THE PHYSICAL, CHEMICAL AND BIOLOGICAL MONITORING

OF

LOS PEÑASQUITOS LAGOON

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by
Gregory D. Williams
Pacific Estuarine Research Laboratory (PERL)
Biology Department
San Diego State University
San Diego, CA 92182-4625

for
Los Peñasquitos Lagoon Foundation
P.O. Box 866
Cardiff, CA 92007

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SUMMARY OF RESULTS

1. The lagoon mouth closed several times during the 1995-96 monitoring period. Annual rainfall was below average for the region.

2. Dissolved oxygen levels were below levels considered safe for channel organisms during the February mouth closure, and a fish and invertebrate kill was observed in the lagoon.

3. Lagoon salinities were unusually low during the summer dry season.

4. Adaptive monitoring of channel waters clarified the role tidal flows have in influencing daily fluctuations in water quality parameters, highlighted spatial patterns of lagoon salinity, especially the unusually low levels in the south arm, and gave some initial information on the volume and location of freshwater inputs.

5. Forty-four invertebrate taxa, including three exotic species, were sampled or observed in the lagoon this year. Diversity was highest in June at all stations.

6. Thirteen fish species were collected in the lagoon this year, including one exotic species, the mosquitofish (*Gambusia affinis*).

7. Permanent vegetation transects in the eastern portion of the lagoon displayed increases in mean percent cover by transition and exotic species and declines in native saltmarsh species.

8. Population estimates of the rare plant, *Lasthenia glabrata*, were unclear, but observations over several dates point to the importance of census timing in relation to rainfall events. Maps of the entire lagoon population of *Lasthenia* were made for the first time using GPS equipment.

9. Multiple construction projects are encroaching on the lagoon's borders and serve to highlight our concern for the continued health of Los Peñasquitos Lagoon and its flora and fauna.

10. Several changes were made in the 1996-97 monitoring contract based on data gathered this year. Additional recommendations are given at the end of the report.

INTRODUCTION

Los Peñasquitos Lagoon (LPL) is a relatively small estuary (154 hectares) in northern San Diego County. It has a drainage basin of approximately 246 sq. km, with major drainages that include Carrol Canyon, Los Peñasquitos Canyon, and Carmel Valley. LPL, like all wetlands in southern California, has a Mediterannean climate characterized by highly seasonal precipitation events occurring primarily during the winter months, and historically high salinities (33 ppt) during the dry summer months.

Historic evidence (including mollusc middens left by indigenous peoples, notes by Spanish explorers, railroad maps from 1888, and photographs) indicates it may have once remained open to the sea year-round. However, increased erosion and the resultant sediment loads due to agriculture and grazing in the early part of this century, combined with railroad embankment construction (1925), lowered the volume of the lagoon (tidal prism) and cut off many tidal channels. A pattern of seasonal mouth closure emerged that was enhanced by coastal highway construction in 1932-3.

In the 1960's, dumping of treated effluent containing nitrates and phosphates from upstream sewage treatment facilities reached new highs. This nutrient addition contributed to algal growth in lagoon waters, and with decomposition of senescent vegetation, led to the depletion of dissolved oxygen and hypoxic conditions. Mosquitos and midges proliferated, and the odors associated with decaying organics increased.

The LPL Enhancement Plan was developed in 1985 by the California Coastal Conservancy to deal with these problems, with funding provided by local developers and homeowners associations. A management program was formulated for the lagoon which called for the monitoring of channel water quality and the mechanical opening of the mouth before water quality became low enough to kill channel organisms.

As part of this management program, the Pacific Estuarine Research Laboratory (PERL), based at San Diego State University, was contracted to monitor lagoon resources and use the data in its studies of regional wetland ecosystems. PERL has monitored the physical and chemical characteristics of Los Peñasquitos Lagoon channel water since 1987, and sampled benthic invertebrates, fish, and saltmarsh vegetation since 1988 (Covin 1987, Nordby and Covin 1988, Nordby 1989, Nordby 1990, Boland 1991, Boland 1992, Boland 1993, Gibson et al. 1994, Williams 1995). These studies have led to the timely opening of the mouth and an increase in our knowledge of the biology of southern California's estuaries (e.g., Nordby and Zedler 1991). We report on the past year's results here.

In our efforts to improve the effectiveness of our monitoring program, several changes were instituted this year. We adopted a more adaptive approach to monitoring the lagoon's water quality, incorporated Global Positioning Systems (GPS) into our census of rare plant distributions, and expanded fish and invertebrate sampling into the upper lagoon. Based on our successes, these and additional changes were incorporated into the 1996-97 monitoring contract.

METHODS

Study Site Descriptions

Water quality was sampled at three stations that have been monitored since 1987: Station 1 (Milligan House), 2 (Railroad Trestles), and 3 (Mouth) (Fig. 1; all figures and tables are at the end of the report). Fish and invertebrate samples were collected at five stations in the lagoon (Fig. 1); fish/invertebrate stations #1-3 have also been monitored since 1987, although #2 is in a different location than water quality station #2. Physical descriptions of these sites are as follows: Station 1 (Milligan house) is located along Carmel Valley Road in the northern arm of the estuary. This is the largest station sampled, with a channel approximately 20 m wide and 1 m deep, with sediments composed primarily of clay and mud. Station 2 (Circle K) is located just east of the railroad bridge and possesses substrate composed of soft, highly organic mud. This is the shallowest (0.2-0.4 m) of the five stations and has a width of approximately 12 m. Station 3 (Mouth) is located in one of the channels closest the lagoon's Pacific Ocean outlet and is most directly exposed to ocean flows. This site has a maximum depth of approximately 1 m, sandy sediments, and a highly variable width (8- 40 m) because of its dynamic hydrology. Station 4 (RR berm), newly added this year (1995-96), is in the southwest portion of the lagoon, directly adjacent to the railroad berm. It is a relatively narrow channel (5-7 m), with steep clay banks and relatively low salinity water. Station 5 (Sorrento Valley Rd), also newly established, is located in the easternmost portion of the lagoon in close proximity to extensive stand of cattails (*Typha sp*.). The depth, morphology, bank vegetation, and water salinity are similar to those of station 4.

Water Quality

Water quality of the lagoon was monitored at three stations that were permanently established in 1987 (Fig. 1). These stations were visited every two weeks (bimonthly), in the early morning (before 9am), and the following characteristics were measured:

- water temperature (at the surface and bottom) in degrees Celsius using a Yellow Springs Instrument (YSI) Model 51B DO/temperature meter;
- dissolved oxygen (at the surface and bottom) in mg/l using a Yellow Springs Instrument (YSI) Model 51B DO/temperature meter;
- water salinity (at the surface and bottom) in ppt using a Yellow Springs Instrument (YSI) Model 33 S-C-T meter; and
- water depth in cm using a calibrated rod or meter stick.

In addition, the condition of aquatic vegetation, the presence of channel organisms, and water clarity were noted at each station. Summary rainfall and air temperature data were obtained from data collected at Lindberg field by the National Weather Service. Mouth closure data were supplemented by daily records maintained by Mike Wells, regional ecologist for the California Dept. of Parks and Recreation.

In response to changing lagoon conditions that were highlighted by bimonthly sampling, we employed additional water quality monitoring procedures:

A. Dataloggers, which sample water quality parameters (salinity, temperature, and DO) every 30 minutes, were deployed near the channel bottom at station 2 during mouth closures, flooding, and fish-kill events to determine the effect of changing mouth conditions on lagoon water quality over small temporal scales.

B. Salinity Transects were conducted to pinpoint the major source(s) of freshwater entering the lagoon. On Aug. 8, 1996, we paddled a canoe from the mouth into the upper reaches of LPL's tidal creeks during an ebbing tide with low exchange (high - 7:24 a.m., +3.8 ft; low - 12:07 p.m., +2.5 ft). At approximately 50-100-m intervals, channel depth was measured with a meter stick, and surface and bottom water samples were collected using a syringe mounted on a probe. Salinities were measured with a temperature compensated refractometer. The composition of sediments was noted and observations on channel fauna were made. Sampling was conducted from 9:25-11:51 a.m. at twenty-two stations located throughout the lagoon.

C. Flow Rates of LPL's major tributaries were measured on several dates to identify the volume and rate of freshwater flows entering the lagoon. On Aug. 15 and Sept. 27, 1996, stream flow rates were measured at each of the major tributaries: Carrol Canyon (south of the lagoon, near where I-5 passes over Sorrento Valley Road), Los Peñasquitos Creek (south of the lagoon, near the Sorrento Valley Rd. bridge), and Carmel Valley (directly east of the lagoon, near the I-5 overpass). Stream cross sectional areas were estimated by measuring the average width and depth of a 4-m section of stream. Water column velocity was estimated by measuring the average time a neutrally buoyant object travelled over this same 4-m section. Discharge rates were estimated using the equation Q=Av, where Q equals discharge, A is the stream cross-sectional area, and v is the mean water column velocity (Gore 1996).

Benthic Invertebrates.

Two sets of benthic invertebrate samples were collected at each of the five channel stations (Fig. 1). First, nine shallow cores were taken to estimate the abundances of small, shallow-dwelling invertebrates. Cores were collected by pushing a cylindrical "clam gun" (15-cm diameter; 176 cm^2 area) 5 cm into the sediment. The nine cores at each station were combined in groups of three, giving a total of three samples per station. The total area of each sample equaled 530 cm^2 (0.053 m^2). Samples were sieved through a 1-mm screen in the field; all easily identified animals were counted and released, others were preserved, identified, sorted, and counted under a dissecting microscope in the lab. To estimate the abundance of large, deep-dwelling invertebrates (mainly bivalves), cores were collected by pushing the same "clam gun" (45-cm length, 15-cm diameter) 20 cm into the sediment. Nine cores, pooled using the same methods as the shallow series, were taken at each station. Samples were sieved through a 3-mm screen in the field. All easily identified animals were counted and released, while others were preserved and identified in the lab. Some preserved individuals have been kept for voucher purposes.

Shallow cores (5-cm depth) were used to quantify most taxa, especially small polychaetes, crustaceans (e.g., amphipods), and other surface-dwelling species (e.g., gastropods or mussels). Deep cores (20-cm) were designed to sample deep burrowing taxa, including most large bivalves and burrowing shrimp. Field observations, including those made of specimens captured during fish seining, added the presence of large or mobile taxa (e.g. decapod crustaceans and large gastropods) not usually sampled quantitatively with the cores.

At each station the water temperature, salinity and dissolved oxygen content were also measured.

Fishes

Adult and juvenile fishes were collected from each of five stations (Fig. 1) during low, slack, neap tides using two blocking nets and one 15-m bag seine composed of 3-mm mesh. At each study site a linear distance of approximately 10 m was measured parallel to the channel and the blocking nets were deployed to confine all fishes within this area. The bag seine was then swept between the two blocking nets and across the channel to the opposite bank (1 pass). Passes were repeated until the fishes effectively captured by seine approached zero. The species composition and number of fishes collected were recorded separately for each pass. Subsamples of at least 25 individuals per species were measured and then released outside the blocking nets. Unique and difficult to identify individuals were preserved for voucher purposes.

Snorkel transects were swum from the mouth of the lagoon to above the railroad bridge on one date to estimate lagoon use by large and difficult-to-capture fishes. Species encountered were identified and their abundance and approximate sizes were recorded.

Vegetation.

Vegetation monitoring was conducted to document changes in the species composition of the saltmarsh and to determine whether historic saltmarsh habitats were being invaded by upland/exotic species. The saltmarsh vegetation was monitored in nine areas at the end of the growing season (23-24 September, 1996) (Fig. 2). PERL has been monitoring five of these areas since 1986 (transects 1- 5), and the other four since 1990 (transects 9 - 12); transects 6-8 have been discontinued and are not indicated on Figure 2.

Two (or more) stakes mark the position of each permanent transect, which vary in length from 30 to 510 m; transects #1, 2, and 3 are comprised of two 50-m sections. A 0.25-m^2 circular quadrat was laid down at five meter intervals along each transect and percent cover of each species and total percent cover were recorded. Cover classes of all species were classified as follows: 1 = <1% cover; 2 = 1-5% cover; 3 = 6-25% cover; 4 = 26-50% cover; 5 = 51-75% cover; 6 = 76-95, 7= 96-100% cover. Individual frequency of occurence and mean cover estimates were calculated and recorded for each transect. Photographs were taken down the length of each marsh transect to serve as a visual record of the site.

Soil salinity measurements were made along each vegetation transect at the end of the growing season (September 1995). At least 5 soil cores were obtained using a 2-m diameter corer at equally spaced intervals along each transect. Saturated soil pastes (Richards 1954) were prepared in the laboratory, because soils were often too dry to express interstitial water in the field. We extruded water from the soil pastes using 10-ml syringes fitted with filter paper and measured salinity with a temperature-compensated refractometer.

Two methods were used to map distributions and measure the relative abundance of the rare Coulter goldfield (*Lasthenia glabrata*), also known as saltmarsh daisy. Our sixth annual census of *Lasthenia* was made around eight of the lagoon's salt pannes/vernal pools on April 16, 1996. A 1-m wide belt transect was run at 5-m intervals through the margin vegetation of each panne, and *Lasthenia* presence or absence was noted. From these data, the percent of panne margin containing *Lasthenia* was calculated. Also, a portion of the panne margin where *Lasthenia* was most abundant was chosen, and stem densities were estimated in a 0.1-m^{-2} area. Bruce Nyden, Dr. Gary Sullivan, and I surveyed the presence of individual and groups of *Lasthenia* using kinematic Global Positioning Systems (GPS) on April 5, 12, and 16, 1996, and plotted these as ARC/INFO coverages on the rectified 1995 Los Peñasquitos Lagoon mosaic.

Birds, Reptiles, Mammals

Seasonal censuses are performed by California State Parks employees, docents from the Torrey Pines State Reserve, and other various volunteer organizations (e.g., San Diego Audobon Society), and are not included in this report.

RESULTS AND DISCUSSION

Channel Water Quality - Bimonthly Monitoring and Annual Trends

Annual rainfall during the 1995-96 rain season was below the long-term average for the region (Table 1). Approximately 13 cm (5.1 in) of rain fell in San Diego County during the 1995-96 rain year (July 1, 1995 through 30 June 1996), with most precipitation (~4.5 cm) occurring from December to March (Table 1, Fig. 3).

Table 1. Monthly rainfall (cm) and long-term monthly averages at Lindbergh Field, San Diego, CA.

Month	(1995-96)	Average (1850-1995)
October '95	0.00	1.05
November	0.76	2.49
December	2.24	4.59
January '96	3.86	4.94
February	2.24	4.85
March	2.79	4.20
April	0.91	1.81
May	0.05	0.67
June	0.00	0.16
July	0.09	0.09
August	0.00	0.21
September	0.03	0.33
Total	13.16	25.37

Biweekly water quality monitoring tracked broad seasonal changes in lagoon water salinity, temperature, and DO at the three sampling stations (Fig. 4). Most water quality parameters were similar across stations, although there were some minor differences in vertical stratification (difference between surface and bottom parameters) among stations. These differences were related to water depth at each sampling site. For example, vertical stratification was most pronounced at station 2, which is located in one of the deepest, slowest flowing parts of the lagoon, while few differences were seen in water quality parameters at the mouth, which is shallow and well-mixed, with high current speeds.

Water temperatures generally declined into the winter months, ranging from highs of 22-24 ˚C in September 1995, to lows of 12-13 ˚C in February 1996 (Fig. 4). Temperatures then increased again during the spring months, and by August 1996 had reached their maximum levels of 24-25 °C. Salinities were erratic over the course of the study, dropping to < 25 ppt at all stations in early November 1995 following the first rain of the season, and during February's mouth closure event. Despite low recorded rainfall during the summer (Fig. 3), salinities (especially at the surface) at all stations were erratic and low (Fig. 4). For example, at the mouth (station 3), surface water salinities fell below 16 ppt on two summer sampling dates although no obvious rain events occurred during this time. Water DO remained within the 4-8 mg/l range at most stations over the course of the year, although bottom DO at station 2 declined during the February mouth closure to below 3 mg/l (a level considered stressful to aquatic organisms).

Lagoon Mouth Conditions

The Los Peñasquitos Lagoon mouth closed completely or partially several times during the 1995-96 season (Table 2). The first partial closure occurred during a neap tide in mid-October (Oct. 15) , when sand deposition at the mouth reduced ocean flows to a small channel 1.0 m wide and 0.1 m deep, with less than a 0.5 m tidal range (pers. obs., Lee Lagrange, Lagoon Monitor). The LPL Foundation widened and deepened the mouth from Dec. 4-6, 1995. A second partial closure, followed by natural tidal reopening, occurred in May 1996.

The lagoon mouth closed completely twice over the January-March quarter; first from January 18 - February 1, 1996, and again from February 11 - 20, 1996 (Table 2). A tidal berm of cobble and sand, produced by storms in November and December, caused a lip to form at the lagoon mouth which prevented full tidal exchange. As a result, water levels were noticeably higher and tidal exchange lower in December and early January. When the mouth closed fully in January, water levels continued to rise due to freshwater runoff, with flooding extending into the high marsh. The berm at the mouth burst naturally on February 1, 1996. The second closure in February was ended by earth movers that excavated and enlarged the channel.

A fish and invertebrate kill occurred in Los Peñasquitos Lagoon following the February closure event (Table 2). This was the first documented fish kill since 1990. In the early morning of February 1, the sand berm at the mouth breached naturally and a channel was scoured to the ocean. Water levels in the lagoon decreased substantially (0.6-1.0 vertical meters); waters were extremely stratified and secchi disk readings showed water clarity at less than 20 cm. A morning inspection revealed the onset of a fish/invertebrate kill. Dead and dying bubble snails (*Bulla gouldiana*), often an early indicator of low dissolved oxygen levels, littered the shoreline at the high-water mark. Many dead or dying fish were stranded in the dirt parking lot to the east of the railroad trestles, including the following species: diamond turbot (*Hypsopsetta guttulata*), California halibut (*Paralichthys californicus*), yellowfin goby (*Acanthogobius flavimanus*), shadow goby (*Quietula y cauda*), arrow goby (*Clevelandia ios*), bay pipefish (*Syngnathus leptorhynchus*), spotted sandbass (*Paralabrax maculatofasciatus*), bay blenny (*Hypsoblennius gentilis*) and topsmelt (*Atherinops affinis*).

In the region surrounding the railroad trestles, where the lagoon is deepest, many other organisms were concentrated in the shallows and surface waters. Large numbers of shore crabs (*Hemigrapsus oregonensis*, *Pachygrapsus crassipes*), shrimp (*Palaemon macrodactylus*), amphipods, and gobies lined the water's edge and burrowed in bank vegetation. At some places along the rip-rap near the trestles, goby densities exceeded $300 \cdot dm^{-2}$. Fishes (topsmelt, gobies, flatfish), stressed by the low dissolved oxygen levels, were observed bobbing to the surface, gulping air, then drifting back to the bottom. Flocks of piscivorous birds, including egrets, herons, terns, and gulls were observed feeding on these fish.

One week after tidal flushing was restored (February 8), a second observational survey of the area was conducted near the railroad trestles. Lagoon waters were much clearer, and the bottom could be seen to a depth of approximately 2 m. Dead and decaying animals from the previous week were on the bottom, including 10 large California halibut (>25 cm total length) and many adult Portunid and Cancer crabs (*Callinectes arcuatus* and *Cancer anthonyi*). Live species observed included oysters (*Crassostrea* sp.) mussels (*Mytilus* sp.) on the pilings, several gobies, schools of killifish, amphipods, and crab larvae.

Adaptive Water Quality Monitoring

Dataloggers were used six times this year to monitor lagoon water quality at station 2 during periods of partial or complete mouth closure. Their results are helpful in understanding the importance of tidal mixing to the lagoon. For example, when tidal mixing was completely cut-off during a 2-week period of mouth closure in January, bottom water salinity and temperatures remained relatively constant. DO levels were at levels considered stressful or toxic for aquatic organisms (< 3 mg/l) and fluctuated slightly over the course of the day (Fig. 5A). After the mouth opened on February 2, tidal mixing gradually resumed, increasing lagoon salinities, reducing temperatures, and raising DO levels almost immediately (Fig. 5B). These values reached equilibrium in 3-4 days, although the period to reach equilibrium likely varies with location within the lagoon, distance from the mouth, and tidal magnitude. During a period of partial tidal influence in late May, the datalogger showed that ocean waters inundated the lagoon only on the higher of two daily high tides

(Fig. 5C). The effect of this seawater influx was almost immediately reflected in station 2 water temperatures, which dropped in synchrony with high tide (Fig. 5C). Salinities showed no change and remained at ocean concentrations (33-35 ppt), although DO levels appeared to increase as tide levels increased. Changes in dissolved oxygen were probably more closely related to the daily light cycle, with oxygen levels rising during the day and declining at night.

Dissolved oxygen levels seem to be the major factor limiting the survival of aquatic organisms in lagoon channels (most cannot survive oxygen levels lower than 3.0 mg/l for extended periods) and may be used as a standard to approximate the "health" of lagoon waters. Several major physicochemical and hydrologic factors affect dissolved oxygen levels: temperature and salinity, nutrient loads, sediment loads, organic carbon levels, and tidal mixing. High temperatures and salinities reduce the solubility of oxygen in water. Elevated nutrient loads and temperatures enhance the growth of aquatic plants, macroalgae, and phytoplankton, all of which utilize oxygen during respiration at night. This can lead to extreme diel fluctuations in water oxygen levels, with lowest levels during the night and morning and highest levels during days and early evenings. When these plants senesce and die, bacteria that decompose them consume large amounts of oxygen. Suspended sediments provide additional substrate for bacterial growth and may enhance this effect. Thus, conditions that increase the likelihood of lagoon waters going anoxic and causing fish/invertebrate kills are as follows: high water temperatures and salinities, elevated nutrient inputs and sediment loads due to runoff from residential areas and/or construction projects, excessive decaying plant matter in the channels, and low mixing. Maintaining an open lagoon mouth can remedy many of these problems because it facilitates tidal flow between the ocean and lagoon. Tidal mixing enhances diffusion of gases in water, flushes excess nutrients and sediments from the lagoon, brings in oxygen-rich seawater, and can improve overall conditions in the channel waters.

Surface water salinities, measured as part of our biweekly water quality monitoring, were unusually low during the summer season despite drought conditions (Fig. 4) and suggested anthropogenic inputs into the system via irrigation runoff or off-season dam releases. Transects running from the mouth to the upper reaches of the lagoon showed that salinities were generally higher at the channel bottom in most locations, but especially at deeper sites. Salinities approximated full-strength seawater (33-35 ppt.) at the mouth. In the relatively shallow southwest (SW) portion, maximum channel depth did not exceed one meter and surface salinities declined precipitously (to below 10 ppt) as we moved up the channel (Fig. 6). In the northern portion, channels were considerably deeper and surface salinities remained much closer to ocean levels (Fig. 6). However, water salinities again declined in the upper channel reaches along the lagoon's eastern periphery, where freshwater from Carmel Valley entered from several small creeks (Fig. 6). In contrast, salinities in a small mid-marsh channel that reached toward the lagoon interior again increased as we moved up and away from sources of freshwater input. At the upper margin of both lower-salinity creeks the channels were choked with mats of the alga *Enteromorpha* sp., while *Typha* sp. was a prominent member of the bank vegetation community. Mosquitofish (*Gambusia affinis*), an exotic fish with broad salinity tolerance, and crayfish were also observed in these areas. Sediments were predominantly sand at the mouth, and became increasingly dominated by clays as we moved up the lagoon channels.

Freshwater flows into LPL were highest in Carrol Canyon (5.1 m^3/min, 8/96 ; 2.3 m^3/min, 9/96) and Los Peñasquitos Canyon (3.2 m^3/min, 8/96; 6.8 m^3/min, 9/96) drainages, and lowest in Carmel Valley (0.5 m^3/min, 8/96; 1.7 m^3/min, 9/96). The relative volume of these estimates is borne out by lagoon salinity patterns, which show that the lowest salinities are in the SW portion of the lagoon, where Carrol Canyon and Los

Penasquitos Creeks enter (Fig. 6). Nonetheless, flows from Carmel Valley are undoubtedly entering the lagoon and affecting the vegetation community. For example, other PERL biologists (Nordby 1990) estimated that 1.42 hectares of saltmarsh in this region were converted to brackish marsh due to freshwater intrusion from 1986 to 1989. Ongoing vegetation surveys, documented with photographs, confirm that this trend is continuing (Williams 1995).

Historic observations describe the salinity of LPL waters as slightly higher than ocean levels (33 ppt) during most months, even at the upper end of the lagoon (Carpelan 1961, Mudie et al. 1974). This has changed as more recent residential development has increased the amount of urban runoff draining into the lagoon. For example, as early as 1973, runoff was estimated at 1500 gal/day, and channel waters were diluted measurably (Mudie 1974). Salinity dilution of coastal lagoons in southern California and other seasonally arid regions has been increasingly identified as a problem that leads to establishment of exotic species and stress to native ecosystems (Zedler 1991). Among the native species likely to be displaced by exotic and upland species invasions into LPL's saltmarsh habitats are sensitive and threatened species, including the Belding's savannah sparrow (*Ammodramus sandwichensis beldingi*) and Coulter goldfield (*Lasthenia glabrata*).

Benthic Invertebrates.

Over 44 invertebrate taxa were found in core samples or observed in the field this year (Table 3). Core samples were numerically dominated by several taxa, including Capitellid and Spionid polychaetes, small gastropods (*Cylichnella culcitella* and *Assiminea californica*), and amphipods. Four amphipod spp. were collected in LPL this year; the two most abundant were *Corophium* sp. and *Grandidierella japonica*. In addition, two abundant and conspicuous crab species (*Callinectes arcuatus* and *Cancer anthonyi*, respectively), previously undocumented during our benthic invertebrate sampling, were observed during the February invertebrate kill (Table 2).

Seasonal invertebrate species richness and abundance trends were driven by gastropod and amphipod diversity and density, which varied by station (Table 3). Species richness was higher at all stations in June than January, while total density was higher in June at stations 1 and 2, and higher in January at stations 4 and 5 (Table 3). Declines associated with anoxic conditions during the mouth closure were not observed in the seasonal invertebrate samples. Although populations could have been boosted due to recolonization, June size classes of sessile species (e.g., jacknife clam,*Tagelus californianus*; n=7, mean length = 41 mm, range 15-58 mm) indicated that many individuals must have survived the February event. In 1994-5, we found different seasonal trends, when invertebrate densities were highest in June and species richness was greatest in December. Further analysis of historic data should be conducted.

Some noteworthy differences in the invertebrate assemblage were apparent across stations (Table 3). The deep channel at station 1 had a diverse assemblage of decapod crustaceans and gastropods, and relatively low total densities. In contrast, benthic samples from the shallow waters of station 2 were characterized by high densities of animals from several taxa, including polychaetes (*Capitella capitata*, *Polydora nuchalis*), gastropods (*Cylichnella culcitella*, *Assiminea californica*), and amphipods (*Corophium* sp., *Grandidierella japonica*). Cores from the sandy sediments of station 3 had the lowest densities and were least similar to any of the other stations**.** Six species were found exclusively at station 3, including sand dollars (*Dendraster* sp.), ghost shrimp (*Neotrypaea californiensis*), an unidentified isopod sp. and egg cockles (*Laevicardium* sp.). Station 4, which is located near the upper extent of tidal action in the southwest corner of the lagoon, consistently had the lowest species richness and was characterized by several low-salinity taxa, including *Argulus* sp., a copepod that parasitizes freshwater fish, and crayfish. Station 5, located in a small channel near the source of Carmel Valley freshwater inputs, had similar species composition as other stations (#2, #3) in the north section of the lagoon.

Exotic invertebrate species observed in lagoon waters include the oriental shrimp *Palaemon macrodactylus*, the amphipod *Grandidierella japonica*, and the Asian mussel *Musculista senhousei*. All three species were introduced from Southeast Asia to California in the 1950-70's, presumably via bilgewater transport (Ricketts et al. 1968, Smith and Carlton 1975, Carlton and Geller 1993) and are present in local marshes (Sweetwater Marsh in San Diego Bay, Boyer et al. 1996; Tijuana Estuary, Williams et al. 1995). *M. senhousei* taken from summer cores at stations 1, 2, and 5, was first documented in LPL in December 1991 at station 3; it has occurred with relative consistency in annual samples thereafter, although it is not extremely abundant. In soft sediments, *M. senhousei* forms dense mats which negatively affect recruitment and survival of native bivalves, but it also serves as a significant prey item for fishes, crabs, and birds (Crooks 1992). *G. japonica,* a non-native amphipod in the family Corophiidae, was identified to species level in our samples this year (1996); previously amphipod taxonomy was not conducted. *G. japonica* was very abundant at station 2 in both seasons, ranging in densities from 340-1466 individuals $\cdot$ m^{-2}. It is now common at least as far north as Everett Harbor, Washington and seems to be associated with soft substrates in brackish or euryhaline water (pers. comment, Jeff Cordell, U. Washington). *G. japonica* is also an important prey item in the Tijuana Estuary fish food-web (Williams and Zedler, in prep.). Quantitative estimates of *P. macrodactylus* were not made in marsh channels, although this shrimp species occurred in several seine samples made at stations 1 and 2 (Table 3). *P. macrodactylus* is now common along most of the Pacific coast, where its spread has been accelerated by its use as bait. While little data exists on its competitive interactions, Ricketts et al. (1968) observed it eclipsing native *Crangon* spp. in numerical abundance; it also serves as an important food resource for fish (Ricketts et al. 1968).

<u>Fish</u>

A total of 1829 fishes, representing 13 species from 10 families, were collected from five stations during the combined January and June 1996 sampling periods (Table 4). Two species, the shadow goby (*Quietula y-cauda*) and topsmelt (*Atherinops affinis*) numerically dominated seine catches in the lagoon, together comprising almost 89% of the total fish catch. The next most abundant species were California killifish (*Fundulus parvipinnis*; 3.6%) and arrow gobies (*Clevelandia ios*; 2.4%), with the remaining 9 species representing less than 6% of the total catch (Table 4). The four most abundant species also had the highest percent frequency of occurrence (% F.O.) in samples. Topsmelt occurred in every sample (100% F.O.), followed next by killifish (70%), shadow gobies (60%), and arrow gobies (50%). While not abundant, juvenile diamond turbot (*Hypsopsetta guttulata*) and California halibut (*Paralichthys californicus*) were collected at four stations located throughout the lagoon (50% FO), showing that the shallow water habitats of LPL are used by these recreationally and commercially important species year-round. Striped mullet (*Mugil cephalus*) were collected in only one sample this year but were frequently observed throughout the lagoon; similarly, spotted sandbass, bay blenny, and yellowfin goby were observed during the fish-kill event, but did not occur in any seine samples. Results suggest that these species are not adequately sampled with the seine or that rocky, structurally complex habitats are not represented in the lagoon sampling regime.

As in most previous years, fish abundance and species diversity levels in 1995-96 showed a distinctly seasonal pattern, with higher values measured in summer than winter periods (Fig. 7, Table 4). Mean average density and species richness, respectively, was 4.4 fish/m^2 and 8 spp. in January, increasing to 6.4 fish/m^2 and 13 spp. in June. Deepbody anchovy, mosquitofish, longjaw mudsuckers, and cheekspot gobies were observed exclusively in summer catches.

Station 1 had the highest fish species diversity of all stations in both January (7 spp.) and June (9 spp.) (Table 4). Catches at station 1, the deepest of the monitoring stations (> 1.25 m), were numerically dominated in both seasons by the shadow goby, a species that prefers deep and densely vegetated benthic habitats (Brothers 1975). Species diversity also increased considerably from January (7 spp.) to June (9 spp.) at station 3. Catches were numerically dominated by topsmelt and included diamond turbot and California halibut in both seasons at this station, which is located in sandy sediments nearest the mouth. The greatest seasonal difference in species diversity was at station 4, which increased from 2 spp in January to 8 spp. in June. Topsmelt dominated catches in either season at station 4. Stations 4 and 5 were first sampled this year to incorporate upper lagoon channels habitats which experience greater freshwater influence; they were the only stations in which mosquitofish were found.

As previously noted, mosquitofish (in the seine surveys) and yellowfin gobies (during the fish kill) were two nonindigenous fish species observed in the lagoon this year. The yellowfin goby, which is native to southeast Asia and was introduced to California through bilgewater transport, may have entered LPL either through introductions by fishermen using them as bait, or via ocean immigration from other nearby sources (e.g., San Diego Bay). Only large adults were observed, suggesting that perhaps reproduction is not occurring in the lagoon for this species. The mosquitofish is native to the southern Midwest and was introduced to brackish and freshwater habitats in the region as part of mosquito abatement programs (Swift et al. 1993). Both species possess broad physiological tolerances, opportunistic feeding behavior, high fecundity, and rapid growth and maturation (Miyazaki 1940, Middleton 1982, Wang et al. 1986). As such, they continue to represent a threat, perhaps already realized, to native marsh communities by potentially altering trophic and spatial patterns of native fish resource use (Taylor et al. 1984).

Snorkel transects were swum on a slowly rising tide on June 21, 1996 to make a qualitative assessment of estuary use by large and highly mobile fish. The lagoon was divided into three major regions based on general habitat structural characteristics: the mouth, the railroad bridge, and the vegetated banks below the bridge. The mouth region was characterized by cold, ocean water and a shallow sandy bottom; the vegetated bank region had warmer, more turbid water, and a sandy mud bottom littered with dead and decaying vegetation (*Macrocystis*), live algae (*Enteromorpha*), beds of *Ruppia*, and diatom mats; and the railroad bridge and rock riprap area had deep (>3 m), turbid, and vertically stratified waters. Visibility was relatively poor (<1.0 m) at all locations and only 5 fish species were observed in the course of our snorkel survey. Staghorn sculpins and both flatfish species (halibut and turbot) were abundant in the sandy sediments near the lagoon mouth and vegetated banks, while topsmelt and opaleye (*Girella nigricans*) were observed in the deeper waters around the railroad bridge pilings. Besides fishes, we also observed egg cockles (*Laevicardium*), many *Navinax* sp., *Bulla* sp., *Hemigrapsus nudus*, and large numbers of *Cerithidia californica*. *Pachygrapsus crassipes* were numerous subtidally, where they were observed feeding on epiphytic algae. Hard structures on the channel bottoms and edges (bridge pilings and rocks) were covered with oysters (*Ostrea lurida* or *Crassostrea gigas*), jingle shells (*Pododesmus* sp.), and mussels (*Modiolus* sp., *Mytilus* sp.).

Vegetation

Vegetation transects throughout the lagoon were established for various reasons; the rationale for each transect's establishment, a brief description, and the change in mean percent (%) cover of dominant vegetation types is listed below. Refer to Table 5 for a listing of plant species, common names, and species codes, and to Table 6 for recent mean percent cover values.

Transect 1 is located in the northwestern portion of the lagoon, west of the railroad and near the north beach parking lot (Fig. 2). It is composed of two parallel 50-m transects running approximately east-west. These transects were established to document the invasion of a pickleweed-dominated marsh by upland weeds. Dominant vegetation types (mean % cover) when the transect was established in 1991 were *Cressa truxillensis* (24.4%), *Distichlis spicata* (22.8%), *Salicornia virginica* (21.8%),*Carpobrotus edulis* (15.9%), and *Ambrosia* sp. (4.6%) (Table 6). Some trends evident this year (1996) are the continued decline of C. *truxillensis* (3.5%) and the expansion of *D. spicata* (43.9%). *C. edulis* cover declined drastically (5%) as a result of manual removal efforts begun this year.

Transect 2 is similar to transect 1, located in the northwestern part of the lagoon near the north beach parking lot, but to the east of the railroad and under some power lines. It consists of two parallel 50-m transects running north-south. Dominant vegetation types at the time of transect establishment in 1991 were *S. virginica* (30.9%), *Jaumea carnosa* (45.5%), *Cuscuta salina* (45.2%), *D. spicata* (22.8%), *Frankenia salina* (19.2), and *C. truxillensis* (14.3%). Few to no exotics were present. General changes that have occurred since 1991 include an increase in the coverage of *D. spicata* (58.2%) and *C. salina* (60.9%), and a decline in *F. salina* (3.3%) coverage. Exotic and upland species were still not present.

Transect 3 is located in the western lagoon, just east of N. Torrey Pines Road. This transect is 100-m long, with 22 quadrats. It was established to document whether *S. virginica* and *F. salina* dominance were correlated with periods of tidal exclusion and changes in soil salinity. There were three codominant vegetation types in 1991: *S. virginica* (55.7%), *D. spicata* (19.9%), and *F. salina* (28.1%). No exotics were observed at this site. Few changes were observed this year, except that *F. salina* (53.2%) has increased in cover.

Transect 4 is also located in western portion of LPL, east of transect 3. It is 80-m long, composed of 17 quadrats, and was established for the same reasons as transect 3. Two species, *S. virginica* and *F. salina*, co-occur here, and both have increased through time as total vegetation cover has increased (from 55.5% in 1991 to 92.4% presently). In 1991 *S. virginica* cover was 38% while *F. salina* was 26.5%. In 1996 *S. virginica* cover increased to 92.4% and *F. salina* decreased to 9.1%. No exotics have ever been recorded at this location. It should be noted that the stake at the southern end of the transect could not be found and may have been removed. A replacement was put in its approximate location, although slight differences may have resulted in skewed cover class estimates.

Transect 5 is located in the southeastern portion of lagoon, close to the upland transition zone. This transect is 50-m long with 11 transects. Dominant species in 1991 were *F. salina* (43.5%), *S. virginica* (39.3%), and *Monanthochloe littoralis* (33.5%). Since 1991 there has been a consistent annual increase in *S. virginica* cover (84% in 1996) while *F. salina* (19%), *M. littoralis* (10.2%) and *C. truxillensis* (0.4%) have decreased. No exotics were ever recorded on this transect.

Transects 9, 10, and 11 are all located in the northeast corner of the lagoon, near the Sorrento Valley and Carmel Valley Road intersection. These sites were set up to monitor the expansion of exotic species near increased Carmel Valley freshwater inflows. Recent construction (1994-96) associated with Sorrento Valley Road modification and sewage line repairs and rerouting has increased disturbance and local patterns of vegetation change.

Transect 9 is 40-m long and comprises 9 quadrats. Dominant species in 1991 were *S. virginica* (81%) and *Typha* sp. (19.6%). There is little current change in the percent cover of dominants, but *Scirpus robustus* has increased from 0% in 1991 to 11% cover in 1996.

Transect 10 is 30-m long and comprises 7 quadrats. The dominant species in 1991 were *S. virginica* (81.1%) and *Typha* (2.3%). Since then, *S. virginica* mean cover has declined (61.6%), while *Typha* cover has increased to 44%. *A. patula*, *Pluchea odorata*, and *Salix* sp. are now established in the area and have cover values of 25%, 11%, and 10% respectively.

Transect 11 is 60-m long and comprises 13 quadrats. It runs west-east, starting in a mid-marsh plain originally dominated by *S. virginica* and *F. salina* (35.6% and 63.6% mean total transect cover, respectively). Percent cover estimates show few exotic and upland species were present in 1991 (Table 6). Presently, however, *Typha* (75%) is the dominant species along most of this transect, while *Conyza canadensis* (8.9%), *P. odorata* (7.7%), *Polypogon monspeliensis* (6.6%), *Salix* sp. (9.5%), and *Cortaderia selloana* (6.6%) now join *S. virginica* (25.1%) as major members of the plant community. *F. salina* cover (13.8%) has declined substantially since initial transect establishment.

Transect 12 runs the length of the eastern marsh, using SDG&E utility lines as a guide. It is the longest of the vegetation transects (510 m) and has 107 quadrats. It was originally established (1991) to provide a rough estimate of exotic invasion within the middle of the marsh. Dominant vegetation types at establishment were *S. virginica* (62.5%) and *F. salina* (14.6%). Also present were non-saltmarsh species, including *Rumex crispus*, *A. triangularis*, *C. canadensis*, *Xanthium strumarium*, and annual grasses. Few obvious changes have been observed in dominants since 1991; however, *X. strumarium* has increased from 0.3% to 5.8%, *P. monspeliensis* from 3% to 7%, and *C. canadensis* from 3% to 7%.

Mean (± SD) soil salinities from each vegetation transect were graphed versus previous years' data (Fig. 8). Trends in soil salinities were unclear, although three transects (#1, 10, and 11) showed a decrease in salinity (Fig. 8). All other transects showed an increase in salinity since 1995 that was perhaps related to low rainfall over the 1995-6 winter rainy season (Fig. 2).

We conducted preliminary *Lasthenia* surveys using GPS on several dates in April 1996, before finally conducting our annual population census on April 16, 1996. GPS allowed us to map the lagoon-wide distribution of *Lasthenia* over three dates (Fig. 9). Plants were more widespread in the lagoon than previous surveys may have indicated, and could be found in four types of habitat: 1) the margins of salt pannes, 2) the margins of vegetated, wet depressions, 3) higher elevation grass and *Salicornia subterminalis* "meadows", and 4) along disturbed roadside edges. In our census, *Lasthenia* occurred within five of the eight pannes which were monitored, and stem densities along panne margins were generally higher than in previous years (Table 7). The multiple observation dates allowed us to assess our current census methods. Germination and development were not synchronous and seemed to be related to local moisture conditions that varied throughout the area and through time. We also hypothesize that *Lasthenia* habitat may be further restricted by soil salinity and competition from other species. Current survey methods should be modified to improve the accuracy and information gained from our monitoring effort. While current census methods are quick and provide a relative measure of plant success, surveys are done at only one fixed time per year and timing is not adapted to marsh conditions (rainfall, flooding, inundation period, temperature) that might affect *Lasthenia* germination. Additionally, the number of transects varies from year to year, methods are hard to replicate by persons unfamiliar with the technique, the survey incorporates only a small portion of the *Lasthenia* population at LPL (pannes in the southern portion of the lagoon), and is inadequate at assessing both the inter- and intra-annual variation in *Lasthenia* population dynamics.

Anthropogenic Effects and Future Impacts

The lagoon continues to experience both the direct and indirects effects of anthropogenic activity upstream and on its periphery. Directs effects, which result in the immediate loss of habitat due to construction or filling, include the construction of wastewater pump station #65, the Sorrento Valley Road straightening and realignment, and Route 56 - I 5 onramp construction. All of these projects have resulted in further loss of native saltmarsh and transitional coastal sage scrub habitats in this area. The current status of mitigation for these sites is unclear.

Indirect effects, while less obvious, also represent serious threats to the long-term health of LPL. Freshwater inflows associated with both point and non-point source runoff continue to enter the lagoon, causing changes in the historic salinity regime of lagoon waters, and likely resulting in plant invasions to local saltmarsh vegetation. The construction of a large housing development and office park on the bluffs to the east of LPL should cause concern for an increase in sediment loads entering the lagoon during times of high runoff.

Several proposed projects may also impact the lagoon and deserve the immediate attention of the LPL Foundation, including the bridge replacement and road widening near the mouth and a bike trail along the railroad line. Finally, raw sewage spills and sediment control violations continue to occur in the lagoon; it is likely many more go unreported and undocumented.

RECOMMENDATIONS FOR 1996-97 LPL MONITORING AND MANAGEMENT

1. Spring cobble removal

The Foundation should continue to manage the lagoon by maintaining an open mouth for most of this season. This is usually achieved by removing rock cobble from the mouth of the lagoon in the spring, between March 1 and April 15 (i.e. after the last winter storm but before too much sand is deposition occurs) (Boland 1993).

2. Freshwater flows

Goals for reducing and controlling freshwater runoff should be established as part of a conclusive ecosystem management plan for the lagoon. We recommend the LPL Foundation Board pursue the issue of off-season freshwater flows immediately, specifically seeking to identify the source of these flows and searching for other possible solutions to their abatement. It is important to recognize that LPL is not an isolated lagoon but part of a larger coastal watershed [ecosystem]. Thus, it is affected by actions far outside its immediate boundaries, and should be managed as such. In order to identify freshwater sources, we recommend adding the following attributes to the monitoring program:

• Flow rates. Flow rates of the three major tributaries (Carmel Creek, Carrol Canyon, and Los Peñasquitos Canyon Creek) should be monitored on a regular (monthly) basis. Flow gauges should be reestablished within each of these drainages.

• Nutrient and sediment inputs. The composition of runoff from upstream sources is unknown and stream inflows may contribute potentially harmful pollutants (pesticides/herbicides, nutrients, heavy metals, sediments, and coliform bacteria) to lagoon waters. Information on nutrient inputs, sediment loads, and other pollutants is needed now to track water quality changes. The Regional Water Quality Control Board should be included in this process.

• Piezometers. Long-term groundwater levels and salinities should be monitored with piezometers at permanent locations throughout the lagoon, especially where plant invasions into the native saltmarsh are occurring.

3. Vegetation

As noted in the 1996-97 monitoring contract, GPS-assisted mapping studies of the lagoon will be used in concert with traditional vegetation monitoring techniques to identify and document areas of exotic invasion and assist in eradication efforts. The relative success and time costs associated with the new GPS methods should be evaluated by the lagoon advisory committee at the completion of the 1996-97 contract year.

We recommend that an adaptable *Lasthenia* monitoring plan be adopted that is consistent from year to year and that accounts for the temporal and spatial variation in patches during a given year. Additionally, we think effort should be directed at investigating the life history of this species; this might best be accomplished within the scope of a graduate dissertation/thesis. Specifically, we recommend:

a. The locations to be monitored (currently "pannes") should be expanded to include the entire range of habitats where *Lasthenia* is found within LPL.

b. Continue to utilize GPS to map the entire LPL *Lasthenia* population. This would allow us to track individual patches through time and assess longer-term patch stability.

c. More than one survey should be taken during a given year to get both early- and late-season patches, and both early- and late-season plants in a given patch. It is likely that these dates will vary from year to year depending upon annual rainfall and temperature patterns.

d. Conduct an intensive monitoring study of *Lasthenia* over the entire growing season to assess reproductive output, seed bank, and controls on germination and establishment. This would facilitate predicting the potential success of *Lasthenia* populations elsewhere.

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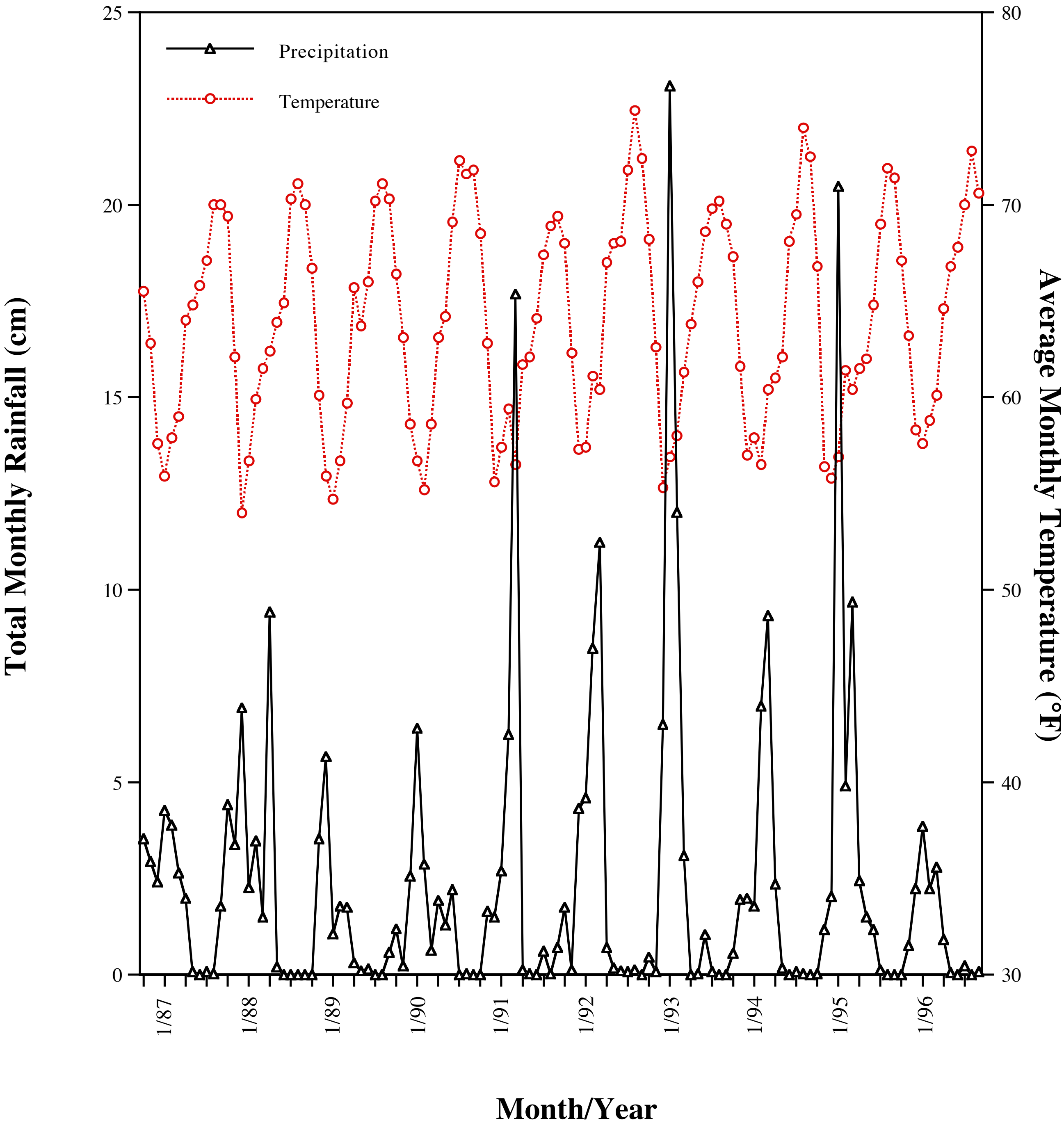


Figure 3. Monthly total rainfall (cm) and average temperature (°F) for ten years (10/86-9/96), including the 1995-96 study period. Data collected from National Weather Station at Lindbergh Field, San Diego, CA.

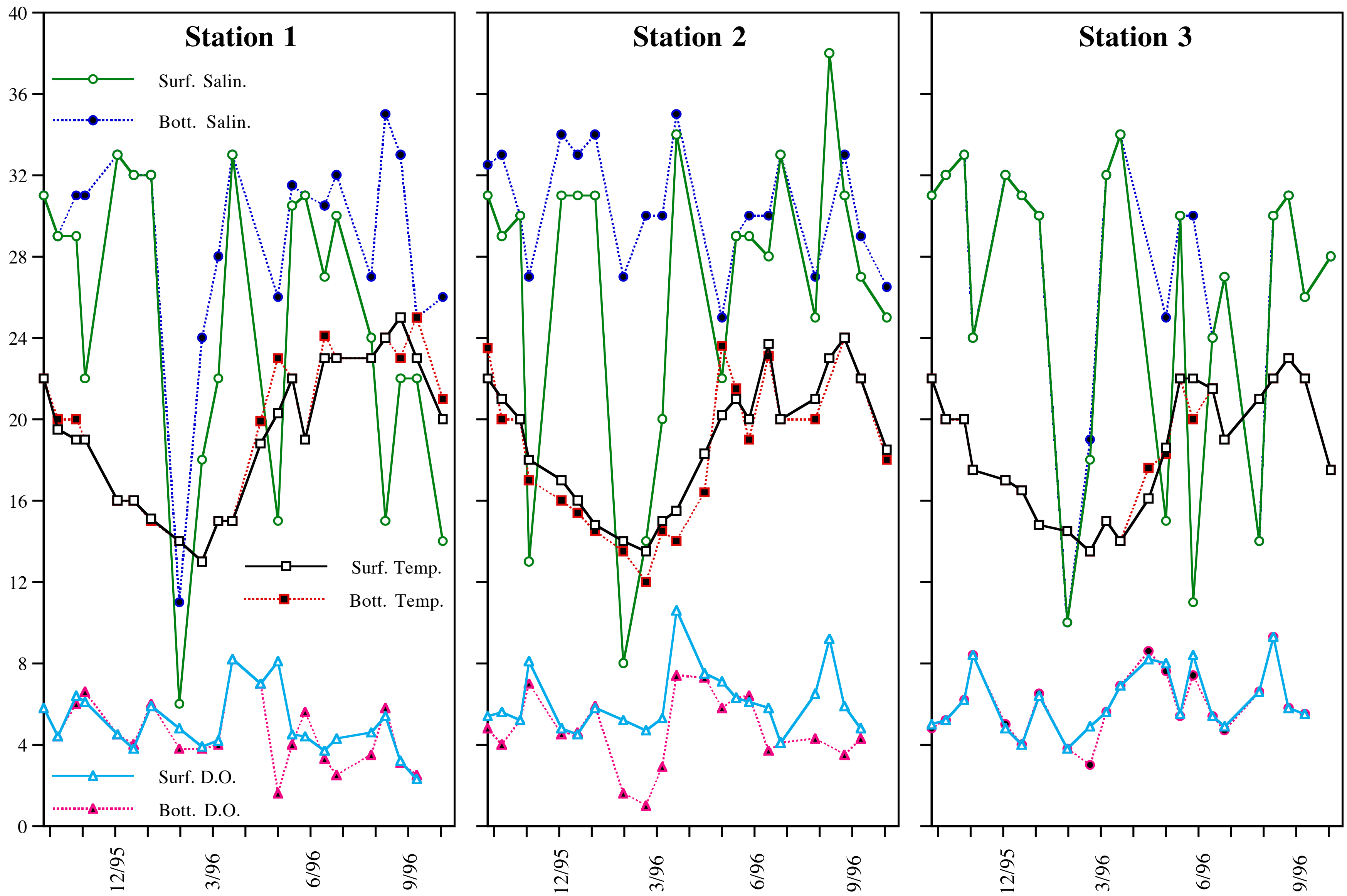
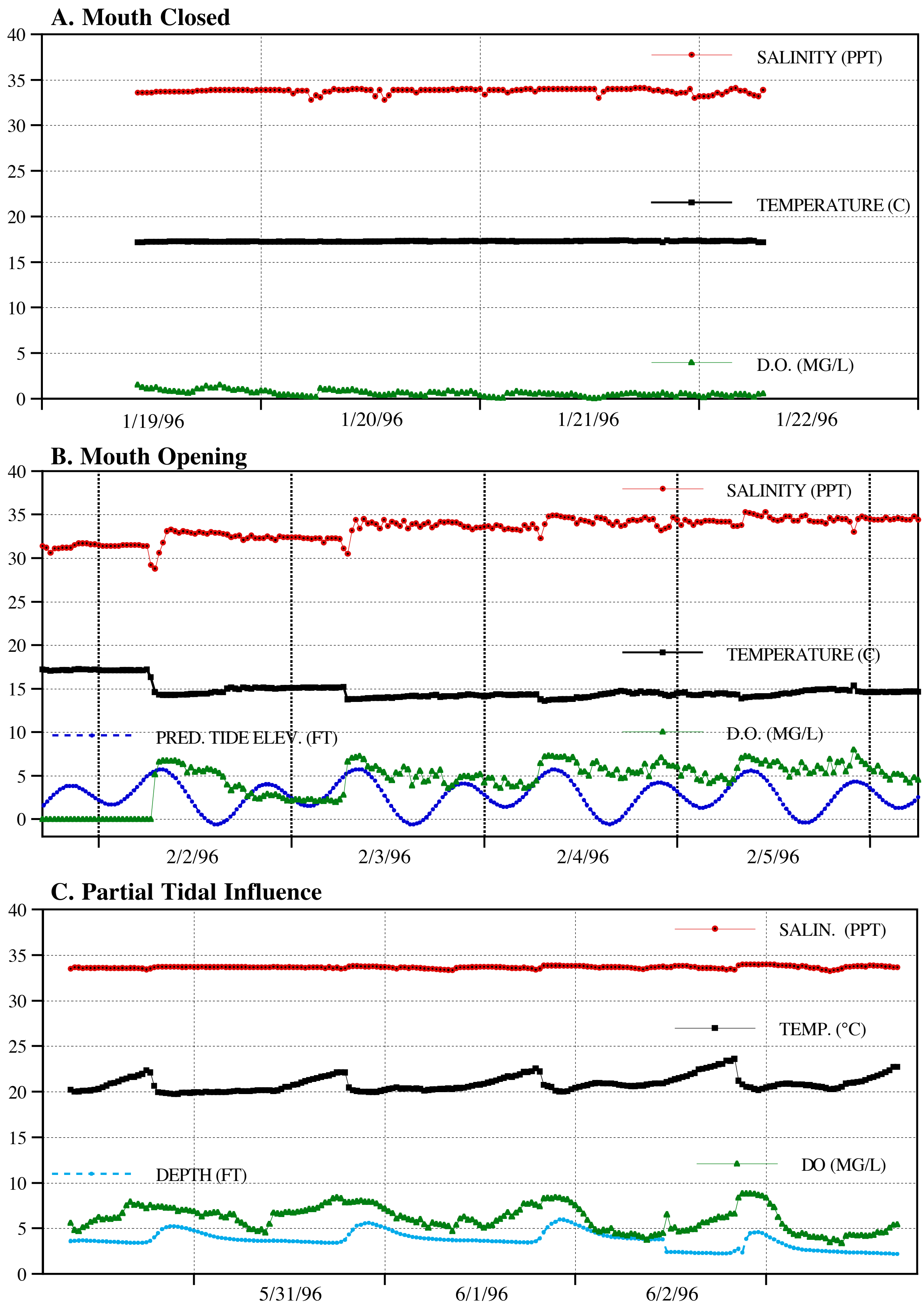


Figure 4. Surface and bottom water salinity (ppt), temperature (°C), and dissolved oxygen (D.O.; mg/l) at each of three Los Peñasquitos Lagoon sampling stations, September 24, 1995 - September 27, 1996.



DATE AND TIME

Figure 5. LPL water quality data, collected by datalogger at station 2 over 30 minute intervals: 1/19/96-1/22/96, 2/2/96-2/6/96, and 5/30/95-6/3/96.