Enhanced plankton production in flood-pulse managed ponds in Suisun Marsh

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Summary

Managed wetlands in Suisun Marsh may present an opportunity to increase food production as part of the Delta Smelt Summer-Fall Habitat Action, but we need a better understanding of how to maximize wetland production in these systems. This project will compare phytoplankton and zooplankton production, and identify drivers of production, in wetlands across seasons and across the landscape (Figure 1). We will observe three wetland types (tidally restored, seasonally managed, and perennially managed) over two consecutive water years to understand how different management schemes affect pelagic food production. The third year will be dedicated towards sample and data analysis and reporting. Aquatic fish food production will be measured as phytoplankton and zooplankton biomass and rates of production. We will use biotic and abiotic features of the wetlands to understand how rates of production vary across wetlands types, including nutrient and organic carbon concentrations, water quality parameters, water exchange, and site geomorphology and management. Such findings will help inform wetland management to complement tidal and tidally-restored counterparts in providing both food (managed wetlands) and refuge (tidal wetlands) to pelagic fishes. The rates of production developed during this project can then be used to parameterize the zooplankton and Delta Smelt bioenergetics models used for the Delta Coordination Group's Structured Decision Making Process.

Phytoplankton and zooplankton—food for pelagic and larval fishes–are scarce in the upper San Francisco Estuary. This is likely the result of over a century of land and water management practices, which have been compounded by the introduction of invasive bivalves that outcompete zooplankton for algae. An important priority of managers in the estuary is to enhance pelagic food for fishes, especially for Delta Smelt (*Hypomesus transpacificus*) and outmigrating juvenile Chinook Salmon (*Oncorhynchus tshawytscha*).

However, a number of habitats remain engines of production. These include floodplains, dead-end sloughs, and wetland ponds. These habitats are only intermittently connected to open waters; they are often actively managed; they may have a barrier (a levee or tide gates) to protect them from invasive species; and they can incubate localized concentrations of pelagic food for fishes. The benefit for fish is notable in Suisun Marsh, which is dominated by managed waterfowl ponds, and which has high representation of fishes from the Pelagic Organism Decline: Delta Smelt (historically), Longfin Smelt (*Spirinchus thaleichthys*), Striped Bass (*Morone saxatilis*), and Threadfin Shad (*Dorosoma petenense*).

Research Questions

This study will answer the following **questions**:

Management Outcomes

1. **What are the annual differences in plankton standing stock and production rates between seasonally managed wetlands, perennially managed wetlands, and tidally restored wetlands?**
   - We hypothesize that annual plankton standing stock and production rates will be lowest in tidally restored wetlands, intermediate in perennially managed wetlands, and greatest in seasonally managed wetlands.
   - Understanding this question will allow the DCG to parameterize SDM models with accurate rates of zooplankton production in Suisun Marsh across habitat types.
2. **How do plankton production rates vary spatially and across seasons between wetland types?**

- We hypothesize that wetland type will have a greater effect on plankton production rates than wetland location within Suisun Marsh. We hypothesize that seasonal variation will be lowest in tidally restored wetlands, intermediate in perennially managed wetlands, and greatest in seasonally managed wetlands.
- Understanding this question will allow the DCG to anticipate the relative benefit of managed wetland actions in different seasons to prioritize timing of flood/drain cycles.

3. **How does timing of plankton production align with known critical periods for Delta Smelt and other native fishes?**
   - We hypothesize that seasonally managed wetlands will produce high plankton concentrations in winter and early spring –coinciding with key larval recruitment periods for native fishes– while tidally restored wetlands and perennially managed wetlands will produce low to intermediate plankton concentrations in summer and fall for adult fish.
   - Understanding this question will allow the DCG to understand whether coordinated flood and drain of managed wetlands will be appropriate for the Summer-Fall habitat action or whether it will be more appropriate in different types of year.

Ecological Mechanisms

1. **What are the effects of wetting and drying (eg, flood pulses) on phytoplankton and zooplankton production in managed wetlands?**
   - We hypothesize that wetting and drying stimulates large nutrient and bioavailable carbon releases, promoting increased plankton production in managed wetlands relative to perennially managed wetlands and tidally restored wetlands.
   - Understanding this question will allow the DCG to recommend the optimal wet/drying cycles for maximum benefit to fish.
2. **How do different sources of organic material (eg, senescent plants and water-soil biogeochemistry) available in Suisun Marsh affect phytoplankton and zooplankton production?**

- We hypothesize that vegetative growth and soils associated with seasonally managed wetlands will increase plankton production.
- Understanding this question will allow prioritization of properties with optimal soil and vegetation dynamics to be included in the coordinated flood/drain action.

Expected Results and Implications

We expect that managed wetlands will produce more phytoplankton and zooplankton per year than perennially managed wetlands and tidally restored wetlands. Seasonal flooding in managed wetlands mimics floodplain processes whereby periods of intermittent flooding stimulate decomposition, release nutrients, and support increased phytoplankton production and accumulation. In turn, floodplain processes in managed wetlands likely support blooms of concentrated zooplankton that have become otherwise scarce in the upper San Francisco Estuary (Figure 1). Although we expect increased annual zooplankton production in seasonally managed wetlands over other management types, there may be trade-offs, which we expect to evaluate. Production may be limited to periods of inundation, but we expect production to be very high during the wetted period. Initial flooding may create temporary hypoxic conditions that limit production early in the hydroperiod. Despite these constraints, we expect net benefits during early-spring larval fish recruitment periods.

We expect that perennially managed wetlands that lack a drying period will decrease in productivity after the first year, and that restored wetlands will have relatively low production during the two sampling years (Figure 2). Because perennially managed wetlands lose flood-pulse effects, we predict they will support intermediate productivity. We expect tidally restored wetlands will harbor the lowest productivity due to high water exchange. Most natural tidal wetlands flood on lunar tidal cycles, which often does not allow for sufficiently long periods of drying and flooding to promote growth, decomposition, and recycling of plant-derived nutrients that fuel the food web.

This project will clarify the rates and durations of heightened production across a range of landscapes, and provide clear management tools and parameters for eco-hydrodynamic or bioenergetic modeling that can support restoration goals for critical species such as Delta smelt in the San Francisco

Estuary. True restoration opportunities are extremely constrained in the San Francisco Estuary, with limited tools that may be used to reach restoration objectives. Our findings will enable privately managed wetlands to actively participate in improving working landscapes for imperiled native species. This may provide an opportunity for collaboration between private stakeholders and local, state, and federal agencies towards reaching shared practical, operational, recreational, and ecological goals.

Figure 1 Conceptual model of hypothesized differences between managed and tidal wetlands in terms of nutrient and carbon pathways to pelagic food production. Colored bars represent alternating frequencies of drying and flooding cycles. In managed wetlands, long cycles promote vegetative growth, sequestration, and decay, which release both carbon and nutrients to fuel microbial and primary food webs. In tidal wetlands, short cycles promote slower phytoplankton growth and more nutrient recycling, enhancing microbial food webs over primary food webs.

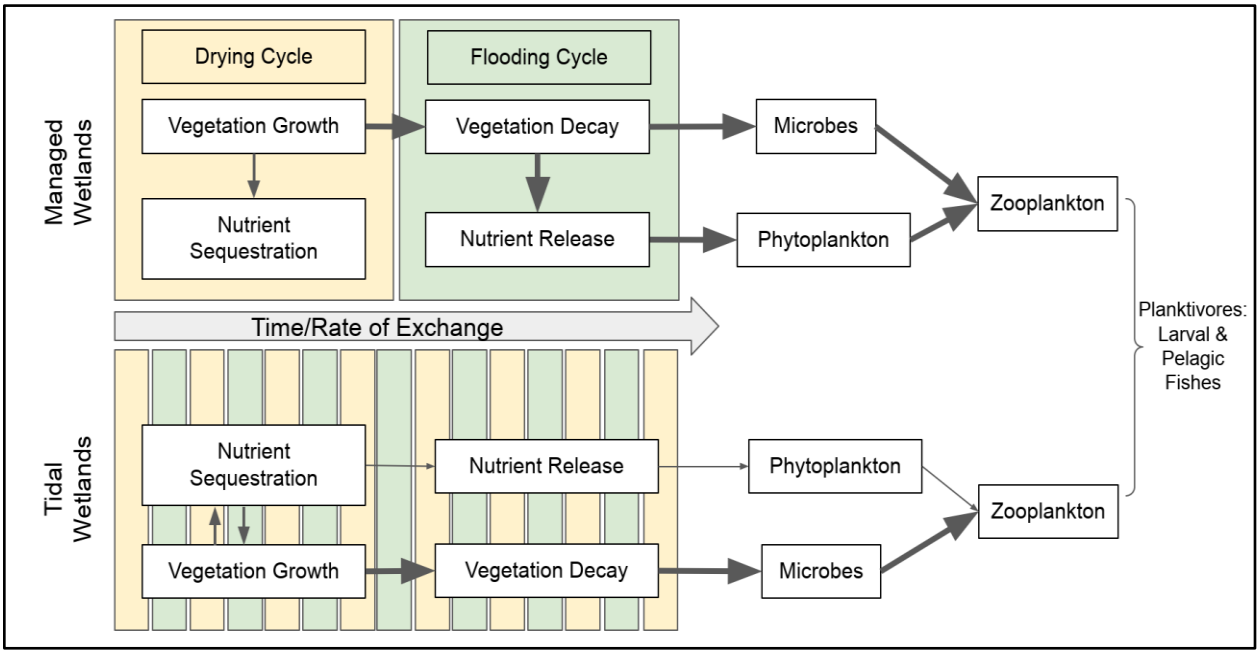
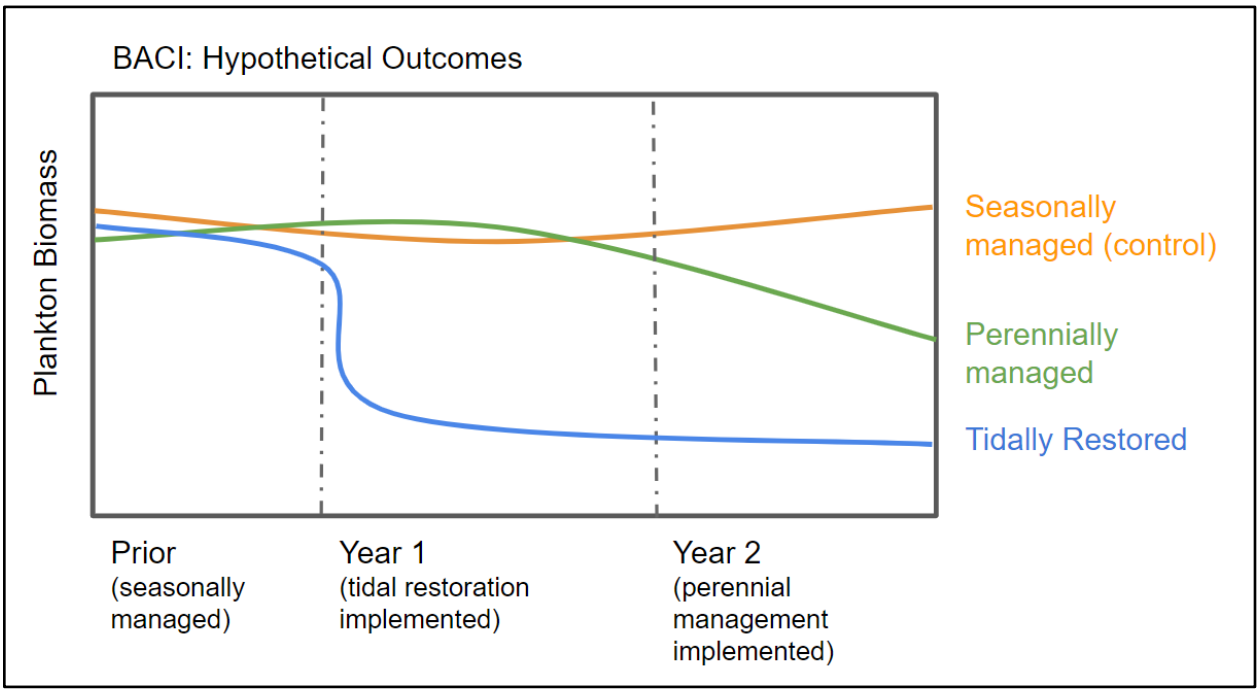


Figure 2 Hypothesized differences in pelagic food production across wetland management treatments. Study sites will include seasonally managed wetlands (control treatment), perennially managed wetlands, and tidally restored wetlands. The perennially managed wetland treatment will be implemented at Year 2.



Methods

This study will take place across a range of sites in Suisun Marsh that represent **seasonally managed and tidally restored wetlands**. The study will leverage existing baseline data that have already been collected on several sites in Suisun Marsh. We will use **perennially managed wetlands** to understand the effect of conversion from managed to tidal wetlands.

The **Seasonally Managed Wetland Treatment** will include sites that dry every summer and flood up again in the fall. We expect that these will be highly productive every year.

The **Tidally Restored Treatment** will include sites that have recently (in the last one or two decades) been returned to open tidal conditions. Our expectation for this treatment to have relatively low rates of pelagic productivity.

The **Perennially Managed Treatment** will include seasonally managed wetlands that will be kept perennially flooded for two years, with no period of drying. By maintaining flooded environments, these sites will allow us to study the pelagic effects of managed wetland conversion to tidally restored wetlands. We expect a notable decline in production rates after the first year. Various wetland properties with flexible operational capacity are available to be used for these treatments.

These experimental studies are important for disentangling the factors that drive productivity including flood-pulses, water residence time, and nutrient availability. Laboratory incubations will further help us disentangle how nutrients are mobilized, phytoplankton production rates, and zooplankton production rates.

Field sampling will be conducted approximately monthly, depending upon site conditions, and flooding/drying cycles. Sample collections will be clustered at each site to minimize intra-site differences, and replicated to account for variation and error.

Field sampling will consist of data collection for a number of variables. *Real-time water-quality measurements* will be made using a YSI EXO multi-parameter sonde which will include dissolved oxygen (mg/L and % ODO), salinity (ppt) and specific conductivity (uS/cm), pH, turbidity (NTU), temperature (°C), and chlorophyll (ug/L). Subsurface whole water grabs will be used to determine chlorophyll-*a* and nutrient and organic carbon concentrations. Similar collections will be made for incubations and mesocosm studies.

Phytoplankton community composition will be collected in 200 mL opaque Nalgene bottles and preserved monthly in 10% Lugol's solution at a subset of stations. Samples will be stored in a 4°C cold room until they are sent to a contractor for identification and enumeration.

Zooplankton samples will be collected using 30cm diameter conical tow nets with 150um mesh which will be handpulled 15 meters. Sample contents will be stained with Rose Bengal dye and preserved in 5% formaldehyde. Zooplankton analysis will be conducted in our lab, using standard subsampling and counting techniques, to evaluate the largest and dominant taxa, which provide the largest contribution to fish food. Copepods and

cladocerans will be identified to species, and other well-represented organisms will be identified to the lowest practicable taxonomic level. Biomass will be estimated from published and experimental literature based upon species and life stage.

Whole water samples will be returned to the laboratory for a series of *incubation experiments*. All incubations will be replicated in growth chambers using a randomized complete block design. These will include studies to evaluate changing nutrient stoichiometry, phytoplankton production, and zooplankton production across flooding and drying periods.

Primary production rates will be measured using closed-container light-dark bottle experiments using non-intrusive dissolved oxygen instrumentation by Precision Sensing GmbH. The flux of dissolved oxygen over light and dark cycles will provide estimates for metabolic rates for Gross Primary Production (GPP), Net Primary Productivity (NPP), and Respiration (R). We will conduct monthly primary production incubations in the fall and quarterly incubations thereafter by incubating water grabs from sampling stations- one station within each wetland and one reference slough station associated with each wetland. In the wetland areas, the incubation samples will be collected in approximately the center of the wetlands. Two replicate 1L samples will be collected at each sampling station for incubations. Once transported to the lab, each 1L sample will be immediately transferred into one ~450 mL jar containing Precision Sensing spots. The jars will be connected to the Precision Sensing continuous logging instruments and software to begin logging dissolved oxygen measurements in 10-minute intervals, and then placed into the temperature-controlled Ocean Designs water bath. We will have the capacity to continuously measure up to 22 samples at a time. A light will be fixed above the incubation chambers and will have a timer to run on 12 hour light to 12 hour dark cycles. The DO flux for the 12 hour light will resemble NPP, while the DO flux for the 12 hour dark will resemble R. The difference between the two will resemble GPP. At the end of incubation periods, chlorophyll a and nutrient samples will be collected to measure the before-and-after conditions of the 24-hour incubations.

We will conduct quarterly zooplankton incubations, by incubating *Eurytemora affinis* (from culture) in 1-L water samples collected from sampling stations. We will filter collected water through 50um and 35 um

mesh to remove zooplankton inhabitants and add 20 copepodites (separated by filtering between 200 and 150 um mesh) which will be allowed to incubate for 1 week in a 12:12 light/dark temperature control room at 20°C +/- 1°C. At the end of the incubation we will preserve specimens in formaldehyde and enumerate adults, eggs, nauplii, and copepodites under a dissection microscope and use literature dry-weight values to estimate zooplankton biomass which will be used to calculate growth rates (ug $C^{-L\ -day}$) within samples.

Mesocosm studies will use sediment and wetland plant samples collected in different wetland areas across key periods to determine their effects on phytoplankton and zooplankton growth and community succession. Incubation and mesocosm studies will be carried out in a controlled-environment room with no more than +/-1°C temperature variation, using full-spectrum lighting.

Using collected field data, we will construct generalized linear models to test the effects of management type, seasonality, dissolved nutrients, and other water quality parameters on ecosystem metabolism, plankton biomass, and plankton growth rates. We will use Ordination and Indicator Species Analysis to model effects of management types on plankton community assemblages in order to identify taxonomic associations with different management regimes. Using data from lab incubation experiments, we will construct sets of generalized linear models to test the effects of different soils, plants, and other organic materials on plankton production.

Field Work and Experiments

Year 1. October 2022 - September 2023

The first year of this project will focus on characterizing trends of chlorophyll *a*, water quality, phytoplankton composition, zooplankton composition, primary growth rates, and secondary growth rates in seasonally managed wetlands, perennially managed wetlands, and tidally restored wetlands (see figure 6). Seasonally managed wetlands will include Luco Pond, Miramonte Duck Club, Denverton Duck Club, and Grizzly King. Tidally restored wetlands will include Tule Red, Wings Landing, and Montezuma Wetlands. Meins Landing will be managed as a perennial wetland for the study period (see maps below). We will coordinate with land managers to plan site visits

around hunting schedules and other events hosted among wetland areas (Table 2)

We will sample all eight wetland areas monthly, so long as water is present on the wetland, constraining sampling to a single week when possible. We will sample water quality using a YSI EXO water quality sonde and conduct rapid zooplankton estimates at six to eight stations (along an established transect) per wetland area and one station at the source slough of each wetland area. We will collect whole water grabs for laboratory analysis of chlorophyll-a and nutrient concentrations at four stations per wetland per month (three within the wetland and one in an adjacent reference slough station). In sum, this will result in 33 water quality samples per month, with an additional 3 randomly selected samples to account for 10% replicate sampling. At two stations per wetland site, we will collect phytoplankton samples by preserving 250-ml whole water grabs in Lugol's solution and zooplankton samples by towing a 30 cm diameter conical net with 150-um mesh for 15 meters and preserving contents in 5% formaldehyde. In total, we will collect 16 preserved phytoplankton samples and 16 zooplankton samples per month.

We will estimate phytoplankton and zooplankton growth rates (ug $C^{-L\ -day}$) and compare growth rates among the three wetland types:

- *Primary production rates* will be measured using closed-container light-dark bottle experiments using non-intrusive dissolved oxygen instrumentation by Precision Sensing GmbH. The flux of dissolved oxygen over light and dark cycles will provide estimates for metabolic rates for Gross Primary Production (GPP), Net Primary Productivity (NPP), and Respiration (R). We will conduct monthly primary production incubations in the fall and quarterly incubations thereafter by incubating water grabs from sampling stations- one station within each wetland and one reference slough station associated with each wetland. In the wetland areas, the incubation samples will be collected in approximately the center of the wetlands. Two replicate 1L samples will be collected at each sampling station for incubations. Once transported to the lab, each 1L sample will be immediately transferred into one ~450 mL jar containing Precision Sensing spots. The jars will be connected to the Precision Sensing continuous logging instruments and software to begin logging dissolved oxygen measurements in 10-minute intervals, and then placed into the temperature-controlled

Ocean Designs water bath. We will have the capacity to continuously measure up to 22 samples at a time. A light will be fixed above the incubation chambers and will have a timer to run on 12 hour light to 12 hour dark cycles. The DO flux for the 12 hour light will resemble NPP, while the DO flux for the 12 hour dark will resemble R. The difference between the two will resemble GPP. At the end of incubation periods, chlorophyll a and nutrient samples will be collected to measure the before-and-after conditions of the 24-hour incubations.

- We will conduct quarterly zooplankton incubations, by incubating *Eurytemora affinis* (from culture) in 1-L water samples collected from sampling stations (same stations as WQ water grabs). We will filter collected water through 50um and 35 um mesh to remove zooplankton inhabitants and add 20 copepodites (separated by filtering between 200 and 150 um mesh) which will be allowed to incubate for 1 week in a 12:12 light/dark temperature control room at 20C. At the end of the incubation we will preserve specimens in formaldehyde and enumerate adults, eggs, nauplii, and copepodites under a dissection microscope and use literature dry-weight values to estimate zooplankton biomass which will be used calculate growth rates (ug $C^{-L\ -day}$) within samples.

Quarterly progress reports will be provided (per deadlines in Deliverables section).

General schedule during hunting seasons (10/22/22 - 1/31/23)

Table 2 The general field and lab schedule during the waterfowl hunting season. Orange = seasonally managed wetlands, blue = tidally restored wetlands, and green = perennially managed wetland.

Task	Mon	Tues	Wed	Thurs	Fri
Field	*Canoe Day* Potrero Miramonte	*Truck Day* Grizzly King Tule Red	*Canoe Day* Denverton Meins Landing	*Canoe or G3 Day* Wings Montezuma Wetlands	—
Lab	Filter chl *a*	Filter chl *a*	Filter chl *a* WQ for Mon/Tues	Filter chl *a*	WQ for Wed/Thurs

Year 2. October 2023 - September 2024

In Year 2, we will continue our monthly monitoring at all wetland sites in an identical protocol from Year 1. Chlorophyll a and water quality data produced from Year 1 will help inform any updated experimental designs for the phytoplankton and zooplankton incubations. We will also begin to conduct mesocosm experiments testing the influence of soil and vegetation on primary and secondary production in Fall vs Spring months (methods TBD). Quarterly progress reports will be provided (per deadlines in Deliverables section).

Year 3. Analysis and Writing

QA/QC of the data and analysis will begin as early as Year 1, with the bulk of analysis and writing being completed following the end of field monitoring and incubation experiments. The results will be written into multiple manuscripts, and synthesized into a single final report for CA DWR.

Sampling Areas and Transect Maps

Below are the planned sampling areas and transects for our field work. Wetland areas range between 200 and 1000 acres in size and are scattered across the natural salinity gradient of Suisun Marsh (Figure 3). Each transect is a little over 1.6 km long, and exclusively includes areas that are predicted to be navigable by canoe during the wetted periods (Figures 4 and 5). Most stations will be accessed via canoe, while others will be accessed by truck.

Figure 3 **Wetland areas to be sampled in Suisun Marsh. Blue areas are tidally restored wetlands; orange areas are seasonally managed wetlands; Meins landing (green) will be the perennially managed wetland.**

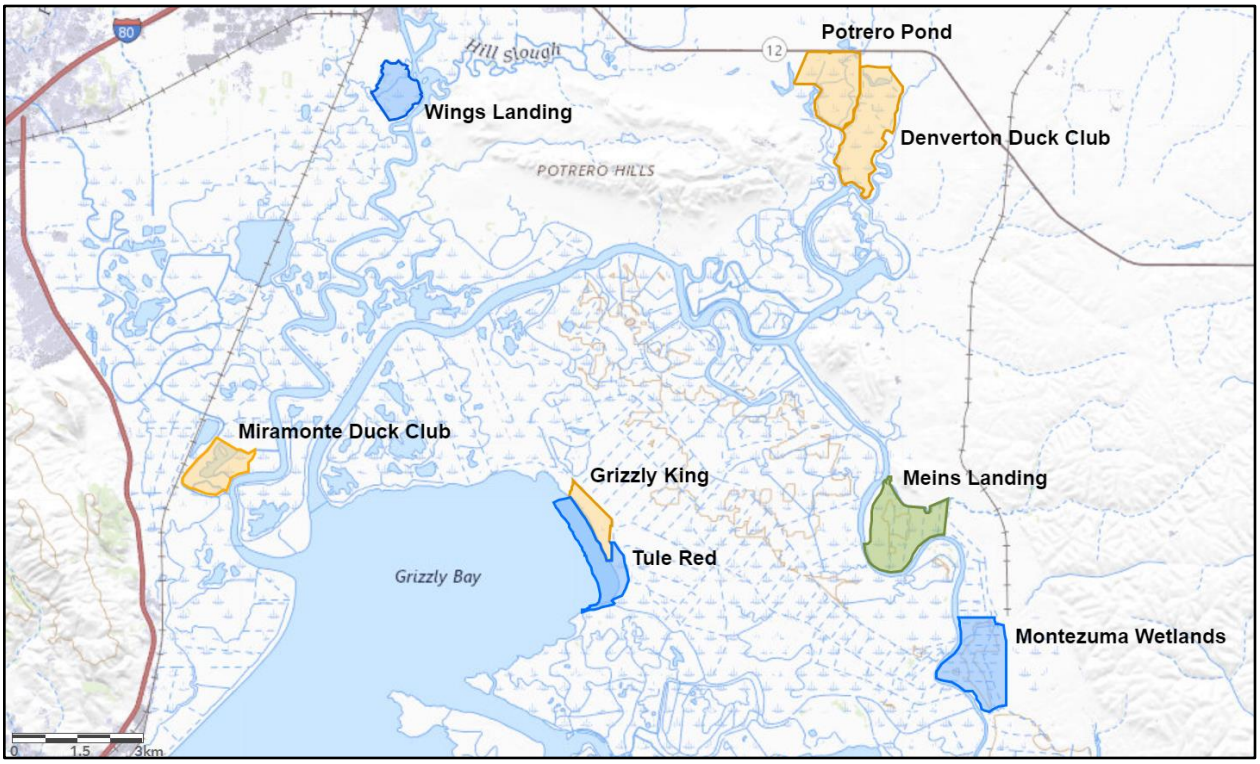


Figure 4 Wetland Sampling transects. Clockwise starting from upper left: Meins Landing, Potrero Pond, Wings Landing, Denverton Duck Club.

Figure 5 Wetland sampling areas. Clockwise starting from top: Montezuma Wetlands, Grizzly King + Tule Red, Miramonte Duck Club

Field Equipment Checklist

WQ + Zoop

- Canoe + paddles, cam straps
- Waders + boots
- PFDs
- YSI Sonde (sonde, cable, handheld, case)
- GPS unit
- Clipboard (floatplan, datasheets, pencils, maps)
- WQ cooler (ice, labeled WQ bottles)
- Field tote
    - zoop net, line, cod end
    - 'quick zoop' bottles
    - splash bottle
    - sonde cleaning kit
    - first aid kit
    - extra rope
    - zip ties
    - miscellaneous tools
- Secchi disk
- Zoop + Phyto cooler (labeled zoop bottles, rose bengal, formaldehyde, 10% Lugols solution)
- Bucket (for slough water grabs)
- Extra labeled WQ bottles (if doing zoop incubations)

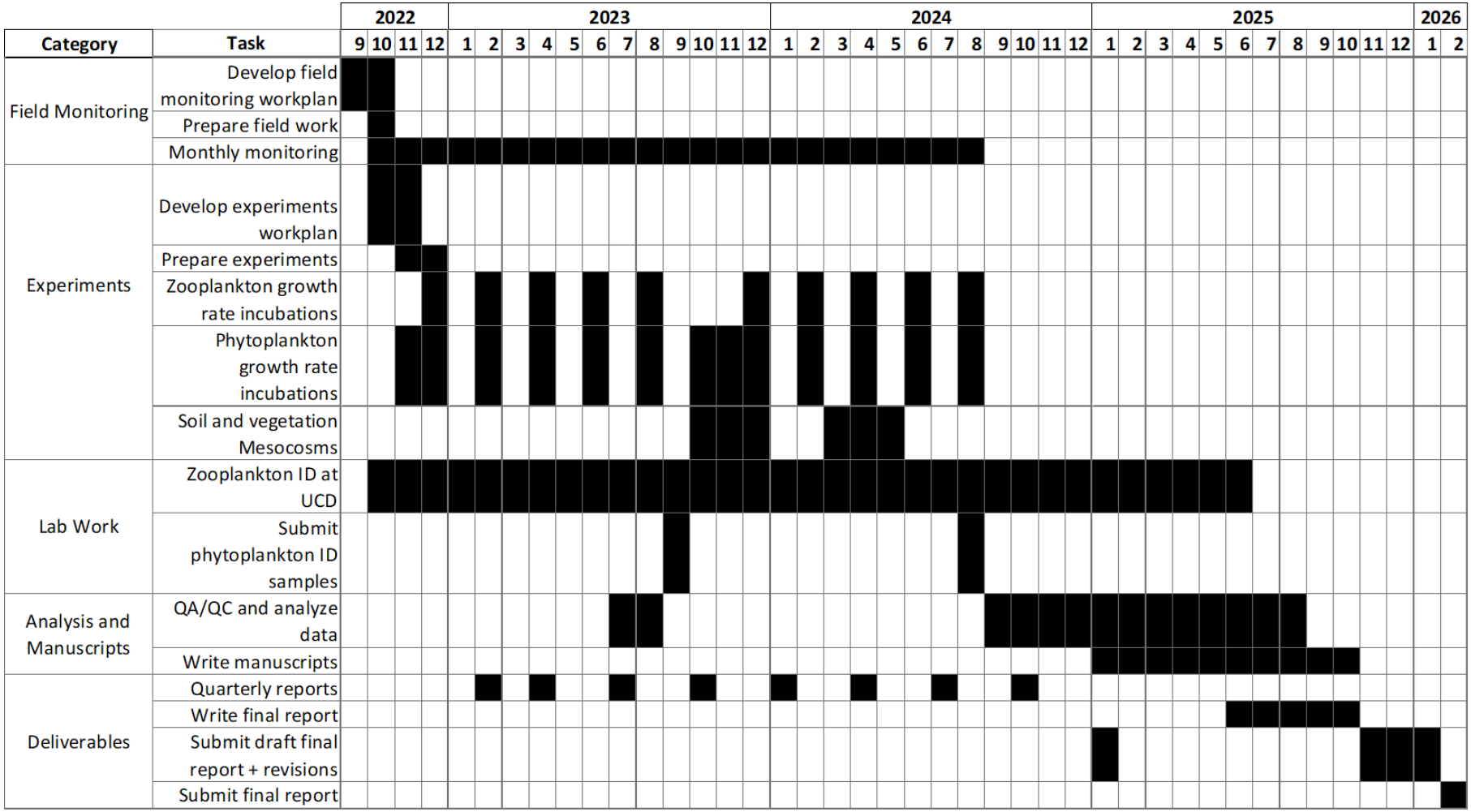
Fish

- Seine
- buckets
- fish measuring boards
- large dip net
- seine datasheets

Table 3 Personnel and Qualified Tasks for field and lab assistance.

Personnel	Field lead	Field hand	Field prep	Chlor filtering	WQ processing	Zoops ID	Zoop Incubations	Phyto Incubations
Kyle Phillips	x	—	x	x	x	x	x	
Alice Tung	x	—	x	x	x			x
Jake Sousa	x	x	x					
Brian Williamshen	x	x						
Kimberly Luke	x	x		x	x	x		
Elsie Platzer		x	x	x	x	x		
Katherine Hostetler		x	x			x	x	
Zoie Jones			x	x	x			x

Figure 6 Project timeline for field monitoring, experiments, lab work, analysis and manuscript writing, and deliverables for 2022-2026.



Deliverables

Table 4 Deliverables and due dates

Item	Date Due
Quarterly reports	1/30, 4/30, 7/31, 10/31
Draft final report	1/1/2025
Final report, manuscripts, data	12/1/2025
Actual draft final report	1/31/2026
Actual final report	2/28/2026