Using Satellite Images to Infer Chlorophyll Levels in Charlie Lake, BC.

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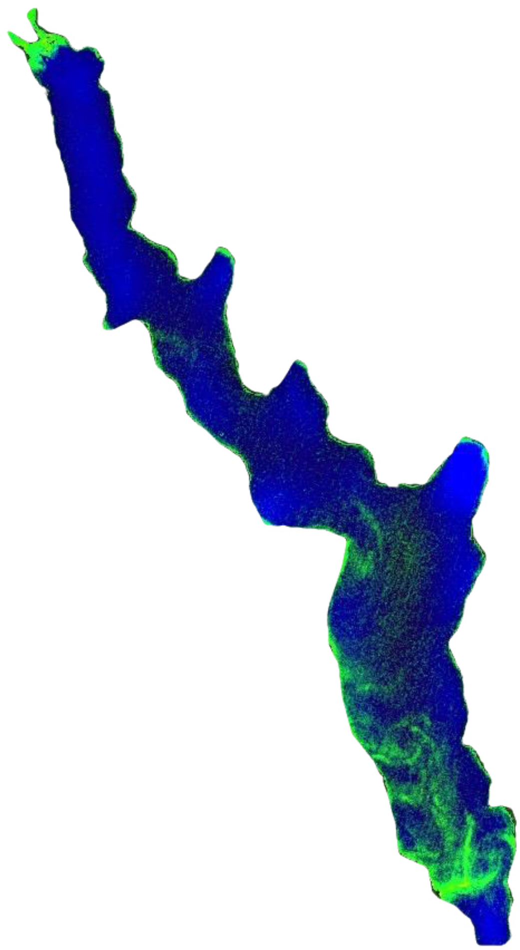

Charlie Lake Conservation Society
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INTRODUCTION

In a previous report (Baccante 2023), I described how satellite images can be used to detect aquatic plants and algae in Charlie Lake, BC, throughout the growing season. The satellite images are from the SENTINEL - 2 space mission, operated by the European Space Agency (see: https://registry.opendata.aws/sentinel-2/).

In this report, I use available field measurements of Chlorophyll_a in Charlie Lake, BC, and see how well they correlate to levels of green colour measured in satellite images. The purpose is to see if Chlorophyll_a levels in Charlie Lake can be inferred by measuring the amount of green in images. This is not an attempt at calibrating satellite images to Chlorophyll_a levels so that the latter can be measured by the former. However, by exploring how these two parameters vary, over the approximate same time period (years) and seasonally (month), it will hopefully provide some guidance if a more comprehensive calibration project is contemplated.

There has been a noticeable increase in published scientific papers on this subject, and it is not the objective of this report to provide an extensive literature review. On-line availability of this and other research makes it easy for anyone to explore.

METHODS

Satellite imagery used for this project is available through the Earth Observation (EO) browser at this page:

https://custom-scripts.sentinel-hub.com/sentinel-2/apa_script/#

By accessing the EO browser here, the satellite images are automatically processed with the Aquatic Plants and Algae Custom Script Detector (APA Script). In a previous project (Baccante 2023), I was using the generic page of the EO browser, where images would have to be processed manually with the script. The website above is dedicated to process the images with the APA Script automatically, thus making the analysis much more efficient.

Once the browser is launched, I typed “Charlie Lake BC” in the search box. Once located, for consistency when comparing images, I zoomed out until the scale indicator in the lower right-hand corner of the map indicated 2 km. Images of Charlie Lake were downloaded and processed following the methods described in Baccante (2023).

The main purpose of this paper is to compare available field measurements of chlorophyll levels in Charlie Lake with the amount of green colour measured on satellite images of the lake. Ideally, it would be preferable to have field measurements of Chlorophyll_a on the same days as the satellite images, or even within 1 or 2 days of each other. Unfortunately those data do not currently exist for Charlie Lake so this is a retrospective look based on availability of reliable Chlorophyll_a measurements.

The time period for available Chlorophyll_a measurements spans from 2016 to 2022, from BC Ministry of Environment sampling, and the most usable satellite images range from 2018 to 2023. An effort was made to use satellite images as close as possible to the same dates as the Chlorophyll_a measurements, but obviously this was not always possible. However, for the purpose of this report, this is not a concern because the objective is not to develop a predictive model, rather, to evaluate if seasonal trends in Chlorophyll_a measurements are similar to the green levels measured in the satellite images. If they exhibit similar seasonal patterns, it can support the case for a field program where Chlorophyll_a field measurements can be coordinated with timing of satellite images.

Resulting data can be then used to develop a calibration model where we can use satellite imagery to estimate Chlorophyll_a levels. This would provide a significant logistical and economic advantage over field measurements. Of course the methodology would be driven by the objectives of the project. Field measurements can detect spatial differences in a lake accurately, but it would require a very high level of sampling effort and sample analysis cost.

If the objective is to detect blooms of specific species of algae or plants, data from satellite images would have to be calibrated specifically to those species. Satellite images are sensitive to certain wavelength bands along the absorption spectrum, and Chlorophyll_a typically reflects solar irradiance around the Red and Infra-Red zone, peaking around 660 nanometers (Figure 1).

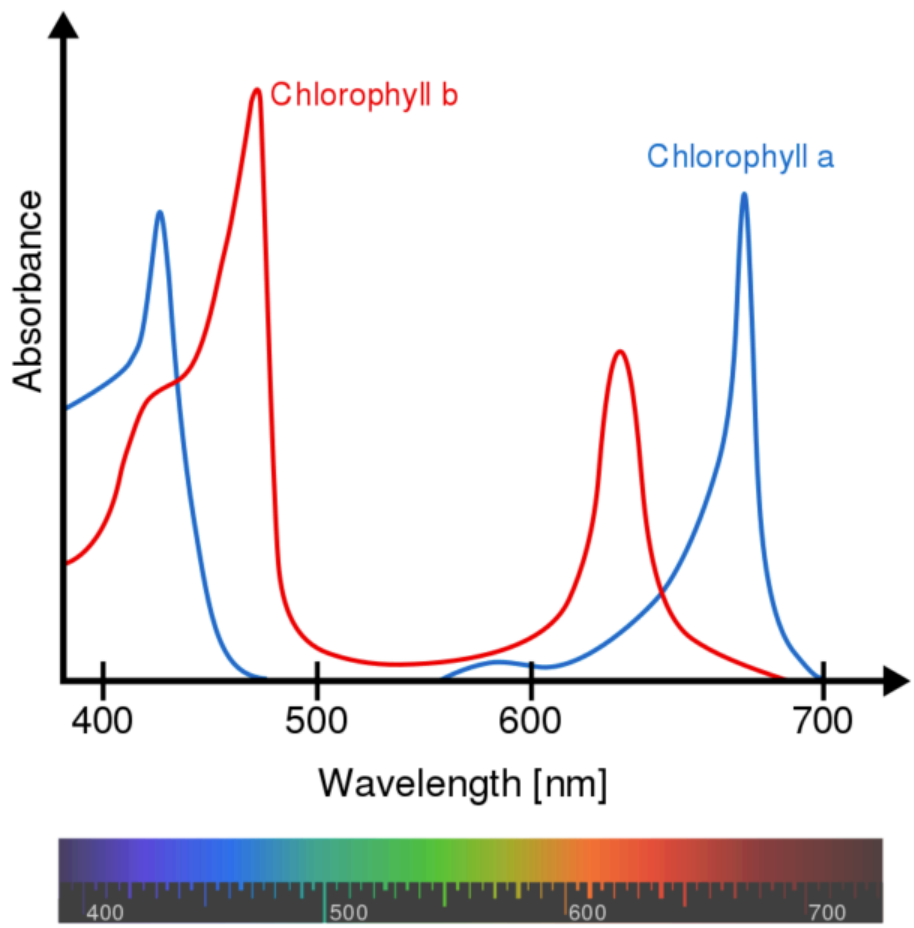


Figure 1: Absorbance spectrum of Chlorophyll a and b.
Chlorophyll reflects green light and absorbs red and blue. From:
https://conductscience.com/spectrophotometer/

Satellites can detect the presence of Chlorophyll_a but cannot discriminate what its source is. If the source of the chlorophyll is important, then algal species should be identified.

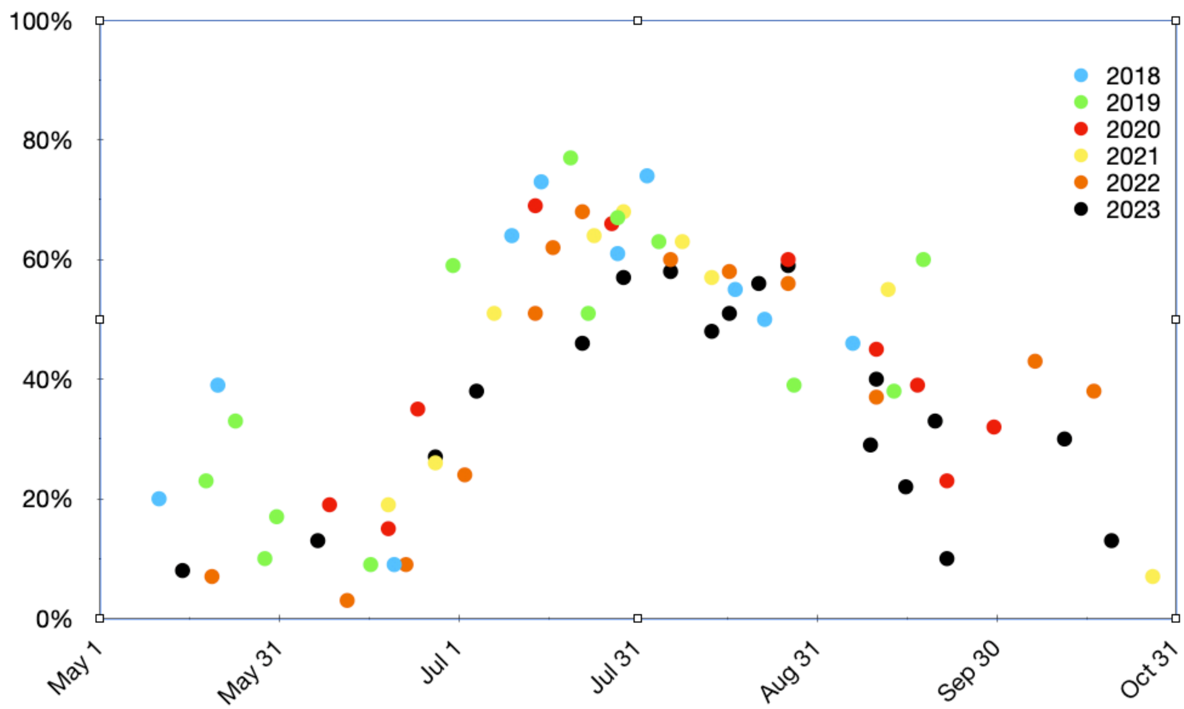
Mean green levels in satellite images were calculated for each month from May to October for the period 2018 to 2023 from a total of 73 satellite images. A total of 37 Chlorophyll_a measurements were available from data provided to the Charlie Lake Conservation Society by BC Ministry of Environment.

Chlorophyll_a measurements were plotted against percent green levels measured on satellite images. A linear regression was fitted to calculate how well the variation in Chlorophyll_a is explained by the variation in green levels.

RESULTS

The annual seasonal variation of green levels analyzed in satellite images shows a fairly consistent pattern between years. Figure 2 shows percent levels of green in images for the period 2018 to 2023, and on average, the green levels increase at a relatively fast rate between May and July, and then decrease at a slower rate towards late September and October.

Figure 2:Percent green levels from satellite images of Charlie Lake B.C. for the period 2018-2023.



When utilizing satellite images, there's a large variation in the usability of those images. A variety of factors impact the quality of the images, for example, atmospheric conditions such as, light aberrations and cloud cover can render images unusable for analysis.

Table 1 and Figure 3 show the range of percent green levels measured on a total of 73 satellite images for the time period 2018 -2023. Table 2 shows a summary of monthly and overall mean values of Chlorophyll_a measurements made between 2016 and 2022 from BC Ministry of Environment, made available to the Charlie Lake Conservation Society.

Table 1: Measured green levels 2018 - 2023

MONTH	MIN	MEAN	MAX	n
May	7.0%	19.6%	39.0%	8
June	3.0%	20.3%	59.0%	12
July	24.0%	58.7%	77.0%	18
August	39.0%	56.7%	74.0%	16
September	10.0%	36.4%	60.0%	14
October	7.0%	26.2%	43.0%	5

Figure 3: Green levels 2018 - 2023

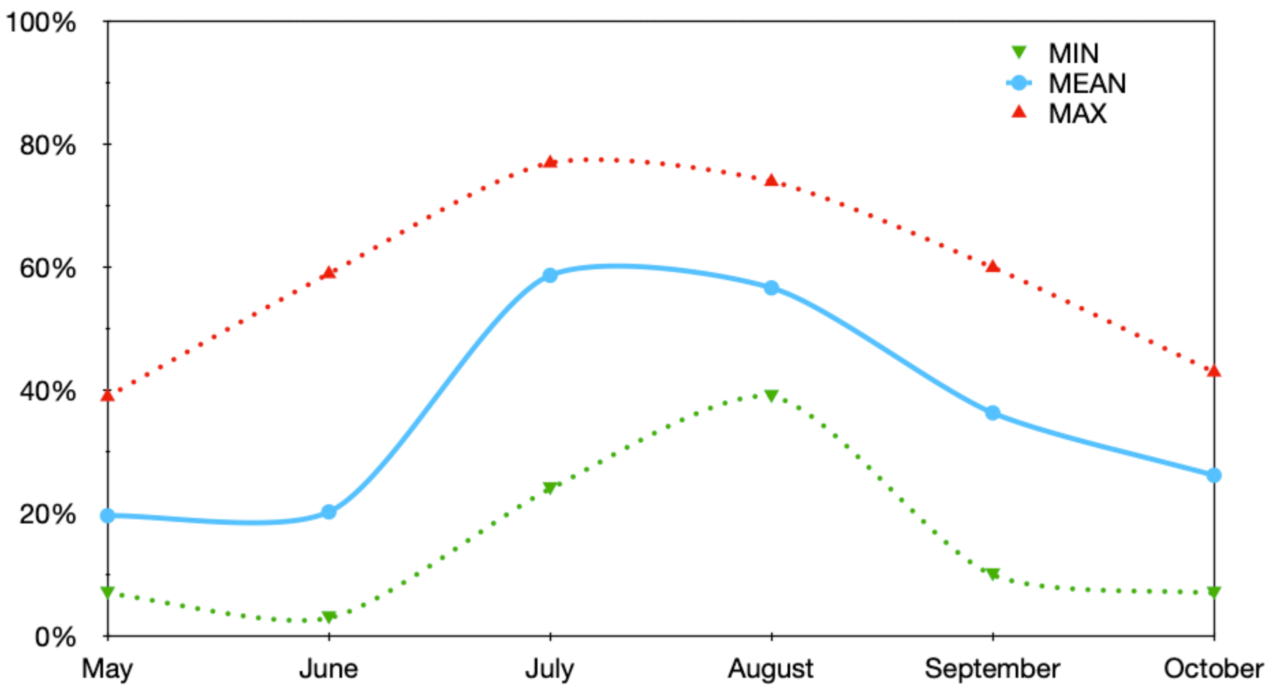


Table 2: Chlorophyll_a (µg/l) measured in Charlie Lake, 2016 - 2022.

MONTH	2016	2017	2021	2022	MEAN
May		7.23			7.23
June	10.32	6.98	11.70	5.20	8.55
July	21.73	45.73		132.20	66.55
August	26.94	74.88		39.30	47.04
September	17.09	34.43	33.85	16.00	25.34
October		19.25			19.25

The available mean Chlorophyll_a levels and the mean green levels from the satellite images, plotted for each month within the specified time periods are shown in Figure 4. Figure 4 indicates that mean Chlorophyll_a and green levels from satellite images follow very similar seasonal patterns. This suggests a high level of correlation which is confirmed by the regression plot in Figure 5.

Figure 4: Monthly means of Chlorophyll_a and green levels.

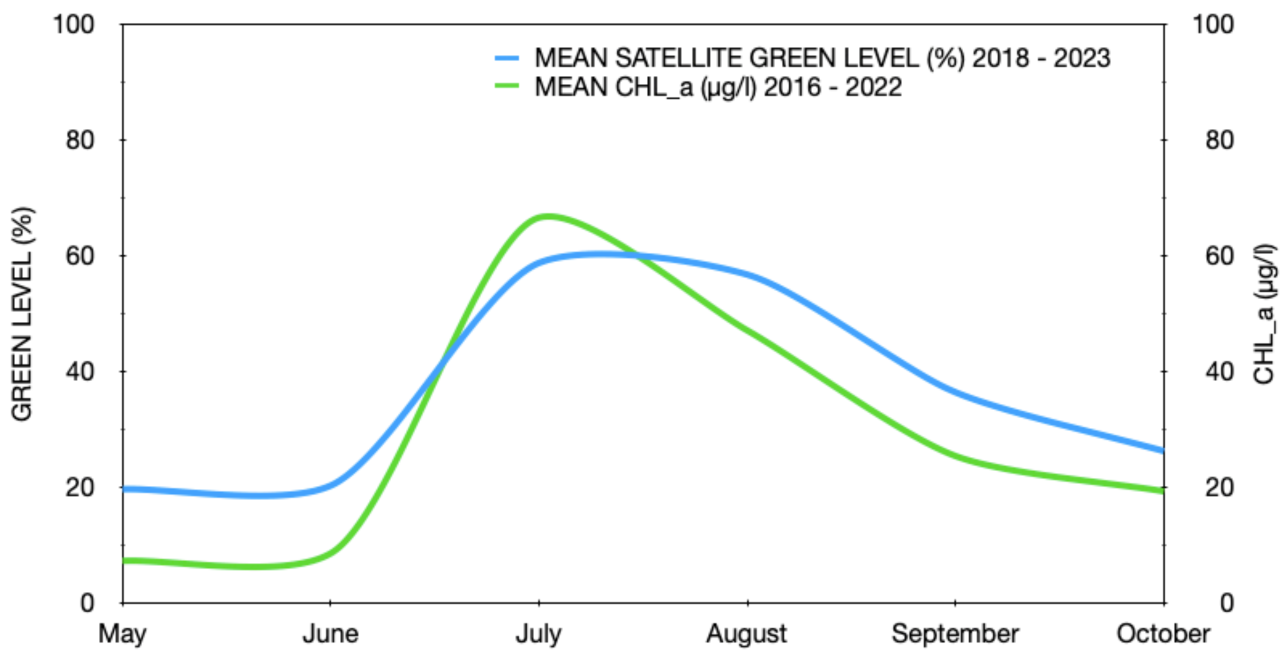


Figure 5: Plot of mean Chlorophyll_a against mean green levels.

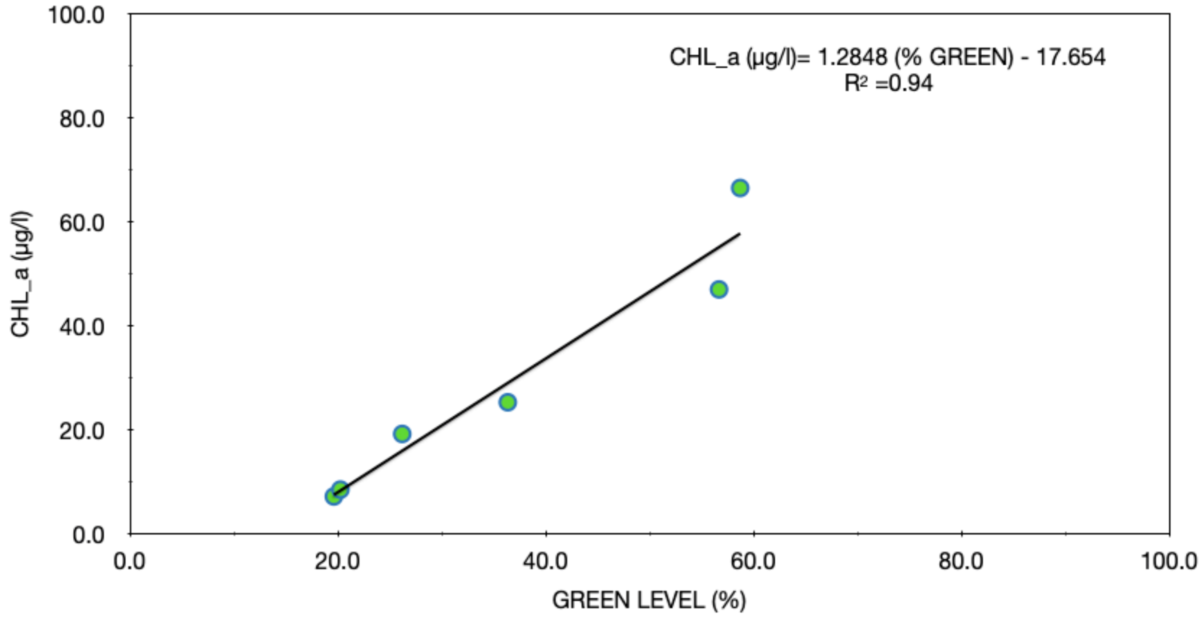


Figure 5 also shows a straight line fitted to the points with a very high regression factor of 0.94. This suggests that 94 percent of the variation in the Chlorophyll_a levels in this data set, can be explained by variation in the green levels measured on the satellite images.

DISCUSSION

Despite the limitations of this data set, the high degree of similarity in seasonal variation of Chlorophyll_a and percent of green colour measured in satellite images, is very encouraging. It suggests that the precision of this relationship can likely be improved by measuring Chlorophyll_a in Charlie Lake on the same days that satellite images are recorded. This can lead to calibration of the two variables, and ultimately to the estimation of Chlorophyll_a measurements using satellite imagery.

Coordinating field measurements of Chlorophyll_a with satellite images should not prove too difficult. At worse, the two may end up being 1 or 2 days apart, but that's well within acceptable levels of precision for the purpose of calibration. Based on availability of Sentinel-2 images for the area covering Charlie Lake, the revisit rate of satellites is very high, every 2 to 3 days (Baccante 2023). By monitoring the dates of the latest satellite images, and choosing days with no cloud cover, field sampling of Chlorophyll_a can easily be done at the appropriate time.

As mentioned earlier, estimating Chlorophyll_a levels from satellite images would provide a very good summary of the seasonal variation in algal blooms. However, it does not provide enough detail to use the results for more specific objectives, for example detecting harmful blooms of specific algae, such as toxic blue-greens. This is beyond the scope, mandate and capability of the Charlie Lake Conservation Society, but hopefully it can serve as a starting point for government agencies responsible for the management and health of the lake.

In fact, satellites are being more and more widely used to detect harmful blooms and issue health advisories. Schaeffer et. al.(2019) from the U.S. Environmental Protection Agency, have developed a phone application that reports satellite-detected cyanobacteria in real time. This can be extremely useful for timely decision-making and response in affected areas that have high human use. The scientific literature dealing with using satellites to monitor algal blooms and many other environmental parameters appears to be growing exponentially, and accuracy of measurements will undoubtedly increase with improving technology.

CONCLUSION

This report was written to expand on the method introduced in Baccante (2023). It is meant to draw attention to how satellite images are becoming more widely available to the general public, and how they can be used to measure environmental parameters and monitor changes in real time. The wide availability of the technology makes it very desirable to be used in citizen science projects, which have become very popular and important by contributing data to scientific projects at a global scale.

The proliferation of phone apps have greatly reduced the steepness of the learning curve normally associated with many environmental monitoring projects. Agencies are already developing web-based and mobile apps that anyone can use to not only monitor changes in environmental conditions, but also provide the tools to contribute their own observations. This contributes large amounts of data to scientists, thus reducing the cost of gathering the data.

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