Department of Biology
San Jose State University
29 January 1987

Mark Capelli
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South Central Coast Area
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Dear Mark:

Enclosed is a copy of my manuscript on lagoons for the "Managing Inflows" conference. It briefly summarizes some of the habitat and water quality effects of freshwater inflow to lagoons. In our studies we found that spring and early summer inflows were very important in filling the lagoon behind the sandbar (providing adequate habitat depth) and converting the lagoon to freshwater (and eliminating salinity, temperature, and potential dissolved oxygen stratification). We found summer breaching of sandbars to be especially damaging because of water quality (temperature and dissolved oxygen) effects, as well as the loss of depth.

I have read the follow-up report on the steelhead of Arroyo de la Cruz Creek, prepared by Jones and Stokes, and have the following comments:

1. That both years of study (1981 and 1985) were relatively dry is a handicap in assessing conditions, since much of the upstream habitat was dry or shallow in both years and late springtime passage to the lagoon was probably limited in both years.
2. The upstream electroshock sampling found primarily young of year steelhead; however, the deeper pools that were snorkeled in July appeared to contain numerous yearling fish. The spot sampling program used does not really give a feel for how common the deep pool habitat was, and thus how abundant yearling steelhead really were in the upstream areas. In my studies of small streams in Santa Cruz County most of the yearling fish were in deeper pools with good escape cover. The shallow riffles, which are easiest to sample with electroshocker, normally had few yearling fish.
3. The deep water of the lagoon (or the pools of the gorge) is a difficult habitat to sample with electroshocker. I'm not sure how they managed to use a backpack shocker with a mean depth of 3.5' (Table 1). Their snorkel results, however, appear to confirm the sample as representative of sizes of fish in the lagoon.
4. The aging of fish in the lagoon by length-frequency may be seriously in error. In the lagoons that we have studied the conditions for growth can be outstanding, if high water temperatures or oxygen/salinity stratification do not occur. Young-of-the-year fish in Pescadero Creek lagoon in 1985 and 1986 grew rapidly and continuously all summer; by November they were only slightly smaller than lagoon yearlings (see attached 1985 data) and about 50% longer than the average stream yearling!

We have concluded that our lagoons are the most valuable rearing habitat in the watersheds. The temperatures for the lagoon in Table 3 are a small sample, but appear to indicate good conditions. If scales were taken, they should be checked to determine the true age structure of the lagoon fish. (The scales may present some problems in reading--we found false annuli in many known-age fish.)

5. The report (page 16) emphasizes the good water quality (low temperature) in the perennial reach in October, but the data in Table 3 show afternoon July water temperatures of 74-76 degrees. It appears that there is a temperature problem in dry years, which have little streamflow.

Taking the above comments and my experiences with stream and lagoon habitat into consideration, I would suggest the following:

A. The upstream reaches do offer some habitat for yearling steelhead, but it is probably quite restricted during years of low streamflow and shallow pools. In wetter years quality and quantity of yearling habitat probably expand substantially.

B. The lagoon probably provides good rearing habitat for young-of-the-year and older steelhead. Wetter years probably provide for a deeper lagoon and the more persistent streamflows in wetter years probably allow more young-of-the-year to reach the lagoon from habitats upstream.

C. Groundwater pumping in the alluvial channel early in the year would reduce the inflow of freshwater to the lagoon, slowing its filling behind the sandbar and also slowing the conversion to freshwater. Pumping before surface and groundwater flow to the lagoon have naturally ceased would reduce habitat quality in the lagoon.

D. Pumping in the channel which results in earlier elimination of surface flows to the lagoon may reduce numbers of young-of-the-year steelhead able to move to the lagoon and to utilize it for rearing. In wet years, when the sandbar forms late, most of the fish using the lagoon for rearing may be young-of-the-year fish. In Pescadero Creek lagoon in 1986 8000-12000 steelhead used the lagoon, and most were young-of-the-year. In Waddell Creek lagoon in 1986 8000-14000 fish used the lagoon, and only about 2000 were yearlings.

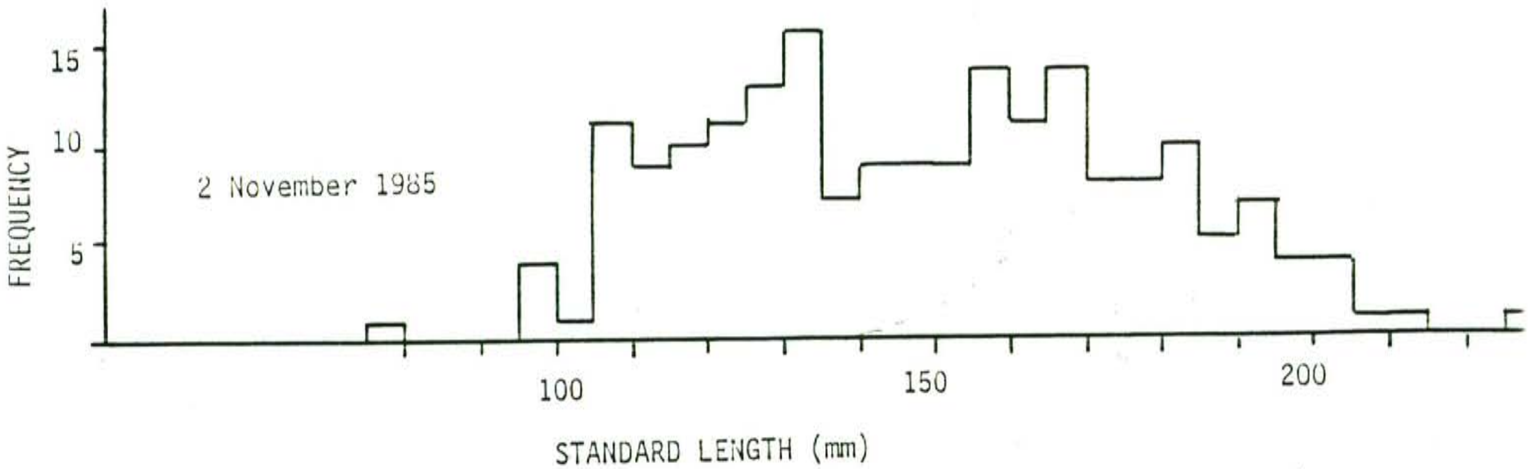
Assessing impacts on lagoons is still rather difficult, because very few detailed studies have been done and because year-to-year and site to site differences appear to be rather large.

Sincerely

Jerry J. Smith

Jerry J. Smith, Ph.D.

cc: Jones and Stokes Associates, Inc.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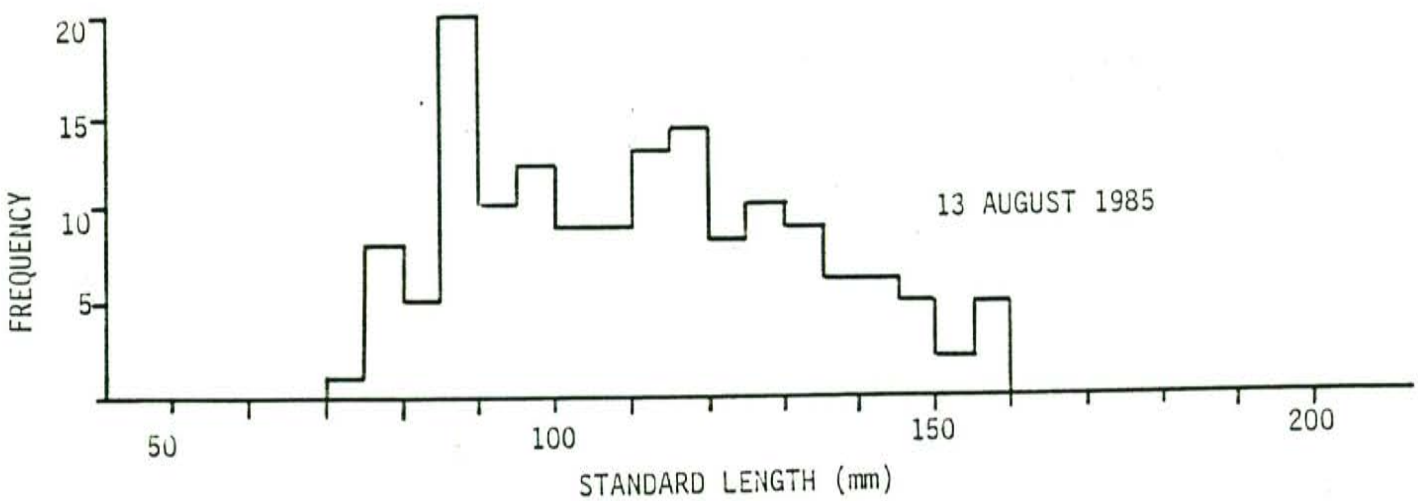
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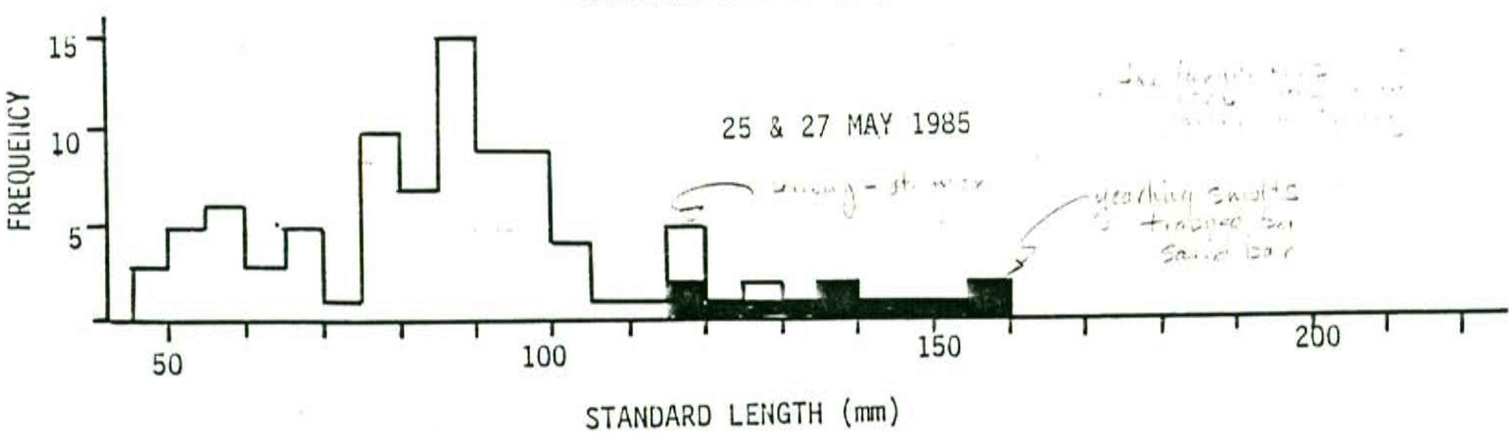
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Effects of Inflows on Water Quality and Habitat Conditions in Small Central California Estuary/Lagoon Systems

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Introduction

The annual summer drought in California results in sharp declines in streamflows in coastal streams. For smaller streams, declining streamflow and summer beach development allow development of a sandbar which dams the stream mouth to produce a lagoon. Despite recent interest in wetlands and estuaries, relatively few studies have been done on lagoons, although they were long ago shown to be important for steelhead (Salmo gairdneri) and salmon (Oncoryhnchus kisutch) (Shapovalov and Taft, 1954). Ignorance has not prevented lagoons from being actively managed by diversion of inflow waters for agricultural and municipal uses, diking of surrounding land for agricultural and flood control purposes, and artificial breaching of the sandbar for recreational access, and flood, odor, and insect control. We summarize results of a study undertaken for the California Department of Parks and Recreation to determine habitat dynamics and fish utilization in four small coastal lagoons.

Study Areas and Methods

Although our primary management interest was in Pescadero

Creek lagoon in San Mateo County, two smaller San Mateo County and one Santa Cruz County estuary/lagoon systems were also investigated. Pescadero lagoon receives the waters of Pescadero and Butano creeks on a broad lowland; the summer lagoon can innundate over 300 acres of wetlands, including partially leveed former farmlands, within Pescadero State Preserve. San Gregorio Creek lagoon primarily occupies a large incised channel; high lagoon water levels spread over the sandy beach area, but upstream they seldom flood much land outside of the main river channel. Waddell Creek lagoon generally has an even smaller embayment, and is primarily a narrow, drowned stream channel. Pomponio Creek lagoon is at the mouth of a very small stream with negligible summer flow; the embayment behind the summer sand bar usually contains mostly saline water from wave overtopping of the bar.

Temperature, salinity, and dissolved oxygen profiles were determined approximately monthly at an average of 16 sites in Pescadero Creek estuary/lagoon in spring, summer, and fall of 1985 and 1986. Fish populations in Pescadero were sampled by beach seine six times each in 1985 and 1986 to determine species, ages and size classes present. In Pomponio, San Gregorio, and Waddell creek lagoons temperature, salinity, and oxygen profiles were determined and fish populations sampled three times in 1985 and four times in 1986. Invertebrate populations at seven sites in Pescadero lagoon were sampled with dredge, sled, and plankton net six times in 1986.

Results

Water Quality and Habitat Conditions

Habitat conditions and water quality in the lagoons were a result of interaction of a variety of factors, including shape and size of the stream channel, timing of bar formation, and flow-related effects upon lagoon depth, salinities, temperatures, and dissolved oxygen. Flow-related effects are summarized below.

Bar Formation. High energy winter storm waves erode beach sand and remove the sandbar, and high stream runoff can widen and deepen the mouth of the lagoon. In 1985 storms were weak and few and much of the beach near all four streams remained intact. Spring and summer low-energy waves rebuilt the beach and sand bars early; at Pecadero Creek the stream mouth had been blocked by a sandbar by the first of May. In February of 1986 intense storms removed much of the sand from the beaches at all four streams. The beach at Pescadero Creek was gradually rebuilt and the sandbar was not fully formed until mid July. Because of the estuary's large size, tidal action on the sand-depleted beach was sufficient to keep the mouth open long after streamflow had been sharply reduced by summer drought and water diversions. At San Gregorio Creek the winter storms removed much of the beach, but also shifted the stream mouth to the north. Since bar formation usually starts at the north end of the beach, the sandbar at San Gregorio actually closed off earlier in 1986 than in 1985.

Once formed the sandbars persist until eroded by winter storms or until they are artificially breached. Artificial breaches at Pescadero Creek in October of 1985 and 1986 (Figures 1A and 1B) and at Waddell and San Gregorio creeks in the summer of 1986 were quickly plugged by wave-deposited sand.

Lagoon Depth. Although the four lagoons were originally in excess of 5 m deep, those conditions reflected the drowning of river mouths cut at lower ocean levels (during the ice ages). Recent watershed erosion has filled the lagoon basins, so that now all four are less than 1 m deep when open to full tidal action. Most of the depth of the summer lagoon is the result of ponding of streamflow and tidal overwash behind the sandbar. In 1985 streamflow was still relatively strong when the early sandbar formed at Pescadero Creek; the lagoon rapidly filled in May (Figure 1A). In 1986 streamflow was relatively low by the time the sandbar formed in July, and the lagoon filled much more slowly. September rain and reduced agricultural diversions pushed the lagoon level up again in September and October (Figure 1B). At San Gregorio Creek early sandbar formation in 1986 resulted in extremely high lagoon water levels, before the sandbar was artificially breached to provide beach access. Pomponio Creek seldom has significant flow by the time the sandbar forms in summer, and the lagoon contains mostly sandbar overwash . Its depth remains less than 1 m until fall rains provide some freshwater input to the lagoon.

Salinity. After bar formation the heavier salt water layer in the lagoon gradually is lost by seepage through the bar and by mixing and dilution with the freshwater inflow. In 1985 the freshwater inflow quickly converted Pescadero Creek lagoon into a freshwater system for the summer (Figure 1C). In 1986 streamflows were low prior to bar formation, resulting in more saltwater in the lagoon at the time of bar formation and much slower conversion to a freshwater lagoon (Figure 1D). Most of the lagoon, including the narrower upper arms, where wind mixing is reduced, had saltwater lenses on the bottom for the entire summer. San Gregorio and Waddell creek lagoons coverted to freshwater systems in 1985, but Pomponio Creek lagoon remained saline in 1985 and 1986 because of lack of freshwater inflow in summer. Artificial breaching of the sandbars at Pescadero Creek lagoon in October 1985 and 1986 and at Waddell and San Gregorio creek lagoons in summer 1986 restored salinity stratification.

Temperature. Stratification by salinity also resulted in temperature stratification in the lagoons. In 1985 in Pescadero Creek lagoon the saline bottom waters in May did not mix with those above and acted as a solar collector. Rapid conversion to freshwater resulted in thorough temperature mixing in the lagoon for most of the summer (Figure 2A). In 1986, however, Pescadero showed a variety of summer temperature profiles. Prior to sandbar closure the turbid water was warmer at the surface, due to solar warming at the surface and tidal cooling of the bottom. After sandbar closure the saline bottom waters acted as a solar collector; bottom waters were warmest and the mean water column temperature was much higher than in 1985 (Figure 2B). Artificial sandbar breaching at Waddell and San Gregorio lagoons in 1986 resulted in salinity and temperature stratification and very warm water temperatures for most of the summer. In Pomponio Creek lagoon, which was both saline and shallow because of a lack of freshwater inflow, summer water temperatures in 1986 averaged greater than 27 degrees C and at some depths exceeded 35 degrees.

Dissolved Oxygen. Salinity and Temperature stratification often resulted in pronounced dissolved oxygen stratification in the lagoons. After sandbar formation deeper bottom waters usually became anoxic because of a lack of mixing; this condition usually persisted until freshwater inflow and wind mixing broke up the salinity stratification. When algae was present on the bottom, extreme diurnal dissolved oxygen swings often occurred, with supersaturated conditions in late afternoon due to photosynthesis and anoxia by morning due to algal respiration (Figure 2C).

Artificial breaching of the sandbars at Pescadero Creek lagoon in 1985 and 1986 and Waddell and San Gregorio creek lagoons in 1986 resulted in a return of stratification and anoxia of bottom waters. Sandbar breaching at Waddell Creek in 1986 also allowed tides to bring in piles of kelp, which decomposed and used up most of the dissolved oxygen in the lagoon (Figure 2D). Although tidal inflow at high tide partially restored dissolved oxygen levels, the only oxygenated refuge for the fish present at low tide was the 10 - 20 cm of freshwater inflow at the surface of the lagoon.

Toxic Inflows. In May 1986 at Pescadero Creek lagoon pesticides in runoff water entered the Butano Creek arm as the tide was ebbing. The pesticide was pulled down the Butano Creek arm of the lagoon and eliminated all fish and invertebrates in the arm. Freshwater flow down Pescadero Creek and tidal mixing appeared to have diluted the pesticide and no mortality was observed in the main body of the lagoon. The stratified estuary may also have kept the pesticide suspended and away from benthic invertebrates. The incident would have gone unnoticed if water quality sampling had not been taking place at exactly the time and place of the kill; hungry birds rapidly cleaned up most of the dead and dying fish and invertebrates.

Fishes

Twenty-one species of fish were collected from the four estuary/lagoon systems in 1985 and 1986 (Table 1). The number of species was greatest for Pescadero Creek lagoon and decreased with decreasing size of the smaller lagoons. Number of species in Pescadero Creek lagoon was greatest in 1986, when delayed sandbar formation allowed juvenile saltwater fishes to enter the estuary through mid July. All four lagoons shared five species of euryhaline fishes: threespine stickleback (Gasterosteus aculeatus) and prickly sculpin (Cottus asper), which were also present in the streams above the lagoons; steelhead (Salmo gairdneri), which were hatched upstream and used the lagoon for rearing or as a migration pathway; and staghorn sculpin (Leptocottus armatus) and starry flounder (Platichtys stellatus), which hatched in salt water and entered the lagoons in winter for usually only one year of rearing.

The large estuarine embayment, with good tidal exchange, appeared responsible for the high diversity of species present in Pescadero in 1986. Conversion of the lagoons to freshwater after sandbar formation, however, appeared to eliminate saltwater species and even some euryhaline species, such as shiner perch (Cymatogaster aggregata) and topsmelt (Atherinops affinis). Juvenile steelhead did well when the systems were fully open to tidal mixing and also when converted fully to freshwater. High water temperatures and reduced invertebrates during the transition from estuary to freshwater lagoon, however, resulted in poor growth rates during the transition.

Discussion: Management Implications

Our results from four different lagoons and from relatively dry and relatively wet runoff years suggest several concerns in the management of lagoons. First, freshwater inflow into the lagoon after bar formation is important in determining depth, salinity, temperature, and dissolved oxygen patterns in the lagoon. Streamflow diversions can therefore greatly alter the quality of the lagoon as a habitat for invertebrates and fish. For juvenile steelhead, maintaining quality lagoon habitat may be especially important, as we have found that San Gregorio and Pescadero creek lagoons may produce more steelhead smolts than the entire remaining watersheds (in preparation).

Secondly, artificial breaching of sandbars can greatly alter lagoon salinity, temperature, and dissolved oxygen, as well as depth. The possible adverse impacts of breaching should be carefully weighed against the apparent benefits before being allowed.

Finally, agricultural and urban waste waters can have drastic, although difficult to document, impacts upon these sensitive and important habitats. Levees or other barriers to contaminated runoff should be evaluated.

Acknowledgements

This study was supported by a grant from the California Department of Parks and Recreation. Colleen Pelles, Thomas Taylor, David Lonzarich, Tim Herring, Phil Oseguada, Donald Alley, Linda Ulmer, Dean Sakae, Stafford Lehr, and numerous

others helped with the field work.

Literature Cited

Shapovalov, L. and A. C. Taft. 1954. The life histories of the steelhead (Salmo gairdneri gairdneri) and silver salmon (Oncorhynchus kisutch) with special reference to Waddell Creek, California, and recommendations regarding their management. Fish Bulletin 98. 303 pp. + apps.

Abstract

Habitat quality for fish and invertebrates was investigated in 4 Santa Cruz and San Mateo county estuary/lagoon systems in 1985-86, and was found to depend upon a complex interaction of factors including depth, freshwater inflow, and sandbar formation. Winter streamflows and ocean wave action determined beach sand dynamics and timing of summer sandbar formation, while spring and summer streamflows determined depth of the summer lagoon and lagoon salinities and temperatures. High streamflows after bar formation resulted in rapid increase in lagoon depth and conversion to freshwater conditions. Low streamflows after bar formation resulted in shallow lagoons, which were warm and saline for much of the summer, and showed complex stratification of temperature, salinity, and dissolved oxygen. Productivity was depressed during the transition from estuary to freshwater lagoon. Freshwater inflows also altered pollution impacts. Stream and tidal flows helped dilute pesticide runoff into one lagoon in 1986. The surface lens of freshwater inflow also provided the only refuge for juvenile steelhead in another lagoon following anoxia due to sandbar breaching and tidal kelp deposition.

Table 1. Fishes utilizing Pescadero, San Gregorio, Waddell, and Pomponio creek lagoons in 1985-1986. R = resident; M = migrant; J = juvenile rearing; S = spawning. ( ) denotes rare occurrance.

Species	Pescadero 1985	Pescadero 1986	San Gregorio	Waddell	Pomponio
Gasterosteus aculeatus	RM	RM	RM	RM	RM
Salmo gairdneri	J	J	J	J	M
Leptocottus armatus	J	J	J	J	(J)
Platichtys stellatus	J	J	J	J	(J)
Cottus asper	JS	JS	J	JS	(J)
Eucyclogobius newberryi	R	R	R		
Cymatogaster aggregata	JS	JS	M	(M)	
Clupea harengus	JS	J	(M)		
Atherinops affinis	M	M			
Acanthogobius flavimanus	(R)				
Oncorhynchus kisutch	M			M	
Cottus aleuticus		(M)	S		
Morone saxatilus		JS			
Parophyrs vetulus		(J)			
Engraulis mordax		(J)			
Citharichthys sordidus		(J)			
Scorpaenichthys marmoratus		(J)			
Hexagrammos decagrammus		(J)			
Pholis ornata		(J)			
Sebates auriculatus		(J)			
Hyperprosopon argenteum		(J)			

Figure Legends

Figure 1. Pescadero Creek lagoon water levels and salinity profiles at the Highway 1 bridge. (A) Gaged height in 1985, with early sandbar formation, and (B) Gaged height in 1986 with sandbar formation in July. Arrows indicate dates of artificial sandbar breaching. (C) salinity profiles in 1985, and (D) salinity profiles in 1986.

Figure 2. Temperature profiles for Pescadero Creek lagoon at the Highway 1 bridge in 1985 (A) and 1986 (B). (C) Salinity, temperature, and dissolved oxygen profiles for Pescadero Creek lagoon upstream of the Highway 1 bridge during a period of lagoon stratification and severe diurnal oxygen fluctuation. (D) Salinity and dissolved oxygen profiles for Waddell Creek lagoon at high and low tides following sandbar breaching and tidal kelp deposition and decomposition.