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The Potential of Different Reflectance-Based Algorithms to Retrieve Phycocyanin Concentration through Remote Sensing: Application to a Hypereutrophic Mediterranean Lake †

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Abstract: Cyanobacterial blooms impacts aquatic environment and human health. Cyanobacterial biomass is usually estimated using traditional time consuming and costly field sampling techniques. Remote sensing approach is time, cost efficient, and feasible for repetitive monitoring. In this work we test the potential of various algorithms to retrieve phycocyanin concentration in a Mediterranean. Field spectroradiometric measurements and sampling were performed during 2016 and 2017. Results obtained proved that various ratio-models can be used for the estimation of phycocyanin with the model "R(700)/R(600)" being the best (R^2 = 0.716). This research highlights the potential of cyanobacteria mapping by the various available satellites.

Keywords: satellite; spectroradiometer; cyanobacteria

1. Introduction

Phytoplankton is the base of aquatic food webs that can be found in both fresh and marine waters [1–3]. The monitoring of their dynamics is essential as they are considered as the biological indicator to evaluate the ecological status of both marine and freshwater. Eutrophication, a process resulting from land degradation [4,5] and anthropogenic activities promote the increase of phytoplankton concentration. Blooms of cyanobacteria, a group of phytoplankton can result in the production of toxins in aquatic ecosystem, threatening human health and aquatic inhabitants [6].

The hazards of cyanobacterial blooms, a worldwide problem, have raised awareness among policy makers to continuously monitor the cyanobacterial biomass in inland water. Cyanobacterial biomass can be estimated using traditional field sampling techniques, laboratory analysis, and cell counting method. Despite being accurate, this method is time-consuming, labor-intensive and cost-ineffective. Remote sensing is considered an alternative monitoring method that is cost and time efficient, and feasible for repetitive and continuous monitoring of phytoplankton and cyanobacteria [7]. Chlorophyll-a (chl-a) pigment was previously used in order to estimate cyanobacterial biomass. It was later proved that chl-a is an inaccurate estimator of cyanobacteria since it is common in all photosynthetic phytoplankton groups. However, phyocycanin (PC) is a unique pigment present in cyanobacteria only rather than other phytoplankton groups.

The progress in remote sensing helped researchers to exploit phycocyanin to develop reflectance-based empirical, semi-empirical, and band ratio algorithms to estimate cyanobacterial biomass. In this research, we aim to test the potential of various published

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algorithms to derive [PC] at Lake Qaraoun using remote sensing techniques to recommend the potential satellite imageries suitable to derive phycocyanin from space.

2. Materials and Methods

2.1. Study Area

Lake Qaraoun is the largest freshwater body in Lebanon. It has a surface area of 12 Km^2, a maximum depth of 60 m, and a maximum volume of about 220 x 10^6 m^3 [8,9]. The reservoir water is used for various purposes, including irrigation, drinking, domestic, recreational activities, and fisheries [2]. Global warming resulted in cyanobacterial blooms of *Microcystis aeruginosa* and *Chrysosporum ovalisporum* in the reservoir [10,11]. In 2012, a cyanobacterial toxin produced by *Chrysosporum ovalisporum*, known as cylindrospermopsin, was detected in the lake [12].

2.2. Field Sampling and Remote Sensing Reflectance (Rrs)

Cyanobacterial species from each subsample were determined based on the taxonomic keys as colony morphology, cell structure and dimensions, and mucilage characteristics [13]. Microscopic identifications and enumeration were performed using a phase contrast microscope (Nikon TE200, Nikon, Melville, New York, USA). Cyanobacteria counting was carried out under a ×40 objective using 40 bands Nageotte chamber.

Water samples for phycocyanin PC laboratory estimation were filtered under low vacuum through a 0.2 μm nucleopore membrane filters (Millipore). PC pigments were then extracted in 50 mM phosphate buffer for further estimation through spectrophotometric method.

Eight field campaigns were conducted during 2016 and 2017 (Figure 1). Field spectroradiometric measurements were carried out using a spectroradiometer (Field Spec 4 ASD) and were acquired in the visible and near-infrared range (350-2500 nm) with 1 nm spectral resolution.

3. Results

Phycocyanin concentration varied between 18 and 170 μg/l during the different field campaigns in 2016 and 2017. Phycocyanin was heterogenous throughout the lake and showed considerable variation in 02 November 2016 ranging between 34 and 170 μg/L (Figure 1a). Two main cyanobacterial genera (*Microcystis sp*. and *Chrysoporum sp.*) were identified during the campaigns in which field spectroradiometer measurements were performed in 2016 and 2017. Proportion of both genera is presented in Figure 1b. *Chrysoporum Sp.* dominates the cyanobacteria population until August when *Microcystis sp.* outcompetes it.

Figure 2 shows spectral features observed in reflectance data from the cyanobacteria dominated turbid water in Lake Qaraoun. It shows absorption peaks highlighting the phytoplankton and PC absorption at the key spectral regions.

The potential of 10 developed algorithms was tested to retrieve phycocynanin concentration in Lake Qaraoun (Table 1). Results showed that both linear models [R(600)+R(648)]-R(624)] as well as [R(600)-R(648)-R(625)] are weakly correlated to measured [PC], with an R^2 = 0.1895 and 0.1217, respectively. On the other hand, $\frac{R(700)}{R(622)}$ strongly correlated to measured [PC], with an R^2= 0.716 (Table 1, Figure 5).

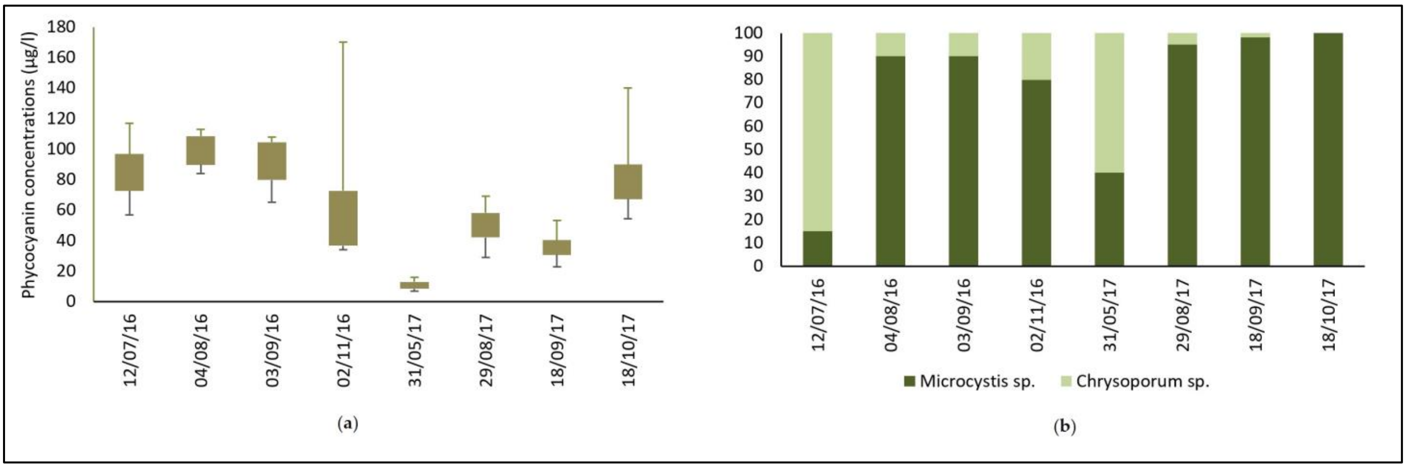

Figure 1. (**a**) Boxplot of the phycocyanin concentrations obtained for different measurements performed in 2016 and 2017; (**b**) Proportion of the main blooming cyanobacterial genera.

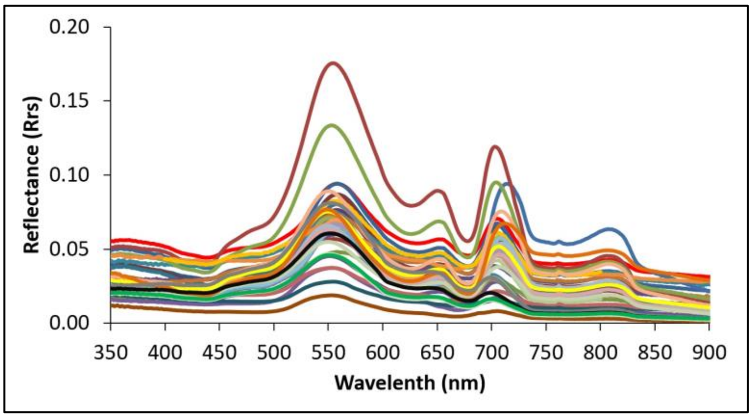

Figure 2. Rrs Spectra acquired from Lake Qaraoun.

Table 1. Coefficient of correlation of the 10 tested phycocyanin-retrieving algorithms.

Algorithm	Name	Reference	R2
$\frac{\boldsymbol{R(650)}}{\boldsymbol{R(625)}}$	SC00	[14]	0.6662
$\frac{\boldsymbol{R(700)}}{\boldsymbol{R(600)}}$	MI09	[15]	0.716
$\frac{\boldsymbol{R(709)}}{\boldsymbol{R(600)}}$	SM12	[16]	0.6607
$\frac{\boldsymbol{R(724)}}{\boldsymbol{R(600)}}$	MM09	[15]	0.5408
$\frac{\boldsymbol{R(709)}}{\boldsymbol{R(620)}}$	SI05	[17]	0.6593
$\frac{\boldsymbol{R(678)}}{\boldsymbol{R(667)}}$	Am09	[18]	0.4176
$\frac{\boldsymbol{R(681)}}{\boldsymbol{R(665)}}$	Be16	[19]	0.4035
$\frac{\boldsymbol{R(700)}}{\boldsymbol{R(622)}}$	Be16	[19]	0.7048
R(600)-R(648)-R(625)	DE93*	[20]	0.1217
R(600)+R(648)-R(624)	DE93	[20]	0.1895

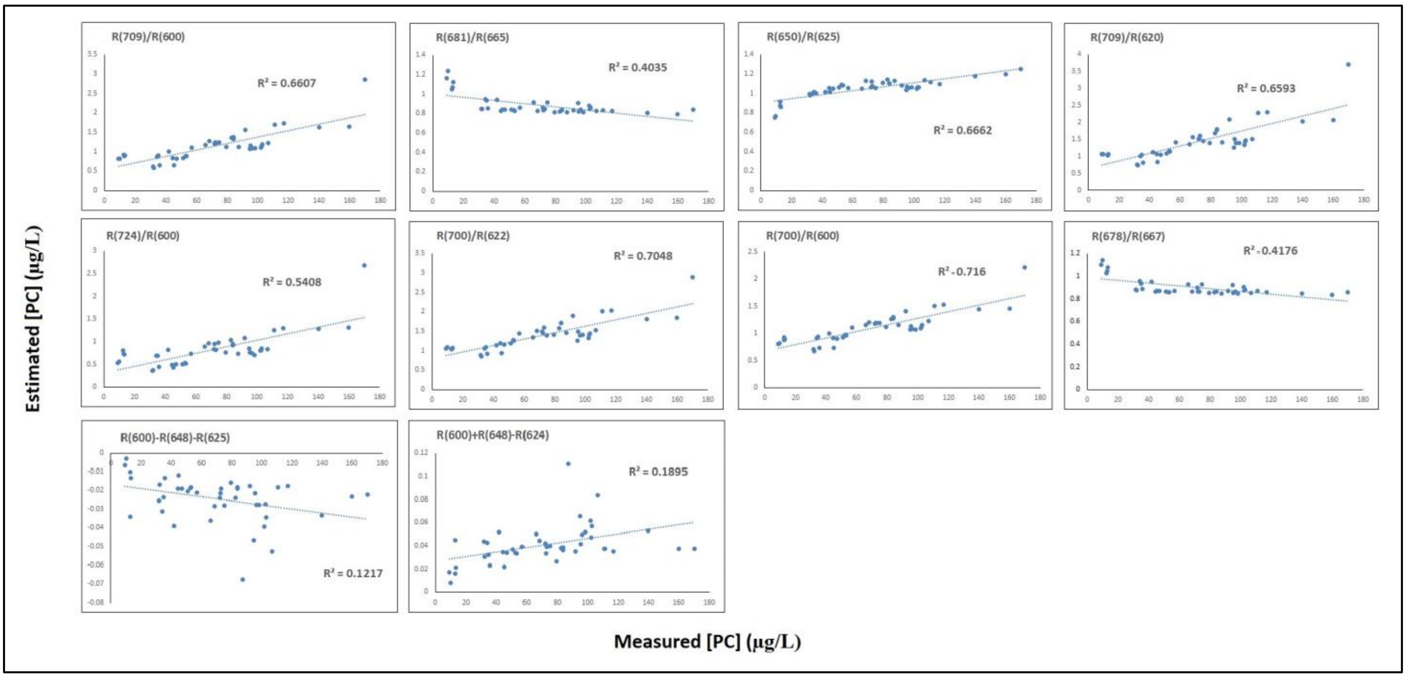

Figure 3. Scatter plots representing the estimated [PC] from each algorithm verses measured [PC] (µg/L).

4. Discussion

Results obtained in this work showed that band ratio algorithms were found better than linear models for the estimation of [PC]. Mishra et al. in 2009 found that some band ratio algorithms are sensitive to chl-a, and are thus unsuitable for estimating [PC]. They proved that the MI09 algorithm "R(700)/R(600)" is not sensitive to chl-a, but sensitive to phycocyanin [21]. This agrees with our results that showed the potential of "R(700)/R(600)" to estimate [PC]. Ogashawara et al., 2013 showed that SC00 model "R(650)/R(625)" has low sensitivity to both PC and chl-a, while SI05 "R(709)/R(620)" is a good estimator of PC, but is also highly sensitive to chl-a [22]. Meanwhile, MM09 "R(724)/R(600)" is highly sensitive to both PC and chl-a, indicating that these algorithms are unsuitable for [PC] retrieval, or suitable only in specific environments. The study also proved that MI09 "R(700)/R(600)" is highly sensitive to PC and have low sensitivity to chl-a. This agrees with our results, indicating that MI09 is efficient and has high potential to retrieve [PC] in nature.

In addition, Lake Qaraoun is subject to various sources of pollution, including industrial wastes, sewage and untreated wastewater, as well as agricultural run-off [9]. These anthropogenic pressures affect the clarity of the water and cause an elevation in turbidity. This in turn may affect the reflectance of various bands used, and hence causes error in estimated [PC]. This poses another problem to using remote sensing tools to derive [PC]. Thus, additional evaluation of the algorithms (particularly "R(700)/R(600)") in other lakes, eutrophic, mesotrophic, as well as oligotrophic, in order to validate the suitability of this algorithm in all regions.

The importance of these algorithms is that they can be used as indicators to choose between different satellite imagery to map CHABs, based on their visible and NIR bands. The phycocyanin in Lake Champlain's Missisquoi Bay, was successfully mapped by applying SI05 "R(709)/R(620)" model on Quickbird and MERIS images [23]. This indicates that, [PC] can be effectively estimated from Quickbird and MERIS images.

In fact, the band ratio algorithms can effectively retrieve [PC] in small aquatic inland waters from Worldview-2, and Sentinel-2 images, and to a lesser extent from Landsat-8 images. Worldview-2 images are the most favorable images for mapping CHABs, followed by Sentinel-2 then Landsat-8 images. The future satellite imaging systems should include a narrow band focused on phycocyanin absorption feature (620 nm) [19].

5. Conclusion

In this work, the model "R(700)/R(600)" was the most suitable algorithm to estimate PC in Lake Qaraoun. Most PC retrieval band ratio algorithms can be applied to satellite images to directly derive PC, and hence map CHABs. Further analysis shall be done in order to test the sensitivity of these algorithms to phytoplankton groups other than cyanobacteria. Further studies are needed as well on new algorithms to retrieve phycocyanin concentration from remote sensing techniques.

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References

1. El Hourany, R.; Fadel, A.; Gemayel, E.; Abboud-Abi Saab, M.; Faour, G. Spatio-Temporal Variability of the Phytoplankton Biomass in the Levantine Basin between 2002 and 2015 Using MODIS Products. Oceanologia 2017, 59, 153–165, doi:10.1016/j.oceano.2016.12.002.
2. Fadel, A.; Sharaf, N.; Siblini, M.; Slim, K.; Kobaissi, A. A Simple Modelling Approach to Simulate the Effect of Different Climate Scenarios on Toxic Cyanobacterial Bloom in a Eutrophic Reservoir. Ecohydrol. Hydrobiol. 2019, 19, 359–369, doi:10.1016/j.ecohyd.2019.02.005.
3. Gregg, W.W.; Conkright, M.E.; Casey, N.W. Ocean Primary Production and Climate : Global Decadal Changes. 2003, 30, 10–13, doi:10.1029/2003GL016889.
4. Darwish, T.; Atallah, T.; Fadel, A. Challenges of Soil Carbon Sequestration in the NENA Region. SOIL 2018, 4, doi:10.5194/soil-4-225-2018.
5. Darwish, T.; Fadel, A. Mapping of Soil Organic Carbon Stock in the Arab Countries to Mitigate Land Degradation. Arab. J. Geosci. 2017, 10, doi:10.1007/s12517-017-3267-7.
6. Fadel, A.; Guerrieri, F.; Pincebourde, S. The Functional Relationship between Aquatic Insects and Cyanobacteria: A Systematic Literature Review Reveals Major Knowledge Gaps. Total Environ. Res. Themes 2023, 8, 100078, doi:10.1016/j.totert.2023.100078.
7. Vincent, R.K.; Qin, X.; McKay, R.M.L.; Miner, J.; Czajkowski, K.; Savino, J.; Bridgeman, T. Phycocyanin Detection from LANDSAT TM Data for Mapping Cyanobacterial Blooms in Lake Erie. Remote Sens. Environ. 2004, 89, 381–392, doi:10.1016/j.rse.2003.10.014.
8. Fadel, A.; Mhawej, M.; Faour, G.; Slim, K. On the Application of METRIC-GEE to Estimate Spatial and Temporal Evaporation Rates in a Mediterranean Lake. Remote Sens. Appl. Soc. Environ. 2020, 20, 100431–100431, doi:10.1016/j.rsase.2020.100431.
9. Fadel, A.; Kanj, M.; Slim, K. Water Quality Index Variations in a Mediterranean Reservoir: A Multivariate Statistical Analysis Relating It to Different Variables over 8 Years. Environ. Earth Sci. 2021, 80, 65–65, doi:10.1007/s12665-020-09364-x.
10. Fadel, A.; Atoui, A.; Lemaire, B.J.; Vinçon-Leite, B.; Slim, K. Environmental Factors Associated with Phytoplankton Succession in a Mediterranean Reservoir with a Highly Fluctuating Water Level. Environ. Monit. Assess. 2015, 187, 633, doi:10.1007/s10661-015-4852-4.
11. Slim, K.; Fadel, A.; Atoui, A.; Lemaire, B.J.; Vinçon-Leite, B.; Tassin, B. Global Warming as a Driving Factor for Cyanobacterial Blooms in Lake Karaoun, Lebanon. Desalination Water Treat. 2014, 52, 2094–2101, doi:10.1080/19443994.2013.822328.
12. Fadel, A.; Atoui, A.; Lemaire, B.; Vinçon-Leite, B.; Slim, K. Dynamics of the Toxin Cylindrospermopsin and the Cyanobacterium Chrysosporum (Aphanizomenon) Ovalisporum in a Mediterranean Eutrophic Reservoir. Toxins 2014, 6, 3041–3057.
13. Komárek, J.; Anagnostidis, K. Cyanoprokaryota 2 Teil: Oscillatoriales; Büdel, B., Gärtner, G., Krienitz, L. & Schagerl, M (eds), Süßwasserflora von Mitteleuropa Band 19/2, Spektrum Akademischer Verlag (Elsevier), 2005;
14. Schalles, J., F.; Yacobi, Y., Z. Remote Detection and Seasonal Patterns of Phycocyanin, Carotenoid and Chlorophyll Pigments in Eutrophic Waters. Ergeb. Limnol. 2000, 55, 153–168.
15. Mishra, S.; Mishra, D.R.; Schluchter, W.M. A Novel Algorithm for Predicting Phycocyanin Concentrations in Cyanobacteria: A Proximal Hyperspectral Remote Sensing Approach. Remote Sens. 2009, 1, 758–775, doi:10.3390/rs1040758.
16. Mishra, S. Remote Sensing of Harmful Algal Bloom, Mississippi State University, Mississippi State, MS, USA, 2012.

17. Simis, S.G.H.; Peters, S.W.M.; Gons, H.J. Remote Sensing of the Cyanobacterial Pigment Phycocyanin in Turbid Inland Water. Limnol. Oceanogr. 2005, doi:10.4319/lo.2005.50.1.0237.
18. Amin, R.; Zhou, J.; Gilerson, A.; Gross, B.; Moshary, F.; Ahmed, S. Novel Optical Techniques for Detecting and Classifying Toxic Dinoflagellate Karenia Brevis Blooms Using Satellite Imagery. Opt. Express 2009, doi:10.1364/oe.17.009126.
19. Beck, R.; Xu, M.; Zhan, S.; Liu, H.; Johansen, R.A.; Tong, S.; Yang, B.; Shu, S.; Wu, Q.; Wang, S.; et al. Comparison of Satellite Reflectance Algorithms for Estimating Phycocyanin Values and Cyanobacterial Total Biovolume in a Temperate Reservoir Using Coincident Hyperspectral Aircraft Imagery and Dense Coincident Surface Observations. Remote Sens. 2017, doi:10.3390/rs9060538.
20. Dekker, A.G. Detection of Optical Water Quality Parameters for Eutrophic Waters by High Resolution Remote Sensing; 1993; ISBN 9090062343.
21. Mishra, S.; Mishra, D.R.; Schluchter, W.M. A Novel Algorithm for Predicting Phycocyanin Concentrations in Cyanobacteria: A Proximal Hyperspectral Remote Sensing Approach. Remote Sens. 2009, 1, 758–775, doi:10.3390/rs1040758.
22. Ogashawara, I.; Mishra, D.R.; Mishra, S.; Curtarelli, M.P.; Stech, J.L. A Performance Review of Reflectance Based Algorithms for Predicting Phycocyanin Concentrations in Inland Waters. Remote Sens. 2013, 5, 4774–4798, doi:10.3390/rs5104774.
23. Wheeler, S.M.; Morrissey, L.A.; Levine, S.N.; Livingston, G.P.; Vincent, W.F. Mapping Cyanobacterial Blooms in Lake Champlain's Missisquoi Bay Using QuickBird and MERIS Satellite Data. J. Gt. Lakes Res. 2012, 38, 68–75, doi: https://doi.org/10.1016/j.jglr.2011.06.009.