Current Report

Introduction

The Department of Water Resources (DWR) and the US Bureau of Reclamation (USBR) are required by Water Right Decision 1641 (D-1641) to collect phytoplankton and chlorophyll a samples to monitor algal community composition and biomass at select sites in the upper San Francisco Estuary (Estuary). The twenty-four sites range from San Pablo Bay to the inland rivers of the Sacramento-San Joaquin Delta ("the Delta"). These sites represent a variety of aquatic habitats, from narrow, freshwater channels to broad, estuarine bays. This report describes the results of these monitoring efforts for calendar year 2020.

Phytoplankton are small, free-floating organisms that occur as unicellular, colonial, or filamentous forms (Horne and Goldman, 1994). Phytoplankton are a key component of the Estuary's food web, serving as food for zooplankton, invertebrates, and certain fish species. Their metabolic processes also impact water chemistry, and their ability to fix carbon through photosynthesis is one of the key processes influencing water quality in the Estuary. Via this process, phytoplankton can affect the pH, dissolved oxygen, color, taste, and odor of natural waters.

Under certain conditions, some species of phytoplankton (e.g., Microcystis aeruginosa) can cause harmful algal blooms (HABs), releasing toxin compounds which can be dangerous or even lethal to animals and humans (Carmichael, 1981). In freshwater, the cyanobacteria, or blue-green algae (class Cyanophyceae), are responsible for producing toxic blooms, particularly in waters that are polluted with phosphates (van den Hoek et al., 1995). Phytoplankton are also useful for assessing water quality (Gannon and Stemberger 1978); their short life cycles allow them to respond quickly to environmental changes, meaning their standing crop and species composition are indicative of source water characteristics (APHA 2012). However, because of their transient nature, patchiness, and free movement in a lotic environment, the utility of phytoplankton as water quality indicators is limited and should be interpreted in conjunction with other biological and physiochemical data (APHA 2012).

In addition to collecting phytoplankton samples to assess community composition, we use the measured concentration of chlorophyll a as a proxy to infer phytoplankton biomass. Chlorophyll molecules are complex phytopigments found in most photosynthetic organisms. There are several types of chlorophyll, which are distinguished by slight differences in their molecular structures and constituents. These include chlorophyll a, b, c, and d, with a being the principal photosynthetic pigment in most phytoplankton. This makes the chlorophyll a pigment a reliable proxy measurement for phytoplankton biomass.

In addition, we measured the concentration of a different pigment in our water samples, pheophytin a. Pheophytin a is a primary degradation product of chlorophyll a. Comparing its concentration relative to chlorophyll a is a useful metric for estimating the general physiological state of phytoplankton populations. When phytoplankton are actively growing, the concentrations of pheophytin a are normally expected to be low relative to chlorophyll a. Conversely, when the phytoplankton have died and are decaying, levels of pheophytin a are expected to be high in relation to chlorophyll a.

Phytoplankton biomass and the resulting amount of chlorophyll a in some areas of the Estuary may be influenced by extensive filtration of the water column by the introduced Asian clam, Potamocorbula amurensis (Alpine and Cloern 1992). Well-established benthic populations of P. amurensis in Suisun and San Pablo bays are thought to have contributed to the low chlorophyll a concentrations (and increased water clarity) measured in these westerly bays since the mid-1980s (Alpine and Cloern 1992).

Phytoplankton are small, free-floating organisms that occur as unicellular, colonial, or filamentous forms (Horne and Goldman, 1994). They primarily serve as an important food source for zooplankton, invertebrates, and certain fish species, although they also have a direct effects on water chemistry. Primary production by phytoplankton, primarily via carbon fixation through photosynthesis, is one of the key processes that influence water quality in the Estuary. Via this process, phytoplankton can affect pH, dissolved oxygen, color, taste, and odor. Under certain conditions, some species (eg. Microcystis aeruginosa) can cause harmful algal blooms (HABs), resulting in animal deaths and human illness (Carmichael, 1981). In freshwater, the cyanobacteria, or blue-green algae (class Cyanophyceae), are responsible for producing toxic blooms, particularly in waters that are polluted with phosphates (van den Hoek et al., 1995). Phytoplankton are also useful for assessing water quality (Gannon and Stemberger 1978); their short life cycles allow them to respond quickly to environmental changes, meaning their standing crop and species composition are indicative of source water characteristics (APHA 2012).

However, because of their transient nature, patchiness, and free movement in a lotic environment, the utility of phytoplankton as water quality indicators is limited and should be interpreted in conjunction with other biological and physiochemical data (APHA 2012).

In addition to collecting phytoplankton samples to assess community composition, we use chlorophyll a concentrations as proxies to calculate phytoplankton biomass. Chlorophylls are complex phytopigment molecules found in all photosynthetic organisms. There are several types of chlorophyll, which are distinguished by slight differences in their molecular structures and constituents. These include chlorophyll a, b, c, and d, with a being the principal photosynthetic pigment in the majority of phytoplankton. This makes the chlorophyll a pigment a reliable proxy measurement for phytoplankton biomass. Furthermore, water samples were analyzed for pheophytin a. Pheophytin a is a primary degradation product of chlorophyll a. Its concentration, relative to chlorophyll a, is useful for estimating the general physiological state of phytoplankton populations. When phytoplankton are actively growing, the concentrations of pheophytin a are normally expected to be low in relation to chlorophyll a. Conversely, when the phytoplankton have died and are decaying, levels of pheophytin a are expected to be high in relation to chlorophyll a. Phytoplankton biomass and the resulting chlorophyll a concentrations in some areas of the Estuary may be influenced by extensive filtration of the water column by the introduced Asian clam, Potamocorbula amurensis (Alpine and Cloern 1992). Well-established benthic populations of P. amurensis in Suisun and San Pablo bays are thought to have contributed to the low chlorophyll a concentrations (and increased water clarity) measured in these westerly bays since the mid-1980s (Alpine and Cloern 1992).

Methods

Phytoplankton

Phytoplankton samples were collected monthly at 24 monitoring sites throughout the Upper Estuary, which were grouped into regions based on their geographic location (Figure 1; Table 1). Samples were collected 1 meter below the water's surface using a submersible pump and stored in 50 mL amber glass bottles. 200 µL of Lugol's solution was added to each sample as a stain and preservative. All samples were kept at room temperature and away from direct sunlight until they were analyzed.

Phytoplankton identification and enumeration were performed by BSA Environmental, Inc. according to the Utermöhl microscopic method (Utermöhl, 1958) and modified Standard Methods (APHA, 2012). An aliquot of sample was placed into a counting chamber and allowed to settle for a minimum of 12 hours. The aliquot volume, normally 10-20 mL, was adjusted according to the algal population density and the turbidity of the sample. Phytoplankton taxa were enumerated in randomly chosen transects for each settled aliquot. This process was performed at 800x magnification using a Leica DMIL inverted microscope. For each aliquot, a minimum of 400 total algal units were counted, with the dominant taxon accounting for a minimum of 100 algal units. For filamentous or colonial taxa, the number of cells per filament or colony was recorded. Raw organism counts were normalized to the sample volume using the following formula:

$$organisms/mL = \frac{CA_c}{VA_fF}$$

where C is the organism count, A_c is the area of the cell bottom (mm^2), A_f is the area of each grid field (mm^2), F is the number of fields examined, and V is the settled volume (mL). This simplifies to:

$$organisms/mL = \frac{C}{cV}$$

where $cV = \frac{A_c}{VA_fF}$ and is equal to the counted volume.

The 10 most common genera were determined by summing the normalized organism counts across all stations and months for each genus. For the bar graphs, average organism counts were calculated per month, per region, and normalized to the number of stations.

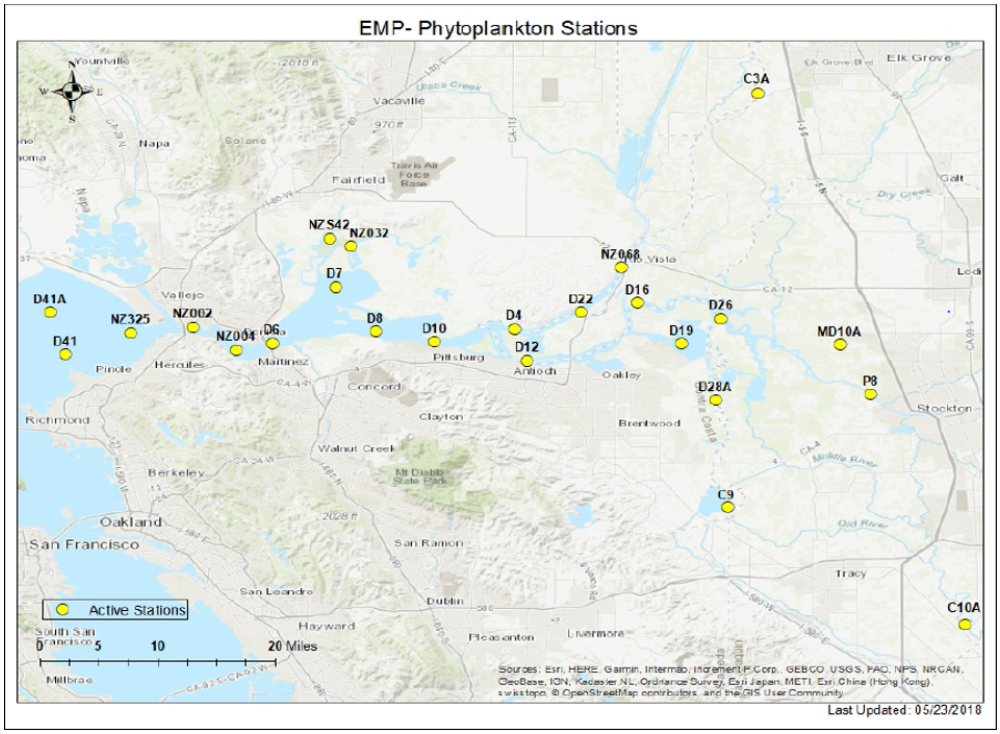

Figure 55: Map of phytoplankton stations sampled by the Environmental Monitoring Program

Table 9: Stations included within each region of the Delta

Region	Stations
Nothern Interior Delta	C3A and NZ068
Southern Interior Delta	C9, C10A, MD10A and P8
Central Delta	D16, D19, D26 and D28A
The Confluence	D4, D10, D12 and D22
Grizzly and Suisun Bay	D7, D8, NZ032 and NZS42
San Pablo Bay	D6, D41, D41A, NZ002, NZ004 and NZ325

Chlorophyll a and Pheophytin a

Samples of chlorophyll a and pheophytin a were collected monthly at 24 monitoring sites throughout the upper Estuary using a submersible pump positioned 1 meter below the water's surface. Samples were collected by filtering a known volume of water through a glass-fiber filter (1.0 µm pore size) at a pressure of 10 mmHg. For turbid water (> 20 NTU), 200 mL was filtered while 500mL of water was filtered when turbidity was < 20 NTU to prevent clogging.

Filters were immediately frozen and transported to DWR's Bryte Laboratory for analysis using spectrophotometry in accordance with the Standard Method 10200 H (APHA, 2012). Samples were processed by mechanically grinding the filter and extracting phytopigments using acetone. Pigment absorption spectra were measured before and after acidification to quantify the amount of chlorophyll a and pheophytin a, respectively. Concentrations were calculated according to a formula specified in the methodology (APHA, 2012). Average analyte concentrations were then calculated per month, per region, and were normalized to the number of stations.

Results

Phytoplankton Identification

All organisms collected in 2020 fell into these ten algal groups: • Pennate diatoms • Centric diatoms • Chrysophytes • Synurophytes • Cyanobacteria • Cryptophytes • Dinoflagellates • Euglenoids • Haptophytes • Green Algae

The 10 most common genera collected in 2020 were, in order: • Eucapsis (cyanobacterium) • Chroococcus (cyanobacterium) • Cyclotella (centric diatom) • Chlorella (green alga) • Plagioselmis (cryptophyte flagellate) • Aulacoseira (centric diatom) • Skeletonema (centric diatom) • Cocconeis (pennate diatom) • Nitzschia (pennate diatom) • Pseudanabaena (cyanobacterium)

Of the ten groups identified, cyanobacteria constituted the vast majority (98.2%) of the organisms collected (Figure 2).

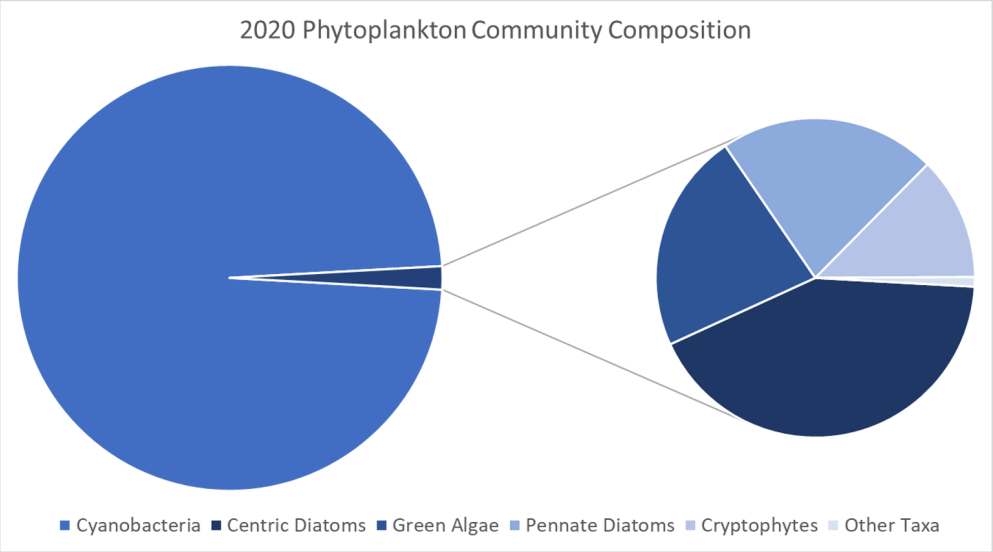

Figure 56: Phytoplankton composition by algal group (other are chrysophytes, ciliates, dinoflagellates, euglenoids, and haptophytes)

Pigment Concentrations

Some stations showed seasonal patterns in chlorophyll a concentration, while others did not. Most maxima occurred in spring and summer, while minima occurred in fall or winter. Monthly chlorophyll a concentrations throughout much of the estuary were low relative to historic levels. Of the 223 samples taken in 2020, 97.3% (217 samples) had chlorophyll a levels below 10 µg/L. Chlorophyll a levels below 10 µg/L are considered limiting for zooplankton growth (Müller-Solger et al., 2002). Of the 6 samples with chlorophyll a concentrations equal to or above 10 µg/L, five were at C10A (June through October) and one was at P8 in August.

The mean chlorophyll a concentration for all samples in 2020 was 2.86 µg/L; the median value was 1.88 µg/L. Both values are slightly higher than in 2019 (mean = 2.26 µg/L, median = 1.67 µg/L). The maximum chlorophyll a concentration in 2020 was 32.50 µg/L, recorded in July at C10A. This is similar to the 2019 maximum (38.10 µg/L). The minimum for 2020 chlorophyll a concentration was 0.53 µg/L, recorded at NZ325 in March, and again at C10A in November. It was nearly identical to the 2019 value (0.55 µg/L). Eight chlorophyll a samples were below the reporting limit.

The mean pheophytin a concentration for all samples in 2020 was 1.65 µg/L, slightly higher than the 2019 value (1.41 µg/L). The median value was 1.16 µg/L, which was also slightly higher than in 2019 (1.02 µg/L). The maximum pheophytin a concentration was 11.69 µg/L, recorded at NZ032 in August. This value was lower than in 2019 (13.55 µg/L). The minimum pheophytin a concentration was 0.50 µg/L, which is equivalent to the reporting limit; this was recorded at 2 stations (NZ002 and NZ004) in February. Twenty pheophytin a samples were below the reporting limit; they were observed primarily in the fall/winter.

Northern Interior Delta

Chlorophyll a average concentrations were higher in early winter, summer, and fall (Figure 3). The highest concentration was recorded at NZ068 in October (2.78 µg/L) and the lowest was recorded at C3A in December (0.53 µg/L), which was one of two recordings of the lowest concentration. The mean and median values were 1.42 µg/L and 1.18 µg/L, respectively. There were no samples below the detection limit.

Pheophytin a average concentrations were highest in the fall; values were similar to chlorophyll a (Figure 3). The maximum (3.20 µg/L) was recorded at NZ068 in September and the minimum (0.52 µg/L) was recorded at C3A in December, although there were four samples below the detection limit (C3A in November, and NZ068 in February, March, and July). The mean and median were 0.98 µg/L and 0.81 µg/L, respectively.

Phytoplankton average densities were highest in early winter and early fall, with cyanobacteria dominating throughout the year (Figure 4; “other taxa” are cryptophytes and dinoflagellates). Pennate diatom density was high in January, and green algae concentrations were relatively high in March and October.

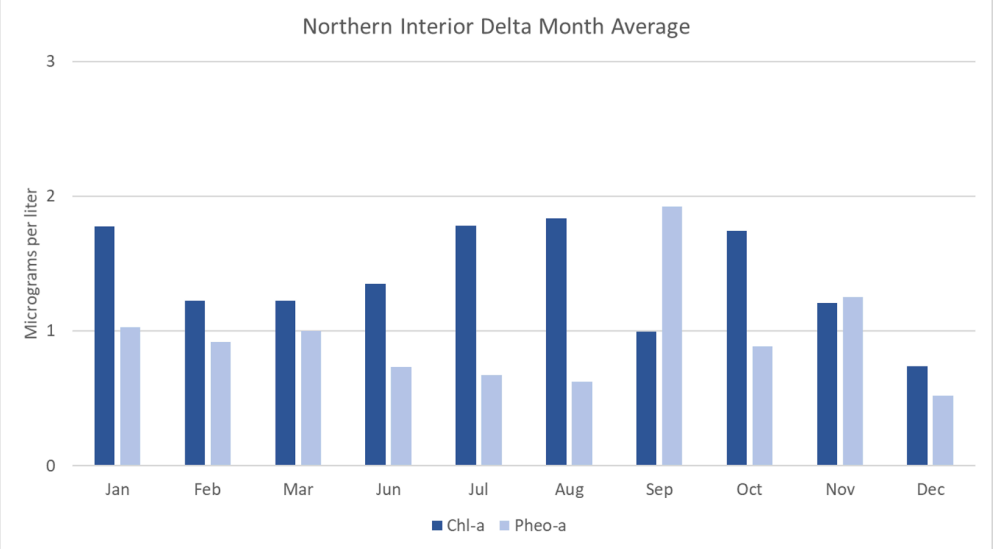

Figure 57: Average chlorophyll a and pheophytin a concentrations in the Northern Interior Delta

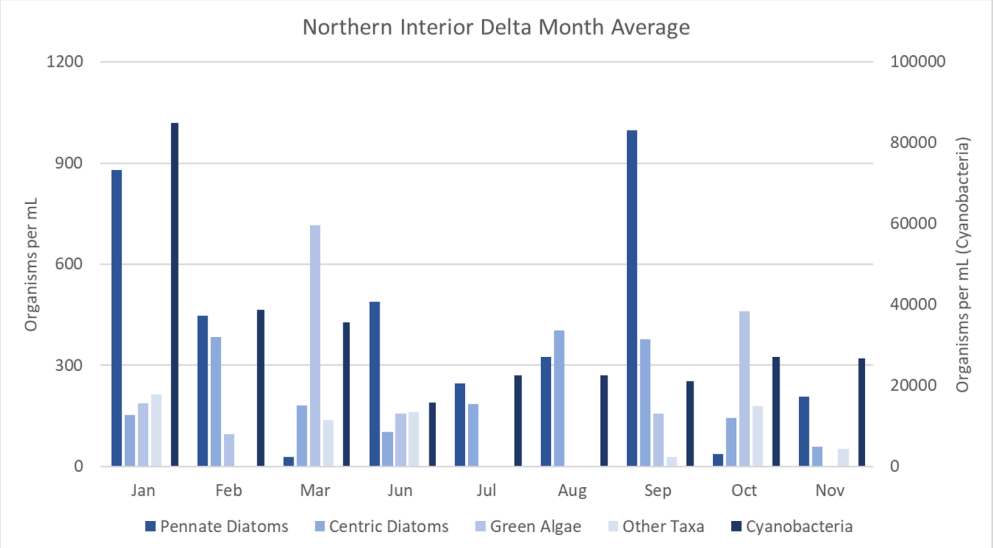

Figure 58: Average organism density in the Northern Interior Delta; other are chrysophytes, cryptophytes, and dinoflagellates

Southern Interior Delta

Chlorophyll a average concentrations were highest in the summer (Figure 5). The maximum was recorded at C10A in July (32.50 µg/L), which also was the maximum for the year; the minimum was at P8 in January (0.64 µg/L). The mean and median were 5.56 µg/L and 2.98 µg/L, respectively. There were two samples below the detection limit at C9 in December and MD10A in January.

Pheophytin a average concentrations were fairly constant throughout the year, with slight spikes in the summer months (Figure 5). The maximum pheophytin a value was recorded at C10A in July (6.06 µg/L); the minimum occurred at P8 in March (0.56 µg/L). The mean and median values were 1.84 µg/L and 1.46 µg/L, respectively. Two samples in January at MD10A and P8 were below the detection limit.

Phytoplankton average densities were highest in the summer and fall, with the highest concentrations occurring in July (Figure 6; “other taxa” are chrysophytes, cryptophytes, euglenoids, and synurophytes). Cyanobacteria dominated throughout the year and centric diatom concentrations were relatively high in the summer months.

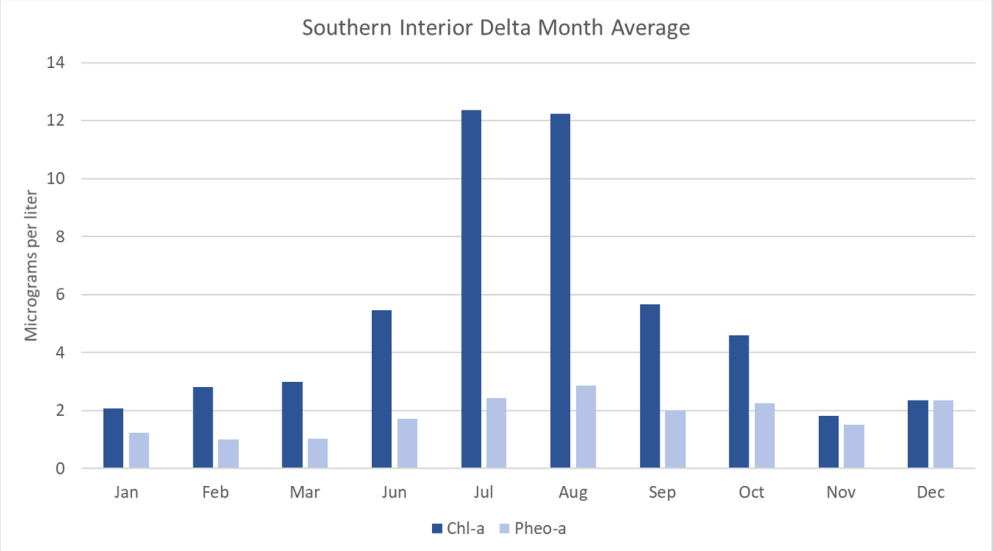

Figure 59: Average chlorophyll a and pheophytin a concentrations in the Southern Interior Delta

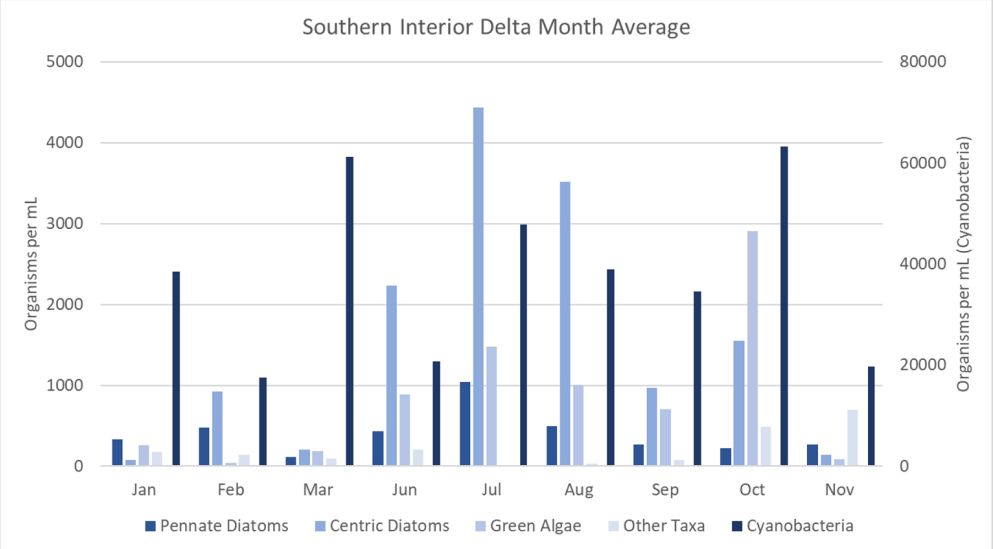

Figure 60: Average organism density in the Southern Interior Delta; other are chrysophytes, cryptophytes, and dinoflagellates

Central Delta

Chlorophyll a average concentrations were highest in the summer and early fall months (Figure 7). The highest chlorophyll a concentration for this region at occurred at D16 in September (8.50 µg/L); the minimum occurred at the same station in January (1.01 µg/L). The mean and median values were 2.63 µg/L and 2.09 µg/L, respectively. There were no samples below the detection limit.

Pheophytin a average concentrations were relatively consistent throughout the year excluding a large spike in November (Figure 7), when the highest concentration in the region was recorded (15.40 µg/L, station D19). The minimum occurred at D19 in October (0.50 µg/L). The mean and median values were 1.28 µg/L and 0.90 µg/L, respectively. There was one sample below the detection limit at D16 in January.

With the exception of cyanobacteria, phytoplankton average densities were low all year except for a bloom of centric diatoms in August (Figure 8; “other taxa” are chrysophytes, cryptophytes, and green algae).

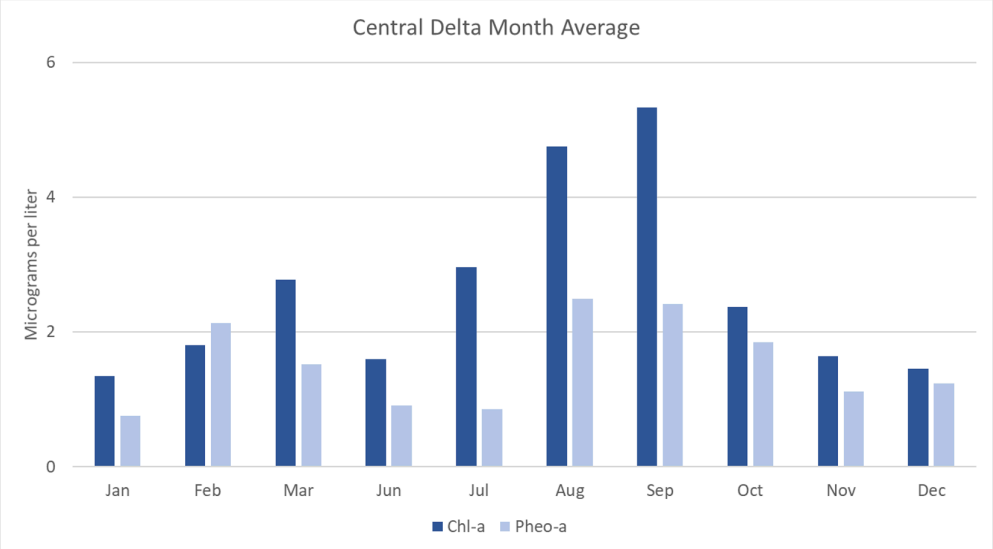

Figure 61: Average chlorophyll a and pheophytin a concentrations in the Central Delta

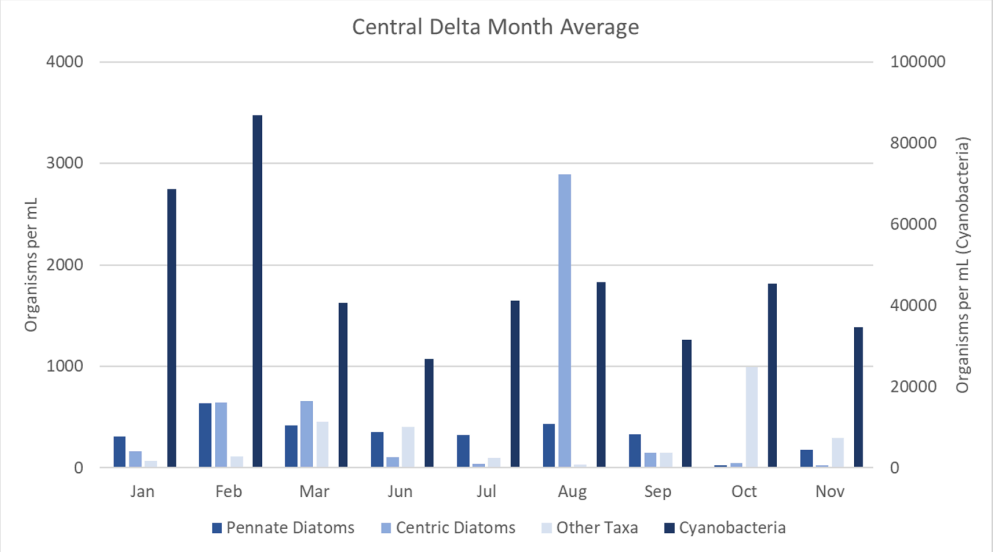

Figure 62: Average organism density in the Central Delta; other are chrysophytes, cryptophytes, and dinoflagellates

Confluence

Chlorophyll a average concentrations were highest during early spring and mid-summer (Figure 9). The highest concentration occurred at D12 in August (5.27 µg/L); the minimum was recorded at D22 in November (0.95 µg/L). The mean and median values were 2.53 µg/L and 2.12 µg/L, respectively. There was one sample below the detection limit at D10 in October.

Pheophytin a average concentrations were relatively consistent throughout the year except for a peak in September, which was the maximum for the year (Figure 9). The maximum concentration was recorded at D22 in September (5.20 µg/L) and the minimum at the same station in January

(0.51 µg/L) (Figure 9). The mean and median for this region were 1.47 µg/L and 1.24 µg/L, respectively. There were two samples below the detection limit at D10 in August and D22 in February.

Phytoplankton average densities were higher in winter and early spring; the peak of “other taxa” in October was mainly cryptophytes and green algae (Figure 10; “other taxa” are chrysophytes, cryptophytes, euglenoids, and green algae). Cyanobacteria also dominated throughout the year.

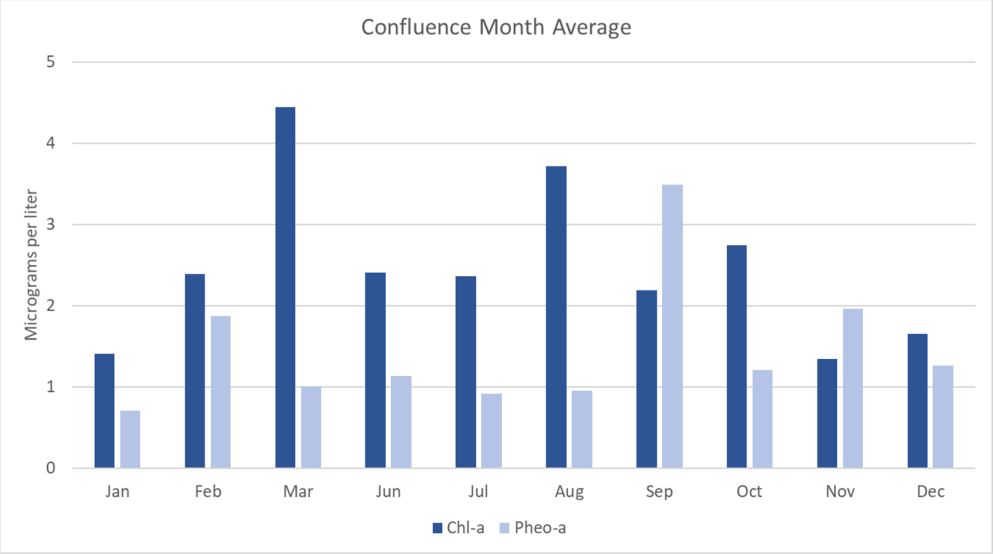

Figure 63: Average chlorophyll a and pheophytin a concentrations in the Confluence

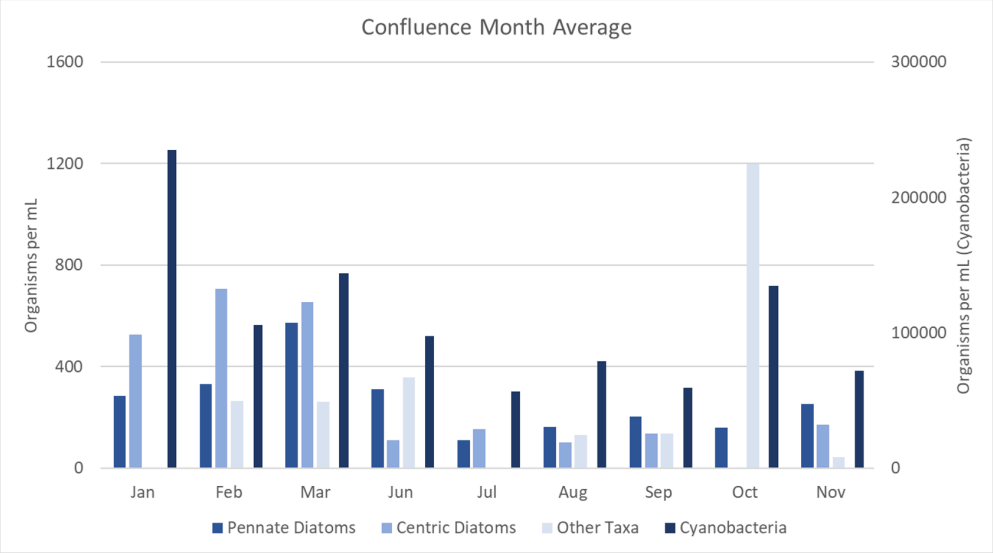

Figure 64: Average organism density in the Confluence; other are chrysophytes, cryptophytes, and dinoflagellates

Grizzly Bay and Suisun Bay

Chlorophyll a average concentrations in this region was relatively consistent throughout the year (Figure 11). The maximum was recorded at NZS42 in August (9.69 µg/L); the minimum was recorded at D7 in January (0.67 µg/L). The mean and median were 2.71 µg/L and 2.05 µg/L, respectively. There were two samples below the detection limit at D7 in August and NZS42 in September.

Pheophytin a average concentrations were relatively consistent throughout the year except for a peak in August, which was the maximum for the year (Figure 11). The maximum concentration was recorded at NZ032 in August (11.69 µg/L) and the minimum at D8 in July (0.56 µg/L). The mean and median were 1.39 µg/L and 1.00 µg/L, respectively. There were two samples below the detection limit at D7 in February and D8 in August.

Phytoplankton average densities were relatively higher early in the year, driven mostly by pennate diatoms, centric diatoms, and cyanobacteria (Figure 12; “other taxa” are cryptophytes, dinoflagellates, euglenoids, green algae, and haptophytes). The peak of “other taxa” in October was driven mainly by cryptophytes and green algae. Except for cyanobacteria, average densities were low compared to other regions (less than 1000 organisms per milliliter

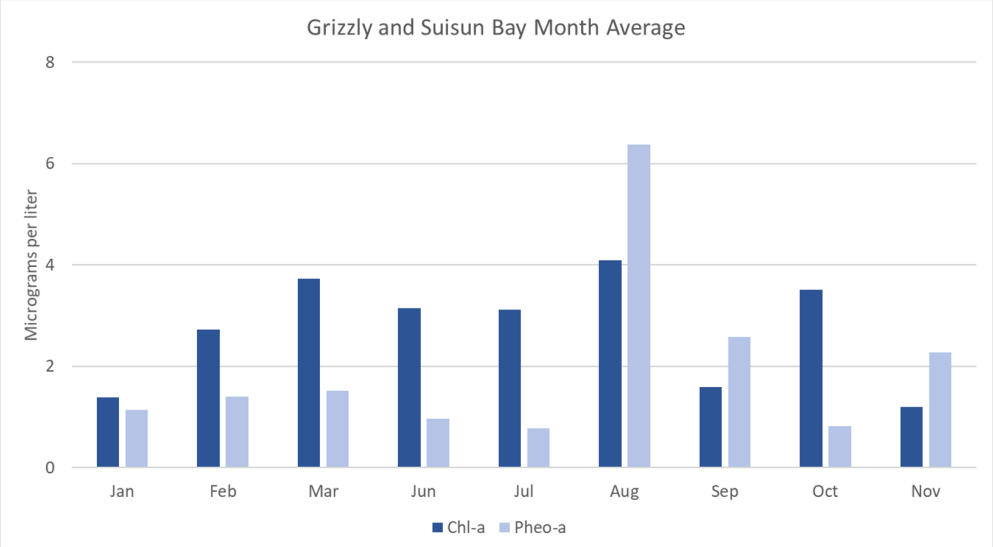

Figure 65: Average chlorophyll a and pheophytin a concentrations in the Grizzly/Suisun Bays

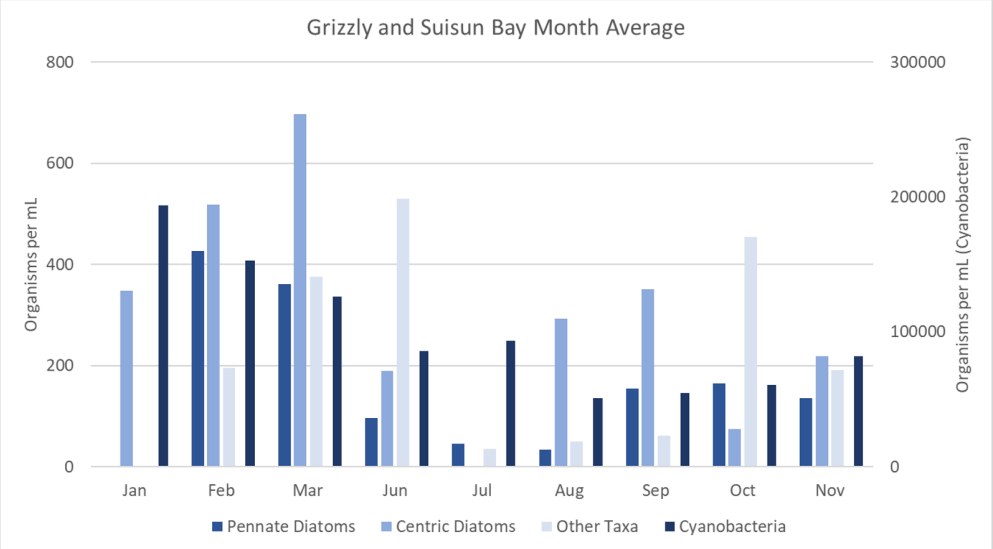

Figure 66: Average organism density in the Grizzly/Suisun Bays; other are chrysophytes, cryptophytes, and dinoflagellates

San Pablo Bay

Chlorophyll a average concentrations were slightly higher in summer and early fall (Figure 13). The maximum was recorded at D41A in September (8.93 µg/L); the minimum concentration was recorded at NZ325 in March, one of two minimums recorded for the year (0.53 µg/L). The mean and median were 2.02 µg/L and 1.71 µg/L, respectively. There were three samples below the detection limit: D6 and NZ325 in August, and NZ002 in November.

Pheophytin a average concentrations were lower in the first half of the year, and higher in the second half (Figure 13). The maximum was recorded at D41A in October (7.72 µg/L) and the minimum at both NZ002 and NZ004 in February, which were the lowest values for the year and also the detection limit (0.50 µg/L). The mean and median were 1.76 µg/L and 0.99 µg/L, respectively. There were nine samples below the detection limit: D41, D41A, and NZ325 in January; D41 and NZ325 in February; NZ325 in March; NZ004 in June and July; and NZ325 in October.

There were peaks of cyanobacteria in January and October; most of the phytoplankton average densities were lower for the rest of the year (Figure 14; “other taxa” are cryptophytes, euglenoids, green algae, and haptophytes). The peak of “other taxa” in June was driven by cryptophytes and green algae.

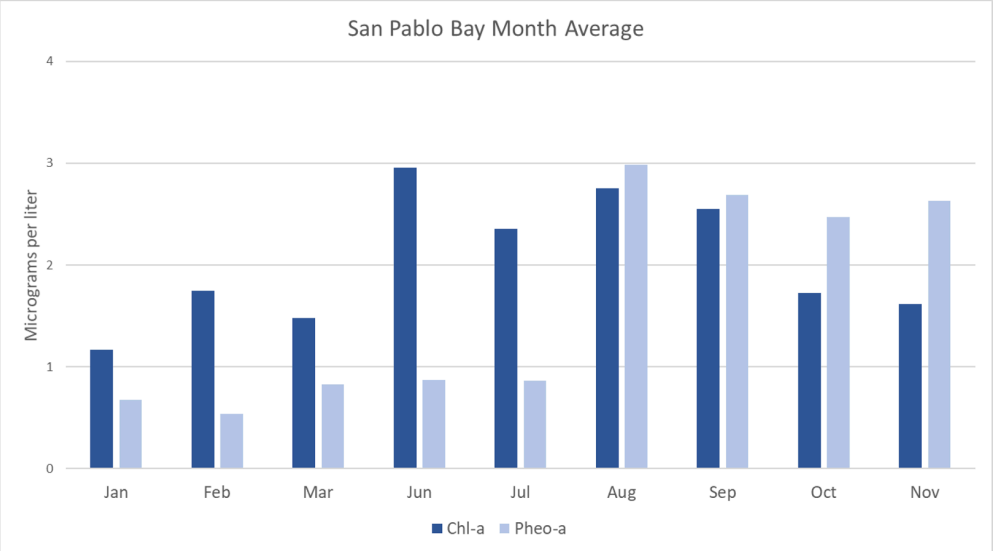

Figure 67: Average chlorophyll a and pheophytin a concentrations in the San Pablo Bay

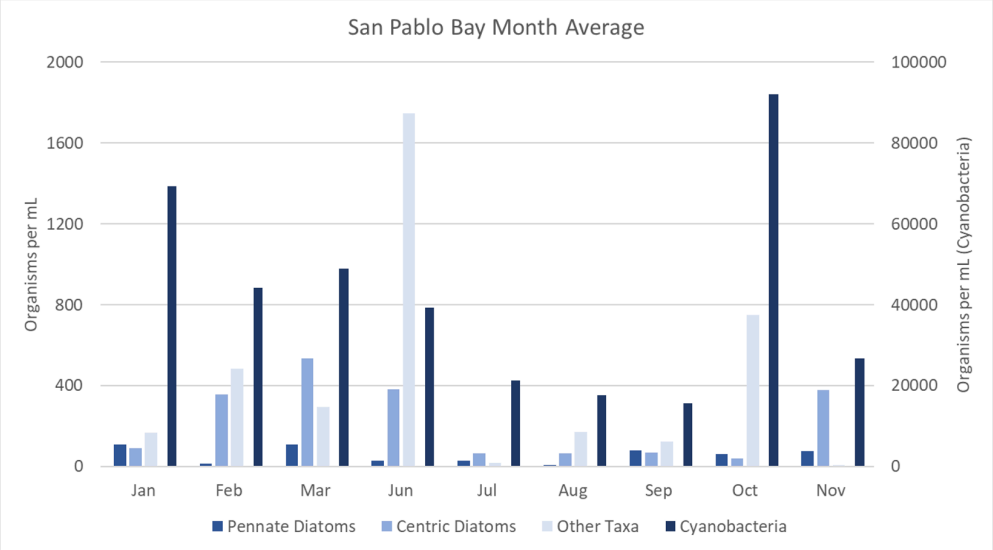

Figure 68: Average organism density in the San Pablo Bay; other are chrysophytes, cryptophytes, and dinoflagellates

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