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 2022.

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).

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 physio-chemical data (APHA 2012).

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:

$$organisms/mL = CA_c\frac{V}{A_f}F$$

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 $cV = A_c\frac{V}{A_f}F$ 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.

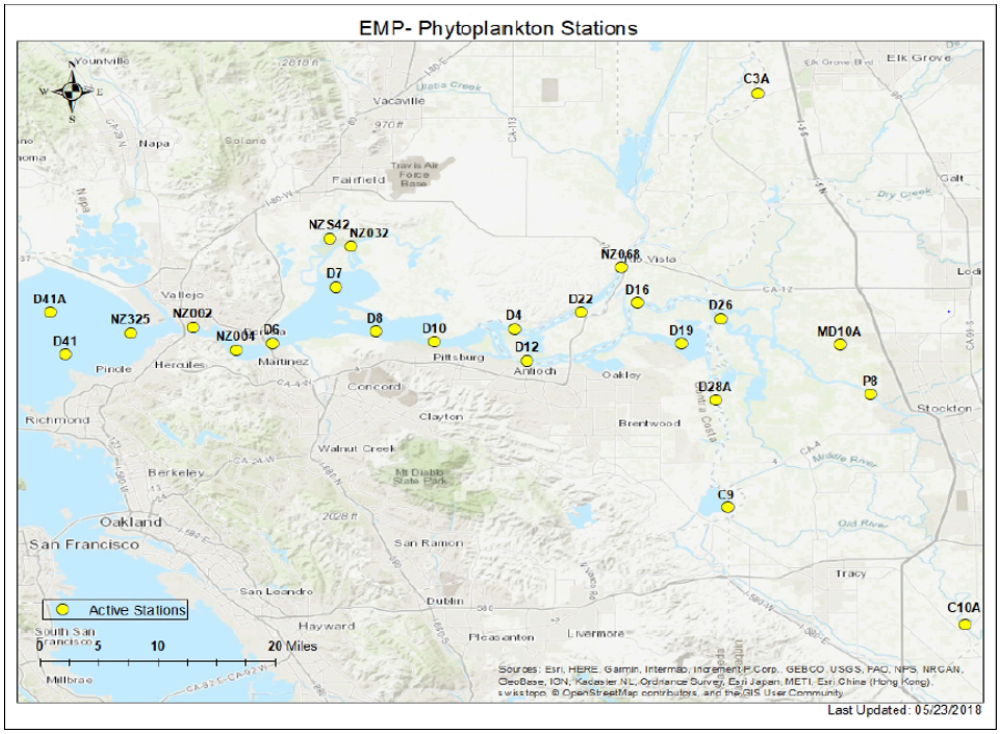

Figure 1: Map of phytoplankton stations sampled by the Environmental Monitoring Program

Table 1: Table 2: 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

Table 1: Stations included within each region of the Delta

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 2022 fell into these 10 algal groups:

- Chrysophytes
- Cryptophytes
- Cyanobacteria
- Diatoms (Pennate and Centric)
- Dinoflagellates
- Euglenoids
- Green Algae
- Haptophytes
- Raphidophytes

The 10 most common genera collected in 2022 were, in order:

- Eucapsis (cyanobacteria)
- Cyclotella (centric diatoms)
- Plagioselmis (cryptophytes)
- Nitzschia (pennate diatoms)
- Chlorella (green algae)
- Cocconeis (cyanobacteria)
- Teleaulax (centric diatoms)

• Cryptomonas (cryptophytes)
• Monoraphidium (pennate diatoms)
• Navicula (green algae)

Of the 10 groups identified, cryptophytes, cyanobacteria, diatoms, and green algae constituted the vast majority (97.7%) of the organisms collected.

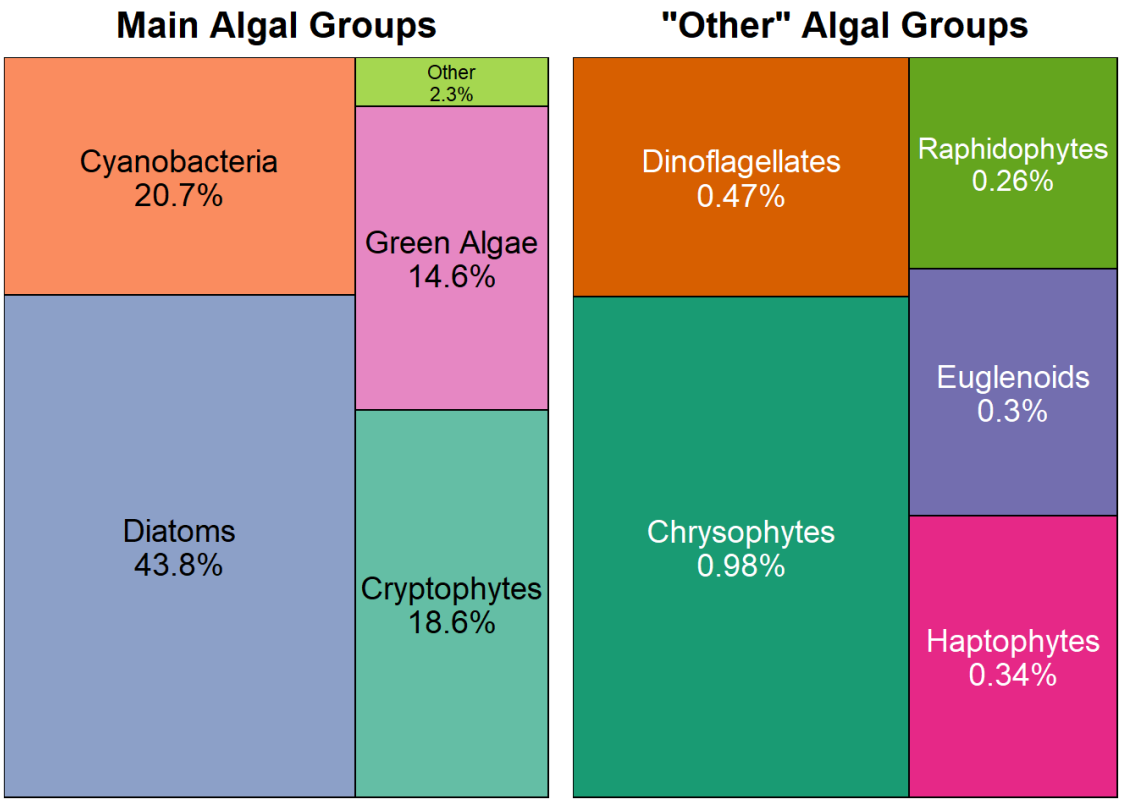

Figure 2: Phytoplankton composition by algal group

Pigment Concentrations

Of the 329 samples taken in 2022, 97.9% (320 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 7 samples with chlorophyll a concentrations equal to or above 10 µg/L, one occurred at NZ325 in April; three occurred in August (NZ002, NZ004, and NZ325); one occurred at NZ325 in February; one occurred at D10 in March; and one occurred at D41A in May.

The median chlorophyll a concentration for all samples in 2022 was 2.08 µg/L; this is lower than in 2021 (median = 2.37 µg/L). The maximum concentration was 49.8 µg/L (recorded at NZ325 in August); this is higher than in 2021 (max = 25.51 µg/L). The minimum concentration was < 0.5

µg/L (the reporting limit); this is identical to 2021 (min = < 0.5 µg/L). 8 samples were below the reporting limit.

The median pheophytin a concentration for all samples in 2022 was 0.88 µg/L; this is lower than in 2021 (median = 1.04 µg/L). The maximum concentration was 6.47 µg/L (recorded at NZS42 in April); this is lower than in 2021 (max = 11.08 µg/L). The minimum concentration was < 0.5 µg/L (the reporting limit); this is identical to 2021 (min = < 0.5 µg/L). 64 samples were below the reporting limit.

Northern Interior Delta

Chlorophyll a average concentrations were higher in summer and lower the rest of the year (Figure 3). The median chlorophyll a concentration for the Northern Interior Delta in 2022 was 1.15 µg/L. The maximum concentration was 3.06 µg/L (recorded at NZ068 in August). The minimum concentration was 0.53 µg/L (recorded at C3A in November). 0 samples were below the reporting limit.

Pheophytin a average concentrations were low throughout most of the year (below 1.5 µg/L) and lower than chlorophyll a except for January and February (Figure 3). The median pheophytin a concentration for the Northern Interior Delta in 2022 was 0.52 µg/L. The maximum concentration was 2.94 µg/L (recorded at C3A in January). The minimum concentration was < 0.5 µg/L (the reporting limit). 11 samples were below the reporting limit.

Phytoplankton average densities were highest in spring and summer, with cyanobacteria dominating throughout the year (Figure 4; "other" are cryptophytes, dinoflagellates, euglenoids, and green algae). There was a peak of cryptophytes in October. There was a small peak of diatoms in December.

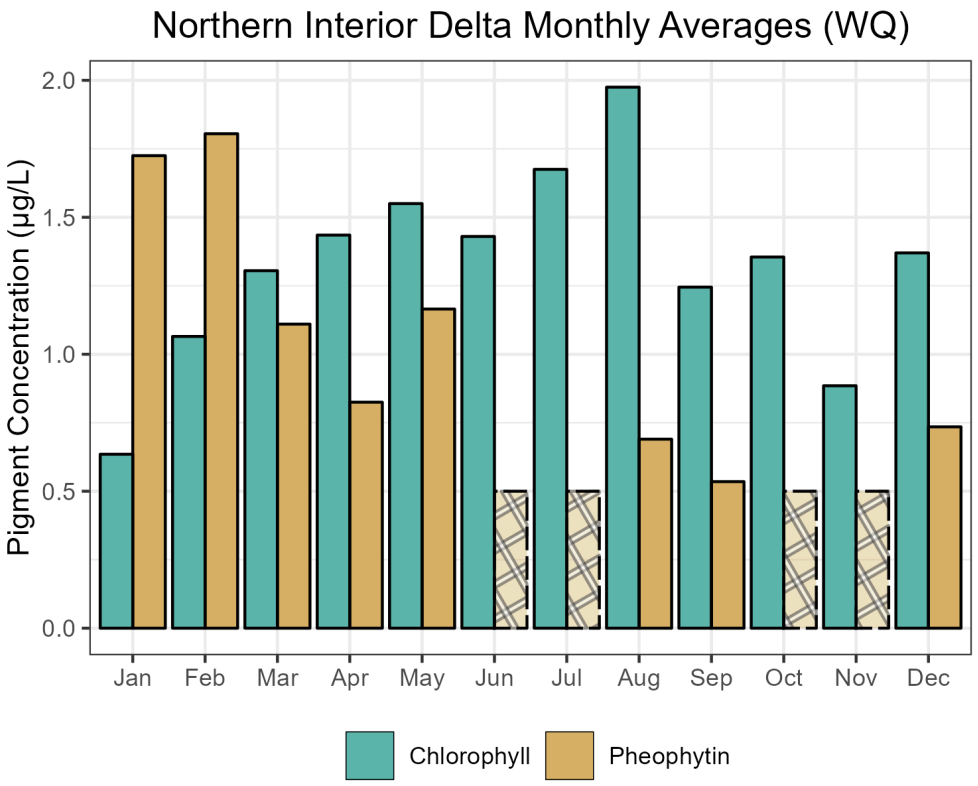

Figure 3: Average chlorophyll a and pheophytin a concentrations in the Northern Interior Delta. Patchwork columns indicate median was below the reporting limit

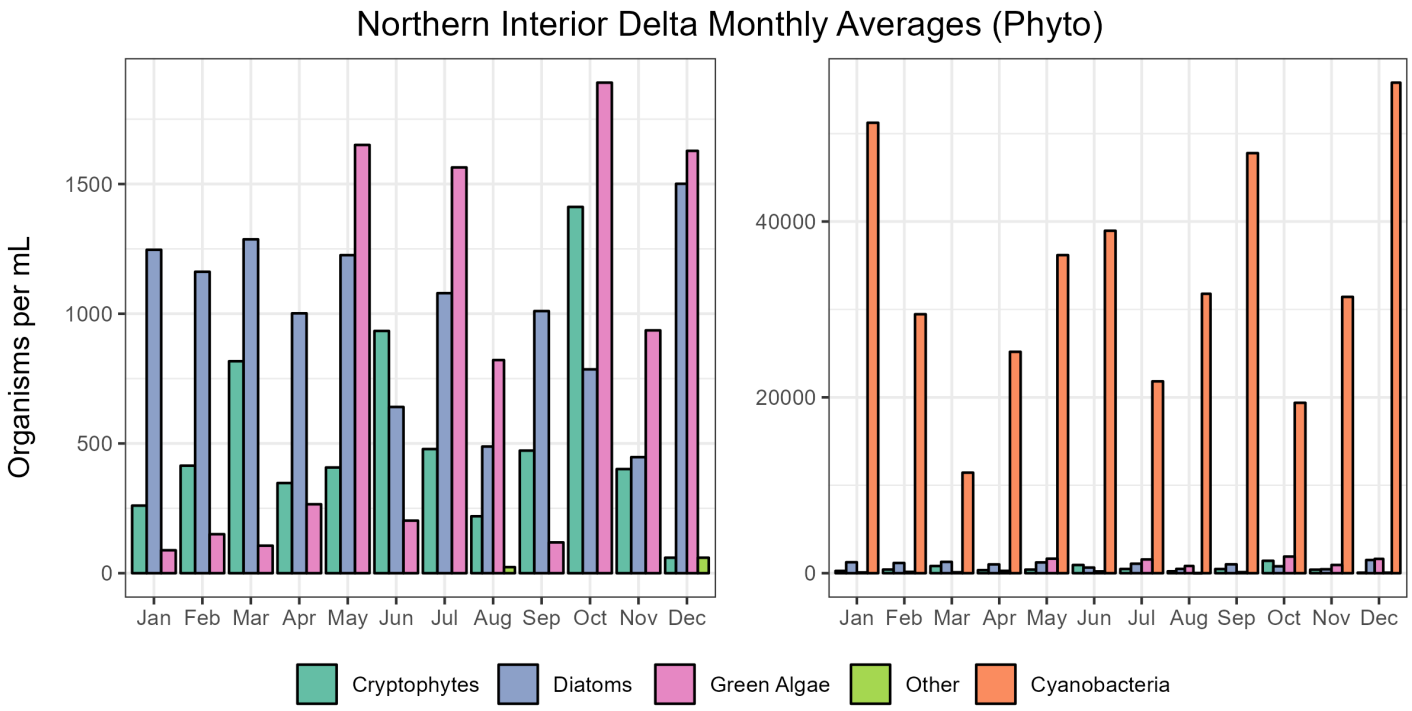

Figure 4: Average organism density in the Northern Interior Delta

Southern Interior Delta

Chlorophyll a average concentrations were highest in summer, peaking around July (Figure 5). The median chlorophyll a concentration for the Southern Interior Delta in 2022 was 1.88 µg/L. The maximum concentration was 7.78 µg/L (recorded at C10A in August). The minimum concentration was < 0.5 µg/L (the reporting limit). 2 samples were below the reporting limit.

Pheophytin a average concentrations were fairly constant throughout the year, and below chlorophyll a, except for January and February (Figure 5). The median chlorophyll a concentration for the Southern Interior Delta in 2022 was 1.88 µg/L. The maximum concentration was 7.78 µg/L (recorded at C10A in August). The minimum concentration was < 0.5 µg/L (the reporting limit). 2 samples were below the reporting limit.

Phytoplankton average densities were highest in the summer (Figure 6; "other" are chrysophytes, cryptophytes, euglenoids, green algae, and haptophytes). Cyanobacteria dominated throughout the year and peaked in August; there was a peak of green algae in July.

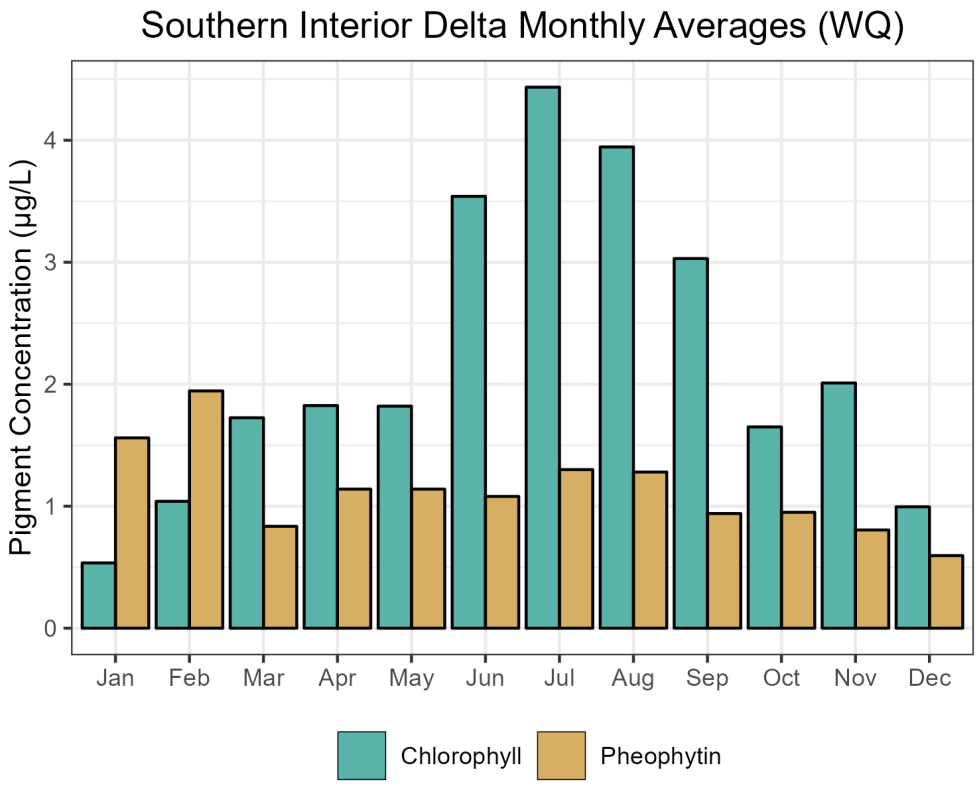

Figure 5: Average chlorophyll a and pheophytin a concentrations in the Southern Interior Delta. Patchwork columns indicate median was below the reporting limit

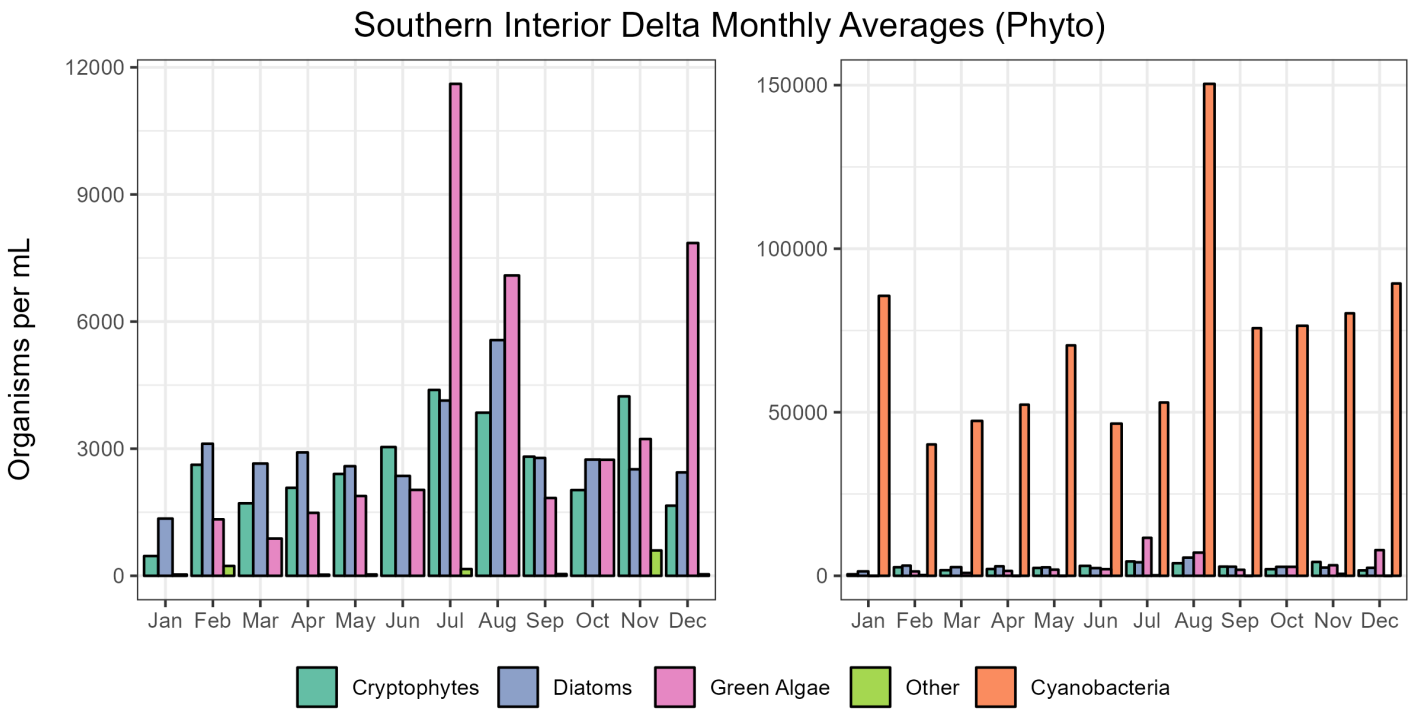

Figure 6: Average organism density in the Southern Interior Delta

Central Delta

Chlorophyll a average concentrations were fairly consistent throughout the year, with the lowest levels in the winter (Figure 7). The median chlorophyll a concentration for the Central Delta in 2022 was 1.79 µg/L. The maximum concentration was 9.21 µg/L (recorded at D19 in April). The minimum concentration was < 0.5 µg/L (the reporting limit). 4 samples were below the reporting limit.

Pheophytin a average concentrations were lower than chlorophyll a for all months except January and Feburary (Figure 7). The median pheophytin a concentration for the Central Delta in 2022 was 1.17 µg/L. The maximum concentration was 2.82 µg/L (recorded at D28A in February). The minimum concentration was < 0.5 µg/L (the reporting limit). 5 samples were below the reporting limit.

Phytoplankton densities highly varied throughout the year (Figure 8; "other" are chrysophytes, cryptophytes, green algae, and haptophytes).

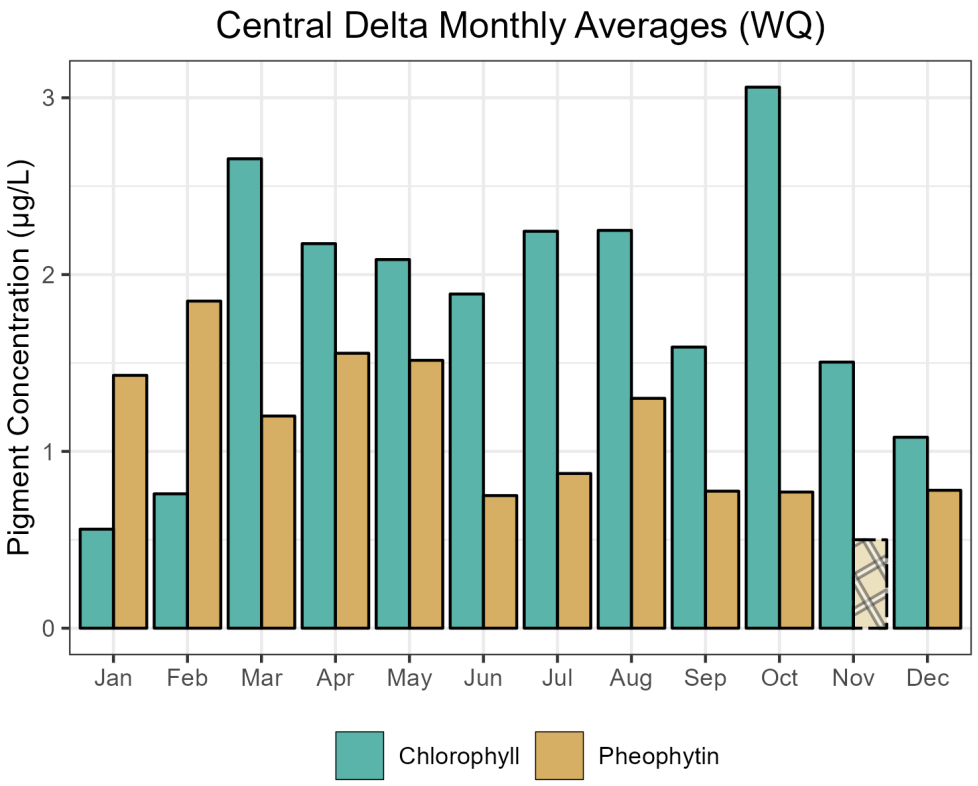

Figure 7: Average chlorophyll a and pheophytin a concentrations in the Central Delta. Patchwork columns indicate median was below the reporting limit

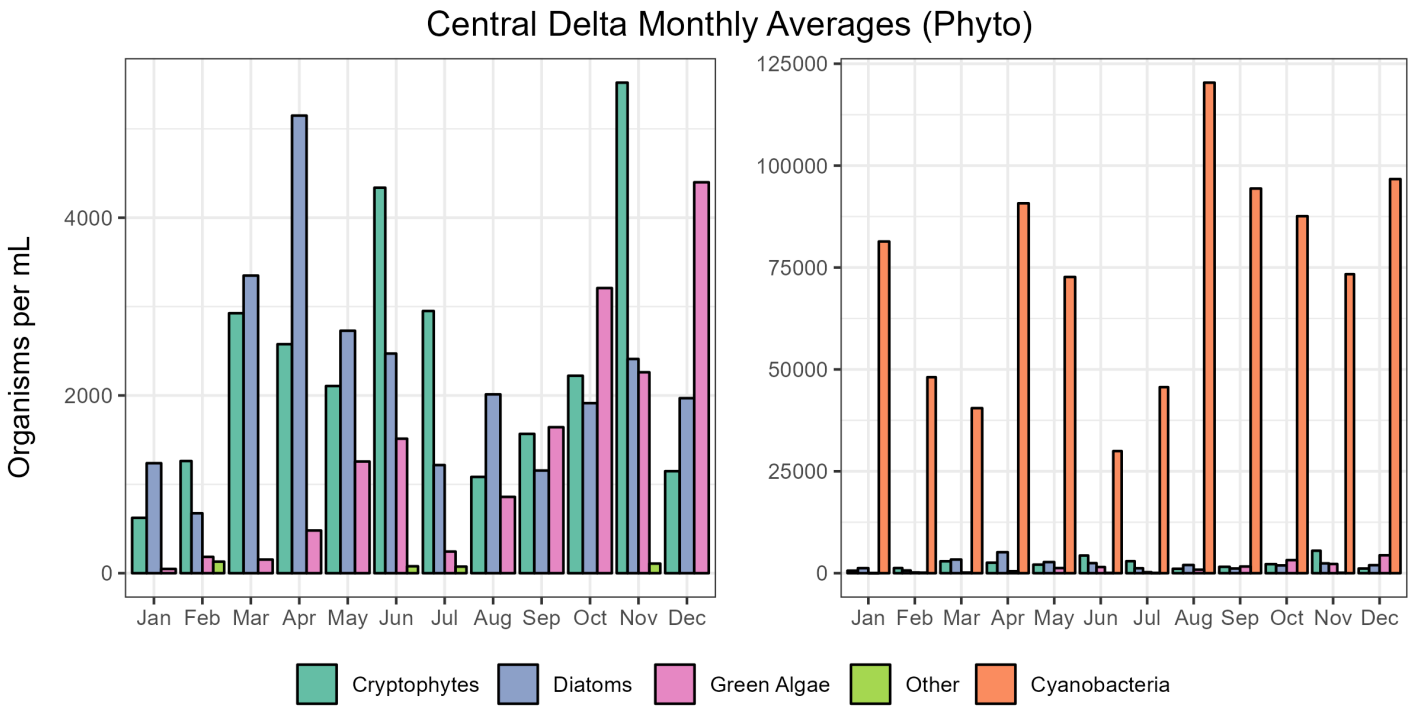

Figure 8: Average organism density in the Central Delta

Confluence

Chlorophyll a average concentrations were highest during early spring (Figure 9). The median chlorophyll a concentration for the Confluence in 2022 was 2.02 µg/L. The maximum concentration was 11.5 µg/L (recorded at D10 in March). The minimum concentration was 0.54 µg/L (recorded at D4 in January). 0 samples were below the reporting limit.

Pheophytin a average concentrations were higher than chlorophyll a concentrations in January and February. They peaked in April (Figure 9). The median pheophytin a concentration for the Confluence in 2022 was 0.84 µg/L. The maximum concentration was 2.95 µg/L (recorded at D12 in February). The minimum concentration was < 0.5 µg/L (the reporting limit). 11 samples were below the reporting limit.

Phytoplankton average densities were highest in December (Figure 10; "other" are chrysophytes, cryptophytes, euglenoids, and green algae). There was a large green algae peak in December.

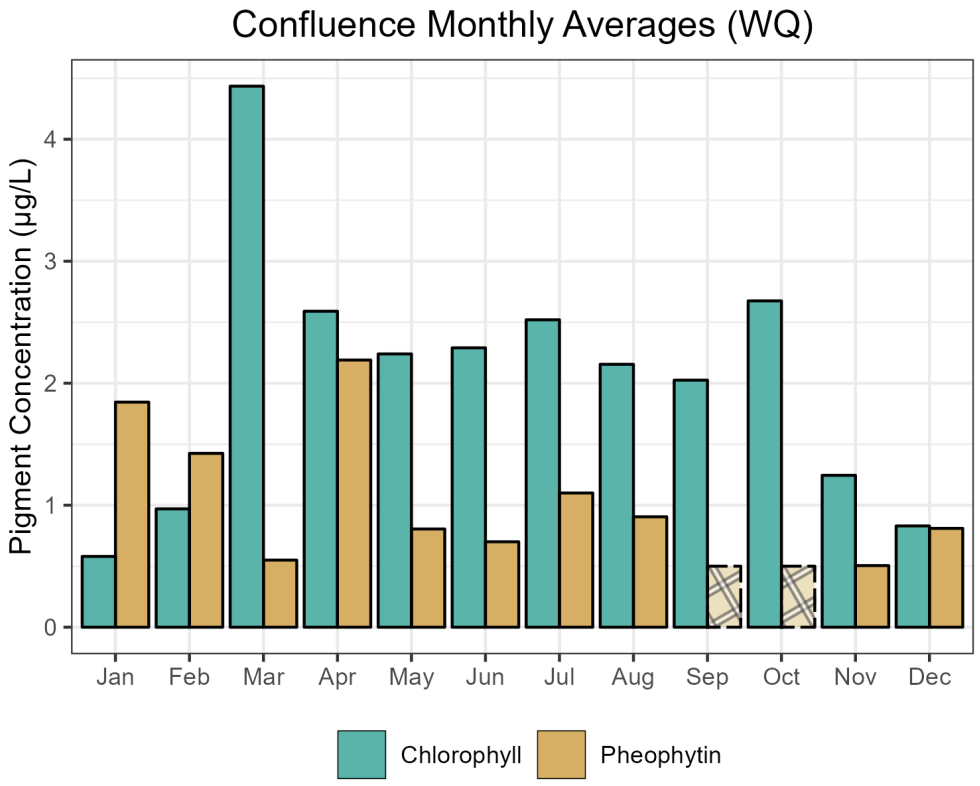

Figure 9: Average chlorophyll a and pheophytin a concentrations in the Confluence. Patchwork columns indicate median was below the reporting limit

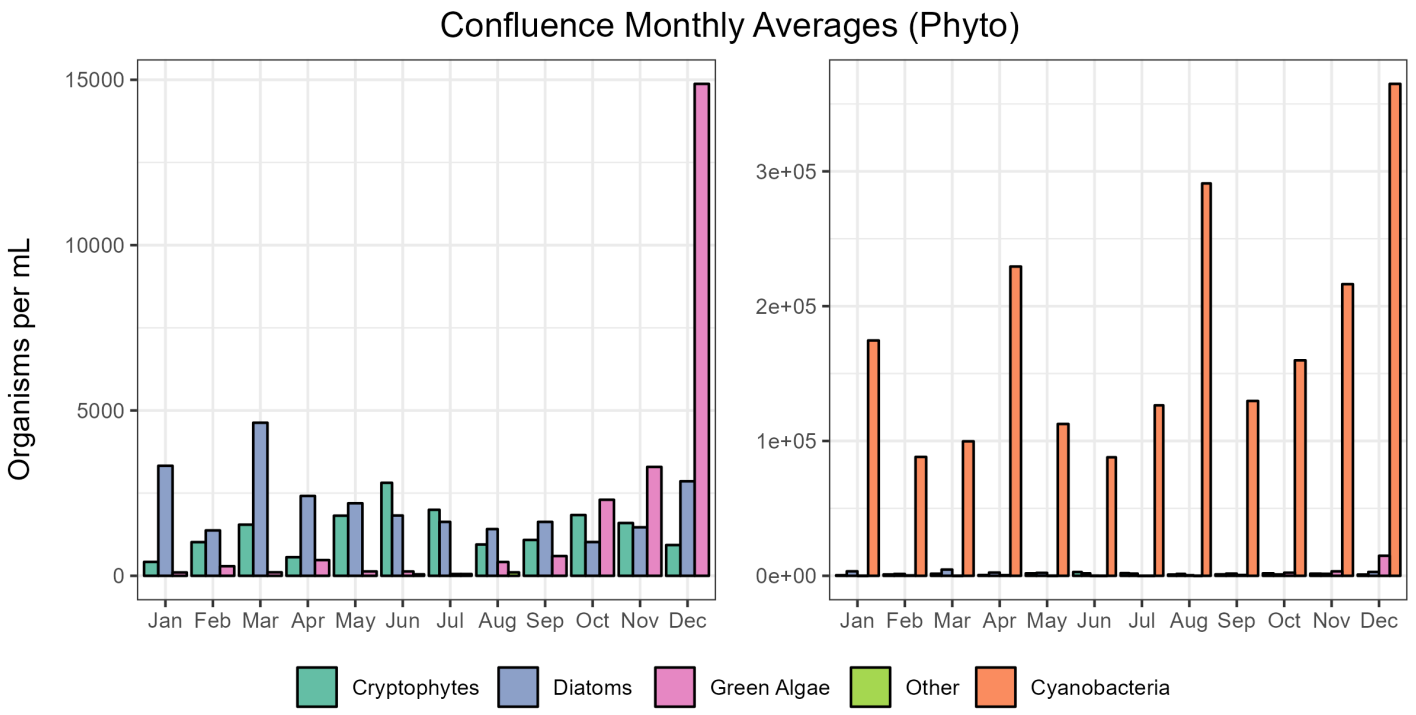

Figure 10: Average organism density in the Confluence

Grizzly Bay and Suisun Bay

Chlorophyll a average concentrations in this region had peaks in February, March, and June (Figure 11). The median chlorophyll a concentration for the Suisun & Grizzly Bays in 2022 was 2.35 µg/L. The maximum concentration was 9.54 µg/L (recorded at NZ032 in June). The minimum concentration was < 0.5 µg/L (recorded at D8 in January). 1 samples were below the reporting limit.

Pheophytin a average concentrations were slightly higher in the late winter and early spring months. It was lower than chlorophyll a with the exception of January (Figure 11). The median pheophytin a concentration for the Suisun & Grizzly Bays in 2022 was 1.07 µg/L. The maximum concentration was 6.47 µg/L (recorded at NZS42 in April). The minimum concentration was < 0.5 µg/L (the reporting limit). 8 samples were below the reporting limit.

Phytoplankton community compositions varied widely throughout the year; February for this region was the one of only two time/place combinations where other taxa were significantly present (Figure 12; "other" are cryptophytes, dinoflagellates, euglenoids, green algae, and haptophytes). There was a large green algae peak in December.

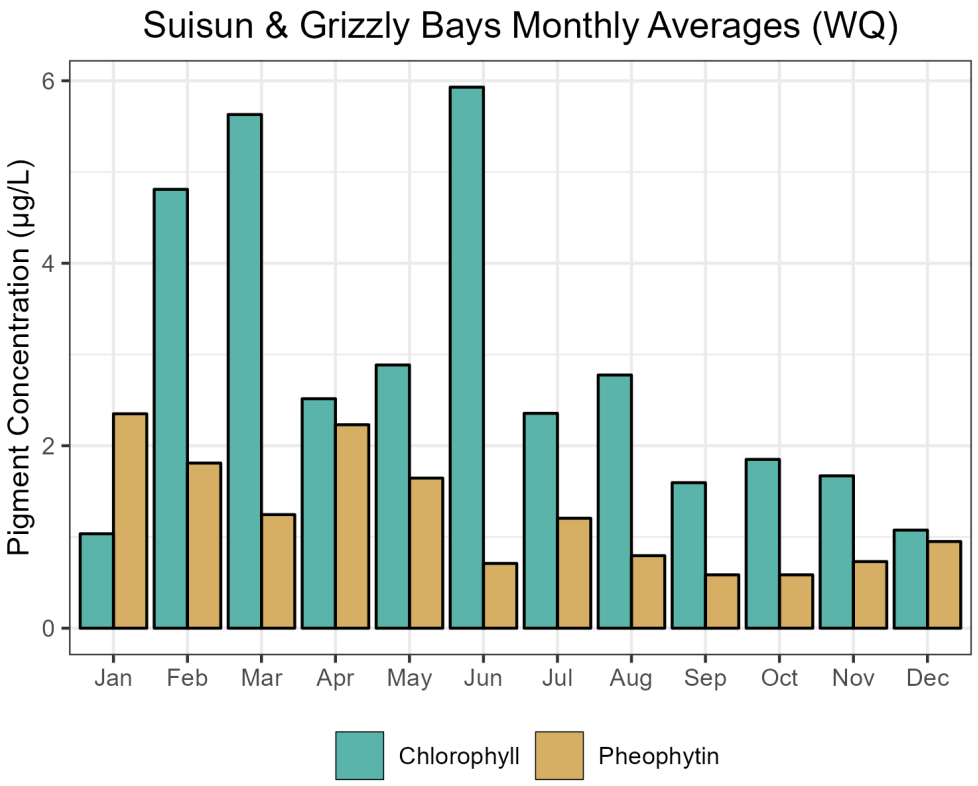

Figure 11: Average chlorophyll a and pheophytin a concentrations in the Grizzly & Suisun Bays. Patchwork columns indicate median was below the reporting limit

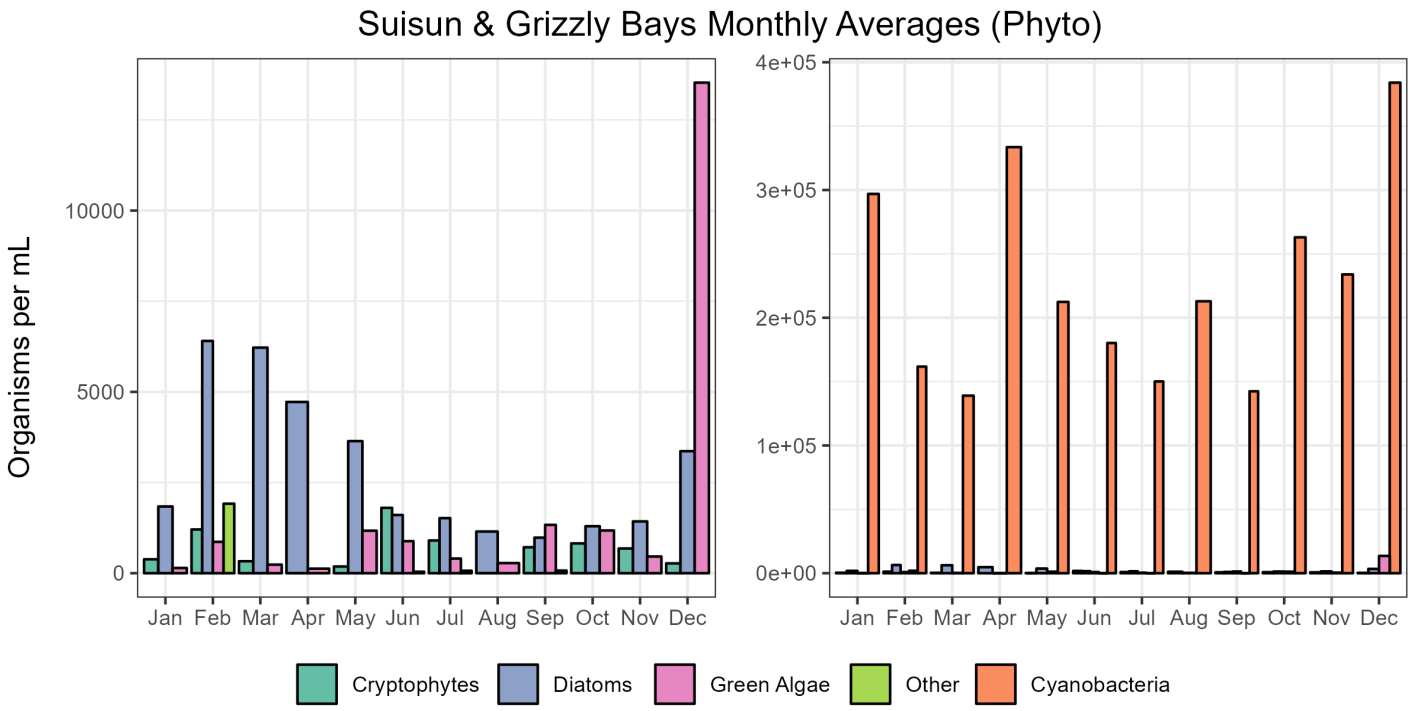

Figure 12: Average organism density in the Grizzly & Suisun Bays.

San Pablo Bay

Chlorophyll a average concentrations were highest in spring and summer (Figure 13). The median chlorophyll a concentration for the San Pablo Bay in 2022 was 2.79 µg/L. The maximum concentration was 49.8 µg/L (recorded at NZ325 in August). The minimum concentration was < 0.5 µg/L (recorded at D41A in January). 1 samples were below the reporting limit.

Pheophytin a average concentrations were highest in July and December; values were low the rest of the year (Figure 13). The median pheophytin a concentration for the San Pablo Bay in 2022 was 0.62 µg/L. The maximum concentration was 5.72 µg/L (recorded at NZ325 in February). The minimum concentration was < 0.5 µg/L (the reporting limit). 21 samples were below the reporting limit.

Phytoplankton community composition varied widely throughout the year; August in the this region was one of only two time/place combinations where other taxa were present, dominating all others except for cyanobacteria (Figure 14; "other" are chrysophytes, cryptophytes, dinoflagellates, euglenoids, green algae, haptophytes, and raphidophytes).

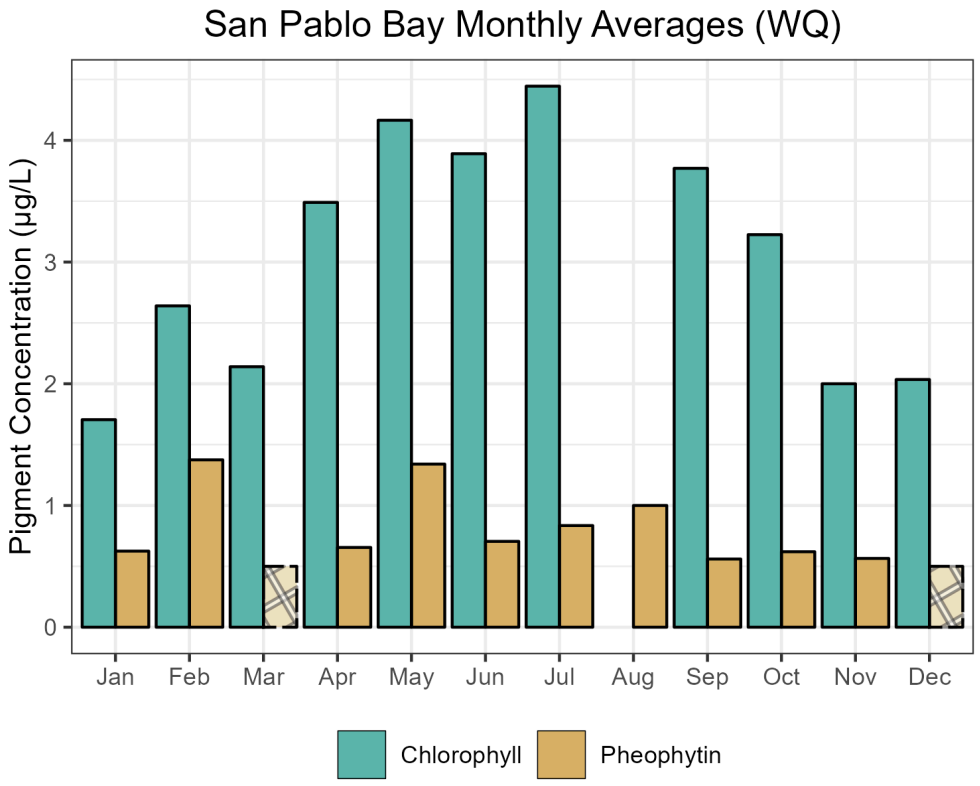

Figure 13: Average chlorophyll a and pheophytin a concentrations in the San Pablo Bay. Patchwork columns indicate median was below the reporting limit

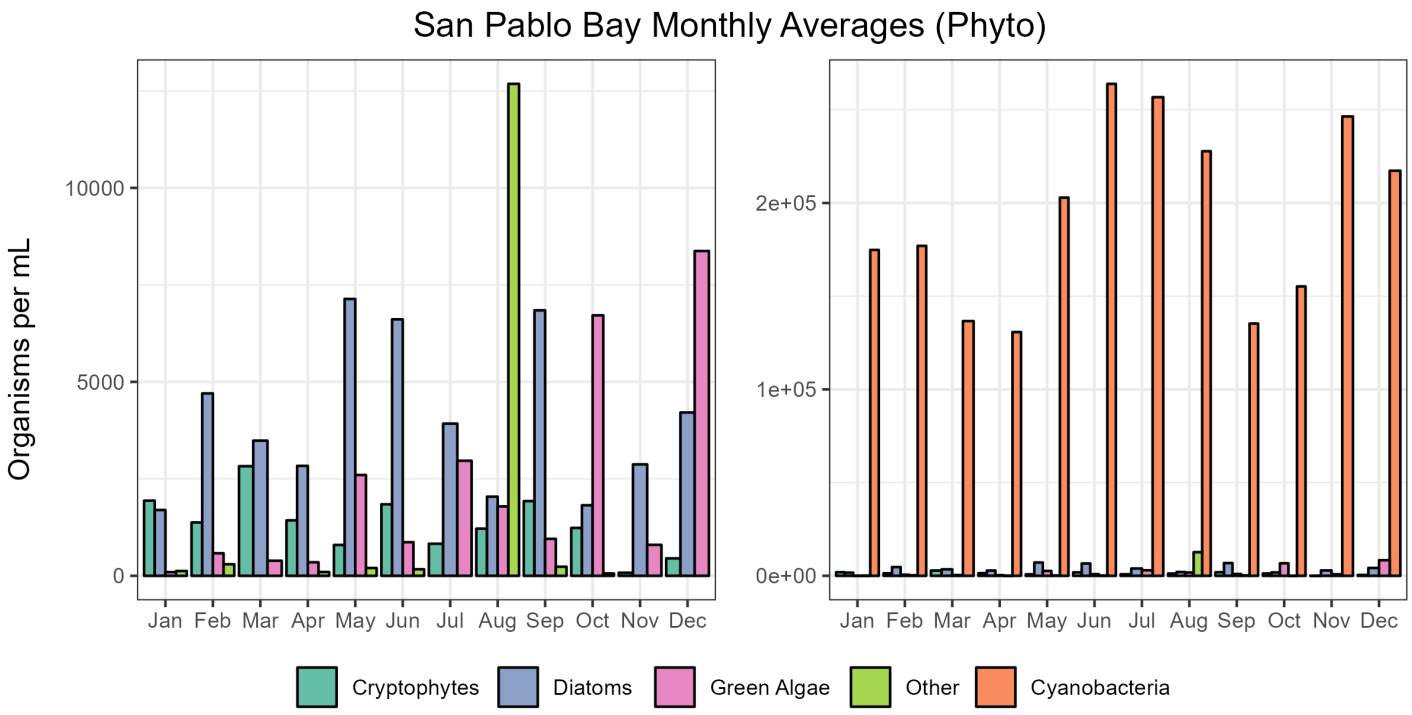

Figure 14: Average organism density in the San Pablo Bay

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