Observing and Measuring Water Quality of Central California Estuaries for Steelhead Trout

(*Onchorynchus mykiss*)

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PROJECT ADVISEMENT

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ABSTRACT

Observing and Measuring Water Quality of Southern California Estuaries for Steelhead Trout

Charles Alexander Taylor

Estuaries support abundant biodiversity but are threatened by anthropogenic influences making it a priority to effectively monitor water quality to identify if and when it becomes detrimental to aquatic life. The purpose of the study was to analyze water quality in local San Luis Obispo estuaries to measure baseline conditions to inform future studies and management and to identify if key water quality parameters such as dissolved oxygen or temperature result in stressful or lethal conditions for steelhead trout (*Onchorynchus mykiss*). An EXO1 multiparameter node (probe) was used to measure dissolved oxygen (mg/l), temperature (in Celsius), conductivity (Us/cm), salinity (parts per thousand), and pH while grab samples were used for comparisons to the ESX01 measurements and determine toxic ammonia, inorganic nitrogen, phosphorus and chlorophyll a concentrations. In addition to probe and grab sampling, the weather and frequency of bar breaching where recorded from three central California coast estuaries, the Villa Creek, Santa Rosa, and San Simeon, from December 2019 to July 2020. At each estuary sampling was concluded at three collection sites representing the front (near the ocean), middle, and back (near river) of the estuary. Notable results from the sampling show that in July dissolved oxygen conditions in Villa Creek estuary were measured at lethal levels for steelhead (0 mg/l) in the upper water layers in July, while in other estuaries the levels remained at tolerant level for steelhead (~ 7 mg/L). Temperature remained relatively stable with one exceptionally high reading in December at San Simeon estuary (over 35 degrees Celsius), but this may have been due to a measurement error.

Keywords: Estuary, Water Quality, Southern California, Environmental Studies, Eutrophication, Tolerance
ACKNOWLEDGMENTS

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Chapter 1: INTRODUCTION

1.1 Background

Estuaries are areas found in coastlines around the globe where rivers exit into the ocean, allowing saltwater and freshwater to mix in a flooded plain. Estuaries are both highly active ecosystems and can support an abundance of biodiversity. These biomes are areas of ecological importance that are disproportionate to their general size (acreage) classifying them as Small Natural Features (SNFs) (Hunter et al., 2017). Estuaries provide a variety of unique ecological services including the support of seabird migrations, fish hatcheries, natural flood control, and carbon storage. These unique habitats are threatened by a variety of anthropogenic events, primarily through the development of natural habitat and pollution via runoff. Even with current conservation efforts, estuaries are still highly vulnerable and require integrative conservation efforts (González et al., 2017). In particular, threats to water health and nutrient stability are prominent in the estuaries of coastal California. Various organic and inorganic chemicals from human runoff severely impact water quality. In some coastal areas, human waste water provides more if not equal amounts of nitrogen for the ecosystem (Howard et al., 2014). Without appropriate research and prevention, the water quality of these biomes could become detrimental to the diverse life it supports.

1.2 Characteristics of Estuary Water Quality

Like any biome on Earth estuaries are interconnected to the larger climate system, water and nutrient cycles. Estuaries serve as a unique transitional ecosystem connecting terrestrial and aquatic biomes. Estuaries are influenced by geomorphology and hydrodynamics in addition to the plants and animals that live in them. Due to the focus of
the project, this literature review will analyze factors directly influencing estuary water quality and steelhead trout (Onchorhyncus mykiss).

Estuary water is influenced by both oceans and rivers. Inflow is classified as water originating from upstream creeks and rivers while outflow is water that flows from the estuary into the open ocean. Common estuaries types in California are ‘closed’ or ‘open-bar’ types. As the name implies these estuaries have a sand bar or other barrier which limits the interaction with the larger ocean (Richards et al. 2018). The sand bar tends to shift and change with the seasons due to ocean currents, tides and the amount of sediment carried from inflow. How long a particular estuary is closed, by a sandbar or barrier, from the ocean can range from seasonal or annual occurrences, to several years or more depending on environmental factors. Because of the gradual nature of opening and closing sandbars, sudden openings caused by weather or human intervention can alter the water quality of the inland estuary (Richards et. al, 2018). Any major alterations of the flow of water in and out of the estuary could impact several water quality characteristics at once. Sudden upwelling of nutrients or salt from the ocean can cause an imbalance in water nutrients which could lead to fish-kill events (Richards et. al, 2018). The flow of freshwater downstream and the interaction of ocean tides (in conjunction with environmental factors like tree cover and water turbidity) influence the major components of water quality; temperature, dissolved oxygen, salinity, nutrients, and algae.

In estuaries water temperature is a key factor influencing water quality. The temperature of the water influences the growth and general development of the fish and plants within the water (Carter et al., 2005). As temperature increases in a body of water,
there is an increased risk of a fish-kill event. This is primarily due to how it interplays with the dissolved oxygen and the salinity of water. Salt is introduced from the ocean and varies in concentration in the estuary depending on tide, weather, and flow and depth of water. Salt concentrations in estuaries generally increase with proximity to the ocean (Figure 1). Dissolved oxygen enters water in three main methods, diffusion from atmosphere, photosynthesis from aquatic plants and mixing of water. Increases in water temperature reduce the solubility of oxygen. Water temperature and salinity are inversely related, as temperature increases, the dissolved oxygen content of the water decreases, and vice versa. Salinity has a similar influence on the solubility of oxygen. The combination of high concentrations of temperature and salinity decrease the dissolved oxygen content in water.

![Salinity in estuaries](image)

*Figure 1: Distribution of salinity in relation to geography in an estuary. Salinity is measured as a unit of electrical conductivity often in microsiemens per centimeter, μS/cm.*

Water temperature and salinity in estuaries do not always correlate to one another due to water depth. Because lower water is colder and denser than surface water, estuary depth and current water level are contributing factors to water quality. Generally, layers
of warmer less salty water form on top of colder saltier water below. The layering of 
water is called stratification, and occurs in oceans, estuaries, as well as lakes and rivers. 
In the upper levels of water, oxygen is more available while benthic layers are more 
prone to loss of oxygen. This is influenced by the upper layer’s exposure to air, and 
decomposition occurring on the bottom layers (decomposition consumes oxygen).

In addition to oxygen, carbon, nitrogen, phosphorus and ammonia are the major 
nutrients that impact life in the water. All living things depend on organic nutrients, 
inorganic nutrients, and the proper function of nutrient cycles. Inversely, nutrient cycles 
are influenced by the living and nonliving environment. One of the basic principles of 
ecology is that all nutrients are cycled continuously from various pools, or stages. The 
majority of carbon found in an estuary is either in living tissue or decomposing in 
sediment layers. As animals eat and grow, carbon moves up the food chain before 
inevitably going back to lower trophic levels through decomposition. When carbon is not 
recycled by decomposition or plant material, it becomes mixed with the sediment. From 
this carbon-rich deposits of peat can form.

Nitrogen and phosphorous are cycled in the terrestrial and aquatic ecology of 
wetlands. Like on land, \( N_2 \) from the atmosphere is fixed from the atmosphere into \( NH_4 \) 
by bacteria, in aquatic environments primarily by cyanobacteria (Eddy, 2005). 
Phosphorous is found in various organic forms and is necessary for energy metabolism in 
plants and algae (Baldwin, 2013). Unionized ammonia (\( NH_3^+ \)), otherwise known as toxic 
ammonia, is formed by the metabolism of protein and is a major waste product of fish.
Unionized ammonia in water is toxic to aquatic life and can be a major limiting factor in 
aquatic ecosystems. A concentration greater than 0.025 mg/l can negatively impact local
fauna. Ammonia often increases with high pH or temperature in the water. Organisms like oysters and other filter-feeders play a key role in cycling excess unionized ammonia out of the water and reducing it to ammonium (NH4) and other harmless forms. In the form of ammonia nitrogen is taken into the larger biotic community through other bacteria and algae as it becomes part of biological tissue. Understanding of organic phosphorous cycling in aquatic ecosystems is not as well understood as nitrogen, but it is generally accepted that they promote plant growth (Baldwin, 2013). Because both nitrogen and phosphorus encourage the growth of plant life, they are considered limiting factors in estuaries.

Plant life, mainly algae and phytoplankton, influence the quality of estuary water. All algae species require nitrogen, phosphorus, carbon and oxygen to grow making them key players in nutrient cycles. Plant productivity is often described in three trophic states; oligotrophic, meso-eutrophic, and eutrophic. Oligotrophic conditions have minimal to zero plant or algal activity and are generally characteristic of Mountain Rivers. Eutrophic conditions are the opposite of Oligotrophic conditions where plants and algae grow beyond usual limitations. Mesotrophic states have moderate growth and represent ideal conditions for most estuaries and wetlands. Nitrogen and phosphorous promote algae growth, while carbon and oxygen are necessary for photosynthesis and cellular respiration. It is through photosynthesis that algae are able to moderate another key factor of water quality pH. The pH scale is the measurement of how acidic or basic a substance is, lower pH correlates with more acidic substances while higher pH correlates to more basic substances. In general, most estuaries maintain a pH slightly above or below neutral, 6-8 (with 7 being neutral). All organisms in an estuary have specific ranges of
tolerance for acidic or basic conditions but most prefer conditions close to neutral. Depending on the pH or temperature of the estuary, and the personal solubility of nutrients or toxic metals with water, various compounds can be more or less accessible to estuarine species. Lower pH in general can alter the availability of unionized ammonia putting fish populations at greater risk of harm. The pH range often shifts daily due to the photosynthetic activity of algae present. As the day progresses, photosynthesis increases with the amount of sunlight present reducing carbon dioxide and increasing the pH of the water. At night the opposite happens, as cellular respiration out competes photosynthesis causing carbon dioxide to increase, decreasing pH. Depending on the time of day, or availability of sunlight an estuary will be more acidic or basic (Figure 2).

![Aquatic Plant Photosynthesis & Respiration](image)

**Figure 2: The relation of pH between night and day in an aquatic ecosystem**

1.3 Estuarine Water Quality Effects on Steelhead and Ecology

One example of a fish species that relies on the conditions provided by an estuary environment is steelhead trout (*Oncorhynchus, mykiss*). Steelhead trout are a salmonid fish species and are well known across the west coast of America as a sport fish.
Steelhead use the estuaries along California as annual spawning grounds. While the steelhead spends the majority of its life in the ocean it only spawns in freshwater, making estuaries and their connected rivers places where they can breed. Steelhead populations have been declining over recent years with the majority of decline happening in Southern California (Moyle et al, 2011). The Southern California population has been listed as endangered on the National Oceanic and Atmospheric Administration (NOAA) directory with the remaining California Population listed as threatened (NOAA, 2020). Their decline has been attributed to the growing urbanization, development, and pollution of rivers and estuaries in the southern end of the state (Crozier et al., 2019). While steelhead populations have fared better in northern California, worsening water conditions as a result of human impacts are a continuing threat to those populations.

One of the most prominent recurring threats to steelhead and various other endemic species in California estuaries is eutrophication. In runoff from anthropogenic sources, there are many potential substances present that can affect estuary ecology. Current theory supports that abnormally high levels of nutrients, common in fertilizers animal and human waste can have devastating consequences (Howard et al. 2014). An excess of nitrates, phosphates and other fertilizing nutrients in an estuary ecosystem increase the potential for eutrophic conditions. In a natural setting these elements are the necessary to promote plant and algae productivity in the estuary. These nutrients enter estuaries naturally from coastal upwelling and upload sources. However, excess amounts of nitrogen and phosphorus can be introduced either through upwelling ocean currents, or discharged runoff from human agriculture and industrial sites.
Discharges of runoff from human sources have been shown to be as influential or even more so than natural coastal upwelling events (McLaughlin et al., 2017). When an excess of these chemical components is introduced they cause a sudden and intense period of plant and algae productivity. While higher productivity may appear to be beneficial, the influx of growth beyond the normal limitations of the estuary causes a mass die off of aquatic plants and algae (Sutula et al., 2014).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Low potential</th>
<th>Moderate potential</th>
<th>High potential</th>
<th>Hypereutrophic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chlorophyll-a (µg/L)</td>
<td>0–5</td>
<td>5–20</td>
<td>20–60</td>
<td>&gt;60</td>
</tr>
<tr>
<td>TIN (mg/L)²</td>
<td>&lt;0.1</td>
<td>0.1–1.0</td>
<td>&gt;1</td>
<td>--</td>
</tr>
<tr>
<td>Orthophosphate (mg/L)</td>
<td>0–0.01</td>
<td>0.01–0.1</td>
<td>&gt;0.1</td>
<td>--</td>
</tr>
<tr>
<td>DO (mg/L)</td>
<td>&gt;5</td>
<td>5–2</td>
<td>2–0</td>
<td>--</td>
</tr>
</tbody>
</table>

Table 1: Water quality parameters and their influence on the potential for eutrophic conditions in a waterbody (source: Clark and O’Connor, 2019).

The resulting die-off leads to an increase in the population of decomposing bacteria and microbes. Since these organisms are not autotrophs they consume oxygen in order to respire, which leads to a sudden drop in the quantity of dissolved oxygen in the water. The depletion in dissolved oxygen in a marine environment is referred to as hypoxia. In hypoxic conditions many larger marine species start to suffocate, which in turn creates more death and decomposition consuming more oxygen. In the case of most salmon and trout (including steelhead) dissolved oxygen below 7.00 mg/l is detrimental to their health. The fatal dissolved oxygen limit for steelhead is 3 mg/l (Matthews and Berg 1997). The most common water quality components measured to determine eutrophic conditions are chlorophyll, total inorganic nitrogen, toxic ammonia, phosphate

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¹Adapted from Bricker et al. (1999)
²TIN = Total inorganic nitrogen (NO3, NO2, and NH4)
and dissolved oxygen, (Table 1). Depending on the conditions present in an estuary, hypoxia caused by an algae bloom can kill a vast majority of underwater life present.

While eutrophic conditions are comprised of various water quality parameters, reductions or excesses of individual parameters can still negatively impact steelhead survivability. Ideal water conditions are rarely if at all present in estuaries or in any aquatic environment, due to constant changes in climate, weather and the surrounding terrestrial environment. For every species, there are ranges of conditions tolerated which vary by life stage. Steelhead eggs and juveniles tolerate temperatures between 4-14°C while Adults can tolerate 23-26°C (Carter, 2005). Stressful temperatures generally occur at temperatures higher than 25°C and lower than 10°C.

1.4 Summary of Estuary Water Quality

Estuaries are key biomes that host an abundance of biodiversity. In countless ways they influence the overall health and security of the oceans, coasts, and even global climate. Despite their influence they are small regions which in recent years have continued to decrease in size and abundance globally (Hunter et al., 2017). According to recent studies there is reason to assume that even current conservation efforts are not effective enough to prevent continuing damage to these ecosystems (González, et al., 2017). They are especially vulnerable in California due to increased development and unintentional pollution. Eutrophication and algae bloom related fish kill events have impacted the vast majority of coastal estuaries in the state. The health and productivity can be reflected in a species such as steelhead trout, whose population is threatened in the southern regions and threatened across the coast (Crozier et al., 2019). In order to assess and prevent future loss, it will be necessary to analyze water quality measurements in
northern California estuaries to identify trends in water conditions that are harmful for Steelhead trout and other species present.

1.5 Goal and Objectives of the Study

The main goal of the study is to analyze measurements of water quality at Villa, San Simeon, and Santa Rosa Creeks estuaries in the central California coast and identify trends in water conditions that could reduce the ability to support the ecosystem of the estuary. There are two main objectives to meet this goal. First, determine through literature the levels of measurement considered “harmful” based on the tolerance of steelhead trout to water quality parameters such as dissolved oxygen, temperature, and toxic ammonia. The second objective is to study the dynamics of key water quality and their interactions to estuary water level data and frequency and duration of bar breaching salinity, nutrients, and algae pigment.

Studying water quality and corresponding impacts on wildlife is difficult due to the many variables that can influence water in estuaries. Steelhead trout is an ideal species to consider as it is both a popular commercial sport fish and an indicator species. Indicator species are species whose presence, relative health, or absence generally corresponds to the health and stability of life in an ecosystem. The study will also analyze additional data such as estuary water level data, frequency and duration of bar breaching, and additional water quality parameters (conductivity/salinity, nutrients, and algae pigment). The combination of elevated nutrient and algae concentrations, in combination with closed mouth conditions in the estuary, are hypothesized to increase temperature, decrease dissolved oxygen concentrations, and increase toxic ammonia concentrations. For a last objective, the data will be analyzed to determine if there is a measurable
difference in the intensity of eutrophic conditions between the Villa Creek and Santa Rosa, San Simeon estuaries. Gathering water quality measurements across the San Luis Obispo coastal region will provide the California Parks service with data needed for continued and effective monitoring of water systems. The collection of data should also provide updates on estuaries that are of concern. This monitoring would then be continued into the future by other members of the Creek Lands Conservancy improving and refining the methods set by this project. Resulting analysis of water quality should identify areas where the steelhead could thrive and where their populations could be threatened.
Chapter 2: METHODS

2.1 Study Areas

There were three estuaries studied within the Central Coast of California based on presence of steelhead and accessibility: Villa, San Simeon and Villa Creek estuaries (Figure 3). An initial site survey was connected on a total of four estuaries, where only three where chosen for the study. The three estuaries had three water sampling sites representing the front (closest to the ocean outlet), middle, and back (closest to river input) of the estuary identified and marked using GPS.

Figure 3: Locations of study estuaries in California. Source: google maps image created and edited by Xander Taylor (August 2020)

Villa creek, also known as the Arroyo Grande estuary, is a coastal sandbar estuary located off the Highway 1 in California (Figure 4). As the name implies it is fed fresh water by Villa Creek. The estuary is located downstream of active ranching and cattle grazing hills. The area contains mostly low coastal grasses, shrubs, and hydrophilic
plants. The area is also notable for large sand dunes which are protected nesting habitat for the endangered Western Snowy Plover (*Charadrius alexandrinus nivosus*) making access to the area limited for those not conducting surveys or other forms of research.

![Figure 4: Google Maps image of Villa Creek estuary dated Dec. 2019, red crosses denote data collection sites.](image)

The Santa Rosa estuary is surrounded by the city of Cambria, California (Figure 5). Some maps also label the estuary as part of Moonstone Beach Park. Another notable feature of the surrounding area is Shamel Park, an active park for dog-walkers and residential families. The estuary is fed by the Santa Rosa Creek.

![Figure 5: Google Maps image of Santa Rosa estuary dated Dec. 2019, red crosses denote data collection sites.](image)
The San Simeon estuary is adjacent to a campground and the Hearst Simeon State Park (Figure 6). There are few buildings adjacent to San Simeon estuary than Santa Rosa, but experiences more human interaction than Villa Creek. Unlike Villa, San Simeon estuary has taller grasses and brush in addition to a small forest further up the San Simeon Creek.

![Google Maps image of San Simeon estuary dated Dec. 2019, red crosses denote data collection sites.](image)

All the selected estuaries have relatively similar climate and vegetation typical of this region of California. The general climate of the area is described as Mediterranean, with short, cool winters and long dry summers. The majority of precipitation occurs in the winter months. Upslope vegetation is a mix of grasslands, chaparral, oak woodlands, and smaller areas of coniferous forest. There are minor variations in geography, but all of the estuaries were considered sandbar estuaries. The estuaries were chosen due to the relative proximity to each other and the presence of steelhead trout.

2.2 Materials and Methodology

The data collections sites chosen prior to field measures and their coordinates recorded. Three collection sites per estuary were located using a Cell phone with GPS.
Two methods of sampling were used, monthly sampling with an EXO1 probe, manufactured by Yellow Springs Instruments (YSI)(Figure 7) and less frequent quarterly ‘grab sampling’ were water samples were sent to labs for testing.

<table>
<thead>
<tr>
<th>Sampling Dates</th>
<th>Probe samples taken?</th>
<th>Grab Samples taken?</th>
</tr>
</thead>
<tbody>
<tr>
<td>12/11/2019</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>1/25/2020</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>1/26/2020</td>
<td>yes (makeup)</td>
<td>no</td>
</tr>
<tr>
<td>2/15/2020</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>3/14/2020</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>4/24/2020</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>5/28/2020</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>6/25/2020</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>07/29/2020</td>
<td>yes</td>
<td>no</td>
</tr>
</tbody>
</table>

Table 2: Sampling dates and data collection methods performed.

Grab samples were used to validate probe measurements, and identify parameters that the probe could not identify such as nitrogen as nitrate, toxic ammonia, and phosphorous. The majority of materials and lab analysis were provided by the California Creek Lands Conservancy. I provided notebooks, transportation, waders, and a personal computer. The onset of the covid-19 pandemic altered our sampling methodology. Sara Russ from Creek Lands Conservation had to take over as main sampler for in April, May and June and due to closure of the San Simeon Campgrounds, only the middle and lower data collection sites could be accessed.

2.3 Probe Sampling

Water quality measurements in the estuaries using the EXO1 probe was done once per month from December, 2019 to July, 2020 (Table 2). Villa Creek, Santa Rosa, and San Simeon estuaries were visited in order; this was initially for convenience and
then repeated for method consistency, visiting each estuary at relatively the same time of day. The EXO1 probe was used to measure for dissolved oxygen, DO (mg/l), Temperature (Celsius), Conductivity (µs/cm), Salinity (ppt), and pH. The EXO1 has an attached cable of at least 10 ft to reach the estuary bottom if necessary. Notes from the sampling were recorded by hand and transferred to digital format following the site visit. Before each sample outing the EXO1 multi-parameter probe was calibrated using the recommended calibration steps noted in the service manual. The EXO1 has GPS capabilities and can record and identify how far it is from a pre-recorded data collection site. A personal computer with EXO1 software was used to download and analyze the gathered data from the probe.

Figure 7: Diagram showing anatomy of the EXO1 multi-parameter snode

For each sampling day the date, time, and local weather conditions were noted in addition to whether the estuary was ‘open’ or ‘closed’ to the ocean (meaning if the estuary was cut off from the sea). Duplicate measurements of temperature, DO, conductivity, and pH were taken at each site at the water surface, and benthic depths if
possible. At each of the three data collection sites per estuary two measurements were taken, one approximately 1 inch in depth from the surface the other one inch from the bottom. For any water sampling site that was inaccessible or too shallow to accurately measure, null data (0) was recorded. The reported water quality values by estuary was the average of the three surface and bottom measurements respectively. If an extra or duplicate measurement was taken, it was included in the average calculation. The process was repeated for all three estuaries. All raw data was saved on the probe itself, before being downloaded and stored as excel worksheets on computers.

2.4 Grab sampling

Once each quarter (3 months; Table 2) grab water samples were collected at the surface of the water at each of the three collection sites at each estuary. Quarterly grab water samples coincided with a monthly EXO1 probe sampling. A total of 28 lab-ready bottles, with labels and a cooler were used for each quarterly grab water sampling. Separate bottles were needed for nitrogen, phosphorous, and for chlorophyll-a lab analysis respectively. Because of this, 9 bottles per estuary were needed, 3 for each collection site during sampling. In addition, one duplicate was taken at random for only one site at one estuary in the survey to test for error. Grab water samples were collected in pre-cleaned bottles supplied by the analytical laboratory. In order to preserve quality, the samples were chilled in a cooler as soon as possible and kept refrigerated until testing. The laboratory used varied due to availability and cost of testing. All grab samples were documented on standardized field forms and sample bottles were labeled with the following: monitoring site ID, date and time of sampling event, and whether the sample is a QA/QC sample, duplicate, etc. This labeling was only necessary for the grab samples.
2.5 Calculations and Analysis

The EXO1 probe parameter collection methods and accuracy information are shown (Table 3).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Method number</th>
<th>Method Description</th>
<th>Method Reference</th>
<th>Instrument accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>170.1</td>
<td>Thermometer</td>
<td>USEPA 2003</td>
<td>0.1 C</td>
</tr>
<tr>
<td>Dissolved oxygen</td>
<td>4500-O</td>
<td>Membrane electrode</td>
<td>APHA 1998</td>
<td>0.03 mg/L (0.03%)</td>
</tr>
<tr>
<td>Conductivity</td>
<td>2510-B</td>
<td>x</td>
<td>APHA 1998</td>
<td>1.0 umhos/cm</td>
</tr>
<tr>
<td>pH</td>
<td>4500-H</td>
<td>x</td>
<td>APHA 1998</td>
<td>0.1s.u.</td>
</tr>
</tbody>
</table>

Table 3: In situ water quality parameter methods and instrument accuracy levels

Salinity (ppt) was determined from the measured conductivity (equation 1)

\[\{(\text{Cond (mS/cm)/1000})^{1.0878}\} * 0.4665 = \text{Sal ppt}\]  

(1)

Conductivity (Cond) was converted from microseimens per centimeter (µS/cm) to miliseimens per centimeter (mS/cm). Equation 2 was used to calculate unionized ammonia:

\[\text{UA} = \text{total ammonia (mg/l)*f/(f+1)}\]  

(2)

Where:

\[\text{pKa} = 0.09018 + 2727.92/T(C)\]

\[f = 1/(10^(\text{pKa-pH})+1)\]

\[T=\text{average temperature}\]
The \( f \) in equation 2 is representative of the fraction of un-ionized ammonia, and \( \text{pKa} \) is representative of the negative base-10 logarithm of the acid dissociation constant \((K_a)\) of the solution. The averages of chlorophyll, dissolved oxygen, pH, temperature, salinity were graphed in a linear scatter plot over time to identify trends. Zero values as a result of error, lack of measurement or values that were not significant were excluded in graphs. Some graphs included a “threshold line” or a marker to indicate steelhead tolerance.

2.6 Considerations

Estuaries are dynamic ecosystems that change with the seasons and weather, and are influenced in turn by the flora and fauna present. Analysis of all potential impacts from the surrounding environment was not feasible. Therefore, assumptions were made on the observable estuary ecology as well as unseen outside interacting forces. Firstly, based on park records and information given by the Creek Lands Conservancy, it was assumed that all selected estuaries sites currently support steelhead trout populations. Based on the findings of previous studies (Carter, 2005; Sutula, et al., 2014) it was assumed that measuring water quality variables can indicate the health or type of habitat available for species. In order to account for site conditions that alter water quality we will focus on identifying whether a specific site is “open” or “closed” during the sampling day. “Closed” conditions, when the outlet of the estuary to the ocean is blocked, are more common in the dry season. “Open” conditions, when the outlet of the estuary is open to ocean water, are more common in the wet season. For our samples, we assume that water quality measurements will not experience significant change if sampled slightly off the confirmed coordinates. Once the water samples have been taken and
preserved, we will assume the data remains accurate barring any unforeseen accidents or major complications. With these assumptions in mind, the study can expand and analyze the results of both the in-situ data from the probe, and the ex situ data from the water samples.
Chapter 3: RESULTS

3.1 Dissolved Oxygen

The presence of DO was recorded through the EXO1 probe. For the majority of recorded samples DO ranged between 10-6 mg/l until the month of July (Figures 10 and 11). Villa Creek estuary DO levels started fairly high in December, and had the highest recorded DO in April before dropping to below the fatal limit of 3 mg/l (Matthew and Berg 1997) for steelhead in July. The graph of bottom layer averages also has the most points below the DO concentration of stressful conditions for steelhead (Figure 11). In the month of July, there was a dramatic drop in dissolved oxygen content in the top and bottom layers in all three estuaries. In July Villa Creek experienced drops in DO below 4.0 mg/l in both top and bottom layers. Only one estuary in July had DO levels the critical threshold necessary for steelhead, which was San Simeon.

![Graph](image)

Figure 8: Dissolved oxygen in milligrams per liter for the top layer of estuary sites over course of study. Points below the red line are levels of do harmful to steelhead and other salmonid species.
Figure 9: Dissolved oxygen in milligrams per liter for the bottom layer of estuary sites over course of study. Points below the red line are levels of DO harmful to steelhead and other salmonid species.

3.2 Temperature

Measurements of salinity and temperature where both obtained using the measurements obtained through the EXO1 probe. There was only one instance of the average temperature rising above the lethal temperature of the steelhead trout. It occurred in December in the San Simeon estuary in surface water measurements (Figure 10). Across all the estuaries, Santa Rosa generally possessed the lowest recorded temperatures (both top and bottom layers) from January to June. Villa creek by contrast was the estuary that was the warmest from January to June. In the months of May through July, both the upper and middle sites of villa creek approached the lethal temperature for steelhead (Figures 10 and 11).
Figure 10: Average temperature in Celsius for the top layer of estuary sites over course of study. The area between the red line and light blue with red outline corresponds to the tolerated temperature for steelhead.

Figure 11: Average temperature in Celsius for the bottom layer of estuary sites over course of study. The area between the red line and light blue with red outline corresponds to the tolerated temperature for steelhead.
3.3 Chlorophyll

The presence of chlorophyll was recorded through both the probe and the grab sampling. Chlorophyll a is a measurement of algae growing in a body of water used to indicate the trophic level of the environment. The grab sample results showed that, chlorophyll a was zero for the majority of the measurements with the exception of Villa Creek and one measurement from Santa Rosa estuary. The estuary with the most consistent concentration of chlorophyll a throughout all samples was the Villa Creek estuary. In particular, in the month of December, the middle of Villa Creek had the highest recorded chlorophyll a value of 21.00 ug/l (table 4). The lower site at Villa Creek had chlorophyll a value detections in March and June. According to the results from the lab San Simeon did not have measurable chlorophyll a from the grab samples. The monthly probe samples measures general chlorophyll concentration in ug/l using spectrophotometry.

<table>
<thead>
<tr>
<th>Chlorophyll a of Estuaries (ug/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>site</td>
</tr>
<tr>
<td>Villa-upper</td>
</tr>
<tr>
<td>Villa-middle</td>
</tr>
<tr>
<td>Villa-lower</td>
</tr>
<tr>
<td>SR-upper</td>
</tr>
<tr>
<td>SR-middle</td>
</tr>
<tr>
<td>SR-lower</td>
</tr>
<tr>
<td>SS-upper</td>
</tr>
<tr>
<td>SS-middle</td>
</tr>
<tr>
<td>SS-lower</td>
</tr>
</tbody>
</table>

Table 4: Table of all recorded Chlorophyll a test results from quarterly grab water samples, darkness of orange highlight relates to the severity/largeness of measured value.

A majority of chlorophyll measurements gathered by the probe turned up negative meaning that the levels of chlorophyll present were negligible and therefore not necessary to graph. Consistently through all monthly samples, Villa Creek and San Simeon
Estuaries have chlorophyll detections, in both the top and bottom layers. Chlorophyll a was not detected in surface layer of the Santa Rosa estuary (Figure 12). Across all sites chlorophyll a was detected at bottom layers at consistently higher chlorophyll levels than the top layer (Figure 13). The largest recorded average of chlorophyll by the probe occurred in March at the top layer of the upper site of San Simeon estuary with an average of 76.51 ug/l (Figure 12). Another notable spike in chlorophyll was recorded in the San Simeon Estuary, at the bottom level of the middle site in February (Figure 13).

Figure 12: Chlorophyll in micrograms per liter for the top layer of estuary sites over course of study.
3.4 Salinity and Closure from the Ocean

Villa Creek estuary had the highest recorded salinity in both top and bottom layer averages for the majority of the year. The highest point of salinity occurred in Villa Creek estuary in March, and then the estuary experienced a sharp decline in salinity before rising in June. Across all estuaries sites, there is a dramatic drop in salinity of the top layers in April (Figure 14). A consistent trend across the top and bottom layers was the sharp decline in salinity in the San Simeon and Santa Rosa estuaries. Santa Rosa initially had the highest salinity in December, but after January, salinity rarely reaches above zero. This trend is also seen in all data collection sites at San Simeon. Villa Creek, in all sites in both upper and lower water layers had the most variation in salinity.
Figure 14: Salinity in parts per thousand for the top layer of estuary sites over course of study.

Figure 15: Salinity in parts per thousand for the bottom layer of estuary sites over course of study.
Tracking and recording an estuaries closure from the ocean was done visually by confirming a lack of flow or significant landmass between the ocean and estuary with photos taken for the record. Villa Creek estuary experienced the most interaction with the ocean, with the only one closure recorded in July (Table 5). The San Simeon and Santa Rosa estuaries had a close number of “closed” months. All months where San Simeon estuary was closed were also months that Santa Rosa was closed. Santa Rosa was the estuary that was the most closed off from the ocean in the sampling year, with Five months total (Table 5). Both Santa Rosa and San Simeon had periods of temporary closure from the ocean starting in February, experiencing a brief opening in April (March and April for san Simeon) before being closed off from the ocean for the rest of the sampling months (Table 5).

<table>
<thead>
<tr>
<th>dates</th>
<th>Villa Creek</th>
<th>Santa Rosa</th>
<th>San Simeon</th>
</tr>
</thead>
<tbody>
<tr>
<td>12/11/2019</td>
<td>open</td>
<td>open</td>
<td>open</td>
</tr>
<tr>
<td>1/25/2020</td>
<td>open</td>
<td>open</td>
<td>open</td>
</tr>
<tr>
<td>1/26/2020</td>
<td>open</td>
<td>open</td>
<td>open</td>
</tr>
<tr>
<td>2/15/2020</td>
<td>open</td>
<td>closed</td>
<td>closed</td>
</tr>
<tr>
<td>3/14/2020</td>
<td>open</td>
<td>closed</td>
<td>open</td>
</tr>
<tr>
<td>4/24/2020</td>
<td>open</td>
<td>open</td>
<td>open</td>
</tr>
<tr>
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<td>closed</td>
<td>closed</td>
</tr>
<tr>
<td>6/25/2020</td>
<td>open</td>
<td>closed</td>
<td>closed</td>
</tr>
<tr>
<td>7/29/2020</td>
<td>closed</td>
<td>closed</td>
<td>closed</td>
</tr>
</tbody>
</table>

Table 5: All recorded instances of “open” and “closed” conditions at study estuaries.

3.5 pH and Toxic Ammonia

The average pH was recorded with the EXO1 probe and used along with total ammonia measurements from lab testing to calculate the unionized ammonia for the respective estuary site. The average pH in the top layers of the estuaries remained relatively consistent (Figure 16). In the lower site of Villa Creek estuary in May, an
acidic value of 5.40 pH was recorded in the bottom layer (Figure 17) however this low pH was not measured in the surface layer (Figure 16). Over the course of sampling, Santa Rosa and San Simeon had fairly consistent pH values. In the top and bottom averages of the Villa Creek sites, pH noticeably dips in January, and then rises again in May and June.

![Figure 16: Average pH recorded for the top layer of estuary sites over course of study.](image)

In both top and bottom averages, San Simeon generally had lower pH values than the other estuaries (Figures 16 and 17). Another trend that is present is that the majority of recorded pH averages are slightly basic (>7.5) in both the top and bottom layers of the data sites.
Figure 17: Average pH recorded for the bottom layer of estuary sites over course of study.

The concentration of unionized ammonia present at each estuary collection site was calculated from grab sample measurements. Unionized ammonia was most notable in the month of December at Villa Creek estuary. In June, moderate levels of unionized ammonia were found in all three estuaries in the study. Values of unionized ammonia greater than 0.025 mg/l begin to negatively impact aquatic life (Eddy, 2005). The highest recorded measurement of unionized ammonia occurred in Villa Creek at 2.30 mg/l in December (Table 6). In March no significant value of toxic ammonia was recorded. In June, unionized ammonia rose again, and once more Villa Creek had the largest recorded values. The Estuary that consistently had the lowest concentrations of unionized ammonia was San Simeon (Table 6).
<table>
<thead>
<tr>
<th>site</th>
<th>December</th>
<th>March</th>
<th>June</th>
</tr>
</thead>
<tbody>
<tr>
<td>Villa-upper</td>
<td>0.58</td>
<td>NA</td>
<td>0.10</td>
</tr>
<tr>
<td>Villa-middle</td>
<td>0.40</td>
<td>NA</td>
<td>0.23</td>
</tr>
<tr>
<td>Villa-lower</td>
<td>2.30</td>
<td>NA</td>
<td>0.23</td>
</tr>
<tr>
<td>SR-upper</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>SR-middle</td>
<td>0.51</td>
<td>NA</td>
<td>0.20</td>
</tr>
<tr>
<td>SR-lower</td>
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<td>NA</td>
<td>0.12</td>
</tr>
<tr>
<td>SS-upper</td>
<td>NA</td>
<td>NA</td>
<td>0.17</td>
</tr>
<tr>
<td>SS-middle</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>SS-lower</td>
<td>NA</td>
<td>NA</td>
<td>0.11</td>
</tr>
</tbody>
</table>

Table 6: Unionized ammonia lab test results organized by month and data collection site. Intensity of orange coloration is related to ammonia toxicity. Red is highest recorded value.
Chapter 4: DISCUSSION

4.1 Noticeable Results from Villa Creek Estuary

The estuary that possessed one month of low DO as well higher instances of unionized ammonia and temperature than the other estuaries, was Villa Creek. In a few instances, one or more parameters of the water quality of Villa Creek estuary were above or below stressful levels to steelhead. The most notable event observed in the monitoring of Villa Creek estuary came in July where the oxygen content in all collection sites was near or below 3.0 mg/l. This level of DO can be lethal to Steelhead (Matthew and Berg, 1997). In December 2019, Villa Creek’s unionized ammonia levels were high enough for the Creek Lands Conservancy to contact the local community in concern for the estuaries’ water quality. Villa is mostly exposed to ranching and farm land. The results of this projects sampling may support the theory that agriculture is having adverse impacts on Villa Creek estuary. Previous studies have also noted that concentrations of ammonia, nitrogen and phosphorous increased in coincidence with spatial proximity and timing of agricultural activities near estuaries (McLaughlin et. al, 2017).

The salinity recorded in the estuary was consistently higher than the other estuaries with the exception of March. This high variance in salt content could be due to the mostly uninterrupted access to the ocean (Table 5). There was one instance in May where temperature exceeded the tolerance limit for steelhead in Villa Creek estuary, but this only occurred in the bottom layer of the middle site. Despite having a higher temperature as well as salinity than the other estuaries in May and June, the dissolved oxygen of Villa Creek remained relatively high in the middle and lower data collection sites in the same months.
In December and June unionized ammonia was present in levels above 0.025 ppt in all data collection sites. A threshold that could indicate potential stressful conditions for aquatic organisms (Eddy, 2005). In July, Villa Creek estuary experienced high pH, temperature and Salinity which coincided with dissolved oxygen well below 7.0 mg/l at all collection sites. The sample results support that Villa Creek estuary is prone to conditions adverse for steelhead and aquatic life, in particular with periods of high temperature, low dissolved oxygen, or unionized ammonia presence.

4.2 Noticeable Results from Santa Rosa Estuary

The second estuary to show some concerning spikes in toxic ammonia levels in December and June, was Santa Rosa. While Villa Creek had higher levels of unionized ammonia in December and June, Santa Rosa estuary had detectable unionized ammonia only in the middle and lower collection sites. One noticeable occurrence in both the top and bottom water layers of Santa Rosa was a decline of salinity where salinity remained close to zero from January through the end of sampling. A recurring trend seen in Santa Rosa estuary’s water quality was a stable pH between 7.0 and 8.5. Santa Rosa also experienced some of the most dramatic changes in water depth as the majority of the lower and middle layers dried up by June. This connects to the high occurrence of closed conditions recorded in the field notes.

4.3 Noticeable Results from San Simeon Estuary

The estuary that had the lowest detection of unionized ammonia was San Simeon. There was two of three samples with detections of unionized ammonia in San Simeon at the end of June. Throughout the sampling year, San Simeon and Santa Rosa estuaries had
similar trends in Salinity. Both estuaries had reductions in salinity in both top and bottom layers starting in February where salinity was close to Zero for the rest of this study’s time period. Seeing as both estuaries where closed off from the ocean for relatively the same time and during the same months, this could explain the shared trend in salinity and perhaps other characteristics as well.

Another interesting trend in San Simeon was sharp rises in chlorophyll levels in March, as measured by the EXO1 probe. The spikes in chlorophyll in San Simeon estuary corresponded with a few slightly lower dissolved oxygen measurements in March, but a correlation between the two cannot be confirmed with the data. There is also the possibility that the probe recorded the high chlorophyll value in March in error.

For the majority of sample months all three estuaries had a similar expected trend line for temperature where it climbed higher into summer from winter. An exception was found in December at all collection sites of San Simeon where temperatures were recorded above the lethal limit for steelhead. As steelhead populations generally start spawning in January, they could be potentially exposed to such temperatures at the start of spawning (Zaitlin, 2009). However this reading could be a technical error. The spike in temperature could also be due to the timing of the estuary sampling, as San Simeon was the last estuary to be sampled in the day and therefore was closest to high temperature at noon. This is the only notable acceptation as San Simeon’s temperature lines up close to the other estuaries for the rest of the sampling year.

4.4 Uncertainty in Results

To improve the overall methodology and strengthen analysis of the results I would recommend some changes. First an analysis of the relation of sand-bar breaching
and water level to water quality. At the planning stage of the project, there was consideration to incorporate water level data from monitoring probes present at each estuary. However data was not available from the water level sensors early enough in the data analysis process. Second, this project had a relatively simple methodology and analysis but suffered from some quality assurance problems. Most notable are the early testing months of January, February, and March where the number of EXO1 probe measurements per data collection site varied. In the first month there was a greater degree of human error with the probe, and inconsistencies in labeling of data measurements. In the month of January, a technical issue with the probe itself required another excursion the day after to retake measurements of two estuaries.

The measurement of surface and benthic water may have led to error. As multiple surveyors participated in sampling, constant technique in measuring top vs bottom water layers may have occurred. Between the results for the top and bottom levels, there were few notable differences in water quality trends. Somewhat expected for example; bottom levels tended to have lower temperatures and higher level of salinity. Bottom level results tended to have the most variation and more zero/immeasurable values across measurements when compared to upper levels. This is most likely due to due to loss of water depth in summer months, eliminating this layers measurement. For the majority of the results, for each estuary trends the top layers are reflected in the bottom layers as well. The consistency may show that there was not much need to differentiate between top and bottom water layers in these estuaries.

After March, the rise in Covid-19 in California interrupted lab analysis of estuary water grab samples at Cal Poly which led to the samples expiring and loss of data. The
pandemic also lead to closures of parks and campgrounds which limited access to the San Simeon estuary. Only the middle and lower data collection sites could be accessed in the months of April, May and June. The closures also extended to SLO Campus and general stay at home orders, as such the primary surveyor (Xander Taylor) had to rely on another trained sampler (Sarah Russ) from the Creek Lands Conservancy to gather data for the months of April, May and June. This switch in sampling personnel may have led to inconsistencies and errors with the project data.

4.5 Improvements for Future Study

In future sampling years, improvements should start with standardizing the sampling protocols and training field technicians these protocols. Many aspects of the sampling can be based on visual judgments (open or closed conditions, top and bottom layers) training multiple surveyors on these interpretations is a necessary first step. Ideally, future grab sample analysis would maintain a consistent lab for testing. This, however, may not be plausible due to budget uncertainty. Once a sampling protocol can be refined, future studies could be extended to more estuaries in the area. Analyzing estuaries more distant from each other, or who have more dramatic variations in geology or climate could show more significant trends in water quality. In addition to including more estuaries in the study, increasing the overall length of the study would be beneficial to the data analysis.

I would recommend future changes and additions to the data analysis. Primarily there should be a greater focus of the role of water depth. As mentioned earlier we were unable to obtain tide and water level measurements from probes stationed at the three estuaries. While the tide and water level data is being recorded separately, comparing that
data with water sampling measurements could give more insight on to the effect of ocean access and tidal flow on the water quality in the estuaries. There appeared to be a lot of consistency between top and bottom layers of the estuary water, with the exception of temperature and salinity.

In order to further improve the data analysis, more primary research should be focused on the life cycle of the steelhead, primarily the migration habits of the trout. It is vital to remember that while water quality may be poor for steelhead at one collection site, the fish could simple move to other locations in the estuary where conditions are tolerable. While the general timeline for spawning ranges from January to April, the initial start or return migration can vary with the particular population. In particular for these estuaries it is beneficial to know where the steelhead populations are summer-run or winter-run. Summer-run populations return to the fresh water in an immature state while winter-run populations arrive in a more mature and developed state (Arciniega et. al. 2016). Identifying specific attributes of the populations would be helpful, but may be limited to empirical research or sourced from local fishing organizations.

The current sampling system also leads to many unreportable measurements due to lack of “bottom” layer measurements. For future sampling, I would recommend an analysis on how much depth is needed for significant difference in water. In addition to comparing the top and bottom level measurements there should also be comparisons of individual data collection sites (upper, middle, lower estuary zones). Separating data in this way would help form a more accurate analysis in determining origins of issues in estuaries.
With consideration regarding these issues taken, continuation of similar estuary monitoring in the future would provide more accurate and usable data for the Creek Lands Conservation. Continuous water quality analysis would support efforts for the protection or restoration of central California estuaries.
Chapter 5: CONCLUSIONS

The goal of monitoring the Villa Creek, Santa Rosa Creek, and San Simeon Creek estuaries was to determine if and when water quality adverse to the steelhead trout occurred and to develop a database to provide a basis for future studies and management. Using trend line and graph analysis, the trends shown enabled some insights in the seasonal suitability of steelhead trout. Generally water quality parameters of dissolved oxygen and temperature were within tolerance limits of steelhead trout. The exception was a drop in dissolved oxygen in Villa Creek in mid-summer to below a lethal threshold for steelhead. The warmest estuary temperatures were during summer, in all estuaries, with one very high temperature occurrence in San Simeon Creek in December 2019. Unionized ammonia was present at levels greater than 0.025 mg/l, a threshold that could indicate potential stressful conditions for aquatic organisms, in all three of the estuaries in the summer quarter sample (June 2020). Incomplete sampling in December 2019 and March 2020 did indicate unionized ammonia in the estuaries where lab analysis was done. Notably Villa Creek had a particularly high reading of unionized ammonia in December, 2019 at 2.30 mg/l. San Simeon Creek showed the highest chlorophyll levels, of the estuaries, during spring. The grab water samples for San Simeon Creek in March were not analyzed in time for Chlorophyll so could not validate this occurrence. However with the higher chlorophyll levels a few sites had slightly lower in San Simeon Creek estuary. The interaction of the 2 parameters does not appear to be significant but should be watched over time. It does suggest a possibility for eutrophic conditions if algal levels were to get extremely high in the future.
What has been recorded in this project shows not only the conditions present in three San Luis Obispo County estuaries but the importance of continued water quality monitoring of coastal estuaries and the species that rely on them.
References


Publications

The results of this project will be published by California Polytechnic State University, San Luis Obispo at the library and online in the Digital Commons. The findings from the study will be published in a manuscript to be submitted to The Cal Poly SLO Library. Abstracts will be prepared and submitted for potential presentations at The California State Parks Office and the California Creek Lands Conservation office.