Lower Catawba River Basin – Stream and Lake Nutrient Water Quality Study

Final Report of the 2019 Study

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Executive Summary

During 2019, South Carolina Department of Health and Environmental Control (DHEC) collected water quality data from six stream sites and 11 lake sites in the Lower Catawba River Basin located in north-central South Carolina. The field sampling program spanned 29 weeks from mid-April through the end of October and builds on studies conducted in previous years by stakeholder partners. Bolstered by years of data collected as part of DHEC's ambient monitoring program, the comprehensive data set will assist in calibrating new watershed, lake hydrodynamic, and lake water quality models. The models will be used to inform the development of site-specific numeric nutrient criteria and a total maximum daily load aimed at addressing water quality impairments in the basin.

Broadly, the objectives of the 2019 field study were to quantify nutrient loadings from the prevalent land use types in the basin and to resolve the relationship between physical and chemical conditions and ecological responses in Fishing Creek Reservoir and Lake Wateree, two hydroelectric reservoirs in the system. Samples were collected on a biweekly schedule for 18 unique chemical water quality parameters in the streams and at multiple depths in the lakes. In addition, total chlorophyll-a and photosynthetic pigment samples along with sensor-based vertical profiles for physical parameters were collected in the lakes. Monitoring systems to continuously record physical parameters at the surface were also deployed at two locations; one in the mid-lake area of Fishing Creek Reservoir and one in Lake Wateree off the Dutchman Creek lake arm.

Over the course of the field program:

- Stream total phosphorus (TP) and total nitrogen (TN) concentrations were generally similar in urban and suburban environments. Forested watersheds produced the lowest in-stream TP and TN concentrations. Hay/pasture land use consistently demonstrated the highest TP and TN concentrations.
- TP and TN concentrations were generally higher in Fishing Creek Reservoir compared to Lake Wateree.
- Six of the nine lake sites in which total chlorophyll-a was sampled produced at least one surface measurement exceeding 40 µg/L. Surface total chlorophyll-a at the two stations in the Dutchman Creek area of Lake Wateree exceeded 40 µg/L 23% and 31% of the time, respectively. The chlorophyll-a maximum was, however, frequently observed below the surface (7% to 77% of the time). The highest rates of subsurface chlorophyll-a maximums occurred in the mid-lake area of Lake Wateree.
- For most mid- to down-lake stations, the phytoplankton community composition early in the season (May and June) was relatively homogenous with important contributions of diatoms, cryptophytes, chlorophytes, and cyanobacteria to total chlorophyll-a. Cyanobacteria increased in presence as the season progressed (July to September) to approximately 50-70% of the total chlorophyll-a.
- Dissolved oxygen at the two surface continuous monitoring stations demonstrated daily ranges (maximum minus minimum) of 2.7 mg/L on average (range of 0.3 to 6.0 mg/L). Daily minimums typically occur overnight and maximums occur during the daytime. Daily maximum pH values exceeded 8.5 on 73% and 76% of the total days for the two stations, respectively, between early June and the end of October.

Overview of the Lower Catawba Stream and Lake Nutrient Study

The Lower Catawba River Basin (Lower Catawba) includes the watershed drainage from the tailrace at Lake Wylie in Fort Mill, South Carolina, to the tailrace at Lake Wateree in Kershaw County, South Carolina. The system is one of the major watersheds for the city of Charlotte, North Carolina, and its south suburbs including rapidly growing York County, South Carolina. More than 30 ambient monitoring locations in the Lower Catawba are included in the state's draft 2018 303(d) list as impaired for total phosphorus, total nitrogen, and/or chlorophyll-a. In addition, blooms of planktonic *Microcystis* and colonies of *Lyngbya wollei*, a filamentous, mat-forming algae are commonly present in Lake Wateree during the hot summer months. These cyanobacteria produce toxins known to cause swimmer's itch, respiratory problems, and taste and odor issues in drinking water. As such, the dischargers in the Lower Catawba have asked South Carolina Department of Health and Environmental Control (DHEC) to develop site-specific numeric nutrient and chlorophyll-a standards for the system and to use those standards to develop a total maximum daily load (TMDL) for the system aimed at addressing water quality impairments impacting designated uses. In April 2019, DHEC implemented the *Lower Catawba River Basin – Stream and Lake Nutrient Water Quality Study* (Nutrient Study) and companion projects to produce an enhanced suite of environmental data. The new data will be coupled with previous studies and ambient water quality monitoring data to develop new watershed, lake hydrodynamic, and lake water quality models which will assist in informing site-specific numeric criteria for the Lower Catawba system. This report is a summary of the outcomes of the Nutrient Study and documents successes and lessons learned for improvement in future project delivery.

Nutrient Study Project/Task Description

Field Logistics

The stream and lake program spanned 29 weeks from 4/16 to 10/31/2019, which includes two weeks covered by the Lower Catawba River Basin Field Sampling and Training Program in April[1]. The stream portion of the training program was largely successful with the exception that station LCT-01 (Little Sugar Creek) was not sampled as the DHEC Bureau of Water (BOW) 303(d), Modeling & TMDL Section (TMDL) was still evaluating an optimal sampling site in Charlotte, North Carolina. Stream site coordinates are presented in Table 1. A sampling event on Fishing Creek Reservoir was not planned as part of the field training program. Three of the five proposed sites in Lake Wateree were sampled on 4/24 due to logistical issues associated with the initiation of the project.

Following the first two sampling events in the lakes (Lake Wateree on 4/24 and Fishing Creek Reservoir on 5/2), an amendment (Amendment hereafter) was prepared to incorporate lessons learned at the originally proposed sites (Amendment to the Lower Catawba River Basin QAPP (April 30, 2019)). The changes included adjusting the number of samples collected at some sites based on depth, addition of two water quality sites in Fishing Creek Reservoir (LCR-05 and LCR-04), and addition of two hydrographic

[1] Development of the comprehensive 2019 field program began in the fall of 2018 and concluded in the early spring of 2019. The project development team consisted of a core group from the BOW TMDL and Aquatic Science Programs (ASP) Sections. Participants from the TMDL group included Wade Cantrell, Yoichi Matsuzuru, Matt Carswell, Wayne Harden, Feleke Arega, and Matthew Baumann. Aquatic Science Programs was represented by Bryan Rabon, Ronnie Martin, and David Chestnut. The QAPP was written by M. Baumann with valuable input from BOW Quality Assurance team (David Graves and Rusty Wenerick) and BEHS management (Susan Jackson, Carey Merriweather, and Paul Miller).

profile sites in the Dutchman Creek area of Lake Wateree (LCR-03A and LCR-03B). These updates are summarized in Section 1 of the Amendment and lake stations are presented in Figure 1 of this report. The Amendment also added dissolved silica to the stream and lake sites and dissolved and total iron to the lake sites based on specific sampling strategies identified in Sections 2 and 3 of the Amendment.

Stream[2] and Fishing Creek Reservoir[3] field sampling was generally conducted on Tuesdays instead of the Tuesday/Wednesday strategy indicated in Table 2 of the Nutrient Study. Sampling on the same day simplified logistics for the field teams and the laboratory. Samples were delivered to the laboratory on the day of collection[4,5]. Lake Wateree sampling also occurred on Tuesdays and samples were delivered the morning after collection due to the relatively long field day. The contingency weeks in November were not needed because weather did not cancel sampling in any week.

All parameters listed in Section A6 of the Nutrient Study were collected largely as presented in the Nutrient Study with a few exceptions. Photosynthetic pigments were collected on every lake trip at one to three depths per site to increase temporal resolution[6]. Field measurements for phycocyanin and turbidity were initiated on the 5/29 sampling of Fishing Creek Reservoir once calibration standards were available. Dissolved BOD_5 collection began on the 6/11 stream sampling event.

Stream sampling was conducted primarily with a metal bucket. Dissolved samples were collected using the vacuum pump system described in the Nutrient Study once dissolved BOD_5 was initiated except for DOC which was filtered using a 25mm pre-combusted glass fiber filter (nominal pore size of 0.7 µm). Prior to 6/11, samples were hand filtered using a syringe and a 25 mm (Whatman) or 33 mm (Millex), 0.45 µm pore size syringe filter cartridge. Sampling was not conducted at RS-17340 on three occasions (9/17/2019, 10/1/2019 and 10/15/2019) and once at RS-19476 (10/15/2019) over the course of the program due to lack of water in the channel.

Lake surface samples (~0.3 m depth) were collected using a van Dorn sampler and subsurface samples were collected using a five liter Niskin attached to a graduated rope with a five pound deadweight[7]. Vertical hydrographic profiles and photosynthetic active radiation (PAR) depths were collected at each site. All filtering was conducted using a syringe and Millex syringe filter cartridge except for DOC which was filtered using a 25mm pre-combusted glass fiber filter. This method of field filtering was more efficient than using a vacuum powered filter manifold on a boat. The field team was able to control and minimize sources of possible contamination using the syringe method.

Continuous monitoring buoys were deployed at LCR-04 in Fishing Creek Reservoir and LCR-03 in Lake Wateree on 6/7. Field collection of data continued until 12/3. The instruments recorded measurements

[2] Stream sampling, which included the Lake Wylie tailrace (a companion study), was conducted primarily by BOW TMDL staff: Susan Waldner, M. Carswell, Y. Matsuzuru, W. Cantrell, F. Arega, and W. Harden.

[3] Sampling of both Fishing Creek Reservoir and Lake Wateree was conducted by a team of TMDL and ASP personnel: Jordan Elmore (BOW Watersheds and Nonpoint Source Section), M. Baumann, R. Martin, Nick Pangborn, and Kay Wilson with periodic assistance from W. Cantrell, Y. Matsuzuru, and F. Arega.

[4] Samples were received by BEHS ARESD personnel: Chris Cole, Chip Conyers, Lauren Faulk, and Tyler Dunlop.

[5] The BEHS ARESD laboratory team included Benjamin Watkins, Eric Sorrells, Georgia Dahlquist, David Holland, Sarah Fisher, Nicholas Carnabuchi, Cassandra Green, Justin Souther as well as C. Conyers, L. Faulk, and T. Dunlop.

[6] Photosynthetic pigment samples were analyzed by the University of South Carolina Estuarine Ecology Laboratory (Dr. Jay Pinckney).

[7] Laboratory total chlorophyll-a samples were processed and analyzed by Emily Bores and Taylor Shearer of ASP.

at 0.6 m to 1.0 m at 15 minute intervals. The buoys were serviced every two weeks, except for the last two series which were serviced after three weeks[8]. Servicing included a cleaning of the buoy and sonde, data download, and replacement of the sensors. Most deployments were successful for the parameters of interest with a few exceptions.

Table 1. Locations and site descriptions of the stream stations.

Station	Lat./Long.	County	Site Description
CW-014	34.9858 / -80.9743	York	Catawba River at US-21
LCT-01	35.1790 / -80.8462	Mecklenburg (NC)	Little Sugar Creek at Hillside Ave.
LCT-02	34.9865 / -81.0085	York	Big Dutchman Creek at Mt. Gallant Rd. (tributary of Catawba River)
LCT-03	34.3679 / -80.9547	Fairfield	Dutchmans Creek at US-21 (tributary of Lake Wateree)
RS-19476	34.8152 / -81.1302	Chester	South Fork of Fishing Creek at S-12-192 Harvey Neely Rd.
RS-17340	34.5900 / -80.9739	Chester	Little Rocky Creek at S-12-52 Ross Dye Rd.

Figure 1. Site locations in Fishing Creek Reservoir and Lake Wateree.

Sensor Data

Surface Parameters

Surface physical parameters were collected at a depth of 0.3 m at each stream site using a calibrated Hydrolab DS5X. Sampling was conducted in the morning; all samples were collected between 08:30 and 15:30, with the majority (90%) collected before 13:00. Routine physical parameters included pH, optical

[8] Servicing of the continuous monitoring systems was conducted by R. Martin, K. Wilson, and M. Baumann.

dissolved oxygen (DO), temperature, chlorophyll-a, and turbidity. The ranges in recorded values for each parameter are presented in Table 2.

Table 2. Range (minimum and maximum) for each field parameter over the 4/16/2019 – 10/29/2019 period at the stream sites. As noted previously, RS-17340 was not sampled on three occasions and RS-19476 was not sampled on one occasion late in the season because of insufficient flow in the channels. Turbidity measurements began on 7/25/2019.

Station	Field pH (SU)	Field DO (mg/L)	Water Temp (°C)	Spec. Cond. (µS/cm)	Chl-a (µg/L)	Turbidity (NTU)
CW-014	6.95 - 7.60	6.34 - 11.32	14.5 - 28.3	13 - 80	2.7 - 23.3	23.3 - 31.1
LCT-01	6.77 - 7.60	4.40 - 8.20	17.6 - 26.3	158 - 329	2.0 - 7.8	1.6 - 19.3
LCT-02	6.59 - 7.70	6.61 - 9.37	14.6 - 27.2	36 - 263	1.6 - 5.3	1.5 - 10.0
LCT-03	6.83 - 7.58	2.84 - 8.86	15.7 - 25.2	119 - 364	1.8 - 9.8	23.4 - 127.0
RS-17340	6.89 - 7.49	4.61 - 8.89	16.5 - 24.3	83 - 129	0.4 - 5.5	24.0 - 31.6
RS-19476	6.89 - 7.35	2.26 - 8.90	15.3 - 25.0	105 - 260	1.6 - 15.3	24.9 - 124.8

An expanded suite of surface measurements was collected at each lake site. Surface readings were recorded at a depth of 0.3 m using a calibrated YSI EXO2 (Table 3). In addition, upper water column features were measured such as penetration depth of photosynthetically active radiation (PAR, 400-700 nm wavelength, µmol m^{-2} s^{-1}) using a LI-COR light meter and a LI-1400 data logger, water clarity expressed as secchi depth, and depths of chlorophyll-a and phycocyanin (a measure of blue-green algae or cyanobacteria) maximums (Table 4). PAR depth was determined as the depth in which PAR decays to 1% of its ambient value. The chlorophyll-a and phycocyanin maximums were determined from the vertical profile downcast and described as either a maximum depth or vertical band where pigment fluorescence was highest.

Table 3. Range (minimum and maximum) for each field parameter at the surface over the 4/16/2019 – 10/29/2019 period at the lake sites. Turbidity and phycocyanin measurements began on 5/29/2019.

Station	Field pH (SU)	Field DO (mg/L)	Water Temp (°C)	Spec. Cond. (µS/cm)	Chl-a (µg/L)	Phycocyanin (µg/L)	Turbidity (FNU)
Fishing Creek Reservoir							
LCR-01	6.77 - 8.69	7.04 - 10.05	20.9 - 31.6	67 - 163	0.8 - 12.4	0.3 - 4.1	3.1 - 27.0
LCR-05	7.16 - 9.40	6.45 - 11.70	21.1 - 31.3	78 - 153	0.9 - 15.7	3.0 - 6.8	1.5 - 11.3
LCR-04	7.24 - 9.32	6.67 - 11.86	21.2 - 31.1	81 - 155	1.0 - 17.3	2.6 - 7.0	1.3 - 11.1
CW-057	6.84 - 9.32	6.71 - 11.27	21.6 - 30.2	72 - 157	1.9 - 12.6	1.2 - 8.5	1.2 - 17.8
Lake Wateree							
LCR-02	6.95 - 9.17	6.35 - 12.12	20.3 - 31.3	74 - 233	0.7 - 17.6	0.6 - 4.9	2.6 - 14.8
CW-208	7.89 - 9.93	6.74 - 13.80	21.5 - 34.5	85 - 223	1.9 - 22.1	2.7 - 11.2	1.4 - 7.1
LCR-03	7.41 - 9.59	6.10 - 12.50	21.6 - 32.6	82 - 232	2.0 - 26.2	3.1 - 11.1	1.3 - 28.9
LCR-03A	7.32 - 9.67	6.04 - 12.66	21.9 - 33.3	82 - 233	5.5 - 20.1	2.3 - 12.1	1.5 - 10.9
LCR-03B	7.54 - 9.78	6.38 - 12.06	21.8 - 33.8	80 - 231	4.9 - 26.8	3.0 - 9.1	1.2 - 9.6
CW-207B	6.99 - 9.47	4.42 - 11.94	21.7 - 31.6	83 - 205	1.5 - 21.2	2.7 - 14.3	1.0 - 3.0
CL-089	6.87 - 9.32	2.25 - 10.09	22.5 - 30.9	79 - 189	1.6 - 19.5	1.4 - 10.4	0.6 - 2.2

Table 4. Ranges of additional upper water column features at the lake sites. PAR depth (photosynthetically active radiation) is the depth of penetration of light usable by photosynthetic organisms (visible spectrum of 400-700 nm). Secchi depth is a measure of the water clarity or transparency and is an indicator of relative turbidity. The algal maxes (chl-a and phycocyanin) were determined from the vertical profile collected at each station and represents either a depth or vertical band of maximum fluorescence depending on the nature of the profile.

Station	PAR Depth (m)	Secchi Depth (m)	Chl-a max (m)	Phycocyanin max (m)
Fishing Creek Reservoir				
LCR-01	1.3 - 2.7	0.25 - 0.75	0.3 - 1.0	0.3 - 0.3
LCR-05	1.1 - 3.3	0.35 - 0.90	0.3 - 1.0	0.3 - 1.5
LCR-04	1.2 - 3.4	0.30 - 0.95	0.3 - 1.3	0.3 - 1.5
CW-057	1.4 - 3.5	0.35 - 1.10	0.3 - 3.3	0.3 - 1.5
Lake Wateree				
LCR-02	1.3 - 3.5	0.30 - 0.90	0.3 - 1.5	0.3 - 1.0
CW-208	1.2 - 3.1	0.50 - 1.10	0.3 - 2.0	0.3 - 2.4
LCR-03	1.6 - 3.3	0.50 - 1.00	0.3 - 1.5	0.3 - 1.6
LCR-03A	1.5 - 3.2	0.50 - 0.80	0.3 - 1.5	0.3 - 1.5
LCR-03B	1.6 - 3.2	0.50 - 0.80	0.3 - 1.5	0.3 - 1.5
CW-207B	2.1 - 4.0	0.50 - 1.20	0.3 - 1.5	0.3 - 1.5
CL-089	2.4 - 4.1	0.70 - 1.30	0.3 - 11.8	0.3 - 8.0

Vertical Profile

Vertical profiles were collected at each lake site visit using the YSI EXO2. The casts were conducted manually, but data were logged by the instrument every two seconds. The sonde was gradually lowered through the water column (downcast) until contact was made with the lake bottom and then retrieved at a similar rate. An Excel tool was created to process raw vertical profile data. The tool extracts the downcast from the profile record by identifying when instrument descent was initiated and when retrieval began after contacting the lake bottom. The bottom depth for the profile could be manually adjusted if necessary to remove the effects of sediment resuspension. The program then averaged the downcast data in half meter intervals. Eight parameters were processed for each profile: water temperature, DO concentration, DO percent saturation, pH, turbidity, specific conductance, chlorophyll-a concentration, and phycocyanin concentration.

In total, 153 vertical profiles were collected as part of the Nutrient Study. Twelve to 15 profiles were collected at each site; the total largely dependent on when the site was established. Additional profiles were collected in association with other aspects of the Lower Catawba program and are considered together with the Nutrient Study profiles.

Because profiles are collected on an approximately biweekly schedule, the data can be used to illustrate the evolution of the water column over the course of the field program, but they do not capture diel variability. Section graphs of water temperature, DO concentration, and specific conductance for each station are presented in Appendix A. The graphs represent an interpolation of the processed profiles and have been formatted to account for common misrepresentations and artifacts. Each station has a unique time axis to minimize extrapolation outside of the period of record. The processed data points from the vertical profiles used for the interpolations are also presented in Appendix A.

Continuous Monitoring

Continuous monitoring systems were deployed at LCR-04 in Fishing Creek Reservoir and LCR-03 in Lake Wateree on 6/7/2019. Twelve consecutive deployments were conducted at each site. Each deployment was two weeks in duration except the last two at each site which were three weeks in length. The buoy systems were recovered on 12/3/2019. A data recording interval of 15 minutes was used for each deployment. Telemetry was not employed, and data were recovered manually during buoy servicing. Battery strength was sufficient for two to three week deployments.

End verifications for DO, pH, and specific conductance were generally successful throughout the program. Dissolved oxygen verified for all deployments except for LCR-03 Series 11 (10/24/2019 – 11/14/2019). However, the sensor deployed for Series 11 at LCR-04 verified with a similar DO concentration. A laboratory temperature anomaly of two degrees Celsius between the two verifications may explain the failure of LCR-03 Series 11. It is unlikely the standard would saturate over the short time period between verifications; therefore, the data for LCR-03 Series were determined acceptable. The pH verification failed for one deployment (LCR-04 Series 5, 8/1/2019). Because the pH transitions between Series 6 and the previous and succeeding deployments were within normal diel variability the data were not rejected. Specific conductance verified for each deployment.

Verifications for the total algae (chlorophyll-a and phycocyanin) and turbidity sensors are not based on meeting specific metrics. Usability of these data were assessed by evaluating both transitions/continuity of pigment and turbidity records from series to series and the results of end verification. Table 5 summarizes the end of deployment verifications for these three parameters. The verifications for chlorophyll-a and phycocyanin were within 10% of the standard for 71% and 82% of the deployments, respectively. Turbidity verifications were within 10% of the standard for 54% of the deployments.

Table 5. Summary of end of deployment verifications for chlorophyll-a, phycocyanin, and turbidity.

	No. of Deployments	< 10%	10-20%	> 20%
Chlorophyll-a	24	17	4	3
Phycocyanin	22	18	3	1
Turbidity	24	13	8	3

Pigments

Fluorometer Based Chlorophyll-a

A total of 305 lakes samples were collected for fluorometer based total chlorophyll-a analysis. Samples were collected at between one and three depths per site depending on location, depth, and program objectives. Of the total, 277 samples were successfully analyzed. Five samples from Fishing Creek Reservoir collected on 5/2/2019 were lost due to a calibration issue with the fluorometer. Ten samples from Fishing Creek Reservoir on 5/15/2019 were lost due to a communication error between field staff and ASP laboratory personnel. Thirteen Lake Wateree samples collected on 8/13/2019 were analyzed beyond the holding time of 36 hours. Though the 8/13/2019 samples cannot be used for assessment purposes, the values have not been discarded for use in modeling activities because they compare well with corresponding High Performance Liquid Chromatograph (HPLC) derived total chlorophyll-a concentrations.

HPLC Based Photosynthetic and Accessory Pigments

A total of 258 samples were collected and analyzed by HPLC for a suite of approximately 22 photosynthetic and accessory pigments and carotenoids attributed to the phytoplankton community. The Nutrient Study identified a once per month (i.e., every other lake trip) sampling strategy; however, sample frequency was increased to every trip to improve resolution while still maintaining the sample budget agreed to with the University of South Carolina (UofSC) Estuarine Ecology Laboratory (Dr. Jay Pinckney). As with the fluorometer chlorophyll-a samples, samples for HPLC analysis were collected at between one and three depths based on location, depth, and program objectives. Samples were filtered (~100 mL was sufficient for HPLC analysis) immediately upon return to the laboratory and stored in a conventional freezer for a maximum of two to three weeks. Frozen samples were delivered to UofSC every two to three weeks.

The abundances of specific phytoplankton groups were estimated from indicator pigment concentrations relative to total chlorophyll-a using the CHEMTAX program[9]. CHEMTAX estimates the contribution of algal taxa by iteratively modifying user-specified pigment: chlorophyll-a ratios (initial matrix) using a steepest descent algorithm to successively reduce the root mean square of the residuals. The initial matrix was adapted from Schluter et al. (2006)[10] for phytoplankton groups known to occur in the lakes of the Lower Catawba Basin based on recent microscopy (cyanobacteria, chlorophytes, diatoms, cryptophytes, dinoflagellates, and euglenophytes).

Water Quality

Streams

Each stream site was sampled 12-15 times over the course of the project (Table 6). As stated previously, stations RS-17340 and RS-19476 were not sampled on three and one occasions, respectively, due to insufficient flow in the streams on scheduled sampling days. As such, each stream station satisfied the completeness data quality indicator (DQI) as no visits were missed as a result of human error. Completeness for each station, as assessed by sample opportunities, is determined to be 100%. Further, the project operated under a biweekly sampling schedule, which ensured that the samples collected at each site were evenly distributed across the study time-frame removing any bias towards a specific period of the season.

[9] Mackey, M.D., Mackey, D.J., Higgins, H.W. and S.W. Wright. 1996. CHEMTAX – A program for estimating class abundances from chemical markers: Application to HPLC measurements of phytoplankton. Marine Ecology Progress Series, 144(1-3), 265-283.

[10] Schluter, L., Lauridsen, T.L., Krogh, G. and T. Jorgensen. 2006. Identification and quantification of phytoplankton groups in lakes using new pigment ratios – a comparison between pigment analysis by HPLC and microscopy. *Freshwater Biology*, 51, 1474-1485.

Table 6. Total site visits and total samples collected for the six stream sites. No site visits were missed as a result of human error. Three samples were not collected at RS-17340 and one sample was not collected at RS-19476 because flow in the stream at the time of sampling was insufficient.

Station	Site Visits	Total Samples
CW-014	15	15
LCT-01	14	14
LCT-02	15	15
LCT-03	15	15
RS-17340	15	12
RS-19476	15	14

Lakes

Each water quality lake site was sampled 13-14 times depending on when the site was initiated (Table 7). LCR-04 and LCR-05 were added after the first trip to Fishing Creek Reservoir. The addition of these sites along with an updated lake sampling strategy was addressed as part of the Amendment. For the Fishing Creek Reservoir sites, completeness is determined to be 100% as no samples or depths were omitted as a result of human decision or error. As stated above, the first trip to Lake Wateree on 4/24/2019 included three of the five anticipated sites. Due to logistical issues and time constraints, sampling of LCR-03 and CW-208 on this date was not conducted resulting in completeness of 93% for these sites. Sites LCR-02, CW-207B, and CL-089 were successfully sampled each trip and therefore are assessed at 100% completeness. As with the stream component, lake sampling followed a biweekly schedule and samples were evenly distributed over the course of the study.

Table 7. Total site visits and total samples collected for the nine water quality lake stations. The only samples missed were CW-208 and LCR-03 on 4/24/2019.

Station	Site Visits	Depths Sampled Per Visit	Total Samples
Fishing Creek Reservoir			
LCR-01	14	1	14
LCR-05	13	2	26
LCR-04	13	3	39
CW-057	14	4	56
Lake Wateree			
LCR-02	14	4	56
CW-208	13	3	39
LCR-03	13	3	39
CW-207B	14	4	56
CL-089	14	4	56

Summary of Findings

Vertical Profile

The following section presents a brief discussion of notable observations in the lake vertical profile data. Section graphs for temperature, dissolved oxygen, and specific conductance generated using the processed vertical profile data for each station are presented in Appendix A.

Temperature

The upstream stations in both lakes (Figure 1; LCR-01 in Fishing Creek Reservoir, ~3.2 m total depth, and LCR-02 in Lake Wateree, ~7 m total depth) demonstrated little temperature stratification over the course of the field program, likely due to the more riverine character of the sites. Both sites exhibited water temperatures of ~20°C in late April and early May. Water temperatures increased throughout the season to maximums of 30 and 31°C, respectively, in mid-August.

Four Lake Wateree vertical profile sites were located in the Dutchman Creek area (Figure 1 inset; LCR-03, LCR-03A, LCR-03B, and CW-208). Temperatures within the upper 2-3 m increased to >30°C in early July and persisted until mid-September. LCR-03 is an open water lake site off the Dutchman Creek arm with a total depth of 4.3 m. The shallow site stratified slightly in mid-July as surface temperatures were ~2°C (33°C) warmer than near the bottom (30-31°C). LCR-03A (mid-lake main channel, 9 m depth) and LCR-03B (Dutchman Creek channel near embayment mouth, 8 m depth) temperature stratified in a similar manner as LCR-03. Despite greater total depths at these sites, bottom temperatures approached 30°C in late July. CW-208 is centered in the Dutchman Creek arm with a total depth of 5.5 m. The site exhibited the warmest surface water temperature observed during the field program at >34°C. As such, the site temperature stratified slightly in late-July and August despite bottom temperatures >30°C.

The mid-lake sites (Figure 1; LCR-04 in Fishing Creek Reservoir, 7.2 m depth, and CW-207B in Lake Wateree, 7.5 m depth) demonstrated little stratification as temperatures were generally consistent vertically.

The general vertical consistency in temperature across the system may be partly explained by lake dynamics and dam operations. Evidence for constant and rapid flow through may be present in the profiles collected at site CL-089 (~17 m depth) in the Lake Wateree forebay (Figure 1). The temperature and DO profiles at the site in late-July indicate potential mixing of higher temperature surface water to the bottom and injection of low DO water to the surface. The profile collected on 7/30/2019 showed uniform water temperatures of 29°C from surface to the bottom with DO concentrations of less than 4 mg/L over the upper ten meters, then decreasing to hypoxic and anoxic conditions in deeper waters. These features persisted over the following month and may indicate a rapid infill and replacement of water in the forebay and mechanical mixing of this region of the lake by dam operations.

Dissolved Oxygen

Concentrations of dissolved oxygen are mediated by both biological and physical processes in the lakes. The two upstream lake stations (LCR-01 and LCR-02) were generally near DO saturation levels. These riverine-like stations have lower stocks of phytoplankton biomass based on both sensor and laboratory chlorophyll-a levels and DO is likely controlled more by physical processes such as water flow and temperature.

Most other stations, including the four Lake Wateree stations near Dutchman Creek appeared to exhibit more biological influence on DO than physical control, particularly in the summer months. At these stations, DO in the upper water column and within the photic zone was supersaturated and under saturated in deeper waters. Further, DO at the surface exhibited diel fluctuations with DO maximums occurring mid-day and minimums occurring overnight consistent with the pattern of daytime photosynthesis and overnight respiration based on continuous monitoring data (discussion to follow).

As suggested previously, the Lake Wateree forebay (CL-089) may be influenced more by dam mechanical operations than by other physical conditions or biological activity. Deeper photic zones, occasionally deep algal maximums (Table 4), and lower total chlorophyll-a concentrations may further highlight the importance of mechanical vertical mixing in this area of Lake Wateree.

Specific Conductance

Specific conductance was typically uniform throughout the water column at all sites and is likely a good indicator of flow through the system. This is evidenced by a high flow rain event that occurred in the Catawba watershed in early June. Prior to this event, ionic strength had been increasing in the system. Following the flushing event, specific conductance decreased by approximately half across all stations. The summer was relatively dry and specific conductance gradually increased for the remainder of the field program. The increase may be due to a combination of evaporation and groundwater input to the system.

Continuous Monitoring

The continuous monitoring program collected quarter hourly surface data (0.6-1.0 m) at LCR-04 in Fishing Creek Reservoir and LCR-03 in Lake Wateree from 6/7/2019 to 12/3/2019 resulting in a 179 day record for each site. As stated previously, end of deployment verifications for DO, pH, and specific conductance were largely successful and as such the records for these parameters as well as temperature are complete and continuous. Chlorophyll-a, phycocyanin, and turbidity presented more challenges related to verification and thus continuity of the record.

Temperature

The continuous temperature records for stations LCR-04 and LCR-03 were generally similar across the periods of record. Surface temperatures were above 25°C when the systems were deployed in early June. From July through early October, surface temperatures were consistently near 30°C. Surface temperatures progressively decreased after approximately the first week of October to 11-13°C when the continuous monitoring systems were retrieved in early December (Figure 2).

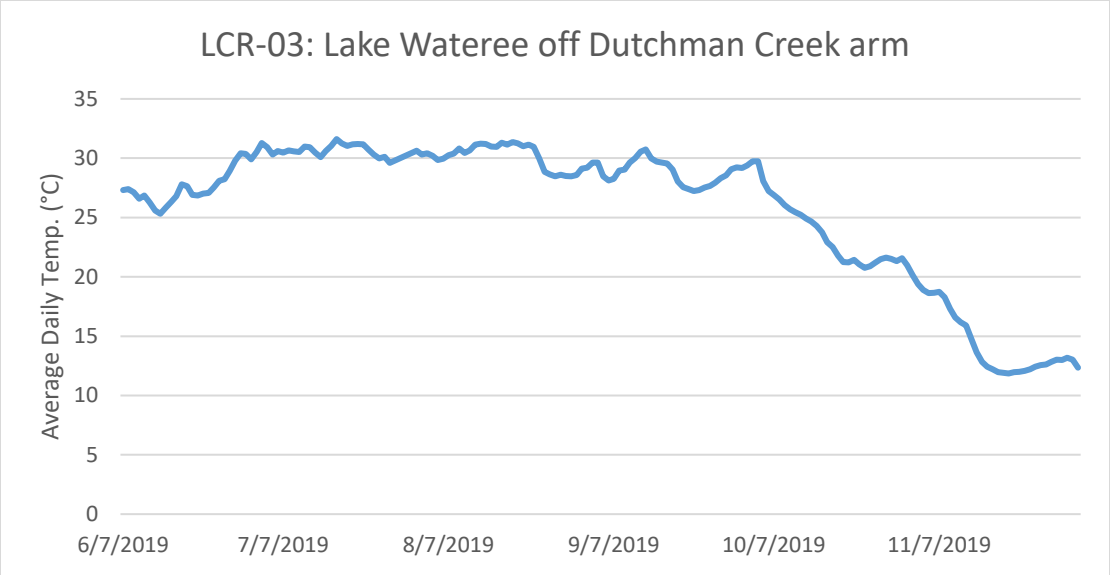


Figure 2. Continuous temperature record for LCR-03 in Lake Wateree at depths 0.5-1.0 m. The temperature record for LCR-04 is not included here as the trajectory for the station is similar in both pattern and magnitude to LCR-03.

Dissolved Oxygen and pH

As stated above, the integrated vertical profile data are useful in illustrating the seasonal progression (week over week) of hydrographic features over the entire water column. However, because the profiles were collected on a biweekly basis, the data do not explicitly capture diel variations in parameters that are, in part, biologically controlled. The continuous monitoring data can be used to show how phytoplankton potentially influence surface levels of DO and pH.

Figures 3 and 4 present daily minimum and maximum DO concentrations at LCR-03 and LCR-04, respectively. Considering only the June-October period, the average difference between daily minimum and maximum DO concentrations was 2.6 mg/L (range: 0.3 mg/L to 5.6 mg/L) for LCR-03 and 2.7 mg/L (range: 0.3 mg/L to 6.3 mg/L) for LCR-04. Figures 5 and 6 illustrate the daily minimum and maximum pH for the two stations. Considering the June through October period, the average difference between daily minimum and maximum pH values was 0.96 SU (range: 0.04 SU to 2.08 SU) and 0.82 SU (0.06 SU to 2.00 SU) for LCR-03 and LCR-04, respectively.

Both pH records exhibited frequent occurrences in which the daily maximum pH would have exceeded the South Carolina state standard range of acceptable pH for freshwaters (6.0-8.5). Elevated pH, as defined by state standards, is typically attributed to algal growth. The monitoring record for LCR-03 is 132 total days between 6/7 and 10/31 omitting a two week period between in late July related to a malfunction of the DO sensor (7/17-7/31; see arrows in Figure 3). The daily maximum pH exceeded 8.5 on 97 days; an exceedance rate of 73% (Figure 5). Similarly, the record at station LCR-04 is 133 total days between 6/7 and 10/31 omitting records between 6/20 and 7/3 due to a failure of the DO sensor (see arrows in Figure 4). Daily exceedances of the pH standard occurred on 76% of the record (101 days; Figure 6).

Further, a 15 day period (9/12 through 9/26) for station LCR-03 produced 11 maximum daily values exceeding a pH of 10 (Figure 5). At station LCR-04, maximum pH exceeded 10 each day for six consecutive days in August (Figure 6; 8/8 through 8/13). These periods of elevated pH coincided with occurrences of

relatively high maximum DO at each site (Figures 3 and 4). Co-occurring high pH and high DO is most likely attributable to upper water column algal growth.

The importance of phytoplankton on diel DO variability can be further investigated using the daily integrated DO records. Figures 7 and 8 present median DO percent saturation on an hourly basis for both stations for the June through October period. The relative changes in DO percent saturation highlight the daily cycle of algal photosynthesis during the day and respiration at night. The ranges in DO percent saturation in each hour were relatively large; however, plots of minimum and maximum DO percent saturations yield the same response of photosynthesis increasing DO percent saturation throughout the daytime hours and nighttime respiration progressively decreasing saturation.

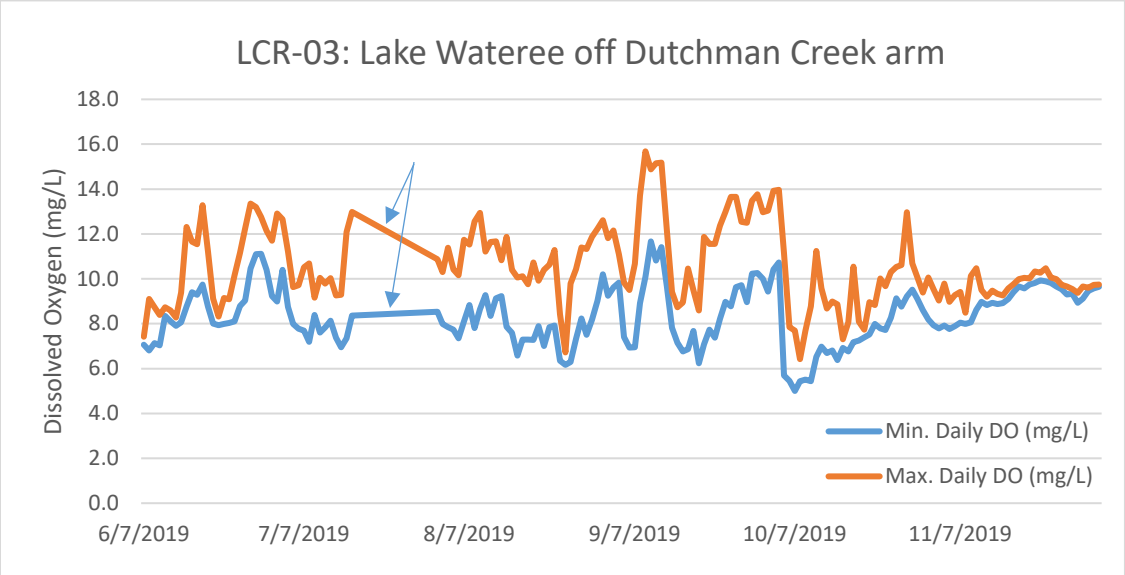


Figure 3. Daily minimum (blue) and maximum (orange) DO concentrations (mg/L) observed at station LCR-03. Data between 7/17 and 7/31 (arrows) are not included due to a combination of an improperly functioning sensor and data loss of a partial record.

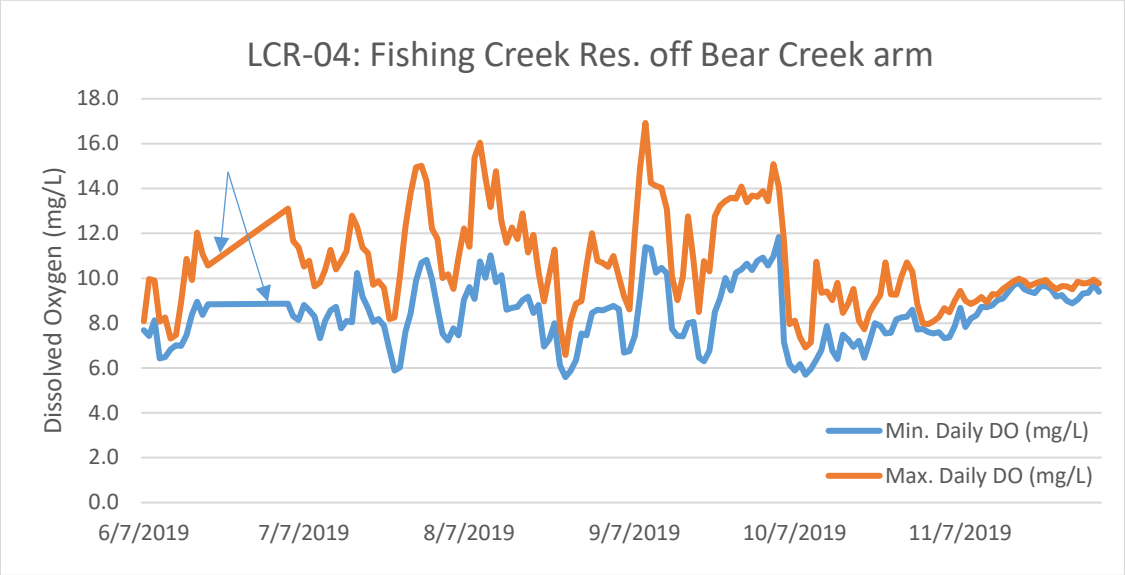


Figure 4. Daily minimum (blue) and maximum (orange) DO concentrations (mg/L) observed at station LCR-04. Data between 6/20 and 7/3 (arrows) are not included due to an improperly functioning sensor.

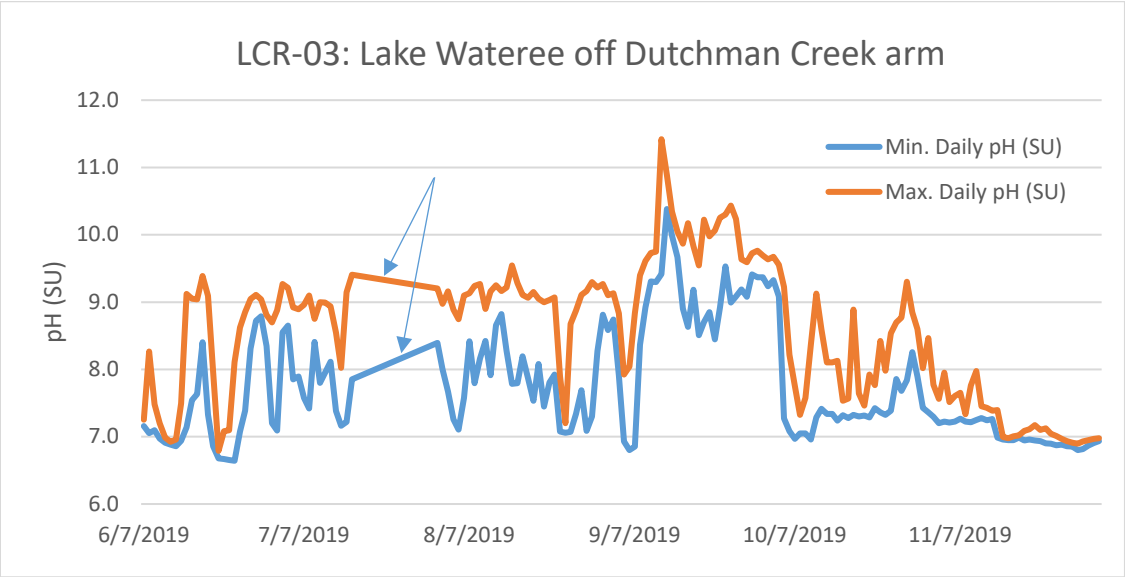


Figure 5. Daily minimum (blue) and maximum (orange) pH observed at station LCR-03. Data between 7/17 and 7/31 (arrows) are not included to allow for direct comparison with the LCR-03 DO record.

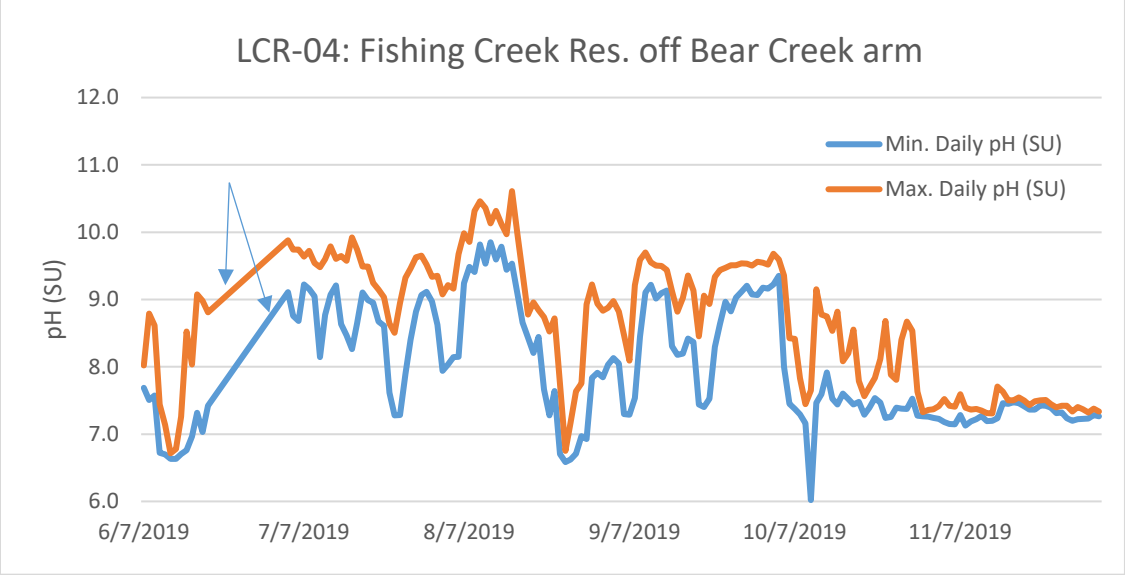


Figure 6. Daily minimum (blue) and maximum (orange) pH observed at station LCR-04. Data between 6/20 and 7/3 (arrows) are not included to allow for direct comparison with the LCR-04 DO record.

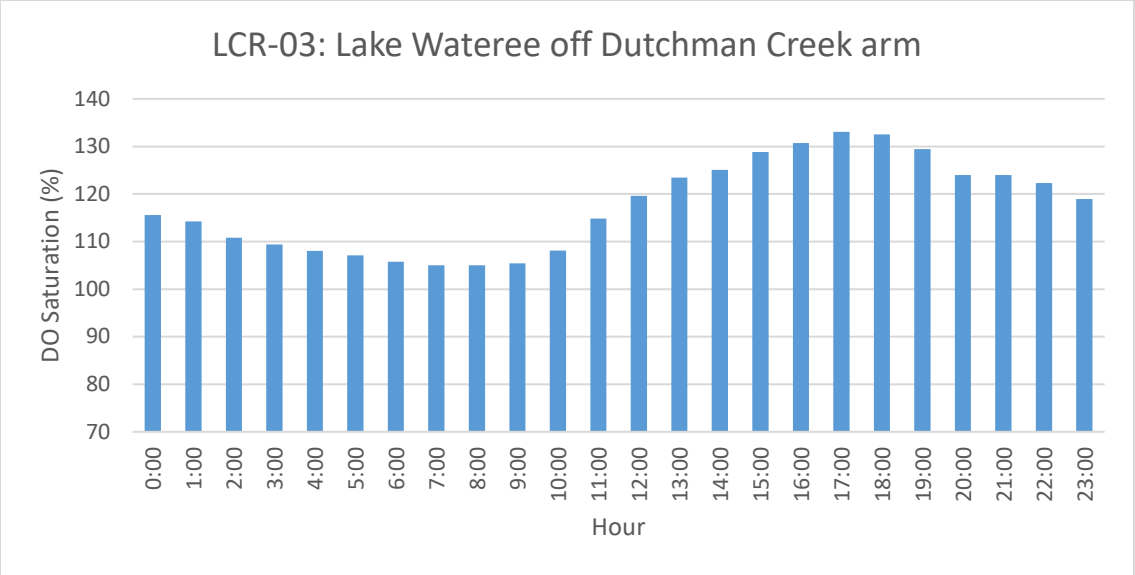


Figure 7. Hour by hour median DO percent saturation for June through October at station LCR-03.

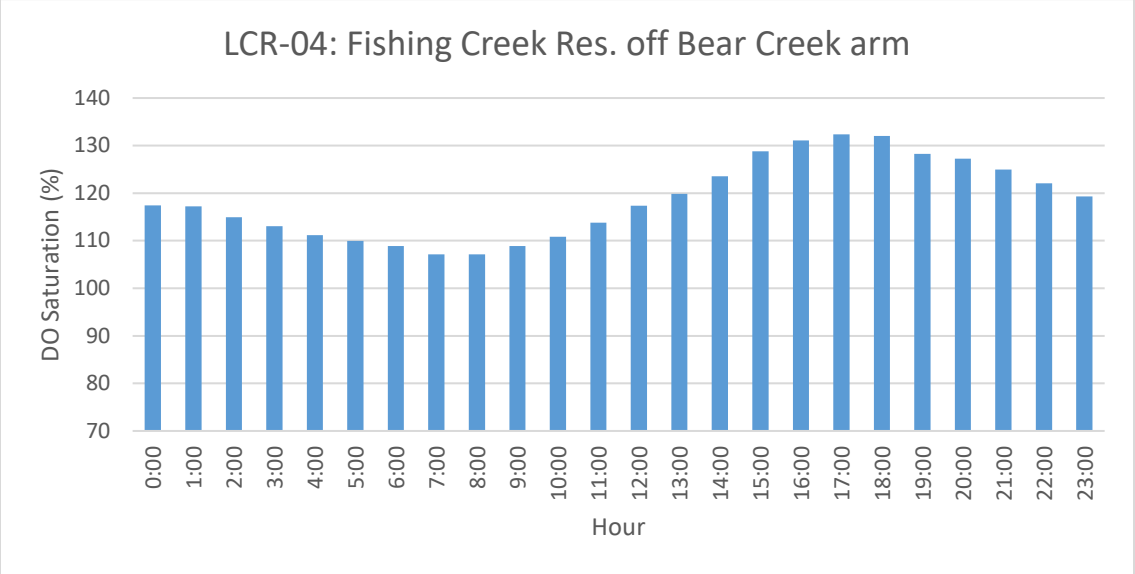


Figure 8. Hour by hour median DO percent saturation for June through October at station LCR-04.

Pigments

Total Chlorophyll-a Technique Comparison

The robust fluorometer and HPLC based total chlorophyll-a data sets provide an opportunity to compare methods for samples collected at many different sites, multiple depths, and across seasons. Simple regression analysis of the data indicates a strong relationship between the methods (Figure 9; $R^2 = 0.94$). The slope of the linear fit (m=0.81) suggests that in general the fluorometer technique yields total chlorophyll-a concentrations ~20-25% greater than the HPLC technique. This is expected as fluorometer based methods cannot fully discriminate between other chlorophylls such as chlorophyll-c and chlorophyllide-a leading to a small overestimation of the 'true' chlorophyll-a concentration (J. Pinckney, pers. comm.).

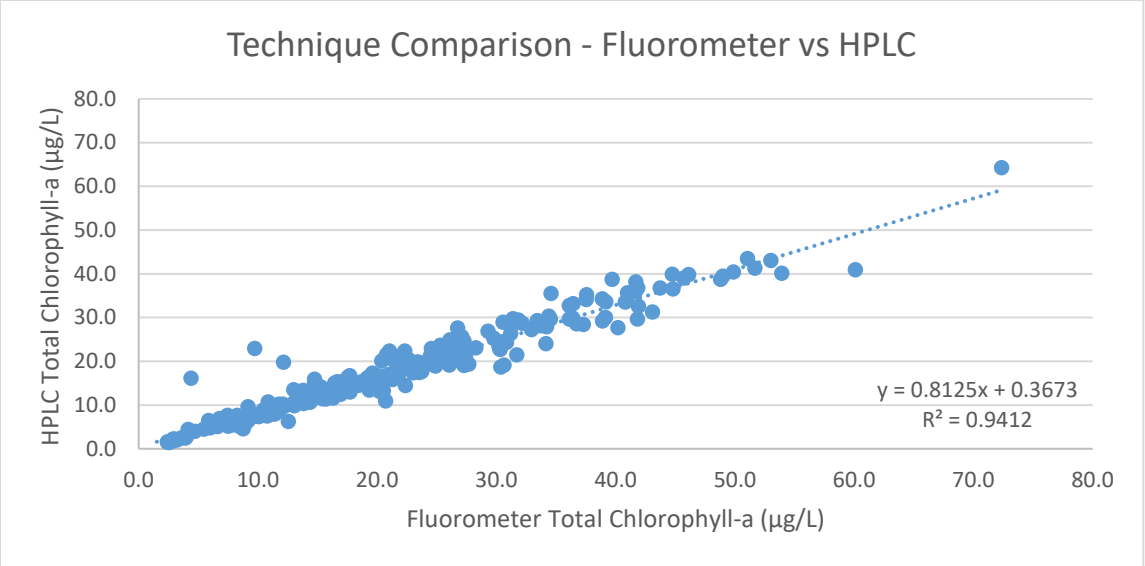


Figure 9. Comparison of total chlorophyll-a concentrations determined using fluorometer and HPLC techniques.

Fluorometer Total Chlorophyll-a Concentrations

Total chlorophyll-a concentrations were highly variable across the system (Figure 10). The upstream stations in both lakes (LCR-01 in Fishing Creek Reservoir and LCR-02 in Lake Wateree) measured lowest in average total chlorophyll-a (12.9 ± 1σ of 7.3 µg/L at LCR-01 and 11.1 ± 8.7 µg/L at LCR-02). The mid-lake areas produced the highest average total chlorophyll-a concentrations in both lakes. Total chlorophyll-a at Fishing Creek Reservoirs stations LCR-05 and LCR-04 were 21.8 ± 10.9 µg/L and 22.6 ± 8.9 µg/L, respectively, compared to 17.8 ± 8.9 µg/L at CW-057 in lake forebay. Similarly, the Dutchman Creek area Lake Wateree stations CW-208 and LCR-03 yielded average total chlorophyll-a concentrations of 30.4 ± 13.1 µg/L and 29.0 ± 13.6 µg/L, respectively, followed by CW-207B at 24.9 ± 12.8 µg/L. The mid-lake averages were approximately twice the average of 13.9 ± 8.9 µg/L for CL-089 in the Lake Wateree forebay (Figure 10). These averages reflect all data collected at each station, which for all stations except LCR-01, includes multiple depths.

Regulatory assessment of these data compares surface values against an ecoregional standard of 40 µg/L. Six of the nine stations would have yielded at least one exceedance of the standard. The stations without an exceedance were the two upstream stations (LCR-01 and LCR-02) and the Lake Wateree forebay station (CL-089). Though not registering an exceedance, stations LCR-02 and CL-089 demonstrated surface total chlorophyll-a concentrations greater than 30 µg/L at least once. Stations CW-208 and LCR-03 exceeded the standard four (31% rate) and three (23% rate) times, respectively. Stations CW-207B and LCR-05 each exceeded the standard twice and LCR-04 and CW-057 recorded one exceedance each.

The chlorophyll-a maximum did not always occur at the surface (Table 4). The sensor-based assessments of the chlorophyll-a maximums (Table 4) are supported by laboratory measurements. The chlorophyll-a maximum occurred at the surface less than half the time at stations CW-057, LCR-03, CW-208, and CW-207B (Table 8). As such, the assessment of only surface values may overlook important water column features such as algal biomass peaks below the surface at 1.5 to 2.0 m (Figure 11). Subsurface chlorophyll-a maximums were often observed at LCR-03 and CW-208 which routinely demonstrated the highest total chlorophyll-a concentrations. These stations were usually sampled mid-day and it is possible that the

relatively high frequency of subsurface chlorophyll-a maximums are related to photoinhibition at the surface. However, CW-057 and CW-207B were sampled in the early to late morning and the maximum chlorophyll-a occurred in the subsurface more than half the time at these stations.

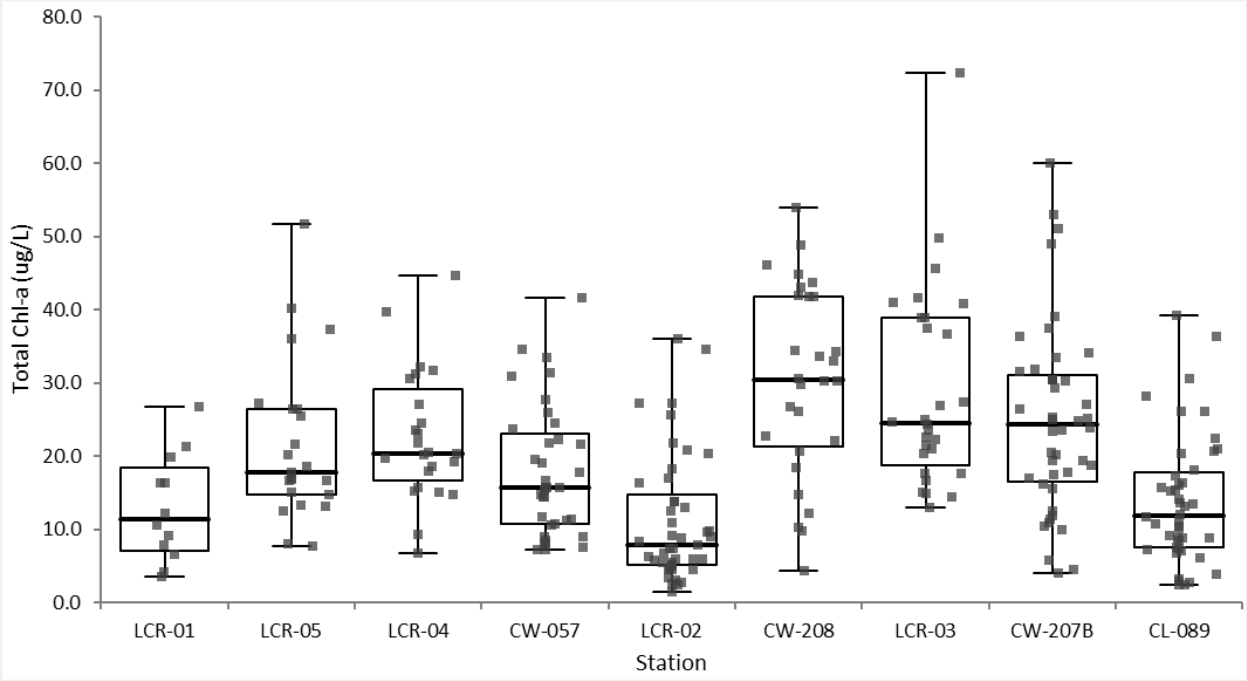


Figure 10. Box plot summary of all fluorometric total chlorophyll-a measurements for each station. Data were collected between late April and late October on a biweekly sampling schedule.

Table 8. Comparison of site visits with surface and subsurface maximum total chlorophyll-a concentrations. LCR-01 measurements occurred only at the surface and LCR-05 included a surface and bottom measurement. As such, these sites are not assessed here.

Station	Surface Maximum	Subsurface Maximum	Surface Maximum (%)
Fishing Creek Reservoir			
LCR-01	NA		
LCR-04	10	2	83%
LCR-05	NA		
CW-057	5	7	42%
Lake Wateree			
LCR-02	9	5	64%
LCR-03	3	10	23%
CW-208	4	9	31%
CW-207B	5	7	36%
CL-809	13	1	93%

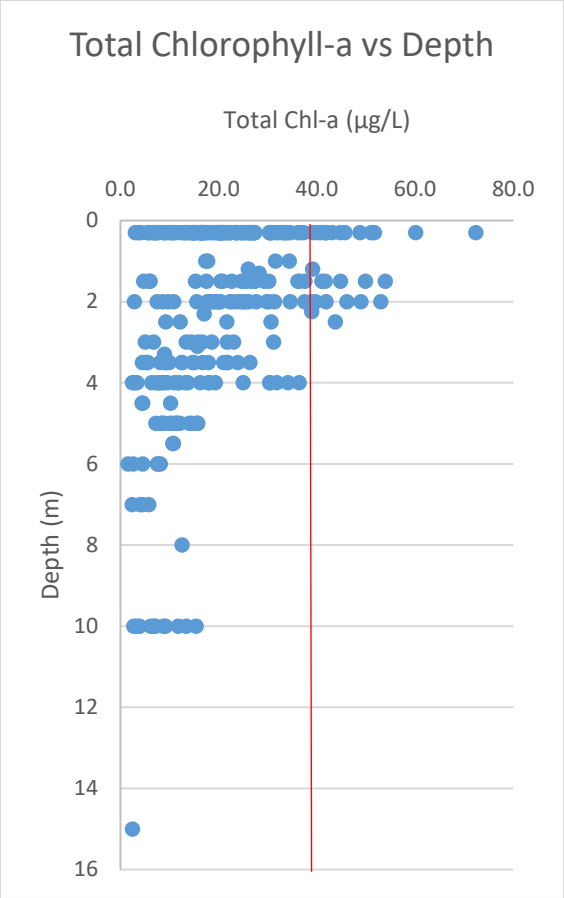


Figure 11. Depth profile of all fluorometric total chlorophyll-a values measured at all stations. The red line indicates the ecoregional chlorophyll-a standard of 40 µg/L.

Phytoplankton Community Composition

The following discussion focuses on the seasonal evolution of the phytoplankton community at station LCR-03. The other stations demonstrated similar characteristics in community composition and time-series plots are included as Appendix B. Early in the growing season (May and June), the phytoplankton community composition was relatively homogenous with important contributions of diatoms, cryptophytes, chlorophytes, and cyanobacteria to total chlorophyll-a (Figures 12 and 13). Cyanobacteria became more prevalent as the season progressed and as surface temperatures increased from 25°C to 30°C (Figure 2). From July through September, cyanobacteria represented approximately 60% of the total chlorophyll-a (Figure 13).

The spike in total chlorophyll-a on 6/18/2019 (Figure 12) coincided with an increase in DO (Figure 3) and pH (Figure 5). Following these spikes, DO and pH rapidly decreased in the following days with daily maximums and minimums converging. These features suggest a phytoplankton bloom and rapid die-off of algal biomass. In addition, the elevated DO and pH concentrations observed for a large portion of September (Figures 3 and 5) may be driven by the near doubling in total chlorophyll-a concentrations measured on the 9/10 and 9/24/2019 visits (Figure 12).

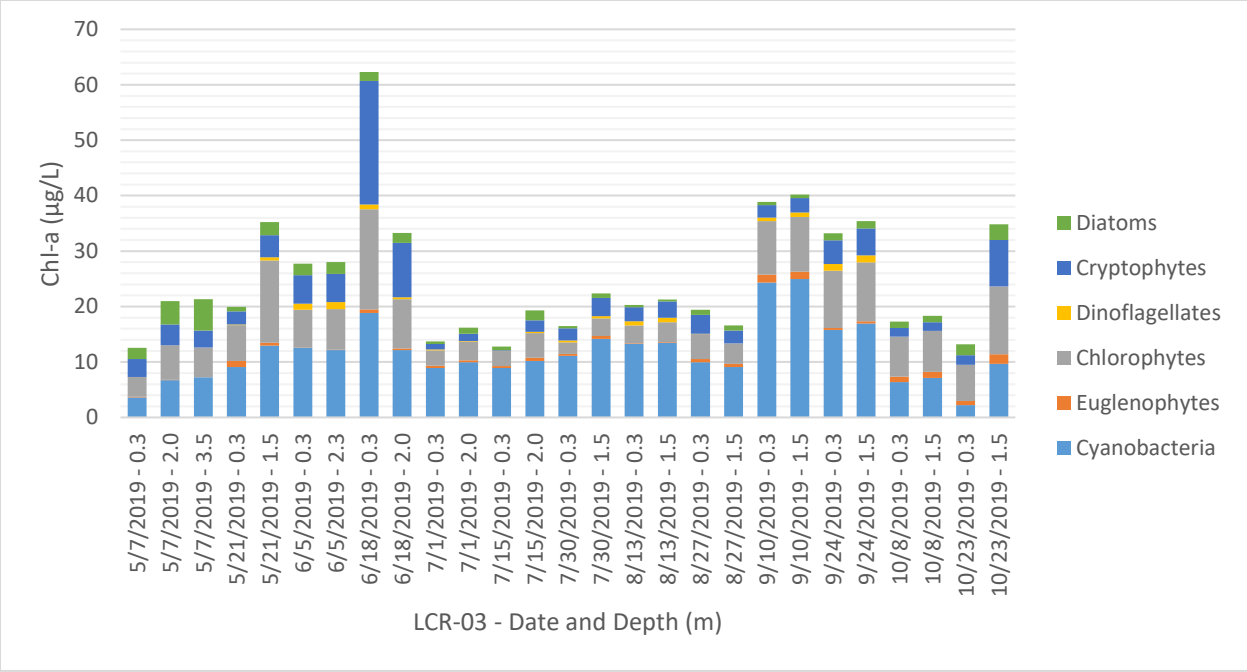


Figure 12. Algal group specific contributions to total chlorophyll-a (HPLC based) from early May through late October at LCR-03.

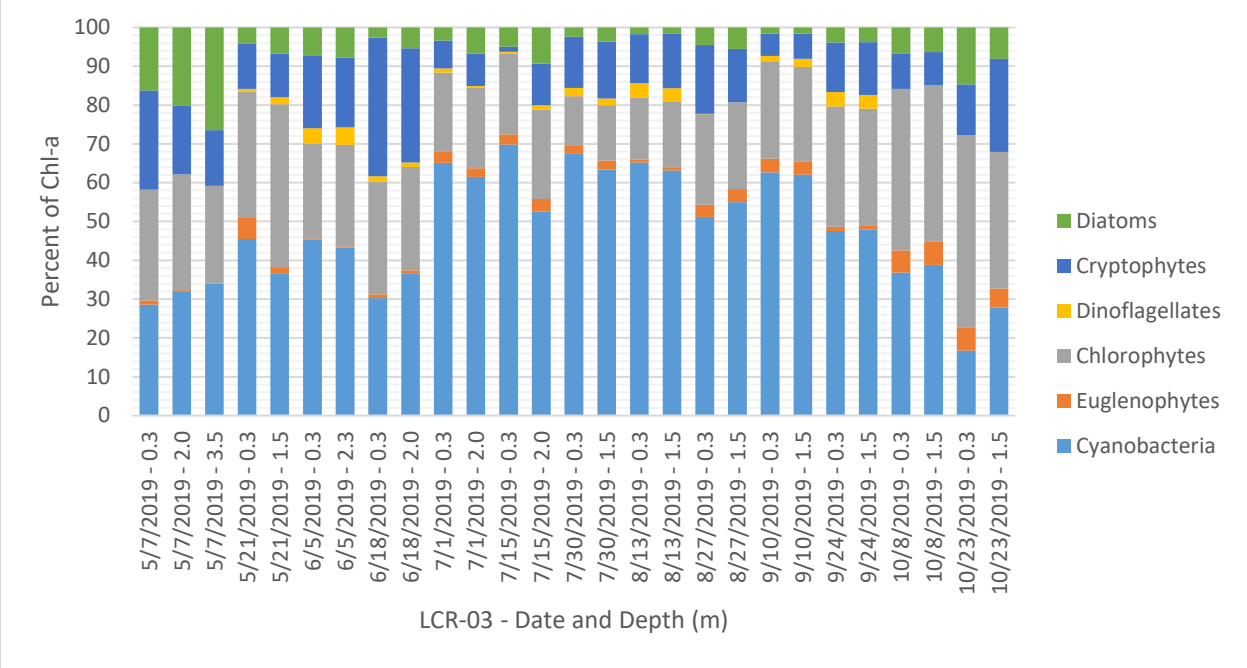


Figure 13. Relative composition of the phytoplankton community at LCR-03.

Water Quality

Data were collected for 18 unique chemical water quality parameters[11]. The water quality data will be used to inform various components of the watershed loading and lake water quality models. The following discussion summarizes the results for total phosphorus (TP) and total nitrogen (TN), two nutrient parameters regulated in lakes by the State. Total nitrogen is not explicitly measured, but reported as the sum of Total Kjeldahl Nitrogen (TKN, sum of ammonia/ammonium and organic nitrogen) and nitrate/nitrite.

The stream data will be used to calibrate a watershed model for the Lower Catawba Basin. The stream stations were selected to capture nutrient loadings from the dominant land use types in the basin: Urban (LCT-01, Charlotte, NC), suburban (LCT-02, York County, SC), forest (LCT-03 and RS-17340), and hay/pasture (RS-19476). Station CW-014 is a Catawba River site in York County, SC, and will not be discussed here. Stream TP concentrations were generally similar in urban and suburban environments (Figure 14, LCT-01 and LCT-02). The forested watersheds (LCT-03 and RS-17340) produced the lowest in-stream TP concentrations. The hay/pasture watershed consistently demonstrated the highest TP concentrations with a median value 3-4 times greater than the urban and suburban watersheds and 6-7 times higher than the forested watersheds. Summary statistics for TN indicate a similar pattern (Figure 15). Concentrations in the urban and suburban watersheds are 2-3 times greater than the forested watersheds. The hay/pasture watershed is also elevated in comparison to the forested watersheds, but in-line with the urban and suburban environments.

The lake data will be used to calibrate a Catawba River/lake water quality model. In general, median TP concentrations are greater at the Fishing Creek Reservoir sites (LCR-01, LCR-05, LCR-04, and CW-057) than the Lake Wateree stations (LCR-02, CW-208, LCR-03, CW-207B, and CL-089) (Figure 16). Maximum TP concentrations for all but the two Dutchman Creek areas sites (CW-208 and LCR-03) exceeded the lake standard of 0.06 mg/L. Figure 16 includes data from all depths sampled at each station and might not reflect a regulatory assessment of the site, which is based only on surface data. The lowest median TP concentrations (aside from CL-089) occurred at the Dutchman Creek area stations that routinely exhibited the highest total chlorophyll-a concentrations (Figure 10). Lake TN summary statistics are similar to TP characteristics (Figure 17) with higher median concentrations in Fishing Creek Reservoir compared to Lake Wateree. The maximum TN concentration at three of four Fishing Creek Reservoir station exceeded the ecoregional lake standard of 1.5 mg/L.

[11] Complete list of chemical parameters: total alkalinity, turbidity, total suspended solids, BOD_5, dissolved BOD_5, Total Kjeldahl Nitrogen, dissolved Total Kjeldahl Nitrogen, ammonia, total phosphorus, dissolved total phosphorus, orthophosphate, dissolved orthophosphate, total organic carbon, dissolved total organic carbon (DOC), nitrate/nitrite, dissolved silica, total iron, and dissolved iron

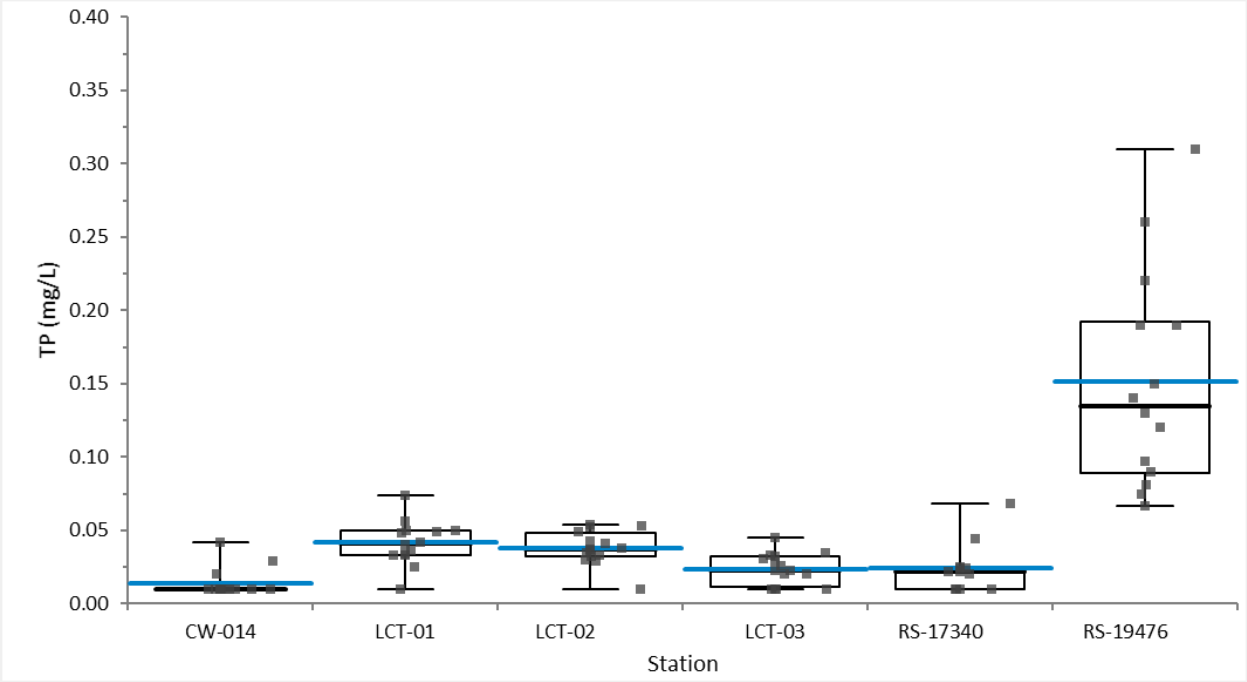


Figure 14. Box plot summary of all total phosphorus concentrations measured at the six stream stations. Data were collected biweekly from mid-April to late October, 2019.

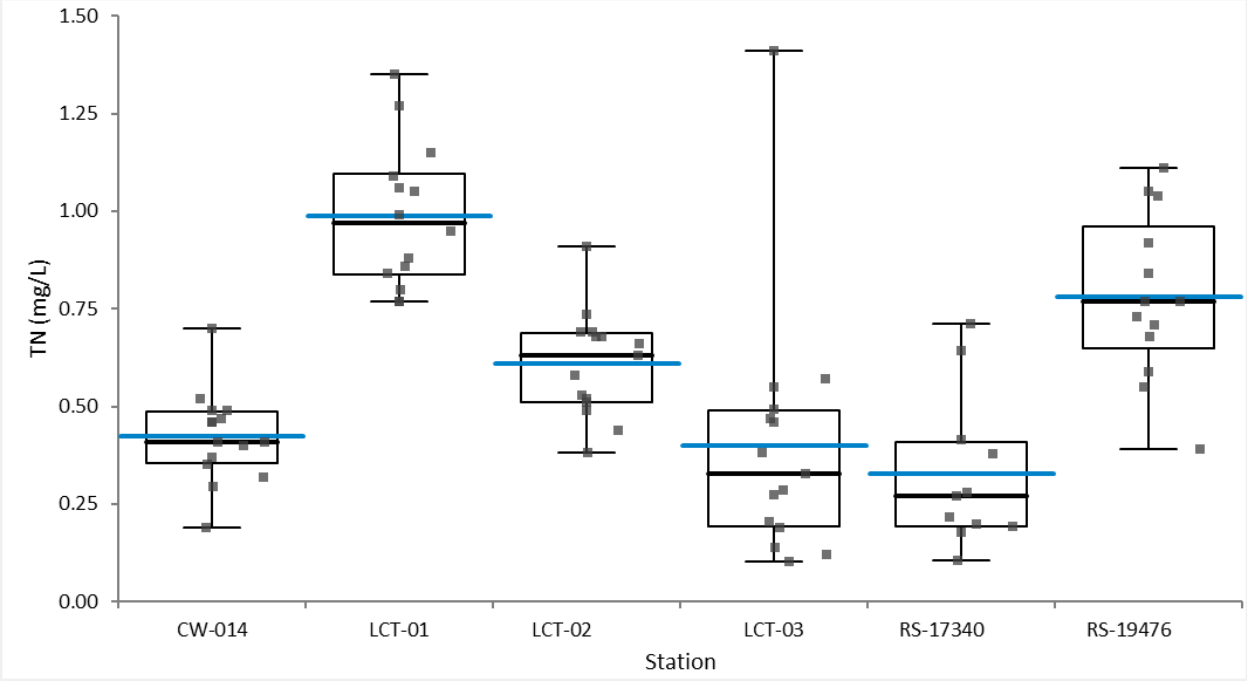


Figure 15. Box plot summary of all total nitrogen concentrations measured at the six stream stations. Data were collected biweekly from mid-April to late October, 2019. Total nitrogen is reported as the sum of Total Kjeldahl Nitrogen and nitrate/nitrite.

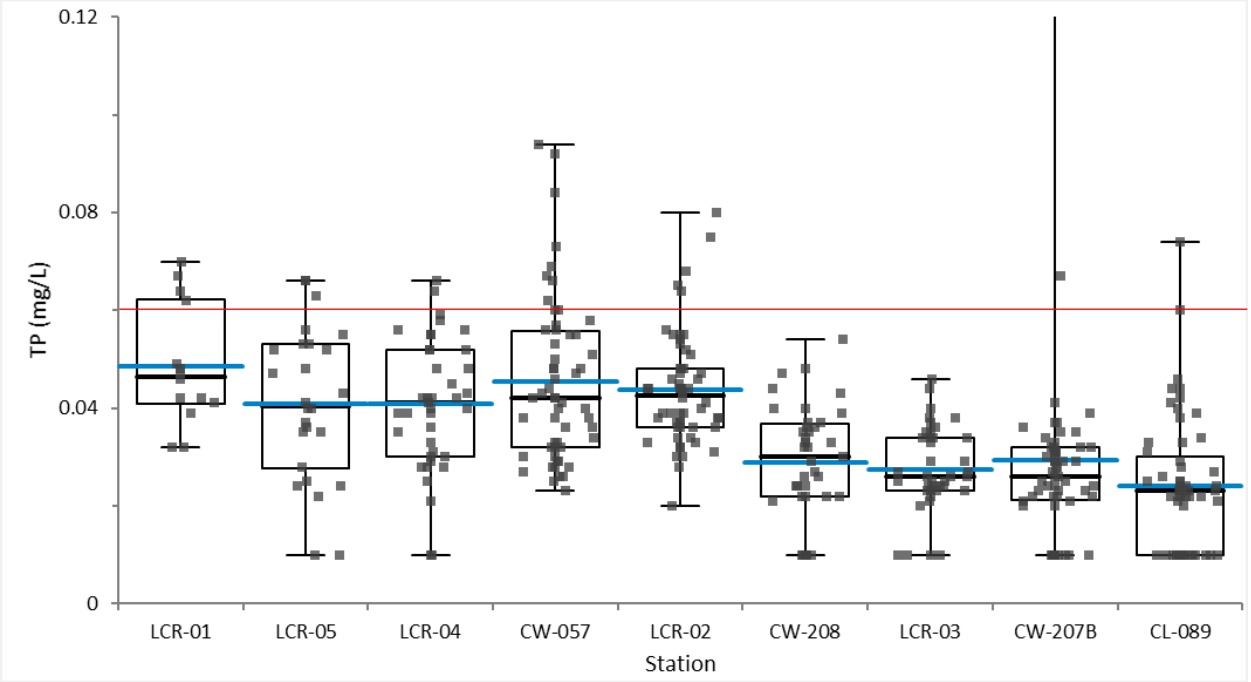


Figure 16. Box plot summary of all total phosphorus concentrations measured at the nine lake stations. Data were collected biweekly from late April to late October, 2019. The maximum CW-207B concentration (0.23 mg/L) is off-axis. The red line indicates the ecoregional lake total phosphorus standard of 0.06 mg/L.

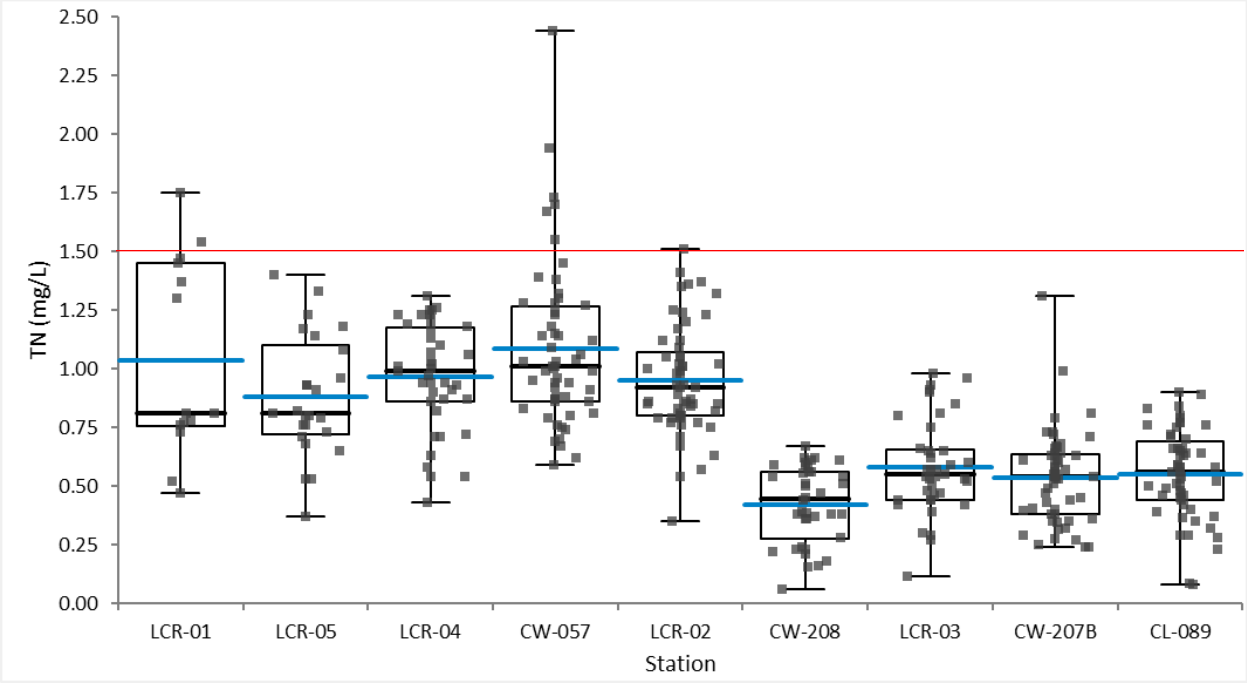


Figure 17. Box plot summary of all total nitrogen concentrations measured at the nine lake stations. Data were collected biweekly from late April to late October, 2019. Total nitrogen is reported as the sum of Total Kjeldahl Nitrogen and nitrate/nitrite. The red line indicates the ecoregional lake total nitrogen standard of 1.5 mg/L.

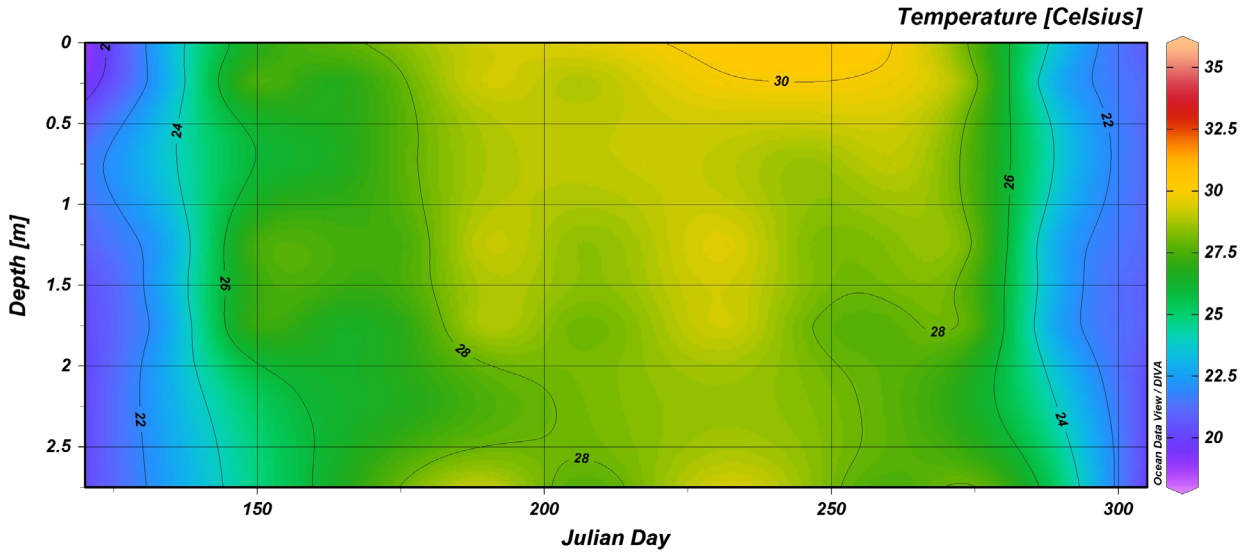
Conclusion

The Nutrient Study summarized here is part of a comprehensive effort to resolve the relationship between physical and chemical conditions and ecological responses in the Lower Catawba Basin. Certain ecological responses impair designated uses in the system and degrade water quality as indicated by the cascade of regulatory 303(d) listings in the basin. This project builds on studies conducted in previous years by stakeholder partners and is bolstered by years of data collected as part of DHEC's ambient monitoring program. The Nutrient Study also co-occurred with several additional projects including a targeted study to measure the water quality of discharge from Lake Wylie, which has been selected as the new model boundary, a lake sediment-oxygen demand study conducted by US Environmental Protection Agency (EPA), and a continuous monitoring and algal growth potential (nutrient limitation) project led by another US EPA team. Further, the DHEC TMDL team is currently involved in a program to quantify watershed loadings to the stream stations described above during winter wet weather/high flow conditions when nutrient runoff is enhanced. That project will be followed by a similar wet weather study in the summer months. The results of the 2019 Nutrient Study also laid framework for a 2020 lake program that will center on expanded continuous monitoring with supporting water quality data collection. Taken together, the aggregated results of these programs fill important data gaps and provide a robust data set to develop, calibrate, and validate coupled watershed and river/lake hydrodynamic and water quality models. The calibrated models will be used in setting site-specific numeric nutrient and chlorophyll-a standards that are protective of designated uses for Lower Catawba Basin.

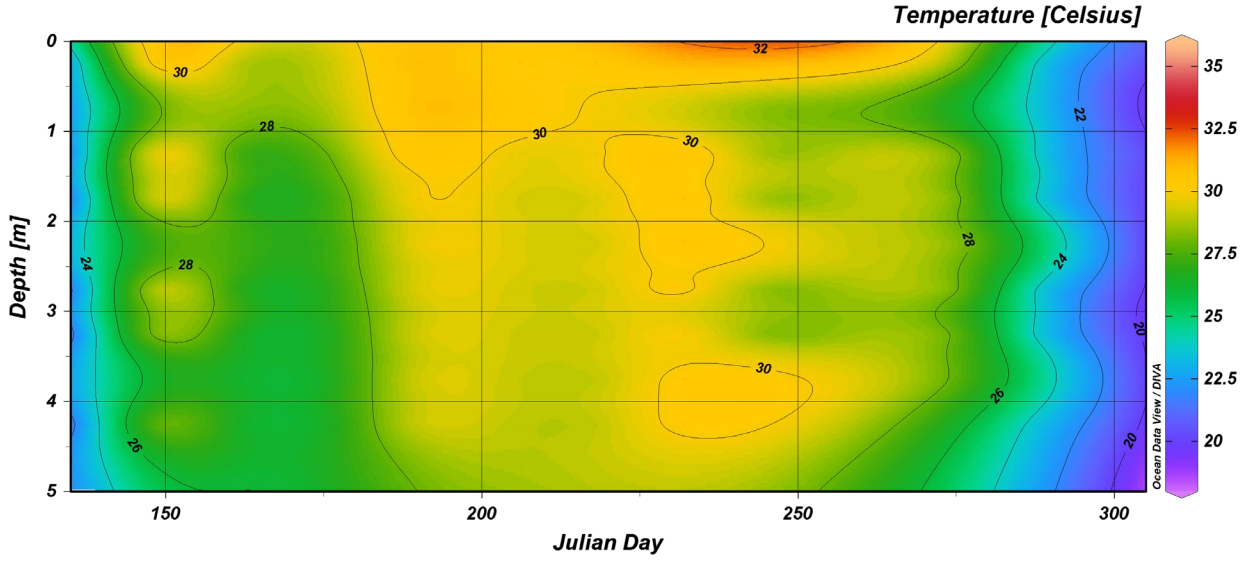
Appendix A – Vertical Profile Section Graphs

Temperature

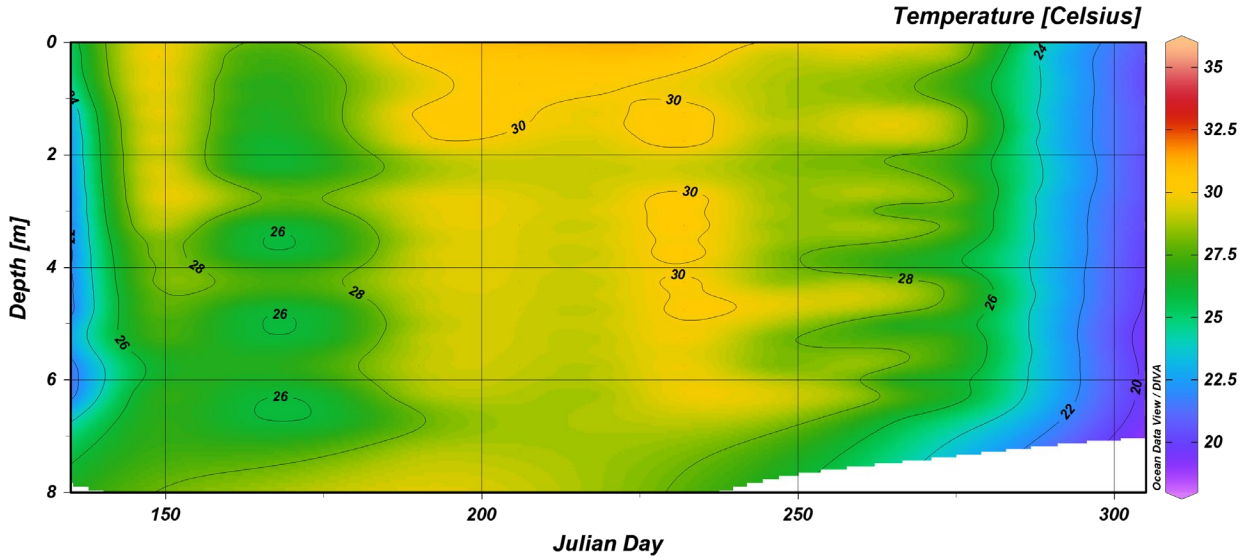
LCR-01



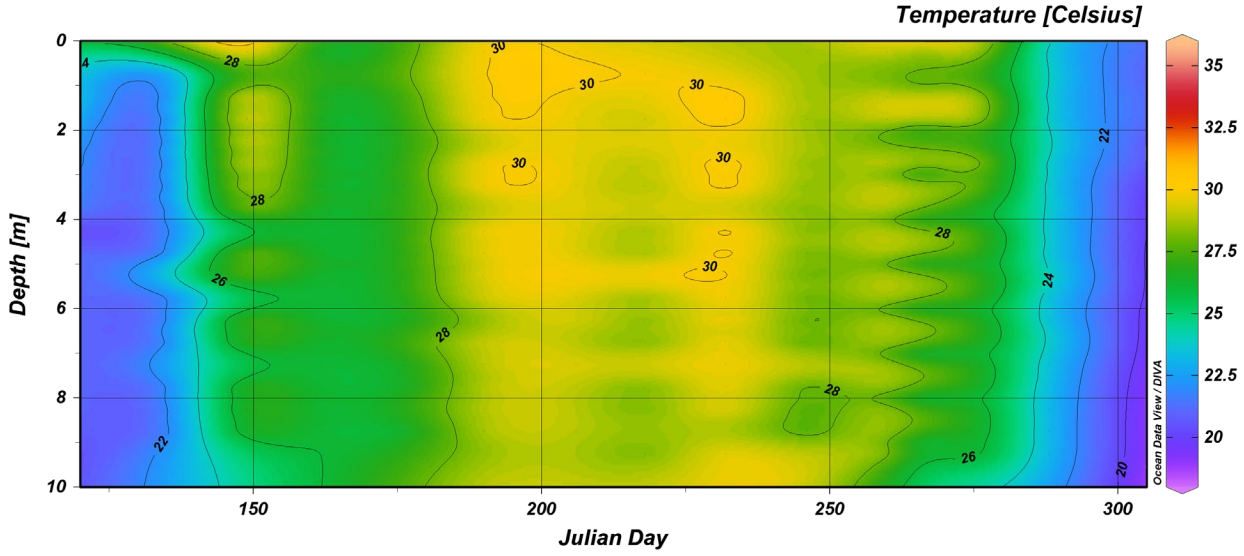
LCR-05



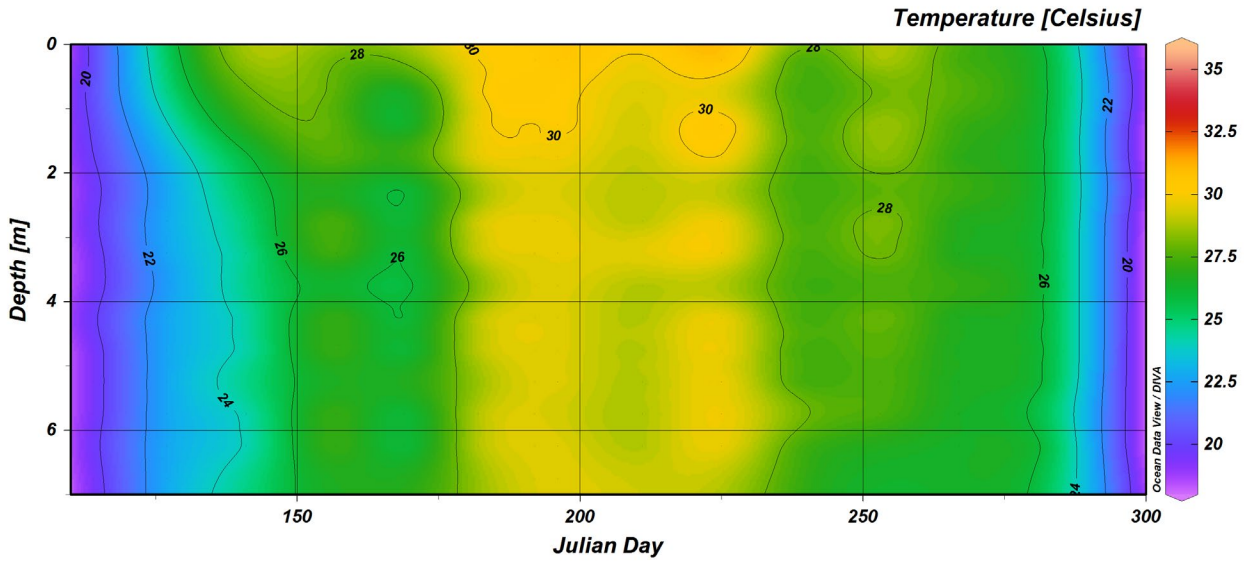
LCR-04


Temperature [Celsius]
Depth [m]
Julian Day
Ocean Data View / DIVA

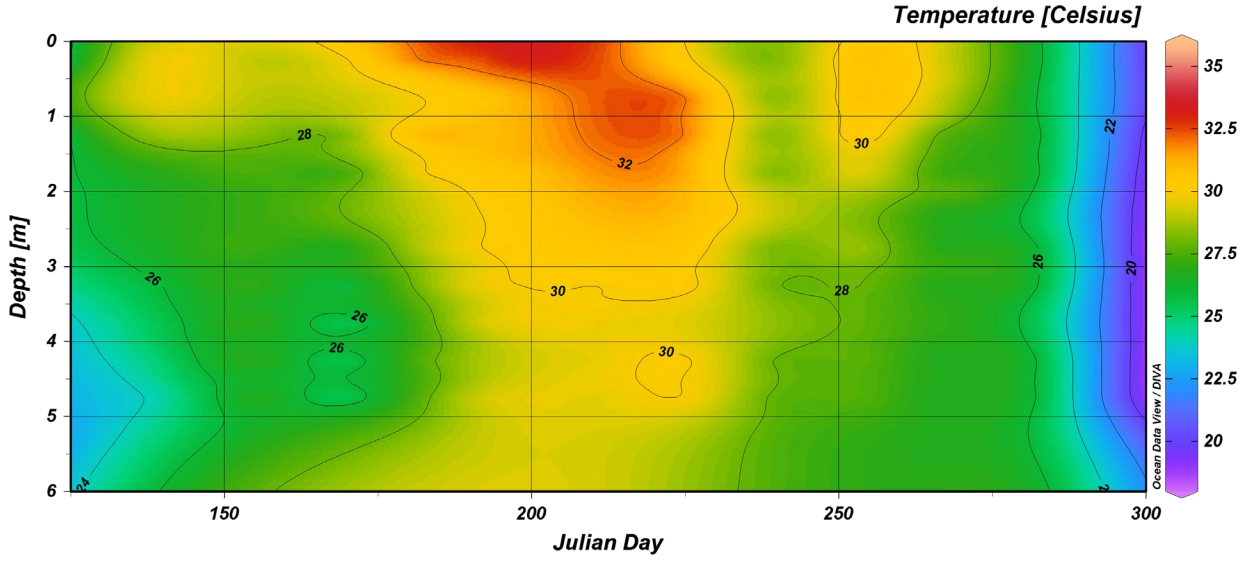
CW-057


Temperature [Celsius]
Depth [m]
Julian Day
Ocean Data View / DIVA

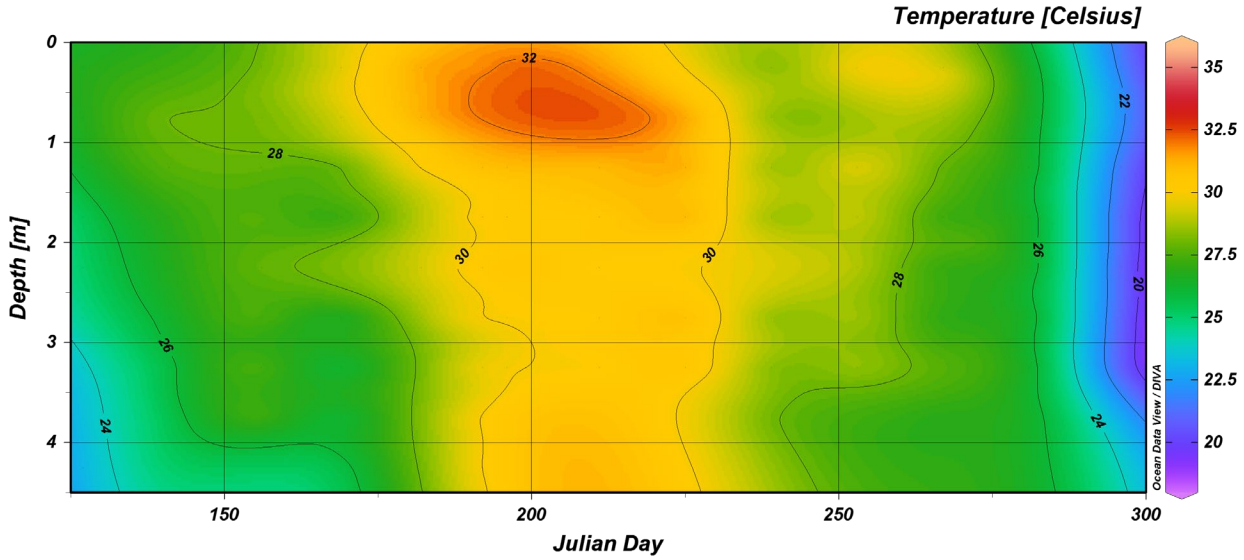
LCR-02


Temperature [Celsius]
Depth [m]
Julian Day
Ocean Data View / DIVA

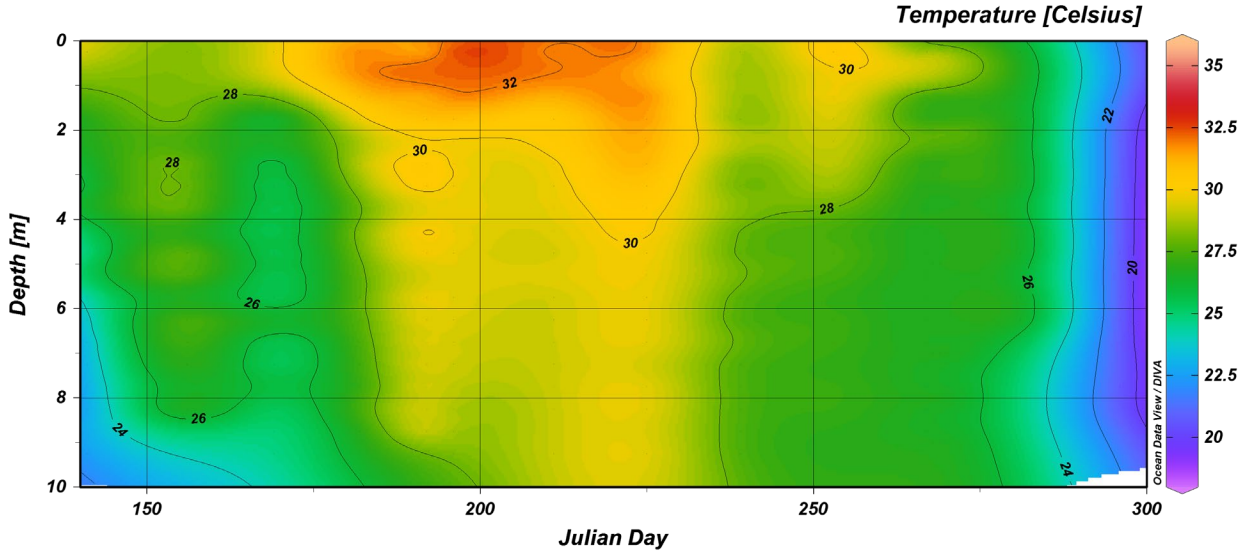
CW-208


Temperature [Celsius]
Depth [m]
Julian Day
Ocean Data View / DIVA

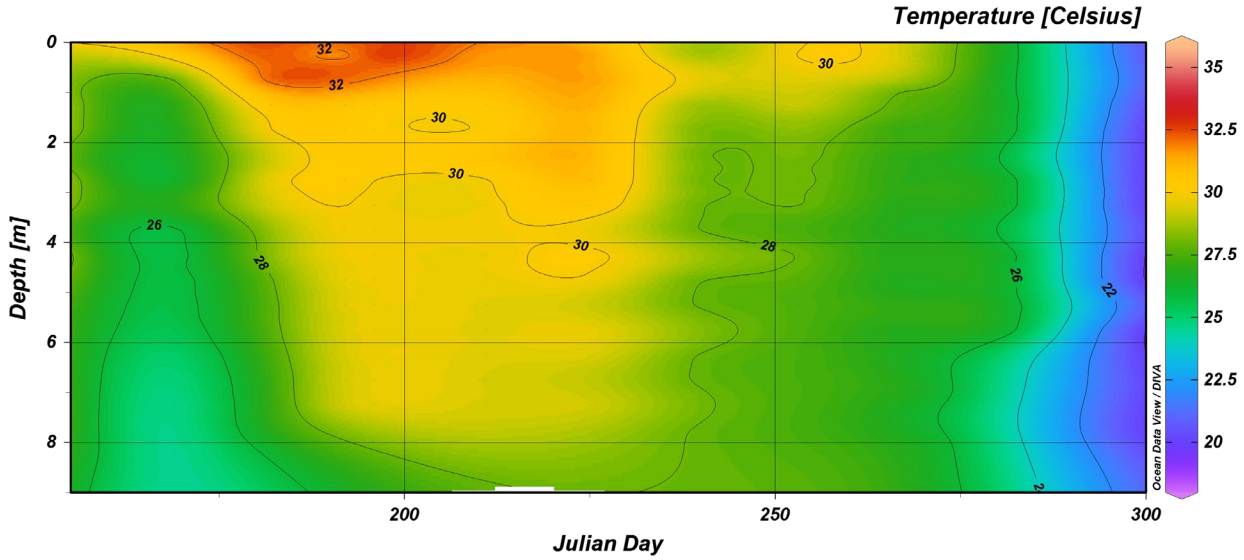
LCR-03



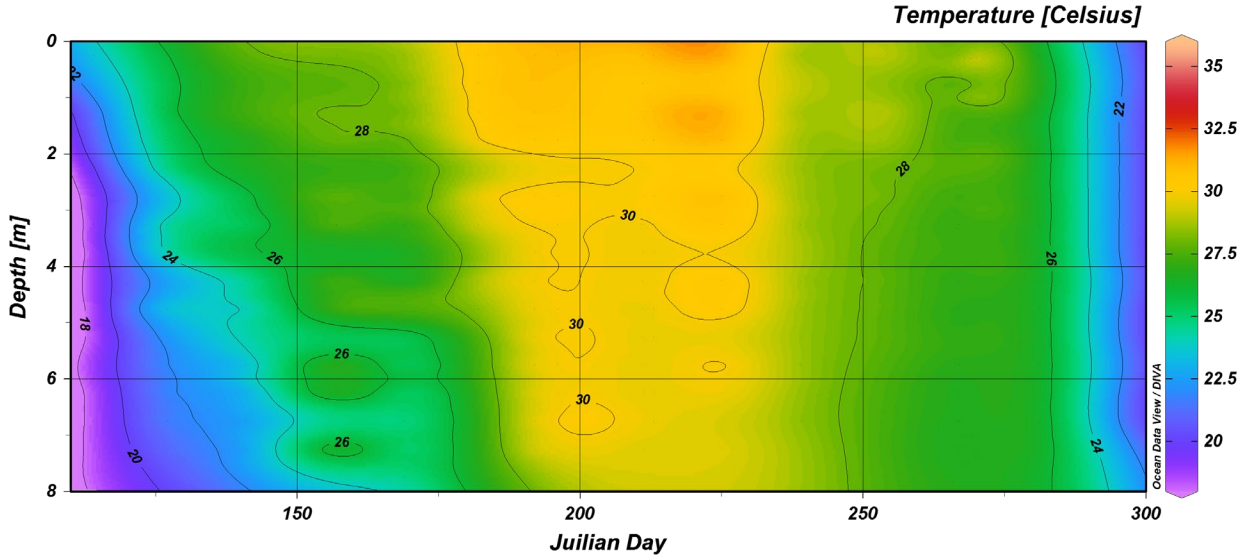
LCR-03A



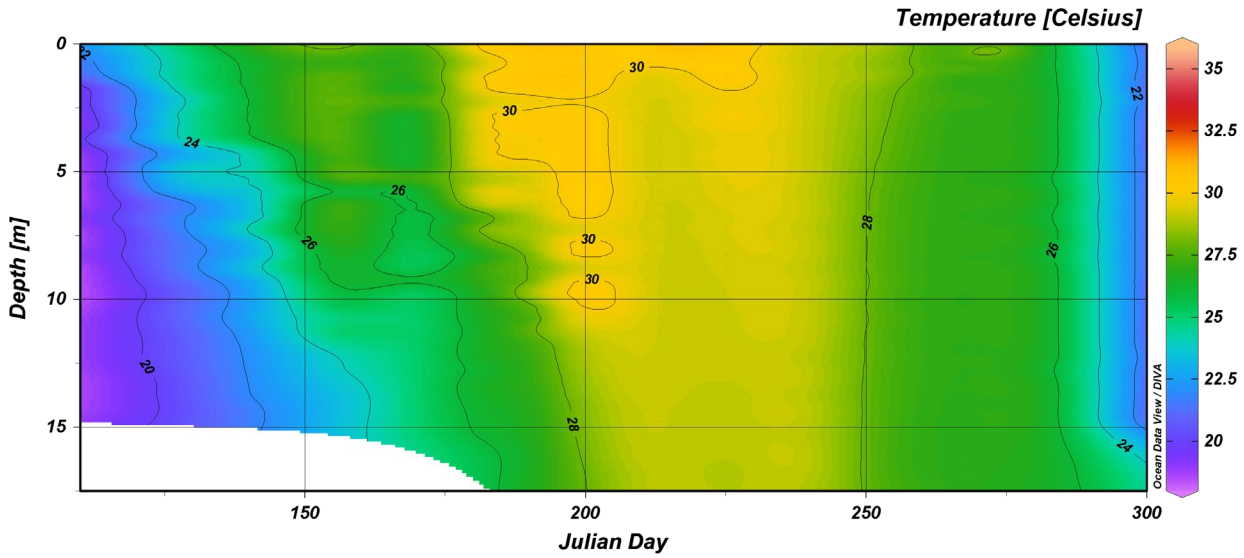
LCR-03B



CW-207B

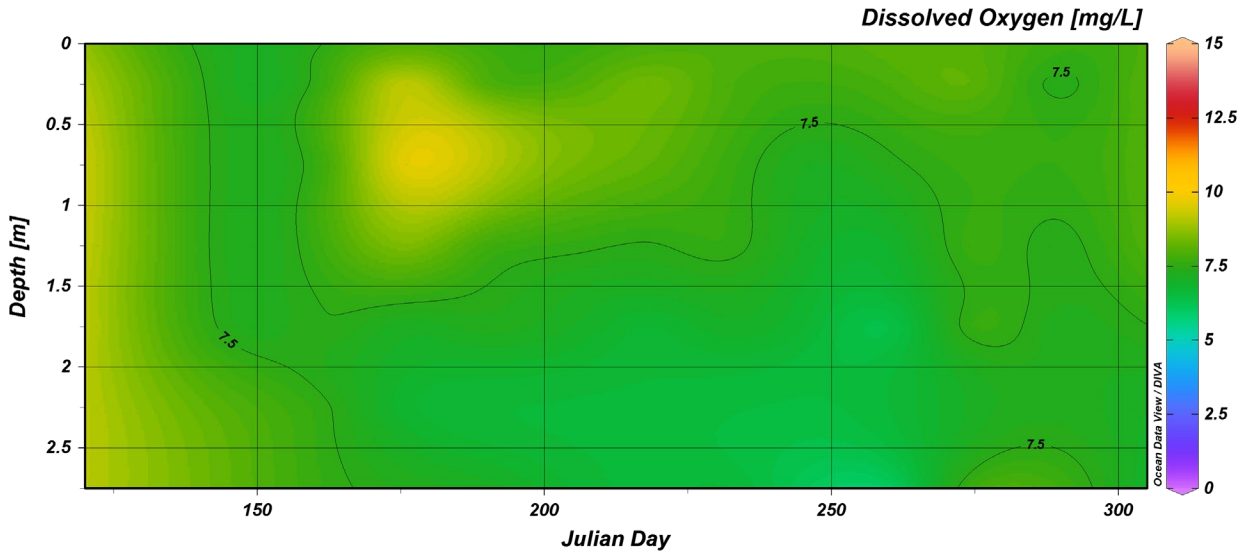


CL-089

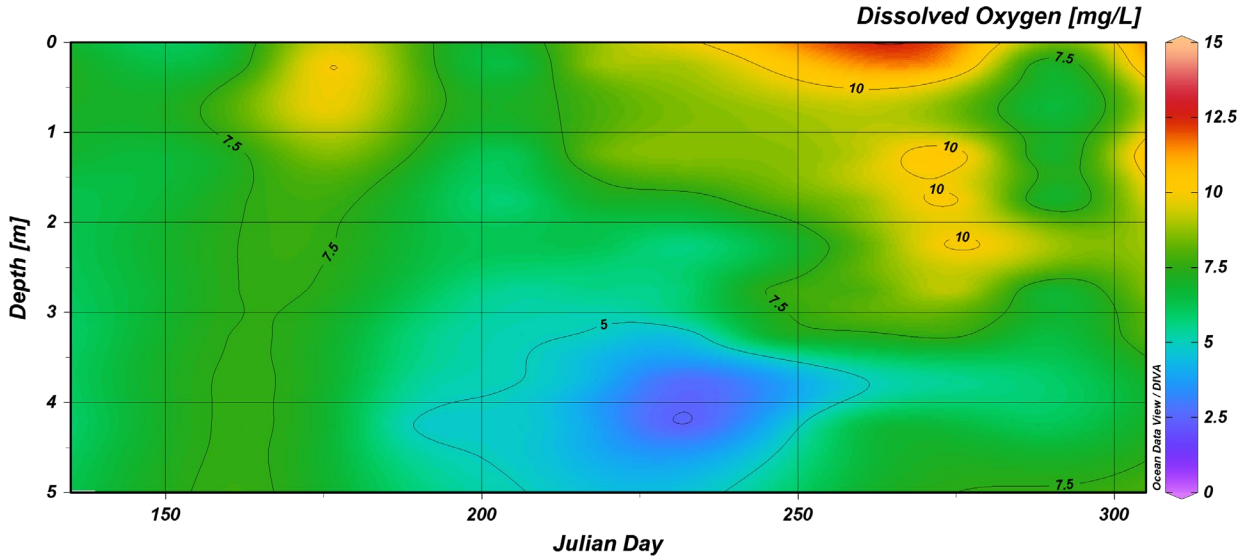


Dissolved Oxygen

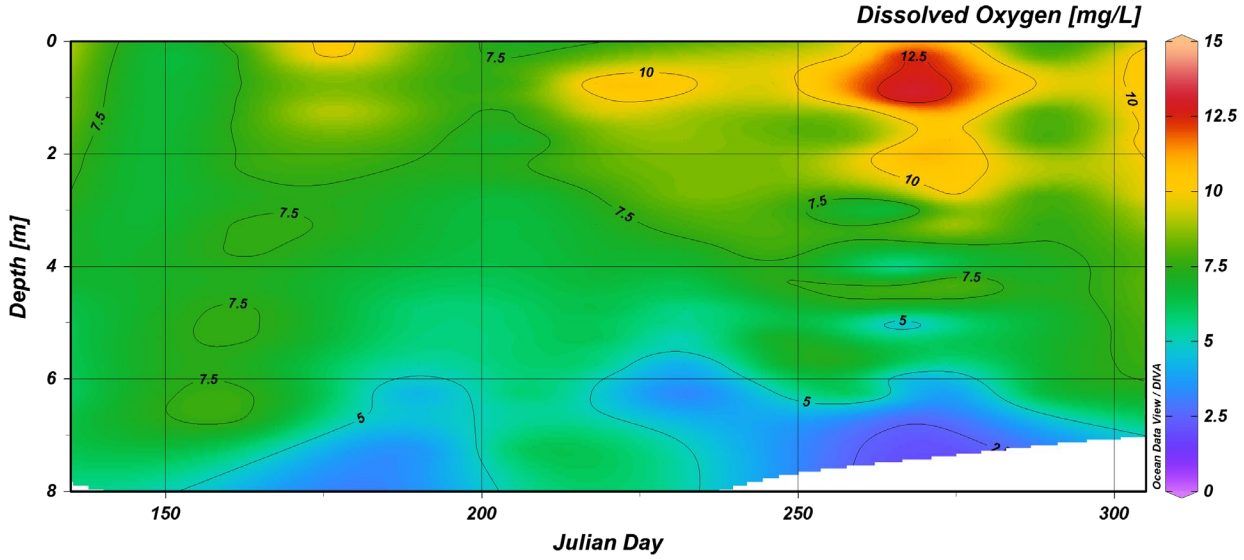
LCR-01



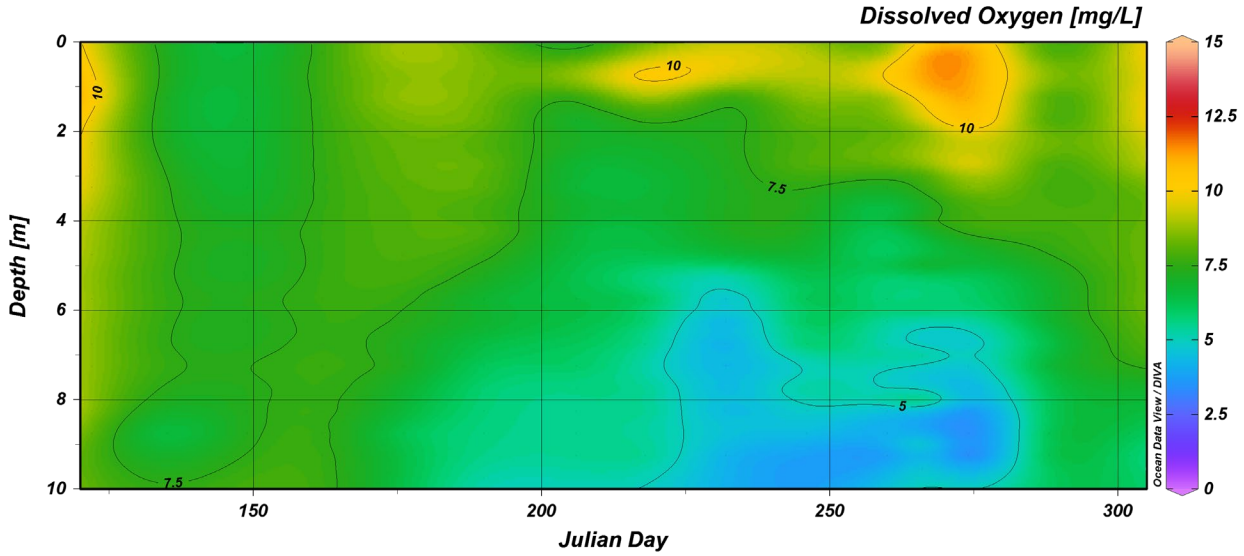
LCR-05


Dissolved Oxygen [mg/L]
Depth [m]
Julian Day
Ocean Data View / DIVA

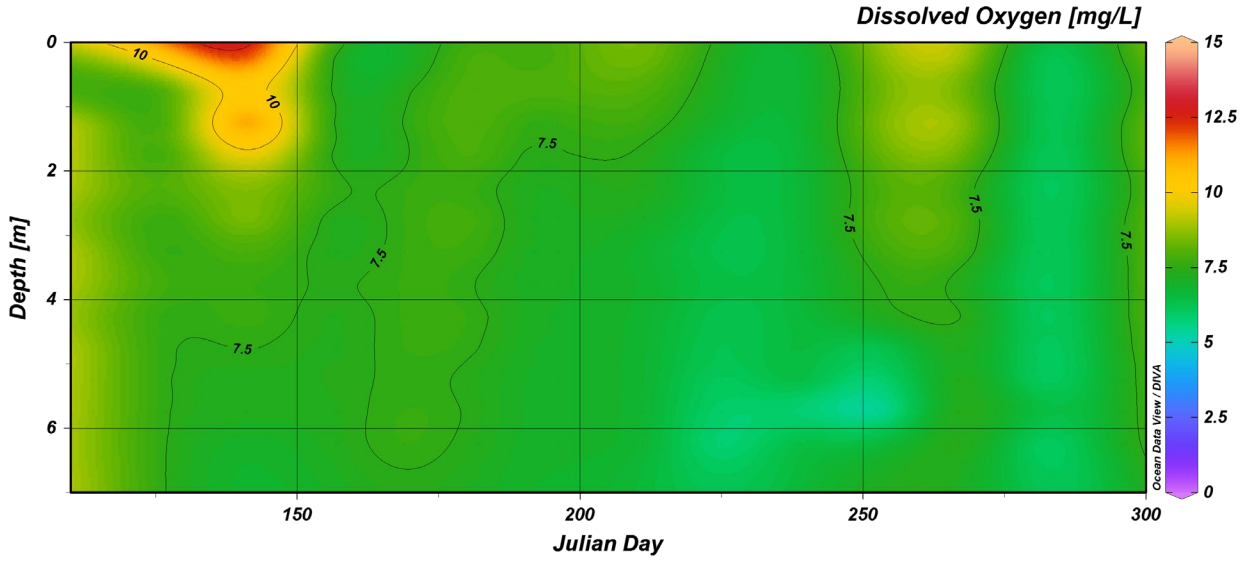
LCR-04


Dissolved Oxygen [mg/L]
Depth [m]
Julian Day
Ocean Data View / DIVA

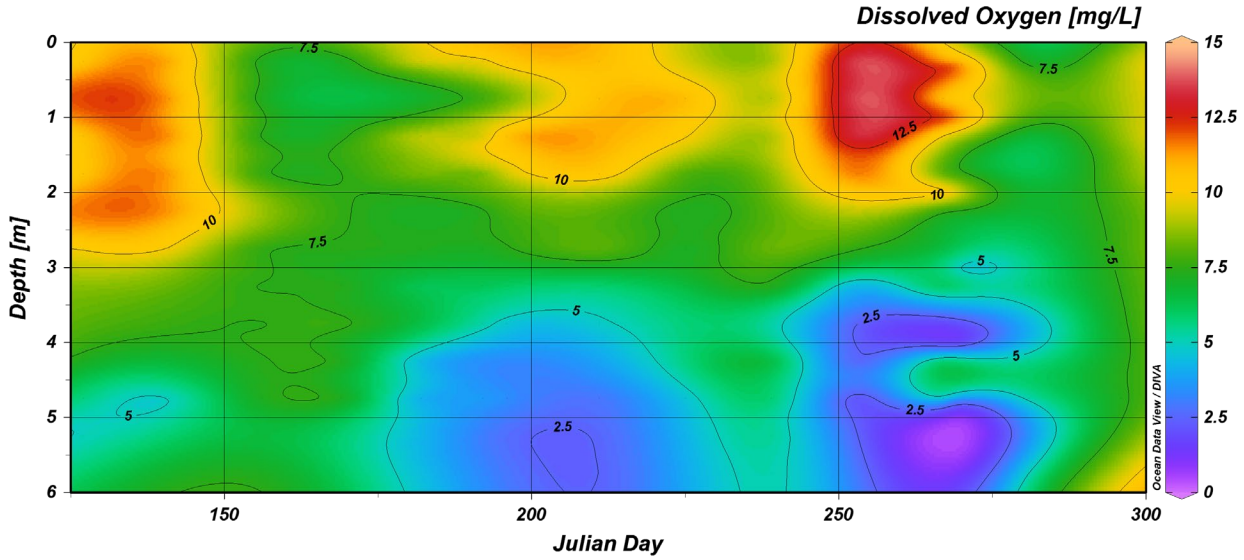
CW-057


Dissolved Oxygen [mg/L]
Depth [m]
Julian Day
Ocean Data View / DIVA
0
2
4
6
8
10
150
200
250
300
15
12.5
10
7.5
5
2.5
0
10
7.5
5

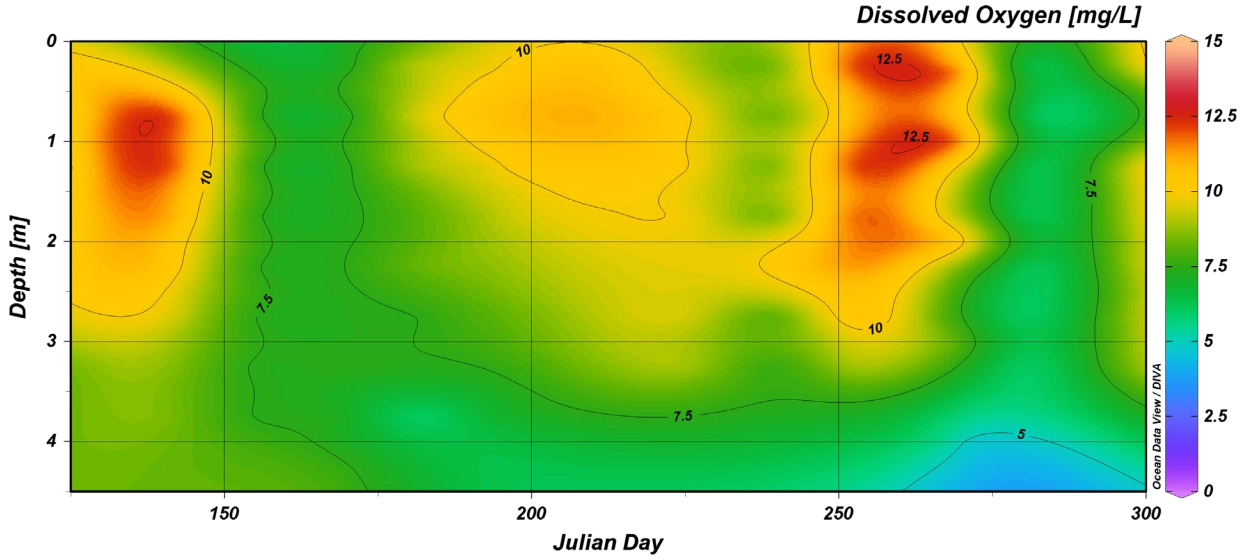
LCR-02


Dissolved Oxygen [mg/L]
Depth [m]
Julian Day
Ocean Data View / DIVA
0
2
4
6
150
200
250
300
15
12.5
10
7.5
5
2.5
0
10
7.5

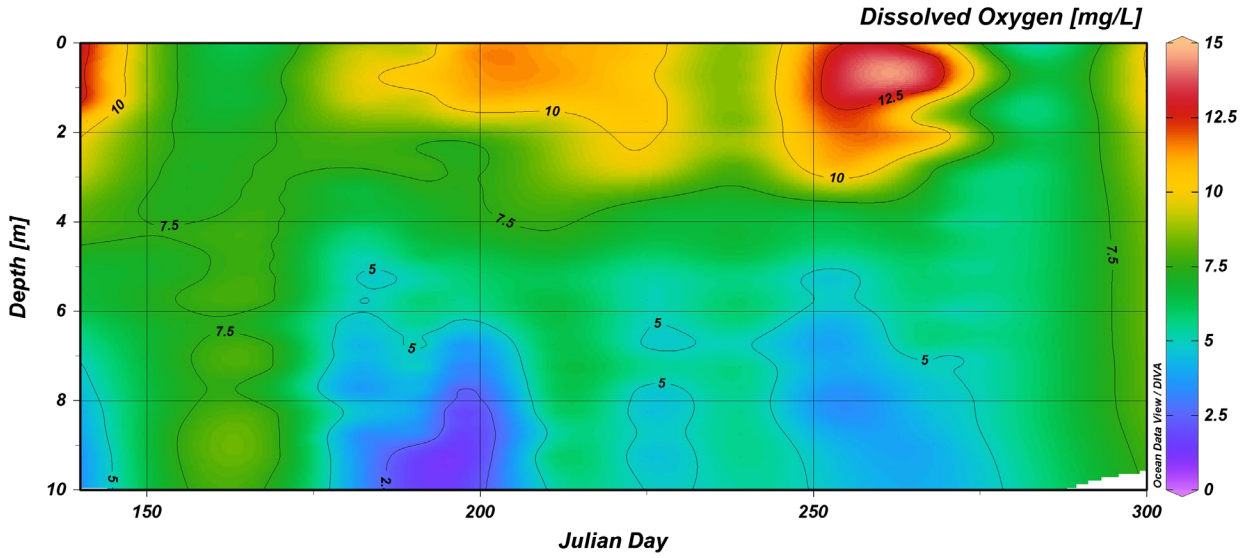
CW-208


Dissolved Oxygen [mg/L]
Depth [m]
Julian Day
Ocean Data View / DIVA

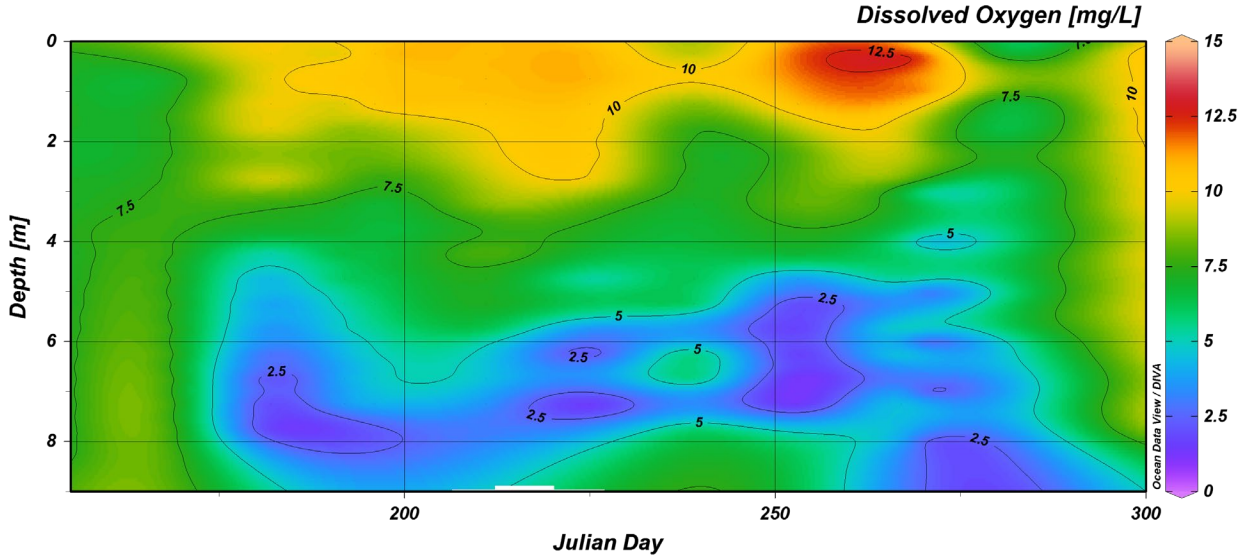
LCR-03


Dissolved Oxygen [mg/L]
Depth [m]
Julian Day
Ocean Data View / DIVA

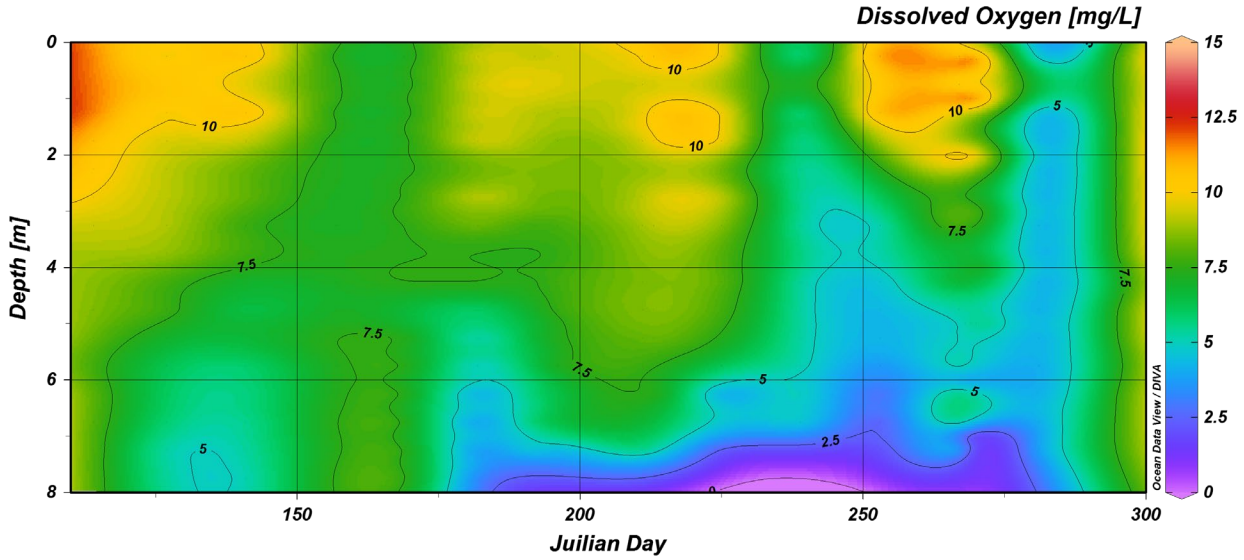
LCR-03A



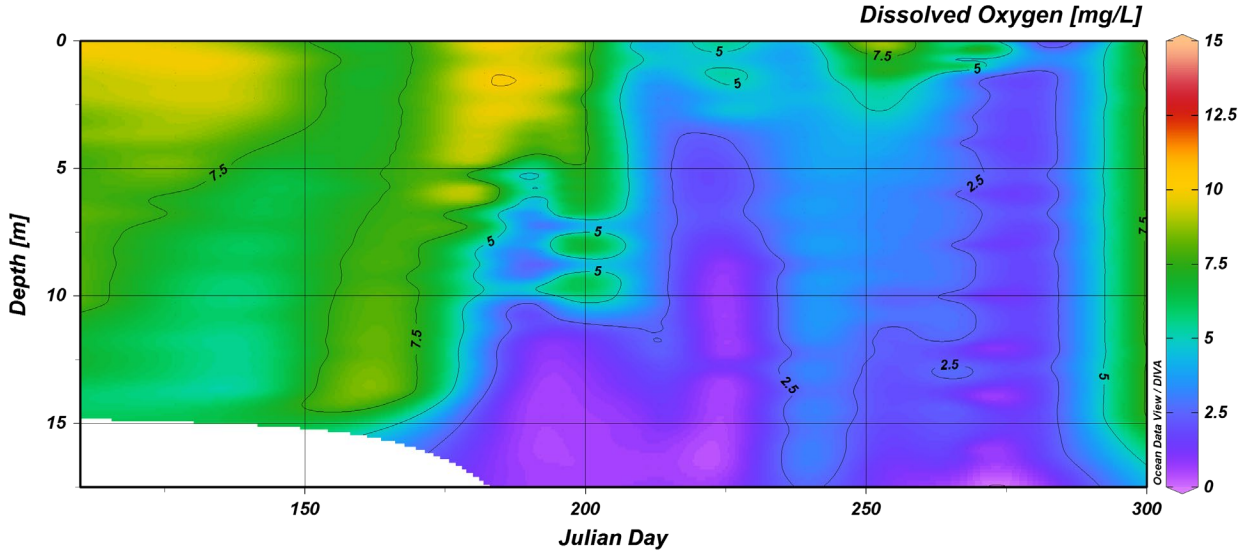
LCR-03B



CW-207B

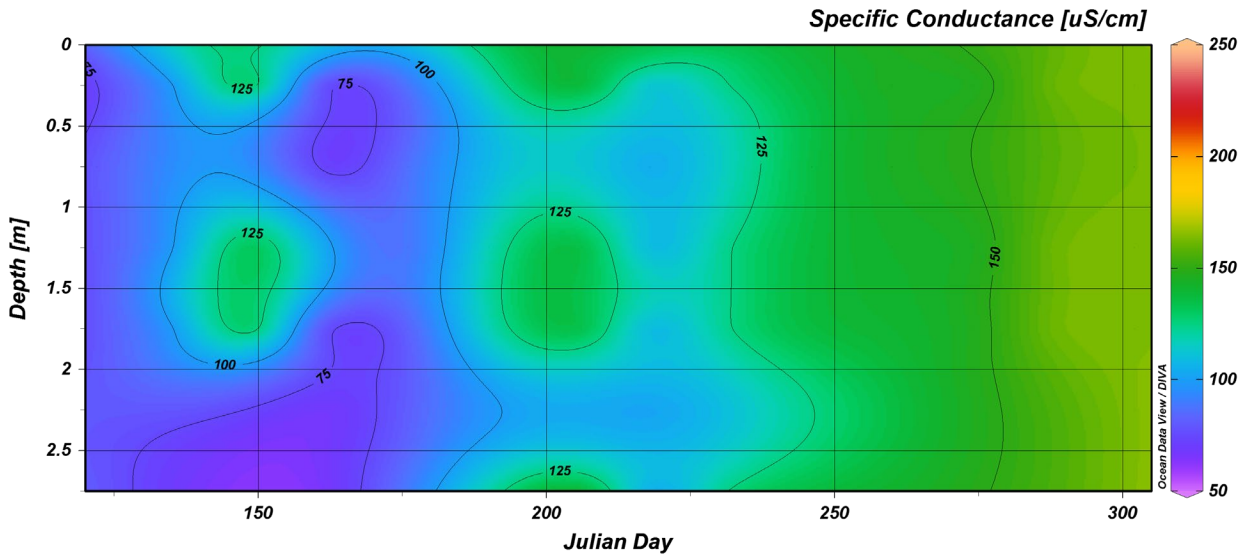


CL-089

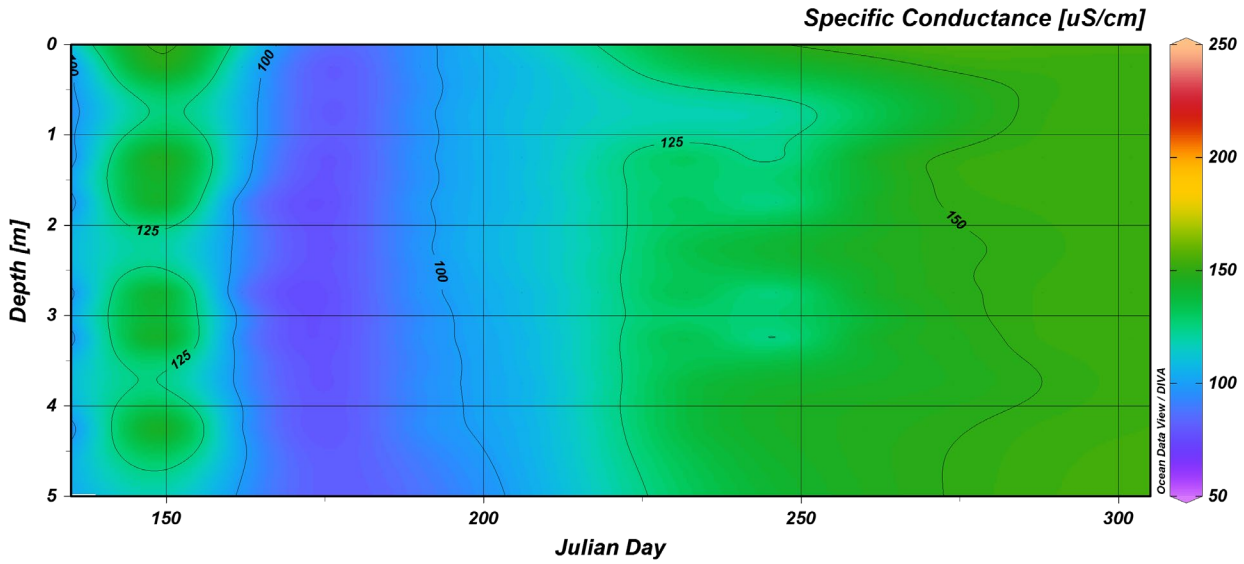


Specific Conductance

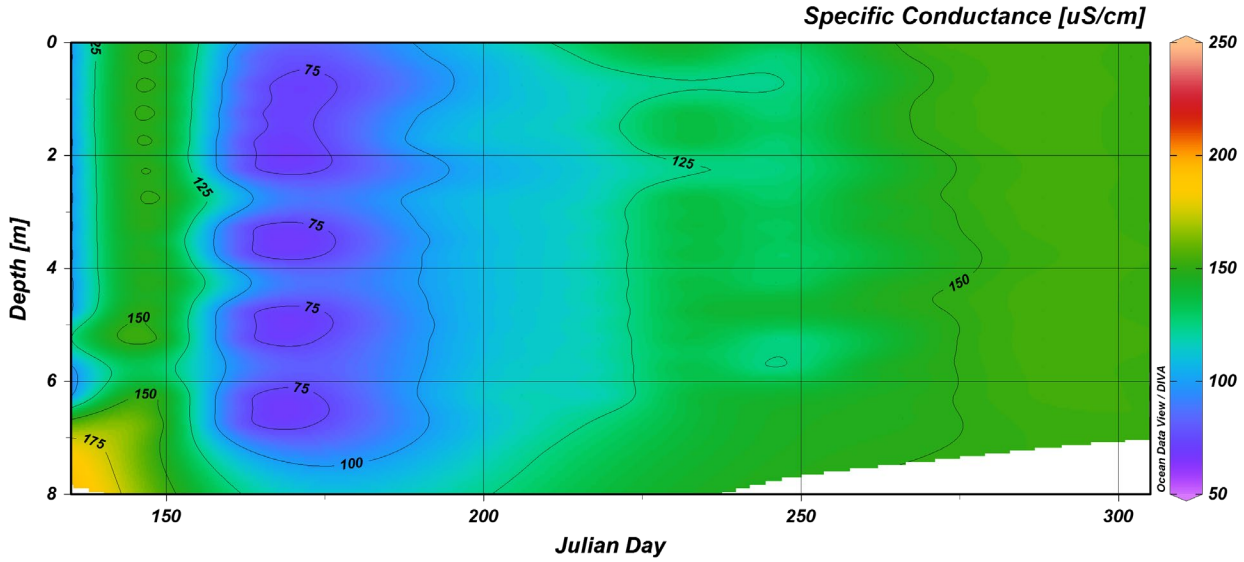
LCR-01



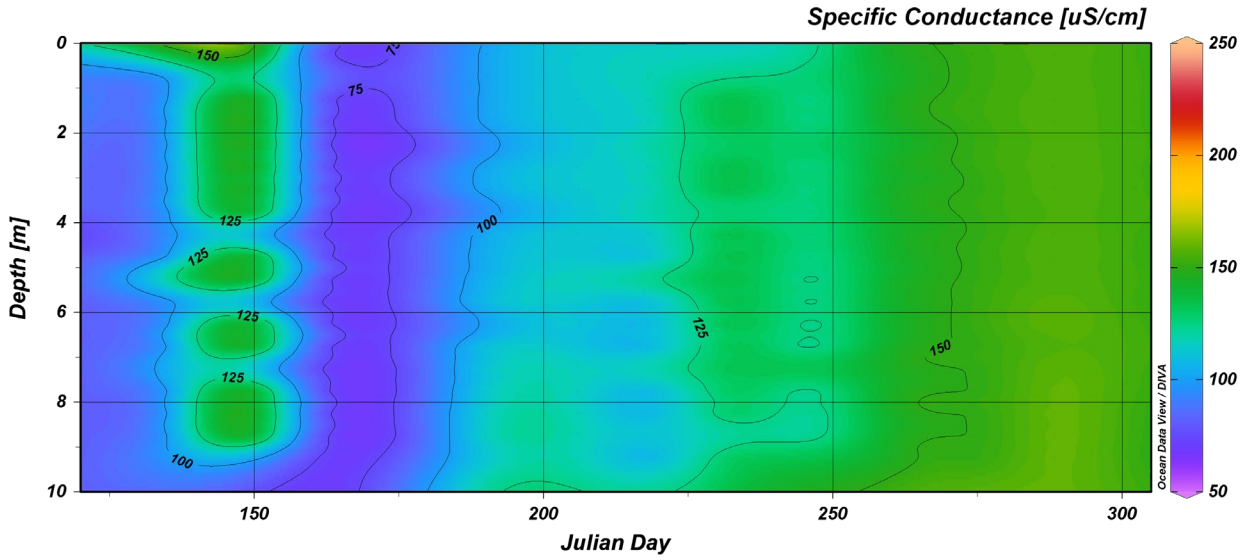
LCR-05



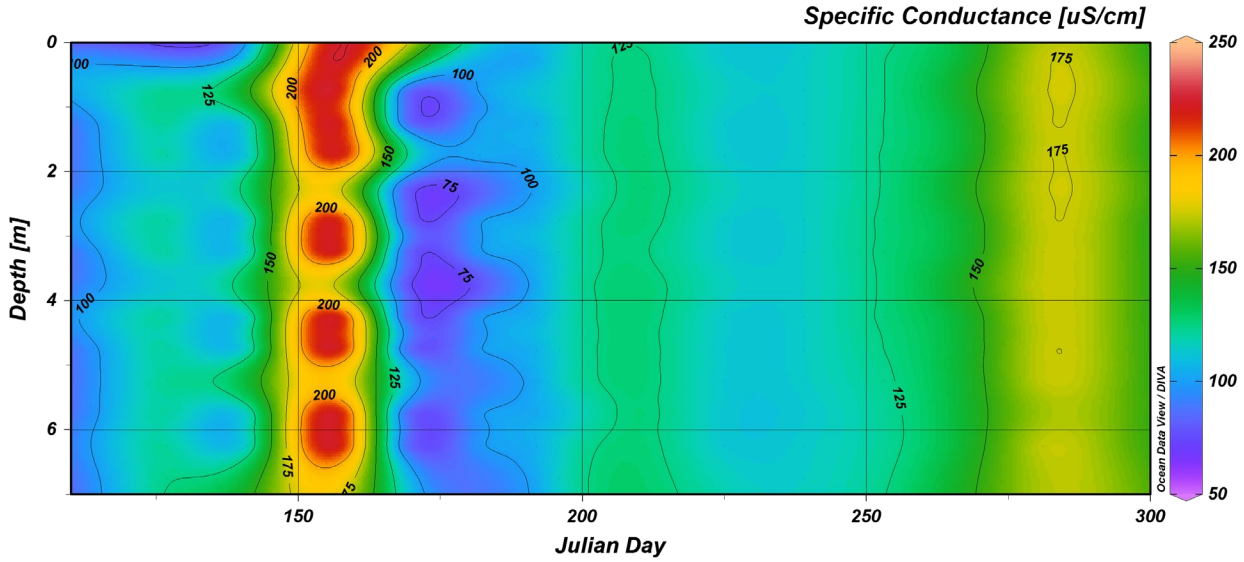
LCR-04


Specific Conductance [uS/cm]
Depth [m]
Julian Day
Ocean Data View / DIVA
0
2
4
6
8
150
200
250
300
250
200
150
100
50
75
125
150
175
100

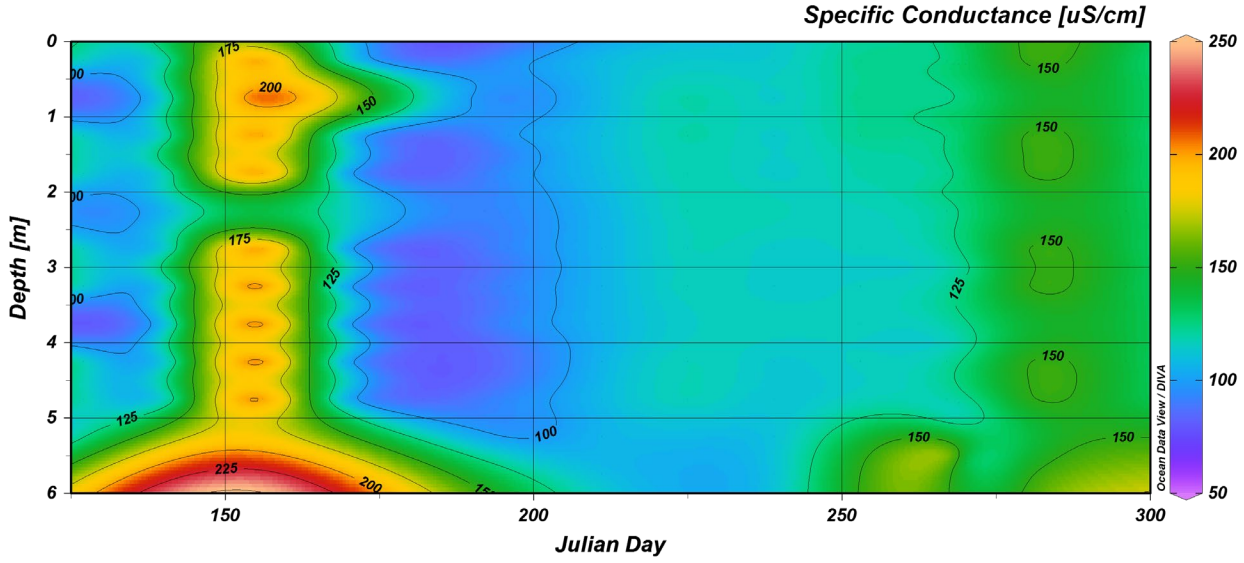
CW-057


Specific Conductance [uS/cm]
Depth [m]
Julian Day
Ocean Data View / DIVA
0
2
4
6
8
10
150
200
250
300
250
200
150
100
50
75
100
125
150

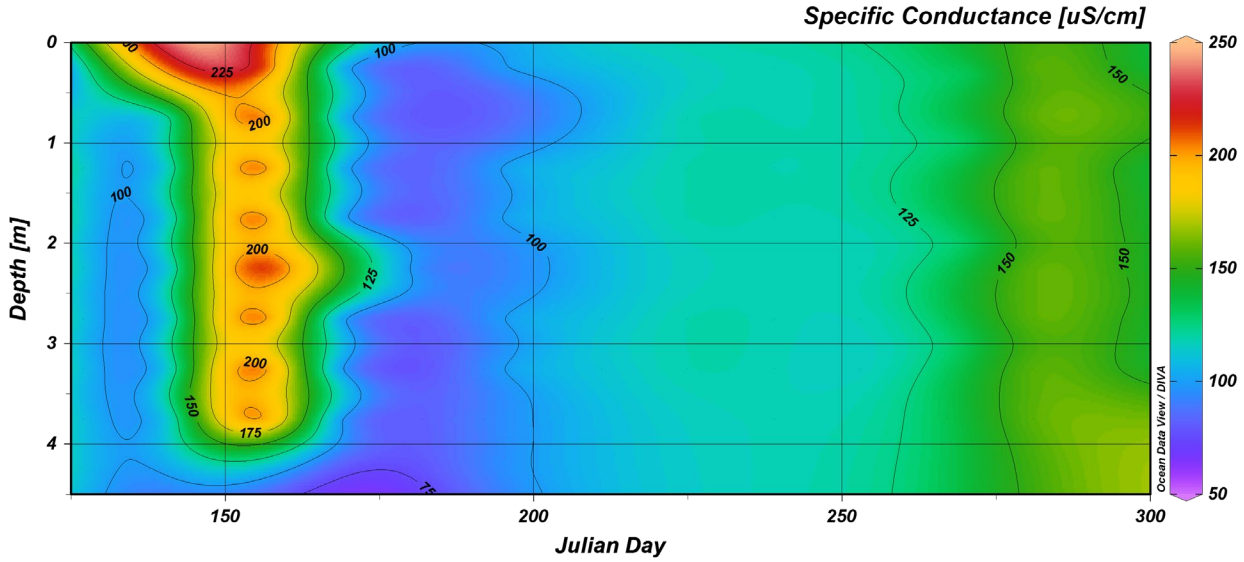
LCR-02


Specific Conductance [uS/cm]
Depth [m]
Julian Day
Ocean Data View / DIVA

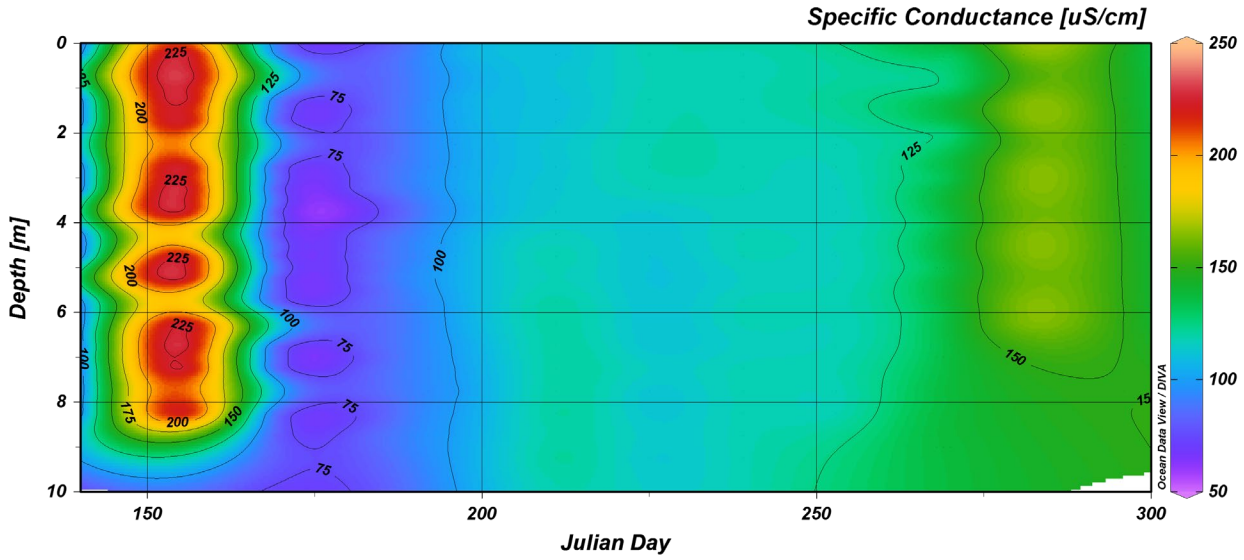
CW-208


Specific Conductance [uS/cm]
Depth [m]
Julian Day
Ocean Data View / DIVA

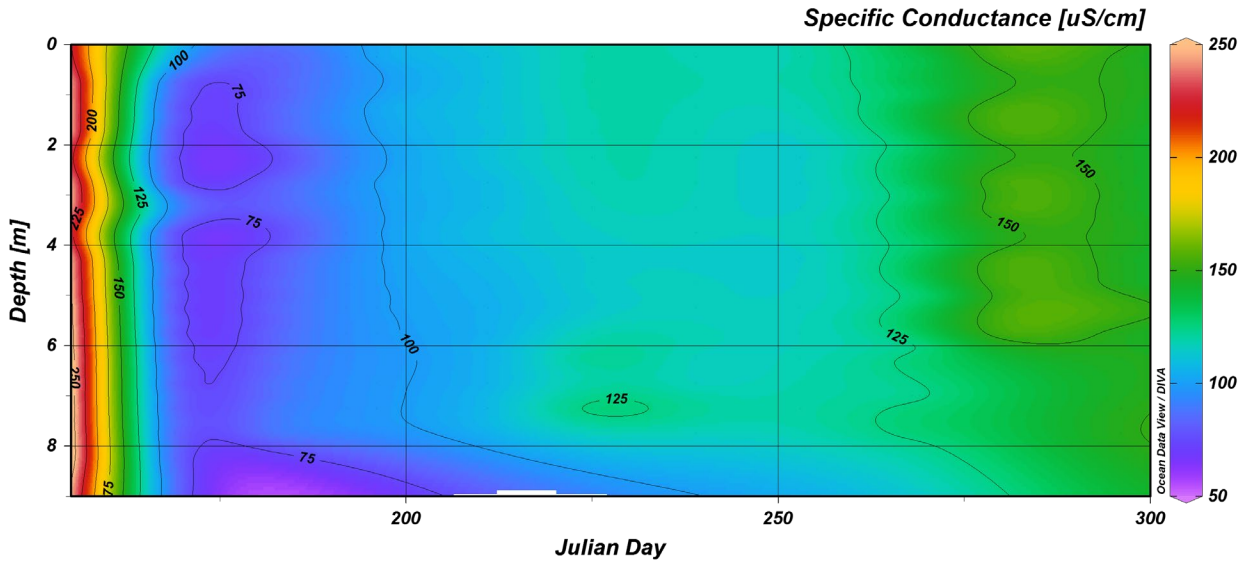
LCR-03



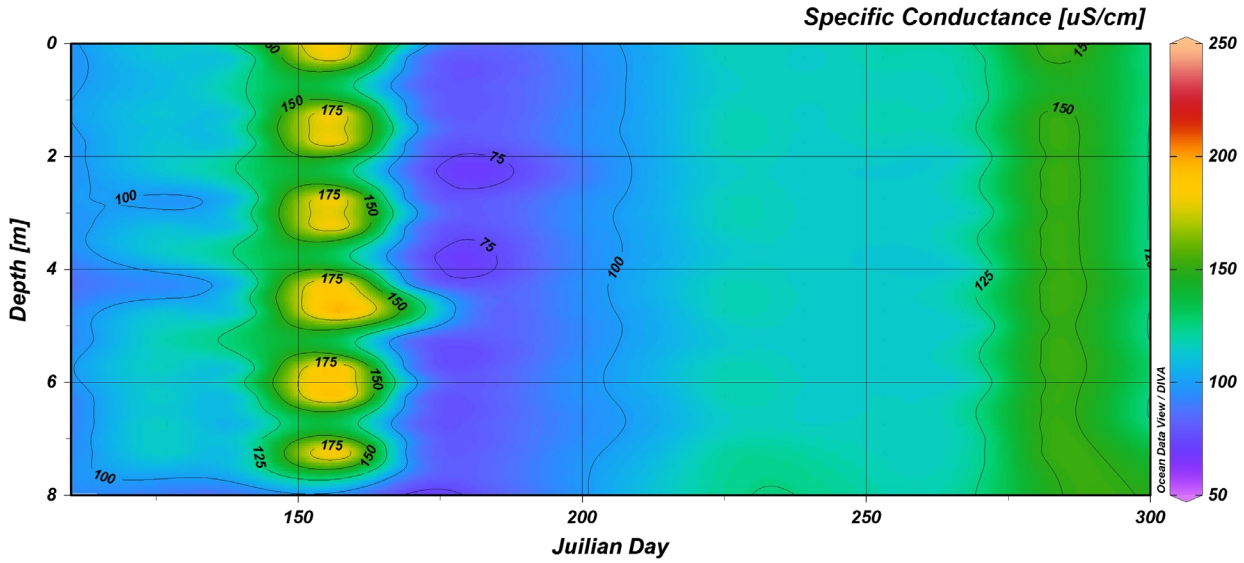
LCR-03A



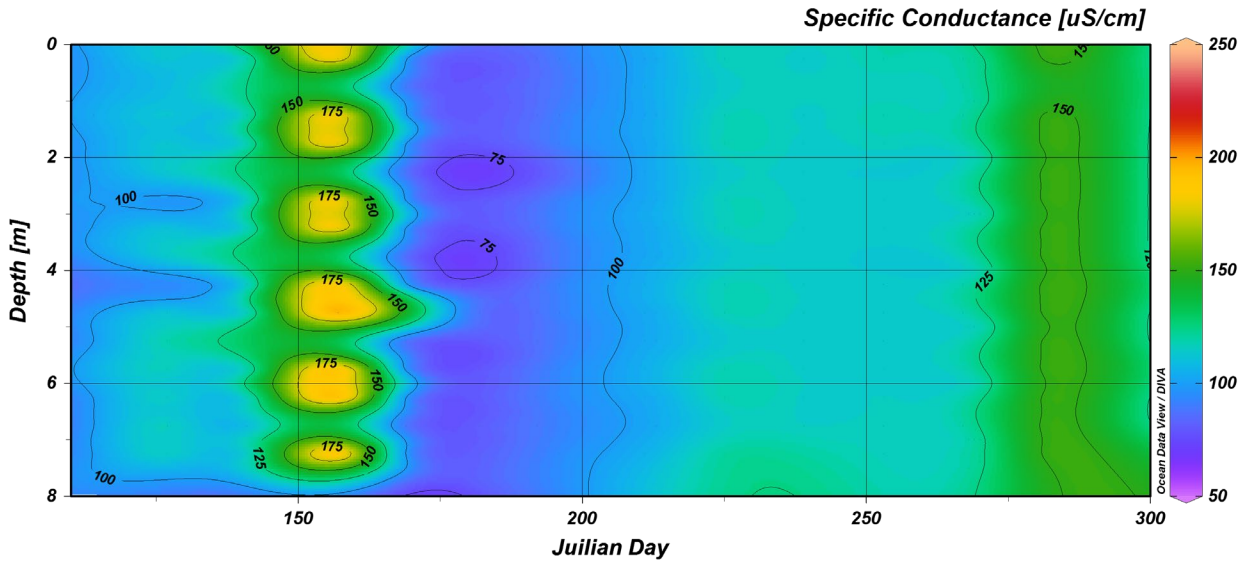
LCR-03B



CW-207B



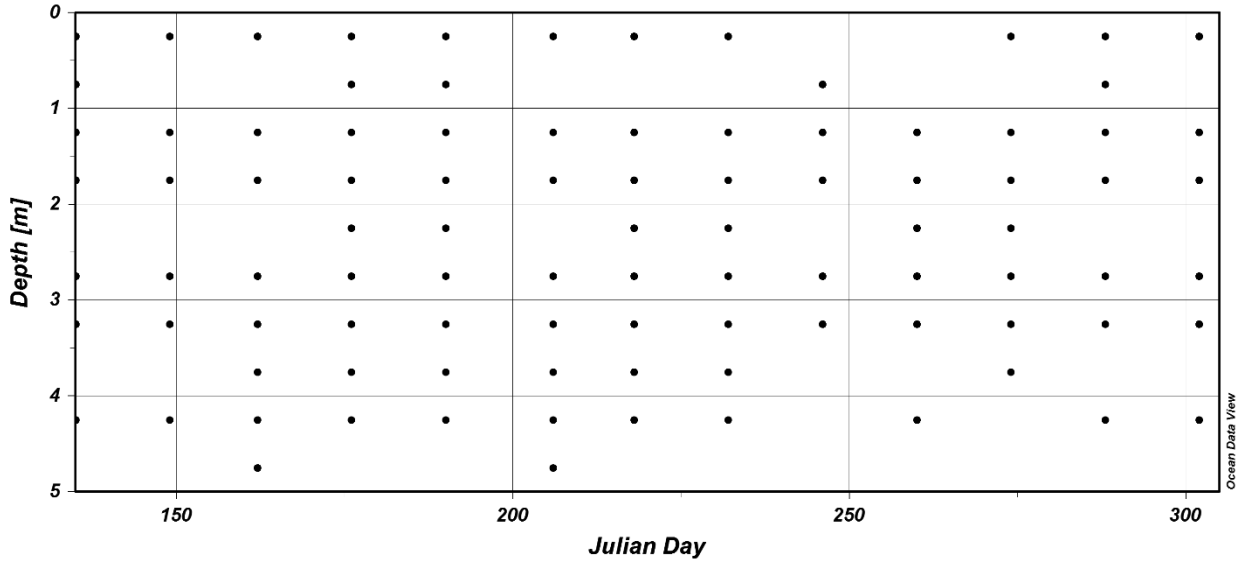
CL-089



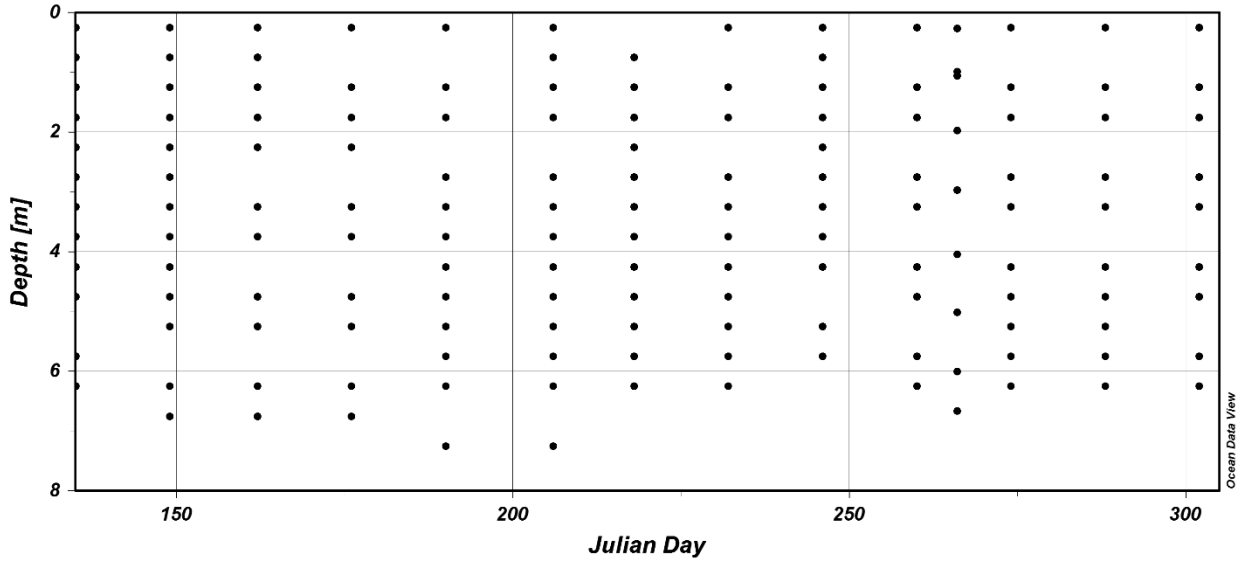
Data Points

LCR-01

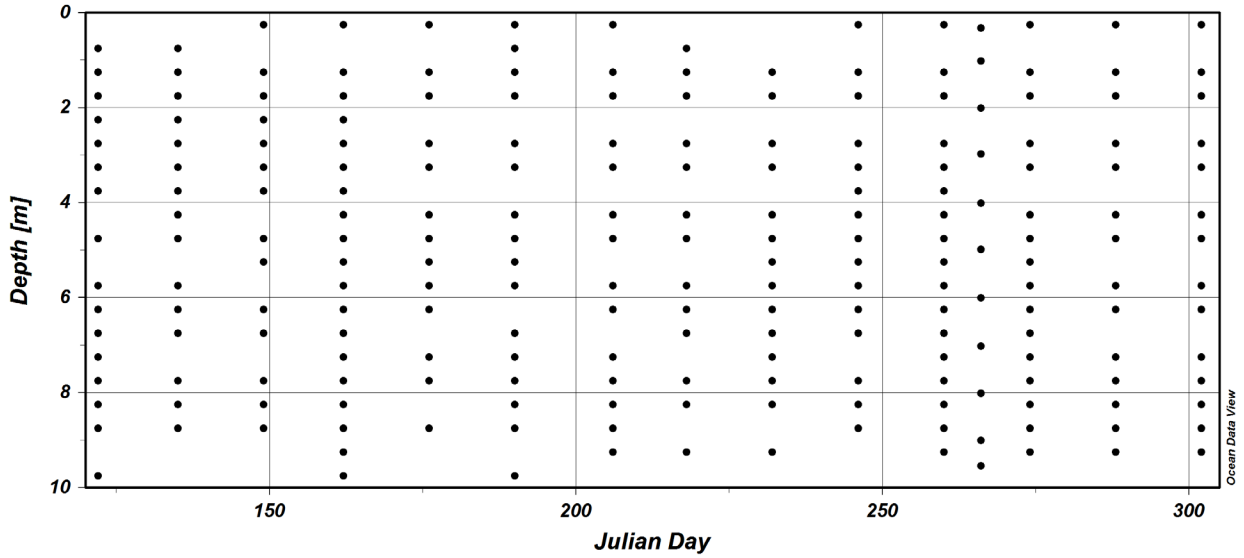
LCR-05


0
1
2
3
4
5
Depth [m]
150
200
250
300
Julian Day
Ocean Data View

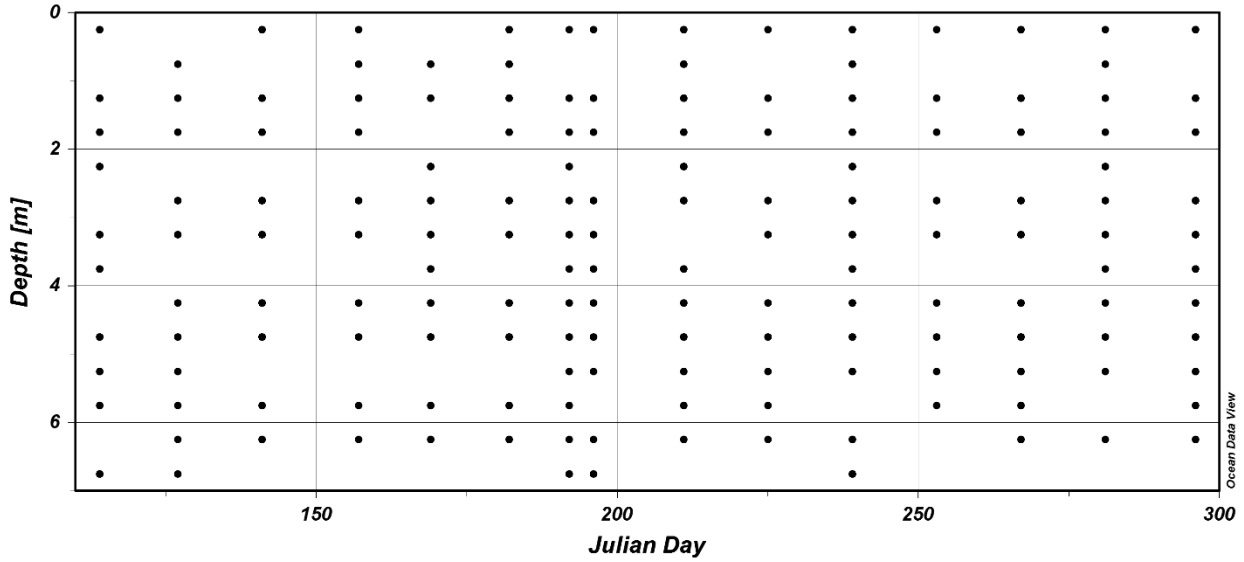
LCR-04


0
2
4
6
8
Depth [m]
150
200
250
300
Julian Day
Ocean Data View

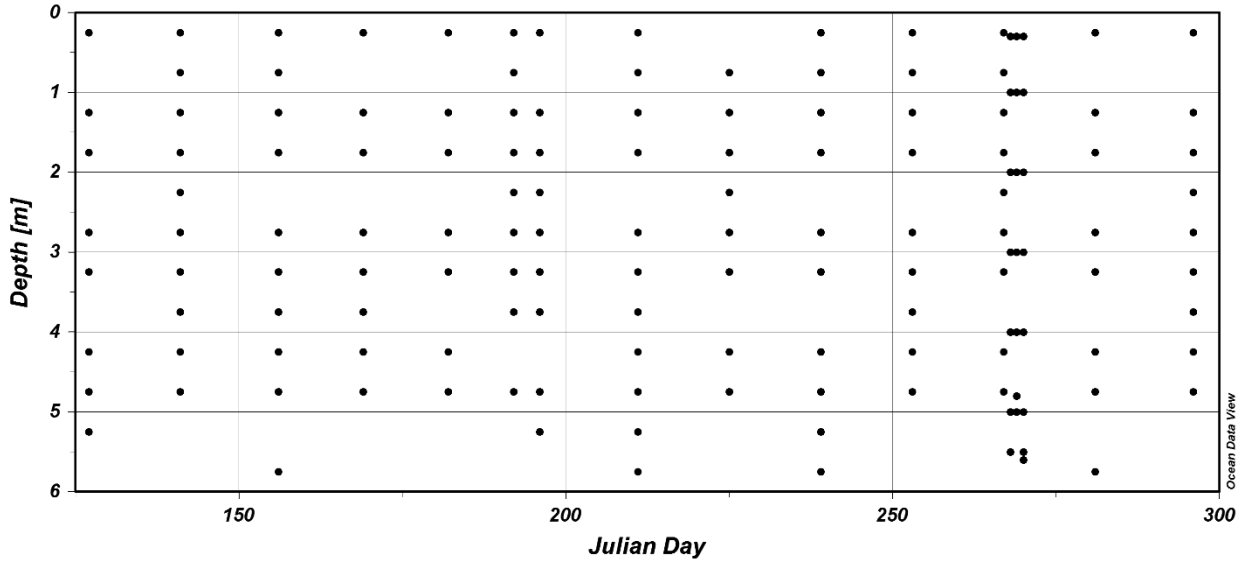
CW-057


Depth [m]
0
2
4
6
8
10
150
200
250
300
Julian Day
Ocean Data View

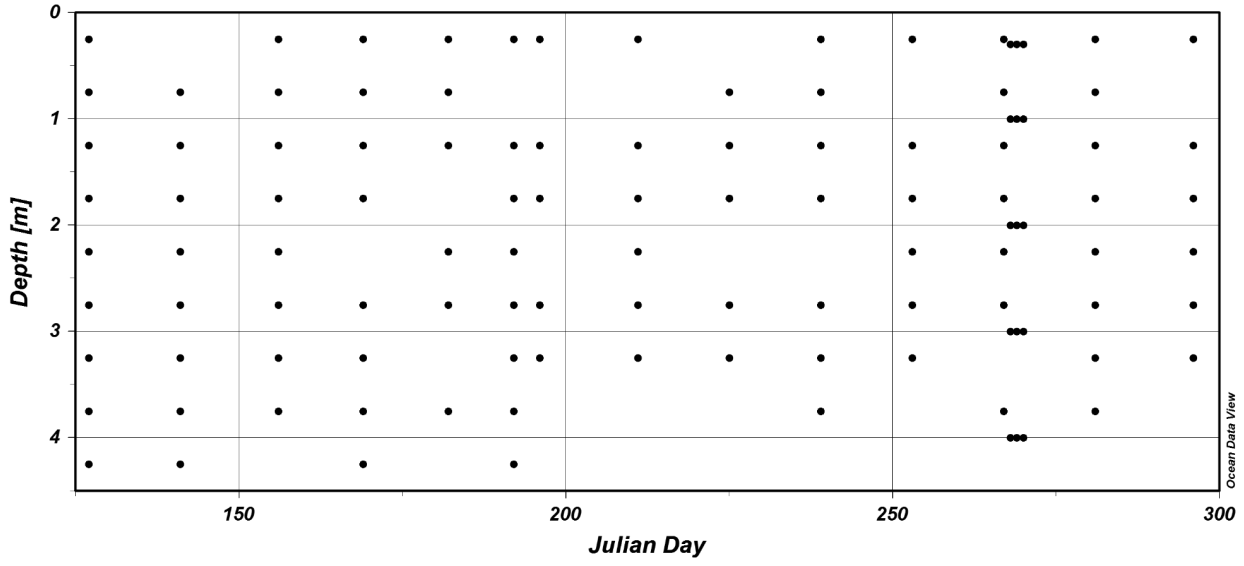
LCR-02


Depth [m]
0
2
4
6
150
200
250
300
Julian Day
Ocean Data View

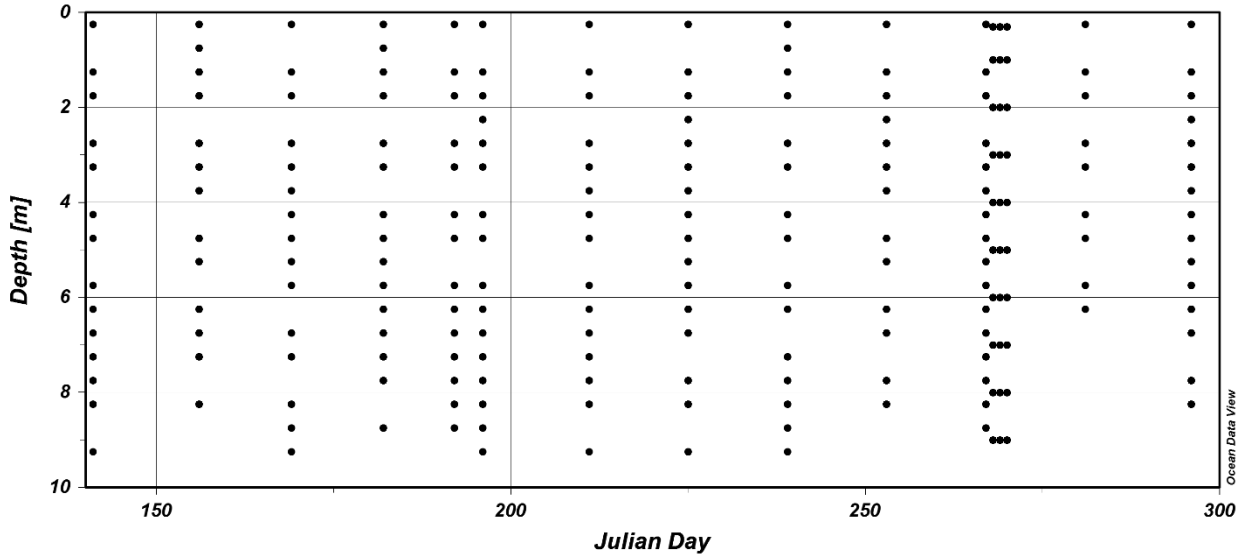
CW-208


Depth [m]
0
1
2
3
4
5
6
150
200
250
300
Julian Day
Ocean Data View

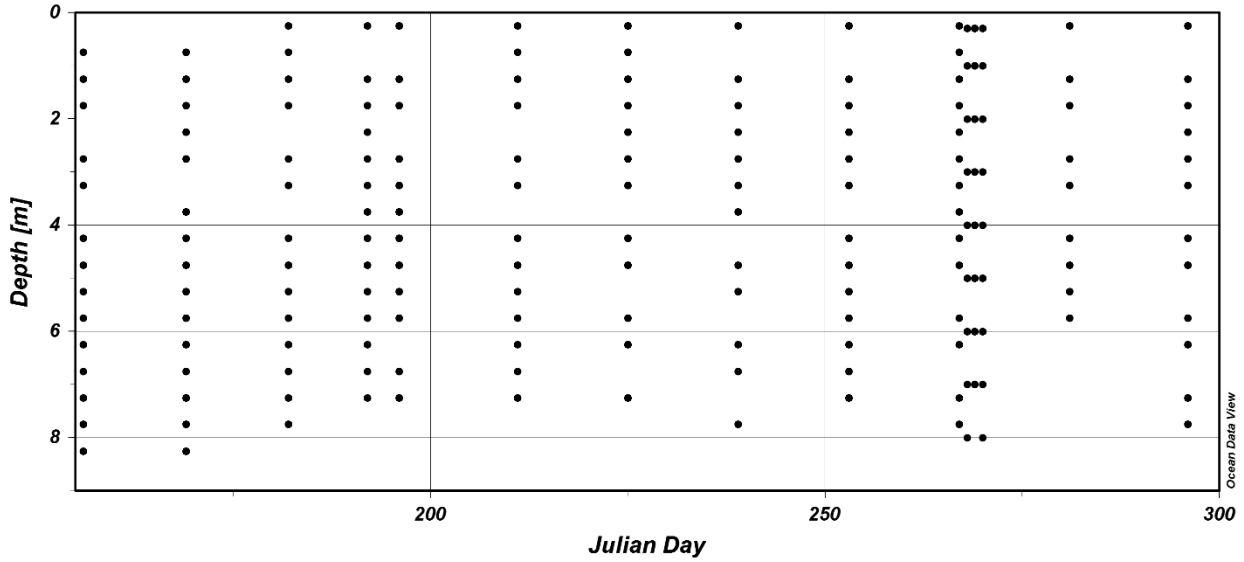
LCR-03


Depth [m]
0
1
2
3
4
150
200
250
300
Julian Day
Ocean Data View

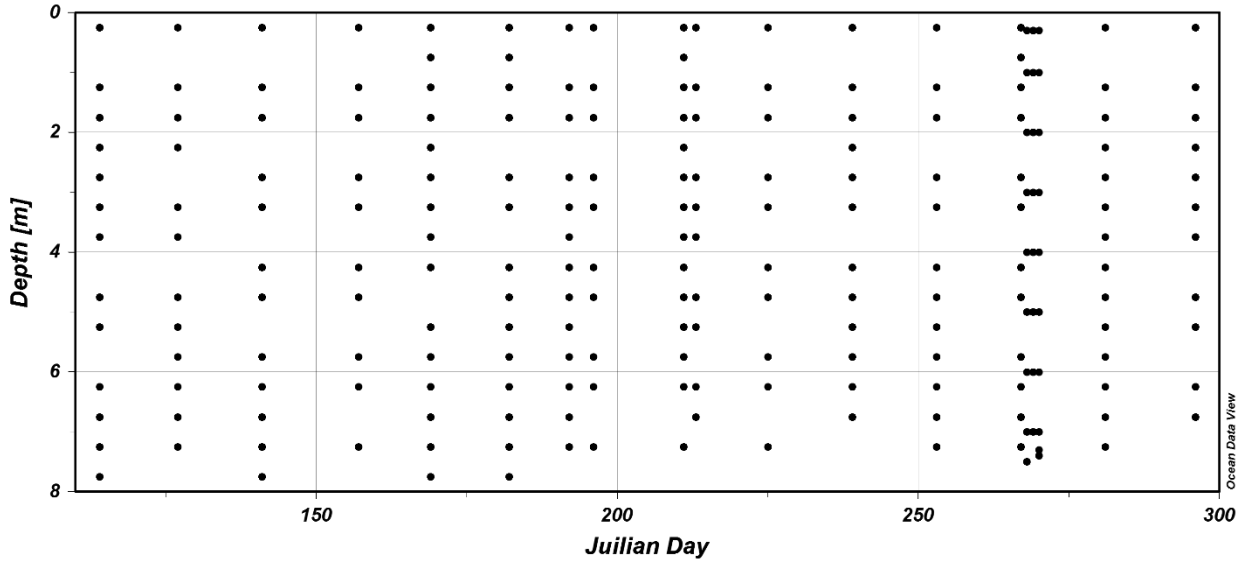
LCR-03A



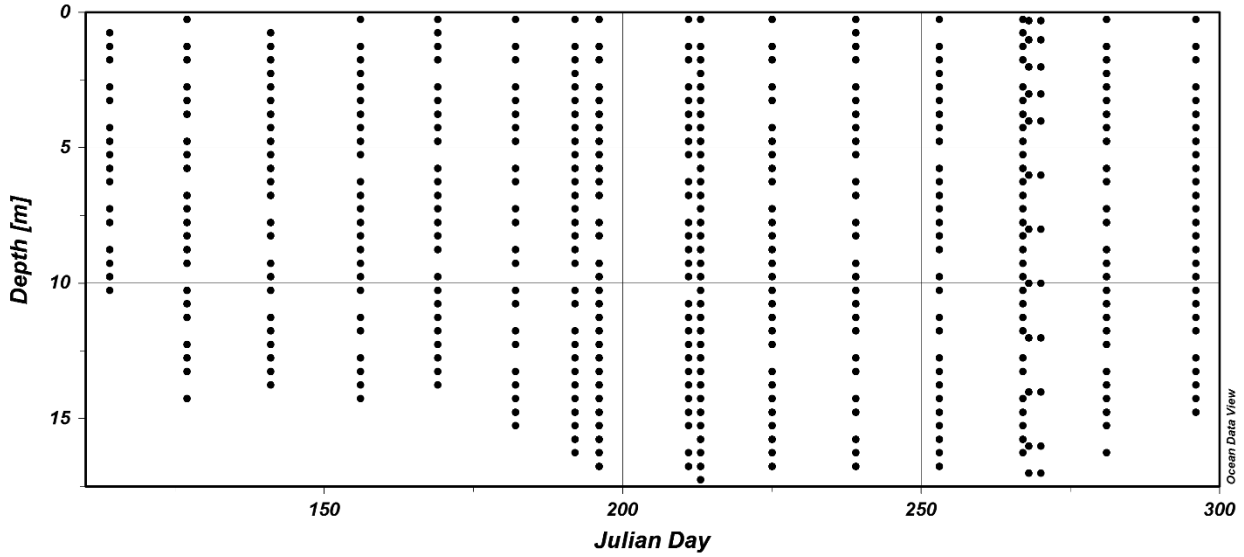
LCR-03B



CW-207B

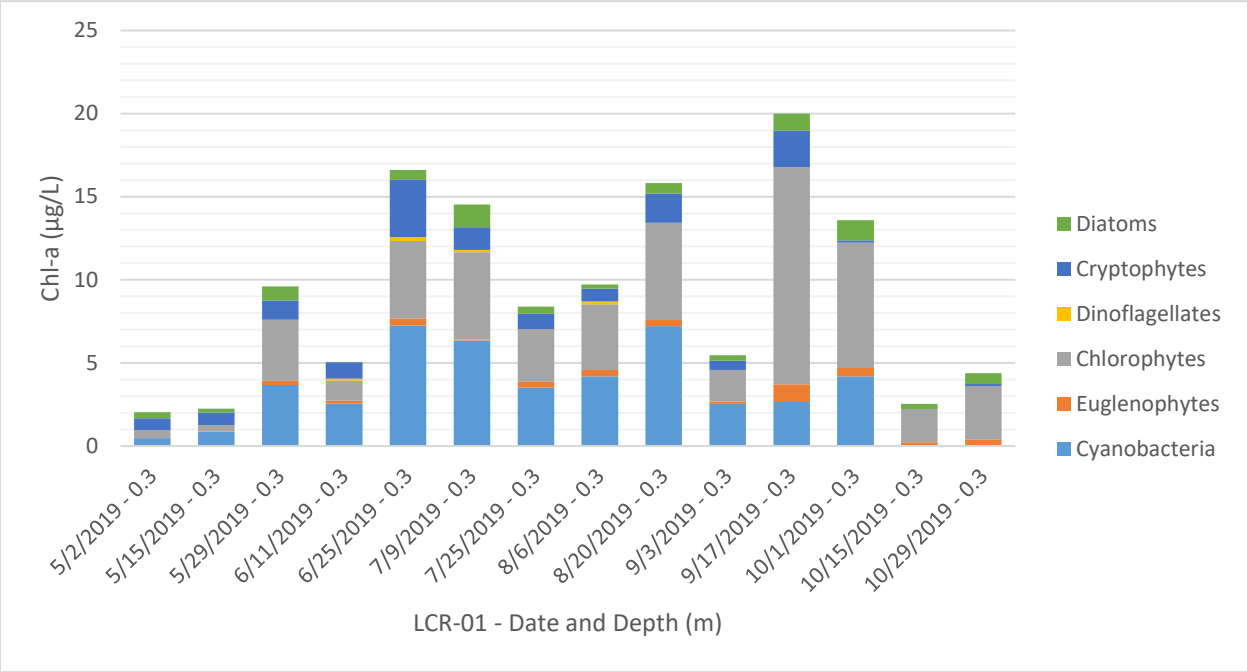


CL-089

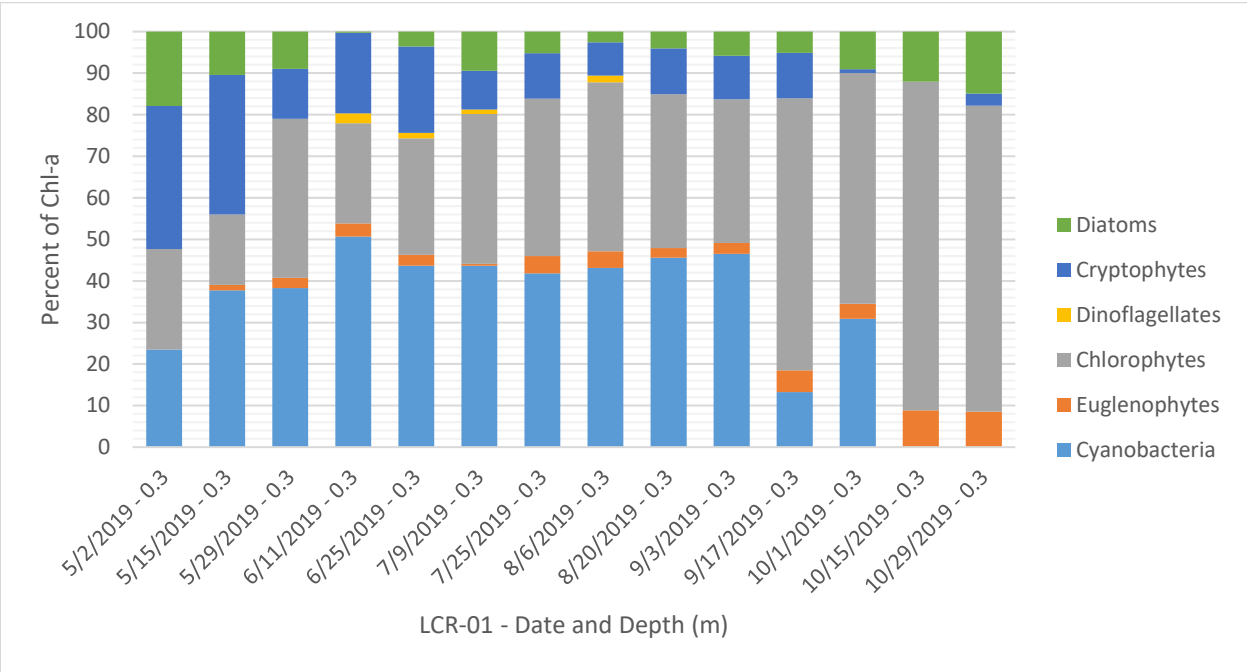


Appendix B – Phytoplankton Community Composition

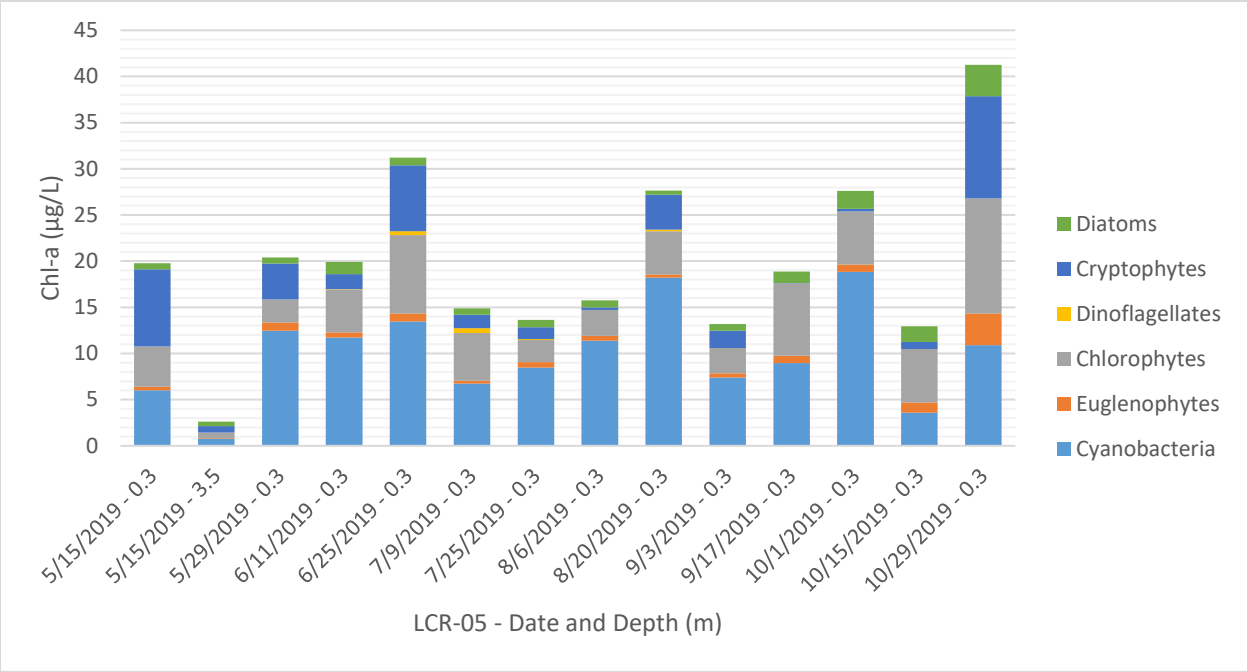
LCR-01 – Absolute Contribution to Total Chlorophyll-a



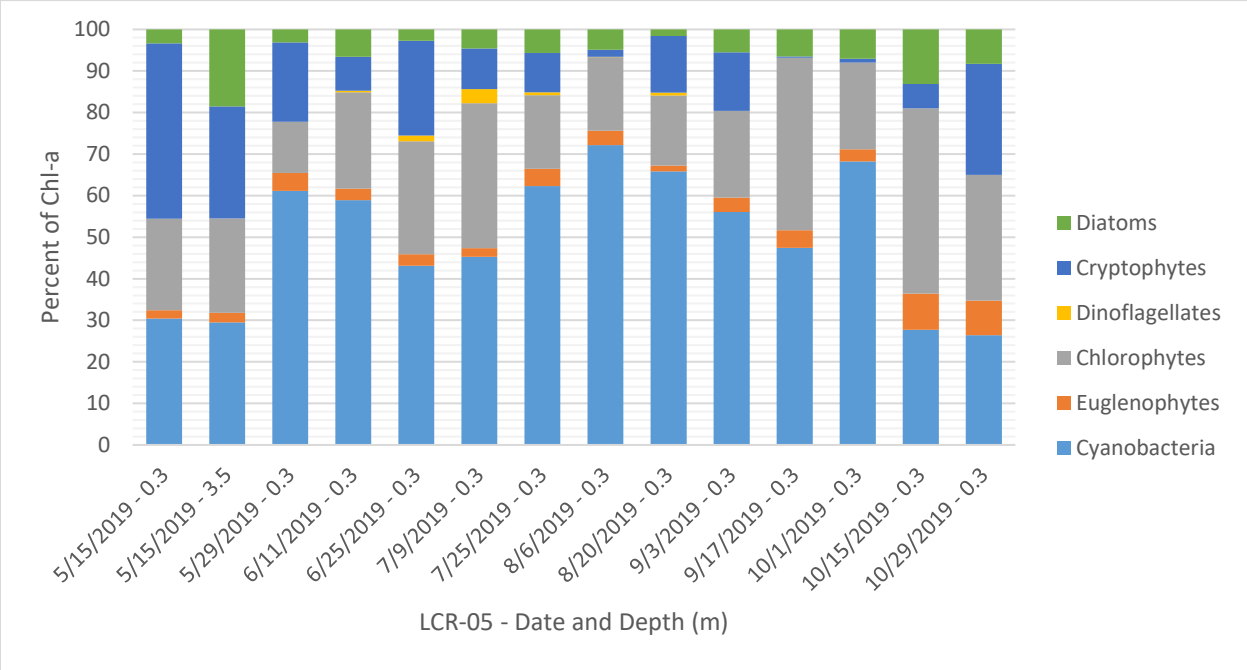
LCR-01 – Relative Contribution to Total Chlorophyll-a



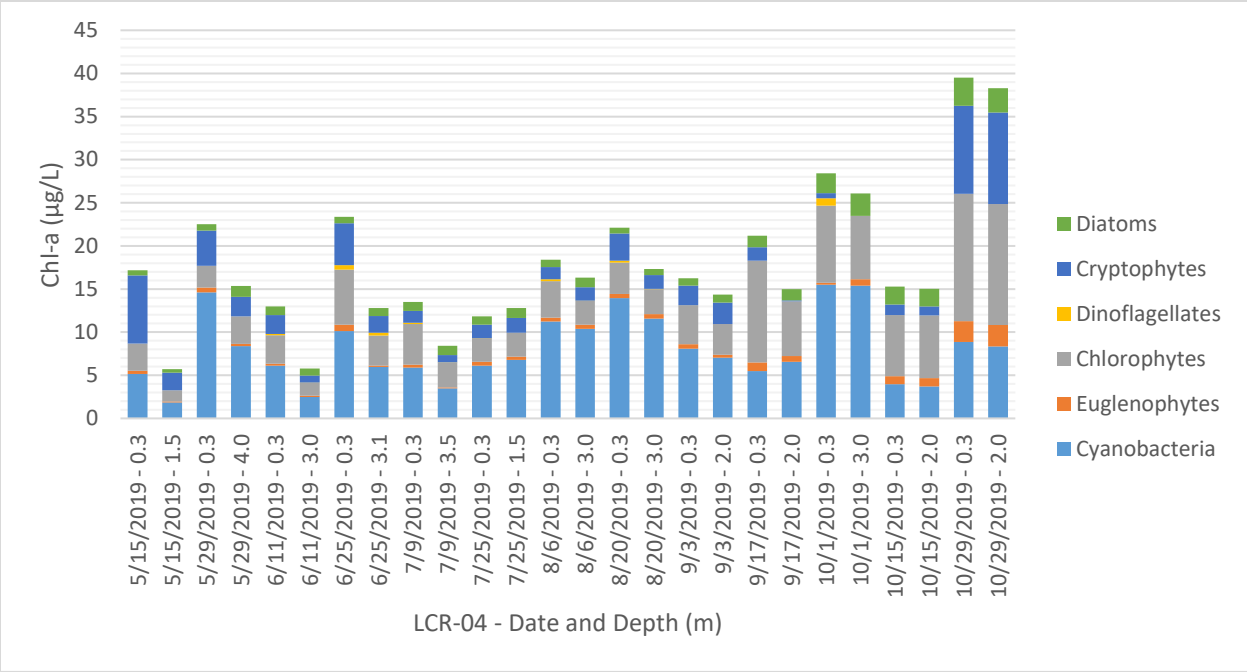
LCR-05 – Absolute Contribution to Total Chlorophyll-a



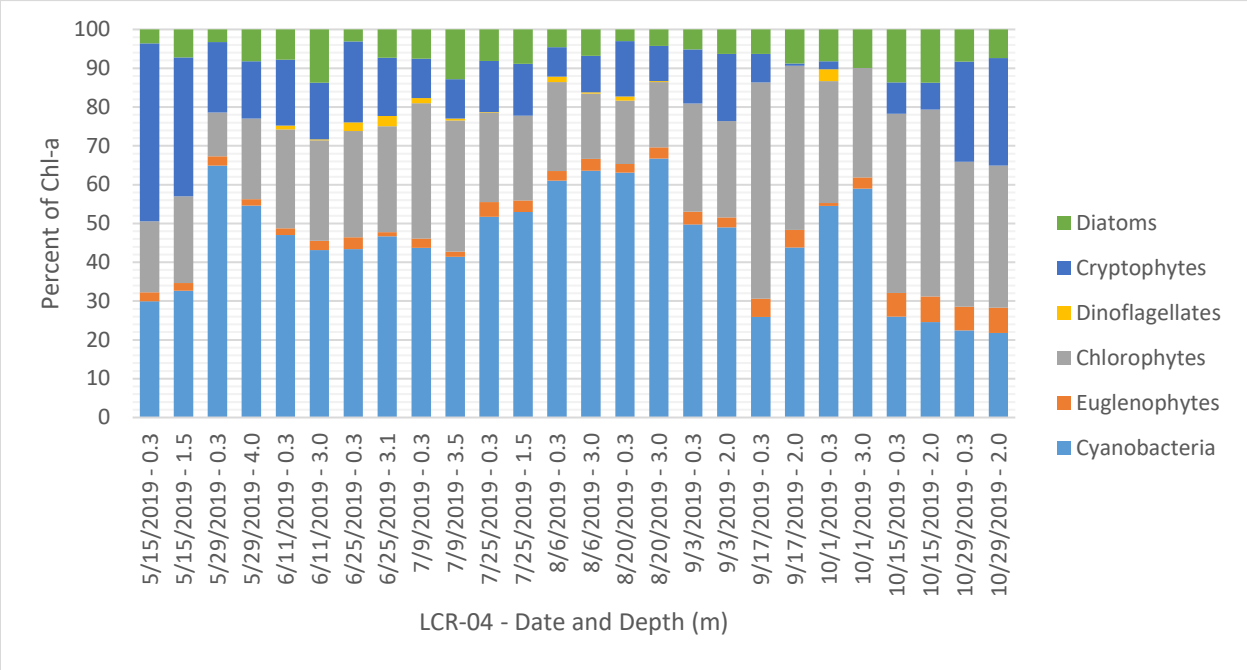
LCR-05 – Relative Contribution to Total Chlorophyll-a



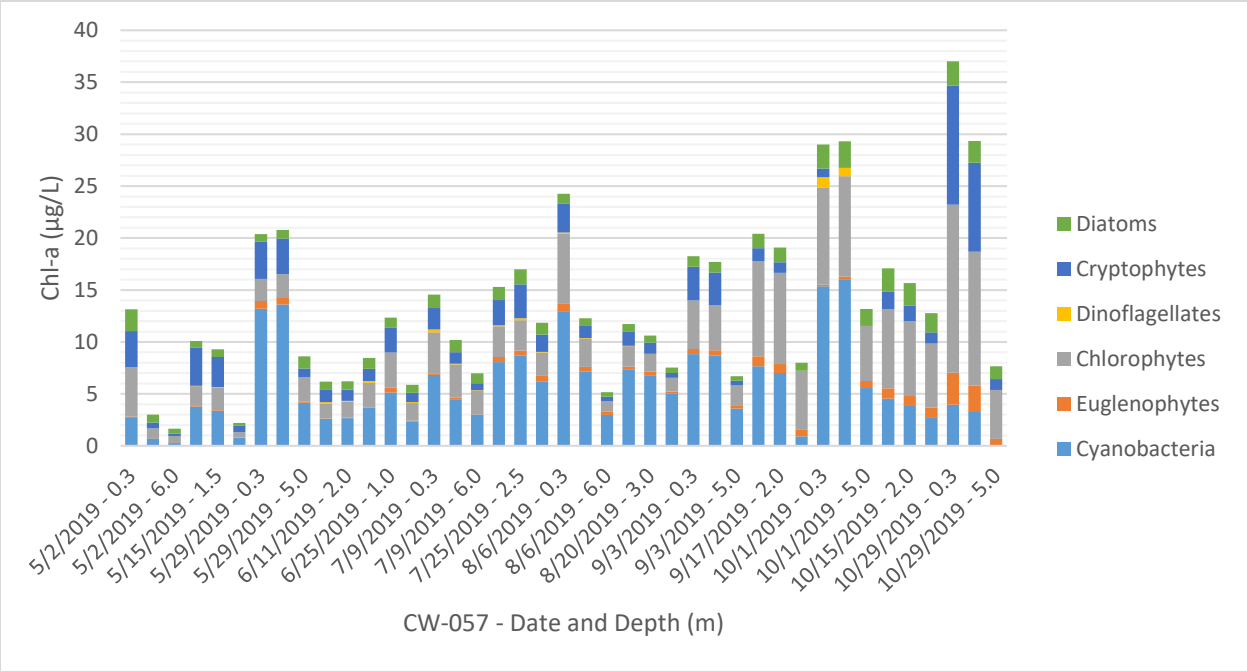
LCR-04 – Absolute Contribution to Total Chlorophyll-a



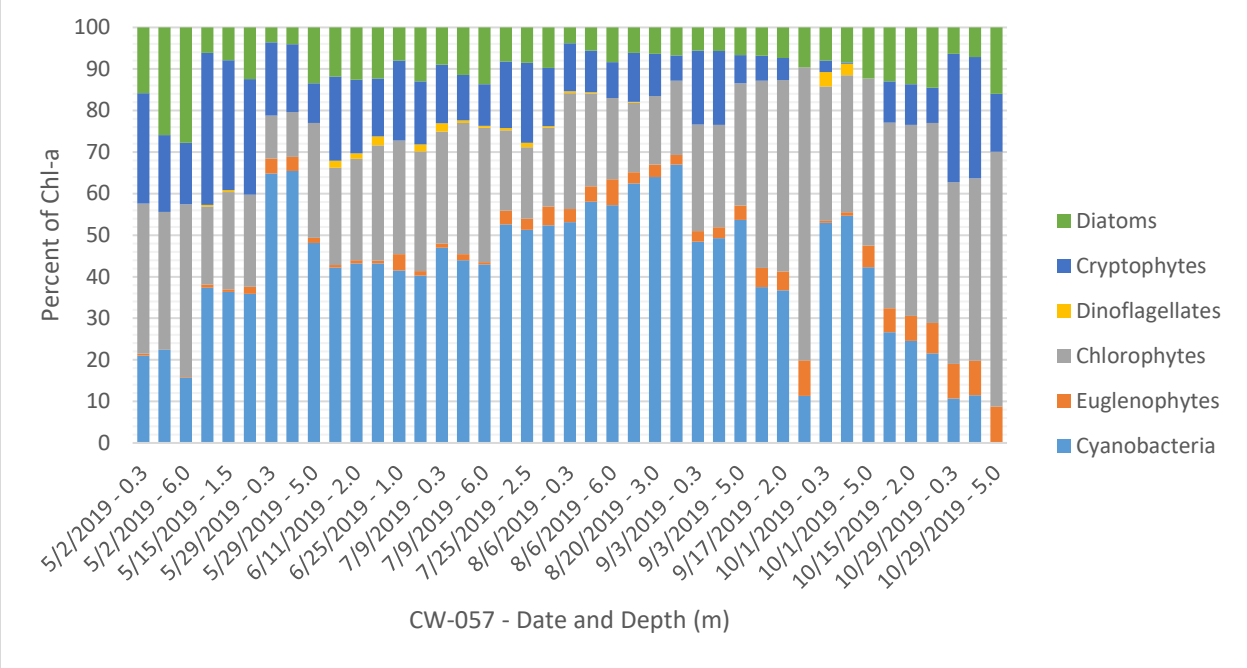
LCR-04 – Relative Contribution to Total Chlorophyll-a



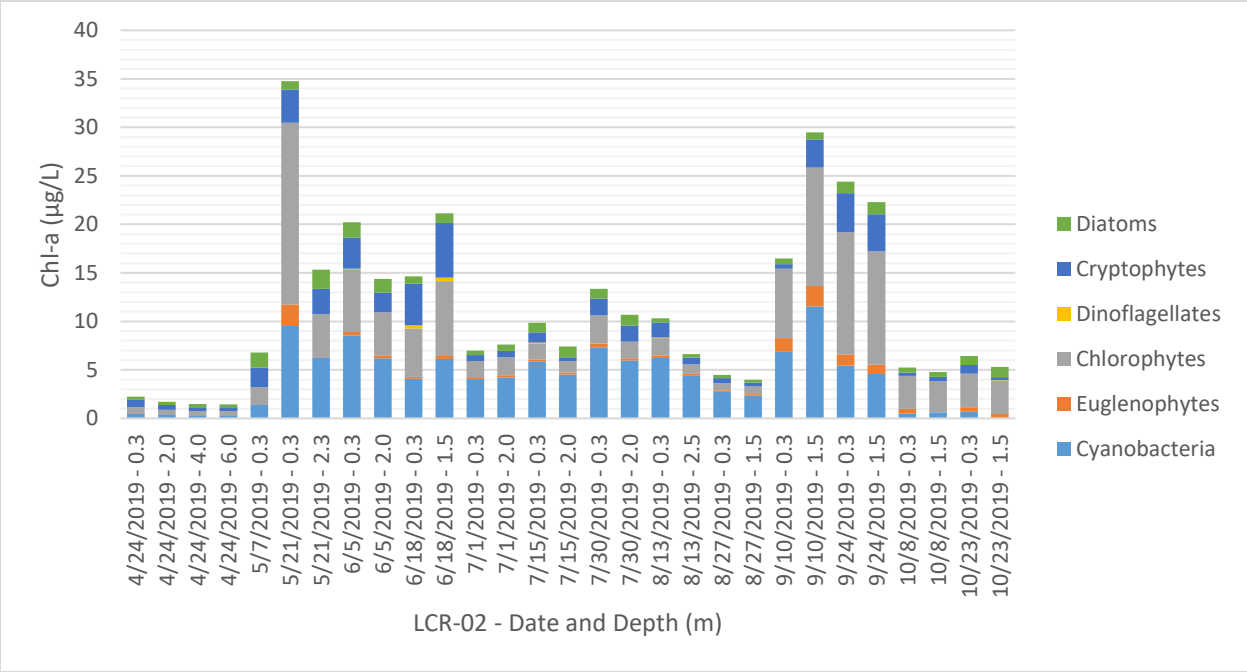
CW-057 – Absolute Contribution to Total Chlorophyll-a



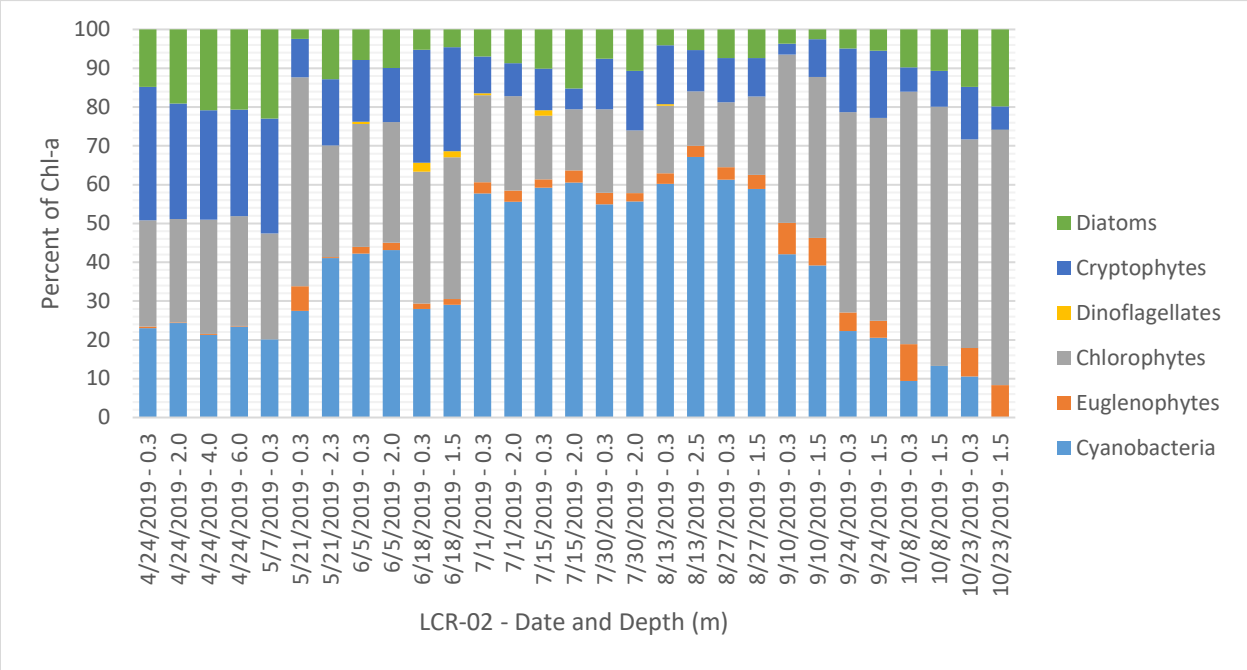
CW-057 – Relative Contribution to Total Chlorophyll-a



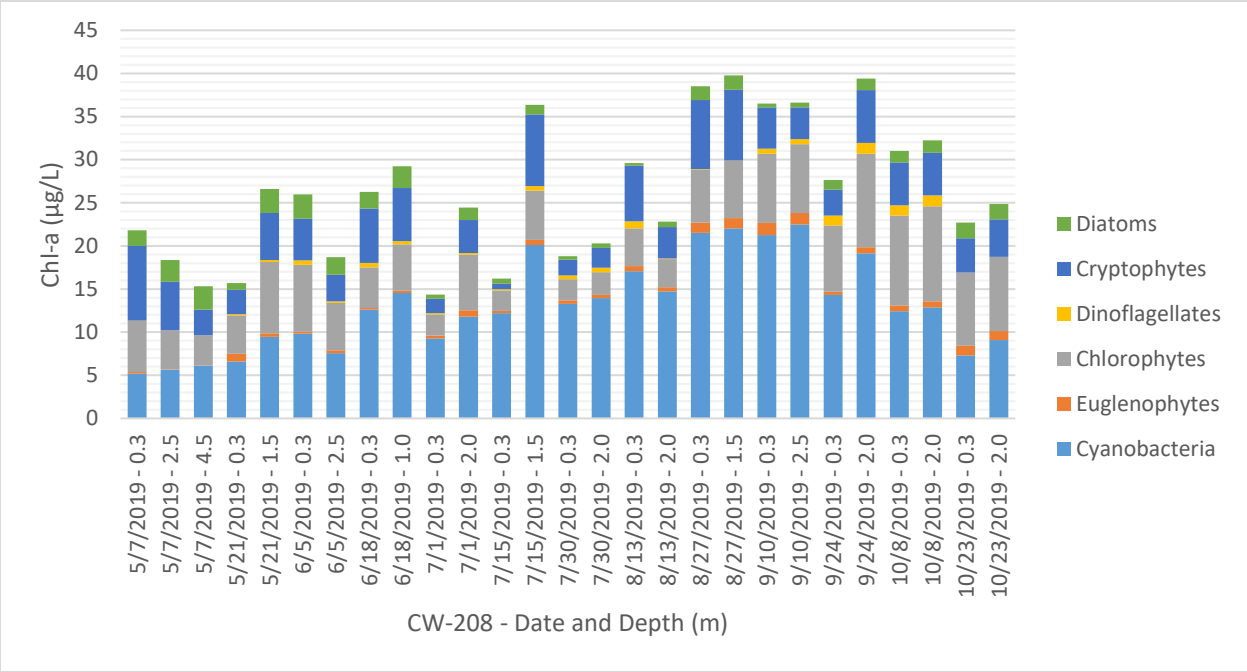
LCR-02 – Absolute Contribution to Total Chlorophyll-a



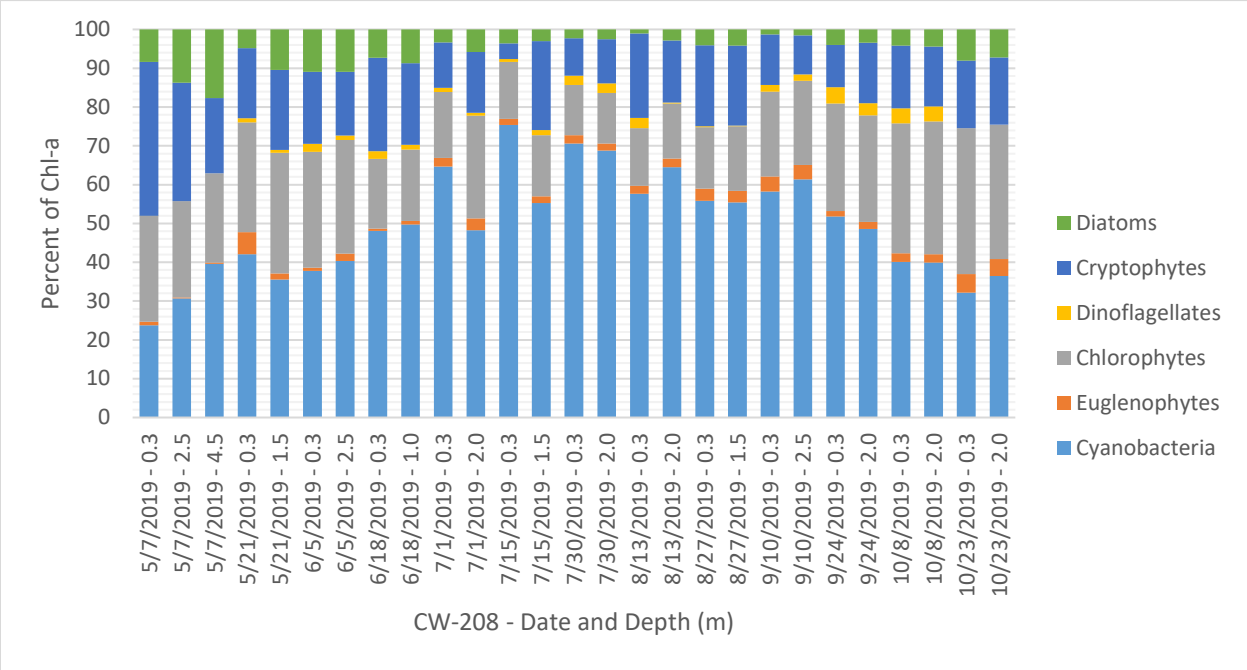
LCR-02 – Relative Contribution to Total Chlorophyll-a



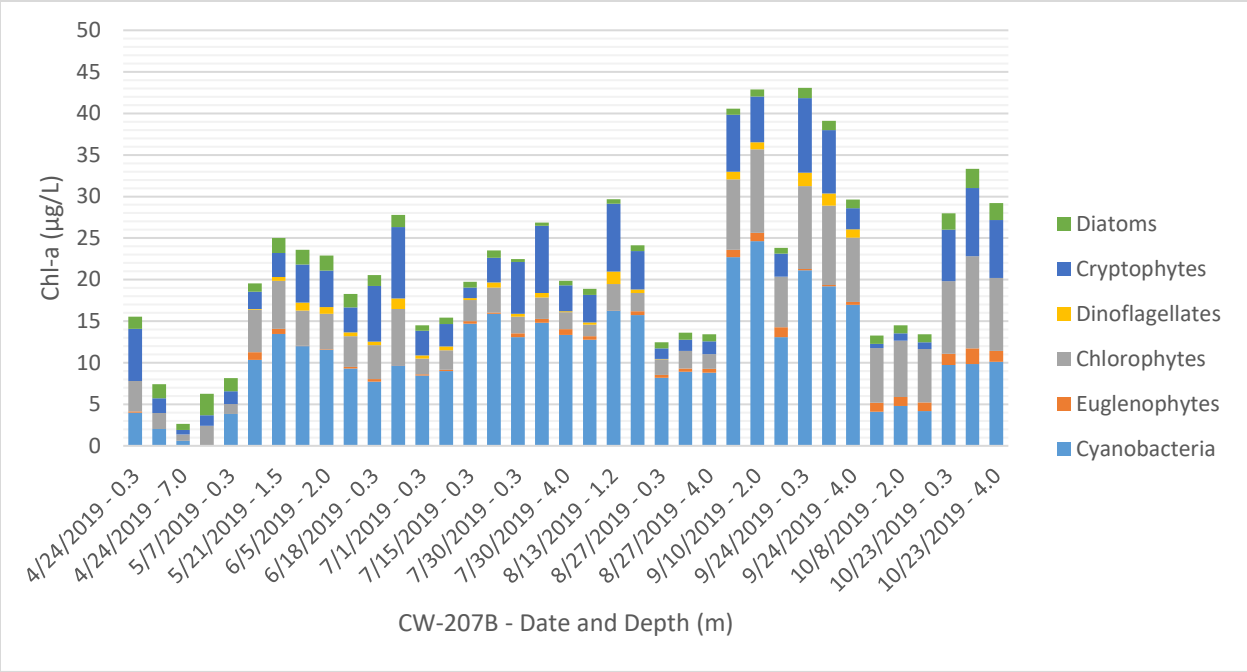
CW-208 – Absolute Contribution to Total Chlorophyll-a



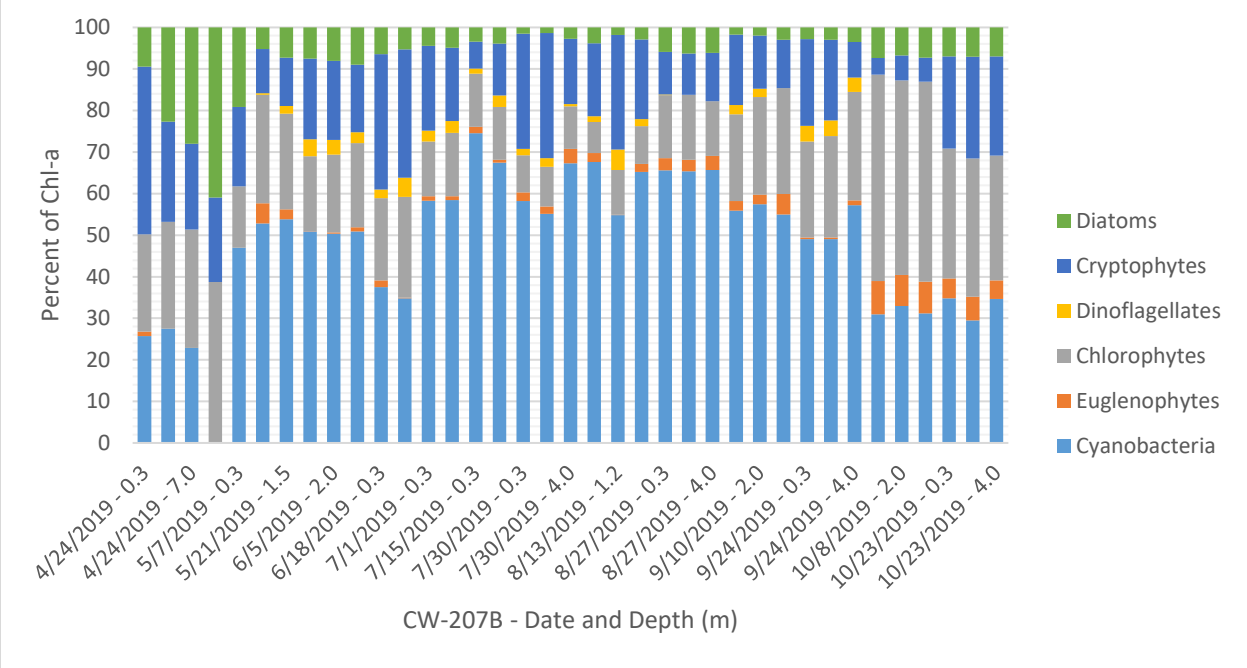
CW-208 – Relative Contribution to Total Chlorophyll-a



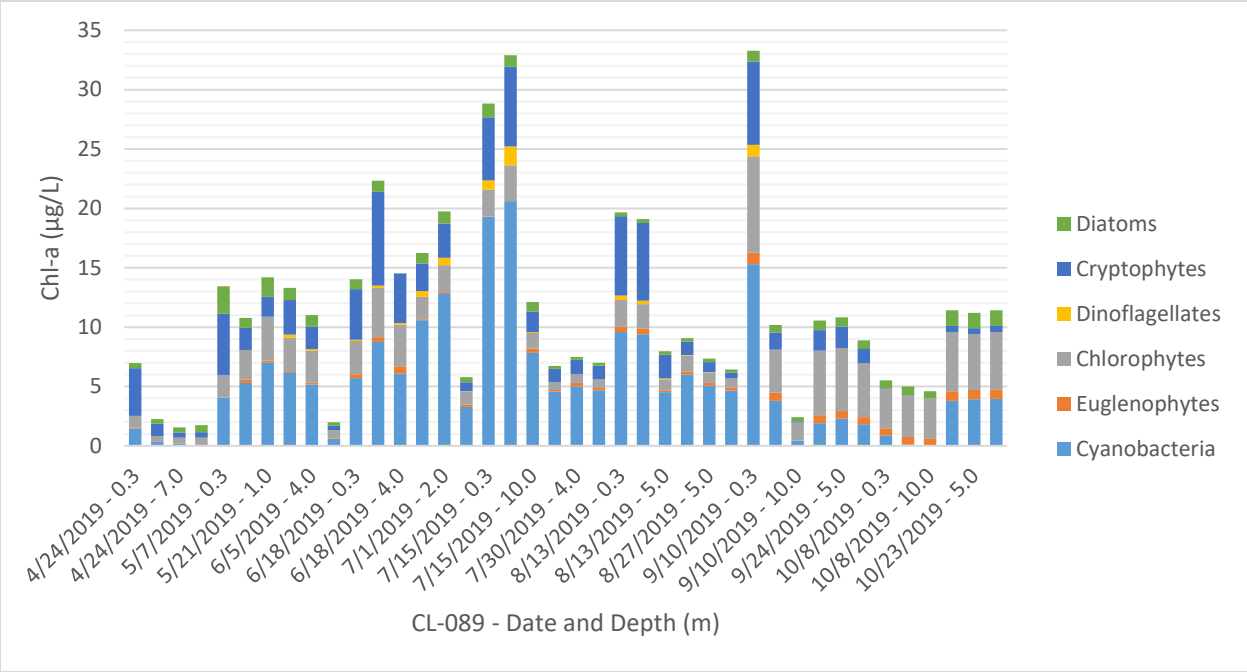
CW-207B – Absolute Contribution to Total Chlorophyll-a



CW-207B – Relative Contribution to Total Chlorophyll-a



CL-089 – Absolute Contribution to Total Chlorophyll-a



CL-089 – Relative Contribution to Total Chlorophyll-a