Central Coast Watershed Studies

CCoWS

Carmel Lagoon Water Quality and Sonar Soundings: Fall 2008

CSUMB Class ESSP660:

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Executive Summary

This report describes the results of an investigation conducted by students in an Advanced Watershed Science and Policy class at California State University Monterey Bay (CSUMB), which focused on documenting and learning about water quality and habitat for steelhead in the Carmel Lagoon. The overarching goal of our study was to continue monitoring the water quality of the entire lagoon for a short period in Fall 2008, to draw comparisons with data collected by the same class in 2007, and to provide a general assessment (a "snapshot") of the quality of steelhead habitat at the time of data collection. In addition to water quality monitoring, relative abundance of juvenile steelhead was estimated using sonar sounding techniques along several transects and we measured thalweg bathymetry for use as a baseline for documenting potential future sedimentation. Results are presented in sections on bathymetry, water quality, and sonar fish surveys. Conclusions drawn from these sections were as follows:

1. By measuring bathymetry along the north-south thalweg of the Carmel lagoon, we were able to establish a baseline for lagoon depth. Our results revealed a variety of depths were present throughout the lagoon, with the greatest depths occurring near the pipe. This bathymetric baseline will be useful in assessing the impact of potential sediment loads entering the Carmel lagoon from upstream fire-affected landscapes.
2. A comparison of water quality parameters between 2007 and 2008 revealed generally similar dissolved oxygen (DO), temperature, salinity, and depth. Depth profiles of water quality parameters at the pipe location in the South Arm showed slight inter-annual variations but overall illustrated a stratified water profile for both years. There was some evidence that the relatively fresh surface layer was thicker and fresher in 2008.
3. To estimate the amount of lagoon habitat available for steelhead use, water quality measurements were taken at 17 points along a longitudinal transect running from the North Arm south to the Odello Arm. Assuming a 0.5 m surface bird predation zone, sub-optimal DO concentrations below 5 mg/L, sub-optimal temperatures above 26°C, and a triangular channel cross-sectional shape, we estimated that there was approximately 16,000 m^3 of useable steelhead habitat in the lagoon.
4. Two aerators were operating near South Arm pipe. The effect of aerators on water quality was briefly investigated. Salinity, dissolved oxygen, and temperature measurements were taken at 5 meter intervals and at 0.25 m depth increments along the South Arm pipe. We found evidence for a slightly decreasing temperature gradient and an increasing dissolved oxygen gradient in the proximity of the aerators while salinity remained approximately constant. The largest changes were located within five meters of the aerators. Sampling from the pipe that is intended to be representative of the greater lagoon would be affected by the local effect of the aerators within about five meters.

5. Longitudinal transects were surveyed throughout the lagoon system with kayak-mounted sonar "fish finders". The sonar systems were set to automatically estimate fish presence. The greatest density of sonar fish detections occurred in the deepest sections of the lagoon near the pipe and the aerators. Estimated fish abundance was somewhat similar between the 2007 and 2008 surveys. With further development of these protocols, sonar can be useful in providing an efficient measure of the relative abundance of fish in Carmel Lagoon. To an extent, the method is already indexing changes in relative fish abundance in a cheap, rapid, and harmless manner.

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1 Introduction

1.1 Background

The Carmel River Lagoon lies at the mouth of the Carmel River south of Carmel-by-the-Sea, California. In 2005 this body of water was identified as critical habitat (70 FR 52630) for steelhead trout (*Oncorhynchus mykiss*), which is listed as threatened under the federal Endangered Species Act. During the winter and spring when the lagoon empties out to the ocean, the lagoon supports migration of juvenile steelhead traveling from freshwater to the ocean, adults traveling upstream to spawn, and adults traveling back to the ocean. When water levels are low in the summer and fall months, the lagoon is sealed off from the ocean by a sand bar. The lagoon water held behind the sand bar provides important rearing habitat for steelhead and provides a brackish environment which steelhead can use to acclimate to saltwater conditions. In addition, many juvenile steelhead smolt in the lagoon during this time (Bond, 2006).

Water quality in the lagoon is an important factor in determining the potential success of juvenile steelhead. In general steelhead prefer lagoons with sufficient depth and volume to avoid predation, low to mild temperatures, high dissolved oxygen, and low salinity (Smith, 1990; Bond, 2006). These environmental parameters have historically shown high sensitivity to the artificial hydrologic impacts introduced to the lagoon as a result of development within the flood plain of the lagoon and the watershed (Watson and Casagrande, 2004).

There are two major factors that contribute to habitat quality at the lagoon: upstream water diversions and mechanical breaching of the lagoon. (K. Urquhart, pers. comm.). Diversions occur primarily through groundwater extraction in the upper watershed. This reduces the volume of freshwater entering the lagoon and potentially degrades water quality by increasing salinity and stratification during the dry season. Historically the Carmel River breached the sand bar separating the lagoon from the ocean during the rainy season each year, naturally draining the lagoon volume within hours (ESSP660, 2007). Under more natural conditions, breaching would occur at the weakest location along the beach. However, homes have been built within and adjacent to the floodplain and associated bluffs and artificial breaching of the lagoon is required to protect these homes. In some years the lagoon is artificially breached during the spring, resulting in near total loss of lagoon habitat for steelhead (Larson et al. 2006). The lagoon has been deliberately breached by stakeholders and agencies since the 1930's (K. Urquhart, pers. comm.); breaching is also occasionally initiated by families enjoying the beach (Larson et al. 2006).

1.2 Goal

ESSP 660 Advanced Watershed Science and Policy is a graduate class taught in the Master of Science in Coastal and Watershed Science & Policy program at California State University Monterey Bay (CSUMB). In 2008, the class was taught in three 5-week modules, each focusing on making a small contribution to a local watershed issue. This report describes the results of one of those 5-week modules, which focused on documenting and learning about water quality and habitat for steelhead in the Carmel Lagoon.

The overarching goal of our study was to continue monitoring the water quality of the entire lagoon for a short period in Fall 2008, to draw comparisons with data collected by the same class in 2007, and to provide a general assessment (a "snapshot") of the quality of steelhead habitat at the time of data collection. In addition to water quality monitoring, relative abundance of juvenile steelhead was estimated using sonar sounding techniques along several transects and we measured thalweg bathymetry for use as a baseline for documenting potential future sedimentation.

1.3 Structure of this report

We present our results in the five sections following this section: one on bathymetry, three on various aspects of water quality, and one on sonar fish survey.

1.4 Study area – Carmel Lagoon

Steelhead trout are considered anadromous, meaning they utilize freshwater rivers for spawning and migrate to the ocean and back. The Carmel Lagoon forms at the mouth of the Carmel River (Fig. 1) when it is prevented from entering the Pacific Ocean by a sandbar. During the summer and fall the sandbar of the Carmel Lagoon is closed, which results in creating an isolated water body suitable for rearing and smolting habitat for steelhead. When the sandbar is open during the winter and spring, steelhead migrate between the river and the ocean. Aquatic habitat types in the lagoon are contingent on water volume, which is determined by river flow, sediment accumulation, wave and tide conditions, and whether the sandbar has been breached or remains intact (Watson & Casagrande, 2004; Casagrande, 2006). In turn, the freshwater inputs and water volume of the lagoon influence key water quality parameters such as dissolved oxygen, temperature, and salinity. Portions of the lagoon are perennial, while other areas are inundated only during high rainfall periods in the winter and spring. As shown on Fig. 1, areas of the lagoon that are permanently inundated (except immediately after severe breaching events) include the main lagoon, the South Arm, a small portion of the North Arm, and a portion of the Odello Extension.

Figure 1. Carmel Lagoon study area.

2 Thalweg bathymetry

2.1 Goal

The goal of collecting bathymetry data in the Carmel Lagoon was to establish a baseline of lagoon depth along the thalweg. As a result of local fires in the summer of 2008, landscapes upstream of the Carmel Lagoon are now highly susceptible to erosion during the upcoming winter storms and could potentially contribute large amounts of sediment to the Carmel lagoon system. Establishing a bathymetric baseline allows assessment of the impact of potential sediment loads entering the Carmel lagoon from upstream fire-affected landscapes.

2.2 Methods

We measured depth of the lagoon along the thalweg using a combination of four measurement devices. Measurements were made during the afternoon hours (12:00-15:30) between October 8 and 23, 2008 at the locations shown in Figure 3.

Figure 2. Measuring lagoon depth at the end of the North Arm using a staff tape.

On October 8, 2008, depth was measured using a staff tape, single-beam sonar mounted on a kayak (Humminbird Piranha Max 15), and a hand-held depth sounder (Depthmate Portable Sounder Model SM-5, SpeedTech Instruments, Great Falls, VA). At each sampling location, a measurement with each of these instruments was taken along with GPS coordinates. Due to difficulty of obtaining accurate readings from the sonar systems in shallow weedy water, eleven of the fourteen depth measurements reported for October 8, 2008 are based on measurements from the staff tape. The last three

depth measurements are based on measurements taken by the hand-held depth sounder (Depthmate Portable Sounder Model SM-5, SpeedTech Instruments, Great Falls, VA) as the depth at these points was too deep for the staff tape to reach the bottom of the lagoon. The measurements taken October 8, 2008 represent only a portion of the thalweg depth in the north end of the lagoon as we were limited in our ability to take measurements at each suspected change in lagoon depth.

On October 23, 2008, depth was measured using only a stadia rod. The single-beam sonar (Humminbird Piranha Max 15) and the hand-held depth sounder (Depthmate Portable Sounder Model SM-5, SpeedTech Instruments, Great Falls, VA) were not used due to the difficulties experienced on October 8, 2008. The staff tape was not used again due to its limitations in deep water and its tendency to bend. At each sampling location, a measurement with the stadia rod was taken along with GPS coordinates. The measurements taken October 23, 2008 provide a reasonably accurate representation of the thalweg depth in the south end of the lagoon, as we were able to take measurements at each suspected change in lagoon depth.

2.3 Results

The results of the bathymetry measurements taken on October 8 and 23, 2008 are shown in Figure 4. A variety of depths were present throughout the lagoon, with the greatest depths occurring near the pipe.

2.4 Conclusion

The goal of establishing a baseline of lagoon depth along the thalweg of the Carmel River was accomplished. Although accuracy was limited north of the pipe, due to poorer instrumentation, the data in general provide a useable baseline for comparison. These data may be used as a baseline for bathymetry data to be collected in October 2009. This comparison could reveal changes in thalweg depth, such as may be due to sediment deposition entering the Carmel lagoon from upstream fire-affected landscapes.

The data collected this year are also be useful for quantifying volume of available habitat for juvenile steelhead in the lagoon. Lagoon depth and volume are critical for steelhead survival, especially during the dry season when surface flows from the Carmel River no longer reach the lagoon.

Figure 3: Thalweg depth measurement locations for bathymetric survey (October 8 and 23, 2008). Data taken at locations north of the pipe (red line) are limited in quality based on the type of measurement devices used. Data quality was enhanced with stadia rod measurements at locations south of the pipe.

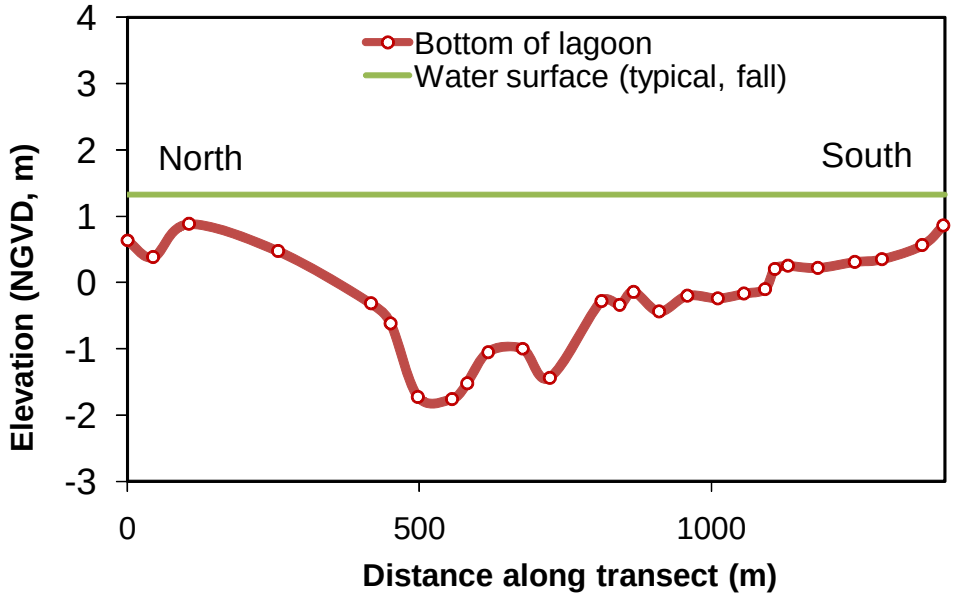

Figure 4. Thalweg profile in Carmel Lagoon running from the North Arm, through the main lagoon where the river enters, through the South Arm, and ending at the terminus of the Odello Arm.

3 Water Quality – Comparison to Previous Year

3.1 Goal

A brief comparison was made between water quality profiles from fall 2008 and fall 2007, in order to determine if the overall stratification patterns were generally similar between years.

3.2 Methods

Measurements were made during the afternoon (12:00–16:00) on October 2 and October 9 2008. We made in situ readings for temperature, dissolved oxygen and salinity with either an YSI Environmental 556 MPS Multiprobe System or a Hach HydroLab DS5X (see ESSP660, 2007, for instrument specifications). We obtained measurements at 0.25 m depth increments and recorded profiles for water quality parameters at the pipe location in the South Arm. Data recorded from site visits made on October 23 2007 and November 6 2007 (ESSP660, 2007) were compared to our results.

Figure 5. Measurement of depth profiles of temperature, salinity, and dissolved oxygen from a canoe near the breach point of the Carmel Lagoon. Note ocean wave in background, and evidence of recent ocean wave overwash in the patterns of kelp debris.

3.3 Results

The results of the depth profile at the pipe location revealed a stratified water profile (Fig. 6). Dissolved oxygen, temperature and salinity all showed gradients with respect to depth. For example, dissolved oxygen (DO) at deeper depths (< −1.5 m NGVD) ranged from 0.2 to 1.9 mg/L, whereas at shallower depths (> 0 m NGVD), DO ranged from 7.8 to 11.2 mg/L. Both temperature (° C) and salinity (ppt) generally showed higher values at deeper depths and lower, somewhat constant readings in shallower water (Fig. 6).

3.4 Comparison to previous year

Inter-annual comparison between 2007 and 2008 confirmed that the overall pattern of stratification was similar between years (Fig. 6). Much of the difference between years can easily be attributed to slight differences in seasonality, timing of sampling, and antecedent weather conditions, and do not indicate any fundamentally different system state. One difference between the profiles that may be indicative of a difference between the two years in general is that the relatively fresh layer was slightly fresher and thicker during sampling in 2008.

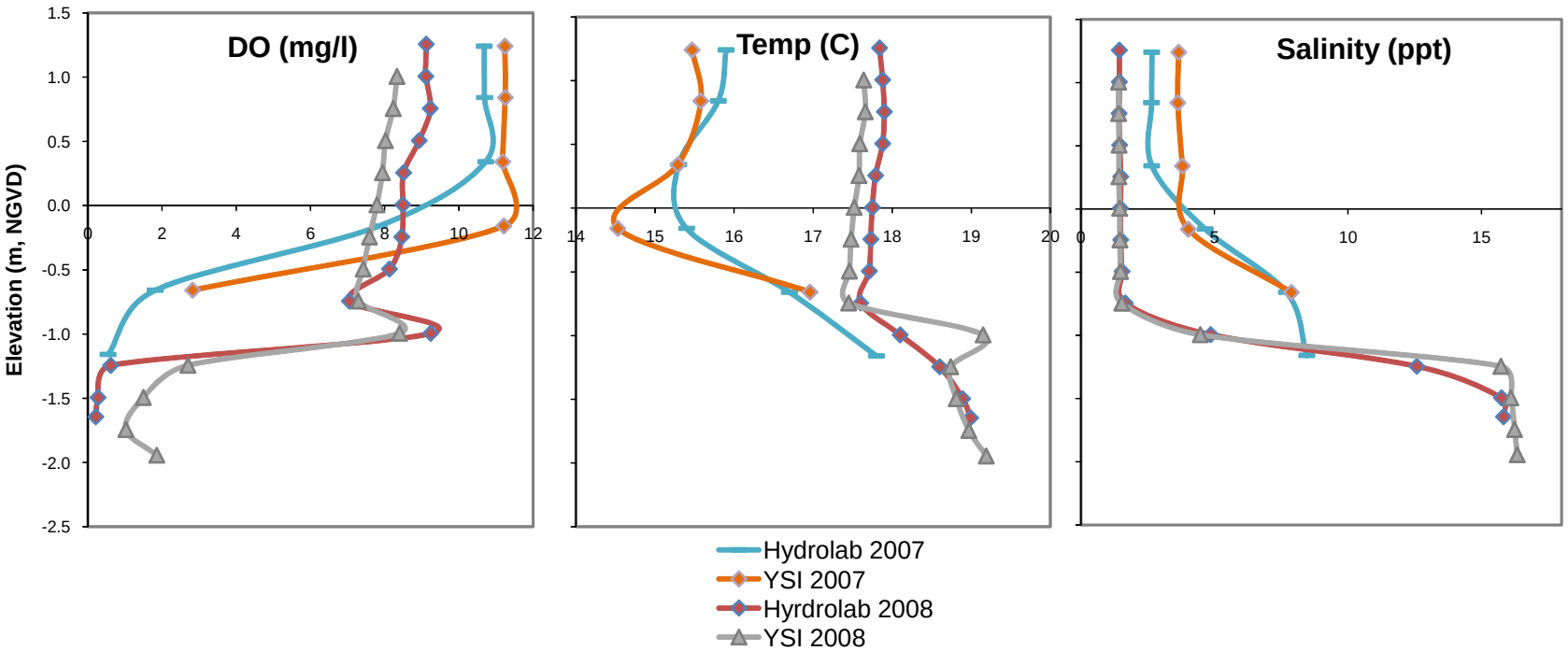

Figure 6. Depth profile comparison of water quality parameters (dissolved oxygen, temperature and salinity) from 2007 to 2008. Profiles demonstrate slight variations from year to year but overall similar patterns.

4 Water Quality – Longitudinal Profiles

4.1 Goal

We measured a sequence of water quality profiles throughout Carmel Lagoon to obtain relative measure of total habitat available for steelhead use.

4.2 Methods

Water quality profiles were measured from a kayak and a canoe on the afternoon of October 9, 2008 at 17 sites along a transect running from the North Arm to the South Arm of the lagoon (Fig. 8). See Section 3 for a description of equipment and measurement methods. For the purpose of this habitat indexing endeavor, we defined 'useable' habitat as areas of the lagoon that met three water quality criteria: depth > 0.5 m, temperature < 26 °C, and DO concentration > 5 mg/L. The parameters at these thresholds are thought to control steelhead habitat selection (see references cited by ESSP660, 2007); however we recognize that they are subjective and open to discussion. Given these criteria, steelhead useable habitat was estimated by plotting water quality criteria along a transect from north to south (Fig. 10), dividing this transect into a continuous sequence sub-transects, estimating the useable volume for each sub-transect, and summing (Table 1). The useable volume of each sub-transect was estimated by first calculating the area of the longitudinal-vertical rectangle extending from the bottom of the 'bird predation risk zone' to the deepest part of the lagoon along the sub-transect. This area was then multiplied by the proportion of the rectangle that was estimated to be useable given the water quality criteria. To calculate volume, the useable area along the sub-transect multiplied by the average channel width at that site, as determined from three measurements per site using Google Earth, scaled by 50% to account for the fact that channel cross-sections tended to be more triangular than rectangular.

4.3 Results

A longitudinal profile of the water quality parameters along the transect showed expected vertical stratification, as well as trends from north to south. A salinity gradient extended from the North Arm south to the Odello Arm (Fig. 9a). The highest salinity (15 ppt) was found just south of the pipe, and lowest salinity (<1 ppt) was recorded at the southern-most point on the transect. Dissolved oxygen concentration generally remained above 5 mg/L, but fell below this and was lowest (<1 mg/L) at the deepest section of the transect (Fig. 9b). A temperature gradient was also found along the transect (Fig. 9c). The coldest temperature (14.8°C) was measured in the North Arm, while the warmest temperature (21.6°C) was found at the southern end of the Odello Arm. Salinity increased with depth and DO decreased with depth, as expected.

Temperature, while generally showing a decreasing trend with depth, remained relatively stable (18.5°C) in the deep region south of the pipe (Fig. 9c).

From the profile and average width measurements, we estimated that there was approximately 16,000 m^3 of usable habitat in the lagoon. The temperature criterion (<26°C) was met in all areas of the lagoon and thus did not limit useable habitat. We adopted a crude 'bird predation depth criterion' such that waters within 0.5 m of the typical fall water surface were not considered useable habitat. A dissolved oxygen criterion of 5 mg/L lead to the deeper waters of the South Arm and North Arm being deemed unusable.

4.4 Comparison to previous year

A few differences were detected between the 2007 and 2008 longitudinal profile. Salinity showed the same general decreasing gradient from north to south between years, however fresher water gained area in 2008 as the fresher boundary of the Odello Arm expanded toward the pipe. Both years showed a well-oxygenated lagoon with the exception of the sump and North Arm shallows. Maximum temperatures in 2008 (21.6°C) were warmer than in 2007 (19°C), but the sampling in 2008 was slightly earlier in the year. The highest temperatures in both years were in the Odello Arm.

4.5 Conclusion

- Salinity increased with depth and decreased from north to south.
- Dissolved oxygen concentration was decreased with depth and was lowest in the sump and North Arm shallows.
- Temperature slightly decreased with depth and increased from north to south.
- Assuming a 0.5 m predation zone, harmful DO concentrations below 5 mg/L, harmful temperatures above 26 °C, and a triangular channel shape, we estimated approximately 16,000 m^3 of useable steelhead habitat in the lagoon channel.

Figure 7: Water quality profile sampling sites used in 2008. The sequence of sites extending from noth to south was used to construct transect plots. The sites in the river (northeast) were excluded from the transect plots.

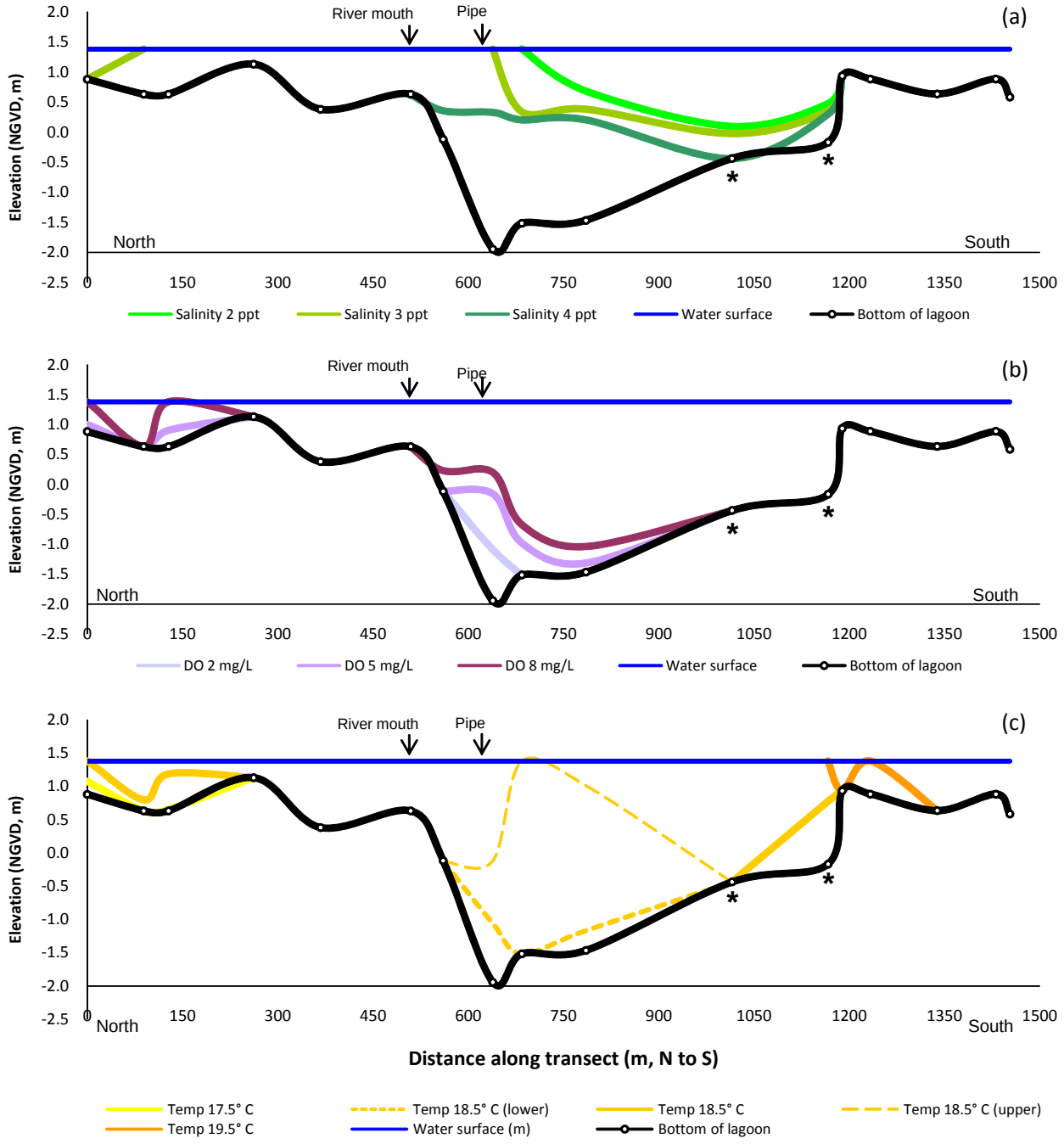

Figure 8. . Isopleths of salinity (a), dissolved oxygen (b), and temperature (c) running from north to south along the main lagoon channel. At some sites, the 18.5° C isopleth occurred at multiple elevations. At these locations, an elevation range in which 18.5° C occurred multiple times was plotted . * indicates locations where dense weeds caused weaker data quality and erroneously greater depths because of kayak drift and instrument drag.

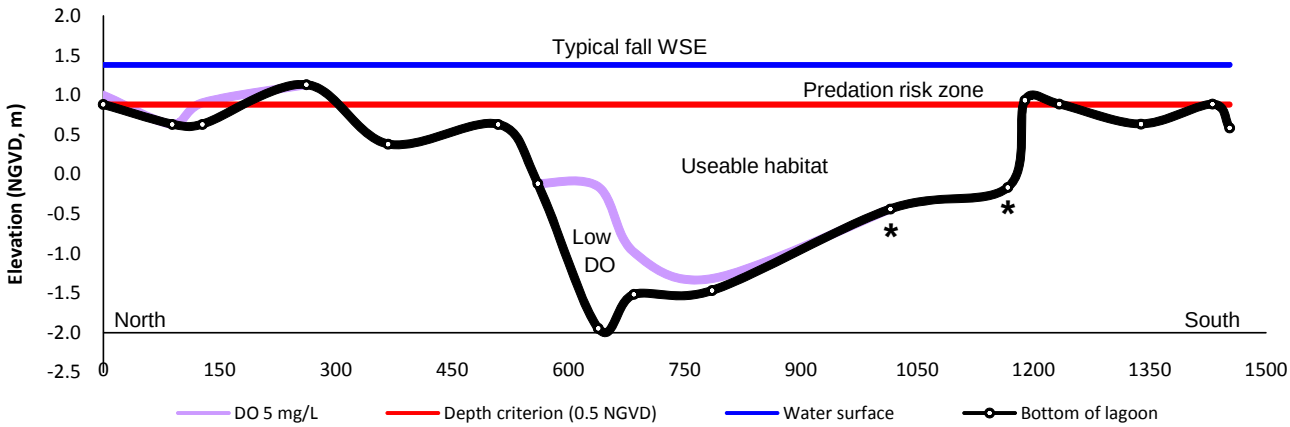

Figure 9. Longitudinal profile of 'useable' habitat along the lagoon channel. To estimate 'useable' habitat, we assumed that a bird predation risk zone lies within 0.5 m of the typical fall water surface elevation (WSE), and that low DO concentrations in the deeper water of the North Arm and the South Arm sump further limit habitat. Temperatures were not high enough to exclude any other areas of the lagoon from useable habitat. * indicates locations where dense weeds caused weaker data quality and erroneously greater depths because of kayak drift and instrument drag.

Section	Distance from north end (m)		Length L (m)	Max thickness of useable layer, T (m)	Average useable thickness, as proportion of max, P	Average useable thickness (m) U = T x P	Channel width, W (m)	Non-rectangular cross-section	Estimated useable volume (m3), V = L x U x W x F
	Start	End							
1	0	89	89	0.25	50%	0.13	5	50%	117
2	89	128	39	0.25	50%	0.13	12	50%	118
3	128	262	134	0.25	0%	0.00	NA	50%	0
4	262	367	105	0.50	33%	0.17	87	50%	1514
5	367	509	142	0.50	66%	0.33	105	50%	4922
6	509	561	51	1.00	66%	0.66	47	50%	797
7	561	639	78	2.82	33%	0.93	16	50%	209
8	639	684	46	2.82	50%	1.41	17	50%	199
9	684	785	101	2.35	80%	1.88	34	50%	1357
10	785	1015	230	2.35	75%	1.76	32	50%	2750
11	1015	1167	151	1.32	85%	1.12	23	50%	1505
12	1167	1189	22	1.05	70%	0.73	29	50%	225
13	1189	1233	44	0.00	0%	0.00	NA	50%	0
14	1233	1339	105	0.25	50%	0.12	52	50%	1379
15	1339	1431	92	0.25	50%	0.12	52	50%	1200
16	1431	1453	22	0.30	0%	0.00		50%	0
Total									16291

Table 1. Measurements and calculations involved in estimating the total volume of habitat 'useable' by steelhead in the lagoon during October 2008. The concept of 'useable' habitat is a simplification, taking into account water quality influences (primarily dissolved oxygen at this time of year) and depth below bird predation.

5 Water Quality – Local Effect of Aerators

5.1 Goal

The goal of this portion of the study was to very briefly examine whether there were systematic dependencies of water quality measurements on proximity to two aerators that were installed adjacent to the pipe. Any dependencies found would have bearing on the appropriate location to measure depth profiles that were intended to be representative of this region of lagoon as a whole.

5.2 Methods

We used the same equipment as in Section 3. The water quality measurements taken were temperature, salinity and dissolved oxygen (DO). We measured three profiles at 5, 10, and 15 m from the west bank respectively. For each profile, measurements were recorded at 0.25 m depth increments. The two aerators were located at approximately 7 and 8 meters from the west bank respectively. The results were plotted as isopleths on a cross-sectional diagram.

More thorough methods could easily be designed if more emphasis were placed on this portion of the study.

5.3 Results

The results suggest that the aerators affect water quality near the pipe (Fig. 11). Dissolved oxygen was higher nearer the aerators. Temperature may have been slightly higher near the aerators, although this pattern was not very clear in the data. Both of these observations were consistent with the operation of the aerators to pump low-oxygen (and incidentally, higher temperature) water from the bottom of the lagoon to the top of the lagoon.

5.4 Conclusion

Proximity to the aerators appeared to influence water quality profile data within a radius of about five meters. Thus, profiles intended to be representative of the broader area should be taken more than five meters from the aerators. This is a preliminary result, based on a brief and minimal investigation.

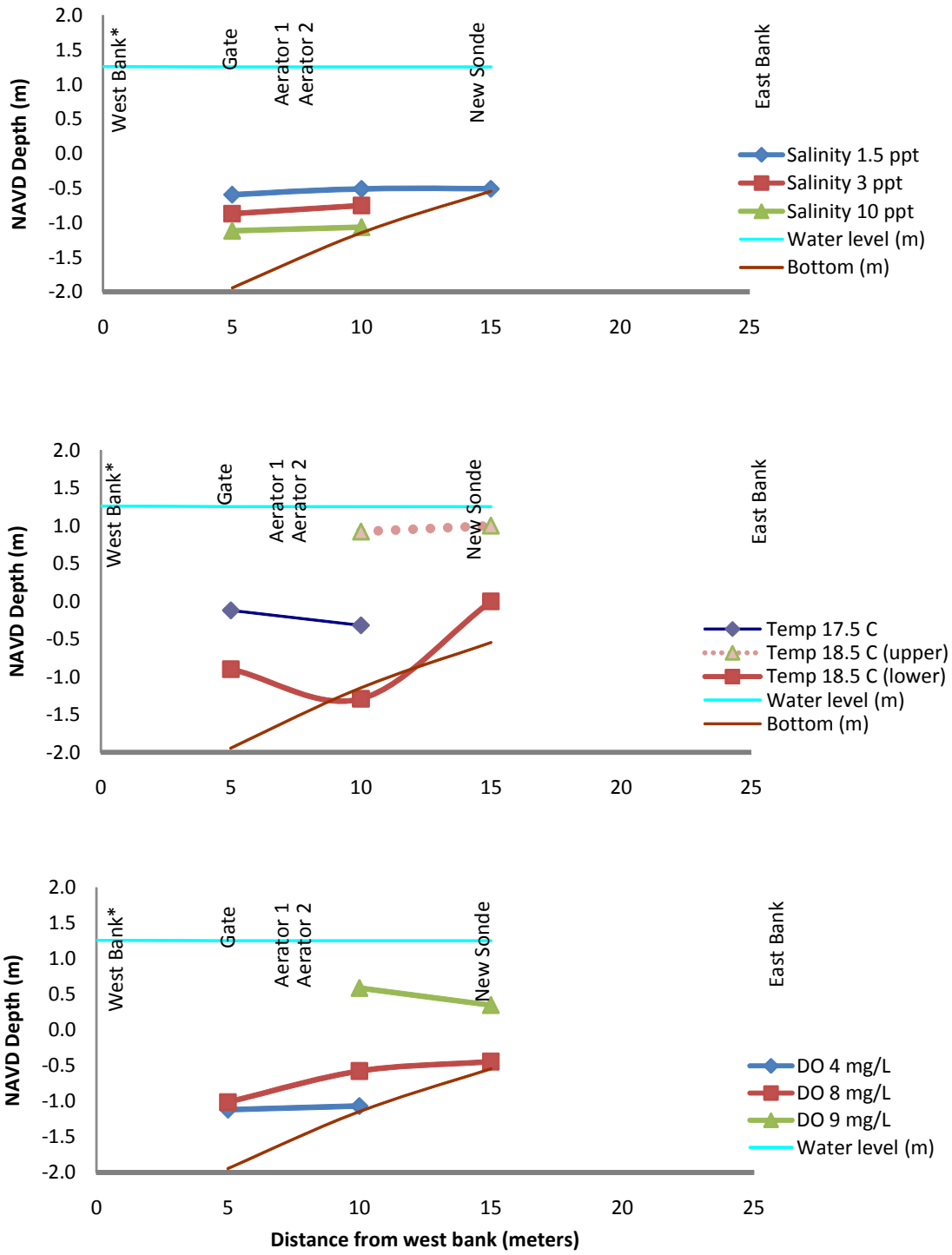

Figure 10. Isopleths of salinity (a), temperature (b), and dissolved oxygen (c) from west to east along the pipeline crossing S2. Locations of gate, aerators, and sonde are approximate only.

6 Sonar Survey for Fish

6.1 Goal

Steelhead population estimates provide critical information to resource managers involved in their restoration. Using sonar methodology initially tested in 2007 (ESSP660, 2007), we sought to further develop protocols that could provide a low-cost, low-impact index for measuring of the relative changes in fish abundance between sampling dates.

6.2 Methods – Sonar Sounding

Surveys were conducted using a *Humminbird 1197c GPS* side-imaging sonar mounted on a kayak and an *Eagle Ultra 3D* multi-beam sonar mounted on a canoe. We used the automatic fish detection systems built into the sonar units. These systems displayed fish icons on the screen when a sonar return was estimated to be a fish, as opposed to, say, a clump of weeds (Fig. 12). We set the sonar units to maximum fish detection sensitivity.

We counted total detected fish along six transects in multiple passes (Figs 13, 14; Table 2). Each transect was surveyed by paddling the canoe or kayak at a slow, steady pace from one end to the other, counting fish, and noting start and end times. We also estimated detection probability as the proportion of the total transect time when the water was clear of sonar-obstructing weeds, and deeper than about 0.6 m. In some locations, aquatic weeds grew from throughout much of the water column and were clearly visible both in the field and on the sonar as complete obstructions to the view beneath them. Also, some simple tests looking at submerged logs suggested that the sonar beams could not detect fish in water shallower than about 0.6 m unless they were immediately beneath the vessel. More formal tests of these detection limits would be useful.

6.3 Results

Table 2 compares fish counts between transects, sonar units, and years. The results were generally similar between sonar units and between years. The methods would be too imprecise at this stage to infer any substantial difference between years or sonar units from these data. Some spatial patterns are evident, such as a consistent finding that most of the detectable fish were in the South Arm on either side of the pipe. Detection probability was very low in the Odello arm both due to weeds and shallow water, so relative fish abundance estimates there were very poor. Detection probability was better in the river arm because although shallow, the water was very clear. Although we visually saw one large adult salmonid in the river arm (approx. 60 cm long), the sonar units never detected fish in this area. Holding the sonar units pointing directly

sideways from the river toward the overhanging vegetation along the banks might improve the sonar detection probability in very shallow water.

To provide some confirmation that the objects detected as 'fish' by the sonar units were in fact fish, we conducted a simple test where we held the vessel and the sonar unit stationary for 5-minutes near the south arm pipe in an area where many fish detections had been recorded. During this time, the side-imaging sonar recorded a large object slowly moving into the field of view at about 2 m depth. The object moved quickly off the screen after a kayak paddle was plunged deep into the area. It is difficult to explain these observations as being due to anything other than a large animal swimming and then fleeing. The animal was almost certainly a large fish. A turtle or a diving bird would move faster, weeds would not move at all, and a frog would be too small and in less saline water.

Local fishermen (pers. comm.) reported that in 2008, unlike any previous years in memory, approximately 50 striped bass were over-summering in the lagoon and could often be seen feeding near the surface at sunset. It is likely that many of the fish detections we recorded in 2008 were bass. While not impossible, it would be difficult to discriminate bass from steelhead on the sonar units. If seining occurs later in the year, this will provide some clarification as to the relative abundance of large bass versus large steelhead in the lagoon in 2008.

6.4 Conclusion

- Development of simple sonar 'fish-finding' protocols in the lagoon to date has been promising. To some extent, the approach is already yielding an index of relative fish abundance that can be rapidly, cheaply, and harmlessly used in the lagoon to index changes in the abundance of medium to large fish.
- The majority of detectable fish occurred in the deepest waters within about 50 to 100 m of the South Arm pipe. In 2007, these detections were most likely steelhead; and in 2008, they may have been either steelhead or bass or both.

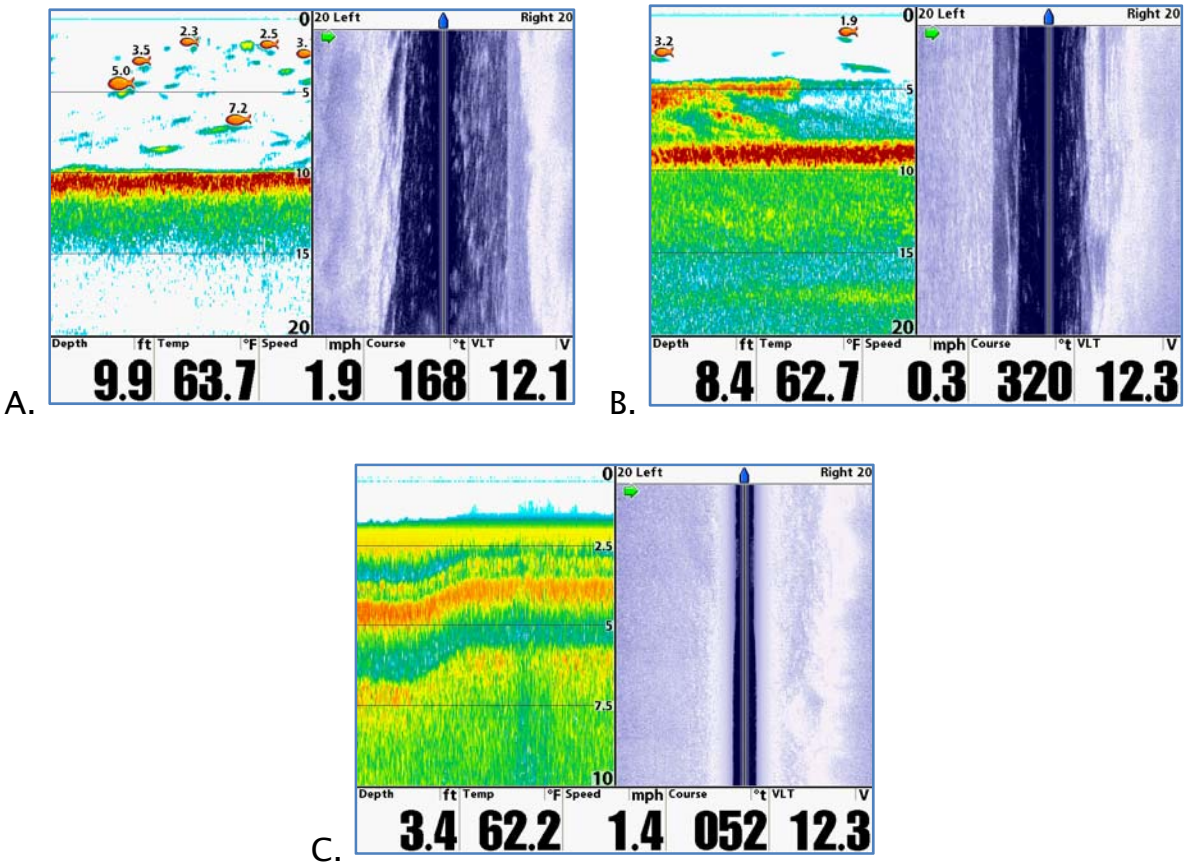

Figure 11. Screen shots from *Humminbird 1197c GPS side-imaging* sonar in three different field situations in the Carmel Lagoon.

The left part of each screen (color) indicates a traditional (single-beam) vertical profile of the water column, with time represented on the x-axis and depth on the y-axis (units in feet). The x-axis is equivalent to location along a transect because of the movement of the vessel along the transect.

The right part of each screen shows the side-imaging data, where the x-axis represents increasing angles to the left and right of the transect center line, and the y-axis represents time and thus location along the transect. Dark colors indicate relatively clear water; light spots indicate fish or weeds; and large light sections indicate either masses of weed, tules on the bank, or the bank itself

Image A reveals relatively deep water, with a clearly define bottom, and a large number of isolated sonar returns consistent with fish. The sonar unit has automatically detected many of these as fish, and estimated their size (size of icon) and relative certainty of detection (numeric display).

Image B was taken close to Image A except that a 3 to 4 feet thick mass of dense weeds was present (red and orange bands thinning toward the right of the color screen) with very limited fish detection probability as a result.

Image C was taken in very shallow water with a light cover of bottom weeds (light blue on the color display). A number of false bottom returns are displayed below the real bottom, presumably due to multiple sonar echoes between the bottom and the surface and the vessel's hull.

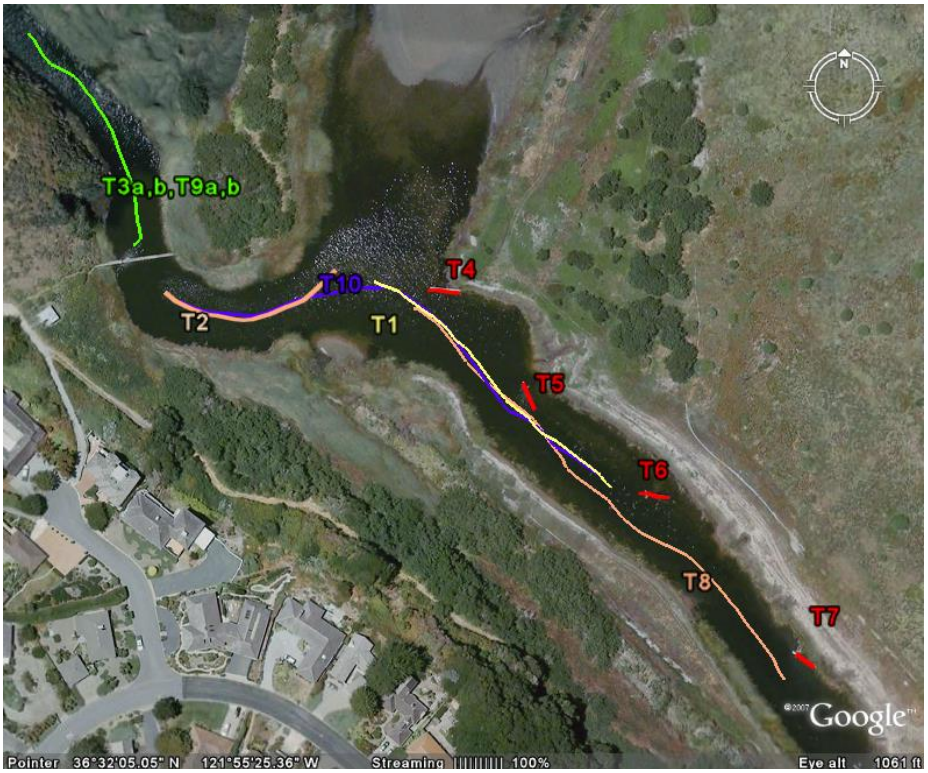

Figure 12: 2007 Sonar transects. Transects T4-T7 were analyzed along artificial logs.

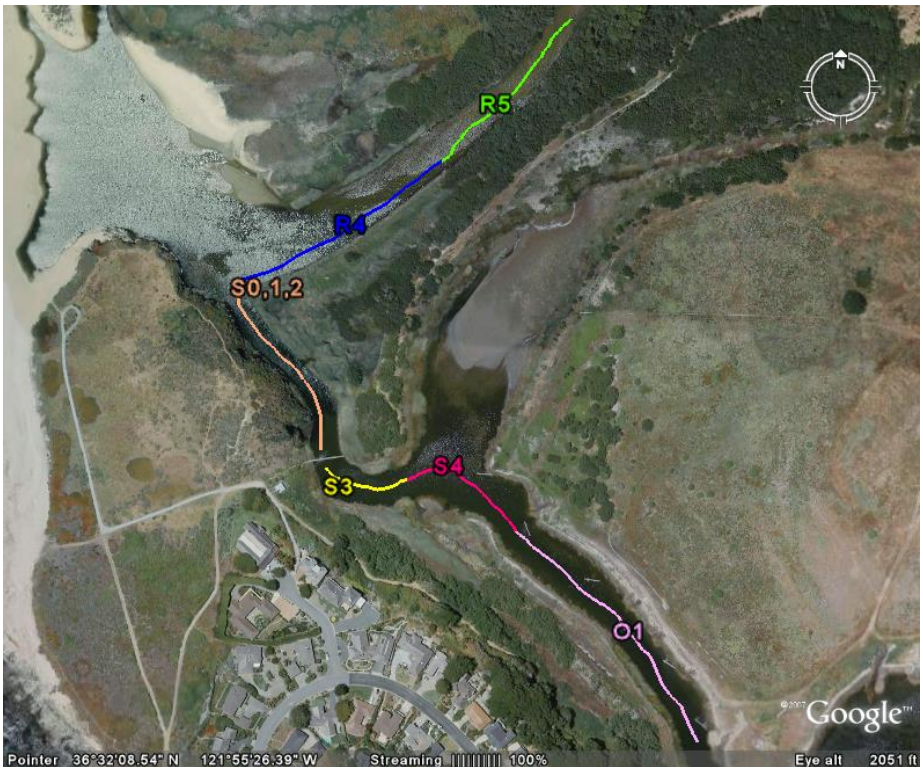

Figure 13: Sonar Transects for 2008 data.

Table 2. Counts of individual fish estimated using sonar automatic fish detection systems along several transects approximately corresponding to established sampling Zones in Carmel Lagoon (R5,R4,S0,S1,S2,S3,S4,O1). A comparison is provided between 2007 data (ESSP660, 2007) and data collected for the present study (2008). Large bold text indicates data from side-imaging sonar, and other text indicates data from the multi-beam sonar. Parenthesized text indicates estimates scaled up to account for estimated low detection probability due to either weeds or shallow water (scaling-up was accomplished by diving by estimated proportion of transect where fish were detectable given sufficient depth and absence of weeds). Vertical lines indicate extent of transects through multiple zones. Some transects were surveyed more than once with a given sonar unit on a given date.

	2007	2008	
Zone	**07-Nov**	**21-Oct**	**23-Oct**
R5		**0 (0)**	**0 (0)** 0 (0)
R4		**0 (0)**	**0 (0)** 0 (0)
S0	80	**13 (26)** **35 (70)** **28 (56)**	**70 (140)** 0 (0) **17 (34)** 57 (114) **45 (90)** 76 (152)
S1	76 64		
S2	56		
S3	9	**4 (8)**	**7 (50)** 41 (293)
S4	24 8	**0 (0)**	
O1	5 1 0 1	**0**	**0 (0)**

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