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## EXECTUIVE SUMMARY

This project assessed the applicability of using a Landsat 5 TM image to accurately estimate chlorophyll *a* concentrations on the San Joaquin River based on band ratios regressions**.** Both band ratio data and discrete chlorophyll data from late July to early August 2010 were used to create an algorithm for estimating chlorophyll *a* concentrations from Landsat 5 TM data. In the end, Landsat 5 TM data were able to accurately estimate chlorophyll *a* concentrations on the San Joaquin River. Overall, there was a strong correlation between the estimated and discrete values ($R^2 = 0.924$). As a result, satellite images could potentially supplement discrete monitoring programs in the region by providing better spatial and temporal coverage of data.

## PURPOSE

Phytoplankton are an important primary source of carbon for the planktonic food web (Sobczak et al. 2002) and can often be used as an important indicator for water quality since phytoplankton responds rapidly to the changes in environmental conditions (Brown et al. 2010). For these reasons, the California Department of Water Resources (DWR) is currently responsible for monitoring phytoplankton biomass in the form of chlorophyll *a* in various regions of the upper San Francisco Estuary. However, discrete chlorophyll *a* monitoring may often not provide adequate spatial or temporal coverage of the chlorophyll *a* distribution in a system (El-Magd and Ali 2008).

In recent years, many researchers and programs have started incorporating remote sensing techniques to achieve greater temporal and spatial coverage of data. In particular, there have been a lot of studies using Landsat imagery to assess the chlorophyll *a* concentrations in various regions throughout the world (e.g., El-Magd and Ali 2008, Matthews 2011, Mayo et al. 1995, Ramakrishna et al. 2008). Despite this, very little has been done with the applicably of using Landsat imagery as part of DWR's long term chlorophyll *a* monitoring program in the upper San Francisco Estuary. Because of this, my project will assess the applicability of using a Landsat 5 TM image to accurately estimate chlorophyll *a* concentrations on the San Joaquin River of the San Francisco Estuary based on band ratios regressions. The results from this project will elaborate upon a previous project by Mejia (2011) that determined the use of remote sensing to supplement DWR's water quality monitoring program for total suspended solids in the upper San Francisco Estuary.

## METHODS

**Data Acquisition**

The Landsat 5 TM image (July 29, 2010) that was used to estimate chlorophyll *a* in the San Joaquin River was retrieved from the US Geological Survey Earth Explorer site (http://earthexplorer.usgs.gov/). Afterwards, discrete chlorophyll *a* data (i.e., ground truth samples) were downloaded from the DWR's Bay-Delta Monitoring and Analysis website (http://www.water.ca.gov/bdma/meta/) (Figure 1). The discrete data that was downloaded for the project was within the timeframe of the Landsat image.

*Figure 1: Discrete chlorophyll a concentrations at selected stations in the San Joaquin River*
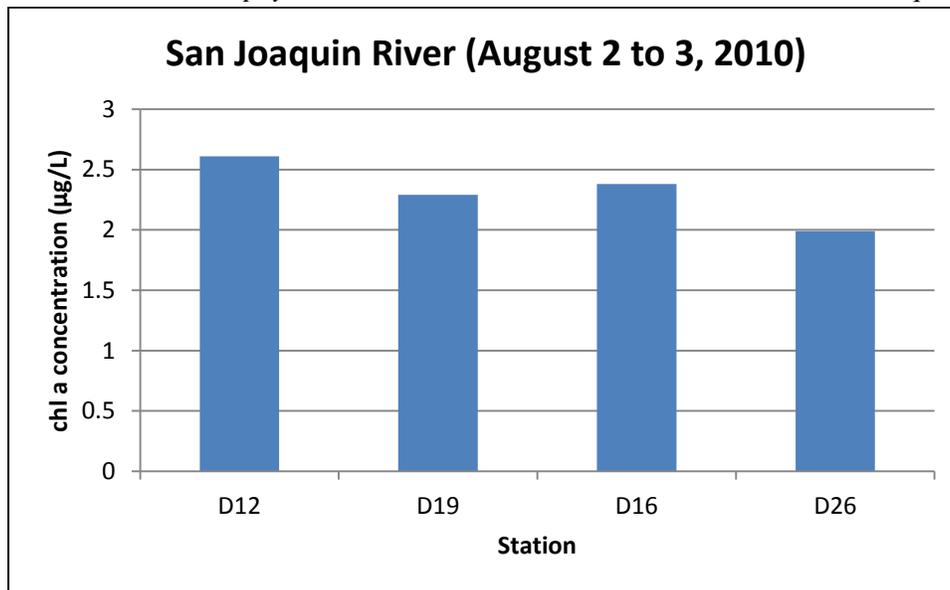


The GPS coordinates of each sampling station was found in the metadata of the Bay-Delta Monitoring and Analysis website. With the GPS coordinates, shapefiles of the discrete data were created and added to ArcMap, along with the Landsat 5 TM files. All spatial data were projected using the WGS 84 UTM Zone 10N projection.

**Image Processing Tasks**
Before any regression modeling could be completed, the Landsat image needed to be transformed into a water only image. The first step was to composite all the Landsat bands into one image through the image analysis window (Figure 2).

*Figure 2: Composite Landsat Image. Green triangles represent discrete sampling locations.*
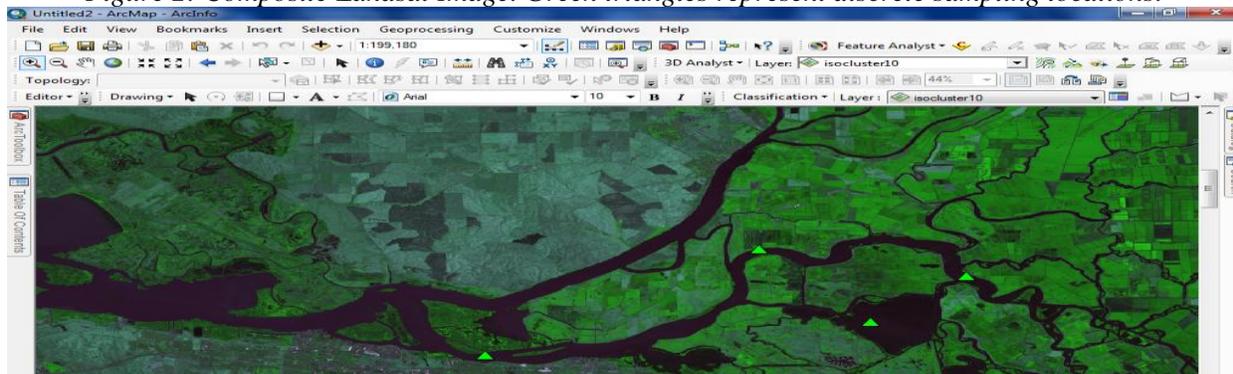


Afterwards, the water land cover type in the image would need to be identified. This was done by running an unsupervised classification with 10 classes (Figure 3).  Based on the results, class 9 was the most appropriate category for water.

*Figure 3: Results from the unsupervised classification.*
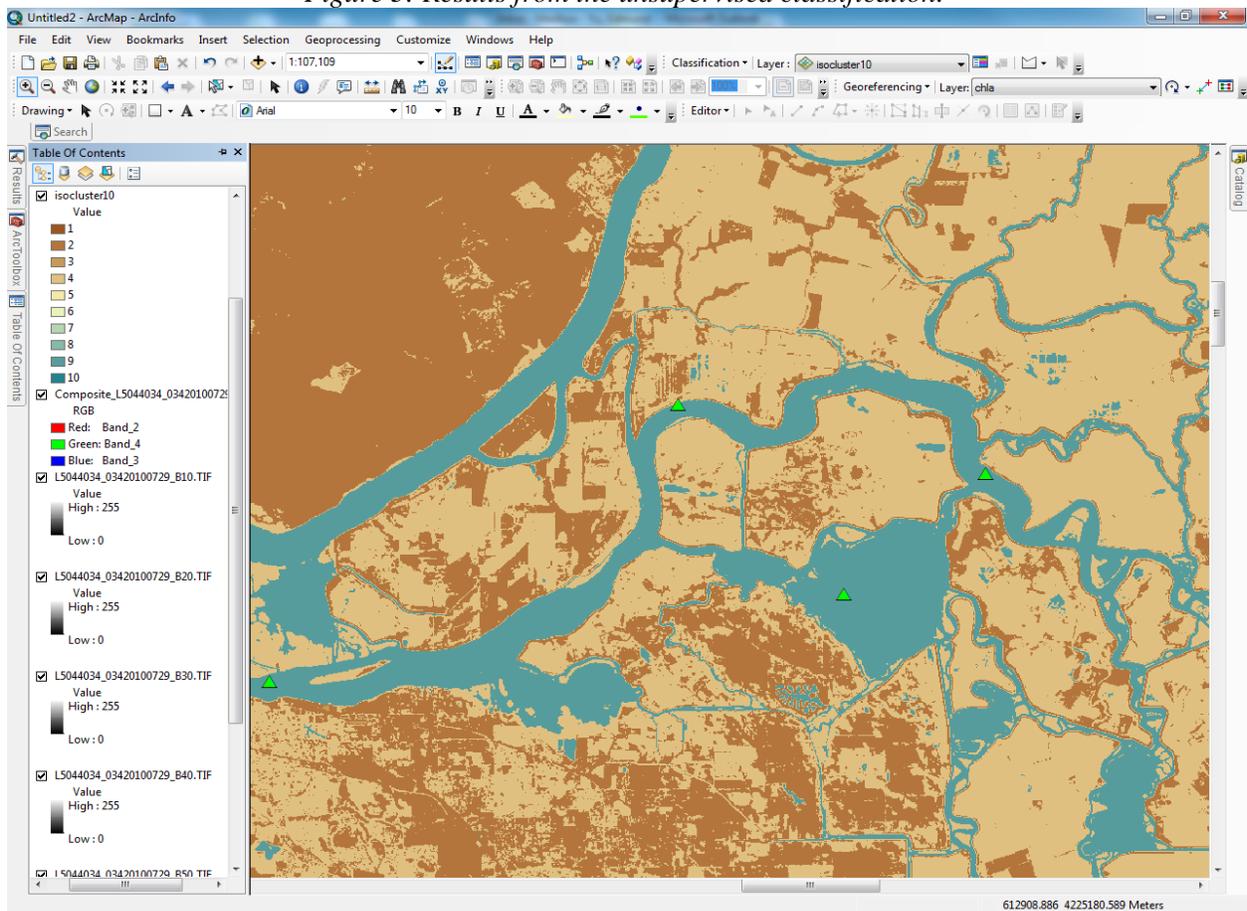


To obtain the wavelengths for each discrete sampling site, training sites were created (Figure 4). Afterwards, the mean wavelengths were obtained  by creating a spectral file of the training sites (Figure 5).

*Figure 4: Example of a training site.*

*Figure 5: Discrete chlorophyll a samples and extracted spectral signatures*

| StationCode | SampleDate | Discrete Chl *a* Result | UnitName | Band 1 | Band 2 | Band 3 | Band 4 | Band 5 | Band 6 |
|---|---|---|---|---|---|---|---|---|---|
| D12 | 8/2/2010 | 2.61 | µg/L | 83.55 | 40.45 | 37.55 | 19.90 | 17.95 | 127.30 |
| D16 | 8/3/2010 | 2.38 | µg/L | 78.42 | 36.75 | 32.00 | 19.33 | 17.25 | 128.08 |
| D26 | 8/3/2010 | 1.99 | µg/L | 72.47 | 32.47 | 26.72 | 17.92 | 16.53 | 129.56 |
| D19 | 8/2/2010 | 2.29 | µg/L | 75.00 | 32.00 | 26.00 | 18.67 | 14.67 | 127.00 |

**Band Ratio Regressions**

Based on the data in Figure 5, band ratio regressions were conducted between discrete chlorophyll *a* data and the different band ratios of the Landsat image. This was done to determine the correlation between the two variables. These regression results can be found in Figure 6.

*Figure 6: Band Ratio Regression Results*
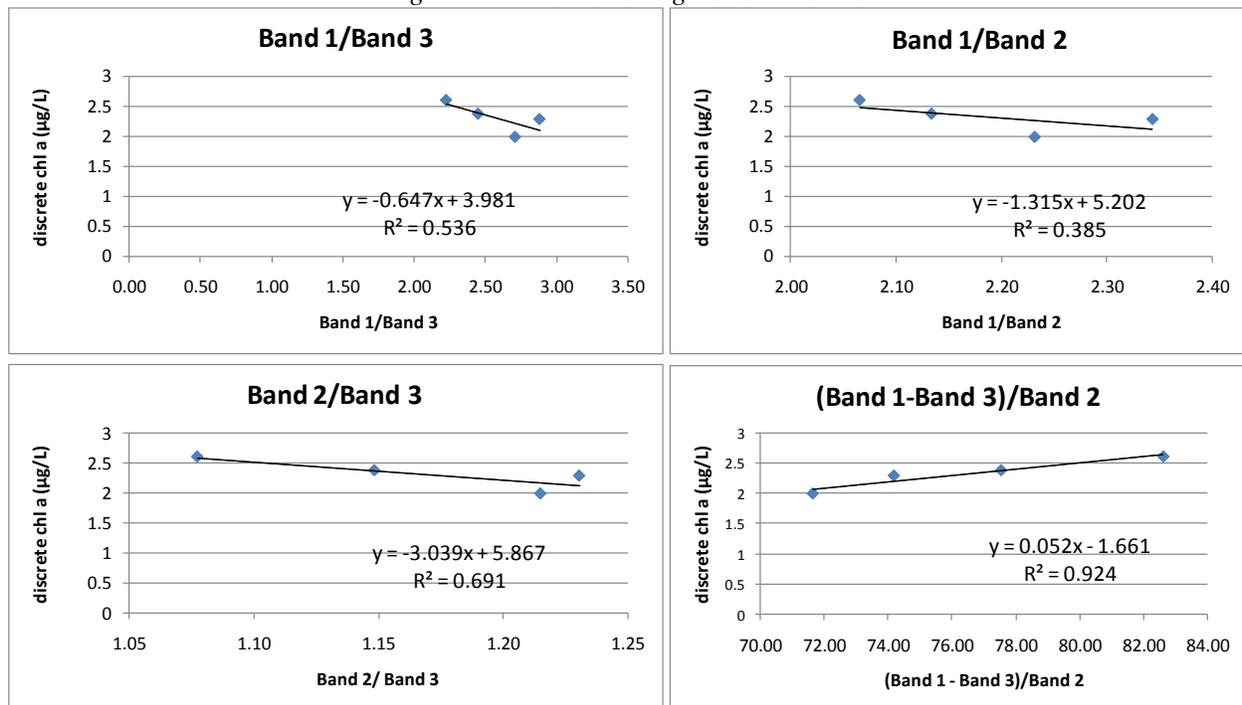


A combination between Band 1, Band 2, and Band 3 were primarily used due to the strong absorption in Band 1 and 3, and the maximum reflectance in Band 2 during the interaction between chlorophyll *a* and electromagnetic radiation (El-Magd and Ali 2008). In the end, Band 1/Band 2 showed the least correlation between the two variables ($R^2$= 0.385). In comparison, (Band 1-Band3)/Band 2 showed the strongest correlation between the two variables ($R^2$= 0.924). This result was consistent with the findings from the Mayo et al. (1995) study that described how subtracting Band 1 from Band 3 would correct for the "radiance from the scattering of non-pigmented particles." In turn, (Band 1 −Band 3)/Band 2 would be the best ratio for estimating chlorophyll *a.* Based on these findings, the following equation was used in the raster calculator to estimate chlorophyll *a* concentrations from the Landsat 5 TM image: y=0.052x -1.661 (where x= (Band 1-Band 3)/Band 2).

# RESULTS AND ANALYSIS

Estimated values from using the equation mentioned above can be seen in Figure 7. In general, there was not a whole lot of variation during this time period.

*Figure 7: Estimated values from the Landsat 5 TM image on July 29, 2010.*
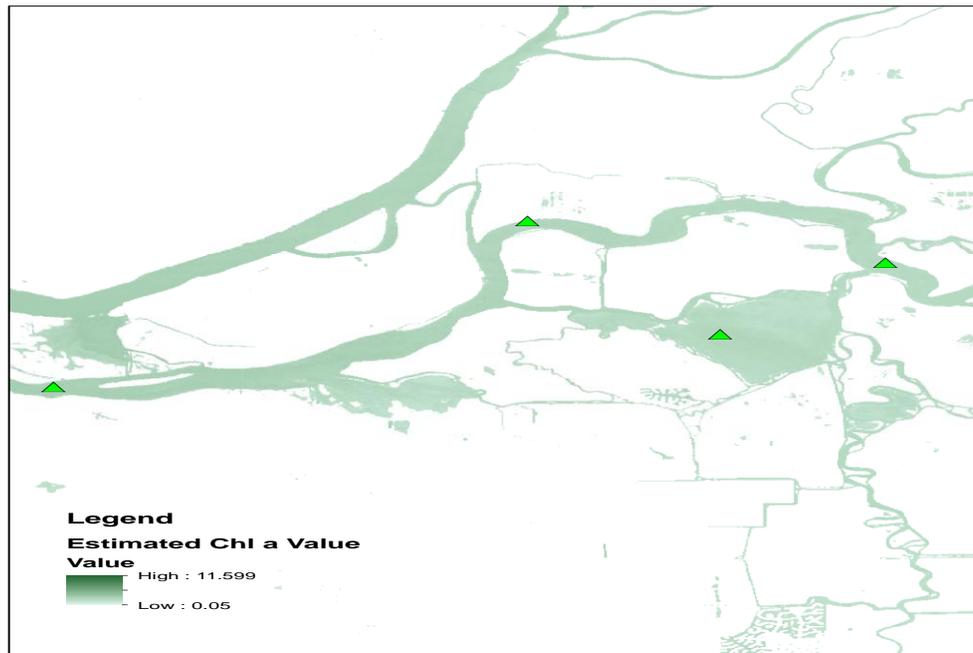


Another regression was conducted to determine the relationship between the estimate chlorophyll *a* values and the discrete chlorophyll *a* values. Overall, there was a strong correlation between the estimated and discrete values ($R^2 = 0.924$). Even so, these results may not apply across seasons. During this time period, chlorophyll *a* values remained low, which may explain the high correlation. Other studies have shown less accurate estimations from Landsat images when chlorophyll concentrations were moderately high (e.g., Ramakrishna et al. 2008)

*Figure 7: Correlation between discrete and estimate chlorophyll a values*
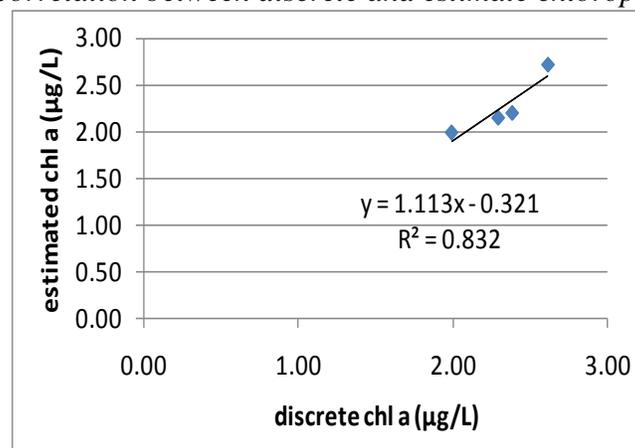
# DISCUSSION

**Issues and Limitations**
This study was primarily limited by the small sample size of discrete samples that were collected by DWR in the San Joaquin River. A larger sample size will be needed for a more robust algorithm. In addition, no atmospheric correction was applied to the Landsat image used in this project. This differs from many other studies that have applied an atmospheric correction when estimating chlorophyll *a* values (e.g., El-Magd and Ali 2008; Mayo et al. 1995).

One huge issue during this project was finding an appropriate algorithm to use for the estimation from the Landsat image. Because of this, many regressions were performed to find the appropriate band ratios. Further research needs to be done on the best algorithm to use for the San Joaquin River.

**Conclusions and Inferences**
In the end, Landsat 5 TM imagery was able to accurately estimate chlorophyll *a* concentrations on the San Joaquin River during late July 2010. As a result, satellite images could potentially supplement DWR's discrete monitoring by providing better spatial and temporal coverage of data. In particular, estimating values with a Landsat image would be important at locations where there is no discrete monitoring. It would be interesting to continue to learn more about the use and accuracy of using Landsat imagery to estimate chlorophyll *a* in other regions of the San Francisco Estuary, where conditions differ from that of the San Joaquin River. Since all the data is available online, this might be something worth investigating.

# REFERENCES

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