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Evaluating Good Water Quality Habitat for Steelhead in Carmel Lagoon

Fall 2009

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Disclaimer:

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Executive Summary

This report describes the research conducted as part of a class project by students in the Advanced Watershed Science and Policy (ENVS 660) course at California State University Monterey Bay. The course focused on documenting and learning about water quality and habitat for steelhead in the Carmel Lagoon. The overarching goal of the project was to estimate the amount of good water quality habitat (GWQH) in the lagoon. GWQH was defined as areas of the lagoon with a dissolved oxygen concentration greater than 5 mg L^{-1}, salinity less than 10 ppt, temperature greater than 26 degrees Celsius, and water depth greater than 0.5 m.

There were four specific goals:

Goal 1: The first goal was to examine the ability of a permanent sonde to capture GWQH changes in the Carmel Lagoon South Arm due to lagoon closure, loss of river connectivity, and artificial freshwater inputs between September 2008 and October 2009. Time periods when these events occurred were analyzed using plots of the data to infer the effects of these events on GWQH. We found that the sonde data provided measurement of the effects of breaching, closure, and wave-overtopping in far greater temporal detail than would be possible with manual measurements. Some of this detail elucidated important information about hitherto poorly understood processes that may be important influences on steelhead habitat in the lagoon. These include the nature of diurnal respiration leading to oxygen depletion following wave-overtopping, and diurnal mid-water photosynthesis leading to an oxygen enriched layer under certain stratified conditions in spring in fall. In the year monitored, the sonde did not record substantial effects due to artificial freshwater inputs, or post-breach fluctuations in river flow.

Goal 2: The second goal was to examine the spatial variation in GWQH in the lagoon and to determine the effectiveness of using a single fixed automatic sonde at site S2 as an indicator of water quality parameters throughout the lagoon. This was achieved using data collected twice a month from a kayak at five locations throughout the lagoon from October 2008 through October 2009. Results revealed that there was substantial spatial and temporal variation in GWQH throughout the lagoon over the time period examined in this report. Specifically, some areas such as location N2 exhibited only 9% of total GWQH-thickness, while location S2 exhibited 46% of GWQH thickness. Ultimately, these results suggest that using the automated sonde to estimate total GWQH in the entire lagoon may prove to over-estimate the true amount of GWQH as other areas tended to have lower amounts of GWQH. However, the degree of over-estimation is somewhat consistent, so a correction factor could be developed and applied to future sonde data in order to provide an approximate lagoon-wide estimate of GWQH.

Goal 3: The third goal was to examine the postulate that a phytoplankton community caused super-saturated oxygen conditions at the halocline of the lagoon. Such conditions are beneficial, since they represent a source of dissolved oxygen that may be utilized by fish and their prey. This postulate was examined by analyzing water samples for phytoplankton identification. Water samples were collected at site S2 on October 13th, 15th, and 20th of 2009. When the halocline was present, we took samples 10 cm below and above the halocline. When there was no halocline present, samples were taken from the bottom, middle, and surface of the water column. Results from microscopy analysis revealed that when a halocline was present, there was a unique dinoflagellate present in the samples. This dinoflagellate, however, was absent in samples collected when there was no halocline or super-saturated zone of oxygen, providing support for the idea that the super-saturated zone may be due to phytoplanktonic oxygen production. It is possible that the taxon responsible for this super-saturation has very specific habitat requirements (salinty & temperature) that could be monitored and optimized through lagoon management.

Goal 4: The fourth goal was to evaluate the use of low-cost sonar equipment to measure fish abundance and produce substrate/habitat maps of the lagoon. To examine the suitability of using of low-cost sonar equipment we completed nine transect surveys of the lagoon on October 20th and 25th of 2009. Surveys were conducted using a Humminbird 1197c sonar system with single-beam sonar, sidescan sonar, GPS, and fish detection capabilities. A total of 22 fish were detected on October 20th and 59 fish on the 25th of 2009. Additionally, the highest numbers of fish detections were observed at the south arm of the lagoon near location S2. Results from the habitat classification maps revealed four main substrate types in the lagoon: silt, silt/submerged vegetation, sand, and gravel. Overall, we were able to quantify fish and habitat types to a certain extent, but our surveys were limited to open water and a narrow 60° angle of coverage below the sonar equipment. Additionally, we were unable to confirm the accuracy of fish detections as we had no comparison fish count data available for when we conducted our surveys. The habitat map in particular revealed that the Odello restoration created substantially different habitat (shallow with profuse epibenthic vegetation) to the pre-existing lagoon habitat such as the deep water of the south arm, or the tule-lined sparse-benthic channels of the north arm.

Future work that would facilitate improved management of the lagoon for steelhead includes: development of software technology to allow real-time on-line visualization of sonde telemetry data in the color graphical format developed here to facilitate rapid management response to poor conditions, further investigation of the microalgal taxa responsible for super-saturation to facilitate possible deliberate management of the lagoon to optimize and expand super-saturated zones, and more thorough and detailed development of the sidescan-based technologies as a basis for better determination of how far beyond the original south arm suitable steelhead habitat actually exists.

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1 Introduction

1.1 Background

California coastal lagoons offer steelhead trout (*Oncorhynchus mykiss)* important habitat by providing connectivity between the upper watershed and the ocean, spatial and temporal refuge for juvenile fish, and a gradual transition between fresh and marine conditions (Smith 1990). However, California's Mediterranean climate provides significant seasonal fluxes in lagoon hydrologic dynamics and water quality parameters. During lower-flow summer conditions, a sand bar at the mouth of coastal streams and rivers can form (Schwarz and Orme 2005). With sufficient freshwater inflow, lagoons remain well-mixed and oxygen rich, supporting juvenile steelhead growth (Bond et al. 2008). During periods of low dissolved oxygen or water temperatures, steelhead may move upstream in search of cooler, more oxygen rich water (Hayes et al. 2008). As summer temperatures cool with the transition to autumn, the lagoon becomes increasingly stratified with respect to temperature and salinity. Corresponding with the maturation of juvenile steelhead, the increasingly saline lagoon bottom provides for saltwater acclimation and enhanced smoltification (Smith 1990, Bond 2006). With the approach of the late autumn or winter wet season, rapidly increasing watershed discharge forcefully ejects the sandbar at the mouth of the lagoon and allows steelhead smolts to move out to sea.

Steelhead trout populations have declined throughout their postulated historical California range as a function of habitat and land use changes and associated reductions of streamflow from water diversions and dam construction (Nehlsen et al. 1991; Busby et al. 1996). The environmental parameters that make up the good water quality habitat (GWQH) needed to support successful steelhead growth and smoltification are particularly sensitive to the artificial hydrologic impacts introduced as a result of development within the upper watershed and in the lagoon flood plain (Watson and Casagrande 2004). Steelhead GWQH includes environmental parameters such as low to mild temperature, high dissolved oxygen, low salinity, sufficient flow to maintain mixing and sufficient depth to reduce stratification and avian predation (Smith 1990, Bond 2006).

Water temperature, dissolved oxygen, and salinity have an effect on both growth rate and survival of juvenile steelhead (ISU 2008). Maximum juvenile steelhead growth rates have been reported between 15 °C and 19° C, with some variation between strains and under different water quality conditions (Wurtsbaugh and Davis 1977, Handeland & Stefansson 2002, Myrick and Cech 2004). Summer lagoon temperatures can rise substantially and at times may approach or exceed the tolerance level of steelhead, ~ 26° C (Myrick and Cech 2004). Dissolved oxygen (DO) is extremely important for fish survival and growth, with best health for cold water fish above 4 mg/L (ISU 2008). Oxygen depletion can be

caused by increasing water temperatures, the decay and respiration of organic waste and aquatic organisms (ISU 2008). Although increased salinity to ocean levels is not lethal to pre-smolt steelhead, growth rates decrease with increasing salinity (Handeland & Stefansson 2002). The higher quantities of macro-invertebrates available in coastal lagoons result in increased growth rate and ultimate size of lagoon-reared steelhead (Bond 2006, Hayes et al. 2008). Sufficient size is essential for to steelhead survival and success in the ocean environment with an accordingly low survival rate of fish smaller than 150 mm (Ward et al. 1989, Bond 2006). Avian predation also drives a depth component of GWQH (Kennedy et al. 2007).

1.2 Project Goals

The goals for this report were four-fold:

1) Evaluate a fixed water quality sonde in the south arm of Carmel Lagoon for its effectiveness in monitoring changes in GWQH over time as a function of lagoon closure, loss of river connectivity, cold water inputs and well operation.
2) Determine whether the fixed water quality sonde data effectively represented or indicated changes in water quality throughout the lagoon
3) Investigation whether a microalgal community was responsible for recurrent mid-column oxygen super-saturation
4) Measure and describe the physical parameters of juvenile steelhead habitat using sonar sounding techniques.

These goals are addressed respectively in each of the subsequent four sections of this report.

1.3 Study Area: Carmel Lagoon

The Carmel River Lagoon, located at the mouth of the Carmel River on the central California coast, has been designated critical habitat for federally threatened steelhead trout (NOAA, 2005). The Carmel Lagoon consists of the outlet of the Carmel River into the main lagoon, a relatively short north arm (North Arm), and a long south arm (South Arm) including the Odello Expansion (Fig. 1). During low flow summer and early autumn conditions, a recurrent sandbar prevents the lagoon from draining into the Pacific Ocean. The pooling lagoon behind the sandbar offers approximately 16,000 m^3 of GWQH and gradual acclimation to increasingly saline concentrations for maturing juvenile steelhead (ESSP 660, 2008). Areas of the lagoon that are permanently flooded include the main embayment, the South Arm, a small portion of the North Arm, and a portion of the new Odello Extension (Casagrande 2006).

Decreased summertime freshwater discharge into the lagoon can result in increased lagoon salinity and stratification (Watson & Casagrande 2004). Freshwater diversions, primarily through groundwater extraction from the upper Carmel River Watershed, amplify the effect of reduced seasonal freshwater flow into the lagoon and can result in complete disconnection with the watershed (Watson & Casagrande 2004). To mitigate reduced freshwater inflow from the Carmel River, freshwater has periodically been released directly into the lagoon or onto the adjacent ground above a shallow aquifer connected to the lagoon by the Carmel Area Wastewater District (CAWD) from the nearby treatment plant, or by CDPR and CRSA from a nearby well.

When winter high discharge events breach and erode the sandbar at the mouth of Carmel Lagoon, nearly the entire lagoon volume can drain within hours, resulting in a significant and persistent alteration of GWQH. Beginning in the early 20th century, local residents and beach users began manually breaching the sandbar prior to natural breaching, to prevent flooding of low-lying homes adjacent to the lagoon within the historic flood plain (ESSP 660, 2008, Larson et al. 2006). More recently, the Monterey County Public Works Department in conjunction with the Monterey County Water Resources Agency (MCWRA) has regularly breached the lagoon hours to days earlier than it would breach naturally (Entrix, 2001). This is done as an emergency action to prevent a threat to public health and private property (ESSP 660, 2007).

Figure 1: Carmel Lagoon study area (ESSP 660, 2007)

2 Habitat Analysis – Sonde Measurement of Water Quality Temporal Variation

2.1 Goal

The goal of this section was to evaluate the effectiveness of the permanent sonde in measuring GWQH changes in the Carmel Lagoon South Arm due to lagoon closure, loss of river connectivity, Carmel Area Wastewater District (CAWD) water release and well operation between September 2008 and October 2009.

2.2 Methods

For our analysis, we examined water quality data recorded by the permanent sonde installed in the South Arm of Carmel Lagoon from 10/01/2008 through 11/02/2009 (K. Gray, Personal communication, California Department of Parks & Recreation, Monterey). Over this period of time, the sonde recorded salinity, dissolved oxygen, temperature and pH data every four hours starting 12am daily. Beginning at 0.6 meters below the water surface, the sonde recorded water quality data at 0.6 meter intervals until the bottom of the lagoon. Using R statistical software (RDCT 2009), we graphed the sonde output for each water quality variable on a time – water elevation plot (Fig. 2). We interpolated between readings to produce solid color graphics and displayed the full range of values for each variable by color variation. Using the plot, we compared water quality conditions before and after the timing of known periods of lagoon closure, loss of river connectivity, and freshwater release. We determined periods of lagoon closure by the slow incline in the hydrograph measured by a pressure sensor mounted adjacent to the sonde. We estimated the loss of Carmel River connectivity by complete drops of the hydrograph from the USGS gage *Carmel nr Carmel* (USGS 2009). The Carmel River Steelhead Association (CRSA) provided data on the timing and volume of fresh water pumping into the lagoon. To determine whether the sonde measured changes in lagoon water quality following lagoon closure, we focused on sonde output after the closure event on May 18, 2009. During this time, the gradual incline in the hydrograph corresponded with lagoon closure. To examine whether the sonde measured GWQH changes due to loss of connectivity between the Carmel River and the Carmel Lagoon, we examined the sonde output around 7/6/2009 when Carmel River discharge ceased (as measured at the Highway 1 Bridge (USGS 2009)). To study whether the sonde measured changes in GWHQ due to artificial freshwater inputs into the lagoon, we examined time periods where documented freshwater inputs occurred.

2.3 Results

We found that the GWQH data collected by the sonde reflected changes to lagoon closure, however, the GWQH consequences of loss of river connectivity, Carmel Area Wastewater District (CAWD) water release and well operation cannot be interpreted from Sonde output alone. Specifically:

1) The sonde captured changes in lagoon water quality that occurred in the spring season after lagoon closure events and the final closure on 05/18/09 (Fig. 3). Following lagoon closure, a freshwater lens appeared, water temperature began to increase, and isolated zones of super-saturated oxygen appeared.
2) The sonde did not detect any apparent water quality changes associated with seasonally reduced flow and disconnection between the Carmel River and the Carmel Lagoon (Fig. 4). The water level receded during the summer months until an approximately constant level was reached. The sonde recorded higher temperatures associated with summer weather and diminished cold water input from the Carmel River.
3) The consequences of wave overtopping events were clearly measured by the sonde. Over-topping events occurred in early February 2009 (about a week prior to a very late breach) and again in Fall (9/12/09) (Figs 5 & 6). Following these events, water level increased, temperatures decreased, salinity increased. Importantly, dissolved oxygen also decreased although not necessarily immediately. The February event appeared to set the stage for the development of a low-oxygen deeper layer and resulting reduction in the thickness of suitable habitat that had not existed prior to wave over-topping. The fall event lead to a more immediate reduction in DO throughout the water column, modulated by a diurnal respiration cycle presumably associated with decaying organic matter washed in by the waves.
4) The sonde measured reconnection of the river to the lagoon as a jump in water elevation on 2/14/09 (Fig. 5), a general decrease in salinity, and a transition to a period of more variable temperature and DO profiles driven most likely by short-term variations in tide, streamflow, and wave energy.
5) The Carmel Area Wastewater District (CAWD) did not add freshwater directly to the lagoon from the treatment plant in 2008 or 2009, but CDPR and CRSA add water from a well via percolation into the ground near the lagoon (F. Emerson & L. Meyers, personal communications 2009). This well-water was added between July 14 and October 14, 2009 at a rate of approximately 790,000 gallons per day (equivalent to 1.23 cfs). The sonde did not measure clear changes in GWQH resulting from these additions in 2009, but may have done so in a year where the preceding conditions were not as fresh as they were in 2009.

In general, the permanent sonde provided far more detailed and frequent information about water quality conditions than was previously possible when collecting data manually.

The sonde may have 'missed' some important details that occur briefly, or in a very localized surface layer. During short lived events, such as sandbar breeching, the permanent sonde may miss important water quality information between readings such as reduced DO under H_2S influence. Programming the sonde to record more frequently during breeching events would increase the likelihood of capturing the changes in the lagoon during such events. The sonde also might have missed important changes in surface water quality characteristics because the first readings started 0.6 meters below the water surface, excluding a layer where steep gradients in water quality parameters exist (Fig. 7).

Some unexplained drift in the alignment between the MPWMD stage readings and the sonde depth readings resulted in some uncertainty regarding the true Lagoon elevation. This should be corrected in future.

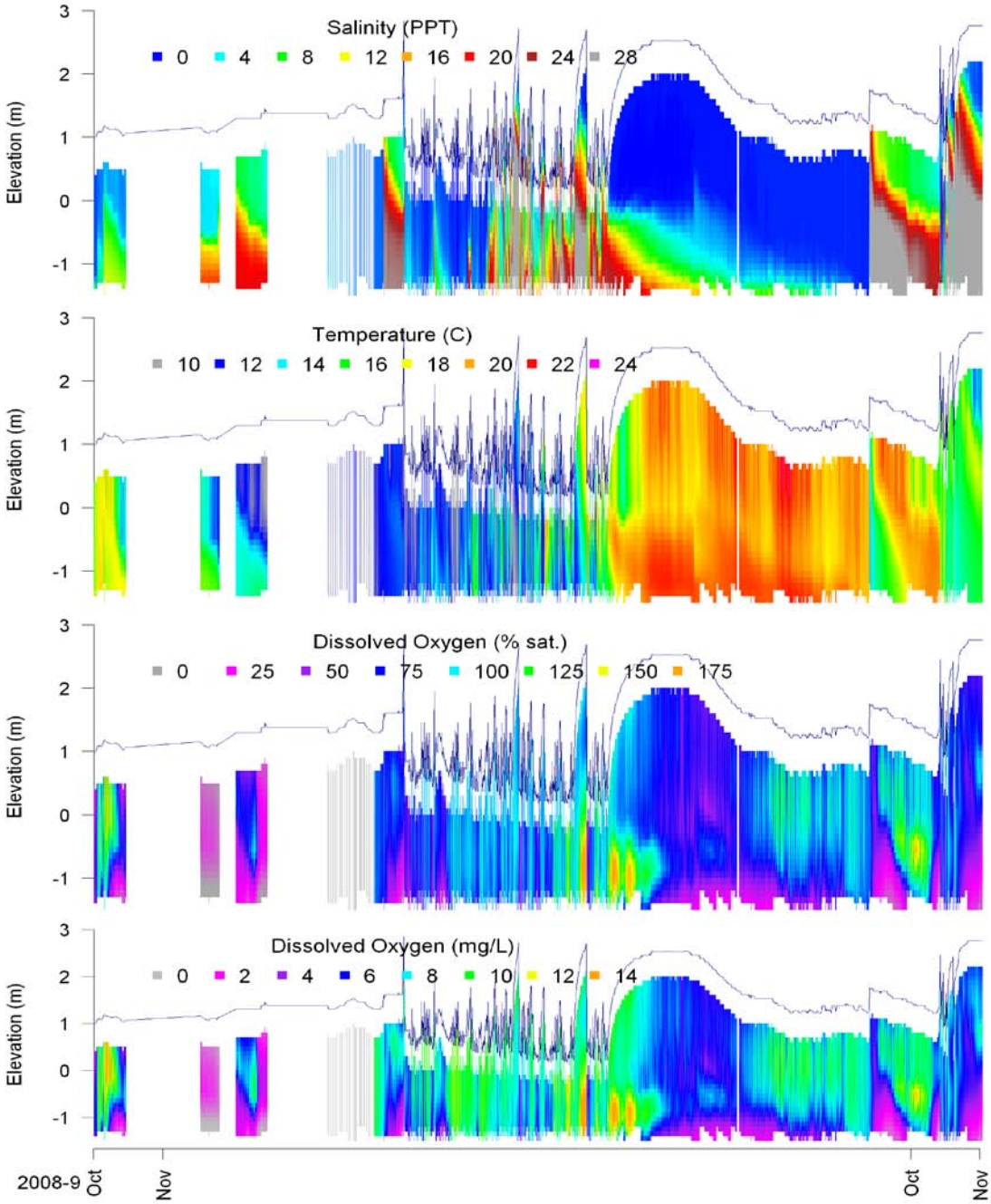

Figure 2: The automated sonde recorded water quality variables from 10/01/08 to 11/02/09 with some periods of inoperability presumably for maintenance. The top 0.6 meters of the water column were not measured by the sonde.

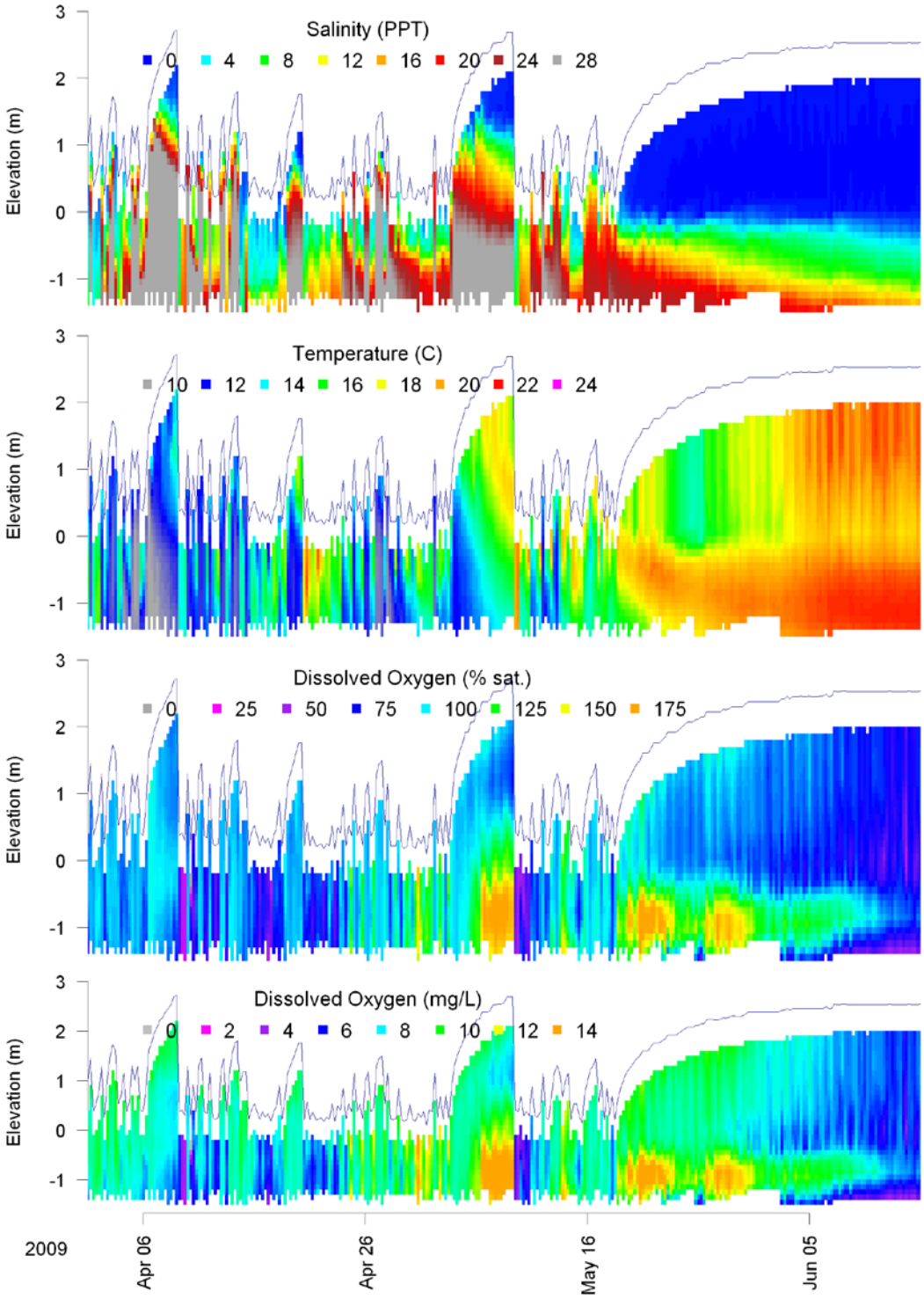

Figure 3: Spring season 2009 demonstrated variability of both the hydrograph and water quality in the lagoon. Post bar-closure conditions are represented by the gradual rise in water level, and bar-breaching is represented by a subsequent drop. As the water warms and stratification occurs, there are periods of high dissolved oxygen depicted by the yellow- orange spectrum in the bottom graphs.

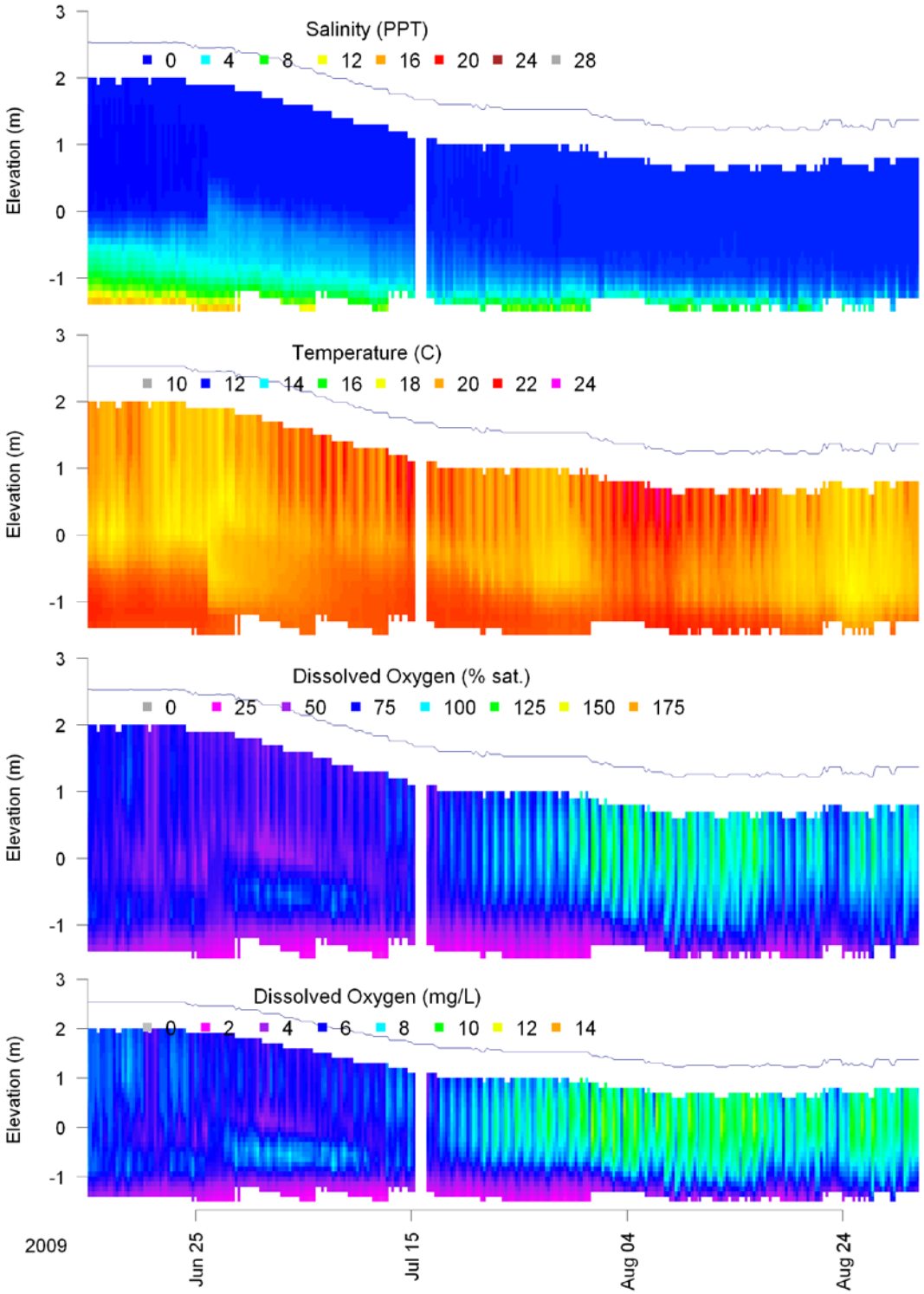

Figure 4: Between 06/15/09 to 09/01/09 the lagoon experienced a gradual decline in water level stabilizing at ~ 1.2 meter stage by MPWMD readings. Intermittent intervals of low dissolved oxygen (2-4 mgL^{-1}) were evident in much of the water column from June 21 through July 13 . High temperatures are depicted for much of the summer peaking from August 3 – 9 above 20˚C through most of the water column.

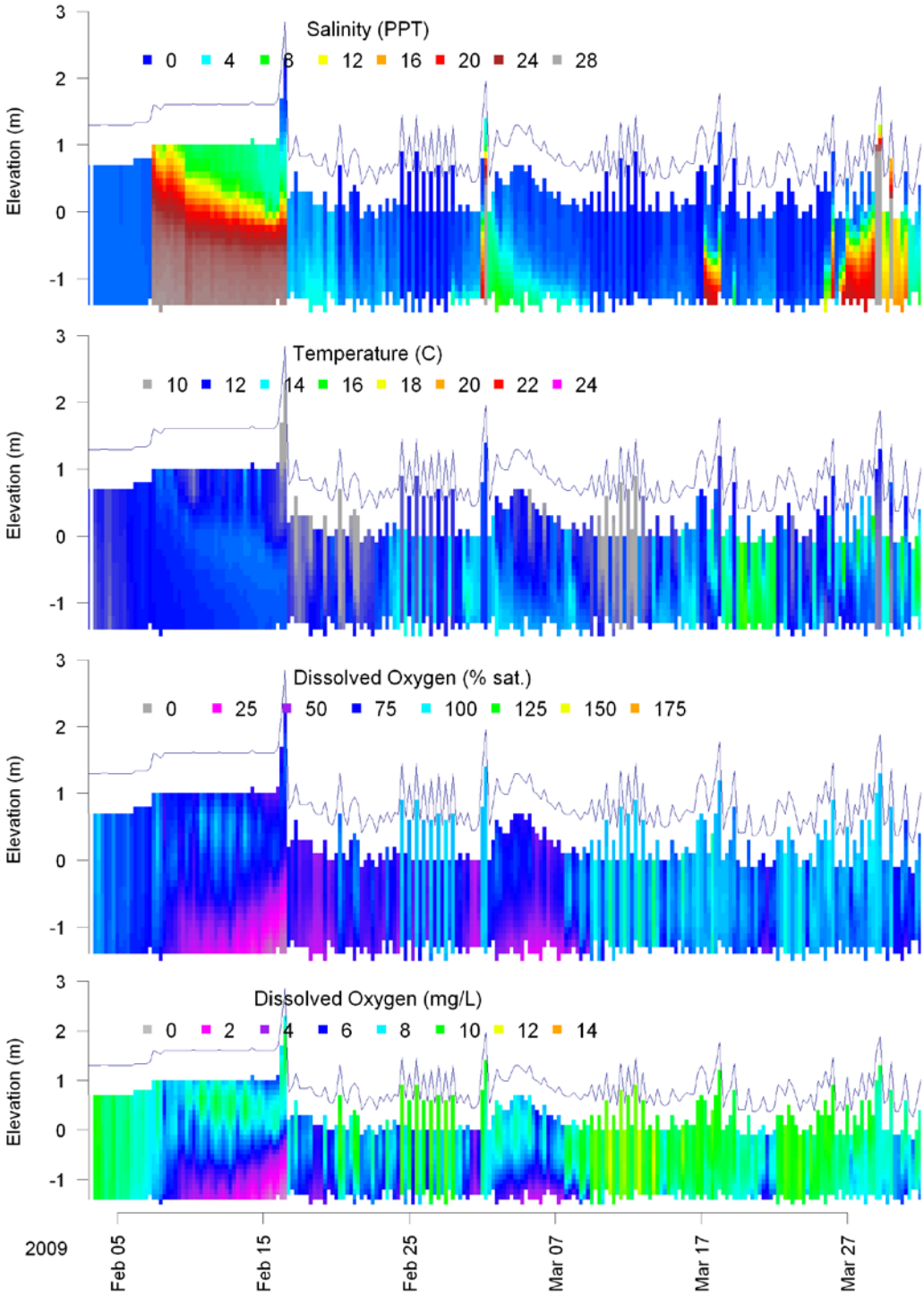

Figure 5: Carmel Lagoon winter water quality conditions from 02/03/09 through 03/31/09. An elevation peak on 02/15/09 resulted from the Carmel River reconnecting with the lagoon. The first breach of the sandbar of the year on February 16 resulted in a sudden drop of lagoon elevation.

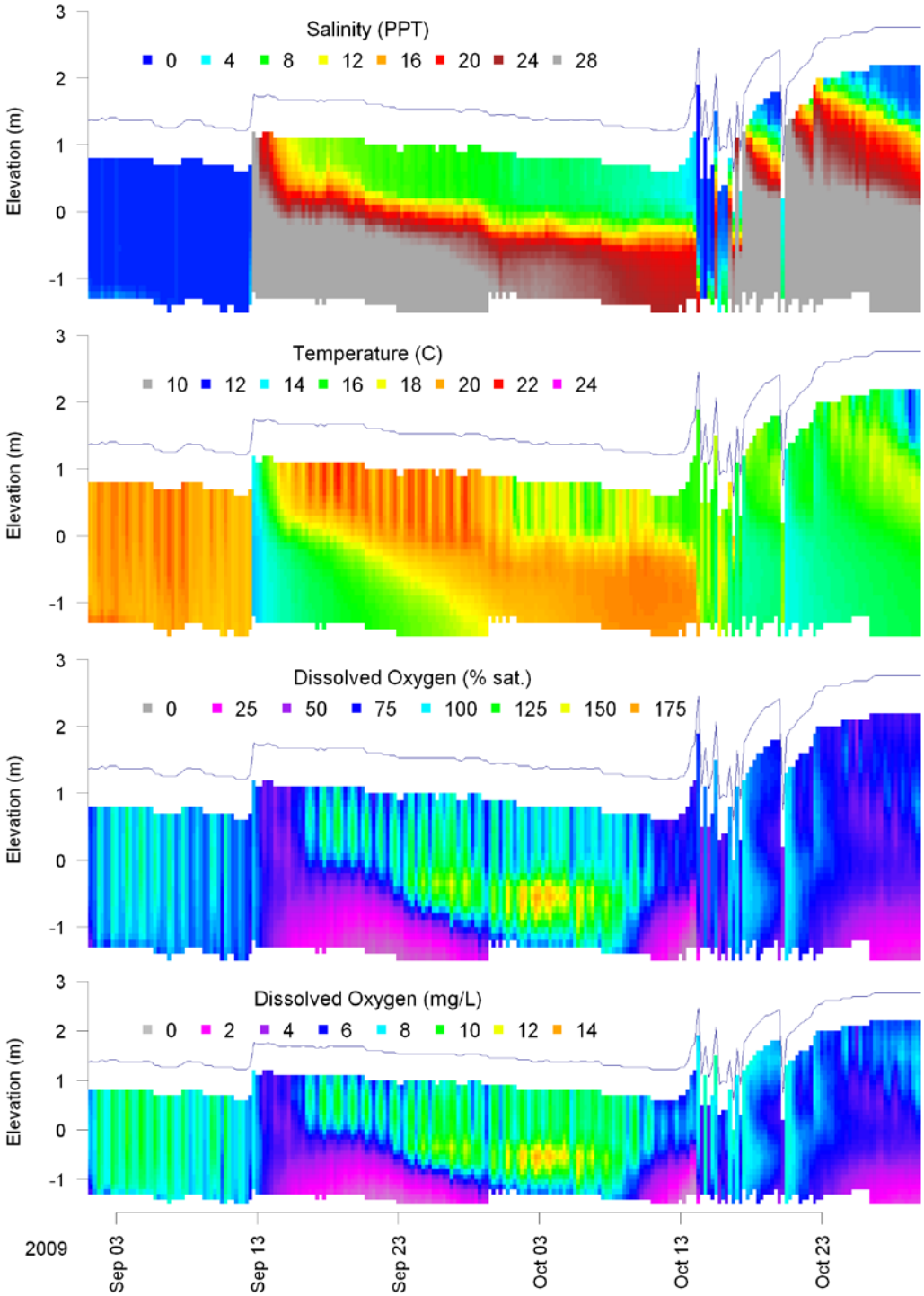

Figure 6: A wave overtopping event on 9/12/09 added 0.5 m of water to the lagoon and turned it saline. October precipitation increased Carmel River discharge from no flow to over 57 m^3s^{-1} in five hours at the Highway 1gage. The breeching of the sandbar on 10/14/09 mixed the water column and extirpated the stratification. Sandbar reforming/ lagoon closure is evidenced by a gradually increasing hydrograph.

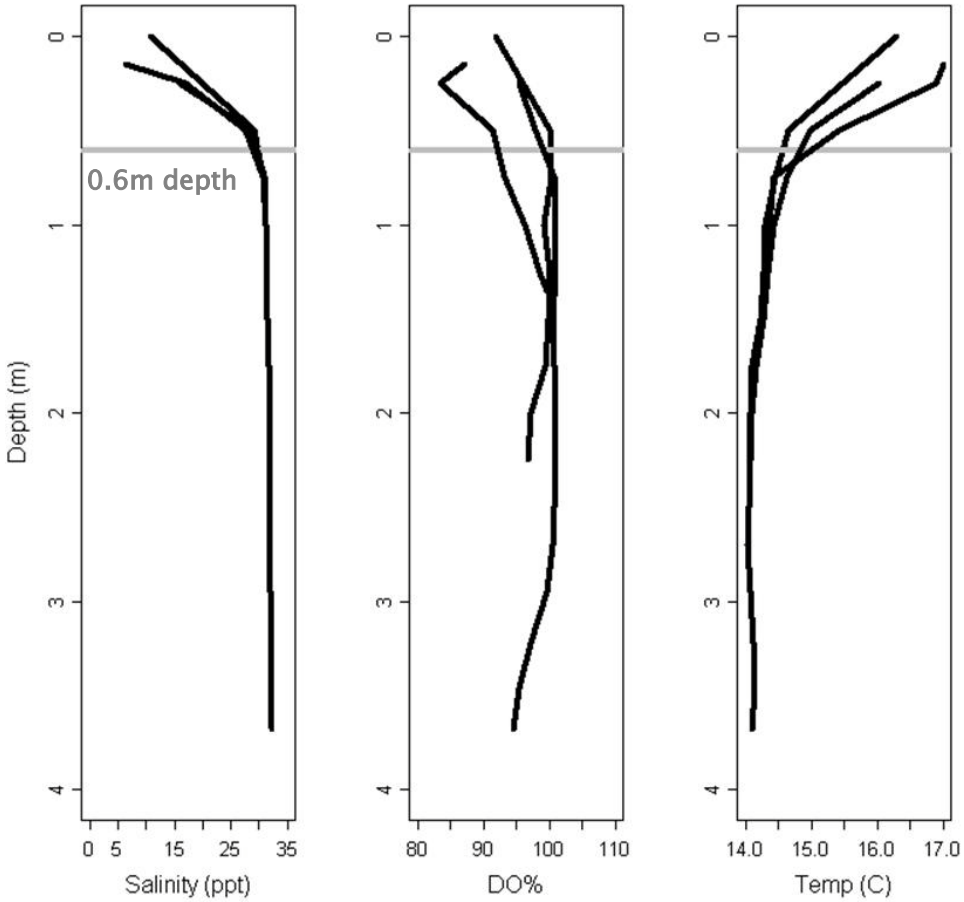

Figure 7. The steep gradients in water quality conditions of the top 0.6 meter surface layer as recorded by portable Hydrolab Multiprobe at the pipe crossing the South Arm of the Carmel Lagoon. These gradients were not detectable by the sonde given its programming during the study period.

3 Habitat Analysis – Spatial Variation

3.1 Goal

The goal of this section was to examine the spatial variation of GWQH in the Carmel lagoon to determine the effectiveness of using a single fixed automatic sonde at site S2 (Fig. 8) as an indicator of water quality parameters throughout the lagoon. If GWQH can be accurately determined from the automated S2 data, it would represent a time and cost effective method of lagoon water quality monitoring. We used one year of automated sonde MPWMD data from site S2 and one year of spatially varied monitoring data from sites N2, R2, S2, O1, and O4 (Fig. 8). The spatially varied data were manually collected from a canoe by MPWMD staff and ENVS 660 graduate students.

The channel distance between the ends of the arms is approximately 1.27 km depending on water level. The approximate channel distances between sites measured on Google Earth are listed in table 1.

Table 1: Distances between sites

Sites	Distance (km)
S2 to N2	0.45
S2 to R2	0.32
S2 to O1	0.28
S2 to O4	0.74

Figure 8. MPWMD and ESSP660 water quality parameter data sites in the Carmel Lagoon

3.2 Methods

MPWMD has assembled water quality data collected throughout the lagoon manually bimonthly since October 2008. We employed the same sampling strategy to familiarize ourselves with the site. To determine whether the automated sonde data at site S2 is representative of the overall lagoon conditions, we collected and compared water quality data from four dispersed sites and the S2 site. To eliminate differences in manual versus automated measurements as discussed, we only compared measurements collected manually from a canoe using the same instrument within each collection day. Using the water quality data, we estimated the available GWQH thickness of at each site and compared the variation between the sites. We graphed isopleths of salinity and dissolved oxygen across all sites throughout the year to determine difference in water quality among the sites.

Data Collection

We measured water quality parameters using HydroLab DS5X water quality multiprobe (Austin, TX) lowered from a canoe two times throughout the lagoon on 10/15/2009 and 10/20/2009. At each site, we constructed a vertical depth at 0.25 m increments down from the surface for salinity, dissolved oxygen, and temperature. Our data set, combined with the data collected by MPWMD from 10/3/2008 and 9/18/2009, formed a total of 24 sampling days covering 10/03/2008 to 10/20/2009. We excluded data collected on 1/9/2009 because of irregularities with collection dates. Stage data were from a pressure transducer mounted at site S2 and tied to the National Geodetic Vertical Datum, NGVD (MPWMD 2005).

Analysis

To compare available GWQH between sites on each collection day, we determined which of the 0.25 m intervals in each depth profile met the criteria for GWQH (Table 2). We summed all the depth intervals that met the standards for GWQH for each day and graphed the total amount of GWQH depth at each site and sampling day over time for visual comparison. We made visual comparisons of individual parameters between sites throughout the year of collected data using isopleth graphs.

3.3 Results

Comparison of data among the sites indicated some spatial variability in water quality parameters between sites (Figs. 9 and 10). The elevation of the 5 mg/L oxygen isopleth varied substantially between sites (Fig. 10), but the elevation of the 10 ppt isohaline did not vary much between sites (Fig. 9).

Site S2 demonstrated consistently greater available GWQH depth than all other sites (Fig. 11). For each sampling date, S2 averaged 47% of the total available GWQH depth, followed in amount by O1, O4, N2, and R2 (Table 3, Fig. 11). The prevalence of GWQH at site S2 is most likely due to site S2 coinciding with the deepest stretch of the lagoon (Figs. 9, and10), and hence there are occasions when other sites have zero GWQH at low water levels.

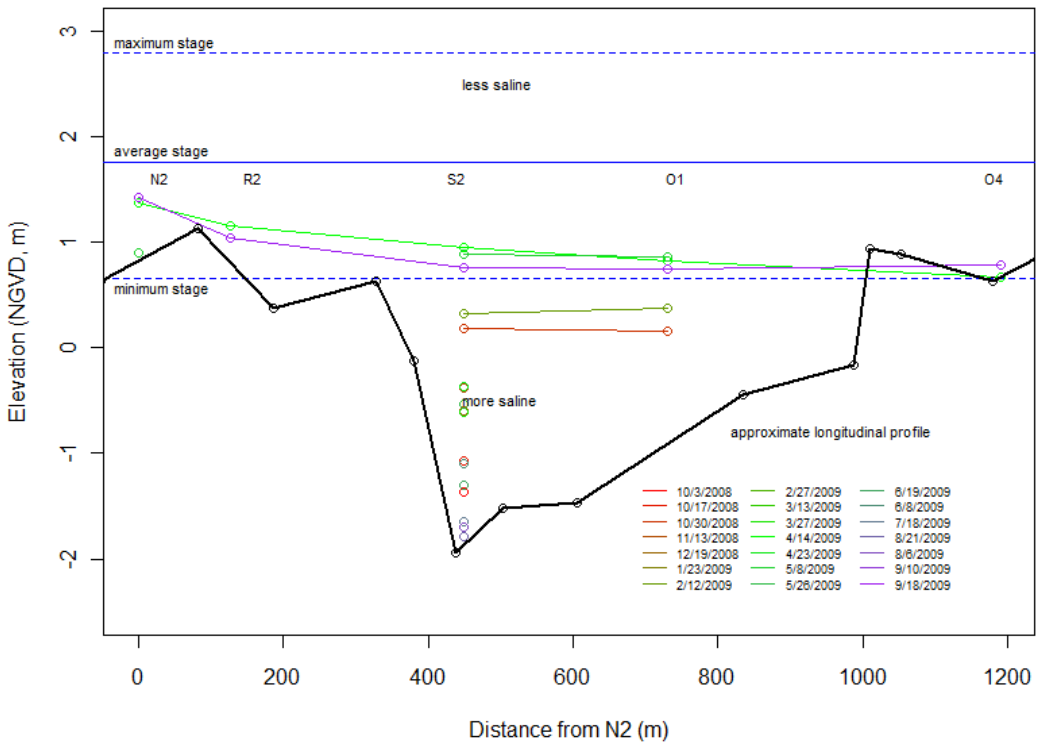

Figure 9: Isopleths interpolated for salinity at 10 ppt from MPWMD data from Nov 2008, to Sep 2009. Lines between points are for visual representation only. There was little variation in salinity between the sites.

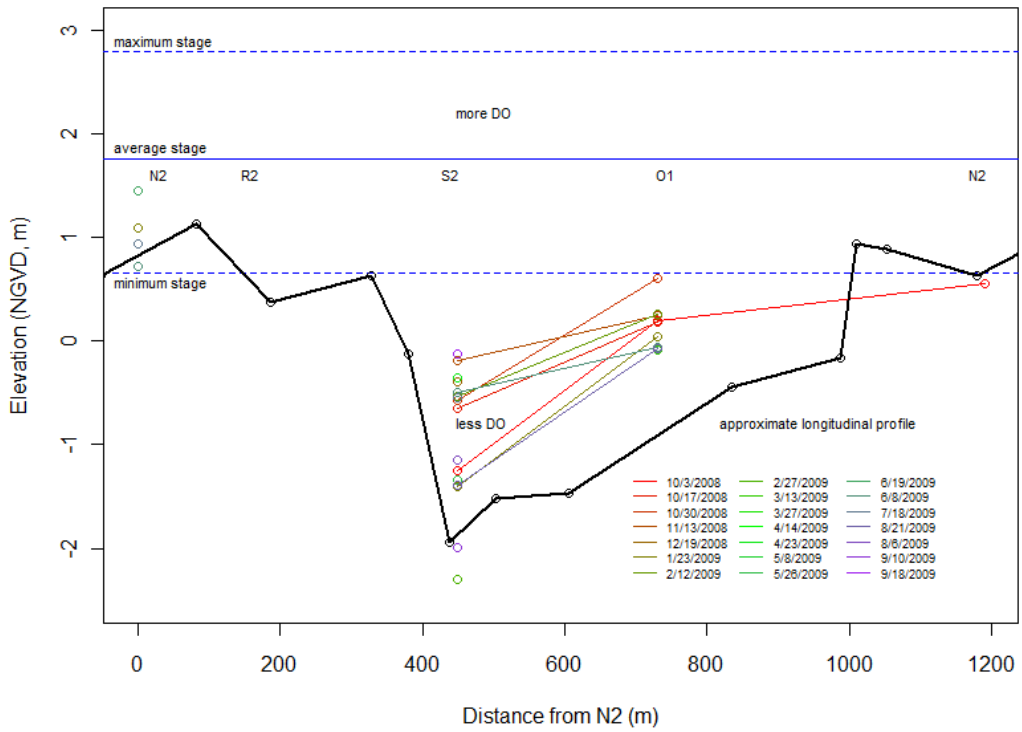

Figure 10: Isograph interpolated for DO at 5mg L^{-1} from MPWMD data from Nov 2008, to Sep 2009. Lines between points are for visual representation only. There was a strong variation in DO between S2 and O1 sites.

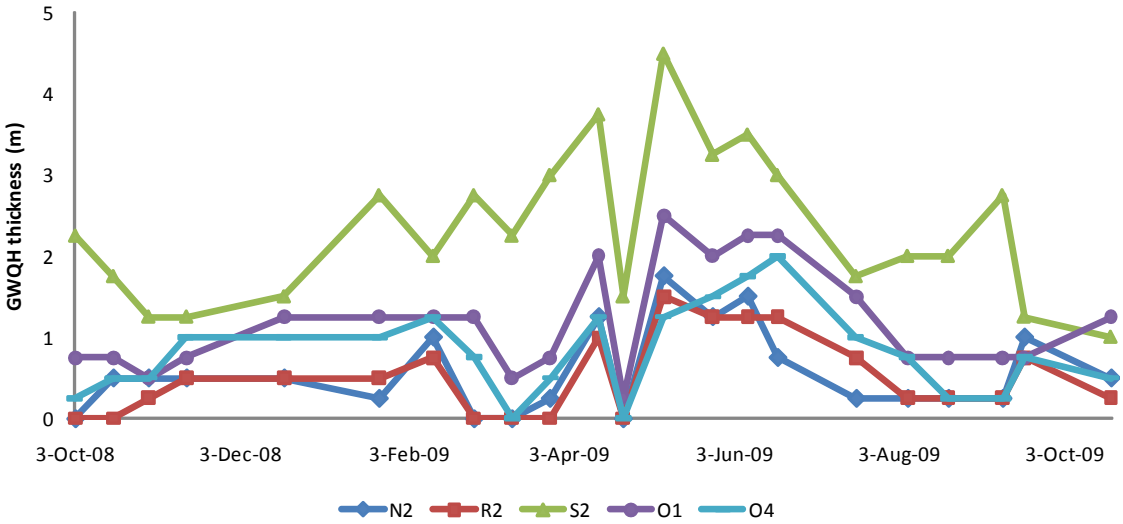

Figure 11: Total thickness of GWQH (m) at the over time at multiple sites. Lines between points are for visual representation only. GWQH variation was apparently correlated primarily with water depth; S2 was deepest and N2 was shallowest.

Table 2. Percent of GWQH depth at each site to total GWQH depth for all sites, averaged over all collection days, n=22.

Site	Percent of total GWQH	Standard Deviation
N2	9	6
R2	8	6
S2	47	17
O1	22	5
O4	14	7

3.4 Conclusion

We conclude that using site S2 data for estimation of available steelhead habitat in the entire lagoon is possible, but some factors must be carefully considered. The amount of GWQH in the lagoon was consistently overestimated by looking at site S2 alone. Available GWQH is linked to depth of water at the various sites, with S2 and O1 being deepest and N2 and R2 the shallowest. If the lagoon is at a low level there still may be GWQH at the deep sites while areas of higher channel elevation remain dry or contain very shallow water. An approximate amount of available GWQH at all sites could be inferred from only S2 data using the proportions in Table 2, but sites N2 and O2 should be checked for dry or very shallow conditions before using this approximation. If sites are dry or have less than 0.5 m of water then there is no available GWQH no matter how much registers at site S2. Site S2 data is best used for knowledge of conditions at the next closest site, O1, which is the next deepest.

Individual water quality parameters are too varied between the sites studied to be able to describe the overall water quality of the lagoon with just single measurement at S2. There were times when water quality at site S2 was very different from other sites.

Future research could focus on the underlying mechanisms of water quality variations among sites, as functions of environmental factors, such as wind, swell, and sun radiation. It would also be worthwhile to determine if the deep areas around sites S2 and O1 provide enough habitat for steelhead to retreat to, when other sites have little or no GWQH. If that is the case, the spatial variation found in GWQH matters less over short timescales as steelhead are highly mobile.

4 Habitat Analysis – Microalgae Effects

4.1 Goal

Sonde readings (and previous manual water quality profiles) have periodically demonstrated super-saturated dissolved oxygen corresponding with the halocline (Fig. 12). Because of the established correlation between phytoplankton and oxygen super-saturation (Jenkins and Goldman 1985, Grzetic et al. 1991) we sought to verify the presence of a phytoplankton community at the halocline that could be a source of the oxygen super-saturation. Such a phytoplankton community could contribute to an increased GWQH (increasing DO) and supplement the base of the lagoon food web (Haines and Montague 1979, Calbet and Landry 2004).

4.2 Methods

We collected water samples for phytoplankton identification and chlorophyll *a* analysis (a a proxy for phytoplankton biomass) on three occasions interspersed over several weeks in October 2009. Because phytoplankton are photoautotrophs and light-limited, we also examined the availability of photosynthetically active radiation (PAR) in the water column. We collected the first sample set at the beginning of a high flow rain event and before the first lagoon breach of the autumn season. We collected the second sample set two days after the breach and the final samples one week after the initial breach. We collected all samples and readings from the midpoint of the pipe over the North Arm of the lagoon.

Prior to the first collection, we located the depth of the oxygen super-saturation zone, (which corresponded with the halocline) (Fig. 18), using a Hydrolab DS1 water quality multiprobe (Austin, TX). Deploying a Van Dorn horizontal water sampler (Wildco Buffalo, NY), we collected two liters of water at the halocline (1.5 meters below the surface) and two liters from 10 cm above and below the halocline. On the second sampling day, we attempted to establish the depth of the halocline to guide sample collection, but due to extensive mixing following the precipitation event and breaching of the lagoon sandbar, a halocline was not present. Instead, we collected two liters of water from the surface, middle and bottom depths of the water column. On the third sampling day, we repeated the sampling protocol from the previous day.

We transported samples destined for chlorophyll *a* analysis in one liter opaque HDPE bottles and samples destined for phytoplankton identification in one liter transparent HDPE bottles. All samples were stored on ice in a dark cooler at 4°C during transportation to the laboratory for analyses. Once at the lab, we vacuum filtered well-mixed aliquots of the chlorophyll *a* samples over Whatmann glass micro fiber GF/F 0.7 mm filters. The volume of the chlorophyll *a* samples filtered depended on the concentration of the

sample. The Filters were extracted in 25 ml of 90% acetone solution, sonicated for two minutes and stored in 50 ml centrifuge tubes at -20 °C. After a minimum of 2 hours, the samples were thawed, centrifuged, and analyzed via fluorescence readings with a Turner Designs P/N 998-7210 fluorometer. Chlorophyll *a* concentration, corrected for phaeophytins, was estimated using the calculations outlined by standard methods (AWWA 2005).

We preserved the samples for phytoplankton identification with 2% Lugol's iodine solution and stored the samples at 4 °C until identification. Prior to identification, we concentrated the samples by centrifugation in 50 ml tubes. We pipetted one milliliter of concentrated sample into Sedgwick-Rafter microscope cells (Wildco, TX), examined the preserved sample over an inverted microscope and photographed the phytoplankton for identification.

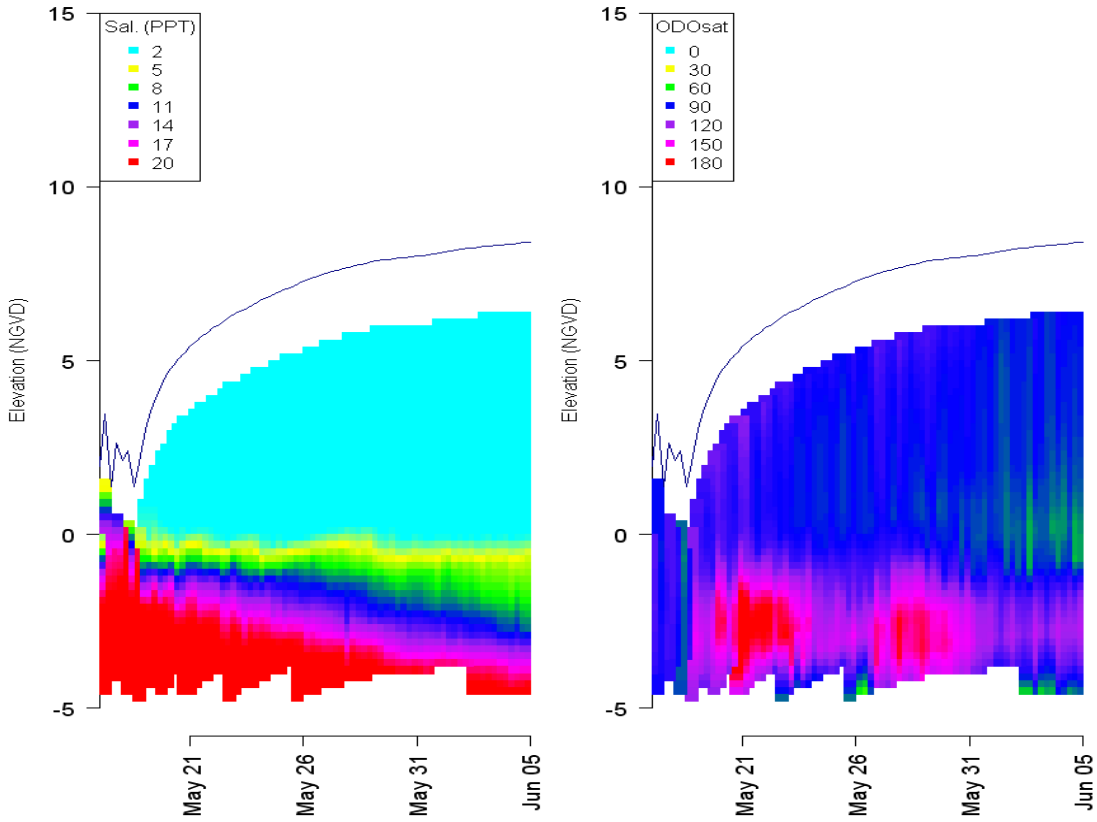

Figure 12: Carmel Lagoon oxygen saturation and salinity profiles from site S2.

4.3 Results

We observed different phytoplankton taxa from samples collected before and after the heavy precipitation and lagoon breaching event. From the pre-breach first sample set, we observed the conspicuous presence of a dinoflagellate *Peridinium* sp. (Fig. 13) at all three sampling depths. We also observed two incidences of the ciliophera *Vorticella* sp. (Fig. 14) above and below the halocline. Besides these alveolates, we did not observe any other phytoplankton. Because we preserved all our samples, we were unable to observe the dinoflagellate swimming pattern needed for dinoflagellate identification beyond genera.

From the second sample set, collected after the lagoon breach and before establishment of a halocline, we did not observe any of the taxa observed in the first sample. We identified the freshwater cyanobacterium *Anabaena* sp. (Fig. 15) and an unidentified filamentous green algae (Fig. 16) both of which we presumed had washed into the lagoon from the upper watershed following the high flow rain event. On the final sampling event, one week past the initial lagoon breach, there was still no halocline observed. From this sample , we observed one incidence of a second dinoflagellate *Ceratium* sp. at 1.5 meters (fig. 17).

The chlorophyll *a* concentration was highest in the samples from the first day, declined from the first to the second sampling and continued to decline to the last sample set (Table 3). Based on the PAR readings, only 40% of the light entering the water column continued to the depth of the observed phytoplankton (Fig. 18).

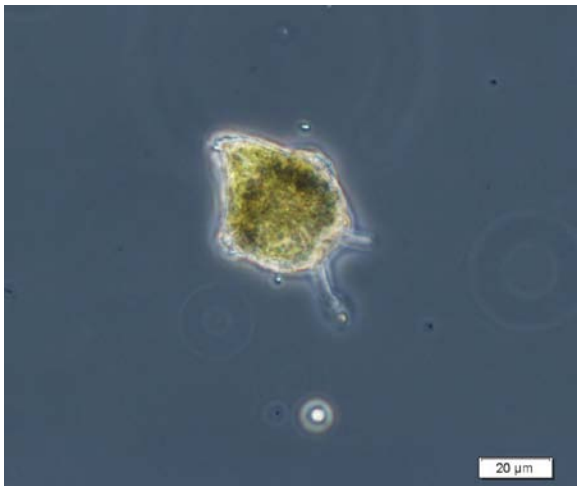

Figure 13 Dinoflagellate *Peridinium sp*. identified in pre-breach samples at all depths.

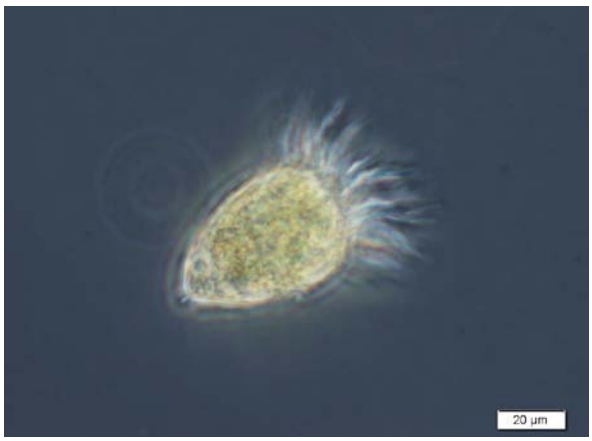

Figure 14: *Vorticella* sp. found in pre-breach samples at 1.4 meters

Figure 15: Freshwater filamentous cyanobacterium *Anabaena* sp. found in post-breach samples.

Figure 16: Unidentified filamentous algae found in post-breach samples.

Figure 17: Dinoflagellate *Ceratium* sp. identified in post-breach sample

Table 3: Chlorophyll *a* concentrations from samples collected at site S2

Date	Elevation NGVD (m)	Chlorophyll *a* (µg/L)
10/13/2009	10 (ft)	34.53
10/13/2009	0	28.50
10/13/2009	**-10 (ft)**	**97.56**
10/15/2009	1.5	6.51
10/15/2009	0	10.82
10/15/2009	-2.5	11.10
10/20/2009	1.5	0.27
10/20/2009	0	1.05
10/20/2009	-3.0	1.08

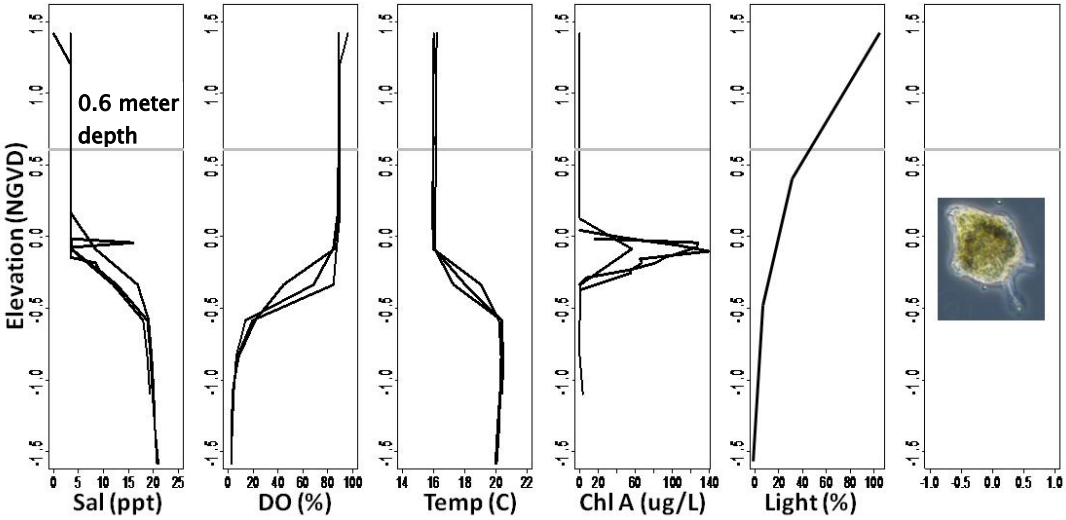

Figure 18: Side by side comparison of profiles of *in situ* water quality variables associated with the presence of the dinoflagellate *Peridinium* sp. collected during the high precipitation event and prior to the breaching of the lagoon sandbar. (Multiple profiles on each chart represent replicates taken at approximately the same time)

4.4 Conclusion

Because of the exceptionally early seasonal storm and resulting high flow rain event, we were unable to collect subsequent-day repeat samplings of the stratified halocline. While the samples collected prior to the breach of the lagoon sandbar demonstrated the prevalence of *Peridinium* sp., we were unable to make any further documentation of this taxon throughout time. The presence of an apparently dominant phytoplankton taxon corresponds with the observed increased chlorophyll *a* and supersaturated dissolved oxygen at the depth where the phytoplankton samples were drawn (Figure 18). However, because we did not collect samples well above or below the halocline, we were unable to confirm whether this dinoflagellate was present throughout the water column or concentrated at the halocline.

The apparent disappearance of *Peridinium* sp., and corresponding decrease in chlorophyll *a* and dissolved oxygen post high flow event and lagoon sandbar breach, could be the result of at least two possible mechanisms. First, the high flow event and subsequent lagoon breach mixed the water column sufficiently to reduce the conditions that supported the development of this dinoflagellate population. Second, the intense mixing and flushing following the breach may have carried this phytoplankton community out of the lagoon.

While PAR availability at the depth of the samples containing phytoplankton seems low, the high *in situ* and extracted chlorophyll *a* levels as well as the spike in dissolved oxygen corroborate the presence of photosynthetic activity (Fig. 18, Table 3).

Future projects should resample at this location when the automated sonde is measuring dissolved oxygen super-saturation. Sampling should also occur at multiple depths, including at the halocline, during the presence and absence of dissolved oxygen super-saturation levels. The installation of chlorophyll *a* sensor on the *in situ* sonde could also yield insight into phytoplankton dynamics in the lagoon. The application of molecular approaches could also be used to identify the phytoplankton to a high order of resolution from a small sample.

5 Habitat Analysis – Sonar based fish and habitat survey

5.1 Goal

Steelhead population estimates are critical for federal agencies and resource managers to effectively manage steelhead recovery. Using low-cost sonar equipment, we sought to effectively measure fish abundance, monitor lagoon substrate and GWQH and develop data acquisition and processing protocols for river systems.

5.2 Methods

We conducted fish and habitat surveys using a Humminbird 1197c sonar system (Eufaula, AL) mounted on a kayak. This system combines single beam sonar, sidescan sonar, GPS, and fish detection capabilities. We mounted the sonar transducer to the front of the kayak and submerged it two inches below the surface for maximum coverage. We attached the GPS antenna directly above the transducer so that both units maintain the same vertical plane to assure accurate transducer-GPS and minimize error. To maintain a relatively constant speed of 2 to 3.5 miles per hour, we employed a *Minn Kota* electric trolling motor (Racine, WI) mounted to the back of the kayak.

Single Beam Sonar: Fish Detection

We used the Humminbird fish detection algorithm, derived from real time data acquisition of single beam sonar, to count fish throughout the lagoon. The Humminbird 1197c system is equipped with a dual beam PLUS sonar at 200khz and 83khz, with the option to use either or both settings. To provide a maximum coverage angle of 60° we employed the 200khz/83khz blended beam setting. We set the fish detection to maximum sensitivity (Setting 10) in order to record even slight evidence of fish presence. We selected transects to allow for the longest straight paths to cover nearly the entire length of the lagoon. Paddling down the center of the lagoon channel taking readings, we completed nine transects of the lagoon on each of our two field days (Fig.19). We documented and summed fish detections, as identified by the fish finder unit, for each transect.

Sidescan Sonar: Substrate and Habitat Analysis

Using the Humminbird side-imaging sonar system, we collected sidescan and GPS data for nine transects (Fig.19). The Humminbird side-imaging sonar system measures 86° on the left and right side of the transducer providing 172° of total coverage. We stored the resulting sidescan and GPS data as raw proprietary 'SON' files on a 8GB SD card.

Raw data playback

Back in the laboratory, we converted the raw SON files to Yellowfin .872 files using HSBI Sonar File Converter software for playback in Yellowfin (Imagenex). We viewed the playback to aid in habitat classification.

Geoprocessing

We also completed a series of geoprocessing steps using the .SON files to make them useful in a GIS. We began by converting the raw .SON files to XTF files using the Son2XTF (Triton, Capitola CA) software. Once in XTF format, we processed the sidescan data using Isis (Triton) and TritonMap programs (Triton) to correct for slant range, adjust contrast, and combine sidescan data with positioning data. We exported the resulting XTF files as 25 centimeter resolution GEOTIFFs projected in WGS1984 UTM Zone 10. Using TNTMips (Microimages, Lincoln NE) software, we cleaned the processed GEOTIFFs to exclude excess and erroneous data. Finally, we combined cleaned GEOTIFFs to create a mosaic which we exported as a TIFF file for use in ArcGIS (ESRI, Redlands CA).

Habitat Classification and Groundtruthing

Using preliminary sidescan maps as a reference, we employed groundtruthing to aid in identifying major sediment and habitat types. We visually identified vegetation and substrate in shallow water and performed sediment grabs at different points along the reach. The GPS location of each sediment grab was collected using the Humminbird GPS system. We produced habitat classification maps by simultaneously interpreting raw video files and geoprocessed sidescan TIFF files along with field notes on visual identification and sediment grabs (Fig. 20) In ArcGIS, the geoprocessed sidescan TIFF file was used as a background layer and polygons were drawn around delineated habitat types. We produced habitat classification maps by drawing polygons around different habitat types determined from processed sidescan TIFF files.

Figure 19: Approximate location of sonar transects surveyed at the Carmel River Lagoon.

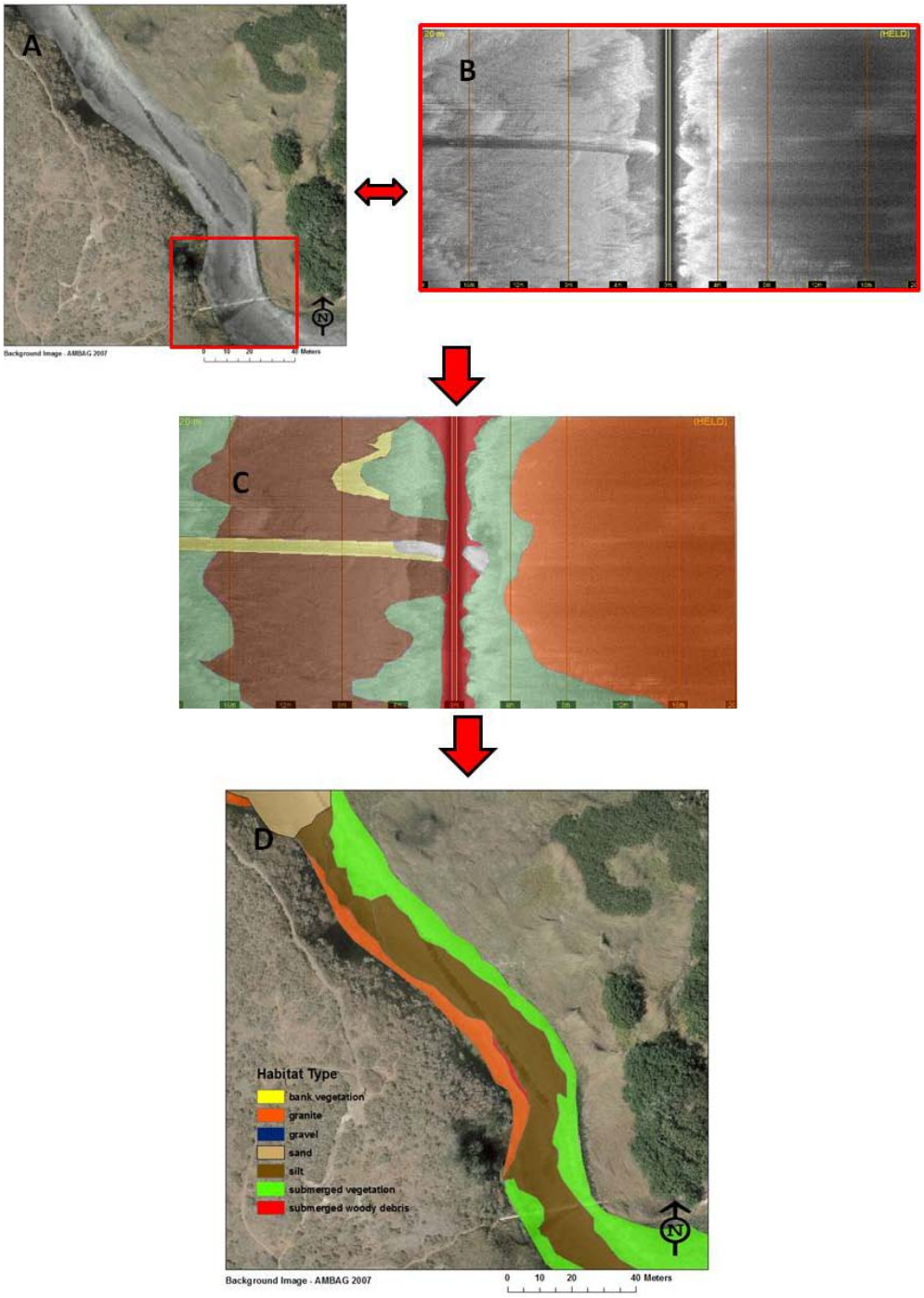

Figure 20. Habitat classification methodology and interpretation. Location: South Arm, Carmel River Lagoon. Geoprocessed sidescan data (A) and raw video sidecan data (B) (Yellowfin export) were used in conjunction with visual field interpretation and sediment grab data to classify habitat. Preliminary classification (C) of raw video sidescan data show submerged vegetation in green, shadows or no data in yellow, the pipe in grey, silt in brown, excess data in orange, and no data in red. Classification of geoprocessed sidescan data result in creation of the final habitat classification map (D).

5.3 Results

Fish Detection

We detected 22 fish on 10/20/09 and 59 fish on 10/25/09 using the Humminbird fish finder (Table 4). Most detections occurred at transects covering deep and possibly heavily vegetated areas providing protection and coverage for fish.

These fish detection results were lower compared to previous surveys (ESSP 660, 2007; ESSP 660, 2008). We hypothesize that the apparent decrease in fish is associated with the manual breaching of the Carmel lagoon that occurred on 10/13/09 and 10/15/09. The increase in fish counts between 10/20/2009 and 10/25/09 may be due to the re-stabilization of lagoon conditions after the second breach.

We also found that the highest number of fish detections occurred in the South Arm of the lagoon on either side of the pipe on 10/25/09 which corresponds with previous surveys (ESSP 660, 2007; ESSP 660, 2008). This suggests that more optimal habitat exists in the South Arm of the lagoon versus the other areas.

Table 4. Humminbird fish detections per transect

	Number of fish observed	
Transect	10/20/2009	10/25/2009
1	0	0
2	0	7
3	0	0
4	7	2
5	4	0
6	1	15
7	2	10
8	3	25
9	0	0

Habitat Classification

Geoprocessed Humminbird sidescan data were successfully overlaid on a USGS DOQ with a high degree of positional accuracy (Figure 21). No additional positional offsets were necessary for the sidescan data. The sidescan data were noisy in areas where water conditions were rough due to high winds and where data overlapped due to slight turns while surveying.

Four major habitat types were identified from visual identification in shallow waters and sediment grabs in deeper waters (Fig 22). Silt was identified as the predominant sediment type in the Odello Extension and South Arm with some areas being silt/ submerged vegetation. Sand was found at the main lagoon, the North Arm and at the mouth of the Carmel River. A mix of gravel and sand was found upstream along the Carmel River.

Figure 21: Geoprocessed sidescan sonar data overlayed on a USGS DOQ. Pixel values represent sonar return intensity. Light colors represent a strong return. Dark colors represent a weak return. Intensity can vary by the composition of the feature, distance of the feature relative to the transducer, and angle of the feature relative to the transducer.

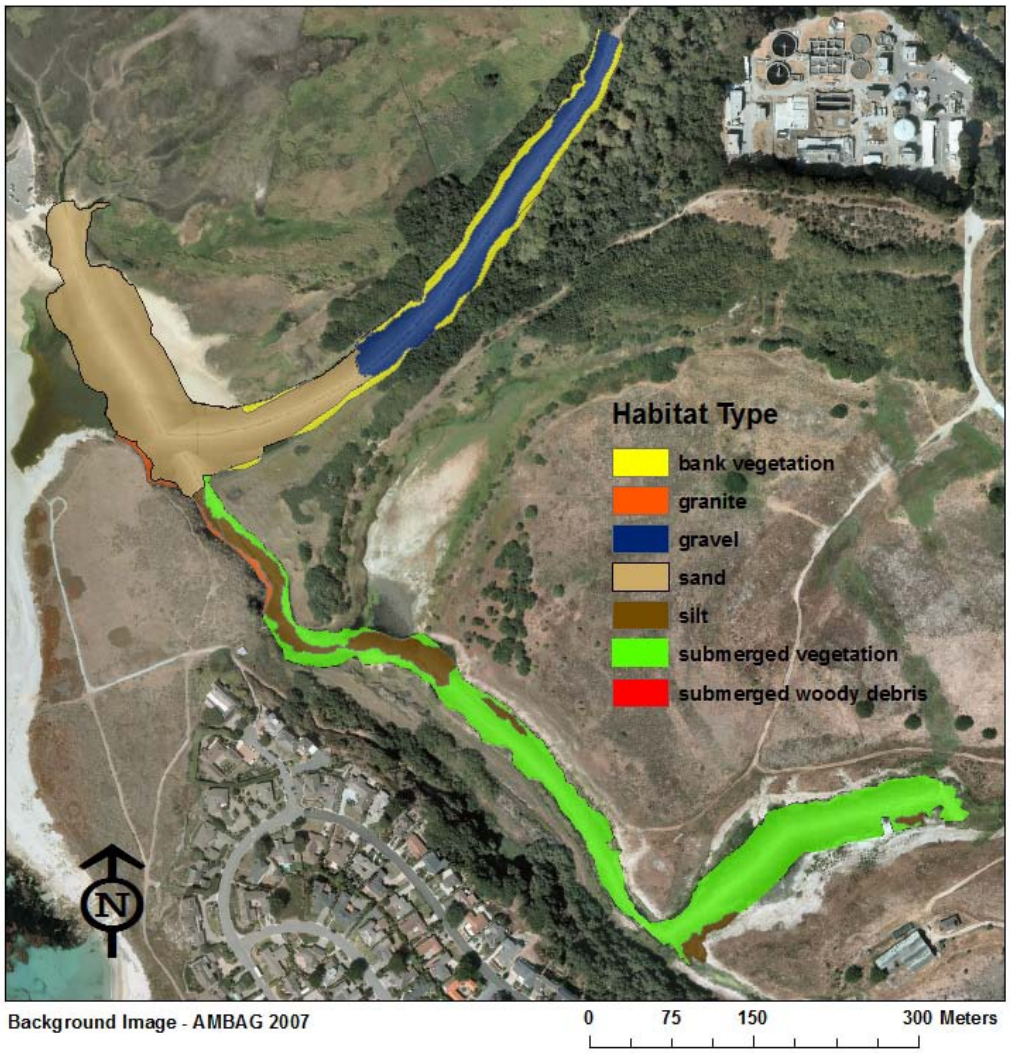

Figure 22: Carmel River Lagoon habitat classification map. Note that this is the preliminary result of efforts to delineate different habitat types and may reflect some inaccuracy or imprecision in places.

5.4 Conclusion

Using a relatively non-intrusive approach and low cost technologies, we were able to quantify fish, to a certain extent, at the Carmel River Lagoon. Our surveys were limited to primarily open water surveys and a narrow 60° single beam sonar for fish detections. With these limitations, we were unable to quantify fish hiding underneath logs or in heavy weeds and experienced low beam widths in shallow waters. Therefore, we were unable to quantify the total number of fish in the lagoon or the manner in which their distribution was determined by available habitat. The use of a trolling motor to power the kayak may have frightened fish into hiding as well. Although we were faced by these

limitations, the use of single beam sonar and Humminbird fish detection algorithms for fish counts seems promising. This approach is relatively non-intrusive, time efficient and cost effective for quantifying the relative abundance of fish in hard to reach or remote areas similar to the Carmel River Lagoon.

The combination of Humminbird side-scan sonar, visual identification and sediment grabs proved to be an effective and cost efficient way to create basic habitat maps. The Humminbird side scan system was capable of acquiring very high resolution data sufficient for identifying underwater weeds, sediment patterns and large objects. Habitat classification was subjective due to the limited degree of shallow and non turbid areas for visual identification and interpretation of sediment grabs relative to the sidescan data. Transitions between different types of sediment were difficult to identify as these weren't very apparent in the sidescan data. Although the resulting habitat maps are limited and reflect some subjectivity, they provided a general idea of what types of habitat are present at the Carmel River Lagoon and are a contribution in support of the management of the lagoon for steelhead habitat.

Future studies should involve planning surveys during optimal environmental conditions, development of a supervised classification method to classify habitat, the use of an underwater camera to groundtruth, and conducting repeat surveys.

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