Nutrient Moored Sensor Program: PROGRAM UPDATE

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Acronyms

BACWA	Bay Area Clean Water Agencies
DWR	California Department of Water Resources
LSB	Lower South Bay
NMS	Nutrient Management Strategy
NMS-MSP	Nutrient Management Strategy Moored Sensor Program
POTW	Publicly Owned Treatment Works
RMP	Regional Monitoring Program for San Francisco Bay
SFB	San Francisco Bay
USGS	United States Geological Survey

1. Introduction

San Francisco Bay (SFB) has high nitrogen and phosphorus concentrations, but has historically not experienced the eutrophication problems typical of other nutrient-enriched estuaries. However, recent observations, based on long-term monitoring data, have identified substantial interannual shifts in the Bay's response, or sensitivity, to nutrients (Cloern et al. 2007, 2010). In addition, special studies and expanded monitoring over the past several years have revealed other water quality conditions — e.g., recurring low dissolved oxygen in some margin habitats, and consistent detection of multiple toxins produced by harmful algae — whose effects on ecological health need to be evaluated and causal factors determined. Concerns about SFB nutrient-related water quality prompted the SFB Regional Water Quality Control Board (SFBRWQCB) and stakeholders to establish the SFB Nutrient Management Strategy (NMS; SFBRWQCB, 2012). The NMS is a collaborative applied science program that over the past several years has been pursuing a diverse set of studies — water quality monitoring, targeted field investigations, and numerical modeling — targeted to inform nutrient management decisions for SFB (Table 1.1).

Table 1.1 Overarching Nutrient Management Strategy Management Questions

1. What water quality conditions would be considered healthy, or protective of beneficial uses?
2. How do observed water quality conditions compare to healthy/protective conditions?
3. What are the dose:response quantitative relationships between nutrient loads and key water quality indicators?
4. If nutrient loads are negatively impacting water quality, what nutrient load reductions are needed to achieve healthy/protective conditions?

The SFB Nutrient Management Strategy Moored Sensor Program (NMS-MSP) was launched in July 2013 to collect nutrient-related water quality data at high temporal frequency as a complement to long-term ship-based monitoring to enhance the characterization of water quality, provide additional mechanistic insights into physical and biogeochemical dynamics, and allow for improved calibration of biogeochemical models. Early work with the NMS-MSP network included installation of three stations in 2013-2014 (Dumbarton Bridge, Alviso Slough, and San Mateo Bridge). A Year 1 progress report (Novick & Senn, 2014) described the goals and status of the NMS-MSP, and documented operating procedures, data quality and data management, and an overview of initial observations. Since 2015, the NMS-MSP network has expanded to 8 stations, distributed across a range of habitats in South Bay and Lower South Bay (LSB).

This report provides an update on the NMS-MSP, organized as follows:

Section 2: Program Update: Current NMS-program and program changes since 2015
Section 3: Program Management: Maintenance, Data QAQC, and Data Management
Section 4: Overview of NMS-MSP Data and Data Applications
Section 5: Direction Over the Coming Years

2. Program Update

2.1 Program Goals

The NMS-MSP YR1 Report (2014) laid out a set of goals and an approach for launching and sustaining the high frequency monitoring program to achieve those goals, which are reproduced here in Table 2.1. The early goals outlined in the Year 1 report focused on program development and site selection, while longer-term goals looked toward implementation as well as the application of continuous data within other components of the NMS (e.g., model calibration, data analysis, condition assessment). Since 2014, NMS-MSP work has moved ahead on several fronts, guided by these goals and in response to emerging NMS program needs. Where relevant, the discussion in the subsequent sections refers back to the original Program Goals and Key Questions in Table 2.1 (noted in brackets with the question number(s), e.g., ***[Q1.1-Q1.2]***). In addition, the report closes in Section 5 by revisiting the original goals, discussing program status relative to these goals, and identifying priority future work (related to new goals).

Table 2.1 NMS Moored Sensor Program Goals (G) and Key Questions (Q), from Yr 1 Report (SFEI 2014).

Goals (G)	**Key Questions (Q)**
1: Identify the best sensors or sensor packages considering program goals and develop capacity to deploy and maintain moored sensors	1.1 What locations are feasible for sensor deployment? 1.2 How frequently do the sensors need to be serviced? How does this vary seasonally? 1.3 What biofouling prevention tools are most effective?
2: Create/adapt procedures for automated data acquisition, data management, and real-time high-frequency data visualization	2.1 What standard procedures exist for data processing (i.e. removing outliers, correcting for fouling/drift)? 2.2 What data processing can be automated? 2.3 What are the data visualization needs of the NMS-MSP, and what is the best way to address those needs?
3: Develop understanding of sensor accuracy and potential interferences	3.1 What parameters can be accurately measured by moored sensors? 3.2 How well does the EXO2 agree with other moored sensors being used in SFB? 3.3 What amount of discrete sampling is necessary to verify or calibrate sensor output? What are the main interferences, and to what degree can we improve measurement accuracy through adjusting for interferences?
4: Establish collaborations with other moored sensor programs	4.1 Where are the other moored sensor stations throughout the Bay? 4.2 What work is needed to integrate existing sensors from multiple programs into one broad network? 4.3 How does the cost of integrating existing programs compare to developing an SFEI moored sensor program at similar sites?
5: Identify NMS-MSP structure that, along with ship-based monitoring, addresses the NMS monitoring and data collection needs	5.1 What is the optimal combination of ship-based and moored stations? 5.2 What spatial distribution (lateral, longitudinal, vertical) of moored sensors, and for which parameters, are needed to sufficiently capture relevant information related to bloom dynamics, oxygen, or nutrient cycling, for improved mechanistic understanding, model calibration, or condition assessment?
6: Use moored sensor data to address priority science questions and data gaps	6.1 What factors influence the onset and termination of a bloom? 6.2 What frequency, magnitude, and duration of a bloom is possible?
7: Use moored sensor data to calibrate/validate water quality models	7.1 What time-series data needed for model calibration can be collected with moored sensors? 7.2 Are there particular locations and/or time periods where additional calibration data are needed (beyond that collected at established moored sensor sites)?
8: Use moored sensor data to assess condition in SFB	8.1 For which nutrient-related indicators would condition assessment benefit from using high-frequency moored sensors? 8.2 If/when nutrient-related impairment occurs along one or more pathways, what extent/duration can it be detected by moored sensors?

2.2 Current NMS-MSP Network

The NMS-MSP has been in operation for just over five years since the first two instruments were deployed in 2013 at Dumbarton Bridge and Alviso Slough. Over that time, monitoring has begun at 6 additional locations, resulting in an 8-station network distributed across LSB and South Bay (Figure 2.1). The expanded network is designed to collect data in physically and biologically distinct areas of the South Bay and LSB ***[Q5.1-5.2, Q6.1-6.2, Q7.1-7.2, Q8.1-8.2]***, and provide a more complete biogeochemical picture of a region with unique tidal patterns, large scale marsh restoration efforts, and continuous nutrient inputs from publicly owned treatment works (POTWs).

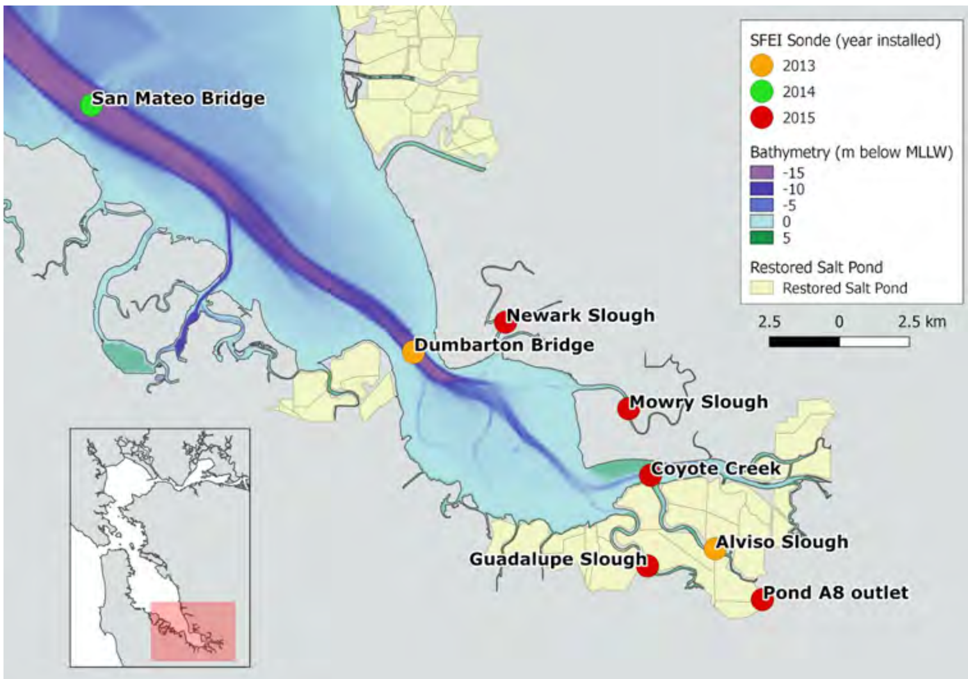


Figure 2.1: NMS-MSP site locations (as of December, 2018).

Following the Dumbarton and Alviso installs, a third station came on-line at San Mateo Bridge in 2014. Five additional sites were installed in 2015 (Newark Slough, Coyote Creek, Mowry Slough, Guadalupe Slough, Pond A8 Feeder Channel). Figure 2.2 illustrates the expansion of the network as a timeline. Table 2.2 summarizes main details of each deployment: type, installation date, vertical position, and deployment styles. The table also provides details on the rationale or criteria that guided site selection. Sites were chosen to represent a range of environmental conditions: deep channel; deep channel/LSB interface; sloughs with and without freshwater input, and sloughs with and without POTW input.

Early analysis of mooring data suggested that DO levels regularly fell below the 5 mg/L Basin Plan standard (SFEI LSB Nutrient Synthesis Report, 2016) in some LSB margin habitats, including habitats that had received little monitoring focus. To address these data gaps ***[Q5.1-5.2, Q7.1-7.2, Q8.1-8.2]***, the NMS-MSP network expanded in 2015 to several slough sites that represented a range of physical conditions: Guadalupe Slough, Alviso Slough, Newark Slough, and Mowry Slough. In addition, Coyote Creek was selected as a confluence site (creek inputs, POTW inputs, exchange with sloughs) with characteristics intermediate between Dumbarton Bridge and the smaller slough sites. A mooring was also added at the Pond A8 Feeder Channel site to measure conditions at the interface between a slough and a restored salt pond.

Figure 2.2: Timeline of NMS-MSP network growth by installation date and project year. Major changes in deployment configurations are denoted with a coloration change. Major instrumentation changes occured in 2018 and are denoted by the label “Primary Instrument: SBE HCEP”. The bottom panel shows the number of servicing trips completed per month at each site. Through December, 2018, there have been approximately 72 total servicing trips (as of summer, 2015, one servicing trip includes two days on the water to be able to service all 8 sites)

Across these sites, sensor packages have been deployed in a variety of configurations based on a combination of site constraints and scientific priorities, with the two primary configurations depicted schematically in Figure 2.3. Lessons learned during early work (logistical or scientific) informed some initial changes to deployment configurations (see Table 2.2 for details). Currently, San Mateo Bridge, Dumbarton Bridge, Newark Slough, and Coyote creek are all deployed at fixed elevations (fixed distance above bed sediments) along a vertical cable (Figure 2.3 A). At the remaining sites (Guadalupe Slough, Mowry Slough, Alviso Slough, and Pond A8 channel) sensors are attached to a cage that rests on the bottom of the channel, with sensor packages oriented horizontally at a distance ~0.5m above the bed (Figure 2.3 B). Figure 2.4 provides pictures of the deployment setup at Dumbarton Bridge, Coyote Creek, and Guadalupe Slough.

Table 2.2 Moored sensor site information and deployment information.

Site Name (Install Date)	Location: Lat, Lon	Deployment Information	Description
Dumbarton Bridge (July 2013)	*37.504167* *-122.119444*	*Habitat:* Open Channel *Deployment*: Moored line, bridge support *Depth:* 1-4 m, fixed elevation (~12.7 m.a.b.[1]) *Instrumentation*: YSI EXO2	Dumbarton Bridge provides an indication of conditions in the Lower South Bay open channel and is the southernmost of NMS-MSP's two bridge sites. In a sense, it is the interface between the Lower South Bay slough/shoal network and the deep channel of the Bay. Typically experiences high levels of fouling and rougher surface waters. USGS also maintains two sensors with data telemetry at this site (1.2 m and 7.6 m from the bottom).
San Mateo Bridge (July 2014)	*37.58444444* *-122.2488889*	*Habitat:* Open Channel *Deployment*: Moored line, bridge support *Depth:* 2-5 m (~19 m.a.b.; post-Oct 2016); 0.5 m (floating; pre-Oct 2016) *Instrumentation*: SeaBird HCEP (post-1/23/2018); YSI EXO2 (pre-1/23/2018)	Provides a second indication of conditions in the open channel of the South Bay. Northernmost site, approximately nine miles north of the Dumbarton Bridge site. Typically experiences high levels of fouling and rougher surface waters. The instrumentation is deployed on a moored line from the deck of the bridge. USGS also maintains two sensors at the San Mateo Bridge, which are 3m and 13.4m from the bottom.
Coyote Creek (May 2015)	*37.46384444* *-122.0241694*	*Habitat:* Creek/Slough Confluence *Deployment*: Moored line, support *Depth*: 2-5 m (1.2 m.a.b.) *Instrumentation*: SeaBird HCEP (post-1/26/2018); YSI EXO2 (pre-1/26/2018)	Coyote Creek receives freshwater input (via Coyote Creek) and POTW input from the City of San Jose (via Artesian Slough). The Coyote Creek site is located at the confluence of Coyote Creek and Alviso Slough. The instrumentation is deployed off of the east tower. Co-located sensors operated by the USGS have been deployed along side SFEI instruments.
Alviso Slough (Sept 2013)	*37.44* *-121.9983333*	*Habitat:* Slough *Deployment*: Cage, resting on bottom *Depth*: 1-4 m (0.5 m.a.b.) *Instrumentation*: YSI EXO2	Alviso Slough receives freshwater input (via Guadalupe River) and has connections to restored salt ponds both upstream and downstream from the sensor site. There is no direct POTW input to Alviso Slough. The instrumentation is deployed in a cage, mid channel. USGS also maintained an Aquadopp current meter (measuring velocity) and YSI sensor at this site, however it was removed in early 2018. ~25m from either bank.
Guadalupe Slough (June 2015)	*37.434675* *-122.0257528*	*Habitat:* Slough *Deployment*: Cage, resting on bottom *Depth*: 0-3 m (0.5 m.a.b.) *Instrumentation*: YSI EXO2	Guadalupe Slough receives freshwater input (via Saratoga Creek). It also receives POTW input from Sunnyvale (via Moffett Channel), and has connections with restored salt ponds (with one connection ~75m downstream of the sensor location). The chosen site is three miles upstream from the mouth of the slough, along a latitude close to the Alviso site. The instrumentation is deployed in a cage, mid channel - the depth of the channel rapidly decreases shortly upstream of the deployment. During some ebb tides sensor is exposed. ~27m from either bank.
Newark Slough (April 2015)	*37.51338333* *-122.0821*	*Habitat:* Slough *Deployment*: Moored line from railroad bridge *Depth*: 0-3 m (0.9 m.a.b., post-Aug 2016); (1.2 m.a.b., pre-Aug 2016) *Instrumentation*: YSI EXO2	Newark Slough is a dead-end slough (no freshwater input), has no salt pond connections, and receives no POTW input. Additionally, it feeds LaRiverie Marsh and is on a latitude just above the Dumbarton Bridge site. The Newark Slough site is located half a mile upstream from the confluence with Plummer creek. The instrumentation is deployed off of the old railroad turnbridge. The height of the instrument was changed from 1.2 m.a.b to 0.9 m.a.b in August, 2016 due to the sensor coming out of the water at low tide. ~20m from west bank and ~45m from east bank.
Mowry Slough (June 2015)	*37.48535556* *-122.0327389*	*Habitat:* Slough *Deployment*: Cage, resting on bottom *Depth*: 0-3 m (0.5 m.a.b.) *Instrumentation*: YSI EXO2	Mowry Slough is a dead-end slough (no freshwater input), has no salt pond connections, and receives no POTW input. Combined with Newark Slough - as of 2002, these sloughs make up the largest harbor seal rookery in SFB. The Mowry Slough site is located just upstream of a confluence with two side channels. The instrumentation is deployed in a cage, mid channel. ~14 m from either bank.
Pond A8 Channel (July 2015)	*37.42347778* *-121.9795361*	*Habitat:* Constructed channel *Deployment*: Cage, resting on bottom *Depth*: 0-3 m (0.5 m.a.b.) *Instrumentation*: YSI EXO2	The Pond A8 Feeder Channel is a small side channel off of Alviso Slough. The caged deployment is located mid channel, just downstream from the flow gate at the restored salt pond A8. USGS used to maintain an Aquadopp current meter that measures velocity and a YSI sensor, however these were removed in early 2018. ~9m from either bank.

[1]m.a.b. = meters above bed

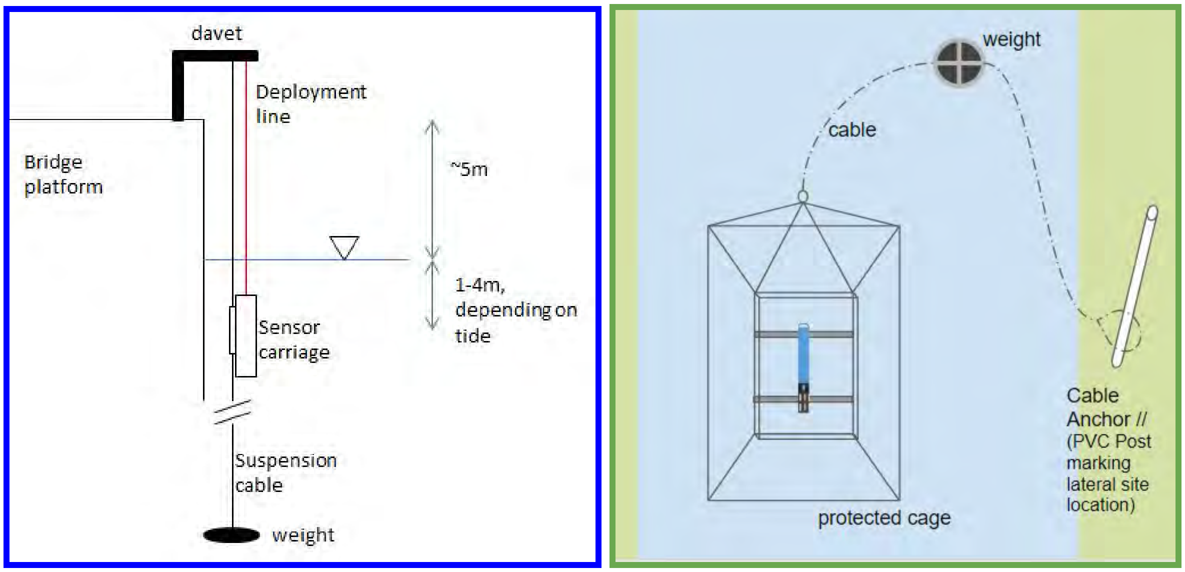


Figure 2.3: Left panel shows cross-sectional sketch of moored line from bridge support deployment method (setup used at San Mateo Bridge and Dumbarton Bridge; Newark and Coyote have similar suspension cable deployments, with Newark deployed from a railroad bridge and Coyote deployed from an electricity tower). Right panel shows plan-view sketch of the slough cage deployment method (cage sits on bottom of slough at the center of the channel; setup used at Guadalupe, Alviso, Mowry, and Pond A8 Feeder Channel). The cages are attached to a cable, which is attached to a weight designed to keep the cable from moving with the currents, and the other side of the cable is hooked over a PVC pole on the side of the channel.

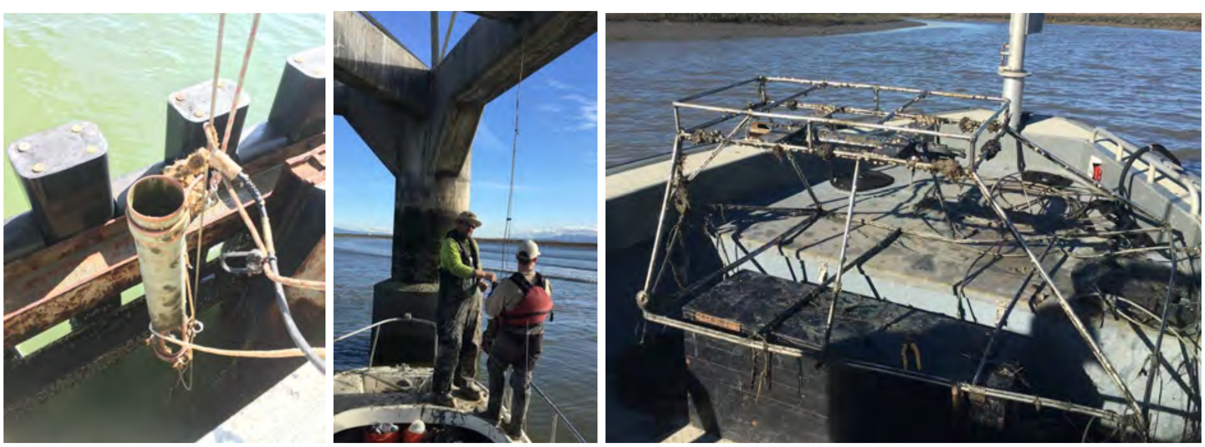


Figure 2.4: Examples of deployment setups. Left: Copper carriage out of water at Dumbarton Bridge. Center: Working on the instrument at Coyote Creek. Right: Guadalupe Slough deployment cage with attached YSI EXO2.

2.3 Instrumentation: Sensors and associated hardware

Table 2.3 provides a description of the instruments used, parameters measured with each instrument, number of instruments in the fleet, and sites where each instrument is currently deployed.

Table 2.3 Moored sensor site information and deployment information.

	YSI EXO 2	SeaBird HydroCAT-EP
	 photo: www.ysi.com	 photo: www.seabird.com
Sites Deployed as of December, 2018	Alviso Slough, Guadalupe Slough, Mowry Slough, Dumbarton Bridge, Newark Slough, Pond A8 Feeder Channel	San Mateo Bridge, Coyote Creek
Parameters Measured	Depth, Temperature, Dissolved Oxygen, Turbidity, Chlorophyll-a, BGA, fDOM, Salinity	— Measured within pump system: Depth, Temperature, Dissolved Oxygen, Salinity, PH — Measured with external optical sensors: Turbidity, Chlorophyll-a

3. Program Management: Maintenance, Data QAQC, and Data Management

3.1 Field Program Maintenance

The SFEI moored sensor field team services the instruments approximately every 3-4 weeks during the spring/summer period, and every 4-5 weeks during the fall/winter period ***[Q1.2-1.3]***. Colder water temperatures during the fall/winter period lead to less biofouling, and therefore longer servicing intervals are possible during this time. With the current network (8 sites), one servicing interval requires two full days on the water, reaching up to 4 sites per day. For boating services (boat use + boat driver), we partner with the USGS Santa Cruz Marine Facility (MarFac). Servicing trips follow similar protocols to those described in the NMS-MSP YR1 report, and generally involve:

1. Cleaning the instruments (removing algal growth, fine sediments, barnacles, fish eggs, etc.)
2. Downloading data
3. Replacing batteries
4. Fixing deployment hardware issues when necessary (e.g. replacing steel cables, rusty shackles, fraying lines, or any other issues that arise in the marine working environment)
5. Field calibrating the instruments when absolutely necessary

We attempt to minimize field calibration whenever possible. Prior to summer, 2018, we did not have enough instruments to be able to hot-swap instruments in the field (remove one instrument and replace it with a lab-calibrated/cleaned instrument). This meant the instruments had to stay in the field nearly year-round. This made it difficult to perform ideal calibrations on the instruments (lab calibrations are preferred to field calibrations), and also led to issues with corrosion and broken probes due to not being able to perform full lab cleanings of the instruments. However, the addition of two SeaBird HydroCAT-EP instruments to our fleet in early 2018, as well as the recent purchasing of enough probes to fully equip our two spare YSI EXO2 instruments, has meant that we are now able to hot-swap up to four YSI EXO2 instruments with each servicing trip. We now perform nearly all calibrations in a lab setting and are able to more thoroughly clean and service the instruments in the lab. This change in the program has led to higher overall data quality, less corrosion damage to the instruments, and more efficient servicing in the field. Data quality has also improved since the two SeaBird HydroCAT-EPs were installed at the San Mateo Bridge and Coyote Creek sites. These instruments were added to the fleet because they are equipped with a flow through pump system that makes the instruments less susceptible to biofouling (water is pumped through a u-shaped tube to be measured, which means that the instrument can still take reliable measurements even when the exterior of the instrument is fouled). When we first deployed the SeaBird instruments, we performed a side-by-side comparison with the EXO2 instruments at both Coyote Creek and San Mateo Bridge. We found that the instruments produced very similar results, giving us confidence to fully make the switch from EXO2 to SeaBird at these two sites with instruments that require less overall maintenance and have better data quality on average.

3.2 Data QAQC and Data Management

3.2.1 Motivation for Data QAQC Investment

The South and LSB environments have high levels of fine suspended sediments and high rates of bio-growth (see Figure 3.1). The fine sediments have a tendency to clog some sensors, particularly the original conductivity probes (see 3.2.3 for more information). Additionally, the bio-growth can impede the visual backscatter measurements taken by probes such as chlorophyll-a, turbidity, and fDOM, as well as change the dissolved oxygen dynamics around the sensor. These issues, along with others described below in section 3.2.3, can lead to poor data quality by causing sensors to measure microclimate environments that form around the sensors and are not representative of the surrounding bay water. When the program was launched, the primary method for identifying and removing bad data was through visual inspection and manual removal, which was both time consuming and had potential for inconsistencies. With more stations added in 2015, and no lessening of data QAQC issues, it became clear that we needed some level of automated QAQC process to produce an efficient, effective, and reproducible method.

At the recommendation of technical advisors and prioritization by NMS stakeholders, we made significant investments in 2017-2018 to develop the tools necessary for an automated and semi-automated QAQC process, as well as for improving overall data management procedures. While this work specifically targets Goal 2 and ***Q2.1-2.3*** (Table 2.1), reliably-high data quality is an essential component of achieving each of the NMS-MSP's Goals. The objectives for developing and implementing automated and semi-automated approaches to QAQC approaches were to ***a)*** allow for consistent statistical checks for outliers and fouling periods; ***b)*** check for bugs in the data output (e.g., there are occasionally timestamp issues due to software bugs in the data download process); ***c)*** write the data to a consistent format for database uploading; and ***d)*** maximize the efficiency for completing ***a-c***.

The QAQC approach is a multi-step process consisting of automated cleaning and formatting procedures for bulk processing followed by a set of semi-automated procedures. An overview description of the processes are described below in Section 3.2.2.

Figure 3.1: Examples of biofouling at San Mateo Bridge. Left panel shows hydroid growth on the deployment line and around the copper carriage. Right panel shows hydroid growth and sediment accumulation around the probes.

3.2.2 QAQC Overview

Data is stored in four levels -- L0, L1, L2, and L3 -- with each level representing a higher level of QAQC performed on the data.

L0 data is stored as raw data with associated metadata. The automated scripts associated with L0 convert YSI EXO2 output and SeaBird HyrdoCAT-EP output to CSV format with identical data columns. The data is stored separately for each site.

L1 data includes the first level of QAQC data cleaning. The primary methods of data cleaning in this step are:

- Setting definite maximum and minimum thresholds for individual parameters and removing data that falls outside of these parameters.
- Conducting a statistical test which removes data points that fall outside of 3 standard deviations from the two hours of data surrounding the point of interest.
- Automatically removing data when the instrument is out of the water.
- Replacing false temperature measurements with the temperature measurements collected by the turbidity probe (aside from the primary temperature measurements collected by the EXO2 instruments, each individual probe collects temperature measurements).
- Recalculating dissolved oxygen (mg/L) with updated temperature values and interpolated salinity values for when salinity is removed.

L2 data includes the second level of QAQC data cleaning, which has statistical methods designed to focus more on removing data during times of fouling. The primary methods of data cleaning in this step are:

- Check the slope between each successive data point for specific conductance, conductivity, and dissolved oxygen, and remove the data point if the slope exceeds predetermined thresholds
- Check the coefficient of variance in a 200 point window surrounding each data point (~1 day around each point). Remove data point if its coefficient of variance window exceeds predetermined thresholds.
- Recalculate dissolved oxygen in mg/L with interpolated salinity for time frames when salinity has been removed.
- Re-enter data during periods of heavy freshwater inflow (periods where daily discharge at Guadalupe River is greater than 150 cfs). Because freshwater inflow causes abrupt changes to many parameters, we often see data being automatically removed when it shouldn't be during periods of high discharge.

Figure 3.2 shows an example of the success of the automated script in filtering out faulty data from L0 to L1 to L2. The red dotted line shows the L2 data — the final product of the automated process — plotted on top of the L1 data (black) and the L0 data (blue). The immediate dips on conductivity are bad readings, and these are almost all filtered out by the automated filtering methods. Filtering this entire process manually for all parameters at eight different sites would be extremely tedious and time consuming. One can see that the automated process does not do a perfect job of filtering out the data, as some of the bad data still remain in the L2 dataset. The process below details the final semi-automated filtering of the remaining bad data, resulting in the L3 dataset.

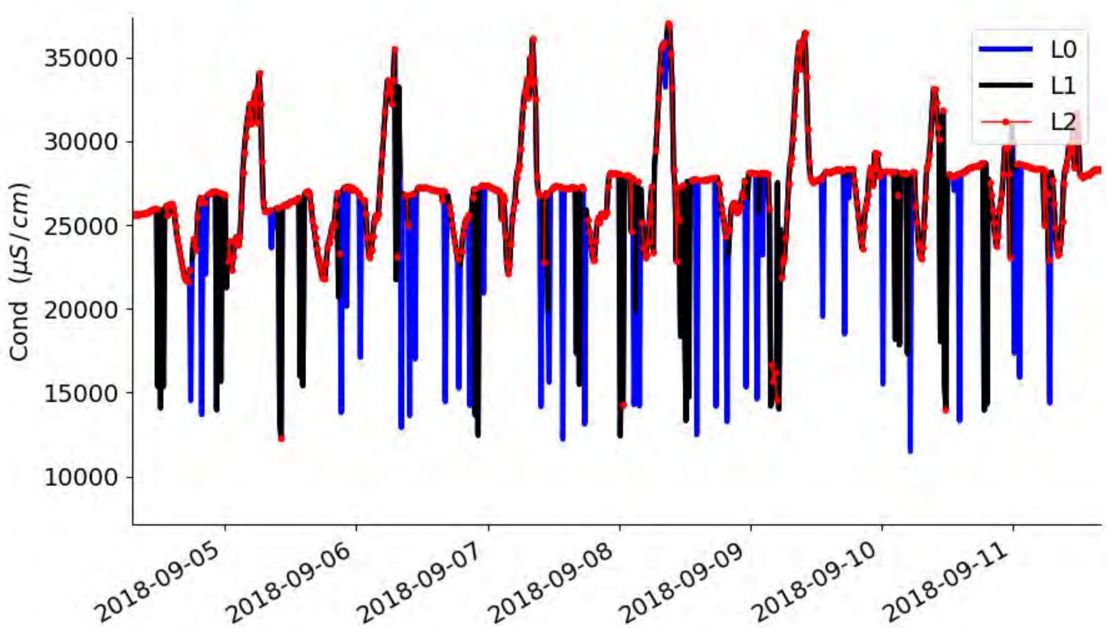


Figure 3.2: Final results of the automated filtering process on conductivity at Pond A8 for a one-week timeframe in September, 2018. The L2 dataset is the final result of the automated filtering process.

L3 data includes the third and final level of QAQC data cleaning, which is the final visual inspection and semi-automated removal of data that is clearly bad data, yet has made it through all levels of the automated scripts. This extra semi-automated step is necessary because the moored sensor data is so noisy by default, that it is extremely difficult to write scripts that are able to fully filter out all bad data and leave in all good data. The automated/semi-automated method that we have developed combines the two approaches, with an attempt to minimize manual effort required. As a note, the integration of the semi-automated QAQC method is rather recent (as of Fall, 2018), and we still have work ahead of us to retroactively QAQC data from previous deployments.

Details of Semi-Automated QAQC Method:

We developed a series of python scripts to assist with the semi-automated QAQC method to create the L3 data. We choose a specific time period of data to filter, and then check that time period for each variable and each station. For the following example, we evaluate fDOM at Dumbarton Bridge from 9/18/2018 to 10/20/2018, in which a specific fouling event occured. The first step is to plot the specific time period together with earlier data from the same station/parameter. Fig. 3.3 shows this below, with the chosen time period in purple. From the plot we are able to see that this fDOM data is different than the preceding fDOM data at the same station.

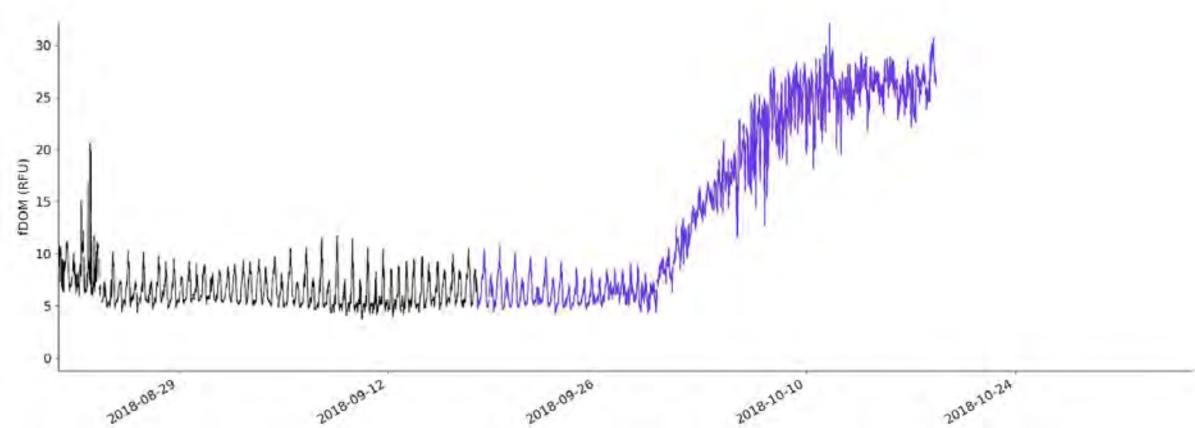


Figure 3.3: fDOM at Dumbarton Bridge for the period of interest (purple) plotted together with preceding data (black) to get an initial look at the data quality.

The second figure produced by the script compares data from the station of interest with another nearby station. For this example, Dumbarton is being shown with Newark Slough, as the data between these two stations generally follows similar trends. The first plot shows depth over time for both of the stations (to check for timestamp errors) and the second shows the parameter that was chosen. Fig. 3.4 shows this two panel figure, and we can see that the fDOM increase at Dumbarton is clearly a fouling event, as the data is not remotely similar for the nearby Newark Slough.

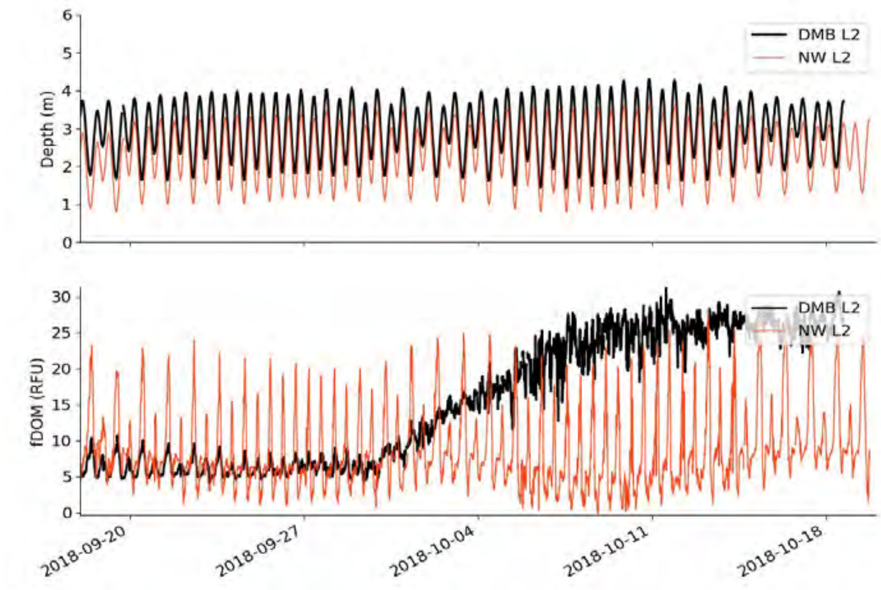


Figure 3.4: L2 Depth and fDOM data from Dumbarton (black) and Newark (orange). We can see that the Dumbarton fDOM data is a fouling event.

The third and final figure from the script shows the L0, L1, and L2 data for the time period of interest (Fig. 3.5). Areas where there are blue and black lines visible with no red over top are locations where the automatic scripts have already removed data. Shown in Fig. 3.5 below, we want to select out the period from A to B to be removed from the dataset (starting at 9/30/2018). We simply click on these points in the plot and the timestamps appear in the Ipython console (Fig. 3.6). We then copy and paste those timestamps into a spreadsheet as the “start” and “stop” times for which to remove data.

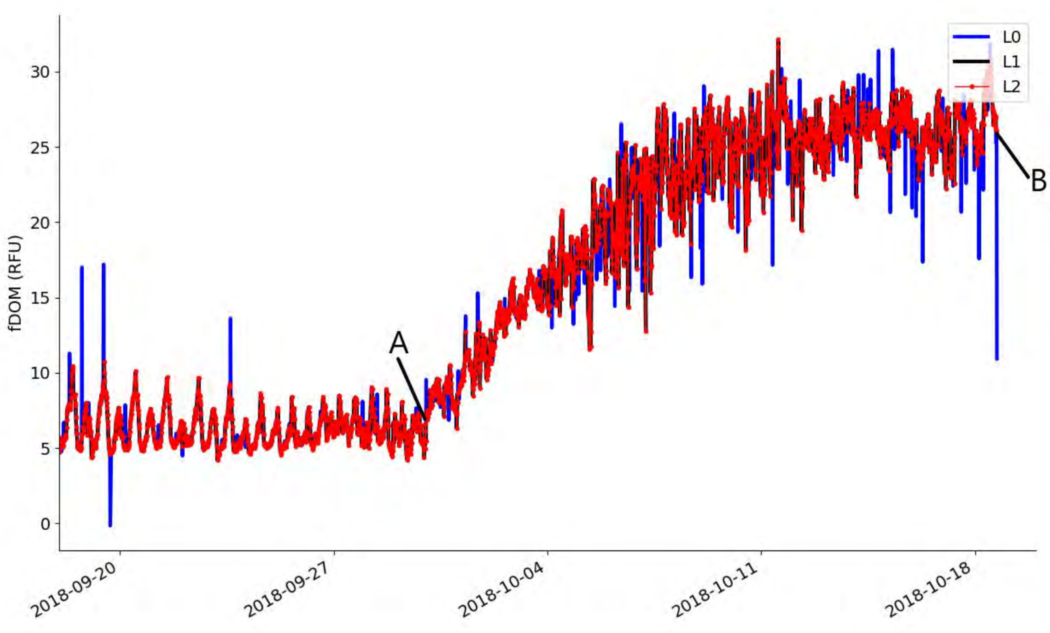


Figure 3.5: L0,L1, and L2 data for the time period of interest. The data after A until B will need to be removed.

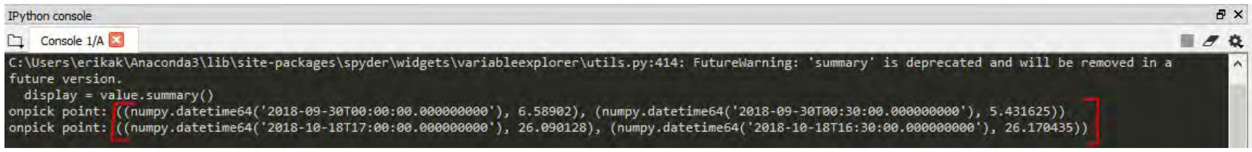


Figure 3.6: Date and time stamps of selected data points shown in the Ipython console. These timestamps are then copied and pasted into the removal spreadsheet. The top point is A, the bottom point is B.

In the final step, the last set of python code reads the logged timestamps of compromised (or suspect) data from the spreadsheet, removes the corresponding data from a copy of the L2 data, and writes the semi-automated cleaned data to a separate file labeled L3. Fig. 3.7 below shows the final L3 data output (black), with the red line indicating data that has been removed through the semi-automated process.

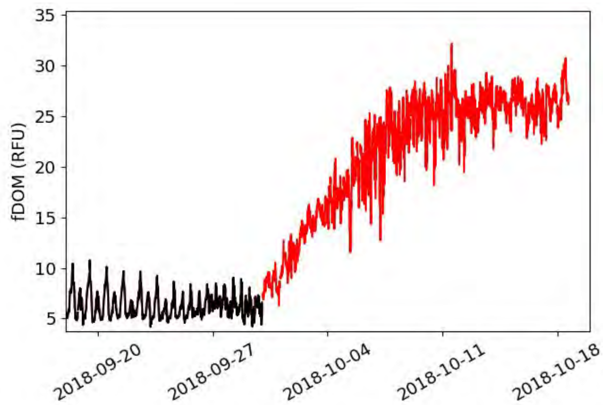


Figure 3.7: Final L3 dataset with the red indicated data that has been removed through the semi-automated selection process.

3.2.3 Summary of Field Issues Leading to QA Problems

Over the five years of the NMS-MSP, there have been extensive improvements in data quality. The environment in which we are collecting data is not ideal for water quality instruments (high sediment loading, large amounts of biogrowth), and thus we have worked hard to maintain the sites with consistent frequency (~3-5 week servicing intervals) and to ensure that we are employing the best methods for reducing bio-fouling and instrument degradation. Some specific measures we have taken to reduce data quality issues include:

- Installing copper carriages for holding the instruments, as well as purchasing copper sonde guards to protect the probes on the YSI EXO2s (copper is a bio-growth deterrent)
- Upgrading all specific conductance/conductivity probes to the “wiped probes” released in October, 2015 by YSI. The wiped probes are a redesign which allows the central wiper on the EXO instruments to clean out the conductivity cell. The inability of the conductivity cell to be wiped on the older probes led to some fouling issues in the early data.
- Installing two SeaBird HydroCAT-EP instruments, which are designed reduce data quality issues due to the flow through pump measurement system.
- Integrating the regular hot-swapping of YSI EXO2 instruments has allowed for more consistent lab-calibration, more thorough cleaning of the instruments, and the ability to address instrument issues in the lab setting.

- We have employed the use of a zinc oxide paste (Boudreaux's) mixed with cayenne pepper as a fouling deterrent at our most heavily fouled sites.

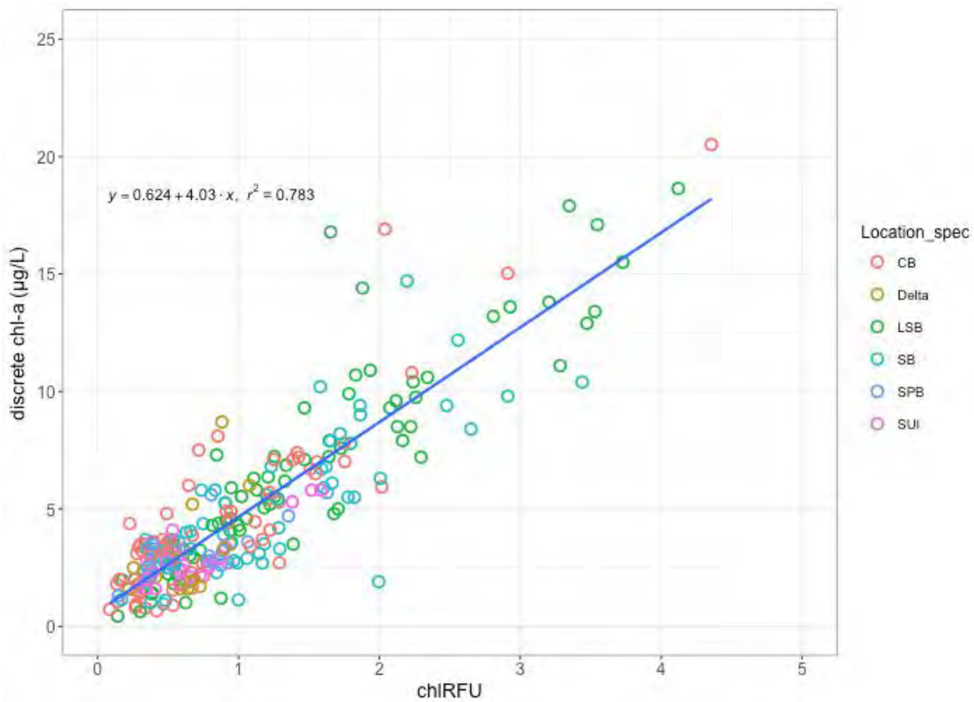
Below are specific problems which have led to data quality issues, and generally the impetus for the fouling prevention steps listed above:

- Large-scale bio-fouling which leads to local marine microclimates. The wiper on the EXO2 instruments is able to clear away debris when fouling is minimal, but when the growth covers the entire sensor package, the data quality degrades. Approximately once per year we see heavy barnacle growth on many of our instruments. This can impede the sensor readings, as well as impede the path of the wiper.
- Marine Isopods: in many of our sites we see small marine isopods (~0.25-1.0 inches long) collect in and around the copper guard protecting the probes. These bugs may be drifting in front of the sensors and causing spikes in the data.
- Fish/fish eggs: In some of our slough sites, we have found that small fish occasionally make their home inside the copper probe guard, and when they do so will often lay eggs on the instrument bulkhead.
- Conductivity probe fouling: As mentioned above, the original conductivity probes quickly experienced fouling issues because the wiper could not access the small space in the conductivity cell. We have now fully replaced our suite of conductivity sensors with the new wiped probes, and have experienced much higher data quality as a result.
- Corroding probe connector pins: We have had issues with corrosion on the connector pins on the probes (that connect the probe to the instrument bulkhead), specifically with the conductivity probes. When the pins corrode, they break off in the bulkhead, resulting in lost data and costly replacement of the probe. This has happened on approximately 10 occasions, and is a result of the instruments being deployed in the saltwater environment, which results in corrosion. We have not faced this issue since instituting our maximum hot-swapping method.

3.2.4 Characterizing the accuracy of in vivo chlorophyll sensors

While some in situ water quality sensors provide accurate and precise measures of their target parameter right off the shelf (e.g., temperature, dissolved oxygen), calibrating and interpreting output from other sensors can be much less straightforward. Chlorophyll-a sensors falls squarely in the category of 'less straightforward'. The EXO2 chl-a sensor, similar to many other field chl-a sensors, quantifies chl-a concentration by excitation-emission spectroscopy, using optical sensors: the sensor emits light at one wavelength (470 nm) that excites chlorophyll-a molecules; excited chl-a molecules subsequently emit light which is measured by the sensor at another wavelength (685 nm), and the total emitted light is proportional to chl-a present. While that seems straightforward, a number of factors can influence the accuracy of this measurement: 1) Only a small volume of water (adjacent to the sensor optics) is actually measured; 2) Particles and molecules of dissolved organic matter (DOM) can interfere with both the excitation and detection by absorbing or scattering some of the light emitted by the sensor or chl-a molecules; 3) DOM and particles may contain non-chlorophyll functional groups whose excitation-emission spectra overlap with those of chl-a, artificially increasing the apparent chl-a signal. 4) The measurement is in vivo - measuring chlorophyll-a inside living phytoplankton cells - and numerous physiological factors can influence the ratio of emitted light per unit chl-a. Therefore, obtaining reliable chl-a concentration data requires field calibration/validation.

To calibrate/validate the chlorophyll-a readings from the YSI EXO2 sensors ***[Q3.2-Q3.3]***, discrete water samples have been collected during deployments over the course of the study and analyzed in the laboratory for chl-a. To date, ~430 discrete samples have been collected alongside EXO2 sensors across a range of open-Bay and slough sites, and paired with measured in vivo fluorescence during the time of collection (Figure 3.8). At open-Bay locations (Figure 3.8 A), discrete chl-a concentration is well correlated with in vivo fluorescence (chlRFU). Although there is a nontrivial amount of scatter in the open-Bay relationship, the fairly strong correlation is nonetheless encouraging considering the wide range of sites or conditions and the fact that no other corrections have been made (e.g., turbidity, fDOM). The relationship between discrete chl-a and chlRFU at slough sites shows more scatter (Figure 3.8 B) and a notably different slope than at open-Bay sites. While we are only in the early stages of analyzing these data, initial work suggests that the strength of the relationships can be improved by correcting for other parameters (e.g., turbidity, fDOM) that may be causing interferences with the in vivo measurement. Some of that analysis is being carried out through a chlorophyll intercalibration study, jointly funded by the NMS and the Delta Regional Monitoring Program, working in collaboration with other programs managing sensor networks in northern San Francisco Bay and Delta (USGS, DWR). The goal of that study ***[Q3.2-Q3.3, Q4.2-4.3]*** is to begin building the technical and institutional foundation that will lead to consistent techniques and consistent data quality for mooring-derived chl-a measurements across the moored sensor programs, so that data can be more readily combined and shared (e.g., for model calibration).



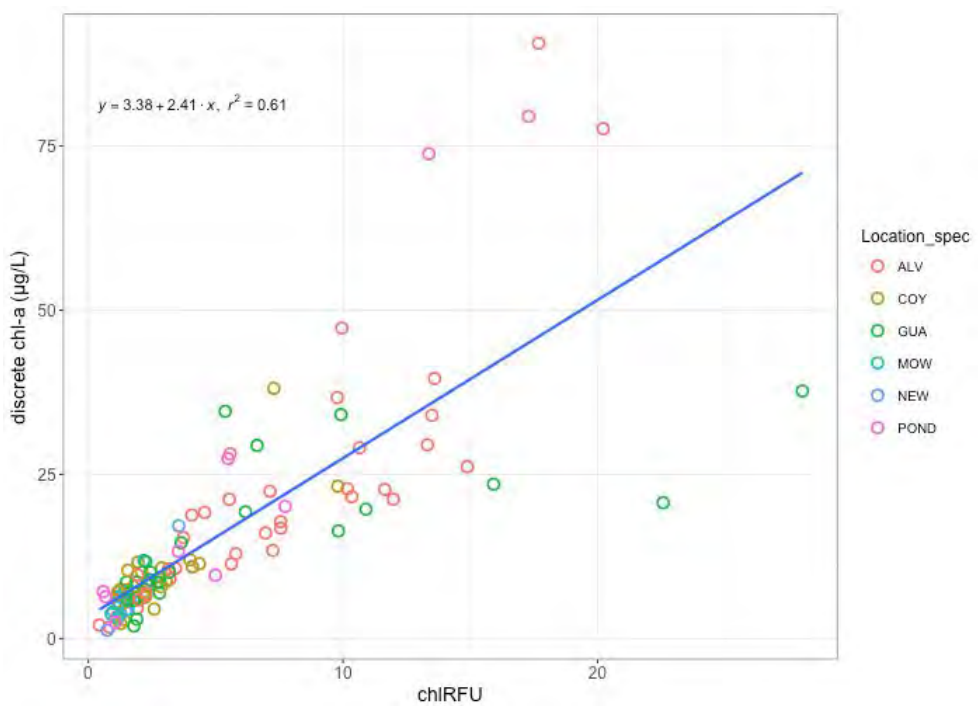


Figure 3.8: Discrete chl-a vs. in EXO2 in vivo fluorescence at open-Bay stations (top, n=308) and slough sites (bottom, n = 122). Note different y-axis and x-axis limits. For open-Bay data, 3 extreme values were removed.

4. Overview of NMS-MSP Data and Data Applications

High-frequency data from the moored sensor network provides a foundational resource to characterize and understand the mechanisms behind water quality dynamics in LSB and South Bay. The fine temporal resolution of the data allows for identifying and exploring patterns that would be missed with less frequent sampling schedules, and the extensive spatial resolution allows for a more detailed understanding of the complex LSB system. The high-frequency data are also needed for calibrating and validating the NMS' hydrodynamic and biogeochemical models, which are essential tools for predicting conditions in SFB water quality and exploring the effectiveness of management options.

This section provides an overview of data collected through the NMS-MSP and associated projects, and briefly highlights several examples of how that data is being used or applied in other NMS work.

4.1 Overview of NMS-MSP Network Data

Figures 4.1 - 4.8 provide an overview of the L3 data for the NMS-MSP's current network from July 2015 - October 2018 (see Table 2.2 for individual site characteristics). In looking across the sites, the dramatic range of environmental conditions present in South Bay and LSB is reflected in the data. For example, the DO is generally highest and has the smallest range at the northernmost San Mateo Bridge. Dumbarton Bridge shows similar patterns to San Mateo, but generally has larger ranges in its parameters as it represents a blend of deep channel and LSB shoal/margin output. The margin sites generally have the largest daily variations in parameter values, with large swings between the ebb and flood tides, and consistently have the largest chlorophyll blooms and the greatest range in DO values (both on the high and low end). Note that for each of Figures 4.1-4.8, we have plotted the timeframe July 1, 2015 to October 20, 2018 in order to best compare across sites, as 6 of 8 sites came online in summer, 2015. Additionally, for San Mateo Bridge and Coyote Creek, there is no chlorophyll-a data displayed after February, 2018. This is the month in which we switched these sites from EXO2 to SeaBird instruments, and the SeaBird instruments do not collect chlorophyll data in RFU units. We are developing methods to convert the SeaBird mass concentration units into chlRFU, but for the purposes of this report the data is not plotted. Many of the sites have turbidity data plotted that exceeds the limits of the y-axis — when this is the case it is generally faulty turbidity data that has not yet been filtered from the dataset, but will be in the coming year. Finally, note that the axes limits across stations are variable.

With 3 years of data now available across the network, it is possible to extract information about patterns of variability at multiple time-scales:

- Hourly variations due to twice-daily high and low tides: Viewed over the full 3 years, the hourly variability looks like a shaded area (vertical width of the data in each plot), but is actually ecologically meaningful changes in 15-minute data, caused by SFB's strong tides which transport water masses with distinct physical and biogeochemical properties past the stationary sensors.

- Spring-neap variations: These appear as the envelopes around the max and min values that vary with a ~2 week period. Stronger and weaker tides transport water from greater distances past the sensors, causing larger and smaller, respectively, tidal ranges in the observed water quality. The strength of tides also influences the amount of sediment that is locally resuspended (higher or lower turbidity) and vertical stratification of the water column (encouraging or disrupting phytoplankton blooms).
- Seasonal variations: multi-month patterns. For some parameters and sites, seasonal patterns contribute some of the largest variations (e.g., temperature, salinity at some sites, dissolved oxygen). For other sites and parameters, tidal variation can be comparable to seasonal variation.
- Interannual variation: For some sites and parameters, interannual variations (above and beyond tidal and seasonal variations) or events are major factors influencing overall variability within the dataset. Large episodic pulses in chl-a at Alviso, Guadalupe, and Pond A8 are interesting and potentially ecologically-important examples. Differences in the magnitudes and timing of small and larger phytoplankton 'blooms' around Dumbarton Bridge are also noteworthy.

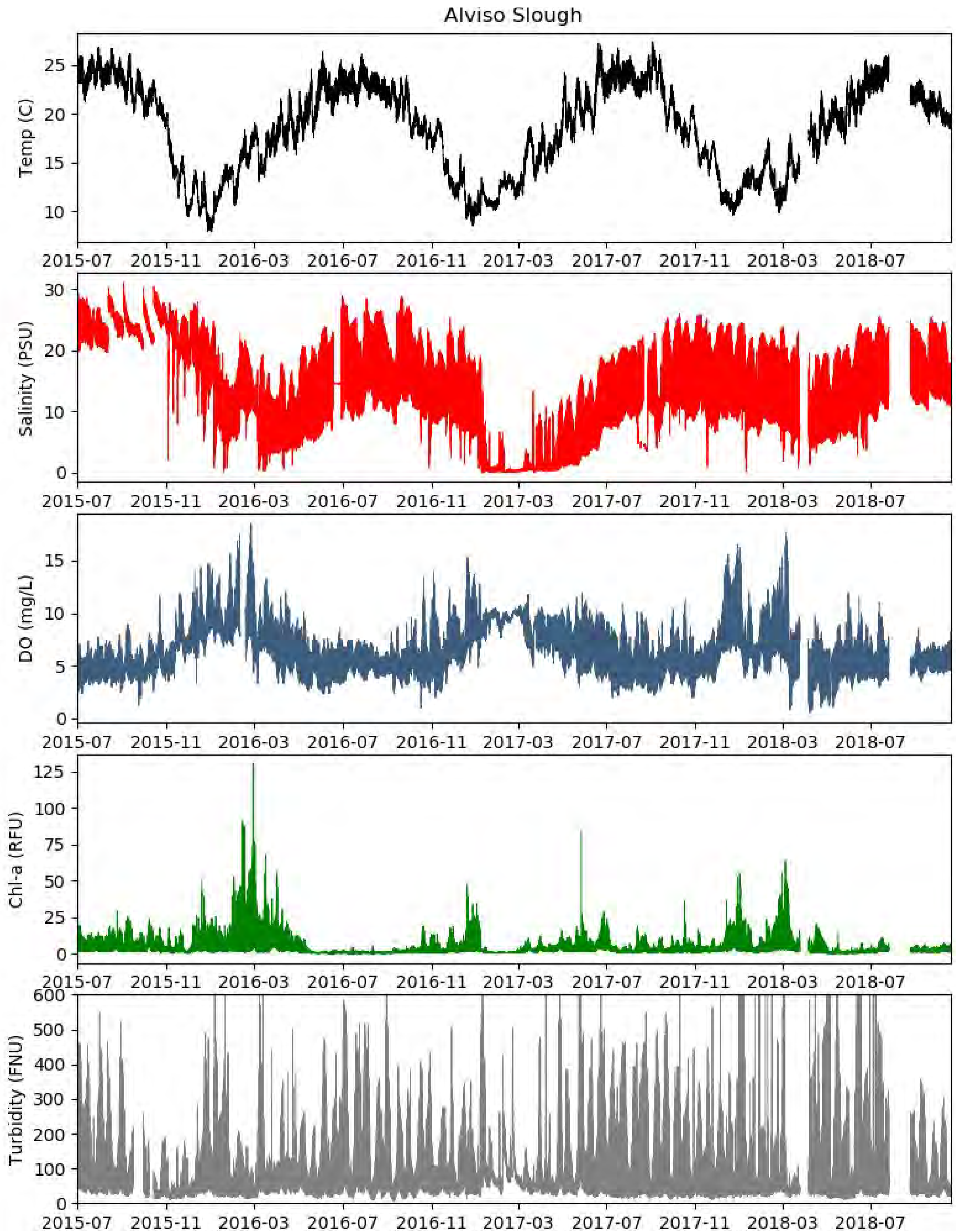


Figure 4.1: July 1, 2015 to October 20, 2018 dataset of five parameters for Alviso Slough

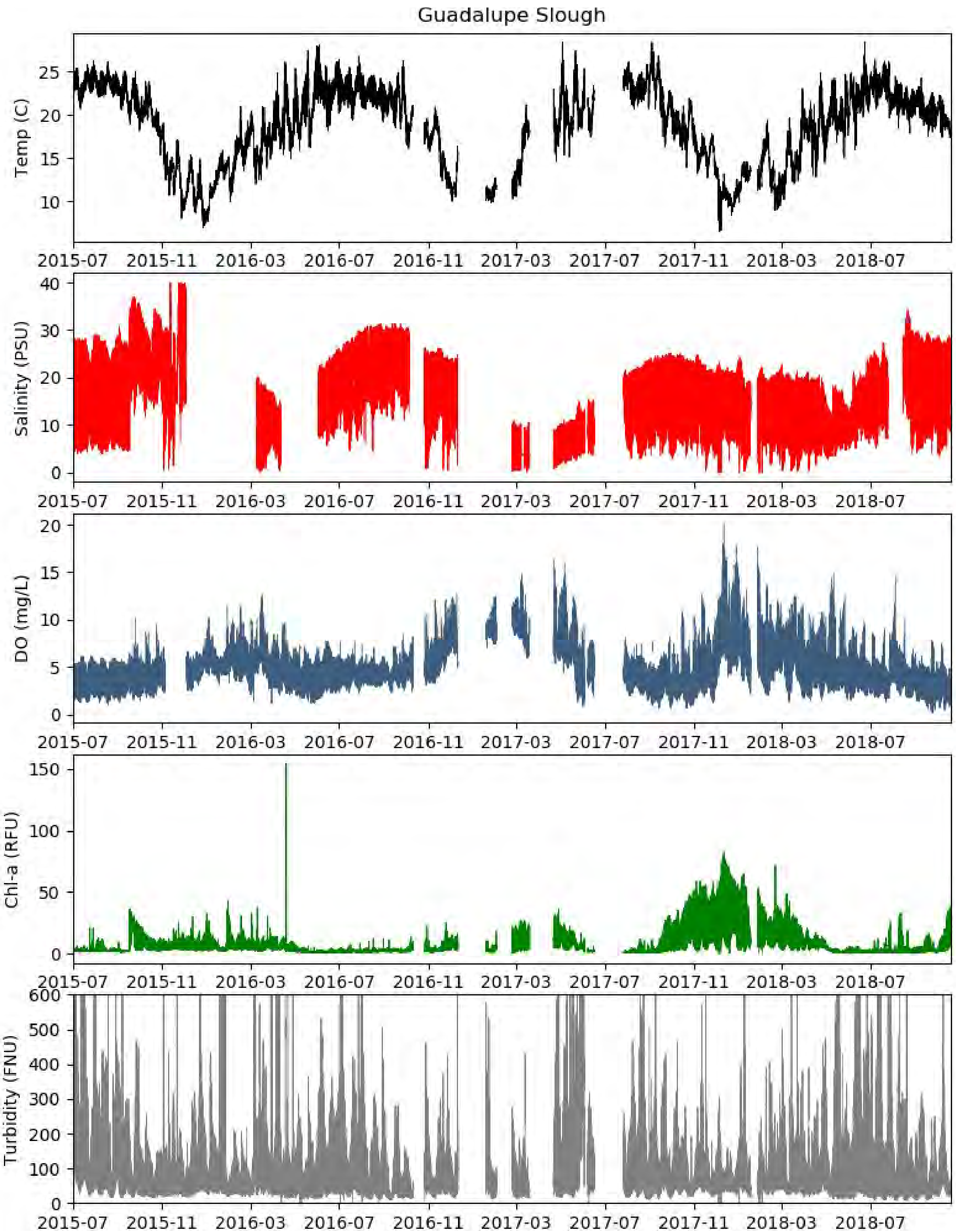


Figure 4.2: July 1, 2015 to October 20, 2018 dataset of five parameters for Guadalupe Slough

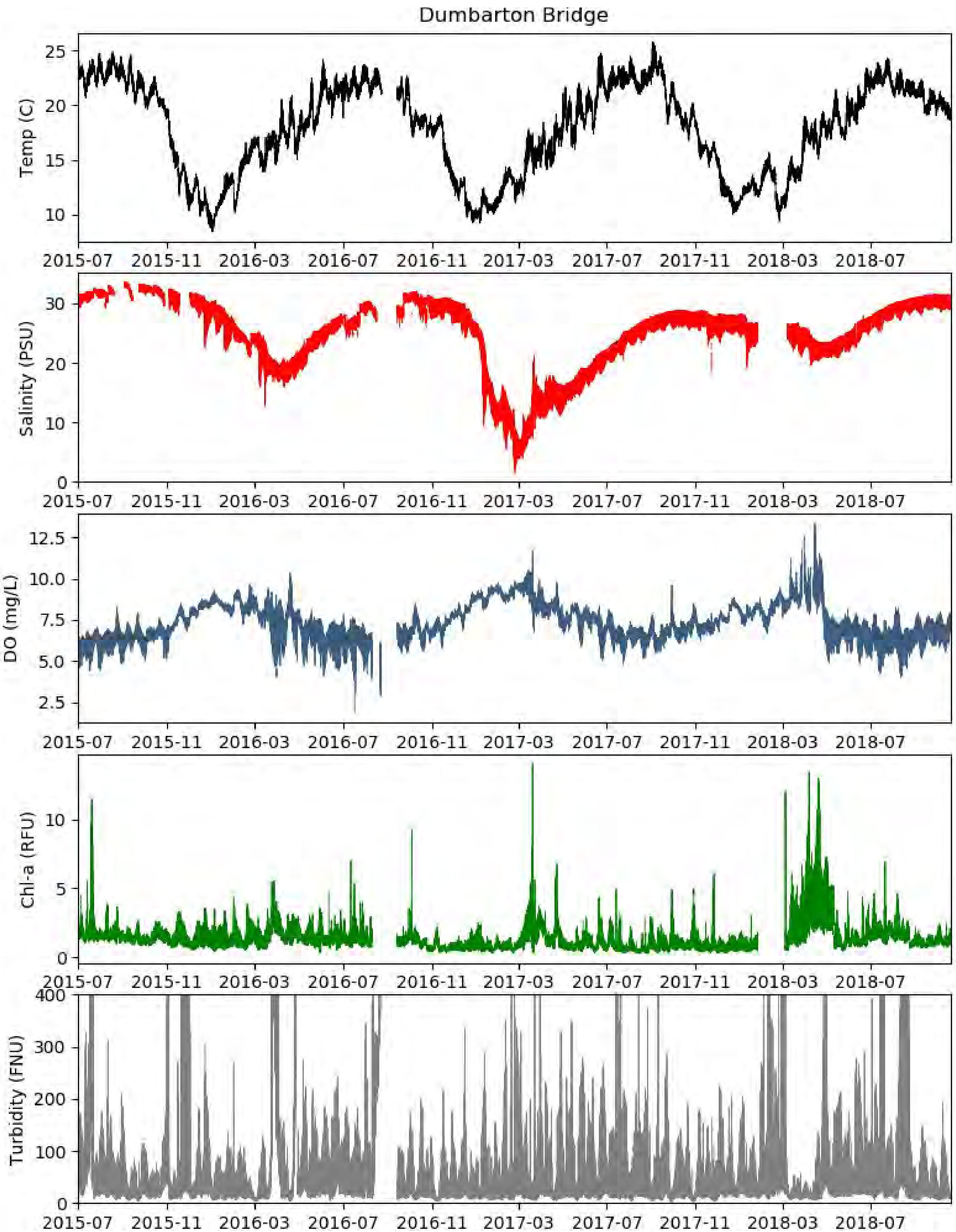


Figure 4.3: July 1, 2015 to October 20, 2018 dataset of five parameters for Dumbarton Bridge

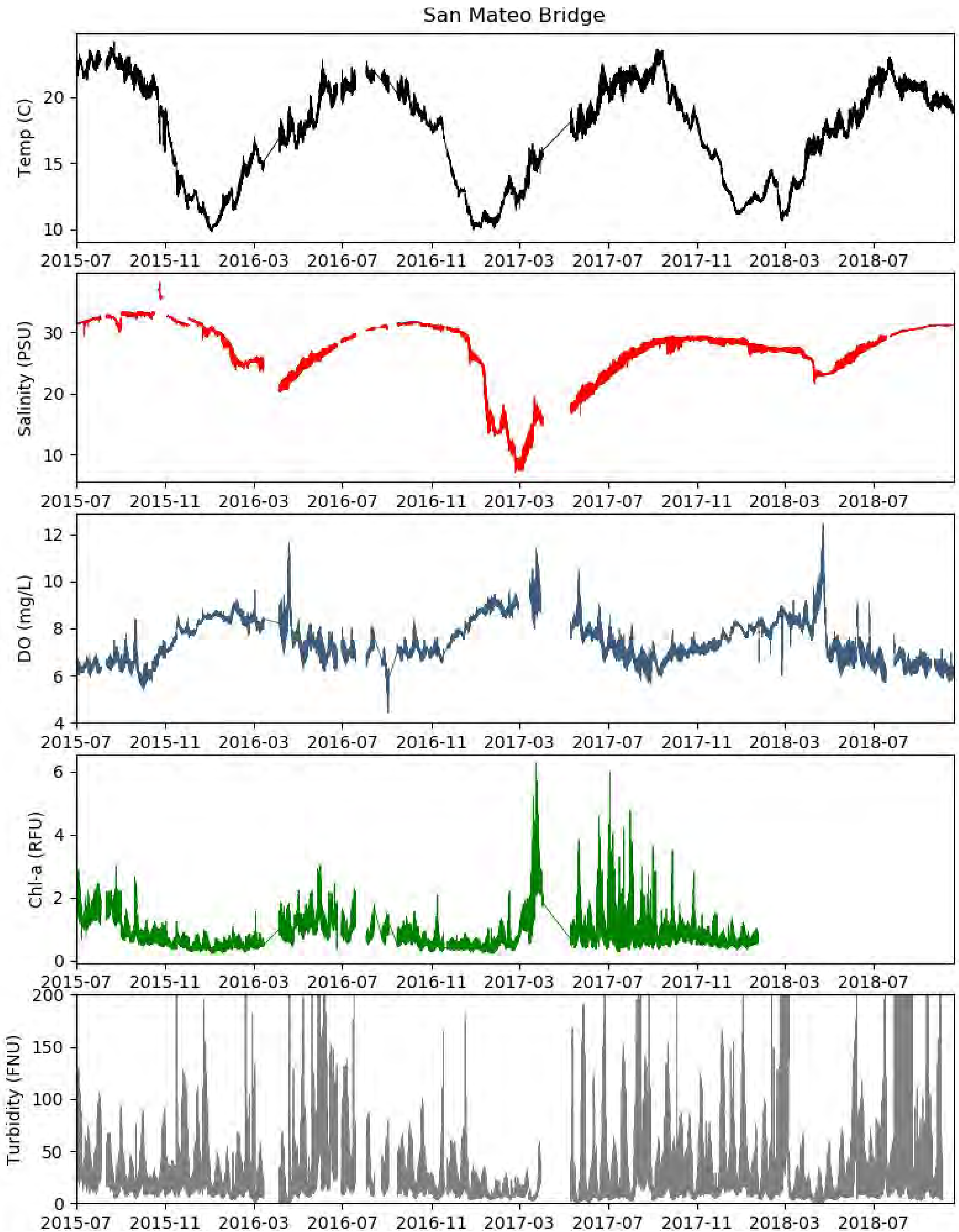


Figure 4.4: July 1, 2015 to October 20, 2018 dataset of five parameters for San Mateo Bridge

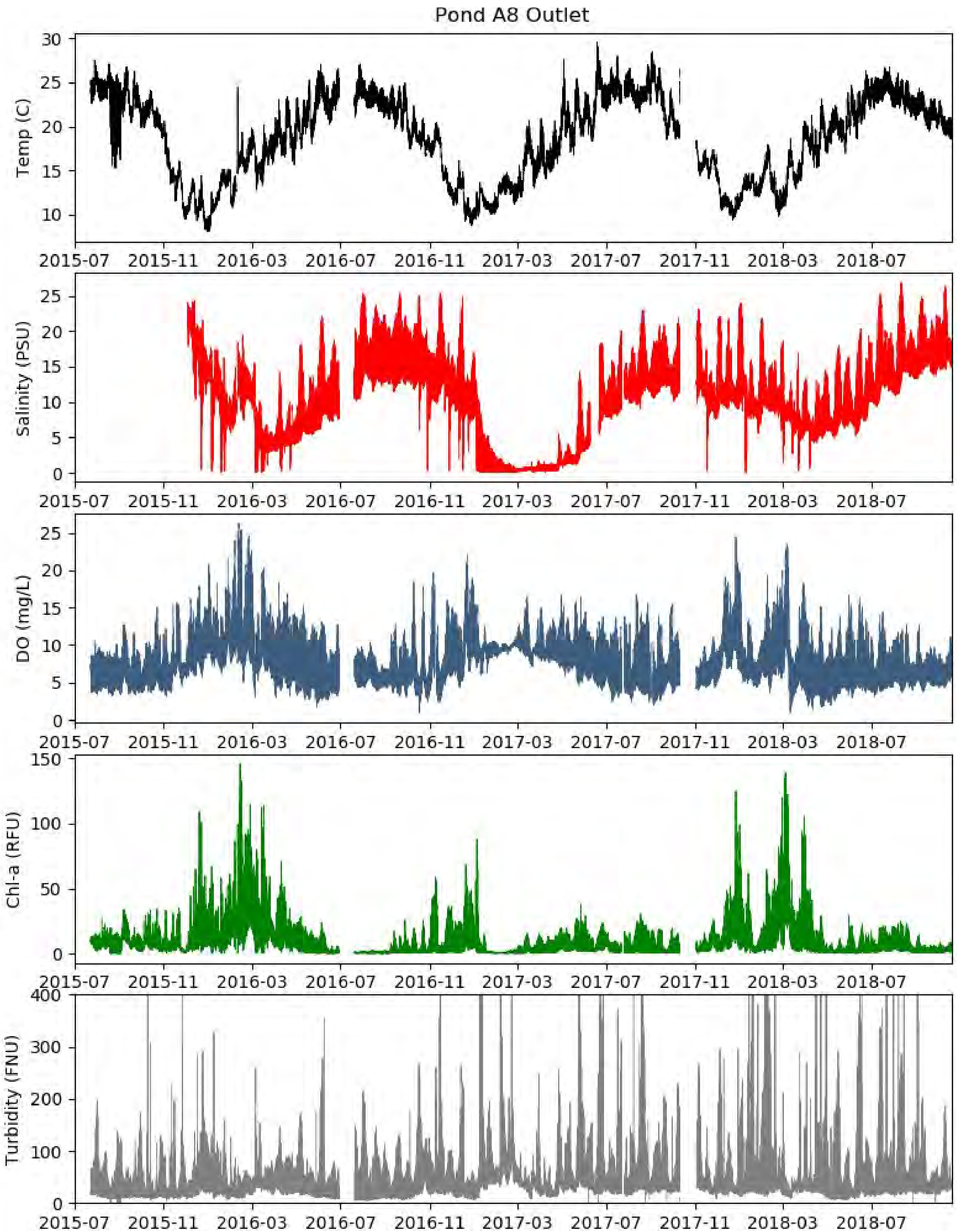


Figure 4.5: July 1, 2015 to October 20, 2018 dataset of five parameters for Pond A8 Outlet

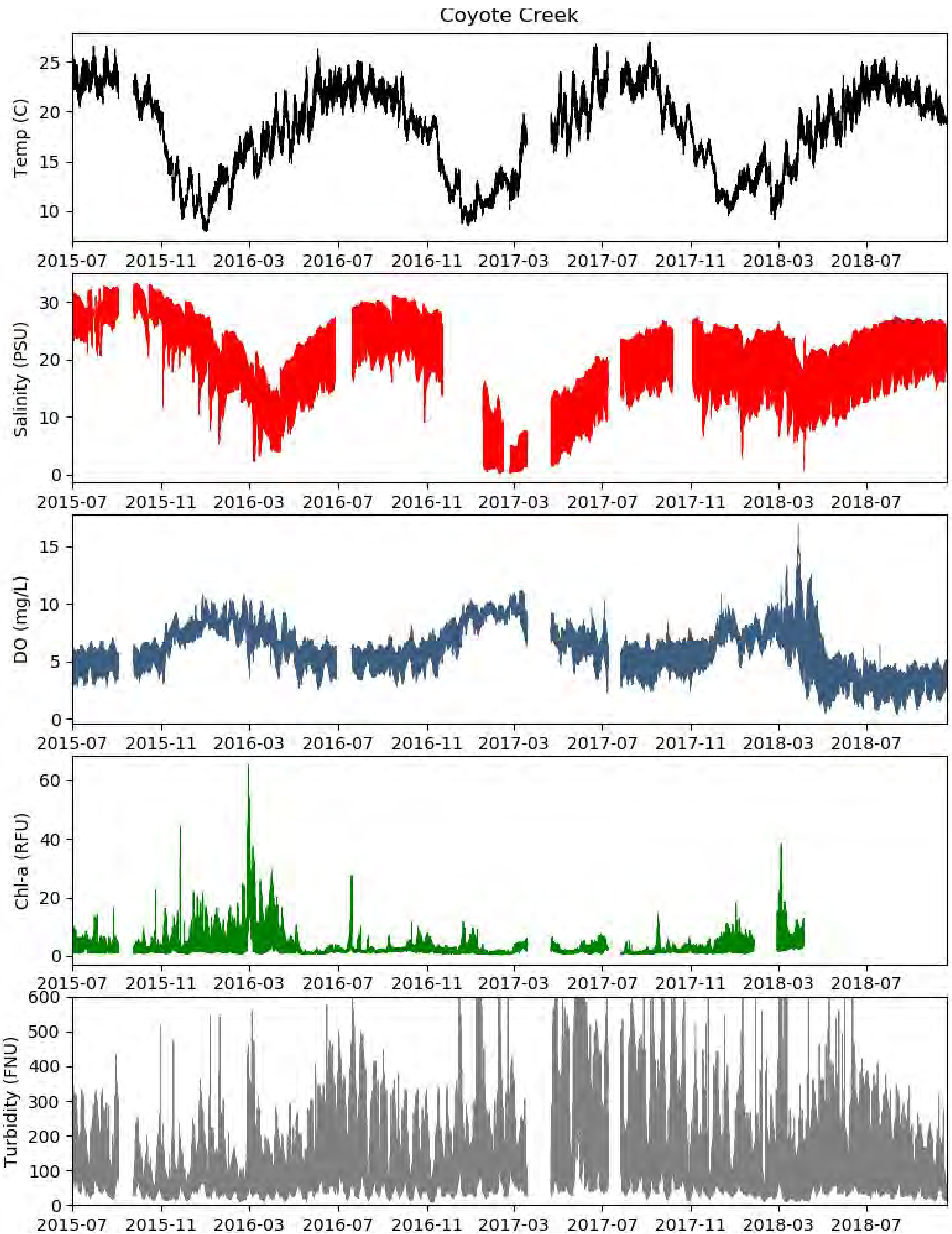


Figure 4.6: July 1, 2015 to October 20, 2018 dataset of five parameters for Coyote Creek

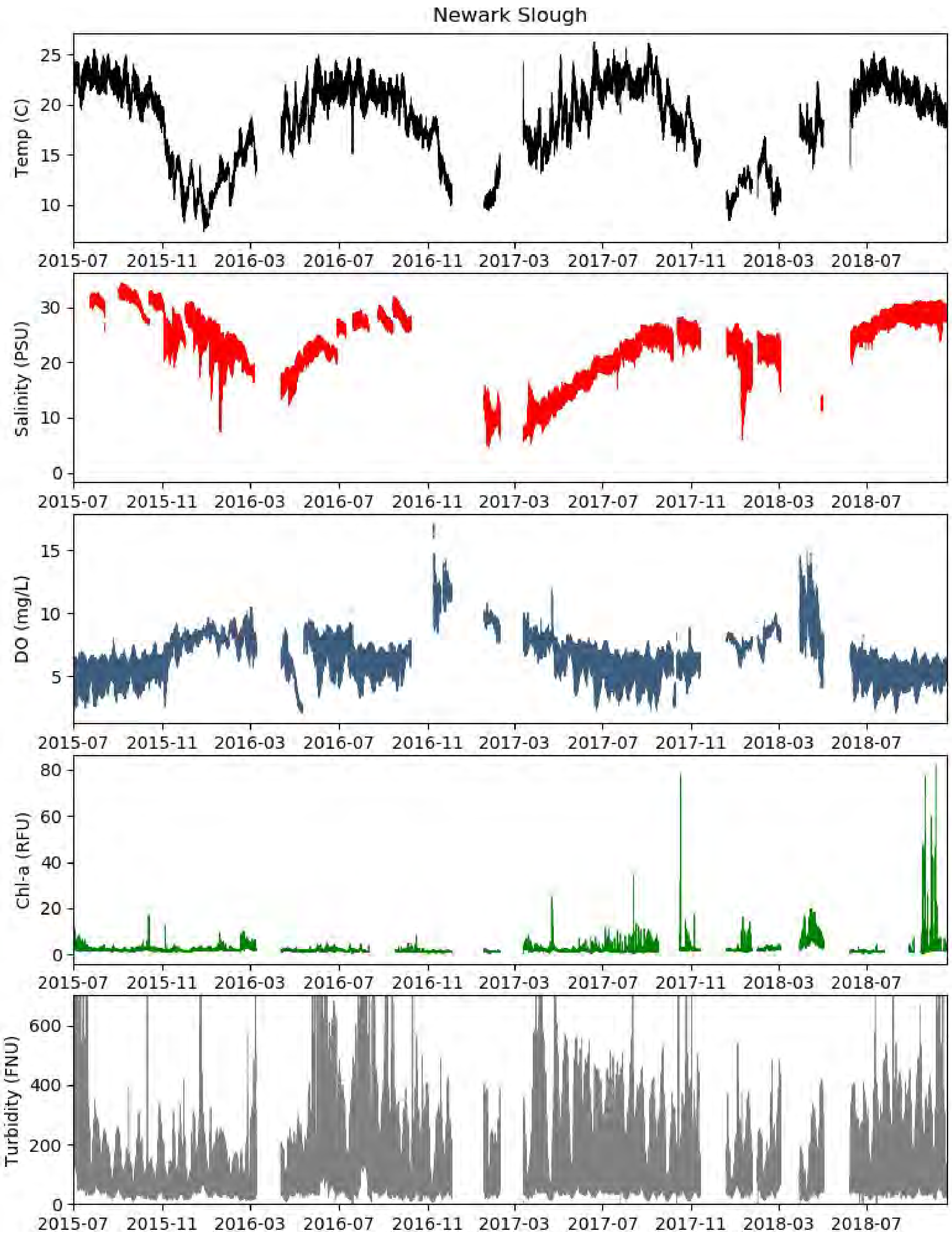


Figure 4.7: July 1, 2015 to October 20, 2018 dataset of five parameters for Newark Slough

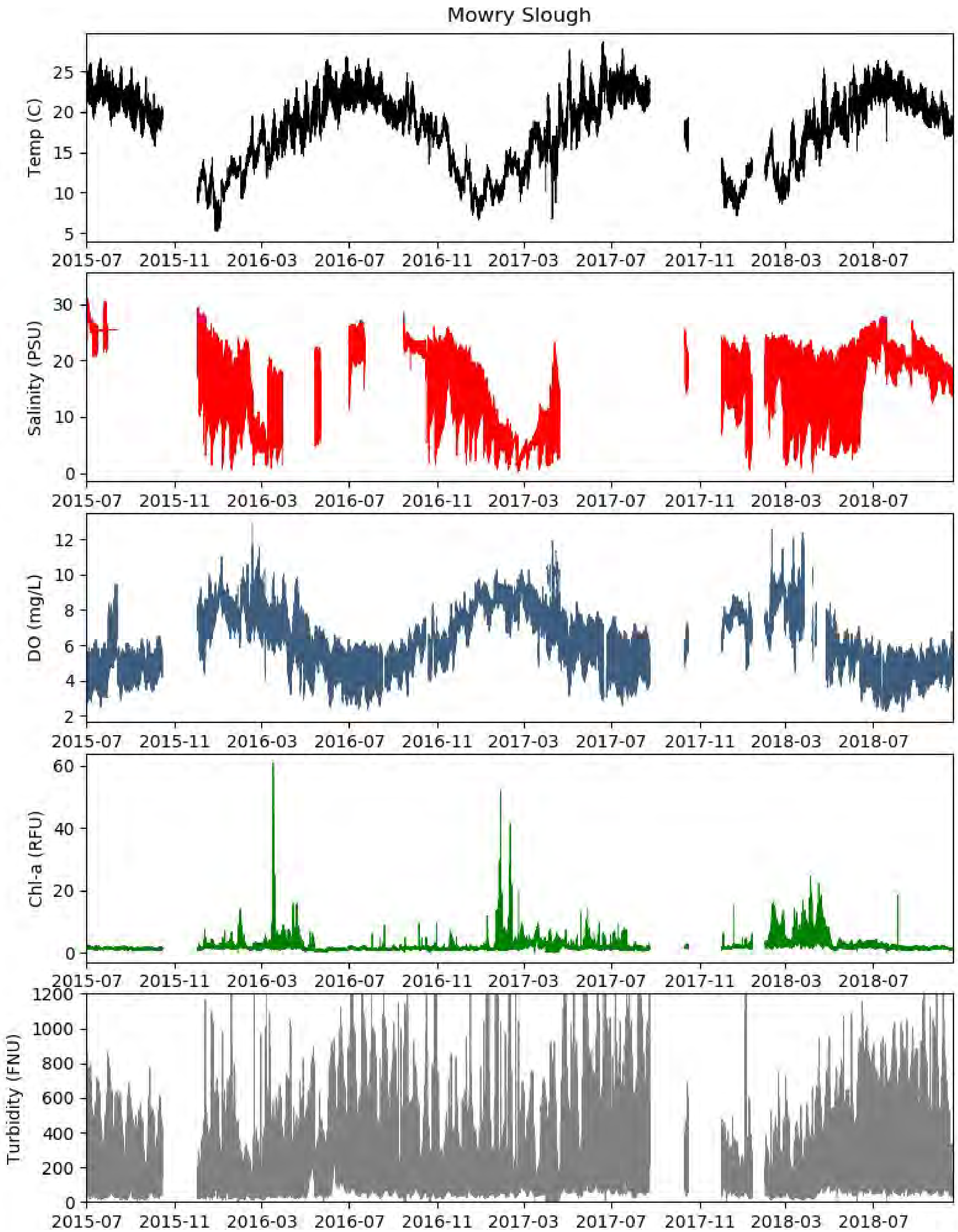


Figure 4.8: July 1, 2015 to October 20, 2018 dataset of five parameters for Mowry Slough

4.2 Example Application of Moored Sensor Data in NMS Projects

As the moored sensor dataset has developed into a multi-year, eight station dataset, SFEI has been able to begin exploring the varying water quality dynamics of the South and LSB environment. Fig 4.9-4.12 provide examples of figures used in the recent DO & fish habitat report that used NMS-MSB data to explore the suitability of different LSB locations as fish habitat for a variety of fish species (MacVean et al., 2018). Fig. 4.9 uses moored sensor network data to demonstrate the seasonal variation of dissolved oxygen (DO) percent saturation amongst the eight stations. With analyses such as these, we are able to explore and better understand differences in the inter-seasonal and inter-station water quality dynamics in the South and LSB.

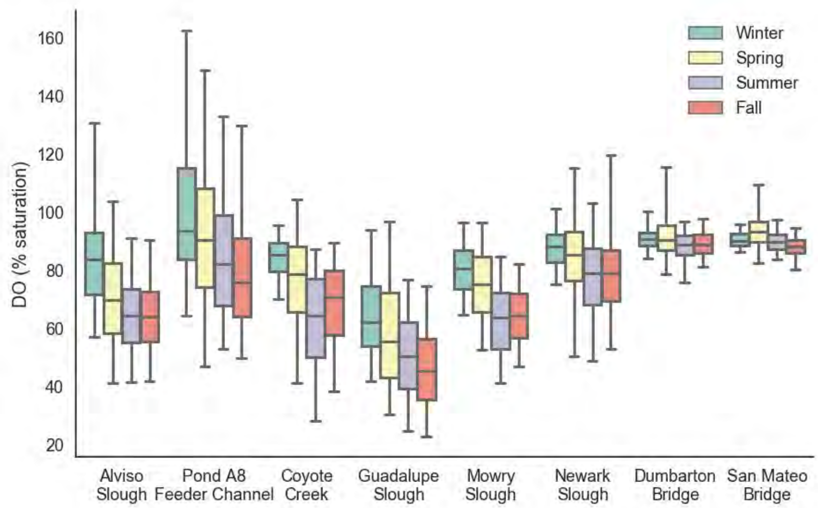


Figure 4.9: Seasonal boxplots of DO % saturation for each high-frequency station

Fig. 4.10 visualizes for each station the July-October high frequency DO patterns for summer 2017, plotted together with a DO threshold line of 5 mg/L. We can see that certain stations often remain above this 5 mg/L threshold, while others in the margins spend extended time periods below the threshold. Fig. 4.11 further explores how station DO stacks up against established thresholds through plotting probability density function curves (PDFs) for each station that demonstrate the typical duration of low DO events below 5 mg/L and 2 mg/L thresholds at each station. Viewed this way, the data provide perspective on relative DO-related habitat condition, how those conditions vary spatially and over time.

Although the moorings provide high resolution data over time, some important uncertainties remain about how conditions vary spatially, specifically in the vertical direction. DO measurements at slough sites occurred 50 cm above bed. It is possible, however, that the water column was not well-mixed, and that DO concentrations were higher at shallower depths, which would have important implications both for condition assessment and in terms of understanding important mechanisms. During some time periods, additional DO sensors were deployed at other depths in the water column in Guadalupe Slough (Figure 4.12) and Alviso Slough. During the August 2016 deployment in Guadalupe Slough, DO concentrations showed similar variations at all depths, except during a few interesting windows (see figure caption).

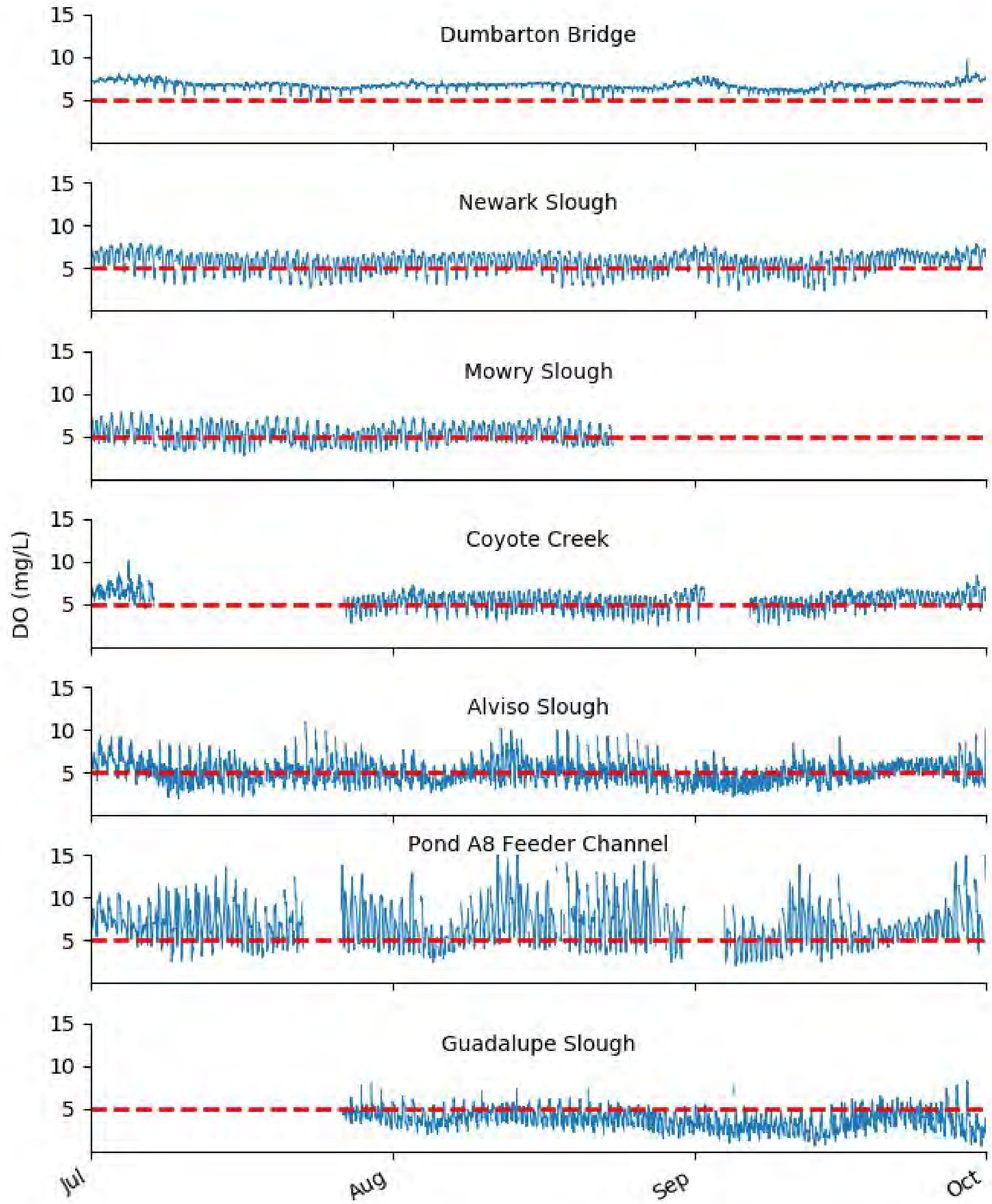


Figure 4.10: High-frequency dissolved oxygen (mg/L) for summer, 2017, plotted with a horizontal threshold guide at 5 mg/L (red).

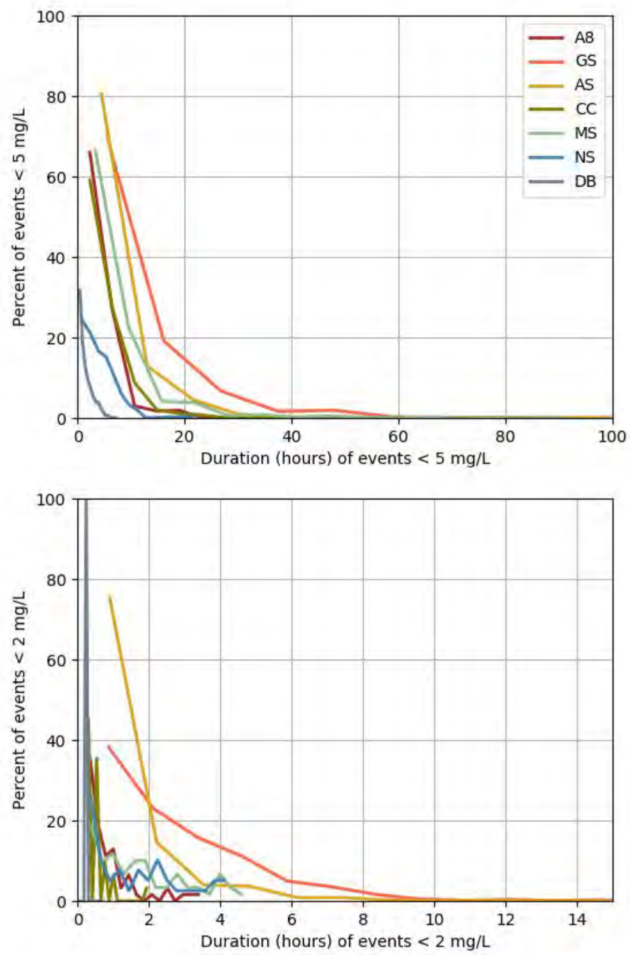


Figure 4.11: Top plot shows probability density functions for the duration (hours) of low DO events below 5 mg/L, and bottom plot shows the same for DO events below 2 mg/L.

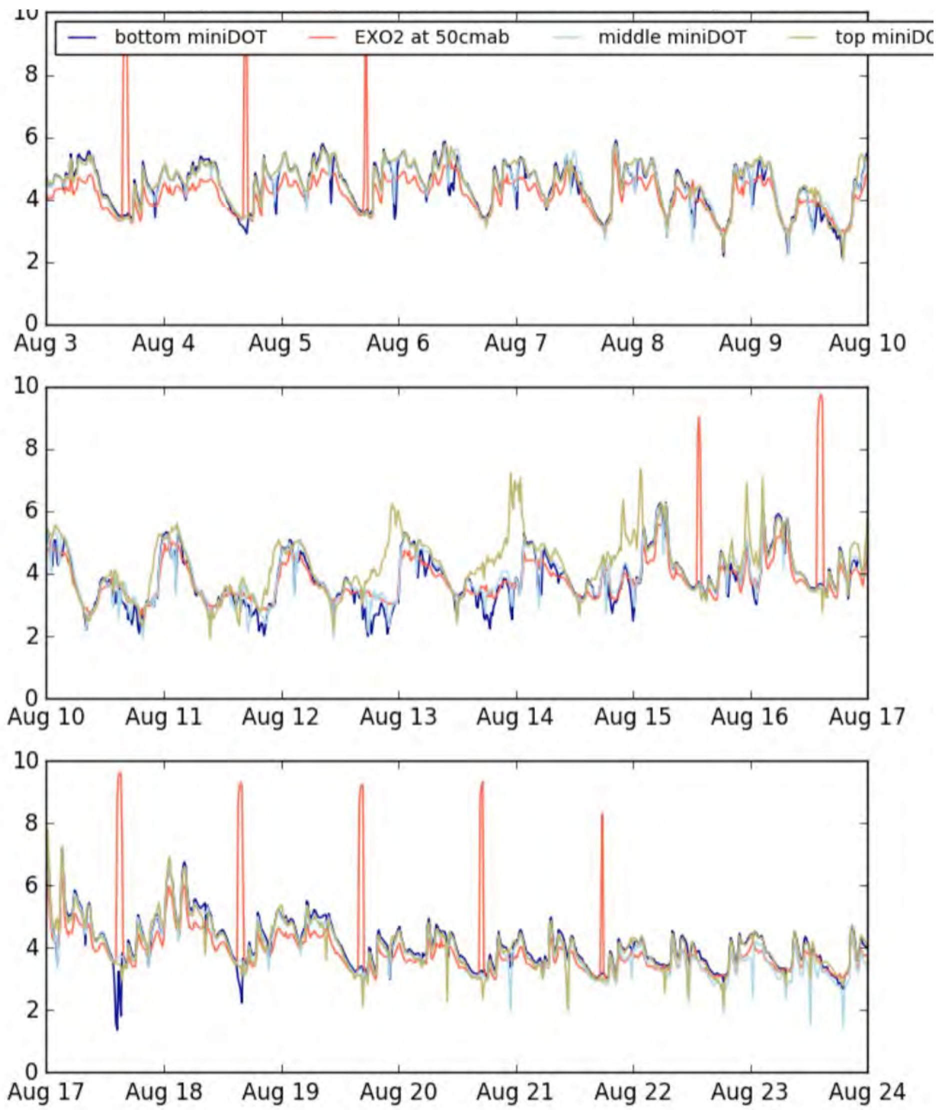


Figure 4.12: DO concentration (mg/L) in Guadalupe Slough during summer, 2016. Four DO sensors were deployed simultaneously at different depths (bottom = within 10 cmab (cm above bed); EXO = 50 cmab; middle = 50 cmab; top = near water surface. In general, all four sensors covaried including during DO minima. The higher surface DO levels between August 12 and August 16 is likely due to surface inputs of high DO (and high chla) water from a salt pond. The EXO2 sensor maxima during some time periods is likely due to the sensor being out of the water at low tide (assuming EXO2 sensor was slightly higher on the instrument package setup).

The water quality dynamics of the South and LSB are spatially and temporally complex, and the data from the moored sensor network demonstrate that complexity and provide an avenue to better understand the mechanisms driving the observed differences in habitat quality.

Fig. 4.13 provides another example of the benefit of implementing a high-frequency sensor network. The figure plots SFEI high frequency chlorophyll-a data at the Dumbarton Bridge site along with corresponding data from USGS cruise water quality data (collected since 1969). The figure demonstrates that the high-frequency data captures phytoplankton blooms that are otherwise missed with the less frequent sampling of the cruise data collections and also shows the close correlation between the SFEI's high-frequency chlorophyll-a output and the USGS discrete samples. Having the high frequency sites throughout the LSB allows us to capture the smaller scale variations that are missed with low-frequency sampling but could have large impacts on overall production and chlorophyll trends, as well as the spatial variation in water quality parameters throughout the South and LSB.

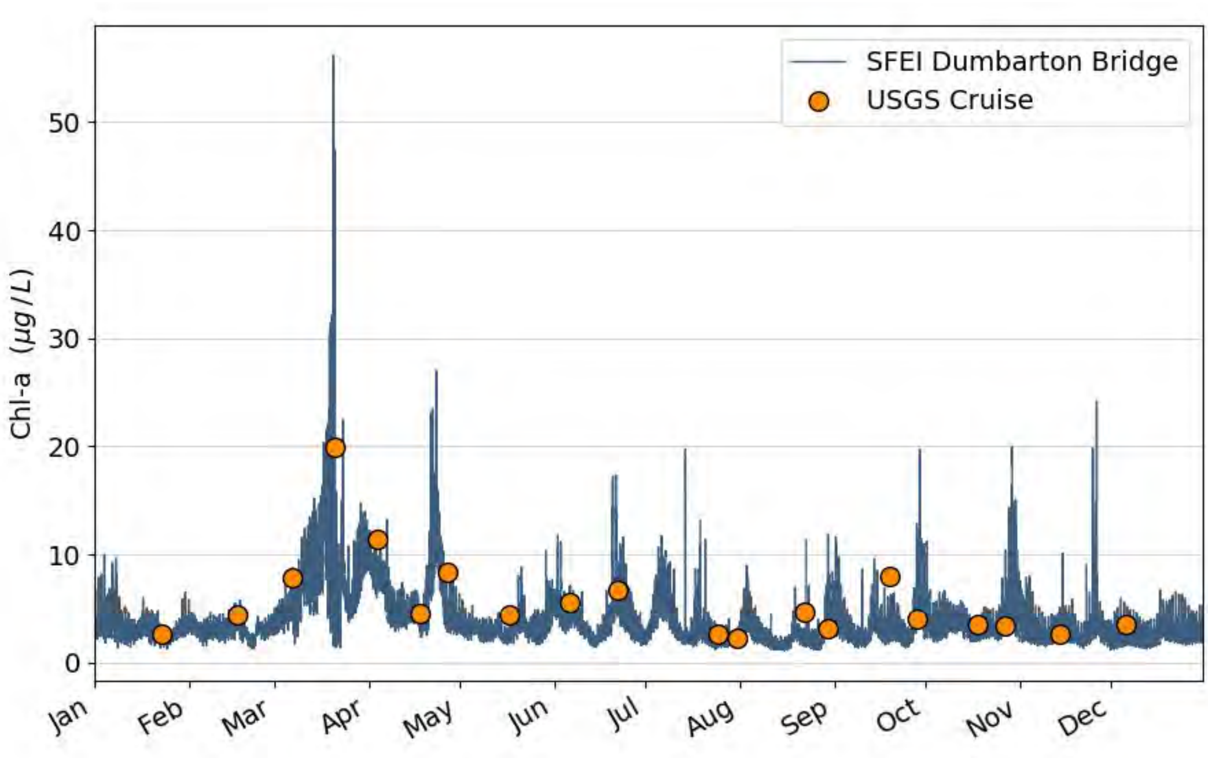


Figure 4.13: High-frequency chlorophyll-a data from SFEI's Dumbarton Bridge site plotted together with USGS water quality cruise discrete chlorophyll-a samples from station 32.

Analyzing chlorophyll-a bloom patterns and the system dynamics that lead to blooms is a key objective of the moored sensor program. Having the high frequency dataset allows us to compare chlorophyll patterns in different regions of the Bay, as well as to look analyze concurrent and preceding environmental conditions relative to blooms. Fig. 4.14 compares chlorophyll patterns in the spring of 2017 between Dumbarton Bridge, San Mateo Bridge, and the shoal environment to the east of San Mateo and Dumbarton. The high frequency shoal deployment has been a pilot project for the NMS monitoring program. Results from three separate deployments have demonstrated that there are key differences between the shoal and the neighboring deep channel.

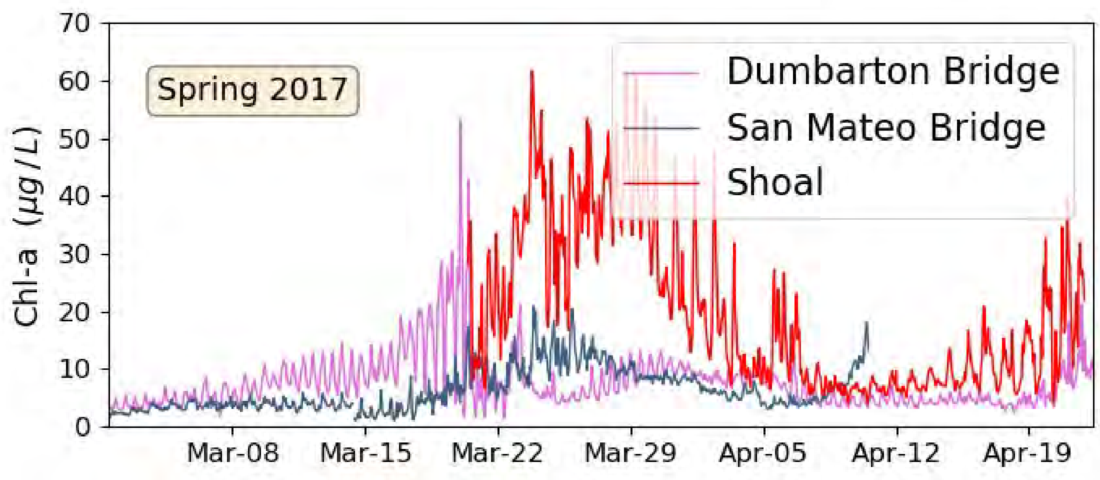


Figure 4.14: High frequency chlorophyll data from Spring, 2017 for Dumbarton Bridge, San Mateo Bridge, and the pilot mooring in the shoal environment to the east of San Mateo Bridge.

Additionally, Fig. 4.15 demonstrates the environmental conditions preceding, during, and after a chlorophyll bloom events at Dumbarton Bridge, which addresses questions 6.1 and 6.2 of goal 6 from the year one report. Plots such as this allow us to see the power of the high-frequency datasets, as we are able to more closely analyze the environmental conditions surrounding water quality events that may be missed under lower-frequency sampling regimes. With the plot below, we are able to see that the bloom co-occurs with local minima in tidal range and turbidity; however, it is difficult to tease out which may play a large effect in chlorophyll dynamics. We plan to continue to use this method of data visualization/analysis over larger time-swaths to tease out the relative influences and causal factors of these environmental conditions on chlorophyll and DO dynamics.

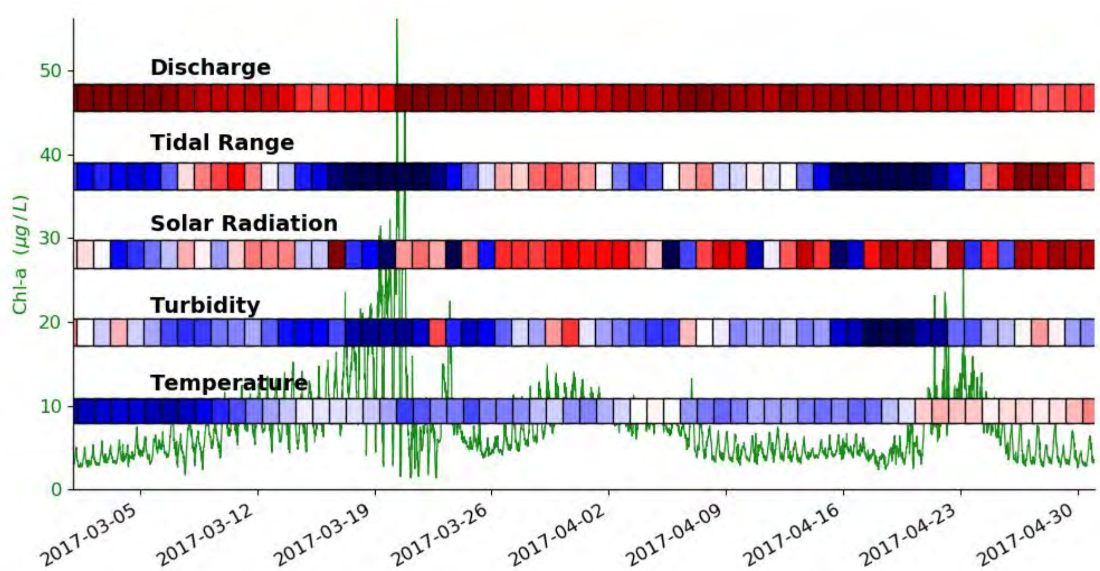


Figure 4.15: The green line shows high-frequency chlorophyll-a for Dumbarton Bridge, and the horizontal colorbars on each plot show the normalized data (scale of 0 (blue) to 1 (red) for each of parameter listed. This allow us to examine whether parameters increase or decrease around chlorophyll events. For example, we can see during the bloom in March that turbidity and tidal range all decreased relative to their normal data output.

Through strategically setting up sensors near salt pond restoration sites, we are able to evaluate the influence of the salt ponds on the surrounding margin areas. For example, in Fig. 4.16, we can see the abrupt spikes in chlorophyll-a that occur at the Guadalupe sensor when water that has drained from the pond makes its way past the sensor over a three day period in November, 2017. Fig. 4.17 shows the bloom event that Fig. 4.16 occurred during. There is a large, multiple month sustained bloom at Guadalupe slough. The bloom event does not seem to be replicated to the same level at Coyote Creek or Dumbarton Bridge. We also notice that during the bloom at Guadalupe Slough, there are many quick spikes in chlorophyll levels; these spikes do not remain at the extreme highs for long, however, chlorophyll remains elevated on average throughout the entire bloom period.

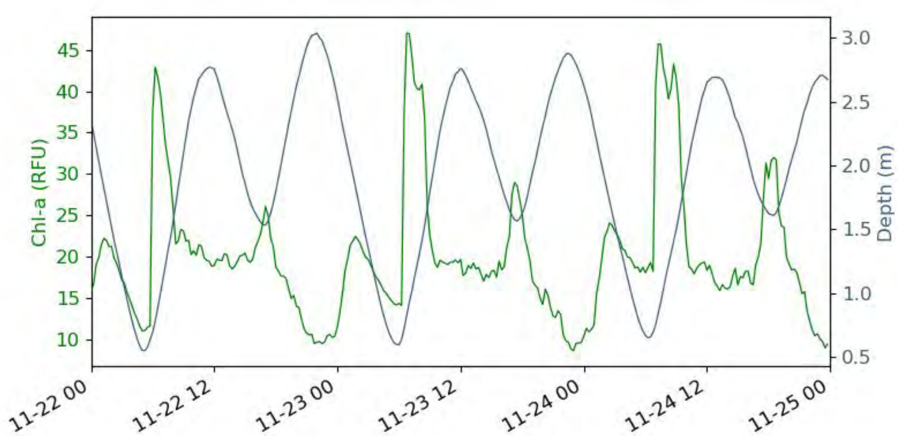


Figure 4.16: Plotting chlorophyll-a (RFU) and Depth (m) for a three day period at Guadalupe Slough in November, 2017. The abrupt increases in chlorophyll occur when water that has drained from the restored salt ponds is carried past the sensor at the start of the flood tide (the pond outlet is ~75 m downstream from the sensor)

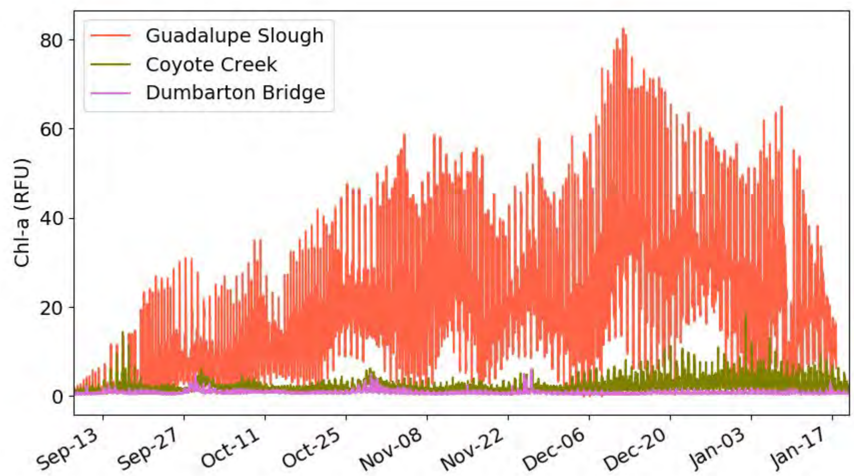


Figure 4.17: Sustained chlorophyll-a bloom at Guadalupe slough starting in September, 2017. Fig. 4.16 (above) occurs during November of this bloom.

4.3 Modeling Calibration/Validation

SFEI is developing extensive hydrodynamic and biogeochemical models for the San Francisco Bay and Delta region. These models will be used to develop an improved understanding the dynamics of the Bay's response to nutrients, and to predict water quality under a range of conditions, including potential changes in POTW nutrient loads. The models require extensive calibration and validation efforts to fine-tune physical and biogeochemical responses to external forcings (freshwater inputs, tides, nutrient loads). Ideally this data would be high-frequency dataset to match the high-frequency time steps (<1 hr) used in the models. Figure 4.18 presents an example of SFEI's model validation efforts through comparing observed and modelled salinity at the Coyote Creek and Guadalupe Slough station locations.

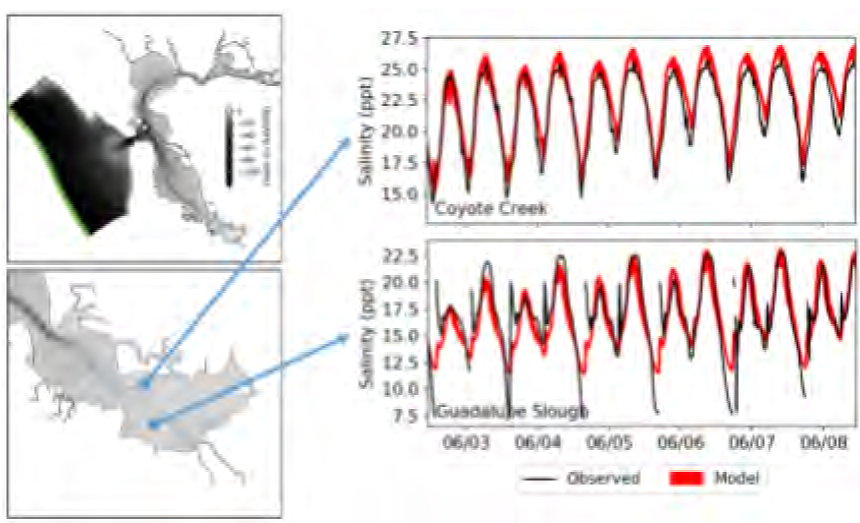


Figure 4.18: Calibrating the LSB hydrodynamic model with moored sensor data

In addition, through a collaboration with UC Berkeley, the NMS has been collecting additional high frequency salinity and velocity data in LSB (Figure 4.19-4.20). Instrumentation was deployed during a diverse range of conditions: Fall 2015 (dry season, end of drought); Winter 2016 (wet season, avg year); Fall 2016 (dry season); Winter 2017 (wet season, very wet). We anticipate these data will being valuable for calibrating the complex physis of LSB, in particular exchange between sloughs, shoals, and channel.

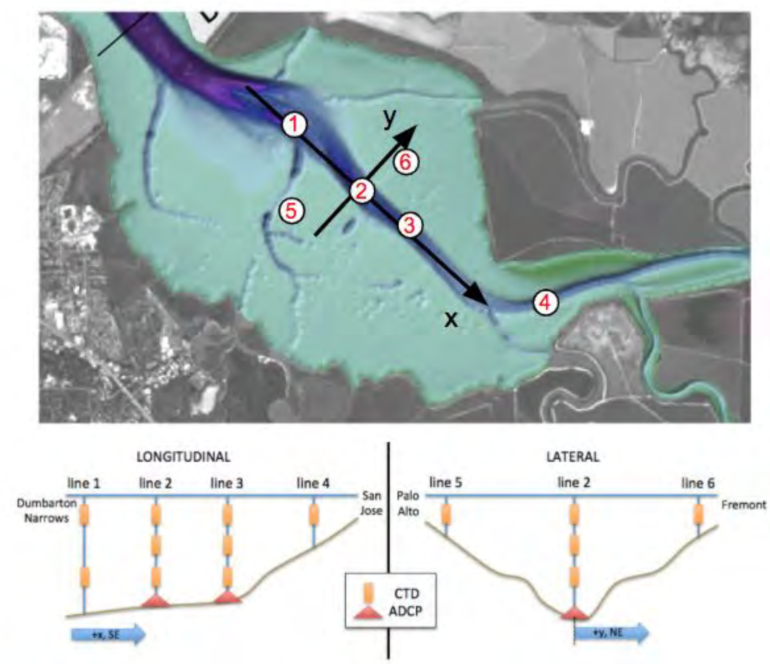


Figure 4.19: Map of deployments in Lower South Bay. Locations of lines and CTDs and ADCPs shown from the top view, longitudinal transect, and lateral transect. Positive x is defined in the southeast direction. Positive y is defined in the northeast direction. Line 2, the centrally located line, lies at y = 0.
Source: O Hoang et al., in prep.

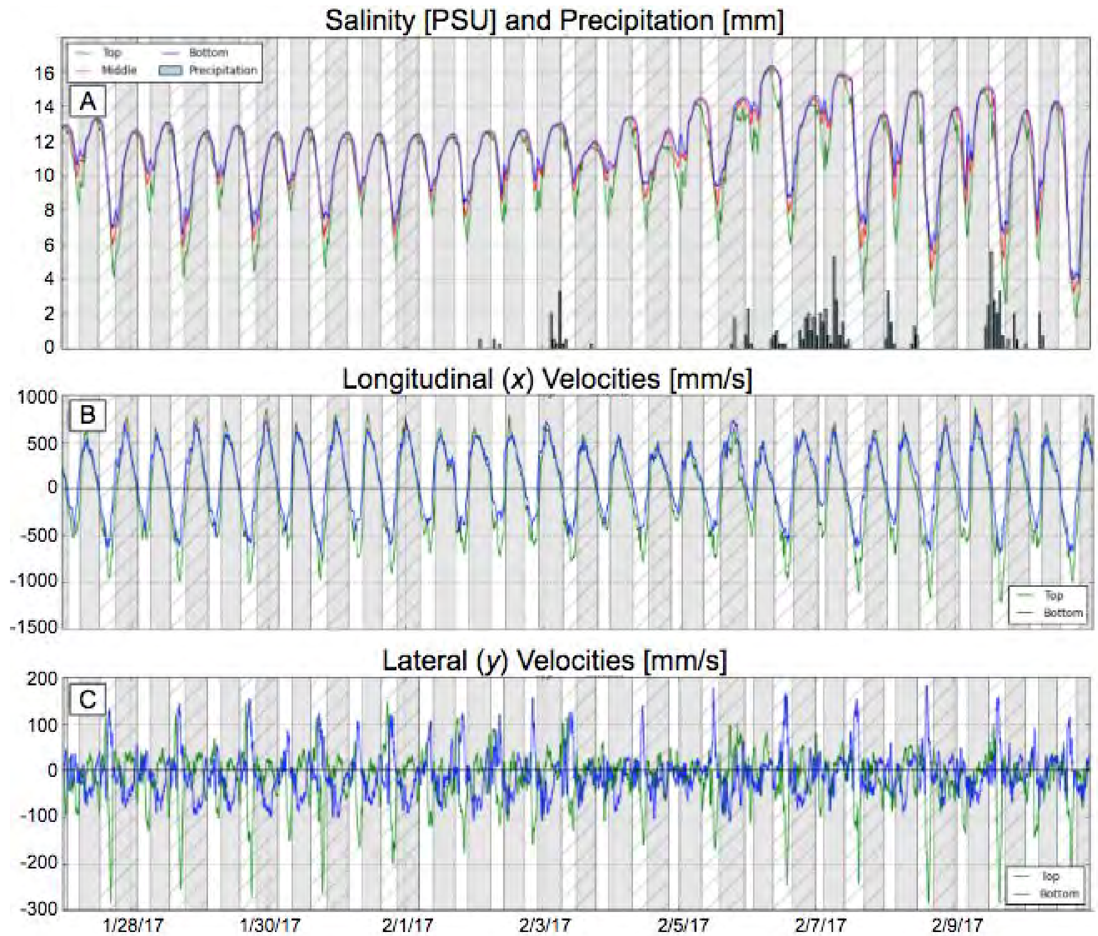


Figure 4.20: Data from Line 2 during a ~2 week window in winter 2017 (1/27/2017-2/10/2017). **A.** Salinity [PSU] and precipitation [mm] vs. time. **B.** Longitudinal velocities (along channel, x-axis) over top 2 m and bottom 2 m of the water column. **C.** Lateral velocities (perpendicular to channel, y-axis) over top 2 m and bottom 2 m of the water column. Flood tides correspond to gray shading. Ebb tides correspond to white shading. Hatching refers to larger flood/ebb tides when there is an asymmetry. Precipitation data from the California Irrigation Management Information System (CIMIS) station in Union City [California Department of Water Resources]. Source for Data and Graphic: O Hoang et al., in prep.

4.4 Data Accessibility

SFEI's moored sensor network data is currently available for visualization purposes on the EnViz data visualization platform (https://www.enviz.org/; Figure 4.21). Users are able to plot water quality parameters from any of the NMS' eight stations, along with data from a subset of USGS and DWR sites in northern SFB and the Delta. SFEI is considering options for making the NMS data fully available for download, aiming for an approach that invests resources at a level commensurate with the need or desire for greater accessibility. The current policy is that the data is available to anyone upon request. One possible option for a low-impact expansion is to periodically upload L3 data to the SFEI-NMS ERDDAP data server and make a link publicly available.

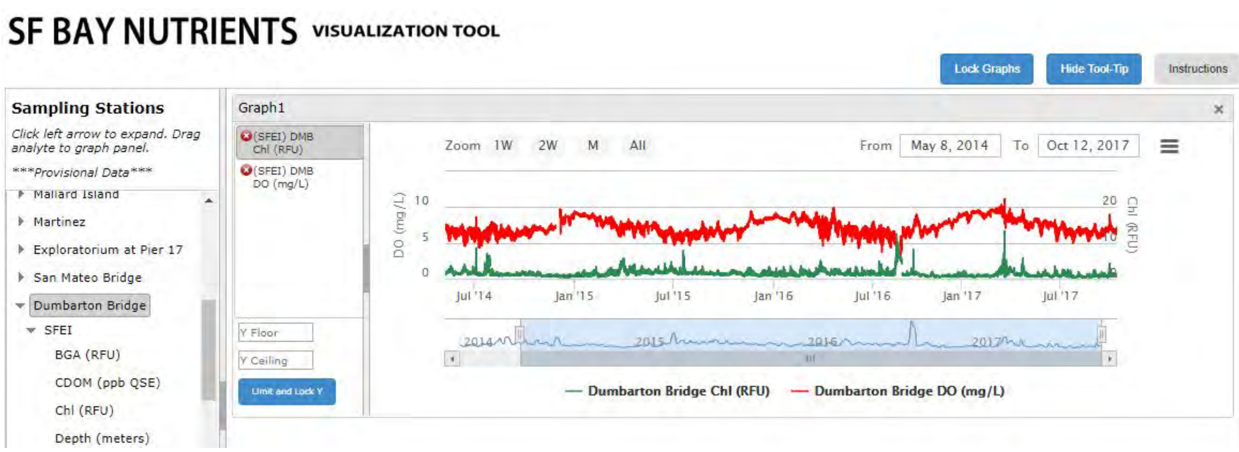


Figure 4.21: Example of an EnViz display panel showing chlorophyll-a plotted together with dissolved oxygen at Dumbarton Bridge

5. Ongoing and Future Work

This section addresses ongoing and future work in relation to the original NMS-MSP goals. Table 5.1 details how the ongoing work addresses the program goals, as well as how we plan to continue addressing these goals moving forward. Future work will involve maintaining certain aspects of the program, as well as modifying the program to continue to address the dynamic needs of the NMS. Highest priority future work includes:

- Deploying 1-2 SUNA nitrate sensors within the NMS-MSP network (co-located with current sites).
- Expanding moored sensor monitoring into the shoal region (east of San Mateo Bridge) based off the successful pilot studies which have indicated key differences in water quality dynamics between the shoal and deep channel.
- Re-evaluate current site locations to determine the highest priority sites to maintain, as well as identify sites that could be shifted to other locations of SFB.
- Expand utilization of data, as well as continue to integrate the dataset with other water quality datasets and projects throughout SFB
- Utilize water years 2014, 2017, and 2018 for calibrating upcoming hydrodynamic and biogeochemical modeling efforts
- Continue the semi-automated QAQC efforts

Table 5.1: Ongoing and future work with regards to the original program goals

Goals (G)	Key Questions (Q)	Ongoing or Future Work and Priorities
1: Identify the best sensors or sensor packages considering program goals, and develop capacity to deploy and maintain moored sensors	1.1 What locations are feasible for sensor deployment? 1.2 How frequently do the sensors need to be serviced? How does this vary seasonally? 1.3 What biofouling prevention tools are most effective?	- Based on current instrument performance we envision migrating to Seabird sensor packages wherever possible, anticipating that they will increase data reliability and allow for less frequent servicing. - Both hot-swapping and increased consistency of 3-4 week maintenance intervals (especially during the summer/fall) has substantially improved data return and data quality, and we intend to continue with that approach.
2: Create/adapt procedures for automated data acquisition, data management, and real-time high-frequency data visualization	2.1 What are standard procedures exist for data processing (i.e. removing outliers, correcting for fouling/drift)? 2.2 What data processing can be automated? 2.3 What are the data visualization needs of the NMS-MSP, and what is the best way to address those needs?	- Newly-developed QA procedures: continue applying on incoming data, and gradually apply to older data. - To date, salinity, temperature, and DO data have received the most QAQC attention. Over the next 2 years, increasing attention will be directed toward chl-a and turbidity data. B/c the semi-automated and any final manual QAQC steps are time-intensive, this work will likely take place in a targeted way (specific years, time periods, events) within the context of other projects (modeling, mechanistic data interpretation). - Real-time access to data (via telemetry) is important for some very practical reasons, like knowing when sensors have failed or fouled. Establishing reliable real-time access remains a moderate to high-priority, but requires dedicated resources - No new substantive work is currently planned on web visualization, but is a possibility if there is interest and need.

3: Develop understanding of sensor accuracy and potential interferences	3.1 What parameters can be accurately measured by moored sensors? 3.2 How well does the EXO2 agree with other moored sensors being used in SFB? 3.3 What amount discrete sampling is necessary to verify or calibrate sensor output? What are the main interferences, and to what degree can we improve measurement accuracy through adjusting for interferences?	- A concerted effort to analyze discrete chlorophyll-a vs. sensor data would be valuable for developing either site-specific, regional, or (ideally) universal relationships for estimating actual chl-a concentration from sensor data, and for quantifying the uncertainty in those estimates. This will become increasingly important as mooring chl-a data begins receiving use in NMS biogeochemical models. Ample data are available for the Bay (>400 samples) and comparable amounts for instruments deployed in the Delta, which could be analyzed numbers for In coordination with Bay-Delta 'intercalibration' work. - One important early outcome of this work (target 2019) would be to identify important data gaps (chl-a concentration ranges, interferences, regions, seasons, etc.), and target additional data collection toward addressing those gaps.
4: Establish collaborations with other moored sensor programs	4.1 Where are the other moored sensor stations throughout the Bay? 4.2 What work is needed to integrate existing sensors from multiple programs into one broad network ? 4.3 How does the cost of integrating existing programs together compare to developing an SFEI moored sensor program at similar sites?	- The first two joint NMS-DRMP projects have been successful and cost-effective. The potential cost-savings of being able to rely on data from well-coordinated independent programs, as opposed to creating redundant networks, is great enough to provide an incentive to continue pursuing and supporting efforts that foster this coordination.
5: Identify NMS-MSP structure that, along with ship-based monitoring addresses the NMS monitoring and data collection needs	5.1 What is the optimal combination of ship-based and moored stations? 5.2 What spatial distribution (lateral, longitudinal, vertical) of moored sensors, and for which parameters, are needed to sufficiently capture relevant information related to bloom dynamics, oxygen, or nutrient cycling, for improved mechanistic understanding, model calibration, or condition assessment?	- Results from the pilot short mooring deployments in 2017 and 2018 on the South Bay shoal indicated that shoal conditions differed substantially from conditions in the channel, consistent with the hypothesis that the shoals are currently an important blind-spot in SFB monitoring. Installing one or more moorings on the shoals of South Bay and potentially San Pablo Bay are a high priority for 2019 and 2020 - Adding additional sensors - specifically SUNA nitrate sensors and potentially ADCPs -- at selected existing stations is another high priority for 2019 and 2020. Ideally these will be timed to complement anticipated intensive field studies to measure biogeochemical transformation rates (nitrification, denitrification, sediment exchange fluxes, respiration / oxygen demand). - We have 1.5-2 years of high-frequency surface DO data in Alviso and Guadalupe Sloughs, along with cage-deployed (0.5m above bottom) EXO2 DO data, which together creates a vertical DO profile. These data have not yet been thoroughly explored, and have the potential to provide valuable information about whether the EXO2 data (0.5m above bottom) are a good representation of DO over the full water column. - With 3+ years of DO data from the dense margin network in LSB, we are considering how much effort should continue there vs. moving field resources to other locations and other management questions. This decision hinges on: any future biota surveys in those areas, and collecting sufficient data to support that work; planned restoration efforts (changing salt pond exchange); impending decisions about establishing site-specific DO objectives
6: Use moored sensor data to address priority science questions and data gaps	6.1 What factors influence the onset and termination of a bloom?	- Work is under way on multiple fronts using the mooring data, with draft reports expected in 2019 exploring the mechanisms related to - Bloom development and bloom dissipation in South Bay (e.g., Figure 4.13, 4.14, 4,15, 4,17) - DO variations at multiple time-scales in LSB sloughs.

	6.2 What frequency, magnitude and duration of a bloom is possible?	- Space-time variation in turbidity
7: Use moored sensor data to calibrate/validate water quality models	7.1 What time-series data needed for model calibration can be collected with moored sensors? 7.2 Are there particular locations and/or time periods where additional calibration data are needed (beyond that collected at established moored sensor sites)?	- NMS-MSP data is currently being used for hydrodynamic model calibration (Figure 4.18) in LSB. - During the current water year for which biogeochemistry is being simulated (WY2013), no NMS-MSP sites had been established. - The next round of water years being simulated (2014, 2017, 2018) have been selected, in part, because of the availability of NMS-MSP biogeochemical data. Simulating and analyzing the output from these years will be among the major focus areas of modeling work in 2019 and 2020
8: Use moored sensor data to assess condition in SFB	8.1 For which nutrient-related indicators would condition assessment benefit from using high-frequency moored sensors? 8.2 If/when nutrient-related impairment occurs along one or more pathways, what extent/duration can be detected by moored sensors?	- NMS-MSP data have been used in a recent project for evaluating DO-related habitat condition in LSB sloughs (SFEI 2018). We expect to continue pursuing this topic in 2019 and 2020.

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