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Water Quality Dynamics of the Mattole River Lagoon and Suitability for Rearing Salmonids in 2006

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Abstract. Warm water temperatures have been implicated as a factor contributing to low survival of juvenile Chinook salmon and steelhead rearing in the Mattole River Lagoon during summer months. To address this concern, water quality conditions were monitored in the Mattole River Lagoon from mid-June through mid-October, 2006 using continuous recording instruments placed at various locations and depths and by roving, synoptic surveys. Resultant data were used to assess the influence of water quality conditions on the suitability of habitats for juvenile salmonids in the lagoon. Specific conductance, water temperature, pH, and dissolved oxygen data were compared with literature-derived threshold tolerances for salmonids and juvenile fish distribution data collected by the Mattole Salmon Group. Between July 23 when the lagoon formed and September 1, the short-term critical maximum temperature of 24.0 °C, which was used to assess acute stress, was not exceeded in any part of the lagoon. However, the maximum weekly average temperature criterion of 19.0 °C that represented a chronic stress condition was exceeded for 16 days in the lower lagoon and 39 days in the upper lagoon. Lower water temperatures were observed in the lower lagoon than in the upper lagoon, which we attributed to tidally controlled accretions of cold, seawater overwash in the lower lagoon. Despite the cooler water temperatures, fewer fish were observed in the lower lagoon compared to the middle and upper sections of the lagoon, suggesting factors other than temperature were influencing fish distribution. In general, dissolved oxygen (DO) concentrations and pH levels were suitable to support survival of salmonids, but at times exceeded the California standards. Greater diel variations in these parameters within the bottom strata of the lagoon due to benthic algae production may have influenced invertebrate production and therefore, fish distribution. Seawater intrusion that occurred in mid-September caused considerable variation in specific conductance and eventual temperature inversions throughout most of the middle and upper lagoon. Here the more dense seawater within the bottom strata of the water column was up to 2.4 °C warmer than the non-saline (fresh) surface water. We hypothesize that temperature inversions and diel fluctuations in DO influenced fish

distribution within the lagoon. Elucidating how fish respond to and survive within these dynamic conditions is important in understanding the influence water quality conditions have on habitat suitability for juvenile salmonids in the lagoon. Recommendations for future studies are provided.

Introduction

Coastal estuaries and lagoons are important habitats for a variety of anadromous salmonids. These habitats are a critical point of transition from seawater to freshwater for immigrating and emigrating salmonids. Juvenile salmonids that emigrate to the ocean may freely rear in the estuary for a short or extended period prior to ocean entry or rear in a lagoon upon emigrating after lagoon formation (Shapovalov and Taft 1954, Young 1985, Smith 1990, Busby 1991, Zedonis 1992, Bond 2006). Numerous studies conducted over several decades have demonstrated the importance of these natural basin features in providing valuable habitat to a variety of salmonids that included steelhead (*Oncorhynchus mykiss*) and Chinook (*O. tshawytscha*) and coho salmon (*O. kisutch*)(Shapovalov and Taft 1954, Reimers 1973, Young 1987, Smith 1990, Busby 1991, Zedonis 1992, Bond 2006).

Downie et al. (2002) suggests that rearing within the Mattole River Lagoon in Northwest California may limit survival of juvenile salmonids and be hindering the recovery of Chinook salmon within the basin . Research conducted in the 1980s revealed that Chinook salmon juveniles that migrate late relative to lagoon formation experience high mortality. Young (1987) estimated 10 to 20% survival of the estimated 40,000 juvenile Chinook salmon trapped in the lagoon from July to October of 1985. In the following year, Barnhart and Busby (1986) estimated approximately 10,000 juvenile Chinook salmon present in the lagoon, but only about 20% survived until late August. In 1987, Busby et al. (1988) estimated between 75,000 to 145,000 juvenile Chinook salmon were present in the lagoon, but nearly all perished over a two-month period. Suggested causes of past high mortalities in the lagoon include high water temperatures (MRC 1995) and exceedence of the carrying capacity in terms of food availability when the lagoon formed in mid-May and mid-June (Busby and Barnhart1995). In contrast, when lagoon formation occurs late relative to emigration of juvenile Chinook, such as after mid-July, few Chinook salmon are typically found in the lagoon (Zedonis 1992; MRC 1995, Downie et al. 2002).

Given the depressed status of the Mattole River Chinook salmon population and that lagoon rearing may represent a bottleneck to their recovery, the Mattole Salmon Group (MSG) is pursuing creative ways of enhancing the population in the basin. One such concept to increase their survival in lieu of a properly functioning estuary/lagoon (MRC 1995) is to capture juvenile Chinook salmon rearing in the lagoon, which are presumed to experience high mortality, and rear them off-site prior to release back in the lagoon after it breeches. To date, this concept remains a viable management action of the North Coast Watershed Assessment Program of the State of California (Downie et al 2002).

Water quality studies have occurred in the Mattole River Lagoon in the past, but have been synoptic in nature (Busby 1987, Zedonis 1991). These studies have provided insights into water quality conditions and likely interactions with fish residing in the lagoon. However, these studies did not employ advanced automated equipment that allows the dynamics of water quality conditions to be examined on a continuous basis in both horizontal and vertical dimensions. Specific objectives of this study were to conduct a thorough investigation of the water quality dynamics of the lagoon in 2006 and relate these conditions to suitability in providing habitat for juvenile salmonids.

Study Area

The Mattole River is located in northwestern California in Humboldt and Mendocino Counties, about 60 km south of Eureka (Figure 1). The Mattole River drainage basin is about 767 km^2 and the main stem is approximately 100 km long. The river flows into an abbreviated estuary at the mouth before entering the Pacific Ocean. The climate of the lower Mattole River basin is moderate due to its close proximity to the Pacific Ocean. The coastal portion of the basin is influenced the primarily by annual air temperatures that range between 4 and 16 °C. Inland portions of the basin are influenced less by the coastal conditions and rather, by inland air temperatures that exceed 38 °C as observed in other portions of interior California.

The basin has one of the highest annual precipitation amounts in California, having a mean rainfall of about 206 cm that occurs primarily between November and April (Downie et al. 2002). The coastal region receives on average 152 cm of rainfall while inland regions average 254 cm (Downie et al. 2002). Winter and spring storms that travel in a northeasterly direction from the Pacific Ocean result in the greatest precipitation due to the close proximity of steep mountains that promotes abundant rainfall (Downie et al. 2002). Despite the high yearly rainfall amounts, summer base flow at the Petrolia gauge can approach 21 cubic feet per second (cfs) due to typically small amounts of summer rainfall, evapotranspiration, and off-channel use of Mattole River water by residents (Downie et al. 2002).

The Mattole River estuary transitions to a lagoon during late spring and early summer in most years. Lagoon formation and its permanency of closure are dependent upon a number physical processes including river flow, waves and long shore ocean, substrata type and abundance, coastline shape, and channel width and volume (Barnes 1984, Smith 1990). Based on 24 of the last 25 years for which records have been maintained, the dates of permanent lagoon formation range from May 26 (1987) to September 8 (1990) and the median date of closure is approximately July 7th (MSG unpublished data). Regression analysis shows an inverse and weak correlation of river flow to date of closure (R^2= 0.3872) validating that other physical processes are important factors influencing lagoon formation (Figure 2). A common attribute of the historic data set is that lagoon formation occurs when flow of the Mattole River was less than 140 cfs at the Petrolia gauge (#11469000). The earliest closure recorded in the last 25 years (May 26, 1987) coincided with the year that Busby et al. (1988) documented high mortality of juvenile Chinook salmon rearing in the lagoon. In 2006, lagoon formation occurred on July 23 when flow of the Mattole River at the Petrolia gage was approximately 74 cfs (Figure 3).

Lagoon formation results in a several-fold increase in the area inundated by ponding of water behind the sand spit or berm that separates the ocean from the river. Busby et al (1988) estimated the surface area of the ponded area to be 3 hectares in 1987. Coastal lagoons re-open and close periodically during the initial phases of development in the spring and early summer and destruction of the bar in the fall (Barnes 1984, Smith 1990, and Bond 2006). Water elevation in the lagoon fluctuates with tides, river flow, and permeability of the berm separating the lagoon and the ocean (Barnes 1984, Smith 1990). Water depth and surface area of the lagoon gradually decrease in late summer because of diminishing river flow (Busby and Barnhart 1995). Lagoon water quality varies with the frequency and magnitude of seawater over wash, residence time of the seawater, and meteorological conditions (Busby et al. 1988, Smith 1990, Bond 2006). Seawater intrusion into the lagoon not only causes an immediate reduction in water temperature, but also results in periodic inverse stratification due to warming of the more dense seawater at the bottom of the lagoon (referred to as meromixis). The extent of meromixis is largely dependent upon the absence of mixing forces (e.g. wind and flow) and their ability to prevent prolonged stratification (Barnes 1984). Meromictic conditions can also result in extreme fluctuations in dissolved oxygen (both high and low) as a result high algae production (Smith 1990). As an open estuary, the diurnal forces of changing stage and flow with each tidal cycle and wind are likely significant enough to prevent wide spread or long term temperature inversions from occurring (Smith 1990). When closed, however, wind-driven mixing can become the primary force to disrupt inverse stratification, which in some cases is limited, resulting in widespread inversions that persist for several days (Smith 1990).

Methods

Continuous Multiprobe Data

DataSondes ®(sondes) that continuously measured and recorded water temperature, dissolved oxygen, pH, specific conductance, and depth were deployed at two sites, referred to as DS 1&2 and DS 3&4 (Figure 1). Each of these sites was characterized by placement of a sonde at the bottom (i.e,.Sondes DS -1 and DS -3) and the surface (i.e. DS- 2 and DS- 4 to characterize vertical variations in water quality. Site selection was based on the proximity to seawater and adequate depth. One site was located near the Pacific Ocean that represented the lower estuary/lagoon, while another site was located~1 km upstream that represented the upper estuary/lagoon. A global positioning system (GPS) was used to record the location of each study site. Sondes recorded data at 30-minute intervals. The Mattole Salmon Group maintained sondes on a biweekly schedule from June 15 to October 19 following quality control measures established by the Arcata Fish and Wildlife Office's (AFWO) multiprobe maintenance and deployment protocol (Appendix A).

Temperatures Loggers

Temperature data loggers (HOBO® Water Temp Pro; Onset® Computer Corporation) were deployed at 7 locations in the lagoon, including the two sites monitored with sondes. All loggers recorded temperature at 1-hr intervals. These loggers have an accuracy rating of +/- 0.2 °C for temperatures between and -20 to 50 °C. Use of loggers was an inexpensive alternative to placing sondes throughout the lagoon, while providing additional information on the spatial and temporal dynamics of water temperature, and inferential evidence of timing and duration of cooler ocean water presence. Deployment dates varied with site; temperature loggers were placed at sites TP -5 and TP – 6 on June 24 and June 16, TP-7, and TP-10 on June 15, TP-8 and TP-9 on July 15, and TP-11 on July 21(Figure 1). Sites TP-5 and TP- 6 corresponded to sonde locations DS-1 and DS-2, but were positioned at depths that were intermediate to the sondes in order to more accurately capture temperature stratification at this lower site. Locations of loggers were identified with a GPS.

In general, all loggers were placed on the bottom; exceptions included the site TP – 5 and TP- 8.that measured temperatures at ~ 3 feet below the surface. Upon extraction on October 20, the accuracy of temperature loggers was assessed and in all cases, fell within the manufacturers specifications of ± 0.2 °C (see Appendix B).

Synoptic Surveys

To supplement data collected using automated sensors, synoptic surveys of diurnal water quality occurred on July 20 (3 days prior to permanent closure) and August 17 to compliment the knowledge base of the water quality conditions in the horizontal and vertical dimensions during high tidal cycles. These surveys provide a "snap-shot" of the water quality conditions at the time of the survey. The July 20 survey occurred from 13:36 to 16:32 hrs and the August 17 survey occurred from 8:09 to 11:12 hrs. A calibrated handheld multiprobe instrument (Hydrolab Quanta®) was used to measure water temperature, dissolved oxygen, pH, and specific conductance at 10 sites in the estuary/lagoon and one site above the first riffle known to represent completely riverine water quality conditions (SS-11, Figure 1). A kayak transported personnel to each study location. Profiles began in the lower lagoon (closest to the Pacific Ocean) and proceeded in an easterly direction ending at site SS-11. At each site, water quality was measured from the bottom to the surface at 1 to 2-ft intervals and the time of measurement was recorded. Time to complete each survey was approximately three hours. Locations of study sites were recorded with a GPS. Many of the sites where synoptic survey data were collected overlapped with sites where continuous monitoring with sondes and temperature loggers occurred. Details of this sampling program are presented in tables of Appendixes D and E.

Salmonid Habitat Use of the Estuary/Lagoon

Concurrent with water quality investigations, the Mattole Salmon Group used direct observation with mask and snorkel to estimate the relative abundance of salmonids using the estuary/lagoon during summer 2006 (Mattole Salmon Group 2007). Snorkel surveys occurred weekly during daylight hours from June 8 to August 30 (12 surveys), with an additional survey occurring on November 1. A team of two or more divers conducted the surveys using a modified ten-pool survey protocol adopted by the California Department of Fish Game (Preston et al. 2002). At least one surveyor from each team was experienced in identifying juvenile salmonids underwater.

The estuary/lagoon was divided into five areas that corresponded to different habitat sections of the estuary/lagoon region [(Figure 1;See Mattole Salmon Group (2007) for more detailed descriptions of survey areas)]. Divers surveyed for fish in all parts of each area that were deep enough to snorkel. Salmonid species were identified and enumerated in the following size classes: <100 mm (<4"), 100 to 200 mm (4" – 8") and > 200 mm (> 8").

Assessing the Suitability of Water Quality for Salmonids

We compared water quality data from 2006 to water quality criteria for salmonids derived from the literature (Table 1) to assess the overall suitability of the lagoon for rearing salmonids.

Specific Conductance — We used specific conductance rather than salinity as a more sensitive indicator of seawater presence in the lagoon. There are no known threshold criteria with specific conductance for salmonids rearing in an estuary/lagoon and as such, no direct assessments of this parameter on fish health or mortality were determined. We recognize that this parameter indirectly influences other water quality parameters and thus, salmonid distribution and overall health. In particular, seawaterseawater intrusion directly influences water temperature, which may increase primary productivity with eventual consequences to dissolved oxygen concentrations and pH.

Water Temperature — The body of literature on suitability of water temperature for salmonids is extensive. Documents completed by the State of California [Regional Water Quality Control Board (RWQCB) 2003; Downie et al. 2002] provide threshold temperature criteria that we used to evaluate the suitability of water temperature for salmonids of the Mattole River Estuary/Lagoon. The weekly average temperature (WAT) of 19 °C was used as an upper temperature threshold for chronic levels of stress and 24 °C was selected as the short-term critical thermal maximum temperature (CTM) (Table 1). The WAT represents the running average of 7 consecutive days of all monitored temperatures (half-hour and hourly measurements) for each site.

Dissolved Oxygen — Dissolved oxygen concentration is a potential limiting factor for salmonids in highly productive environments such as estuaries and lagoons. We used the EPA (1986) criteria of 4 and 6 mg/L as the threshold for severe and slight production impairment to characterize the influence of DO on rearing salmonids and rearing habitat suitability (Table 1).

pH — The pH is also an important factor to consider when examining water quality and its overall effect on fish production and health. The pH of a water body is altered by respiration and photosynthesis , increasing during the day and decreasing at night. Respiring plants release CO2 into the water, causing the pH to decline. During photosynthesis, plants take up CO2 and the pH increases. Other constituents may also become toxic at certain pH levels. For example, ammonia toxicity is directly affected by water temperature, oxygen concentration and salinity, but is primarily determined by pH of the water (Piper et al. 1982). An increase in pH by one unit alone may increase the fraction of unionized ammonia (NH_3) ten-fold (Piper et al. 1982). The Basin Plan for the

North Coast Region of the Regional Water Quality Control Board (1994) lists a suitable pH range for the Mattole River as 6.5 to 8.5, which we used in this evaluation (Table 1).

Table 1. Water quality criteria used to qualify the suitability of the Mattole River Lagoon for rearing salmonids from June to October, 2006.

Water Quality Parameter	Juvenile Salmonid Species[a]	Suitability	Reference
Water Temperature			
Long Term Averages (Weekly Avg Temp)	≥ 19 °C	Unsuitable	Downie et al. 2002, RWQCB (2003)
	17 to 19 °C	Marginal	Downie et al. 2002, RWQCB (2003)
	< 17 °C	Suitable	Downie et al. 2002, RWQCB (2003)
Short-Term Critical Thermal Maximum (Daily Maximum)	≥ 24 °C	Unsuitable (Death is usually imminent)	Downie et al. 2002, RWQCB (2003)
Dissolved Oxygen			
Daily Minimum	= 6 mg/L	Marginal (Slight Production Impairment)	EPA (1986)
Daily Minimum	≤ 4 mg/L	Unsuitable (Severe Production Impairment)	EPA (1986)
pH			
Daily Range	6.5 to 8.5 pH units	Suitable	RWQCB (1994)

Results

Continuous Water Quality Data

Specific Conductance — Sonde data provided in-depth detail of the temporal and spatial influence of seawater intrusion into the lagoon. In the lower lagoon, the diel variation of specific conductance was highest in the lower stratum (DS- 1) and just prior to lagoon formation (Figure 4). Relatively high specific conductance of the surface stratum (DS- 2) also occurred but with less frequency than the lower stratum. Upon lagoon formation, the most influential seawater intrusion to the lagoon occurred in mid-September and resulted from a combination of high tides and large wind-waves (Figure 5). During this event, specific conductance of the bottom (DS-1) and surface strata (DS-2) were as high as 19,613 and 14,668 µS/cm, respectively.

Seawater intrusion also altered the specific conductance in the surface and bottom stratum of the mid-region of the lagoon (Figure 6). Timing of increased specific conductance of this region of the lagoon was quite similar to that of the lower lagoon but the magnitude of increase was less than the lower lagoon (Figure 6). Periods of highest specific conductance in the lower stratum occurred prior to lagoon formation and in mid-September when a large seawater overwash occurred. Following lagoon formation, the highest measurements occurred in mid-September in the bottom strata (DS-3; 22,649 µS/cm) and surface strata (DS-4; 1,666 µS/cm) similar to what we observed in the lower lagoon.

The lower strata of the mid-region of the lagoon exhibited higher specific conductance than the lower strata of the lower lagoon. We believe that these results are real and reflective of different water exchange dynamics that occur in the lower and middle portions of the lagoon. Specifically it appears that seawater in the lower lagoon can be flushed back through the sand berm with freshwater during low tides while at upstream sites, especially at the Woodzilla site, which is deeper than the area between it and the lower lagoon, flushing of the dense seawater layer requires much more time.

Water Temperature — Water temperatures of the surface (DS-2) and bottom (DS -1) of the lower lagoon were highly variable prior to lagoon formation and became much less variable and warmer after the lagoon formed (Figure 7). Prior to lagoon formation, diel fluctuations in surface water temperature ranged from 11 to 24 °C. Following lagoon formation, diel fluctuations at the surface were typically less than 1.5 °C and daily maximums were typically less than 22 °C, which is below the short-term CTM of 24 °C. Water temperatures were, for the most part, similar in the upper and lower strata at these sites. The exception occurred in mid-September during the period of high seawater intrusion into the lagoon when the lower stratum was about 2 °C cooler than the surface stratum.

Water temperatures of the middle lagoon (sites DS-3 and DS- 4) were also variable and, similar to that observed in the lower lagoon before and after lagoon formation. Prior to lagoon formation, diurnal fluctuations in water temperature ranged between 13 and 24 °C at both stations. After the lagoon formed, diel fluctuations were typically between 1.5 and 3.0 °C (Figure 8). Here again, the CTM of 24° C was not exceeded. Seawater intrusion that occurred in mid-September reduced temperatures of the lower stratum to less than 16 °C for two days, which was about 3° C lower than the surface water (Figure 9). Following these two days, a temperature inversion occurred in late afternoon that resulted in denser seawater of the lower stratum being between 1.0 and 2.4 °C warmer than the surface water.

Site TP-7 exhibited considerable diurnal variations in water temperature prior to lagoon formation and reduced variation following lagoon formation (Figure 10). This trend is consistent with temperatures observed at downstream sites as well as at the neighboring site, DS-3. Site TP-7 also exhibited a temperature reduction associated with seawater intrusion that occurred in mid-September. As we did not collect surface water temperature at this site, we were unable to confirm if a temperature inversion also occurred at TP-7.

Water temperatures at sites representing the upper lagoon (i.e.TP-8 and TP-9) indicated the surface stratum was, in general, slightly warmer than the bottom stratum and that diel fluctuations in both strata ranged between 2.0 and 4.4 °C (Figure 11). After lagoon formation, water temperatures at these sites exhibited slightly greater diurnal fluctuations as compared to sites of the middle and lower lagoon (e.g. DS-1, DS-2, DS-3 and DS-4). A temperature inversion occurred at sites TP-8 & TP-9 in September at the same time it was observed at sites DS-3 and DS-4 (Figure 9). Close examination of this event revealed the water temperature near the bottom of the lagoon was similar to that of the surface during the late afternoon, but that the bottom layer remained up to 4 or 5 °C warmer than the surface water in the morning hours (i.e., 10:00 hrs when water temperatures were lowest).

In contrast, Sites TP-10 and TP-11 located at the very top of the lagoon exhibited similarly large diel fluctuations in water temperature before and after lagoon formation, indicating these sites were monitoring riverine conditions. Exceedence of the CTM of 24° C occurred on a couple of days immediately following closure of the lagoon but thereafter, temperatures declined (Figure 11). The diel fluctuations of temperatures at sites TP-10 and TP-11 ranged between 4 and 5 °C. We do not believe that seawater reached either of these sites during the monitoring period and that the extent of seawater influence was located somewhere between TP- 8 and TP- 10.

Weekly Average Temperatures — Prior to lagoon formation, weekly average temperatures (WAT) differed with depth and region of the estuary (Figure 12). Site DS-1, representing the bottom of the lower lagoon, stands out as having the coldest WAT, which we attributed to frequent intrusions of cooler seawater. On July 12, for example, the WAT of the bottom stratum of the lower lagoon was about 14.6 °C while the surface stratum (DS-2) and other sites upstream were greater than 19.5 °C. Sites of the upper estuary (i.e. TP -8, 9 and 10) had the warmest WAT, often exceeding 22 °C.

Following lagoon formation, water temperatures throughout the lagoon stabilized due to increased thermal mass afforded by ponding of river water and tidal over wash into the lagoon (Figure 12). Immediately following closure, the WAT of the entire lagoon (both surface and bottom) peaked between 21 and 22 °C, and decreased thereafter. However, the WATs still exceeded the chronic criterion of 19° C for about 16 days in the lower lagoon and almost 39 days (until September 1) in the upper lagoon. The WAT criterion of 19°C was exceeded in the lower lagoon by 39 to 44% for the period of July 23 to September 1, compared with the 49 to 83% for the middle lagoon followed by the 83 to 98% in the upper lagoon (Appendix C).

Average water temperatures for the period July 23 to September 1 in the lower, middle, and upper regions of the lagoon were 19.1, 19.6, and 20.0 °C, respectively.

pH — Over the period of study, the pH of the lower lagoon varied in both the surface (DS -2) and bottom (DS -1) strata and the bottom exhibited slightly greater variation (Figure 13). We believe that the greater variation observed in the bottom strata was likely a result of photosynthesis and respiration by benthic algae, which were observed by MSG staff. In both strata, the pH typically ranged between 8 and 9 and on one occasion approached 9.2. The peak pH (9.2) and largest diel fluctuations in pH (0.8) of the bottom stratum occurred on August 25. A peak pH of 9.2 was recorded in the surface stratum on September 15 but possible reasons for the high value are not clear. It appears that this region of the lagoon continually experienced pH ranges that exceeded the maximum criterion established by the Regional Water Quality Control Board.

The pH of the middle lagoon was similar in both strata but exhibited lower daily minima as compared to the lower lagoon. Following lagoon formation, pH ranged from a high of about 9.1 (July 24) to a low of about 7.4 (Figure 14). Similar to the lower lagoon, pH in the middle lagoon continually exceeded the maximum criterion of 8.5 for nearly all days sampled. Unfortunately, we did not have a continuous recorder in the river above the lagoon to help distinguish differences in pH attributable to seawater influences.

Dissolved Oxygen — Daily minimum DO concentrations in the surface stratum of the lower lagoon were generally above 7 mg/L while the bottom stratum typically exhibited DO concentrations above 6 mg/L (Figure 15). An exception to this occurred on August 26 in the lower stratum when DO ranged from 4.7 to 18.2 mg/L. The lowest DO concentration occurred at 07:30 hrs and the highest at 18:00 hrs. Peak DO concentration represented about 211% saturation. As noted previously, this large fluctuation was believed to be associated with the diel cycles of respiration and photosynthesis of benthic algae. Large fluctuations in pH that occurred during the same time provide additional support of this contention.

The daily minimum DO concentration of the surface stratum of the middle lagoon was generally above 7 mg/L with the exception of a few days following lagoon formation (Figure 16). After lagoon formation, DO concentrations steadily increased and minimums were typically above 8 mg/L by early September. Daily maximums were generally greater than 10 mg/L throughout the monitoring period.

Prior to lagoon formation, large diel variations in DO were observed in the lower stratum of the middle portion of the lagoon. Daily minimums were positively associated with high specific conductance readings and highs and lows corresponded well with typical times of photosynthesis (daytime) and respiration (nighttime) presumably due to high benthic algae production.

Daily minimum DO concentrations of the lower strata of the middle lagoon ranged between 4 and 6 mg/L on several days in August and September, many of which coincided with times of seawater overwash. Examination of the hourly data revealed daily maximums occurred in the late afternoon and minimums occurred from 0700 to 0800 hrs. We believe these trends corresponded to diel variations that were associated with photosynthesis of benthic algae.

Synpotic Water Quality Surveys

Specific Conductance — The July 20 survey revealed a strong chemocline from 6.0 to 7.5 feet below the water surface at sites SS-1 and SS-4 (Figure 17, Appendix D). Specific conductance of water near the bottom of the lagoon was more than an order of magnitude greater than the surface water, indicating the presence of seawater. Site SS- 2 also showed slightly higher conductivity at the bottom as compared to that measured within the top 4 ft of the water column. The surface stratum at sites closest to the ocean exhibited slightly greater conductivity than the more riverine-like sites located upstream.

In contrast, the August 17 survey indicated the lagoon was essentially fresh water, even near the bottom within the deepest sections of the lagoon located near the ocean (Figure

17, Appendix E). Sonde data confirmed the lagoon was essentially fresh water on this date.

Water Temperature — Vertical profiles conducted at eleven sites before (July 20) and after lagoon formation (August 17) showed considerably different thermal regimes (Figure 18, Appendix E). The July 20 survey revealed a dynamic thermal regime both laterally and vertically. Water temperature at sites closest to the ocean were up to 4 °C colder than those measured at sites in the middle and upper lagoon. Sites SS- 1, 5, and 9 displayed a gradual decrease in temperature with depth. Temperature differences observed at SS- 1 was believed to be a result of coldwater inputs from seawater intrusion as indicated by the higher specific conductance. In contrast, the subtle decreases in water temperature with depth that occurred at SS-5 and SS-9 may have been a result of stratification due to lack of mixing or cooler groundwater input. We do not believe the temperature difference was attributed to seawater intrusion based on consistency in specific conductance through the water column. Site SS- 4 indicated a temperature inversion had occurred; where water at 6 to 7 ft below the surface was above 23.0 °C and almost 2.5 °C warmer than the surface.

In contrast, the August 17 survey revealed the lagoon was considerably cooler than the July 20 survey and near isothermal conditions were present at all study locations (Figure 18). Sites SS- 4, 5, 7, and 10 were the only sites that displayed slight thermal stratification and these variations were typically less than 0.5 °C.

pH — The pH ranged from 8.3 to 9.0 across all sites on July 20 (Figure 19, Appendix E), similar to those observed in the continuous sonde record. The most notable differences occurred in the bottom stratum of the water column of SS- 1 and 4. Site SS- 4 exhibited the greatest differences where the pH was uniform (8.4 pH units) from the surface to a depth of 5.8 ft and increased sharply to 9.0 at the bottom.

On August 17, pH was generally lower than in July and ranged between 7.5 and 8.0. Unlike the July survey, no discernable vertical differences in pH were evident at any study sites.

Dissolved Oxygen — On July 20, DO concentrations ranged from 8.5 to 10.5 mg/L in the surface stratum and between 9.0 and 24.1 mg/L in the bottom stratum (Figure 20, Appendix E). Surface water was typically near saturation, but the bottom layers were as great as 300% saturation at SS- 4 and 150% at SS- 1. Elevated DO in the lower strata was believed to be from photosynthesis by benthic algae.

During the August 17 survey, DO concentrations varied slightly between sites and did not vary at depth. In contrast to the earlier survey, the lack of vertical differences in DO was indicative that little primary productivity was occurring in the lower strata.

Spatial and Temporal Distribution of Juvenile Salmonids

Chinook Salmon — Observations of juvenile Chinook salmon occurred only in areas 2, 3, 4, and 5 from June 8 to July 27 (Figure 1, Figure 21). Area 1 also likely contained fish, but poor visibility inhibited effectiveness of direct underwater observation. Nearly all observations occurred in June prior to lagoon formation. Diminishing counts of Chinook salmon occurred from June 15 (count=1445) to July 12 (count=30), with 12 observed on July 27, the first sample date following lagoon formation (July 23). This reduction in observations prior to lagoon formation suggests that the nearly all Chinook salmon departed the estuary and entered the ocean.

Steelhead — Steelhead of all size classes were observed in every survey but their distribution and abundance varied spatially (Figure 21). All three size-classes of juvenile steelhead were most abundant in Areas 2, 3, and 4 but rarely observed in Areas 1 and 5, again probably due in part to poor visibility. By far the greatest number of steelhead (<100 mm) were observed in Area 4 (~ 10,000 on July 20) followed by Area 3 and Area 2. Steelhead from 100 – 200 mm were most abundant in Areas 3 and 4 followed by Area 2, with a peak count of approximately 5,500 on August 2. Steelhead (>200 mm) were most abundant in Area 2 and the peak count was 300 on July 12.

Good visibility and greater habitat complexity of Areas 2, 3 and 4 were likely reasons for the higher observed abundance of steelhead at these locations. These areas contain riparian willows that afforded cover and presumably, terrestrial invertebrates as potential food. The most suitable salmonid rearing habitat was likely area 4 due to (1) presence of flowing river water and typical positive rheotaxic response of salmonids to flow, and (2) the great abundance of riparian cover.

Discussion

Water temperature is one of the most useful variables used to assess the suitability of aquatic systems for rearing salmonids as it significantly influences energetics, physiological development, competition, and immunological function of fish (Armour 1991), and primary and secondary productivity within the system. In our study, observed daily maximum water temperatures were less than the short-term CTM of 24 ° following lagoon formation. However, the criterion for chronic stress (WAT of 19°C) over the period of July 23 to September 1 was exceeded 39 to 44% of the time in the lower lagoon, 49 to 83% in the middle region and 83 to 98% in the upper lagoon (Appendix C). These data suggest thermal conditions of the lagoon were sub-optimal at times, and may have impaired the development and growth of salmonids. Although water temperatures did not exceed the acute level that directly produces mortality, the high proportion of time water temperatures remained above a chronic level in the upper lagoon where fish were most abundant likely had deleterious effects on fish survival. .

Although water temperatures of the lower lagoon were slightly colder than the middle and upper portions of the lagoon, the greatest abundance of salmonids were found rearing in the middle and upper portions of the lagoon indicating factors other than water temperature were responsible for their distribution. These results are similar to research conducted on the Mattole River lagoon in the late 1980s (Young 1987, Busby et al. 1988, Zedonis 1992) as well as research conducted on the Gualala River lagoon in (Sotoyome National Conservation District and California Coastal Conservancy 2005) and lagoons of the Pescadero, San Gregorio, and Waddell creeks (Smith 1990). A common theme from these studies is that water quality (DO, Temp, and Salinity) of the lower portions of these lagoons appear too dynamic and represent stressful conditions for rearing salmonids (in particular steelhead) and the invertebrate food sources that they rely upon (Busby et al. 1988, Smith 1990). Active avoidance of the lower regions of the lagoons by salmonids during periodic seawater overwash in the Mattole and other estuaries/lagoons, also suggests that rearing habitat availability fluctuates spatially and temporally affecting the carrying capacity of the lagoon. In turn, the periods of reduced carrying capacity may result in further stress to the fish resulting in reduced growth, and lower survival (Chapman 1966).

The large seawater intrusion that occurred in September of 2006 probably had a substantial influence on the distribution of fish and survival of less mobile invertebrates in the lagoon. Not only did this event result in abrupt salinity changes throughout most of the lower strata of the entire lagoon, but it also resulted in a temperature inversion and night-time reductions in DO in the middle portions of the lagoon where presumably the greatest number of salmonids were rearing. Smith (1990) concluded that growth of juvenile steelhead was excellent and invertebrate abundance was high when the lagoons of Pescadero, San Gregorio, and Waddell creeks were converted to freshwater and poor during periods of persistent stratification. Smith (1990) also concluded that survival of steelhead was poor and invertebrate abundance was low during periods of prolonged warm, stratified conditions. Findings of Smith (1990) would suggest that salmonids rearing in the Mattole lagoon during the September overwash event experienced stressful conditions that may have lead to reduced growth and lowered survival. Unfortunately, no concurrent studies to examine fish distribution and invertebrate abundance occurred immediately before, during, and after the event to provide an improved understanding of how fish coped with these altered water quality conditions. Clearly, additional work is needed to determine how even short term seawater intrusions affect the suitability of the lagoon for rearing.

Smith (1990) concluded that good habitat conditions of coastal lagoons can be managed through increasing summer base flow to rapidly flush stratified saline water from the lagoon. In the case of improving flow into the Mattole River lagoon, we are not certain to what degree this is possible, but do believe this is likely one of the most significant variable influencing the quality and quantity of salmonid habitat of the lagoon. Certainly, the current efforts by the Sanctuary Forest, who created a program called “The Mattole Flow Program” that aims to increase mainstem summer base flow to improve pool habitat for rearing salmonids in the upper basin represents a good start. However, even this water conservation program is relatively small and is not likely to improve water flow conditions in the lower portion of the drainage basin to any large degree if much at all (Eric Goldsmith Pers. Comm.) We are hopeful, however, that water conservation programs in the basin can be expanded to a point where flow to the lagoon are sufficient to improve rearing conditions for the typically large numbers of salmonids that over summer in the lagoon.

Recommendations

Water Quality Monitoring

A water quality monitoring program should be implemented on an annual basis or, at a minimum, during years when the lagoon forms in late May or early June when emigrating Chinook salmon may become trapped. Results of such studies will play a critical role in understanding the dynamics of water quality on overall habitability and survival of this species in the lagoon. In turn, these data may be useful in defining potential future management actions such as a "rescue-rearing" program or artificial breeching of the sand spit.

Ammonia toxicity can be an important factor affecting health and survival of salmonids (Piper et al 1986). The lagoon offers a near ideal location for ammonia concentration to be elevated because of relatively high nutrient loads typical of this environment and periods of low dissolved oxygen concentrations and high pH, in particular at the sediment interface. We recommend collecting water samples for ammonia concentration analyses at two to three locations (lower and mid-lagoon) during periods of warm weather, when algae mats are formed. Sampling should occur soon after lagoon formation and following periods of seawater intrusion.

Habitat Enhancement in the Lagoon

The North Coast Watershed Assessment Plan for the Mattole River provides a list of possible restoration activities for the Mattole River estuary/lagoon (Downie et al. 2003). Establishing cover for rearing salmonids should remain a goal to enhance the habitability of the lagoon and lower reaches of the Mattole River. While water quality is likely the most important factor affecting salmonids rearing in the lagoon, enhancement of physical habitat could enhance survival by reducing the energetic demand for acquiring food and by reducing exposure to predation. Restoring cover in the form of riparian vegetation should continue in spite of the dynamic river channel of the lower several miles of the river including the estuary. Here, the goal should be to plant native tree species for eventual woody debris recruitment to create preferred fish habitats in the lower river and lagoon.

Additions of other large wooden structures that withstand high winter flows can help create scour holes and provide structural cover as well as cover at depth. An existing wooden structure located in the middle of the estuary and lagoon, also known as "Woodzilla" by local residents, is a great example of a habitat structure that provides habitat diversity for emigrating and rearing salmonids and will likely continue to provide valuable cover over many years due to its large size (author's observations). Addition of more similar structures may also prove beneficial.

Freshwater inflow into lagoons improves water quality conditions for salmonid rearing (Smith 1990). This may represent the most important factor affecting the habitat quality of the lagoon. Increased inflow results in more rapid transport of seawater out of the lagoon when intrusion occurs, restoring the overall stability of the rearing environment. As such, upstream water conservation strategies that increase base flows in the Mattole

River, such as those identified in Downie et al. (2002), are likely to improve the overall suitability and carrying capacity of the lagoon for rearing salmonids.

Salmonid Population Monitoring in the Lagoon

A monitoring program that evaluates general trends in fish population structure of the lagoon should be instituted on an annual basis. This is especially important if lagoon formation occurs from May to mid or late June when emigrating Chinook salmon may become trapped. Further, it is quite valuable information when coupled with data on spatial and temporal dynamics of water quality. Fish count surveys such as those conducted by the MSG represent a good example and provide general information on the spatial and temporal distribution of fish population within the lagoon. Fish count surveys will be very important in verifying Chinook salmon survival and use of the lagoon throughout the summer and fall.

Efforts to continue to document spatial and temporal distributions of salmonids in the lagoon should consider using other methods of sampling to limit any bias that may exist by use of a single method alone. Besides direct observation (e.g. snorkeling), there are many other methods such as seining, fyke nets, and underwater video to verify presence or absence of fish in locations that might otherwise be difficult to sample by direct observation alone. A good example where several different methods might be employed would include the lower lagoon where poor visibility due to wind mixing and salinity is typically encountered. Using multiple methods is critical to improving our confidence of where, when, how many, and what species are using each area of the lagoon. In turn, it is only through a robust sampling design that credible conclusions can be made.

In addition, a fish-tagging program that allows tracking of individual juvenile salmon and steelhead should be considered in future years. Such a study would allow for a more precise understanding of diel and seasonal habitat use of salmonids in the Mattole River Lagoon, including preference and avoidance of water quality conditions or various habitats (rocks, riparian, and artificially placed log structures). Technological advances in the design of acoustic and radio transmitters now let researchers to tag fish as small as 20 g and 7.4 g, respectively (tag ≤ 5% fish weight). Although the effectiveness of radio transmitter function decreases with increased salinity, radio telemetry may still be especially suited for studies in the lagoon because fish distribution and abundance data from the present study suggest limited distribution of salmonids in the lower lagoon area where elevated salinity temporally exists. Thus radio transmitters could be useful in studies of the smaller juvenile Chinook salmon. In studies where the detection of individuals in the more saline waters of the lower lagoon was desired, acoustic transmitters would be required, as radio signals do not efficiently transit seawater. Although this may preclude the use of juvenile Chinook salmon, juvenile steelhead (> 120 mm) which are typically quite abundant in the lagoon could potentially serve as surrogates for Chinook salmon due to their similar physiological regulation and development (Zedonis 1992, MRC 1995). Ideally, a combination of acoustic and radio telemetry approached would used, especially during the first year, to fully describe the temporal and spatial distribution of fish throughout the lagoon relative to water quality conditions.

Rescue Rearing Program

Based on the 2006 data, and the limited number of Chinook salmon that were observed in the lagoon, we cannot determine the utility of a "rescue rearing" program for Chinook salmon that may rear in the lagoon over summer. We feel that the concept has merit but should continue to undergo joint review by the several agencies whom which have responsibility for the resources of the basin including the Mattole Salmon Group, Mattole Restoration Council, California Department of Fish and Game, Bureau of Land Management, the National Marine Fisheries Service, and U.S. Fish and Wildlife Service. Further, we recommend that efforts continue in increasing our understanding of habitat use and water quality conditions of the lower Mattole River and its estuary/lagoon. This will help ameliorate anthropogenic threats, such as reduced flow and increased sediment delivery to the estuary/lagoon that may improve the survival advantage to emigrating Chinook salmon.

Acknowledgements

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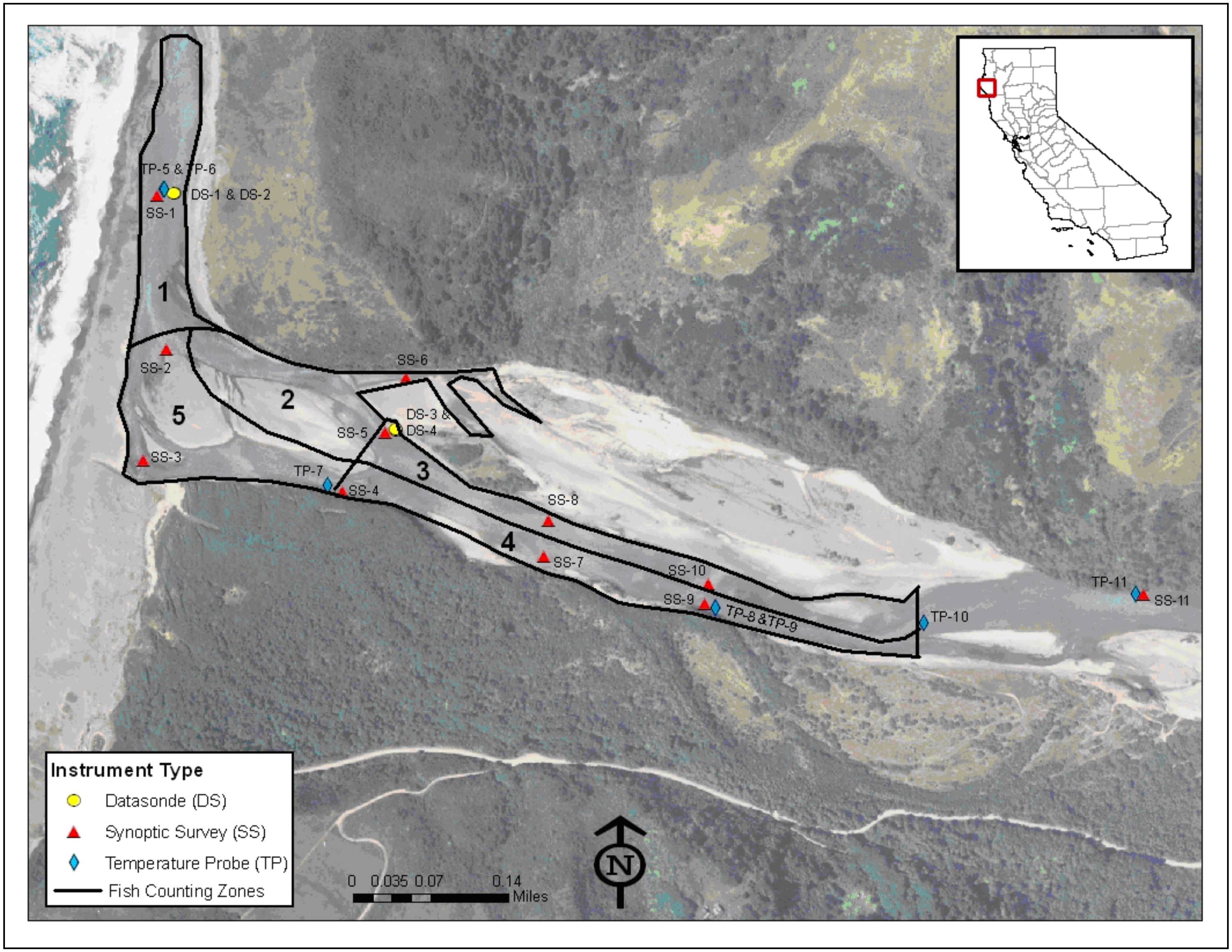

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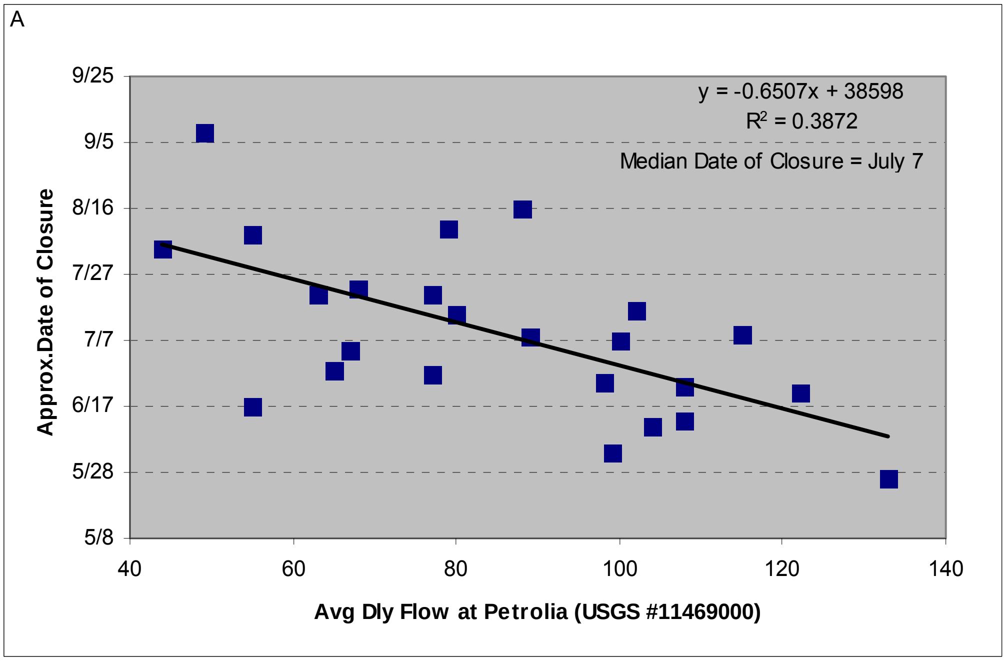
Figure 1. Water quality stations in the Mattole River estuary/lagoon. Imagery is from 2005 prior to lagoon formation. The solid black line represents an approximation of the waters edge and boundaries for fish counting zones (large numbers).



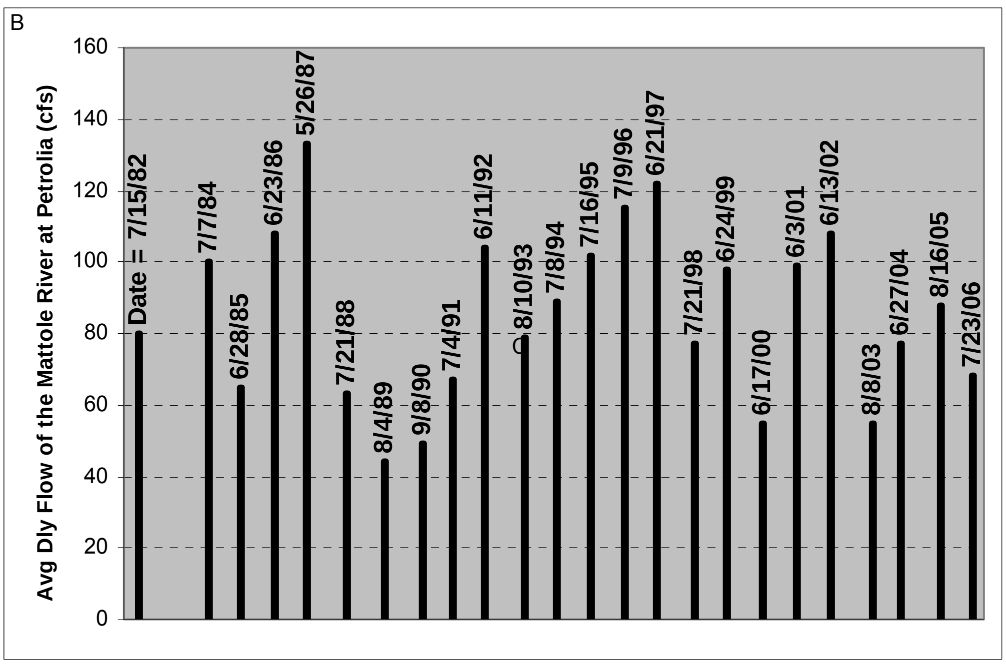


Figure 2. Relationship of permanent closure of the Mattole River Lagoon relative to flow (cfs) at the Petrolia gage (A), and time series of dates of permanent lagoon closure from 1982 to 2006 (B). Note the lagoon did not form in 1983.

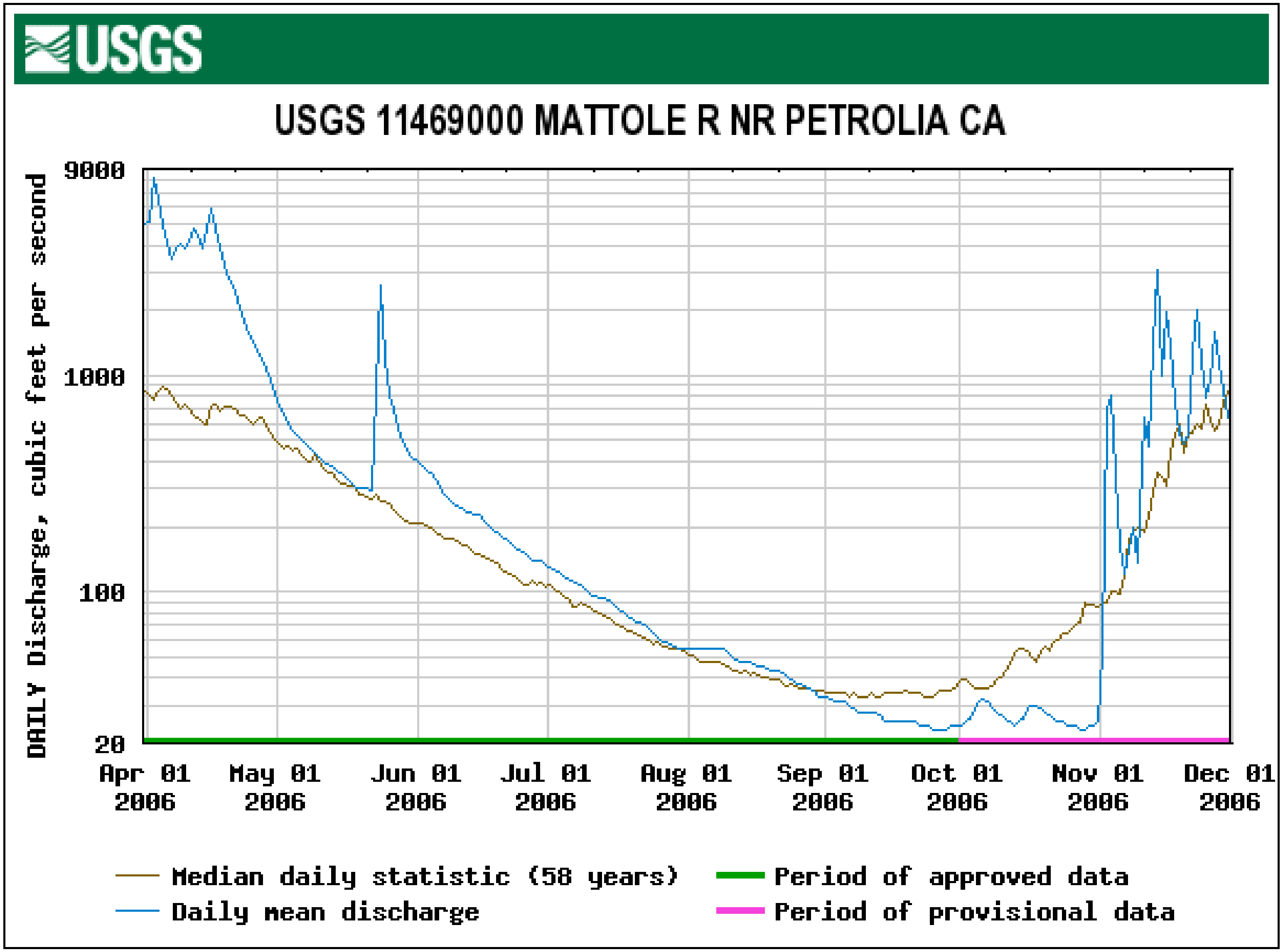


Figure 3. Flow of the Mattole River at Petrolia in 2006 and comparison of the 2006 flows to median conditions (USGS gage 1146900).

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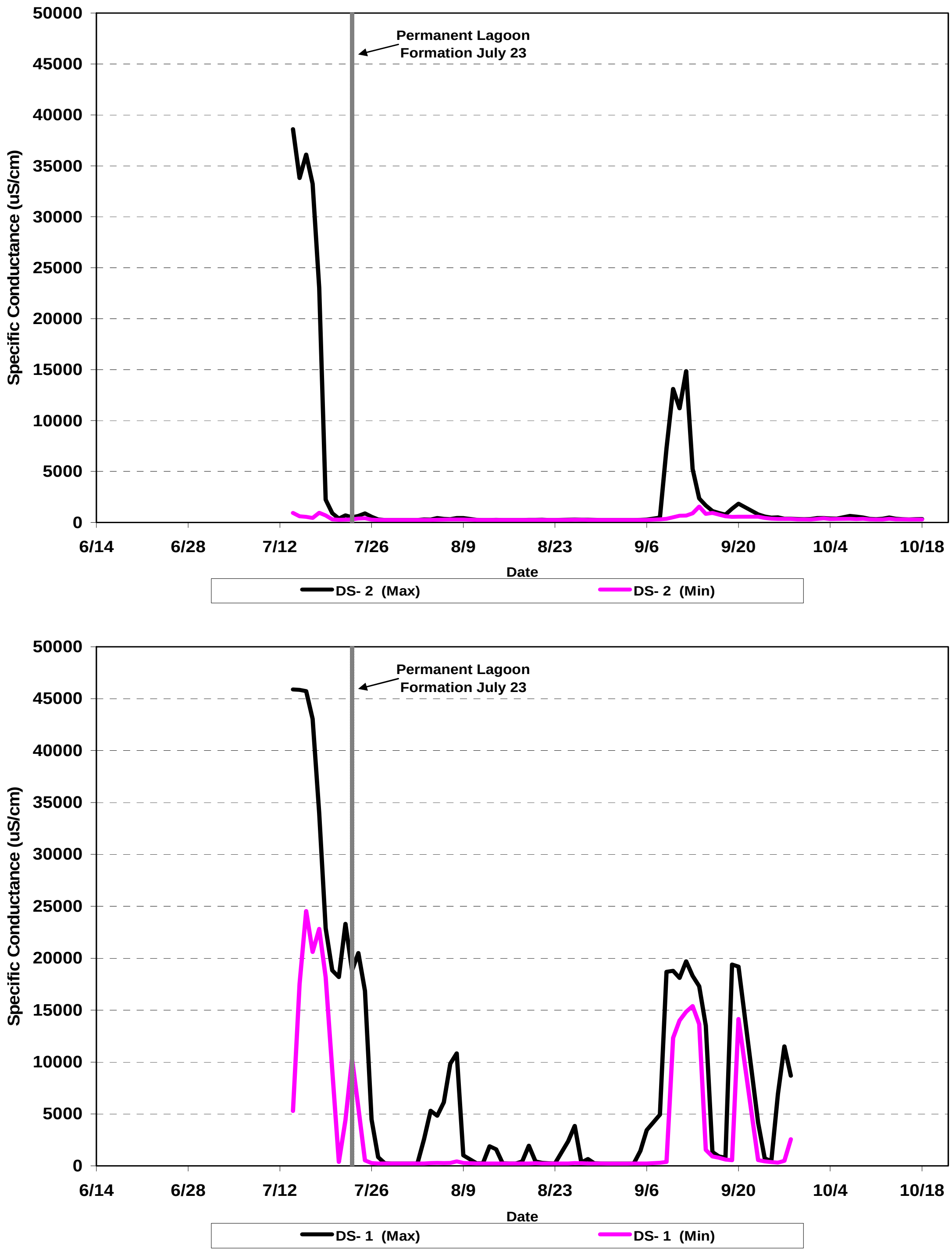

Figure 4. Maximum and minimum daily specific conductance of the surface strata (top figure; DS -2) and the bottom strata (bottom figure; DS-1) of the lower estuary/lagoon in 2006. Data collected with sondes.

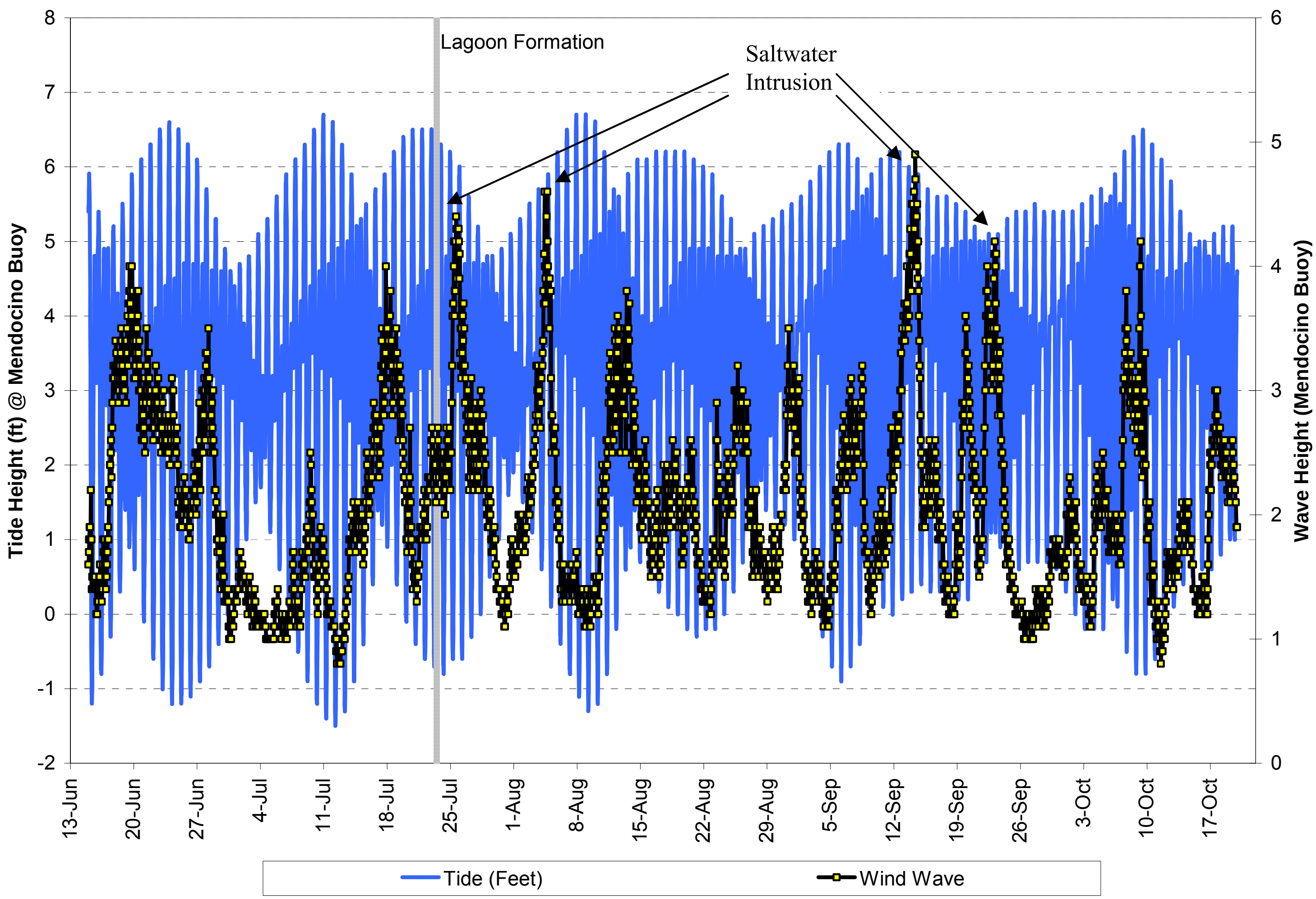

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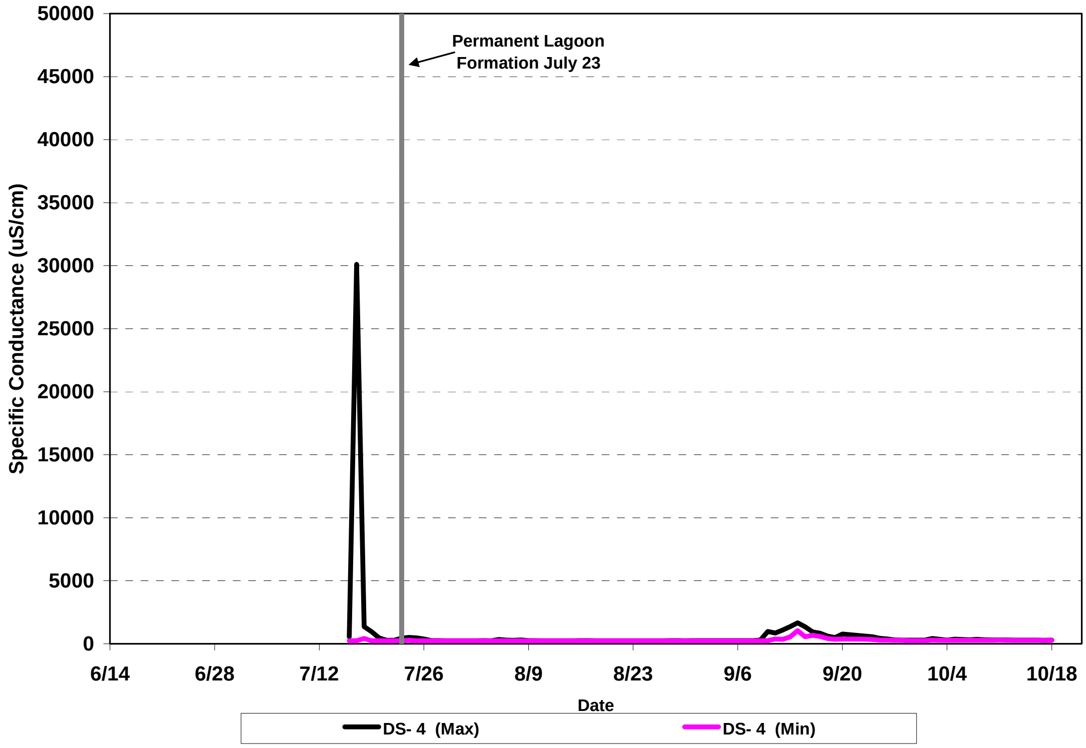
Figure 5. Tides and wind wave heights from the offshore NOAA buoy at Mendocino.



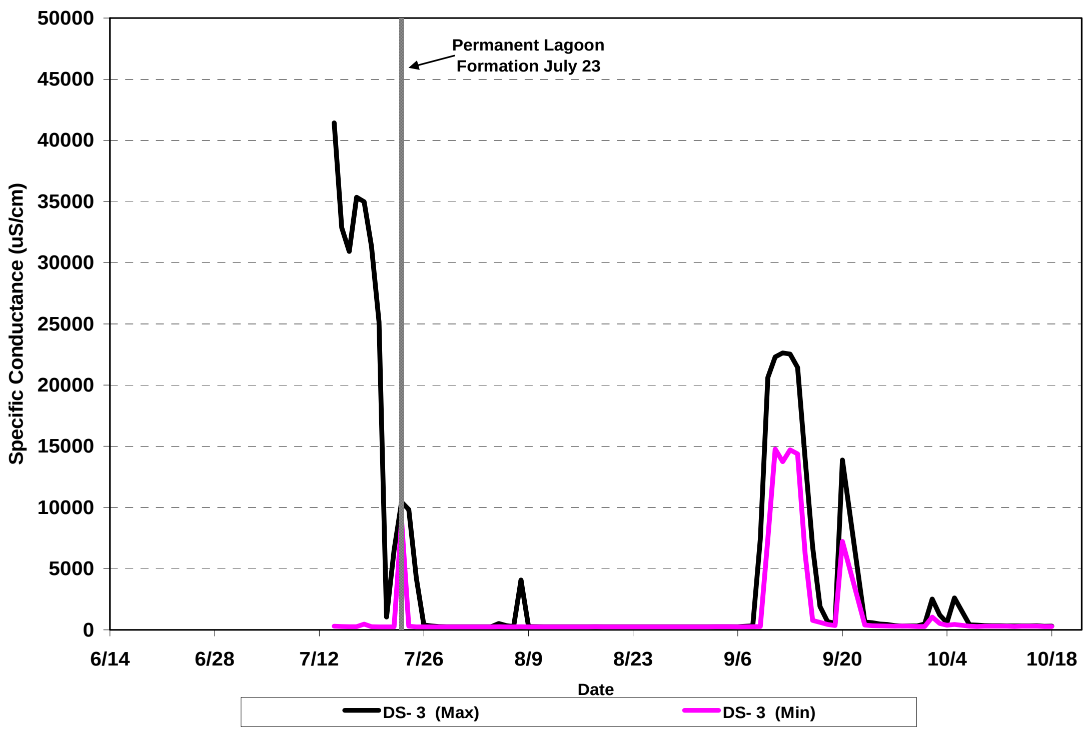


Figure 6. Maximum and minimum daily specific conductance of the surface strata (top figure; DS -4) and the bottom strata (bottom figure; DS-3) of the middle estuary/lagoon in 2006. Data collected with sondes.

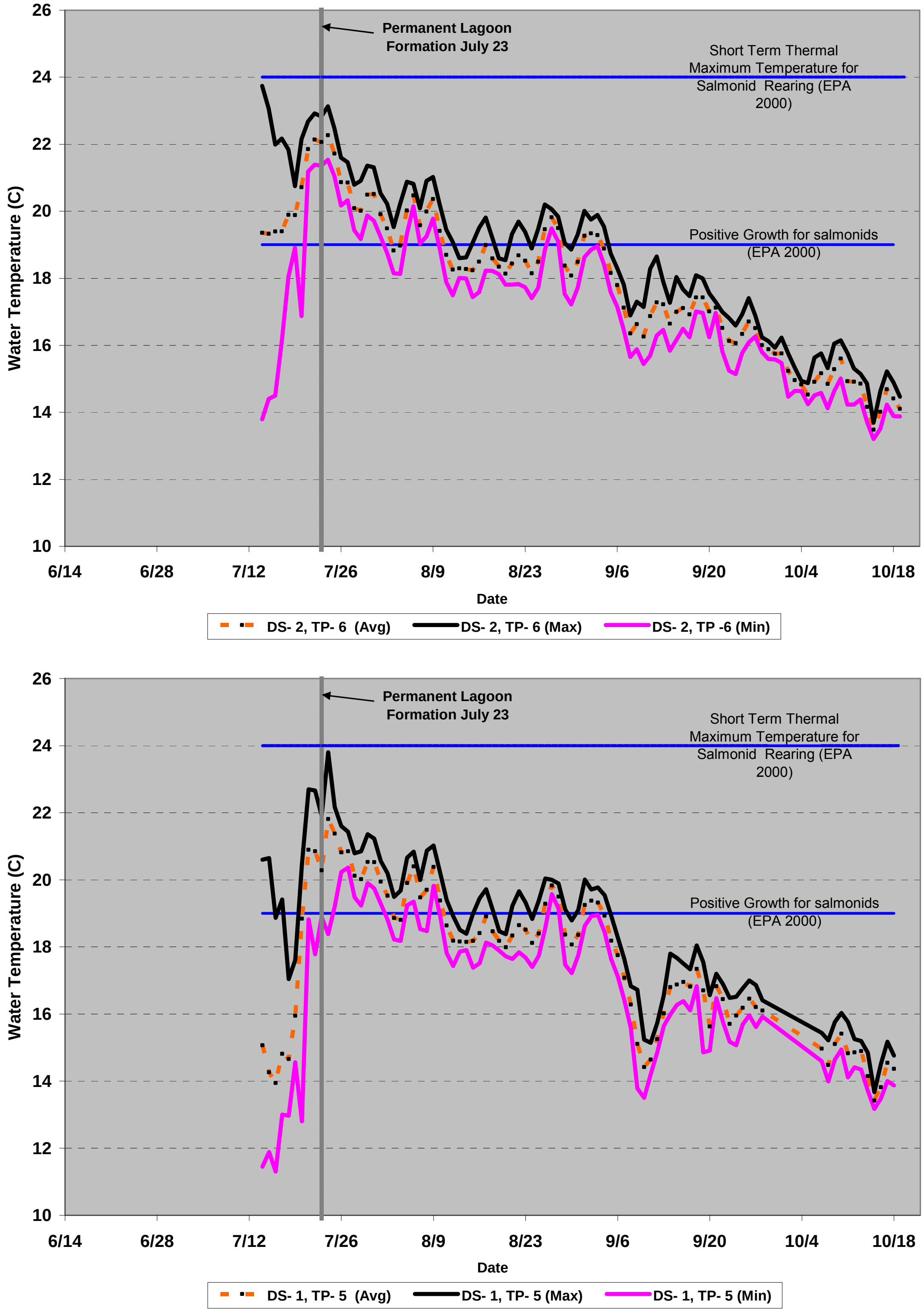
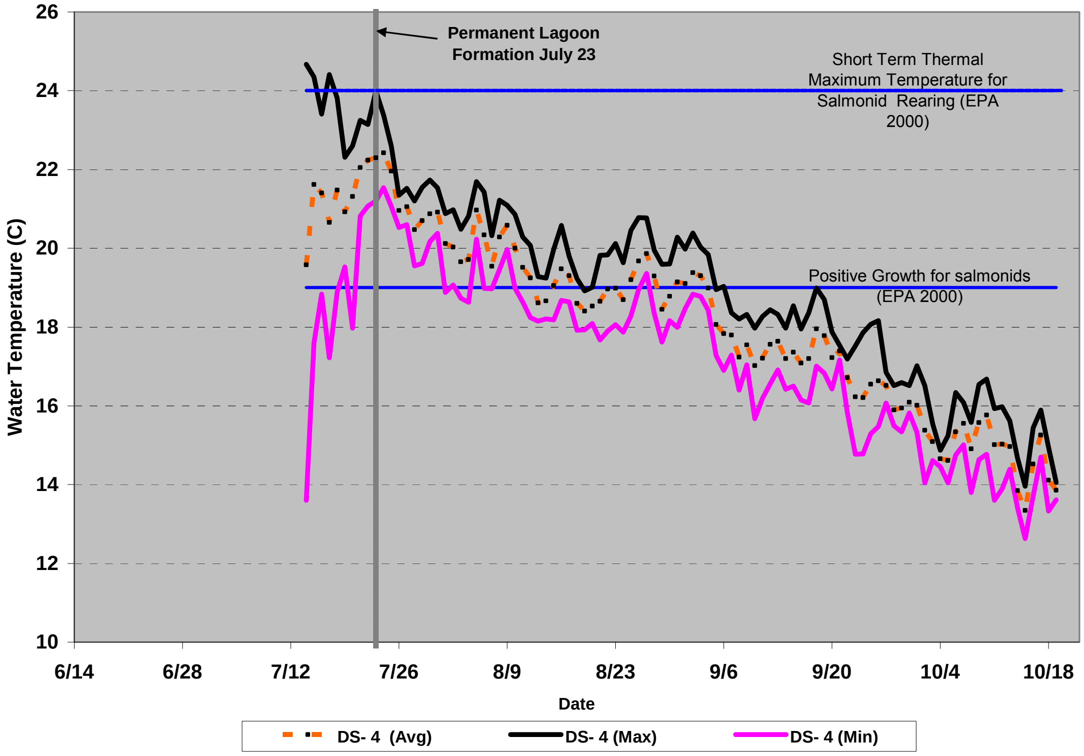


Figure 7. Average, maximum, and minimum daily water temperature of the surface strata (top figure; DS -2/TP-6) and the bottom strata (bottom figure; DS-1/TP-5) of the lower estuary/lagoon in 2006. Data collected with sondes and temperature loggers.



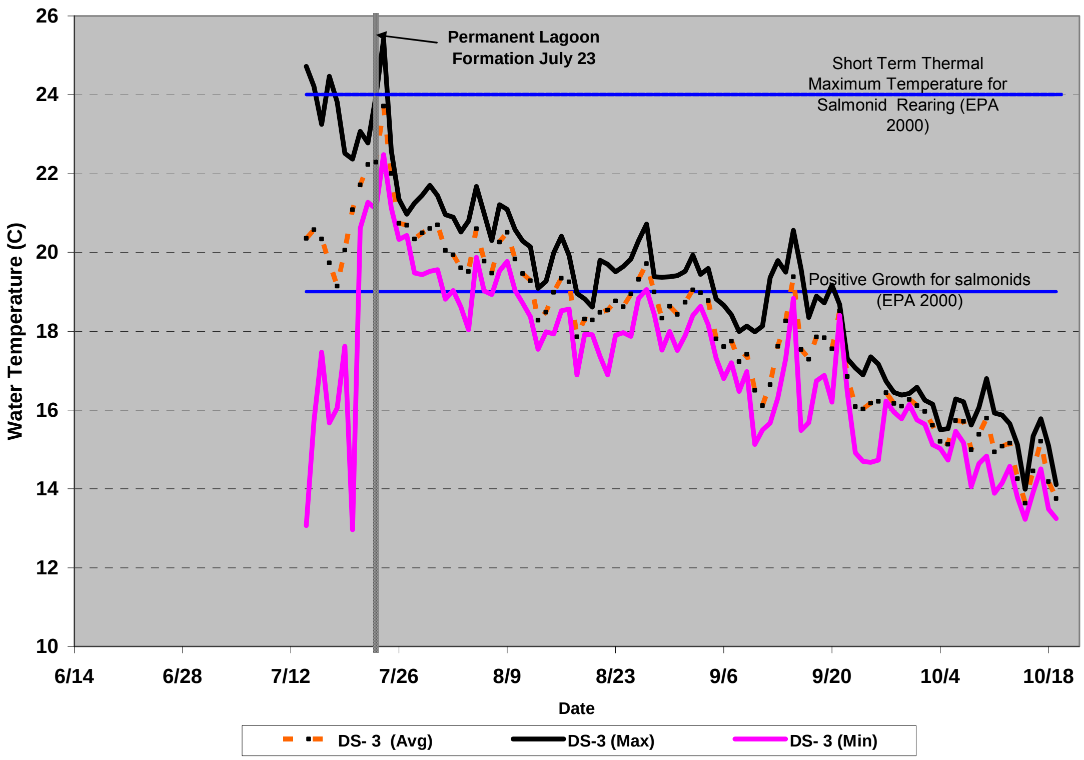
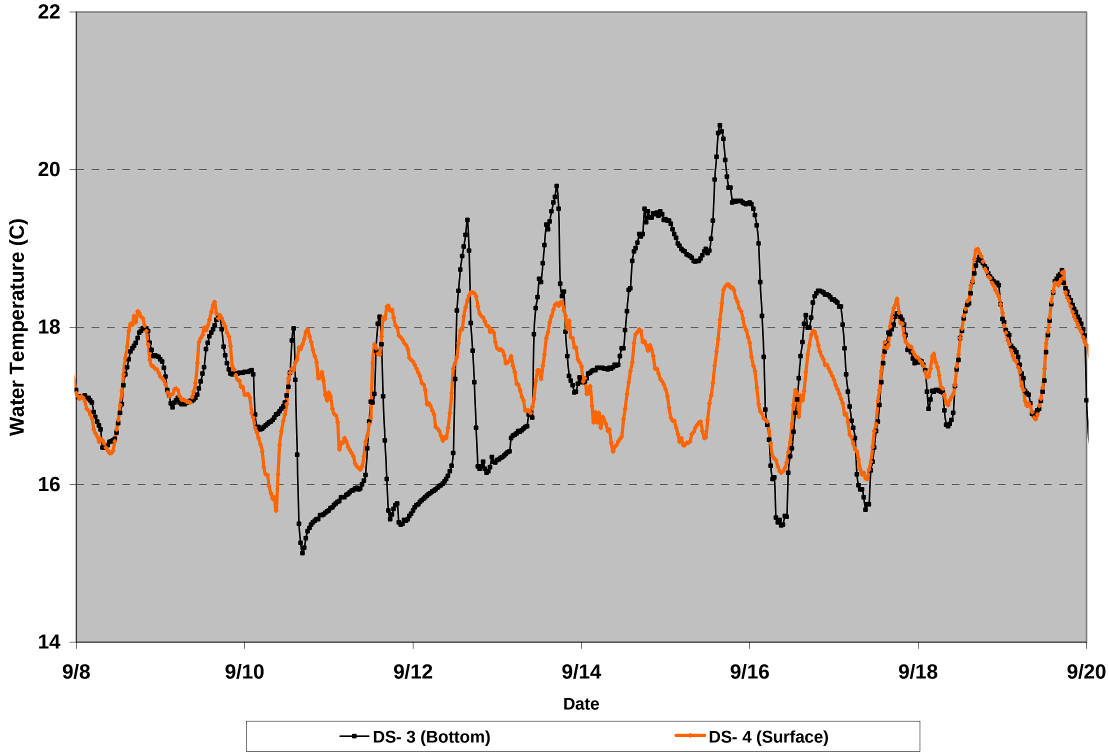


Figure 8. Average, maximum and minimum daily water temperature of the surface strata (top figure; DS -4) and the bottom strata (bottom figure; DS- 3) of the middle estuary/lagoon in 2006. Data collected with sondes.



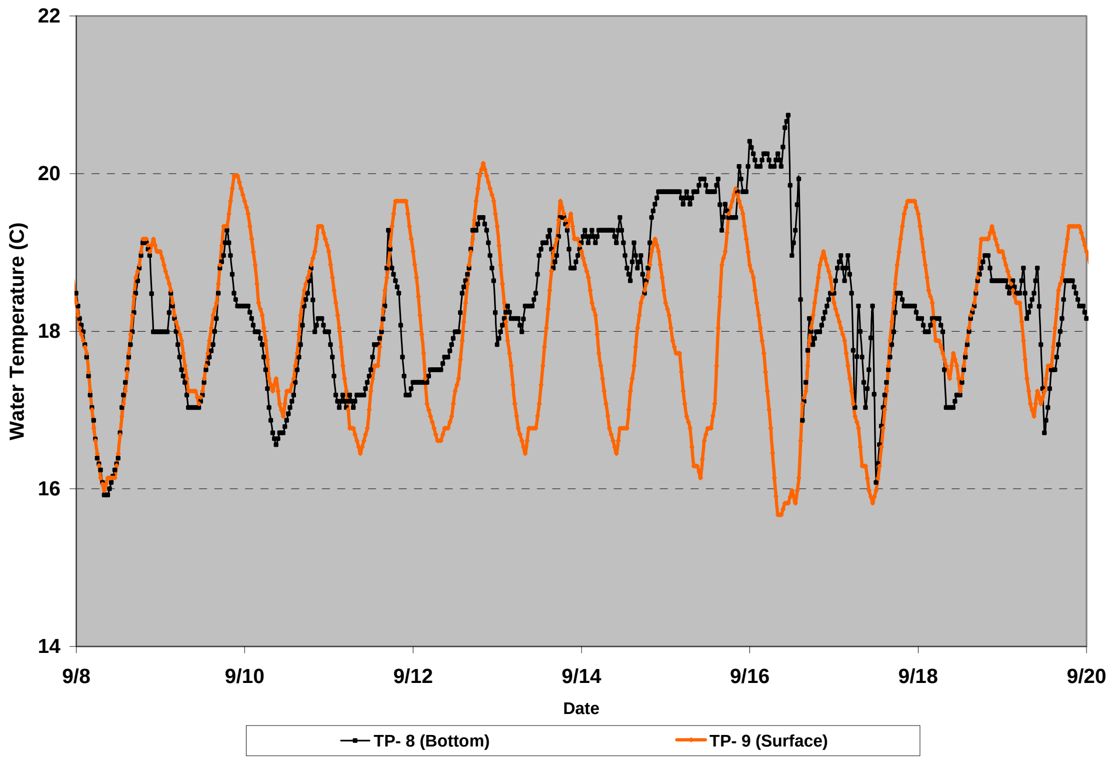


Figure 9. Hourly water temperatures at sites DS-3 and DS-4 (top figure) and TP- 8 and TP- 9 (bottom figure) showing temperature inversions that occurred as a result of extensive seawater overwash into the lagoon in September 2006.

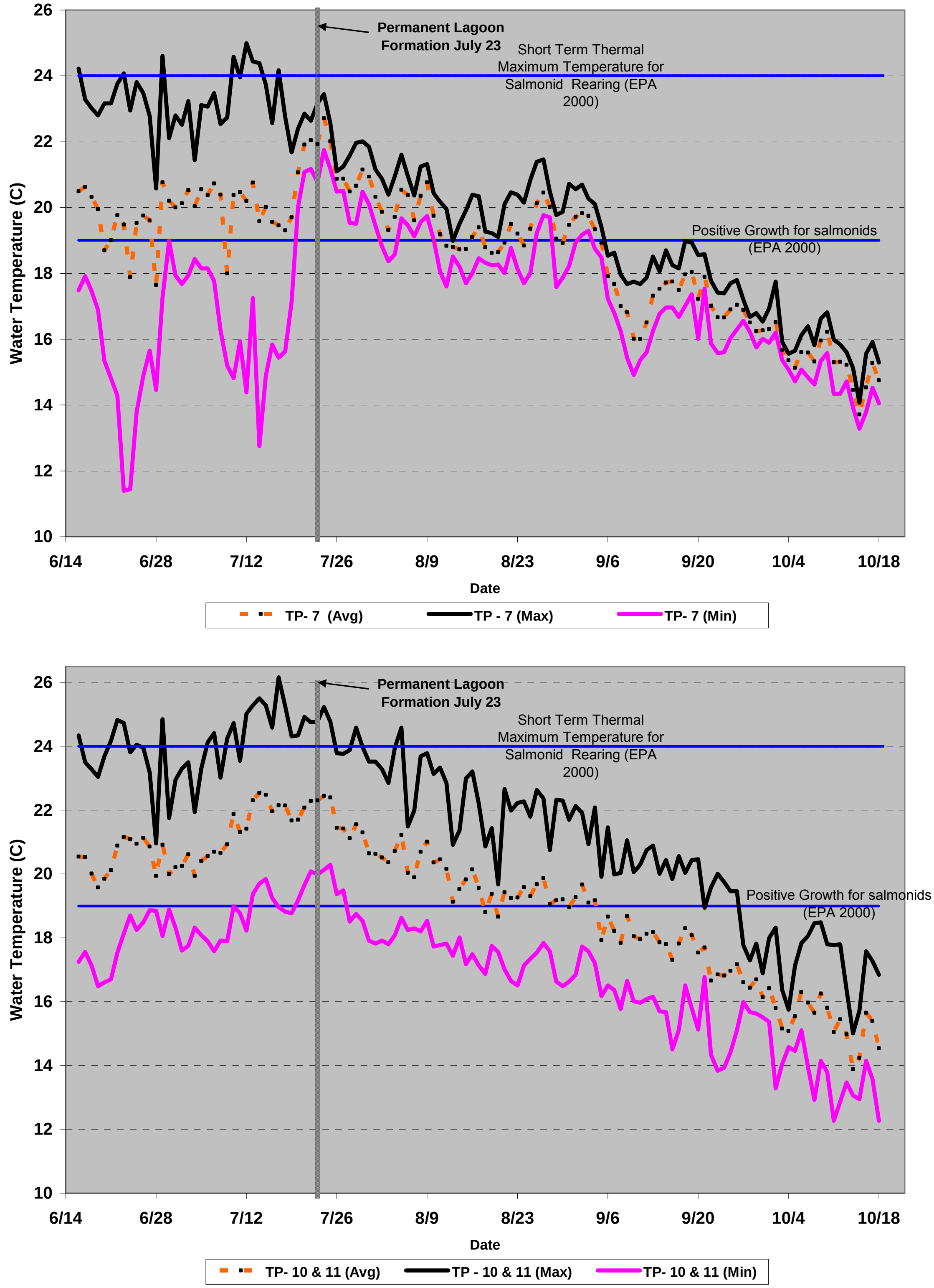
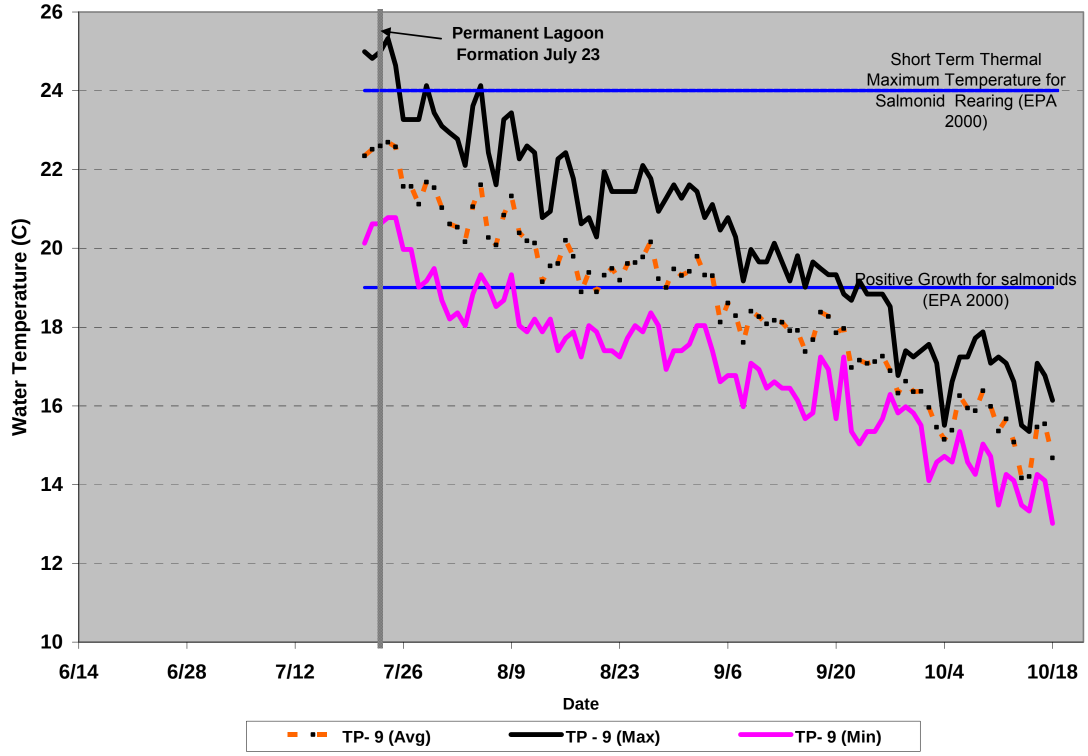


Figure 10. Average, maximum, and minimum daily water temperature at TP- 7 (top figure) and TP- 10 & 11 (bottom figure) of the middle and upper estuary/lagoon in 2006. Sites TP-10 and TP- 11 represented river water quality and were identical. Data collected with temperature loggers.



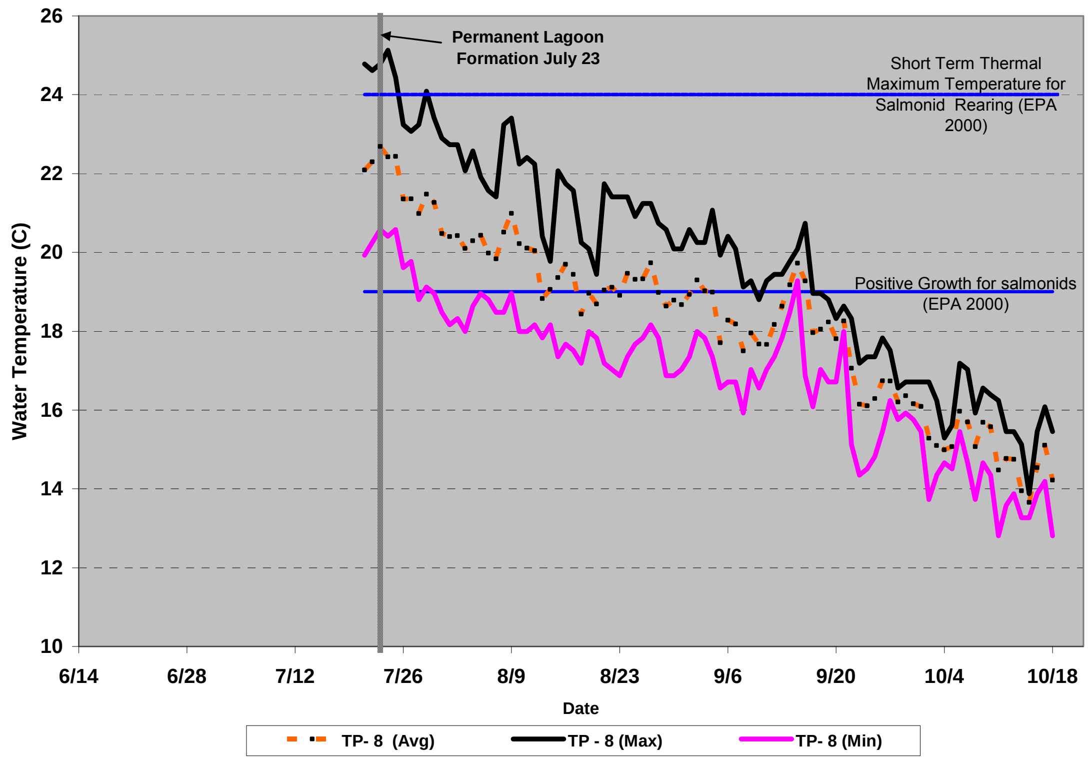


Figure 11. Average, maximum, and minimum daily water temperature of the surface strata (top figure; TP -9) and the bottom strata (bottom figure; TP- 8) of the upper estuary/lagoon in 2006. Data collected with temperature loggers.

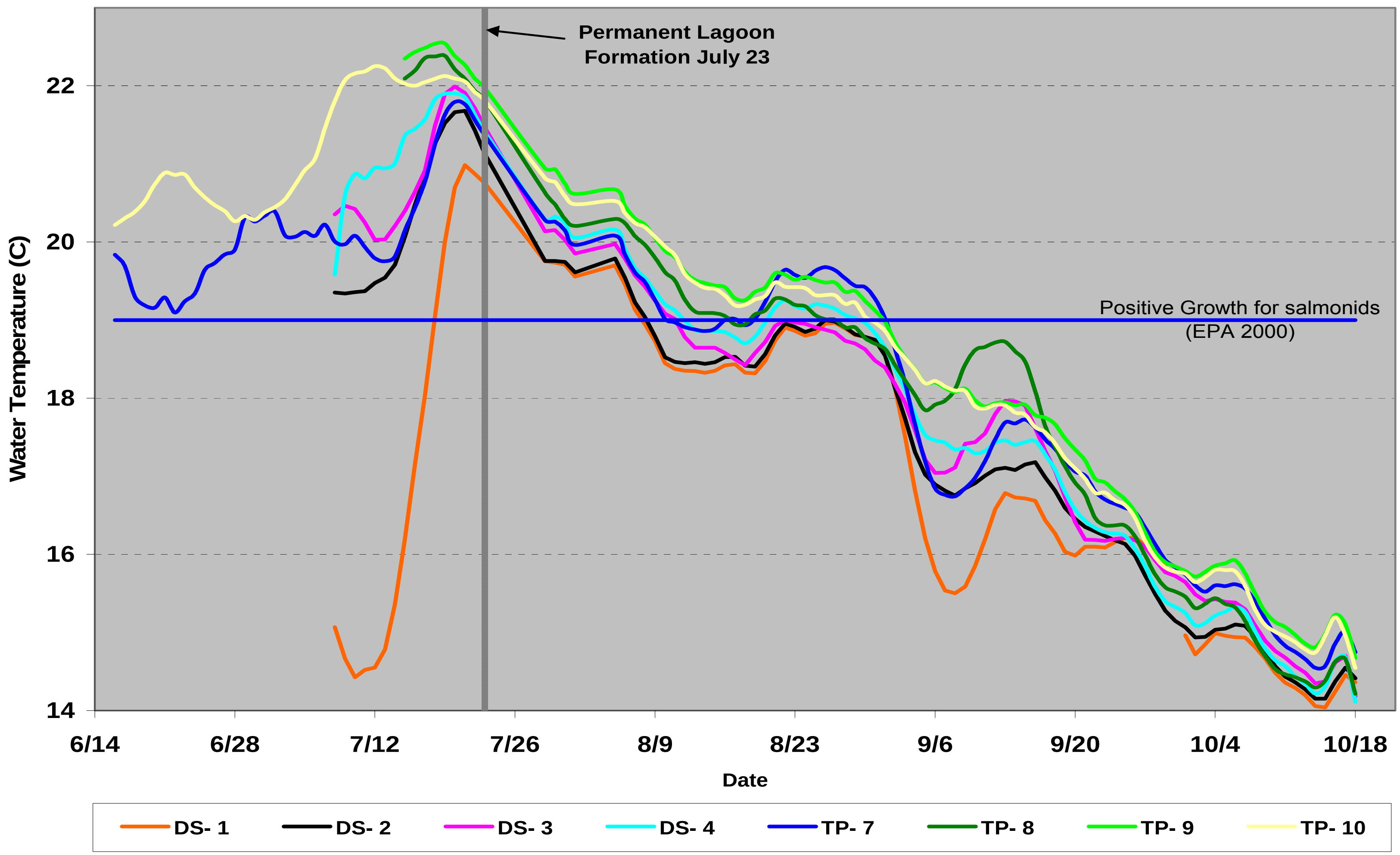


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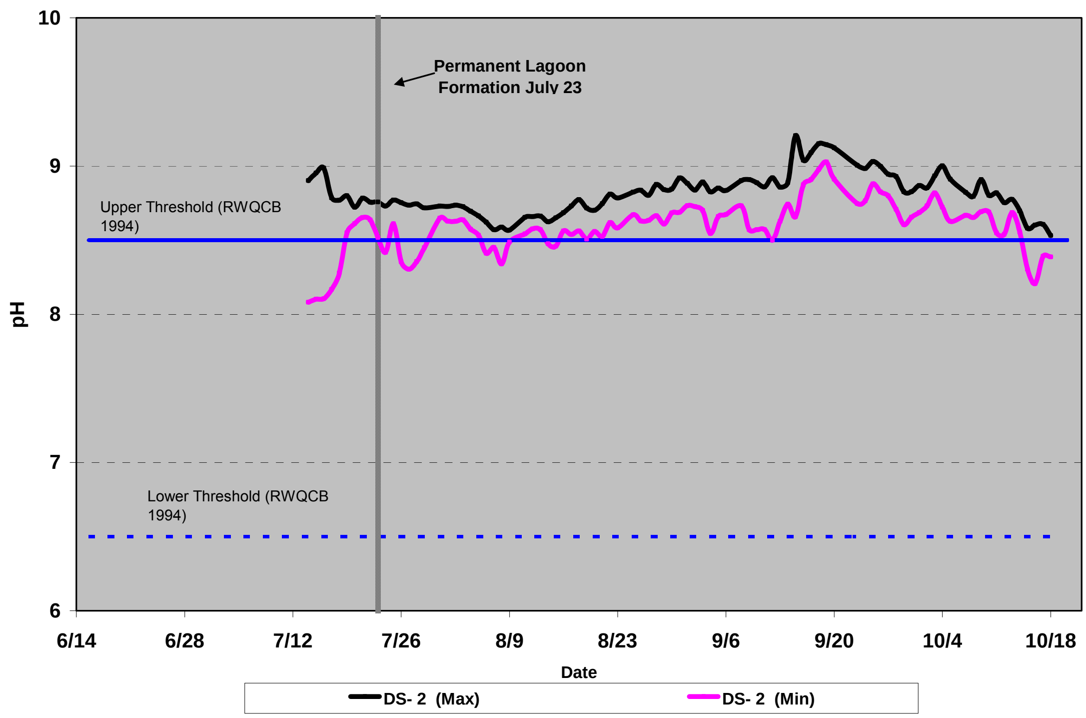
Figure 12. Weekly average temperatures (running mean) of study sites in the Mattole River estuary/lagoon, 2006.



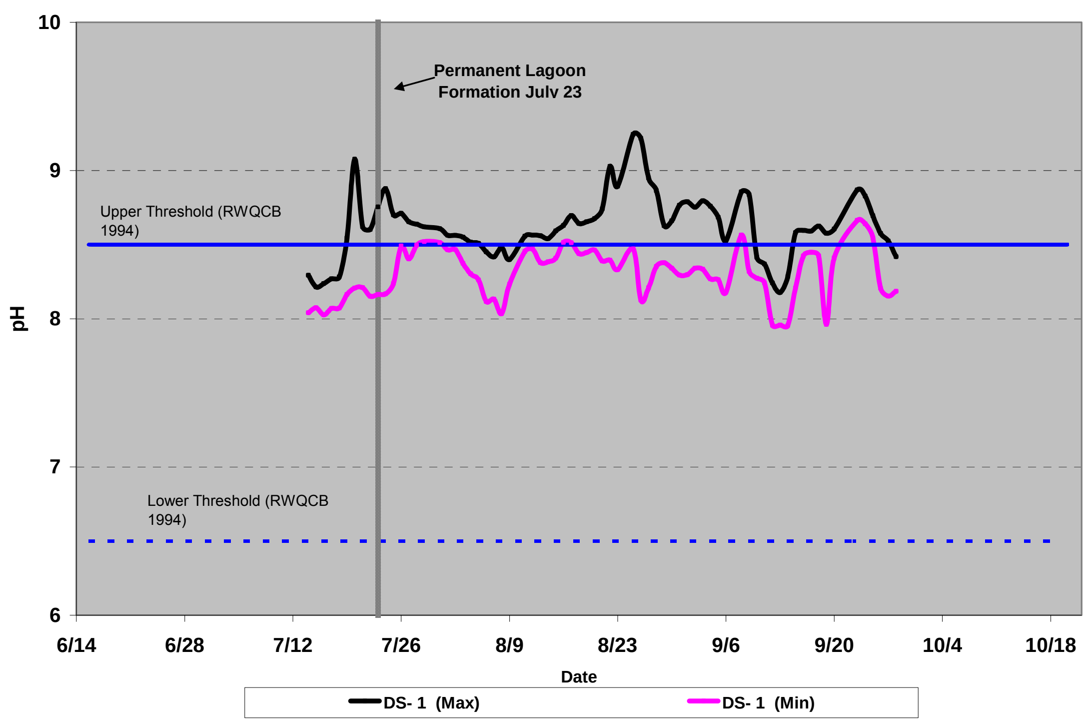
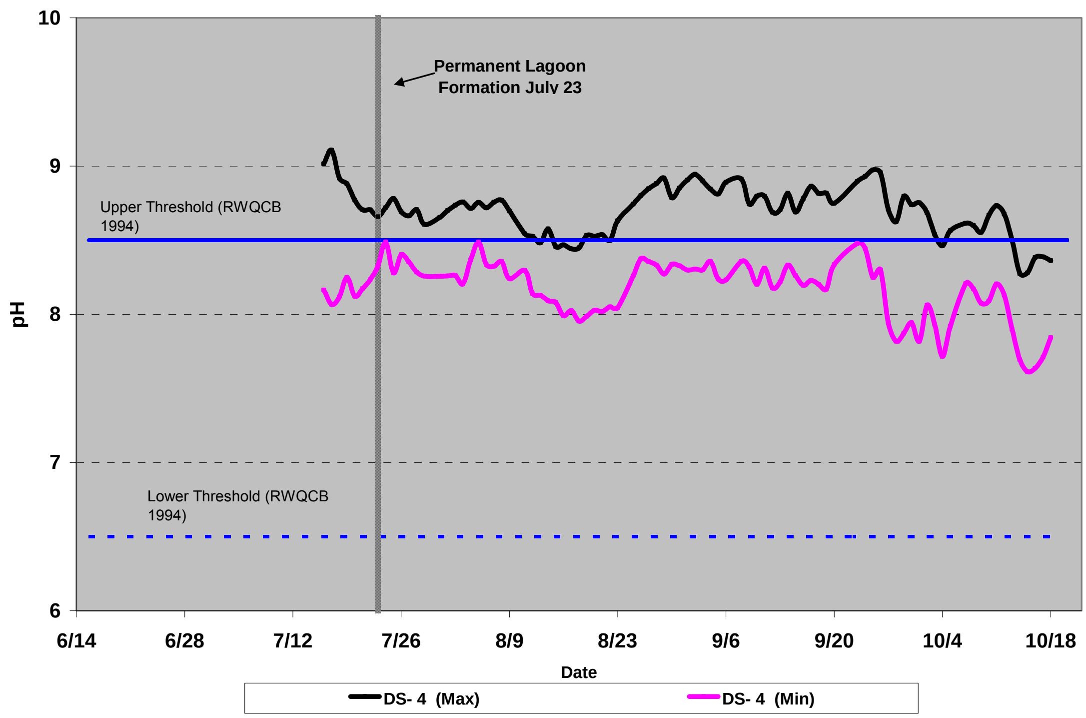


Figure 13. Maximum and minimum pH of the surface strata (top figure; DS -2) and the bottom strata (bottom figure; DS-1) of the lower estuary/lagoon in 2006. Data collected with sondes.



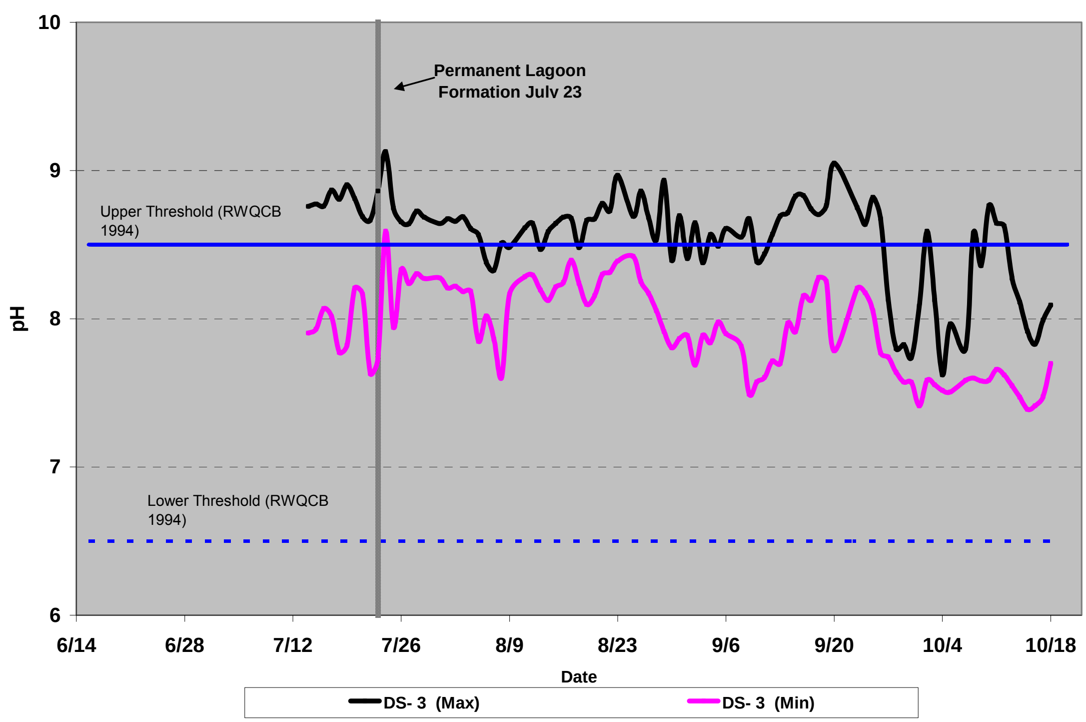
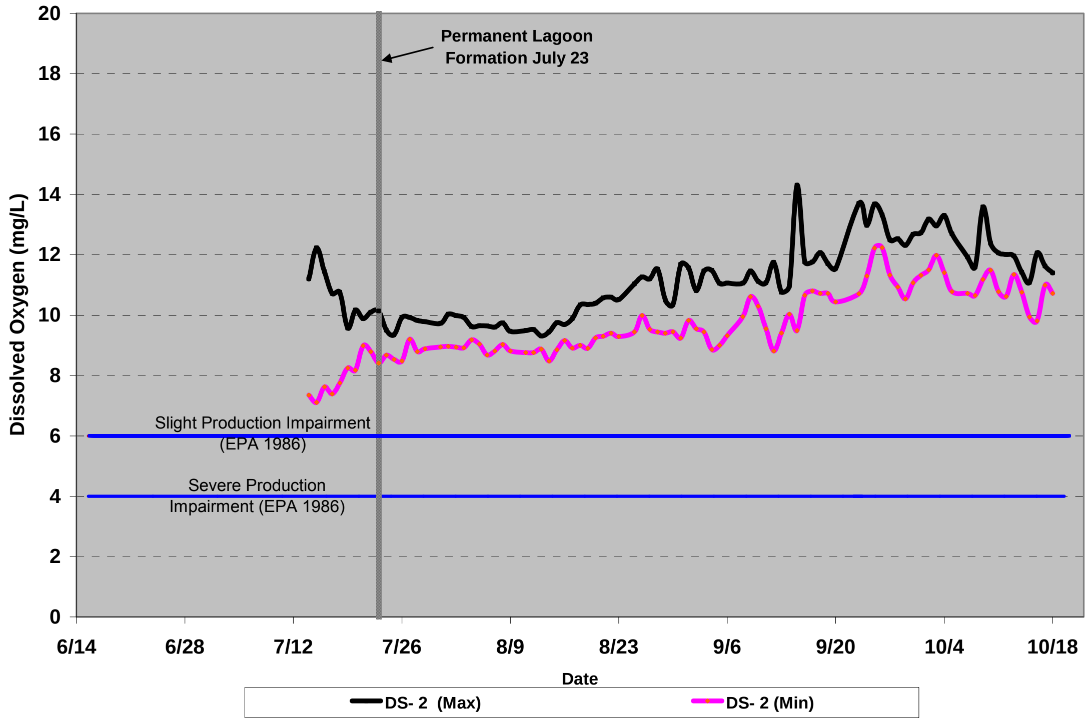


Figure 14. Maximum and minimum daily pH of the surface strata (top figure; DS -4) and the bottom strata (bottom figure; DS-3) of the middle estuary/lagoon in 2006. Data collected with sondes.



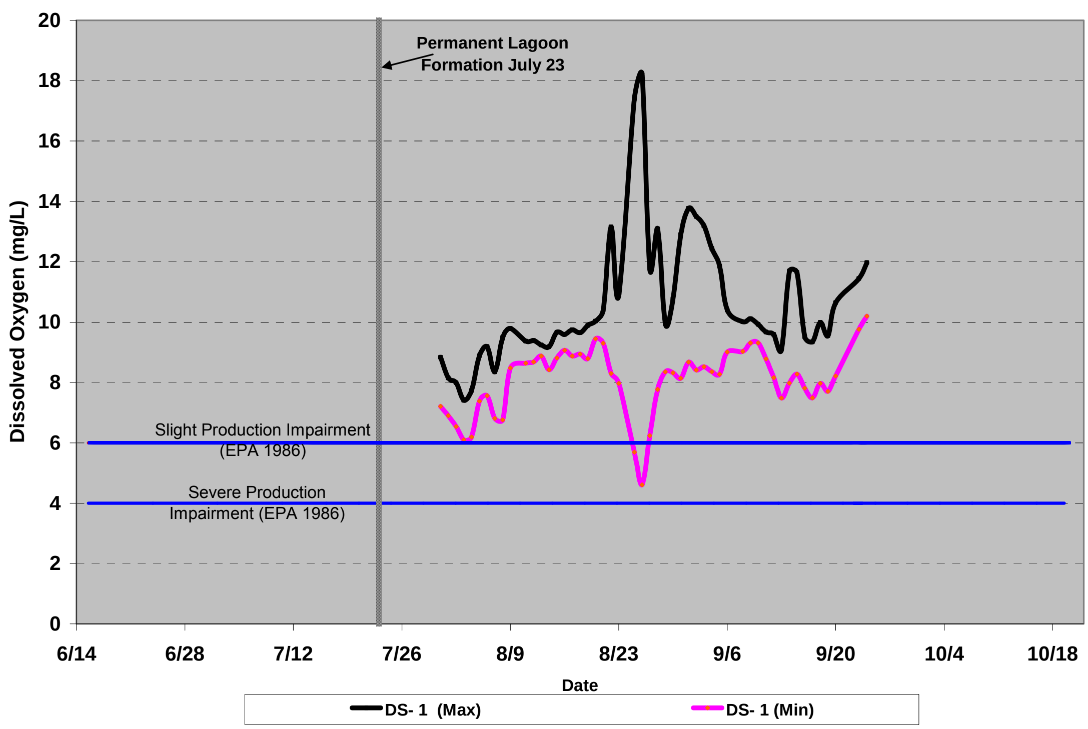
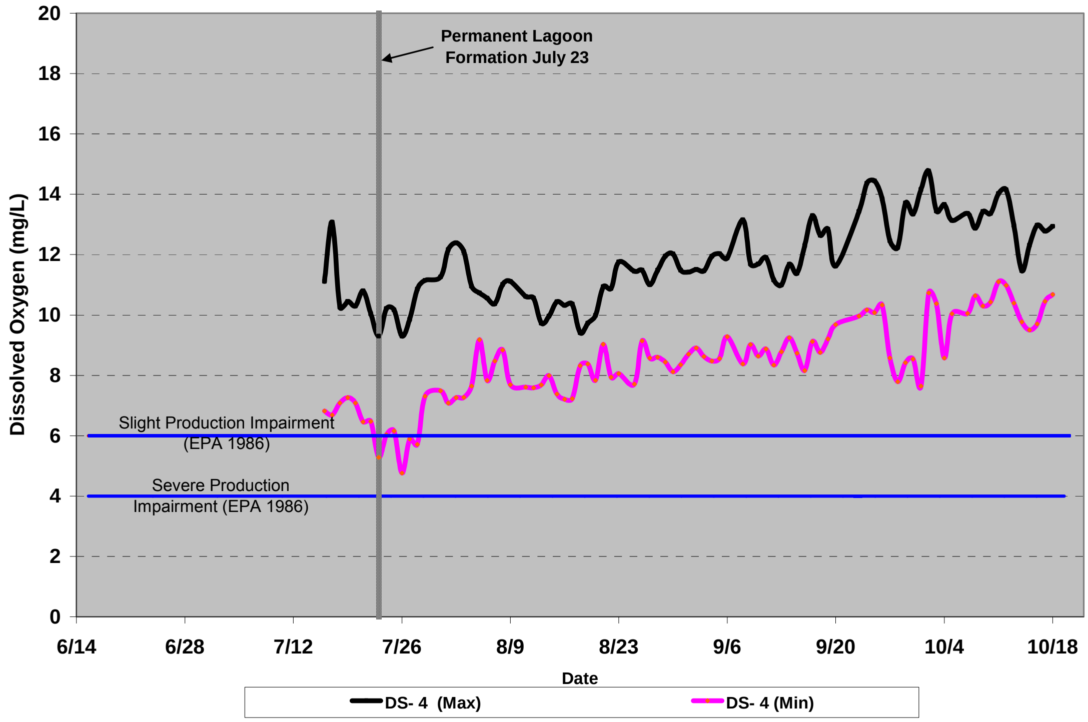


Figure 15. Maximum and minimum daily dissolved oxygen concentrations (mg/L) of the surface strata (top figure; DS- 2) and the bottom strata (bottom figure; DS -1) of the lower estuary/lagoon in 2006. Data collected with sondes.



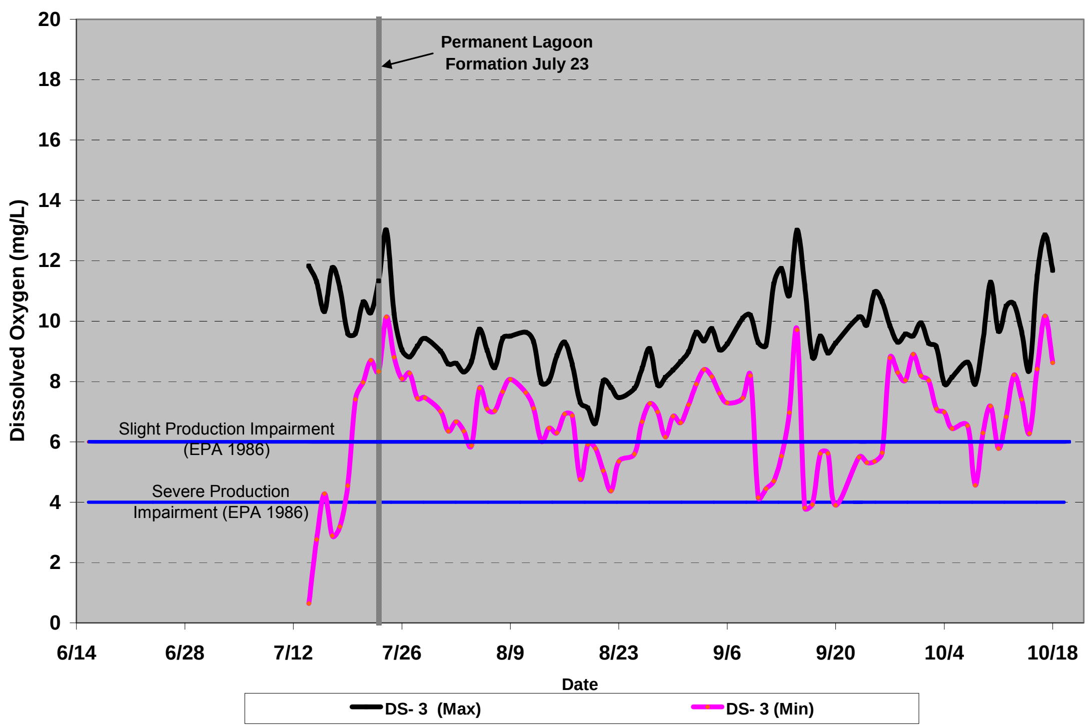


Figure 16. Maximum and minimum daily dissolved oxygen concentrations (mg/L) of the surface strata (top figure; DS- 4) and the bottom strata (bottom figure; DS -3) of the middle estuary/lagoon in 2006. Data collected with sondes.

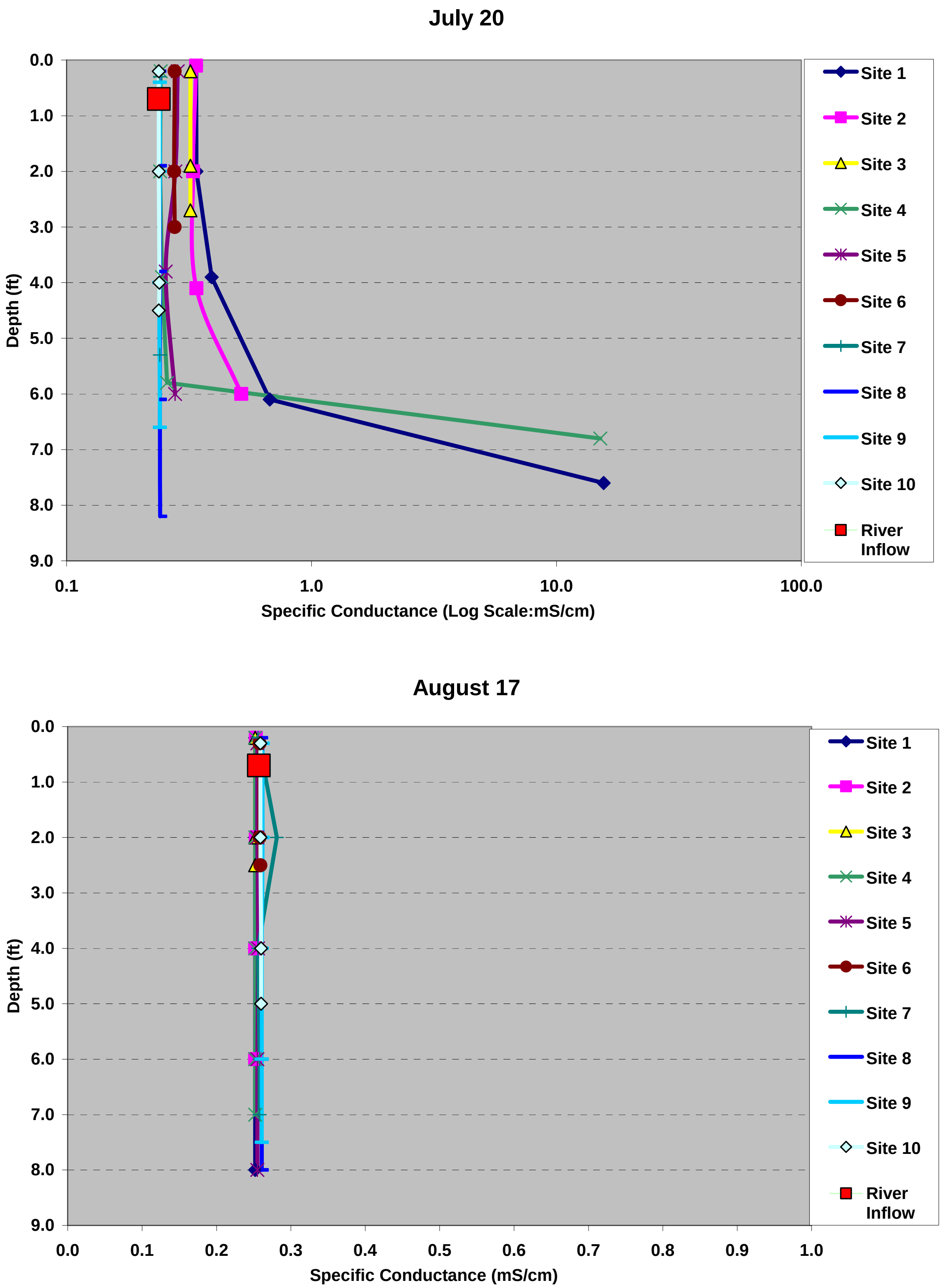


Figure 17. Vertical profiles of specific conductance in the Mattole River estuary/lagoon at several study sites on July 20 and August 17, 2006. Refer to Figure 1 for specific locations.

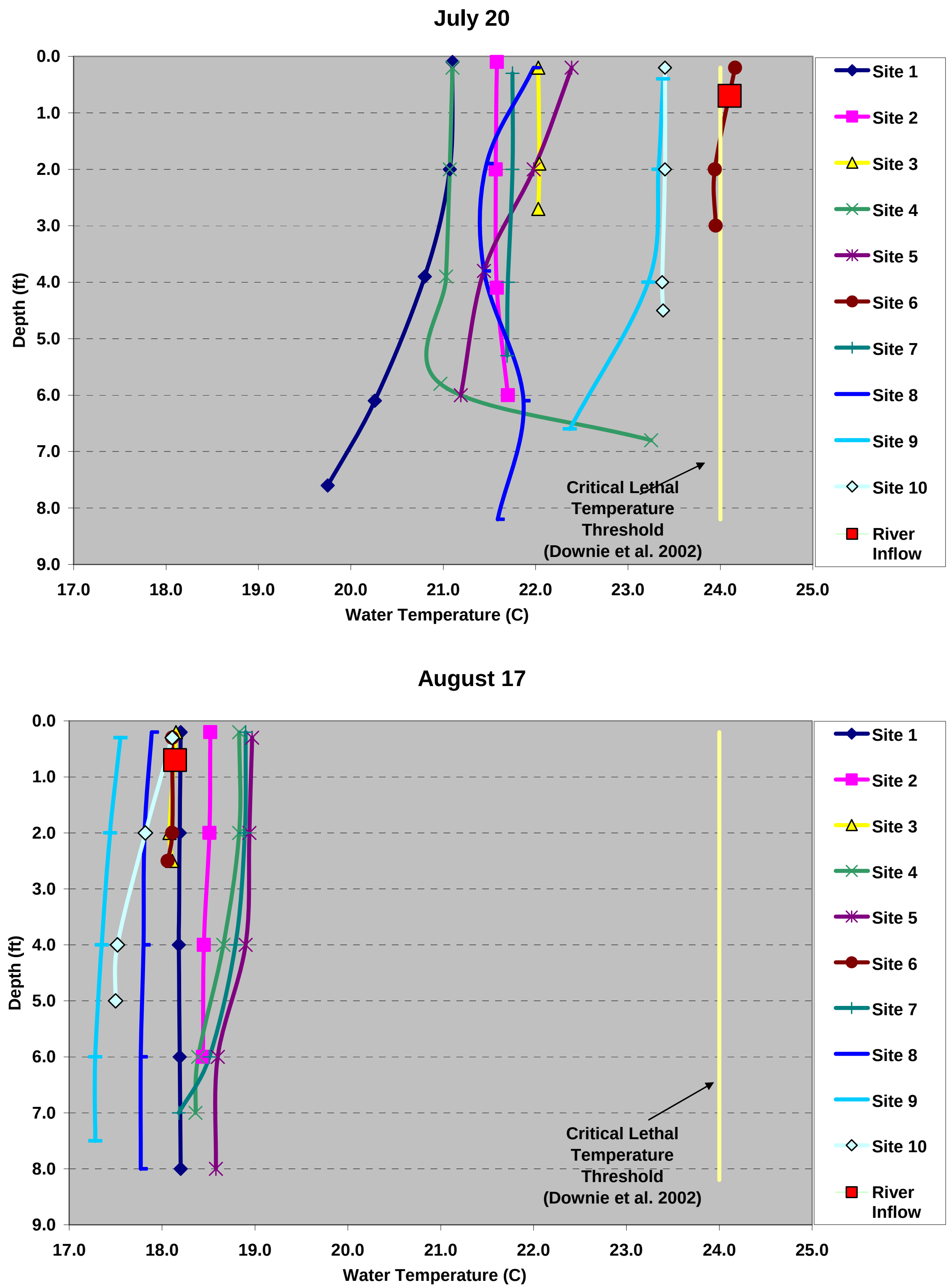
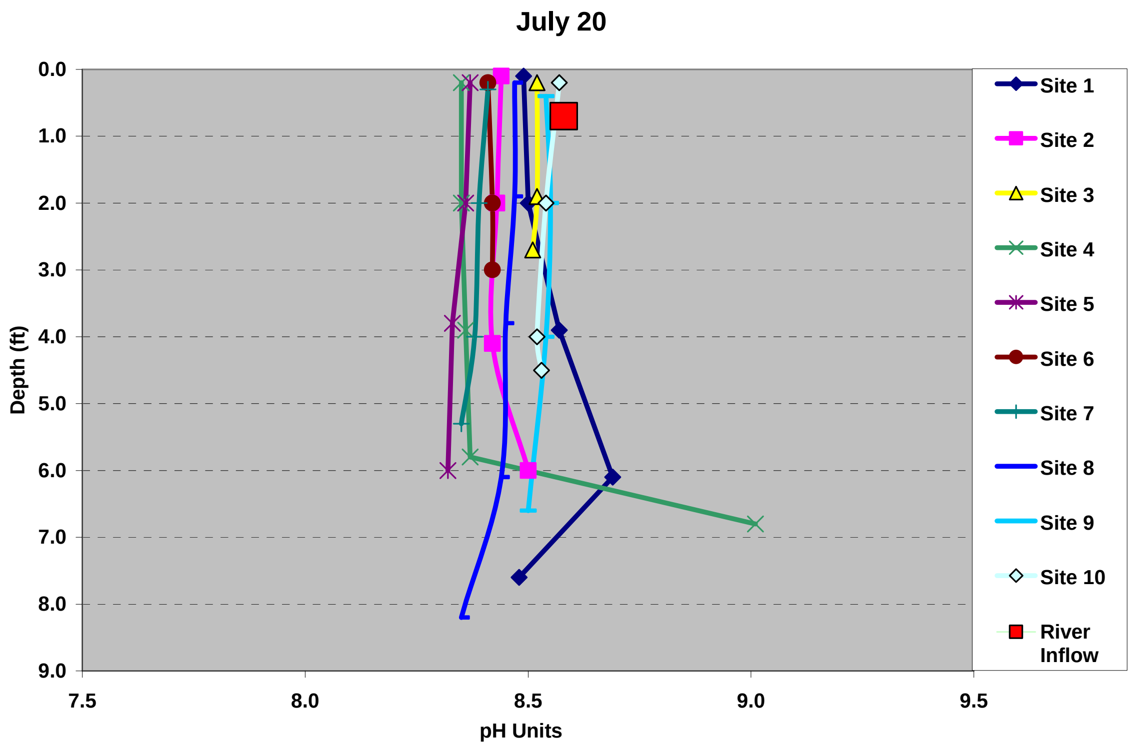


Figure 18. Vertical profiles of water temperature in the Mattole River estuary/lagoon at several study sites on July 20 and August 17, 2006. Refer to Figure 1 for specific locations.



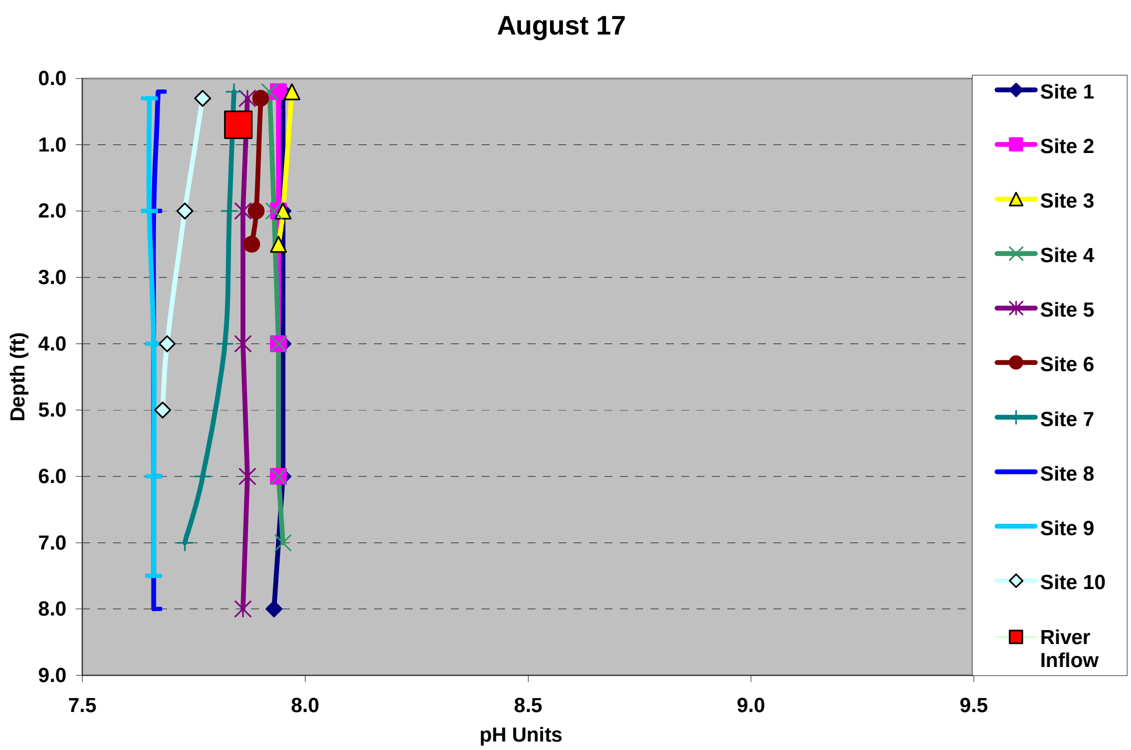
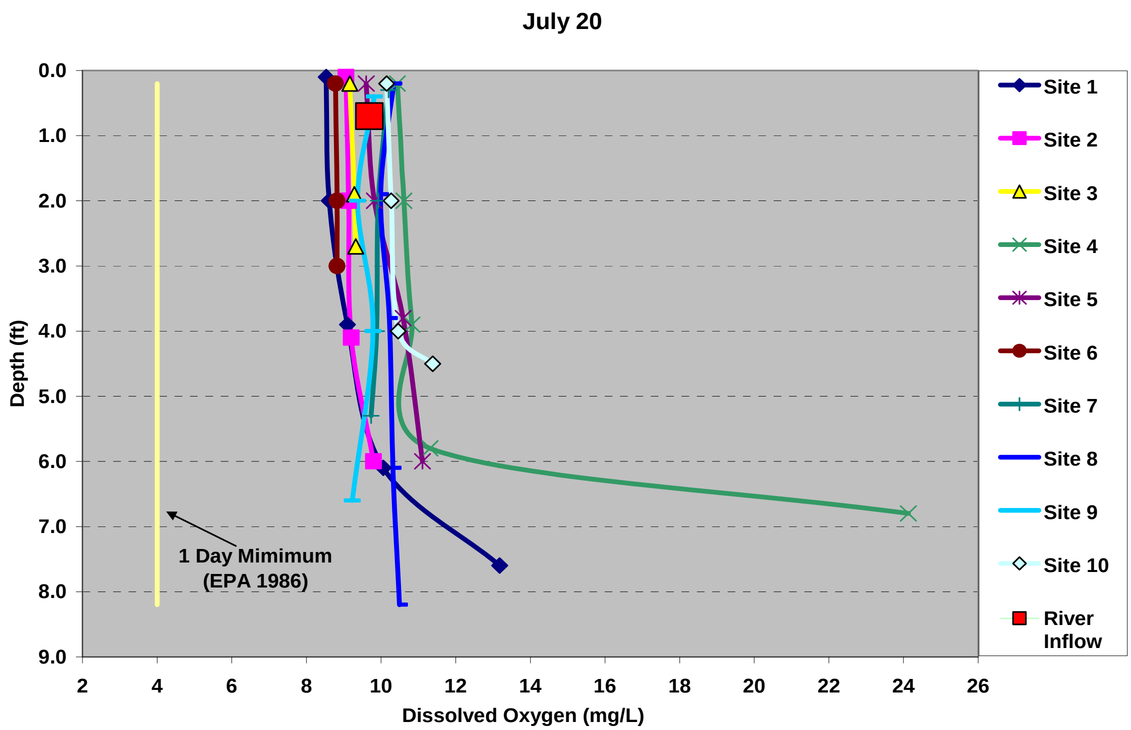


Figure 19. Vertical profiles of pH in the Mattole River estuary/lagoon at several study sites on July 20 and August 17, 2006. Refer to Figure 1 for specific locations.



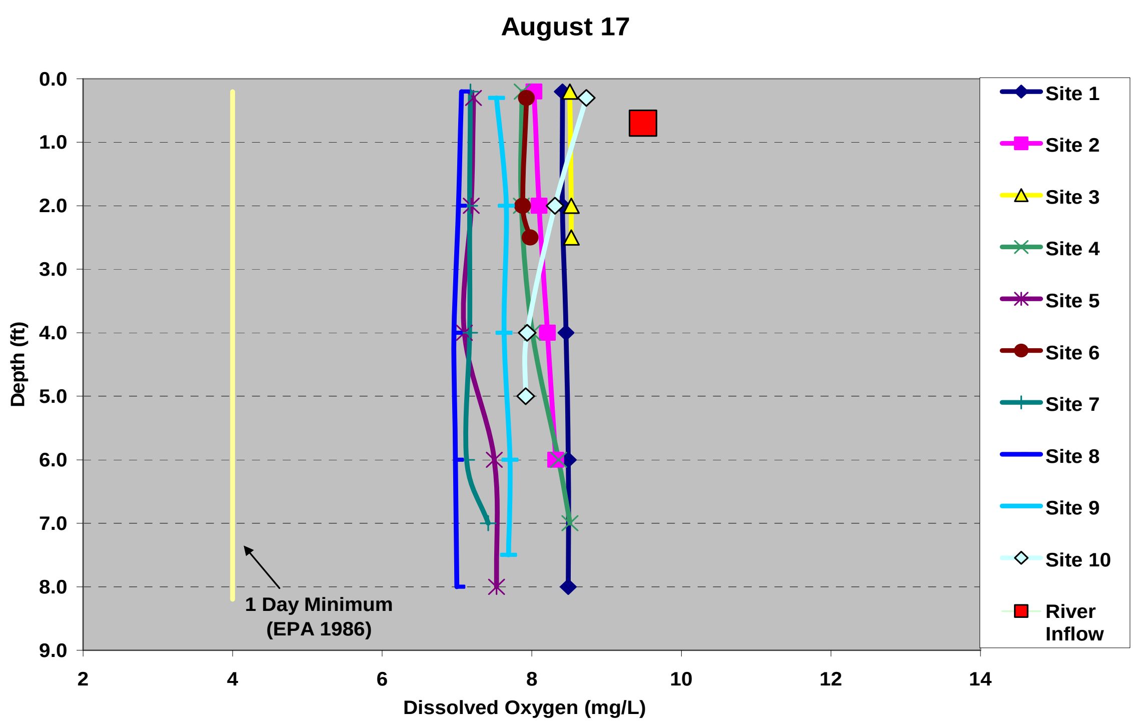


Figure 20. Vertical profiles of dissolved oxygen (mg/L) in the Mattole River estuary/lagoon at several study sites on July 20 and August 17, 2006. Refer to Figure 1 for specific locations.

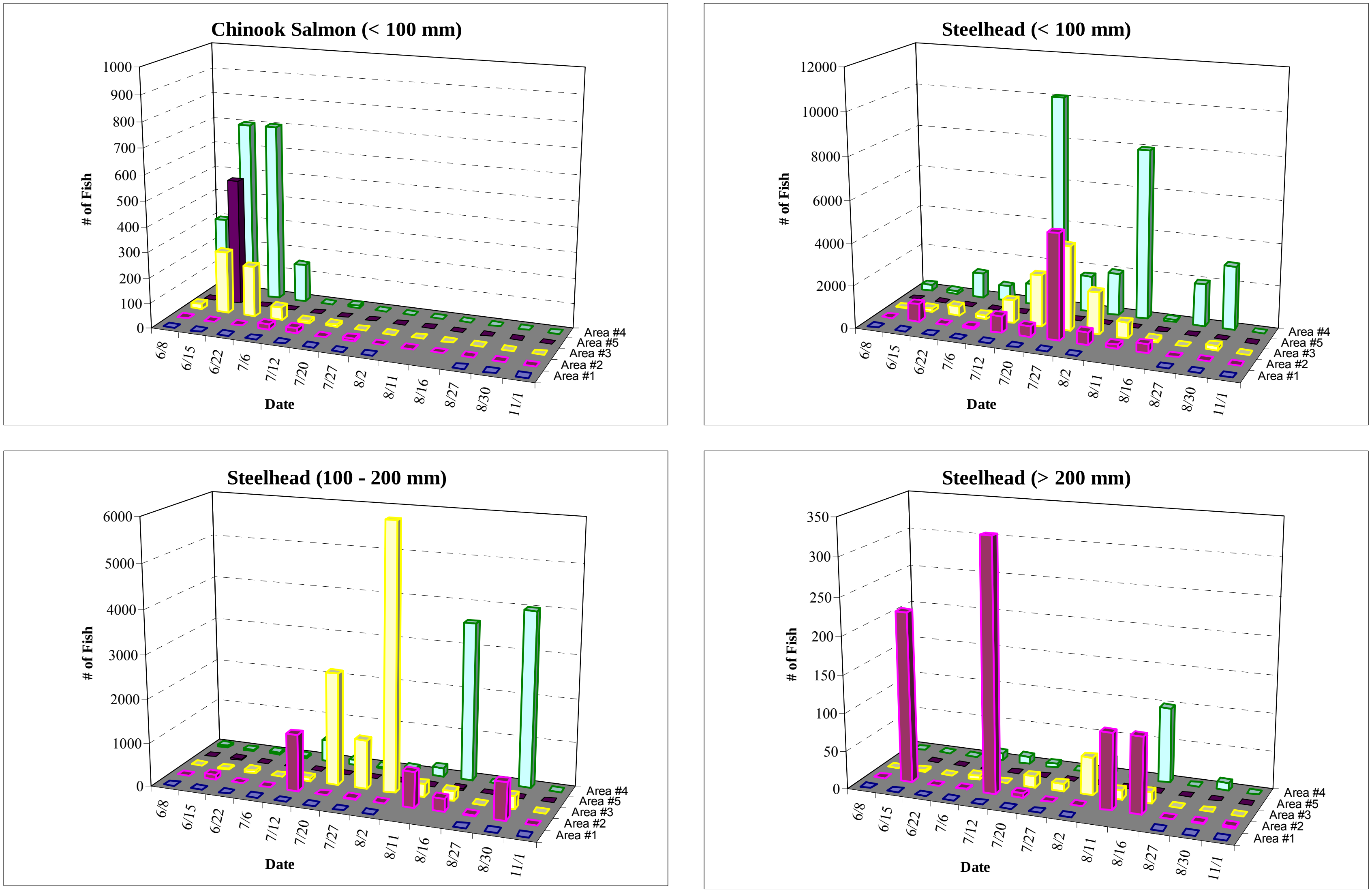


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Figure 21. Numbers of juvenile Chinook salmon and steelhead of various size classes counted by paired divers in five areas of the Mattole River estuary/lagoon in 2006. Data are from MSG (2007).

Appendixes

Appendix A. Arcata Fish and Wildlife Service's 2006 Multiprobe Maintenance and Deployment Protocol

Arcata Fish and Wildlife Service's 2006 Multiprobe Maintenance and Deployment Protocol

By

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June, 2006

The use of firm, trade, and brand names in this report is for identification purposes only and does not constitute endorsement by the U.S. Fish and Wildlife Service.

PURPOSE STATEMENT

The challenge associated with water quality monitoring is to collect data that consistently represents the environmental conditions. To be able to best represent these conditions, it is important to develop a thorough protocol to obtain comparable data. To ensure the collection of good data, a quality assurance/quality control (QA/QC) program must be incorporated into the plans.

This document is part of a continuing effort for the Arcata Fish and Wildlife Office (AFWO). Based on information learned from the literature, during trainings and in the field, our project has made efforts to continually improve our protocol based on the latest industry trends and most applicable field techniques. Our database development has driven our QA/QC practices and has yielded important information regarding the effectiveness of field techniques. This document was largely put together to assure that the different persons involved with the Water Quality Monitoring Project are consistent in the protocols that they use in the field. Specifically, this document covers protocols for the calibration and collection of continuous and spot data with multimeter probes (e.g. Hydrolab DataSondes and Quanta's).

QUALITY ASSURANCE/QUALITY CONTROL

Two major components of QA/QC are accuracy and precision. Accuracy is how close the results are to a true or expected value. Instrument calibration is the necessary first step to assure accurate performance in the field. Precision, on the other hand, is the amount of agreement (or random error) among repeated independent measurements of the same parameter. Comparisons between instruments, whether in the field or laboratory, allow for an understanding of instrument precision. The protocol identified herein, describes techniques used to obtain accurate and precise data.

If you have not operated these instruments before, it is necessary that you spend some time reading the users guide, past reports, and practicing the calibration of the instrumentation. Demonstration of the instrumentation by veteran users is valuable and should be sought where available. As with any equipment, the knowledge you attain with the instrumentation will translate to collecting better quality data. Attention to detail with the calibration procedures is required in order to obtain good data quality and defensible results.

DATASONDE AND QUANTA UTILIZATION

Step 1: Is Your DataSonde Ready To Be Used?

Many things are necessary to consider before the start of the field season, upon receiving a DataSonde from the manufacturer, or pulling one out of storage. For example, how long since the pH reference solution was changed? Will the calibration solutions expire during the season? These are but a few questions you must ask yourself before using the instrumentation. A thorough examination of the manufacturers recommended maintenance schedule will generally supply you with a list of things to consider. In some cases, previously collected data may provide some evidence as to where probes are starting to fail, allowing you to obtain a replacement probe early in the season. Making sure the instruments have met the maintenance schedules and are running correctly before the season starts serves as a first line of defense to help assure that data collection efforts are successful. AFWO regularly conducts a preseason comparison study that allows us to compare instrumentation together under the same conditions, prioritize probes needing replacement and promote general sonde maintenance. The preseason instrument checks further limits instrumentation failures in the field and prevent excessive bias from being introduced into the data. (Some preseason work has been done to evaluate the new sondes but 8 of our 10 sondes are currently backordered, restricting any testing we can do at this time.)

Step 2: Preparation of the Instrument for Deployment

Study Sites, Housing and Security

The monetary value of the instruments and the importance of the data collected require that water quality instruments be secure when in the field. Study locations are chosen at the discretion of the researchers and must meet the study's objectives. In many cases, instrument placement includes considerations of vandalism, ecological effects, access, etc. An ideal site is one that is representative of the section of water being measured and has some object such as large riparian trees, bedrock or pilings that can provide a secure point of attachment for the equipment. With bedrock, boulders, or old bridge pilings, a hole can be drilled and an eyebolt glued into place to ensure a permanent anchor that is more secure than a riparian tree. Plan to drill the hole as close to the water level during low flows to reduce the visibility of the eyebolt. Place the DataSonde in a 4- 6" ID perforated aluminum housing to protect the sonde during unattended monitoring. Attached to the housing should be a section of chain which is locked to the anchor. Another lock will be used to ensure the sonde is not removed from the housing. Where possible, avoid sites that have frequent visitors and try to conceal it to avoid unnecessary attention. Care should be taken to prevent placement of the probe-end of the sonde in areas with silt or algae. Housings that include "legs" to raise the sensor end above the substrate are useful in these situations. Additionally, wading upstream of a deployed sonde disturbs sediments or algae and should be avoided prior to the sonde recording to prevent erroneous readings.

Sampling Intervals

Based on previous experience and protocols developed by the USGS, our water quality instrument will be deployed for two weeks intervals in 2006. Based on the expected resistance to fouling of the new instruments, this interval should be adequate to obtain readings that will portray in river conditions. Due to the highly productive nature of the Klamath River, if fouling is causing an unaccountable level of error in the probes, the deployment interval may be shortened or other changes affected to obtain quality data. During previous field seasons, post calibration protocol involved measurements at the end of the deployment that attempted to estimate the effects of biofouling. Through this recovery, biological fouling was not shown to consistently bias any of the probes, regardless of the site or season sampled. Because two week deployments are near both the limit of the desirable deployment interval and the expected battery life, it is important to be able to service the sonde on the two week schedule and not allow for longer deployments.

Parameter Set-up

The Surveyor® data logger and display, used in conjunction with the DataSonde multiprobe, allows the user to set the DataSonde to record the desired parameters, calibrate the instrument, and download the sonde files. For specific methods on using the Surveyor, refer to the Surveyor 4 Water Quality Data Display User's Manual (Hydrolab, 1999).

When first hooking up the DataSonde to the Surveyor, set the date and time on the DataSonde. This step is crucial to maintaining consistent data throughout the season. Make sure to check the DataSonde clock against a watch or cell phone clock that is known to be correct every field visit to maintain accuracy of the sonde recording time.

All parameters and units to be measured should be set through the Surveyor to record in the following sequence. Enter each of these parameters separately and in the order they are to be displayed on the screen (from left to right). Parameters include: Date, Time, Temp (^{o}C), Specific Conductivity (µS/cm), pH, Luminescent Dissolved Oxygen, (mg/L), Luminescent Dissolved Oxygen (% Saturation), I Batt (internal battery level) and other optional parameters such as depth (meters) and salinity (pss). This sequence provides all the data necessary for the database in an easily importable format.

File Creation

The creation of a file describes where an instrument will be placed, the time frame in which it will be deployed and extracted, and its recording interval. Define the file name by using the site abbreviation followed by the underscore symbol then the deployment date. For example, TR_070305 is a file that was deployed in the Trinity River on July 3rd, 2005. This pattern is important for accurate tracking and management of files. Specific site abbreviations for the Klamath River are as follows, OR= Orleans Gage, SV= Seiad Gage, IG= Iron Gate Hatchery Bridge. For situations where multiple sondes are located in an area, other naming conventions such as numbers (MT1_072406, MT2_072406, etc.) may be used but be certain to record such information and not mix up which sonde is placed where.

When setting the start time, make sure it is set on the half hour and there is enough time to get the unit in the water to stabilize before the recording starts. The stop date should be set for at least a week past the date you expect to extract the unit. This gives the user time to reschedule an extraction in case of unforeseen circumstances. Stop time should be set for sometime after dark so that an extraction audit is not missed in the middle of the last day of the file. Set the instrument to record every 30 minutes; on the Surveyor this is an interval time of 003000. Set sensor warm up for 000030 to give the instruments thirty seconds to warm up before taking the recording. The circulator in not necessary and the warm up time is reduced this year due to improved technology of the LDO probe.

At this point, the file setup is complete but be sure to go back through the menu to double check and make sure the file has been created correctly. Because of the difficulties with the Surveyor buttons, the dates and times for the deployment and extraction should be reviewed. In addition to the file being created make sure that the DataSonde is also set up in the Autolog format so that in the case of a file problem, hourly data will still be recorded.

Step 3: DataSonde Field Timeline

Upon arrival at each monitoring site, numerous tasks must be performed to successfully meet the QA/QC protocol and service the DataSonde. Properly filling out the calibration sheet is critical to collecting all the data that is needed for the evaluation of the sonde file. Here is an overview of a typical field tour consisting of extracting the sonde, performing scheduled maintenance, redeploying and returning the next day to calibrate for dissolved oxygen.

1. Arrive on site and acclimate pH and conductivity standards to ambient stream temperature in order to accurately post calibrate/calibrate the DataSonde. There are two possible methods to do this.
   - Method One: Collect water from the stream that is representative of the ambient stream temperature. Place the stream water, pH and conductivity buffers, as well as jugs of deionized water in a cooler to equalize the standards to ambient stream conditions. This acclimation procedure can take 15-30 minutes. Be very careful to have all lids properly capped so that buffers are not contaminated by stream water. Water from another reach of the river may be used so that the buffers can be acclimating during the drive to the next site.
   - Method Two: place the standards and deionized water in a durable mesh laundry bag and secure it in the stream. This will allow for a more rapid heat transfer and more precise acclimation to the site specific stream temperature.
2. Record current barometric pressure at the site along with other environmental conditions, such as, weather, changing water levels, etc. Calibrate the Quanta if it has not been calibrated already. If it has been calibrated, adjust the dissolved oxygen (percent saturation) for current site barometric pressure and deploy next to the sonde at least five minutes before the half hour. This will give the Quanta time to stabilize while also allowing it to be recorded at the same time as the sonde.
3. As close to the half hour as possible, but always within +-5 minutes, record the Quanta information. Only after the sonde has recorded on the half hour (preferably wait five minutes), carefully remove the sonde from the housing trying not to disturb any fouling on the probes.
4. Place the sonde and the Quanta within a bucket or cooler filled with stream water. Connect the sonde to the Surveyor and once both probes are stabilized, record both values. This will provide a comparison within the same parcel of water before cleaning the sonde.

5. Clean the sonde probes with a mild soap (Dr. Bronners, or alternative) and Q-tips or Kim wipes being especially careful with the probes and sensor area.
6. Replace the cleaned sonde back into the bucket with the Quanta and allow them to stabilize before taking readings from the two instruments again. This will act as a post cleaning comparison to determine the amount of fouling associated with the sonde probes.
7. Remove the sonde from the bucket and begin the post calibration of the DO probe. See the post calibration section for a detailed description of techniques. While the DO probe is stabilizing, this is a good time to perform file maintenance by downloading the old file and creating a new file. Make a note of the DO level so you can track how quickly the probe is stabilizing.
8. Perform post calibration on the specific conductivity and pH probes using stream acclimated standards.
9. Change batteries before every deployment making sure to grease the o-rings with silicone. Old batteries can be reused for flashlights, etc. before being recycled. Check sonde clock against verified watch and recalibrate if off by more than 1 minute. Make sure that a single watch is used week after week to maintain the same time comparisons. Set the watch using a computer's clock, and check it and reset if necessary regularly.
10. Redeploy the DataSonde and obtain Quanta information at the time of the first half hour recording of the sonde.

Step 5: Post Calibration/ Calibration

Calibration of the instrumentation in the field to a standard of known value is critical for accurate and precise measurements of the multiprobes. Post calibration of the instruments is similarly necessary to understand how the instrument is performing at the end of the deployment period. The post-calibration check is vital to the QA/QC process and provides a necessary evaluation of the instrumentation for the previous deployment. This check is required to estimate the electronic drift and for dissolved oxygen only, the effects of biofouling, of a dataset after instrument extraction. In the case of pH and specific conductivity, because the instrument has already been cleaned, the post-calibration also calibrates the instrument for the next deployment. Temperature probes do not undergo a weekly post-calibration process.

Consistently following the post calibration/calibration procedures outlined below will help ensure the data is of good quality. In addition, inconsistent application of a rigid protocol weakens the confidence of the data that in turn may inhibit the ability to draw any conclusions from the study. In general, when waiting for a parameter to stabilize, write down on the side or make a mental note of what the value is and when you check periodically, see whether it is still drifting one way or another. When the parameter stops drifting in one direction, it is a good sign that it is beginning to stabilize. This method works for any parameter you are calibrating for.

Dissolved Oxygen

Dissolved oxygen sensors are sophisticated electronic instruments that require frequent calibration and delicate handling. While the newer technology LDO sensors do not require regular maintenance, the Clark cell DO probes on the Quanta do require regular changing of the membrane to maintain accuracy. Protect the instruments from sudden impacts, drastic temperature changes, and extremes of heat and cold.

Maintenance issues of the Quanta dissolved oxygen probe generally are associated with the membrane. The thin Teflon membrane is affected by biological fouling changing the permeability rate of oxygen through the membrane. Replacing the membrane and electrolyte solution every deployment should eliminate or limit any bias due to a change in oxygen permeability. Accuracy and precision of dissolved oxygen data is not only dependent on the frequency of sampling and environmental conditions where the samples are being taken (e.g. eutrophic water), but also on the extended use of the instrument. It is necessary to regularly calibrate the DataSonde for dissolved oxygen. Calibrate for dissolved oxygen in mg/L based on DO % saturation at 100%. The US Fish and Wildlife Service recommends using the Air saturated water method for calibration of the LDO probe and the modified wet towel method for calibration of the Quanta. According to Hach, the air saturated method does not work effectively for the membrane style probes. The methods are described below.

Air Saturated Water: DATASONDE 5 with LDO probes

Remove the field cup of the sonde and replace it with the calibration cup.

1. With a 1-2 liter bottle, fill it with ½ Liter of water that has been at equilibrium with atmospheric pressure for at least 12 hours. This would be water that has been sitting in an uncapped container, at least overnight.
2. Make sure the water in the bottle is close to temperature equilibrium with the calibration environment.
3. Seal the bottle and shake it vigorously for 1 minute.
4. With the sensors facing upright, pour the water into the calibration cup until it is within 1/2" of the top. Cover the calibration cup with the cap upside down to stop the exchange of air without pressurizing the cup. Keep the sonde out of direct sunlight, or wrap the sonde in a wet towel to prevent the sonde and sensors from changing temperature.
5. Determine the barometric pressure using a calibrated handheld barometer.
6. Wait 3-5 minutes to assure the LDO sensor has reached the same temperature as the water bath.
7. Record the DO mg/L reading.
8. Enter the BP into the sonde to calibrate for DO % saturation.
9. Once it has stabilized to the new calibration, record the final calibrated value in mg/L.

Modified Wet Towel Method: QUANTA with Clark cell DO probe

Remove the field cup of the DataSonde or Quanta. Use the corner of a non-abrasive tissue such as Kim-wipe to absorb any water on the surface of the

membrane. Be careful not to remove any fouling material from the membrane at this time. Alternatively, allow the membrane to air dry if hot and dry conditions are present. Air drying may only take a few minutes and improves the accuracy of the biofouling estimate.
Place a small wet sponge in the bottom of the sensor area, wedging it between the probes while avoiding direct contact with both the DO membrane and the temperature probe. Replace the field cup and wrap the sonde in a white towel that has been soaked in water and gently wrung out so it is not dripping wet. The towel should cover the entire sonde and go around the sensor area at least twice. Make sure the field cup is completely covered with the towel to make sure the probe is in a 100 percent saturated environment. Allow the dissolved oxygen mg/L readings on the Surveyor to stabilize (about 10-15 minutes) and record the mg/L value as the initial reading. After you record the initial reading calibrate for Dissolved Oxygen % saturation by entering the current site barometric pressure from the Surveyor or a handheld barometer. Wait for the new value to stabilize then record the value in mg/L as the final reading. The difference between the initial and final reading will incorporate the effects of bio-fouling and electronic drift over the course of the deployment.

Specific Conductance/ Salinity
Calibration should occur with a standard that brackets the range of conditions expected in the field. A two-point calibration of zero and a 1000 or 1413 µS/cm is appropriate for most northern California freshwater systems. Higher conductivity solutions should be used for saline or brackish waters. As long as both conductivity and salinity are set to record on the sonde, calibrating for conductivity will act as the calibration for salinity.

With the conductivity and pH solutions acclimated to the stream temperature, calibration can commence. Rinse the probes three times with DI water. Drain the calibration cup and dry the inside of the cell thoroughly with a Q-tip. Calibrate the zero point for specific conductivity by allowing the probe to stabilize in air. Record the initial reading for the air calibration then calibrate the DataSonde for specific conductivity in air by entering in the Surveyor 0.0 µS/cm. It is necessary to perform the air calibration on the instrument even when the instrument may initially read 0.0 µS/cm because this creates the start point for the slope equation to determine conductivity.

Follow this by rinsing sparingly three times with the standard solution. When rinsing, be sure to swirl the solution adequately to remove or continually dilute any residual DI water remaining in the calibration cup. Discard standards appropriately after each use. When in the field, please store any used solutions in a sealed container to be disposed of later into a sewage or septic system. Fill the calibration cup with enough standard to cover the probe and allow a few minutes for readings to stabilize. After stabilization, record the value as the initial reading. Calibrate the DataSonde for specific conductivity by entering the standard solution value. Record the final value once the new reading stabilizes. Rinse the probes three times with DI water.

pH

Calibration for pH is also performed after cleaning the probe with alcohol and is performed in the field with buffers that have been allowed to reach ambient stream temperature. Use standards that bracket expected environmental conditions. For the Klamath River, pH standards of 7.0 and 10.0 are appropriate.

Rinse the calibration cup and associated probes three times with DI water. Rinse sparingly three times with pH 7.0 buffer that has been equilibrated to ambient stream temperature. Be sure to swirl the solution adequately to remove or continually dilute any residual DI water in the calibration cup. Fill with pH 7.0 buffer and allow the meter readings to stabilize. Record this as the initial value, which also is the post-calibration check, and then enter the buffer value of 7.0_ (varies based on temperature of the standard) into the laptop. Enter this as the final calibration value once it stabilizes. Now pH 10.0 must be calibrated. Repeat the same process this time switching to pH 10.0 buffer. Be sure to rinse with DI water and buffer three times before calibrating.

As part of regular maintenance, the first field visit of each month should involve changing of the pH reference electrolyte. Following post calibration of the pH probe, unscrew the teflon junction of the pH reference probe and pour out the solution and refill with fresh solution. If the KCl pellets inside have dissolved, replace them with 3 additional pellets. These pellets help keep the KCl solution saturated. Once the solution is replaced, screw the teflon junction back on making sure there is no air trapped within the reference probe. After this is done, recalibrate the pH probe to ensure accurate readings for the next deployment.

Depth

Remove water from the calibration cup and point the sensors down. Enter 0 for the standard (air). This calibration should be done following the conductivity calibration (Hydrolab, 2006).

Water Temperature

Before and after the field season, it is pertinent to verify that the thermisters of each instrument meet the manufacturer's specifications. Verification builds the researchers confidence that the data that has been or will be collected is of good quality; this may be especially true as the instruments age. The verification process takes place in a water bath and should span a temperature range that is representative of the field setting. This should be done both at the beginning and end of the field season; in multiyear studies this can be accomplished with one experiment. Verification studies conducted by the AFWO following the 2001 through 2003 field seasons found that all multiprobes were within $\pm$ 0.2°C when compared to a NIST thermometer. It is not possible to calibrate for temperature on a weekly basis although it is necessary to verify that the instruments are performing as specified. A check between the DataSonde and auditing Quanta will reveal differences that need further attention. In order to ensure a continuous record of water temperature throughout the season additional calibrated temperature probes (e.g. Optic Stowaways) should be placed at the study sites. These will also act to independently verify the sonde temperature's accuracy.

CITATIONS

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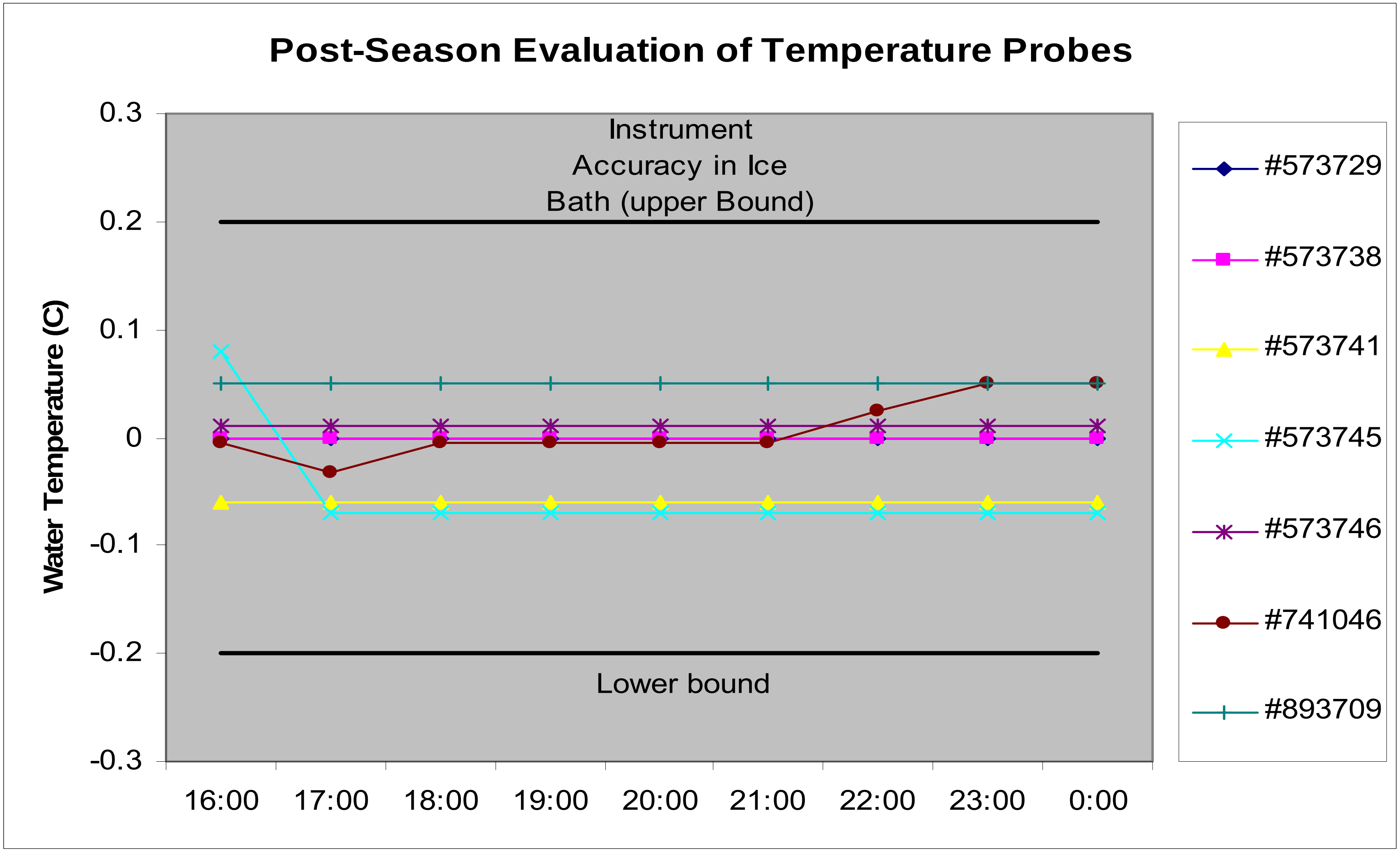
Hydrolab Surveyor 4 Water Quality Data Display User's Manual. Revision D, April 1999.

Turner R., and P. Zedonis, 2004. Comparison of Instruments Used in Water Quality Investigations of the Klamath River in 2003. U.S. Fish and Wildlife Service, In Press.

Appendix B. Results of the quality control testing of temperature loggers used in the study of water temperature dynamics in the Mattole River estuary/lagoon in 2006. Note, all loggers were well within the expected range of ± 0.2 °C in the ice bath.



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Appendix C. Weekly average water temperatures of the Mattole River estuary /lagoon from June 16 to September 1 and statistics on exceeding 19 °C. All stations represent bottom temperatures except DS-2, DS-4 and TP-9, which represent surface water temperatures. Data collected by continuous monitoring equipment. See Figure 1 for specific locations of each study site.

Water Temperatures (WAT) of the Mattole River Estuary/Lagoon 2006
Study Site and Lagoon Area Represented

	Lower Lagoon		Middle Lagoon			Upper Lagoon		River
Date	DS1	DS2	DS3	DS4	TP-7	TP- 8	TP- 9	TP - 10
6/16/2006	--	--	--	--	19.8	--	--	20.2
6/17/2006	--	--	--	--	19.7	--	--	20.3
6/18/2006	--	--	--	--	19.3	--	--	20.4
6/19/2006	--	--	--	--	19.2	--	--	20.5
6/20/2006	--	--	--	--	19.2	--	--	20.7
6/21/2006	--	--	--	--	19.3	--	--	20.9
6/22/2006	--	--	--	--	19.1	--	--	20.9
6/23/2006	--	--	--	--	19.2	--	--	20.9
6/24/2006	--	--	--	--	19.3	--	--	20.7
6/25/2006	--	--	--	--	19.6	--	--	20.6
6/26/2006	--	--	--	--	19.7	--	--	20.5
6/27/2006	--	--	--	--	19.8	--	--	20.4
6/28/2006	--	--	--	--	19.9	--	--	20.3
6/29/2006	--	--	--	--	20.3	--	--	20.3
6/30/2006	--	--	--	--	20.3	--	--	20.3
7/1/2006	--	--	--	--	20.3	--	--	20.4
7/2/2006	--	--	--	--	20.4	--	--	20.4
7/3/2006	--	--	--	--	20.1	--	--	20.5
7/4/2006	--	--	--	--	20.1	--	--	20.7
7/5/2006	--	--	--	--	20.1	--	--	20.9
7/6/2006	--	--	--	--	20.1	--	--	21.1
7/7/2006	--	--	--	--	20.2	--	--	21.5
7/8/2006	15.1	19.4	20.4	19.6	20.0	--	--	21.8
7/9/2006	14.7	19.3	20.5	20.6	20.0	--	--	22.1
7/10/2006	14.4	19.4	20.4	20.9	20.1	--	--	22.2
7/11/2006	14.5	19.4	20.2	20.8	19.9	--	--	22.2
7/12/2006	14.5	19.5	20.0	20.9	19.8	--	--	22.2
7/13/2006	14.8	19.5	20.0	20.9	19.8	--	--	22.2
7/14/2006	15.4	19.7	20.2	21.0	19.8	--	--	22.1
7/15/2006	16.2	20.1	20.4	21.4	20.1	22.1	22.3	22.0
7/16/2006	17.1	20.5	20.6	21.4	20.4	22.2	22.4	22.0
7/17/2006	18.0	20.9	20.9	21.6	20.8	22.4	22.5	22.1
7/18/2006	19.0	21.3	21.5	21.8	21.2	22.4	22.5	22.1
7/19/2006	20.0	21.5	21.9	21.9	21.6	22.4	22.5	22.1
7/20/2006	20.7	21.7	22.0	21.9	21.8	22.2	22.4	22.1
7/21/2006	21.0	21.7	21.9	21.9	21.8	22.1	22.3	22.1
7/22/2006	20.9	21.4	21.7	21.6	21.6	21.9	22.1	21.9
7/23/2006	20.8	21.1	21.5	21.4	21.4	21.8	22.0	21.8
7/24/2006	20.8	20.9	21.2	21.2	21.3	21.6	21.8	21.7
7/25/2006	20.6	20.7	20.8	21.0	21.0	21.3	21.6	21.4
7/26/2006	20.4	20.4	20.5	20.7	20.8	21.0	21.3	21.2
7/27/2006	20.2	20.2	20.4	20.6	20.6	20.9	21.2	21.0
7/28/2006	19.9	19.9	20.3	20.4	20.4	20.7	21.0	20.9
7/29/2006	19.8	19.8	20.1	20.3	20.3	20.6	20.9	20.8
7/30/2006	19.7	19.8	20.2	20.3	20.3	20.5	20.9	20.8
7/31/2006	19.7	19.7	20.0	20.2	20.2	20.3	20.8	20.6
8/1/2006	19.6	19.6	19.9	20.1	20.0	20.2	20.6	20.5
8/2/2006	19.5	19.6	19.9	20.1	20.0	20.2	20.7	20.5
8/3/2006	19.6	19.7	20.0	20.2	20.1	20.3	20.8	20.6
8/4/2006	19.7	19.8	20.0	20.2	20.2	20.3	20.8	20.6
8/5/2006	19.7	19.8	20.0	20.2	20.1	20.3	20.7	20.5
8/6/2006	19.5	19.5	19.8	19.9	19.8	20.2	20.5	20.4
8/7/2006	19.1	19.2	19.6	19.7	19.6	20.1	20.3	20.2
8/8/2006	18.9	19.0	19.4	19.5	19.5	20.0	20.2	20.2
8/9/2006	18.7	18.8	19.2	19.4	19.3	19.8	20.1	20.1
8/10/2006	18.4	18.5	19.1	19.2	19.0	19.6	19.9	19.9
8/11/2006	18.4	18.5	19.0	19.1	19.0	19.5	19.8	19.8
8/12/2006	18.4	18.4	18.8	19.0	18.9	19.3	19.6	19.6
8/13/2006	18.3	18.5	18.6	18.9	18.9	19.1	19.5	19.5
8/14/2006	18.3	18.4	18.6	18.9	18.9	19.1	19.5	19.4
8/15/2006	18.4	18.5	18.6	18.9	18.9	19.1	19.4	19.4
8/16/2006	18.4	18.5	18.6	18.8	19.0	19.1	19.4	19.3
8/17/2006	18.4	18.5	18.5	18.8	19.0	18.9	19.3	19.2
8/18/2006	18.3	18.4	18.4	18.7	18.9	18.9	19.3	19.2
8/19/2006	18.3	18.4	18.6	18.8	19.0	19.1	19.4	19.3
8/20/2006	18.5	18.6	18.7	19.0	19.2	19.1	19.4	19.3
8/21/2006	18.7	18.8	18.9	19.2	19.5	19.3	19.6	19.5
8/22/2006	18.9	19.0	19.0	19.3	19.6	19.3	19.6	19.4
8/23/2006	18.9	18.9	19.0	19.2	19.6	19.2	19.5	19.4
8/24/2006	18.8	18.8	19.0	19.1	19.5	19.2	19.6	19.4
8/25/2006	18.8	18.9	18.9	19.2	19.6	19.1	19.5	19.3
8/26/2006	19.0	19.0	18.9	19.2	19.7	19.0	19.5	19.3
8/27/2006	19.0	19.0	18.8	19.1	19.6	19.0	19.5	19.3
8/28/2006	18.9	18.9	18.7	19.1	19.5	18.9	19.4	19.2
8/29/2006	18.8	18.8	18.7	19.0	19.4	18.9	19.4	19.2
8/30/2006	18.8	18.8	18.6	19.0	19.4	18.8	19.2	19.0
8/31/2006	18.7	18.7	18.5	18.8	19.3	18.7	19.1	19.0
9/1/2006	18.5	18.5	18.4	18.6	19.0	18.6	19.0	18.9
Statistics for Exceedance of 19 C (WAT) June 16 to July 23 (prior to lagoon formation)								
Days of Exceedance	5	15	15	15	37	8	8	37
% Time Exceeded	14	41	41	41	100	22	22	100
Statistics for Exceedance of 19 C (WAT) July 23 to September 1 (after Lagoon formation)								
Avg Temp	19.1	19.2	19.4	19.6	19.7	19.7	20.1	20.0
Days of Exceedance	16	18	20	29	34	34	40	39
% Time Exceeded	39	44	49	71	83	83	98	95

Appendix D. Water quality monitoring data from the Mattole River estuary during the July 20, 2006 synoptic survey. A Hydrolab Quanta multiprobe instrument was used to collect these data. Data collected by the Mattole Salmon Group.

Synoptic Survey #1. Mattole River Estuary

Date
07/20/06

Crew
MSG: Sean James, Reid Bryson
USFWS: Randy Turner

Staff Gage

Height	Time	Multiprobe Quanta #
NA	NA	00069

Notes:
Sites recorded on printed 2005 Mattole Estuary aerial photo for future reference.
Data for sites 7 and 8 switched from their positions on the data sheet to reflect a consistent south to north and east to west progression.
Permanent estuary closure occurred on July 23, or three days following this survey.

Site	Latitude (DMS)	Longitude	Time	Depth from Surface (ft)	Temp (°C)	Sp Cond (mS/cm)	pH	DO (mg/L)	DO (% Sat)	Notes
1	40* 17' 50.360" N	124* 21' 17.491" W	13:36	7.6	19.75	15.600	8.48	13.18	152.5	Bottom, At Sonde MT1
1	40* 17' 50.360" N	124* 21' 17.491" W	13:41	6.1	20.26	0.675	8.69	10.06	111.2	6ft
1	40* 17' 50.360" N	124* 21' 17.491" W	13:46	3.9	20.80	0.391	8.57	9.10	101.6	4ft
1	40* 17' 50.360" N	124* 21' 17.491" W	13:49	2.0	21.07	0.339	8.50	8.61	96.4	2ft
1	40* 17' 50.360" N	124* 21' 17.491" W	13:51	0.1	21.10	0.338	8.49	8.53	95.7	0ft, At Sonde MT2
2	40* 17' 42.764" N	124* 21' 13.876" W	14:04	6.0	21.70	0.517	8.50	9.80	111.4	6ft
2	40* 17' 42.764" N	124* 21' 13.876" W	14:07	4.1	21.58	0.339	8.42	9.20	104.2	4ft
2	40* 17' 42.764" N	124* 21' 13.876" W	14:08	2.0	21.57	0.328	8.43	9.13	103.3	2ft
2	40* 17' 42.764" N	124* 21' 13.876" W	14:09	0.1	21.58	0.338	8.44	9.06	102.7	0ft
3	40* 17' 38.534" N	124* 21' 12.571" W	14:17	2.7	22.03	0.320	8.51	9.32	106.4	Bottom
3	40* 17' 38.534" N	124* 21' 12.571" W	14:19	1.9	22.04	0.320	8.52	9.28	106.1	2ft
3	40* 17' 38.534" N	124* 21' 12.571" W	14:21	0.2	22.03	0.320	8.52	9.16	104.6	0ft
4	40* 17' 36.622" N	124* 21' 04.626" W	14:33	6.8	23.25	15.100	9.01	24.13	298.2	Near small woody debris on South Bank
4	40* 17' 36.622" N	124* 21' 04.626" W	14:36	5.8	20.97	0.257	8.37	11.31	126.8	Near small woody debris on South Bank
4	40* 17' 36.622" N	124* 21' 04.626" W	14:37	3.9	21.03	0.245	8.36	10.83	121.3	Near small woody debris on South Bank
4	40* 17' 36.622" N	124* 21' 04.626" W	14:38	2.0	21.07	0.241	8.35	10.61	118.9	Near small woody debris on South Bank
4	40* 17' 36.622" N	124* 21' 04.626" W	14:40	0.2	21.10	0.242	8.35	10.44	117.2	Near small woody debris on South Bank
5	40* 17' 39.440" N	124* 21' 01.752" W	14:50	6.0	21.19	0.277	8.32	11.11	125.0	At Sonde MT3, At Fish Jungle Gym
5	40* 17' 39.440" N	124* 21' 01.752" W	14:52	3.8	21.44	0.254	8.33	10.59	119.6	At Fish Jungle Gym
5	40* 17' 39.440" N	124* 21' 01.752" W	14:54	2.0	21.98	0.278	8.36	9.82	112.1	At Fish Jungle Gym
5	40* 17' 39.440" N	124* 21' 01.752" W	14:56	0.2	22.39	0.284	8.37	9.60	110.4	At Sonde MT4, At Fish Jungle Gym
6	40* 17' 41.986" N	124* 21' 0.800" W	15:01	3.0	23.95	0.276	8.42	8.82	104.6	Between Fish Jungle Gym and North Bank
6	40* 17' 41.986" N	124* 21' 0.800" W	15:03	2.0	23.94	0.275	8.42	8.82	104.5	Between Fish Jungle Gym and North Bank
6	40* 17' 41.986" N	124* 21' 0.800" W	15:05	0.2	24.16	0.276	8.41	8.78	104.4	Between Fish Jungle Gym and North Bank
7	40* 17' 33.210" N	124* 20' 52.415" W	15:35	5.3	21.69	0.240	8.35	9.73	110.5	At LB across from LWD upstream of Willow Island
7	40* 17' 33.210" N	124* 20' 52.415" W	15:38	4.0	21.70	0.240	8.38	9.88	112.1	At LB across from LWD upstream of Willow Island
7	40* 17' 33.210" N	124* 20' 52.415" W	15:41	2.0	21.75	0.240	8.39	9.93	112.8	At LB across from LWD upstream of Willow Island
7	40* 17' 33.210" N	124* 20' 52.415" W	15:43	0.3	21.75	0.240	8.41	10.2	115.9	At LB across from LWD upstream of Willow Island
8	40* 17' 35.584" N	124* 20' 52.006" W	15:18	8.2	21.59	0.241	8.35	10.49	118.6	At LWD on RB upstream of Willow Island
8	40* 17' 35.584" N	124* 20' 52.006" W	15:20	6.1	21.87	0.240	8.44	10.32	117.7	At LWD on RB upstream of Willow Island
8	40* 17' 35.584" N	124* 20' 52.006" W	15:23	3.8	21.44	0.240	8.45	10.22	116.6	At LWD on RB upstream of Willow Island
8	40* 17' 35.584" N	124* 20' 52.006" W	15:26	1.9	21.47	0.240	8.47	9.99	114.0	At LWD on RB upstream of Willow Island
8	40* 17' 35.584" N	124* 20' 52.006" W	15:28	0.2	21.98	0.239	8.47	10.34	118.0	At LWD on RB upstream of Willow Island
9	40* 17' 31.170" N	124* 20' 42.322" W	15:56	6.6	22.37	0.240	8.5	9.23	105.5	LB near Staff Gage
9	40* 17' 31.170" N	124* 20' 42.322" W	16:00	4.0	23.22	0.239	8.54	9.78	114.1	LB near Staff Gage
9	40* 17' 31.170" N	124* 20' 42.322" W	16:03	2.0	23.33	0.240	8.55	9.37	109.8	LB near Staff Gage
9	40* 17' 31.170" N	124* 20' 42.322" W	16:05	0.4	23.38	0.240	8.54	9.82	115.1	LB near Staff Gage
10	40* 17' 32.366" N	124* 20' 42.135" W	16:11	4.5	23.38	0.238	8.53	11.38	133.3	RB across from Staff Gage
10	40* 17' 32.366" N	124* 20' 42.135" W	16:13	4.0	23.37	0.239	8.52	10.46	122.6	RB across from Staff Gage
10	40* 17' 32.366" N	124* 20' 42.135" W	16:16	2.0	23.40	0.238	8.54	10.27	120.4	RB across from Staff Gage
10	40* 17' 32.366" N	124* 20' 42.135" W	16:18	0.2	23.40	0.238	8.57	10.15	119.1	RB across from Staff Gage
11			16:32	0.7	24.10	0.238	8.58	9.69	115.1	Above first riffle representing riverine water quality

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Appendix E. Water quality monitoring data from the Mattole River lagoon during the August 17, 2006 synoptic survey. A Hydrolab Quanta multiprobe instrument was used to collect these data. Data collected by the Mattole Salmon Group.

Synoptic Survey #2. Mattole River Lagoon

Date
08/17/06

Crew
MSG: Reid Bryson

Notes:
All depths are approximate since Quanta used has no depth sensor.
Lattitude and Longitude readings not taken due to faulty GPS receiver.

Staff Gage

Height	Time	Multiprobe Quanta #
2.47	11:28	#0666

Site	Latitude	Longitude	Time	Depth from Surface (ft)	Temp (Celcius)	Sp Cond	pH	DO (mg/L)	DO (% Sat)	Notes
1			8:09	8.0	18.20	0.252	7.93	8.49	89.8	Bottom, At Sonde MT1
1			8:14	6.0	18.19	0.252	7.95	8.49	89.8	
1			8:16	4.0	18.18	0.252	7.95	8.46	89.4	
1			8:18	2.0	18.19	0.252	7.95	8.41	89.0	
1			8:20	0.2	18.20	0.252	7.95	8.41	88.9	At Sonde MT2
2			8:33	6.0	18.44	0.252	7.94	8.32	88.4	
2			8:36	4.0	18.45	0.252	7.94	8.21	87.3	
2			8:38	2.0	18.51	0.253	7.94	8.10	86.1	
2			8:39	0.2	18.52	0.253	7.94	8.03	85.4	
3			8:46	2.5	18.11	0.252	7.94	8.53	90.1	
3			8:49	2.0	18.08	0.252	7.95	8.53	90.2	
3			8:52	0.2	18.15	0.252	7.97	8.51	89.9	
4			9:00	7.0	18.36	0.252	7.95	8.51	90.3	Near small woody debris on South Bank
4			9:02	6.0	18.39	0.252	7.94	8.36	88.8	Near small woody debris on South Bank
4			9:05	4.0	18.66	0.252	7.94	8.01	85.5	Near small woody debris on South Bank
4			9:06	2.0	18.83	0.252	7.93	7.86	84.2	Near small woody debris on South Bank
4			9:08	0.2	18.83	0.252	7.92	7.87	84.2	Near small woody debris on South Bank
5			9:15	8.0	18.58	0.255	7.86	7.53	80.2	At Sonde MT3, At Fish Jungle Gym
5			9:16	6.0	18.60	0.255	7.87	7.50	80.0	At Fish Jungle Gym
5			9:19	4.0	18.90	0.256	7.86	7.10	76.1	At Fish Jungle Gym
5			9:20	2.0	18.94	0.255	7.86	7.19	77.2	At Fish Jungle Gym
5			9:23	0.3	18.97	0.255	7.87	7.22	77.5	At Sonde MT4, At Fish Jungle Gym
6			9:31	2.5	18.06	0.259	7.88	7.98	84.2	Between Fish Jungle Gym and North Bank
6			9:34	2.0	18.11	0.258	7.89	7.88	83.2	Between Fish Jungle Gym and North Bank
6			9:36	0.3	18.11	0.258	7.90	7.93	83.7	Between Fish Jungle Gym and North Bank
7			9:46	7.0	18.18	0.258	7.73	7.42	78.4	At LB across from LWD upstream of Willow Island
7			9:49	6.0	18.51	0.258	7.77	7.13	75.9	At LB across from LWD upstream of Willow Island
7			9:51	4.0	18.79	0.256	7.82	7.17	76.7	At LB across from LWD upstream of Willow Island
7			9:53	2.0	18.89	0.281	7.83	7.17	77.0	At LB across from LWD upstream of Willow Island
7			9:56	0.2	18.90	0.256	7.84	7.18	77.0	At LB across from LWD upstream of Willow Island
8			10:05	8.0	17.77	0.261	7.66	7.00	73.3	At LWD on RB upstream of Willow Island
8			10:08	6.0	17.77	0.261	7.66	6.98	73.3	At LWD on RB upstream of Willow Island
8			10:10	4.0	17.80	0.260	7.66	6.96	73.1	At LWD on RB upstream of Willow Island
8			10:12	2.0	17.81	0.261	7.66	7.02	73.6	At LWD on RB upstream of Willow Island
8			10:15	0.2	17.89	0.260	7.67	7.06	74.0	At LWD on RB upstream of Willow Island
9			10:25	7.5	17.28	0.261	7.66	7.69	79.8	LB near Staff Gage
9			10:28	6.0	17.28	0.261	7.66	7.71	80.0	LB near Staff Gage
9			10:31	4.0	17.35	0.261	7.66	7.63	79.4	LB near Staff Gage
9			10:34	2.0	17.44	0.262	7.65	7.66	79.8	LB near Staff Gage
9			10:37	0.3	17.55	0.262	7.65	7.53	78.6	LB near Staff Gage
10			10:46	5.0	17.50	0.260	7.68	7.92	82.5	RB across from Staff Gage
10			10:48	4.0	17.52	0.260	7.69	7.94	82.8	RB across from Staff Gage
10			10:53	2.0	17.82	0.259	7.73	8.31	87.2	RB across from Staff Gage
10			10:56	0.3	18.11	0.259	7.77	8.73	92.1	RB across from Staff Gage
11			11:12	0.7	18.14	0.257	7.85	9.49	100.2	Above first riffle: representing riverine water quality