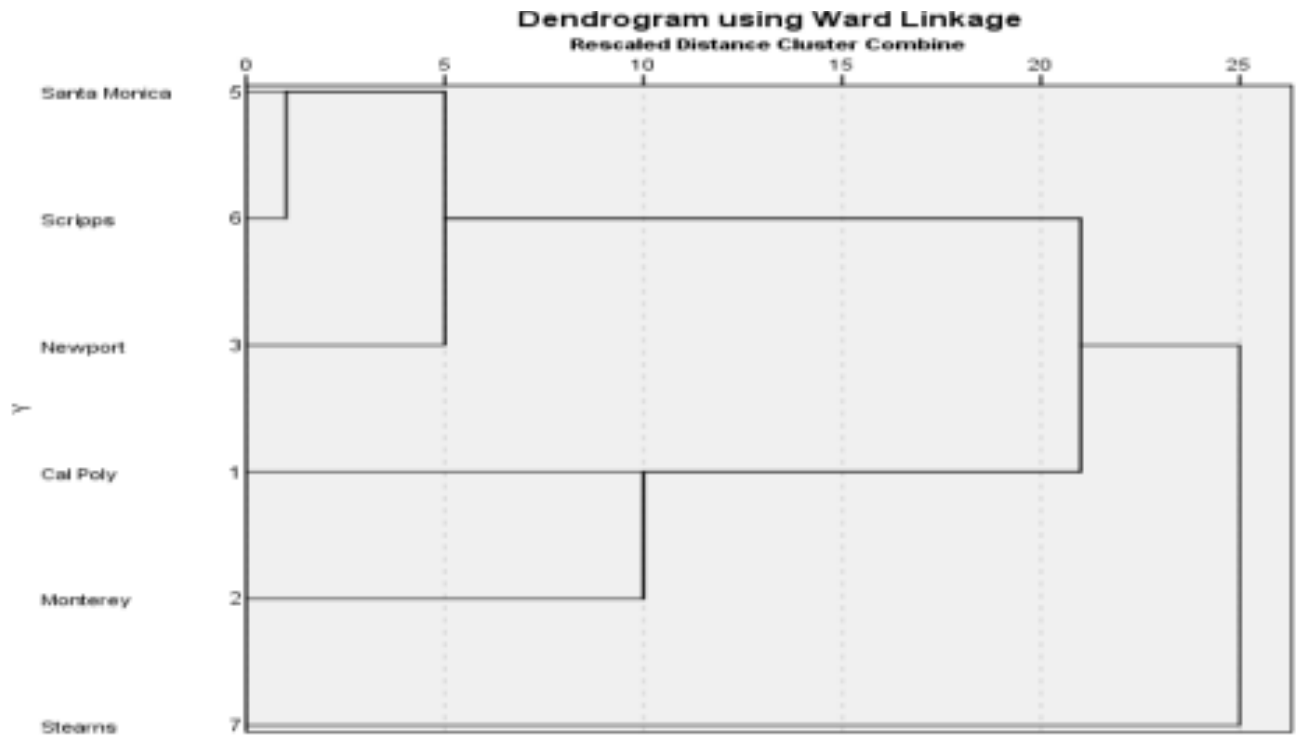
## 2012HAB Species



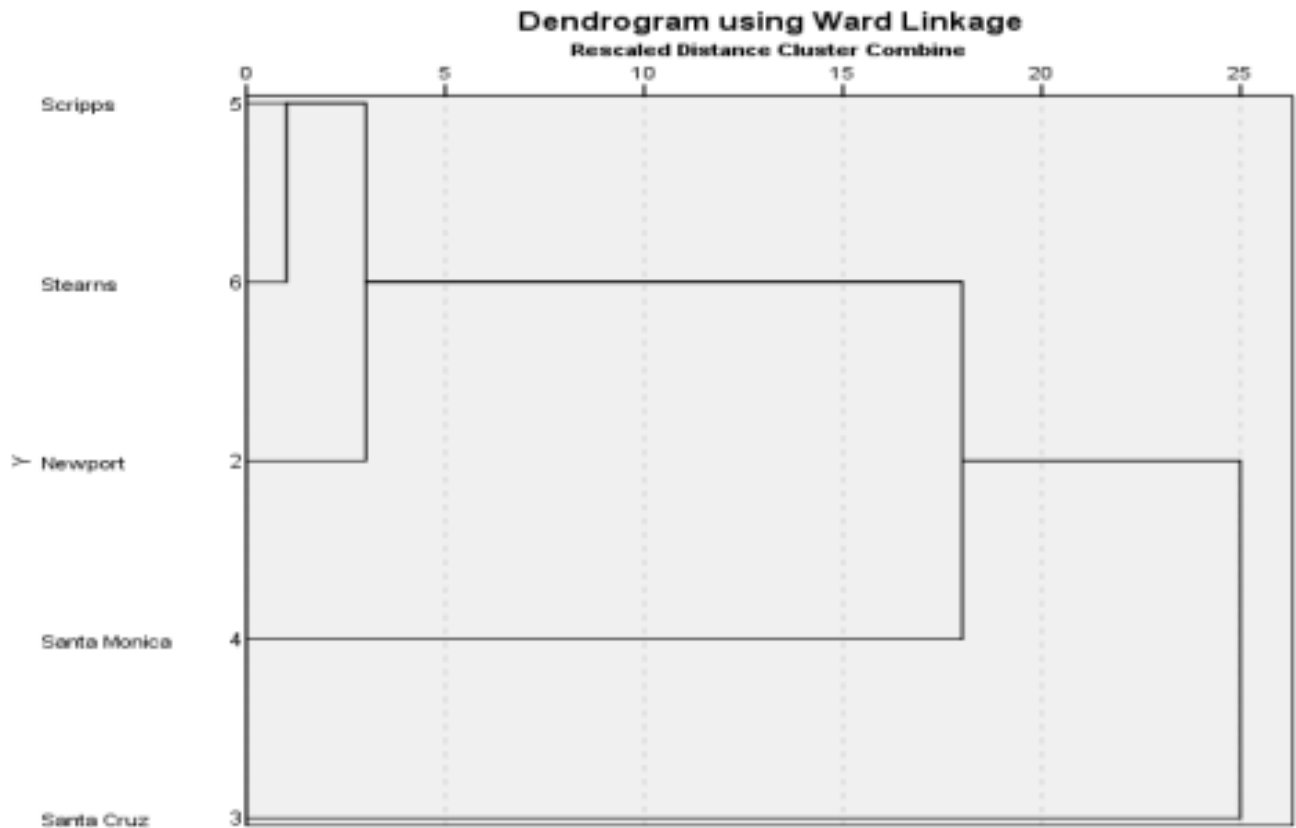
## 2012 Sea Surface Temperature and Chlorophyll



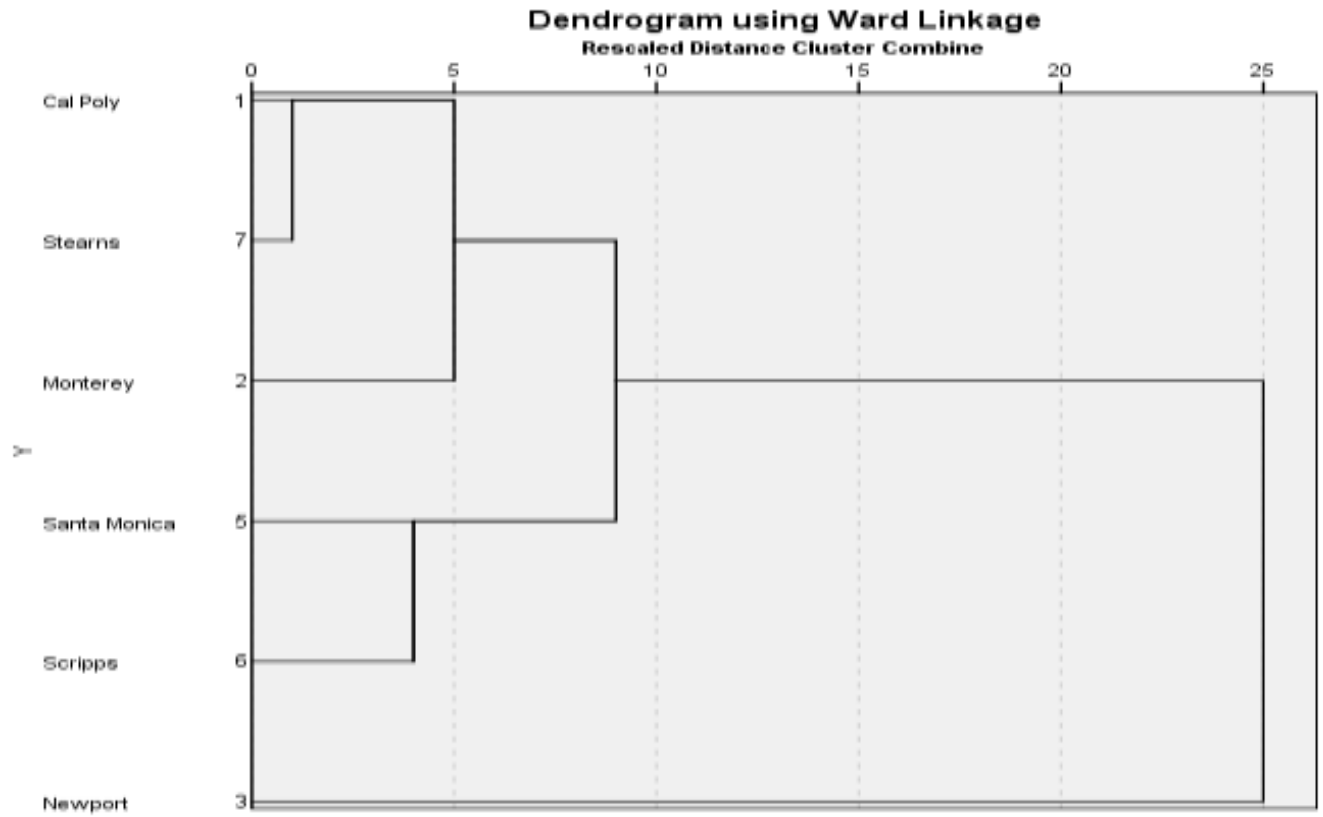
### 2013 HAB Species



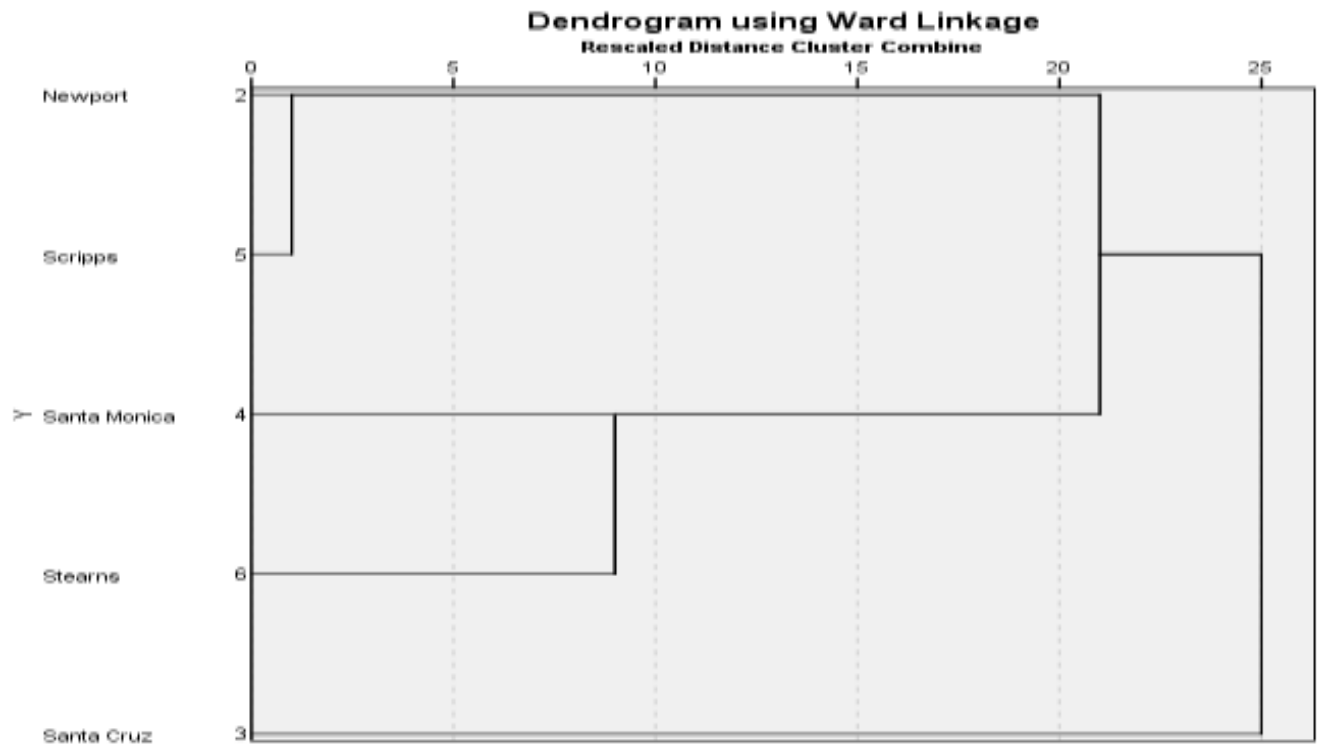
### 2013 Sea Surface Temperature and Chlorophyll



2014 HAB Species



2014 Sea Surface Temperature and Chlorophyll



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