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 2021.

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). Sampling occurred from March through December; sampling for January and February were cancelled because of the COVID pandemic. 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.

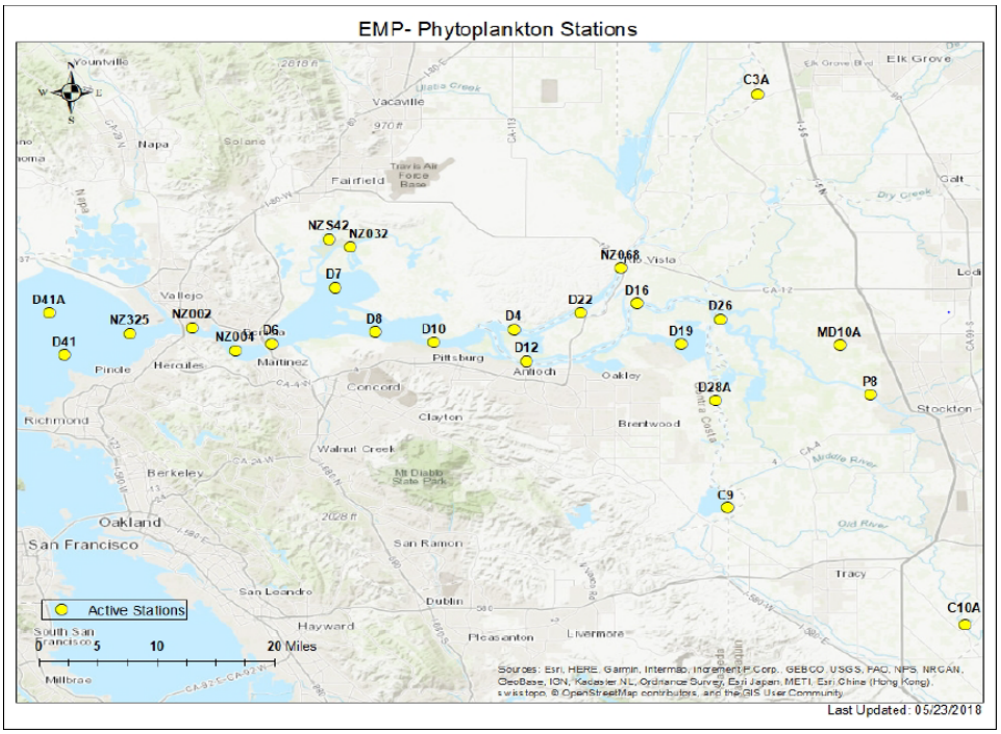

Figure 53: Map of phytoplankton stations sampled by the Environmental Monitoring Program

Table 8: 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. Sampling occurred from March through December; sampling for January and February were cancelled because of the COVID pandemic. 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 2021 fell into these nine algal groups:

- Diatoms (pennate and centric)
- Chrysophytes
- Synurophytes
- Cyanobacteria
- Cryptophytes
- Dinoflagellates
- Euglenoids
- Haptophytes
- Green Algae

The 10 most common genera collected in 2020 were, in order:

- Eucapsis (cyanobacterium)
- Plagioselmis (cryptophyte)
- Cyclotella (centric diatom)
- Microcystis (cyanobacterium)

• Chlorella (green alga)

• Aulacoseira (centric diatom)

• Cryptomonas (cryptophyte)

• Cocconeis (pennate diatom)

• Dolichospermum (cyanobacterium)

• Drepanochloris (green alga)

Of the nine groups identified, cyanobacteria, diatoms, and cryptophytes constituted the vast majority (99.3.%) of the organisms collected (Figure 2).

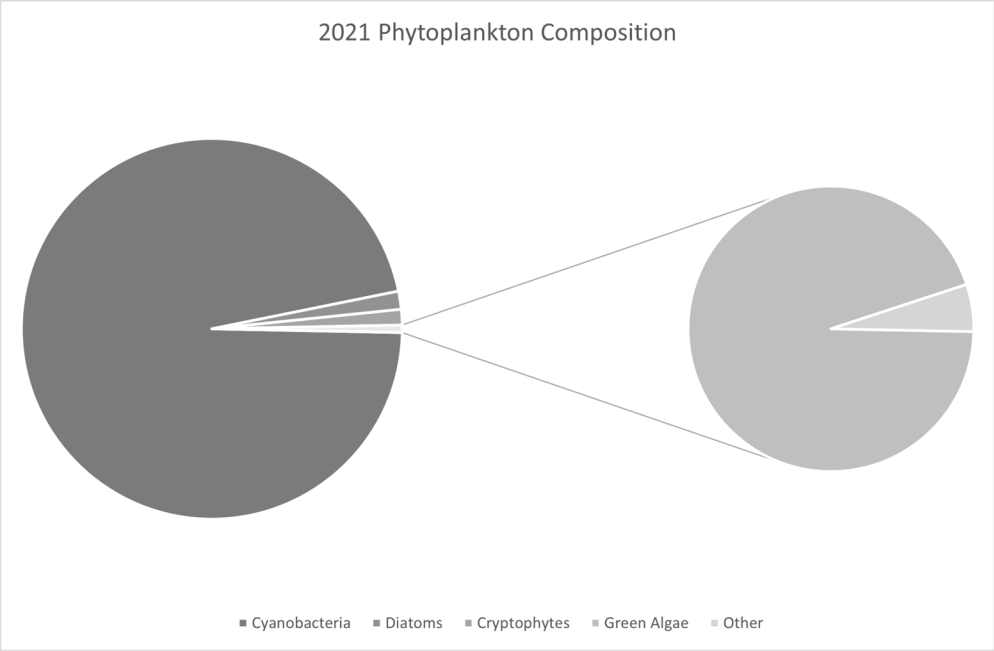

Figure 54: Phytoplankton composition by algal group (other are chrysophytes, ciliates, dinoflagellates, euglenoids, and haptophytes)

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 240 samples taken in 2021, 96.7% (232 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 8 samples with chlorophyll a concentrations equal to or above 10 µg/L, one occurred at C10A in March; three occurred in April (C10A, D22,and NZS42); one occurred in June (D41A); and three occurred in August (D19, D26, and D28A).

The mean chlorophyll a concentration for all samples in 2021 was 3.37 µg/L; the median value was 2.49 µg/L. Both values are higher than in 2020 (mean = 2.86 µg/L, median = 1.88 µg/L). The maximum chlorophyll a concentration in 2021 was 25.51 µg/L, recorded in March at C10A. This is lower than the 2020 maximum (32.50 µg/L). The minimum for 2021 chlorophyll a concentration was 0.51 µg/L, recorded at C3A in November. It was nearly identical to the 2020 value (0.53 µg/L). Nine chlorophyll a samples were below the reporting limit.

The mean pheophytin a concentration for all samples in 2021 was 1.49 µg/L, slightly lower than the 2020 value (1.65 µg/L). The median value was 1.17 µg/L, nearly identical to the 2020 value (1.16 µg/L). The maximum pheophytin a concentration was 11.08 µg/L, recorded at NZ032 in April. This value was slightly lower than in 2020 (11.69 µg/L). The minimum pheophytin a concentration was 0.50 µg/L, which is equivalent to the reporting limit; this was recorded at D41 in September. Thirty-four pheophytin a samples were below the reporting limit; they were observed at various stations throughout the year.

Northern Interior Delta

Chlorophyll a average concentrations were higher in early spring, and lower the rest of the year (Figure 3). The highest concentration was recorded at NZ068 in April (5.12 µg/L) and the lowest was recorded at C3A in November (0.51 µg/L). The mean and median values were 2.09 µg/L and 1.55 µg/L, respectively. There were three samples below the detection limit.

Pheophytin a average concentrations were low throughout the year (below 1.5 µg/L); values were generally lower than chlorophyll a (Figure 3). The maximum (2.12 µg/L) was recorded at NZ068 in December and the minimum (0.56 µg/L) was recorded at C3A in November. There were seven samples below the detection limit, occurring at both stations in the region throughout the year. The mean and median were 1.09 µg/L and 0.93 µg/L, respectively.

Phytoplankton average densities were highest in spring and summer, with cyanobacteria dominating throughout the year (Figure 4; “other” are euglenoids, haptophytes, and synurophytes). There was a peak of cryptophytes in March, with smaller peaks occurring again in July and August. There was a small peak of diatoms in November.

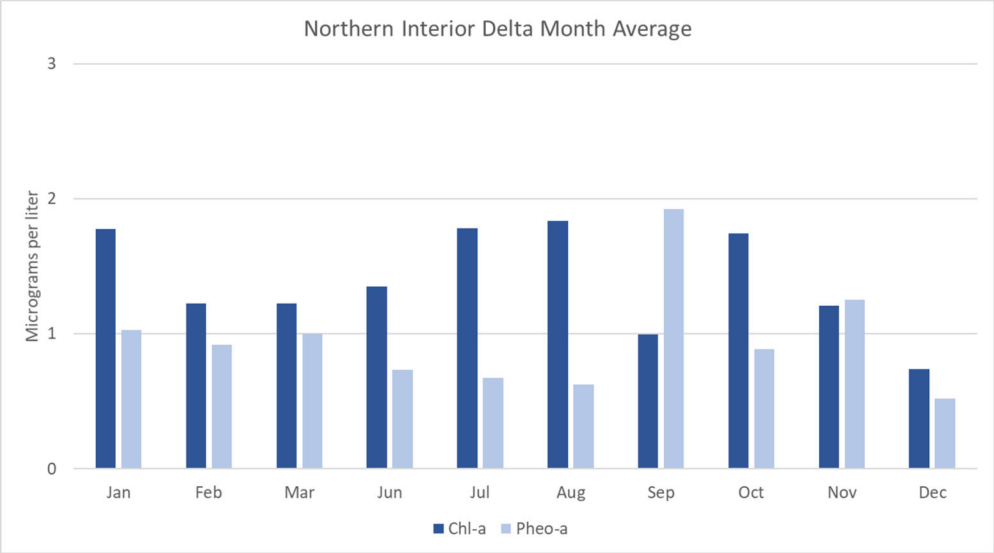

Figure 55: Average chlorophyll a and pheophytin a concentrations in the Northern Interior Delta

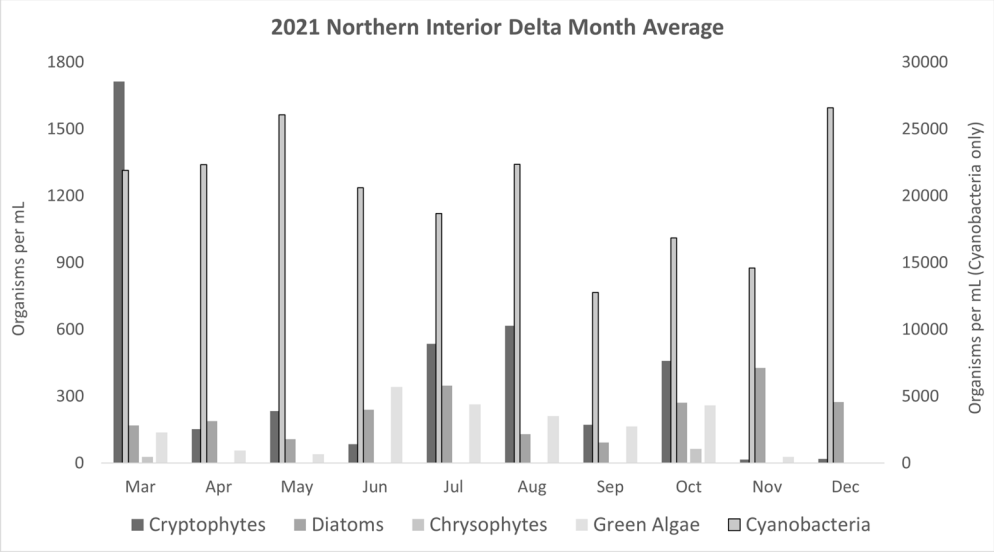

Figure 56: Average organism density in the Northern Interior Delta

Southern Interior Delta

Chlorophyll a average concentrations were highest in spring and summer (Figure 5). The maximum was recorded at C10A in March (25.51 µg/L), which also was the maximum for the year; the minimum was at MD10A in November (0.68 µg/L). The mean and median were 3.48 µg/L and 1.98 µg/L, respectively. There was one sample below the detection limit at C9 in December.

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 C9 in July (3.47 µg/L); the minimum occurred at P8 in October and C10A in August (0.57 µg/L). The mean and median values were 1.33 µg/L and 1.15 µg/L, respectively. Two samples in March and June at P8 were below the detection limit.

Phytoplankton average densities were highest in the spring and summer with the highest concentrations occurring in April and August (Figure 6; “other” are euglenoids, synurophytes, and haptophytes). Cyanobacteria dominated throughout the year; there was a peak of diatoms in April, and small peaks of cryptophytes in March and May.

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

Figure 58: Average organism density in the Southern Interior Delta; other are euglenoids, haptophytes, and synurophytes

Central Delta

Chlorophyll a average concentrations were low all year except for a large peak in August, which was the maximum for the year (Figure 7). The highest chlorophyll a concentration occurred at D28A in August (15.50 µg/L); the minimum occurred at the same station in November (0.72 µg/L).

The mean and median values were 3.54 µg/L and 2.21 µg/L, respectively. There were three samples below the detection limit, all occurring in fall or winter, at D16, D26, and D28A.

Pheophytin a average concentrations were similar in pattern to chlorophyll a; values were low all year except in August (Figure 7), when the highest concentration in the region was recorded (4.72 µg/L, station D28A). The minimum occurred at D19 in May (0.52 µg/L). The mean and median values were 1.39 µg/L and 1.18 µg/L, respectively. There was one sample below the detection limit at D16 in May.

With the exception of cyanobacteria, phytoplankton average densities were low all year except for a peak of diatoms in November (Figure 8; “other” are euglenoids, haptophytes, and synurophytes).

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

Figure 60: Average organism density in the Central Delta; other are euglenoids, haptophytes, and synurophytes

Confluence

Chlorophyll a average concentrations were highest during early spring and mid-summer (Figure 9). The highest concentration occurred at D22 in April (12.07 µg/L); the minimum was recorded at D4 in October (0.53 µg/L). The mean and median values were 3.07 µg/L and 2.27 µg/L, respectively. There were no samples below the detection limit.

Pheophytin a average concentrations were relatively consistent throughout the year and lower than chlorophyll a concentrations except for the last three months of the year (Figure 9). The maximum concentration was recorded at D10 in December (3.08 µg/L) and the minimum at D4 in June (0.57 µg/L) (Figure 9). The mean and median for this region were 1.58 µg/L and 1.26 µg/L, respectively. There was one sample below the detection limit at D10 in June.

Phytoplankton average densities were higher in spring; cyanobacteria were the most dominant, and a large peak of cryptophytes occurred in March (Figure 10; “other” are euglenoids, haptophytes, and synurophytes). There were large peaks of diatoms in April and December.

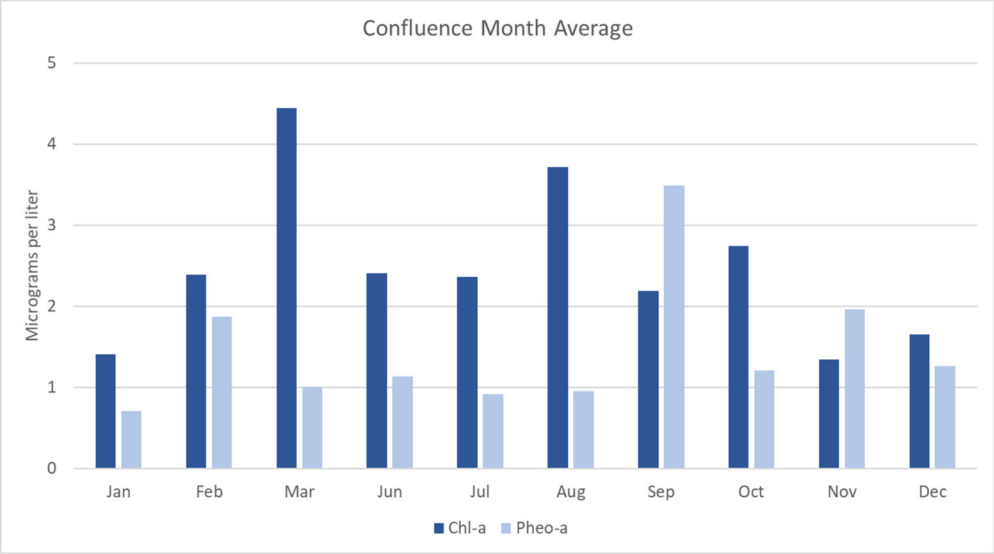

Figure 61: Average chlorophyll a and pheophytin a concentrations in the Confluence

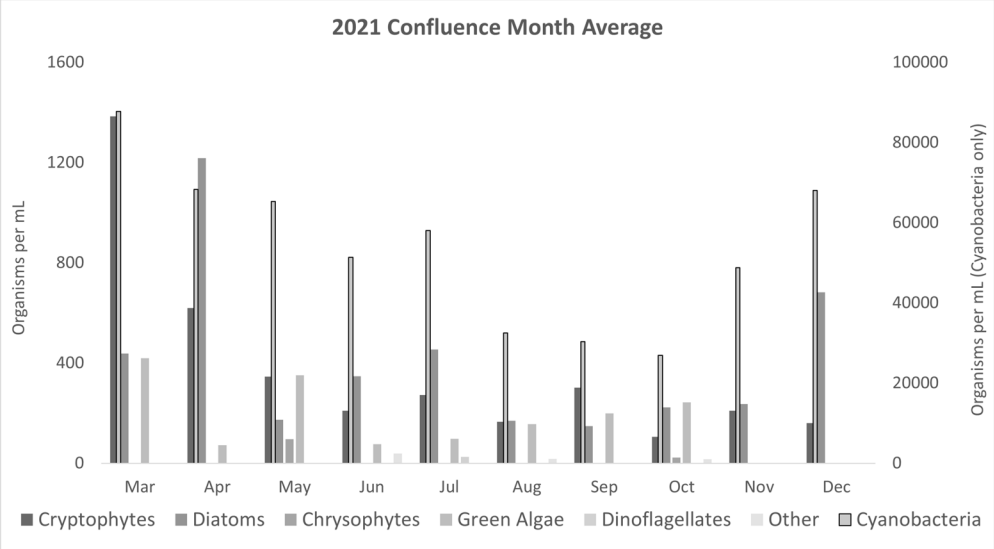

Figure 62: Average organism density in the Confluence; other are euglenoids, haptophytes, and synurophytes

Grizzly Bay and Suisun Bay

Chlorophyll a average concentrations in this region were highest in spring and summer, dropping sharply after August (Figure 11). The maximum was recorded at NZS42 in April (16.85 µg/L); the minimum was recorded at D8 in December (0.96 µg/L). The mean and median were 4.08 µg/L and 3.25 µg/L, respectively. There was one sample below the detection limit at NZ032 in December.

Pheophytin a average concentrations were relatively consistent throughout the year except for a peak in April, which was the maximum for the year (Figure 11). The maximum concentration was recorded at NZ032 in April (11.08 µg/L) and the minimum at D8 in March (0.51 µg/L). The mean and median were 1.87 µg/L and 1.32 µg/L, respectively. There were four samples below the detection limit: in March at D7 and NZ032 and in June at D8 and NZ032.

Phytoplankton average densities were highest in spring, with cyanobacteria dominating again (Figure 12; “other” are euglenoids, haptophytes, and synurophytes). There were peaks of cryptophytes and green algae in March, followed by a diatom peak in April.

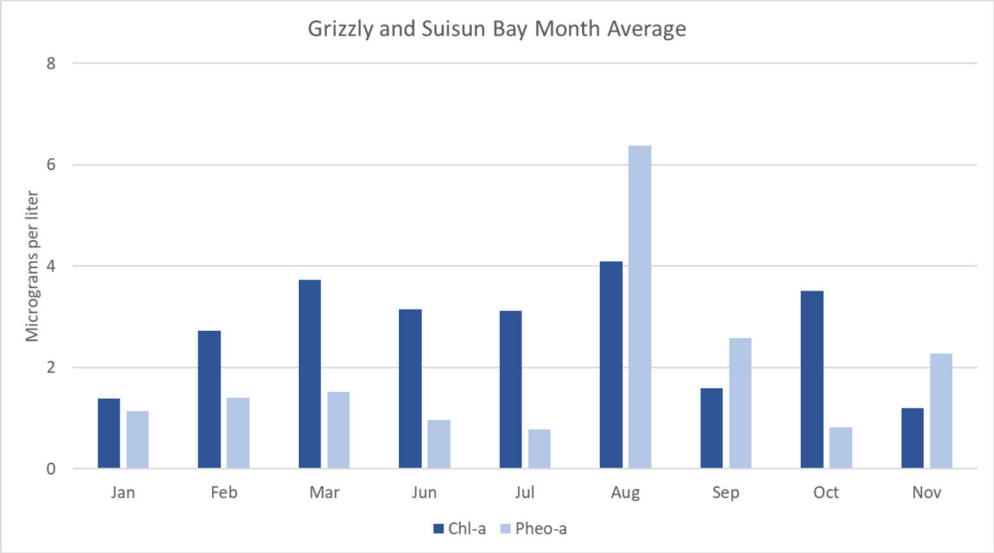

Figure 63: Average chlorophyll a and pheophytin a concentrations in the Grizzly/Suisun Bays

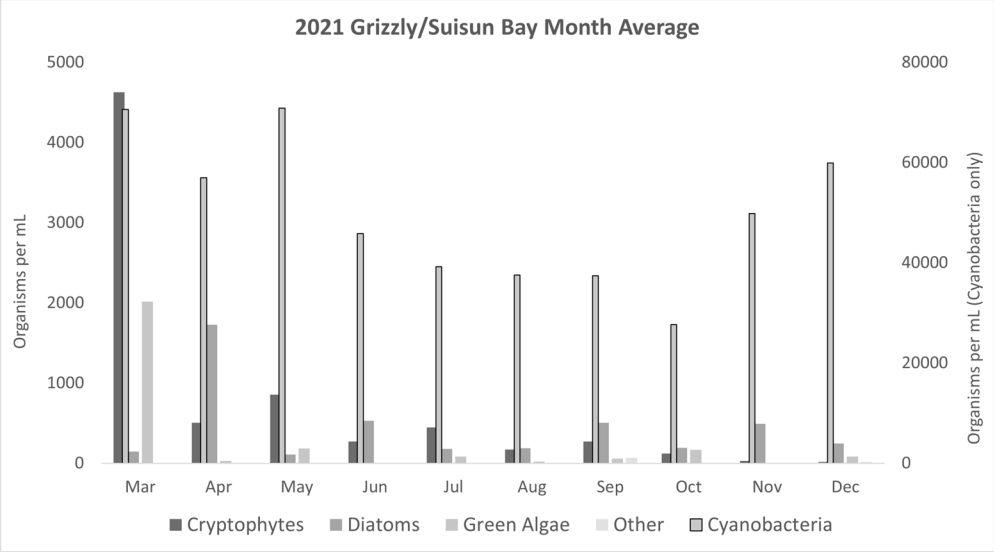

Figure 64: Average organism density in the Grizzly/Suisun Bays; other are euglenoids, haptophytes, and synurophytes

San Pablo Bay

Chlorophyll a average concentrations were highest in spring and summer (Figure 13). The maximum was recorded at D41A in June (13.00 µg/L); the minimum concentration was recorded at D41 in December (0.73 µg/L). The mean and median were 3.30 µg/L and 2.97 µg/L, respectively. There was one sample below the detection limit at NZ004 in September.

Pheophytin a average concentrations were highest in July and December; values were low the rest of the year (Figure 13). The maximum was recorded at D41A in July (7.59 µg/L) and the minimum at D41 in September, which was the lowest value for the year and also the detection limit (0.50 µg/L). The mean and median were 1.44 µg/L and 0.98 µg/L, respectively. This region

had the most samples below the detection limit at 19 total; all of the March samples were below the detection limit, with the remaining non-detects occurring in multiple months at multiple stations.

There were peaks of cyanobacteria throughout the year; cryptophyte peaks occurred in March and May, followed by diatom peaks in June and July (Figure 14; “other” are euglenoids, haptophytes, and synurophytes).

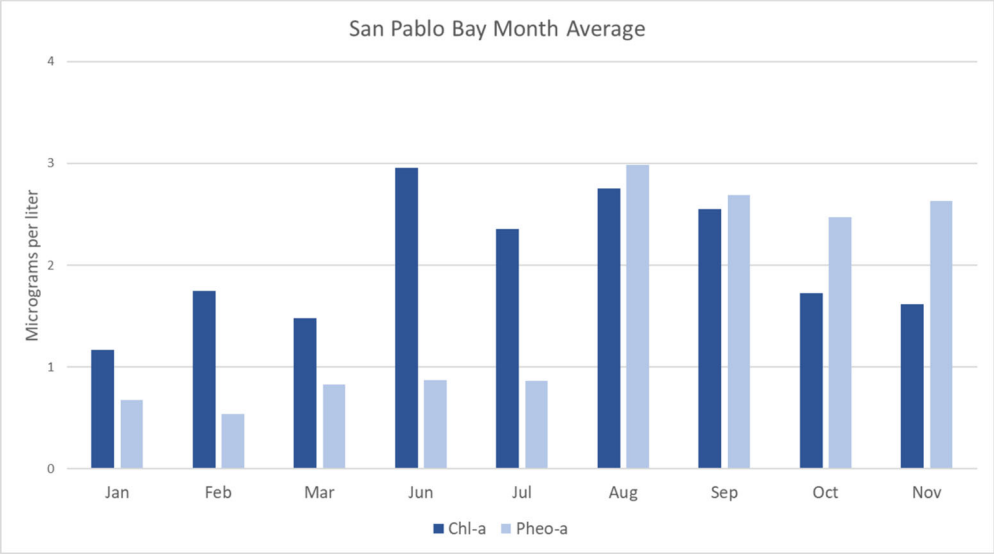

Figure 65: Average chlorophyll a and pheophytin a concentrations in the San Pablo Bay

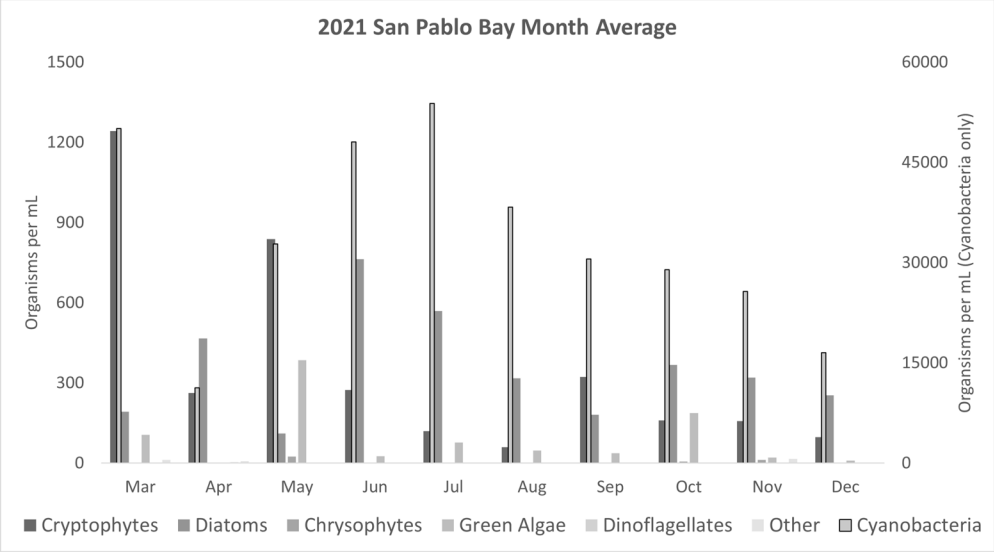

Figure 66: Average organism density in the San Pablo Bay; other are euglenoids, haptophytes, and synurophytes

References

[APHA] American Public Health Association, American Waterworks, and Water Environmental Federation. 2012. Standard Methods for the Examination of Water and Wastewater. 22nd ed. Washington, D.C.: American Public Health Association.

Alpine, A. E., and Cloern, J. E. 1992. Trophic interactions and direct physical effects control phytoplankton biomass and production in an estuary. Limnol. Oceanogr. 37: 946-955

Carmichael, W., ed. 1981. The Water Environment, Algal Toxins and Health. Plenum Press, New York, N. Y.

Gannon, J. E. and R. S. Stemberger. 1978. Zooplankton (especially crustaceans and rotifers) as indicators of water quality. Trans. Amer. Microsc. 97:16.

Horne, A. and Goldman, C. 1994. Limnology. 2nd ed. New York, New York, McGraw-Hill, Inc.

Müller-Solger AB, Jassby AD, Müller-Navarra DC. 2002. Nutritional quality of food resources for zooplankton (Daphnia) in a tidal freshwater system (Sacramento-San Joaquin River Delta). Limnology and Oceanography 47(5): 1468-1476.

Utermöhl, H. 1958. Zur Vervollkommnung der quantitativen Phytoplankton Methodik. Mitt. Int. Verh. Limnol. 9: 38.

van den Hoek, C., D.G. Mann, and H.M. Jahns. 1995. Algae: an introduction to Phycology. Cambridge University Press, United Kingdom.