Comparative Lagoon Ecological Assessment Project (CLEAP)

Santa Cruz County, California

Client: Santa Cruz County Resource Conservation District
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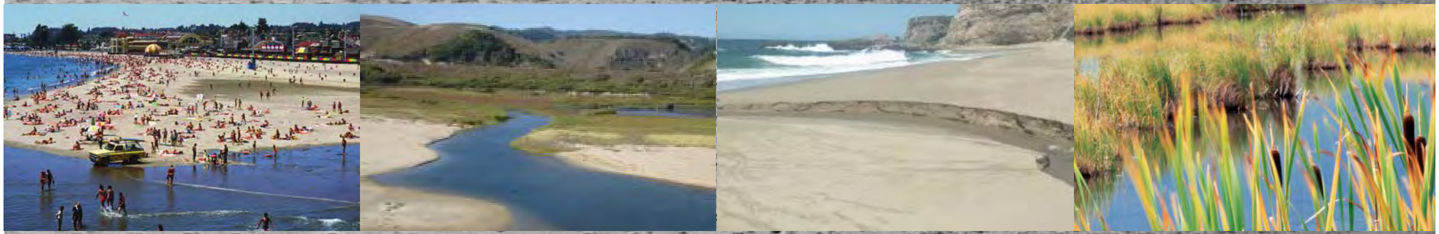

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1. Executive Summary

PROJECT INTRODUCTION

The coastal lagoon ecosystem of California provides a wide array of ecological and social value, yet little information currently exists on what is, or how to best evaluate, relative lagoon condition. The unique hydrodynamics of these seasonal estuaries has lent to the high ecological diversity and value of coastal lagoons. Human development within the historic marsh and a variety of land use activities in the contributing watersheds has variably impaired lagoons throughout the California Coast. The Comparative Lagoon Ecological Assessment Project (CLEAP) is an intensive physical, chemical and biological data collection effort focused upon a subset of coastal lagoons in Santa Cruz County to refine the tools available to evaluate relative lagoon condition, provide insight to lagoon function, improve our enhancement strategies for these unique ecosystems and focus future adaptive management efforts.

Lagoons are located where coastal streams meet the ocean and thus are the terminal delivery point for pollutants generated within their respective watersheds. Due to their location at the coast, lagoons play a significant role in water quality in nearshore waters, which in turn affects the maintenance of rearing habitat for cold water fisheries, public beach recreation, and other key coastal beneficial uses. The coastal lagoons of Santa Cruz County are essential for sustaining numerous native fish and wildlife species, including several that are threatened or endangered. The lagoons also benefit human communities by providing flood protection, recreation, and wildlife viewing opportunities. Unfortunately most lagoons in Santa Cruz County are currently in a state of ecological decline due in large part to historic physical modifications, past and current land use, and conflicts with property protection and public safety. Evidence of the decline of the lagoon systems in Santa Cruz County is demonstrated by increases in water quality impairments including elevated bacterial levels, low dissolved oxygen, increased algal growth, excessive sediment, elevated nutrient levels, and continuing impacts on public recreation near the lagoons. Posted health warnings due to elevated bacterial levels in the summer are common at beaches adjacent to the San Lorenzo River Lagoon, Aptos Creek Lagoon, and Soquel Creek Lagoon, as well as others (Ricker and Peters 2005).

In addition to the human impacts of poor water quality, the population declines in several critical species of concern has caused federal, state and local agencies and organizations to focus on improving the ecological function of coastal watersheds and the associated lagoon systems. These efforts have been hampered by the lack of a robust, ecosystem-based dataset that clarifies the unique ecological function of each lagoon. For enhancement efforts to succeed, lagoon conditions need to be more comprehensively documented within individual systems over time and compared across systems to note trends and differences. This will assist in understanding what components of lagoons have the greatest influence on condition and provide a process to monitor changes in lagoon physical, chemical and ecological conditions in response to enhancement efforts. CLEAP was designed to jump-start this data gap and begin development of a more quantifiable conditions evaluation and adaptive management process for California lagoon systems.

CLEAP focused on collecting and evaluating an extensive amount of physical, chemical and biological data from 5 Santa Cruz County lagoons that were determined to represent a range of conditions impacted by human activities. The 5 lagoons were selected using a detailed comparative matrix of 11 lagoons in Santa Cruz County. The specific lagoons selected for detailed evaluation were Scott Creek Lagoon, Laguna Creek Lagoon, San Lorenzo River Lagoon and Aptos Creek Lagoon (Figure 8.2). Each of these lagoons was also identified as a high priority watershed for future enhancement opportunities either within the lagoon, the contributing watershed, or both. Soquel Creek Lagoon has been actively managed by the City of Capitola for decades and was included in the CLEAP evaluations to represent a managed control lagoon.

CLEAP was initiated in the summer of 2003 as part of the Integrated Watershed Restoration Program (IWRP) for Santa Cruz County administered by the Resource Conservation District of Santa Cruz County and the California Coastal Conservancy. IWRP is a voluntary, non-regulatory program composed of advisory members from federal, state, and local resource agencies to improve fish passage and habitat, reduce sedimentation, and restore wetlands and lagoons in Santa Cruz County. The CLEAP team combined the expertise and priorities of a diverse group of scientists, natural resource managers and regulatory agencies to design and implement a comprehensive, lagoon-specific data collection effort (see Figure 8.1 for summary of CLEAP process). A Technical Advisory Committee (TAC) was convened for CLEAP to assist with the site selection process, study design, data analysis, and provided constructive comment on CLEAP findings and recommendations. The TAC was composed of the following agencies: NOAA Fisheries Habitat Branch, NOAA Fisheries Southwest Fisheries Science Center, California Department of Fish and Game, California Coastal Commission, Central Coast Regional Water Quality Control Board, California Department of Parks and Recreation, Monterey Bay National Marine Sanctuary, Santa Cruz County Department of Environmental Health, City of Capitola and City of Santa Cruz.

STRIVING TOWARD QUANTIFIABLE ADAPTIVE MANAGEMENT – INTEGRATING SCIENCE AND ENHANCEMENT

Numerous recent peer-reviewed articles addressing the enhancement of coastal ecosystems argue that the scientific approach of assessment, restoration and adaptive management must be an interdisciplinary collaboration to truly improve our understanding of these systems (Cloern 2001, Boesch 2002, Fano et al. 2003, Lundberg 2005, Karr and Chu 1999, etc). It is critical to design research and assessments that combine hydrology, biogeochemistry, physical characteristics, and ecological interactions from the base of the food chain through higher trophic levels in order to better grasp functional interactions and dependencies. Even with improvements in the scientific approach to coastal ecosystem function, there remains a communication gap between researchers and resource managers as to the success and/or impacts of restoration measures on ecosystem function (Nixon 1995, Cloern 2001, Lundberg 2005, Fano et al. 2003, Karr and Chu 1999, Wetzel 2001, etc).

As the field of ecological management of aquatic systems progresses, there is an imminent need to develop reliable indicators to evaluate natural resource condition. These same indicators can be used to quantify the changes enhancement efforts have on the ecosystem in question. The incorporation of quantitative information about system function into restoration decisions will guide an effective “adaptive management” process. If clear, quantifiable goals, indicators and targets are defined prior to enhancement actions, then post-implementation performance of a system can be measured. To define these goals, an understanding and identification of the aquatic system components that are expected to respond in a predictable manner to successful enhancement efforts is necessary. Decisions to modify existing conditions and continue improvements through adaptive management will then be based upon measurable parameters that have a documented physical, chemical or biological functional relationship to the broader project goals, rather than reliance on qualitative opinions of priority actions.

In order to approach natural resources from an adaptive management perspective the following questions must be addressed:

- What are the assumed causes, or stressors (independent variables), impairing the function of the system in question? Which are the priority stressors to address? Which stressors can be realistically modified?

- What are measurable indicators (dependent variables) of system function that will respond in a predictable manner to positive improvements to the above stressors? Successful indicators are direct proxies to assess the function of physical, chemical or biological components of the system in question and, ideally, are cost-effective and repeatable parameters to track and monitor over many years.

- What are the pre-restoration/enhancement values or conditions of the indicator parameters that collectively are assumed to represent relative condition? In order to quantify success, pre-restoration (baseline) conditions must be documented for a collection of system parameters that are expected to respond in a predictable manner to habitat improvements. From existing conditions, realistic goals of expected enhanced condition characteristics can then be formulated.

- What are the standardized data collection protocols of the selected indicators (pre- and post-project) to ensure changes in indicator values over time will be the result of system changes, not sampling variability?

Only when resource managers have better documented the ecosystem function of these specialized habitats can they apply these questions to prioritizing enhancement actions. According to Walters (1997), natural resource management and adaptive management should not be learning by trial and error, but learning by careful testing. Trial and error management is costly, time consuming and unnecessary. By initiating a comparative study of the similarities and difference of the physical, chemical and biological conditions across a range of human impacted lagoons, CLEAP has laid a preliminary framework for future data collection and analysis that can lead to more consistent data collection in lagoon systems, more informed enhancement strategies and effective adaptive management of Santa Cruz coastal lagoons and beyond.

CLEAP OUTCOMES

CLEAP focused on 5 primary project outcomes:

i. Collect, manage, present and interpret site-specific and comparative physical, chemical and biological data from five Santa Cruz County lagoons to improve our understanding of the ecological function of the selected Santa Cruz County lagoon systems.
ii. Review, summarize, and demonstrate the applicability of recent nation-wide research concerning wetland condition monitoring and assessment, and provide tools for future cost-effective quantitative lagoon condition evaluations and adaptive management programs based on the analysis of potential stressors and indicators.
iii. Provide an extensive baseline dataset (as an MS access database) and the associated sampling protocols to which future observations in Santa Cruz lagoons and beyond can be compared to improve our regional understanding of lagoon conditions.
iv. Develop and document potential parameter protocols, data interpretation methods, and data presentation techniques that can be refined, standardized, and applied to other coastal lagoon monitoring subject to lagoon-specific goals. This will greatly improve our ability to compare conditions of different lagoons in response to different stressors as well as track individual lagoon conditions over time.
v. The CLEAP team worked with the Technical Advisory Committee to develop high-level guidelines for future enhancement strategies for CLEAP lagoons, with the understanding that any potential site-specific projects brought forth by future project proponents will require additional assessment and incorporation of protective measures for all sensitive species that inhabit the lagoon systems.

CLEAP APPROACH

Human impacts on natural resources are inevitable throughout the world, and the coastal lagoons of Santa Cruz County have not been immune. Historical analysis of the CLEAP study sites revealed extensive physical changes to all of study sites. These modifications include channelization and reduced surface area, levees, dams and other alterations, and disconnections in floodplain and system hydrology. Reclamation of historic floodplain and marsh areas, and subsequent floodplain development, have significantly reduced and modified the natural function of the majority, if not all, of Santa Cruz lagoons and most statewide. Water diversion from the upper watersheds, both legal and illegal, have reduced the annual water supply to coastal streams and lagoon systems in Santa Cruz County. Urban and agricultural development in the watersheds and near the lagoons has resulted in point and non-point sources for pollutants, particularly nutrients, and excessive sediment. Seasonal illegal breaching of summer sandbar conditions is a common act by local surfers, residents, and beach users. These physical modifications as a result of human activities are key to our understanding of today's lagoon ecosystem function. They get to the root cause of many of the resulting symptomatic impacts, such as degraded water quality, habitat simplification, reduction in vegetative complexity, reduced summer flows, and other factors, that impair the ecological sustainability of the study lagoons.

Because these physical and chemical alterations are so prevalent and large-scale, it is unrealistic to expect that most of our lagoon systems can be restored to a pre-human-influenced state. Leading scientists around the world argue that we can not manage ecosystems per se because the natural ecosystem no longer exists, but rather we must learn to manage ecosystems with people as integral parts. Developing innovative ways to balance the needs and actions of humans and aquatic ecosystems should be considered as both a long-term challenge and priority. To achieve this, it is critical to understand what impacts these physical and chemical modifications have on ecological function and the biota the lagoons support. CLEAP approached the lagoons with the perspective that opportunities exist to increase the ecological susceptibility of these systems, despite the inevitable human pressures. Thus, CLEAP explored the range of lagoon conditions of the 5 selected sites to evaluate our hypotheses of potential primary factors that may influence relative lagoon conditions in Santa Cruz County. The findings from CLEAP can be used to expand key observations to lagoons outside of Santa Cruz County in an effort to develop a broader approach to evaluate and track California lagoon function.

The CLEAP approach is based on four primary hypotheses:

1. The primary human-induced stressors influencing the ecology in the majority of California coastal lagoons are physical and water quality modifications, which include human reclamation of the historic marsh, freshwater diversions, illegal sandbar breaching, and nutrient enrichment well over natural levels.

2. Select biological components of California coastal lagoons vary in response to different degrees of human-induced stressors. The five lagoons were included in this study because they were determined to represent a range of human-induced impacts, which allows investigation into varying biotic responses to different physical and water quality conditions.

3. Specific physical components of a lagoon system, including morphology, circulation, stratification and hydrology, make the system (or specific locations within a lagoon system) more susceptible to eutrophication and its associated water quality problems, than others (Monbet 1992, Beck and Bruland 2000, Cloern 2001, Luther et al 2004, etc).

4. Evaluating lagoons from a multi-trophic level perspective, rather than from a single-species perspective, provides a more comprehensive understanding of how and what specific physical and chemical conditions within lagoons and associated human impacts may influence overall lagoon ecology.

The CLEAP data collection and data evaluation approach relied heavily upon existing aquatic resource assessment techniques. These techniques were developed from a diverse assortment of resources including: the U.S. EPA's Guide to Wetland Assessment (USEPA 2002), Karr and Chu's approach to monitoring biotic integrity to evaluate aquatic system condition (Karr and Chu 1999), and over 40 peer-reviewed publications on coastal ecosystem function, water quality, and identification of biological indicators in aquatic systems (see References; Section 17).

Section 8 documents existing literature and scientific processes associated with biogeochemistry, nutrient cycling and eutrophication, and explores how the CLEAP team hypothesizes these processes may relate to lagoon condition. This background information is provided to educate readers on the wide array of scientific research identifying eutrophication as a significant ecological issue in the world's human-impacted waters and to document possible direct physical and chemical processes within Central California lagoon systems that may exacerbate the impacts of nutrient enrichment. Based on the existing scientific evaluations in other coastal systems and the highly dynamic nature of coastal lagoons, CLEAP investigators were interested in evaluating the link between the base of the food chain ecology and the physical and water quality conditions in these coastal systems.

In 2003, qualitative and quantitative data from 11 local lagoon systems were used to empirically rank Santa Cruz County lagoon systems from least to most impacted by human activities (Section 9) and the subset of five lagoons for detailed evaluations were selected to represent a range of local lagoon conditions. Monthly lagoon-specific physical, chemical and biological monitoring, termed a Lagoon Sampling Day (LSD), was conducted in each of the five CLEAP lagoons during the dry months of the year in 2004 and 2005, when differences in condition across lagoons were most likely to occur (May-October). Automated instrumentation was used to obtain continuous physical and chemical data within each of the five lagoons. Detailed sampling methods and protocols employed are presented in Sections 10 and 11. Over 1.25 million data points were collected during the CLEAP efforts and are stored in a customized MS Access Database.

Coupled with detailed evaluations of the interactions of physical and chemical conditions within the selected lagoons, monthly data collection efforts included observations, surveys and sampling of four trophic levels within the lagoons: primary producers, zooplankton, benthic invertebrates and fisheries. Biological monitoring techniques and protocols were developed for each trophic level based on previously documented methods in similar aquatic systems, cost-effectiveness of the method, and the ability of method to provide repeatable results to compare biological observations across lagoons. Within a comparative lagoon framework, CLEAP integrated evaluations across lagoon systems to investigate the potential functional relationships between watershed conditions, lagoon conditions and resident ecological communities.

Section 12 explains in depth the concept of "stressors" and "indicators". The initial stressor and indicator development, testing, and findings were conducted to provide a tangible and step-by-step documentation of how ecological researchers across the country have increased the power of physical, chemical and ecological data to improve our understanding of complex datasets obtained from dynamic natural systems. Both the initial statistical metric testing (Section 12) and the across-lagoon comparisons of various stressor and indicators values (Sections 13 and 14) provided preliminary insight into the existing conditions of CLEAP lagoons. Hopefully, resource agencies will see value in continuing to identify and refine a suite of parameters that can collectively indicate relative lagoon condition and will most likely demonstrate a predictable response to changes (either positive or negative) in lagoon conditions over time. Standardizing the data collection and analysis protocols in this manner, subject to lagoon-specific goals, facilitates comparisons between lagoons or within the same lagoon system over time. This is particularly useful if funding for monitoring is limited so that the resources available can be targeted wisely.

While the CLEAP work on stressor and indicator metric testing is preliminary, CLEAP represents a comprehensive first step to broaden our scientific understanding of California lagoon ecology and how these lagoon systems may respond to different variables. Additional study is required to continue to evaluate lagoon processes over longer study periods and in a greater number of lagoons, to better refine our ability to identify lagoon-specific stressors, to consistently evaluate relative lagoon condition, and to implement effective adaptive management programs.

CLEAP LIMITATIONS

CLEAP was developed to collect a significant amount of physical, chemical and biological data with limited funding and resources. Of the most important outcomes of CLEAP is the creation, documentation, and presentation of many tangible tools that provide a stepping-off point from which to implement lagoon ecological analysis that can expand our understanding of how best to evaluate and enhance today's human-impacted lagoons. Below we document the specific limitations (Section 6) of the CLEAP effort to ensure that neither the intent nor results of this project are misinterpreted by the reader.

1. CLEAP efforts have generated a significant interdisciplinary dataset of lagoon physical, chemical and biological conditions from 5 specific lagoons located in Santa Cruz County, CA. The sites were selected to represent a range of habitat conditions, thus improving the power of comparison across these lagoons. The specific condition observations and functional interactions observed in each Santa Cruz County lagoon may or may not be indicative of conditions expected in lagoons outside of this restricted region. The expansion of a subset of CLEAP parameters to incorporate greater regional and/or statewide representation of coastal lagoons will continue to improve our knowledge of how to evaluate and track lagoon condition throughout the State of California.
2. The detailed CLEAP dataset consists of data from only 2 years of observations. Natural variability is impossible to resolve on such a short time scale and continuing to build a long-term dataset of a selection of CLEAP parameters in CLEAP lagoons will significantly improve our understanding of the Santa Cruz County lagoon condition.
3. There are no pristine, undisturbed California lagoons. Nor is there a lagoon still operating within its natural morphology. A natural baseline evaluation of lagoon condition is unobtainable in Coastal California lagoons, and future evaluations should consider aquatic ecosystem function with humans as integral parts. To compensate for the lack of a pristine endpoint, the CLEAP approach relied heavily on extensive existing successful research and evaluations on similar natural system types (Section 6 and Section 12) to identify potential stressors and indicators that may differ across the habitat condition range represented by the 5 CLEAP lagoons.
4. The CLEAP team does not believe that a definitive list of Central California lagoon stressors and indicators is contained herein, nor do we argue that our efforts have exhausted all possible options of successful lagoon stressors and indicators. Rather, this tangible example of data collection, data reduction, data evaluation and data application can be used to inform, standardize and expand future lagoon-condition evaluations both within Santa Cruz County and beyond. Ultimately, successful stressors and indicators of lagoon condition can be directly measured and monitored to evaluate existing conditions and can be tracked over time to

potentially evaluate the effectiveness of future lagoon enhancement and watershed management efforts.

5. The metric development and preliminary testing as presented in Section 12 has a number of limitations, including:

- All stressor and indicator values from May to October were aggregated over a 2-yr period. A month-by-month evaluation would eliminate some of the data differences as a result of seasonal and climatic differences, though it was not conducted due to resource limitations.
- All stressor and biological indicator values were aggregated regardless of sandbar status, and thus circulation, conditions.
- The study was limited to only 5 lagoon systems in a very localized regional context. However, the relative human gradient that the CLEAP lagoons represent does provide power to these evaluations where we are looking to identify predictable changes in biological metrics (indicators) across a range of human impacts.

6. All environmental sampling techniques for physical, chemical and biological parameters have temporal and spatial limitations. There is inherent variability in hydrology, tides and climate on both short and long time scales. In addition, each lagoon is physically complex and both horizontal and vertical differences exist throughout the lagoon, resulting in a patchy biotic distribution. The CLEAP data collection and analysis efforts took all reasonable steps to ensure the most representative and consistent sampling of the subject lagoons, with a focus on minimizing as much natural variability within and across sites given available resources. Thus non-random (targeted) sampling was conducted to constrain as much natural variability as possible, increasing our confidence that variations in the data across sites was due to actual differences in site conditions and not due to diel, tidal or climatic differences.

7. The data contained in this report and the database was collected as part of an investigation into lagoon system conditions and functional processes, and to provide a baseline for future programs working to characterize conditions and enhance the ecological sustainability of the lagoon systems. While we cannot control the use of the data by others, we want to emphasize that any attempts to use the data or results contained in this report should be carefully assessed by local, state, and federal resource agencies.

SPECIAL NOTE ON THREATENED AND ENDANGERED LAGOON SPECIES

The listed species of interest that may inhabit Santa Cruz coastal lagoons include steelhead trout (*Oncorhynchus mykiss*), coho salmon (*Oncorhynchus kisutch*), tidewater gobies (*Eucyclogobius newberryi*), red-legged frogs (*Rana aurora draytoni*), and San Francisco garter snakes (*Thamnophis sirtalis tetrataenia*). Due to funding limitations and project scope, CLEAP efforts only included evaluations of listed fisheries, teaming with the NOAA NMFS laboratory, and did not include sampling, habitat mapping or other considerations associated with reptiles or amphibians. As future management, enhancement and restoration actions are considered in specific lagoon systems, project designers and agency staff must evaluate potential actions in light of existing species recovery and management plans, including (but not limited to) the Department of Fish and Game State Coho Recovery Plan, Department of Fish and Game Steelhead Management Plan, the USFWS Recovery Plan for the Tidewater Goby and the USFWS Recovery Plan for the California Red-Legged Frog. A draft recovery plan by NOAA for Central Coast Coho Salmon was completed in June 2007 with a final plan to be completed in December 2007. Any on-the-ground lagoon restoration projects should involve early consultation with the appropriate resource and regulatory agencies to ensure that sufficient protective measures are in place to minimize risk to all threatened and endangered species present.

KEY FINDINGS

As discussed above, CLEAP was designed to gather baseline conditions data for five Santa Cruz County lagoons, focusing on documenting physical and water quality modifications (stressors) and the resultant conditions of the primary producers, zooplankton, benthic invertebrates, and fisheries communities (Sections 10, 11 and 12). Additionally, CLEAP has analyzed this data in an effort to identify particular correlations and indicators that might help focus lagoon condition evaluations in the future. CLEAP has also presented detailed data collection protocols and presentation methods (Sections 7, 8 and 9) for all parameters collected and evaluated. It is hoped that by establishing a dialogue advocating the need for standardization in data collection, formulation of process-oriented hypotheses of key factors influencing lagoon condition and comparisons of data across lagoon systems regionally and statewide, we will improve our understanding of how to identify what factors may be influencing the differences across lagoon conditions. As we improve our ability to best evaluate lagoon condition, our strategies for effective enhancement will be more informed in a quest toward preserving these dwindling critical ecosystems.

Below are a collection of highlights from Sections 12 through 15.

- PHYSICAL MORPHOLOGY: The morphology of all the CLEAP lagoons has been significantly altered to accommodate human development needs. The existing summer lagoon surface area of each CLEAP lagoon is 20% or less of its natural area. The existing morphology of the CLEAP lagoons is characterized by a straightened, leveed channel that contains the majority of winter flows and the summer-impounded water during lagoon conditions. All of the CLEAP lagoons have significantly lower width: depth ratios than the pre-disturbed lagoon. This significant alteration in lagoon morphology equates to a more localized lagoon footprint, minimal marsh shallow water habitat and complete alteration of the historic vegetation communities, summer lagoon storage capacity, hydrodynamics, biogeochemical cycling and other physical and chemical processes. The alteration of lagoon morphology has essentially resulted in a complete transformation of all natural lagoon processes, a transformation that has likely resonated throughout the biological communities as well.

- CLOSURE TIMING and DURATION: When seasonal stream discharge recedes to late spring conditions, the timing of seasonal sandbar closure is likely driven by coastal dynamics as observed by the coincidental sandbar closure of CLEAP lagoons during spring tidal conditions and south swell events (Section 13). The coastal swell must deliver enough sediment to the beach berm to exceed the elevation of the lagoon water surface. Comparative observations at Laguna Lagoon (with a natural mouth morphology) versus San Lorenzo and Aptos (with bridge constrictions in close proximity) consistently display differences in the ability of the sandbar to remain intact. Cross-sectional constrictions of lagoon width near the mouth, such as bridge structures, likely delay the formation of a sustained sandbar barrier. The water surface elevation in these constricted lagoons will quickly exceed the elevation of the sandbar due to the low lagoon width:depth ratio. Heavily flood-controlled lagoons must accommodate lagoon water storage along the beach environment due to the significant reduction in the surface area of the lagoon and the associated lack of horizontal water spreading capacity within the leveed channel.

- SEASONAL VARIATIONS: Santa Cruz County coastal lagoons transition from a deltaic river-dominated system in the winter and spring, to a backwater brackish environment in the summer and fall. These changes in circulation and climate result in a relative increase in primary production rates and organic matter accumulation in each CLEAP lagoon from winter to summer. Future efforts to evaluate the relative condition of California coastal lagoons are recommended to focus on the summer and fall conditions when surface water flows recede, lagoon sandbar forms, water temperatures and light availability increase, and organic productivity is relatively elevated. These seasonal conditions are when the differences in physical, chemical and biological (i.e., stressor and indicator) conditions are expected to be greatest between the less impacted and more impacted lagoons, thus providing the most effective evaluations of relative lagoon condition.

- EUTROPHICATION and WATER QUALITY: Eutrophic conditions are created by the excessive availability of dissolved inorganic nitrogen (DIN) (the limiting nutrient in CLEAP lagoons) and the exponentially increased rate of primary production as a result of increased light availability and water temperatures (Wetzel 1991, Section 6). Seasonal variations in circulation and climate during the summer and fall would have naturally increased the rate of primary production in summer lagoon environments. Particularly fast-growing phytoplankton and macro algae blooms will sink and accumulate at the bottom of the lagoon. This material is then respired and oxygen and other electron acceptors are consumed, creating poor water quality, as indicated by repressed DO and ORP levels (see Section 6). The most impacted lagoons (Aptos and San Lorenzo) were observed to possess a greater frequency and magnitude of low DO and ORP levels over the course of the study (Figures 11.33-11.41). These observations are supported by the metric testing (Section 10) where a number of DO and ORP metrics were identified to statistically correlate to an array of biological indicators (Table 10.5).

  CLEAP observations suggest that physical human modifications to the lagoons have exacerbated eutrophication and the associated water quality impacts in these naturally productive environments for a number of reasons:

  CLEAP lagoons are subjected to higher N and P loading over natural levels as a result of urban, rural and agricultural human activities, thus we suspect primary production rates may be elevated relative to the natural summer California lagoon. In addition to increased nutrient loading, the morphology of the lagoons has been significantly simplified creating a much smaller surface area footprint of the lagoon, relative to the expansive historic marsh areas. Today there is a more localized accumulation of organic matter, increasing the oxygen demand at the sediment interface, which is directly responsible for low DO and the associated water quality impacts of anoxic conditions (see Section 6). The leveed morphology also increases surface water temperatures and the persistence of density stratification, both of which will exacerbate repressed oxygen supply to respiring organic material at the sediment interface in these lagoons.

  The CLEAP lagoons displayed a range of the degree of eutrophication as measured by DO, ORP (oxidation reduction potential), chlorophyll values and primary producer % cover observations (Table 10.4). The most impacted CLEAP lagoons, Aptos and San Lorenzo, possess significantly higher DIN inflow concentrations than the other lagoons (0.44 and 0.27 mg/L respectively). In addition, these two lagoons are located in urban areas, characterized by strictly defined levees with minimal riparian vegetation or canopy, which was coincident with surface water temperatures 2.5-4°C higher than other lagoons (Section 11). At these two lagoons, the substrate of the lagoon transitions from sand in the spring to organic detritus by late summer/early fall. Stratification was observed to be persistent in these lagoons, but the duration of sustained closure was limited due to both natural and human causes. In Aptos and San Lorenzo, we suspect that while nutrient loading to these urban lagoons is relatively elevated, the degree of eutrophication is exacerbated by high solar exposure, extreme daily maximum surface water temperatures and lack of emergent or submerged vegetation to uptake and fix nutrients.

Similar to Aptos and San Lorenzo Lagoons, the Scott Side Channel also possessed consistently low DO, low ORP and elevated chlorophyll. The Scott Side Channel is a hydrologically isolated deep channel, subjected to the same, relatively low, DIN tributary inputs as the main Scott Lagoon. The Scott Side Channel substrate was observed to be organic detritus throughout the seasonal observations from spring through fall, suggesting a lack of winter scour and organic detritus removal during high flow events. The respiration of organic matter at the bottom of relatively shallow water column (< 10 ft) can be a significant supply of DIN to the primary producer community (Wetzel 1991, Sutula, et al 2005). In addition the channel surface water temperatures were consistently 3-5 °C higher than the main Scott lagoon stations (Section 14), further elevating summer primary production rates. In the instance of Scott Side Channel, we suspect a significant supply of DIN is provided from the persistent organic matter detritus at the sediment interface. The hydrologic isolation of this station (SC3) has created a micro environment with poor water exchange and elevated surface water temperatures, preferentially exacerbating primary production rates.

Most stations located within Laguna Lagoon, Scott Lagoon and Soquel Lagoon were characterized by more stable DO conditions (< 3 mg/L), lower chlorophyll values and minimal organic detritus accumulation in the summer and fall. Coincidentally, these lagoons possess relatively lower mean DIN inflow concentrations, greater riparian cover and shading, and consistent presence of emergent and SAV communities. The less frequent density stratification further reduces the potential water quality impacts by allowing oxygen produced in the surface by photosynthesis to be available at the sediment-water interface where respiration occurs.

CLEAP observations suggest that nutrient loading, lagoon morphology, riparian canopy and the persistence of stratification appear to directly influence the susceptibility of a lagoon (or a location within a lagoon) to eutrophic conditions. These observations are supported by the statistically significant correlations between these stressor metrics as presented in Tables 10.6A and 10.6B). These observations also suggest that opportunities exist to enhance specific lagoons by implementing enhancement strategies that increase winter flushing and scour of summer organic material accumulation, increase summer water exchange and reduce maximum daily summer water temperatures.

- DENSITY STRATIFICATION: Density stratification was observed to exacerbate poor water quality conditions in CLEAP lagoons (Table 10.6) as well as correlate with an array of biological indicators (Table 10.4). However, a completely fresh water column within the summer lagoons did not always correlate to higher dissolved oxygen concentrations and low primary production rates, as observed in Aptos and San Lorenzo Lagoons. Primary production and organic matter accumulation at the sediment-water interface will occur if DIN and light are available and temperatures are elevated in the surface waters, regardless of the presence of a saline bottom water layer. Other contributing factors, such as temperature, solar exposure, nitrogen loading, nitrogen availability, water mixing, morphology, etc., must be considered in order to better predict if a sustained summer sandbar and freshwater conversion will equate to improved summer lagoon water and ecological quality in Santa Cruz County lagoons. In some instances, the elimination of stratification may increase the oxygen availability at the benthos to prevent anoxic conditions, but it is possible that elevated organic production in systems like Aptos Lagoon could exceed the oxygen supply of the water column (producing anoxic conditions) even if density stratification is not present. The occurrence of such events are typical of nutrient enriched fresh water lakes (Lake Washington, Seattle) and brackish estuaries (Malibu Lagoon or Chesapeake Bay), and in such instances the nutrient sources to the system must be addressed for enhancement efforts to be effective.

- PRIMARY PRODUCER COMMUNITY: The primary producer community assemblages, distribution and density appear to provide quickly obtainable information that can provide insight into relative lagoon condition. The lagoon hydrology and chemical conditions are extremely dynamic, particularly in the summer months when circulation, tidal and climatic regimes can vary on hourly time scales. The primary producer communities provide a direct link to these dynamic variables because of their very short life cycles and quick response to the surrounding physical and chemical environment. Based on research throughout the world (Monbet 1992, Siver 1995, Duarte 1995, Barbour et al 1999, Bachelet et al 2000, Cloern 2001, Fano et al 2003, etc), primary producer community characteristics in highly dynamic aquatic systems can be very effective indicators of nutrient availability, physical circulation regime, degree of pollution and other potential stressors on an aquatic system. Because these organisms form the base of the trophic structure, it is assumed that observations of the primary producer communities can provide insight to the relative quality of habitat for higher organisms. CLEAP observations suggest there is promise to utilize components of the primary producer communities as partial indicators of lagoon condition.

  The magnitude, density and composition of the primary producer community within CLEAP lagoons displayed distinct differences across the lagoons that represent a range of habitat conditions. Applying observations throughout the world by Duarte (1995), the composition of the primary producer community can have a distinct impact on the entire aquatic community and the primary producer assemblage can vary along a nitrogen availability gradient. Duarte (1995) documents that a dominance of fast-growing phytoplankton can out-compete slow-growing SAV species by clouding surface waters and limiting light to the benthos. A dominant phytoplankton and macro algae community results in excessive accumulation of organic matter at the bottom of the lagoon due to the short life spans, which leads to low DO and other water quality issues. CLEAP evaluated the differences in the dominant primary producer communities across lagoons in light of specific physical and chemical factors that may influence why these differences exist.

The magnitude and type of primary producer communities varied across the CLEAP lagoons and observations suggest that physical and chemical conditions of each of the lagoons may influence these differences in the summer lagoon conditions. The metric testing revealed an array of correlations between primary producer metrics and circulation regime, nutrient characteristics, stratification, DO and ORP conditions (Table 10.4). Observations of the dominant primary producer community present in CLEAP lagoons shifted from standing SAV communities in the less impacted summer lagoons, such as Laguna and Scott, to more short-lived phytoplankton dominance in the more impacted lagoons, as observed in Aptos and San Lorenzo. Aptos and San Lorenzo consistently possessed more frequent and relatively larger phytoplankton blooms (as measured from chlorophyll and primary producer abundance). Coincidently, Aptos and San Lorenzo also have greater solar exposure (lack of riparian canopy), less water mixing and water exchange within the closed lagoon conditions, a greater distribution of land uses suspected to contribute chronic nutrient loading to the lagoon, and higher tributary DIN concentrations. Interestingly, Scott Side channel displayed water quality characteristics similar to Aptos and San Lorenzo (high chlorophyll, stratification and low DO). While the Scott Side Channel is subjected to the same inflowing waters as the main portion of Scott Lagoon, the side channel is hydrologically restricted with elevated water temperatures and poor water exchange. These findings further support the hypothesis that morphology of the lagoon, or portions of the lagoon, can have a profound effect on the water quality and associated biota at the base of the food chain.

- ZOOPLANKTON: The zooplankton community evaluations were both expensive (> $100 per sample) and required a high level of training for field data collection and species enumeration. While future scientific ecological evaluations of the zooplankton community dynamics in coastal lagoons would greatly improve the application of this trophic level as lagoon biological indicators, the current level of understanding of lagoon zooplankton species and community assemblage is too underdeveloped for simple application by natural resource manager to assess and/or track lagoon condition.

- BENTHIC INVERTEBRATES: CLEAP findings provide ample evidence to suggest benthic invertebrate metrics (such as species diversity, number of taxa, and presence/absence of intolerant species) may be useful future biological indicators of lagoon conditions. The most consistent and dramatic predictable differences in benthic invertebrate metrics across CLEAP lagoons were observed in the benthic grab sample community at sampling stations in closer proximity to the mouth of the lagoon. Figure 12.17 illustrates that the sites with the most frequent observations of poor water quality (Aptos, San Lorenzo and Scott Side Channel) had very low species diversity (<0.2) and/or very low number of organisms (<50 individuals) during the majority of observations. Little benthic invertebrates taxonomy has been conducted in the saline/brackish environment typical of California coastal lagoons, and significant opportunities exist to expand the benthic bioassessment work conducted for CLEAP. A library of all species collected in CLEAP lagoons has been cataloged and preserved and is available to other researchers who wish to further characterize these communities.

- FISHERIES: The CLEAP observations suggest that the utilization and tracking of definitive fish data within lagoons to evaluate lagoon water quality and lagoon function is difficult because the conditions within each lagoon that support these listed species may be different. Neither salmonid population estimates, salmonid growth rates, salmonid presence/absence, nor tidewater goby presence/absence showed a consistent response to habitat stressors from the preliminary metric testing. Nor do the steelhead populations, growth rates, or other metrics representing sensitive fish species across lagoons and within lagoons provide any statistical correlation to variations of lagoon conditions (Section 10). Steelhead were present in all lagoons evaluated. Coho salmon are at the southern extent of their range and are not expected to be observed in three of the five CLEAP lagoons. Tidewater gobies have very specific, shady, shallow, sand-substrate requirements, all of which limited the use of the fish metrics as specific indicators in this study.

- FISHERIES: The distribution of salmonids and tidewater gobies within each lagoon provides some information on relative habitat utilization and needs. At Scott Lagoon, minimal to no fish were caught within the Side Channel from July through October each year. In Aptos Lagoon, salmonid abundance significantly declined each late summer to early fall. In Aptos, San Lorenzo and Soquel a greater number per unit effort of salmonids were consistently captured under the bridge structures than in un-shaded locations. CLEAP fish sampling become selective in mid-summer 2004 to focus on the shaded locations of San Lorenzo Lagoon to increase our catch per unit effort. In the North Coast lagoons, the distribution of the fish did not necessarily correspond with sun exposure, and in fact our observations were quite the opposite with great density of steelhead and coho sampled in the open channel areas. The greatest tidewater goby populations were consistently observed in Laguna Lagoon at the shallow margin between the beach environment and the first occurrence of emergent vegetation. This habitat transition has been eliminated in Scott, San Lorenzo, Soquel and Aptos Lagoon due to the presence of a bridge and/or artificial levees. Tidewater gobies were never observed in the managed Soquel Lagoon.

- FISHERIES: One of the primary target conditions of coastal watershed and lagoon natural resource management is the preservation and enhancement of the listed anadromous fish populations. One key assumption is that improvements in Santa Cruz lagoon conditions, which include fish food, protection and habitat, will directly result in an increase in the viability of the long-term anadromous fish populations. The condition, population, growth and utilization of these species in the lagoon and the increased oceanic survival of salmonids in the ocean is one overall goal of Santa Cruz lagoon management. However, annual population estimates within a lagoon each year provide limited information on the snapshot in time of salmonid and/or goby lagoon utilization. Sampling inefficiencies, excessive sampling costs, fish mobility, salmonid year class life histories, and many other factors make our ability to interpret differences in the fish data as differences in lagoon quality very difficult. In order to conduct the definitive, long-term salmonid evaluations necessary to confidently infer that salmonid utilization of a specific lagoon has increased and that ocean survival and spawning of the fish that utilized the lagoon has also increased (if positive management changes in the lagoon were implemented), fish monitoring must track individual fish for 2-3 yrs. These fisheries research efforts are complicated and expensive, but would obviously be extremely valuable and are currently being undertaken by federal research agencies such as NOAA, NMFS. In lieu of such detailed fish sampling, CLEAP has laid the framework to improve our ability to assess and track within-lagoon conditions by using more cost-effective and easily attainable robust datasets, with the implied assumption that improving the lagoon conditions, as our best current understanding of condition is defined, will benefit the sensitive fish species. The refinement and testing of our evaluation of relative habitat conditions and which physical, chemical and biological parameters will best indicate condition, must continue to evolve. Future efforts need to continue to identify and test within-lagoon conditions that are assumed to increase sensitive species habitat quality, survival, reproduction and long-term population resilience.

PRELIMINARY LAGOON ENHANCEMENT STRATEGIES

The following guidelines were developed with input from the CLEAP Technical Advisory Committee. As stated above, any site-specific projects need to be reviewed by the resource agencies to ensure protection of sensitive species and their habitat.

Opportunities to enhance today's lagoons are significantly limited by the multitude of human modifications to the lagoon and associated watershed. Flood control, water supply, non-point source pollution, urban lands, agricultural lands, beach recreation, etc. all have an influence on the reality of the summer California lagoon. We must devise a process to best evaluate relative lagoon condition based on our best understanding currently. We must then hypothesize what factors are influencing a specific lagoon to have a less or more desirable condition. These hypotheses, coupled with existing opportunities, identify the processes and components of the system that we want to target as a result of treatment, i.e. our enhancement strategy. We then apply treatment and evaluate our new condition. Did our treatment work, why or why not? Now we have hypotheses and processes to test and learn from. From these lessons we can revise our approach to measuring lagoon condition and we can modify our approach to enhancement. This, by definition, is adaptive management.

General recommended strategies to improve and protect Santa Cruz lagoons include:

- Explore innovative techniques to manage water supply to meet both human and local aquatic ecology needs, including timing of intakes and/or releases to better accommodate both water supply and ecological components of the lagoon systems.
- Develop long-term strategies, community education, and best management strategies to reduce the non-point source loading of nutrients and other pollutants to the local watershed. All community members and local agencies can work toward reducing nutrient loading into local water resources through limiting fertilizer applications, improving septic systems, and implementing more environmentally sustainable agricultural practices.
- Develop and post signs at lagoon mouths to educate the community regarding the value of a summer sandbar that remains intact and to deter unauthorized breaching.
- Seriously explore feasible opportunities to expand the surface area of urban lagoons.
- Implement enhancement projects within the lagoons that increase physical lagoon complexity in an effort to provide a greater variety and abundance of ecological niches within the lagoon system to support a more stable and diverse food supply for the endangered fisheries.
- Implement enhancement measures that create habitat niches directly utilized by endangered aquatic species, including salmonids and tidewater goby.
- In lagoons where eutrophic conditions exist, implement enhancement measures that will reduce the availability of nitrogen (the limiting nutrient) by reducing summer water temperatures, reducing solar exposure, and maximize water exchange during closed conditions. Morphologic modifications that take advantage of winter storm flow flushing and bed scour of all locations

within the lagoon will reduce the accumulation and persistence of organic detritus at the sediment-water interface within the lagoon, a process that is hypothesized to directly contribute to deleterious summer lagoon water quality conditions.

STRATEGIES FOR NORTH COAST LAGOONS: The enhancement strategies for each lagoon should be different and site-specific enhancement effort considerations should be process-oriented and incorporate the opportunities and constraints at each unique lagoon. Using the CLEAP lagoons as an example, the primary opportunity associated with the North Coast lagoons, Scott and Laguna, is the lack of current and future flood control to protect the historic marsh. While historic agricultural reclamation, railroad and Highway One construction significantly altered the morphology of the historic lagoons, opportunities now exist to remove the predominant morphologic constrictions and enable the 21st century lagoons to reestablish a new morphologic equilibrium. Removal of existing levees and legacy human structures can be coupled with strategic placement of grade controls and wood structures to facilitate the expansion of the summer lagoon marsh surface area, create more natural summer sandbar formation dynamics and allow the system to restore a more natural seasonal functionality. The North Coast lagoons have relatively lower DIN loading pressures in comparison to the urban lagoons located in the City of Santa Cruz and City of Aptos, thus CLEAP observations of water quality and local biota communities suggest that simple morphologic changes may be sufficient to mitigate the water quality issues observed at these sites, such as in the Scott Side Channel or the Laguna South Pond. Thus, the strategy for enhancement in these North Coast systems from a CLEAP perspective would be to remove existing hydrologic constraints, move as little earth as possible, and create a physical environment where the lagoons can reestablish a more complex, hydrodynamic and sediment distribution equilibrium.

STRATEGIES FOR URBAN LAGOONS: In the urban lagoons, winter flood control at the lagoon marsh is a priority to protect local real estate. However, any opportunities to increase lagoon surface area should be seriously pursued. The flood control restriction needs limit the marsh/lagoon surface area available during the summer backwater conditions. In addition, the urban lagoons have greater annual DIN loading as a result of urban pressures, upper watershed septic systems and other non-point sources from human activities. The ultimate lagoon enhancement goal of the urban lagoons should be to identify management strategies that facilitate a sustained summer backwater lagoon environment without the gradual decline of lagoon water quality during the summer and fall. Based on the comparative evaluation across CLEAP lagoons, opportunities exist to modify the specific factors influencing summer primary production rates, primary producer communities and organic matter accumulation in summer Santa Cruz lagoons. Hydrologic modifications that utilize the winter high stream flows and elevated tidal inflow events to remove organic detritus from the lagoon substrate (a DIN source) and replace the organic material with low nutrient containing sand are expected to reduce the summer lagoon susceptibility to eutrophication. Increasing shading by riparian canopy will reduce both surface water temperatures and light availability, as demonstrated in Soquel Lagoon. Morphologic modifications that can maximize summer lagoon water exchange and mixing will assist with eliminating stratification, as well as reduce maximum daily surface water temperatures. Planting and promoting SAV communities in the urban lagoons will provide shading and habitat in the simplistic sand channels as well as uptake and store DIN over the entire summer season. SAV species are relatively shallow rooted and the organic material can be expected to be exported from the lagoon system each winter during storm flow events.

LAGOON COMPLEXITY: Enhancement opportunities that increase the physical complexity of the lagoon should be a priority, including vegetation diversity, channel complexity, sediment-sorting complexity, shading complexity and other components that will increase the diversity of the physical setting. A more physically diverse lagoon will possess a greater number of biological niches and directly increase opportunities for increased species diversity of lower trophic levels and great refuge opportunities for sensitive fish species. The overwhelming distribution of salmonids in shaded locations within the morphologically simple urban lagoons suggest shading and structure refuge may be preferentially used by resident salmonids. Again, the specific conditions of each physical niche to be created should be evaluated to ensure the changes will not exacerbate the summer water quality.

FUTURE WORK

Understanding the condition and ecological state of these lagoons has important ramifications for sensitive species recovery and is an important piece in overall watershed enhancement efforts to sustain more viable watershed systems with humans as an integral part. The CLEAP efforts provide a tangible example of an interdisciplinary evaluation of coastal lagoon systems and advance our scientific understanding of the complex lagoon systems common to the Central California coast. CLEAP provides an array of tools with which future lagoon evaluations can be refined to both focus assessments of lagoon conditions and track the performance of future lagoon enhancement efforts. Consistent long-term datasets that document lagoon condition will undoubtedly improve our collective ability to report and track the change in this natural resource condition over time. Future efforts such as a Coastal California lagoon rapid bioassessment, applications for the existing California Rapid Assessment Method (CRAM) methodology, and/or the future development of a Coastal Lagoon Index of Biological Integrity (IBI) could all incorporate techniques, protocols, data and data analysis efforts employed by CLEAP.

CLEAP efforts have laid some preliminary framework, identified successes and failures of CLEAP efforts, and created a preliminary list of recommended stressors and indicators (Section 16) that are expected to provide insightful and cost-effective long-term datasets for coastal lagoon systems. The actual selection and implementation of a collection of parameter evaluations within particular lagoon systems in the future must consider the goals of the specific lagoon evaluation and select the most appropriate and (assumed) powerful indicators to observe over time based upon those specific goals. Sections 10 and 11 detail all of the protocols and techniques implemented by CLEAP in an effort to minimize natural, seasonal, and daily variability within these dynamic system. Given existing information, we expect these preliminary metrics to change in a predictable direction (dose-response) if the pressures of human impacts can be alleviated and/or mitigated. We hope that the resource agencies responsible for managing and restoring these lagoons will make use of the CLEAP data and methodology and will continue to build and refine them into the future.

2. Project Introduction

The Comparative Lagoon Ecological Assessment Project (CLEAP) was initiated in the summer of 2003 as part of the Integrated Watershed Restoration Program (IWRP) for Santa Cruz County administered by the Santa Cruz Resource Conservation District and the Coastal Conservancy. IWRP is an interagency comprehensive restoration program to facilitate and coordinate projects to improve fish and wildlife habitat and water quality in Santa Cruz County watersheds using a voluntary, non-regulatory approach. The first phase of IWRP (pre-implementation), which includes CLEAP, was funded by a grant from the Coastal Conservancy with the Santa Cruz County Resource Conservation District (RCD) acting as the fiscal agent.

CLEAP is an effort to integrate the enhancement and science needs facing Santa Cruz County coastal lagoons to improve the future ecological sustainability of these unique ecosystems. The location of lagoons at the terminus of developed watersheds, the recreational pressure at local beaches, the diverse and extensive biological communities naturally present in these systems, and the extent of human modifications to local lagoon systems make the future of effective lagoon enhancement an important focus for natural resource managers on the Central California Coast. CLEAP is the first project on the Central Coast to combine interdisciplinary scientific data collection with specific enhancement concerns to provide useful tools to improve the restoration of lagoon systems well into the future.

The CLEAP process has united a technically diverse group of scientists and resource managers who have worked collectively to improve our understanding of Santa Cruz coastal lagoon function and develop enhancement tools based on regional lagoon data. Dr. Nicole Beck of 2NDNATURE is the lead consultant and has designed, managed and implemented an intensive and focused data collection effort on Santa Cruz County lagoons. Key team members include Dr. Ellen Freund, a research fishery biologist from the National Marine Fisheries Service (NOAA NMFS), Jeff Hagar, fisheries biologist of Hagar Environmental Sciences, Amy Little, M.S. ecologist, Michelle Shouse, M.S. (USGS) benthic invertebrate scientist and Department of Fish and Game (DFG) benthic scientist Jim Harrington. Donna Meyers of the National Marine Sanctuary Program (NOAA/NMSP), Kate Goodnight (Coastal Conservancy), Karen Christensen (Santa Cruz Resource Conservation District) and John Ricker (County of Santa Cruz Department of Environmental Health) provided invaluable direction on management and policy needs of the local resource managers throughout the CLEAP project to improve the integration of science with policy.

A Technical Advisory Committee (TAC) was convened for CLEAP to assist with the 2003 site selection process. The TAC represented the following agencies in its membership: NOAA Fisheries Habitat Branch, NOAA Fisheries Southwest Fisheries Science Center, California Department of Fish and Game, California Coastal Commission, Central Coast Regional Water Quality Control Board, California Department of Parks and Recreation, Monterey Bay National Marine Sanctuary, Santa Cruz County Department of Environmental Health, City of Capitola and City of Santa Cruz. The TAC provided technical advice regarding study design, commented on data analysis and provided constructive comment on CLEAP findings and recommendations. The TAC met six times throughout the three year time period of the project. The TAC assisted with lagoon selection, study parameters, study design features, and data analysis approach. Based on TAC recommendations, benthic macroinvertebrate sampling were added to the monitoring efforts. At the conclusion of the data collection, the TAC reviewed and commented on the stressors and indicator development and data analysis approach. Finally the TAC was convened to provide input on enhancement objectives for each of the study lagoons and comment upon the draft final project report.

Acknowledgements

CLEAP would not have been possible without the cooperation, contribution and volunteer efforts of many TAC members and local citizens. Donna Meyers (NOAA/NMSP), Kristen Kittleson (County of Santa Cruz Environmental Health), Gary Kittleson (Kittleson Environmental Consulting), Chris Coburn (NOAA/NMSP), Chris Berry (City of Santa Cruz Water Department), and Matt Baldzikowski (City of Santa Cruz Water Department) all volunteered to assist with CLEAP field data collection at various times throughout the project. Numerous field volunteers provided well-needed assistance with water quality and fish sampling throughout the project, namely Jeff Perez, Chris Adams, Tasia Balding, Alida Lindsley, Julie Cahill, and Kevin McCoy.

3. Problem Statement

WHY DO WE CARE ABOUT LAGOONS[i]?

California coastal lagoons have both a high human and ecological value in today's society, yet there is little question that the health of many Santa Cruz lagoons is currently below its achievable level due in large part to adjacent land use and inevitable human stressors. Lagoon systems are located at the interface of coastal streams with the ocean and thus are the terminal delivery point for pollutants generated within their respective watersheds. The location of these water bodies at the coast has a significant role in coastal water quality and the protection of recreational, cold water fisheries and other key beneficial uses. Water quality impairments common in local lagoon systems include elevated bacterial levels, low dissolved oxygen, increased algal growth, excessive sediment, and elevated nutrient levels. Posted health warnings due to elevated bacterial levels in the summer are common at beaches adjacent to San Lorenzo Lagoon, Aptos Lagoon, and Soquel Lagoon, as well as others (Ricker and Peters 2005).

From an ecological perspective, the life cycles of a number of organisms are adapted to the seasonal conditions within these lagoons. The species of special interest that utilize coastal lagoons as critical rearing habitat include the steelhead (*Oncorhynchus mykiss*) and, to a lesser extent, the coho salmon (*Oncorhynchus kisutch*). Steelhead were listed under the Endangered Species Act (ESA) as a threatened species on August 18, 1997; the threatened status was reaffirmed on January 5, 2006 and includes all naturally spawned populations of steelhead (and their progeny) in streams from the Russian River to Aptos Creek, Santa Cruz County, California (inclusive). Coho salmon were originally listed as threatened on October 31, 1996 and later upgraded to endangered status on June 28, 2005. The listing includes all naturally spawned populations from Punta Gorda in Northern California extending south to and including the San Lorenzo River in Central California. The highly-productive nature of the lagoon environment makes it a key component of the juvenile salmonid life. The tidewater goby (*Eucyclogobius newberryi*) was federally listed as endangered February 4, 1994. Endemic to California, the tidewater goby is found primarily in waters of coastal lagoons, estuaries, and marshes.

Loss of lagoon habitat, hydrologic modifications, lack of cover, increased predation, historic over fishing, and overall decline of ecological health have all contributed to the population reductions of these species in Santa Cruz County stream systems. Deleterious water quality conditions in the lagoons can result in fish disease, growth limitations and even deaths. The worst-case scenario of current local lagoon health is Pescadero Marsh in San Mateo County[ii]. Pescadero Marsh has been documented to experience annual fish and invertebrate die-offs coincident with the sandbar breach and draining of the summer lagoon since 1997 (CA State Parks 2004). The specific conditions leading up to the Pescadero Marsh kills are yet unresolved, but poor water quality, low dissolved oxygen (DO) and associated eutrophic conditions have been recently recorded in the closed marsh system (CA State Parks 2004). There is evidence to suggest other local lagoon systems are susceptible to similar inclement water quality.

The status of the threatened and endangered fish species in the lagoons is one of the reasons federal, state and local funding efforts have been targeted to improve the ecological health of California watersheds and associated lagoon systems. Aquatic resource enhancement must assist California lagoon systems to reach a new, sustainable, healthy equilibrium. Ecological diversity and long-term stability must be maintained, despite the inevitable accumulation of human stressors. Improvements in lagoon ecology should focus on understanding and enhancing the entire life-support system. Successful lagoon function enhancement will undoubtedly go hand in hand with increased habitat value and population enrichment for the critical species of concern.

IS OUR MANAGEMENT KEEPING UP WITH SCIENCE?

The terms “management” and “enhancement” are used throughout this document. The CLEAP team defines management as hands-on, continuing efforts within a lagoon system that are conducted with the intent of improving some predefined aspects of the aquatic system. Management efforts may or may not have physical, chemical and biological health as the primary objectives. For example, flood control management is not intended to improve the natural function of the lagoon system, but rather reduce the frequency and magnitude of localized flooding. The purpose of CLEAP is not to devise hands-on management alternatives for Santa Cruz lagoon systems. The CLEAP approach is focused toward improving our understanding of natural lagoon function and applying that knowledge to develop conceptual enhancement approaches to California lagoons. The difference between management and enhancement then is that enhancement efforts are physical, chemical or potentially biological changes introduced to the system with the intent of nudging the system to reestablish a new sustainable equilibrium given the inevitable human stressors. In contrast, management requires annual maintenance and manipulations to ensure that the objectives of the management plan are satisfied.

The ultimate goal of coastal lagoon enhancement should be to restore a sustainable and healthy ecosystem during both open and closed lagoon conditions. The resident biota have adapted to survive the seasonal variability within the coastal lagoons. It is during closed lagoon conditions when water quality problems are most likely to occur. The subsequent sandbar breach can cause both human health concerns at the neighboring coastal beaches and potential ecological concerns for the local biota due to episodic deleterious water quality conditions. The systematic identification of the stressors responsible for the development of deleterious water quality conditions during the warm months of the year will facilitate focused enhancement actions as we strive to restore coastal lagoon health. The CLEAP team by no means advocates summer lagoon breaching to reduce eutrophication and associated water quality issues. Rather the current challenge facing the natural resource managers, scientists and engineers is to enhance functional components of these systems that will make them less susceptible to eutrophic conditions.

Existing Santa Cruz County Lagoon Management/Enhancement

The only active lagoon management plan in the County is being implemented in accordance with recommendations in the 1990 Soquel Creek Lagoon Management and Enhancement Plan and the subsequent update of the Plan in 2004 (Alley et al. 2004). Managed by the City of Capitola, the mouth of Soquel Creek is manually closed each spring by the formation of a sand barrier with heavy machinery. The water level is maintained by a vertical concrete riser at the mouth, transporting excess freshwater to the coastal ocean via a buried pipe throughout the summer months of each year. Fisheries biologists with DW Alley & Associates and the city of Capitola oversee the closure activities to minimize impacts on resident biota and maximize the removal of organic detritus. Efforts are made to accelerate the physical conversion of the system to freshwater by a series of breaches and closures in concert with the tidal cycle. The lagoon remains closed until the first major winter rain event, when it is manually breached to prevent local flooding. Regular ancillary water quality testing and bird surveys are coupled with efforts to estimate summer/fall steelhead population numbers. These data are summarized in annual reports submitted to the City of Capitola (DW Alley and Associates 1992-2003). The 2004 Soquel Creek Lagoon Management and Enhancement Plan Update also includes recommendations for maintaining water depth and fish cover, minimizing summer water temperatures, and improving water quality of urban runoff. The long-term monitoring and implementation of the Management Plan has improved the adaptive management process for Soquel Lagoon and nearly 15 years of salmonid monitoring data and juvenile salmonid population estimates are available as a result.

Santa Cruz Watershed and Stream Enhancement

Over the past decade, numerous watershed enhancement and restoration plans have been developed, or are currently underway, for Santa Cruz County watersheds. The plans include recommendations for riparian restoration, fish passage improvements, bank stabilization, sediment source reduction strategies, and other efforts to improve primarily upstream watershed conditions for steelhead and coho salmon. In 2003, IWRP funded the design and permitting for many of these restoration recommendations throughout local watersheds and the implementation of these projects has been initiated. However, many of these plans focus on upstream issues due to a lack of resources to study the complexities of lagoon ecological health.

Through the IWRP program a large amount of resources are being allocated toward watershed enhancement and fish passage improvements. The large number of upstream restoration projects makes the CLEAP baseline data collection in high priority lagoons applicable for the evaluation of the success of these upstream and lagoon enhancement efforts in the years to come. The CLEAP establishment and documentation of detailed protocols will also be very useful as performance evaluations of enhancement efforts are expected. The data and observations from CLEAP will be used to improve our functional understanding of coastal lagoon function, increasing the integration between science and enhancement approaches and thereby increasing the effectiveness of valuable resources.

INTEGRATING SCIENCE AND ENHANCEMENT

Numerous recent peer-reviewed articles addressing the enhancement of coastal ecosystems argue that the scientific approach of assessment, restoration and adaptive management must be an interdisciplinary collaboration to truly improve our understanding of these systems (Cloern 2001, Boesch 2002, Fano et al. 2003, Lundberg 2005, Karr and Chu 1999, etc). Robert Wetzel, author of the well-accepted Limnology text (1975, revised 2001), is quoted:

> *"I argue that one cannot manage aquatic ecosystems effectively without understanding how they operate in response to interactions of physical, chemical, and biotic environmental factors. This insistence is analogous to the statement that one cannot effectively manage human health without understanding human physiological and biochemical interactions with environmental variables."*

The advancing study of ecological function integrates many scientific disciplines to facilitate a comparative analysis of the underlying mechanisms of ecosystem variability. Our understanding of coastal aquatic systems must combine hydrology, biogeochemistry, physical characteristics, and ecological interactions, from the base of the food chain through every trophic level. Even with improvements in the scientific approach to coastal ecosystem function, there remains a communication gap between researchers and resource managers (Nixon 1995, Cloern 2001, Lundberg 2005, Fano et al. 2003, Karr and Chu 1999, Wetzel 2001).

Existing Science on California Coastal Lagoons

Very little scientific information is available regarding the complex ecological function of Central California lagoons, with peer-reviewed publications limited to the nearby estuaries of Elkhorn Slough National Estuarine Research Reserve (ESNERR) and San Francisco Bay. Neither of these systems are representative surrogates for the typical small California coastal lagoon ecosystems that are prevalent along the California coast.

Unlike estuaries on the eastern seaboard, the wet winters and very dry summers of California result in dramatic differences in annual water circulation in these systems. In the winter, the lagoon channels are deltaic river mouths with extreme tidal and streamflow variations. Storm hydrographs result in episodes of sediment scour and deposition in the locations of lagoons well-connected hydraulically to the ocean tides and watershed streamflows. When streamflows and tidal swells recede in spring and summer, a sandbar barrier naturally forms at the mouth creating a backwater lagoon environment. The annual hydrologic variability of these lagoons makes them unique from typical estuaries, lakes or wetlands. Without a scientific understanding of seasonal lagoon function and the primary causes of water quality and habitat change, the identification of effective management and restoration alternatives may be ill-informed and future evaluations of effectiveness will be difficult to quantify.

“Grey literature” exists on specific aspects of local lagoons including salmonid assessments (DW Alley and Associates 1992-2003, Smith 1987 and 1990, HT Harvey and Associates 2003), benthic invertebrate sampling (Johnston 2005, Robinson 1993) and biogeochemical evaluations (Swanson Hydrology + Geomorphology 2001, 2002). The typical data collection in local lagoons has focused on one discipline (e.g., hydrology, benthic invertebrates, salmonid populations), spanned 1-3 years of data collection, and is usually limited to one lagoon system. Salmonid work conducted by J.J. Smith in the late 1980’s compared the salmonid habitat and utilization of four lagoon systems in north Santa Cruz/south San Mateo County locations (Smith 1987, 1990). In many instances, fisheries monitoring is accompanied by periodic vertical profiles of ancillary water quality parameters (i.e., DO, temperature, salinity, conductivity). However, the complex biogeochemical nature of lagoons results in extreme daily variations in many water quality parameters. The temporal variability of these systems is not well represented by monthly spot measurements, as they provide only a snapshot of the dynamic nature of these systems.

The lagoon environment is also present along the Southern California coastline, but again, the majority of lagoon research is reported in grey literature. Tetra-Tech (2002) conducted watershed modeling to assist with the development of the Malibu Creek nutrient total daily maximum load (TMDL). Ambrose and Orme (2000) produced a comprehensive Lower Malibu Creek and Lagoon resource enhancement and management report and Sutula et al. (2005) conducted a 2-year evaluation on the role sediment regeneration plays in supplying nitrogen (the limiting nutrient) to the primary producer communities in Malibu Lagoon for the Los Angeles Regional Water Quality Control Board (RWQCB). To date, there are limited published scientific resources addressing the complex biogeochemical and ecological function of California coastal lagoons.

Striving towards Quantifiable Adaptive Management

“Adaptive management rigorously combines management, research, monitoring, and means of changing practices so that credible information is gained and management activities are modified by experience” (www.google.com).

As the field of ecological restoration of aquatic systems progresses, there is an imminent need to develop reliable indicators to quantify the changes enhancement efforts have on the ecosystem in question. The incorporation of quantitative information about system function into management decisions will guide an effective “adaptive management” process. If clear, quantifiable goals are defined prior to enhancement and management actions, then post-implementation performance of a system can be measured. To define these goals, an understanding of the aquatic system components that are expected to respond to successful improvements is necessary. The possibility of measurable indicators of habitat improvements are numerous, but a few examples of quantifiable restoration project goals of a stream or lagoon system may include:

- For a bank stabilization project, a 15% downstream physical sediment load reduction 3 years post-project, as monitored by turbidity sensors and water grab samples analyzed for suspended sediment concentrations (SSC).
- A 15% reduction in the number of days when there are continuous 6 hour intervals of DO < 3 mg/L, as measured by dissolved oxygen sensors. Six years following implementation, the reduction of this chemical metric may be 25%. This goal would be a direct measurable indicator in a lagoon system following restoration efforts where water quality improvement was a priority goal.
- A 15% increase in the percent of the benthic invertebrate population that is salmonid prey, 3 years following an enhancement action with the specific goal of improving ecological integrity and habitat quality for salmonids.

As the long-term datasets are compiled for sediment load reduction, dissolved oxygen improvements, increases in biological performance indicators, or other specific indicators and associated performance goals, managers are able to evaluate the following:

- Is the restoration/enhancement meeting the intended physical, chemical, and/or biological goals? Are there measurable improvements to key components of the system?
- What adaptive changes can be made to the enhancement efforts to improve the performance of the key components characterizing the system in question?
- Are the quantitative improvement targets outlined at the onset of the project realistically attainable?

Decisions to modify existing conditions and continue improvements through adaptive management will then be based upon measurable parameters that have a documented physical, chemical or biological functional relationship to the broader project goals, rather than reliance on qualitative opinions of priority actions.

In order to approach natural resources from an adaptive management perspective the following questions must be addressed:

- What are the assumed causes, or stressors, impairing the health and function of the system in question? Which are the priority stressors? Which stressors can be realistically modified?
- What are measurable indicators of system function that will respond in a predictable manner to positive improvements to the above stressors acting on the aquatic system? Successful indicators are direct proxies to assess the function of physical, chemical or biological components of the system in question and, ideally, are cost-effective parameters to monitor over many years.
- What are the pre-restoration/enhancement values or conditions of the indicator parameters? In order to quantify success, pre-restoration (baseline) conditions must be documented for a collection of system parameters that are expected to respond to habitat changes. From existing conditions, realistic goals of expected enhanced condition characteristics can then be formulated.
- What are the standardized data collection protocols of the selected indicators (pre- and post-project) to ensure changes in indicator values over time will be the result of system changes, not sampling variability?

Only when resource managers have documented the ecosystem function of these specialized habitats can they apply these questions to prioritizing restoration and enhancement actions. According to Walters (1997), adaptive management should not be learning by trial and error, but learning by careful testing. Trial and error management is costly, time consuming and unnecessary. We believe CLEAP is laying the framework for effective restoration and adaptive management of Santa Cruz coastal lagoons, with applications to other lagoon systems throughout the state.

CLEAP has focused on prioritizing 4 project outcomes:

i. Collect, manage, present and interpret site specific and comparative physical, chemical and biological data to improve our understanding of Central California coastal lagoon function.
ii. Provide an extensive baseline dataset (as an MS Access database) and the associated sampling protocols to which future monitoring data can be compared as long-term watershed and lagoon enhancement measures are implemented.
iii. Prioritize data collection parameters, data interpretation methods, and data presentation techniques for future coastal lagoon monitoring based on the power of specific parameters to indicate lagoon habitat quality.
iv. Identify restoration and enhancement approaches to preserve and restore the ecological function of the study lagoons.

CLEAP has utilized the power of comparative analysis to improve our understanding of the physical, chemical and ecological function of California lagoon systems. We have aimed to measure and evaluate the consequences of human actions on lagoon ecology by discovering biological patterns that relate to anthropogenic stressors. The expansion of our knowledge concerning the primary causes of lagoon function decline will aid in the future guidance towards prioritization and development of successful restoration and enhancement actions.

CLEAP goals and objectives were defined at the project onset with the project team and TAC are provided in the following section.

Footnotes:

[i] An estuary is an arm of the sea that extends inland to meet the mouth of a river. A lagoon is a shallow body of water, especially one separated from a sea by sandbars (Webster's Dictionary). Technically these lagoon systems are estuaries when the sandbar is absent and lagoons when the summer sandbar forms and isolates the river mouth from coastal tidal action. Because CLEAP is focused on the function of these systems during lagoon conditions, these systems will be referred to as lagoons throughout this document.

[ii] Pescadero Marsh was not included in CLEAP for detailed study because the Coastal Conservancy grant is specifically for Santa Cruz County resources.

4. Goals and Objectives

Goal 1: Identify historical conditions of the study lagoons and discuss the extent of alteration due to land use changes and other human influences.

Objectives

1a. Analyze historic lagoon conditions relative to existing morphology.
1b. Document chronology of land use changes from aerial photography and historical information to identify impacts on lagoon conditions.
1c. Compile information on physical and chemical habitat conditions to reevaluate lagoon condition (pristine to highly impacted).

Goal 2: Utilize an array of habitat conditions to identify present-day ecological function (biological response to physical and chemical conditions) of the study lagoons.

Objectives

2a. Design a sampling plan that enables collection of data in a manner that allows comparison of conditions across lagoons.
2b. Identify the relationships between the physical conditions of each seasonal lagoon (including bar formation and stability, freshwater inflow, lagoon morphology, solar and wind exposure, water column stratification, and the extent of conversion to freshwater) and how these influence water quality and the biogeochemical processes in each lagoon.
2c. Identify the extent that water quality and the individual lagoon biogeochemical processes may be limiting habitat suitability and ecological health in each lagoon.
2d. Compile across-lagoon comparisons of nutrient inflows, primary production rates, phytoplankton communities, zooplankton communities, benthic invertebrate communities, and higher organisms (primarily steelhead) between lagoons. Determine if correlations can be drawn based on the respective physical and chemical conditions and the biological responses observed in each lagoon.
2e. Collect data on the types and relative abundance of fish present in the lagoon sampling locations, including data on the life cycle stage of the captured fish. To the extent possible, make estimates regarding rate of growth and residence times of steelhead and coho salmon in the lagoon sampling locations.
2f. Utilize ecological data to evaluate relative efficiency of energy transfer up the food chain in each lagoon.
2g. Identify biological parameters (i.e., biological indicators) that may display a dose-response to differences in habitat conditions (i.e., stressors).
2h. Determine if the CLEAP dataset maybe effectively characterized by an Index of Ecological Integrity (IEI).

Goal 3: Establish monitoring protocols and provide baseline data for future monitoring efforts to assess pre- and post-restoration conditions and to quantify future restoration success.

Objectives

3a. Document monitoring protocols so that they may be replicated in future study and monitoring efforts.
3b. Prioritize future monitoring parameters based on ability to indicate changes in lagoon system, simplicity of data collection analysis, and economic factors.

Goal 4: Identify restoration and enhancement approaches to preserve and restore the ecological function of the study lagoons.

Objectives

4a. Identify restoration and enhancement alternatives for the study lagoons and, to the extent feasible, for other lagoons that may have similar physical and chemical conditions.
4b. Make recommendations for a cooperative management approach between management and regulatory agencies.
4c. Identify future study needs.

5. Hypotheses and Constraints

The CLEAP data collection design aimed at understanding the complex interactions between the physical and chemical conditions of California coastal lagoons. Based on our current understanding of lagoon function, physical and chemical conditions that may have the potential to stress the local biota were used to develop quantitative stressor metrics. Lending from previous techniques, we identify biological indicators that have responded to these stressors. Both the stressors and indicators may be used as future management tools to assess habitat quality of other lagoon systems, as well as monitor the success of any restoration and enhancement efforts. Below are the primary hypotheses driving the CLEAP efforts, followed by the major constraints and limitations of the project. We acknowledge that many other hypotheses and constraints exist and are discussed throughout this report, but those provided below are the big-picture factors from which most other ideas or issues will stem.

HYPOTHESES

Hypothesis #1. Select biological components of California coastal lagoons vary in response to different degrees of human-induced stressors. The five lagoons selected for detailed assessment represent a range of human-induced stressors and thus various stressor conditions and indicator responses should also represent a range across lagoon conditions.

Hypothesis #2. The primary human-induced stressor influencing the ecology in the majority of Coastal California lagoon's is eutrophication.

Hypothesis #3. Summer and early fall are the times when water quality problems that influence lagoon ecology are most likely to occur, especially during times when circulation is reduced due to sandbar closure.

Hypothesis #4. Specific components of lagoon morphology, circulation, substrate, and hydrology make a lagoon system (or specific locations within a lagoon system) more susceptible to eutrophication, and its associated water quality problems, than others.

Hypothesis #5. Eutrophication results in primary and secondary effects that may affect all local trophic communities.

LIMITATIONS

Limitation #1. All environmental sampling techniques for physical, chemical and biological parameters have temporal and spatial limitations. There is inherent variability in hydrology, tides and climate on both short and long time scales. In addition, each lagoon is physically complex and both horizontal and vertical differences exist throughout the lagoon, resulting in a patchy biotic distribution. The CLEAP data collection and analysis efforts took all reasonable steps to ensure the most representative and consistent sampling of the subject lagoons, given available resources.

Limitation #2. The accuracy of our capability to distinguish between natural and human-induced variation in the data may be limited within the time scale of this study. Increasing the duration of monitoring over the long-term will improve the ability to differentiate between natural and anthropogenic variations.

Limitation #3. There are no pristine, undisturbed California lagoons without significant non-point nutrient sources, modified watersheds or modified lagoon morphologies. Neither is there a lagoon still operating within its natural morphology. A natural baseline index of biological integrity is unobtainable for phytoplankton, zooplankton, benthic invertebrate and fish communities in Coastal California lagoons. To compensate for the lack of a pristine endpoint, CLEAP hypotheses and indicator selection relies heavily on:

1. The extensive existing research on successful biological indicators in other systems,
2. The power of comparative analysis of similar functional systems (in this case lagoons) with varying degrees of human impacts (Karr and Chu 1999, US EPA 2002), and
3. Two complete seasons of CLEAP high-resolution spatial and temporal sampling in five summer lagoons with concurrent observations of physical, chemical and biological conditions.

6. Project Approach

Figure 6.1 presents a flow chart of the CLEAP process from inception to the development of lagoon enhancement recommendations. At the initiation of the project in 2003, the CLEAP project team created a matrix to rank Santa Cruz County lagoons from most impacted to least impacted. This matrix facilitated the selection of five lagoons for a detailed study that collectively would represent a range of ecological conditions in coastal lagoons in Santa Cruz County.

The relative location of the Santa Cruz County Lagoons is presented in Figure 6.2. CLEAP then utilized the power of comparative analysis along a human disturbance gradient to improve our understanding of the physical, chemical and ecological function of Coastal Californialagoon systems.

LAGOON OBSERVATIONS

Detailed data and information collection was utilized to document the complex interactions between physical, chemical and biological processes and improve our understanding of coastal lagoon function. The physical and chemical conditions existing in the lagoon and its respective watershed directly influence the water column conditions within which the resident biota exist. Thus, the biological communities will vary in response to the relative health and quality of their aquatic habitat. CLEAP efforts combine both the existing conditions observed within each lagoon over 2 years of intensive data collection and the statistical analyses of the causal relationships between lagoon stressors and indicators to document key processes that influence lagoon function. Below a discussion of stressors and indicators is provided, followed by a discussion of how other researchers evaluating the health and function of natural systems have used these tools.

STRESSORS AND INDICATORS

The interpretation and analysis of CLEAP 2004 and 2005 data is focused upon identifying statistically significant relationships between system stressors and indicators of habitat quality and biological integrity.

The majority of parameters selected for monitoring and evaluation are assumed either to:

1. directly or indirectly influence habitat quality and ecological health (**STRESSOR**), or
2. have the potential to serve as an biological **INDICATOR** to evaluate ecosystem health.

The isolation of the causes of ecological impacts (stressors) in Coastal California lagoons will guide effective enhancement decisions into the future. The best way to understand the biological response to a particular stressor would be to vary the stressor experimentally in frequency, duration and magnitude. By isolating and testing one potential stressor at a time, one could evaluate how sensitive the system is to an isolated parameter that causes biological stress. For example, a person has an allergic skin reaction. The doctor will vary the magnitude, frequency and duration of exposure to a variety of typical stressors known to cause skin rashes in order to definitively isolate the patient's allergy. One means to evaluate the sensitivity of the biology to various stressors is to develop empirical models and then vary the stressor and observe the system's response.

In lieu of modeling, multi-site observations along a gradient of potential stressors can be a powerful alternative design that still allows the testing of stressors to induce a biological response. The US EPA (2002) Wetland Assessment Manual suggests a targeted selection of sites along a disturbance gradient to investigate potential cause and effect relationships. CLEAP has implemented a targeted spatial

PHASE I

AUGUST 2003
CLEAP Scope of Work defined and accepted

AUGUST – OCT 2003
Wide array of data and information collection from 11 Santa Cruz County Lagoons (Figure 6.2) including watershed characteristics, water quality, primary producer communities, management issues, degree of modification etc.

OCT 2003 – JAN 2004
Developed Santa Cruz Lagoon Matrix using key lagoon parameters assumed to influence or indicate lagoon ecological health. Each metric was assigned a score (1, 3, 5) and 22 metrics were summed for Lagoon score. Lagoons are ranked from most impacted to least impacted.

FEB 2004
Santa Cruz Lagoon Matrix refined by project team and TAC, and documented in 2003 CLEAP Technical Report. Five Santa Cruz County lagoons, representing a range of habitat conditions, were selected for 2 years of detailed monitoring.

PRIORITY LAGOONS

• **Scott Creek Lagoon** • **Laguna Creek Lagoon** • **Soquel Creek Lagoon** • **San Lorenzo River Lagoon** • **Aptos Creek Lagoon**

PHASE II

APRIL – OCT 2004
Implemented summer/fall monthly extensive data collection in the 5 selected lagoons.

FEB 2005
Developed interim 2004 CLEAP Technical Report to review 2004 data, refine and communicate project objectives, and document sampling methods and protocols.

APRIL – NOV 2005
Continue extensive summer/fall monthly data collection in the selected lagoons.

NOV 2005 – MARCH 2006
Created MS Access Database of 2004 and 2005 CLEAP data. Contains nearly 1.25 million data points.

Documented existing conditions for 2004, 2005 and utilized these to develop and test stressors and indicators of lagoon health.

Held Technical and Management TAC meetings to communicate and refine CLEAP approach and findings.

PHASE III

APRIL 2006
Combined CLEAP technical findings with Santa Cruz County Lagoon enhancement needs to prioritize lagoons for enhancement options.

Developed conceptual lagoon management and enhancement recommendations for selected lagoons.

SEPTEMBER 2006
Released
DRAFT FINAL CLEAP REPORT.

Received, responded to, incorporated comments.

OCTOBER 2006

Produced FINAL CLEAP REPORT

SUMMARY OF CLEAP PROCESS

FIGURE 6.1

DESIGNED BY

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www.2ndnatureinc.com

PROJECT LOCATION MAP

FIGURE 6.2

monitoring design by the detailed monitoring of five different Santa Cruz County lagoons that were determined to represent a range of human impacts. The US EPA (2002) directs that habitat conditions and associated biological responses should be observed during times when potential problems might occur, thus CLEAP monitoring focused on the summer and fall when water quality conditions in lagoons are known to be relatively degraded and the lagoons are in a closed condition.

Estuaries are among the most dynamic aquatic environments on Earth, however the scale of natural variability in these systems is seldom defined or recorded. Using indicators, it is possible to evaluate the fundamental condition of the environment and its response to stressors without having to capture the full complexity of the system (Whitfield and Elliot 2002). Environmental indicators not only help track changes in an ecosystem, they also simplify the state of environmental reporting in two ways. First, indicators have a well understood meaning and can be measured regularly, yielding valuable information about important aspects of the environment. Secondly, environmental indicators can simplify communication of the biological data regarding the health of the environment (Australian and New Zealand Environment and Conservation Council 2000).

Below we present a detailed literature review, further defining potential stressors and indicators with respect to California lagoon function. The CLEAP team assumes each stressor and indicator is a metric, thus defining metric as a quantitative value to express a condition. In addition, the CLEAP team has documented some of the key processes and associated references in coastal aquatic science necessary to identify mechanisms that affect water quality, primary productivity, ecological diversity and community variability in coastal lagoons. The CLEAP efforts identify a list of potential stressors influencing lagoon function and biological indicators of lagoon health. These initial detailed data collection efforts can refine future lagoon assessments. The identified stressors and indicators will facilitate our ability to target specific function components of California coastal lagoon systems that can be evaluated pre and post enhancement efforts to fulfill quantitative adaptive management goals.

STRESSORS (INDEPENDENT VARIABLES)

System stressors, as we are using them, are the direct or indirect result of human alterations that are assumed to negatively influence biological integrity. Popular stressors used by rapid biotic assessments include watershed factors like percent impervious area, watershed population density and percent developed land in a watershed (Karr and Chu 1999, US EPA 2002). Percent imperviousness and other regional watershed-wide impacts are typically used for rapid bioassessments to assist managers with prioritizing locations for future management. These regional stressors represent the collective impact of human development on the receiving waters and may not necessarily identify specific problems that managers can utilize for decision-making. For example, percent impervious area represents the compounded impacts of watershed population density, hydrologic routing changes from impervious cover, potential increases in pollutant and sediment delivery to the receiving surface waters, and other anthropogenic changes that ultimately affect the downstream aquatic system. The determination that increases in percent impervious coverage within the contributing watersheds elicits decline in species diversity does not provide managers with a specific stressor that can be altered in order to improve habitat quality. What the managers gain is a knowledge that more urbanized watersheds, as expressed by percent impervious coverage, are more likely to need additional management attention to achieve ecological stability.

The extensive physical, chemical and biological dataset generated for CLEAP aims to identify both regional stressors across watersheds, as well as more site-specific stressors. Utilizing biological indicators that respond to specific stressors can better focus and guide management of our resources (Niemi et al. 2004). The most useful stressors will satisfy one or more of the following criteria:

1. The stressor displays a statistically significant causal relationship with an array of biological or habitat condition indicators. The power of the indicator is maximized when it can identify primary causes of ecosystem decline (Niemi et al. 2004).
2. The stressor can be directly measured and monitored to evaluate existing conditions and the future effectiveness of enhancement efforts designed to alleviate the stressor.
3. Quantifiable proxies of the stressor exist, allowing cost-effective long-term monitoring to evaluate the persistence of the stressor following enhancement.
4. The stressor may be directly modified during restoration and/or enhancement efforts.

Investigations that can identify the primary stressors causing ecosystem decline will guide future restoration and enhancement more effectively.

Eutrophication

A stressor assumed to be impacting ecological and water quality health in coastal Santa Cruz County lagoons is eutrophication. Eutrophication was defined by Nixon (1995) as “an increase in the rate of supply of organic material to an aquatic ecosystem”. Below we review the causes and effects of eutrophication, as well as components of aquatic systems that reduce an environment’s susceptibility to the impacts of eutrophication.

Primary Causes of Eutrophication: Nutrient Enrichment

Nutrient enrichment is one of the most pervasive problems identified in coastal waters and estuaries as a result of human development (Nixon 1995, Cloern 2001, NRC 2000, to name a few). Urban development, septic systems, residential fertilizers, animal waste, and agricultural land use are the primary non-point sources of nutrients to coastal waters, though many others exist. The science of the primary and secondary effects of nutrient enrichment in coastal waters continues to be developed and includes a wide array of scientific interactions and processes. The ecological and habitat effects of nutrient enrichment are complex and can include increased biological productivity, accelerated biogeochemical cycling, and ecological simplification.

Aquatic systems respond directly to nutrient enrichment with an increase in primary productivity, and organic matter loading is the result of photosynthesis by primary producers (organisms that utilize photosynthesis to convert inorganic matter to organic). Eutrophic environments have elevated rates of primary production due to the fertilization of the waters with nutrients that usually limit the rates of photosynthesis, primarily nitrogen (N) and phosphorous (P). Lake Tahoe’s renowned clarity is due, in part, to the historic lack of nitrogen and phosphorous needed by the primary producer community (Reuter and Miller 2000). One primary cause of the recent clarity decline of Lake Tahoe is the increased loading of N and P from stream erosion, disruption in natural soil-water interactions, fertilizer applications, atmospheric deposition, and the exponential increase in other human activities over the past 40 years.

In addition to N and P, other micronutrients (iron (Fe), silicon (Si), manganese (Mn), zinc (Zn)) are also required for plant, algal and phytoplankton growth. The relative needs of these micronutrients can vary by species. Light is another requirement of photosynthesis and primary production rates will be limited by available light. Thus, deep or turbid waters will have light limitations for algae, phytoplankton, submerged aquatic vegetation (SAV), or any other photosynthetic flora.

Photosynthetic rates increase exponentially with increased water temperature (Figure 6.3), explaining why eutrophication in coastal environments is more of an issue in summer versus winter. Nutrients, light and temperature directly affect the organic material input rates to an aquatic ecosystem (i.e., magnitude of eutrophication). These key variables will be referred to regularly throughout this report.

Effects of Eutrophication: Biogeochemical Cycling

EQ1 illustrates the conversion of inorganic nutrients into organic material as a result of photosynthesis. The conversion of nitrate (NO_3^-), ammonia (NH_4^+), phosphate (HPO_4^{2-}) and other nutrients to organic biomass ($C_{106}H_{263}O_{110}N_{16}P_1$) results in the decreased concentrations of these compounds in the waters where light is available. In most productive waters, the limiting nutrient is not detectable by standard analytical methods, or is at very low concentrations, because as soon as a few molecules are available, the primary producers utilize it immediately and produce organic matter. The N:P molar ratio[i] of coastal waters can be compared to Redfield's ratio to determine if the particular system is N or P limited (N:P (P-limited) > 16 > N:P (N-limited)). Source reduction management approaches to alleviate eutrophication should focus on controlling the supply of the limiting nutrient to the aquatic system in question.

$$\text{INORGANIC: } 106CO_2 + 122H_2O + 16NO_3^- (NH_4^+) + 1HPO_4^{2-} + \text{micronutrients} + \text{light}$$

$$\text{Respiration} \uparrow \; \downarrow \text{Photosynthesis}$$

$$\text{ORGANIC: } (C_{106}H_{263}O_{110}N_{16}P_1) + 138O_2$$

EQ1. Above is a balanced photosynthesis/respiration chemical reaction for aquatic systems. Photosynthesis is the conversion of inorganic compounds to organic material. The typical primary producer molar requirement of carbon:nitrogen:phosphorous (C:N:P) ratio is 106:16:1 (Redfield et al. 1963). Oxygen is produced as a result of photosynthesis. Respiration is the exact opposite of photosynthesis, where heterotrophic bacteria convert organic matter for energy and consume dissolved oxygen (DO) in the process.

EQ1 illustrates that photosynthesis produces oxygen, and respiration of organic matter consumes dissolved oxygen (DO). The production and consumption of oxygen is one of the most well-documented direct effects of eutrophication. No other environmental variable of such ecological importance to estuarine and coastal marine ecosystems has changed so drastically and quickly in locations around the world as DO. Oxygen concentrations can be supersaturated in aquatic areas where primary producers are active. In locations where (e.g., bottom waters) or at times when (i.e., night time) respiration activity exceeds photosynthetic oxygen input rates, nutrient concentrations can be elevated and dissolved oxygen levels will typically be below atmospheric saturation. The decomposition of an increased supply of organic matter often results "in depletion of dissolved oxygen (hypoxia) in stratified bottom waters at levels too low to sustain fishes and invertebrates" (Boesch 2002). Anoxia has been denoted as the cause of widespread water quality and ecological impacts throughout the world (Nixon 1995, Diaz 2001). Many invertebrate and fish species become stressed in low oxygen conditions (< 3 mg/L), making them more susceptible to diseases and death (Theede 1973, Diaz 2001). Fish, shellfish and benthic organisms cannot survive in anoxic conditions (DO=0 mg/L) for extended periods of time.

Changes in oxygen concentrations impact the biogeochemistry of other elements in the water column. For example, extreme daily variations in dissolved oxygen can alter the concentrations and availability of phosphorous, nitrogen and redox-sensitive[ii] trace metals. Daily variations in DO throughout the Elkhorn Slough water column during decreased circulation conditions can create similar daily changes in dissolved Mn, Fe, N and P species concentrations (Beck and Bruland 2000). Figure 6.4 presents the thermodynamic order of alternative electron sources that bacteria will utilize to continue to respire organic matter in an anoxic environment. Alterative energy sources for respiration include manganese oxide (MnO_2), nitrate (NO_3^-), iron oxide (FeO_3), and sulfate (SO_4^{2-}).

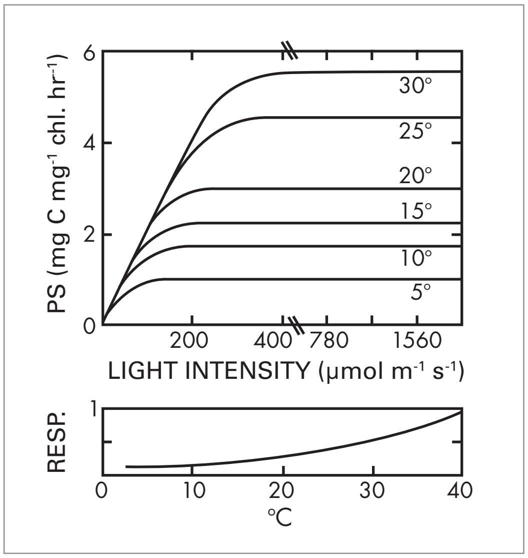


Figure 6.3. Primary Factors Limiting Photosynthesis
Light, nutrients and water temperatures are the primary factors limiting photosynthetic production. In the presence of a sufficient nutrient supply, photosynthetic production rates (PS) increase exponentially with increasing light availability and maximum production is limited by water temperatures. As water temperatures increase, the maximum respiration rates (RESP.) also increase. (Figure taken directly from Wetzel 2001.)

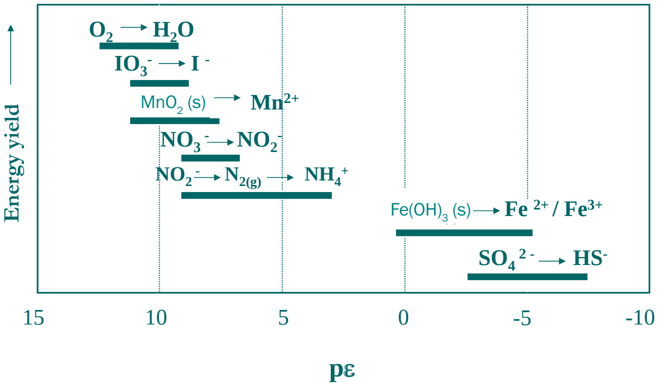


Figure 6.4. Thermodynamic Sequence of Energy for Respiring Bacteria
Heterotrophic bacteria respire organic matter utilizing O_2 as an energy source. When the oxygen supply becomes limiting, the respiring bacteria can utilize alternative energy sources to continue to convert organic matter to inorganic constituents. Each step down the table results in less energy per mole produced than when the bacteria consume O_2. This table indicates both the source of energy (i.e., oxygen, nitrate, sulfate) and the associated byproducts of the respective redox reactions (i.e., water, nitrogen gas and/or ammonia, hydrogen sulfide). (Figure taken from Beck and Bruland 2000.)

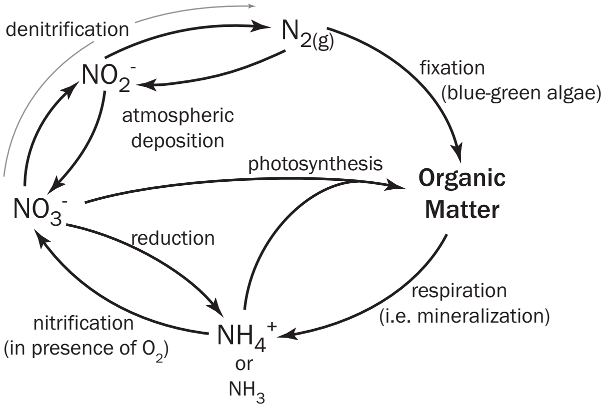


Figure 6.5. Nitrogen Cycle
Nitrogen is the limiting nutrient in most coastal waters and NO_3^- and NH_4^+ are both biologically available forms of nitrogen. In the absence of oxygen, bacteria will use NO_3^- (nitrate) as an energy source to respire organic matter (denitrification). Complete denitrification to nitrogen gas (N_2(g)) leads to a net loss of nitrogen from the system. The breakdown of organic matter recycles NH_4^+ from the biomass back into the water column, which can exacerbate eutrophic conditions, especially in anoxic waters. However, in the presence of oxygen, NH_4^+ will oxidize to NO_3^-, which is then available for denitrification and complete removal from the system. (Figure modified from Schlesinger 1991.)

Dramatic seasonal and daily variations of biogeochemical changes have been well documented in eutrophic coastal environments, including Elkhorn Slough (Beck and Bruland 2000, Caffrey 2004), Waquiot Bay on the Massachusetts coast (D'Avanzo and Kremer 1994), Chesapeake Bay (Boyton et al. 1996, Malone et al. 1996), South San Francisco Bay (Cloern 1996, Beck et al. 2002), and N.E. Greece Lagoons (Sylaios and Theocharis 2002) to name a few. Low dissolved oxygen and elevated ammonia (NH_4^+) and hydrogen sulfide (HS^-) concentrations have been documented to create toxic conditions and can result in episodic kills of resident organisms (Theede 1973, Officer et al. 1984, Seliger et al. 1985, Bagarinao and Lantin-Olaguer 1999, Luther et al. 2004).

Nitrogen cycling

From a biogeochemical perspective, the cycling of nitrogen in eutrophic environments can be very important. In many instances, primary production in coastal environments is limited by the supply of nitrogen. Figure 6.5 presents the complexity of the nitrogen cycle. Nitrate (NO_3^-) is the preferred form of N for primary producers, but ammonia (NH_4^+) is also biologically available. Photosynthesis results in the uptake of inorganic nitrate (NO_3^-) or ammonia (NH_4^+) and its conversion into organic matter. The respiration of organic matter (EQ1 and Figure 6.5) recycles inorganic ammonia (NH_4^+) and releases it into the water column. In the presence of oxygen, NH_4^+ will be oxidized to NO_3^-. The reduction of NO_3^- to inert nitrogen gas ($N_{2(g)}$) is termed denitrification. Denitrification can be important in N-limited environments because it results in a net loss of nitrogen from the system, which could directly reduce photosynthetic production in N-limited systems. However, the recycling of N (lack of denitrification and increases in ammonia concentrations) in an N-limited system can exacerbate eutrophic conditions due to increased biogeochemical cycling and availability of N for primary production. In addition, elevated levels of NH_4^+ (i.e., mM concentrations or > 14 mg/L) are known to be toxic to certain fish species (Bagarinao and Lantin-Olaguer 1999).

Sulfur cycling

When other sources of energy for respiration are depleted, sulfate (SO_4^{2-}) will be reduced (when available), resulting in the production and release of hydrogen sulfide (H_2S or HS^-) into the water column and pore waters (Figure 6.4). Sulfide toxicity has been observed in some fish species at micromolar concentrations (> 30 ug/L) (Bagarinao and Lantin-Olgauer 1999). Hydrogen sulfide present in the water can be extremely toxic to fish because it blocks oxygen transfer to the blood by binding to the ferrous component of hemoglobin (Theede 1973, Smith et al. 1977). Fish kills observed in coastal environments have been attributed to elevated levels of H_2S in the water column. Luther et al. (2004) suspect that H_2S may have a greater role in coastal fish kills than has been documented by researchers investigating causal factors. One of the limitations to monitoring H_2S levels in natural systems is that in-situ analytical methods were not well developed until recently and can be time-consuming, complex and expensive. Currently, the most cost-effective and sensitive in-field method to detect the presence of H_2S is the smell of "rotten-eggs".

"Filters" to Alleviate Eutrophication

The human induced changes to aquatic systems are a reality. We cannot avoid flood control needs or completely eliminate the inevitable nutrient enrichment of urban storm water within developed watersheds. Many researchers who study the impacts of nutrient enrichment on aquatic system function have identified site-specific differences that have made one estuary, lake, wetland or lagoon more vulnerable to eutrophication than others. There are inherent physical and biological attributes of aquatic systems that can act in concert either to increase or decrease the susceptibility of a system to nutrient enrichment (Cloern 2001). The specific conditions that may reduce the impacts of nutrient enrichment have been termed "filters" by Cloern (2001). Identification of these filters will greatly improve our strategic power to manage these *coastal* systems (Cloern 2001, Boesch 2002, Lundberg 2005). Beyond a community-wide commitment to long-term source control through best management practices, the key to successful future lagoon enhancement may be to find solutions that enhance those mechanisms or “filters” that reduce the susceptibility of coastal lagoons to eutrophication. Other researchers have shown that this susceptibility to nutrient enrichment can be reduced by altering circulation, nutrient uptake pathways, biological community assemblages, and physical morphology (Cloern 2001, Boesch 2002).

The CLEAP approach is focused on identifying the “filters” that make some lagoon systems less susceptible to nutrient enrichment than others. The effects of nutrient enrichment resonate far beyond the direct increase in organic input rates and can dramatically impact water quality, alter the community structure of all resident organisms, and ultimately degrade habitat quality and ecological health.

Water circulation

One key filter is circulation, which facilitates water mixing and exchange. Even subtle circulation in the form of water exchange can limit primary production rates and thus make a system less susceptible to the effects of elevated nutrient concentrations. For example,

- Circulation can reduce water temperatures.
- Circulation can bring oxygenated water to locations of high organic matter production.
- Circulation can dilute available nutrient pools.
- Circulation can reduce light availability.
- Circulation can increase denitrification rates, which is a direct net reduction in the available pool of N (the limiting nutrient in most coastal aquatic systems).
- Circulation can reduce the magnitude and stability of water column stratification.

The impact of circulation on primary production has been well documented by many researchers. Monbet (1992) found a strong correlation between the degree of circulation of any location in an estuary and the standing chlorophyll concentrations (a proxy for organic matter in the water column) for any given nitrate concentration. Separating locations or estuaries into microtidal (low circulation; < 2m tidal variation) and macrotidal (moderate circulation; > 2m tidal variation), Monbet (1992) found nearly 2 times more primary production in the microtidal estuaries when dissolved inorganic nitrogen (DIN)[iii] concentrations, the limiting nutrient, were the same (Figure 6.6).

Circulation has been deemed the primary cause of the extreme eutrophication differences observed between Chesapeake Bay and San Francisco Bay. While both estuaries have essentially the same annual N and P loading and standing concentrations, Chesapeake Bay does not experience the same magnitude or frequency of tidal flushing and freshwater inflows compared to San Francisco Bay (Figure 6.7). Cloern (2001) attributes the lower primary production (measured as chlorophyll a in Figure 6.7) in San Francisco Bay to reduced surface water temperatures and reduced light availability from turbid well-mixed waters. In contrast, Chesapeake Bay is highly eutrophic and possesses a number of associated water quality and ecological effects of eutrophication, including elevated chlorophyll levels and bottom water anoxia (Cloern 1996, 2001).

In poorly circulating waters, vertical salinity and/or temperature differences can result in stratification. A stratified water column results in isolation of the surface and bottom waters. A significant difference in the surface and bottom water temperatures and/or salinity values can act as a chemical barrier in the water column, periodically preventing chemical exchange across the vertical gradient. The relative stability and persistence of the stratification can depend on many factors, including the relative

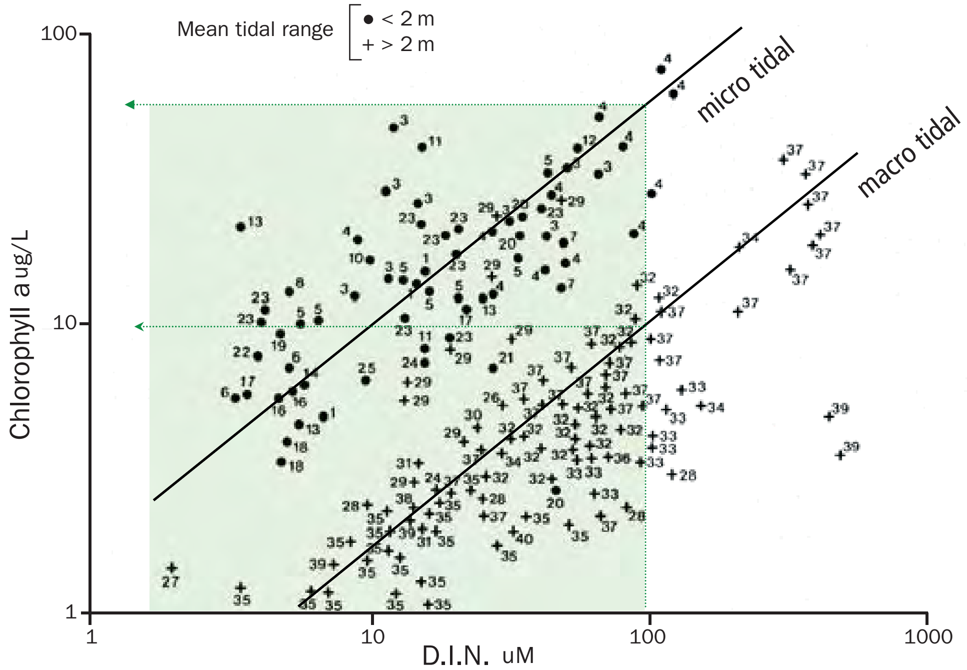


Figure 6.6. Circulation Effects on DIN-Chlorophyll a Relationship

Example of a biological response (measured as chlorophyll a) to increasing dissolved inorganic nitrogen concentration (DIN), observed in estuaries across the world. Closed circles represent the DIN and associated chlorophyll a for microtidal estuaries and plus signs are observations in estuaries with relatively higher daily circulation (macrotidal). Best fit lines indicate that nearly an order of magnitude more primary production is observed in the poorly mixed estuaries, given the same DIN concentration. (Figure modified from Monbet 1992.)

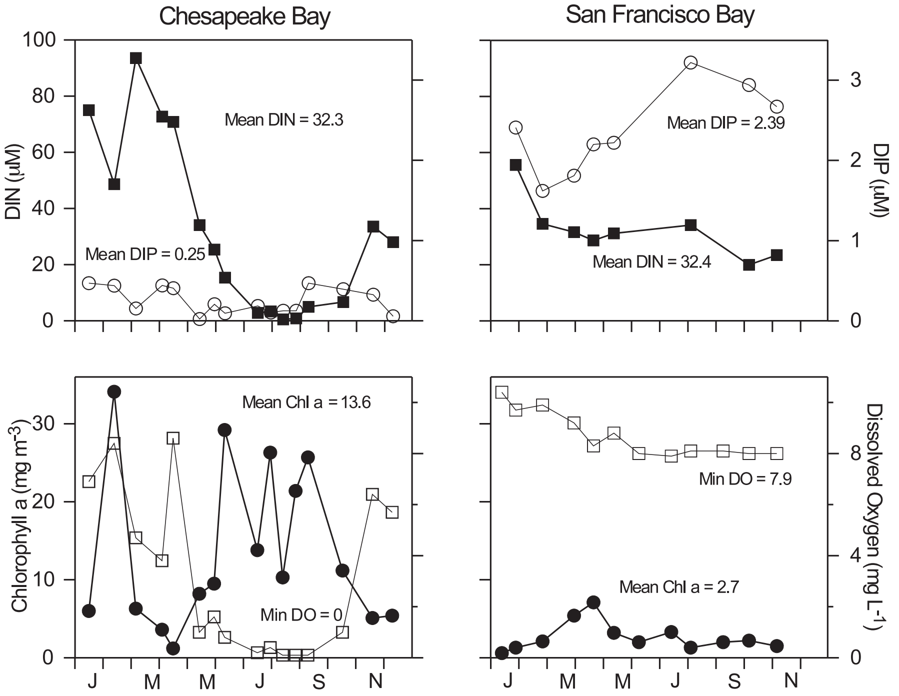


Figure 6.7. Comparison of Water Quality in Chesapeake and San Francisco Bays

Seasonal changes in water quality constituents of the Chesapeake Bay and northern San Francisco Bay for the year 1997. Upper panels show monthly measurements of dissolved inorganic N (DIN) and P (DIP) in surface waters; bottom panels show near-surface chlorophyll a concentration and dissolved oxygen (DO) concentration in bottom waters. Notice similar DIN and DIP concentrations, but very different primary production and DO conditions. The elevated primary production in Chesapeake Bay is attributed to the relatively calmer waters of this system, making it more susceptible to eutrophication. Data are from the Chesapeake Bay Program Monitoring station 3.3C (http://mddnr.chesapeakebay.net/eyesonthebay/index.cfm) and the US Geological Survey Station 9 in northern San Francisco Bay (http://sfbay.wr.usgs.gov/access/wqdata). (Figure taken directly from Cloern 2001.)

magnitude difference of the thermal or saline conditions, water circulation or climatic factors. One of the largest concerns with stratified aquatic systems is that the oxygen reservoir produced in the surface waters by photosynthesis and through exchange with the atmosphere may not be available to the respiring bacteria at the sediment-water interface. This can result in critical bottom water quality conditions, including low dissolved oxygen, elevated ammonia levels, and elevated hydrogen sulfide levels. Stratification can stress bottom water quality in systems that may not have excessive primary production rates. In highly eutrophic systems, stratification will further exacerbate bottom water quality degradation, but stratification is not necessary for respiration to exceed the available supply of oxygen where a large amount of primary production occurs.

Circulation can also increase denitrification rates in eutrophic systems. Denitrification (Figure 6.5) occurs when respiration rates by bacteria exceed the available supply of oxygen and the bacteria utilize nitrate as an alternative energy source. Ammonia released from respiration must be oxidized to nitrate for denitrification to occur. Thus water exchange and the introduction of oxygen to locations of respiration will reduce ammonia recycling rates by biota and result in N concentration reductions. From a management perspective, enhancing physical and chemical mechanisms that promote the removal of the limiting nutrient is a desirable outcome.

A local example of the effects of circulation on denitrification capacity is a study conducted by Caffrey et al. (2003) in Elkhorn Slough. The researchers compared the denitrification rates at well-mixed tidally-influenced locations to those observed at hydrologically constricted sites within the Slough. They found that the better circulating locations where there was an intermittent supply of oxygen to the surface sediments displayed 25% greater denitrification rates than those locations where circulation was poor and water residence times were relatively longer. Caffrey et al. (2003) applied the well-known biogeochemical principals to a natural environment, documenting that the delivery of O_2 (as supplied by water exchange) to locations of elevated NH_4^+ will oxidize ammonia to NO_3^- and facilitate the completion of the denitrification cycle (Figure 6.5). Again, denitrification can be considered a positive feedback where the available supply of DIN is reduced as N_2 gas is lost from the system.

Poor circulation has been blamed for the recurring fish kills in dead-end canals located in the Delaware Inland Bays (Luther et al. 2004). The regional nutrient enrichment effects were exacerbated in narrow deep channels where water residence times were extended, stratification persisted and surface water temperatures became elevated. Calm summer conditions were associated with the development of bottom water anoxia and elevated H_2S concentrations in these constricted locations. Summer storm events mixed the water column, suspending toxic levels of H_2S and causing fish and invertebrate die-offs. Control sites within Delaware Bay had relatively open water, shallower morphology and, thus, lower hydraulic residence times and less dramatic stratification. These sites did not experience the same magnitude of H_2S concentration buildup and the associated conditions compromising the health of the local biota during mixing events (Luther et al. 2004).

Physical morphology

Physical morphology has been dramatically altered at the land-sea interface throughout the world to expand the surface area of coastal development, agricultural activities and other anthropogenic land use needs. California has lost an estimated 91% of its original wetland surface area (Dahl 1990). Physical morphology is a key component to differences in localized water circulation and horizontal mixing. The morphology of aquatic systems is a physical component that can be altered by restoration and enhancement actions in coastal bays, wetlands, estuaries, and lagoons.

The direct cause of eutrophication and associated water quality problems is an excess of biologically available nutrients. The susceptibility of an aquatic system to eutrophication can be highly dependent upon the frequency of water circulation, exchange and mixing, which, in turn, can be dependent on the morphology of the system. Many site-specific examples with observed high susceptibility to eutrophication possess reduced water exchange characteristics relative to other locations within the same system. The morphological characteristics differed from the rest of the system, but these sites are subject to the same upstream land use conditions and incoming water chemistry as other locations (Beck and Bruland 2000, Cloern 2001, Caffrey et al. 2003, Luther et al. 2004).

Sutula et al. (2005) conducted an investigation in Malibu Lagoon to compare the importance of sediment remobilization and exchange of nutrients with surface waters relative to the loading of other non-point nutrient sources to the lagoon. They estimated 18% of the annual nitrogen load (limiting nutrient) was from biogeochemical recycling at the sediment-water interface, and recycling rates were higher where organic detritus accumulation was greater. Sediment analyses supported the linear dependence of the concentration of total nitrogen (TN) with decreasing grain sizes of the lagoon substrate (Figure 6.8). In locations where coarser material was the predominant substrate, the relative supply of biologically available N (from respiration and partial denitrification) during the summer growing months was much less. The locations where the substrate was dominated by organic detritus were where shear bed velocities and sediment scour were muted during storm flow events through the lagoon. Again, significant differences in the magnitude of eutrophication were observed at separate stations within the same system (in this case, lagoon). These biogeochemical differences can be attributed to differences in morphology that result in hydraulic variations.

Freshwater inflow

When considering the life cycle of anadromous fish populations, the availability of instream flows during the dry months of the year can be a critical component of their survival. Fish seeking refuge from inclement waters in the lagoon will need to migrate upstream when the sandbar is closed and insufficient instream flow can prevent migration and/or limit lagoon habitat and water volumes. Below we provide existing knowledge and additional questions that are addressed using the CLEAP dataset to improve our understanding of the role of freshwater on lagoon function:

- The freshwater inflow into a closed summer lagoon will likely transport relatively cooler water to the lagoon and provide some water circulation at the lagoon/stream interface.
- Freshwater inflow is necessary to convert a brackish lagoon to freshwater.
- Can a uniform freshwater column of a coastal lagoon be considered a “filter” to reduce the susceptibility of the system to eutrophication?
- Freshwater inflow volumes may not be the only factor influencing conversion to a freshwater column. We suspect site-specific morphology, lagoon bed elevation, proximity to ocean, location exposure, or other factors also influence the persistence of saline waters, and thus stratification, within a lagoon.
- Does the conversion of a lagoon water column to freshwater alleviate all inclement water quality problems associated with eutrophication in coastal lagoons?

All of the CLEAP streams have had historic and existing streamflow extractions that reduce the streamflow discharge into the summer much below natural levels. However, residential, commercial and agricultural water supply needs are a reality of an urbanized society. The natural resource management challenge is to identify enhancement options that enhance and maintain ecological integrity in the context of inevitable human stressors.

Toxicity Effects

In industrial and heavy agricultural locations, chronic or acute exposure to toxic chemicals can have significant impacts on species survival and subsequent ecological structure. It remains undetermined if sources of mercury, pesticides, herbicides or other organic chemicals could be a secondary impact on the biology of the selected CLEAP Santa Cruz lagoons. The potential for toxicity effects on lagoon ecology should be evaluated and considered on a lagoon by lagoon basis depending upon watershed land use and potential sources of toxic compounds. Review of current water quality studies that included analysis of toxicity provided the following information.

- Elevated DDT and chlorodane levels were recently observed in mussels planted at the mouth of Laguna Creek and at “The Hook” (a surf spot at the end of 41st Ave in Capitola) (CClean 2005), suggesting that local sources of organic pollutants still exist.

- The north county lagoons, Laguna and Scott, both have agricultural sites in close proximity to their respective creek and lagoon. Other than potential contaminants associated with agricultural activities, there are no documented current point sources of trace metals or organic pollutants in the primary CLEAP lagoons.

- The Salz Tannery had historically released elevated levels of toxic ^{6}Cr (chromium VI) directly into the surface waters of San Lorenzo River (Abu-Saba 1998), another potentially toxic trace metal that can cause ecosystem simplification. The Salz tannery has been out of operation since 2001.

- Trace metals and organics persist predominately adhered to sediments, and the dramatic amount of annual sediment mobilization and reorganization in the flood-controlled Santa Cruz county lagoons makes long-term persistence of these chemicals at toxic levels today questionable.

- Urban areas are known to accumulate elevated levels of trace metals ((copper (Cu), zinc (Zn), lead (Pb), mercury (Hg)) in stormwater that can be toxic to aquatic organisms (Nichols et al. 1986).

- Both non-point and point sources of toxic trace metals and organics to the local lagoons have been significantly reduced over the last few decades.

- The California Department of Fish and Game (DFG) and Central Coast Regional Water Quality Control Board (RWQCB) conducted a bioassessment on 14 California coastal lagoons from Waddell Creek in Santa Cruz County to Carpinteria Creek in Santa Barbara County (CA DFG 2001). The goal of the assessment was to define benthic invertebrate metrics along a sediment contamination gradient in the freshwater locations just upstream of the associated lagoons. The data did not support a strong group relationship between sediment organic and trace metal contamination and biological endpoints. Some of the lagoons included in the DFG study have much greater potential for sediment contamination than the CLEAP lagoons, based on existing and historic upstream land use practices. The DFG researchers suggest the disconnect between pollutants and biotic integrity could be a product of other overriding stressors or physical/habitat differences between sites and recommended quantifying and testing other stressors, such as various land use practices or water flow augmentation with the biological metric values. The CLEAP team suggests the other significant stressors influencing California lagoons are associated with eutrophication.

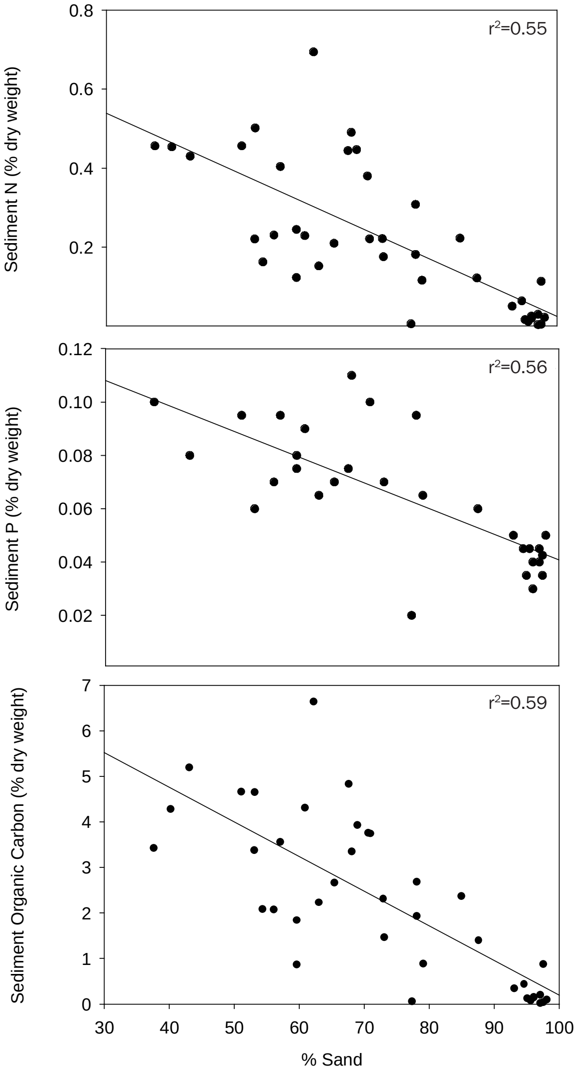
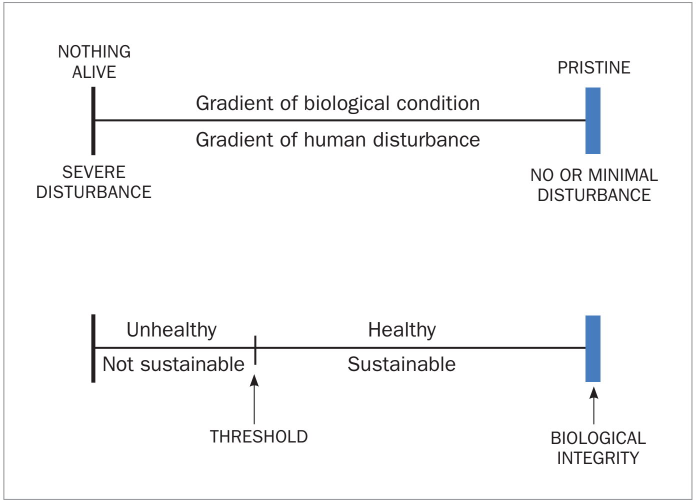


Figure 6.8. Sediment Grain Size and Nutrient Content
Sutula et al. (2005) illustrate the decreasing content of organic carbon, nitrogen and phosphorous as grain size increases from clay to silt to sand in the sediments of Malibu Lagoon, CA. Nutrient and carbon content in sediments consistently increase with decreasing grain sizes in most aquatic environments due to the larger surface area of smaller particles.

Figure 6.9. Continuum of Human Influence on Biological Condition
At one extreme of habitat quality, conditions are so severe nothing is living. At the other extreme, nature is free of human impacts and the community structure and species composition is "natural". As the magnitude, frequency and/or duration of stressors on the ecosystem vary, different organisms will be more adapt to the specific environmental conditions. Changes in the biological assemblage can either progress along a gradient, showing a consistent change with variations in the associated stressors (top), or there is a threshold condition that, once crossed, will dramatically alter the biotic integrity of the system (bottom). (Figure from Karr and Chu 1999.)



CLEAP STRESSORS

The existing physical and chemical data collected from CLEAP lagoons has been used to create metrics (quantified values and/or proxies) for a wide array of potential stressors impacting or limiting ecological health. These stressor metrics range in type from watershed land use, lagoon morphology, hydrology, circulation, and climate to the nutrient, physical and chemical conditions of the lagoon water column. A full list and discussion of CLEAP stressors is presented in Section 10. The stressors can be used to identify primary components of lagoon systems that may limit habitat quality.

WHAT IS A BIOLOGICAL INDICATOR OF ECOLOGICAL HEALTH?

The simplification of native ecological communities is well documented as a secondary effect of eutrophication and can be attributed to the competitive advantage of tolerant organisms possessing physiological mechanisms to survive in stressed conditions. CLEAP data collection has assumed that the spatial and temporal occurrence of eutrophication (and its associated effects) in Santa Cruz County lagoons will be marked by concurrent modifications to phytoplankton, zooplankton, benthic and fisheries communities. Because of the direct connection between stressors and ecosystem changes, biological measurements make ideal indicators of ecosystem health.

In the last decade, there has been an emergence of management tools that rely on biological indicators to aid in the assessment of ecosystem health. The development of indices that incorporate biological measurements to complete habitat assessments has been widely accepted by government resource agencies (US EPA, NRC, DFG, etc). Over the past decade, environmental monitoring has shifted from a narrow focus on chemical conditions to also include biological/ecological measures. These biological/ecological measures are components of the system that vary in predictable ways depending on habitat quality. The premise of the selection and monitoring of biological indicators is that “the most effective measure of the integrity of a water body is the status of its living systems” (Karr and Chu 1999). The general approach of utilizing biological attributes from a variety of trophic levels to indicate ecological health has been applied to hundreds of natural environments throughout the world by different researchers (Table 6.1). An academic journal entitled *Ecological Indicators* was established in 2001 in response to the need to integrate the monitoring and assessment of ecological and environmental indicators with management practices (see http://www.environmental-expert.com/magazine/elsevier/ecolind/). According to many, the future of assessing environmental quality and the relative success of enhancement efforts lies in development and implementation of biological indices.

Throughout the CLEAP process we refer to ‘ecological health’. Karr and Chu (1999) suggest that good ecological health implies a sustainable network of biota that is balanced and integrated. A sustainable ecosystem has established dynamic equilibrium and, while short-term variations may exist, all levels of the trophic structure are balanced and can recover from any reasonable disturbances. When the disturbances make an environment intolerable for sensitive species, ecosystem simplification occurs and native species (usually those intolerant to stress) are removed from the food web. Figure 6.9 is taken directly from Karr and Chu (1999) to illustrate the idea of a disturbance gradient or threshold, where some level of impacts to an aquatic system can be tolerated by the biota because the ecological system is resilient and healthy. However, at some point the stressors overwhelm biological equilibrium and a change in community structure occurs. At the extreme end of disturbance, nothing is living, while in the intermediate, exotic opportunistic species may replace the natives. This impacts nutrient and energy dynamics, alters food transfer between trophic levels and fragments populations. These biological changes associated with a range of disturbances are measurable and can be used as indicators to monitor ecosystem health.

Table 6.1. Examples of the array of natural environments and taxa utilized as successful biological indicators of ecosystem health. This is not meant to be an exhaustive list, but rather provide quality research examples of the multitude of biological groups used to indicate the health of a variety of aquatic environments.

Resource type and location	Trophic level	Reference
Estuaries		
Chesapeake Bay	Benthic invertebrates	Weisberg et al. 1993
San Francisco Bay	Phytoplankton	Cloern 2001
South Africa	Fish	Harrison & Whitfield 2004
Spain	Benthic invertebrates	Borja et al. 2000
Lagoons		
Italy	Primary producers, Benthic invertebrates	Fano et al. 2003
Southern France	Macro-algae	Mouillot et al. 2005a
Southern France	Fish, Benthic invertebrates, Macro-algae	Mouillot et al. 2005b
France	Macro-algae	Bachelet et al. 2000
Lakes		
Switzerland	Phytoplankton	Bürgi & Stadelmann 2002
Denmark	Fish, SAV, Chlorophyll a	Sondergaard et al. 2005
Fresh water streams		
Southern California	Benthic invertebrates	Ode et al. 2005
Mid-Atlantic	Macro-invertebrates	Klemm et al. 2003
New South Wales, Australia	Fish	Harris & Silveira 1999
Tennessee Valley	Benthic invertebrates, Fish	Kerans & Karr 1994

Many ecologists draw a parallel between biological monitoring to protect water resources and tracking personal health or national economies. Measuring personal health or the economy is nebulous, so we use indicators to assess condition, such as body temperature, blood pressure, lung capacity, inflation rates, consumer price index, and unemployment rates. The doctor or economist does not rely on only one of these indices to assess human or economic health, but rather multiple measures to give a more accurate diagnosis. The same is true for ecological health. A number of independent, sensitive indicators should be used in concert to assess and track biological integrity and ecosystem health.

BIOLOGICAL INDICATORS (DEPENDENT VARIABLES)

The most valuable indicators illustrate the link between the observed biological response and the cause of change.

Using the power of multi-site observations across a disturbance gradient, biological measurements can be compared from different site conditions in order to identify successful biological indicators of lagoon health. Successful biological attributes that provide reliable and predictable signals about resource conditions are desired. The selection of an indicator begins with an understanding of the natural history, ecological principles and the potential effects of the primary stressors on the system in question.
The indicator must then be tested to evaluate if it responds systematically to a range of the assumed stressors. A successful biological indicator will display a quantitative change across a range or gradient to one or more stressors. Ideal biological indicators should:

- produce specific and predictable responses to changes in habitat quality,
- be sensitive to a gradient of physical, chemical and/or biological factors , and
- be relatively easy to measure and interpret.

To properly evaluate and monitor ecosystem health a number of successful indicators should be used collectively. The collection and assimilation of a number of indicators from one type of natural environment is termed a multi-metric index. An Index of Biological Integrity (IBI) is the most well known multi-metric biological index, though many variations of biological indices have been developed. The CLEAP efforts identify potentially successful stressors and indicators of lagoon systems, but do not integrate the values of each indicator to develop a multi-metric biological index for the CLEAP lagoons. The CLEAP findings will be useful for a future IBI of coastal lagoons.

The collection of indicators used to assess a specific environment should represent an assemblage of key biological processes, trophic level interactions and habitat quality. Many researchers have identified biological attributes from a variety of taxa that successfully characterize ecological condition. Below we provide general biological indicators that other researchers have used to indicate ecological health along a disturbance gradient for a variety of taxa (Karr and Chu 1999, Fano et al. 2003, Ode et al. 2005, Weisberg et al. 1993, and all referenced in Table 6.1):

- measures of biodiversity including species richness and taxonomic composition,
- relative abundance of tolerant or intolerant (sensitive) species,
- biomass variations,
- abundance and/or productivity of functional groups,
- feeding relationships among trophic levels, and
- abundance and/or productivity of “key” species.

Many groups of organisms have been proposed and used as indicators of environmental and ecological change (Table 6.1). Although no single group is favored by all biologists, it appears that fish, macro-invertebrates, and primary producers have received the most attention in aquatic systems. CLEAP tested the possibility of various biological indicators from phytoplankton, zooplankton, benthic invertebrates and fish to indicate California coastal lagoon health.

The stressors have been selected with the hypothesis that each stressor value across CLEAP lagoons will represent a range of values. When relying upon the response of biological indicators to system stressors, the focus of monitoring is to detect changes in the indicator values that are the result of varying intensities of the specific stressor. A significant limitation in our reliance on successful biological indicators is in the difficulty in resolving variation due to natural variability and those due to human impacts. Long-term datasets will allow us to distinguish effects of anthropogenic influences versus natural climatic and physical variations, but in a relatively short-term study like CLEAP, some uncertainty will persist due to the complexity of nature.

POTENTIAL BIOLOGICAL INDICATORS FOR CLEAP

Below we provide a review of biological indicators and community characteristics that the CLEAP team (including consultants, clients and TAC) believes are applicable to aquatic habitat quality of Central California lagoons. In general, the biological indicators explored for CLEAP focus upon species diversity, species richness, dominance of tolerant or intolerant species, and percent community composition of key feeding groups within each of the four primary biological groups investigated: primary producers, zooplankton, benthic invertebrates, and fish.

Primary Producers

A primary producer is any organism that utilizes photosynthesis to convert chemical energy to organic biomass. All primary producers have minimum requirements for growth, namely water, light and nutrients. Thus, variations in the physical and chemical conditions within a lagoon will select for different distributions of the primary producers that compose the base of the food chain. The primary producer community assemblage can have a profound effect on the water quality and habitat conditions in aquatic environments, which will affect higher trophic levels. Many researchers have shown the community assemblage of primary producers in coastal environments is an indication of the habitat quality and resource availability (Duarte 1995, Cloern 2001, Lundberg 2005).

Supported by previous observations and studies throughout the world, Duarte (1995) presents the theory that the dominant primary producers in an aquatic system respond to increased nutrient loading through a shift from slow-growing sea grasses to large macro-algae to fast-growing macro-algae to phytoplankton domination. This shift in vegetation along the available nutrient gradient is due to the ability of each class of primary producers to compete for the potentially limiting resources (light and nutrients[iv]). SAV species are rooted in the sediments and can obtain a significant portion of their nutrient requirements from the sediments themselves, as well as through efficient internal nutrient cycling. SAV species, such as slow-growing grasses, have lower nutrient requirements (per dry weight of biomass) than rapid-growing algae or phytoplankton; thus in shallow clear waters with low nutrient concentrations, SAV species will thrive and dominate the primary producer community (Duarte 1995). From a management perspective in a coastal system, SAV is a preferred dominant species because the flora is relatively long-lived and generates much less organic detritus for the respiring bacteria community than fast-growing macro-algae and phytoplankton. SAV also offers habitat for fish and invertebrates, including refuge and spawning habitat. Scientists have observed coincidental changes in the coastal ecosystem fauna as a result of SAV loss driven by eutrophication (Dexter 1985). When the rapid blooms of macro-algae and phytoplankton occur in the surface waters, light availability to the SAV species rooted to the substrate is reduced. Nutrient-enriched systems dominated by free-floating algae and/or phytoplankton will inhibit the light availability for SAV communities, thereby further selecting for the dominance of the surface-floating species. The increased frequency of blooms by algae and phytoplankton during eutrophication are associated with high respiration rates (as bacteria metabolize the organic material associated with the dead algae and phytoplankton that sink to the sediment) and reduced dissolved oxygen levels in the bottom waters of aquatic systems.

> “*As a combined result, nutrient and carbon recycling is much faster in systems dominated by phytoplankton and ephemeral macroalgae than in those systems dominated by SAV and slow-growing macroalgae*” (Duarte 1995).

Preliminary observations of Santa Cruz lagoons in 2003 showed a range of primary producer communities across the County. Many of the urban and more impacted systems appeared to be dominated by ephemeral macro-algae and phytoplankton. In contrast, the systems that were assumed to be less impacted by human development had more SAV.

Phytoplankton

Detailed phytoplankton community assessments were included in CLEAP due to the very short life cycle of these organisms (order of days) and the potential for these communities to respond quickly to changes in habitat quality. We suspect that community composition, relative distribution of phytoplankton species, and phytoplankton biomass all have potential to indicate the health of the lagoon’s food chain base. All species of phytoplankton have optimal growth conditions, requiring certain salinity conditions, temperature range, nutrient regime, light levels, pH, and system stability. Other organisms are able to gain access to this energy by consuming the phytoplankton and assimilating the nutrients. The organisms of higher trophic levels then excrete nutrients into the water, which are used by phytoplankton or microbes. Ultimately the phytoplankton form the base of the trophic pyramid, and it would appear that they have some control on the relative abundance of all other organisms.

A stable phytoplankton community will be relatively diverse and should consist of at least 15-20 species (D. Hunter pers comm). We also suspect a more stable lagoon will have a greater diversity of phytoplankton groups present. There is no assertion that more species suggests greater stability, but a simplified community structure dominated by a small number of species indicates dominance by opportunistic organisms, potentially limiting the energy transfer potential to higher organisms. Preliminary observations in CLEAP lagoons suggests the phytoplankton community assemblage in coastal lagoons represents a wide array of species distribution, density and cell sizes. These variations can be captured by the creation and testing of a variety of metrics to express the relative differences in the phytoplankton communities observed across the CLEAP lagoons.

There are two primary limitations associated with utilizing phytoplankton as biological indicators. First is the potential variation of these communities within each lagoon. The quick response of phytoplankton to available resources, coupled with their relatively short life cycle, can make these communities fairly transient across a particular lagoon. The phytoplankton sampling strategy of a lagoon composite from 5 distinct stations was implemented to capture some of the lagoon variability. In addition, top down grazing pressures on phytoplankton communities are continuous. The presence of desirable phytoplankton species are likely reduced by consumption preferentially over less desirable species. These top down pressures likely influence the species composition represented by sampling. Early morning phytoplankton sampling, prior to maximum feeding times by zooplankton, may have reduced the grazing effects on the samples.

Zooplankton

Zooplankton, a primary consumer, is an essential link between algal populations, which use light and nutrients, to larger organisms (e.g., salmonids and invertebrates), which feed on zooplankton. Zooplankton populations are essentially controlled by three factors: temperature, food availability and predation (Downing 1984). As a primary consumer, zooplankton is near the base of the food chain and has a relatively short life cycle, with organisms living on the order of weeks. The short life cycle of zooplankton makes them a potentially effective biological indicator of any shifts in their immediate environment (e.g., increases in nutrient loading, management fish additions or removals, water chemistry fluctuations, or hydrologic changes).

The zooplankton community link to both primary producers and organisms higher in the food chain make it difficult, without careful examination, to extract a complete picture of which dynamics are driving the influence on one another. Researchers have designed experiments to demonstrate how population controls are exerted on zooplankton communities from either trophic pressure above (i.e., predation) or below (i.e., food supply). In recent years, zooplankton studies have shifted from characterizing species and populations in individual systems to describing whole system functionality of zooplankton with respect to phytoplankton and fish (Jónasson et al. 1974, Andersen and Jacobsen 1979, Riemann and Sondergaard 1986). This new approach is primarily driven by ascertaining zooplankton production. Zooplankton characteristics can be compared to components of phytoplankton or fish and used as biological indicators to evaluate the stability of the interactions between trophic levels as a measure of ecological health.

Some of the disadvantages of using zooplankton as a biological indicator include, but are not limited to, the labor involved with sample collection, the skill required by a taxonomist performing enumerations under a microscope, the discrete nature of the collection making it difficult to capture samples representative of the entire lagoon, and the preferential time of day for collection eliminating some diel horizontal migrating organisms. Lastly, the nature of the zooplankton organism, being linked to both primary producers and organisms higher in the food chain, makes it difficult to ascertain which dynamic is the driving influence. Because of the complexity of factors influencing zooplankton communities and the difficulty in taxonomic identification, biological assessments developed for management outside of academic research are rare. While these challenges exist, CLEAP efforts will evaluate zooplankton biological patterns within the lagoon system and assess the applicability of employing zooplankton indicators for future evaluations of lagoon health.

CLEAP data collection has allowed an investigation of both the community assemblage and dynamics of secondary production (i.e., zooplankton) in Santa Cruz lagoons, in addition to evaluations of direct or indirect impacts from neighboring trophic groups through several potential zooplankton community indicators. Potential zooplankton community indicators that will be investigated in Santa Cruz lagoons include zooplankton community and species relative size distribution, and dominance and/or % contribution of key species, such as rotifers or cladocerans. Other potential zooplankton metrics include the relationship between phytoplankton and zooplankton biomass and between zooplankton and planktivorous fish communities. These comparisons may allow evaluations of the relative energy transfer efficiency from one trophic structure to the next.

Benthic Invertebrates

Many biological indicator studies utilize soft-bottom communities because macro-benthic animals are relatively sedentary and cannot avoid deteriorating water/sediment quality conditions. Benthic invertebrates have relatively longer life spans than phytoplankton and zooplankton and thus will integrate water/sediment quality conditions over time. These communities consist of different species that exhibit varying tolerances to stress and have an important role in cycling nutrients and materials between the underlying sediments and the overlying water column. Some species of benthic invertebrates are prime fish food, especially for resident lagoon salmonids, and therefore community composition can be used to evaluate the relative food availability for fish.

The collection and identification of benthic invertebrates is also popular in stream assessments, because they are relatively easy to collect and species identification is not as specialized as phytoplankton, zooplankton or macro-algae identification. Fortunately, a wide array of existing biological indicators have utilized benthic invertebrates to develop biological metrics in fresh water streams in California, including Ode et al. (2005) and the Coastal Lagoons Biomonitoring Project (CA DFG 2001)[v]. The limitation is that none of the previous benthic metrics established in California systems have been completed in the saline portions of the lagoons. Specific species compositions within the lagoon environment are different than the communities reported in existing freshwater California IBIs. However, the basic metric components are similar and benthic indicators hold a lot of promise for future lagoon monitoring.

Fish

Fish can be useful biological indicators because they provide an integrated view of the local environmental and trophic conditions. In the case of the lagoon environment, fish are the primary species of regulatory concern, thus finding a means to combine fish community monitoring with the use of the data as an ecological indicator of lagoon health will be cost-effective. Fish have been lauded as indicator organisms for biological monitoring for numerous reasons (Karr 1981b), including the following:

- Fish are typically present in all but the most polluted [lagoons].
- Fish are relatively easy to identify and can be sorted, processed, and then returned to the water.

- Life history information is well understood for many species.
- Fish communities may contain a range of trophic levels (omnivores, herbivores, insectivores, planktivores, piscivores) and thus will respond to various perturbations in the environment, both terrestrial and aquatic.
- Because fish are relatively long-lived, comparisons across years can help pinpoint periods of unusual stress.
- The public may be more interested and familiar with fish community data than zooplankton or vegetation communities.

Karr (1981b) and Hocutt (1981) mention significant disadvantages of using fish as biological indicators, including:

- Many fish species are highly mobile and may make daily or seasonal migrations, which may result in sampling bias.
- Fish have complicated behaviors that may place them in suboptimal environments. For example, a predator might forage temporarily in water that would be unsuitable for its long-term survival. Physiological limits to environmental parameters may not necessarily be behavioral limits (Dixon 1977).
- Sampling gear is intrinsically selective and is not 100% efficient.
- Estuarine environments that have been altered by humans may still contain a diverse community of fish.
- Interpretation of fisheries data may be misleading, due to sampling limitations or species distribution on date of sampling.

Many studies around the world have successfully used assessments of fish “health” in order to evaluate estuarine habitat integrity (Deegan et al. 1997, Hughes et al. 2002, Breine et al. 2004, Harrison and Whitfield 2004). These measures of health can range from the cellular level all the way to the fish community level. For the purposes of CLEAP, health is evaluated from the individual to the population and community levels. Several fish metrics, including species diversity, abundance and biomass, growth rates of salmonids, and a variety of community assemblages, are considered for potential biological indicators. The following are site-specific factors of the CLEAP study, which necessitate consideration with regards to the fish sampling data:

- All attempts were made to be consistent with sampling methods and efforts at each site; however, as lagoon volumes changed throughout the season, sampling efficiencies also changed. Because the fish communities found at CLEAP sites have a relatively low diversity, reactions to habitat perturbations may be very subtle and sampling methods may not have been comprehensive enough to measure them accurately.
- Both steelhead (*Oncorhynchus mykiss*) and coho salmon (*O. kisutch*) were collected. These two species are listed under the US Endangered Species Act and are valued by sportfishers, stimulating significant interest. Because the extreme southern extent of the coho salmon range falls in the middle of the latitudinal span of CLEAP study sites, presence or absence of this species may complicate data interpretation. In fact, in 2005, the existing range of coho salmon was extended south when the southernmost location of coho salmon (Laguna Lagoon) was discovered during CLEAP sampling. While the coho salmon and steelhead in the lagoons are of interest, it must be stressed that these fish are heavily dependent on the condition of upstream habitats earlier in their life histories. These upstream habitats were not studied within the realm

of CLEAP and may have a strong influence on the salmonid data.

- Much interest has focused on the salmonid populations residing in the lagoons. CLEAP monitoring efforts concentrated on determining salmonid growth rates, residence times, and relative population sizes. All salmonids collected were weighed and measured (all other fish species were counted and representative subsamples were weighed and measured if abundance was greater than 50 individuals).

Footnotes:

[i] Note that N:P ratio must be calculated using the molar equivalent of the concentrations. N:P ratios using ug/L (ppb) or mg/L (ppm) are incorrect because organisms have molar requirements of each compound, not mass requirements. Proper N:P ratios should be calculated using uM concentrations of the biologically available species of N and P within the systems in question. Conversion of molar concentrations to mass concentrations is based on molecular weight. Unit conversions for common chemical species in this project are as follows: 1 uM NOx (as N) = 14 ug/L, 1 uM NH_4^+ (as N) = 14 ug/L, 1 uM PO_4 (as P) = 31 ug/L, 1 uM Si = 28 ug/L.

[ii] Redox sensitive is a term to identify compounds that contain oxygen and can be used as alternative energy sources for respiring bacteria when the availability of oxygen is limited (i.e. suboxic, hypoxic and/or anoxic). Unit conversion is as follows: 1uM NOx

[iii] DIN = NO_3^- + NH_4^+ i.e., total biologically-available nitrogen supply DIN (dissolved inorganic nitrogen) equals NO_3^- (nitrate) plus NH_4^+ (ammonia).

[iv] Water is rarely limiting in a coastal environment.

[v] Both of these bioassessments relied upon on the California Stream Bioassessment Procedure (CSBP) produced by Jim Harrington (Harrington 1999). The CSBP is a regional adaptation of the U.S. Environmental Protection Agency (EPA) Rapid Bioassessment Protocols (Barbour et al. 1999) and is recognized by the EPA as California's standardized bioassessment procedure (Davis et al. 1996). The CSBP is a cost-effective tool that utilizes measures of the stream's benthic macro-invertebrate (BMI) community and its physical/habitat structure.

7. Lagoon Matrix and Site Selection

The data collection efforts for CLEAP began in August of 2003. Following site selection procedures outlined by the EPA Wetland Assessment Manual (2002), the goal of CLEAP site selection was to focus data collection efforts on a selection of lagoons that represented a range of habitat conditions based on local land use and human impacts. The primary purpose of the 2003 CLEAP efforts was the integration of a wide array of management, watershed, and lagoon information and existing data to create a comparative matrix of the lagoons in Santa Cruz County. From this matrix a range of lagoons could be selected for further study.

A list of potential habitat condition parameters was compiled, ranging from land use influences to physical, chemical, and biological characteristics and vegetation and fisheries conditions (Table 7.1). Some parameters were easily measured and thus site specific data collected in the late summer/early fall of 2003 was used. Other parameters were more costly and time consuming to obtain quantitative data so data collected by others, qualitative observations, local opinions and/or best professional judgment was used. Based on the available information, each metric in each of the 11 Central California lagoons (Figure 6.2), was assigned a 5 (approaching optimal or natural conditions/low impact), 3 (impacted conditions) or 1 (impaired conditions) value. The scores of 15 priority metrics (highlighted in Table 7.1) for each lagoon were totaled and used to rank the lagoon's habitat conditions from least to most impacted (Table 7.2). Using the same approach, a second matrix was developed to prioritize the same 11 lagoons with respect to the feasibility of implementing future enhancement recommendations (Tables 7.1 and 7.2). The habitat conditions and management matrices were then used by the Technical Advisory Committee (TAC) to select five lagoons for the subsequent two years of detailed monitoring. The lagoons monitored in detail for 2004 and 2005 summer seasons are highlighted in Table 7.2.

Table 7.1. 2003 CLEAP Lagoon Matrix Parameters (see 2003 CLEAP Technical Report for more details). The highlighted parameters were used to create the rankings in Table 7.2.

Parameter	Ranking on measurements or qualitative information	Priority metric?
HABITAT CONDITION PARAMETERS		
Anthropogenic Land Use Influence		
Reduction in lagoon surface area from 1850	Qualitative	Y
Reduction in summer freshwater inflows	Qualitative	Y
Urban pressure in watershed	Qualitative	Y
Agricultural pressure in watershed	Qualitative	Y
Septic pressure in watershed	Qualitative	Y
Erosion/sources pressure	Qualitative	N
Physical Characteristics		
Watershed area (mi^2)	Measured	N
Lagoon surface area (ft^2)	Measured	N
Average water depth (ft)	Measured	N
Estimated volume (ft^3)	Qualitative	N
Degree of channelization	Qualitative	Y
Substrate complexity	Qualitative	Y
Solar exposure	Qualitative	Y
Secchi depth/ Water clarity	Measured	Y
Average number of days closed (May-Oct)	Measured	N
Consecutive days closed	Measured	N
Potential wind stress	Qualitative	Y
Chemical Characteristics		
Depth-integrated DO (mg/L)	Measured	Y
Maximum DIN closed (uM)	Measured	Y
Average DIN closed (uM)	Measured	N
Average SRP closed (uM)	Measured	N
Average closed N:P	Measured	N
Dissolved silica (uM)	Measured	N
Biological Characteristics		
Max 2003 closed chlorophyll a (ug/L)	Measured	Y
Phytoplankton taxa diversity (# of taxa)	Measured	N
Abundance of phytoplankton (cells/L)	Measured	N
Size distribution of phytoplankton (average)	Measured	N
Zooplankton taxa diversity	Measured	N
Abundance of zooplankton (indiv/m^3)	Measured	N
% zooplankton species - herbivorous	Measured	N
Vegetation Conditions		
Algal state	Qualitative	Y
Wetland plant species density	Qualitative	N
% distribution of SAV in lagoon area sampled	Qualitative	N
Fisheries Conditions		
Potential for Salmonids	Qualitative	Y
Degree of human impact on salmonid population	Qualitative	N
Upstream barriers impacting salmonid migration	Qualitative	N
MANAGEMENT CONDITION PARAMETERS		
Degree of management	Qualitative	Y
Potential for habitat improvement	Qualitative	Y
Management feasibility based on funding, resources and stake holder commitment	Qualitative	Y
Potential benefit of planned restoration/ management actions in watershed to lagoon function	Qualitative	Y

Table 7.2. 2003 CLEAP Lagoon Matrix Ranking Results. Lagoons presented in order from least impacted to most impacted with priority lagoons for 2004-2005 detailed monitoring selected by the CLEAP TAC highlighted. The main goals of site selection were to create a comparative analysis of lagoons representing a range of habitat conditions while prioritizing lagoons with high management concerns. See Figure 6.2 for location of lagoons.

Lagoon	Habitat Conditions Ranking (85 possible points)	Management Ranking (20 possible points)
Waddell	65	4
Scott	63	10
Laguna	62	12
Soquel	51	14
Pescadero	45	10
Corcoran	42	8
Schwan	41	4
Moran	39	6
San Lorenzo	37	16
Aptos	34	14
Watsonville	34	12

8. Lagoon Characterization Methods

LAGOON MODIFICATION CHRONOLOGY

The historical analysis was performed over the duration of the CLEAP data collection efforts. Initial analysis began with amassing a collection of historical aerial photographs of the Santa Cruz County coastline from the resources of the UCSC Map Room, Fairchild Aerial Photography Collection of Whittier College, and WAC Corporation (www.waccorp.com). Maps of historic topographic surveys performed in 1853 and 1910 by the US Coast and Geodetic Survey were found at the California State Lands Commission. These maps, along with the aerial photographs, were used to create a visual time line of changes to the Santa Cruz County lagoons. To fill in the gaps left by the aerial search, particularly pre-1920, a search for articles and historical ground photos of the lagoons was then performed. Much information was found from Santa Cruz Public Libraries website (www.santacruzpl.org), including articles on the history of Aptos and the Coast Dairies Property. Visits to the Santa Cruz Museum of Art and History Library and the Capitola Historic Museum yielded numerous photos from the 1870s and on, giving a visual history of the San Lorenzo, Soquel, and Aptos Lagoons. Additionally, Carolyn Swift, the director of the Capitola Historic Museum, was an invaluable resource, providing the Historical Context Statement for the City of Capitola (Swift 2004) and with the names of several long-time residents to contact for further information, including Dick Nutter and Frank Perry. A digital clearinghouse of the historic aerials and maps obtained as part of the CLEAP efforts has been produced for the Santa Cruz County Resource Conservation District.

LAGOON MORPHOLOGY

Key aspects of lagoon morphology were estimated from a variety of data collection techniques. The most accurate acquisition of lagoon morphology would entail detailed topographic and bathymetric surveys. The cost of accurate surveys for each of the 5 priority lagoons was cost-prohibitive for this project. This is especially true considering the dynamic nature of the lagoon sediments. A detailed bathymetry in the fall of one year would be rendered grossly inaccurate the subsequent spring, following any significant winter flows and associated sediment reorganization.

Historic and current lagoon surface areas were estimated using aerial photography, historic and current maps, field observations and GIS tools. Historic lagoon areas are based on a Coast Geodetic Survey map created of the Santa Cruz County Coastline in 1853. The map was digitally scanned, geo-referenced and the historic lagoon area was estimated using GIS analyst tools. Based on recommendations from the TAC and field observations, current lagoon surface area is defined as the inundated area where surface water flow direction is not visibly identifiable during steady state closed conditions. As continuous water depth records reveal (YSI data), each closed lagoon reaches a water storage equilibrium (water inputs = water outputs) and subsequent water depth changes over a weekly timescale are minimal. Site specific observations of the past 3 years were used to document the aerial extent of the lagoon inundation in August and/or September of each year. Lagoon surface area and configurations vary from year to year based on beach morphology and stream storage capacity. Closed lagoon surface areas presented herein are an average area of the steady-state lagoon surface based on team members' observations throughout the 3 year study. The lagoon areas are presented in acres (rather than ft^2) to reflect the confidence of these estimates.

Deeper bathymetric locations within the lagoons are more susceptible to salt water entrapment, thermocline development and limited horizontal water mixing during reduced circulation conditions. A primary assumption in maintaining adequate water quality in these lagoons is the importance of horizontal and vertical water exchange. Based on two years of monthly site visits for water quality, benthic invertebrate and fish sampling, the project team has estimated the locations of anomalously deep pockets within each lagoon and a GIS analysis was used to calculate the surface area for each deep area and totaled for each lagoon..

The relative extent of lagoon morphologic constriction was quantified using a technique similar to a stream channel entrenchment ratio developed by Rosgen (1996). The entrenchment ratio is calculated by dividing the flood-prone channel width by the bankfull channel width and expresses the vertical containment of a river at any particular location. Flood-prone channel width is the stream width at a discharge level twice the bankfull depth. The entrenchment ratio provides an index to quantify the relative incision or constriction of a stream within its floodplain. The morphology of a natural meandering stream will have access to its floodplain during elevated streamflow conditions and thus will possess a large entrenchment ratio (> 2.2) (Rosgen 1996). The cross-sectional area of a flood-controlled stream will show little difference whether at bankfull or flood stage (ratio <1.4). The entrenchment ratio concept has been applied to develop an index of lagoon morphology. Flood control, levee development and/or other morphological changes have significantly restricted the surface area of some lagoons during summer closure. The entrenchment of each lagoon station was calculated by: Lw/Sw where Sw is the station water surface width at 1-2ft tidal elevation (AMSL) in April and Lw is the closed lagoon water surface station width. The respective widths were either measured in the field or scaled using GIS analyst tools.

LAGOON EXPOSURE

Estimates of lagoon station exposure were developed using field observations, station wind speed measurements and lagoon aerial photographs. Each lagoon station was assigned a value from 1 to 5 for relative susceptibility to wind and sunlight exposure. Wind speed was measured at each station during lagoon sampling days using a hand-held anemometer. Field monitoring data was used to rank the relative wind exposure of each lagoon station, using 1, 3 and 5. A 1 indicates the station is protected and has little to no wind stress throughout the day, 3 suggests the station is exposed to the wind but wind speed rarely exceeded 5 mph during field observations, and a 5 indicates the station is fully exposed to coastal wind and wind speeds often exceeded 5 mph. The relative wind exposure scale is based on the premise that increasing wind exposure is a positive physical condition enhancing surface water mixing within the lagoons. The sunlight exposure scale was inverted, as exposure to solar radiation will directly increase water temperatures potentially exacerbating eutrophication. A 1 was assigned to fully exposed areas with no vegetation cover (a station located on beach sand was given a 1), 3 was given to those sites exposed for a limited portion of the day (usually morning or afternoon) due to a cliff or vegetation, and 5 was assigned to sites protected from the sun for the majority of daylight hours, due to dense riparian cover along the lagoon bank. The station values were averaged for each lagoon. At those lagoons where stations were concentrated in either the upstream or downstream end of the lagoon, intermediate stations were added to more accurately portray the overall lagoon surface area’s exposure to wind and sunlight. For instance, at Soquel Creek Lagoon, stations 4 and 5 are evenly distributed along the upstream end of the lagoon, but stations 1 through 3 (including 1.5 and 2.5) are more heavily concentrated in the downstream area. Values were therefore added between sites 3 and 4 and sites 4 and 5 to compensate for the downstream weighted average.

CLIMATIC CONDITIONS

Real-time climate data was obtained online from the California Irrigation Management Information Systems (CIMIS) (http://www.cimis.water.ca.gov/cimis/welcome.jsp). CIMIS operates and maintains over a 120 automated weather stations throughout the state. Unfortunately, there are no ideal active weather stations to accurately depict the daily climatic conditions at the Santa Cruz County lagoons. At the onset of CLEAP, the UC Santa Cruz Engineering Department operated an automated weather station at Long Marine Lab, located on the coastline at the northern border of the City of Santa Cruz. However, the weather stations and online data access have been inoperable since late 2003. Therefore, the majority of the precipitation, solar radiation, air temperature and land surface wind speeds presented in this analysis are the average values of two active CIMIS stations, #129 Pajaro[i] and #104 DeLaveaga[ii]. The DeLaveaga station is centrally located (east/west) within Santa Cruz County, but at a 300' elevation. The Pajaro station is 3.2 miles from the coastline but located at the southern extent of Santa Cruz County and at the center of the Monterey Bay. Rainfall, fog layers and summer climate on the Santa Cruz Coast follow distinct elevation gradients, though inherent daily variations are common. Given the available weather information, we believe the climatic average of these two sites is a reasonable estimate of daily and seasonal variations experienced at the subject lagoon sites.

WATERSHED CHARACTERISTICS

GIS was utilized to calculate the watershed and land use distribution data for each of the project lagoons. The majority of the shapefiles were provided by the County of Santa Cruz. Each lagoon watershed area was calculated by summing the surface area of all contributing sub-watersheds. Many of the watershed land use distribution estimates were created by GIS parcel, zoning and land use data provided by Santa Cruz County. Population density was calculated as the sum of the population of each parcel within the studied watersheds and divided by the total watershed area. Land use was determined from the County Assessor Use Codes (each parcel has a unique use code). The areas of all parcels with agricultural and urban use codes were summed and the corresponding percentages were determined for each watershed. Where individual parcels intersected watershed boundaries, the information pertaining to these parcels (population, land use, etc.) was reduced by a percentage equal to the parcel area within the watershed divided by the total area of the parcel. The population directly affected by flood control was calculated by totaling the population of each parcel that overlapped with the historic lagoon area (without flood control). Septic population density was determined by summing the population of the watershed serviced by septic and dividing by the surface area of this portion of each respective watershed.

Impervious surface area within each watershed was determined by combining the following two area calculations:

1. The total road length for each watershed was multiplied by an assumed width of 60 feet for all major highways (Highway 1 and 17) and by 24 feet for all minor roads.
2. The Assessor Use Code for each parcel assigns an assumed percentage of imperviousness. This percentage was multiplied by the total area of the parcel and totaled for each watershed.

These two area calculations were added together to determine the approximate total impervious area per watershed.

AUTOMATED INSTRUMENTATION

CLEAP data acquisition included the installation and maintenance of 9 different automated water quality data loggers deployed from April to November in 2004 and 2005. The 8 multi-parameter data loggers are manufactured by Yellow Springs Instruments (www.ysi.com). Four YSI 600 OMS units were deployed in the surface waters to monitor surface water temperature, salinity and chlorophyll concentrations on 30 minute intervals in Laguna, Soquel, San Lorenzo and Aptos. Four YSI 600XLM units were deployed in the bottom waters of the same lagoons to simultaneously monitor lagoon water depth, bottom water temperature, salinity, pH, oxidation reduction potential (ORP) and dissolved oxygen. All YSI instruments were deployed in 2" PVC perforated housings. Bottom water units were either installed in the stream bed attached to a fence post or mounted to bridge footings or another secure substrate. Surface water instruments were attached to a buoy to ensure constant monitoring of the surface water conditions at each site (see photos below). Every 20 to 40 days, the instruments were retrieved and the recent data was downloaded using EcoWatch software and a laptop computer. The digital data was transferred from the field laptop to the company server immediately upon return to the office. The batteries were replaced, the unit was calibrated per protocols for the respective parameters provided by the manufacturer and then redeployed. The calibrated values were recorded in a field data instrument maintenance log to track calibration and data maintenance efforts.

Photos of YSI instruments installed at Laguna and Aptos Creek Lagoons. Bottom water instruments are installed within PVC pipes; surface water instruments are attached to buoys.

In Scott Lagoon, NMFS installed and maintained 2 YSI 600XLM instruments, one in the surface and one in the bottom waters. These instruments recorded water temperature, salinity, DO and pH on 15 minute intervals and the NMFS data has been integrated into the CLEAP database. CLEAP installed and maintained an In-Situ miniTroll (www.in-situ.com) to collect depth data on 30 minute intervals. The In-Situ instrument was downloaded every 30-60 days, the batteries were replaced as necessary, and the instrument was maintained per manufacturer's instructions. All maintenance activities were recorded in the instrument log.

Water temperature, salinity and chlorophyll were monitored. Instrument failure did occur on some occasions resulting in sustained data gaps. The low cost and high resolution of these water quality datasets makes this type of monitoring in dynamic aquatic systems like coastal lagoons very valuable. The limitation of these instruments is that the information is limited to one distinct horizontal location and two distinct vertical locations in each lagoon. Detailed lagoon vertical profiles were collected at lagoon sampling stations (at least 5 per lagoon) during each LSDs to calibrate and evaluate how representative the instrument locations were to the greater lagoon area. Vertical profiles consisted of DO, temperature, salinity and conductivity readings every 0.2.m using a YSI 85 Handheld instrument.

LAGOON WATER BUDGETS

The two primary influences on lagoon water volumes are freshwater inflow rates and tidal exchange. Santa Cruz 30 minute tidal elevation data was obtained using the WXTIDES32 software program (http://wxtides32.com). Real time and daily mean streamflow discharge data was obtained from the USGS

California streamflow data clearinghouse (http://waterdata.usgs.gov/ca/nwis/sw) for San Lorenzo River (ID #11161000) and Soquel Creek (ID #11160000). Aptos Creek was gaged by the USGS intermittently from 1958 to 1985. Hydrologic analysis contained within the Aptos Creek Enhancement Plan (Coastal Watershed Council 2003) included an empirical relationship to predict Aptos Creek daily discharge as a function of Soquel Creek discharge. CLEAP calibrated the empirical estimates with manual discharge measurements in the field. Streamflow discharge in ungaged streams was manually measured monthly utilizing standard USGS measurement techniques (velocity-area method for total discharge and six-tenths method for determining velocity). Lagoon storage volume changes over the season were based on (1) water depth from YSI instrumentation in lagoon corrected to estimated average lagoon depth from vertical profile data and (2) lagoon surface area from GIS calculations. Surface area of each lagoon was calculated for both open and closed conditions and appropriately used for volume calculations depending upon sandbar status and visual extent of inundation observations documented in the field.

CIRCULATION REGIME

In order to standardize circulation differences across different lagoons and to provide a quantitative technique to define circulation, the CLEAP team calculated the 2 hour derivative of the water depth variations (dz/dt) in each lagoon as monitored by the in-situ YSI instruments. Visual observations of the derivative patterns clearly illustrate the variations in circulation in each of the five lagoons (see Figure 11.17). In order to correct for variations of the instruments from the mouth of the lagoon, the magnitude of each lagoon derivative during 3 simultaneous spring tidal cycles in April were compared. To standardize the derivative scales, San Lorenzo dz/dt was divided by 1.6 and Soquel was divided 1.2 to make the derivative range similar to the other lagoons during these 3 spring tidal cycles. Using visual site observations in concert with the results presented in Figure 11.17, the following circulation criteria were created based on the 12 hour running average (R-ave) of the depth derivative (dz/dt):

Macro tidal: R-ave > 0.1 following regular tidal patterns
Micro tidal: R-ave < 0.1 following regular tidal patterns or
0.05< R-ave <0.15 following irregular tidal patterns
Closed: R-ave < 0.05

BIOLOGIC COMMUNITY DIVERSITY CALCULATIONS

Simpson Index of Diversity was used as a metric to evaluate community diversity for all observed levels of the trophic structure. Value ranges from 0-1 where the higher the value the more diverse the sample. This calculation takes into account both number of species (species richness) and number of individuals of each species (species evenness).

- Defined as 1-D where D is Simpson Index defined as $D=[\Sigma n(n-1)]/[N(N-1)]$, where n is the total number of organisms of a particular species and N is the total number of organisms of all species.

STRESSOR AND INDICATOR TESTING

The methodology of the stressor and indicator analysis is presented in detail in Section 10 Evaluation of Lagoon Metrics.

Footnotes:

[i] #129 (Pajaro) is located at the Santa Cruz/Monterey County Border adjacent the Pajaro River[2]. (elevation 65 ft MSL, latitude 36°54’12”N, longitude 121°44’31”W).

[ii] #104 DeLaveaga located in the City of Santa Cruz (elevation 300 ft MSL, latitude 36°59’52”N, longitude 121°59’45”W).

9. Field Data Collection Methods

The degree of human impact and alterations to each coastal lagoon varies across Santa Cruz County. Since decades of data collection and monitoring are not available to assess the changes in strategic lagoon parameters in concert with increased development, CLEAP has utilized the spatial variability across lagoons as a comparative tool to improve our overall understanding of the physical, chemical and biological function of these unique ecosystems. Assessments of wetlands utilizing a spatial comparison to identify causal stressors impacting ecosystem health are recommended by many references. CLEAP approach and data collection design relied heavily on the EPA's Methods for Evaluating Wetlands (US EPA 2002) and Karr and Chu (1999) "*Restoring Life in Running Water*, *Better Biological Monitoring*", in addition to an extensive collection of peer-reviewed journal articles referenced throughout this report.

FIELD MONITORING SCHEDULE

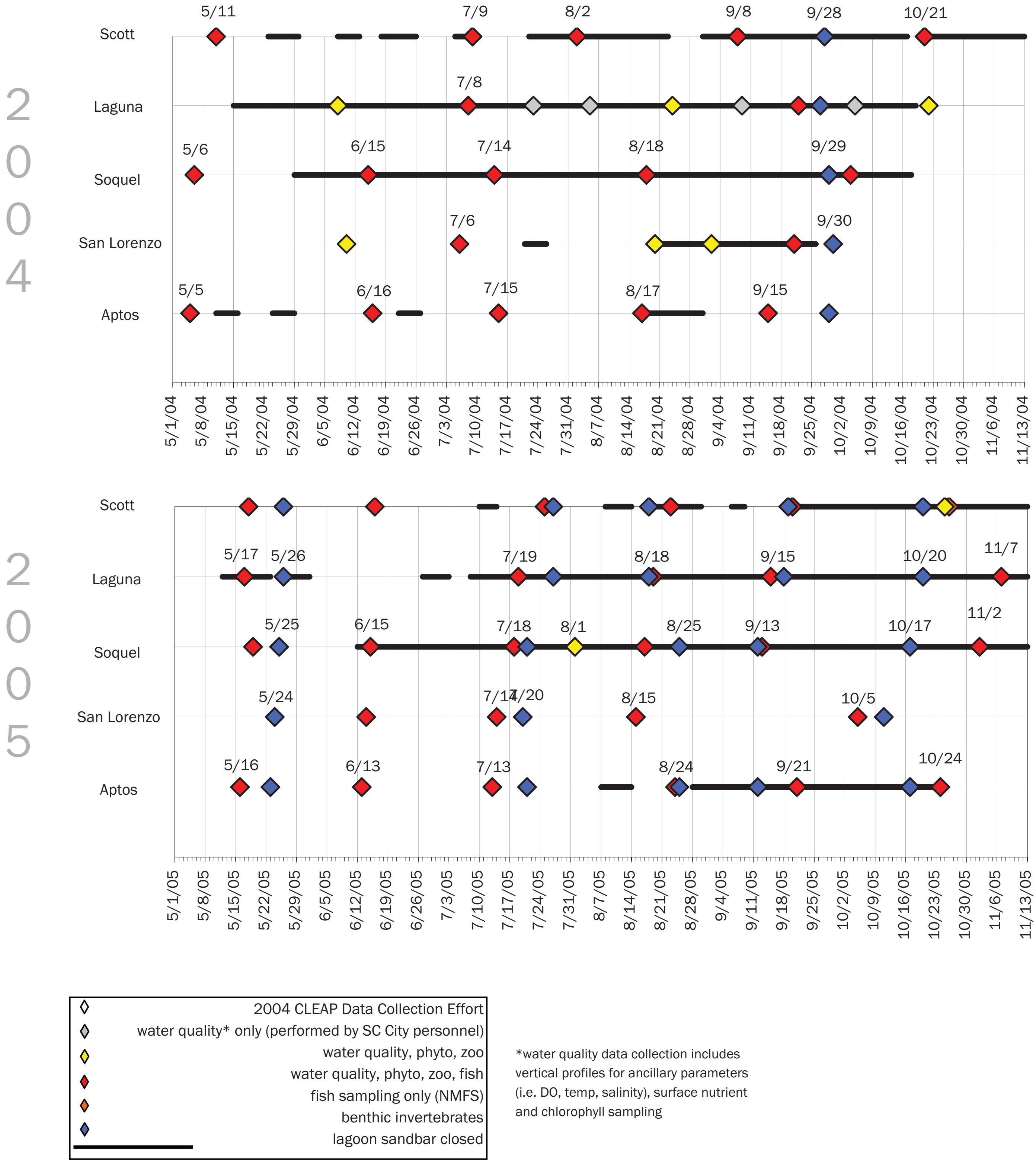
Lagoon Sampling Days (LSDs) were conducted nearly monthly in each of the 5 lagoons from May to late October/early November in 2004 and 2005. Below are the data collection techniques, sampling handling protocols, and data management procedures for each of the parameters measured during a LSD.

As recommended by the EPA Wetland Bioassessment Methods (US EPA 2002), CLEAP data collection and lagoon function evaluations are focused on physical, chemical and biological conditions during the potentially critical times of the year (May through October/November) when lagoon circulation and water exchange rates naturally decline and warmer climatic conditions exist. Figure 9.1 is a graphic summary of the field data collection efforts for 2004 and 2005 at each lagoon. The goal of the data collection protocols was to constrain the potential spatial and temporal variability of conditions across lagoons as best as possible to ensure reasonable confidence that observed differences in the lagoon parameters over the monitoring period were reflective of changes within the system and not artifacts of sampling variability. With this goal in mind, the time of day for each station and monitoring parameter was standardized within each lagoon throughout the 2004-2005 sampling for most parameters[i].

The majority of monthly chemical and biological data collection occurred on the same day, termed a Lagoon Sampling Day (LSD). The exception being benthic invertebrate sampling that was conducted within one week of the LSD for each site due to the time required to conduct benthic monitoring. All parameter sampling was initiated at the same time of day and all data collection progressed from downstream stations to upstream stations. Vertical profile, base of the food chain ecology and nutrient sampling were conducted primarily in the morning hours (07:00-09:30), with occasional supplemental afternoon sampling to improve YSI instrument calibration and our understanding of daily variations of water quality conditions. When the lagoon sandbar was open, all efforts were made to sample water quality, primary producers and zooplankton on days with morning outgoing tides to minimize the oceanic influence. Benthic sampling was initiated at each site on the same time of day and stations were sampled in the same order each visit. Fish sampling was always initiated between 09:00 and 09:30 and proceeded from downstream to upstream sites, thus each site was monitored at the same time of day each visit.

LAGOON SAMPLING STATIONS

Figures 11.3, 11.5, 11.7, 11.9, and 11.12 are current aerial photographs that document the data collection stations within the monitored lagoons. At the onset of 2004, five to six sampling stations within each lagoon were established to maximize spatial representation of the data collection while ensuring all data collection areas had reasonable agreement. One of the greatest limitations of the



*water quality data collection includes vertical profiles for ancillary parameters (i.e. DO, temp, salinity), surface nutrient and chlorophyll sampling

SANDBAR DYNAMICS AND FIELD SAMPLING SUMMARY

FIGURE 9.1

spatial representation was that each lagoon sampling for fish must be completed within one day to accommodate project resources. Access, deep water and other fish seining logistics made sampling within some locations of each lagoon impossible. The water quality, base of the food chain ecology and benthic invertebrate sampling stations were adjusted to overlap with the fish sampling locations as best as possible. The station locations and sampling logistics within each lagoon will be further explained in the methods sections for each respective monitoring parameter.

PARAMETER SELECTION

The selected parameters represent a wide array of physical, chemical and biological characteristics of the summer lagoons that the project team and TAC identified as key components that may improve our understanding of lagoon function, serve as an indicator of ecosystem health and directly address management objectives.

The specific datasets collected and maintained for CLEAP are listed in Table 9.1. Associated with each parameter is the source of data, the frequency of collection per year, the number of data points in the CLEAP database, and the relative annual cost per data point on a scale of 1-5 (see code at end of table). The relative cost per data point is based on the amount of time and training necessary to collect the data in the field, the cost of laboratory analysis (if applicable), and the level of expertise necessary to compile, manage and interpret the data. While many of the biological parameters have a high cost per data point, the data collection protocols, management techniques and interpretation tools provided by CLEAP aim to reduce the degree of expertise necessary to collect and manage these valuable biological datasets during future lagoon habitat condition assessments. The relative cost rankings should also provide information to prioritize the monitoring parameters for future projects given monitoring objectives and associated resources.

Table 9.1. 2004-2005 CLEAP Monitoring Parameters

Field Parameter	**Frequency***	**Main Purpose**	**Data Source**	**# of Data Points**	**Relative Cost per data point** ψ
Lagoon Inputs					
• Streamflow discharge into lagoon	monthly	• Lagoon water budget • Monthly nutrient loading to lagoon	2NDNATURE USGS where available	80	1
• Streamflow nutrient concentrations	monthly	• Monthly nutrient loading to lagoon	2NDNATURE collected, filtered, froze samples UCSC researcher Dr. L. Anderson performed nutrient sample analyses.	370	3
Lagoon Exposure					
• Riparian % cover	1x	• Lagoon exposure to wind and solar radiation	2NDNATURE	450	1
• Wind speed in lagoon	monthly	• Lagoon water surface wind exposure	2NDNATURE		1
Automated YSI's 2 per lagoon: one on surface and one at bottom					
• Water depth • Water temperature • Salinity • Conductivity • Dissolved oxygen (bottom only) • Chlorophyll (bottom only)	30 min	• Continuous record of ancillary parameters in each lagoon. • Lagoon water budget • Lagoon water quality • Lagoon water quality response to circulation changes on short time scales	2NDNATURE NMFS maintained Scott Lagoon Instruments	1.2 million	2

Field Parameter	Frequency*	Main Purpose	Data Source	# of Data Points	Relative Cost per data point $^{\psi}$
Vertical Profiles 5-6 stations per lagoon; measurements taken every 0.2 m					
• Water depth • Water temperature • Salinity • Conductivity • Dissolved oxygen	monthly	• Calibrate YSI data • Expand ancillary water quality data horizontally and vertically throughout lagoons	2NDNATURE	8,250	1
Physical Conditions 5-6 stations per lagoon					
Substrate Conditions	monthly	• Seasonal lagoon dominant grain size • Proxy for potential sediment nutrient regeneration	2NDNATURE	400	1
Grab Water Samples 5-6 stations per lagoon; surface water all events, occasional bottom water samples					
Filtered (0.45µm, i.e. dissolved) nutrient samples (nitrate, nitrite, ammonia, soluble reactive phosphorous, silica)	monthly	• Lagoon nutrient concentrations • Biogeochemical cycling • Potential indicator of habitat quality	2NDNATURE collected, filtered, froze samples UCSC researcher Dr. L. Anderson performed nutrient sample analyses.	2,150	3
Chlorophyll *a*	monthly	• Calibrate YSI • Expand YSI data to greater lagoon area • Potential biological indicator		280	3
Biological Conditions					
Phytoplankton community • species ID • species cell • biovolume per species • # of cells per species	monthly	• Lagoon phytoplankton community changes during peak growing season • Correlation between primary producer community characteristics and other trophic structures and water quality • Potential biological indicator	2NDNATURE collected and fixed samples for storage. UCD D. Hunter performed phytoplankton identification and sample analyses.	3,400	5
Submerged aquatic vegetation (SAV) community • Species ID • Species % cover	monthly	• Lagoon SAV conditions during peak growing season • Correlation between primary producer community characteristics and other trophic structures and water quality	2NDNATURE collected data with ID assistance from K. Kamer of Moss Landing Marine Laboratory	115	2
Zooplankton community • Species ID • Species cell size • Species biovolume • Species feeding technique	monthly	• Compare lagoon zooplankton community dynamics • Relationship of secondary grazers to food source (phytoplankton) and predators (benthic invertebrates) • Potential biological indicators	2NDNATURE collected and fixed samples for storage. Former USGS J. Orsi performed zooplankton identification and sample analyses. A. Little evaluated and interpreted data.	1,100	5
Benthic invertebrate community • Species ID • # of individuals per species • Dominant size per species	monthly	• Compare lagoon benthic community dynamics • Relationship of benthic community to other trophic levels • Potential biological indicators	2NDNATURE collected and fixed samples for storage. USGS M. Shouse designed protocols and QA/QC sample ID and enumeration. M. Shouse evaluated and interpreted data.	3,500	3

Field Parameter	Frequency*	Main Purpose	Data Source	# of Data Points	Relative Cost per data point ψ
Fisheries community • Species ID • # of individuals per species • Individual weight and length • growth rates of recaptured steelhead (pit tags)	monthly	• Compare lagoon fish community dynamics • Lagoon steelhead growth rates • Relationship of fish community to other trophic levels • Potential biological indicators	E. Freund of NMFS oversaw and managed fisheries sampling. 2NDNATURE assisted with data collection and data management. E. Freund evaluated	45,000	5

∗ No data collection occurred between December and early April each year.
ψ relative cost of data point per year codes.
1 Inexpensive data to obtain and some training required
2 Inexpensive per point but regular calibration by trained personnel necessary
3 moderate cost and some training required
4 moderate cost but expert needed to interpret raw data
5 expensive and expert needed to interpret data
(Cost based on data collection, sample handling, laboratory sample analysis (if necessary) and data interpretation.)

DATA COLLECTION METHODS

Lagoon Sampling Day (LSD) Water Quality Monitoring

- Station physical conditions
  - Hand-held anemometer was used to record wind speed at each lagoon station. Anemometer was held into wind for one minute and an average reading was recorded digitally into a handheld Palm Pilot.
  - Dominant grain size was visually observed from bank to bank at each station location. The predominant grain size was recorded digitally into a handheld Palm Pilot.
  - Both wind speed and grain size data was transferred directly from Palm Pilot to MS Access Database upon return to the office.
- Vertical profiles
  - Morning ancillary water chemistry parameters (DO, temperature, salinity, and conductivity) collected with a hand held YSI-85 multi-parameter probe (www.ysi.com) from a Sevylor inflatable raft at 0.2m intervals by securing a weight to the YSI probe and measuring tape-marked depths. With every vertical profile, water clarity was measured using a Secchi disk. Data was entered digitally into a handheld Palm Pilot using MS Access database field forms designed specifically for CLEAP. All vertical profile values were repeated by the data entry personnel to verify accuracy during time of data input in the field.
  - In 2005, afternoon vertical profiles were conducted at one station in the lagoon during times of reduced circulations to provide comparisons to morning sampling results.
  - All vertical profile data was transferred directly from the Palm Pilot to MS Access Database upon return to the office.
- Surface water nutrient sample collection concurrent with vertical profiles at all stations. During periods of lagoon closure, or when vertical profiles revealed marked differences between surface and bottom water, bottom nutrients samples were collected using a 2.2L Van Dorn horizontal beta bottle sampler. Periodically, afternoon vertical profile and sample collection were repeated at one station in each lagoon to provide comparisons to morning sampling
  - *Nutrient Sample Collection and Handling Protocol*
    Sample was collected into 250ml clear bottles rinsed instream 3 times, labeled and put on ice until filtered. Sample was filtered in field or office within 3 hours of collection

using 0.45uM Aqua Prep filter, Masterflex tubing, battery operated pump, and pre-rinsed, labeled 30ml bottles. Samples were stored in freezer until delivery to lab. Chain of custody documenting sample label, date collected, and sample ID accompanied samples to lab. At least one field replicate was collected during each sampling effort to quantify sampling precision.

- o *Nutrient Sample Analysis Methods*
  Filtered samples were quick thawed and analyzed for biologically available nutrients: dissolved nitrate (NO_3^-), nitrite (NO_2^-), ammonia (NH_4^+), phosphate (PO_4^{2-}, aka soluble reactive phosphorous (SRP)), and silica (SiO_2) by UCSC researcher Dr. Linda Anderson using peak area technique on an automated spectrophotometric flow injection analyzer (Lachat, Quickchem 8000). Laboratory blanks and SRMs (standard reference materials) analyzed to determine analytical detection limits and accuracy.
- o *Nutrient Sample Data Management*
  All CLEAP nutrient sample results are stored by site, station, date and water column location and digitally maintained in the MS Access Database (CLEAP_DATA.mdb).

- Surface chlorophyll sample collection concurrent with vertical profiles at each station. During periods of lagoon closure, or when vertical profiles revealed marked differences between surface and bottom water, occasional bottom waters were collected using the Van Dorn sampler. Periodically, afternoon vertical profile and sample collection were repeated at one station in each lagoon to provide comparisons to morning conditions.
  - o *Chlorophyll a Sample Collection and Handling Protocol*
    Surface sample was collected into 250ml amber bottles rinsed instream 3 times, labeled and put on ice until filtered. Sample was filtered in field or office within 3 hours of collection. Whatman 0.45um 25mm glass microfiber filters were placed on a screen using forceps. Using a graduated cylinder a measured amount of sample was added to funnel fitted over filter and pumped through filter using a hand pump. When filtering was complete, filter was removed with forceps and folded into aluminum foil square. The foil was labeled with the station number, date, and amount of sample filtered. The filters were stored in Ziploc bag labeled by site and date and frozen until delivery to lab. Chain of custody documenting bag label, sample label and ID, and volume sampled accompanied sample delivery to lab. At least one replicate was collected during each sampling to determine sampling precision.
  - o *Chlorophyll a Sample Analytical Methods*
    Chlorophyll sample analysis was performed by Dr. Linda Anderson (UCSC) following the flourometric determinations as outlined by Parsons et al. (1984).
  - o *Chlorophyll Sample Data Management*
    All CLEAP nutrient sample results are stored by site, station, date and water column location and digitally maintained in the MS Access Database (CLEAP_DATA.mdb).

LSD Biological Monitoring

- Phytoplankton community sampling were performed concurrent with vertical profiles at each lagoon station.
  - o *Phytoplankton Sample Collection and Handling Protocol*
    Composite grab sample was collected in near surface water (to 0.5m depth) at each station. Equal volumes (25mL) of sample were collected at each station and combined into one 125mL polyethylene bottle properly labeled with site and date. Composite was treated with Lugol's at 1% of total sample volume (measured with pipette), cap was wrapped with electrical tape to avoid spillage, and bottle was stored until delivered to phytoplankton taxonomist for analysis. Chain of custody

documenting sample label, ID, date and time of collection accompanied sample delivery to taxonomist. Four field replicates for phytoplankton community precision were collected each year for a total of eight sample replicates over the course of the study. The high cost per sample limited the number of replicates submitted for this project.

- *Phytoplankton Sample Analytical Methods*
  Phytoplankton community analysis performed by Deborah Hunter of UCD. Using microscope and standard phytoplankton references, Ms. Hunter provided cells per liter and biovolume (um^3/L) per species, species type, and total sample.
- *Phytoplankton Sample Data Management*
  Database format was created for the phytoplankton community data for each lagoon sample data and maintained in the CLEAP MS Access Database. Ms. Hunter ensured each phytoplankton value entered into the database is verified by a trained laboratory assistant to assure consistency with the laboratory workbook.

- Submerged aquatic vegetation (SAV) and macroalgae visual percent cover surveys were performed concurrently with vertical profiles monitoring.
  - SAV and macroalgae % cover was visually estimated at each station within the lagoons. The cross-sectional length at each station measured and percent cover of each SAV and macro algae was estimated within each cross-section. Field personnel recorded percent total cover, percent cover by species, and depth to surface at each station. An average percent cover was then calculated for each lagoon during the respective LSD. In 2004, SAV and macro algae samples collected were put in labeled Ziplocs and placed on ice until delivery to macro algae expert (Krista Kamer, PhD (Moss Landing Marine Laboratory - MLML) for identification. In 2005, SAV and macroalgae samples were collected periodically throughout the monitoring season and frozen. Samples were quick thawed and delivered to MLML for confirmation of sample species identification by Michael Graham, PhD. SAV and algal identification utilized dissecting and compound scopes and guides to wetland algae and plant species (Abbott and Hollenberg 1976). Database format was created for SAV/ macroalgae survey data and all observations were stored in the CLEAP MS Access Database.

Examples of aquatic vegetation observed during CLEAP monitoring. From left are the enteromorpha, ulva (both macroalgaes) and potamogeton (an SAV).

- Zooplankton community sampling performed concurrently with vertical profiles at 2-3 stations per lagoon.
  - *Zooplankton Sample Collection and Handling Protocols*
    A vertical tow net with 80um mesh net (Wilco Wisconsin Net 40-A50) was fitted with a 40-D70 Wisconsin bucket (also with 80um mesh net). A mechanical digital flowmeter

(General Oceanics 2030R) was attached to the mouth of the net to quantify tow volume. Initial flowmeter count was recorded digitally. Net was then submerged from side of Sevylor inflatable raft and drug alongside of moving boat. All effort was made to maintain the boat at a constant speed and in a constant direction during the tow. A 15' rope tied to top of net allowed oblique tows from the bottom to the surface of the water column to ensure a representative sample was collected. At the completion of the tow the net was removed from the water and end flowmeter count was recorded. Using squirt bottle, net and bucket were thoroughly rinsed to concentrate sample at base of bucket. Clamp at base of bucket was released and sample was collected in 125ml plastic bottle. Within each lagoon, replicate tows were taken at 3 sampling stations and the replicates were combined for a composite sample. Zooplankton samples were preserved in 5% buffered formalin with Rose Bengal dye, sealed with black electrical tape to avoid spills, labeled with site and date, and stored until delivered to expert for taxonomic identification. Sample chain of custody included lagoon, station, date and time collected, and calculation of field sample volume.

Field sample volume calculation:
Distance (m) = [($Count_{end}$-$Count_{beg}$)*26,873]/999999, where $Count_{beg}$ is the pre-sample flowmeter reading, $Count_{end}$ is the post-sample flowmeter reading, and 26,873 is the flowmeter's rotor constant.
Volume (m^3) = [3.14*($(dia)^2$]/4]*Distance, where dia is the diameter of the net (130mm) and Distance is the value calculated above.

- *Zooplankton Sample and Data Analysis*

  Zooplankton analysis performed by Jim Orsi (formerly of USGS). Concentrated samples were diluted to a volume of 50 to 400ml, and typically 1ml subsamples were examined in a Sedgewick-Rafter cell. All taxonomic groups were counted, and the total lengths of the first 20 individuals in each category were measured. Copepods, cladocerans, and rotifers were identified to species or genus, and rotifers were identified as herbivorous or carnivorous. Copepod nauplii were separated into the non-feeding (N1-2) and feeding (N3-6) stages by using 0.20um as a rough dividing length. Harpacticoid copepods (primarily associated with the benthos) were not considered in biomass or grazing computations due to their unlikely impacts on planktonic communities in this system.

  Calculation of zooplankton sample biovolume (mg C/m^3) totals
    - Species abundance (#/m^3) = species count *dilution factor
    - Species biomass (mg C/m^3) = abundance * known value of species individual biomass (mg C)
    - Sample biomass = sum of biomass for all species observed in sample.

  Zooplankton biomass was the cumulative biomass of 47 individual taxa/life stages, computed as the product of abundance and carbon biomass for each taxon. Taxon-specific biomass was first computed from either length measurements and published length-dry weight (DW) relationships (Burgis 1975, Dumont et al. 1975, Bottrell et al. 1976, Uye 1982, Culver et al. 1985, and C. Hall (pers. comm.)) or published dry weight measurements (Dumont et al. 1975, Ruttner-Kolisko 1977, Makarewicz and Likens 1979, Rosen 1981, Hutchinson 1982, Brock 1985, Culver et al. 1985, Lawrence et al. 1987, Malley et al. 1989, Pauli 1989, Wetzel and Likens 1991, Kobayashi et al. 1996, Lucas et al. 2002). Dry weight estimates were then converted to carbon assuming that the ratio of carbon: dry weight is 0.48 for all taxa (Andersen and Hessen 1991).

- *Zooplankton Sample Data Management*
  Database format created for zooplankton data and all data stored in CLEAP MS Access Database. Mr. Orsi ensured that all values entered into the database were verified against his laboratory notebook. Due to the high cost of zooplankton sample enumeration, no replicates were submitted to the zooplankton specialist for analysis.

Following the completion of the above monitoring, LSDs included seining and processing (measuring weights, lengths and tagging) of fish species.

Fisheries

- In 2005 fish sampling in all five lagoons was performed by Dr. Ellen Freund's National Marine Fisheries Service team. Sampling locations and sample collection protocols were standardized for each lagoon and remained consistent throughout the 2005 season. A 30m beach seine (wings made of 2cm stretched mesh and bag of 1cm stretched mesh) was used at each site. Figures 11.3, 11.5, 11.7, 11.9, and 11.12 indicate the seining locations for each lagoon. Each captured fish was identified to species. Every individual was counted, then fork length and mass were measured. If numbers of individuals of a given species were too great, a sub-sample of 50 individuals was measured and weighed, but all individuals captured were included in the final count whether they were weighed and measured or not. Salmonid species over 65mm in fork length were anesthetized, weighed and measured, and scanned for PIT tags using a PIT tag reader (www.biomark.com). If no previous PIT tag was found, one was implanted by trained fisheries personnel. PIT tags allowed for individual steelhead identification facilitating growth calculations and residence time estimations upon recapture. All fisheries data were entered electronically in the field using Palm Pilots and ultimately stored in the CLEAP MS Access Database.
- In 2004 fish sampling and data collection were conducted by two groups. Hagar Environmental Services (HES) sampled San Lorenzo and Laguna Lagoons. The NMFS group sampled Scott, Soquel and Aptos Lagoons. There was some variation in sampling techniques between the two groups. Details and variations in the fish sampling efforts are summarized in the 2004 CLEAP Technical Report. Briefly, HES used three different seines to sample within San Lorenzo, depending on the location and water depth (large purse seine: 150ft long, 8ft high with ¼-in mesh was deployed by boat at deeper sites; medium beach seine: 100ft long, 6ft high with ¼-in mesh was used where wading was practical; small beach seine: 50ft long, 6ft high and ⅛-in mesh was used along the shore to capture smaller species). At Laguna, HES used the small beach seine as well as an electrofisher during the September 2004 sampling. In both 2004 and 2005, the NMFS group used a modified beach seine that had a bag built in comprised of smaller mesh (30m long with wings made of 2cm stretched mesh and bag of 1cm stretched mesh), which was either deployed by boat in deeper sites, or dragged like a regular beach seine when possible. All fisheries data are stored in the CLEAP MS Access Database.

Fish sampling in Soquel Lagoon, May 2004.

Benthic Invertebrates

Benthic invertebrate sampling was conducted in each lagoon within 1 week of the respective Lagoon Sampling Day in 2005. In 2005 sampling took place 5 times in all lagoons. Due to initial resource limitations, benthic sampling was conducted only one time in 2004 in all 5 lagoons.

- *Benthic Sample Collection and Handling*
  Upstream and downstream stations were established in each lagoon and three samples were collected per station (*right bank, benthic grab, left bank*). The sampling protocols for CLEAP were developed in consultation with Jim Harrington, benthic specialist with the California Department Fish and Game.
    - Right and left bank samples were taken using a slack net sweep with a mesh of 500 microns. A depth of 0.5m was used to establish range of sweep to the shore. The distance from bank to 0.5m depth was measured and recorded to establish sweep starting point. With net on lagoon bottom, a bouncing motion was used to disturb sediments, sweeping net to the bank and then up the bank from the sediments to include emergent vegetation habitat. If depth at bank was greater than 0.5m, depth was recorded and vertical sweep up bank from lagoon bottom was conducted. Each sample was washed through a 500um screen and transferred to labeled 1qt HDPE containers for analysis.
    - Benthic grab was performed at deepest part of channel using a petite ponar grab. Substrate and ancillary water quality parameters (depth, DO, temperature, salinity, conductivity) in bottom waters were recorded prior to sampling. Grab was lowered from side of Sevylor inflatable raft to collect bottom sediment sample. Once grab hit the substrate, it was raised to surface and sample was emptied into a wash bucket with a 500um screen at bottom. Sample was washed through 500um screen and transferred to labeled 1qt HDPE containers for analysis
    - Following in-field analysis (described below) sample was transferred, maintaining its integrity, into storage jars and preserved with 95% Ethanol.
- *Benthic Sample Analysis Methods*
  Samples were analyzed in field. Visual identification of species performed by expert (Michelle Shouse, USGS) who trained 2NDNATURE staff member M. Mathias with reference to invertebrate identification books. A preserved library of all invertebrate species encountered has been created. Individual counts were approximated when greater than 20. Species length range were measured with calipers and dominant size noted. At least one sample from each lagoon sampling effort was reanalyzed by M. Shouse in the laboratory to provide further identification of unknown organisms as well as enumeration QA/QC. All data was recorded directly into the CLEAP digital database.

CLEAP MS Access Database

Over 1.25 million data points were generated during the 2004 and 2005 sampling seasons and all are contained in the CLEAP MS Access Database. The CLEAP database can be obtained from the Coastal Conservancy at the completion of this project. The database not only simplified data analysis and metric development efforts for CLEAP, but provides a simple and accessible means to extract CLEAP data in the future. While the CLEAP effort provides a large variation of lagoon data analysis and presentation, the database will allow additional scientific evaluation of future lagoon questions.

DATA COLLECTION AND MANAGEMENT QA/QC

Field data QA/QC was a high priority for the CLEAP team members. The sampling parameters and sampling plan developed for CLEAP were integrated into digital field data forms where all field data was collected and stored. Detailed Palm Pilot field sheets were created to ensure that all relevant field conditions, station and site information, and detailed data were consistently collected and stored. These digital field datasheet form the hierarchy of the CLEAP MS Access Database structure and include all of the physical, chemical and biological data collected at each lagoon over the project duration. Maggie Mathias of 2NDNATURE was the lead field manager on site for every LSD effort conducted on behalf of CLEAP and she was assisted by additional trained field staff for all efforts. She ensured that each data field in the Palm Pilot field data sheets was completed at each station prior to proceeding onto the next location. Fisheries sampling efforts were lead by Ellen Freund of NOAA NMFS, and typically involved 4-6 personnel from both NMFS and 2NDNATURE. Prior to LSD completion, 2NDNATURE staff reviewed the LSD digital file onsite to ensure the information was consistent and accurate with the conditions experienced at the site. The digital data was immediately transferred onto the 2NDNATURE server upon return to the office and reviewed one last time for completeness and accuracy.

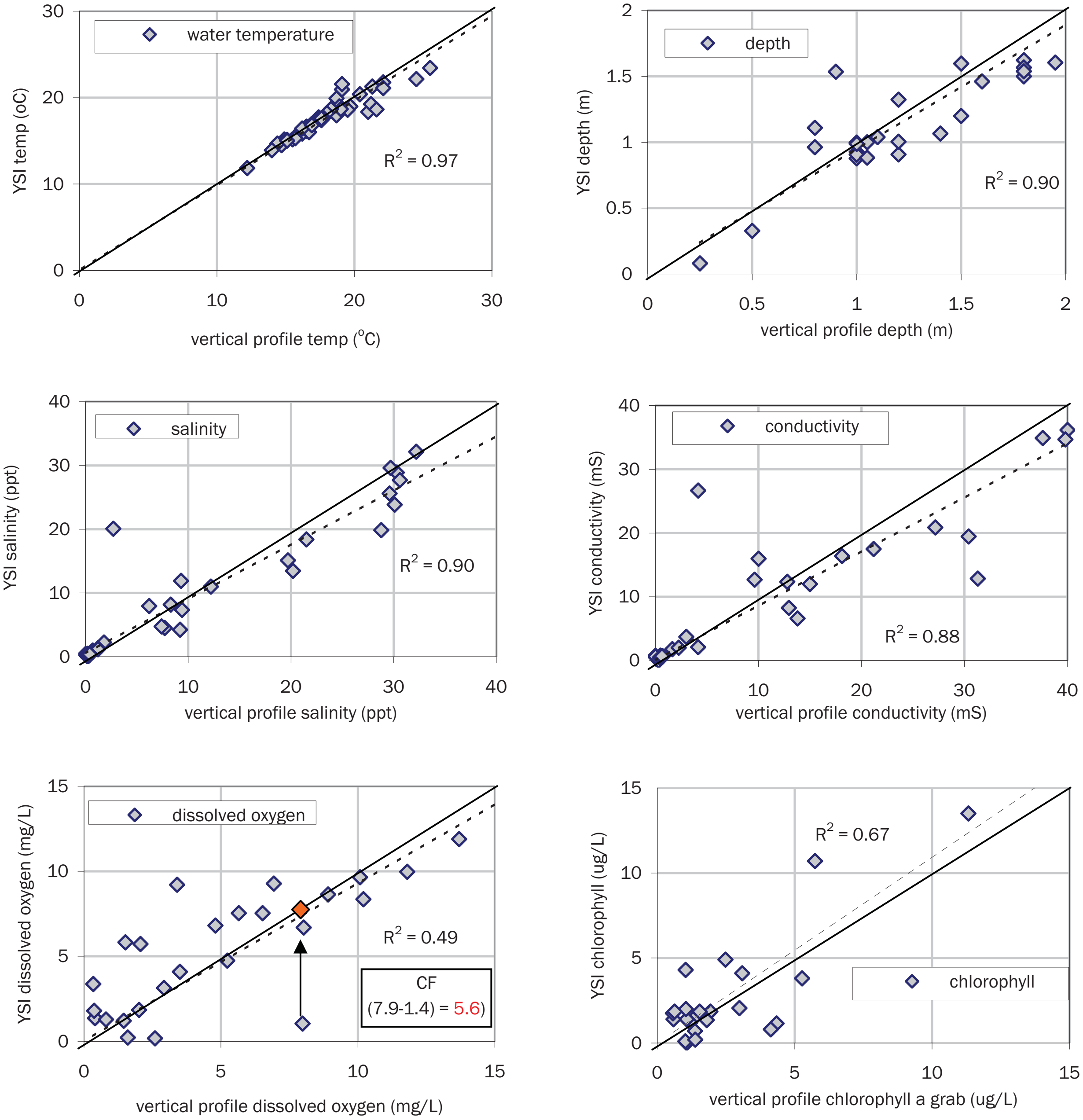
Detailed Chain of Custody forms were completed at the end of every LSD for all samples to be submitted to laboratories or other researchers for additional analyses. The Chain of Custody forms were executed by the sampling and receiving parties upon transfer of the respective samples. The CLEAP team understands the importance of field replicates to quantify field precision during sampling. In some instances, particularly the phytoplankton and zooplankton samples, the high cost of replicate samples were prohibitive and thus replicate samples were limited to save resources. Below we briefly review the QA/QC procedures for the main parameters monitored for CLEAP, any data correction techniques and any relevant precision estimates based on replicate sampling.

Automated Instrumentation QA/QC

While continuous datasets provide enhanced details of physical and chemical lagoon conditions that are impossible with grab sampling and spot measurements, continued accuracy of some parameters can be difficult using automated instruments. The technology to accurately measure water depth, conductivity, salinity, pH and water temperature with automated instruments is better developed than the techniques for dissolved oxygen, oxidation reduction potential and chlorophyll (Figure 9.2). Thus, long-term data sets of the latter parameters require calibration and data adjustments to improve accuracy. Correlation plots between vertical profile (VP) spot measurements and YSI values were created for each lagoon. Individual values exceeding a relative 80% difference were investigated to ensure VP and YSI data were taken from the same vertical location in the water column with similar physical conditions (temperature and salinity agreement). Conditions at adjacent VP stations during this time were also reviewed and considered to ensure the VP data was representative of a greater lagoon area. Once these conditions were verified, the YSI DO data for the time period of deployment bracketing the VP measurement of interest was adjusted to the known (VP) value and a correction factor (CF) was calculated (Figure 9.2). This correction factor was then used to adjust the DO time series bracketing the known values (ranging from 8-15 days in duration). A similar procedure was used to correct and calibrate the automated YSI chlorophyll data using the grab sample results from the VP station adjacent to each YSI for each particular lagoon sampling day.

Field Information QA/QC

All meta field data information during LSDs was collected digitally in the field using a Palm Pilot. Field data collection forms were created to ensure all necessary site and station information was collected and data fields were completed prior to leaving each station. The digital field forms provide a simplified



YSI temperature, depth, salinity and conductivity values are consistently within 80% of the values obtained by vertical profile spot measurements in the field. Solid lines are 1:1 relationships and dotted lines are linear trend (and associated R^2 values) of existing data. Automated technology to monitor DO and chlorophyll result in less accurate data over long deployments. Vertical profile DO and grab sample chlorophyll a values for each sampling are used to adjust YSI continuous datasets for the dates bracketing the specific vertical profile measurement. An example of a DO correction factor (CF) applied to San Lorenzo bottom water YSI data from 7/18/05 to 7/24/05 is illustrated above.

means to record all necessary site information including sandbar status, climatic conditions, date/time, station substrate conditions, station algal and SAV conditions, water sample bottle numbers, vertical profile values, phytoplankton sample volumes, zooplankton sample volumes, etc. Immediately upon return to the office the forms were downloaded to the company server and reviewed for accuracy and completeness.

Water Quality Sampling QA/QC

One field replicate was collected during each sampling effort to quantify sampling precision for nutrients and chlorophyll. Laboratory replicates were analyzed for one out of every ten samples to verify analytical precision. Table 9.2 provides the average precision (expressed as % difference) for each of the field and laboratory replicates and triplicates collected for CLEAP. The laboratory precision is consistently below 10% error. The field replications showed strong agreement with the exception of the average ammonia precision of 19%. Analytical and field blanks were used to quantify the analytical detection limits for each constituent of interest and the respective values are provided in Table 9.2.

Table 9.2. Nutrient sampling precision and analytical detection limits for 2004 and 2005 sampling.

	NH_4	NOx	NO_2	PO_4	SiO_2	Chlorophyll
Field replicates % difference (n)	19% (23)	6% (25)	9% (3)	11% (25)	11% (25)	11% (14)
Lab replicates% difference (n)	4% (28)	5% (28)	8% (12)	4% (28)	2% (15)	8% (28)
Analytical detection limit (uM)	0.60	0.11	0.47	0.03	0.39	n/a
Analytical detection limit (ug/L)[ii]	8.4	1.5	6.6	0.93	10.9	0.10

Phytoplankton and Zooplankton QA/QC

The phytoplankton sample volume collected in the field was recorded at each station in the MS Access Database via the hand-held Palm Pilot. Four field replicates for phytoplankton community precision were collected each year for a total of eight sample replicates over the course of the study. The high cost per sample limited the number of replicates submitted for this project. Minimal sample enumeration differences were identified within the replicates. In each sample, the number of species were consistently within 5% and species identifications were consistent, but sample biovolume total as enumerated by the specialist varied by an average of 7%.

The flow meter value (used for zooplankton sampling only) pre and post sampling was recorded in the Palm Pilot and repeated between both field personnel to ensure accuracy. Due to the high cost of zooplankton sample enumeration and the inherent heterogeneous distribution of zooplankton no replicate samples were collected.

Benthic Sample Enumeration QA/QC

The initial 2004 and early 2005 benthic sampling efforts for CLEAP were led by benthic specialist, Michelle Shouse, and assisted by 2NDNATURE field personnel to ensure proper training on sample collection and enumeration techniques. M. Mathias was the lead 2NDNATURE benthic field personnel and conducted every benthic data collection effort on behalf of CLEAP and was accompanied by another trained field personnel to conduct the benthic sample collection and subsequent sample enumeration. Benthic sample enumeration was conducted within hours of field collection. Once species identification and individual numbers in sample were agreed upon the sample values were entered directly into the Palm Pilot database. At least one sample from each LSD was preserved in ethanol and reserved for Michelle Shouse to QA/QC. Of those QA/QC samples, 95% were found to be within +/- 5% of the abundance enumerations recorded in the field.

Fish Sampling QA/QC

All fish data, including species identification, fork length, weight, seining location and other relevant metadata were collected in the field (either on paper or into Palm Pilot databases). When entered, values were verbally repeated to ensure accurate documentation. Because HES and NMFS shared duties for fish sampling in 2004, there are subtle differences in data collection during that year. HES used paper spreadsheets for data collection, which were later entered into an MS Excel spreadsheet, transferred to 2NDNATURE and then deposited into the master MS Access database. In 2004 and 2005, NMFS entered the majority of the field data directly into a Palm Pilot MS Access database (using Pendragon Forms Manager 2000 software). There were occasions when some fish data were collected on paper spreadsheets; these data were later entered into the MS Access database upon return from the field.

Footnotes:

[i] For consistency, 'site' refers to a specific lagoon as a whole and 'station' refers to a specific location within a lagoon.

[ii] Unit conversion of uM to ug/L: 1uM NH_4^+, NO_x, NO_2 (as N) = 14ug/L, 1uM PO_4 (as P) = 31ug/L, 1uM Si = 28ug/L.

10. Evaluation of Lagoon Metrics

Quantitative metrics were used to simplify the CLEAP dataset while preserving its power to inform key processes and indicators of lagoon function. CLEAP was designed to gain comparative information from the range of habitat conditions represented by the five selected lagoons. Potentially successful stressors require a range of values across conditions and sites. A successful biological indicator will possess a predictable dose-response to variations in the intensity of a particular stressor.

There are three primary applications of the CLEAP stressor and indictor evaluations.

1. The results from the metric testing improve our understanding of lagoon function and primary conditions within a lagoon that influence habitat quality. The results and applications of the stressor and indicator testing will be discussed further in the Central California Lagoon Function (Section 11), CLEAP Lagoon Existing Conditions (Section 13) and Recommendations (Section 14).
2. These efforts identify baseline stressor values and associated biological responses expected within Santa Cruz coastal lagoons. Future enhancement efforts within CLEAP specific lagoons can use this information to target changes that are expected to reduce the frequency and magnitude of the identified stressor values in each lagoon. Post-enhancement monitoring can focus upon the stressors and indicators that are most appropriate to evaluate the performance of future enhancement efforts.
3. The extensive data collection and analysis efforts performed by CLEAP can be used to refine future evaluations of Coastal California lagoons. The identification of stressors and indicators that directly influence the habitat quality of coastal lagoons provides cost-effective assessment tools for future evaluations of other Coastal California lagoons, including an extensive Coastal California Lagoon rapid bioassessment, the California Rapid Assessment Method (CRAM) for wetlands, and/or the development of a Coastal Lagoon Index of Biological Integrity (IBI).

Static Stressors

Stressors have been developed and used in rapid bioassessments to express the degree of anthropogenic impacts on an aquatic system. Typically, rapid bioassessments create and test easily obtainable watershed and physical conditions that are assumed to have an influence on more site-specific characteristics that impair biological integrity. Common bioassessment stressors include % impervious coverage, population density, and snapshots of nutrient concentrations. For CLEAP, a list of watershed and lagoon features that could have an indirect influence on the susceptibility of a lagoon to inclement habitat conditions and variations in biological integrity was developed (Table 10.1). Table 10.1 presents the ID code, description, data source, unit of measure, and calculation details for each static stressor. These physical broad-scale disturbances are referred to as “static stressors”, as their conditions do not measurably change over short-time scales and there is only one value per lagoon. For the purpose of a future lagoon rapid bioassessment, these stressors could be useful. However, comparing these static stressors to the high resolution (monthly) biological data of CLEAP proved problematic. For each lagoon, there is one x-value (static stressor) plotted against several y-values (biological indicator) that vary with each sampling effort. These relationships can be heavily skewed by outlier values. Reducing the biological data to one value for the season is possible (to create five by five point comparisons), but was not performed for the CLEAP analysis. However, once the ‘successful’ dynamic stressors were identified, we tested the power of the broader watershed land-use and lagoon characteristics (static stressors) to predict the season specific impacts determined to influence biological health. The metrics in Table 10.1 may be useful for regional or local bioassessments of Coastal California lagoons.

Dynamic Stressors

The CLEAP high resolution data was used to create stressor metrics based on site-specific conditions that are assumed to have a more immediate influence on biological health. We suggest that refining the stressors beyond general watershed land use or immediate lagoon conditions will provide resource managers with specific information on system function, in addition to identifying biological indicators of lagoon health. The detailed physical, hydrologic and chemical data collection efforts were used to create a list of site and time specific “dynamic stressors”. The dynamic stressors preserve the extreme variability of the lagoon environment as it responds to many interacting conditions. Dynamic stressors are metrics that express physical and chemical conditions observed on, or leading up to, each lagoon sampling day (LSD) when the biological data was collected. Table 10.2 presents the ID code, description, data source, unit of measure, and calculation details for each dynamic stressor. The general categories of potential dynamic stressors include:

- lagoon morphology as it responds to circulation changes (MO)
- inflow hydrology (H) and nutrient loading (NU)
- lagoon circulation regime leading up to the lagoon specific LSD (CIRC)
- climatic conditions four days prior to and including the lagoon specific LSD (CL)
- nutrient and water column conditions observed during lagoon specific LSD (NU)
- degree of stratification and absolute temperature/salinity conditions in the water column four days prior to and including the lagoon specific LSD (PH)
- bottom water dissolved oxygen, pH and ORP levels four days prior to and including the lagoon specific LSD (CC)

Biological Indicators

The CLEAP team utilized examples from existing literature and successful biological indicators identified by others (Karr and Chu 1999, Ode et al 2005, US EPA 2002, etc.). Various expressions of community composition of each trophic structure were included in the list of potential biological indicators (Table 10.3). Table 10.3 also includes the metric specific ID code, detailed description, calculation details and expected response of the indicator as a stress increases. Potential indicators of habitat health for each trophic level include:

- Dominance of tolerant species
- Dominance of intolerant/sensitive species
- Species diversity
- Total number of species
- Food quality of community for predators, and
- Other expressions of community composition that were expected to vary in response to different habitat conditions.

STRESSOR AND INDICATOR TESTING

The respective values for each of the 69 dynamic stressors and 76 biological indicators (Tables 10.2 and 10.3) were calculated using the CLEAP database and MS Access programming tools. The respective stressor and indicator values were imported into MS Excel and, using Visual Basic programming, an automated matrix was developed to test a total of 5244 relationships. For each relationship, the Pearson’s correlation coefficient and associated p-value were calculated. Correlation coefficients possessing p-values significant at a range of 95-99% confidence were noted within the matrix by 5% value. Correlations possessing a p-value significant above 99% confidence (p-value < 0.01) were noted with a 1% value. Non-significant correlations (< 95% confidence to reject the null hypothesis that the relationship occurred by chance) were ignored. Any stressor or indicator that produced no statistically significant causal relationship (p-value > 0.05) was eliminated.

Following this initial screening of the correlation between lagoon stressors and indicators, 477 tests were significant at the 95% confidence and 171 of those were significant to the 99% confidence interval. To improve the power and sensitivity of each individual metric, the testing and rejection of redundant metrics ($r^2 > 0.7$) was conducted as employed by Ode et al. (2005). Visual correlation plots were created of all remaining stressor/indicator relationships to verify the correlation coefficients and p-values were not significantly skewed by a few outlier values and the stressor values represented a well-distributed range.

These efforts resulted in a collection of successful dynamic stressors and biological indicators that, together, improve our understanding of lagoon function. Table 10.4 is the resultant matrix of the most powerful stressors and indicators as determined by the CLEAP observations. Key stressor ID codes are across the top row and powerful biological indicator ID codes are represented in the left column. Each strong statistically significant relationship (> 99% confidence) is indicated in yellow and the correlation p-value is provided. Relationships with p-values between 0.05 and 0.01 are noted in grey. Graphical examples of a subset of the strong statistically significant stressor/indicator relationships are provided in Figure 10.1. The graphical relationship was examined for each stressor/indicator pair with p-value < 0.01 and used to refine the final matrix of successful stressors and indicators presented in Table 10.4.

SUCCESSFUL STRESSORS INFLUENCING BIOLOGICAL HEALTH

A second testing effort was conducted to identify causality between the degree of human disturbances to the lagoon and the more specific chemical and physical conditions that are directly influencing the integrity of the local biology. The specific dynamic stressor metrics that met the criteria described in the section above and successfully documented a causal influence on biological health are presented in Table 10.5. Based on the total number and quality of the statistically significant relationships, the most influential lagoon-specific conditions influencing biological health are the degree of water column stratification and the degree of biological metabolism, as measured by DO, pH and ORP. Also showing significant correlations to biological indicators were the degree of circulation as dictated by the sandbar status, nitrogen loading and relative nitrogen availability.

The dynamic stressor values that displayed consistent and strong correlations with biological conditions (Table 10.5) were further evaluated to determine if specific physical features of the lagoon or its watershed made density stratification or impaired dissolved oxygen, pH and ORP levels more likely. Thus, we tested the causal relationship between land use, morphology, hydrology, climate and circulation (as expressed by both static (Table 10.1) and dynamic (Table 10.2) stressors) against the key lagoon water quality stressor metrics (PH and CC metrics in Table 10.5). The matrix of the stressor correlation testing is presented in Table 10.6. As in Table 10.4, all metrics not displaying statistically significant relationship were eliminated from the table to simplify the presentation.

Land use distribution, as expressed by relative density of population, septic systems and impervious surfaces, possessed consistent positive correlations with tributary DIN concentrations (all p-values < 0.000001). Population density (LA1), percent septic (LA2) and percent impervious (LA6) also statistically correlated with the lagoon circulation regimes. The more urbanized lagoons have greater flood control needs and thus the seasonal duration of closure decreases with increasing urbanization. Other static stressors did not produce statistically significant causal relationships with specific lagoon physical and chemical conditions.

The lower table (B) in Table 10.6 presents the p-values of the successful watershed and lagoon conditions (Table 10.5) having the strongest influence on the lagoon water column stressors. The most notable of findings is that not one of the hydrologic metrics (H) showed a statistically significant correlation to water column stratification or dissolved oxygen levels. While surface water limitations will certainly affect habitat and biological health if there is not enough water volume within the lagoon, inflowing volumes may not be the controlling factor influencing stratification or biological metabolism. Lagoon morphology, as expressed by summer depth to width ratios (MO5) and % of lagoon bathymetry below MSL (MO6), displayed numerous statistically significant correlations (all p-values < 0.008) with density stratification and bottom water dissolved oxygen, pH and ORP metrics.

BIOLOGICAL INDICATORS OF LAGOON HEALTH

A list of the most powerful biological indicators of lagoon health is provided in Table 10.7. Similar to successful biological indicators determined by other biotic assessments, species diversity, species density and the relative presence of sensitive species were the most effective biological indicators identified by CLEAP. Each of the 4 trophic structures investigated had at least two successful metrics showing a dose-response to variations in the successful lagoon stressors (Table 10.5).

Biological indicators of the primary producer community showed the most frequent and powerful responses to variations in the physical and chemical conditions. As suspected, the dynamic variability of lagoons has a significant influence on the short-lived organisms at the base of the food chain. Changes in lagoon water quality have an immediate influence on density and distribution of the phytoplankton community. The longer-lived higher trophic structures are both influenced by changes in the primary producer community, as well as the physical water column conditions within the system.

Species diversity for both benthic invertebrate and fish communities showed numerous strong correlations to variations in lagoon conditions. Unfortunately, there were few direct links observed between the intensity of stress and those metrics focused upon the sensitive fish species, namely salmonids. The mobility of fish species, inherent complexity in sampling and compounding environmental effects on the quantification of salmonid populations are all potential reasons for these results. The CLEAP metric development and results provides an additional subset of information to improve our understanding and evaluations of lagoon function. There are likely additional explanations for the presence or absence of statistically significant relationships that may not include causality, and future lagoon evaluations should continue to build upon the preliminary CLEAP efforts. Discussions of stressor and indicator results and associated applications will continue in subsequent sections.

	ID	STRESSOR NAME	DESCRIPTION	Qualitative/ Estimated/ Measured	CALCULATION	UNITS	DATA SOURCE
Watershed Land Use	LA1	Population Density	Population of people dependent on watershed	MEASURED	Population / watershed SA	people/mi^2	County census, GIS
	LA2	Septic Density	Percent of watershed serviced by septic systems	MEASURED	# of parcels on septic / watershed area of septic service	people/mi^2	County GIS, aerials
	LA3	% Agriculture	Percent of watershed as agricultural land use	MEASURED	Agriculture land use SA / watershed SA	%	County GIS, aerials
	LA4	% Urban	Percent of watershed as urban land use	MEASURED	Urban land use SA / watershed SA	%	County GIS, aerials
	LA5	% Septic + Agriculture + Urban	Combined percent of watershed as septic, agriculture, and urban	MEASURED	Septic SA + agriculture SA + urban SA / watershed SA	%	County GIS, aerials
	LA6	% Impervious surface	Percent of watershed with impervious surfaces	ESTIMATED	Impervious SA / watershed SA	%	County GIS, aerials
	LA7	Flood control population	Population of people located within 100 floodplain of lagoon.	MEASURED	Population in floodplain	# of persons	County GIS, aerials
Lagoon Morphology	MO1	Average Wind Exposure	Exposure of lagoon surface to wind stress	ESTIMATED	AVE of station wind exposure ranking: 1= 80% of wind readings < 1mph, 3= 80% of wind readings 1 < wind < 5 mph, 5= 80% of wind readings > 5 mph	1, 3, 5 ranking	wind measurements, field observations
	MO2	% LSA Reduction	LSA reduction from pre-1900 to present day	ESTIMATED	(Pre-modified LSA - LSA 2005) / pre-modified LSA	%	historic/current aerials
	MO3	Average Lagoon Entrenchment Ratio	Measure of vertical containment of lagoon within active stream channel	QUALITATIVE	Channel width at bankfull / channel width at 2x bankfull; See Term Sheet for definition of bankfull	ratio	aerials, field observations
	MO4	Average Solar Exposure	Exposure of lagoon surface to direct sunlight	QUALITATIVE	AVE of station solar exposure ranking (months of July + August): 1= direct sunlight > 6 hrs, 3= 3hrs < direct sunlight < 6 hrs, 5= direct sunlight < 3 hrs	1, 3, 5 ranking	field observations
	MO5	Spring substrate	% of lagoon with substrate grain size silt or finer	ESTIMATED	AVE of stations substrate conditions 1= sand or greater, 3 = sandy/silt, 5 = organic silt/clay	1, 3, 5 ranking	field observations
Hydrology	H1	Seasonal Q Reduction	Percent reduction in fresh water inflow	MEASURED	(May 15 mean daily Q - Sept 15 mean daily Q) / May 15 mean daily Q (AVE of WY04 and WY05)	%	monthly manual measurements or USGS gage data

Metric terms and acronyms are defined in Tables 10.8 and 10.9.

POTENTIAL STATIC STRESSORS

TABLE 10.1

	ID	STRESSOR NAME	DESCRIPTION	Qualitative/ Estimated/ Measured	CALCULATION	UNITS	DATA SOURCE
Lagoon Morphology	MO5	Surface Area : Mean Depth Ratio	Ratio of LSA to lagoon mean depth during LSD	ESTIMATED	LSA / mean depth on LSD	ratio	County GIS, aerials, YSI depth data
	MO6	% Lagoon w/ Bathymetry below MSL	Percent of LSA where channel bed elevation is below sea level	ESTIMATED	Area below MSL / LSA	%	field observations, aerials
	MO7	AVE Lagoon Substrate	Lagoon substrate grain size	ESTIMATED	AVE of all stations: 1= average grain size < sand, 3= average grain size = sand, 5= average grain size > sand	1, 3, 5 ranking	field observations
Hydrology	H2	% LV as Freshwater Input	Ratio of lagoon volume to daily freshwater inflow	ESTIMATED	Mean daily Q (ac-ft) / LV (ac-ft)	ratio	Q measurements, GIS, aerials
	H3	Q	Daily mean freshwater inflow	MEASURED	Manual or USGS Q value	cfs	monthly manual measurements, USGS gage data
	H4	Normalized Q /WS SA	Daily mean freshwater inflow/WS SA	MEASURED	Manual or USGS Q value/WS SA (mi^2)	cfs/mi^2	monthly manual measurements, USGS gage data
Circulation Regime	CIRC1	Circulation Regime	Lagoon circulation regime prior to LSD	MEASURED	See Glossary	CLOSED, MICRO or MACRO	YSI depth data
	CIRC2	# of days CLOSED	Number of continuous CLOSED days prior to LSD	MEASURED	Sum Days CLOSED if LSD CLOSED	days	YSI depth data
	CIRC3	# of days MICRO	Number of continuous MICRO days prior to LSD	MEASURED	Sum Days MICRO if LSD MICRO	days	YSI depth data
	CIRC4	# of days MACRO	Number of continuous MACRO days prior to LSD	MEASURED	Sum Days MACRO if LSD MACRO	days	YSI depth data
	CIRC5	Monthly Fraction CLOSED	Fraction of 30 days prior to LSD CLOSED	MEASURED	Sum days CLOSED / 30	ratio	YSI depth data
	CIRC6	Monthly Fraction MICRO	Fraction of 30 days prior to LSD MICRO	MEASURED	Sum days MICRO / 30	ratio	YSI depth data
	CIRC7	Monthly Fraction MACRO	Fraction of 30 days prior to LSD MACRO	MEASURED	Sum days MACRO / 30	ratio	YSI depth data
Climatic Conditions	CL1	MAX Wind Speed	MAX daily wind speed	MEASURED	AVE (Daily MAX WIND SPEED prior to LSD)	mph	CIMIS Pajaro and DeLaveaga Weather Stations
	CL2	MAX AIR TEMP	MAX daily air temperature	MEASURED	AVE (Daily MAX AIR TEMP prior to LSD)	^oC	CIMIS Pajaro and DeLaveaga Weather Stations
	CL3	MAX Solar Radiation	MAX daily solar radiation	MEASURED	AVE (Daily MAX SOLAR RADIATION prior to LSD)	W/m^2	CIMIS Pajaro and DeLaveaga Weather Stations
	CL4	Daily TEMP Scalar	Scaled AIR TEMP value representing daily variation of AIR TEMP and daily MAX AIR TEMP prior to LSD	MEASURED	AVE (Daily MAX AIR TEMP * 0.75 - Daily AIR TEMP STDEV * 0.25) prior to LSD / project MAX	range 0-1; increasing stressor with increasing value	CIMIS Pajaro and DeLaveaga Weather Stations
	CL5	Annual Rainfall	Sum of daily rainfall for water year	MEASURED	SUM (Daily rainfall for range of water year)	inches	CIMIS Pajaro and DeLaveaga Weather Stations
Nutrient Conditions	NU1	DIN-in Loading	Daily DIN loading rate to lagoon	MEASURED	(Daily AVE Q * [DIN-in]) / LSA	$mg/ft^2/day$	Q measurements, stream water sampling
	NU 1.5	DIN- in CONC	Montlhly tributary DIN concentrations	MEASURED	Concentration of DIN measured in respective tributaries during sampling in closest proximity to LSD	mg/L	Tributary sampling
	NU2	SRP-in Loading	Daily SRP loading rate to lagoon	MEASURED	(Daily AVE Q * [SRP-in]) / LSA	$mg/ft^2/day$	Q measurements, stream water sampling
	NU3	[DIN-btm]:[SRP-btm] Ratio	Molar ratio of DIN to SRP in lagoon bottom waters	MEASURED	AVE of station ([DIN-btm] / [SRP-btm])	ratio	LSD water sampling
	NU4	[DIN-sfc]:[SRP-sfc] Ratio	Molar ratio of DIN to SRP in lagoon surface waters	MEASURED	AVE of station ([DIN-sfc] / [SRP-sfc])	ratio	LSD water sampling
	NU5	N:P In Ratio	Daily ratio DIN to SRP loading to the lagoon	MEASURED	DIN-in loading / SRP-in loading	ratio	Q measurements, stream water sampling
	NU6	Si-in Loading	Daily silica loading rate to the lagoon	MEASURED	(Daily AVE Q * [Si-in])/ LSA	$mg/ft^2/day$	Q measurements, stream water sampling
	NU7	Lagoon [DIN-sfc]	Mean DIN concentration in lagoon surface waters	MEASURED	AVE of station [DIN-sfc]	ug/L	LSD water sampling
	NU8	Lagoon [NH_4^+-sfc]	Mean NH_4^+ concentration in lagoon surface waters	MEASURED	AVE of station [NH_4^+-sfc]	ug/L	LSD water sampling
	NU9	[NH_4^+ -sfc]: [DIN-sfc] Ratio	Fraction of [DIN-sfc] that is [NH_4^+-sfc]	MEASURED	AVE of station ([NH_4^+-sfc] / [DIN-sfc])	ratio	LSD water sampling
	NU10	Lagoon [SRP-sfc]	Mean SRP concentration in lagoon surface waters	MEASURED	AVE of station [SRP-sfc]	ug/L	LSD water sampling
	NU11	Lagoon [Si-sfc]	Mean Si concentration in lagoon surface water	MEASURED	AVE of station [Si-sfc]	ug/L	LSD water sampling
	NU12	Lagoon [DIN-btm]	Mean DIN concentration in lagoon bottom waters	MEASURED	AVE of station [DIN-btm]	ug/L	LSD water sampling
	NU13	Lagoon [NH_4^+-btm]	Mean NH_4^+ concentration in lagoon bottom waters	MEASURED	AVE of station [NH_4^+-btm]	ug/L	LSD water sampling
	NU14	[NH_4^+-btm]: [DIN-btm] Ratio	Fraction of [DIN-btm] that is [NH_4^+-btm]	MEASURED	AVE of station ([NH_4^+-btm] / [DIN-btm])	ratio	LSD water sampling
	NU15	Lagoon [SRP-btm]	Mean SRP concentration in lagoon bottom waters	MEASURED	AVE of station [SRP-btm]	ug/L	LSD water sampling
	NU16	Ammonia stratification	Molar ratio of surface water to bottom water NH_4^+	MEASURED	AVE of station ([NH_4^+-sfc] / [NH_4^+-btm])	ratio	LSD water sampling
	NU17	Sfc N:Si Ratio	Molar ratio of nitrogen to silica in lagoon surface waters	MEASURED	AVE of stations ([DIN-sfc] / [Si-sfc])	ratio	LSD water sampling
	NU18	Daily sfc DIN am-pm Change	Percent change of DIN surface water concentrations between morning and afternoon sampling on LSD	MEASURED	([DIN-sfc] am - [DIN-sfc] pm) / [DIN-sfc] am	%	LSD water sampling
	NU19	Daily btm DIN am-pm Change	Percent change of DIN bottom water concentrations between morning and afternoon sampling on LSD	MEASURED	([DIN-btm] am - [DIN-btm] pm) / [DIN-btm] am	%	LSD water sampling
	NU20	Daily sfc SRP am-pm Change	Percent change of SRP surface water concentrations between morning and afternoon sampling on LSD	MEASURED	([SRP-sfc] am - [SRP-sfc] pm) / [SRP-sfc] am	%	LSD water sampling
	NU21	Daily btm SRP am-pm Change	Percent change of SRP bottom water concentrations between morning and afternoon sampling on LSD	MEASURED	([SRP-btm] am - [SRP-btm] pm) / [SRP-btm] am	%	LSD water sampling

Metric terms and acronyms are defined in Tables 10.8 and 10.9.

	ID	STRESSOR NAME	DESCRIPTION	Qualitative/ Estimated/ Measured	CALCULATION	UNITS	DATA SOURCE
Water Column Physical Conditions	PH1	Vertical TEMP Variation	Vertical water TEMP variation comparison between sfc and btm waters prior to LSD	MEASURED	AVE(DiffSTDEV_TEMP / project MAX); DiffSTDEV_TEMP = ABS(STDEVsfcTEMP - STDEVbtmTEMP)	range 0-1; increasing stressor with increasing value	YSI TEMP data
	PH2	Vertical SAL Variation	Vertical salinity variations comparison between sfc and btm waters prior to LSD	MEASURED	AVE(DiffMAG_SAL / project MAX); DiffMAG_SAL = ABS(AVEsfcSAL - AVEbtmSAL)	range 0-1; increasing stressor with increasing value	YSI SAL data
	PH3	Longitudinal TEMP difference	Difference in sfc TEMP from upstream to downstream lagoon stations	MEASURED	DS sfc TEMP - US sfc TEMP	°C	VP data
	PH4	Daily sfc MAX TEMP	AVE of daily MAX sfc TEMP prior to LSD	MEASURED	AVE (Daily sfc TEMP MAX prior to LSD)	°C	YSI TEMP data
	PH5	TEMP Stratification Stability	Vertical water column TEMP stratification stability prior to LSD	MEASURED	AVE{((DiffSTDEV_TEMP * 0.75) + (DiffMAG_TEMP * 0.25)) / project MAX}	range 0-1; increasing stressor with increasing value	YSI TEMP data
	PH6	SAL Stratification Stability	Vertical water column SAL stratification stability prior to LSD	MEASURED	AVE{((DiffSTDEV_SAL * 0.25) + (DiffMAG_SAL * 0.75)) / project MAX}	range 0-1; increasing stressor with increasing value	YSI SAL data
	PH7	Daily sfc TEMP and Variation	Value representing daily variation and daily MAX sfc TEMP prior to LSD	MEASURED	AVE{(((Daily sfc TEMP MAX * 075) - (Daily sfc TEMP STDEV * 0.25)) - project MIN) / (project MAX - project MIN)}	range 0-1; increasing stressor with increasing value	YSI TEMP data
	PH8	Daily btm TEMP and Variation	Value representing daily variation and daily MAX btm TEMP prior to LSD	MEASURED	AVE{(((Daily btm TEMP MAX * 075) - (Daily btm TEMP STDEV * 0.25)) - project MIN) / (project MAX - project MIN)}	range 0-1; increasing stressor with increasing value	YSI TEMP data
	PH9	Daily btm MAX SAL	AVE of daily MAX btm SAL prior to LSD	MEASURED	AVE (Daily btm SAL MAX prior to LSD)	ppt	YSI SAL data
	PH10	# of days AVE SAL <3ppt	Number of days in 30 prior to LSD, AVE daily btm SAL <3ppt	MEASURED	Sum of days btm SAL Daily AVE <3ppt	days	YSI SAL data
	PH10.5	# of days AVE sfc TEMP > 22°C	Number of days in 30 prior to LSD, AVE daily sfc TEMP >22°C	MEASURED	Sum of days sfc TEMP Daily AVE >22°C	days	YSI TEMP data
	PH11	# of days AVE btm TEMP > 22°C	Number of days in 30 prior to LSD, AVE daily btm TEMP >22°C	MEASURED	Sum of days btm TEMP Daily AVE >22°C	days	YSI TEMP data
	PH12	% of water column below halocline	AVE lagoon volume below halocline prior to LSD	MEASURED	AVE (% water column below halocline at each station)	%	VP data
	PH13	% of water column below oxycline (<3mg/L)	AVE lagoon volume below oxycline prior to LSD	MEASURED	AVE (% water column below oxycline at each station)	%	VP data
	PH14	% of water column below thermocline	AVE lagoon volume below thermocline prior to LSD	MEASURED	AVE (% water column below thermocline at each station)	%	VP data
Chemical Conditions	CC6	# of hours DO < 3 mg/L	Number of hours YSI btm DO < 3 mg/L prior to LSD	MEASURED	Sum hours DO < 3 mg/L	hours	YSI DO data
	CC7	Daily DO Stability	Scaled DO value representing daily DO variation and daily MIN prior to LSD	MEASURED	[AVE{((Daily DO MIN * 075) + (Daily DO STDEV * 0.25)) / project MAX}] * (-1) + 1	range 0-1; increasing stressor with increasing value	YSI DO data
	CC8	# of hours DO < 5 mg/L	Number of hours YSI btm DO < 5 mg/L prior to LSD	MEASURED	Sum hours DO < 5 mg/L	hours	YSI DO data
	CC9	# of hours DO < 1 mg/L	Number of hours YSI btm DO < 1 mg/L prior to LSD	MEASURED	Sum hours DO < 1 mg/L	hours	YSI DO data
	CC10	# of days MAX DO < 5 mg/L	Number of days in 30 prior to LSD, YSI btm DO MAX < 5 mg/L	MEASURED	Sum days DO Daily MAX < 5 mg/L	days	YSI DO data
	CC11	% volume of DO < 3 mg/L	% of lagoon with DO < 3 mg/L in 30 days prior to LSD	MEASURED	(AVE z<3mg/L)/(TZ)	%	VP data
	CC12	% volume of DO < 1 mg/L	% of lagoon with DO < 1 mg/L in 30 days prior to LSD	MEASURED	(AVE z<1mg/L)/(TZ)	%	VP data
	CC13	# of days MIN DO = 0 mg/L	Number of days in 30 prior to LSD, YSI btm DO MIN = 0 mg/L	MEASURED	Sum days DO Daily MIN = 0 mg/L	days	YSI DO data
	CC14	AVE btm DO MAX	AVE of daily DO MAX prior to LSD	MEASURED	AVE (Daily DO MAX prior to LSD)	mg/L	YSI DO data
	CC15	AVE btm DO MIN	AVE of daily DO MIN prior to LSD	MEASURED	AVE (Daily DO MIN prior to LSD)	mg/L	YSI DO data
	CC16	AVE daily MIN ORP	AVE of daily ORP MIN prior to LSD	MEASURED	AVE (Daily ORP MIN prior to LSD)	mV	YSI ORP data
	CC17	AVE daily MAX pH	AVE of daily pH MAX prior to LSD	MEASURED	AVE (Daily pH MAX prior to LSD)	pH value	YSI pH data
	CC18	AVE daily MIN pH	AVE of daily pH MIN prior to LSD	MEASURED	AVE (Daily pH MIN prior to LSD)	pH value	YSI pH data
	CC19	Daily ORP Stability	Scaled ORP value representing daily ORP variation and daily MIN prior to LSD	MEASURED	[AVE{(((Daily ORP MIN - project MIN) * 075) + (Daily ORP STDEV * 0.25)) / project MAX}] * (-1) + 1	range 0-1; increasing stressor with increasing value	YSI ORP data

Metric terms and acronyms are defined in Tables 10.8 and 10.9.

POTENTIAL DYNAMIC STRESSORS (PAGE 2 OF 2)

TABLE 10.2

	ID	INDICATOR NAME	DESCRIPTION	CALCULATION	EXPECTED RESPONSE TO STRESSORS	UNITS	DATA SOURCE
Primary Producers	PP1	% Biovolume as Tolerant Species	By biovolume, percent of sample that are tolerant species	Biovolume (dinoflagellates + chrysophytes + cyanophytes) / sample biovolume	INCREASE	%	LSD PHYTO sampling
	PP2	% Biovolume as Cyanophytes	By biovolume, percent of sample that are cyanophytes	Biovolume cyanophytes / sample biovolume	INCREASE	%	LSD PHYTO sampling
	PP3	% Cells as Tolerant Species	By cell count, percent of sample that are tolerant species	# cells (dinoflagellates + chrysophytes + cyanophytes) / sample total cell count	INCREASE	%	LSD PHYTO sampling
	PP4	% Cells as ZOO Food Source	By cell count, percent of sample that is a source of food for ZOO	# cells cryptomonads / sample total cell count	DECREASE	%	LSD PHYTO sampling
	PP5	Number of Species Groups	Total number of species groups in sample	Count species group in sample	DECREASE	number	LSD PHYTO sampling
	PP6	% of MAX Number of Taxa	Percent of PHYTO taxa found in this sample relative to project MAX	Number species groups in sample / project MAX	DECREASE	%	LSD PHYTO sampling
	PP7	PHYTO Biovolume	PHYTO biovolume in sample	Sum species biovolume (sum of total number of cells per species * average species cell volume provided by taxonomist)	DECREASE	um^3/L	LSD PHYTO sampling
	PP8	Species Group Diversity	Simpson's index of diversity for sample based on species groups	1 - D; D = [Sum(n*(n - 1))] / [N*(N - 1)]; n = number of cells by species groups, N = number of cells in sample	DECREASE	range 0-1; increasing diversity with increasing value	LSD PHYTO sampling
	PP9	Dominance	Relative dominance of PHYTO species composition	# species group required to equal 90% sample biovolume	DECREASE	number	LSD PHYTO sampling
	PP10	% Biovolume as ZOO Food Source	By biovolume, percent of sample that is a source of food for ZOO	Biovolume cryptomonads / sample biovolume	DECREASE	%	LSD PHYTO sampling
	PP11	% Biovolume as Chlorophytes	By biovolume, percent of sample that are chlorophytes	Biovolume greens / sample biovolume	INCREASE	%	LSD PHYTO sampling
	PP12	% Biovolume < 20um in Length	By biovolume, percent of sample that are less than 20 um in length	Biovolume of species with biovolume < $320um^3$ / sample biovolume	INCREASE	%	LSD PHYTO sampling
	PP13	% Cells as Chlorophytes	By cell count, percent of sample that are chlorophytes	# cells greens / sample total cell count	INCREASE	%	LSD PHYTO sampling
	PP14	% Cells as Cyanophytes	By cell count, percent of sample that are cyanophytes	# cells cyanophytes / sample total cell count	INCREASE	%	LSD PHYTO sampling
	PP15	% Cells < 20um in Length	By cell count, percent of sample that are less than 20 um in length	# cells of species with biovolume <$320um^3$ / sample total cell count	INCREASE	%	LSD PHYTO sampling
	PP16	CHLORO YSI MAX	AVE of daily MAX CHLORO prior to LSD	AVE (Daily MAX CHLORO prior to LSD)	INCREASE	ug/L	YSI CHLORO data
	PP17	Daily CHLORO Change	Percent change of sfc CHLORO between morning and afternoon sampling on LSD	(sfc CHLORO am - sfc CHLORO pm)/ sfc CHLORO am	INCREASE	%	LSD CHLORO sampling
	PP18	CHLORO to PHYTO Biovolume Ratio	Ratio of CHLORO concentration to PHYTO biovolume sampled on LSD	AVE of station CHLORO concentration / PHYTO biovolume	INCREASE	ratio	LSD CHLORO, PHYTO sampling
	PP19	% SAV	Percent SAV coverage in lagoon	AVE (station % cover, vegetation)	INCREASE	%	LSD % cover observations
	PP20	% Macrophyte Presence	Percent of lagoon with macrophyles present	AVE (station % cover, macrophyte)	INCREASE	%	LSD % cover observations
	PP21	Species Diversity by Individual Species	Simpson's index of diversity based on individual species	1 - D; D = [Sum(n*(n - 1))] / [N*(N - 1)]; n = number of cells by individual species, N = number of cells in sample	DECREASE	range 0-1; increasing diversity with increasing value	LSD PHYTO sampling
	PP22	Number of Individual Phytoplankton Taxa	Total number of individual species in sample	Count individual species in sample	DECREASE	number	LSD PHYTO sampling
	PP23	Diatom Species Diversity	Simpson's index of diversity based on diatom species in sample	1 - D; D = [Sum(n*(n - 1))] / [N*(N - 1)]; n = number of cells by individual diatom species, N = number of diatom cells in sample	DECREASE	range 0-1; increasing diversity with increasing value	LSD PHYTO sampling
	PP24	Number of Diatom Species	Total number of diatom species in sample	Count individual diatom species in sample	DECREASE	number	LSD PHYTO sampling
	PP25	Chrysophyte Species Diversity	Simpson's index of diversity based on chrysophyte species in sample	1 - D; D = [Sum(n*(n - 1))] / [N*(N - 1)]; n = number of cells by individual chrysophyte species, N = number of chrysophyte cells in sample	?	range 0-1; increasing diversity with increasing value	LSD PHYTO sampling
	PP26	Number of Chrysophyte Species	Total number of chrysophyte species in sample	Count individual chrysophyte species in sample	?	number	LSD PHYTO sampling
	PP27	% Cells as Dinoflagellates	By cell count, percent of sample that are dinoflagellates	# cells dinoflagellates/sample total cell count	?	%	LSD PHYTO sampling
	PP28	% Biovolume as Dinoflagellates	By biovolume, percent of sample that are dinoflagellates	Biovolume dinoflagellates/sample biovolume	?	%	LSD PHYTO sampling

Metric terms and acronyms are defined in Tables 10.8 and 10.9.

	ID	INDICATOR NAME	DESCRIPTION	CALCULATION	EXPECTED RESPONSE TO STRESSORS	UNITS	DATA SOURCE
Zooplankton	Z001	ZOO Biomass	ZOO biomass in sample	Sum (species abundance * known value of species individual biomass provided by taxonomist)	DECREASE	mg C / m^3	LSD ZOO sampling
	Z002	% Tolerant Species	Percent of sample that are rotifers	Biomass rotifers / sample biomass	INCREASE	%	LSD ZOO sampling
	Z003	Number of Taxa	Total number of species in sample	Sum species in sample	DECREASE	number	LSD ZOO sampling
	Z004	% of MAX Number of Taxa	Percent of ZOO taxa found in this sample relative to project MAX	Number species in sample / project MAX	DECREASE	%	LSD ZOO sampling
	Z005	Species Diversity	Simpson's index of diversity for sample	1 - D; D = [Sum(n*(n - 1))] / [N*(N - 1)]; n = number of cells by individual species, N = number of cells in sample	DECREASE	range 0-1; increasing diversity with increasing value	LSD ZOO sampling
	Z006	Dominance	Relative dominance of ZOO species composition	# taxa required to equal 90% sample biomass	DECREASE	number	LSD ZOO sampling
	Z007	% Herbivore	Percent of sample that are herbivorous species	Biomass herbivore species / sample biomass	DECREASE	%	LSD ZOO sampling
	Z008	% Omnivore	Percent of sample that are omnivorous species	Biomass omnivore species / sample biomass	INCREASE	%	LSD ZOO sampling
	Z009	% Biomass < 100 um	Percent of sample with individual biomass < 100 um	Biomass < 100 um / sample biomass	INCREASE	%	LSD ZOO sampling
	Z0010	% Fish Food	Percent of sample with individual biomass > 1000um	Biomass > 1000 um / sample biomass	DECREASE	%	LSD ZOO sampling
Benthic Invertebrates	BI1	% Annelid	Percent of sample that are annelids	# annelid / sample population	?	%	LSD BENTHIC sampling*
	BI2	BENTHIC population	Number of BENTHIC individuals in sample	Count number of individuals	DECREASE	number	LSD BENTHIC sampling*
	BI3	Species Diversity	Simpson's index of diversity for sample	1 - D; D = [Sum(n*(n - 1))] / [N*(N - 1)]; n = number of cells by individual species, N = number of cells in sample	DECREASE	0-1 increasing diversity with increasing value	LSD BENTHIC sampling*
	BI4	Dominance	Relative dominance of BENTHIC species composition	# taxa required to equal 90% total sample population	DECREASE	number	LSD BENTHIC sampling*
	BI5	% Fish Food	Percent of sample that is a source of fish food	# (amphipod + isopod + mysid+ insect larvae) / sample population	DECREASE	%	LSD BENTHIC sampling*
	BI6	% Corixidae	Percent of sample that are corixidae	# corixidae / sample population	?	%	LSD BENTHIC sampling*
	BI7	% Corophium	Percent of sample that are corophium	# corophium / sample population	?	%	LSD BENTHIC sampling*
	BI8	% Isopod	Percent of sample that are isopods	# isopod / sample population	DECREASE	%	LSD BENTHIC sampling*
	BI9	% Copepod	Percent of sample that are copepods	# copepod / sample population	?	%	LSD BENTHIC sampling*
	BI10	Number of Taxa	Total number of species in sample	Count species in sample	DECREASE	number	LSD BENTHIC sampling*
	BI11	% of MAX Number of Taxa	Percent of BENTHIC taxa found in this sample relative to project MAX	Number species in sample / project MAX	DECREASE	%	LSD BENTHIC sampling*
	BI12	Species Diversity (Littoral)	Simpson's index of diversity for littoral sweep samples taken at downstream sites	1 - D; D = [Sum(n*(n - 1))] / [N*(N - 1)]; n = number of cells by individual species, N = number of cells in sample	DECREASE	0-1 increasing diversity with increasing value	LSD BENTHIC sampling*
	BI13	Littoral BENTHIC Population	Number of BENTHIC individuals in littoral sweep samples at downstream sites	Count number of individuals in littoral sweep samples at downstream site	DECREASE	number	LSD BENTHIC sampling*
	BI14	Species Diversity (Benthic)	Simpson's index of diversity for benthic grab samples taken at downstream sites	1 - D; D = [Sum(n*(n - 1))] / [N*(N - 1)]; n = number of cells by individual species, N = number of cells in sample	DECREASE	0-1 increasing diversity with increasing value	LSD BENTHIC sampling*
	BI15	Benthic BENTHIC Population	Number of BENTHIC individuals in benthic grab samples at downstream sites	Count number of individuals in benthic grab samples at downstream site	DECREASE	number	LSD BENTHIC sampling*

Metric terms and acronyms are defined in Tables 10.8 and 10.9.

POTENTIAL BIOLOGICAL INDICATORS (PAGE 2 OF 3)

TABLE 10.3

	ID	INDICATOR NAME	DESCRIPTION	CALCULATION	EXPECTED RESPONSE TO STRESSORS	UNITS	DATA SOURCE
Fish	FSH1	Steelhead Population Size	Steelhead population size estimated from PIT tag recaps	Mark and recapture	DECREASE	number	LSD FISH SAMPLING
	FSH2	Steelhead Forklength Growth Rates	Changes in steelhead forklength over time	Mean (change in FL / time of recaps)	DECREASE	mm/day	LSD FISH SAMPLING
	FSH3	Tidewater Goby Presence	Presence of tidewater goby in lagoon	1= present, 0= absent	DECREASE	0, 1	LSD FISH SAMPLING
	FSH4	Steelhead survival rate	Presence of steelhead from previous season estimated from PIT tag recaptures	Mark and recapture	DECREASE	number	
	FSH5	Seasonal Steelhead Growth Rate Comparison	Comparison of MAX and MIN steelhead growth rates	MAX growth rate - MIN growth rate for each LSD	DECREASE	mm/day	LSD FISH SAMPLING
	FSH6	Steelhead Catch per Unit Effort (Abundance)	Total number of steelhead per number of seine hauls	# steelhead / # seine hauls	DECREASE	number	LSD FISH SAMPLING
	FSH7	Steelhead Catch per Unit Effort (Biomass)	Steelhead biomass per number of seine hauls	Steelhead biomass / # seine hauls	DECREASE	g	LSD FISH SAMPLING
	FSH8	FISH Catch per Unit Effort (Abundance)	Total number of FISH per number of seine hauls	# FISH / # seine hauls	DECREASE	number	LSD FISH SAMPLING
	FSH9	FISH Catch per Unit Effort (Biomass)	Sample biomass per number of seine hauls	FISH biomass / # seine hauls	DECREASE	g	LSD FISH SAMPLING
	FSH10	Rank Steelhead Disease	Rank of average steelhead black spot infection (2005 data)	1= none, 3= light, 5= heavy	INCREASE	1, 3, 5 ranking	LSD FISH SAMPLING
	FSH11	Coho Salmon Presence	Presence of coho salmon in lagoon	1= present, 0= absent	INCREASE	0, 1	LSD FISH SAMPLING
	FSH12	Number of Taxa	Total number of species in sample	Sum species in sample	DECREASE	number	LSD FISH SAMPLING
	FSH13	% of Max Number of Taxa	Percent of FISH taxa found in this sample relative to project MAX	Number species in sample / project MAX	DECREASE	%	LSD FISH SAMPLING
	FSH14	FISH Biomass	FISH biomass in sample	Sum species biomass (sum of total number of individuals * individual biomass)	DECREASE	g	LSD FISH SAMPLING
	FSH15	Species Diversity	Simpson's index of diversity for sample	1 - D; D = [Sum(n*(n - 1))] / [N*(N - 1)]; n = number of cells by individual species, N = number of cells in sample	DECREASE	range 0-1; increasing diversity with increasing value	LSD FISH SAMPLING
	FSH16	Dominance (Biomass)	Relative dominance of FISH species composition by biomass	# taxa required to equal 90% total biomass	DECREASE	number	LSD FISH SAMPLING
	FSH17	Dominance (Abundance)	Relative dominance of FISH species composition by abundance	# taxa required to equal 90% total sample abundance	DECREASE	number	LSD FISH SAMPLING
	FSH18	Steelhead Catch Biomass	Biomass of steelhead in sample	Sum steelhead biomass	DECREASE	g	LSD FISH SAMPLING
Energy Transfer	ET1	Primary Producers	Food web energy transfer of SAV to PHYTO	SAV % cover / PHYTO biovolume	DECREASE	ratio	LSD PHYTO sampling
	ET2	PHYTO to ZOO	Food web energy transfer of PHYTO to ZOO	ZOO biomass / PHYTO biovolume	DECREASE	ratio	LSD PHYTO, ZOO sampling
	ET3	ZOO to FISH	Food web energy transfer of ZOO to FISH	FISH biomass / ZOO biomass	DECREASE	ratio	LSD ZOO, FISH sampling
	ET4	BENTHIC to FISH	Food web energy transfer of BENTHIC to FISH	FISH biomass / BENTHIC population	DECREASE	ratio	LSD BENTHIC, FISH sampling
	ET5	BENTHIC to FISH II	Food web energy transfer of BENTHIC to FISH	FISH population / BENTHIC population	DECREASE	ratio	LSD BENTHIC, FISH sampling

Metric terms and acronyms are defined in Tables 10.8 and 10.9.

POTENTIAL BIOLOGICAL INDICATORS (PAGE 3 OF 3)

TABLE 10.3

Biological Indicators		Dynamic Stressors	Circulation		Climate		Nutrient Loading				Lagoon Nutrients				Bottom Water Salinity	
			duration CLOSED	duration MACRO	MAX wind	MAX solar radiation	DIN-in Load	DIN-in Conc	SRP - in Load	DIN:SRP sfc	DIN:SRP btm	NH4 conc sfc	NH4:DIN sfc	Si conc sfc	btm MAX SAL	duration SAL < 3 ppt
		ID	CIRC2	CIRC4	CL1	CL3	NU1	NU1.5	NU2	NU5	NU3	NU8	NU9	NU11	PH9	PH10
Phytoplankton Community	% ZOO food	PP4											0.0005			0.01
	# of groups	PP5		<0.05								<0.05	<0.05	0.00002		
	Group diversity	PP8		<0.05											<0.05	0.004
	Dominance	PP9		0.008			<0.05							<0.05		
	Species diversity	PP21					<0.05						<0.05			
	# of taxa	PP22										0.004	0.006	0.00001		
	# of diatom species	PP24		<0.05								0.0003	0.00002	0.0002		
	# chrysophyte species	PP26	<0.05				<0.05			<0.05			<0.05	<0.05		
Aquatic Vegetation Community	% SAV cover	PP19	0.0006			<0.05	<0.05	0.0070					<0.05		<0.05	0.006
	% macro algae cover	PP20		<0.05	<0.05	0.0004	0.007				<0.05			<0.05		
Zooplankton Community	% toerant species	ZO02								0.002			<0.05		0.003	
	# of taxa	ZO03			0.0009	0.00004	0.0009		0.0005							
	Species diversity	ZO05					<0.05		<0.05			<0.05	<0.05			
	Dominance	ZO06				0.001	<0.05		<0.05							
Benthic Invertebrate Community	Species diversity	BI3	<0.05					<0.05							0.0007	0.00004
	# of taxa	BI10	0.008													
	benthic grab species diversity	BI14						0.003							0.0002	0.0004
Fish Community	Fish per unit effort	FSH8					<0.05		0.003	0.001	<0.05			<0.05		
	# of taxa	FSH12												<0.05	0.002	0.0001
Energy Transfer between Trophic Levels	Benthic to Fish	ET4								<0.05	0.000005					

Graphic example of stressor-indicator relationship presented in Figure 10.1.

Biological Indicators		Dynamic Stressors	Degree of Stratification				Dissolved Oxygen Dynamics					pH and ORP Dynamics			
			TEMP stratification	SAL stratification	TEMP stratification	SAL stratification	duration DO < 3 mg/L	Daily DO stablity	duration DO < 5 mg/L	duration DO < 1 mg/L	btm MIN DO	daily MIN ORP	daily MAX pH	daily MIN pH	daily ORP stability
		ID	PH1	PH2	PH5	PH6	CC6	CC7	CC8	CC9	CC15	CC16	CC17	CC18	CC19
Phytoplankton Community	% ZOO food	PP4	<0.05		<0.05	<0.05			<0.05			0.0095		<0.05	0.0097
	# of groups	PP5										<0.05			<0.05
	Group diversity	PP8	<0.05		<0.05	0.001	0.004		<0.05	0.006		0.003			0.003
	Dominance	PP9				<0.05						<0.05			<0.05
	Species diversity	PP21										0.009			
	# of taxa	PP22													
	# of diatom species	PP24										0.002			
	# chrysophyte species	PP26			<0.05	<0.05								0.0031	
Aquatic Vegetation Community	% SAV cover	PP19													
	% macro algae cover	PP20													
Zooplankton Community	% toerant species	ZO02	<0.05	<0.05		0.007	<0.05	<0.05	<0.05		0.007	<0.05	0.0018	0.0001	<0.05
	# of taxa	ZO03													
	Species diversity	ZO05										0.0006			0.0006
	Dominance	ZO06													
Benthic Invertebrate Community	Species diversity	BI3		0.006		0.002		<0.05	<0.05		0.001				
	# of taxa	BI10		<0.05											
	benthic grab species diversity	BI14		0.0008		0.003	0.005	0.0001	0.0004		0.003	0.006		<0.05	
Fish Community	Fish per unit effort	FSH8									<0.05				
	# of taxa	FSH12	0.001	<0.05	0.002	<0.05	<0.05	<0.05	0.004		0.003				
Energy Transfer between Trophic Levels	Benthic to Fish	ET4													

Table Key

Blank cells indicate p-value of Pearson’s correlation <95% confidence of rejecting the null hypothesis (p>0.05).

Grey cells indicate p-value of Pearson’s correlation 95% <p-value < 99% confidence (0.05<p<0.01).

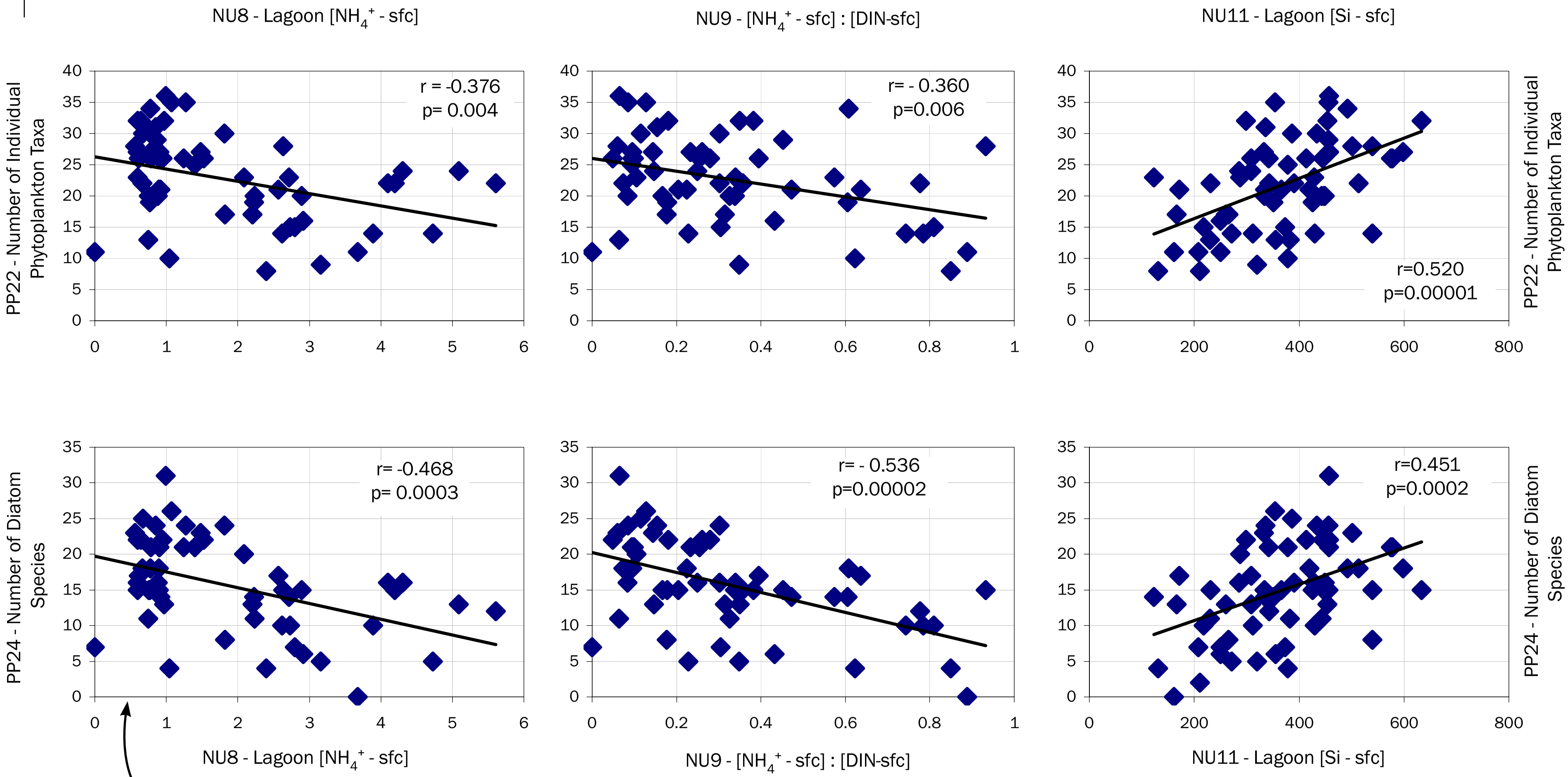
Yellow cells indicate p-value of Pearson’s correlation >99% confidence (p<0.01) and calculated p-values are provided.

Unsuccessful metrics have been removed for simplicity. The Pearson’s correlation coefficent and associated p-values were calculated for all of the dynamic stressors (Table 10.2) and biological indicators (Table 10.3). A total 4615 correlation tests were conducted. Statistically significant relationships to the 95% confidence interval were noted (p<0.05, or a 95% confidence level that the relationship is not due to chance). ‘Successful’ stressors display a range of values across CLEAP observations and have at least one strongly significant (p<0.01) correlation to a biological indicator. Successful indicators are any that show at least one strongly significant correlation to a dynamic stressor. Correlation graphics for each relationship were reviewed to ensure the data were not heavily skewed by an outlier value.

RESULTS OF SUCCESSFUL STRESSOR-INDICATOR TESTING

TABLE 10.4

Graphic representation of successful stressor-indicator relationships circled in Table 10.4. Dynamic stressors (independent variable) are plotted against biological indicators (dependent variable) with linear regression trendlines (black line). Pearson correlation coefficents (r) and p values are also providedl. All successful relationships were plotted to ensure the stressors represented a well-distributed range of values and correlations were not heavily skewed by outlier values.



As lagoon NH_4^+ concentration increases (increasing stress), the number of diatom species in lagoon phytoplankton community declines. The Pearson's correlation coefficient is -0.46, indicating the negative relationship. The correlation is significant to the 99.9997% confidence interval.

EXAMPLE CORRELATION TEST PLOTS OF SUCCESSFUL DYNAMIC STRESSORS AND BIOLOGICAL INDICATORS

FIGURE 10.1

	ID	STRESSOR NAME	DESCRIPTION	Qualitative/ Estimated/ Measured	CALCULATION	UNITS	MAX stress to biology	DATA SOURCE
Circulation Regime	CIRC2	# of days CLOSED	Number of continuous CLOSED days prior to LSD	MEASURED	Sum Days CLOSED if LSD CLOSED	days	low value	YSI depth data
	CIRC4	# of days MACRO	Number of continuous MACRO days prior to LSD	MEASURED	Sum Days MACRO if LSD MACRO	days	variable	YSI depth data
Climate	CL1	MAX Wind Speed	MAX daily wind speed	MEASURED	AVE (Daily MAX WIND SPEED prior to LSD)	mph	low value	CIMIS Pajaro and DeLaveaga Weather Stations
	CL3	MAX Solar Radiation	MAX daily solar radiation	MEASURED	AVE (Daily MAX SOLAR RADIATION prior to LSD)	W/m^2	high value	CIMIS Pajaro and DeLaveaga Weather Stations
Nutrient Loading	NU1	DIN-in Loading	Daily DIN loading rate to lagoon	MEASURED	(Daily AVE Q * [DIN-in]) / LSA	$mg/ft^2/day$	high value	Q measurements, stream water sampling
	NU2	SRP-in Loading	Daily SRP loading rate to lagoon	MEASURED	(Daily AVE Q * [SRP-in]) / LSA	$mg/ft^2/day$	high value	Q measurements, stream water sampling
Lagoon Nutrients	NU3	[DIN-btm]:[SRP-btm] Ratio	Molar ratio of DIN to SRP in lagoon bottom waters	MEASURED	AVE of station ([DIN-btm] / [SRP-btm])	ratio	high value	LSD water sampling
	NU5	N:P In Ratio	Daily ratio DIN to SRP loading to the lagoon	MEASURED	DIN-in loading / SRP-in loading	ratio	high value	Q measurements, stream water sampling
	NU8	Lagoon [NH_4^+-sfc]	Mean NH_4^+ concentration in lagoon surface waters	MEASURED	AVE of station [NH_4^+-sfc]	ug/L	high value	LSD water sampling
	NU9	[NH_4^+-sfc]: [DIN-sfc] Ratio	Fraction of [DIN-sfc] that is [NH_4^+-sfc]	MEASURED	AVE of station ([NH_4^+-sfc] / [DIN-sfc])	ratio	high value	LSD water sampling
	NU11	Lagoon [Si-sfc]	Mean Si concentration in lagoon surface water	MEASURED	AVE of station [Si-sfc]	ug/L	low value	LSD water sampling
Physical water column conditions	PH1	Vertical TEMP Variation	Vertical water TEMP variation comparison between sfc and btm waters prior to LSD	MEASURED	AVE(DiffSTDEV_TEMP / project MAX); DiffSTDEV_TEMP = ABS(STDEVsfcTEMP - STDEVbtmTEMP)	range 0-1; increasing stressor with increasing value	high value	YSI TEMP data
	PH2	Vertical SAL Variation	Vertical salinity variations comparison between sfc and btm waters prior to LSD	MEASURED	AVE(DiffMAG_SAL / project MAX); DiffMAG_SAL = ABS(AVEsfcSAL - AVEbtmSAL)	range 0-1; increasing stressor with increasing value	high value	YSI SAL data
	PH5	TEMP Stratification Stability	Vertical water column TEMP stratification stability prior to LSD	MEASURED	AVE{((DiffSTDEV_TEMP * 0.75) + (DiffMAG_TEMP * 0.25)) / project MAX}	range 0-1; increasing stressor with increasing value	high value	YSI TEMP data
	PH6	SAL Stratification Stability	Vertical water column SAL stratification stability prior to LSD	MEASURED	AVE{((DiffSTDEV_SAL * 0.25) + (DiffMAG_SAL * 0.75)) / project MAX}	range 0-1; increasing stressor with increasing value	high value	YSI SAL data
	PH9	Daily btm MAX SAL	AVE of daily MAX btm SAL prior to LSD	MEASURED	AVE (Daily btm SAL MAX prior to LSD)	ppt	high value	YSI SAL data
	PH10	# of days AVE SAL <3ppt	Number of days in 30 prior to LSD, AVE daily btm SAL <3ppt	MEASURED	Sum of days btm SAL Daily AVE <3ppt	days	low value	YSI SAL data
Chemical water column conditions	CC6	# of hours DO < 3 mg/L	Number of hours YSI btm DO < 3 mg/L prior to LSD	MEASURED	Sum hours DO < 3 mg/L	hours	high value	YSI DO data
	CC7	Daily DO Stability	Scaled DO value representing daily DO variation and daily MIN prior to LSD	MEASURED	[AVE{((Daily DO MIN * 075) + (Daily DO STDEV * 0.25)) / project MAX}] * (-1) + 1	range 0-1; increasing stressor with increasing value	high value	YSI DO data
	CC9	# of hours DO < 1 mg/L	Number of hours YSI btm DO < 1 mg/L prior to LSD	MEASURED	Sum hours DO < 1 mg/L	hours	high value	YSI DO data
	CC15	AVE btm DO MIN	AVE of daily DO MIN prior to LSD	MEASURED	AVE (Daily DO MIN prior to LSD)	mg/L	low value	YSI DO data
	CC16	AVE daily MIN ORP	AVE of daily ORP MIN prior to LSD	MEASURED	AVE (Daily ORP MIN prior to LSD)	mV	high value	YSI ORP data
	CC17	AVE daily MAX pH	AVE of daily pH MAX prior to LSD	MEASURED	AVE (Daily pH MAX prior to LSD)	pH value	low value	YSI pH data
	CC18	AVE daily MIN pH	AVE of daily pH MIN prior to LSD	MEASURED	AVE (Daily pH MIN prior to LSD)	pH value	high value	YSI pH data
	CC19	Daily ORP Stability	Scaled ORP value representing daily ORP variation and daily MIN prior to LSD	MEASURED	[AVE{(((Daily ORP MIN - project MIN) * 075) + (Daily ORP STDEV * 0.25)) / project MAX}] * (-1) + 1	range 0-1; increasing stressor with increasing value	high value	YSI ORP data

Metric terms and acronyms are defined in Tables 10.8 and 10.9.

The details of the ‘successful’ dynamic stressors presented in Table 10.4. These ‘successful’ dynamic stressors represent a range of values across lagoons and statistically correlate (p<0.01, or a greater than 99% confidence level that the relationship is not due to chance) to at least one of the powerful biological indicators (Table 10.7).

CLEAP SUCCESSFUL DYNAMIC STRESSORS TABLE 10.5

Table A. Correlations between static stressors and successful dynamic stressors.

Dynamic Stresssors		Static Stressors	Watershed Land Use		
			population density	septic density	% impervious
		ID	LA1	LA2	LA6
Circulation regime	duration CLOSED	CIRC2	<0.05		
	duration MACRO	CIRC4	0.004	0.006	0.0004
Nutrient Loading	DIN-in Load	NU1	<0.05		<0.05
	DIN-in Conc	NU1.5	0.00000009	0.00000002	0.000001
	DIN:SRP btm	NU3			<0.05
	DIN:SRP sfc	NU5		<0.05	<0.05
Degree of stratification	TEMP stratification	PH5		<0.05	
	SAL stratification	PH6		0.007	0.002
Bottom water salinity	btm MAX SAL	PH9	<0.05	0.003	0.0002
	duration SAL < 3 ppt	PH10	0.0004	0.000001	0.0000005
Dissolved oxygen dynamics	duration DO < 3 mg/L	CC6	<0.05	0.002	<0.05
	Daily DO stablity	CC7	<0.05	0.0006	0.003
	duration DO < 5 mg/L	CC8	0.0009	0.00003	0.0001
pH and ORP dynamics	daily MIN ORP	CC16		<0.05	
	daily MIN pH	CC18	<0.05	0.009	
	daily ORP stability	CC19		<0.05	

The Pearson's correlation coefficient and associated p-values were calculated for the relationships between CLEAP static stressors (Table 10.1) and the successful dynamic stressors (Table 10.5). The objective was to identify which static stressors were influencing the 'successful' dynamic stressors. The results of the correlation testing (presented above) with all metrics that did not produce statistically significant correlation eliminated . Of the static stressors calculated, only watershed land use metrics were found to have a statistically significant influence on lagoon conditions (p-values < 0.01).

Table B. Correlations between successful dynamic stressors.

			Lagoon Morphology		Hydrology		Circulation		Nutrient Loading		Lagoon Nutrients	
			SA: depth	% < MSL	Q	Q/ watershed SA	duration CLOSED	duration MACRO	DIN-in Load	DIN-in Conc	DIN:SRP sfc	NH4: DIN sfc
		ID	MO5	MO6	H3	H4	CIRC2	CIRC4	NU1	NU1.5	NU5	NU9
Degree of stratification	TEMP stratification	PH1	0.0027	0.0080	<0.05	<0.05			0.0018		0.0023	
	SAL stratification	PH2	0.0022	0.0013			0.0061	<0.05			0.0013	
	TEMP stratification	PH5		0.0000						0.0004	0.0001	<0.05
	SAL stratification	PH6	0.000002	0.0006			0.0043	<0.05		<0.05	0.0013	
Bottom water salinity	btm MAX SAL	PH9	0.0012	0.0017			0.0006	<0.05	<0.05	0.0075	0.0005	
	duration SAL < 3 ppt	PH10	0.0001	0.0005			0.0003			0.0000003	0.000000002	<0.05
Dissolved oxygen dynamics	duration DO < 3 mg/L	CC6		0.0020			<0.05			0.00001	<0.05	
	Daily DO stablity	CC7		0.0074		<0.05	<0.05			0.0000002	0.0002	
	duration DO < 5 mg/L	CC8		0.0023		<0.05	<0.05			0.0000000005	0.00002	0.00005
	duration DO < 1 mg/L	CC9		<0.05						0.0067		
	btm MIN DO	CC15	0.0002	0.0014			0.0097			0.0001	0.0006	
pH and ORP dynamics	daily MIN ORP	CC16		<0.05					<0.05	0.0058		0.0020
	daily MAX pH	CC17		0.0048			<0.05		<0.05	<0.05		
	daily MIN pH	CC18		0.00001			0.0007		<0.05	<0.05		
	daily ORP stability	CC19		<0.05					<0.05	<0.05		0.0014

The successful dynamic stressors (Table 10.5) were tested for statistically significant correlations to one another. The successful dynamic stressors representing morphologic, hydrologic, circulatory, or nutrient conditions (column headings) were correlated to those successful dynamic stressors representing lagoon water quality conditions (row headings). Results are presented in the table above.

Table Key:
Blank cells indicate p-value of Pearson's correlation <95% confidence of rejecting the null hypothesis (p>0.05).
Grey cells indicate p-value of Pearson's correlation 95% <p-value < 99% confidence (0.05<p<0.01).
Yellow cells indicate p-value of Pearson's correlation >99% confidence (p<0.01) and calculated p-values are provided.

	ID	INDICATOR NAME	DESCRIPTION	CALCULATION	RESPONSE TO INCREASING STRESSOR	UNITS
Primary Producers	PP4	% Cells as ZOO Food Source	By cell count, percent of sample that is a source of food for ZOO	# cells cryptomonads / sample total cell count	DECREASE	%
	PP5	Number of Species Groups	Total number of species groups in sample	Count species group in sample	DECREASE	number
	PP8	Species Group Diversity	Simpson's index of diversity for sample based on species groups	1 - D; D = [Sum(n*(n - 1))] / [N*(N - 1)]; n = number of cells by species groups, N = number of cells in sample	DECREASE	range 0-1; increasing diversity with increasing value
	PP9	Dominance	Relative dominance of PHYTO species composition	# species group required to equal 90% sample biovolume	DECREASE	number
	PP19	% SAV	Percent SAV coverage in lagoon	AVE (station % cover, vegetation)	INCREASE	%
	PP20	% Macrophyte Presence	Percent of lagoon with macrophyles present	AVE (station % cover, macrophyte)	INCREASE	%
	PP21	Species Diversity by Individual Species	Simpson's index of diversity based on individual species	1 - D; D = [Sum(n*(n - 1))] / [N*(N - 1)]; n = number of cells by individual species, N = number of cells in sample	DECREASE	range 0-1; increasing diversity with increasing value
	PP22	Number of Individual Phytoplankton Taxa	Total number of individual species in sample	Count individual species in sample	DECREASE	number
	PP24	Number of Diatom Species	Total number of diatom species in sample	Count individual diatom species in sample	DECREASE	number
	PP26	Number of Chrysophyte Species	Total number of chrysophyte species in sample	Count individual chrysophyte species in sample	INCREASE	number
Secondary Producers	ZOO2	% Tolerant Species	Percent of sample that are rotifers	Biomass rotifers / sample biomass	INCREASE	%
	ZOO3	Number of Taxa	Total number of species in sample	Sum species in sample	DECREASE	number
	ZOO5	Species Diversity	Simpson's index of diversity for sample	1 - D; D = [Sum(n*(n - 1))] / [N*(N - 1)]; n = number of cells by individual species, N = number of cells in sample	DECREASE	range 0-1; increasing diversity with increasing value
	ZOO6	Dominance	Relative dominance of ZOO species composition	# taxa required to equal 90% sample biomass	DECREASE	number
Benthic Invertebrates	BI3	Species Diversity	Simpson's index of diversity for sample	1 - D; D = [Sum(n*(n - 1))] / [N*(N - 1)]; n = number of cells by individual species, N = number of cells in sample	DECREASE	0-1 increasing diversity with increasing value
	BI10	Number of Taxa	Total number of species in sample	Count species in sample	DECREASE	number
	BI14	Species Diversity (Benthic)	Simpson's index of diversity for benthic grab samples taken at downstream sites	1 - D; D = [Sum(n*(n - 1))] / [N*(N - 1)]; n = number of cells by individual species, N = number of cells in sample	DECREASE	0-1 increasing diversity with increasing value
Fish	FSH8	FISH Catch per Unit Effort (Abundance)	Total number of FISH per number of seine hauls	# FISH / # seine hauls	DECREASE	number
	FSH12	Number of Taxa	Total number of species in sample	Sum species in sample	INCREASE	number
Energy Transfer	ET4	BENTHIC to FISH	Food web energy transfer of BENTHIC to FISH	FISH biomass / BENTHIC abundance	INCREASE	ratio

Metric terms and acronyms are defined in Tables 10.8 and 10.9.

Details of ‘successful’ biological indicators shown in Table 10.4. These ‘successful’ biological indicators display a statistically significant and predicatble response (p<0.01, or a greater than 99% confidence level that the correlation is not due to chance) to at least one of the powerful dynamic stressors presented in Table 10.5.

CLEAP SUCCESSFUL BIOLOGICAL INDICATORS

TABLE 10.7

Term	Definition	General Calculation	Information/Data Sources
STATIC STRESSOR	Any seasonal change in stressor is not measurable	One value per lagoon	Watershed conditions, some physical morphology (GIS, maps, aerials)
DYNAMIC STRESSOR	Stressor condition changes throughout season, a condition that can be quantified to characterize during each lagoon sampling effort	One value per lagoon per LSD	Field observations, LSD data sampling
	High resolution data	Calculation is composite of conditions 4 days prior to, and including, LSD.	YSI data (salinity, temperature, water depth, pH, DO, ORP), CIMIS weather data
	Monthly data	Utilization of most applicable data in regards to LSD conditions (pre- or post-LSD). Takes into account time of separation, circulation regimes, climate, etc.	Nutrient sampling, nutrient loading, streamflow (for non-USGS gaged streams)
ASSUMED MAX STRESS TO BIOLOGY	Evaluation of effect of static and dynamic stressors on biology. Higher value designates that the higher the stressor value, the greater the stress exerted on lagoon biology. Lower value designates that the lower the stressor value, the greater the stress on lagoon biology.	Values based on site-specific measured data, professional knowledge of hydrology, geomorphology, and aquatic chemistry.	Professional expertise, field observations
QUALITATIVE	Measure of degree of confidence in metric	Ranking of conditions given existing data, information and professional judgment	Aerials, field observations
ESTIMATED	Measure of degree of confidence in metric	Value based on some level of measurements but methods not rigorous enough to be termed "measured"	County GIS data, aerials, field observations
MEASURED	Measure of degree of confidence in metric	Values based on site-specific measured data	LSD data sampling, YSI data, USGS / monthly streamflow
dz/dt	Change in water depth with respect to time	Derivative of water depth on 2-hr time intervals	YSI water depth time series
MACRO	Macro Exchange: Time periods of significant daily water circulation in most lagoon locations due to strong physical connection of lagoon to ocean tides	12-hr R-AVE of dz/dt > 0.1 with regular patterns	YSI water depth time series data, supplemented with visual observations
MICRO	Micro Exchange: Time periods of muted water circulation due to reduced tidal influence as a result of elevated beach berm at mouth and lengthened outlet flow path	0.05 < 12 hr R-AVE of dz/dt < 0.15 with time series deviating from typical tidal patterns, or 12 hr R-AVE of dz/dt < 0.1 with diel patterns matching typical 8hr tidal variations	YSI water depth time series data, supplemented with visual observations
CLOSED	Closed Lagoon: Time periods when surface water connection between coastal ocean and lagoon is eliminated due to presence of sandbar at lagoon mouth	12 hr R-AVE of dz/dt < 0.05	YSI water depth time series data, supplemented with visual observations

METRIC TERM GLOSSARY

TABLE 10.8

Acronym	Definition
[DIN-btm]	Concentration of the nutrient constituent as measured in the bottom waters of the lagoon (DIN used as example)
[DIN-in]	Concentration of the nutrient constituent as measured in the streamflow inflowing into the lagoon (DIN used as example)
[DIN-sfc]	Concentration of the nutrient constituent as measured in the surface waters of the lagoon (DIN used as example)
ABS	Absolute value
AIR TEMP	Air temperature measured in ^{o}C
am	Sample collected between dawn and 9 am
AVE	Average of values
Bankfull	Streamflow discharge that, on average, has the most influence on the morphology of a channel (moving sediment, forming/re-forming bars, creating bends and meanders). Bankfull flow has a statistical reoccurrence interval of 1.5 years.
BENTHIC	Benthic invertebrates
btm	Bottom waters
CHLORO	Chlorophyll a
CONC	Concentration
DiffMAG_TEMP	Difference in the daily average of a water quality parameter between the surface and bottom waters (TEMP used as an example)
DiffSTDEV_TEMP	Difference in the daily standard deviation of a water quality parameter between the surface and bottom waters (TEMP used as an example)
DIN	Dissolved inorganic nitrogen ($NOx + NH_4^+$), a biologically available N species
DO	Dissolved oxygen measured in mg/L
DS	Downstream sampling station
dz/dt	Change in water depth with respect to time (ft/hr)
FL	Fish forklength
GIS	Geographic Information Systems: Spatially rectified aerials and data layers obtained from the County, City or other sources
LSA	Lagoon surface area
LSD	Lagoon sampling day: Day when water quality and all biological conditions are monitored. Typically 4-5 LSD's per season per lagoon.
LSD BENTHIC sampling*	Benthic sampling in 2004 limited to one LSD
LV	Lagoon volume
MAX	Maximum value of data
MIN	Minimum value of data
MSL	Mean sea level (ft)
ORP	Oxidation/reduction potential: Measure of the relative potential of the water body to oxidize or reduce redox compounds. Values of 100 or greater indicate an oxidized system, and decreases in ORP signify lack of oxygen and reduction of other electron acceptors.
PHYTO	Phytoplankton
pm	Sample collected between noon and 4 pm
PRIOR TO LSD	High resolution data is composited from 4 days prior to, and including, day of LSD
project MAX	The MAX value for the specific metric across all lagoons and all conditions. Metrics are typically divided by project MAX to scale all of the metric values from 0-1.
project MIN	The MIN value for the specific metric across all lagoons and all conditions. Some project MAX values are adjusted by project MIN values to scale minimum of range to 0.
Q	Instaneous stream flow discharge (cfs)
R-AVE	Running average
SA	Surface area (ft^2)
SAL	Water salinity measured in ppt
SCALAR	Normalizing all values for a metric to the maximum value of that metric. All metric values are divided by the project maximum and scaled from 0 to 1.
sfc	Surface waters
Site	A particular lagoon
SRP	Soluble reactive phosphorous (aka HPO_4^{2-}), a biologically available P species
Station	A sampling location within a lagoon
STDEV	Standard deviation of values
TEMP	Water temperature measured in ^{o}C
US	Upstream sampling station
V	Water Volume (ft^3 or acre-ft)
WY	Water year: Defined from October 1 to September 30
YSI	Yellow Springs Instruments multiparameter data loggers: surface water YSI 6000MS, bottom water YSI 600XLM
ZOO	Zooplankton

GLOSSARY OF ACRONYMS

TABLE 10.9

11. Central California Lagoon Function

The pursuit of understanding coastal lagoon function is an iterative process and subsequent focused investigations will continue to expand our knowledge of how lagoon processes should be incorporated into future lagoon enhancement efforts. One of the three main objectives of CLEAP (Section 4) is to apply the detailed data collection efforts of 2004 and 2005 to the expansion of our understanding of lagoon function.

The results from the stressor and indicator testing (Section 10) are combined with site specific observations, existing conditions data, and professional judgment to document key processes influencing coastal lagoon function. A large collection of data graphics summarize the wide array of data and information collected on behalf of CLEAP. The graphics presenting the physical and chemical components of the systems are provided at the end of this section (Section 11: Central California Lagoon Function). The biological lagoon data from 2004 and 2005 is presented by trophic structure in Section 12 (Biological Communities). Many of these graphics represent average lagoon conditions during specific LSD's and may not preserve the intra-lagoon variation in many instances. The following discussions may not refer to the graphics in specific order and the discussion of each graphic is not exhaustive.

LAGOON MORPHOLOGY AND HUMAN MODIFICATIONS

Pre-European Central California Lagoon Systems

The natural morphology of Central California lagoon systems was created by the local geology, sea level variations, contributing stream hydrology, and sediment transport dynamics. The coastal lagoons are bound laterally by well-preserved marine terraces in and around Santa Cruz, California. A marine terrace begins as a wave cut platform at the land-sea interface. Eustatic sea level changes, sea cliff erosion, and tectonic uplift work together to transform the wave cut platform into a marine terrace. Terrace age increases with elevation above sea level, with remnant indicators of older coastal terraces becoming less apparent due to weathering and erosion. The youngest marine terrace was the coastal beach environment during the last interglacial period and sea level high stand, approximately 50,000 years ago (Perg et al 2001). This terrace is the current site of many agricultural fields due to its flat topography and productive soils. Hundreds of thousands of years of sediment transport and incision through the terraces have allowed the streams to maintain a gradually sloping hydrologic connection with the coastal ocean.

The most recent marine terrace along the Santa Cruz County coast, north of the City of Santa Cruz. photo provided by http://www.californiacoastline.org/

All of the five CLEAP lagoons are naturally confined by these marine terraces, occupying paleo-stream channels that were downcut during previous sea level low stands and have filled with sediment and developed a marsh flood plain as sea level has risen to its current elevation. Prior to human modifications, the summer lagoon and winter flood flows inundated significant portions of the remnant marsh areas. Historic maps and physical channel formation processes suggest historic lagoons had a defined, yet dynamic, main low flow channel and an adjacent floodplain/marsh. The natural morphology of the main channel in a lagoon is likely to follow similar formation processes as a stream channel. The concept of the bankfull discharge has been well developed as the volumetric flow that has the greatest influence on channel morphology. Bankfull discharge reoccurs every 1.5-2 yrs on average and is a flow large enough to transport sediment and shape the channel and frequent enough to have a significant influence in channel morphology (Leopold et al 1992). Larger flow volumes do not occur often enough and smaller flows do not have the competence to move sediment and impact channel shape. While there are no unmodified lagoon channels we can use to evaluate the exact channel volume responsible for low flow morphology, we suspect the natural lagoon morphology was directly related to the available surface area of the lagoon, watershed hydrologic and sediment characteristics, and coastal tide hydraulics.

The difference between a lagoon environment and stream channel is the dynamic interaction between tidal influx and stream discharge. The hydraulic location where the forces of these two water masses interact is a depositional environment. This location of no net water movement or sediment transport is extremely dynamic on daily time scales, and varies with the tidal height, swell power and the stream discharge. The complex hydraulics and extremely high sediment loads at the land/sea interface likely made the location of the main channel in a natural lagoon much more variable than what is observed today in these modified systems. The 1928 aerial of Scott Lagoon illustrates the large natural meander pattern of the low flow channel through the shallow relief of the lagoon environment (Figure 11.4). This image also provides evidence of old main channel scars to the south and the north of the existing channel, indicating the very high sediment load and main channel migration patterns within a lagoon. The low gradient and high sediment loads in a natural Coastal California lagoon created longer meander patterns of the defined channels than present in today's modified morphologies. The dynamic depositional environment of an unmodified lagoon was likely characterized by an elevated shallow groundwater table, typical of a backwater marsh environment.

The winter lagoon system is a deltaic river mouth, experiencing competing hydrologic forces between storm runoff events that transport sediment to the ocean, and tidal wave action that introduces saline waters and coastal sediments into the lagoon area. Prior to flood control and reclamation actions, winter storms experienced frequent out of bank flow and nutrient-rich sediment deposition into the marsh area. We would expect the location of the main lagoon channel to migrate throughout the marsh area as large depositional events would move the active location of the low flow channel.

During summer sandbar lagoon formation, the historic area of inundation was characterized by extensive areas of shallow marsh habitat and deeper water where the main low flow channel was located. The 1853 US Coast Geodetic Map was used to compare the historic and existing lagoon morphologies for San Lorenzo and Aptos Lagoons (Figures 11.10 and 11.13). By 1853 the configuration of the San Lorenzo Lagoon has already been modified and encroached by human activities, but remnants of shallow adjacent marsh areas are apparent. The image of Aptos Lagoon as depicted on the 1853 map illustrates the expansive surface area and distribution of lower lying land bound within the sandstone bluffs through which Aptos Creek and its lagoon had carved. Before human land use constraints isolated the creek along the northern bluff, it meandered between the two bluffs as sediment deposition influenced the active location of the low flow channel.

Little historic literature exists concerning the biological communities of the lagoons. The most useful historic accounts address the productive and abundant salmonid populations that utilized the lagoon system during the summer and fall seasons, suggesting a stable and productive ecological community able to support these higher trophic levels.

LAGOON MODIFICATION CHRONOLOGY

More than 130 years of human alterations have profoundly impacted the natural morphology, water quality and habitat conditions of Santa Cruz County lagoons. Flood control, bridge construction, railroad crossings and marsh reclamation have constrained the main channels of the lagoons. The low flow channels were historically modified to expand agricultural or urban land usage, and today levees contain nearly all flow volumes in relatively straight channels. These modifications have enlarged the low flow channel geometry, disconnected the low flow channels from the productive marshes (floodplain areas), significantly reduced the lagoon surface areas, and transformed the summer lagoons into relatively deep straight, and in some cases, incised channels.

Development highlights of each CLEAP lagoon are presented in Figure 11.15. The development chronology of the human changes to the Santa Cruz County lagoons can be divided into two stories based on geography. Scott and Laguna Watersheds are located on the less populated, agricultural North Coast. San Lorenzo, Soquel and Aptos Watersheds are within the urbanized cities of Santa Cruz, Capitola and Rio Del Mar. San Lorenzo, Soquel and Aptos Lagoon areas have high priority flood protection and no summer lagoon deviations from the defined channels were observed or expected. With small levee breach exceptions, Laguna and Scott Lagoon also are disconnected from their floodplains during the majority of the year.

North Coast Lagoons

The rugged coastline of the North Coast of Santa Cruz County, with its rocky outcrops and high cliffs, curtailed early settlement. Thus, human development that would impact the North Coast lagoons occurred at a much slower pace and to a lesser extent than those lagoons located within the protection of the Monterey Bay coastline. In the late 1800s, the few people who had settled along the North Coast were predominately dairy farmers (ESA 2004) with little impact on the morphology of the adjoining lagoons. In 1906, the construction of the North Coast Railroad bisected the floodplains of most North Coast lagoons with wooden trestles, including San Vicente, Liddell and Wilder Creeks (ESA 2004). The trestles spanned the floodplain of the lagoons at a height of 50ft and were filled solid with earthen materials. Each creek was diverted through a 10ft diameter tunnel along the northern bluff, forever restricting the natural meander patterns of the incoming tributaries to the lagoons.

Laguna Creek travels beneath the North Coast Railroad tunnel, prior to entering the lagoon area. The adjacent freshwater supply and flat, nutrient rich soils of the lagoon floodplains were ideal locations for early cultivation crops. Based on a time series of aerial photographs, an agricultural presence persisted intermittently through 2000 within the marsh of Laguna Lagoon. The low flow channel was relocated along the northern bluff by 1928 to accommodate cultivation of these adjacent marsh areas (Figure 11.6). The main Laguna channel exists in this configuration today, bound by earthen levees and much shorter and straighter than its natural morphology. Remnants of a concrete dam structure are located approximately 150ft downstream of the Railroad tunnel (Site LA5; Figure 11.5), acting as grade control and channel confinement in the upper Laguna Lagoon. We suspect the dam was constructed to impound freshwater flows to create a nearby irrigation source.

Currently, the Laguna Lagoon earthen levee has failed in one location, creating a small channel that allows water to access an isolated low lying area of the marsh (Station LA3.5; Figure 11.5). The levee breech is characterized by a small scour channel less than 4ft wide. Remnants of the levee have created a sill between the main channel and the open pond (Station 3.5), constricting the hydrologic connection of this area. The sill elevation is estimated to be 2.0-2.5ft AMSL. When the water surface elevation in the main channel exceeds approximately 2.0ft AMSL, water will enter the open pond area. Outflow from the pond occurs when the water surface elevation in the main lagoon is lower than the sill elevation. Observations indicate that sustained low water conditions in the main lagoon can completely disconnect the two water bodies, hydrologically isolating the open pond. With the exception of the open pool area, extensive marsh inundation was limited to fall months when winter rains increase water flux to the lagoon prior to the breach of the sandbar (see photo below). Laguna Lagoon is the only lagoon included in CLEAP that does not have bridge constriction located near the mouth of the lagoon.

Laguna Creek Lagoon on October 21, 2004, following the first rain event of the season. The lagoon is at the maximum surface area of indundation observed during CLEAP.

The channel and marsh of Scott Lagoon are also constrained between the two natural sandstone bluffs, and emergent vegetation inland of the coastal beach zone is apparent in 1928 (Figure 11.4). While Scott Creek lagoon avoided the railroad bisection in 1906 (the builders chose to cross the marsh further upstream), the agricultural influx to the North Coast resulted in reclamation of the Scott Lagoon floodplain for cultivation. The 1928 aerial of Scott Creek provides a good example of the natural morphology of these North Coast lagoons. The shallow slope of the Scott Creek/ocean interface created a wide meander bend pattern of the main channel. By 1928, the upstream portion of Scott Creek Lagoon had been channelized to accommodate agricultural activities on the north bluff. In 1929, California Coastal Highway One was constructed and bisected the mouth of Scott Creek, performing the floodplain division that had befallen the other North Coast lagoons two decades earlier. Highway One dissects the lagoon approximately 1500ft from the ocean and defines the transition from beach sand environment to marsh/lagoon habitat. The lagoon is constricted by a 120ft opening beneath the Highway One Bridge (see photo below). Highway One bridge development and agricultural pressures resulted in the straightening and confinement of Scott Creek perpendicular to the ocean. The northern meander bend was abandoned, earthen levees were constructed and the summer lagoon inundation area was reduced by an estimated 84% (Table 11.1).

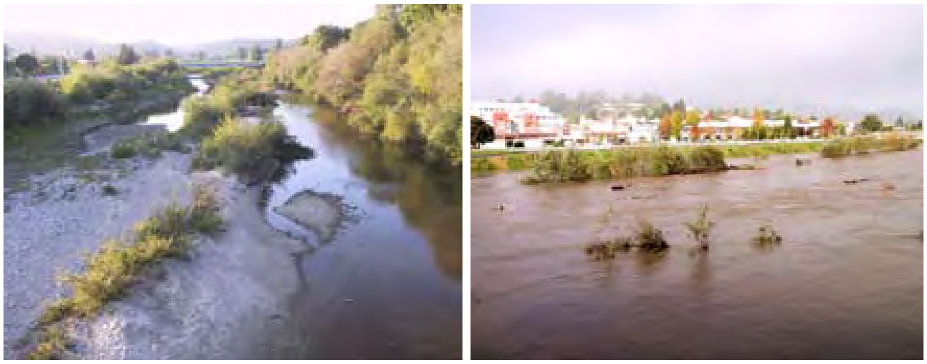
Highway One bridge crossing (120ft wide) at Scott Creek Lagoon, looking upstream on May 11, 2004.

There is minimal hydrologic access to the lagoon floodplain due to levee presence at Scott Lagoon, and this disconnection may have been exacerbated by channel incision. Like Laguna, the earthen levee built at Scott Creek to restrict the creek's flow path has deteriorated in one location. Upstream of the Highway One Bridge a deep side channel pocket has formed perpendicular to the main lagoon channel (referred to by CLEAP as the Scott Side Channel (station SC3); Figure 11.3). Site observations suggest that the width and length of the Scott Side Channel has progressively expanded between 2003 and 2005. A deep isolated hole is located to the south of the lagoon area and appears to be fed by groundwater and a small watershed to the east (Figure 11.3), since there is no evident surface water connection between the lagoon and this south pool. Adjacent marsh inundation is limited to fall months when winter rains increase water flux to the lagoon prior to the breach of the sandbar (see photo below). The agricultural fields within Scott Lagoon Marsh were abandoned between 1960-1970 and today Scott Creek Watershed contains sparse rural residential development and agricultural lands.

Scott Creek Lagoon in the Fall of 2003 following the first winter rains displays the maximum inundation observed during CLEAP observations.

Urban Lagoons

The urban lagoons, situated on the more habitable coastline of the protected Monterey Bay, experienced an accelerated rate of human development and morphologic manipulation. European settlement led to major agricultural influence in the Santa Cruz County urban area. By the late 1800s, the urban lagoon floodplains were moderately populated and being altered to fit the needs of its inhabitants. Prior to the flood of 1862, the San Lorenzo River flowed along the base of the western bluff of Mission Hill and toward Neary's Lagoon. Large flows were reported to create considerable erosion as the San Lorenzo River undercut the western terraces (McMahon 1997). A bulkhead was constructed to divert the river east (what is now Bulkhead St. near the intersection of River and Water Streets), providing the City of Santa Cruz with early flood control. Simultaneously, many property owners on the western bank raised their property with 4ft or more of earthen fill to reduce the hydrologic connection of the river and Neary's Lagoon during flooding events. As the town of Santa Cruz continued to grow, the floodplain of the San Lorenzo River was further constrained by the businesses settling along its western bank and the construction of numerous bridges across the lagoon. By 1853, the floodplain of the San Lorenzo Lagoon (Figure 11.10) was occupied by a considerable presence of cultivated fields. In 1876 the Santa Cruz County railroad was completed from Santa Cruz to Watsonville (Swift 2004). Railroad trestle bridges were constructed over the urban lagoons instead of the earthen walls created along the North Coast. In some instances the trestles were placed in close proximity the ocean, constricting the cross-sectional area and permanently constraining the morphology of the urban lagoons, particularly San Lorenzo and Soquel Lagoons. The Santa Cruz Beach Boardwalk was constructed in the early 1920's with the Giant Dipper Rollercoaster completed in 1925. Severe flooding in the winters of 1938, 1941 and 1955 within the lower San Lorenzo River prompted the U.S. Army Corps of Engineers (ACOE) flood control project. By 1960, the San Lorenzo River was straightened and confined by levees to its current configuration. In order to provide the necessary flood capacity, the ACOE flood control project included annual channel dredging and sediment removal from the San Lorenzo River oceanward of Highway One, eventually ceasing entirely in the 1990's. The saga of San Lorenzo River flood control between the City of Santa Cruz and the ACOE has a long history that continues today.



Different flow conditions on the San Lorenzo River. Photos taken upstream of Soquel Avenue Bridge on April 20, 2004 (left) and December 16, 2002 (right) with mean daily discharges of 87 and 13,000 cfs, respectively. (Source: USGS gage #11161000)

Recreational activities were the major influence for the early alterations within Soquel and Aptos Lagoons. Camp Capitola was founded in June of 1874 and through the 1870's remained a typical, unadorned summer campground (Swift 2004). In 1882 the camp was subdivided, giving rise to more permanent structures, such as summer homes, Victorian cottages, and ornamental gardens. As the area attracted more summer tourists in the 1890's, a 160-room hotel, summer vacation rentals, and resort concessions were built. Increasing summer populations directly affected the Soquel Lagoon. In 1880's the creek was confined to the northern bluff to allow for more beachfront and the lagoon mouth was dammed to form a summer swimming area. The appeal of the freshwater pool meant more concentrated efforts to manually build a summer sandbar. In 1899 a 3ft diameter pipe was buried under the beach from the lagoon to the ocean to maintain the summer lagoon elevation (Swift pers. comm.2005). In the early 1920's a water slide was built from the top of one of the adjacent buildings at the mouth of the lagoon to entice tourists and in 1926 the creek was dredged to improve summer boating. During the early 1900's the Soquel Lagoon was heavily fished and known for its productive trout populations.

Early 1920s photograph of the water slide constructed in Soquel Lagoon to attract summer tourists. (Photo courtesy of Capitola Historical Museum.)

The 1853 US Coast Geodetic Map depicts Aptos Lagoon nearly unmodified (Figure 11.13). The 1875 construction of the Spreckels' Aptos Hotel on the floodplain constricted the natural meandering of the creek (Hibble 2000), but a photograph from 1920-22 indicates Aptos Creek was still able to meander towards the southern bluff (see photo below). While the tourism industry was slower to come to Rio Del Mar than Capitola, the changes were no less dramatic. By the mid-1920's the lagoon was moved to the northern bluff and in 1926 the Aptos Lagoon floodplain (aka Rio Flats) was leveled and raised 7' to accommodate housing subdivisions (Hibble 2000). In 1928 the mouth of Aptos Lagoon was also manipulated to improve recreational use and referred to as the "world's largest freshwater swimming pool" with a bathing pavilion (Hibble 2000). The cement wall along the north bank and boat launching platforms from the Aptos Bath House still remain today.

Photo on left of Aptos Lagoon looking south taken circa 1922, pre-development. The low flow channel can be seen in the foreground. Photo on right taken in 1931, following the leveling and raising of the Aptos Lagoon floodplain to develop Rio Flats. Photos courtesy of Capitola Historical Museum.

Aptos bathhouse of the late 1920s. Aptos Lagoon was manipulated to create the 'world's largest freshwater swimming area'. Photo courtesy of Capitola Historical Museum.

The flood control and straightening of the stream/lagoon systems have transformed what were high surface area summer lagoons with a main low flow channel into constricted flood-controlled systems. Today, little change in lagoon surface area occurs as summer water volumes increase following sandbar formation.

CURRENT WATERSHED CONDITIONS

Figure 6.2 presents the relative locations of each of the lagoons investigated as part of CLEAP. The primary watershed conditions calculated for CLEAP focus on any land use or human development conditions that are assumed to potentially impair lagoon health (Table 11.1). Watershed land use distribution variables illustrate a range of development density and other land use characteristics across the five lagoons, as intended by their selection in 2003. The North Coast watersheds are slightly impacted by rural residential and agricultural uses. The urban watersheds have greater flood control needs and denser residential pressures. As shown by the degree of anthropogenic influence, one of the main limitations of CLEAP is the lack of a relatively undisturbed lagoon watershed to serve as a reference condition. Table 11.1 also identifies the primary tributaries contributing to each of the subject lagoons investigated by CLEAP, since these tributaries provide the chemical and hydrologic link between upper watershed land use and potential impacts to the lagoons at the watershed terminus.

CLIMATIC CONDITIONS 2004 AND 2005

Climatic variables assumed to influence lagoon function are presented in Figure 11.16. Annual precipitation will influence streamflow hydrology, sediment transport dynamics and the summer water budget within the lagoons when the freshwater supply may be limiting. Water year 2005 (WY05) produced over 15in more precipitation than WY04, with total precipitation values of 34.6in and 19.1in, respectively. The average annual rainfall for Santa Cruz County is 31in (http://www.co.santa-cruz.ca.us/cao/econprof.htm), indicating WY04 was a below average water year and WY05 was slightly above average. The amount of Spring rainfall will impact the summer lagoon water budget. Over 15in of rain fell after February 1st in 2005, giving rise to the differences seen in stream hydrology between the two water years.

The intensity of daily solar radiation and air temperatures significantly increase in the summer months, potentially having a profound effect on photosynthetic rates at the base of the food chain as a result of increased light availability and warmer temperatures (Figure 11.16). The availability of solar radiation in the surface waters of each lagoon depends upon both the climatic conditions as well as the relative exposure and susceptibility of the lagoon to solar radiation. Table 11.1 provides the results of the qualitative exposure rankings for each lagoon. In addition to being drier, 2004 summer weather included days of higher solar radiation and associated daily air temperatures, with over 14 days exceeding 30^{o}C (Figure 11.16).

Coastal wind speeds can influence lagoon water exchange, reduce surface water temperatures and potentially increase the thickness of the surface water layer influenced by atmospheric oxygen exchange. During micro tidal or closed conditions, wind stress within the lagoon may be a significant energy source inducing water movement. The lack of lagoon specific weather data limits our ability to draw statistical conclusions about the role of wind mixing on water quality conditions, but observations in CLEAP and other lagoons suggest that locations protected from daily wind mixing may be more susceptible to eutrophic conditions.

SANDBAR DYNAMICS AND LAGOON FORMATION

The sandbar dynamics of a coastal lagoon are of particular interest when evaluating lagoon function. The frequency and duration of lagoon closure in Santa Cruz County influences:

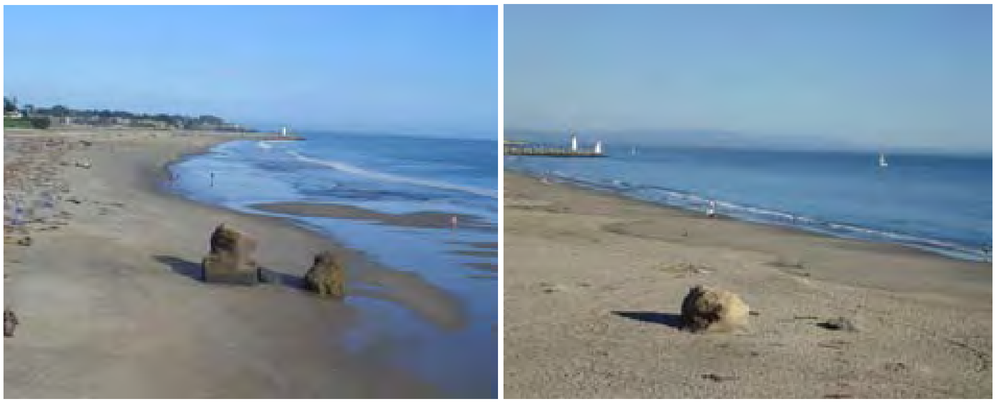
- the degree of water circulation
- the adjacent shore zone beach water quality
- the lagoon water quality and associated ecological consequences
- the lagoon water budget and
- the movements and migration of fish species between the lagoon and the coastal ocean.

	Scott Lagoon	**Laguna Lagoon**	**Soquel Lagoon**	**San Lorenzo Lagoon**	**Aptos Lagoon**
Watershed Characteristics					
Latitude and Longitude (Source USGS)	370228N 1221334W	365900N 1220314W	365818N 1215707W	365751N 1220045W	365811N 1215707W
Watershed Area (sq miles)	29.8	7.8	42.6	135.9	24.3
% Watershed Impervious	0.6	2.6	4.7	8.8	4.6
% Watershed Urban	0.0	0.0	4.8	6.8	8.2
% Watershed Agriculture	0.0	0.7	0.4	0.1	1.1
Population Density (persons/sq mile)	9	133	395	508	409
Septic Density (persons/sq mile)	9	133	175	269	219
Flood Control Population Directly Impacted (persons)	0	0	227	2726	295
Main Tributaries	Scott Creek	Laguna Creek	Soquel Creek	San Lorenzo River Branciforte Creek	Aptos Creek Valencia Creek
Lagoon Characteristics					
Lagoon Surface Area - Historic (sq ft)	1.178 x 10^6	9.26 x 10^5	8.57 x 10^5	7.445 x 10^6	9.67 x 10^5
Lagoon Suface Area - Open (sq ft)	1.65 x 10^5	1.15 x 10^5	2.57 x 10^5	1.371 x 10^6	1.07 x 10^5
Lagoon Surface Area - Closed (sq ft)	1.84 x 10^5	2.8 x 10^5	2.57 x 10^5	1.497 x 10^6	1.73 x 10^5
Lagoon Surface Area % Reduction	84	70	70	80	82
Lagoon Exposure Ranking (1 - high stress to lagoon, 5- low stress)	2.85	2.80	4.05	2.35	2.45

CLEAP WATERSHED CHARACTERISTICS

TABLE 11.1

The Coastal California lagoon systems experience dramatically different seasonal characteristics. During the winter months, ocean sand delivery dynamics remove a significant portion of the coastal beach berm to storage in the nearshore, resulting in 8-15 ft lower sandbar elevations at the break zone (beach interface) (Shepard 1963). The relatively lower beach during the winter months, coupled with increased streamflow, results in much stronger and more frequent water circulation within the lagoons between November and April each year. When the river mouth is connected to, and influenced by, the coastal tidal variations, these systems are technically estuaries. The beach depositional environment of the coastal ocean significantly changes in the late spring/early summer. Sand stored in the nearshore environment during the winter is transported on shore as wave action has greater energy when approaching the beach than when leaving. This physical characteristic naturally creates sandbar barriers at the mouth of the coastal watersheds, forming summer backwater lagoon systems. The winter beach is much steeper and has a lower shore zone elevation than the summer beach.



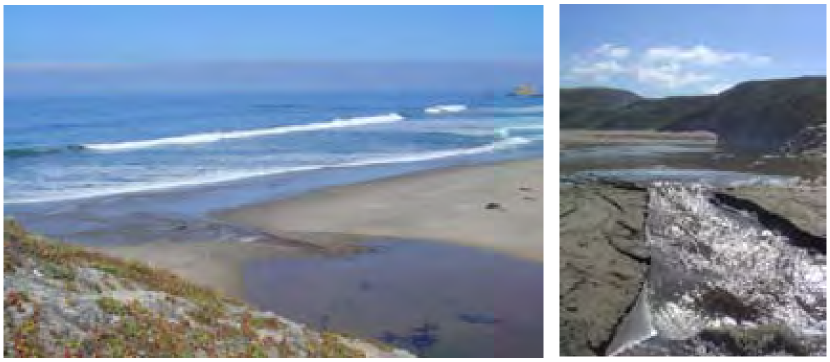
Seabright Beach bordering San Lorenzo River Lagoon to the east. Photo on left taken March 2004; photo right, October 2004. Notice the differences in the exposure of the two rocks in the foreground.

Tidal conditions, sandbar depositional environments, freshwater inflow and lagoon morphology all play a role in the timing and duration of summer lagoon formation. However, we suggest the dominant processes controlling the timing and duration of sandbar closure vary, depending upon lagoon and beach morphology.

The five CLEAP lagoons have very different physical and hydrologic characteristics. Figure 11.18 summarizes the circulation regime, as dictated by the sandbar status of each lagoon during the study period. The most obvious difference with respect to sandbar stability is that the unmanaged, flood-controlled lagoons (Aptos and San Lorenzo) show a much less stable sandbar due to lack of water storage and/or unauthorized manual breaches as discussed in more detail below.

Soquel Lagoon is manually closed the week prior to Memorial Day weekend and manually breached prior to first major winter rain event each year per the 2004 Soquel Creek Lagoon Management and Enhancement Plan Update (Alley et al. 2004). The water levels in Soquel Lagoon are maintained by a sill that constantly drains surface water to the Monterey Bay via a permanent concrete flume. Because the open and closed status of this lagoon is completely artificial and has been since the early 1900's, little information concerning the natural behavior of the sandbar can be gained from Soquel Lagoon.

Based on our observations in the four other CLEAP lagoons, we suggest there are windows of lagoon closure opportunity, dictated by the tidal cycle and swell dynamics that deliver sediment to the coastal beach at the mouth of the lagoons. These opportunities for closure only occur in the spring/summer months when the streams are approaching baseflow conditions and the coastal sandbar elevations are gradually increasing. Spring tides are more likely than neap tides to induce bar closure because the higher the tidal elevation, the further landward beach sediment is deposited. The initial moments of sandbar closure are tenuous. If the hydrologic separation can be maintained through the next low tide, the sandbar elevation can be gradually increased with each subsequent high tide and beach deposition event. Intermittent hydrologic separation between the ocean and lagoon were observed on many LSDs, where the high spring tide separated the two water masses, but during the subsequent low tide the lagoon edge would scour a channel to reestablish hydrologic connection with the ocean. During these tenuous times, the elevation difference between the lagoon water surface elevation and the top of the sandbar is a matter of inches. The inadvertent act of a beachgoer manipulating the channel mouth, or the intentional opening of a channel at this critical time may be enough to prevent closure, partially explaining the extreme seasonal circulation variations observed at the lagoon mouths located on popular beaches.



Mouth of Laguna Lagoon on June 19 2005. Intermittent breach as tide receeds.

The lagoon mouth morphology, as well as that of the entire lagoon, appears to have an influence on the hydrologic behavior during the initial closure. An unconstrained lagoon mouth can laterally expand as the sandbar elevation gradually increases. A wider cross-sectional flow area reduces the hydraulic power of the lagoon waters trapped behind the sandbar. The lack of hydraulic power to maintain a scour channel when the tide recedes will keep the lagoon waters impounded through the next tidal cycle, allowing more sand to be delivered with the next high tide and continuing until the water surface elevation of the lagoon is many feet below the sandbar elevation.

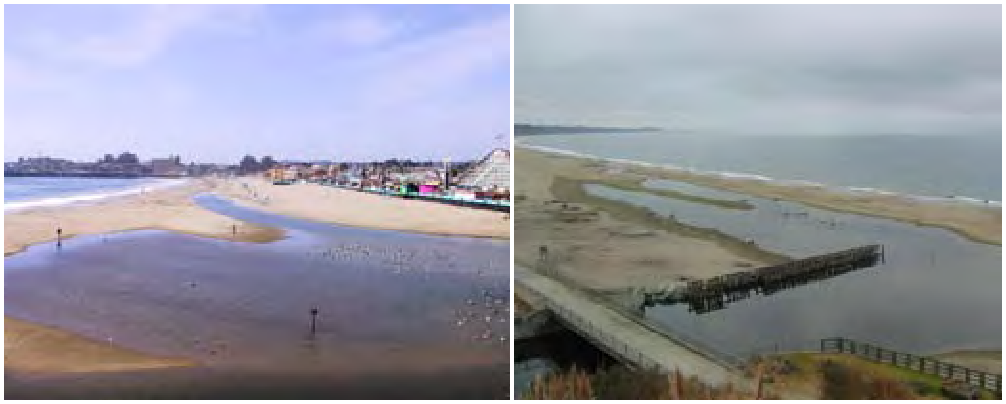
Laguna Creek Lagoon in September 2005, following 10 weeks of sustained closed conditions. Elevation difference between lagoon water and peak of sand bar is approximately 4 ft.

Laguna Lagoon is the most representative example of natural, unconstrained sandbar dynamics in this study. Laguna Creek is a partially confined lagoon with limited access to its floodplain due to the railroad crossing and historic reclamation of the lagoon areas for agriculture (Figure 11.6). The final 300m of Laguna Creek, however, currently possess a relatively natural morphology, unconstrained by human structures. During both 2004 and 2005 Laguna was the earliest lagoon to close and remained closed until winter rains exceeded the storage capacity of the lagoon (Figures 9.1 and 11.18). Laguna is the smallest watershed investigated (7.8 mi^2) and thus is expected to have much lower inflows that the other CLEAP lagoons. We believe both natural seasonal reductions in freshwater inflow and the more natural morphology of the lagoon/ocean interface are the primary factors controlling the early closure and sustained presence of the sandbar at this lagoon.

The three other lagoons (Scott, San Lorenzo and Aptos) provide interesting comparisons with respect to the timing of lagoon formation and duration of closure. On July 15 2004, a moderate south swell hit the Monterey Bay coastline (National Data Buoy Center Station #46042; http://www.ndbc.noaa.gov) at the same time as a spring tidal cycle (Figure 11.19). Prior to this date, the sandbars at the mouths of Scott, San Lorenzo, and Aptos Lagoons were all open to the ocean. According to streamflow measurements, the freshwater inflow to Scott, San Lorenzo, and Aptos were 2, 10, and 0.5 cfs, respectively (Figures 11.19, 11.25 and 11.27), yet in each lagoon the sandbar formed for the first time in 2004 during these tidal conditions (Figures 9.1 and 11.18). The 2005 sandbar closure timing appears to be more variable than the previous, drier, 2004, but both San Lorenzo and Aptos experienced closures the week of August 24, 2005. This week is characterized by another spring tide (Figure 11.20) coupled with a slight south swell.

In flood-controlled lagoons and those with constrictions at the mouth, such as bridge footings, the duration of the sandbar presence appears to be shortened. When summer outflow from a lagoon is laterally constrained, it will maintain a smaller, more concentrated cross-sectional channel at the ocean interface. Therefore, the sandbar must attain a higher elevation than under natural conditions to impound the outflowing water. Given the same lagoon discharge, a smaller cross-sectional area will possess a higher velocity at the ocean interface (Q= v * A, where Q is discharge, v is velocity and A is cross-sectional area). A relatively higher flow velocity will increase the ability of the water to transport sand and maintain hydrologic connection with the ocean during the subsequent low tides, preventing closure. In these instances, sequential high tidal events may need to be coupled with a slight swell to deposit significant amounts of sand on the beach, exceed the elevation of the lagoon waters and impound the lagoon through the subsequent low tide.

The duration of closure is dependent upon the water storage capacity of the lagoon. If the lagoon water surface elevation exceeds the sandbar elevation, the lagoon will breach. Once closed, the sandbars of the North Coast lagoons remained intact until the fall rains exceeded the water storage capacity of these systems. From CLEAP observations, the flood-controlled lagoons (San Lorenzo and Aptos) have significantly reduced surface water areas and lagoon water storage volumes. These two flood-controlled lagoons have limited and variable closure durations (Figure 9.1) relative to North Coast lagoons, because the lack of water storage allows the lagoon water level to exceed the sandbar elevation. While numerous unauthorized manual breachings prohibited Aptos Lagoon from natural sandbar conditions during CLEAP monitoring (State Park Rangers, Personal Communication 2004/2005), it is clear that in order for both San Lorenzo and Aptos Lagoons to remain closed for more than 7-10 days, a significant amount of water storage must be accommodated along the open beach.



San Lorenzo Lagoon Fall 2002 and Aptos Lagoon in September 2005. Due to a lack of upstream water storage, these two lagoons inundate the open beach.

Circulation Regime

As discussed in Section 5, the magnitude of water circulation in coastal lagoons is expected to influence water quality and associated ecological health. Site observations indicated three distinct circulation regimes are experienced by coastal lagoons. Borrowing from Monbet (1992), the derivative of the continuous water depth records for each lagoon was used to characterize the circulation conditions as result of sandbar dynamics (Figure 11.17). Figure 11.18 summarizes the seasonal circulation conditions for each lagoon. Macrotidal indicates that the lagoon hydrology is consistently influenced by the coastal tidal variations, as seen by daily lagoon water level variations following the tidal cycle. Microtidal suggests that the sandbar presence has partially isolated the lagoon from tidal variations. In a microtidal lagoon, daily water mixing is reduced and the depth derivative deviates from the typical diel tidal pattern. A closed lagoon indicates sandbar presence and the lack of surface water connection between the lagoon and the coastal tides. Data across lagoons could then be evaluated with respect to circulation regime as well as other factors.

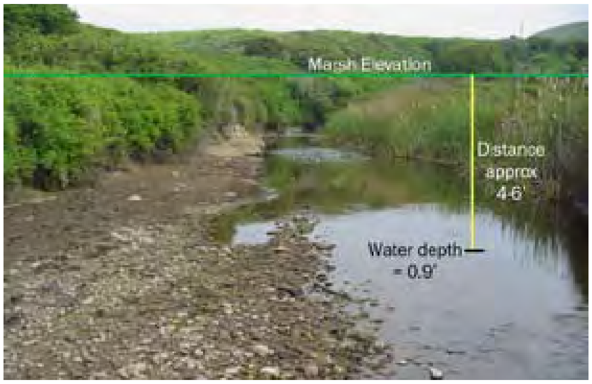
LAGOON WATER BUDGETS

The seasonal water budgets are unique for each lagoon, thus providing a range of conditions due to lagoon morphology, flood control needs, and inflowing water supplies. Figures 11.19-11.28 present the relevant coastal tidal cycles, streamflow and estimated lagoon water volumes for each lagoon from May until the fall breach events. The lagoon volume is the product of the continuous water surface elevation data and the estimated lagoon surface area during open and closed conditions (Table 11.1). The lagoon volumes are presented in acre-ft to reflect our confidence in these numbers.

The changes in lagoon water surface elevation over time (i.e., derivative) indicate the circulation regime variations within each lagoon (Figure 11.17). When open, the coastal lagoon water budgets are dominated by watershed freshwater inflow and tidal inflow from the coastal ocean. Extreme variations in lagoon water surface elevation indicate a strong tidal connection with the coastal ocean. Daily lagoon depth variations indicate a well-circulating system, typical of the lagoon environment during the late spring/early summer. Rapid increases in water surface elevation correspond with sandbar development and hydrologic disconnection of the lagoon from the coastal ocean. If the sandbar barrier remains intact through one or more tidal cycles, the lagoon water surface elevation will gradually increase as freshwater accumulates within the lagoon. Our observations suggest that if the lagoons are able to experience a sustained closure for greater than 7-10 days in duration, a hydrologic equilibrium is reached (Figures 11.19, 11.20, 11.22, and 11.28). At equilibrium, inputs to the lagoon equal outputs. The main water input to a closed lagoon is streamflow and outputs are dominated by seepage through the sand berm at the mouth of the lagoon, infiltration to groundwater and evapotranspiration. No efforts were made to determine the relative quantitative contribution of each water loss term, but reasonable assumptions may be made based on the characteristics of each lagoon.

Lagoon water budget comparisons of the North Coast Lagoons between the two water years of observation highlight potential key components of physical lagoon function. WY04 had a relatively wet December and nearly 6 inches of precipitation in February (Figure 11.16), but very little rain in the spring. The stream discharge into the North Coast lagoons in May 2004 was a third of the inflow volumes in May 2005 (Figures 11.19-11.22). Following sandbar closure, Laguna and Scott Lagoon experienced significant water volume loss during August and September during WY04. Following sandbar closure in mid-July 2004, Scott Lagoon reached the lagoon water volume equilibrium near 20 ac-ft. As the summer progressed, the lagoon began to lose water at variable rates, yet site observations through August and early September 2004 noted that the sandbar was intact. Laguna Lagoon water level monitoring records were sporadic due to instrument failure (Figure 11.21), but visual observations and vertical profile water depth measurements (Figure 11.44) support the significant loss of water in Laguna Lagoon during the sustained 2004 closure. These patterns were not observed at other sites or during the wetter WY05 at these lagoons.

We suggest that the existing morphology of the two North Coast Lagoons exacerbates the susceptibility of these lagoon water budgets to dry year conditions. The key morphologic components are the incised, disconnected channel and the lagoon plan view morphology. Historic reclamation and levee construction have virtually eliminated the connection of the main channel from the larger marsh floodplain, particularly during drier years. The low gradient and high sediment loads in a natural Coastal California lagoon created longer meander patterns of the defined channels than present today (see the 1928 Scott Lagoon aerial, Figure 11.4). A meandering channel has a natural sinusoidal pattern that uniformly distributes the energy of water and sediment transport. The length of a meandering channel is longer, and therefore the bed is less steep than a straight channel given the same elevation change (Leopold et al. 1992). Scott and Laguna lagoon channels are significantly straighter and shorter than the natural morphology. These straightened, steeper flow paths increase channel slope, thereby increasing flow velocities and the erosion potential within the main channel, creating channel scour and bed incision. Today's straight channels are also leveed, constraining the majority of high flows within the channel due to physical disconnection with the adjacent floodplain. The containment of high flows within the channel further exacerbates channel incision. Site morphology observations suggest that the main channels in Scott and Laguna Lagoons are incised at least 4ft below the historic marsh elevation (see photo below).

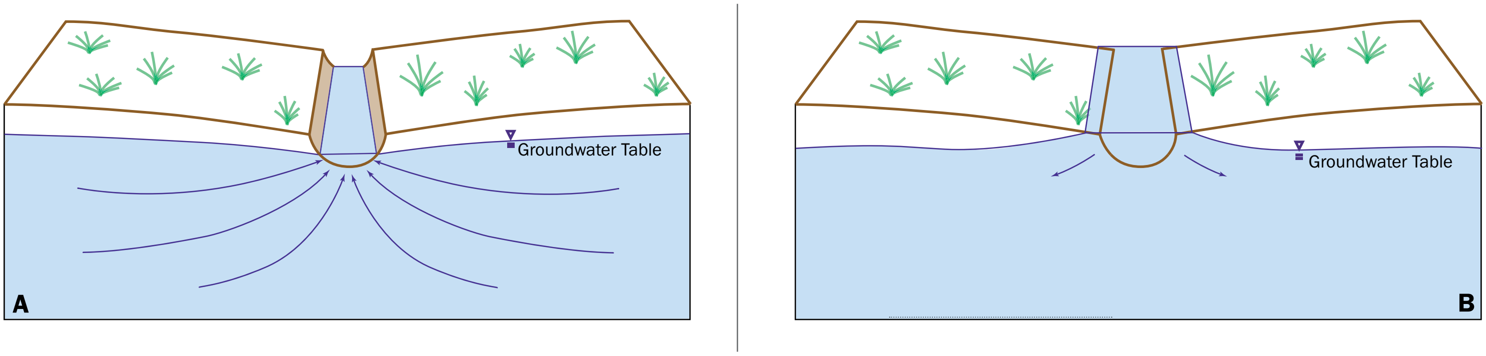


Difference in marsh and lagoon bed elevation in May of 2005 at Laguna Creek Lagoon.

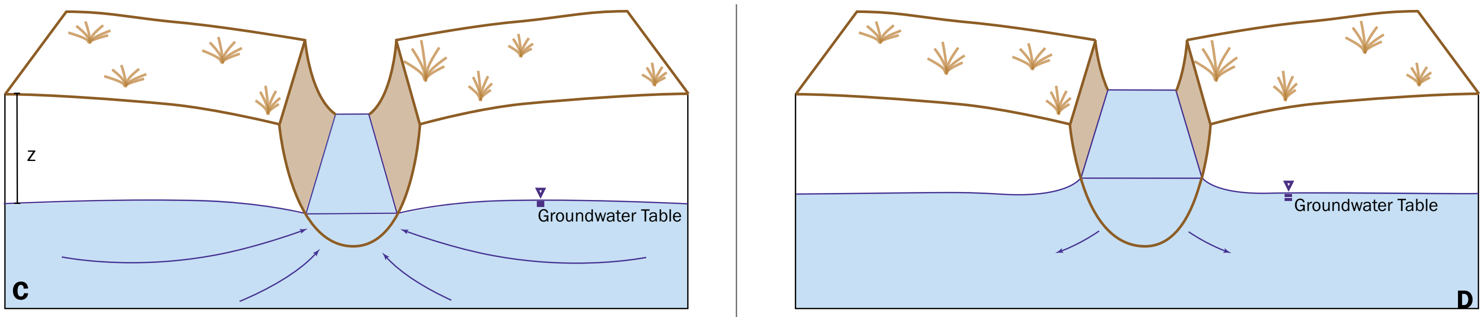
An incised lagoon channel will directly alter the surface water (above ground) and groundwater interactions at these sites. Figure 11.1 is a schematic comparing the surface water/groundwater interactions between a more natural channel cross-section and an incised channel. An incised channel reduces the elevation of the adjacent shallow groundwater table, which in turn significantly reduces the moisture content in the marsh soils necessary to sustain wetland vegetation.

The seasonal timing of surface water/groundwater interactions are also assumed to be affected by a constrained, incised lagoon morphology. The Mediterranean climate of Central California results in a seasonal transition of coastal systems from “gaining” streams and lagoons to “losing” systems in the spring or summer each year. A “gaining” system indicates net water flows from the adjacent groundwater table to the surface water system (Figure 11.1, panels A and C). A “losing” system is the opposite, where the elevation of the adjacent groundwater table is relatively lower than the surface water elevation and the net flow of water is from the stream into the groundwater. The present-day North

Natural Lagoon Channel Morphology



Straightened, Incised Lagoon Morphology



Spring Conditions
Macrotidal Lagoon

Late Summer / Early Fall Conditions
Closed Lagoon

Schematics illustrating the seasonal differences in the surface water (water above the ground) / groundwater interactions of a low flow lagoon channel. Conditions associated with a more natural lagoon low flow channel are shown in the upper panels, A and B. The surface water/groundwater interactions in an incised channel are shown in C and D.

We expect that during spring/macrotidal conditions (Diagrams A and C) the lagoon channel will typically be gaining water from the elevated surrounding shallow groundwater table following the winter rains. The difference of the depth to groundwater (z) is compared between a more natural lagoon channel at grade and conditions associated with an incised channel (Diagrams A and C). The adjacent groundwater table elevation as a result of an incised lagoon channel is inherently lower relative to the ground surface elevation (greater height of z).

As the season progresses, the lagoon becomes impounded due to sandbar formation. The dry summer months of the Central California mediterranean climate result in the gradual reduction of the groundwater table elevations. Lagoon environments transition to losing systems where the net direction of water transfer changes from spring conditions (lower groundwater levels and surface water infiltrating to groundwater), further reducing the local groundwater table elevation (Diagrams B and D). We suspect the disconnect of an incised channel from its floodplain may increase the annual duration a lagoon spends as a “losing” system.

(Adapted from Fetter 1994.)

Coast lagoon morphology has significantly reduced the frequency and duration of over bank inundation, thus limiting the area of surface water/groundwater interactions to the specific location of the existing lagoon channel rather than throughout the greater marsh area. It follows that an incised, constrained lagoon likely spends a greater fraction of the year as a “losing” stream for any given water year than a lagoon channel whose surface water inundation interacted with a greater area of the marsh. We suspect existing lagoon morphology characterized by narrow, incised, constricted channels renders these systems more susceptible to water limitations during drier years.

We also suspect a disproportionate amount of surface water may be lost from Scott and Laguna Lagoons by horizontal seepage through the sandbar. Over 50% of the summer surface water lagoon environment for each site is located adjacent to the beach sand berm due to the existing human-created morphologies. The coastal berm is a homogenous sand deposit with hydraulic conductivity rates on the order of 10^{-2} cm/sec, four orders of magnitude higher than infiltration rates expected through clayey sands characteristic of the marsh/floodplain areas (i.e., 10^{-6} cm/sec) (Fetter 1994). The combination of raising the elevation grade of the main low flow channel, relocating a greater fraction of the lagoon within the historic marsh soils with high organic content, and increasing the frequency and duration of inundation will likely increase the ability of lagoons to retain surface water (and thus lagoon habitat) during drier years. Additional monitoring of seasonal groundwater table and surface water elevation interactions would further clarify these assertions.

Comparison of Laguna Lagoon in August of both 2004 (left) and 2005 (right). 2004 taken from bluff at ocean with dry open pond in the upper right; 2005 taken from RR tracks, open pond in foreground.

In the unmanaged urban lagoons, San Lorenzo and Aptos, the primary lagoon water budget finding is that both unauthorized sandbar manipulations by humans and lagoon storage limitations inhibit natural sandbar function. During both observation years these two lagoons did not remain closed for longer than 1 month. The lagoon habitat contained within the levees progressively deepens as the sandbar presence persists, with little additional increase in lagoon surface area or habitat complexity. In response to lack of water storage within the historic lagoon area, the mouth of the lagoon progressively migrates laterally down the beach. The lack of adequate water storage capacity of the two flood controlled lagoons results in 20-30% of the lagoon characterized as exposed open water atop beach sand.

BIOGEOCHEMICAL CYCLING

The CLEAP data collection efforts focused upon characterizing and comparing the biogeochemical conditions in each of the five subject lagoons that were assumed to represent a range of water quality conditions due to variations in watershed land use, lagoon morphology, and lagoon management.

N:P Ratios

In order to focus aquatic resource management, identification of the nutrient limiting biological metabolism (i.e. photosynthesis) is important. As described in Section 5 of this report, aquatic photosynthetic organisms require a DIN:SRP (dissolved inorganic nitrogen: soluble reactive phosphorous, aka N:P ratios) molar ratio of 16 (Redfield 1963). Therefore a lagoon N:P > 16 is P-limited and a ratio less than 16 is N-limited. As suspected, all of the lagoons CLEAP investigated are N-limited, meaning primary producers will run out of N prior to exceeding the supply of P. The relative degree of nitrogen limitation, expressed by the N:P ratios, did vary across lagoon (Figure 11.52) and was identified as a lagoon stressor correlated to biological health (Table 10.4). The seasonal time series of the N:P ratio within each lagoon can provide information concerning the relative phytoplankton production peaks. In eutrophic systems seasonal reductions in the N:P ratios likely correlate to increased phytoplankton production rates (Boyton et al 1996). The surface water lagoon DIN:SRP ratio is a successful stressor correlating to biological indicators. Future source control efforts should implement best management practices that make the reduction of N loading to the local surface waters a priority since N is the nutrient limiting primary production in the CLEAP lagoons.

Tributary Nutrient Loading

Monthly nutrient sampling and streamflow measurements were conducted in the respective tributaries to each lagoon for the critical months in 2004 and 2005. Figure 11.29 compares the dissolved inorganic nitrogen (DIN; sum of nitrate (NOx) and ammonia (NH_4^+)), soluble reactive phosphate (SRP) and silica (Si) concentrations for each tributary over the course of the study. The DIN and SRP tributary loading typically followed the trend of less impacted to more impacted watersheds, and the DIN loading and tributary concentrations were positively correlated with the land use characteristics, including septic density, population density and % impervious surfaces. The DIN concentrations in Valencia Creek (a predominantly septic tributary to Aptos Lagoon) were consistently higher than concentrations observed in any other tributary, with a peak DIN concentration of 175uM (2.45mg/L) in October 2004. Valencia Creek is followed by San Lorenzo River and Branciforte Creek with the next highest DIN concentrations averaging 24.4uM (0.34mg/L) and 12.3uM (0.17mg/L), respectively, during summer discharge conditions. Soquel Creek and Aptos Creek consistently had the lowest DIN concentrations, typically below 5.7uM (0.08mg/L).

Figure 11.30 presents the daily DIN, SRP and Si loads delivered to the respective lagoons for the critical months of 2004 and 2005. The loads are presented on a log scale to improve comparisons across sites. Since loading estimates are heavily dependent upon discharge, the significantly greater streamflow into San Lorenzo Lagoon results in nearly an order of magnitude more DIN, SRP and Si delivered to the lagoon. The watershed area of Aptos is nearly half of Soquel Watershed, yet its DIN tributary loads are consistently higher. Scott and Soquel tributaries contain slightly higher SRP and Si than the other lagoon tributaries, excluding San Lorenzo. DIN inflow concentrations, DIN inflow loads, and SRP inflow loads from the tributaries were successful stressors identified by the metric analyses (Table 10.5),

Normalizing the daily nutrient loads to lagoon surface area provides a first-order comparison of nutrient conditions if biological process did not modify nutrient concentrations in the water column and the nutrients delivered were evenly distributed throughout the lagoon (Figure 11.31). DIN loading per ft^2 of lagoon remains the greatest for San Lorenzo, followed by Aptos and Scott Lagoons. The SRP loading per ft^2 of lagoon was most frequently greatest in urbanized Aptos, Soquel and San Lorenzo Lagoons. Aptos and Soquel Lagoons have elevated silica concentrations and loading values that are probably more an influence of the local geology than specific watershed land use activities.

Lagoon Nutrient/Chlorophyll Levels

The surface water and bottom water nutrient concentrations are significantly influenced by biological metabolism as nutrients are removed from the water column during photosynthesis and returned to solution during respiration. Thus standing nutrient concentrations observed in the lagoons are not necessarily indicative of the degree of eutrophication, but rather a snapshot of the magnitude of the available nutrient pool.

Figures 11.52 and 11.53 present the average surface water and bottom water nutrient concentrations, surface water DIN:SRP ratios and chlorophyll concentrations for each 2004 and 2005. While these graphics simplify the power of the CLEAP nutrient sampling data, they do provide a first-order comparison across lagoons and seasons. The DIN and SRP loading values in Figure 11.29 show a range increasing from the less developed to more urbanized watersheds. The San Lorenzo Lagoon consistently had the highest NOx surface water concentrations with peak values over 60uM (0.70mg/L). Aptos Lagoon NOx concentrations were consistently near 10uM (0.14mg/L). Nitrate concentrations truly appear to be limiting in Scott, Laguna and Soquel Lagoon with lagoon averages and individual station concentrations typically below 5uM (0.07mg/L).

Elevated ammonia levels in surface water conditions can suggest increased biogeochemical cycling rates, as explained in Section 5 and shown in Figure 6.5. Ammonia is the form of nitrogen released from respiration and, in reduced (i.e. limited oxygen supply) conditions, nitrification of ammonia to nitrate is not expected. In most instances, nitrate concentrations in the lagoon surface waters were consistently higher than the ammonia levels, though the Scott Side Channel and San Lorenzo Lagoon did have exceptions. Both San Lorenzo Lagoon and the Scott Side Channel have been observed to have reduced conditions (low DO, low pH and low ORP) coincident with elevated NH_4^+. The drier 2004 season is characterized by lower peak NOx concentrations and higher minimum NH_4^+ levels in all lagoons. However, there are no distinct annual differences in the surface water N:P ratios. These phenomena suggest that when freshwater inputs are reduced to summer lagoons the presence of ammonia relative to nitrate may increase. Nitrate is the preferred form of nitrogen for primary producers, thus subtle shifts in N species may impact the composition of the primary producer communities.

San Lorenzo and Aptos Lagoon consistently had the highest average SRP values, followed by Soquel, Scott and Laguna Lagoon. The majority of SRP levels were below 4uM (0.13mg/L), but based on N:P ratios below 16, ample supply of SRP is available for primary producers. SRP surface water and bottom water concentrations, when expressed as lagoon averages, have no discernible differences. This vertical consistency is not surprising since P is not a redox element and does not follow complex biogeochemical cycling patterns like nitrogen.

Surface water Si concentrations also display an annual difference, where the minimum Si levels were much higher during the wetter 2005 season, the exception being the Upper San Lorenzo Lagoon. Aptos and Soquel consistently have higher Si concentrations, likely indicative of the upper watershed geology.

While the bottom water sampling was limited, the lagoons with elevated surface water nitrate do display relatively low bottom water NOx concentrations (Figure 11.53). Each occurrence of an exceptionally high bottom water NH_4^+ value corresponds to low bottom water DO conditions. Again this follows the nitrogen cycling pattern of respiration of organic matter, which releases NH_4^+ in the absence of oxygen.

Average surface water lagoon chlorophyll values were typically lower than 10ug/L, though San Lorenzo Lagoon and Scott Side Channel were sampled during phytoplankton blooms when the majority of stations exceeded 20ug/L. In some instances, San Lorenzo, Scott Side Channel and Aptos showed fairly significant intra-lagoon variations of chlorophyll levels. San Lorenzo Lower, Scott Side Channel and Aptos Lagoon afternoon chlorophyll samples were at least 50% higher than morning chlorophyll concentrations. These diel chlorophyll variations were typically not discernible in Scott Main Lagoon, Soquel and Laguna Lagoons. Chlorophyll levels are typically higher in the bottom water samples (Figure 11.53) relative to surface waters due to benthic algal production in some systems and the migration of organic matter to the bottom of the lagoon prior to decay.

Substrate Conditions

Sediment characterization for CLEAP was limited to visual observations of dominant grain size at each lagoon station. No sediment nutrient sampling was performed, but it is well established that in productive aquatic environments, the nitrogen concentrations of the sediment will increase with decreasing grain size (Stumm and Morgan 1996, Sutula et al. 2005; see Section 6 for a more complete discussion).

The substrate conditions within the CLEAP monitoring stations followed expected patterns. Locations within lagoons that possessed morphologic components that restrict winter scour and exacerbate summer organic production, such as Scott Side Channel and Laguna Lagoon open pond (Site 3.5), were observed to have fine-grained organic rich substrates in May (denoted as a 5 in Table 11.2). Observations in the flood-controlled Aptos and San Lorenzo Lagoons indicated pebble to sandy substrates in May, progressing to locations of fine-grained organic rich material by September each year (Table 11.2).

Table 11.2. Seasonal differences of dominant substrate conditions at select lagoon stations observed during CLEAP monitoring. Key to values: 1- Substrate dominated by sand or larger; 3- dominated by silt; 5- dominated by organic detritus

Lagoon : Station		May observations	Sept/Oct observations
Scott	SC1	1	5
	SC5	1	1
	SC3	3	5
Laguna	LA1	1	1
	LA5	1	5
	LA3.5	5	5
Soquel	SQ1	1	4
	SQ5	1	1
San Lorenzo	SL1	1	4
	SL5	1	1
	SL7	1	1
Aptos	AP2	1	5
	AP5	1	5

Physical Water Column Conditions

Figures 11.32-11.41 display the surface water temperature, salinity and chlorophyll (top panels) and lagoon water surface elevation and bottom water salinity, water temperature, DO, pH and ORP (bottom panels). All parameters are on a simultaneous time scale for each lagoon. These continuous (30-minute interval) seasonal datasets allow detailed comparisons of the interaction of key water quality variables within each lagoon on daily, monthly and seasonal time scales. Select vertical profile data from each lagoon are presented in Figures 11.42-11.51. Below we discuss the key physical and chemical processes that can be inferred from these continuous data series and the stressor and indicator testing results, as they relate to lagoon function and ecological health.

Absolute Temperature

The magnitude of the lagoon water temperature ultimately controls the rates of primary productivity and respiration (Figure 6.3). Surface water temperatures in the lagoons are influenced by the degree of circulation (due to either wind or tidal variations), local climate, lagoon exposure characteristics, and the relative ability of each lagoon to capture and retain heat. Surface water temperatures peak in July and August in each lagoon, with subtle daily variations superimposed on the seasonal patterns. When the lagoon is hydrologically connected to the tidal ocean, bottom water temperatures mimic surface water conditions. When circulation is reduced to either microtidal or closed conditions, bottom water temperatures can be influenced by the magnitude of density stratification as the bottom waters are insulated from the daily air temperature differences. Evapotranspiration by emergent vegetation can reduce surface water temperatures and reduce the exposure of the surface waters to effective solar radiation. Extreme lagoon water temperatures can have an impact on habitat quality for all the organisms residing there.

Salinity Stratification

Stratification, whether created by salinity or temperature, creates a barrier that prevents chemical mixing between two distinct water masses, the surface and bottom waters. Simultaneous comparison of surface water and bottom water salinity and/or temperature provides an evaluation of the degree to which the lagoon water column is stratified. When the lagoon mouth is open, both surface water and bottom waters display significant daily variations in salinity, indicative of a well-mixed water column. Salinity stratification in coastal lagoons occurs following reductions in circulation (i.e., the sandbar develops), causing saline waters to become trapped within the lagoon. A freshwater lens will form atop the denser saline waters. As the duration of sandbar closure progresses, the saline lens is compressed at the bottom of the lagoon. By dilution and gradual seepage through the sandbar, the bottom water salinity gradually declines.

Soquel Lagoon is manually closed each year with the intent of eliminating saline water impoundment in the summer lagoon as a primary management strategy (Figures 11.36-37). Comparing CLEAP observations, the extent to which the bottom water salinity declines in unmanaged lagoons appears to vary with relative lagoon depth, channel bed morphology and the degree of hydrologic connection of a particular location to the greater lagoon area. The elimination of salinity stratification is less likely in locations where water exchange is severely limited, such as dead-end channels and backwater locations. Stratification may also persist in anomalously deep locations within a lagoon, generally characterized by CLEAP as locations below MSL.

Observations at unmanaged lagoons suggest vertical salinity variations during closure occur regularly. Continuous records from Scott and Laguna Lagoons indicate short durations of bottom water salinity levels < 2ppt, suggesting intermittent conversion of the water column to freshwater. With the exception of Laguna Lagoon in 2004, reintroductions of saline waters and the reestablishment of stratification in these North Coast lagoons during closure were common. In 2004, the lower Laguna Lagoon was less than 2ft deep and had a freshwater column for the majority of the summer closed season. In 2005 the average Laguna Lagoon depth was closer to 3ft and salinity stratification was eliminated at variable rates following saline water introductions to the lagoon, due to waves overtopping the sand bar. While some variability exists the rate at which the water column at Laguna Lagoon became vertically homogeneous following saline water introduction, but in general the rate of saline water decline in the bottom waters decreased as the season progressed (Figure 11.35). The last observation of a fresh water column in Laguna Lagoon was just following the LSD on September 15, 2006 when a very large south swell hit the Central Coast (National Data Buoy Center Station #46042; http://www.ndbc.noaa.gov) introducing a significant volume of saline waters to the lagoon. Both the volume of saline waters introduced in mid-September (estimated volume increase of 4.5 ac-ft) and dry season tributary discharge (September 19, 2006 Laguna Creek Q= 0.4 cfs) contributed to lack of a fresh water column for the remainder of the season. Following September 15, 2006, the magnitude of vertical salinity stratification declined following each saline water introduction, but a homogeneous water column (fresh water throughout) was not observed again that season.

Based on CLEAP observations, we suspect that channel morphology plays a role in the physical ability of an lagoon to convert to fresh water. In the lower San Lorenzo Lagoon, a deep scour channel is located at the outer meander bend along the east mudstone bluff. Average water depths typically exceeded 6ft where the YSI instrument was located. A sustained 3 week sandbar closure occurred in late August through September 21, 2004 where the bottom water salinity in lower San Lorenzo Lagoon reached an equilibrium of 8ppt (Figure 11.38), thus not converting to a homogenous fresh water column. During this closure San Lorenzo River discharge entering the lagoon remained between 3.5 and 5.9 cfs (USGS). Scott Side Channel (SC3) was typically stratified and is characterized by a channel bed approximately 2ft deeper than the adjacent main channel of Scott Lagoon (SC4). Water movement in Scott Side Channel is also significantly constricted and isolated relative to the wider main lagoon and rarely was a vertically homogenous water column with respect to salinity observed. The channel bed morphology and hydrologic connections within the lagoon may limit the expulsion of saline waters at the bed.

Aptos Lagoon never appeared to completely convert to a freshwater column according to vertical profile observations (Figures 11.50-51). The 2005 YSI data (Figure 11.41) does show low bottom water salinity values during the sustained closure of Aptos Lagoon, but this instrument was located 0.5ft above the bottom. The bottom water salinity variations were characterized by vertical fluctuations in the location of the halocline concurrent with little to no incident increases in lagoon water levels. These observations suggest some bottom water salinity increases are likely associated with circulation events, such as wind mixing landward and reducing the depth of the halocline relative to fixed vertical location of the automated instrument.

Temperature Stratification

Reverse thermoclines can occur in density-stratified (vertical salinity variations) summer lagoons. A reverse thermocline is characterized by bottom water temperatures exceeding surface water temperatures. Density stratification of the water column buffers the bottom waters from the daily climatic temperature variations. There were many instances during vertical profile observations (Figures 11.42, 11.48, and 11.49) when a significant vertical salinity gradient existed, yet the reverse thermocline was subtle or a typical thermocline was present (surface waters warmer than bottom waters). Since salinity stratification was so dominant in unmanaged lagoons, the potential occurrence and associated response of these lagoons to typical thermal stratification (warmer surface waters overlying cooler bottom waters) was rarely observed. Temperature stratification is reported to exacerbate eutrophic conditions and associated water quality issues in lacustrine systems. The likely potential exists for thermal stratification to develop in lagoon systems that do convert to fresh water following sustained closure. The freshwater column of Soquel Lagoon did not display any evidence of thermal stratification, but the dense riparian canopy and limited exposure makes this lagoon less susceptible to thermal stratification.

Dissolved Oxygen Budget

The continuous surface water chlorophyll and bottom water DO time series provide simultaneous evaluation of lagoon biological metabolism. The surface water chlorophyll records provide a measure of the degree of phytoplankton and/or macroalgae present in the surface water. The 12-hr running averages of the chlorophyll records are provided to smooth the short spikes in the data and identify the occurrence of bloom events in each lagoon. Peaks in chlorophyll indicate increases in short-lived organic material created in the system. In each lagoon at least one chlorophyll bloom (characterized by a 12-hr chlorophyll average > 15ug/L) occurred during reduced circulation conditions. The frequency and magnitude of summer chlorophyll blooms were greatest in Aptos, followed by San Lorenzo, Laguna, and Soquel. Intermittent instrument failure and the lack of YSI 600OMS units deployed in Scott Lagoon and Scott Side Channel limited the application of the continuous chlorophyll dataset.

The dissolved oxygen concentrations in the lagoon bottom waters respond to a number of factors. Introduction of well-oxygenated coastal waters to the lagoon can influence the DO concentrations, resetting the concentrations close to atmospheric equilibrium (100% saturation). When macrotidal conditions exist, especially in the cooler spring months, DO levels slightly fluctuate around 4-6mg/L. In a lagoon with reduced circulation, the DO budget is dominated by photosynthetic input and respiratory removal. While each lagoon record is different, as lagoon circulation decreases in warmer climatic conditions the magnitude of daily DO variations increases and the minimum daily DO values are reduced. These daily variations of DO are expected in productive environments, but biotic stress, especially to sensitive species, may occur when minimum daily DO concentrations are consistently below 2mg/L (Livingston 2001).

The time series of pH and ORP provide supplemental information concerning the water quality conditions within the lagoons. Both pH and ORP are influenced by the magnitude of biological metabolism at the base of the food chain (Stumm and Morgan 1996). When DO concentrations < 2mg/L are concurrent with relative reductions in the pH and ORP values, the aquatic system is significantly limited in its supply of oxygen. ORP is the oxidation/reduction potential, where positive values indicate an oxygenated water column and increasingly negative values signify the system is technically more reduced (i.e. limited) with respect to oxygen (Stumm and Morgan 1996). In oxic waters, ORP varies linearly with the logarithm of the oxygen concentration. When oxygen is depleted, the bacterial community is utilizing additional energy sources (electron acceptors) to reduce (respire) the organic matter supply. The more negative the ORP value the further the respiring organisms have progressed down the thermodynamic redox sequence presented in Figure 6.4 (Koch 1985). A slight oxygen limitation will induce denitrification, then progress to manganese reduction and, at ORP values < -200, sulfate reduction. The production of hydrogen sulfide is then likely occurring. A pH below 7.5, in and of itself, is not a stress to biotic organism, but rather the simultaneous reduction in DO, ORP and pH is an indication of a severely oxygen-limited environment.

Available YSI data (Figures 11.32 - 11.41) suggests that Aptos and San Lorenzo Lagoons had the most dramatic episodes of synchronous DO, pH and ORP depressions not associated with lagoon breach events. Each lagoon, including Soquel Lagoon, was observed to have at least one such incident coincident with sandbar breaching, though the duration and magnitude of such reduced conditions varied significantly across sites. We suspect these episodic anoxic events have a profound effect on the biological conditions, imposing physiologic stress on sensitive species and creating conditions that allow opportunistic species to thrive. Stressor metrics that express lagoon minimum dissolved oxygen, pH and ORP values showed strong correlations to biological conditions (Table 10.5). The strongest biological indicators (Table 10.7) suggest community simplification (as measured by species diversity and taxa density indices) in the lagoons where episodic anoxic events occur.

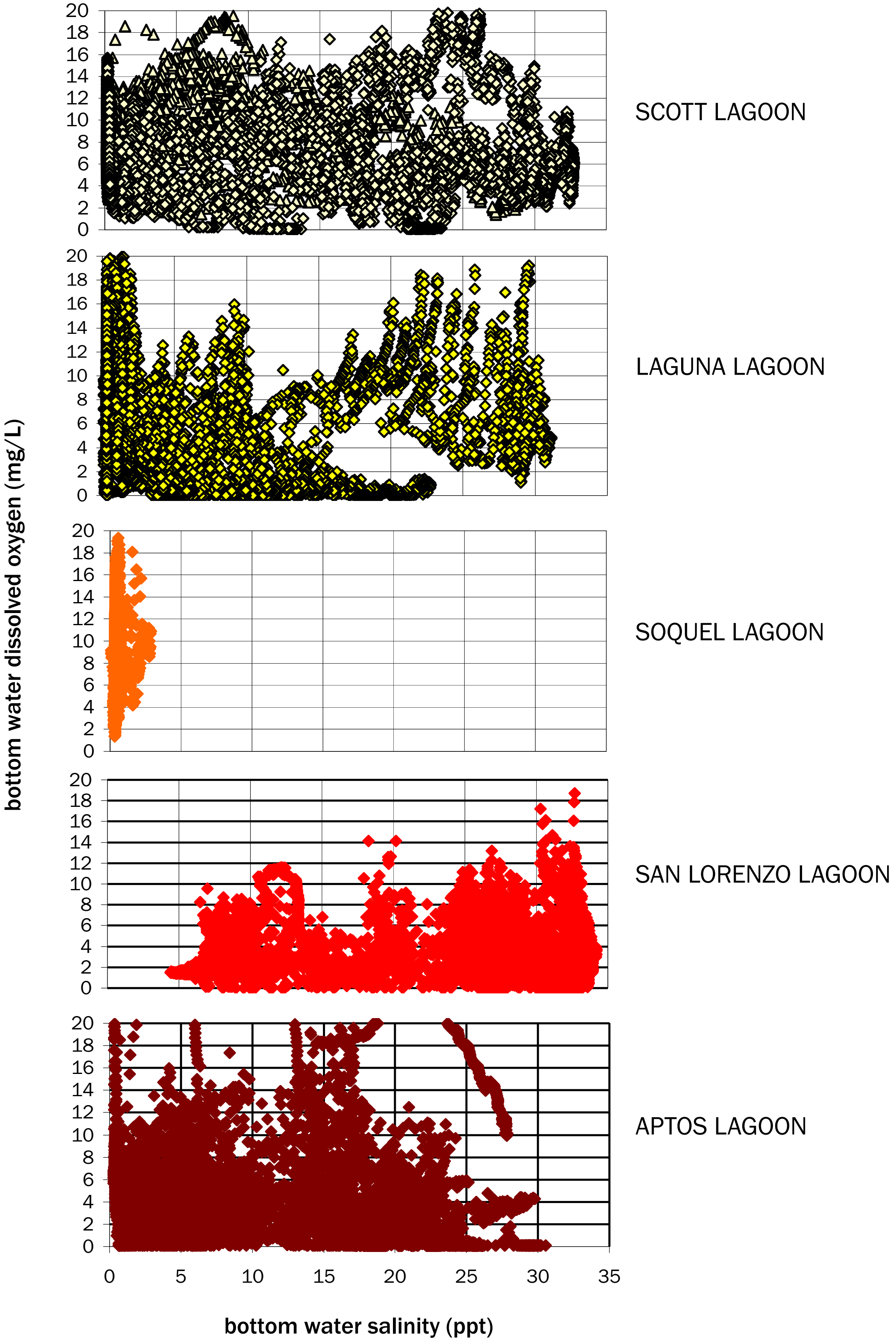
Stratification Impacts on Dissolved Oxygen (DO)

As discussed above, there are two types of stratification that can exist in Coastal California lagoon systems, density (driven by salinity differences) and thermal (controlled by vertical temperature differences). The dissolved oxygen budget in an aquatic lagoon environment when tidal inflow is reduced is dominated by production of DO through photosynthesis and consumption by respiration. Photosynthesis will predominantly occur in the surface waters, due to the availability of light. The majority of respiration, and associated DO consumption, will occur at the sediment/water interface where organic matter accumulates. Stratification, either thermal or density, will create a chemical barrier and isolate the bottom water oxygen supply from the surface water reservoir. Thus, any oxygen produced in the surface layer by photosynthesis is not readily available to the respiring bacteria in the benthos and bottom water DO concentrations will rapidly decrease. There is no question that stratification will often exacerbate repressed bottom water DO concentrations where organic material accumulates at the sediment water interface. However, the elimination of salinity stratification in Coastal California lagoons will have little influence on primary production rates when DIN and light (the two limiting factors) are available.

The elimination of vertical stratification, either by temperature and/or salinity, will increase the immediate dissolved oxygen reservoir available to the benthic bacteria respiring organic matter. In many instances in Scott and Laguna Lagoons, the running daily average of DO concentration increases when the vertical salinity gradient is reduced, due to the ability of the surface water DO now to mix to deeper depths (Figures 11.32-35). There are also many instances in the more nutrient-enriched systems of San Lorenzo and Aptos Lagoons that have a greater biological oxygen demand (BOD), where a reduction in the vertical salinity gradient had no noticeable improvement to the DO levels (Figures 11.38-41) in the bottom waters.

Figure 11.2 shows the correlation between bottom water salinity and dissolved oxygen values during summer and early fall closed or microtidal conditions for each lagoon. In Scott Lagoon, not one instance of bottom water salinity < 5ppt correlated to DO concentrations below 1mg/L. Thus in a system less susceptible to eutrophication the additional reservoir of DO made available by the elimination of density stratification proves ample supply to the satisfy the respiring bacteria DO needs. The data from Laguna Lagoon suggests the maximum DO concentration in the bottom water is strongly influenced by the magnitude of the halocline during certain conditions, but many low bottom water salinity readings were concurrent with DO < 1mg/L, suggesting variable DO responses to salinity stratification elimination. Over 2 complete seasons, San Lorenzo Lagoon rarely experienced bottom water salinity values below 8ppt so no information is available on the correlation between DO and low salinity values. A number of fresh bottom water observations (salinity < 3 ppt) in Aptos were recorded with a wide range of DO concentrations, including numerous anoxic occurrences. While a strongly stratified lagoon will limit the dissolved oxygen reservoir, there were many observations where a freshwater column does not necessarily correlate to tolerable dissolved oxygen levels (> 2mg/L).

One of the main goals of the 2004 Soquel Creek Lagoon Management and Enhancement Plan Update (Alley et al. 2004) is to ensure the water column converts to freshwater as a result of manual sandbar formation efforts. All vertical profile and continuous ancillary water quality data collected for CLEAP in a closed Soquel Lagoon illustrates this goal of eliminating stratification is accomplished. Water quality stability in Soquel Lagoon, as monitored by the dissolved oxygen dynamics (Figures 11.36-37), is also maintained, showing significantly reduced daily fluctuations and elevated daily average and minimum concentrations relative to the other CLEAP lagoons.



Simultaneous YSI bottom water salinity and dissolved oxygen comparisons for CLEAP lagoons. Only data from microtidal or closed conditions are presented.

BOTTOM DISSOLVED OXYGEN VERSUS SALINITY

FIGURE 11.2

Susceptibility to Eutrophication

Soquel Lagoon has a number of characteristics that makes this lagoon potentially less susceptible to eutrophication than other CLEAP lagoons. One very important component driving the success of management is that Soquel Lagoon has DIN loading rates and concentrations from Soquel Creek consistently lower than 10uM. These inflowing concentrations are significantly lower than the levels observed entering San Lorenzo and Aptos Lagoons. Soquel Lagoon also has a more extensive riparian cover than other CLEAP lagoons, reducing the magnitude and duration of daily solar exposure. Soquel Lagoon morphology is a flood-controlled trapezoid, simplifying the task of converting the lagoon to freshwater and increasing lagoon water exchange and simple water movement during closed conditions.

Water level management and freshwater conversion of a coastal lagoon may only make lagoons with consistently low to moderate DIN inflowing concentrations (< 10uM, 0.14mg/L) less susceptible to eutrophication. Nitrogen-enriched systems may continue to have significant phytoplankton and/or macroalgal blooms, regardless of the absence of density stratification. While the supply of oxygen to the benthos in an unstratified water column may be increased on short-time scales, if biological oxygen demand exceeds supply, inclement water quality conditions will occur. The CLEAP stressor and indicator testing has supported that inclement water quality conditions, as expressed by dissolved oxygen metrics, directly influence the biological integrity of the lagoons. Excessive organic matter inputs as a result of nutrient availability have created anoxic conditions in streams, lakes, and other coastal systems that do not possess the same degree of density stratification observed in the Coastal California lagoons.

A potential exception to the above statement occurs in systems where a top down control limits the rate of phytoplankton production (eutrophication) in a nutrient enriched system. In the San Francisco Bay, the ubiquitous Asian Clam community filters the entire water column and controls the magnitude of the phytoplankton blooms. When physical and tidal dynamics create a vertically-stratified water column in the South San Francisco Bay, the benthic grazers become decoupled from the surface water primary producers and significant chlorophyll blooms can occur (Cloern 2001). Benthic grabs as a component of the benthic invertebrate sampling have indicated the presence of a small clam community in the Upper San Lorenzo Lagoon, with a total of 4 clams (or remnants of clam shells) collected from all of the ten benthic grabs in the Upper San Lorenzo Lagoon. No other evidence to suggest the existence of a benthic filter feeder community has been observed in the lagoons.

The magnitude of organic matter production should be a primary concern when determining enhancement alternatives for urban lagoons. In moderately productive systems with relatively low DIN inputs, such as Scott and Laguna Lagoon, elimination of stratification may be sufficient to avoid deleterious water quality conditions as measured by dissolved oxygen. In more nutrient impacted systems, additional enhancement alternatives may need to be considered to adequately reduce the susceptibility of the system to eutrophication.

Sandbar Breach Water Quality

Evaluations of coastal lagoon health must consider the episodic conditions as a result of the fall sandbar breach. The most dramatic and apparently predictable sandbar breach conditions have been observed in San Mateo County at Pescadero Marsh. Pescadero Marsh is a hydrologically modified coastal lagoon system impaired by marsh reclamation for cultivation, extensive levee presence, cross-sectional constriction at the mouth of the lagoon by the Highway One Bridge, and dense agricultural and rural residential land uses in the contributing watershed. Since 1997, fish and invertebrate die-offs have been consistently observed coincident with the breach of the summer lagoon (CA State Parks 2005). These kills include the loss of hundreds of threatened juvenile steelhead. Questions have been raised as to whether the steelhead mortality is due to exposure of high salinities. The fish kills in Pescadero seem to occur before tidal action can transport significant amounts of seawater into the lagoon. Nonetheless, the steelhead there should have some capacity to function in elevated salinities. Studies on downstream migrating juvenile steelhead in Scott Creek showed elevated gill Na^+, K^+-ATPase levels (Hayes et al. 2004), including the ability to tolerate seawater even before they have encountered elevated salinities.

While visual observations following the fall breach of CLEAP lagoons have not identified evidence of biological mortality as observed in Pescadero Marsh, water quality records in Laguna (Figures 11.34-35), San Lorenzo (Figures 11.38-39) and Aptos Lagoons (Figure 11.41) all indicate coincident reductions in DO, pH and ORP during breach events. Even the controlled breaches of the Soquel Lagoon sandbar, a lagoon which consistently possesses DO levels above 5mg/L, create slight episodic reductions in DO and pH as a result of lagoon drainage (Figures 11.36-37). The hydraulic turbulence and benthic material resuspension created as a result of this dramatic circulation shift are assumed to be the primary factors impairing water quality.

During reduced circulation conditions, increases in water temperature and light availability are coupled with longer lagoon hydrologic residence times, thus inducing elevated primary production rates relative to macrotidal conditions. As illustrated by the Scott Side Channel, morphology (including elevation of the channel bed, water exchange dynamics and relative exposure) can make a system more susceptible to eutrophication, exacerbating the production and accumulation of organic matter at the sediment water interface. In locations where organic detritus accumulation rates are elevated, deleterious water quality conditions during subsequent breach events are more likely. The organic matter layer at the base of an aquatic system will continue to consume oxygen and other electron acceptors such as nitrate, manganese oxide and sulfate as long as organic material is delivered to the sediments (Figure 6.4). The by-products of these reduced chemical compounds include ammonia, hydrogen sulfide and methane, all potentially toxic to aquatic species. Episodic breach events initially drain the oxygenated surface water layer from the lagoon. When the depth of hydraulic turbulence reaches the sediment interface, the decomposing organic material and associated reduced compounds will be suspended into the water column. Questions remain whether the mortality of resident organisms is due to fine organic material overwhelming the water column or the presence of reduced chemical compounds at toxic concentrations. Regardless of the specific mechanism causing biotic mortality, the physical and chemical processes that create these deleterious water quality conditions during lagoon breaches are the same.

The lack of direct correlations between salmonid community metrics of mean size, growth rates, or population estimates as biological indicators of lagoon water quality conditions suggests that the mobility of fish allows them to avoid deleterious bottom water conditions that invertebrates and primary producers in the benthos cannot. However, circumstances could develop where toxic conditions during breach events cannot be avoided, and episodic fish kills may be the result. Therefore identifying physical components of a summer lagoon that make it less susceptible to eutrophication is arguably a key to successful management.

FUNCTIONAL LAGOON ENHANCEMENT APPROACH

Based on our existing knowledge of lagoon function as discussed above, we present generalized concepts to focus future enhancement approaches of Coastal California lagoons. The challenge to natural resource managers is to identify enhancement components of natural systems given the inevitable human stressors including flood control, water supply, non-point source pollution, and urban encroachment. Enhancement priorities should initially address the key lagoon components that may limit the threatened salmonids and tidewater goby. CLEAP evaluated components of the greater ecosystem within which these fish exist to improve our ability to refine the approach of future enhancement actions.

The primary potential limitation to these species is the physical lagoon condition, with the seasonal water budget as the first priority. Water quality implications aside, insufficient water will significantly impair the fish communities by reducing available habitat and significantly increasing exposure to predation and disease. In lagoons with potential water limitations, the priority for enhancement should be to develop alternatives to maximize the residence time of surface water (water above ground, not surface water layer) of the freshwater that does enter the micro tidal and/or closed summer lagoon. Increasing surface water retention times will increase the volume of the summer lagoon, improve the health of the marsh riparian zone by increasing soil moisture retention, and provide a more stable physical lagoon environment. Increasing habitat complexity within the lagoons will provide a greater variety of niches for aquatic organisms and efforts should include increasing in-channel vegetation and woody debris to improve cover for the salmonids. Climatic variability is a natural reality and drought conditions will limit the summer lagoon water budgets. Focused enhancement efforts may improve water retention from the existing modified conditions, but will have little improvement during sustained drought conditions.

The CLEAP data suggests that the volume of freshwater inflow to a lagoon during the summer and fall may not have a strong of an influence on lagoon water quality as characteristics of lagoon morphology and nutrient loading. The volume of freshwater inflow likely has an influence on the rate of salinity reductions in hydrologically connected locations within lagoon systems during sandbar development. Additionally, a homogenous fresh-water column may improve low bottom water DO and other water quality parameters, but these bottom water conditions may be temporary as organic matter will continue to accumulate at the sediment interface if nutrients and light are available. In systems where the primary component potentially limiting biological health is poor summer lagoon water quality, the physical enhancement alternatives should be designed with the intent of reducing lagoon susceptibility to eutrophication. Enhancement alternatives should focus on the physical and chemical components of the system that will:

- reduce the availability of DIN
- reduce available solar radiation,
- reduce surface water temperatures,
- reduce primary production rates of fast-growing phytoplankton and macroalgae communities[i]
- improve within lagoon water exchange during sandbar presence, and
- eliminate stratification (both thermal and salinity).

A lagoon management approach that maintains a hydrologic connection with the coastal ocean throughout the year would likely reduce the potential for eutrophication, merely as a result of increased and sustained circulation and tidal mixing. However such management is NOT recommended NOR advocated, because it would eliminate the ecologically valuable summer lagoon the many native species have evolved to utilize. CLEAP stressor indicator testing suggests that some biological indicators decline the longer a summer lagoon remains open. The challenge to scientists, engineers and natural resource managers is to identify innovative enhancement approaches that will allow today's summer lagoons to reach a new sustainable equilibrium despite the inevitable human stressors such as flood control, non-point source pollution, encroachment, and human water supply needs. Ideal enhancement approaches should consider components that will allow the sandbar and associated lagoon system to function in an unmanaged fashion, devoid of annual maintenance, manipulations and/or sand bar breaching.

Source Control

Non-point source control of nitrogen and associated pollutants to the coastal lagoons should be a collective priority. The primary source of nitrogen to CLEAP lagoons are septic systems, urban activities and agricultural practices. Unidentified sewer system leaks may also be a significant source of DIN to the coastal systems. Management strategies to encourage septic system upgrades should be explored. Routine sewer system maintenance should be a priority. Public awareness of best management practices with respect to residential fertilizer applications, car washing and dog waste will also collectively reduce the contribution of DIN from urban areas. Agricultural fertilization and cultivation best management practices that reduce excessive fertilization, soil loss and untreated runoff should be enforced.

Morphology

The most sustainable enhancement efforts within a lagoon involve physical changes to the existing morphology. The natural lagoon morphology was much more complex than today's flood-controlled systems. Lagoon enhancement opportunities should explore mechanisms by which to increase the channel complexity and physical lagoon variability during reduced circulation conditions. In urban areas, enhancement must work within the confines of local flood control to improve the recreational and ecological beneficial uses.

The morphology of the lagoon should be designed to induce the following processes during winter lagoon conditions.

- Maintain adequate and required flood control for adjacent properties.
- Induce hydraulic flushing and sediment scour during winter flows of all locations inundated during summer lagoon conditions. The goal is to maximize the distribution of a sand substrate and minimize the spatial presence of a fine organic substrate throughout the lagoon in April each year. Creating a morphology that will facilitate the natural hydraulic winter removal of fine organic material and replacement with sand will reduce the contribution of sediment regeneration to the lagoon DIN budget during the summer and fall.
- Increase the complexity and variability of the lagoon cross-section. Channel complexity will approach more natural morphologic conditions, increasing the spatial distribution of variations in substrate, increase grain size sorting, and create a less uniform lagoon water column depth.

The above physical flow and morphologic components of the winter lagoon set the stage for the summer lagoon morphology goals.

- Increase the complexity and variability of the lagoon cross-section. Channel complexity will approach more natural morphologic conditions, increasing available habitat for fish, benthic invertebrates and other aquatic organisms.
- Minimize dead-end hydrologically isolated locations within the lagoon and maximize within-lagoon water movement during reduced circulation regimes. Reductions in water stagnation will increase the DO budget available at the sediment/water interface, increase denitrification rates, and reduce the recycled amount of available recycled NH_4^+.
- The natural winter flow bed scour will remove organic detritus and replace with sand to reduce the summer DIN regenerated from the sediments and available to the primary producers.
- Eliminate anomalous deep pockets in the channel bed and improve the system's ability to eliminate density stratification during reduced circulation regimes.

Morphologic components that can reduce the maximum daily surface water temperatures will reduce primary production rates as well as reduce the potential for thermal stress to biotic organisms. Increasing lagoon surface exposure to daily wind stress will increase water exchange within a closed lagoon. In the instance of the vertical cement walls at Aptos Lagoon, the use of natural materials in levee construction will greatly reduce the lagoon's ability to retain solar radiation. Riparian cover could also reduce surface water exposure, as in Soquel Lagoon.

Footnotes:

[i] The DIN availability and cycling differences between slow-growing (i.e. submerged aquatic vegetation (SAV) and fast-growing (i.e. macroalgae and phytoplankton) will be discussed in detail in Section 12.

SITE LOCATION MAP OF SCOTT CREEK LAGOON

FIGURE 11.3

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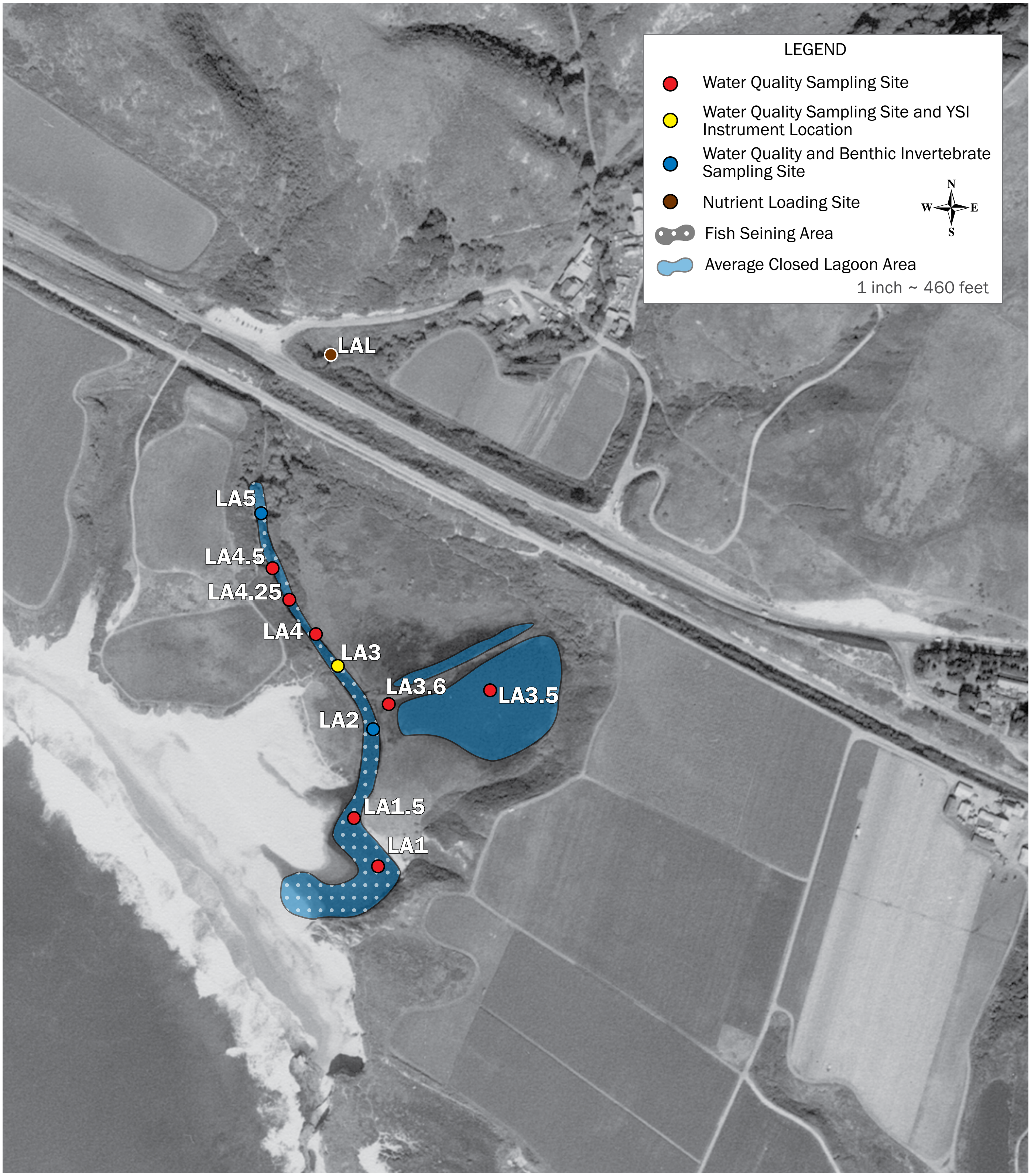
1inch~570 feet

1928 aerial provided by UCSC Map Room.

1928 AERIAL OF SCOTT CREEK LAGOON

FIGURE 11.4



SITE LOCATION MAP OF LAGUNA CREEK LAGOON

FIGURE 11.5

1 inch ~ 460 feet

1928 aerial provided by UCSC Map Room.

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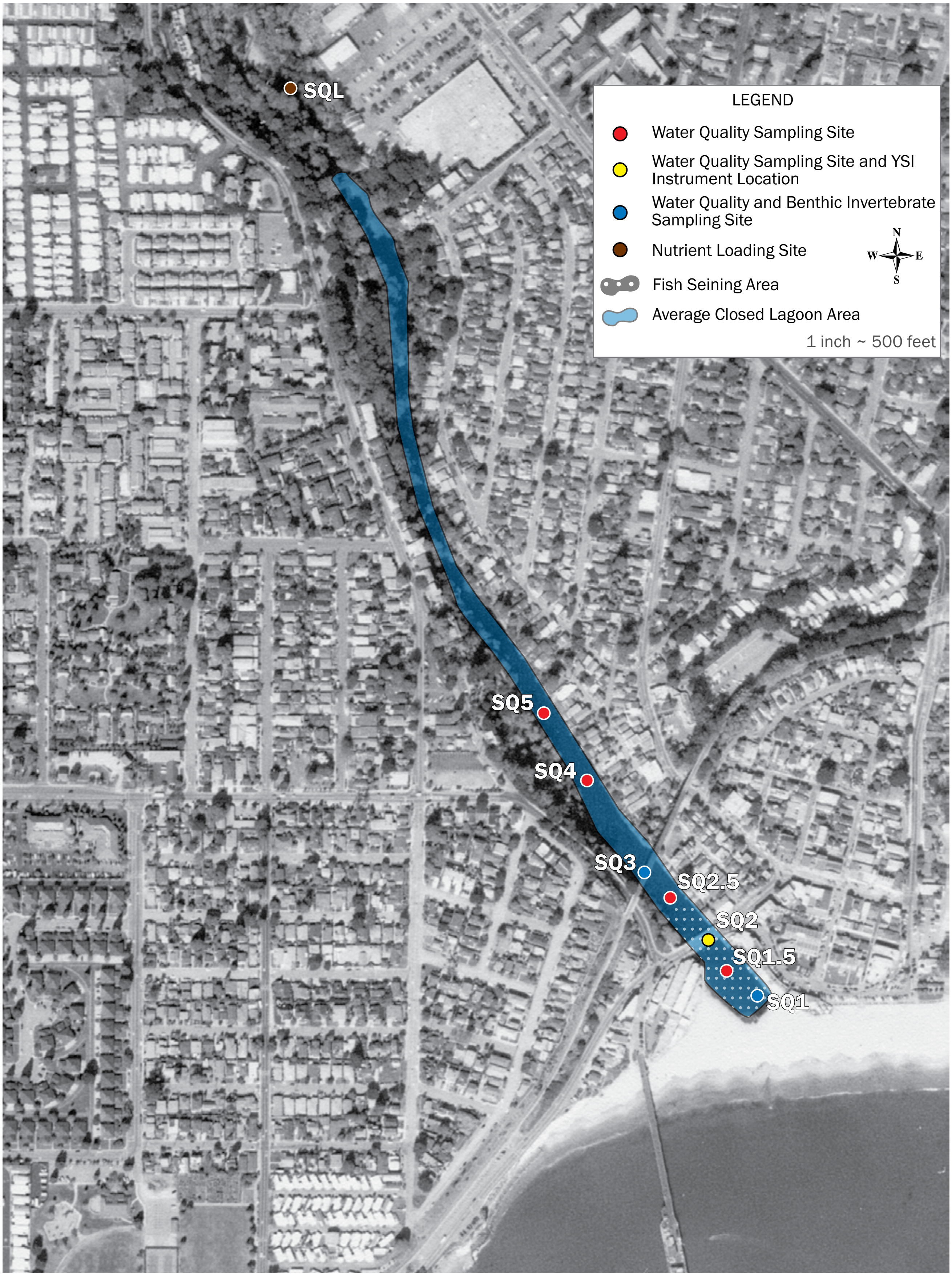
1928 AERIAL OF LAGUNA CREEK LAGOON

FIGURE 11.6



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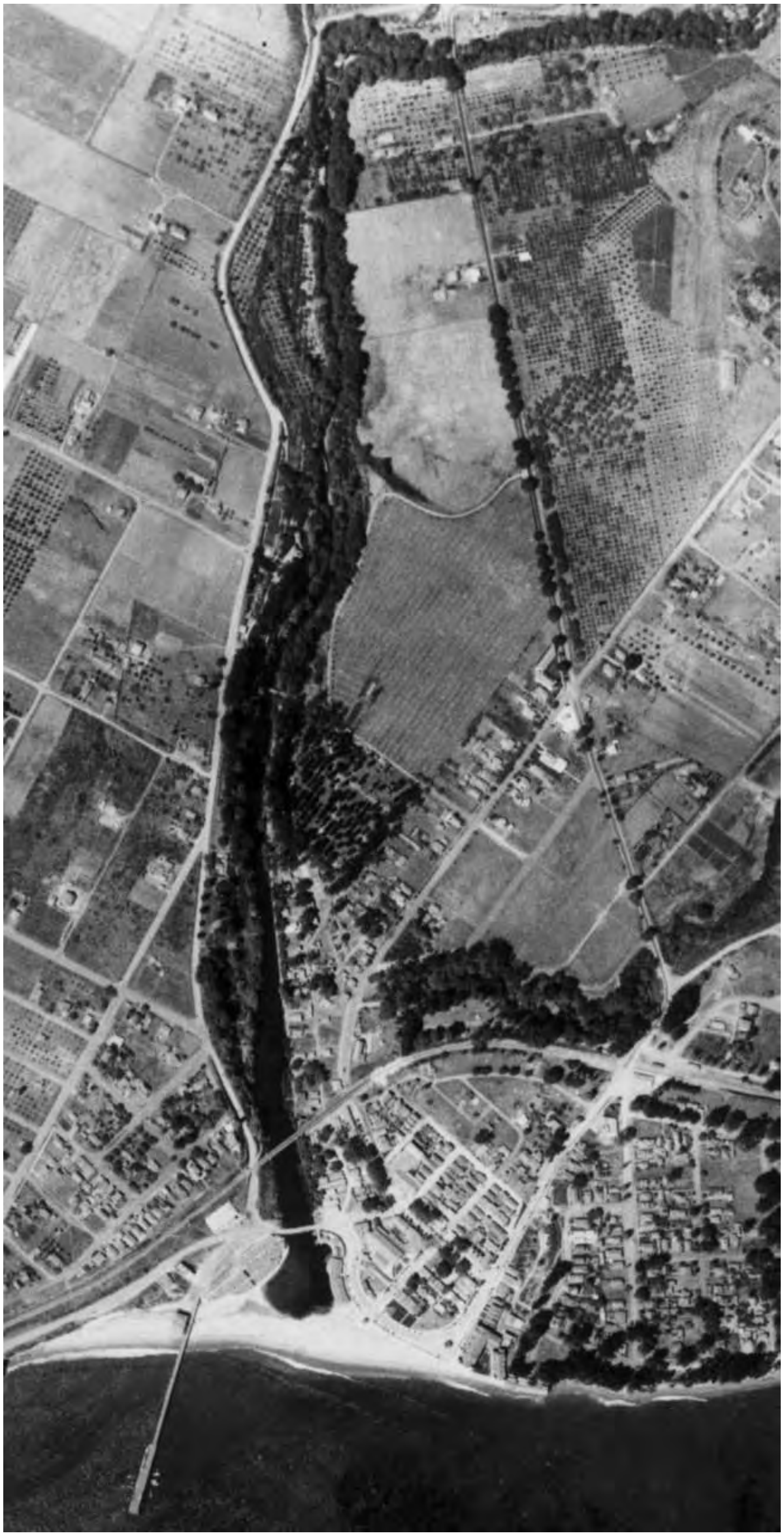
SITE LOCATION MAP OF SOQUEL CREEK LAGOON

FIGURE 11.7

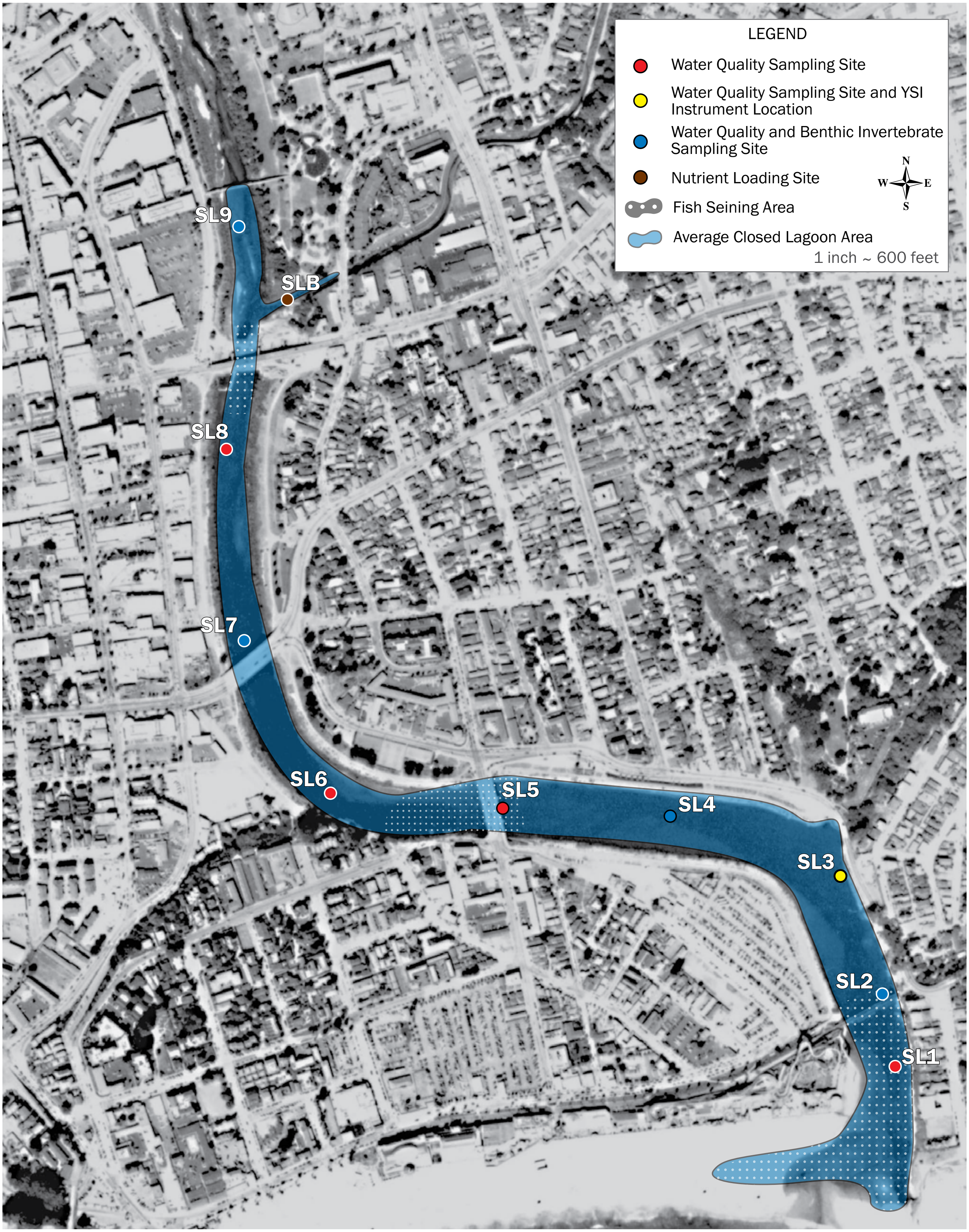


1 inch ~710 feet

1928 aerial provided by UCSC Map Room.

1928 AERIAL OF SOQUEL CREEK LAGOON

FIGURE 11.8



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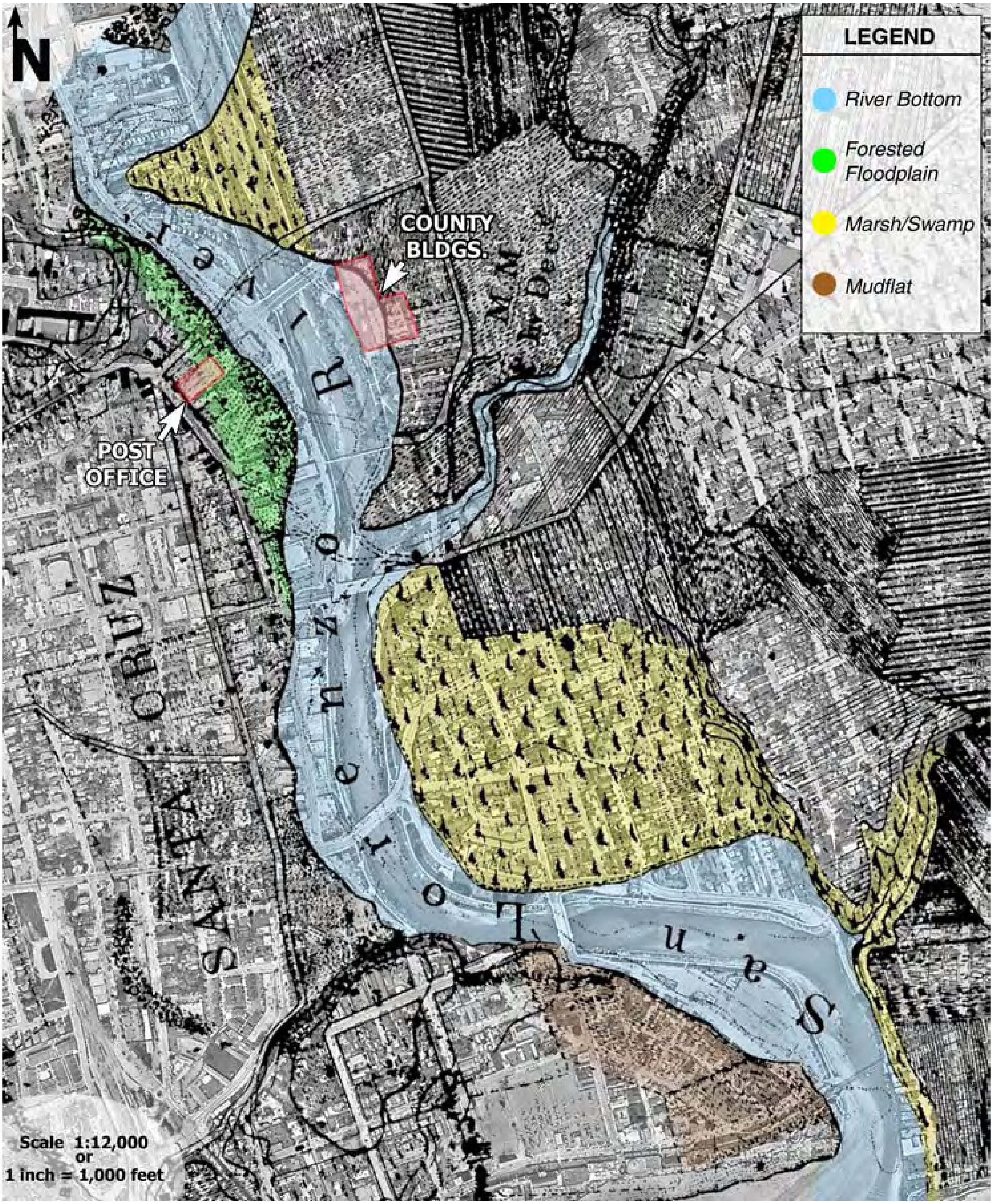
SITE LOCATION MAP OF SAN LORENZO RIVER LAGOON

FIGURE 11.9



1853 US Coast Survey overlain on 1999 aerial
(Source: Swanson Hydrology + Geomorphology 2002).

SAN LORENZO RIVER LAGOON COMAPARISON:
HISTORIC (1853) VS PRESENT DAY (1999)

FIGURE 11.10

1 inch ~1400 feet

1931 aerial provided by UCSC Map Room.

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1931 AERIAL OF SAN LORENZO RIVER LAGOON

FIGURE 11.11

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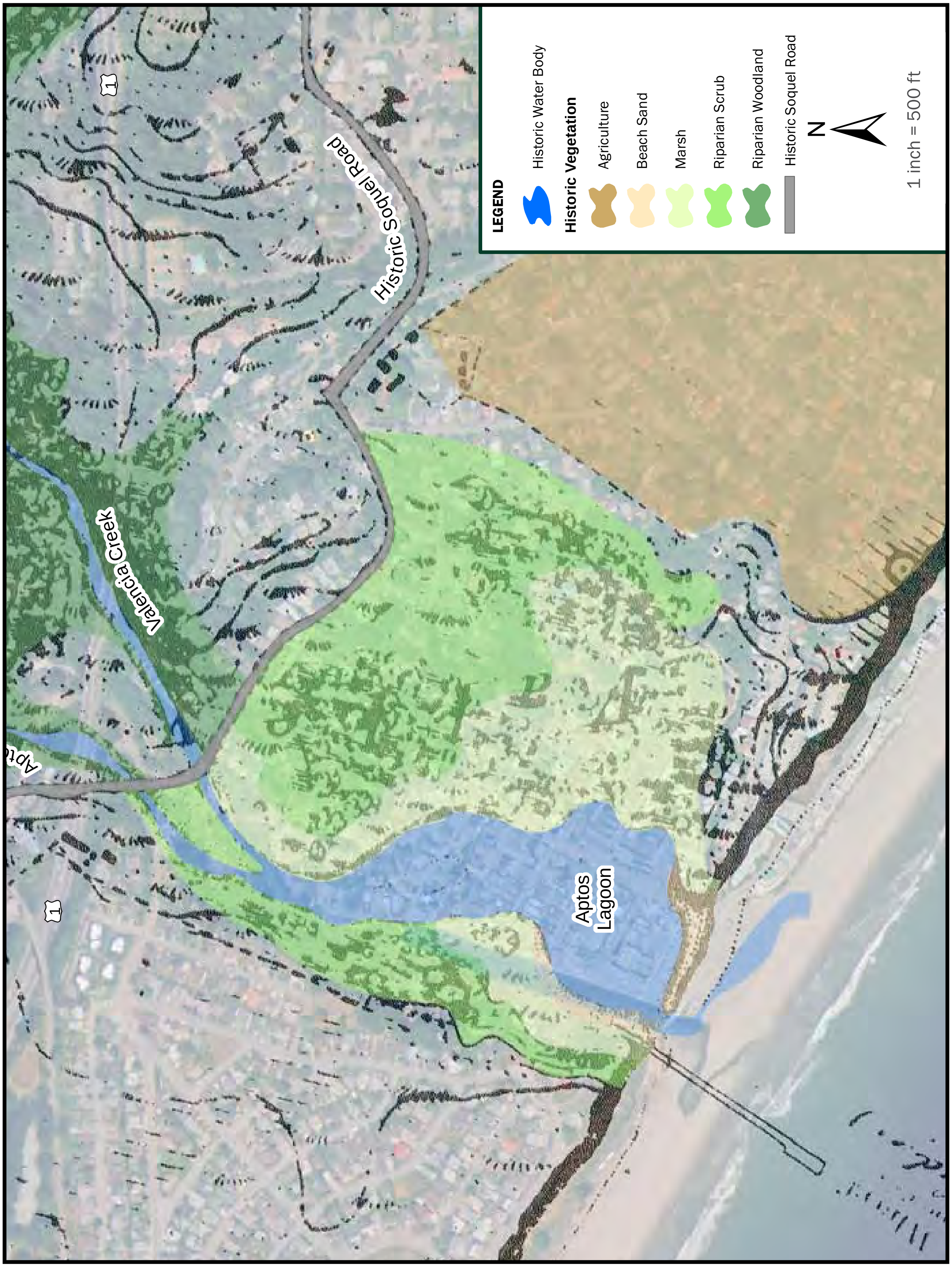
SITE LOCATION MAP OF APTOS CREEK LAGOON

FIGURE 11.12

1853 US Coast Survey overlain on 2000 color aerial provided by WAC Aerial.



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APTOS CREEK LAGOON COMPARISON:
HISTORIC (1853) VS PRESENT DAY (2000)

FIGURE 11.13

1 inch ~ 500 feet

1928 aerial provided by UCSC Map Room.

1928 AERIAL OF APTOS CREEK LAGOON FIGURE 11.14

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HISTORY OF SANTA CRUZ COUNTY LAGOONS

NORTH COAST

Primary Coastal Land Use is Livestock Operations (to 1900)[1]

No Californians Living on North Coast in 1860[1]

Coastal Road to Pescadero Exists but Difficult to Traverse (1880)[1]

North Coast RR Built (1906)[1]

Coastal Highway1 Built Discecting Coastal Lagoons and Altering Stream Paths (1929)[1]

LAGUNA

Private (Horace Gushee) Irrigation Project Diverting 50% of Stream Flow (1873)[1]

Popular Recreation Spot Upstream on Laguna Creek (1880-1900s)[1]

RR Crossing Constricts Channel and Bisects Floodplain (1906)[1]

River Channelized Along North Bluff; Agricultural Fields on Northern Floodplain; Abandoned South Meander Channel Backs Up During Closure (1928)[2]

SCOTT

RR Crossing Built Upstream of Lagoon, Avoiding Major Impact and Allowing Scott to Become Key Fisheries Resource (1906)[1]

Agriculture Present in Floodplain of Upper Lagoon; Creek Meanders Along North Bluff; South Tributary Flows Through Marsh to Meet Main Channel (1928)[2]

1850 | 1860 | 1870 | 1880 | 1890 | 1900 | 1910 | 1920

SANTA CRUZ METROPOLITAN

Santa Cruz to Aptos RR Built & Trestles Span Lagoons (1874)[3]

Coastal Subdivision Boom (1920s)[1]

SAN LORENZO

Potato Agriculture Boom (1850s)[4]

Riverbanks are Forest Groves of Willows, Water Maples, Alders, Laurels, Redwoods (1850s)[4]

Water Street Bridge Constructed (First Bridge to Cross River) (1868)[4]

Rennie Slough (at Cathcart) is Popular Swimming Hole - Warm, Deep, and Sheltered by Trees (1870s)[4]

Coastal WharfBuilt (1875)[4]

State Declares San Lorenzo River 150' Wide to Prevent Encroachment (1872)[4]

Covered Bridge Built at Soquel Avenue (1874)[4]

When River Mouth Dammed Docks Rent Rowboats to Fisherman (1880s to 1920s)[4]

Rennie Slough Filled & Becomes Town Fairground (1880s)[4]

Lagoon Created for Santa Cruz Venetian Water Carnival (1895)[4]

Riverside and Soquel Bridges Present (1910)[2]

Opera Island (at Jesse Street Bend) used for Stage Performances (1912)[4]

SOQUEL

Soquel Landing Flat (Lagoon Floodplain) Used for Shipping, Fishing, and Agriculture (1850s & 1860s)[3]

Coastal Wharf Built (1857)[3]

Official Opening of Camp Capitola (1874)[3]

Cottages, Cabins, Tents, Dance Hall & Livery in Camp Capitola; Adjoining Floodplain Planted in Sugar Beets and Barley (1876)[3]

Beach Area Subdivided for Summer Homes (1882)[3]

Lagoon Mouth Altered to Accomodate Camp Capitola (1884)[5]

Dammed Lagoon Mouth for Recreational Swimming (1884)[6]

Hihn Company Closed Creek Mouth & Buried 3" Pipe to Back Up Lagoon (1899)[6]

Tourist SIte Marketed as 'Capitola-by-the-Sea; Complete with Slide into Lagoon (1903)[6]

Venetian Villa Apartment Complex is Constructed on West Side of Lagoon (1924)[3]

Rispin Dredged Creek for Tourism and Boating (1926)[6]

Creek Channelized and Floodplain Urbanized (1928)[2]

APTOS

Coastal Wharf & Sawmill Built (1850-51)[7]

Spreckles Aptos Hotel Opens on Upper South Lagoon Floodplain (1875)[7]

River Mouth Opens Along South Bluff; Floodplain is Undisturbed (1910)[8]

River Meanders along Swampy Floodplain to South Bluff (1920-22)[6]

Rio Flats (Aptos Lagoon Floodplain) levelled and Lagoon Area Significantly Reduced and Raised with 7ft of Fill (1926)[7]

Aptos Lagoon Leveed in Present Location Against North Bluff. Rio Del Mar Roads and Some Buildings Present (1928)[2]

---

[1]-ESA 2004

[2]-Aerial Imagery

[3]-Swift 2004

[4]-Santa Cruz Public Library website (www.santacruzpl.org)

[5]-Santa Cruz Surf 3:1 9/26/84

[6]-Swift, C. 2005 pers. comm.

[7]-Hibble 2000.

[8]-US Coast and Geodetic Surveys

CLEAP LAGOON HISTORY: 1850 TO 1930

FIGURE 11.15

HISTORY OF SANTA CRUZ COUNTY LAGOONS

NORTH COAST

Largest Storm of Record (1955)[4]

LAGUNA

Abandoned South Channel Backed Up During Lagoon Closure; Dam Present and Riparian Cover Minimal; Agricultural Fields Abandoned (1943)[2]

Agricultural Fields in Use (1953)[2]

Levee Dissecting Floodplain Present; South Channel Backed Up; Dam Present and Riparian Cover Absent (1963)[2]

Creek Channelized; Northern End of Floodplain in Agriculture; Connection to Side Pool is Along South Bluff (1979)[2]

Floodplain Levees Popped; Southern Floodplain Flooded; Agriculture Abandoned (1987)[2]

SCOTT

South Tributary Captured by Retention Pond & Separated from Main Channel; Levee Popped Upstream of Highway 1, Flooding Old Meander Bend Along North Bluff (1943)[2]

Side Channel Present; Meander Bend Appears to be Abandoned (1953)[2]

Main Channel Braided; High Sediment Load (1963)[2]

Agriculture Present in Floodplain of Upper Lagoon; Channel Straightened and in Present Day Location; Side Channel Present (1972)[2]

Agricultural Field in Upper Lagoon Abandoned (1986)[2]

Parts of Upper Lagoon Floodplain Reclaimed from Agricultural Uses (2002)[2]

1930 | 1940 | 1950 | 1960 | 1970 | 1980 | 1990 | 2000

SANTA CRUZ METROPOLITAN

Largest Storm of Record (1955)[4]

SAN LORENZO

Opera Island Incorporated into Boardwalk Parking Lot due to Levees (1950s)[4]

ACOE Flood Control Levees Constructed; Channel Dredged up to 8ft below MSL (1959)[4]

SOQUEL

Lagoon in Present Formation; Flume Present for Lagoon Closure (1930)[6]

First Begonia Festival Held (1954)[3]

Capitola loses beach due to Santa Cruz Harbor Construction (1964)[3]

Rock Jetty Built on Eastern Bluff to Restore Shoreline Beach (1968)[3]

APTOS

Beach Club Opens (1937-1945)[6]

Little to No Riparian Cover Along Lagoon Channel (1948)[2]

Some Riparian Cover Along Lagoon Channel (1963)[2]

Rio Del Mar Flats Highly Developed; No Pedestrian Bridge at Mouth (1972)[2]

Pedestrian Bridge Present; Little Riparian Cover Along Left Bank Upstream of Levee (1978)[2]

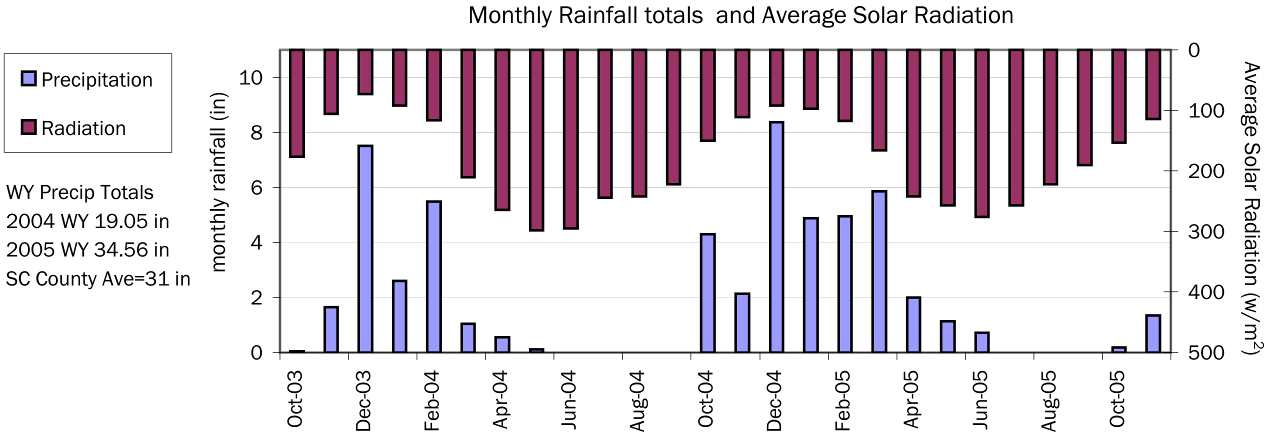
Heavy Riparian Cover Present Along Channel Upstream of Levee (2002)[2]

---

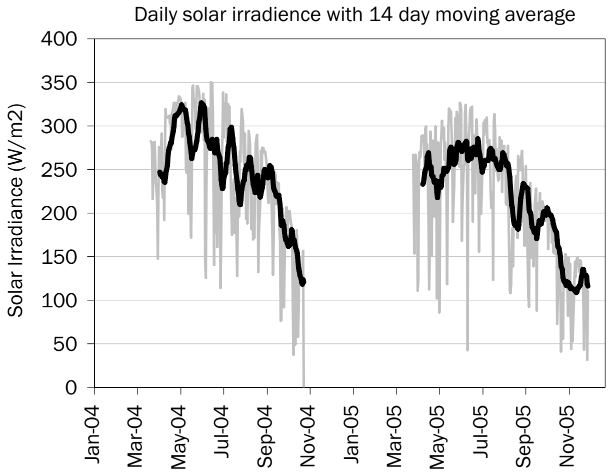
[1]-ESA 2004
[2]-Aerial Imagery
[3]-Swift 2004
[4]-Santa Cruz Public Library website (www.santacruzpl.org)
[5]-Santa Cruz Surf 3:1 9/26/84
[6]-Swift, C. 2005 pers. comm.
[8]-Hibble 2000
[9]-US Coast and Geodetic Surveys

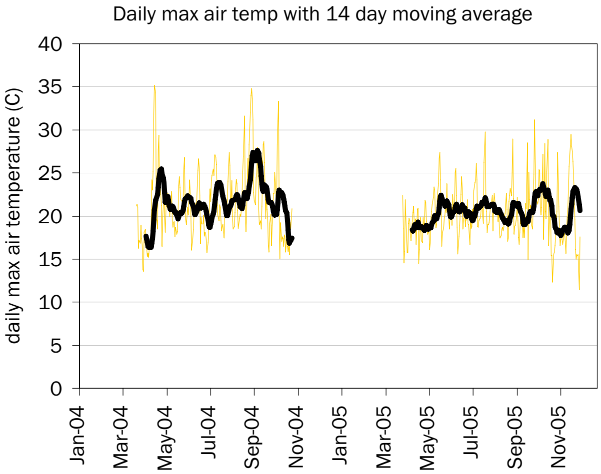
CLEAP LAGOON HISTORY: 1830 TO PRESENT DAY

FIGURE 11.15



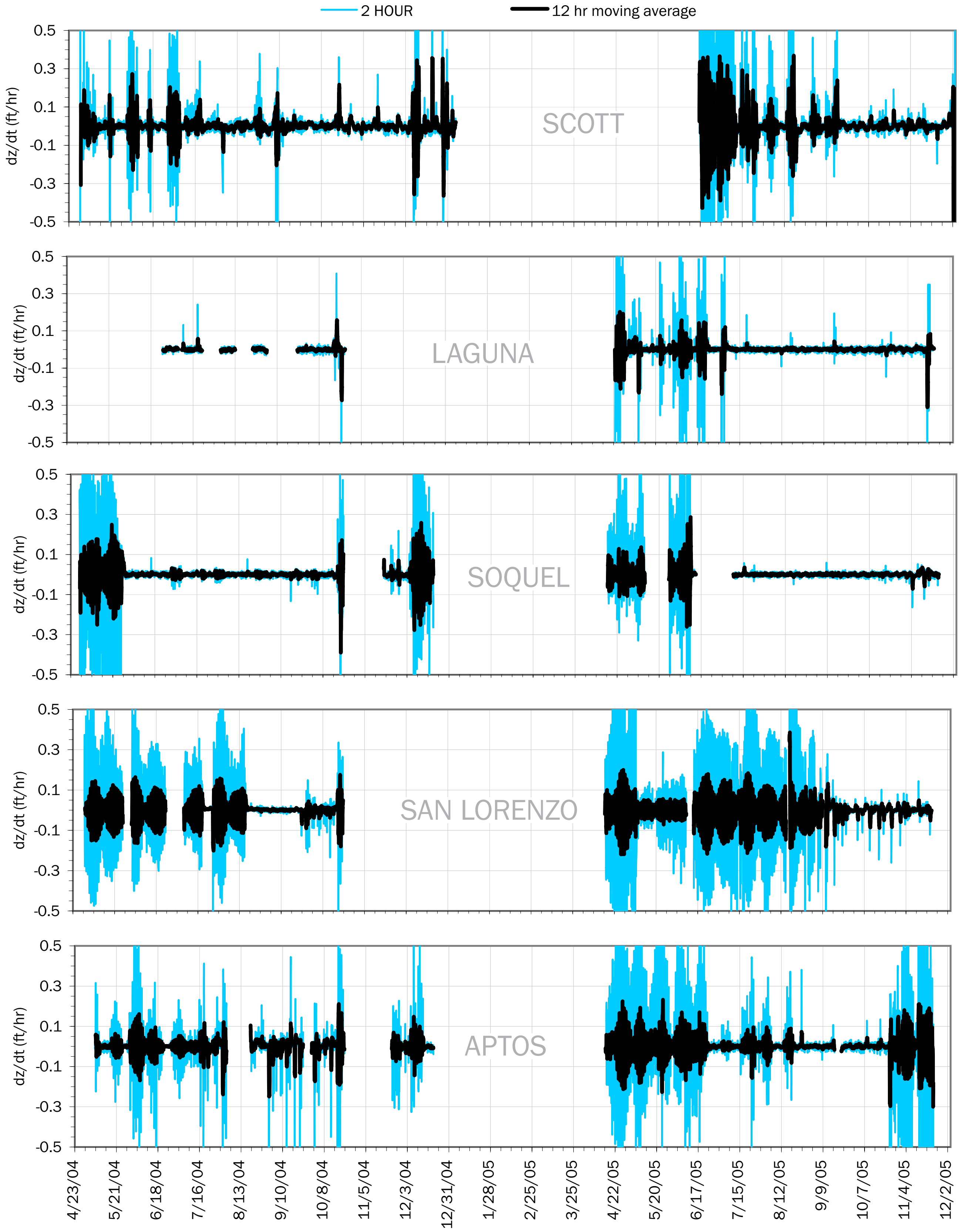
WY Precip Totals
2004 WY 19.05 in
2005 WY 34.56 in
SC County Ave=31 in





Weather data provided by CIMIS website (www.cimis.water.ca.gov). Data represents an average of two weather stations: DeLaveaga station (#104) is located in Santa Cruz, CA at an elevation of 91.4 MSL and Pajaro station (#129) is located adjacent to the Pajaro River at 65 MSL.

2004 AND 2005 SANTA CRUZ COUNTY WEATHER DATA FIGURE 11.16



Change in lagoon water depth on 2-hour intervals from YSI 600XLM instruments installed in the bottom waters of each lagoon.

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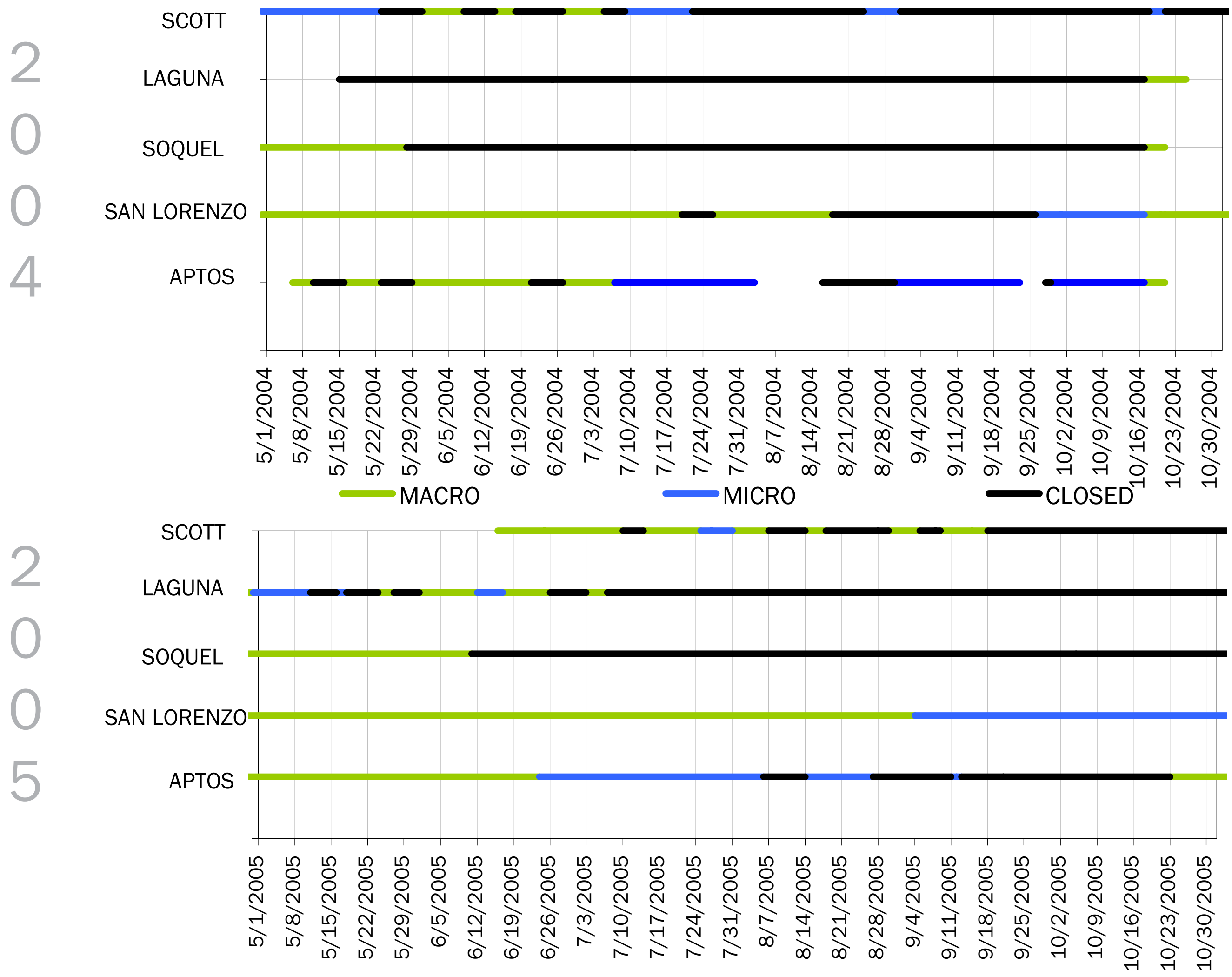
DERIVATIVE OF LAGOON DEPTH

FIGURE 11.17

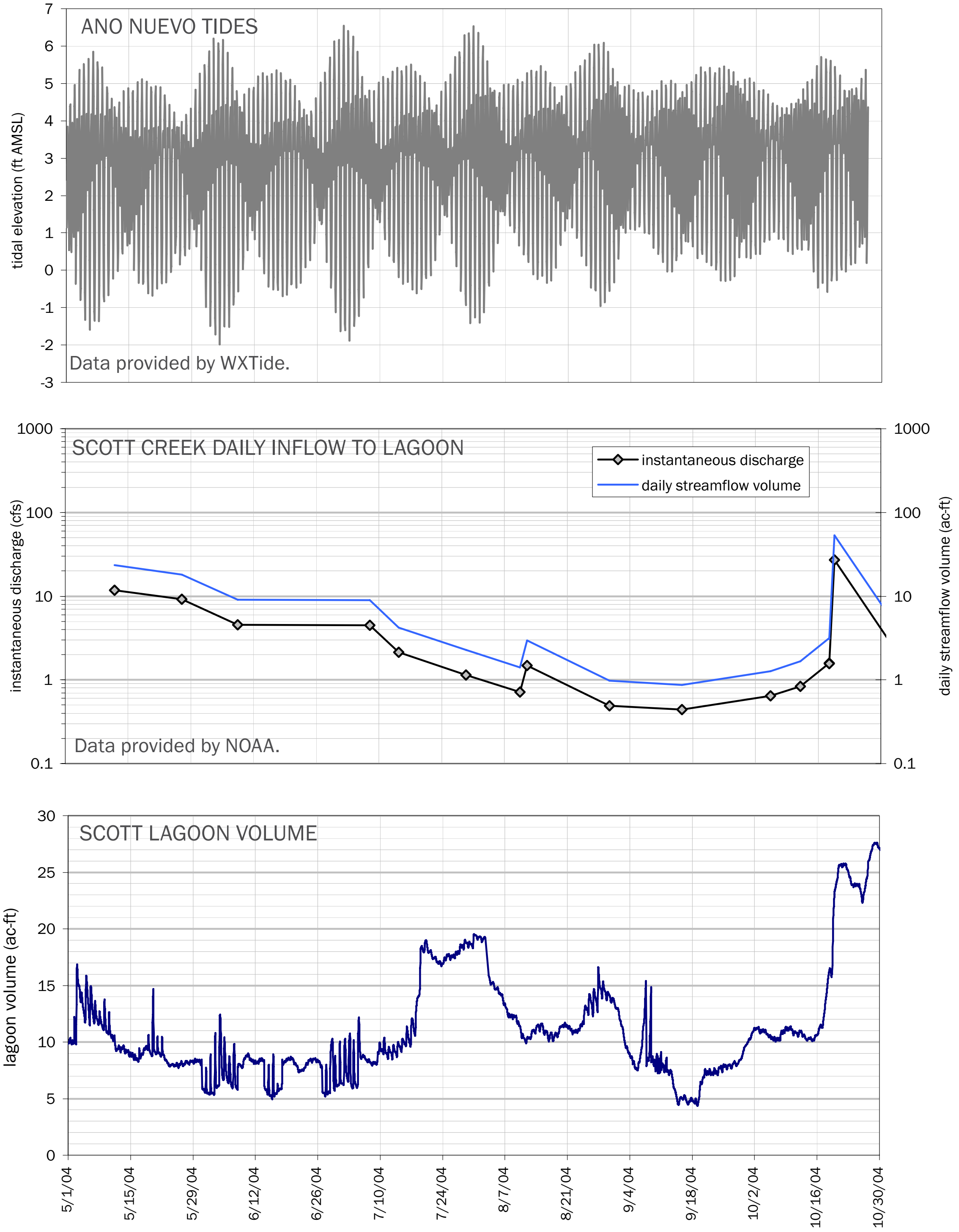


Circulation Criteria based on 12-hr running average (R-ave) of dz/dt patterns (see Figure 11.17):
MACRO: R-ave>0.1 following regular tidal patterns
MICRO: R-ave<0.1 following regular tidal patterns or 0.05<R-ave<0.15 with deviations from tidal pattern
CLOSED: R-ave<0.05

Lagoon	% Days Macrotidal	% Days Microtidal	% Days Closed Conditions
Scott 2004	10.9	23.9	65.2
Scott 2005	43.5	4.3	52.2
Laguna 2004	0.0	6.1	93.9
Laguna 2005	14.7	9.2	76.1
Soquel 2004	18.4	0.0	81.6
Soquel 2005	22.8	0.0	77.2
San Lorenzo 2004	62.1	12.1	25.9
San Lorenzo 2005	69.6	30.4	0.0
Aptos 2004	32.2	44.7	23.0
Aptos 2005	34.2	31.5	34.2

CIRCULATION REGIMES FIGURE 11.18

2004 SCOTT LAGOON HYDROLOGY



MAY 2004 N Beach Pool

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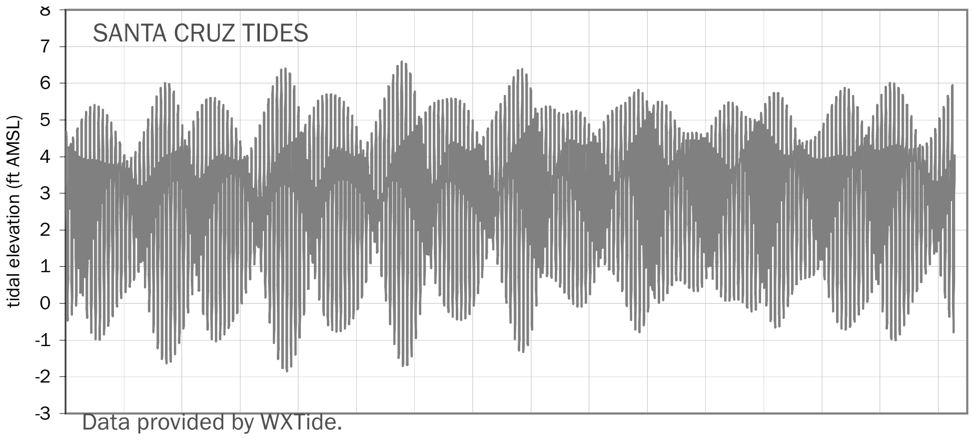
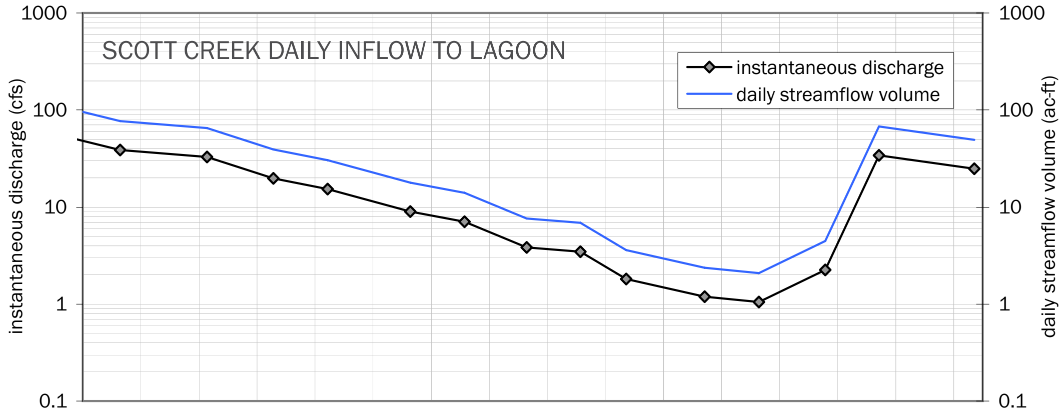
2004 SCOTT LAGOON WATER BUDGET

FIGURE 11.19

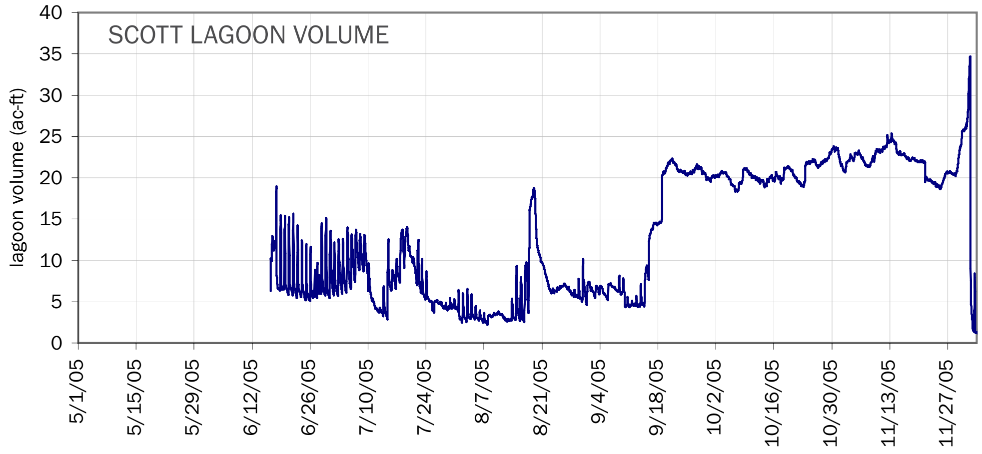
2005 SCOTT LAGOON HYDROLOGY



Data provided by WXTide.



Data provided by NOAA.

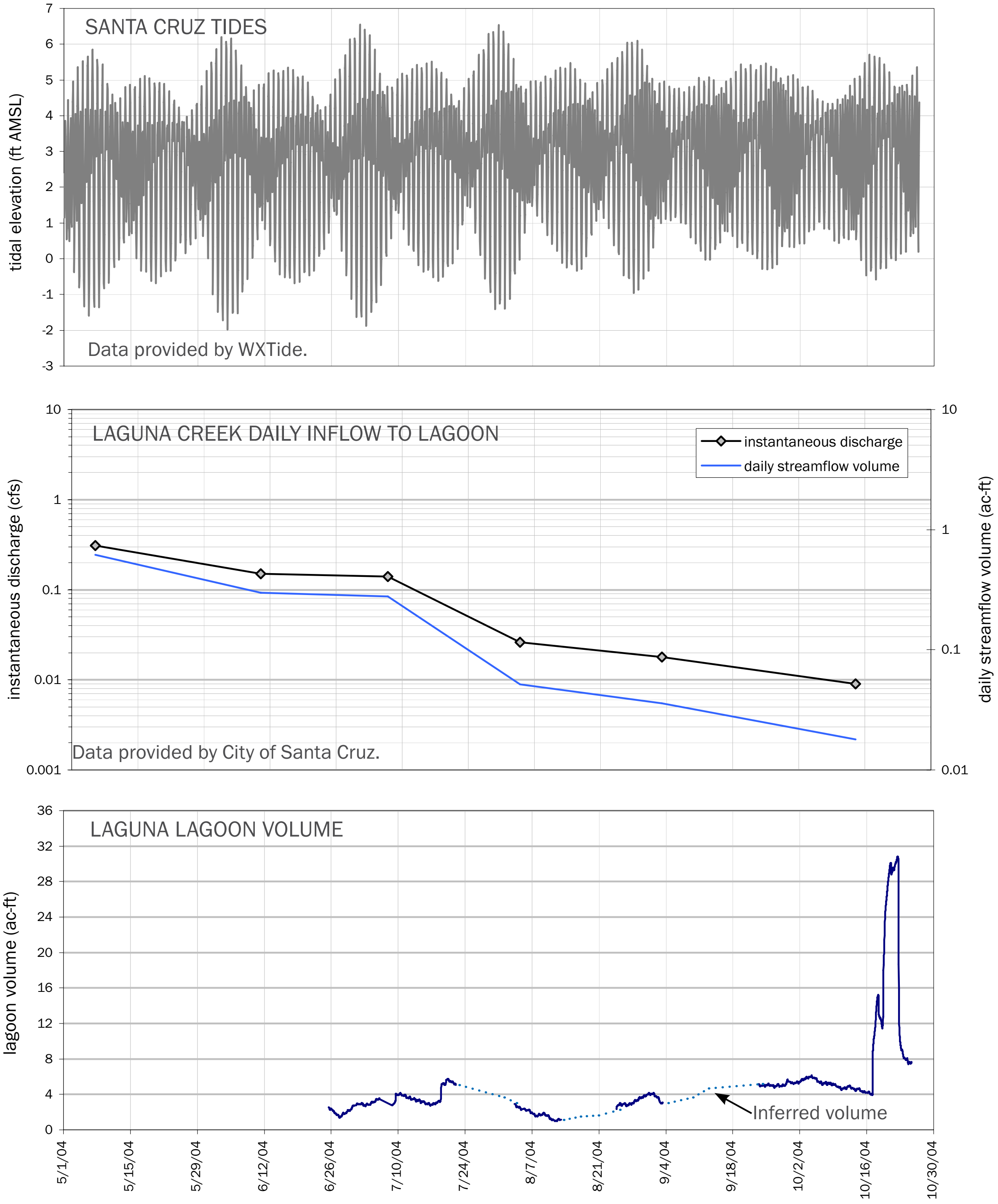


Instrument failure limited resolution of Scott lagoon volume.

Sept 2005 S Beach Pool

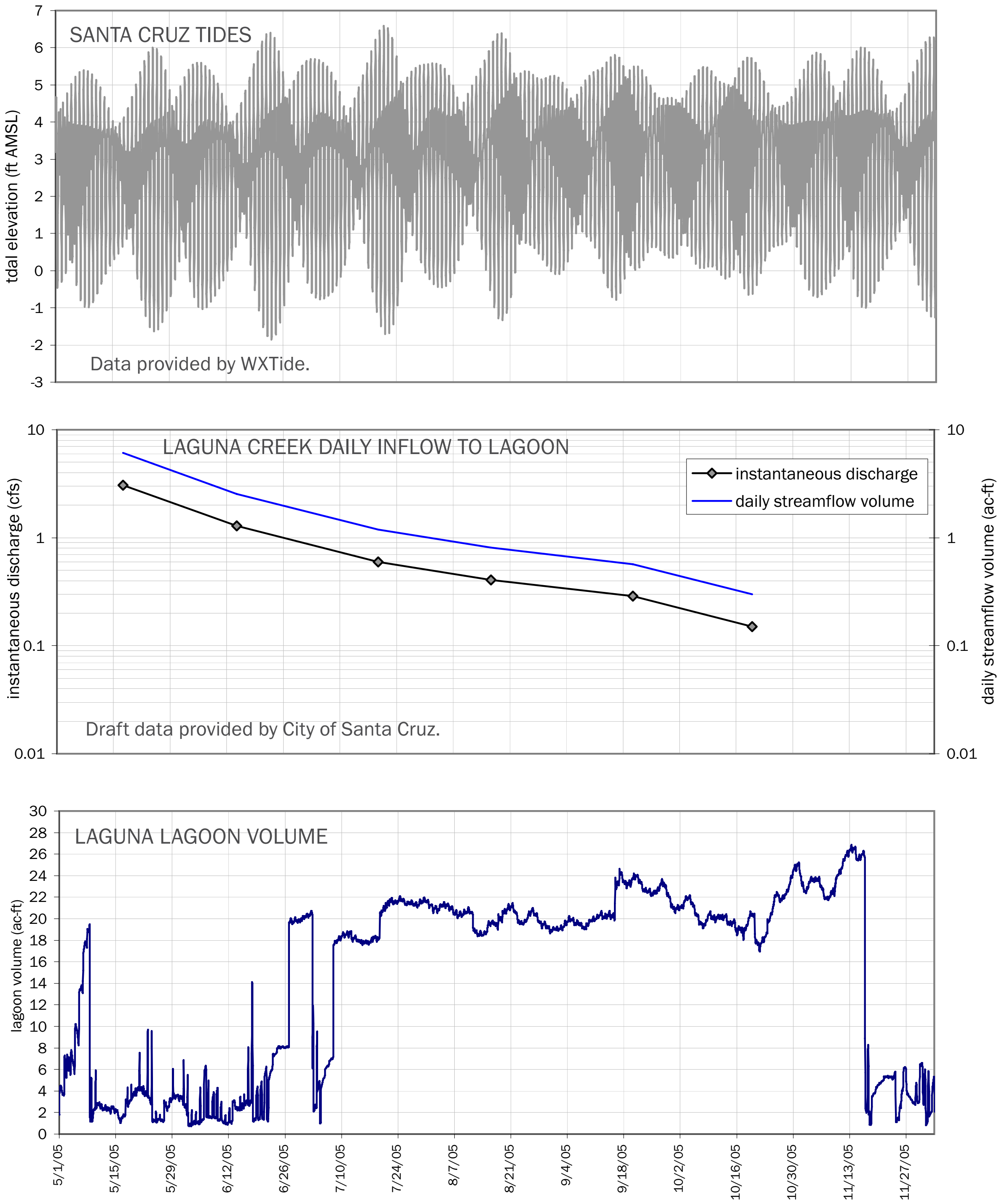
2005 SCOTT LAGOON WATER BUDGET FIGURE 11.20

2004 LAGUNA LAGOON HYDROLOGY



YSI instrument failure limited resolution of Laguna lagoon volume.

2005 LAGUNA LAGOON HYDROLOGY




August 2005

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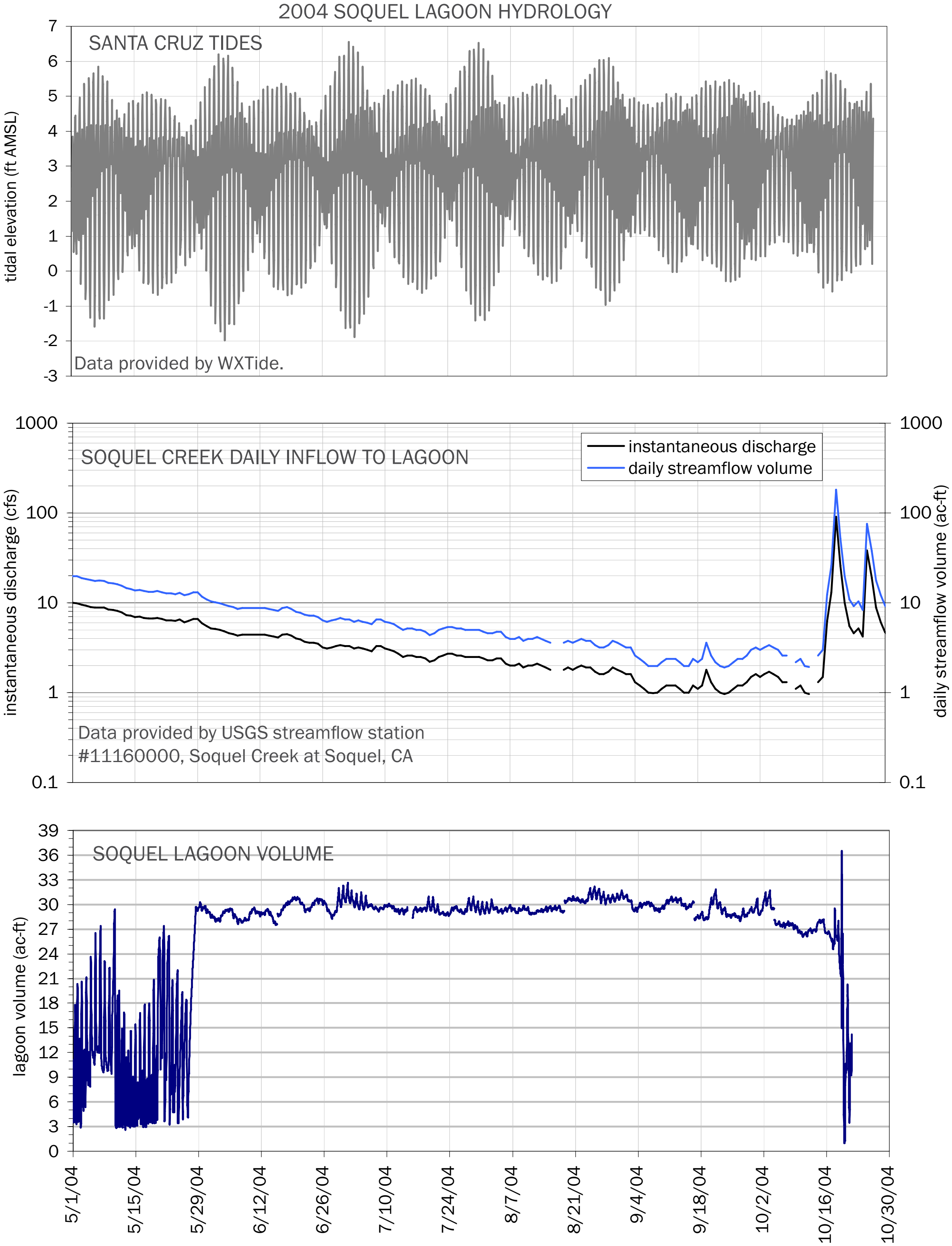
2005 LAGUNA LAGOON WATER BUDGET

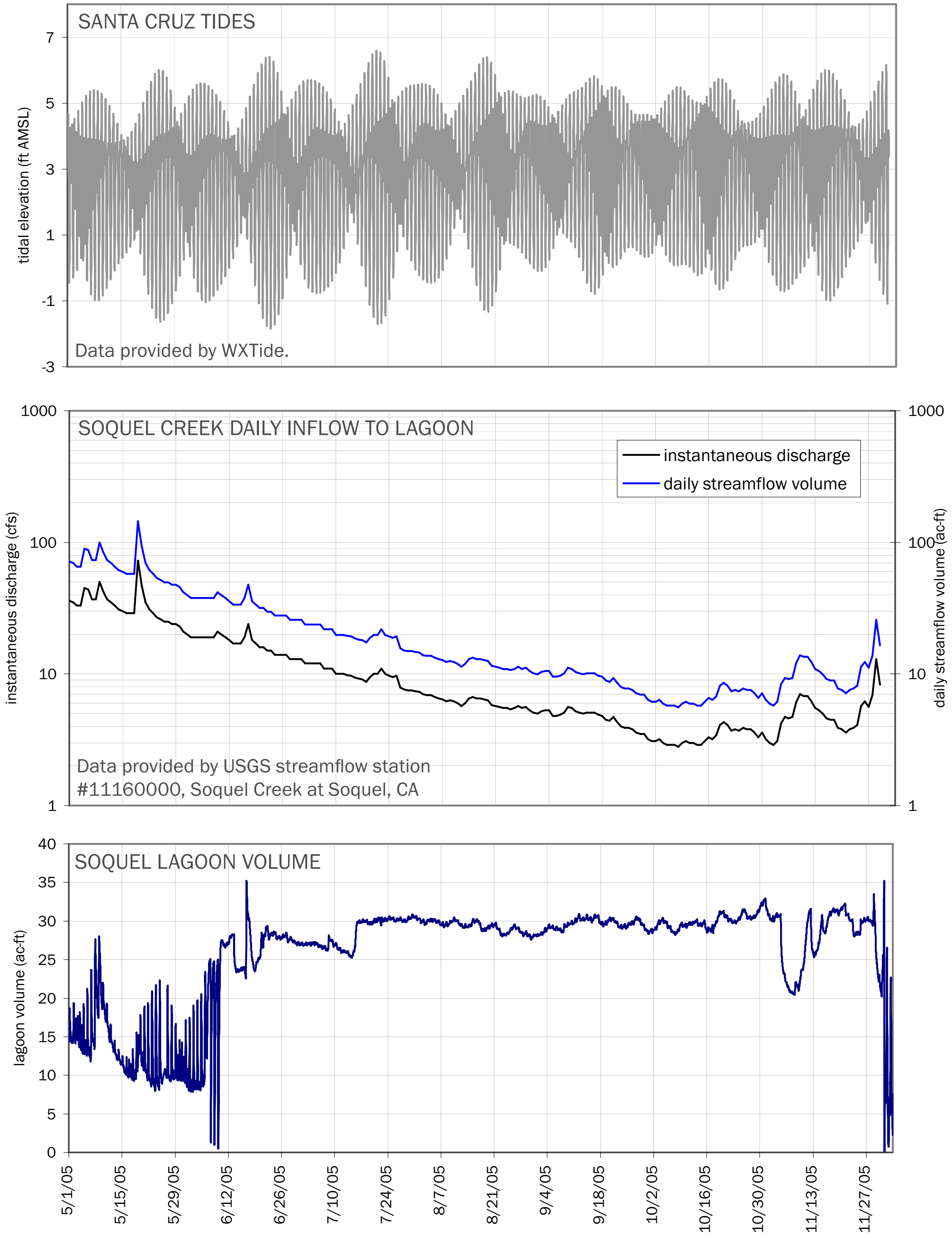
FIGURE 11.22



2004 SOQUEL LAGOON WATER BUDGET

FIGURE 11.23

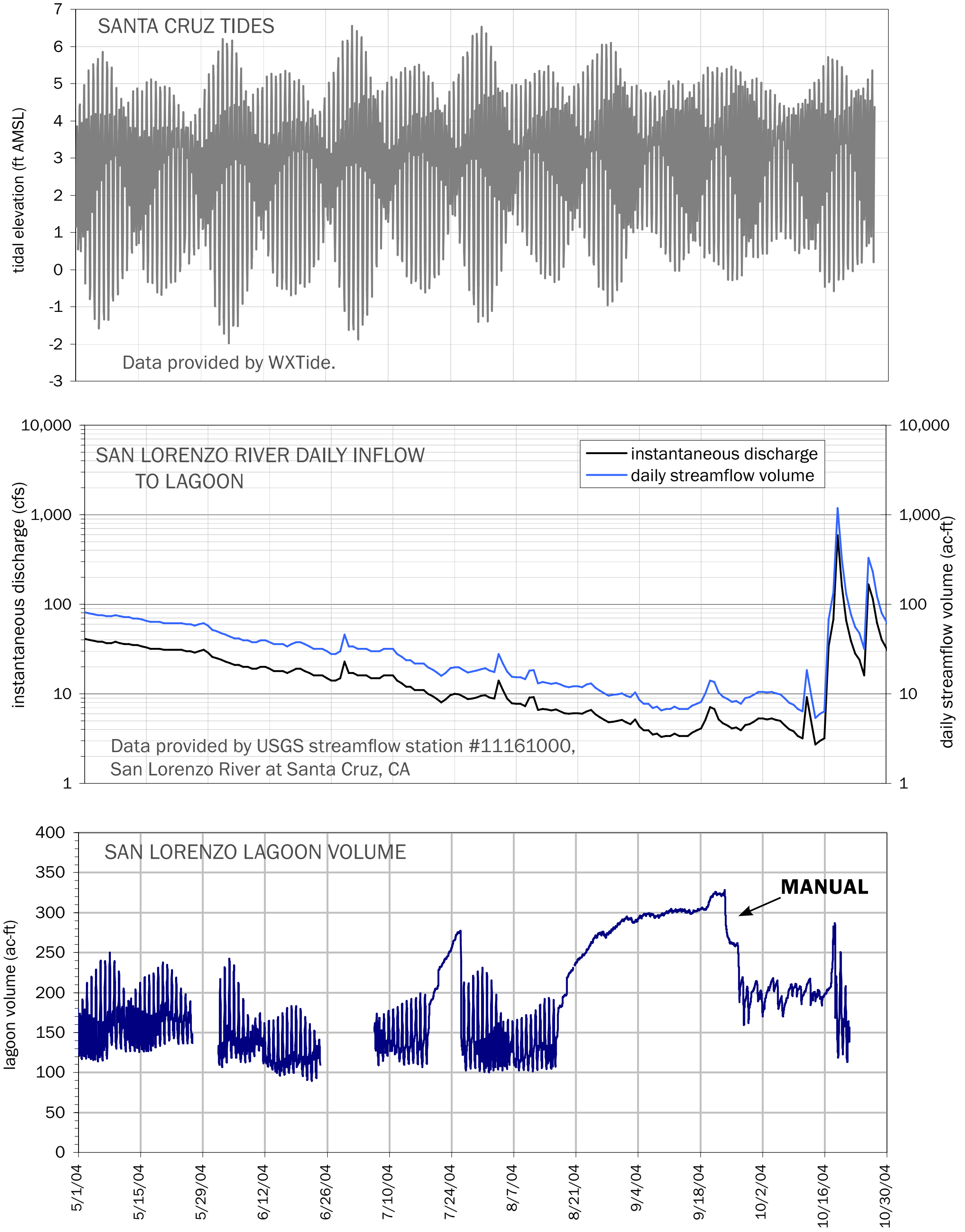
2005 SOQUEL LAGOON HYDROLOGY



2005 SOQUEL LAGOON WATER BUDGET

FIGURE 11.24

2004 SAN LORENZO LAGOON HYDROLOGY



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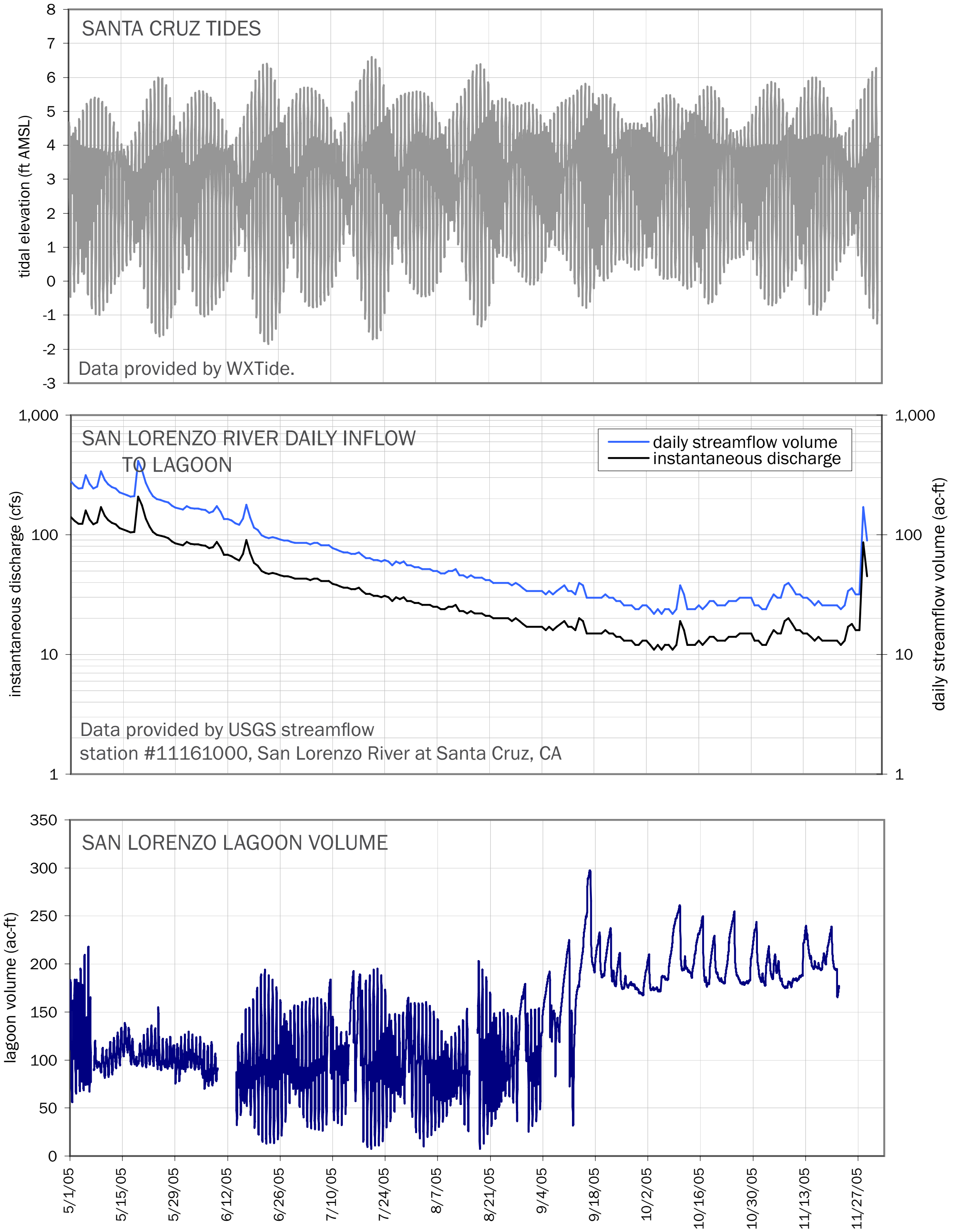
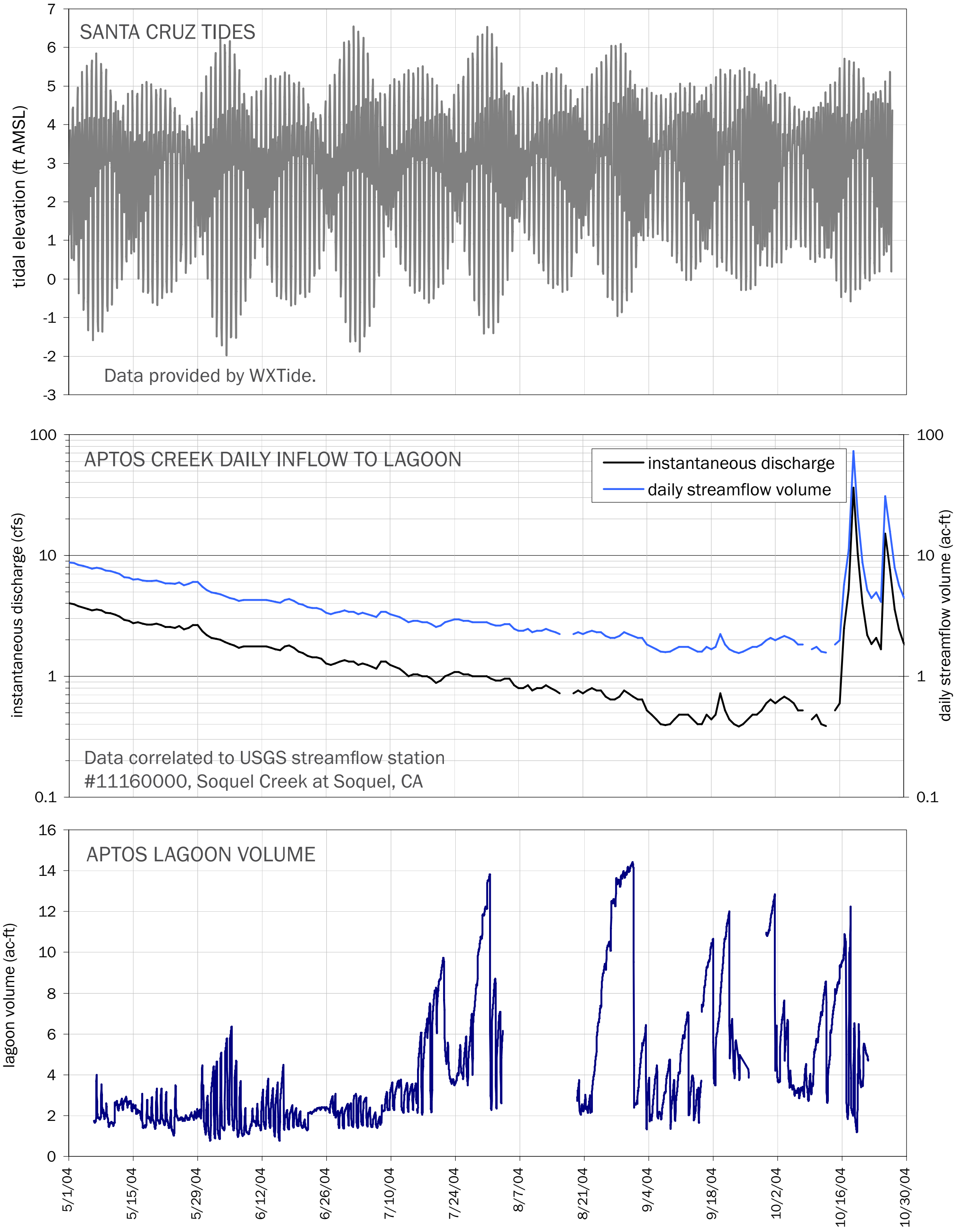
2004 SAN LORENZO LAGOON WATER BUDGET

FIGURE 11.25

2005 SAN LORENZO LAGOON HYDROLOGY



2004 APTOS LAGOON HYDROLOGY



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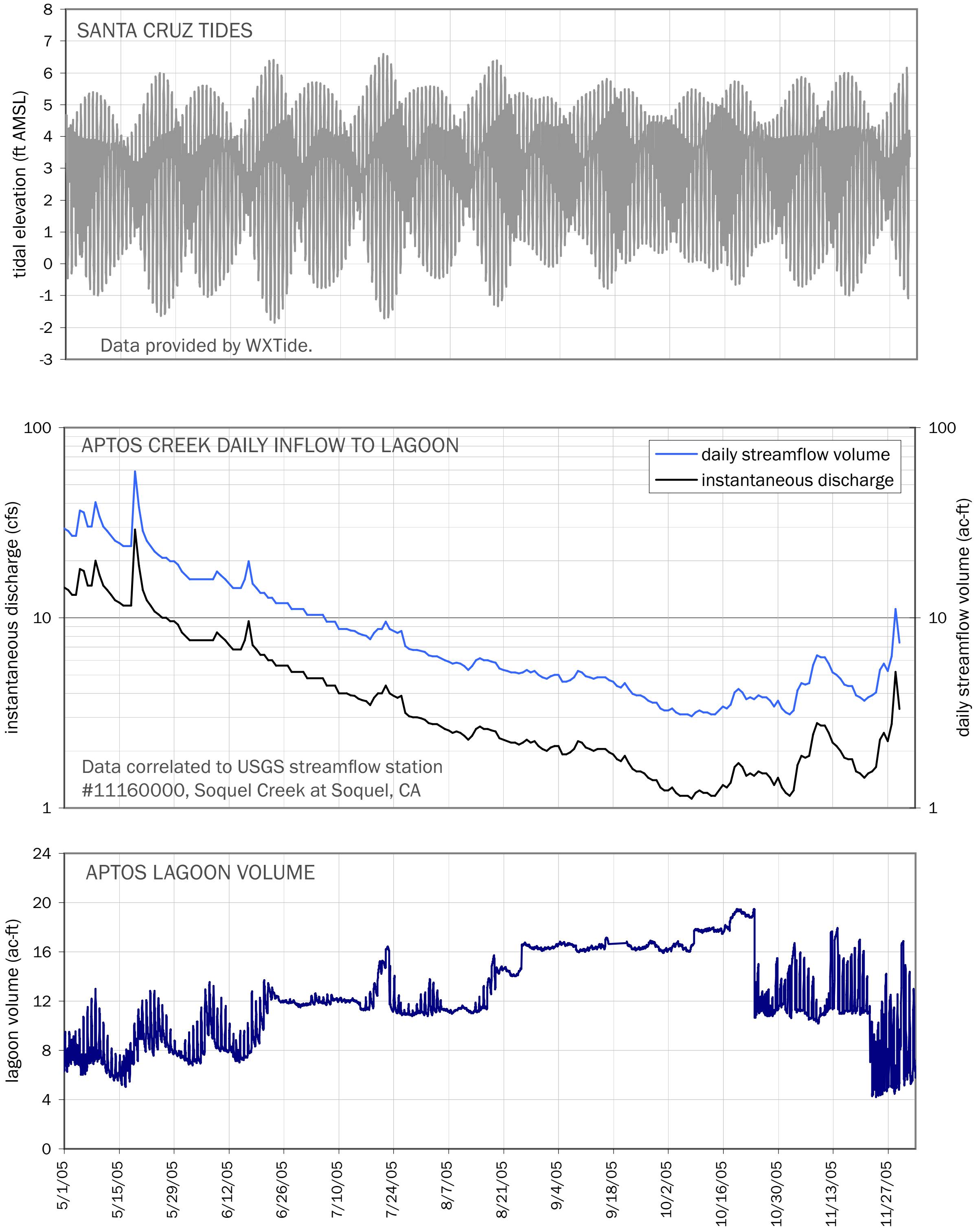
2004 APTOS LAGOON WATER BUDGET

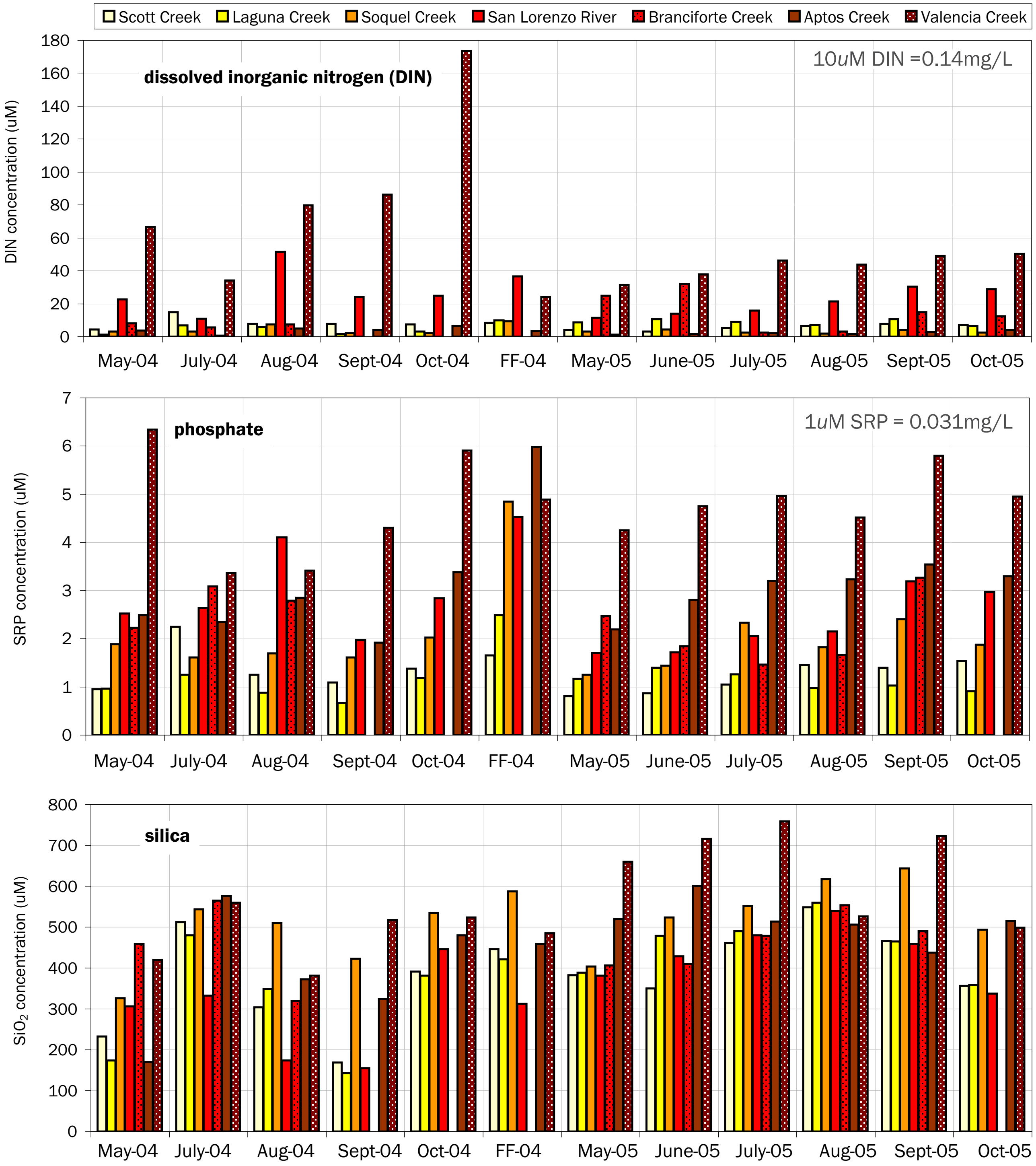
FIGURE 11.27

2005 APTOS LAGOON HYDROLOGY



2005 APTOS LAGOON WATER BUDGET

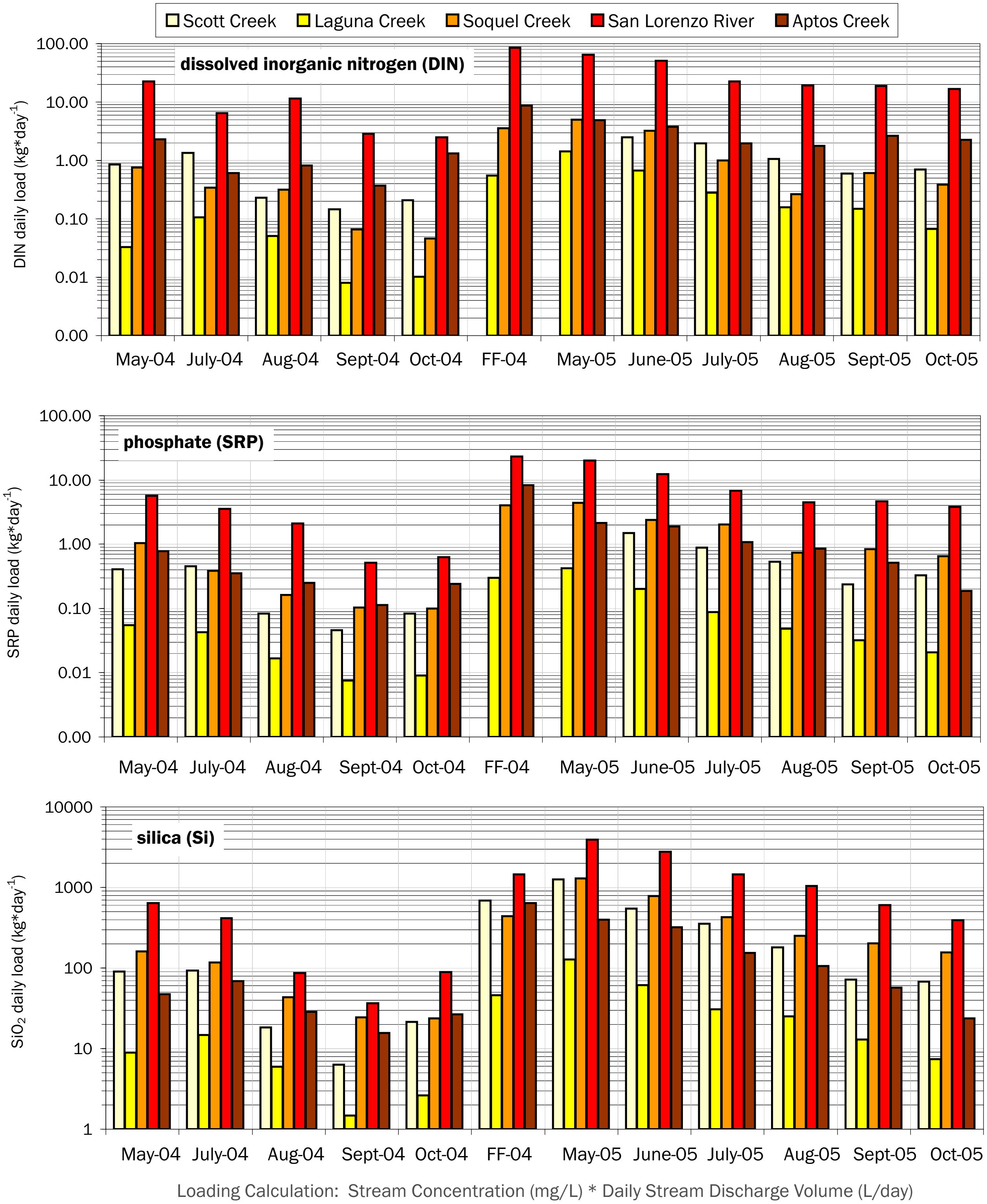
FIGURE 11.28



Note: Branciforte Creek is a tributary to the San Lorenzo River Lagoon and Valencia Creek is a tributary to the Aptos Creek Lagoon.

MONTHLY TRIBUTARY NUTRIENT SAMPLING CONCENTRATIONS

FIGURE 11.29

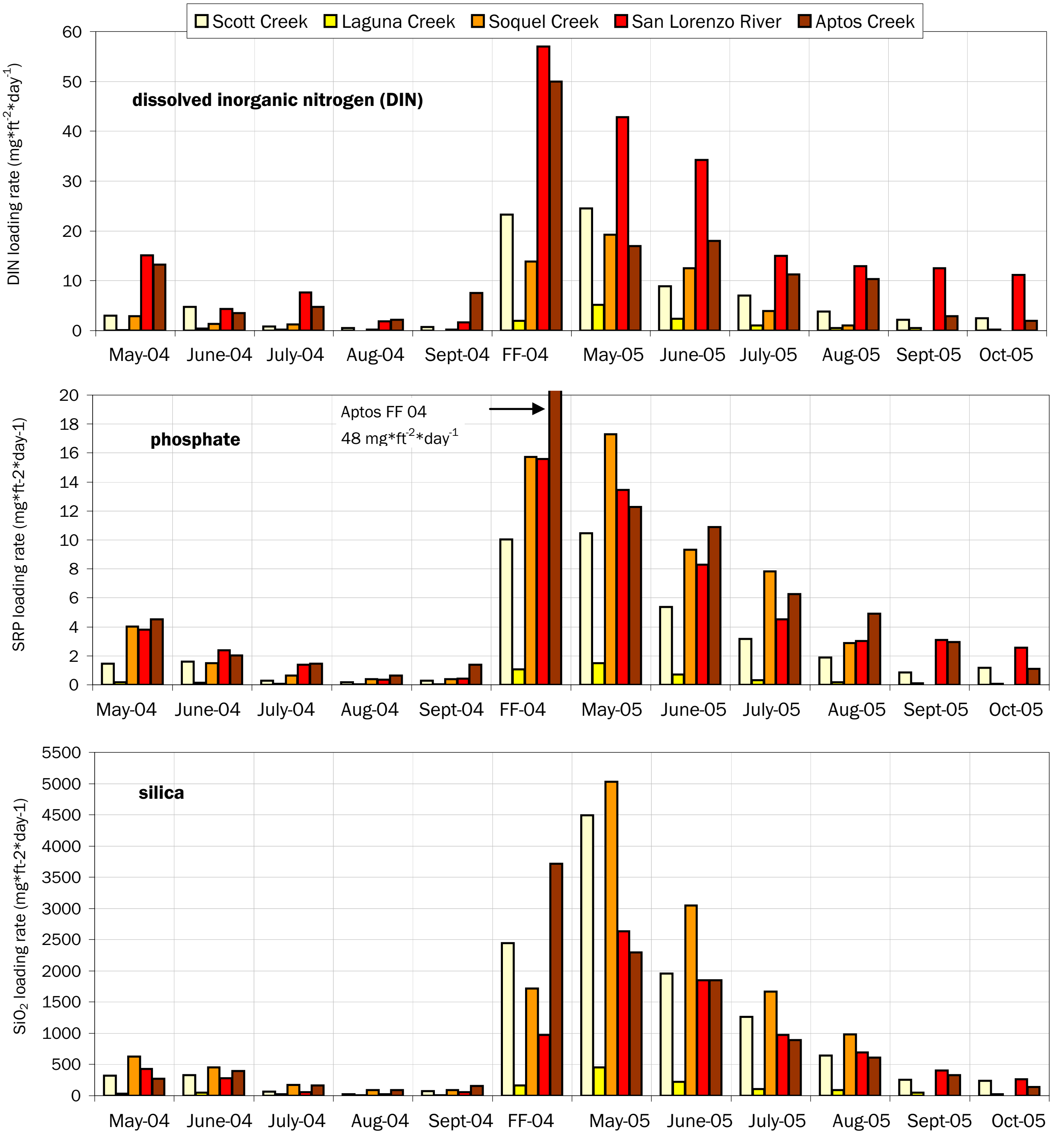


Loading Calculation: Stream Concentration (mg/L) * Daily Stream Discharge Volume (L/day)

Note: Loading to San Lorenzo Lagoon is sum of respective nutrient loads from Branciforte Creek and San Lorenzo River. Loading to Aptos Lagoon is sum of respective nutrient loads from Aptos and Valencia Creeks.

DAILY TRIBUTARY NUTRIENT LOADING TO LAGOONS BY MONTH

FIGURE 11.30



Lagoon surface area (SA) adjusted depending upon open or closed lagoon conditions.

Loading Calculation: Stream Concentration (mg/L) * Daily Stream Discharge Volume (L/day) / Lagoon SA (ft^2)

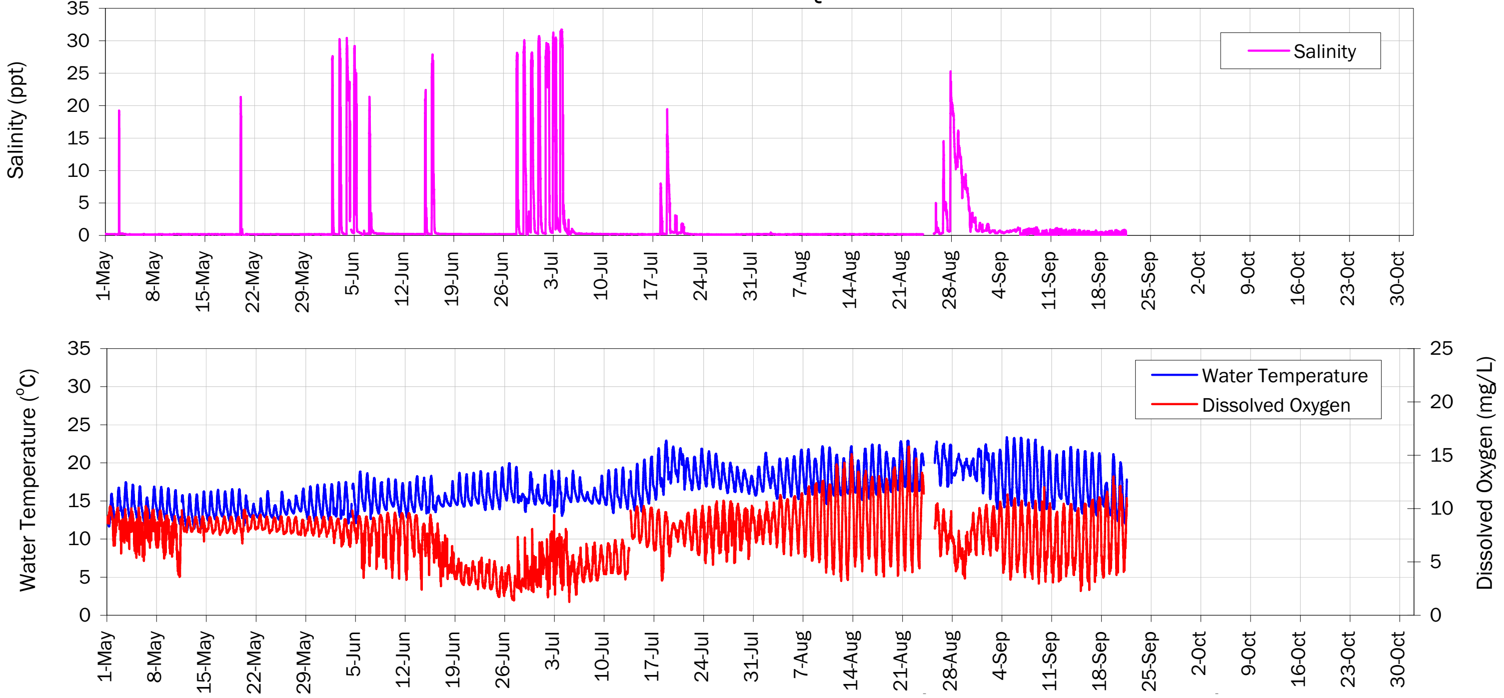
Note: Loading to San Lorenzo Lagoon is sum of respective nutrient loads from Branciforte Creek and San Lorenzo River. Loading to Aptos Lagoon is sum of respective nutrient loads from Aptos and Valencia Creeks.

MONTHLY TRIBUTARY NUTRIENT LOADING NORMALIZED TO LAGOON SURFACE AREA

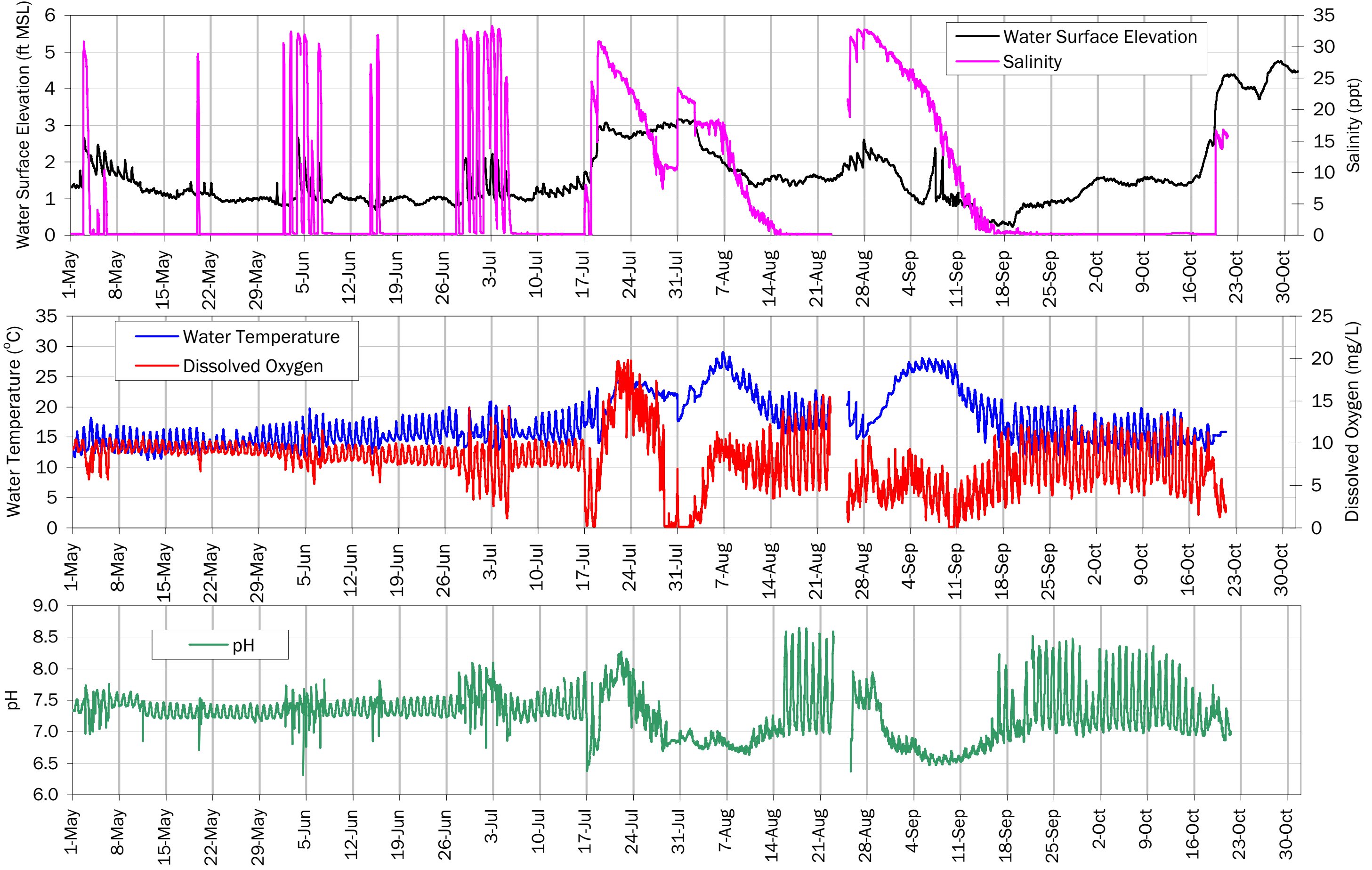
FIGURE 11.31

2004 SCOTT CREEK LAGOON

SURFACE WATER QUALITY



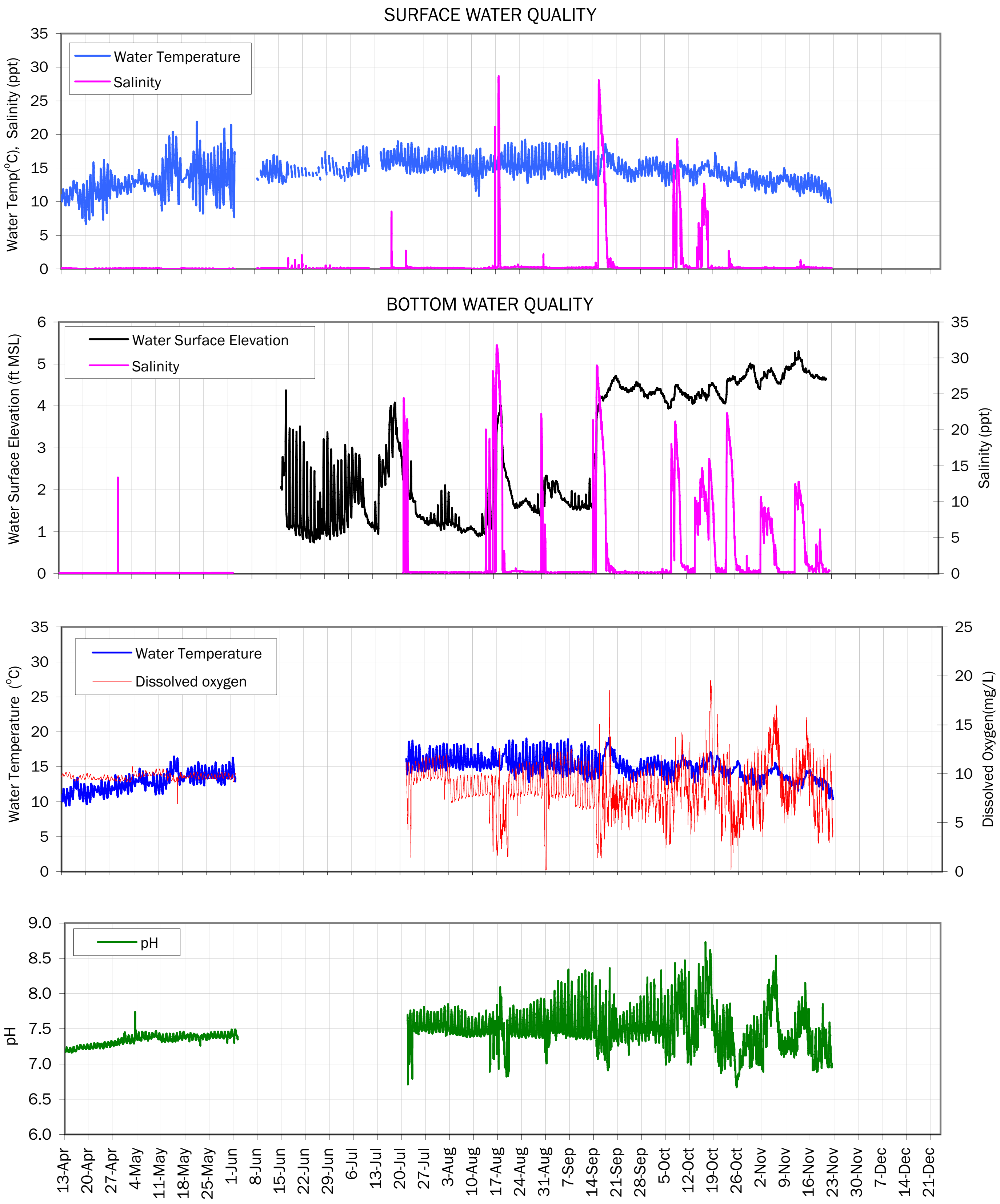
BOTTOM WATER QUALITY



Bottom water instrument is located 0.5 ft above the lagoon bottom.

YSI 600XLM instruments at Scott Lagoon are operated and maintained by NOAA. These YSI models do not record chlorophyll, ORP, or depth data. Water depth data is recorded by an In-Situ miniTroll maintained by 2NDNATURE.

2005 SCOTT CREEK LAGOON



YSI 600XLM instruments at Scott Lagoon are operated and maintained by NOAA. These YSI models do not record chlorophyll, ORP, or depth data. Water depth data is recorded by an In-Situ miniTroll maintained by 2NDNATURE.

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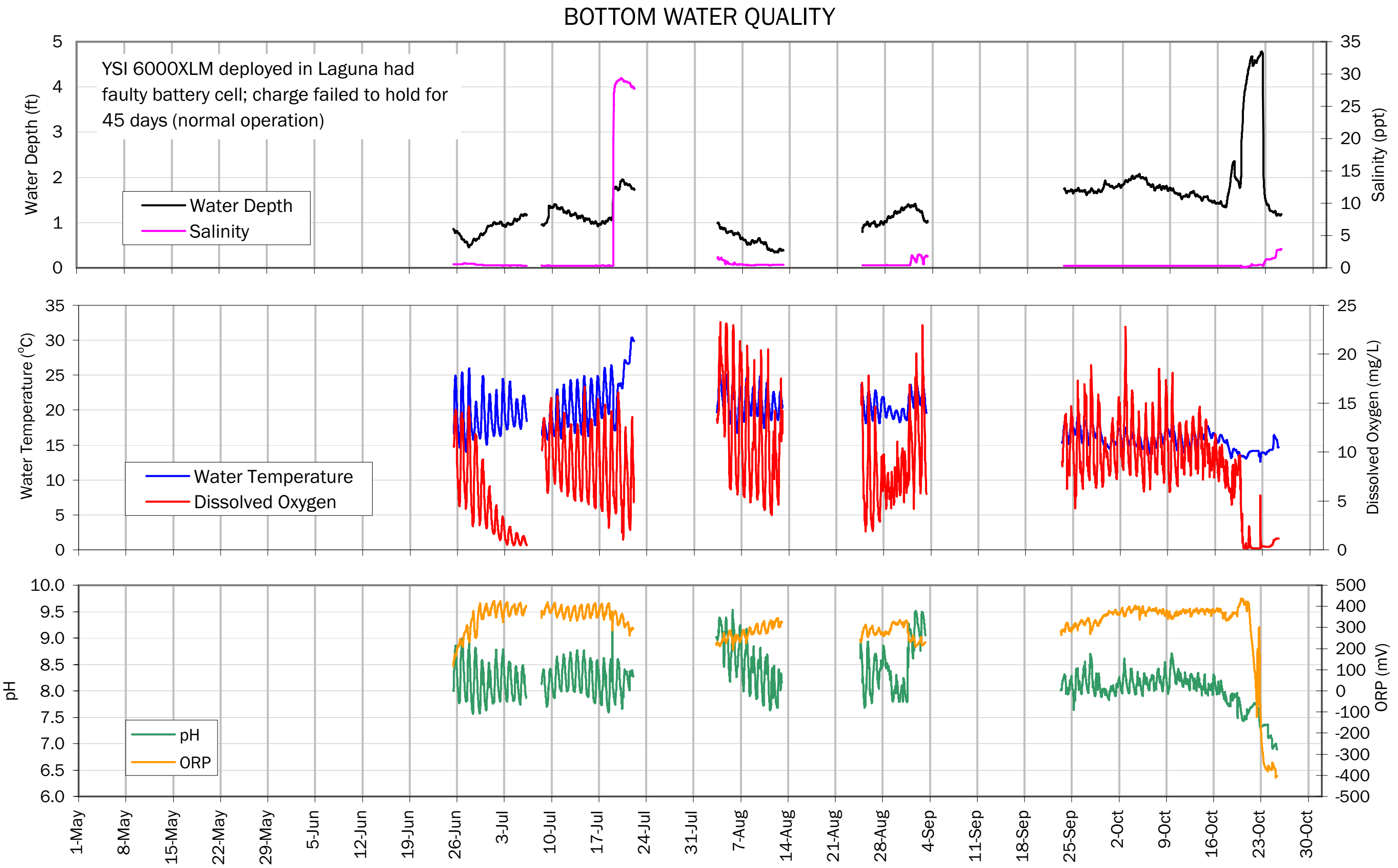
2005 SCOTT LAGOON CONTINUOUS WATER QUALITY MONITORING

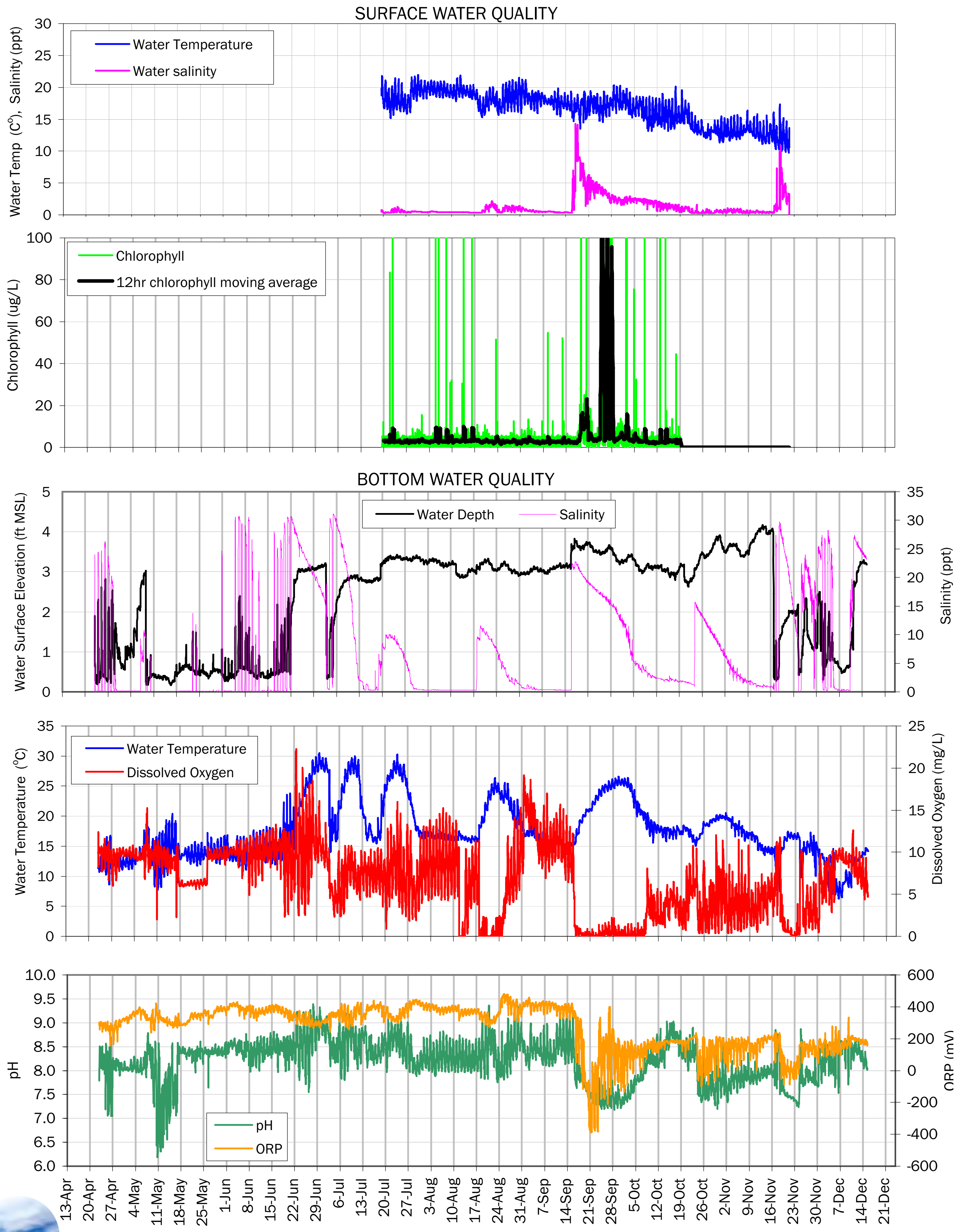
FIGURE 11.33

2004 LAGUNA CREEK LAGOON



YSI 600XLM was installed in bottom waters June 25, 2004, 0.5ft above the lagoon sediments. 2NDNATURE estimates that the lagoon closed May 15, 2004. No surface instrument was installed at Laguna Lagoon during the 2004 monitoring season.

2005 LAGUNA CREEK LAGOON



YSI 600XLM was installed in bottom waters, 0.5ft above the lagoon sediments. YSI 6000MS was attached to buoy floating at lagoon water surface.

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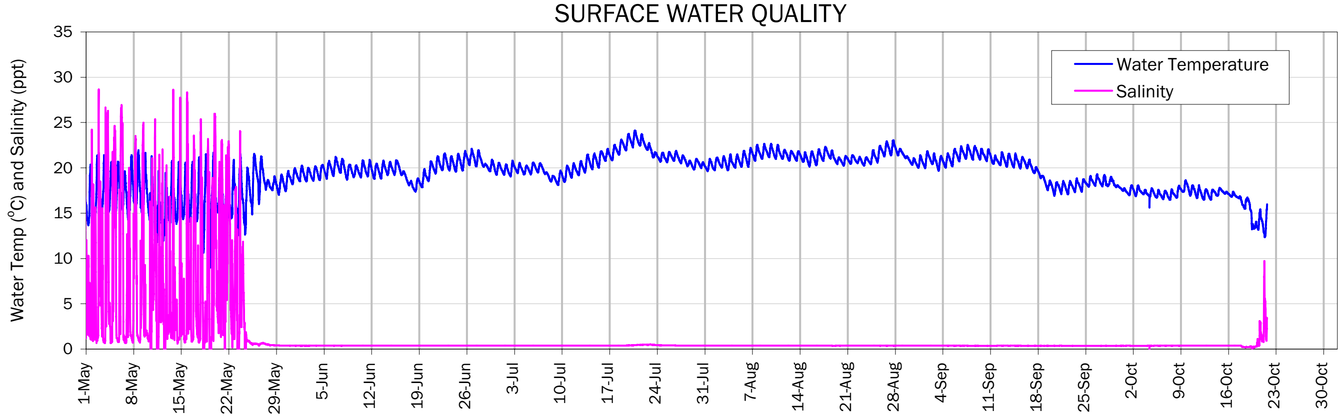
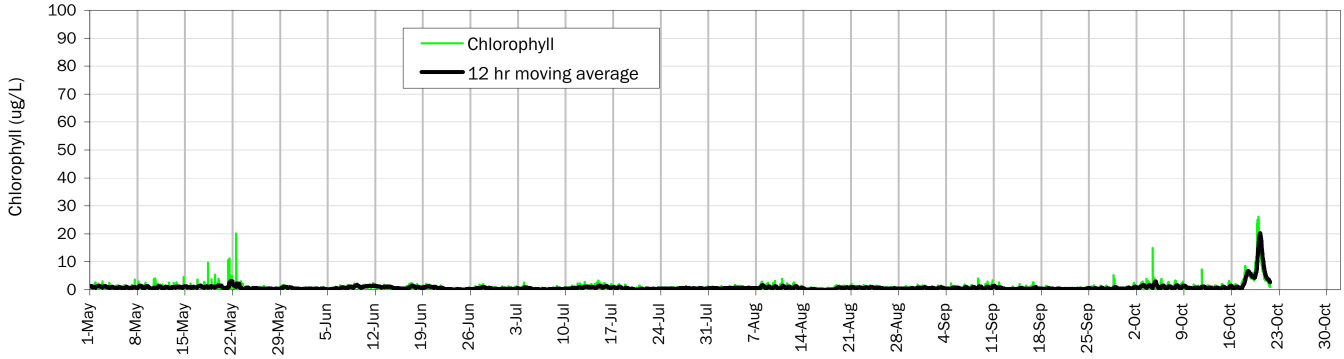
2005 LAGUNA LAGOON CONTINUOUS WATER QUALITY MONITORING

FIGURE 11.35

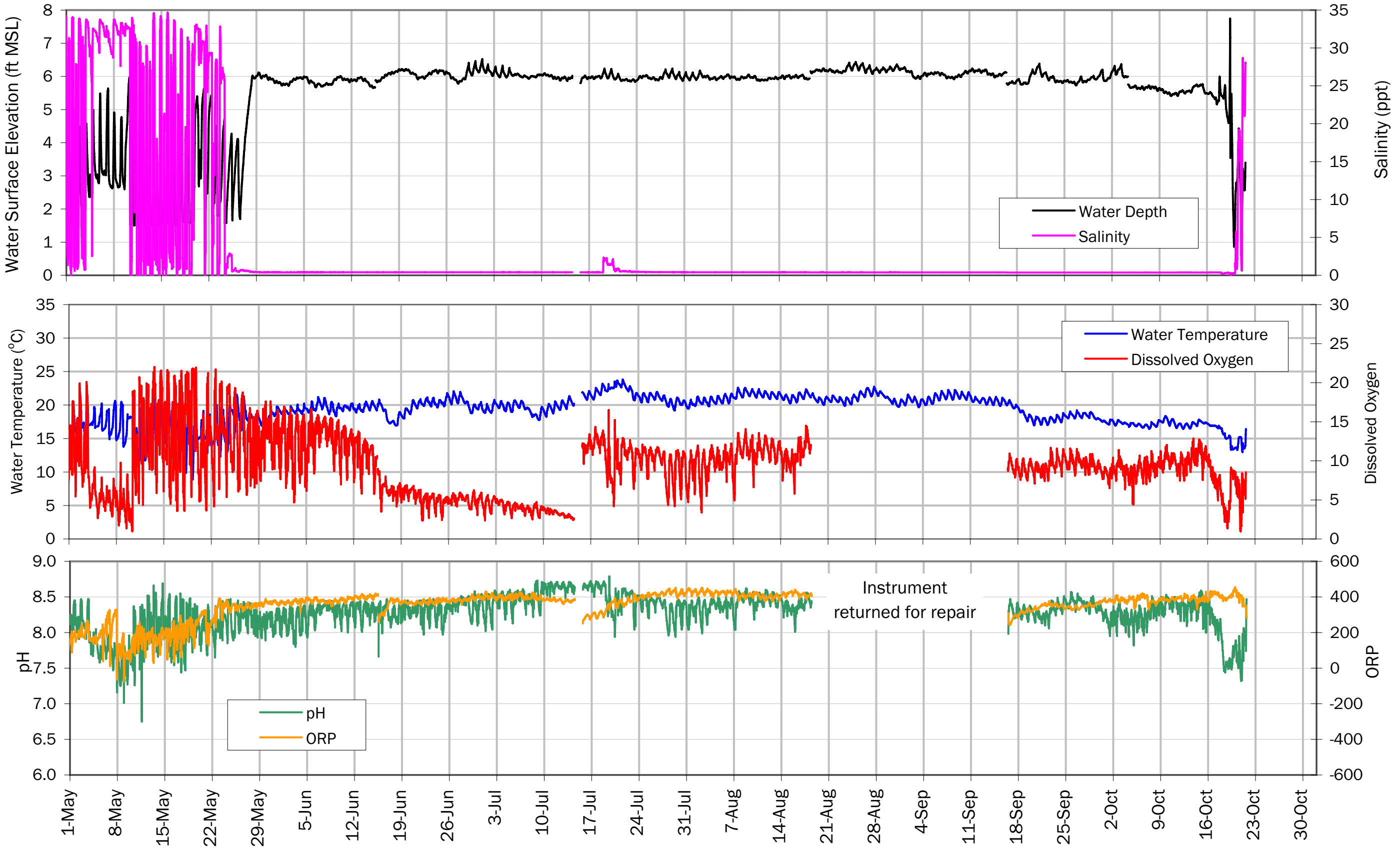
2004 SOQUEL CREEK LAGOON

SURFACE WATER QUALITY





BOTTOM WATER QUALITY

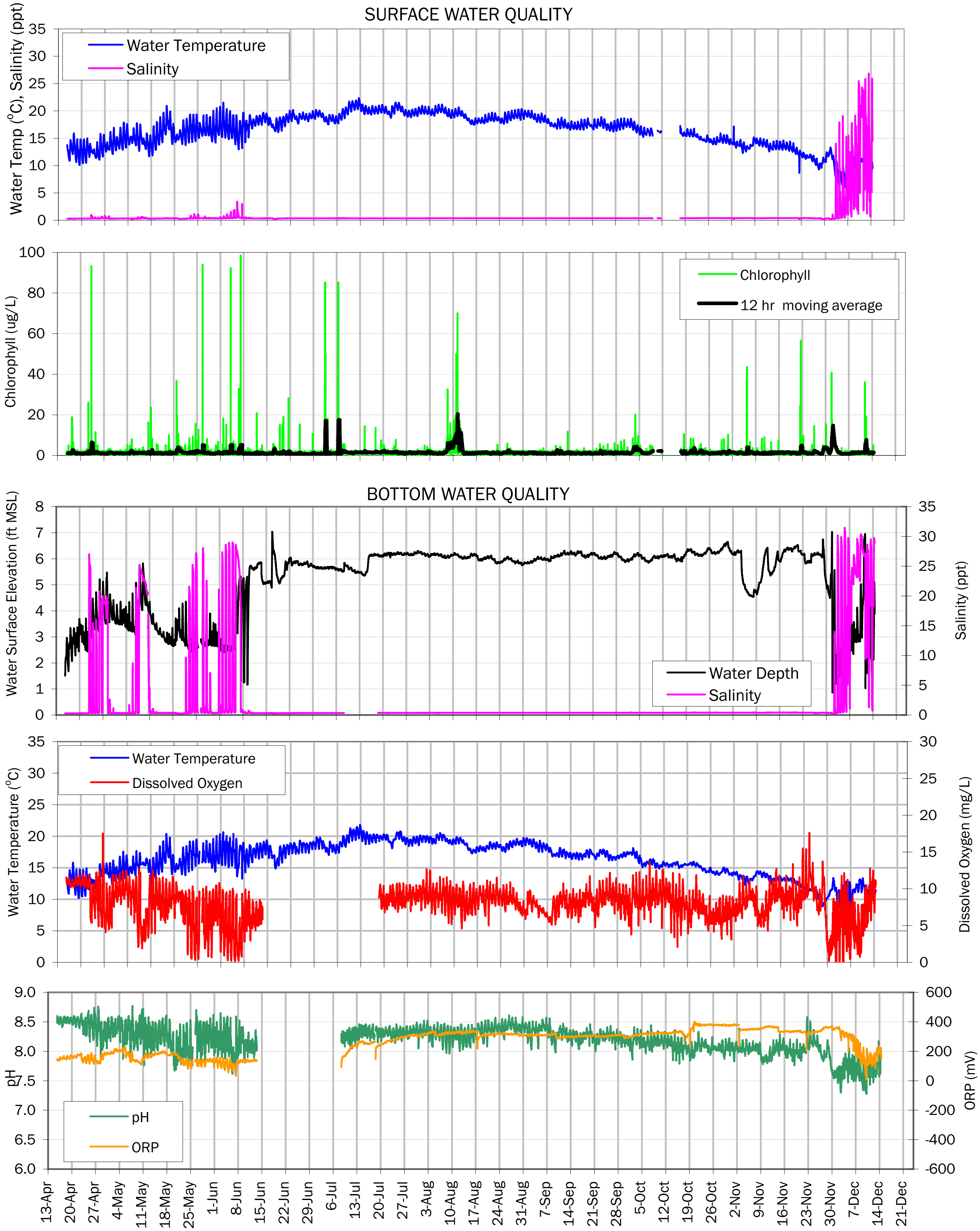


YSI 600XLM was installed in bottom waters, 0.5ft above the lagoon sediments.
YSI 6000MS was attached to buoy floating at lagoon water surface.

2004 SOQUEL LAGOON CONTINUOUS WATER QUALITY MONITORING

FIGURE 11.36

2005 SOQUEL CREEK LAGOON


SURFACE WATER QUALITY

BOTTOM WATER QUALITY

YSI 600XLM was installed in bottom waters, 0.5ft above the lagoon sediments. YSI 6000MS was attached to buoy floating at lagoon water surface.

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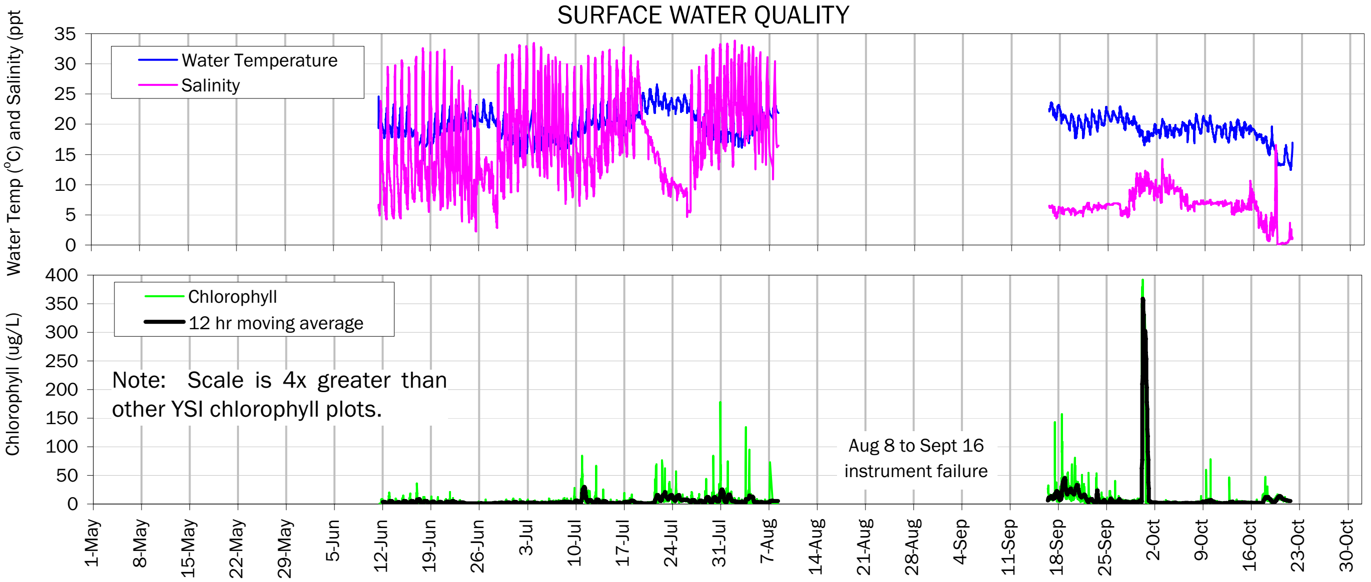
2005 SOQUEL LAGOON CONTINUOUS WATER QUALITY MONITORING

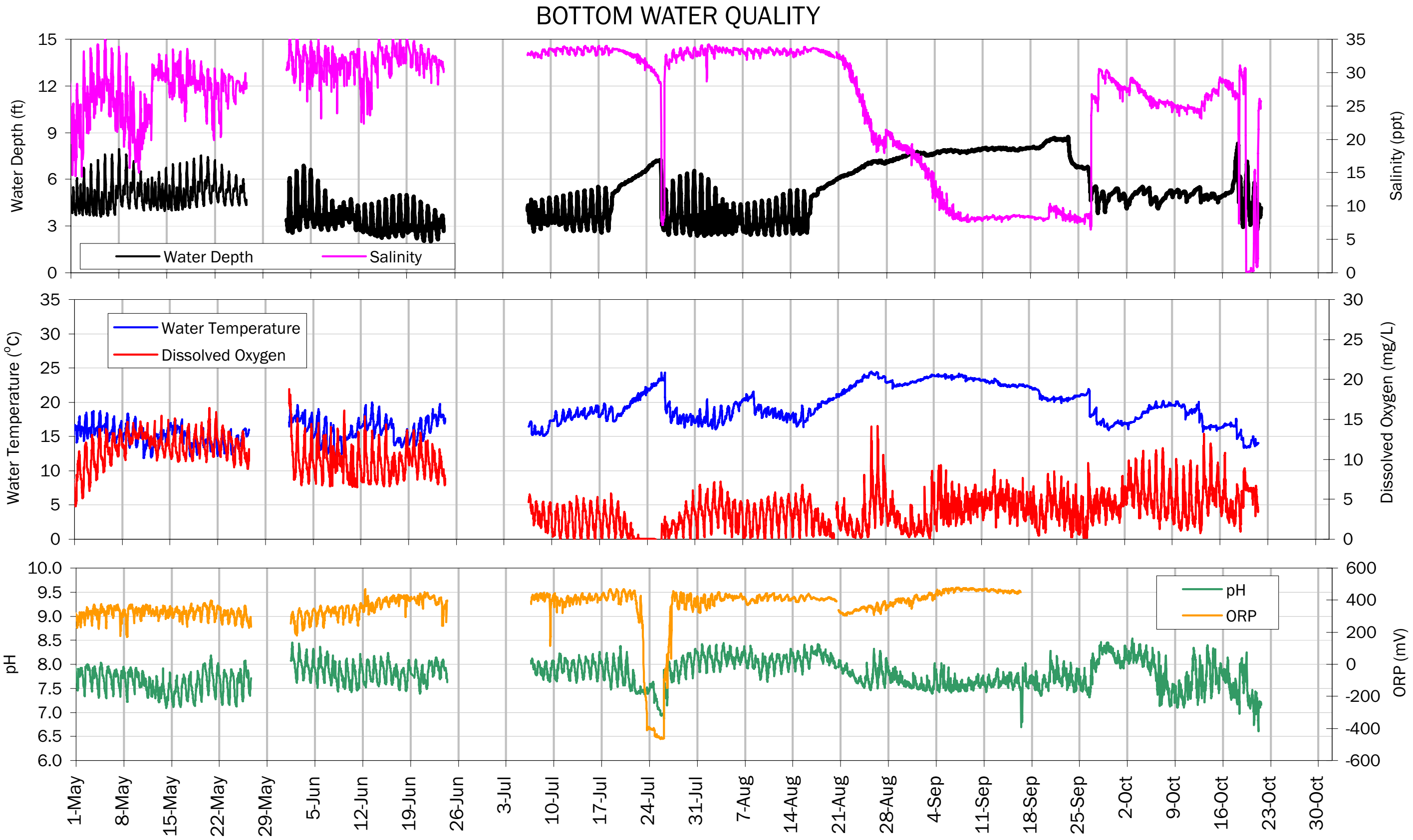
FIGURE 11.37

2004 SAN LORENZO RIVER LAGOON



Note: Scale is 4x greater than other YSI chlorophyll plots.

Aug 8 to Sept 16 instrument failure

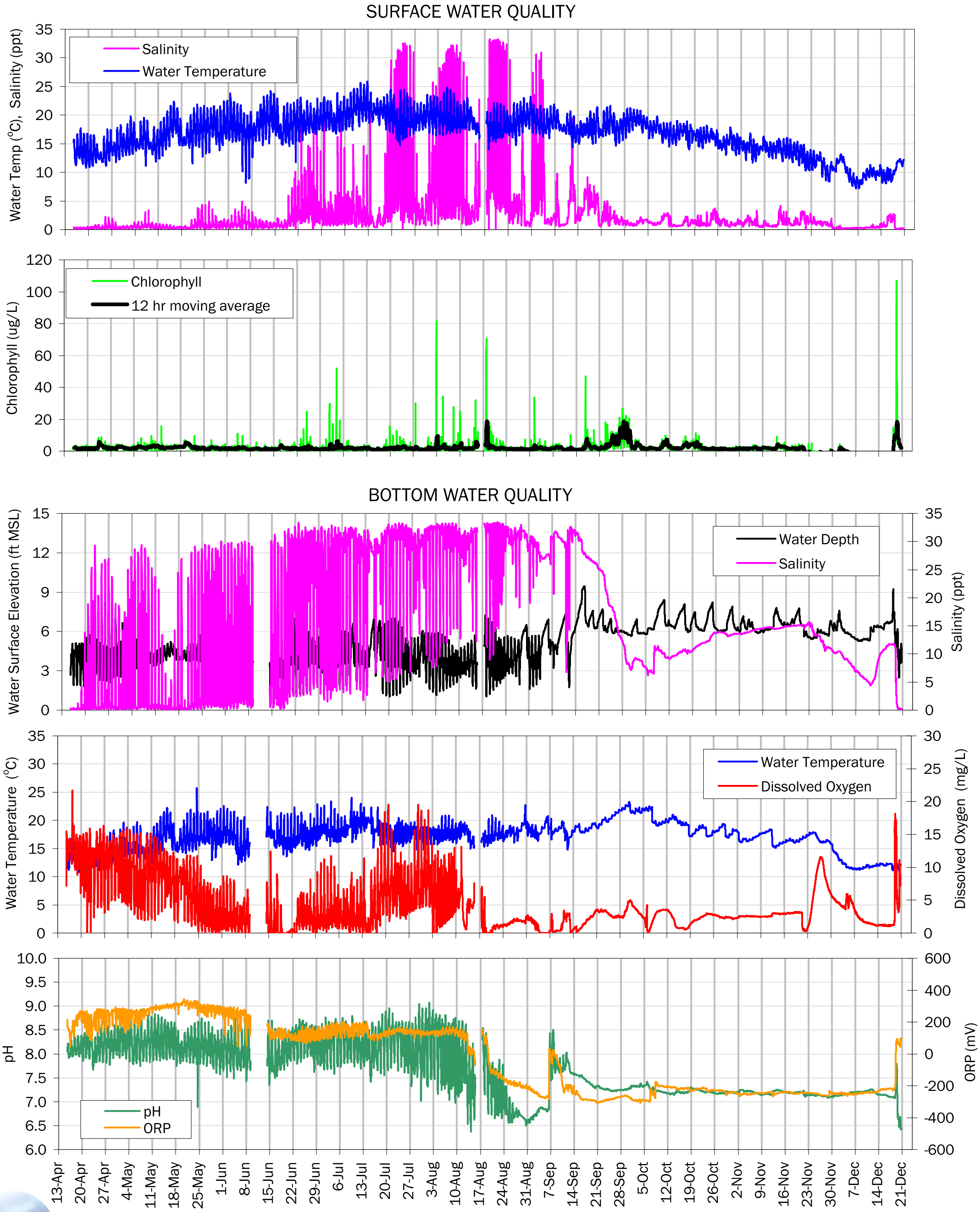


YSI 600XLM was installed in bottom waters, 1.5ft above the lagoon sediments. YSI 600OMS was attached to buoy floating at lagoon water surface.

2004 SAN LORENZO LAGOON CONTINUOUS WATER QUALITY MONITORING

FIGURE 11.38

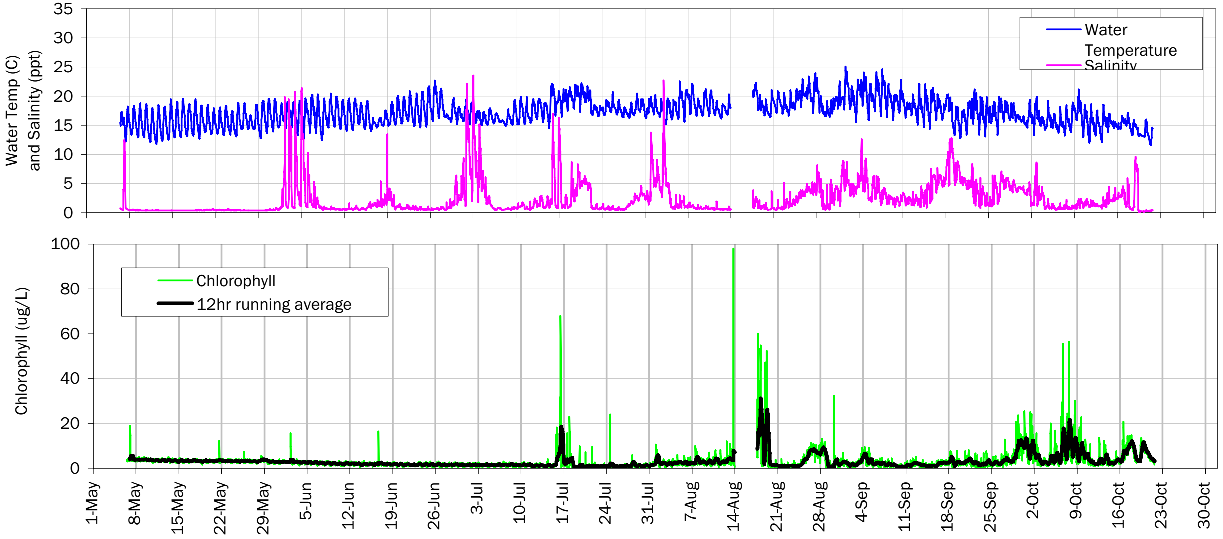
2005 SAN LORENZO RIVER LAGOON



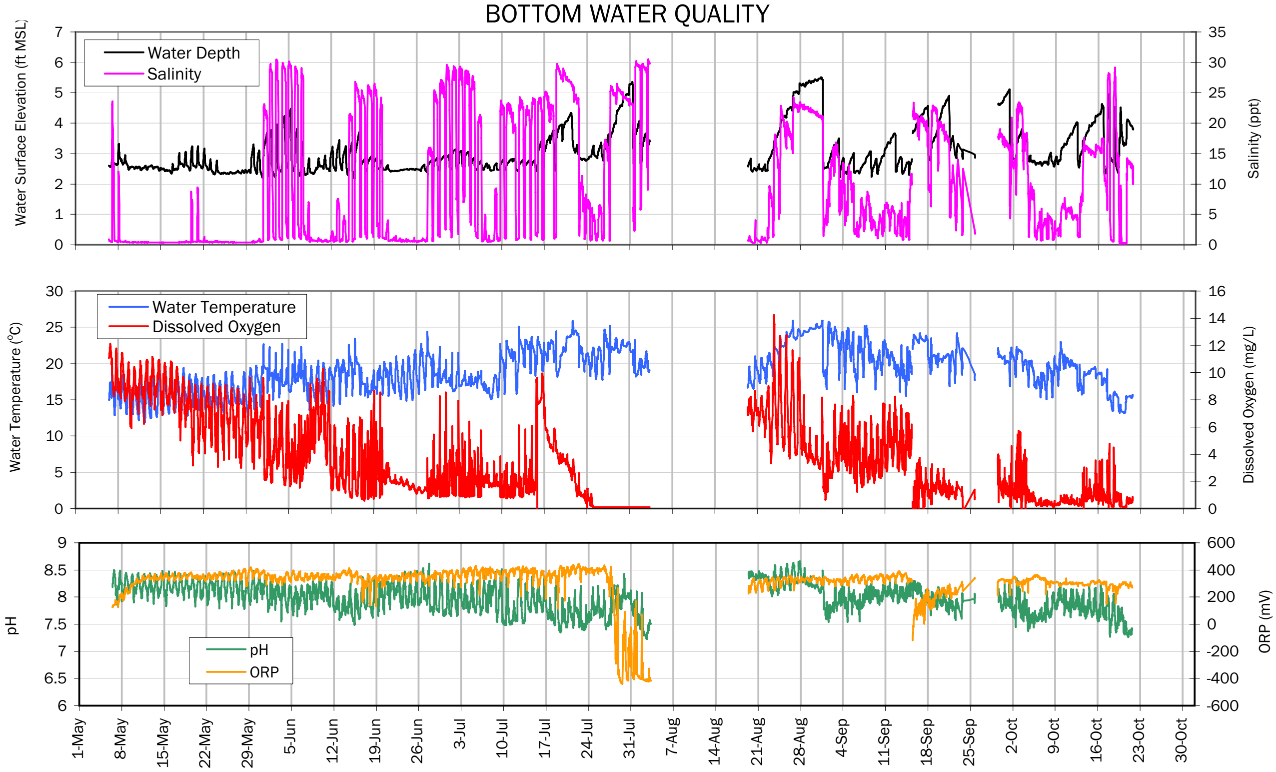
YSI 600XLM was installed in bottom waters, 1.5ft above the lagoon sediments. YSI 6000MS was attached to buoy floating at lagoon water surface.

2004 APTOS CREEK LAGOON

SURFACE WATER QUALITY

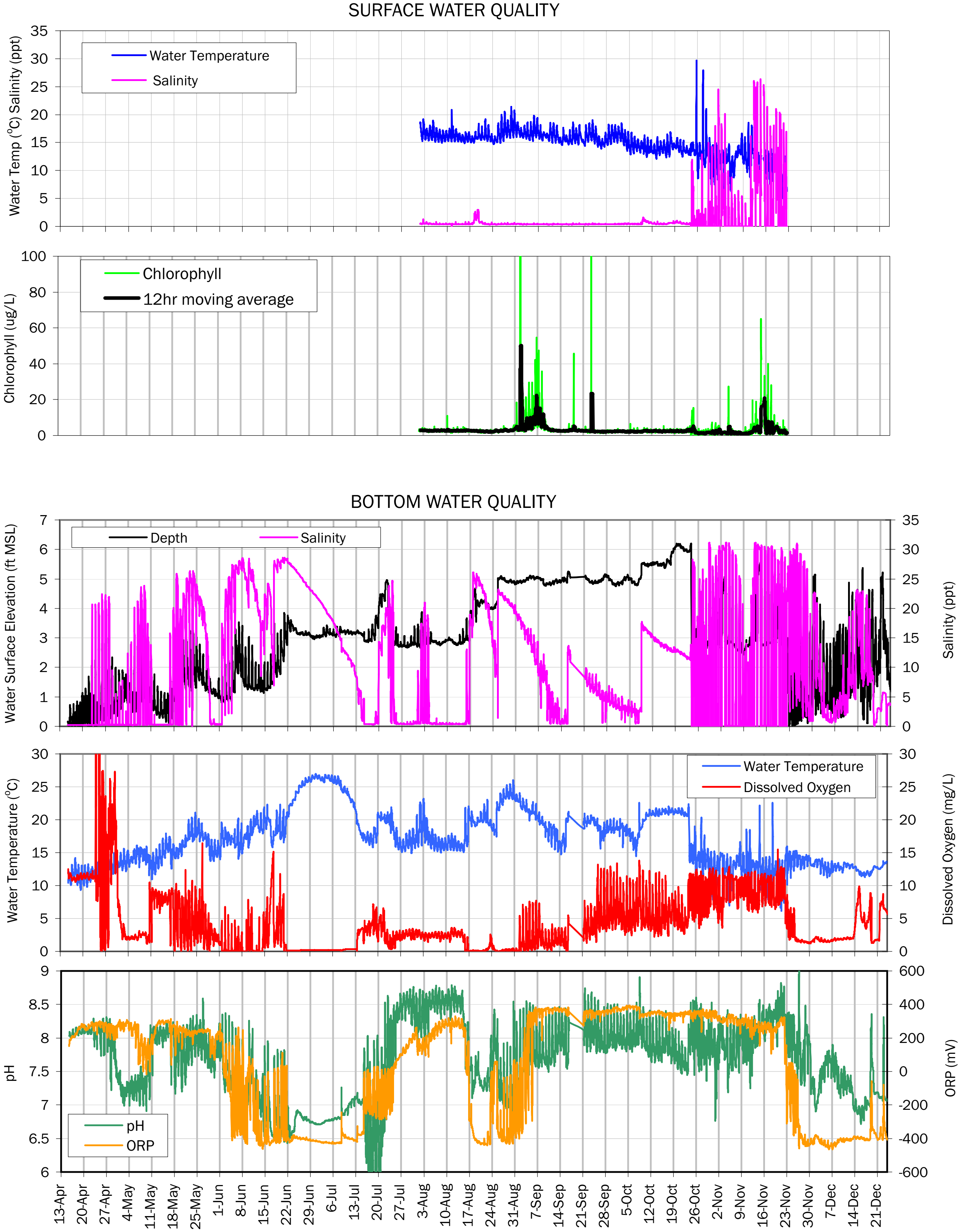


BOTTOM WATER QUALITY



YSI 600XLM was installed in bottom waters, 0.5ft above the lagoon sediments.
YSI 6000MS was attached to buoy floating at lagoon water surface.

2005 APTOS CREEK LAGOON



YSI 600XLM was installed in bottom waters, 0.5ft above the lagoon sediments. YSI 6000MS was attached to buoy floating at lagoon water surface.

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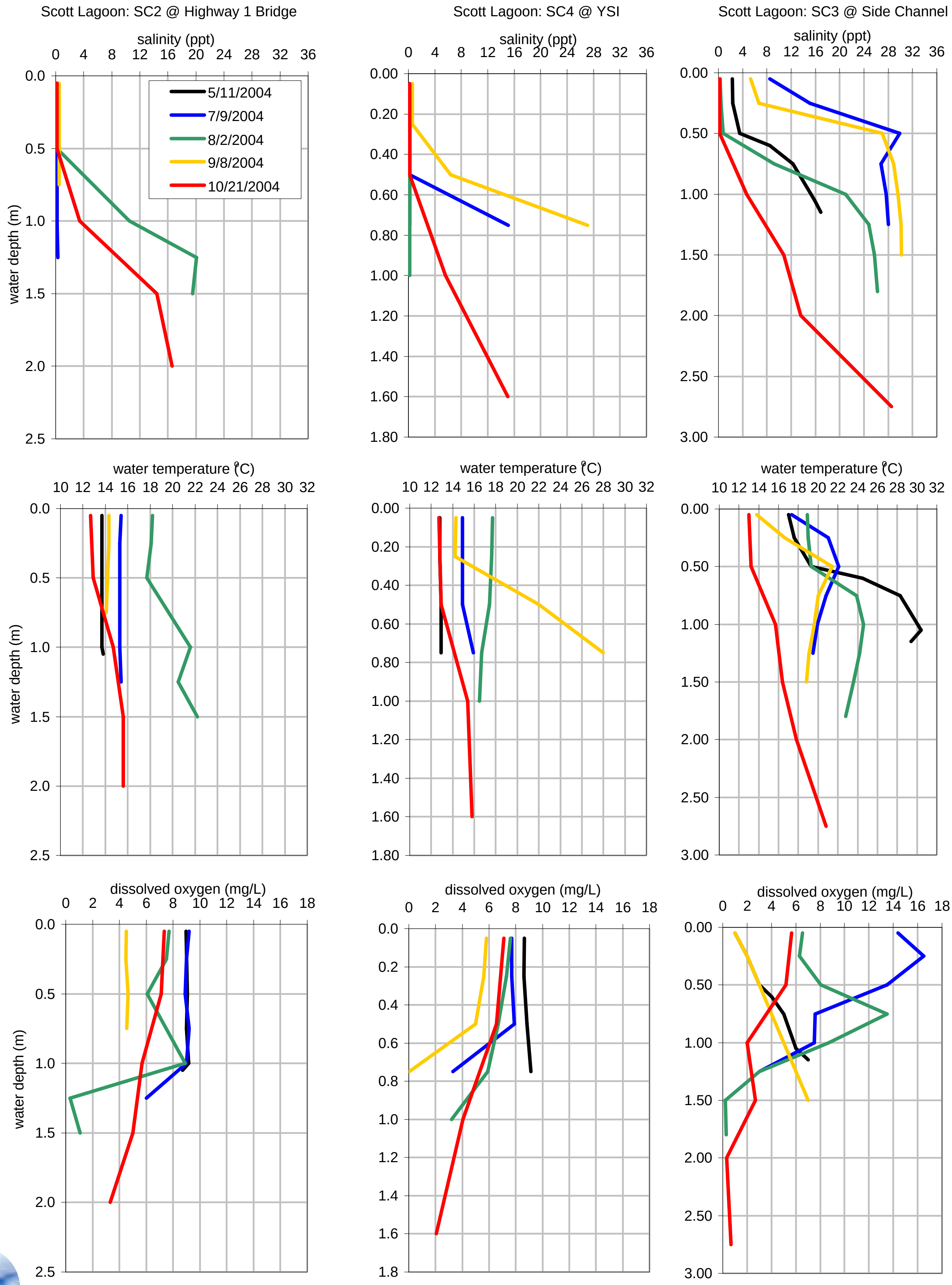
2005 APTOS LAGOON CONTINUOUS WATER QUALITY MONITORING

FIGURE 11.41

2004 SCOTT CREEK LAGOON

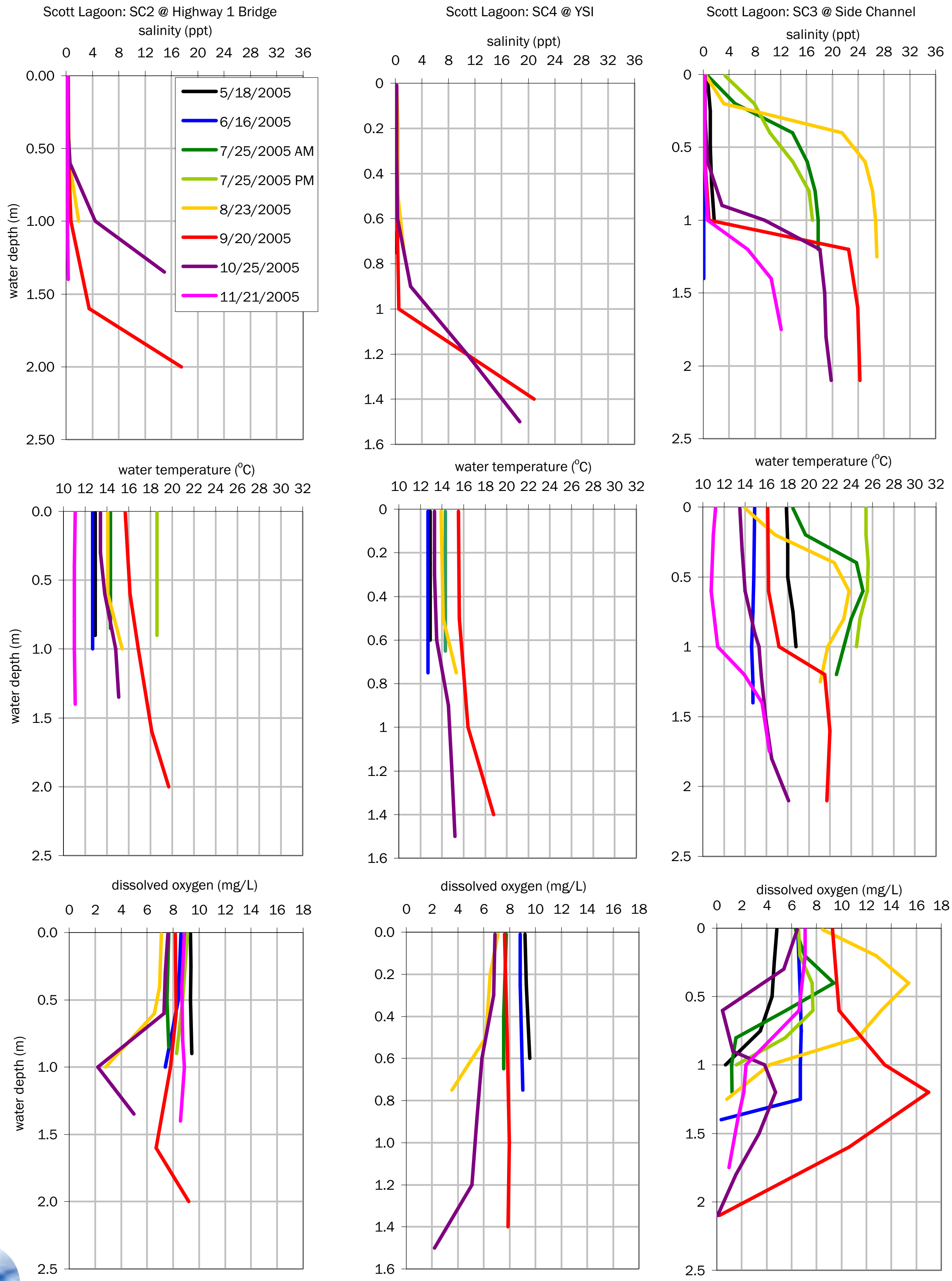


Time series vertical profile data for salinity, water temperature, and dissolved oxygen taken during lagoon sampling days. Unless otherwise noted, all data is from morning sampling.

2004 SCOTT LAGOON VERTICAL PROFILE DATA

FIGURE 11.42

2005 SCOTT CREEK LAGOON



Time series vertical profile data for salinity, water temperature, and dissolved oxygen taken during lagoon sampling days. Unless otherwise noted, all data is from morning sampling.

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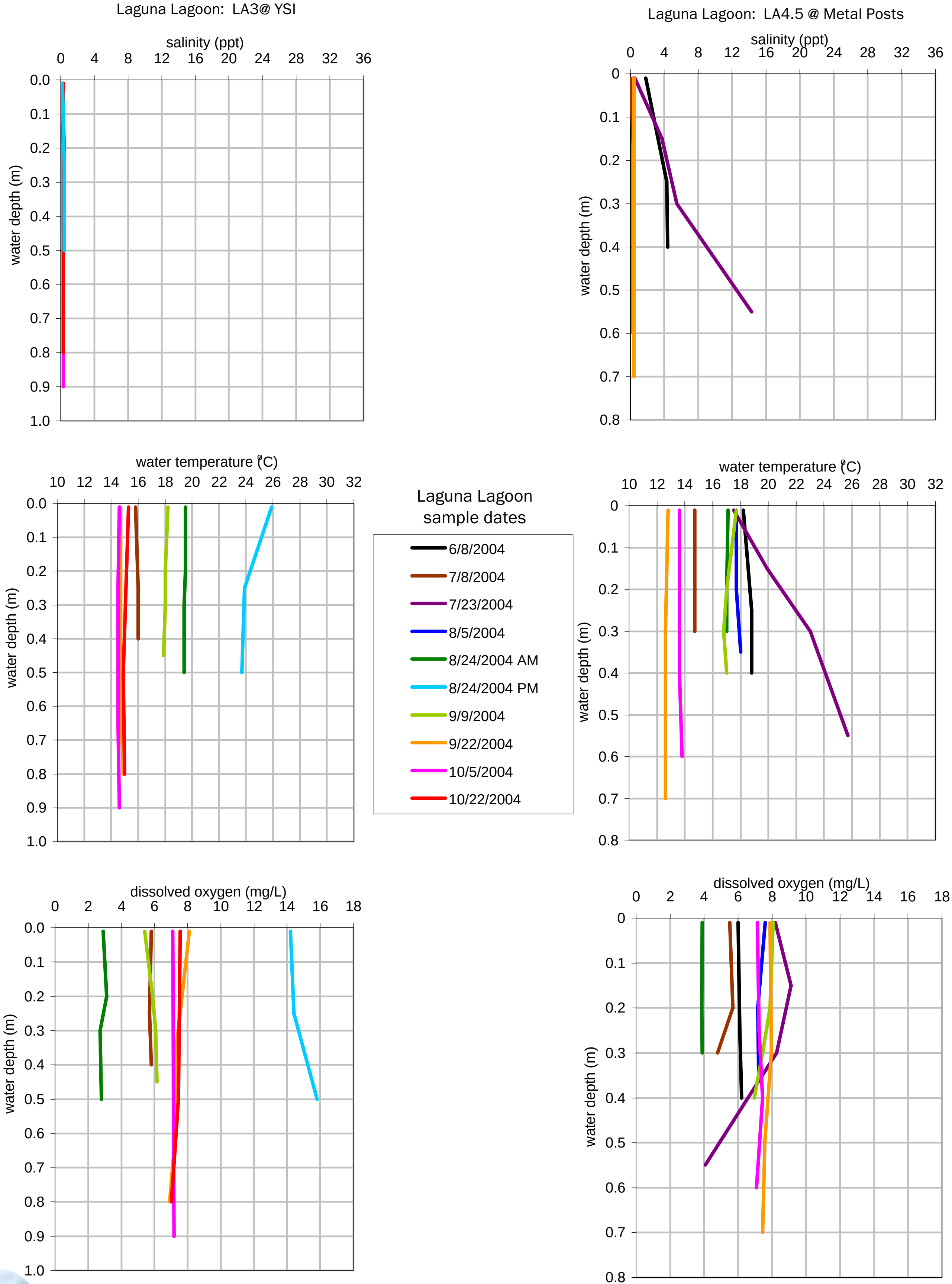
2005 SCOTT LAGOON VERTICAL PROFILE DATA

FIGURE 11.43

2004 LAGUNA CREEK LAGOON



Time series vertical profile data for salinity, water temperature, and dissolved oxygen taken during lagoon sampling days. Unless otherwise noted, all data is from morning sampling.

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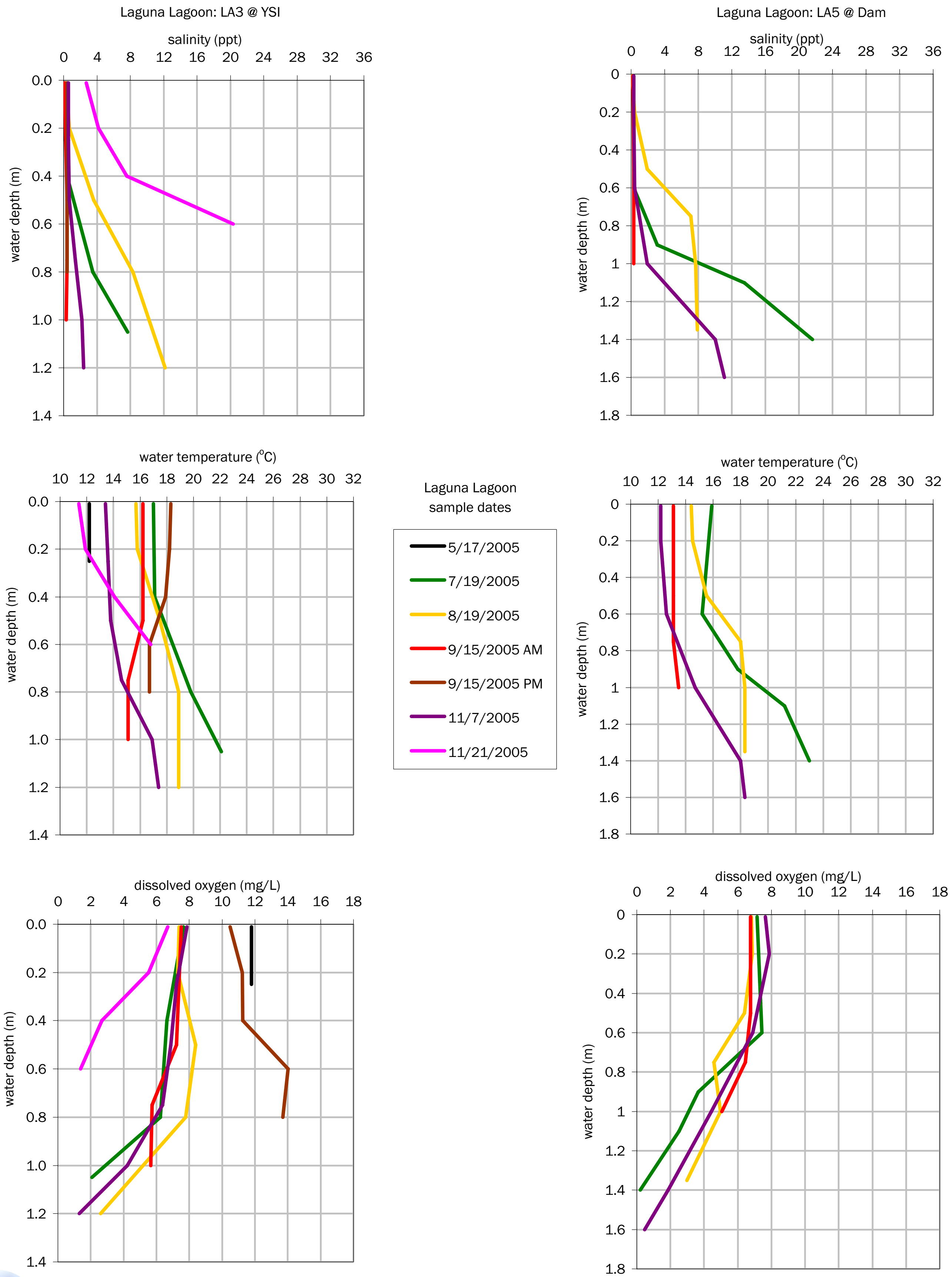
2004 LAGUNA LAGOON VERTICAL PROFILE DATA

FIGURE 11.44

2005 LAGUNA CREEK LAGOON



Time series vertical profile data for salinity, water temperature, and dissolved oxygen taken during lagoon sampling days. Unless otherwise noted, all data is from morning sampling.

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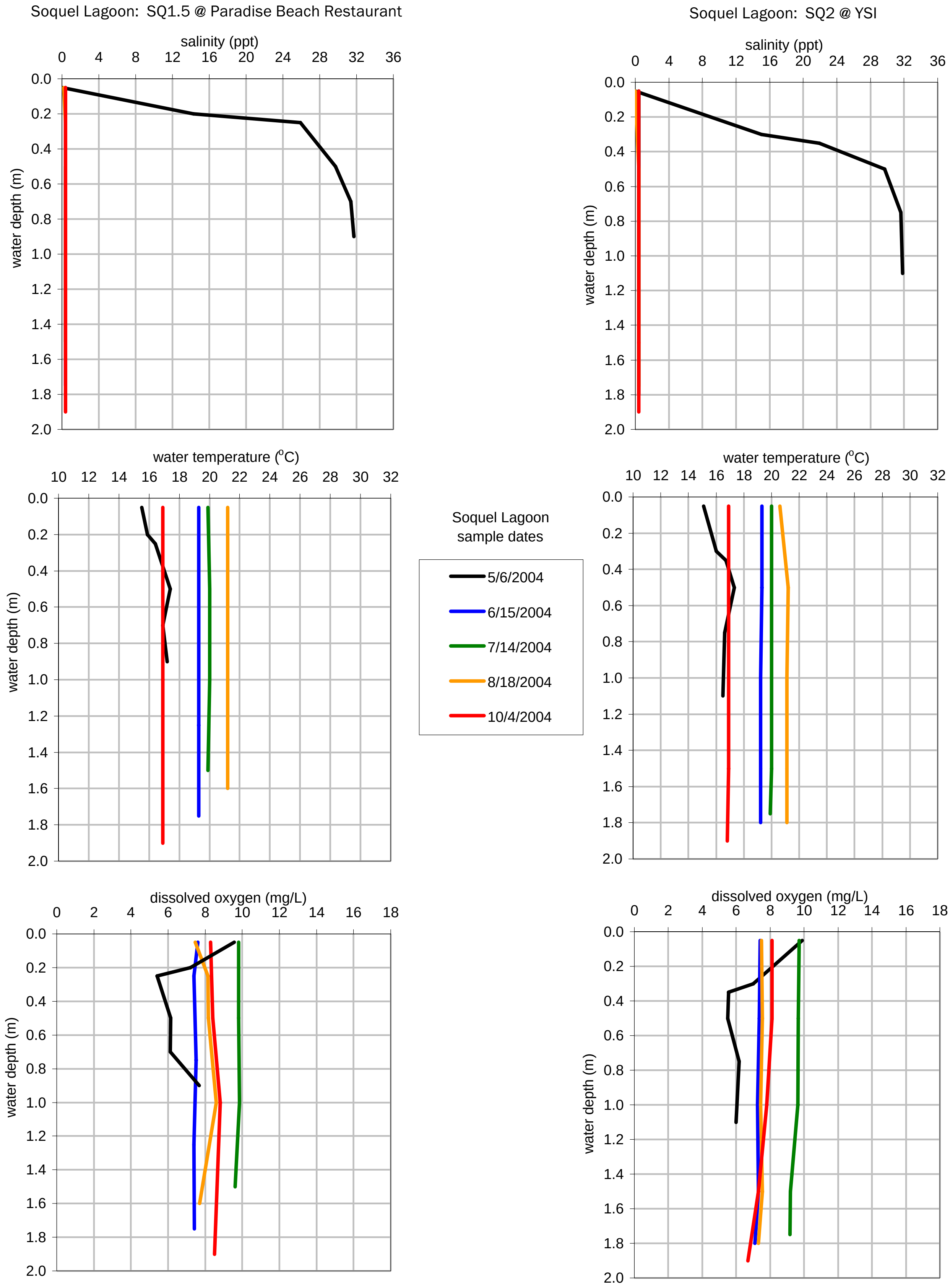
2005 LAGUNA LAGOON VERTICAL PROFILE DATA

FIGURE 11.45

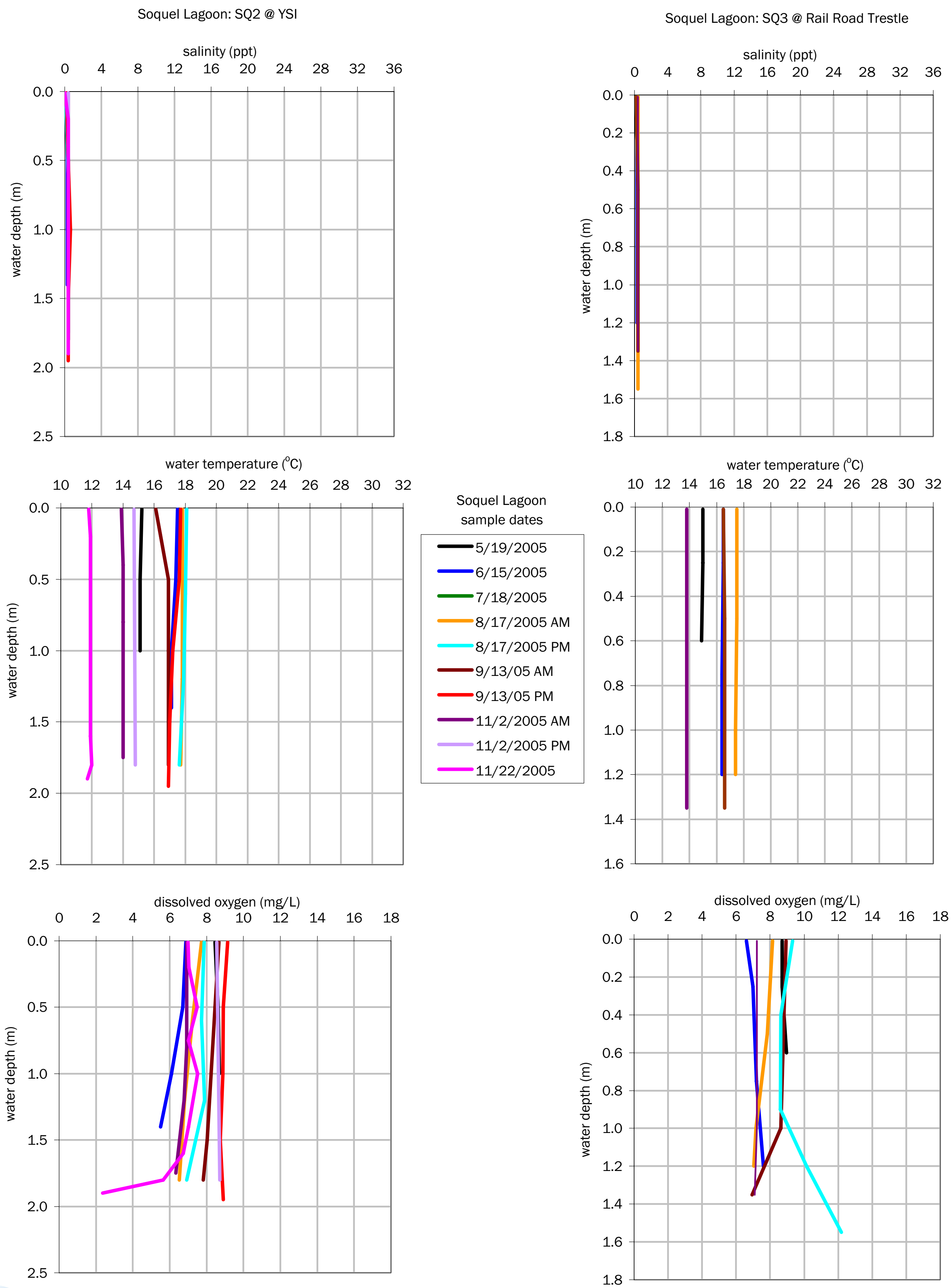
2004 SOQUEL CREEK LAGOON



Time series vertical profile data for salinity, water temperature, and dissolved oxygen taken during lagoon sampling days. Unless otherwise noted, all data is from morning sampling.

2004 SOQUEL LAGOON VERTICAL PROFILE DATA FIGURE 11.46

2005 SOQUEL CREEK LAGOON

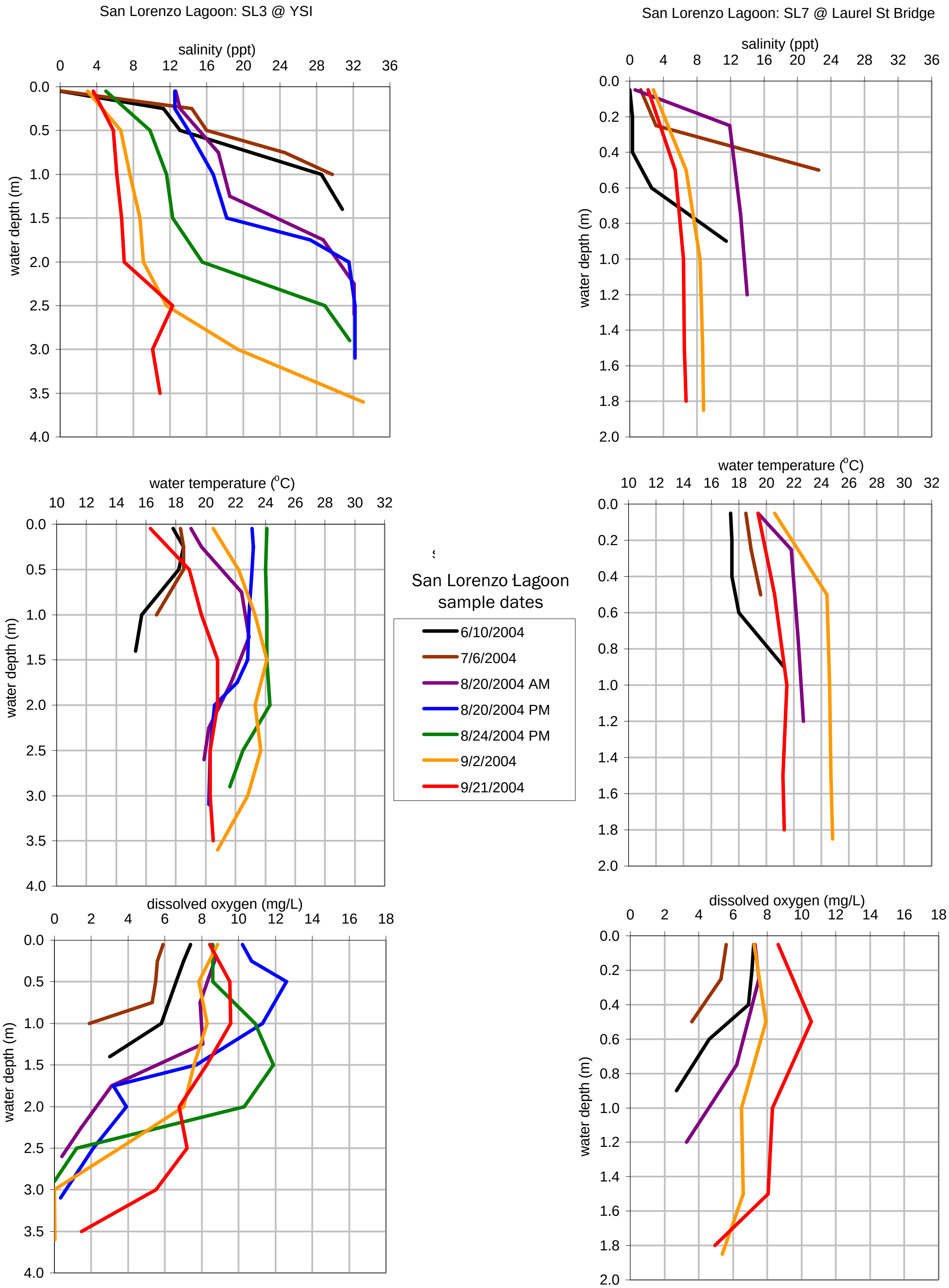


Time series vertical profile data for salinity, water temperature, and dissolved oxygen taken during lagoon sampling days. Unless otherwise noted, all data is from morning sampling.

2005 SOQUEL LAGOON VERTICAL PROFILE DATA

FIGURE 11.47

2004 SAN LORENZO RIVER LAGOON

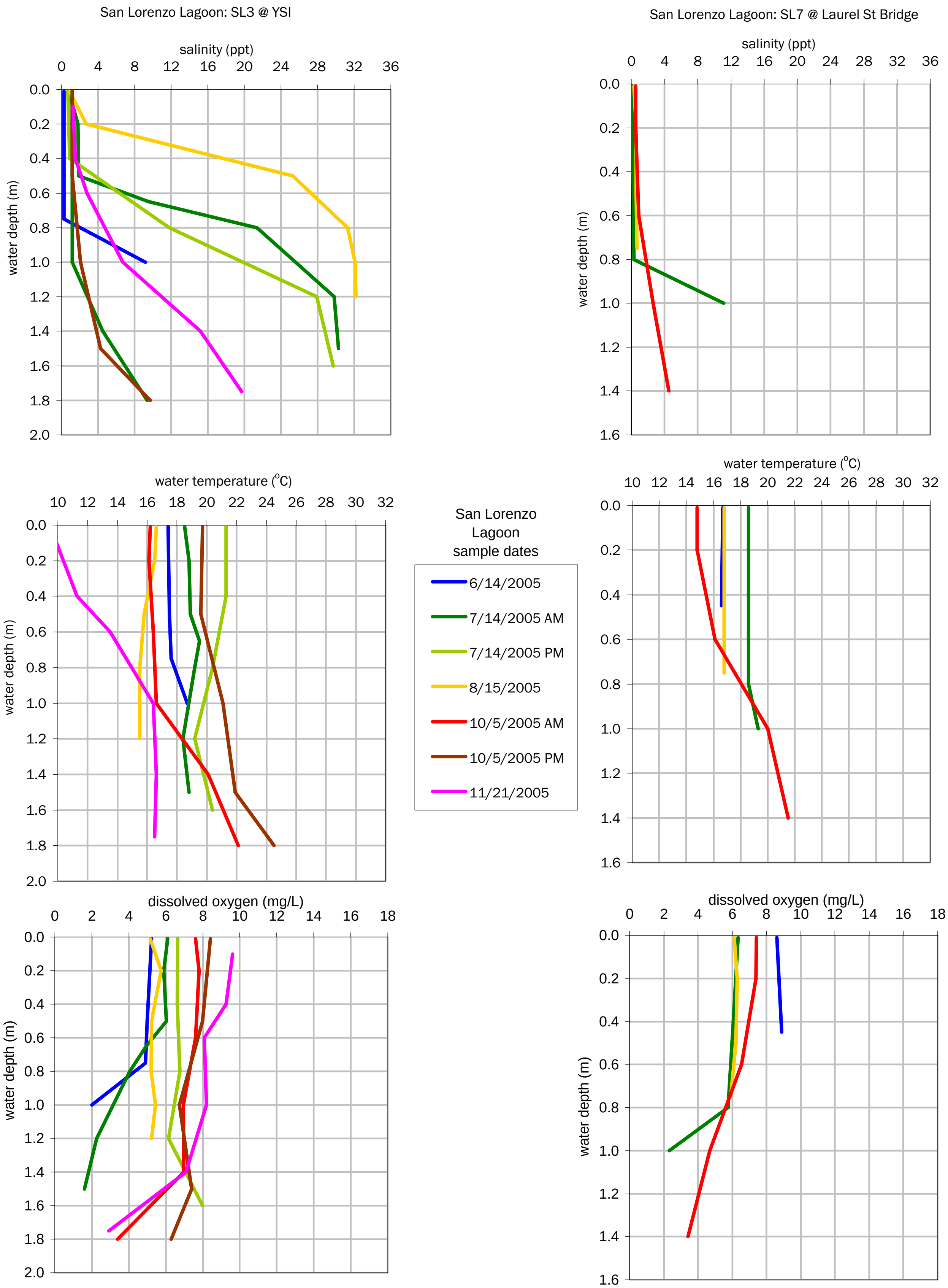


Time series vertical profile data for salinity, water temperature, and dissolved oxygen taken during lagoon sampling days. Unless otherwise noted, all data is from morning sampling.

2004 SAN LORENZO LAGOON VERTICAL PROFILE DATA

FIGURE 11.48

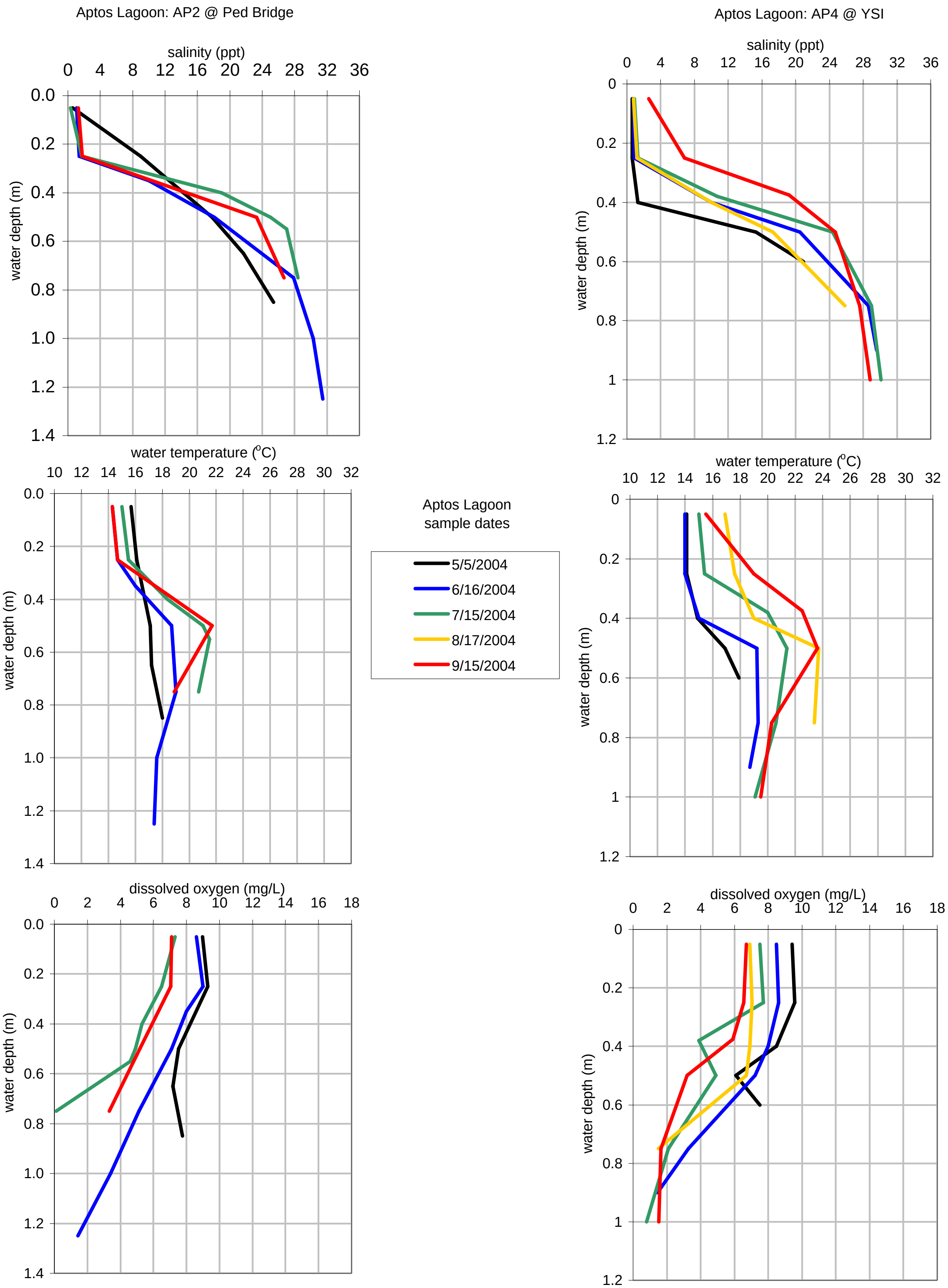
2005 SAN LORENZO RIVER LAGOON



Time series vertical profile data for salinity, water temperature, and dissolved oxygen taken during lagoon sampling days. Unless otherwise noted, all data is from morning sampling.

2005 SAN LORENZO LAGOON VERTICAL PROFILE DATA FIGURE 11.49

2004 APTOS CREEK LAGOON

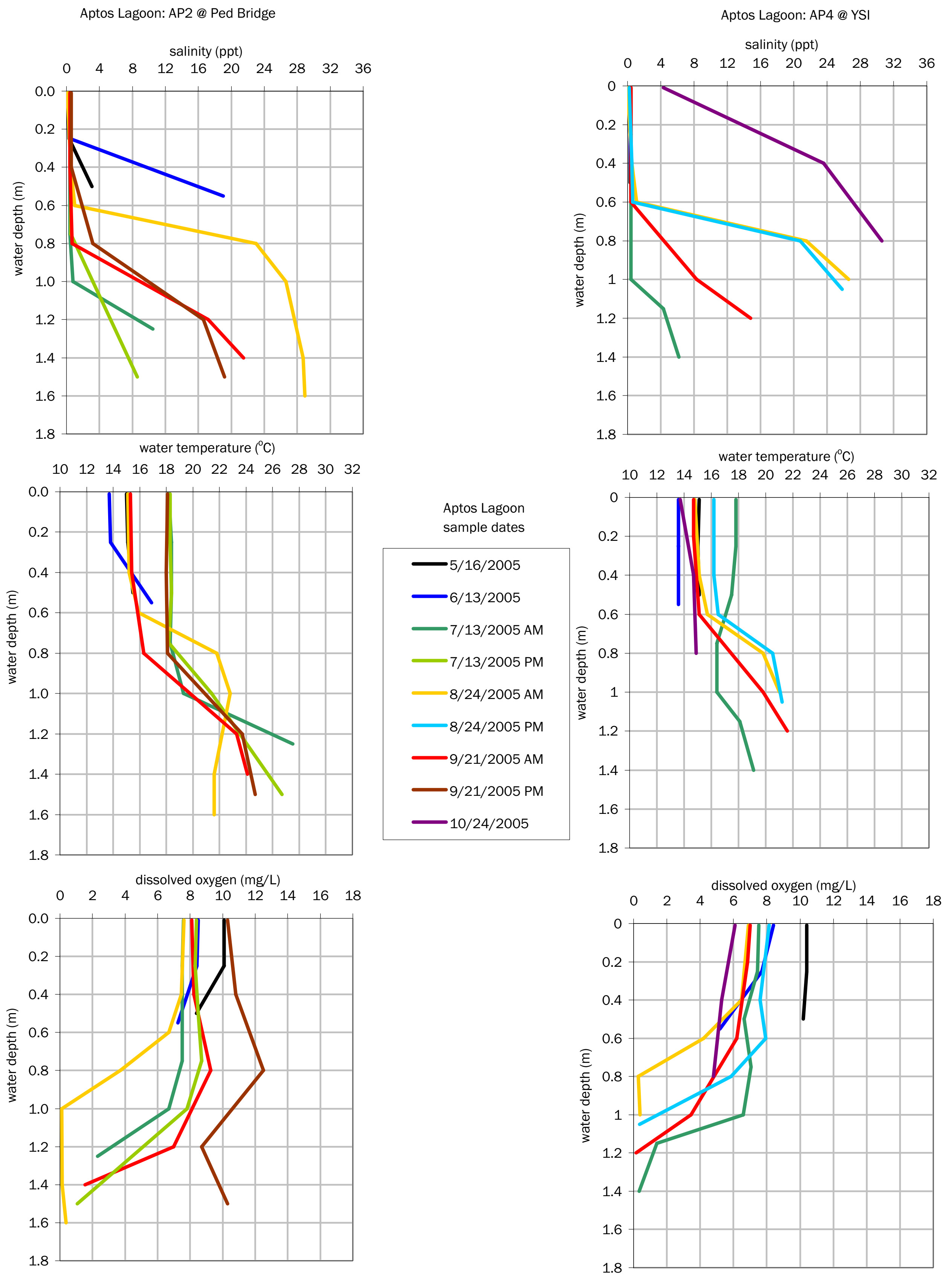


Time series vertical profile data for salinity, water temperature, and dissolved oxygen taken during lagoon sampling days. Unless otherwise noted, all data is from morning sampling.

2004 APTOS LAGOON VERTICAL PROFILE DATA

FIGURE 11.50

2005 APTOS CREEK LAGOON



Time series vertical profile data for salinity, water temperature, and dissolved oxygen taken during lagoon sampling days. Unless otherwise noted, all data is from morning sampling.

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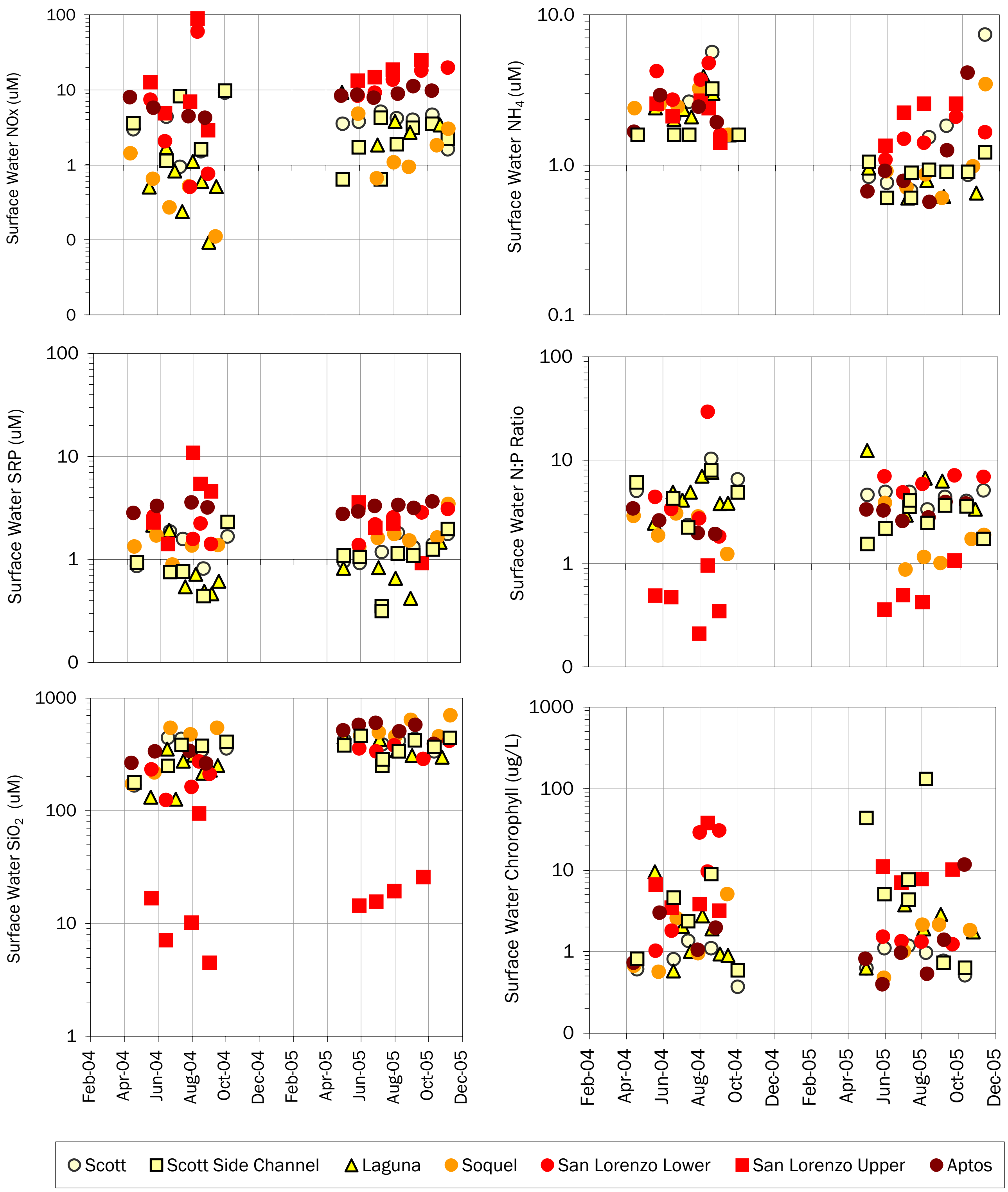
2005 APTOS LAGOON VERTICAL PROFILE DATA

FIGURE 11.51

Lagoon **Surface Water** Station Averages for each LSD



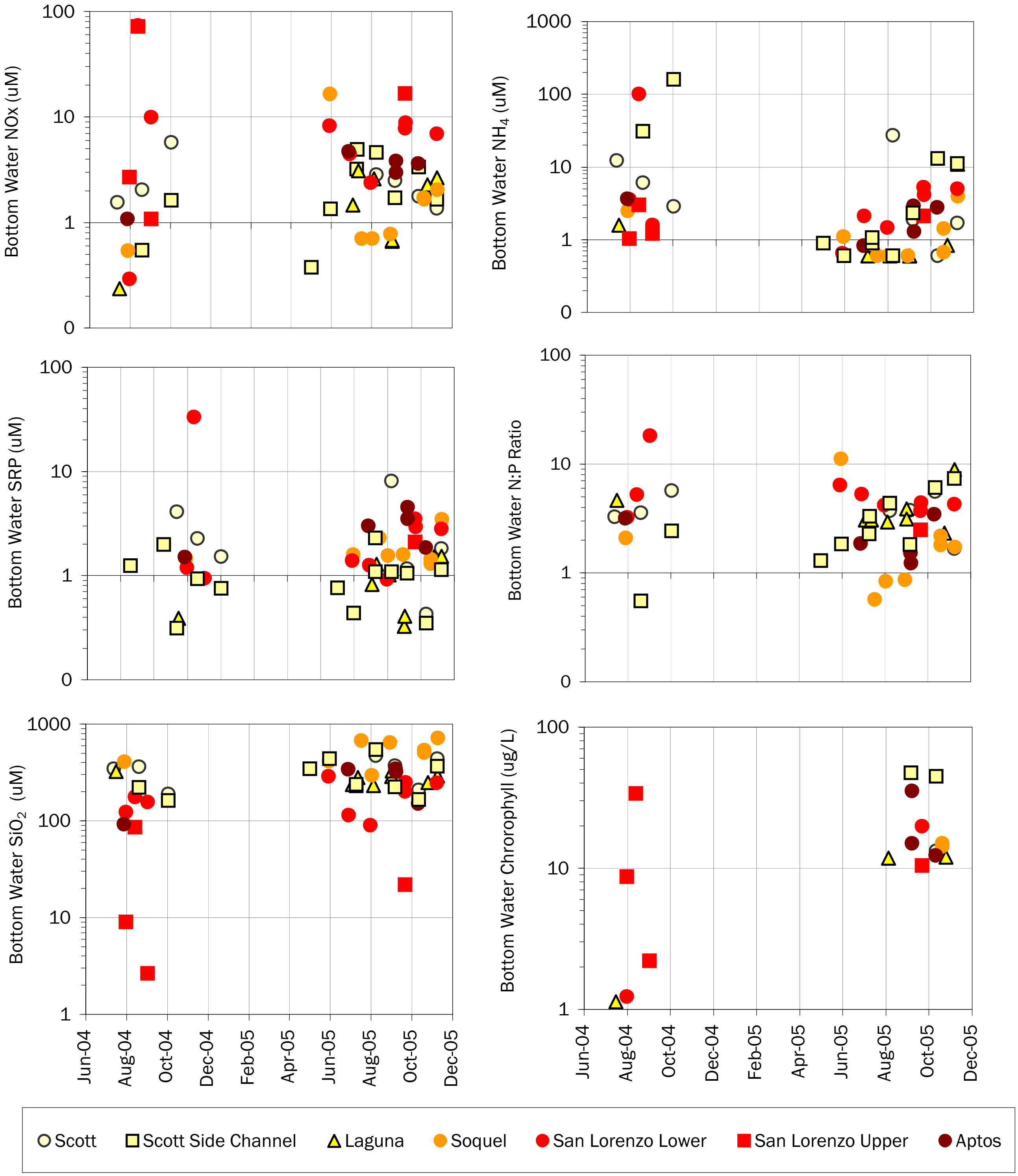
1 uM NOx/NH$_4^+$ = 14 ug/L

1 uM SRP = 31 ug/L

1 uM Si = 28 ug/L

SURFACE WATER NUTRIENT AVERAGE CONCENTRATIONS FIGURE 11.52

Lagoon **Bottom Water** Station Averages for each LSD



1 uM NOx/NH$_4^+$ = 14 ug/L
1 uM SRP = 31 ug/L
1 uM Si = 28 ug/L

12. Biological Communities

With the exception of fisheries monitoring, little detailed ecological work has been conducted in Central California coastal lagoons. The following section discusses the primary community dynamics observed during CLEAP and the role we suspect key species, or other components of the ecosystem, play in indicating lagoon health. The results of the metric testing are combined with lagoon-specific biological observations to discuss each trophic structure investigated.

PRIMARY PRODUCER COMMUNITY

The key primary producer components investigated on behalf of CLEAP are the seasonal composition and abundance of phytoplankton, macroalgae and submerged aquatic vegetation (SAV) communities. The most detailed evaluations focused upon the phytoplankton community dynamics in these lagoons. Visual estimates of % cover at each lagoon station and general identification of the macroalgae and submerged aquatic vegetation present during each LSD were documented. Both the qualitative and quantitative data collection on primary producer communities in the CLEAP lagoons demonstrates that these sites do represent a range of conditions. Stressor and indicator testing indicated a strong relationship between nine of the 28 primary producer metrics and the priority lagoon stressors, suggesting the relative dominance and species distribution of the primary producer community are promising biological indicators of Coastal California lagoon health.

Chlorophyll data provides a measure of the relative density of fast-growing primary producers. The relative magnitude of surface water chlorophyll levels was monitored by the continuous optic florescence probes (YSI 6000MS) deployed in each lagoon (except Scott Lagoon). We are hesitant to rely on the absolute chlorophyll readings from the YSI data because of the extreme variations in consecutive independent readings and inconsistency in chlorophyll monitoring across all sites. Additionally, the heterogeneous distribution of macroalgae mats can skew individual spot measurements. Regardless, the 12-hr running average chlorophyll patterns identify specific algal and/or phytoplankton blooms within the lagoons. We qualify a bloom when the 12-hr running average exceeded 15ug/L. Significant chlorophyll blooms were observed on one occasion in Laguna 2005 and Soquel 2005 (Figures 11.35 and 11.37). Chlorophyll blooms in San Lorenzo and Aptos Lagoons during the summer and fall were relatively common during both years (Figures 11.38-41).

Each LSD included surface water chlorophyll sampling at all lagoon stations in the morning and at one station 6-8 hrs later. The morning LSD surface water chlorophyll sampling indicated average lagoon concentrations below 10ug/L in most lagoons, with the San Lorenzo Lagoon and Scott Side Channel being the exceptions (Figure 11.52). The relatively nutrient-enriched lagoons (San Lorenzo and Aptos Lagoon) displayed marked diel chlorophyll level differences during July and August observations. These daily variations were rarely observed in the lagoons with low to moderate DIN loading (Scott Main Channel, Laguna, Soquel). Periodic bottom water samples from the lagoons were analyzed for chlorophyll and these values typically exceeded surface water concentrations. In locations where the lagoon waters are relatively shallow and clear, sufficient light is available at the sediment water interface to allow benthic algal production. In general, the water clarity, as measured by secchi depth, declined in the more impacted lagoons of San Lorenzo and Aptos, as well as Scott Side Channel (Figures 12.1-2). In most instances, poor clarity was coincident with elevated phytoplankton biovolume (Figures 12.1-2, 12.4, 12.6), suggesting water clarity impairments are the result of increased biological matter in the water column and not inorganic particle suspension. However, the results of the metric testing suggest the absolute magnitude and daily differences of chlorophyll in the water column, measured either by the automated sensors or grab sampling, were not the most powerful indicators of biological health.

Metrics that express the dominant primary producer in the system, as measured by % SAV distribution (PP19) or % macrophyte cover (PP20), showed strong correlations to lagoon nutrient loading variations. The dominant primary producer community varied across the years of observations in a couple of lagoons. For instance, a prominent SAV Potamogeton community was well established in Laguna Lagoon during 2004 with minimal macroalgal observations. In 2005 a SAV community was absent and a significant Ulva macroalgal bloom occurred in mid-September (Figures 11.35, 12.1-2). The direct cause for this shift is unknown. One notable difference is that DIN concentrations and loads in Laguna Creek in 2005 were nearly double the loading and inflow concentrations observed in 2004. The relative availability of DIN may have had an influence on the ability of SAV to establish in Laguna Lagoon in 2005. Observations of inter-annual shifts in the presence of SAV also occurred at Soquel Lagoon; 2003 and 2004 were characterized by an SAV community that occupied nearly 50% of the lagoon, yet less than 10% coverage of SAV was observed in 2005 (Figures 12.1-2). San Lorenzo and Aptos Lagoons were consistently dominated by phytoplankton and macroalgal blooms. SAV species were never observed in either of these lagoons over the course of CLEAP monitoring.

The dominant primary producer community metrics showed a number of strong correlations to the lagoon water quality. Though the observations in CLEAP lagoons are limited, existing data and research suggests the presence of a moderate SAV community may improve the habitat quality of a coastal lagoon for the juvenile populations of the anadromous fish species. A diverse primary producer community that includes the moderate cover of SAV could provide a number of physical and chemical benefits. SAV grows relatively slowly, which reduces rate of organic matter delivery to the sediments as well as reducing nitrogen cycling rates by fixing nutrients for a longer time-period. When in moderate densities, the SAV will provide shade, cover to limit predation and a substrate for zooplankton, invertebrates and fish to forage. Enhancement approaches may consider the cultivation of SAV communities in the urban lagoons, though caution must be taken to avoid the transition of one monoculture of phytoplankton to a dense SAV community, potentially creating new impairments to a lagoon system.

Macroalgae bloom (Ulva)
in Aptos Lagoon
July 2005

Phytoplankton bloom
in San Lorenzo Lagoon
Aug 2004

SAV (Potomogeton)
in Laguna Lagoon
Sept 2004

Phytoplankton Community Assemblage

The community composition, relative distribution of phytoplankton groups and species, and phytoplankton biovolume provide insight into the health of the lagoon's food chain base. All algal species have optimal growth conditions, requiring a certain range of temperatures, salinity conditions, nutrient regime, light levels, pH, and system stability. Thus, certain physical and chemical lagoon conditions are more optimal for some phytoplankton assemblages over others and the dynamic variability of lagoon circulation and water quality directly influences the variations observed in the composition of the base of the food chain. As a food source, the type, relative size and biovolume of available phytoplankton directly impact the grazers who eat them. A stable primary producer phytoplankton community will be relatively diverse and consist of a large number of species, as supported by the success of the primary producer metrics that expressed phytoplankton group and species diversity. A simplified community structure indicates dominance by opportunistic organisms, limiting the energy transfer potential to higher organisms.

The distribution of the primary 7 phytoplankton groups observed in the CLEAP lagoons is presented in Figures 12.3 and 12.5. Figures 12.4 and 12.6 provide the total sample biovolume and Simpson Index of Diversity values based on phytoplankton group distribution. Metrics expressing phytoplankton species diversity and relative community dominance (PP5, PP8, PP9) appear to be strong indicators of lagoon stability, statistically correlating to nutrient, stratification, and water quality stressors (Table 10.4). Nearly every lagoon displayed a seasonal variation in the primary phytoplankton group, with the exception of San Lorenzo Lagoon, which remained dominated by diatom species throughout the 2005 sampling efforts. Within these groups, nearly 250 different phytoplankton species were identified in the CLEAP lagoon samples. Forty percent of the lagoon samples consisted of only one group composing over 90% of the phytoplankton community biovolume. This single phytoplankton group dominance and community simplification was more common in samples collected from the more impacted San Lorenzo and Aptos Lagoons.

Diatoms are the most persistent and common phytoplankton species in the lagoons, with 137 different species identified, though some species were more common than others. The number of diatom species (PP24) showed statistically significant relationships to lagoon ammonia variations (NU8, NU9) and silica concentrations (NU11). A characteristic feature of diatom cells is that they are encased within a unique silica cell wall, thus the correlation with Si availability is not surprising. The second and third most common species were chlorophytes and dinoflagellates with 60 and 16 different species, respectively. Nuisance phytoplankton blooms in estuarine environments are typically dominated by cyanobacteria and dinoflagellate species (Paerl 1988). Late summer 2004 conditions in San Lorenzo and Aptos were characterized by dinoflagellate blooms. Dinoflagellates were also found to dominate Scott Lagoon in early 2004 samplings, but 20% of those samples were waters collected from the Scott Side Channel (SC3) prior to separate analysis of station SC3.

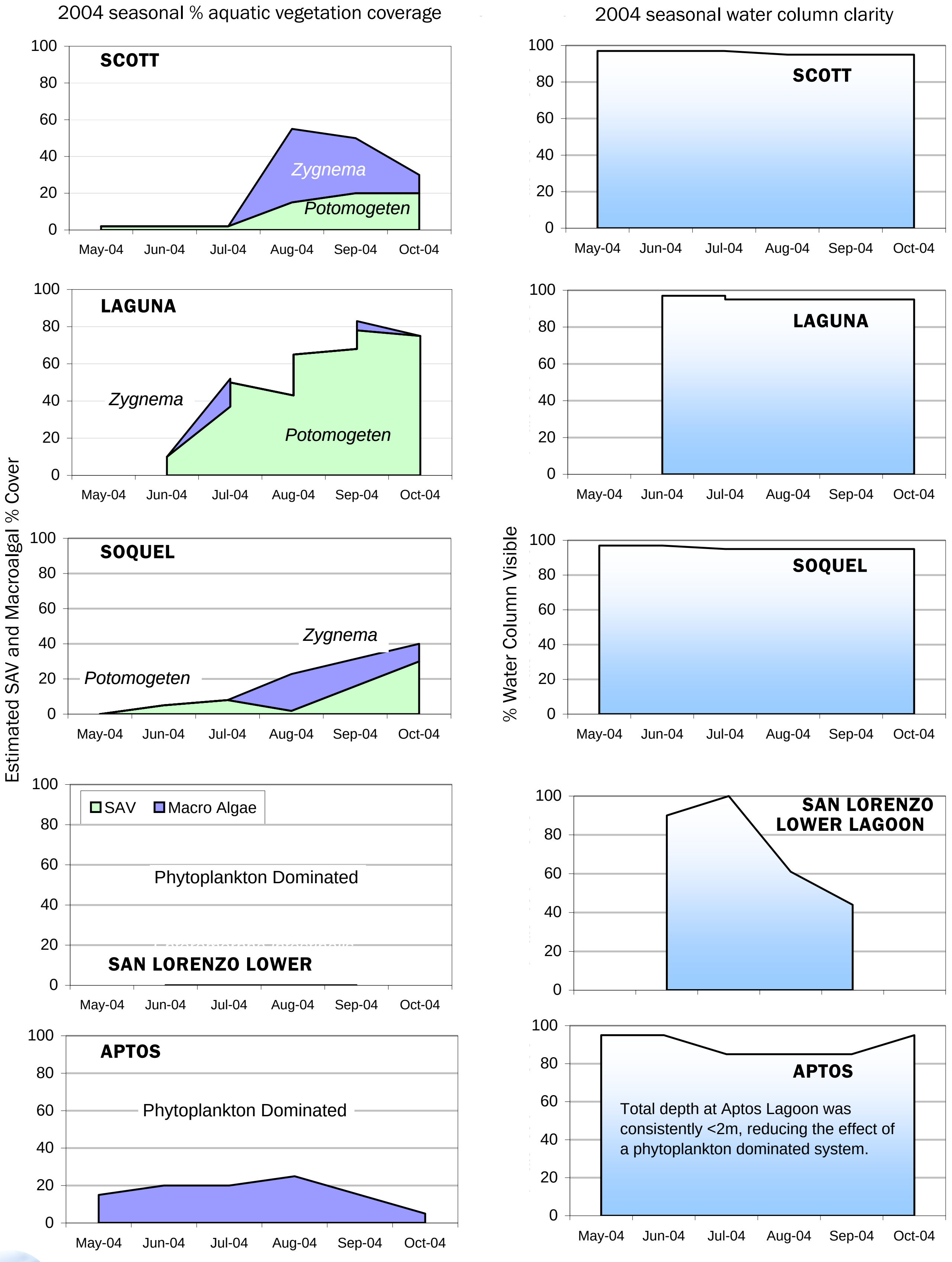
The most common phytoplankton species in the CLEAP lagoons based on total cell abundance were *Merismopedia warmingiana* (Cyanophyte), *Cryptomonas sp* (Cryptomonad), and *Planophila laetevirens* (Chlorophyte) (Table 12.1). The most common species in the lagoons based on biovolume were *Cryptomonas sp* (Cryptomonad), *Cystodinium sp.* (Dinoflagellate), and *Cryptomonas marssonii* (Cryptomonad). Cryptomonads are typically a good food source for zooplankton communities due to the relatively elevated fatty acid content of this phytoplankton (Ahlegren et al 1992). Chrysophytes are regarded as a poor food source since these species are typically opportunistic and can dominate the phytoplankton community when available nutrient levels are low. They have previously been deemed good biological indicators in lake food chain stability (Siver 1955). In fact, the number of chrysophyte species in a lagoon (PP26) showed a direct relationship to lagoon water quality (Table 10.4).

Table 12.1. Top 10 most common phytoplankton species observed in CLEAP Lagoons by total cell abundance and total biovolume.

Rank	Most abundant by total cells			Most abundant by total cell biovolume		
	Species	Group	cells/L	Species	Group	um^3/L
1	*Merismopedia warmingiana*	Cyanophyte	8.5E+07	*Cryptomonas sp.*	Cryptomonad	13455
2	*Cryptomonas sp.*	Cryptomonad	7.2E+07	*Cystodinium sp. (vegetative cell)*	Dinoflagellate	10333
3	*Planophila laetevirens*	Chlorophyte	5.1E+07	*Cryptomonas marssonii*	Cryptomonad	8469
4	*Cryptomonas marssonii*	Cryptomonad	1.8E+07	*Spirogyra sp.*	Chlorophyte	8296
5	*Rhodomonas minuta*	Cryptomonad	1.4E+07	*Glenodinium edax*	Dinoflagellate	6258
6	*Hyaloraphidium contortum*	Chlorophyte	8.7E+06	*Stephanodiscus hantzschii*	Diatoms	5673
7	*Cystodinium sp.*	Dinoflagellate	5.8E+06	*Planophila laetevirens*	Chlorophyte	3316
8	*Flagellates (<5um)*	Chrysophyte	5.4E+06	*Astasia dangeardii*	Euglenophyte	2719
9	*Achnanthes microcephala*	Diatom	4.0E+06	***Gymnodinium fuscum***	**Dinoflagellate**	**2446**
10	*Astasia dangeardii*	Euglenophyte	4.0E+06	*Ceratium hirundinella*	Dinoflagellate	2168

A selection of Chrysophytes and Dinoflagellate species can survive where others cannot, sometimes supplementing photosynthesis with the consumption of bacteria. Significant blooms of the Dinoflagellate species, *Gymnodium fuscum* (bolded in Table 12.1), were observed in the Scott Side Channel, San Lorenzo Lagoon and Aptos Lagoon. *Gymnodium* species have been associated with toxic red tides in the Gulf of Mexico and English Channel, producing neurotoxins (Paerl 1988).

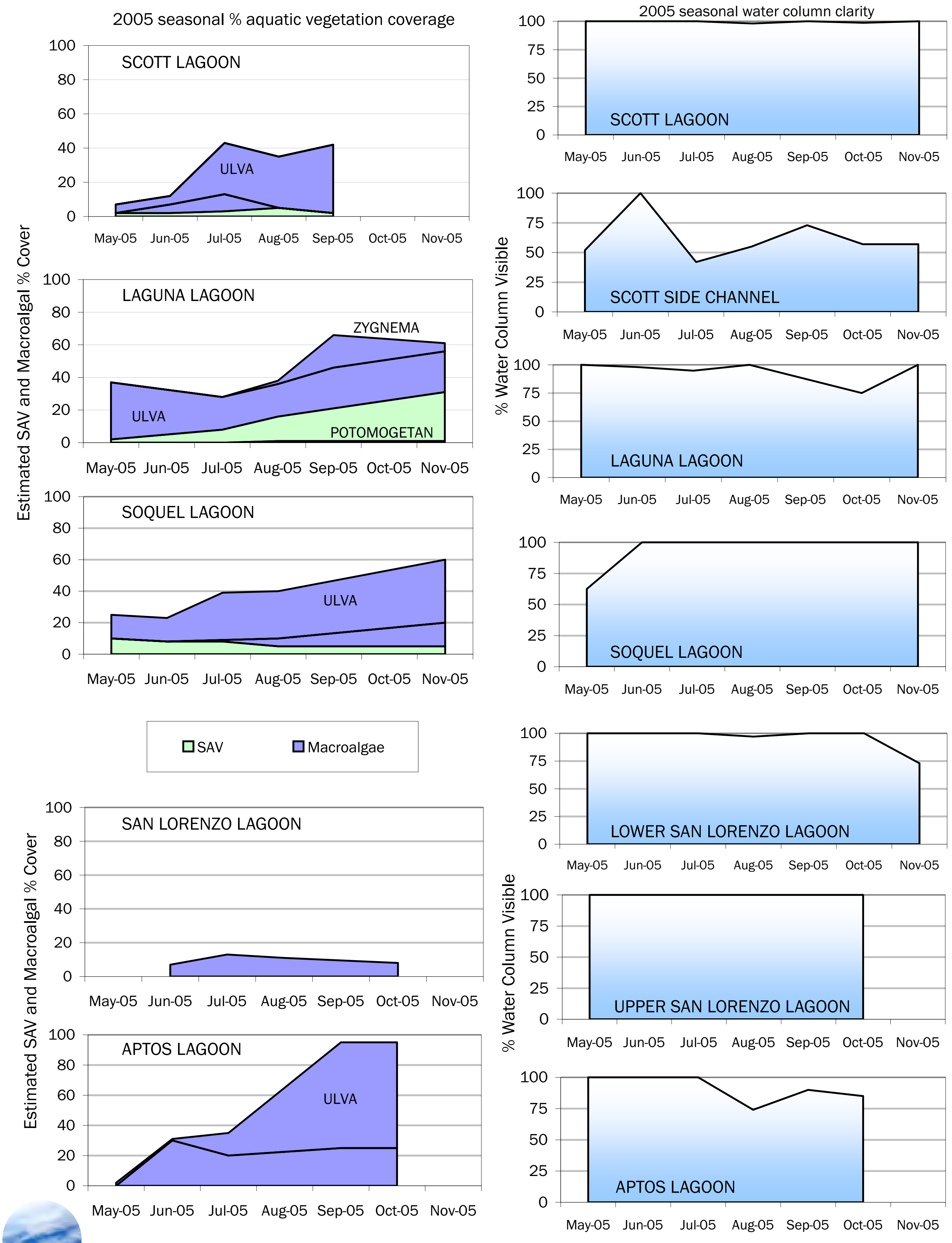
The biovolume and relative species diversity patterns are different between the lagoons with lower DIN and higher DIN availability (Figures 12.4 and 12.6). Seasonal peaks in primary production biovolume in Scott Main Channel, Laguna and Soquel are coincident with species diversity values of 0.5 or greater in nearly every instance of a bloom. In contrast Scott Side Channel, Aptos and San Lorenzo are more susceptible to eutrophication and phytoplankton blooms correspond to diversity values below 0.2 in all but one occasion, suggesting a greater tendency of blooms to consist of a few opportunistic species dominating the phytoplankton community. Reminder that Simpson's Index of Diversity values range from 0-1 with increasing values representing increasing diversity (both number of species and abundance evenness).



% water column visible determined using secchi disk measurements at each lagoon.

2004 SAV PERCENT COVER AND WATER COLUMN VISIBILITY

FIGURE 12.1



% water column visible determined using secchi disk measurements at each lagoon.

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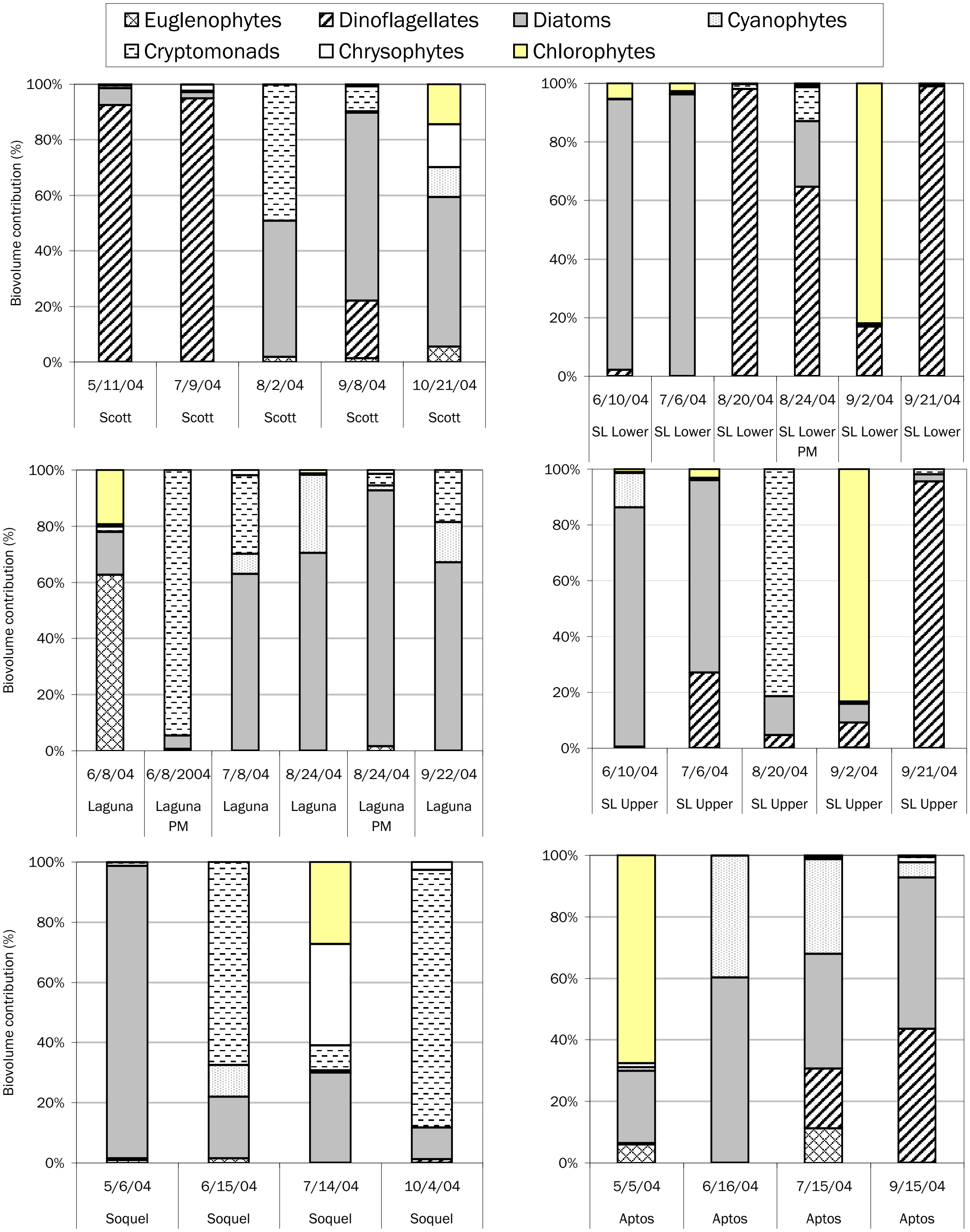
2005 SAV PERCENT COVER AND WATER COLUMN VISIBILITY

FIGURE 12.2

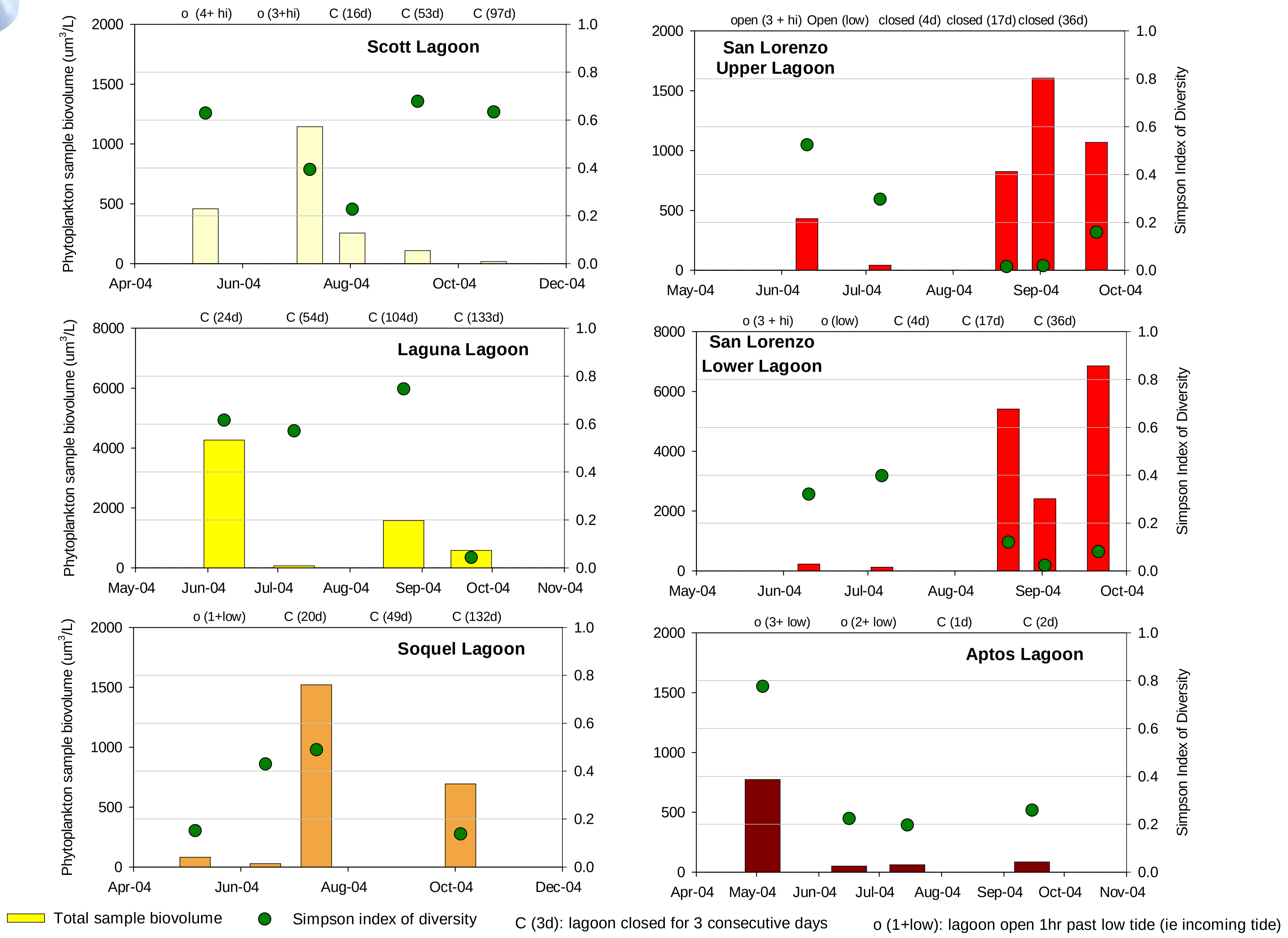


% biovolume contribution of phytoplankton species per sample (um^3/L).

2004 PHYTOPLANKTON COMMUNITIES

FIGURE 12.3

The physical condition of lagoon and the days since closure or the tidal conditions (if open) are provided for each sampling point. The Simpson Index of Diversity is calculated based on the cell abundance of phytoplankton species groups found in Figure 12.3 and as defined by the indicator metric, PP8.



Note the changes in scale for phytoplankton sample biovolume.

2004 PHYTOPLANKTON SAMPLE BIOVOLUME AND SIMPSON INDEX OF DIVERSITY

FIGURE 12.4

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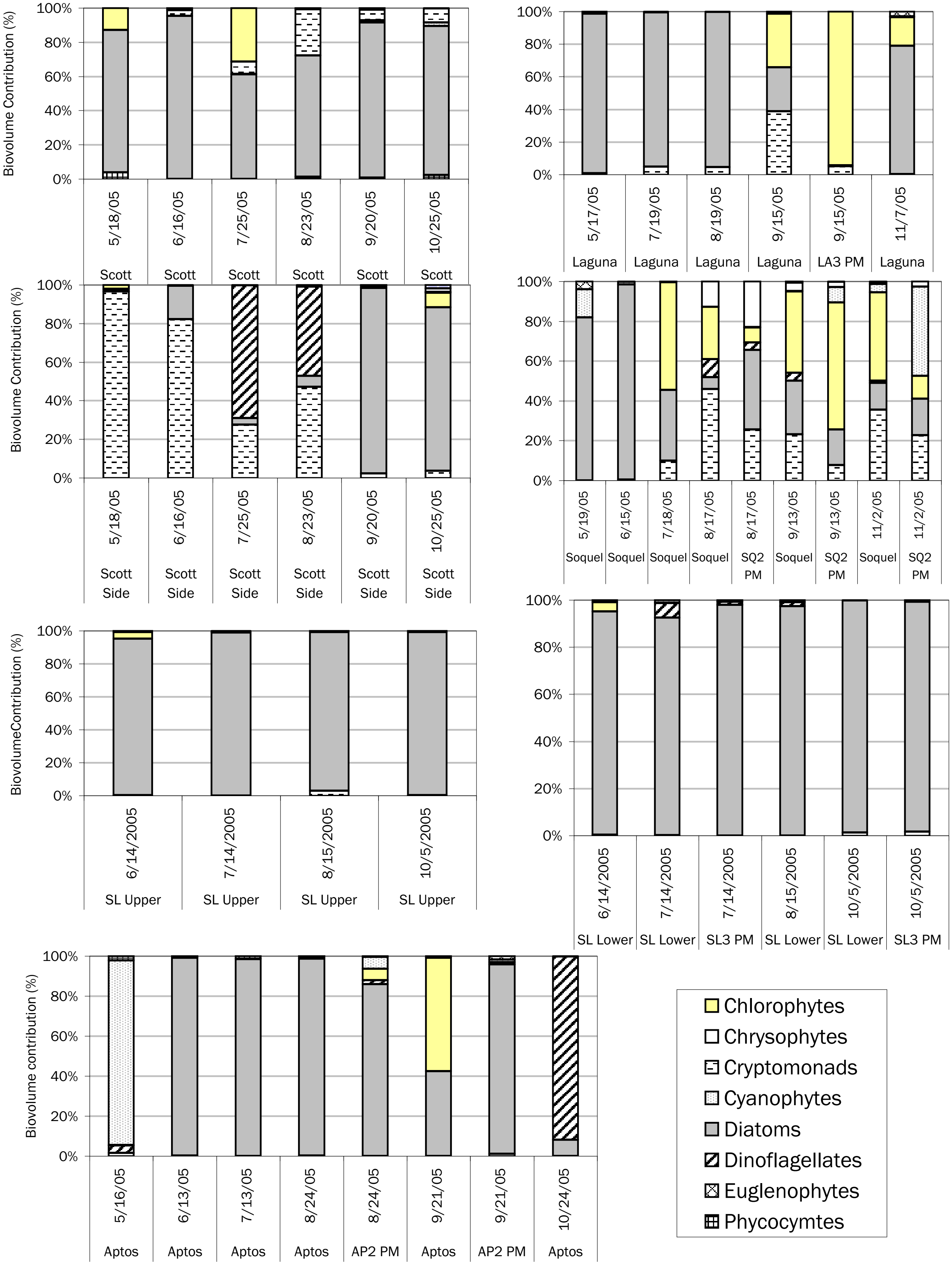
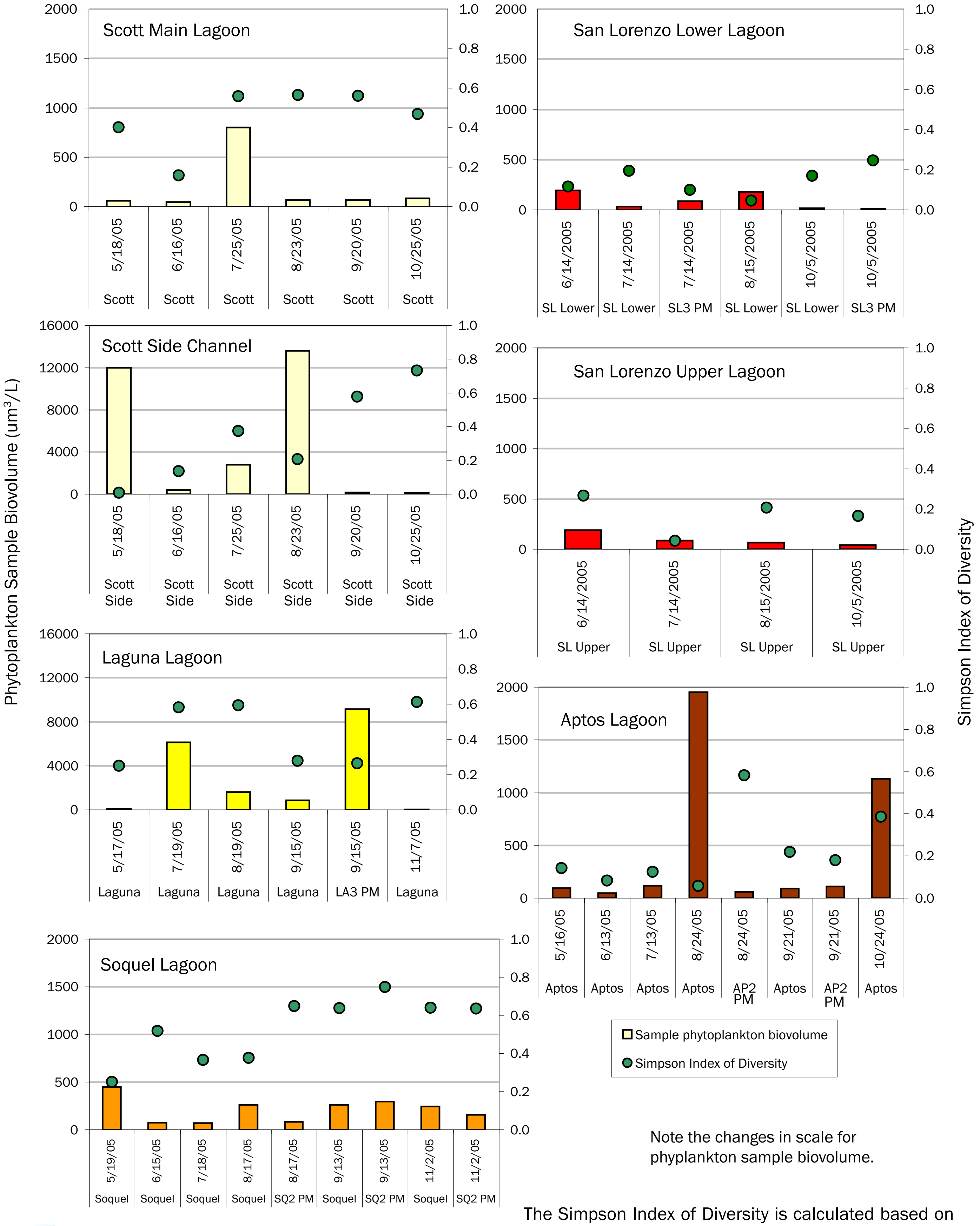


% biovolume contribution of phytoplankton species per sample (um^3/L).

2005 PHYTOPLANKTON COMMUNITIES

FIGURE 12.5



Note the changes in scale for phyplankton sample biovolume.

The Simpson Index of Diversity is calculated based on the cell abundance of phytoplankton species groups found in Figure 12.5 and as defined by the indicator metric, PP8.

2005 PHYTOPLANKTON SAMPLE BIOVOLUME AND SIMPSON INDEX OF DIVERSITY

FIGURE 12.6

ZOOPLANKTON COMMUNITY

As described in Section 5, zooplankton's link to both primary producers and organisms higher in the food chain makes it difficult, without careful examination, to extract a complete picture of which dynamics are influencing the zooplankton community. The CLEAP efforts were less focused on the specific controls influencing zooplankton populations and more focused on using zooplankton community observations to determine if primary consumers are strong biological indicators of lagoon health. Because the zooplankton community is capable of responding to changes within the environment on the order of weeks to months, if a lagoon experiences changes in the physical or chemical environment, then the zooplankton community is expected to respond. In CLEAP lagoons, the primary changes are associated with circulation regime and climatic variations. Therefore, we review the observations in each lagoon to identify potential patterns within the zooplankton data available.

Zooplankton consume autotrophs (i.e. phytoplankton) and are consumed by other heterotrophs. While autotrophic organisms rely on sunlight for energy, heterotrophs feed on other organisms to survive. Just as autotrophs cannot absorb 100% of the light the sun transmits, consumers cannot use 100% of the energy from their prey for their basic metabolic functions (for example, energy is diverted to waste, stored for reproduction, and used for metabolic processes). Typically, between 10 to 20% of the energy associated with one trophic level is transferred to the next trophic level and generally consumers feed on organisms about a tenth of their size (Barnes and Mann, 1991). By examining the size distribution of the zooplankton biomass, we may begin to understand the energy transfer dynamics between zooplankton and the higher trophic levels. If significant zooplankton biomass is measured in an ecosystem, but a majority of the zooplankton biomass is locked up in the smallest metazoan, a lot of energy will be lost by the consumer eating a large number of small organisms. Therefore, it is assumed that very small-sized zooplankton communities will limit the transfer of food energy to grazers in a lagoon environment.

Zooplankton size dynamics, as well as population biomass, can play an important role in sustaining fish populations. First, fish must be able to see their prey. Fish larvae are approximately 5mm and likely feed on organisms one tenth of their size, or 0.5mm. Second, fish larvae require regular food intake during early critical stages once the yolk sac is depleted. Located in the same planktonic environment as fish larva, zooplankton may play a critical role in sustaining fish larvae populations in lagoons. If the zooplankton and fish populations are in balance, either fish will be forced to find alternative food sources (because there is not enough zooplankton) or insufficient grazing of the zooplankton population will lead to deleterious water quality conditions. Either extreme can lead to an inefficient system and poor lagoon health. Are the organisms grazed by fish and other larger organisms, or do they die and contribute to the organic detritus at the bottom of the lagoon? Given CLEAP observations, it is impossible to determine the fate of the zooplankton community present at the time of monthly samplings.

The CLEAP study looked at four main components of the zooplankton community: species distribution (Figures 12.7 and 12.10), sample zooplankton biomass, sample species diversity (Figures 12.8 and 12.11), and sample zooplankton cell size distribution (Figures 12.9 and 12.12). Community composition and diversity are assumed to be an indication of ecosystem health. Similar to other trophic structures, zooplankton blooms composed of a few opportunistic species (i.e. low diversity) would suggest an impaired system, potentially limiting the efficiency of energy transfer to higher organisms. A variety of potential biological indicators were developed based on the available dataset across lagoons. The metric testing resulted in 4 successful zooplankton biological indicators, including relative sample density of rotifers (ZOO2), total number of zooplankton taxa (ZOO3), species diversity (ZOO5), and sample dominance (ZOO6), correlating to water column stressors.

An element of the CLEAP project includes documenting zooplankton species for the first time in Central California coastal lagoons. An overview of the seasonal presence of zooplankton species in San Lorenzo, Laguna, Scott, Aptos and Soquel Lagoons are divided by year, season, and zooplankton species (Table 12.2).

Table 12.2. Seasonal presence of zooplankton species across lagoons. An '04' indicates species observed in lagoon in 2004 season, and '05' indicates presence in 2005 season, and 'X' indicates species observed during season for both years. Seasons are designated by MJJ: May, June, July, AS: August, September, and OND: October, November, December.

	SAN LORENZO			**LAGUNA**			**SCOTT**			**APTOS**			**SOQUEL**		
COPEPODS	**MJJ**	**AS**	**OND**	**MJJ**	**AS**	**OND**	**MJJ**	**AS**	**OND**	**MJJ**	**AS**	**OND**	**MJJ**	**AS**	**OND**
Eurytemora affinis	04	04	05	**X**	05	05	04	**X**	**X**	**X**	**X**		04		
Acanthocyclops vernalis					**X**			05					05	05	
Tisbe	**X**	04		**X**	05		**X**	**X**	05	**X**	05		04		**X**
Harpacticoids	**X**	04	05		**X**	05	**X**	**X**	**X**	05	05	05			05
Unknown Copepods		05			05			05	05			05		05	05
Diaptomus		05													
Oithonid Copepods		05													

	SAN LORENZO			**LAGUNA**			**SCOTT**			**APTOS**			**SOQUEL**		
CLADOCERANS	**MJJ**	**AS**	**OND**	**MJJ**	**AS**	**OND**	**MJJ**	**AS**	**OND**	**MJJ**	**AS**	**OND**	**MJJ**	**AS**	**OND**
Alona					05									05	
Chydorus															05

	SAN LORENZO			**LAGUNA**			**SCOTT**			**APTOS**			**SOQUEL**		
ROTIFERS	**MJJ**	**AS**	**OND**	**MJJ**	**AS**	**OND**	**MJJ**	**AS**	**OND**	**MJJ**	**AS**	**OND**	**MJJ**	**AS**	**OND**
Branchionus	04	04		05	**X**		05	05	**X**		05		05		05
Trichotria										**X**			05	05	05
Lepadella					05	05		04						05	05
Keratella				05											
Monostyla					04			04					05	05	04
Notholca					05	05			05						
Unknown	05			05	05		05	05	05			05	05	05	
Polyarthra															04
Synchaeta												05			
Hexarthra					05						05			05	
Trichocerca														05	
Epiphanes		05												05	
Lecane														05	
Euchlanis dilatata											05				

	SAN LORENZO			**LAGUNA**			**SCOTT**			**APTOS**			**SOQUEL**		
OTHER ORGANISMS	**MJJ**	**AS**	**OND**	**MJJ**	**AS**	**OND**	**MJJ**	**AS**	**OND**	**MJJ**	**AS**	**OND**	**MJJ**	**AS**	**OND**
Alona	04		**NONE REPORTED**		**X**	**NONE REPORTED**	**NONE REPORTED**				**NONE REPORTED**			05	04
Ostracods	**X**			**X**	04					04			05		04
Polychaeta Larvae		**X**								04					
Tintinnids	**X**	**X**			05				05	**X**		05		05	
Larvacea		05													
Medusae		05													
Notiloca					05										
Peridinians/Ceratium		05													
Amphipods								04							
Barnacle Nauplii	04									04					

Eurytemora affinis is the most dominant species in the CLEAP lagoons. It was long considered a native on California shores, but recent genetic studies suggest E. affinis may have been introduced from the East Coast (Orsi 2001). Regardless of its origin, *E. affinis* has been determined to play an important role as a fish food source in the Sacramento-San Joaquin River Delta region. In the upper reaches of San Lorenzo and Aptos Lagoons in September 2004, *E. affinis* accounted for 98% and 99% of the zooplankton biomass, respectively. Aptos Lagoon experienced two peaks of E. affinis in 2005 in both July and September. We suspect the presence of *E. affinis* in these lagoons indicates zooplankton is a food source for fish in these lagoons. *E. affinis* was observed in relatively small numbers in Soquel and Laguna Lagoons.

The rotifer zooplankton have been identified by other researchers as tolerant opportunistic species, and thus the rotifer abundance and relative biomass were expected to increase as water quality declined. However, rotifer observations in the lagoons showed opposite trends. The most abundant rotifer populations were found in Soquel Lagoon, the system representing the lowest stressor values of water quality conditions in most instances. Because of this dominance the metric expressing relative contribution of rotifers in the lagoons (ZOO2) displayed 6 statically significant correlations with lagoon stressors. However, the response of the rotifers did not follow expected patterns as the contribution of rotifers consistently increased with decreasing stress.

The size distribution of zooplankton biomass and associated seasonal patterns vary with lagoon and year (Figures 12.9 and 12.12) with no overriding obvious trends. Zooplankton lengths are typically between 100um (0.1 mm) and 500um (0.5 mm) within Coastal California lagoons averaging approximately 65% of the zooplankton biomass in this size range. In general, at least one zooplankton bloom was captured by sampling in each lagoon during each season of observations. Table 12.3 summarizes the average annual zooplankton biomass observed in each lagoon and provides details of the peak seasonal zooplankton bloom in each lagoon. San Lorenzo and Soquel Lagoon annual sampling biomass peaks were observed in the fall each year. The timing of elevated zooplankton biomass observations varied across years at Scott, Laguna and Aptos Lagoon. Soquel Lagoon typically possessed a small zooplankton community biomass compared to the other lagoons. The fraction of the community that is less than 0.5 mm for each peak zooplankton biomass observation is also provided. Both Laguna and San Lorenzo Lagoons were observed to have seasonal blooms consisting of 100% small cells (<0.5mm). The largest blooms observed were in Aptos Lagoon during both years, and each bloom had a fairly even distribution of cell sizes, 41% and 22% < 0.5 mm for 2004 and 2005, respectively.

Table 12.3. Seasonal comparisons of zooplankton community dynamics across lagoons.

Lagoon	2004		2005	
	Zoo mean biomass (mg C/m^3)	Date and magnitude (mg C/m^3) of peak biomass: (% < 0.5 mm)	Zoo mean biomass (mg C/m^3)	Date and magnitude (mg C/m^3) of peak biomass: (% < 0.5 mm)
Scott	4.48	July 9: 14.1 (80%)	1.40	Oct 25: 5.2 (35%)
Scott Side Channel	N/A		2.34	Oct 25: 6.3 (70%)
Laguna	2.72	Sept 22: 9.8 (25%)	3.83	July 19: 14.0 (100%)
Soquel	1.27	Oct 4: 4.9 (63%)	0.09	Nov 2: 0.16 (75%)
San Lorenzo Upper	2.88	Sept 2: 10.2 (12%)	2.35	Oct 5: 6.7 (17%)
San Lorenzo Lower	2.82	Sept 2: 12.3 (100%)	3.51	Oct 5: 12 (15%)
Aptos	8.54	Sept 15: 17.1 (41%)	11.9	July 13: 40.8 (22%)

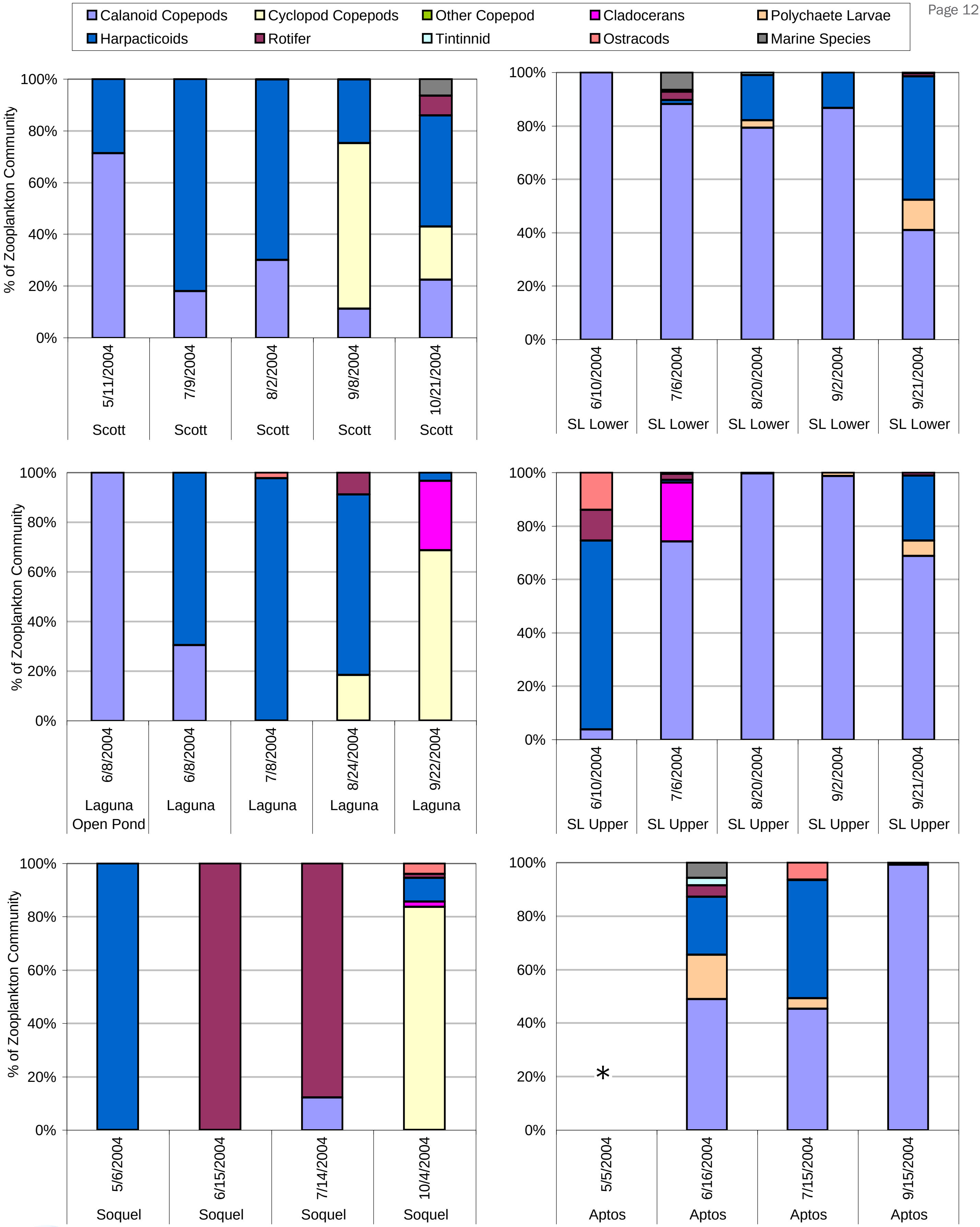
In all lagoons in 2004, the peak zooplankton biomass corresponded to a species diversity values greater than 0.5 (Figure 12.8). In 2004, zooplankton organisms smaller than 100um occupied less than 20% of the biomass in each lagoon (Figure 12.9). The one exception to this was in September 2004 in lower San Lorenzo lagoon where 100% of the zooplankton biomass was less than 100um (Figure 12.9). The San Lorenzo zooplankton community shift corresponds with a significant monoculture bloom of dinoflagellate phytoplankton (Figures 12.3) during closed conditions.

In 2005, the zooplankton size distribution was much smaller in all of the lagoons compared to 2004 (Figures 12.9 and 12.12). However, the peak biomass in each lagoon, excluding Laguna, possessed relatively larger sized communities than observations during non-peak conditions. The most interesting are the zooplankton dynamics in Aptos 2005 (Figures 12.11-12). Two bloom events were observed on July and September sampling, noted by significant increases in zooplankton biomass and cell size distribution shifts. However, the species diversity values show the dominance of the copepod E. affinis, a potential food source for fish.

We use Scott and Aptos Lagoons to explore the potential relationships of zooplankton data to observations at other trophic levels. Scott and Aptos had the highest seasonal average and highest peak zooplankton biomass in 2004 (Table 12.3). The peak zooplankton observation in Scott 2004 occurred early in the year (July), during macrotidal conditions. The bloom was a relatively small cell sized community (80% < 0.5mm) with a species diversity value of 0.76. The species diversity within Scott Lagoon remained elevated throughout the year as the dominant cell size observed within the lagoon shifts to larger and larger sized zooplankton, but with decreasing community biomass. In contrast, no zooplankton were captured in Aptos Lagoon in May 2004, but relative cell size, species diversity and biomass gradually increased as the season progressed. Based on our general statements about zooplankton size and bloom dynamics, the observations in Aptos 2004 exhibit signs of a healthier zooplankton community. The zooplankton community remains diverse throughout the season and the size distribution gradually increases.

We can then explore relationships between zooplankton trends and the seasonal trends of the fish community and water quality in each lagoon. Fish catch per unit effort (CPUE) and steelhead CPUE (Figures 12.23 and 12.26) show different seasonal trends between Scott and Aptos Lagoon. The number of fish and steelhead captured within Scott Lagoon gradually increased over the season, while the peak CPUE in Aptos was observed in July and a seasonal low in November 2004. The dominant community of zooplankton that grew in abundance and size in Aptos Lagoon over 2004 was the potential fish food, E. affinis. While these comparisons must be taken lightly, the lagoon substrate within Aptos lagoon during the November sampling contained excessive organic matter, poor water quality and reduced fish populations. The increased zooplankton biomass in the lagoon may have contributed to this high amount of decaying organic matter, due to decreased fish abundance and potentially decreased consumption of the zooplankton in the lagoon. Obviously, our interpretations are very speculative without controlled and detailed studies of the trophic structure interactions within the lagoon environment.

The existing dataset has provided a preliminary evaluation of the main species observed within coastal lagoons and a number of statistical correlations between stressors and the general zooplankton community diversity and distribution. The complexity of the zooplankton communities is reflected in the wide variability both within and across lagoons. Energy transfer dynamics and relative zooplankton community cell size metrics did not show strong correlations to lagoon stressors. These secondary producers obviously respond rapidly to changes within the lagoon, but there remains a lack understanding of how to decipher the primary influence on the lagoon zooplankton community using CLEAP observations. Based on CLEAP results, the future applied use of zooplankton communities in lagoon evaluations appears limited.



% zooplankton community is based on biomass (mg C/m^3) contribution to total sample biomass.

*Samples were taken for all dates shown for each lagoon. Lack of data for species distribution is due to the absence of zooplankton taxa in the sample.

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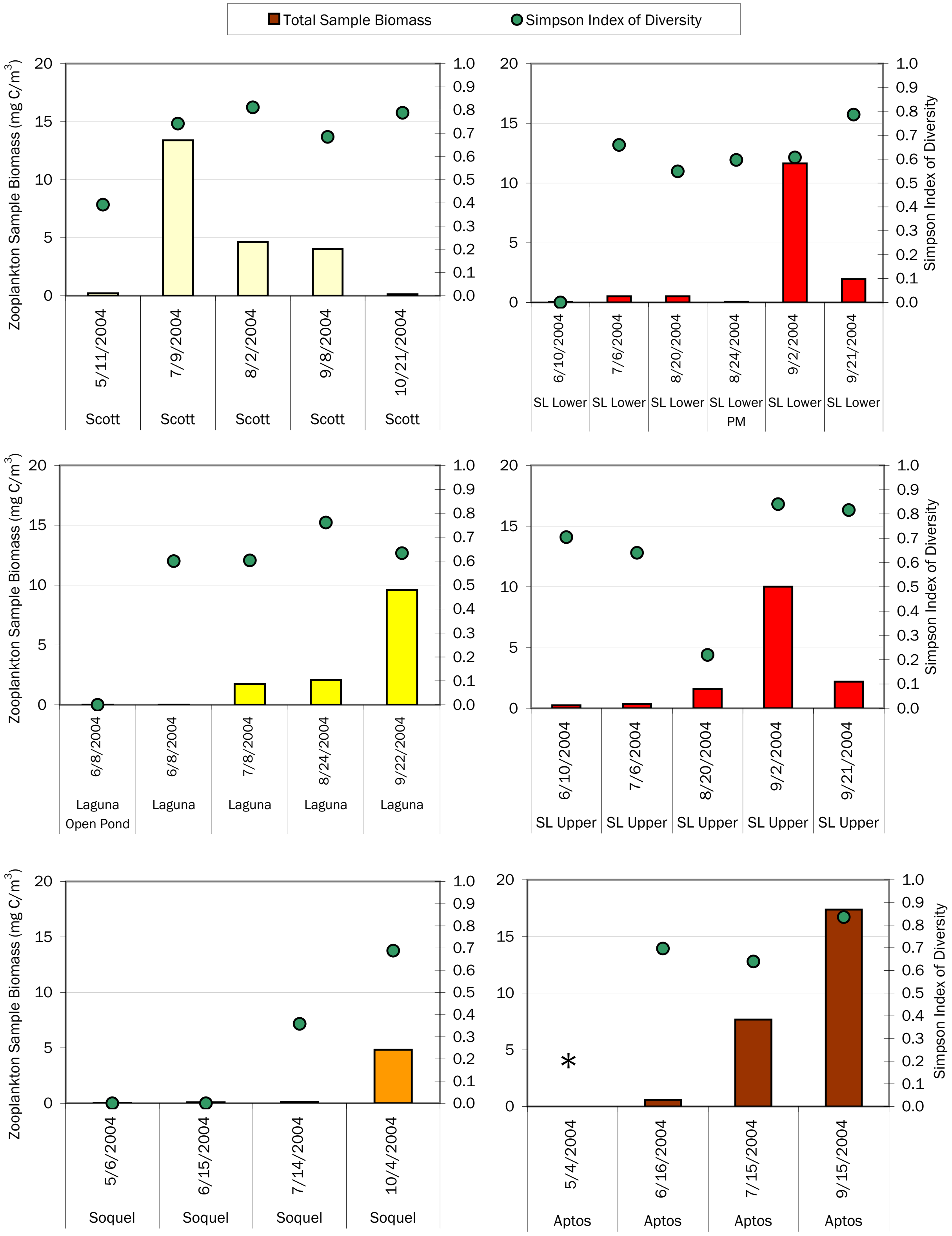
2004 ZOOPLANKTON SPECIES DISTRIBUTION

FIGURE 12.7

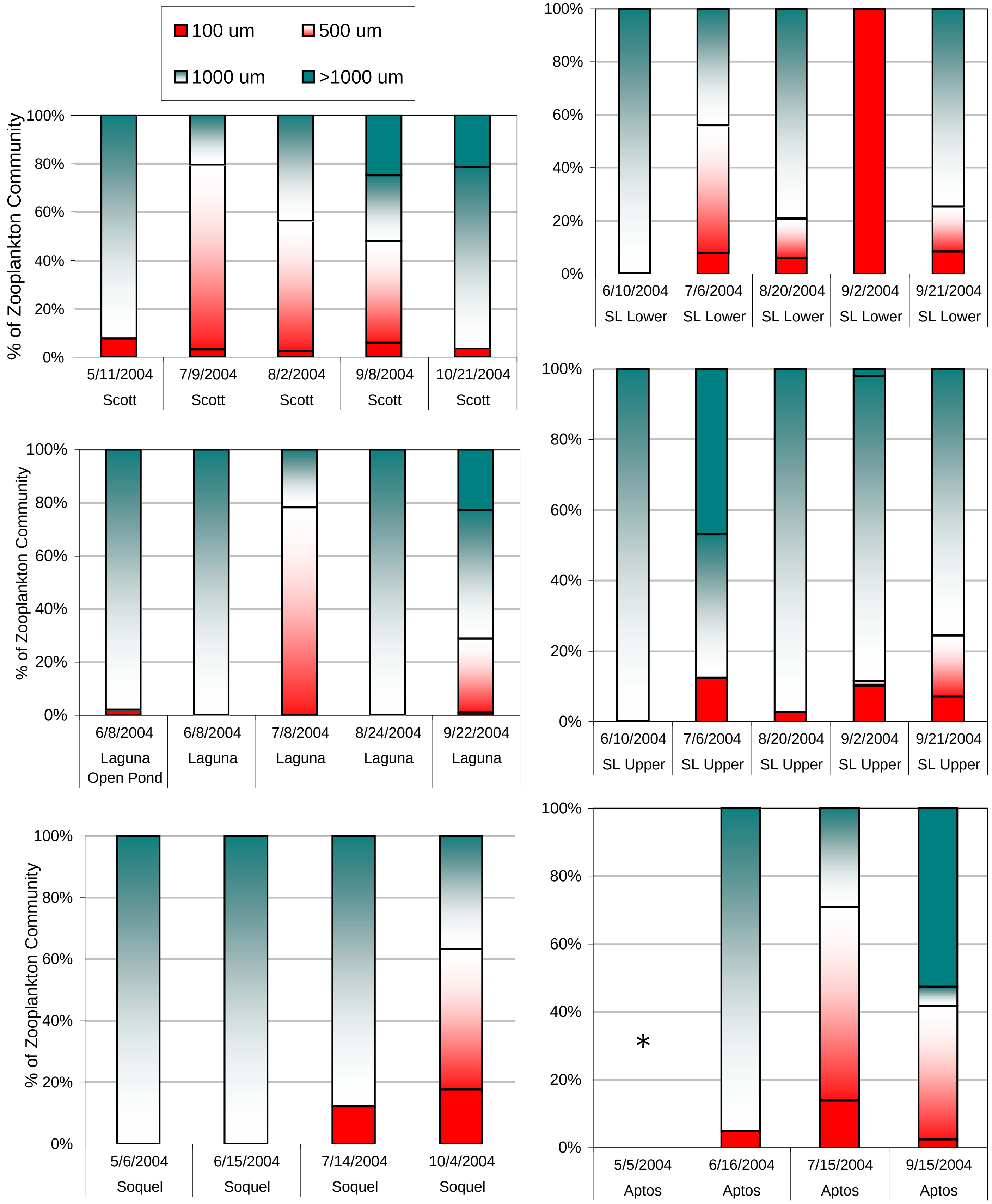


*Samples were taken for all dates shown for each lagoon. Lack of data for species distribution is due to the absence of zooplankton taxa in the sample.

Simpson's Index of Diversity calculated using # of cells per species per sample, not zooplankton species biomass.

2004 ZOOPLANKTON SAMPLE BIOMASS AND SIMPSON INDEX OF DIVERSITY

FIGURE 12.8

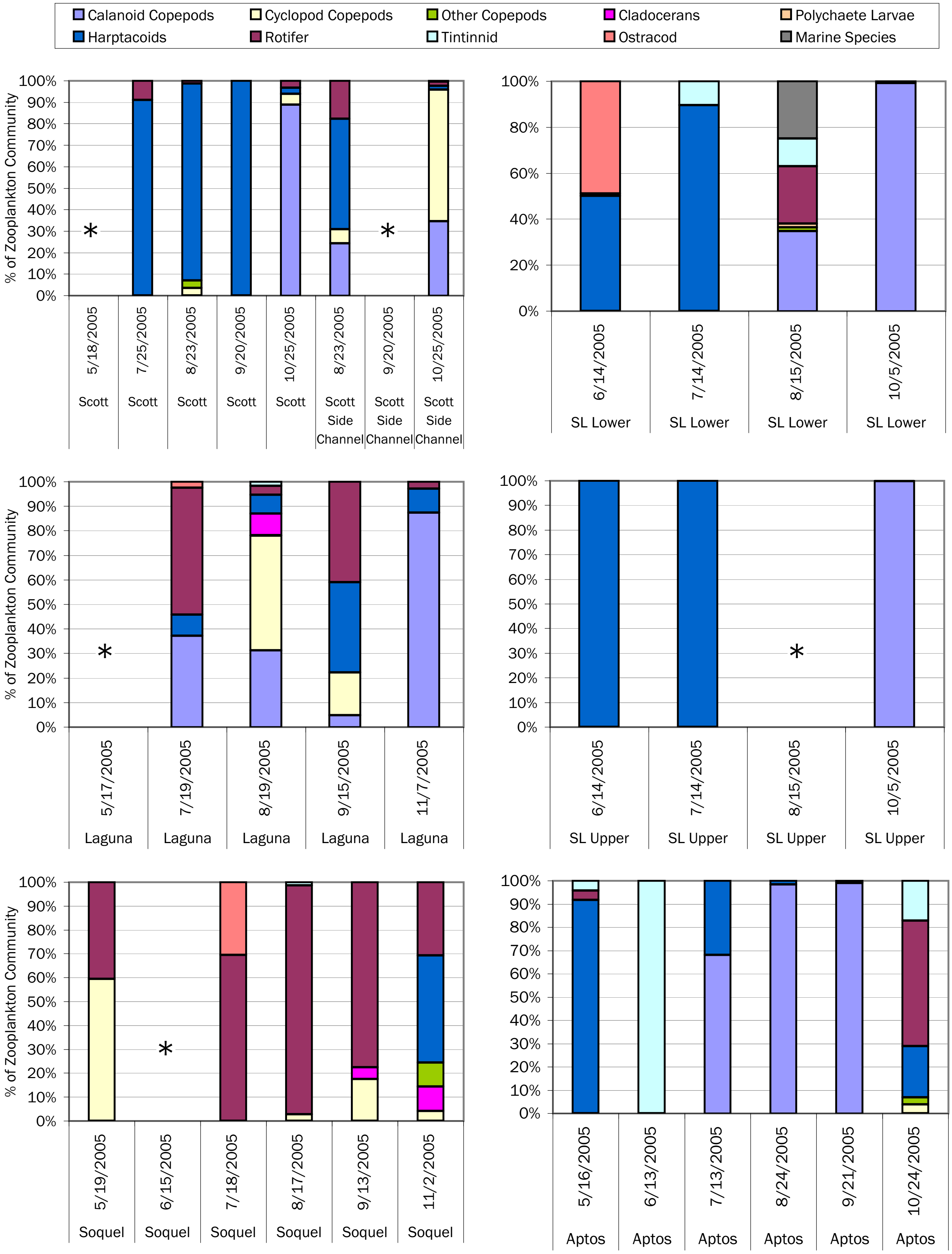


% zooplankton community is based on biomass (mg C/m^3) contribution to total sample biomass.

*Samples were taken for all dates shown for each lagoon. Lack of data for species distribution is due to the absence of zooplankton taxa in the sample.

2004 ZOOPLANKTON CELL SIZE DISTRIBUTION

FIGURE 12.9

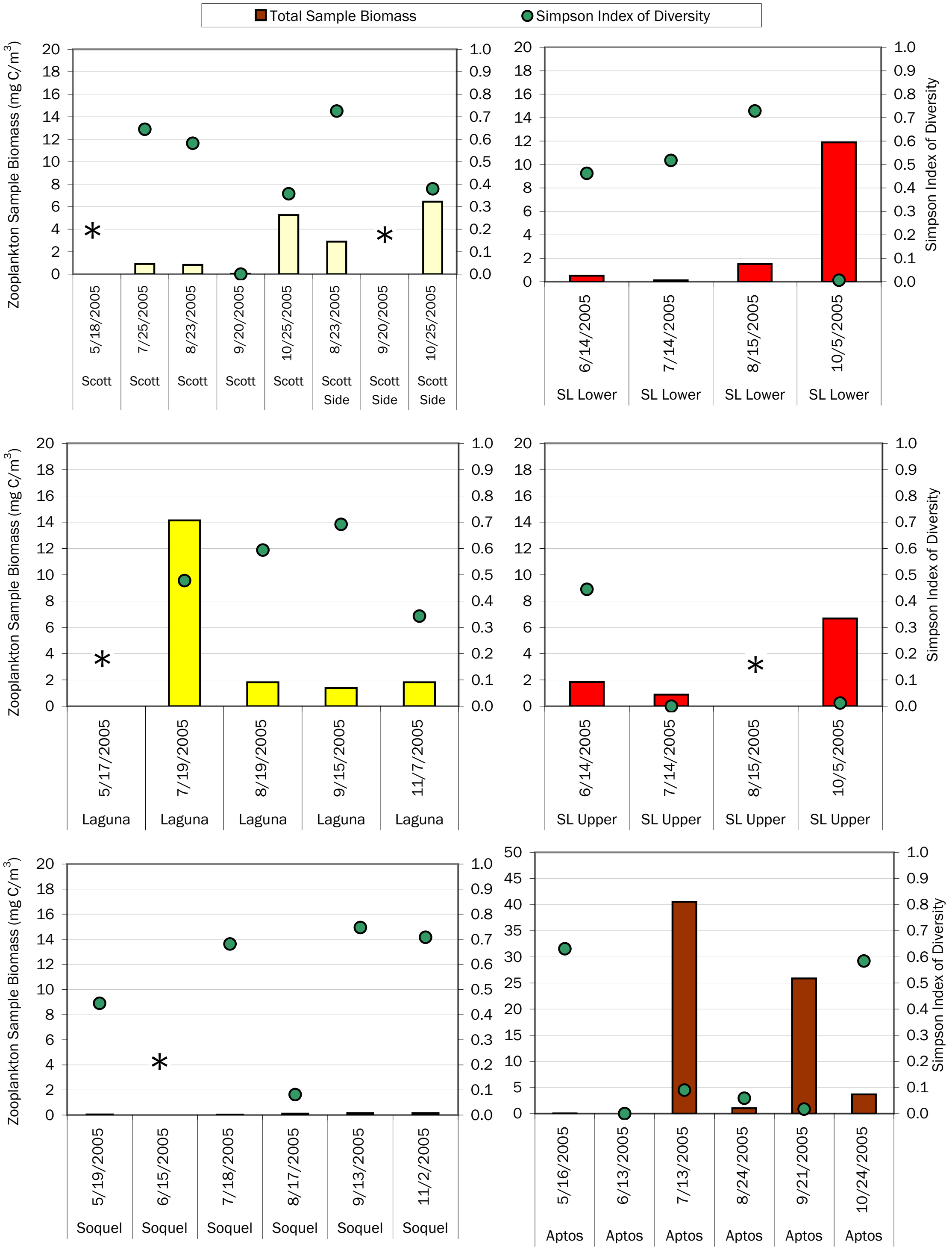


% zooplankton community is based on biomass (mg C/m^3) contribution to total sample biomass.

*Samples were taken for all dates shown for each lagoon. Lack of data for species distribution is due to the absence of zooplankton taxa in the sample.

2005 ZOOPLANKTON SPECIES DISTRIBUTION

FIGURE 12.10

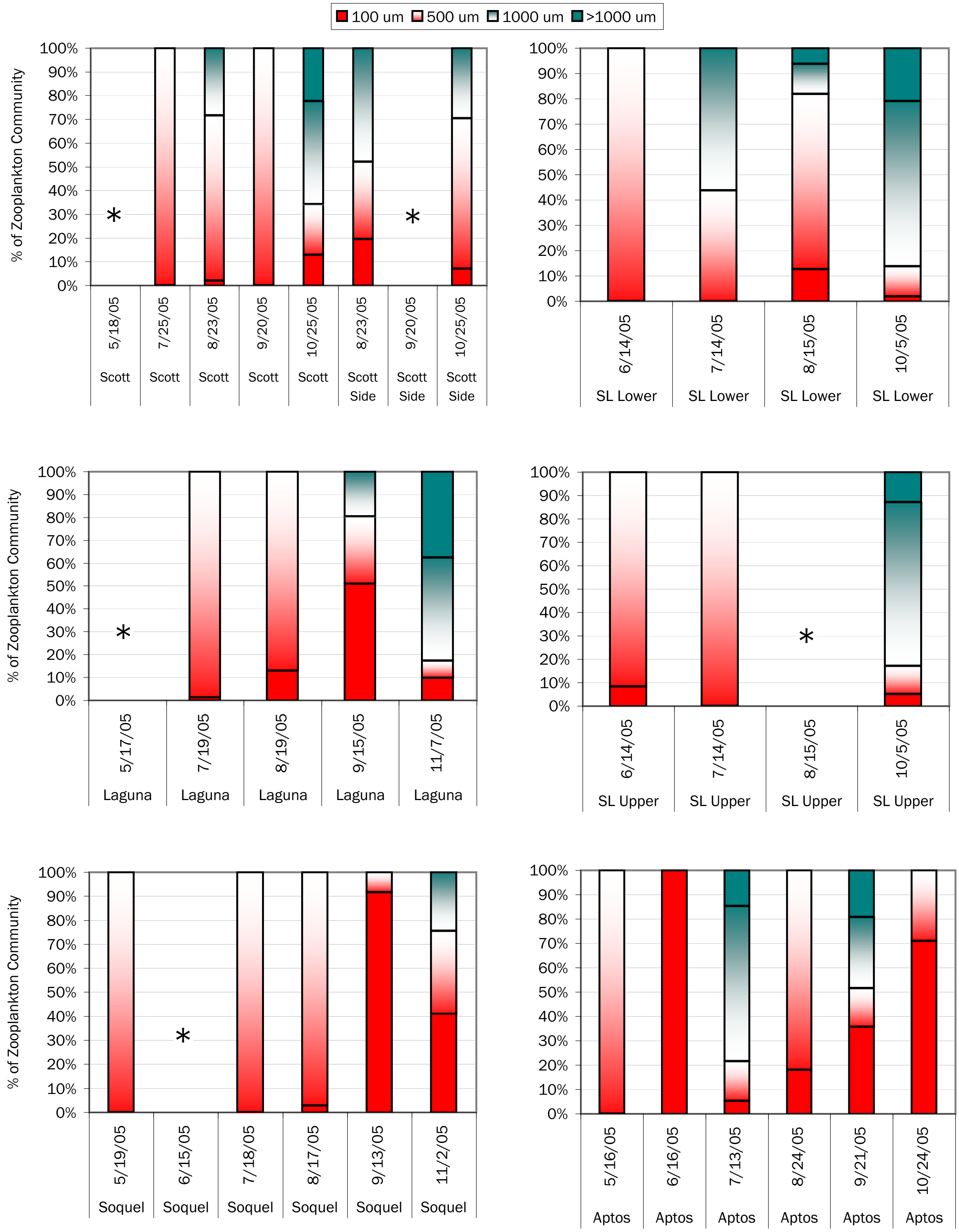


*Samples were taken for all dates shown for each lagoon. Lack of data is due to the absence of zooplankton taxa in the sample.

Simpson's Index of Diversity calculated using # of cells per species per sample, not zooplankton species biomass.

2005 ZOOPLANKTON SAMPLE BIOMASS AND SIMPSON INDEX OF DIVERSITY

FIGURE 12.11



% zooplankton community is based on biomass (mg C/m^3) contribution to total sample biomass.

*Samples were taken for all dates shown for each lagoon. Lack of data for cell size distribution is due to the absence of zooplankton taxa in the sample.

2005 ZOOPLANKTON CELL SIZE DISTRIBUTION

FIGURE 12.12

BENTHIC INVERTEBRATES

The CLEAP benthic invertebrate community sampling was created to expand our understanding of benthic invertebrates in the Coastal California lagoon environments and to determine if benthic invertebrate community metrics could serve as successful biological indicators of lagoon health. The benthic invertebrate data collection and enumeration was designed to be a cost-effective evaluation of the invertebrate community with emphasis on the organisms that had a high potential to be salmonid food, namely isopods, amphipods, mysids, and insect larvae (Martin 1995). As stated in the above zooplankton discussion, the most effective transfer of energy occurs when predators are 10 times larger than their prey. Thus, the most effective food source for salmonids is expected to be visible and identifiable by the human eye (> 1 mm in size).

Currently, little detailed taxonomy of benthic invertebrates is available from the brackish/saline waters of Coastal California lagoons. Identification of the sampled organisms was performed by CLEAP field personnel immediately following collection, and QA'ed later by M. Shouse. Further identification of some uncommon and/or unfamiliar organisms was performed by M. Shouse in the laboratory to improve our enumerations to the extent possible. The CLEAP monitoring has produced one of the first libraries of benthic invertebrates collected in the potentially brackish downstream locations within Coastal California lagoons. However, future taxonomy of the Coastal California lagoon benthic invertebrates is necessary. Specimens of each species collected by CLEAP have been preserved and are available for reference.

Due to the limitations in existing lagoon invertebrate taxonomy, the organisms observed in the lagoons were identified to different levels of specificity. Table 12.4 provides the common name and invertebrate group (as classified by CLEAP) of all organisms observed in the invertebrate sampling. Based on visual comparisons of the organisms within the CLEAP library, we have provided an estimate of the number of potentially different species represented by the benthic common name used by CLEAP. The lack of taxonomic consistency is likely a limitation of the current benthic dataset. However, these efforts provide an excellent base from which future benthic taxonomy in coastal lagoons and the existing library can be used to refine these cost-effective enumeration techniques. Given the existing limitations, we proceed with presenting key observations of the benthic invertebrate data.

The benthic metrics that have shown a consistent response to stressors are lagoon species diversity per sampling date (BI3 - composite of all samples per lagoon per LSD), number of taxa (BI10 – composite of total number of species in all samples per lagoon per LSD), and species diversity in the benthic grabs at the downstream stations (BI14) (Table 10.4).

Lagoon Composites

The lagoon benthic sampling consisted of littoral sweeps and benthic grabs at two cross sections within each lagoon. The stations were selected to represent conditions in the lower and upper lagoon as defined in each site location map. The upper boundary of each lagoon was identified as the inland location where the hydrologic conditions transitioned from visual surface water flow to no apparent downstream water movement during steady state lagoon conditions. During spring macrotidal conditions this upstream boundary of the lagoons has been observed to possess salinity values < 5ppt during high tides. Therefore all benthic monitoring occurred in the lagoon stations where brackish conditions do exist at least during macro-tidal conditions. The lower lagoon (downstream) stations were typically brackish for the majority of the year, stratified during closed conditions and, in some instances, a freshwater column during sustained closed conditions. Thus, some difference in invertebrate composition may be due to variations in physical conditions, such as salinity, rather than water quality and habitat conditions.

Table 12.5 lists the common name of the organisms in descending order of total abundance in all CLEAP lagoons (composite of all samples collected). The species identified as potential salmonid food are highlighted. Figure 12.13 presents the community composition in the Fall 2004 sample and across the 2005 monitoring, showing no clear trends across lagoons. However, metric testing indicated species diversity (as presented in Figure 12.14) correlated with 5 different water column condition stressors, including salinity stratification and bottom water DO levels (Table 10.4). The lowest lagoon species diversity values are observed at Scott Side Channel, Lower San Lorenzo and Aptos Lagoons. The lagoon composite of the invertebrate data was also used to evaluate the total abundance of the fish food organisms and their relative % contribution to the entire invertebrate sample (Figure 12.15). The lowest abundance and amount of potential fish food were observed in Scott Side Channel. The Fall 2004 sample in Aptos was also very low, corresponding to poor water quality conditions and a rapidly declining salmonid catch late in the season (Figures 11.40 and 12.34). San Lorenzo Lagoon, however, consistently had a very high abundance, over 90% of which were fish food species (Figure 12.15). Mysids, small-sized shrimp-like species, reached over 20-25 mm in the Lower San Lorenzo, 10mm longer than mysids observed in the other lagoons and large enough to be captured during fish seining efforts. The elevated salmonid prey supply likely contributes to the elevated size of the August 2005 salmonids captured in the San Lorenzo Lagoon (Figure 12.33).

Table 12.5. Top 10 most common benthic invertebrates (by abundance) observed during CLEAP monitoring. Calculated from all samples taken in all lagoons during 2004 and 2005. Rows highlighted in yellow are species identified as potential fish food (Martin 1995).

Rank	Common Name (as identified by CLEAP)	Abundance (# individuals)
1	Isopod	7346
2	Amphipod	3509
3	Corophium	2491
4	Water Boatman	1414
5	Copepod	1289
6	Mysid	964
7	Annelid	630
8	Ostracod	603
9	Midge Larvae	519
10	Insect Larvae	499

Downstream Stations

Typically, the downstream stations in the CLEAP lagoons show a greater range of habitat conditions across lagoons. The downstream stations of the urban lagoons, Aptos and San Lorenzo, are more impaired, simplified and generally possess poorer water quality than the upstream stations selected for benthic invertebrate monitoring. Even in Soquel Lagoon, station SQ2 is relatively more exposed and impacted by human modifications and recreational disturbances compared to the well-shaded, wider conditions at the upstream SQ3 station (Figure 11.7). Therefore, we included an evaluation of the downstream stations in anticipation of a greater response by invertebrate communities to more dramatic differences in habitat conditions. Within the downstream station we investigated the differences between the littoral (shoal) and the benthos (bottom) communities. Benthic grab samples captured the organisms living within the sediments, as well as those on the surface. The littoral sweeps sampled organisms living on the surface of the sediments and within any submerged aquatic vegetation (SAV).

Benthic invertebrates have been one of the most popular trophic levels used in rapid bioassessments and indices of biological integrity developed for specific habitats. The community composition and invertebrate abundance were expected to display variations correlating to the intensity of habitat stressors, thus serving as a potential biological indicator of lagoon health. Since the detailed taxonomy of the benthic invertebrates collected from the CLEAP lagoons remains a work in progress, the CLEAP efforts focused upon identifying components of the communities observed that appear to show a distinct response to variations in habitat conditions.

Table 12.6 presents the abundance of the invertebrates observed at only the downstream stations for all lagoons. Eight of the top ten most common in the entire lagoon (Table 12.5) are also common at the downstream stations (Table 12.6), with slight variations in relative abundance. The fraction of the total number of specific organisms observed in the benthic grab sampling was calculated. Since each station consisted of three samples, right and left bank littoral sweeps and one benthic grab, comparisons of the relative distribution of each species can be used to evaluate the niche of some organisms. Life cycles, physical niches, salinity tolerances, etc. will all make certain organisms more likely to be in certain locations within the lagoon. Table 12.6 indicates that corophium, annelids and caddisfly larvae are predominantly benthos species and mysids, water boatman and ostracods are littoral (shoal) species.

Table 12.6. Top 10 most common benthic invertebrates (by abundance) sampled in the downstream stations during CLEAP monitoring. Calculated from samples taken at downstream stations in all lagoons during 2004 and 2005. Rows highlighted in yellow are species identified as sources of fish food (Martin 1995).

Rank	Common Name (as identified by CLEAP)	Abundance (# individuals)	% Found in Benthic Grab Samples
1	Isopod	2658	14.3
2	Amphipod	2023	36.8
3	Corophium	1651	72.9
4	Mysid	660	0.0
5	Water Boatman	598	0.2
6	Annelid	309	72.8
7	Midge Larvae	181	45.9
8	Ostracod	148	3.4
9	Insect Larvae	81	4.9
10	Caddisfly Larvae	75	93.3

The benthic grab community consists of fewer number of species than the littoral sweep samples, and is heavily dominated by amphipods and corophium, with moderate and similar abundances of isopods, annelids and insect larvae across all lagoons (Figure 12.16) The community in the littoral zones of the lagoons appears to be generally more diverse than the benthos with 6 species comprising 90% of the community distributions observed. Isopods, amphipods and corophium dominate the ranking, followed by mysids, aquatic insects, insect larvae, and ostracods, respectively (Table 12.6). The lagoon-wide average Simpson Index of Diversity for the downstream littoral sweep community was 0.56 +/- 0.17, supporting higher diversity and little variation across lagoons and seasonal observations. In contrast, the lagoon-wide downstream benthos community diversity average was 0.37 +/- 0.25, with a strong variation across lagoons and seasonal conditions (Figure 12.17). Figure 12.17 graphically illustrates the very low abundance and relative diversity of benthic invertebrates in the most impacted bottom waters observed at Scott Side Channel and Aptos Lagoon. The high benthos abundance values observed in July and September 2005 is dominated by a well-established corophium community in San Lorenzo Lagoon.

Based on the presence of corophium at San Lorenzo and Soquel Lagoon, this fish food species appears to tolerate various ranges of salinity and bottom water quality. Figure 12.18 refines the comparisons of the relative availability of fish food in the benthos across lagoons. The very low abundance of invertebrates in the Scott Side Channel and Aptos Lagoon suggests either the conditions are too extreme and their threshold of tolerance has been exceeded, or there are other life cycle differences making some systems more suitable than others. The downstream benthos invertebrate diversity values (metric BI14) possess a predictable decrease with a variety of increasing stressors, thus it is identified as a successful biological indicator (Table 10.4).

Intolerant Species

Using tolerance rankings provided by an invertebrate website maintained by the New South Wales Department of Water and Conservation (www.bugsurvey.nsw.gov.au), the CLEAP team identified three species observed in CLEAP lagoons that are classified as intolerant to stress. Table 12.7 documents the presence/absence of each of these three sensitive species over the benthic invertebrate monitoring efforts. General conditions to which the organisms are sensitive are also provided in Table 12.7. Soquel and Laguna show the greatest frequency of these species. These species also have variable levels of tolerance to salinity, thus explaining a portion of the presence/absence trends.

- Mites were observed in each lagoon in the spring with the exception of Aptos Lagoon, suggesting the conditions in Aptos Lagoon are too impaired to support these species, even during higher freshwater inflow conditions. Mites persist in Soquel Lagoon and intermittently in Laguna Lagoon. If freshwater is the only condition selecting for these species, we would expect to see them persist in the fresh flowing waters of the Upper San Lorenzo (Sites SL6 and SL9).

- Caddisfly larvae are sensitive to low DO levels and some require/prefer leaf litter as a food source. Thus, densities of caddisfly larvae have been correlated to aquatic environments with dense riparian canopies. Portions of Laguna, Soquel, San Lorenzo and Aptos Lagoons have well developed riparian vegetation and an ample supply of leaf litter. The absence of these species in Aptos, and sparse presence in San Lorenzo, may be due to the combination of a brackish lagoon and water quality impairments.

- Mayfly nymphs are observed later in the year and have been identified as a good fish food source for salmonids. The sparse observation of these sensitive species in San Lorenzo and their absence in Aptos may be indicative of the elevated temperatures and impaired DO levels, but salinity presence in these systems could also influence mayfly nymph presence/absence.

The presence/absence of intolerant species was not included in the metric testing, but based on the above observations, further identifications and observations of intolerant invertebrate species in coastal lagoons could prove to be a valuable biological indicator.

Common Name as Identified by CLEAP	Benthic Invertebrate Group as Utilized by CLEAP	Phylum	Class	Order	Sub Order	Family	Tolerance Ranking[1]	Potential # of Different Species[2]
Annelid	Annelids	Annelida						<5
Polychaetes	Annelids	Annelida	Polychaeta					<5
Nereid	Annelids	Annelida	Polychaeta	Aciculata		Nereididae		1
Sabellid	Annelids	Annelida	Polychaeta	Canalipalpata		Sabellida		1-3
Arachnid	Arachnids	Arthropoda	Arachnida					<5
Mite	Arachnids	Arthropoda	Arachnida	Acarina			6	<5
Amphipod	Amphipods	Arthropoda	Crustacea	Amphipoda			3	1-3
Corophium	Amphipods	Arthropoda	Crustacea	Amphipoda		Corophiidae		1-3
Copepod	Copepods	Arthropoda	Crustacea	Copepoda				1-3
Isopod	Isopods	Arthropoda	Crustacea	Isopoda				<5
Anthuridea	Isopods	Arthropoda	Crustacea	Isopoda	Anthuridea			1-3
Mysid	Mysids	Arthropoda	Crustacea	Mysida				1-3
Ostracod	Ostracods	Arthropoda	Crustacea	Ostracoda				<5
Aquatic Insect	Aquatic Insects	Arthropoda	Insecta					1
Insect Larvae	Insect Larvae	Arthropoda	Insecta					<25
Beetle	Aquatic Insects	Arthropoda	Insecta	Coleptera		Dytisidae	2	1-3
Water Fly	Aquatic Insects	Arthropoda	Insecta	Diptera				1-3
Maggot/ Fly Larvae	Insect Larvae	Arthropoda	Insecta	Diptera			3	3
Midge Larvae	Insect Larvae	Arthropoda	Insecta	Diptera			3	<5
Mosquito Larvae	Insect Larvae	Arthropoda	Insecta	Diptera		Culicidae	1	<5
Mayfly Nymphs	Insect Larvae	Arthropoda	Insecta	Ephemeroptera			9	1-3
Water Boatman	Aquatic Insects	Arthropoda	Insecta	Hemiptera		Corixidae	2	1-3
Water Strider	Aquatic Insects	Arthropoda	Insecta	Hemiptera		Genidae	4	1-3
Water Treader	Aquatic Insects	Arthropoda	Insecta	Hemiptera		Mesovelidae	2	1-3
Backswimmer	Aquatic Insects	Arthropoda	Insecta	Hemiptera	Heteroptera	Notonectidae	1	1-3
Caddisfly Larvae	Insect Larvae	Arthropoda	Insecta	Hydrobiosida			8	<5
Hydra	Hydra	Cnidaria (Coelenterata)	Hydrozoa			Hydridae	2	1-3
Snail	Mollusks	Mollusca	Gastropoda				1	<5

[1] Source: www.bugsurvey.nsw.gov.au; Scaling: 1 (most tolerant) to 10 (least tolerant).

[2] Potential number of different species collected from CLEAP lagoons. Further taxonomy unavailable.

TAXONOMIC IDENTIFICATION OF CLEAP BENTHIC INVERTEBRATES

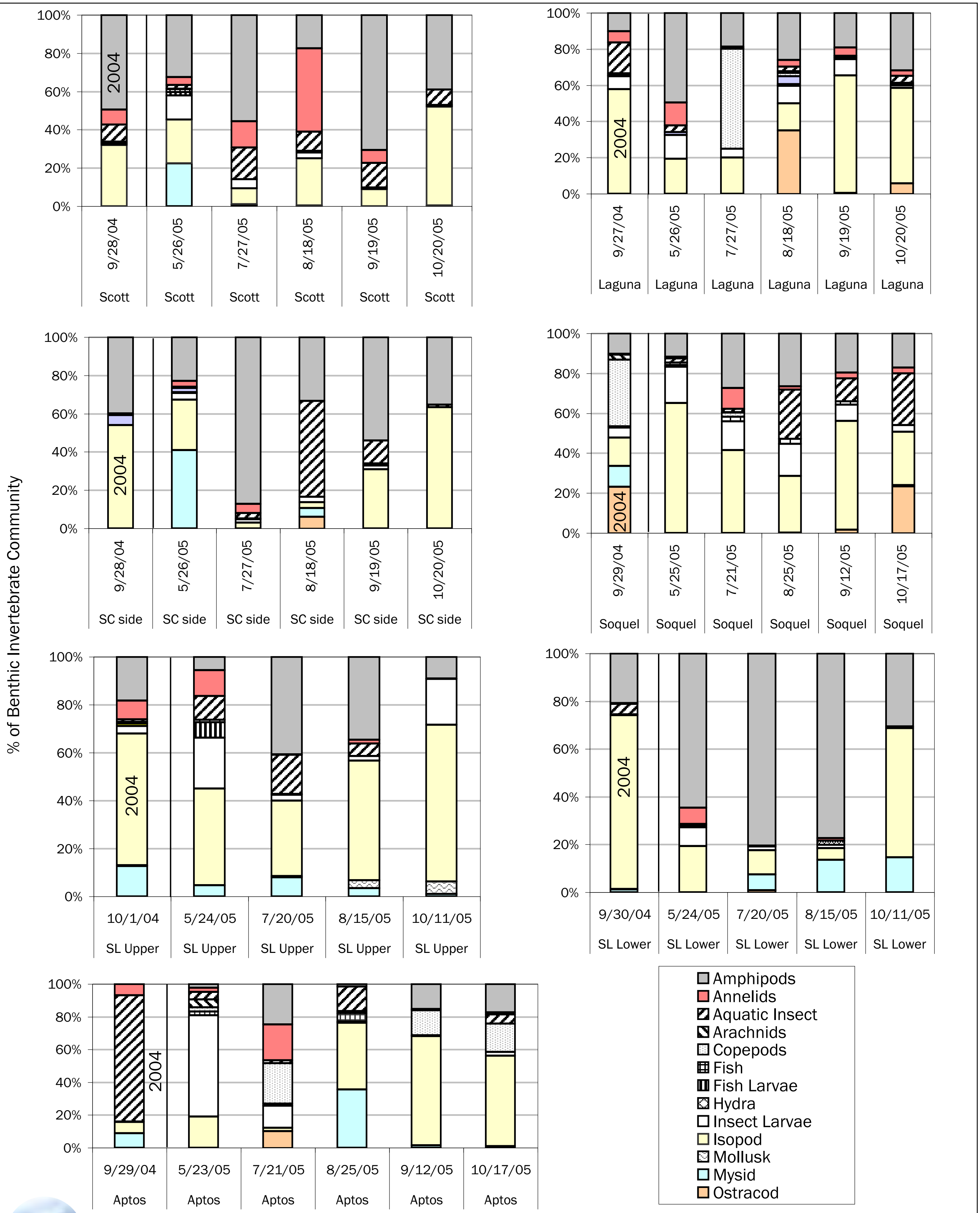
TABLE 12.4

Benthic Invertebrate	Sensitivity[1]	Scott			Laguna		Soquel		San Lorenzo				Aptos	
		SC2	SC5	SC3	LA2	LA5	SQ1	SQ3	SL2	SL4	SL6	SL9	AP2	AP5
Mite	Sensitive to changes in the environment. Freshwater species who prefer slow-moving water.								Sep-04					
			May-05			May-05	May-05			May-05	May-05	May-05		
							Jul-05	Jul-05						
							Aug-05	Aug-05						
					Sep-05		Sep-05	Sep-05						
						Oct-05		Oct-05						
Caddisfly Larvae	Cannot tolerate low DO levels. Some prefer leaf litter for food.						Sep-04	Sep-04	Sep-04					
			Jul-05			Jul-05								
					Sep-05	Sep-05	Sep-05							
Mayfly Nymph	Sensitive to low DO levels, chemical pollution, flow rate and sunlight.						Sep-04	Sep-04				Sep-04		
					Jul-05	Jul-05								
					Aug-05	Aug-05		Aug-05						
		Sep-05	Sep-05											
				Oct-05	Oct-05			Oct-05						

[1] Source: www.bugsurvey.nsw.gov.au

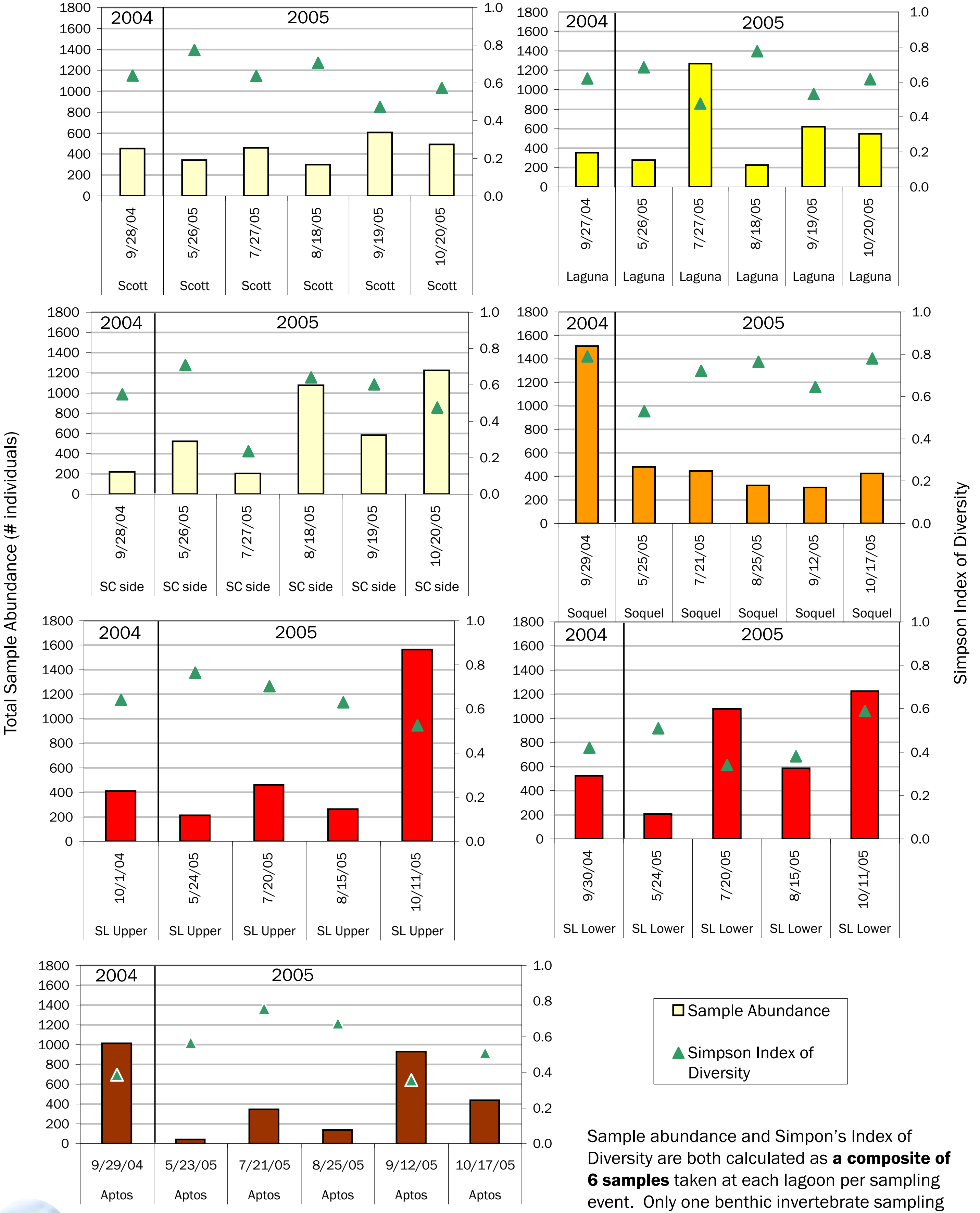
PRESENCE/ABSENCE OF SENSITIVE BENTHIC INVERTEBRATES SPECIES

TABLE 12.7



% benthic invertebrate community is based on the composite abundance of each benthic invertebrate group (Table 12.4) in **all 6 samples collected at each lagoon** per sampling event. Only one benthic invertebrate sampling was performed at each lagoon in 2004.

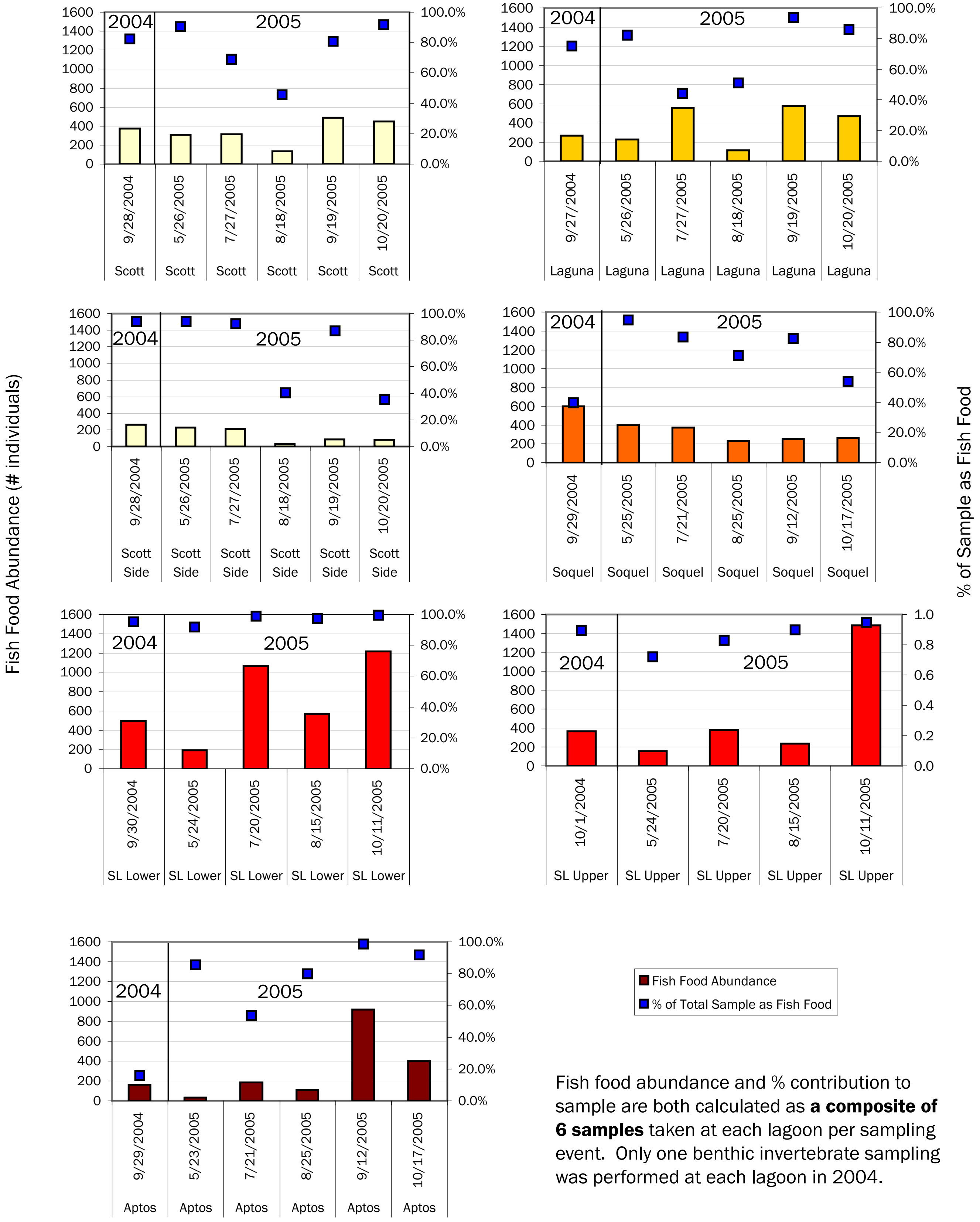
BENTHIC INVERTEBRATE COMMUNITIES FIGURE 12.13



Sample abundance and Simpon's Index of Diversity are both calculated as **a composite of 6 samples** taken at each lagoon per sampling event. Only one benthic invertebrate sampling was performed at each lagoon in 2004.

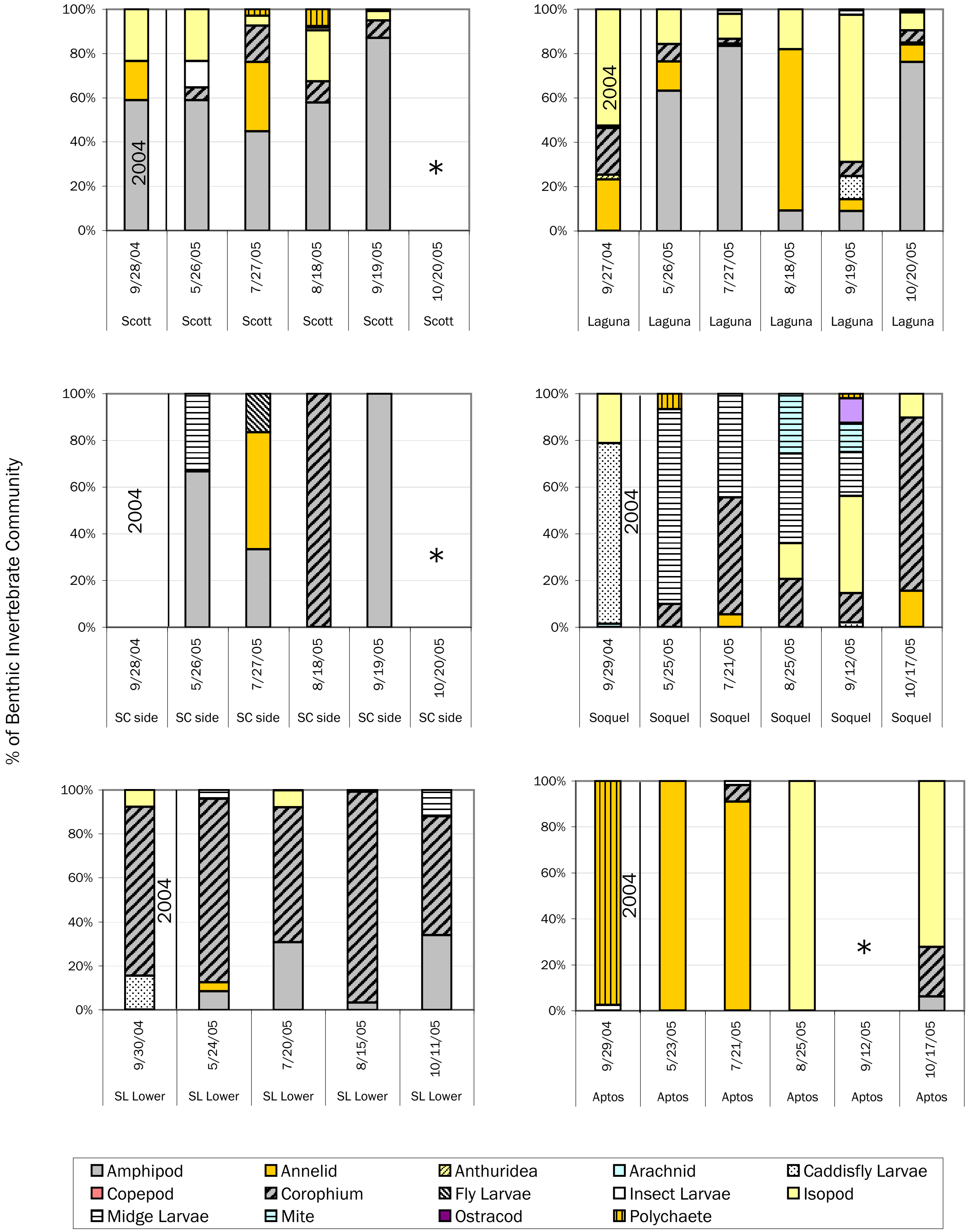
BENTHIC INVERTEBRATE ABUNDANCE AND SIMPSON INDEX OF DIVERSITY

FIGURE 12.14



Fish food abundance and % contribution to sample are both calculated as **a composite of 6 samples** taken at each lagoon per sampling event. Only one benthic invertebrate sampling was performed at each lagoon in 2004.

FISH FOOD COMPOSITION OF BENTHIC INVERTEBRATE SAMPLES FIGURE 12.15

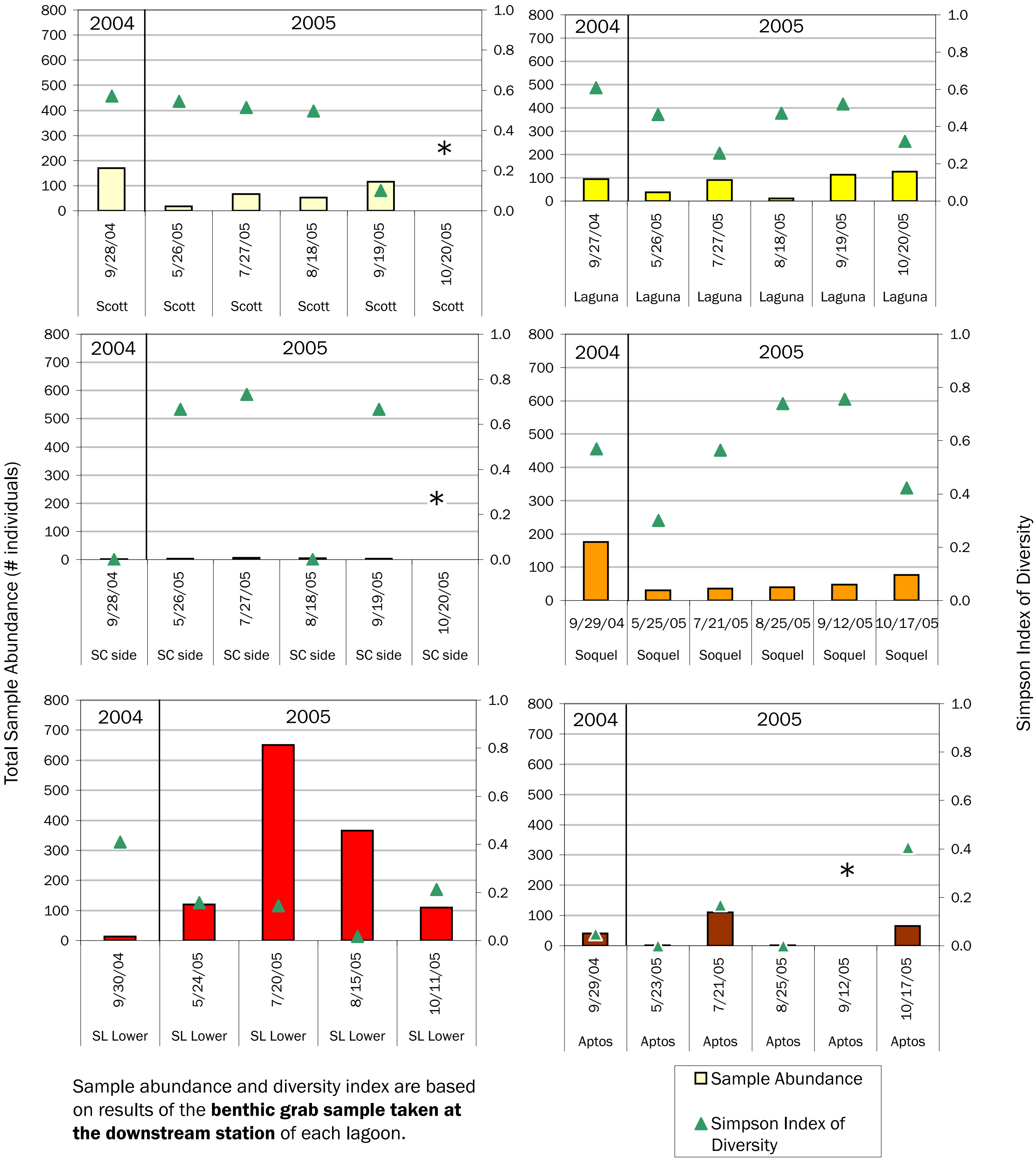


*Samples were taken for all dates shown for each lagoon. Lack of data for species distribution is due to the absence of benthic invertebrate taxa in the sample.

% benthic invertebrate community is based on individual common name abundance contribution to the **benthic grab sample taken at the downstream station** of each lagoon. Individual species enumerations based on common names described in Table 12.4, unlike Figure 12.13 which is based on benthic invertebrate groups shown in Table 12.4.

BENTHIC INVERTEBRATE COMMUNITIES OF DOWNSTREAM STATION BENTHIC GRABS

FIGURE 12.16

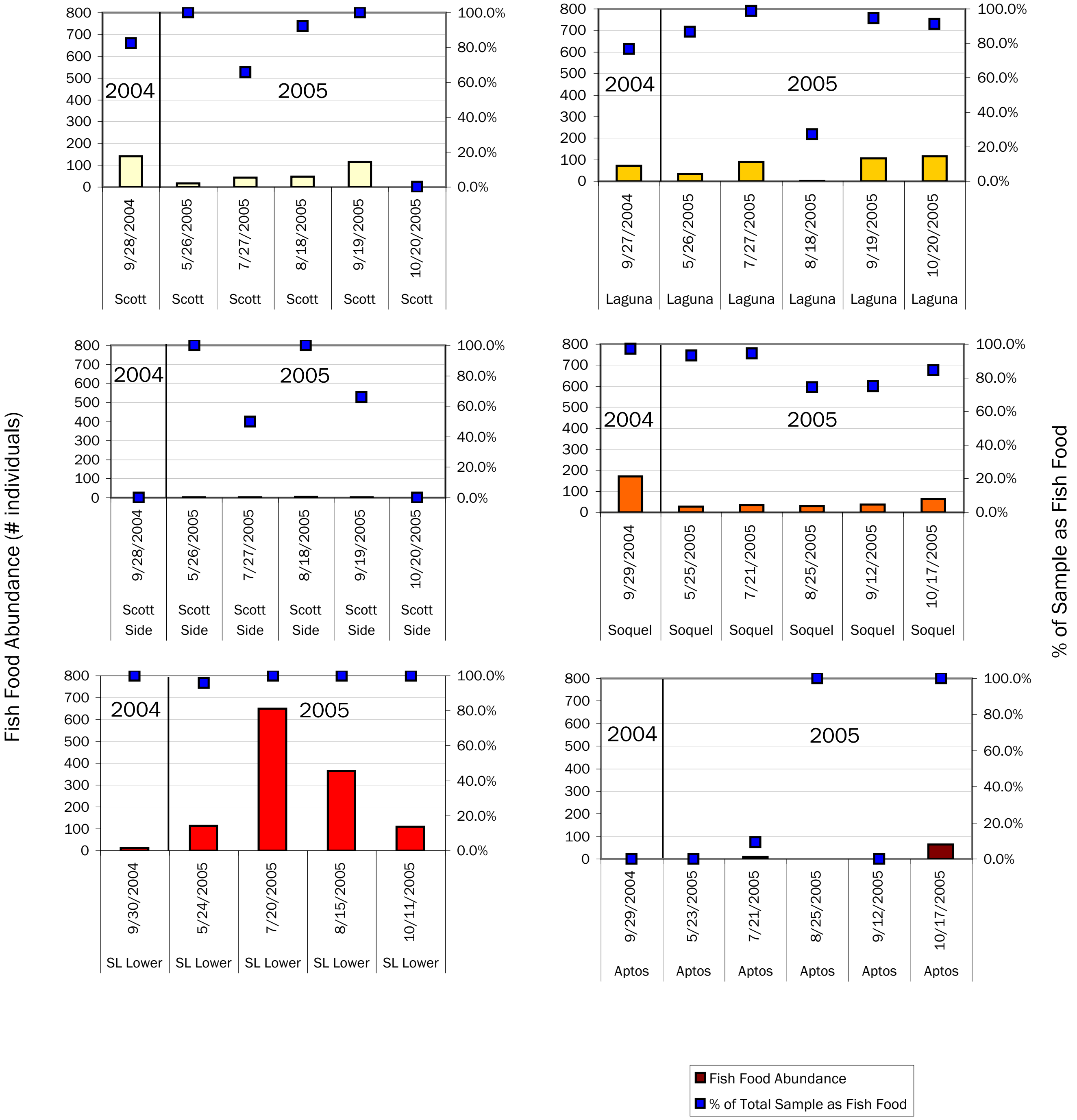


Sample abundance and diversity index are based on results of the **benthic grab sample taken at the downstream station** of each lagoon.

*Samples were taken for all dates shown for each lagoon. Lack of data for sample abundance and diversity is due to the absence of benthic invertebrate taxa in the sample.

BENTHIC INVERTEBRATE ABUNDANCE AND SIMPSON INDEX OF DIVERSITY FOR DOWNSTREAM STATION BENTHIC GRABS

FIGURE 12.17



Fish food abundance and % contribution to sample are based on results of the **benthic grab sample taken at the downstream station** of each lagoon.

FISH FOOD COMPOSITION OF BENTHIC INVERTEBRATE SAMPLES FROM DOWNSTREAM STATION BENTHIC GRABS

FIGURE 12.18

FISHERIES

Fisheries sampling duties were shared between Hagar Environmental Sciences (HES) and NMFS in 2004. HES used different seines for different physical conditions and to target different sized fish, as well as an electrofisher on one occasion (see Section 9 for details). NMFS was responsible for fish sampling in 2005, and methods were standardized across all lagoons. The seine used by NMFS did not target particularly small fish, although very small fish (<3cm forklength) were captured regularly. Due to changes in sampling conditions on the different sampling days, the seine may have been more or less efficient at capture of large versus small fish. When there were significant macroalgal blooms or SAV growth, the seine was difficult to pull through the water. It is under these conditions, however, when smaller fish may have been more efficiently targeted because they tend to get tangled in the macroalgal material. It is important to note that attempts were made to maintain consistent effort with regard to fish collection throughout 2005, however, depending on lagoon depth, water flow and SAV or algal growth, sampling efficiency may have been affected. These changes in efficiency could not be measured or monitored under the scope of this study.

Using fish as indicators of biological integrity is a complicated issue. Karr (1981) identified numerous advantages and disadvantages of using fish as indicator organisms for biological monitoring. Because fish are usually at or near the top of a balanced trophic structure, they may integrate any perturbations affecting the presence or stability of other trophic levels. Fish are relatively easy to identify, and often times fish communities include a range of species from a variety of trophic levels, although this is not the case in the CLEAP lagoons. Fish are typically present in most streams, unless they are highly degraded. Importantly for CLEAP, the general public is very interested in the condition of the fish community. While the list of disadvantages is shorter, these factors are no less important. The selectivity of sampling gear may not reveal the complete fish community. Fish are highly mobile on diel and seasonal time scales and in response to anthropogenic factors. Sampling fish takes a lot of manpower (i.e., resources). Fish health and growth rates have also been used as proxies for water quality. During the 2005 sampling, black spot disease (a parasitic infestation caused by neascus-type trematodes [family *Diplostomidae*] resulting in slightly raised black spots easily identified on the skin of fish) was noted and included in the CLEAP database.

In the CLEAP lagoons, there are relatively few species of fish, and they do not represent a very wide range in trophic levels (Figure 12.21). Three species found in the CLEAP lagoons are listed under the Federal Endangered Species Act. Tidewater gobies (*Eucyclogobius newberryi*) were listed as endangered in 1994. These fish were captured in four out of the five CLEAP lagoons (they were not found in Soquel in either year and were only captured in San Lorenzo in 2004). Tidewater gobies are typically found in fresh to brackish lagoons and prefer salinities less than 10ppt (Moyle 2002). Because gobies are not particularly good swimmers, their populations may plummet if temperatures increase over 25^{o}C and salinities increase (Moyle 2002). Steelhead (*Oncorhynchus mykiss*) along the central California coast were listed as threatened in 1997. Steelhead were captured in each CLEAP lagoon in both 2004 and 2005. The effect of temperature on these fish has been studied primarily in more northerly populations that experience cooler water temperatures than those typical of the CLEAP lagoons. Acclimation temperature may influence how temperature affects growth and what might be the upper lethal temperature. In wild juvenile steelhead, growth was high between 15^{o} and 19^{o}C and upper lethal temperatures are in the range of 24^{o} to 27^{o}C (Richter and Kolmes 2005). Coho salmon (*Oncorhynchus kisutch*) were first listed in 1996 and are currently considered endangered. The CLEAP study lagoons are at the extreme southern extent of the coho salmon range. While coho were historically found in all of the CLEAP lagoons (Spence et al. 2005), the populations are currently weak or nonexistent in most of the creeks. Juvenile coho were only found in Scott and Laguna Lagoons in 2005. Although coho were found in Bean Creek, a tributary of the San Lorenzo River, in 2005 (Alley 2006), they were not found in the San Lorenzo Lagoon. In their review of upper temperature limits for coho, Richter and Kolmes (2005) state that optimal juvenile coho growth occurs around 15°C with growth ceasing above 20.3°C. Data compiled for this review are from studies conducted in the Pacific Northwest. Fish in Santa Cruz County encounter very different temperature regimes over the course of the year compared to fish from farther north and may have different optimal growth temperatures. This has yet to be determined.

The CLEAP lagoons in 2004 and 2005 were typically dominated by two fish species: steelhead (juveniles) and threespine stickleback (juveniles and adults, *Gasterosteus aculeatus*). Steelhead biomass was usually the largest part of total catch, except in San Lorenzo, where topsmelt (*Atherinops affinis*) moved into the lower reaches of the estuary in great numbers during macrotidal conditions from offshore (Figure 12.22). Staghorn sculpin (*Leptocottus armatus*), prickly sculpin (*Cottus asper*) and starry flounder (*Platichthys stellatus*) were all commonly caught in each of the lagoons (Figure 12.21). Figure 12.21 shows all species captured during the CLEAP study by lagoon and by year.

Fish species richness was relatively consistent across time in each lagoon, ranging from the lowest number of species present (3) in Soquel (October 2004 and September and November 2005) to the highest species richness (14) in San Lorenzo July 2004 (Figure 12.19). There were no discernible patterns of time series species richness across lagoons.

Simpson Index of Diversity was calculated to incorporate both species richness and evenness. Values were quite variable across time and across creeks (Figure 12.20). Values were lowest in the summer and fall of 2004 in Soquel and Aptos, even though species richness was relatively high, due to large numbers of sticklebacks. The same pattern did not occur in 2005. The index of diversity across all CLEAP lagoons was on average higher in 2005 compared to 2004.

Catch data were normalized using different techniques in an effort to tease apart whether fishing effort and/or lagoon volumes influenced the total catch (Figures 12.23-25). Figure 12.23 shows the total biomass of fish catch normalized by fishing effort (number of seine hauls)- Catch Per Unit Effort (CPUE). Ideally this could provide data on relative fish densities, but because of the different morphologies and conditions within each lagoon, this should be considered cautiously. Figure 12.24 shows total fish catch normalized by lagoon volume, with lagoon volume graphically provided, smoothing some of the peaks in catch data (see Figure 12.23) across time. However, in Aptos Lagoon, when catch data is normalized to lagoon volume, 2004 shows a much higher catch density than 2005. Finally, when catch data is normalized to both fishing effort and lagoon volume (Figure 12.25), again there is the greatest variability in Aptos Lagoon with 2004 showing CPUE/lagoon volume values up to 10 times greater than those in 2005. These differences in Aptos do not seem to be due to different strengths of steelhead year classes, but because of much larger stickleback catches in 2004. Reasons for these differences in stickleback populations across the two years are unknown.

The salmonid presence in the CLEAP lagoons are of major importance to TAC members and interested parties. As mentioned previously, coho salmon populations in this region are currently weak, and coho were collected on only 4 out of 48 LSDs when fish were included in the sampling effort. The details of coho presence will be addressed further in sections describing the existing conditions of each lagoon later in this report (Section 14).

Steelhead were captured in each lagoon both years (Figures 12.23 and 12.26). Most steelhead greater than 65mm fork length were PIT tagged. Upon recapture, growth rates and residence times could be estimated from these fish (Figure 12.36). These recaptures could also be used to estimate population size, although this was not the aim of the CLEAP study. Because sampling was monthly at best, population estimates may be overestimated, the greater the probability that fish may move out of the lagoon (either back upstream or out to sea, if possible) or may be lost due to mortality. Both of these possibilities would result in inflated population estimates. Nevertheless, population sizes were estimated with the recapture data and are shown in Figure 12.27. Note that data from D. W. Alley and Associates' yearly Soquel Lagoon population estimate are also included and corroborate well with our estimates. This is an important finding because it compares two different mark-recapture protocols- one which took place over the course of one week (D.W. Alley and Assoc.) and the CLEAP sampling which occurred monthly. In Scott and Aptos Lagoons, steelhead population sizes are comparable across both 2004 and 2005. In Soquel Lagoon, population estimates from 2004 are high compared to 2005, but still within one standard deviation of the highest estimate in 2005. There are no obvious seasonal patterns in numbers of steelhead that populate any of the lagoons.

Figures 12.28-35 show length-frequency histograms of steelhead captured in each lagoon by month. These plots show which year classes were utilizing the lagoons during the different times of the year and suggest how quickly these groups grew over time. Interestingly, patterns of utilization seem to be different in each year and each lagoon. In one year, early populations may be dominated by young-of-the-year (YOY) steelhead with very few age 1+ fish present, and another year may be dominated by the 1+ fish. These variations may be important because the juveniles that are found in the lagoon moved there from locations further upstream in the watershed where they hatched (whether actively swimming downstream or passively being swept downstream to the lagoon, but not out to sea). Cues that signal YOY fish to move downstream may be different from those to which 1+ fish respond, resulting in different patterns of utilization of the lagoons by these different age classes. Alternatively, cues may be similar in both age classes, but relative strengths of the year classes may be expressed by their presence or absence in the lagoons. These data will be discussed in greater detail in Section 14.

Fish as Biological Indicators

Species diversity and taxa richness are key metrics established by many other researchers and substantiated by CLEAP for phytoplankton, zooplankton and benthic invertebrates. The fish communities within the Coastal California lagoons are limited to a small number of total taxa compared to the phytoplankton community, in which over 250 different species were identified. The urban lagoons have a greater number of total fish taxa (maximum 14) than the North Coast Lagoons due largely to movements of near-shore marine fish into the lagoons. These fish may aggregate more within the Monterey Bay, rather than along the exposed coast adjacent to the North Coast Lagoons, making them more likely to move into the urban lagoons.

There were no direct correlations between lagoon stressors and the sensitive fish species (i.e. steelhead, coho salmon and tidewater goby). Because fish are relatively long-lived, they can integrate conditions over the timeframe of years, as well as seasons. The limited data of the CLEAP study (only 2 years) makes large-scale patterns within the fish data difficult to tease out. Long-term studies (approx. 5-10 years) of the lagoon fish communities could prove beneficial for determining baseline data as well as monitoring any changes associated with restoration and enhancement. Future studies can use the CLEAP data as a starting point, and with increased amounts of data, aspects of the salmonid data (growth, populations numbers, age class composition) may develop into important new biological indicators.

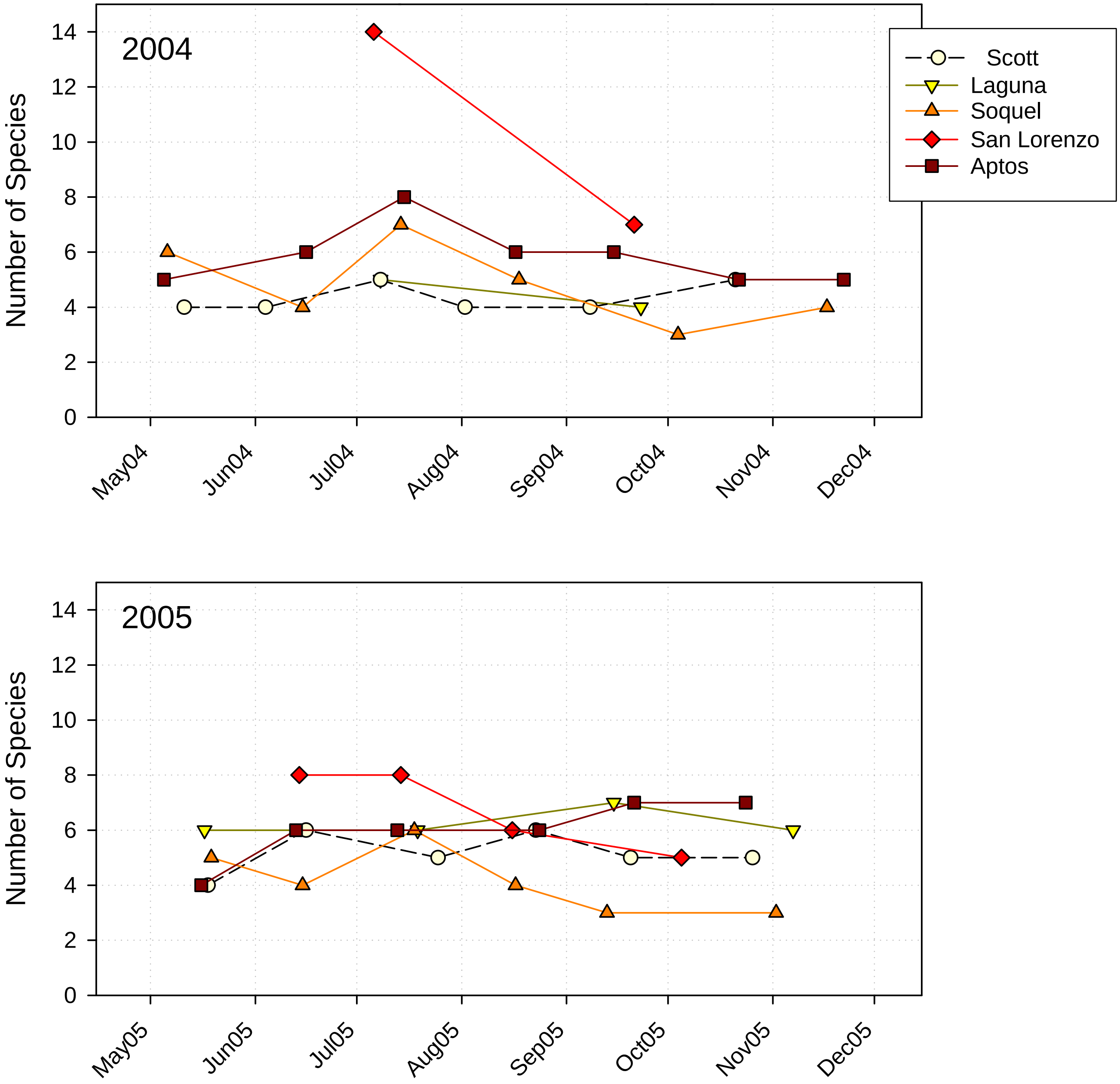
Steelhead and coho salmon are of particular interest to the public because of their value as sport fish and to resource managers because of their listing under the Federal Endangered Species Act. Our juvenile steelhead population estimates have relatively large errors associated with them (especially in

San Lorenzo and Soquel, see Figure 12.27), but it must be noted that population estimation was not the focus of the CLEAP study. The objectives of future monitoring must be established by considering a cost/ benefit analysis between obtaining accurate population estimates and procuring long-term population trends. Acquiring accurate population estimates numerous times throughout the year requires excessive handling of fish because each time an estimate is desired, a tag-recapture protocol must occur across a relatively short time scale (ideally on the order of days). The CLEAP study aimed at gaining reliable knowledge throughout the year while limiting handling of the fish to monthly at most. This approach allows for estimates of population size (with potentially large errors) as well as monthly comparisons of size distributions and growth rates. By understanding which age classes use the lagoons and when, under the variable summer conditions, we can further our knowledge of the habitat needs of the species - important information for future lagoon enhancement efforts. This type of monitoring of salmonids within the lagoon environment should continue. It is important to remember that these lagoons do not work in isolation- upstream habitats and changing ocean conditions have an influence on the persistence of steelhead and coho salmon as well. Monitoring movements of juvenile steelhead and coho in and out of the lagoon (upstream and out to sea) would provide much needed information on exactly how and when these species utilize the lagoon. This kind of fieldwork was beyond the scope of CLEAP, but would be extremely valuable in future efforts.

Presence/absence of coho salmon in Central Coast Lagoons is not currently a reliable indicator of lagoon health, since these lagoons are at the southern range of the species distribution, and upstream habitat may play a more important role in coho population health compared to the lagoon. Presence/ absence of tidewater goby may not be a reliable biological indicator due to the absence of this species in the managed Soquel Lagoon.

Although fisheries metrics did not succeed as biological indicators, their use for restoration monitoring is still beneficial. With any enhancement or restoration action, managers will want to know if fish are utilizing the enhanced portions of the lagoons, and whether any restoration is benefiting the fish in any way. Benefits can be revealed in the form of greater numbers of individuals (not from species known to be particularly tolerant of poor water quality), increased numbers of age classes present, decreased mortality and increased individual growth rates.

At a bare minimum, fisheries monitoring of restoration or enhancement projects should focus on enumeration of species present, counting numbers of individuals and determining locations within the lagoon that fish are utilizing (i.e. Are they inhabiting and/or feeding within the enhanced portion of the lagoon, or are they avoiding it?). Fisheries monitoring is expensive, whether paying for manpower or autonomous monitoring equipment. Ideally, fisheries monitoring would involve tracking of numerous individuals, allowing information on residence times within particular portions of the lagoon to be discovered, and over time, growth rates to be calculated. This could take the form of numerous PIT-tagged fish moving within a lagoon equipped with in-stream PIT-tag antennae (autonomous monitoring stations located at important sites throughout the lagoon) that would archive fish movement between locations of interest. These monitoring stations are expensive to install initially and require maintenance by a technician familiar with the equipment, however they would provide vast amounts of data with constant monitoring of fish movements. Alternatively, a study employing the CLEAP fish monitoring techniques could be useful, where PIT-tagged individuals are recaptured at various locations within the lagoon, thus showing site utilization (only at certain points in time), and the recaptures would provide growth rate data. The cost-benefit analysis of the type and quantity of fisheries data must be considered carefully for each future fish data collection efffort.



The number of fish species captured in each lagoon is relatively constant across both 2004 and 2005, except in San Lorenzo which shows a large decrease in species captured between July and September in 2004.

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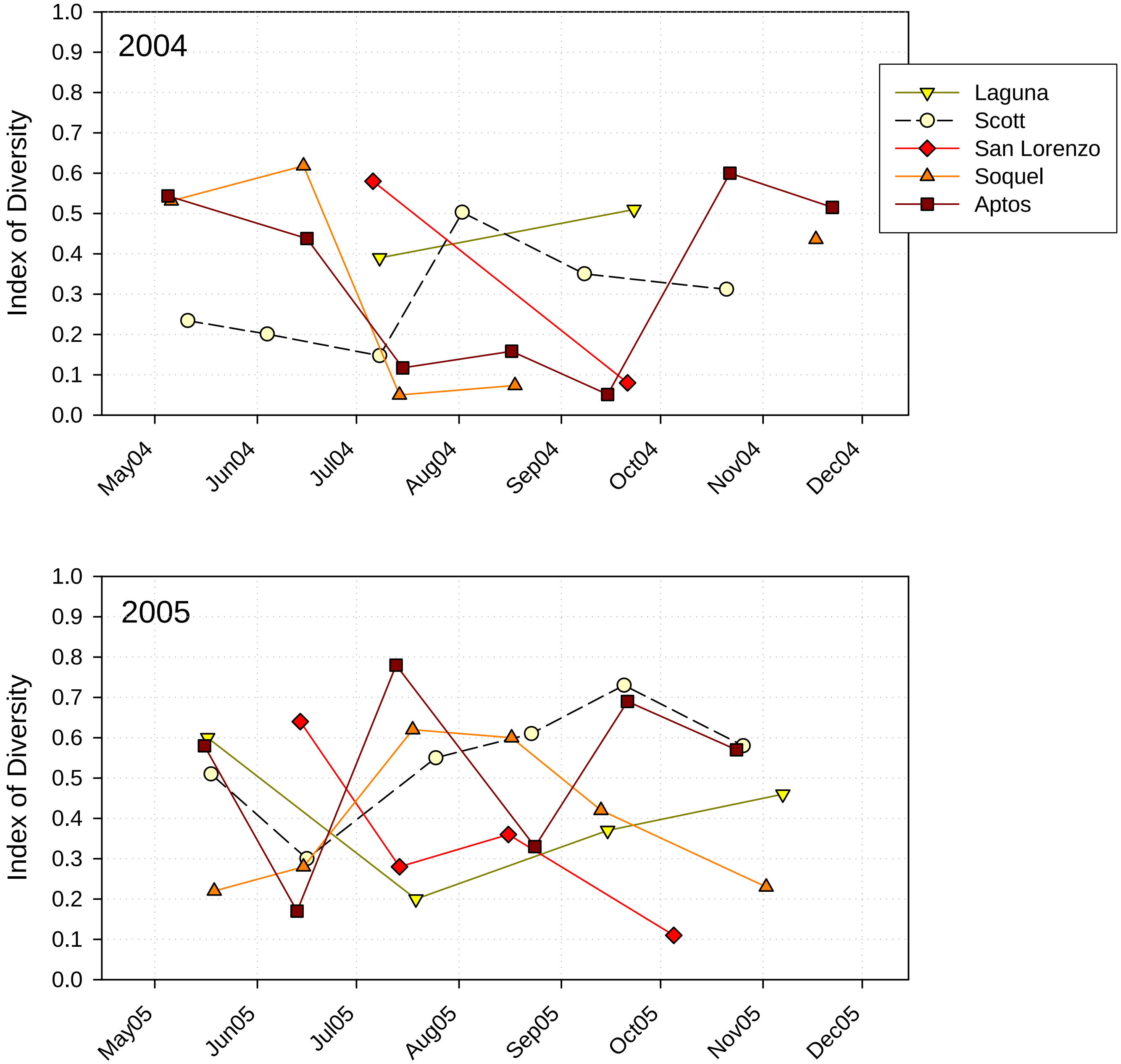
FISHERIES SPECIES RICHNESS BY LAGOON

FIGURE 12.19



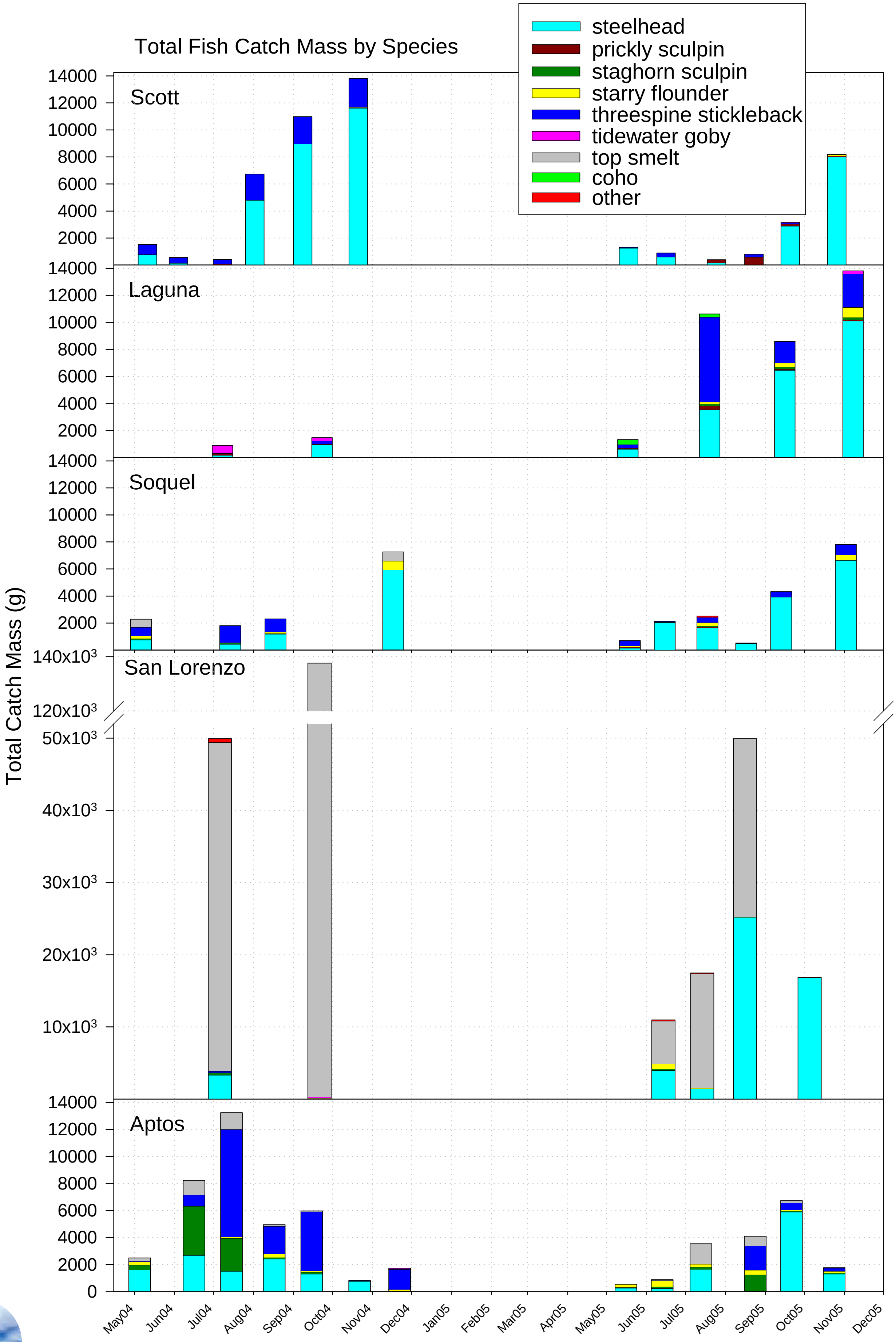
Simpson's Index of Diversity accounts for both species richness and evenness. The index increases with increased diversity.

FISHERIES SIMPSON INDEX OF DIVERSITY BY LAGOON

FIGURE 12.20

	Scott 2004	Scott 2005	Laguna 2004	Laguna 2005	Soquel 2004	Soquel 2005	San Lorenzo 2004	San Lorenzo 2005	Aptos 2004	Aptos 2005
Steelhead (*Oncorhynchus mykiss*)	🟨	🟨	🟨	🟨	🟧	🟧	🟥	🟥	🟫	🟫
Coho Salmon (*Oncorhynchus kisutch*)		🟨		🟨						
Threespine Stickleback (*Gasterosteus aculeatus*)	🟨	🟨	🟨	🟨	🟧	🟧	🟥	🟥	🟫	🟫
Staghorn Sculpin (*Leptocottus armatus*)	🟨	🟨	🟨	🟨	🟧	🟧	🟥	🟥	🟫	🟫
Prickly Sculpin (*Cottus asper*)	🟨	🟨	🟨	🟨	🟧	🟧	🟥	🟥	🟫	🟫
Starry Flounder (*Platichthys stellatus*)	🟨	🟨		🟨	🟧	🟧	🟥	🟥	🟫	🟫
Tidewater Goby (*Eucyclogobius newberryi*)	🟨	🟨	🟨	🟨			🟥		🟫	🟫
Topsmelt (*Atherinops affinis*)					🟧		🟥	🟥	🟫	🟫
Shiner Surfperch (*Cymatogaster aggregata*)							🟥	🟥		
Surf Smelt (*Hypomesus pretiosus*)							🟥			
Bay Pipefish (*Syngnathus leptorhynchus*)					🟧		🟥		🟫	
Dwarf Surfperch (*Micrometrus minimus*)							🟥			
Sacramento Sucker (*Catostomus occidentalis*)					🟧	🟧	🟥	🟥		
Pacific Herring (*Clupea pallasii*)							🟥	🟥		
Arrow Goby (*Clevelandia ios*)							🟥			
Redtail Surfperch (*Amphistichus rhodoterus*)									🟫	
Barred Surfperch (*Amphistichus argenteus*)								🟥		

Colored squares indicate which species were present in each lagoon during the course of each sampling season.



Composition of fish catch is shown as the contribution towards total biomass by each species. Note that the scale for the San Lorenzo graph is an order of magnitude larger than the others.

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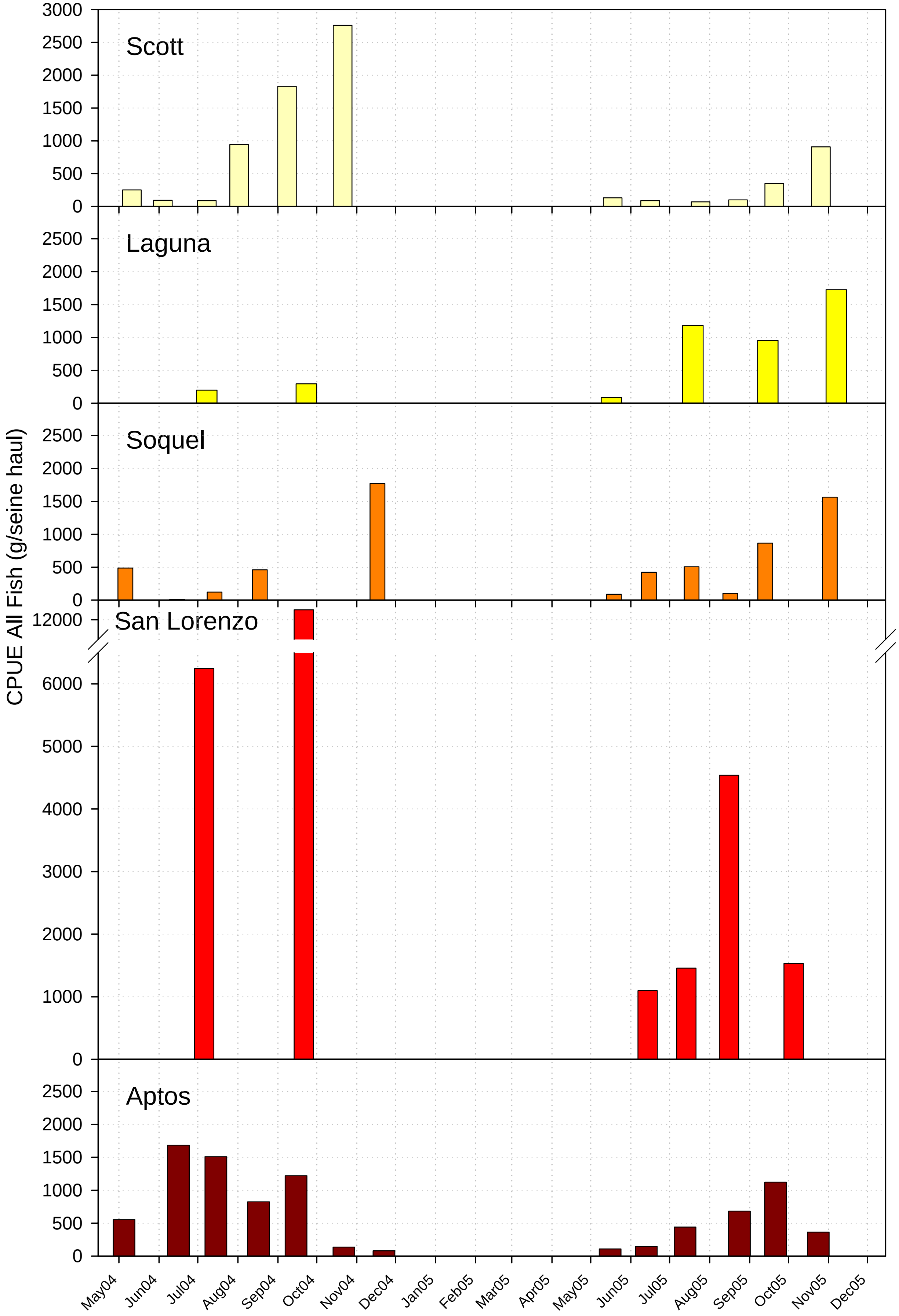
TOTAL FISH CATCH BIOMASS BY SPECIES

FIGURE 12.22



Total catch per unit effort (CPUE) is calculated as the total mass of the catch divided by the number of seine hauls for each sampling day. Note that the scale for San Lorenzo is much larger than the others.

ALL FISH CPUE

FIGURE 12.23

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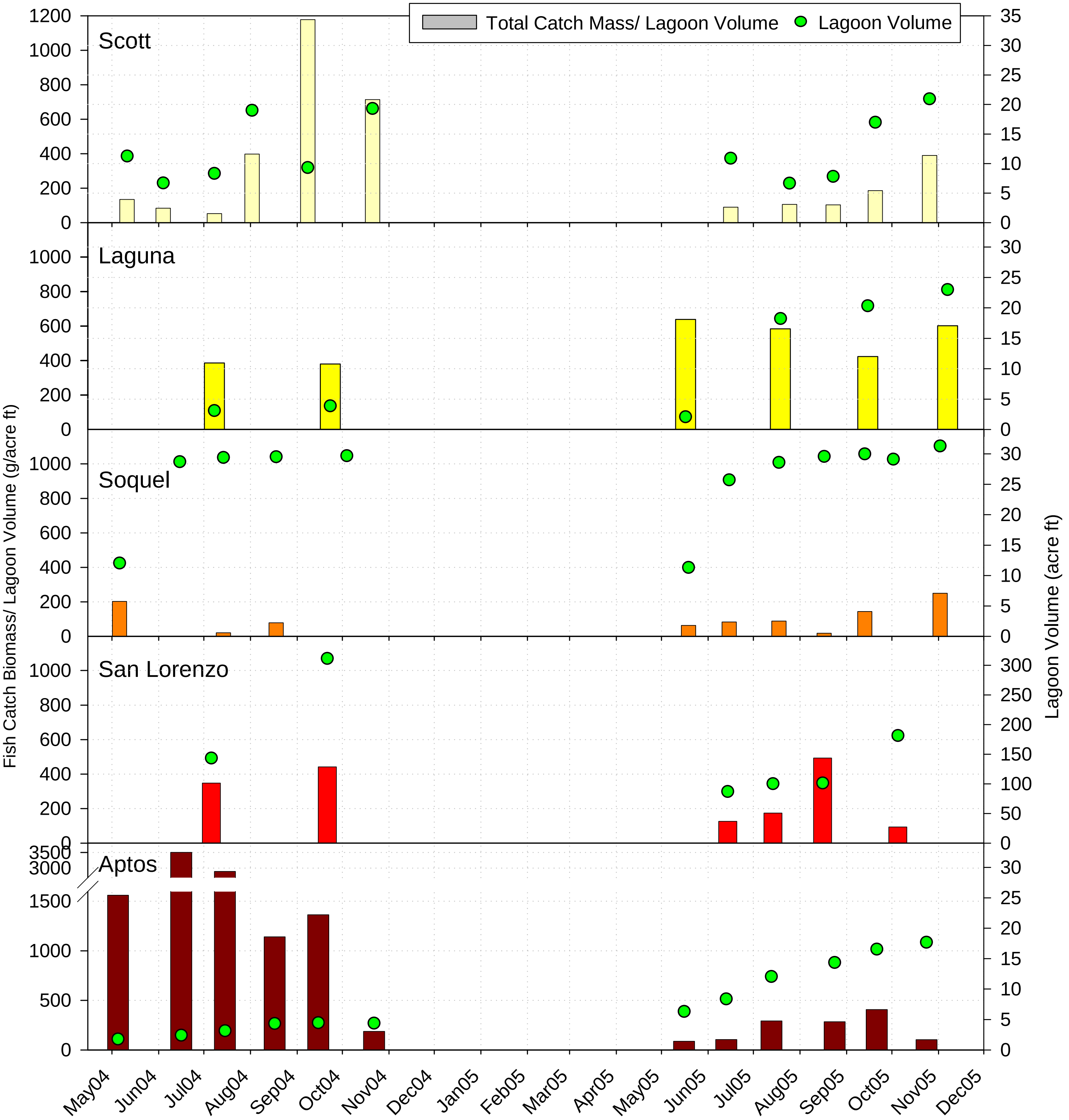
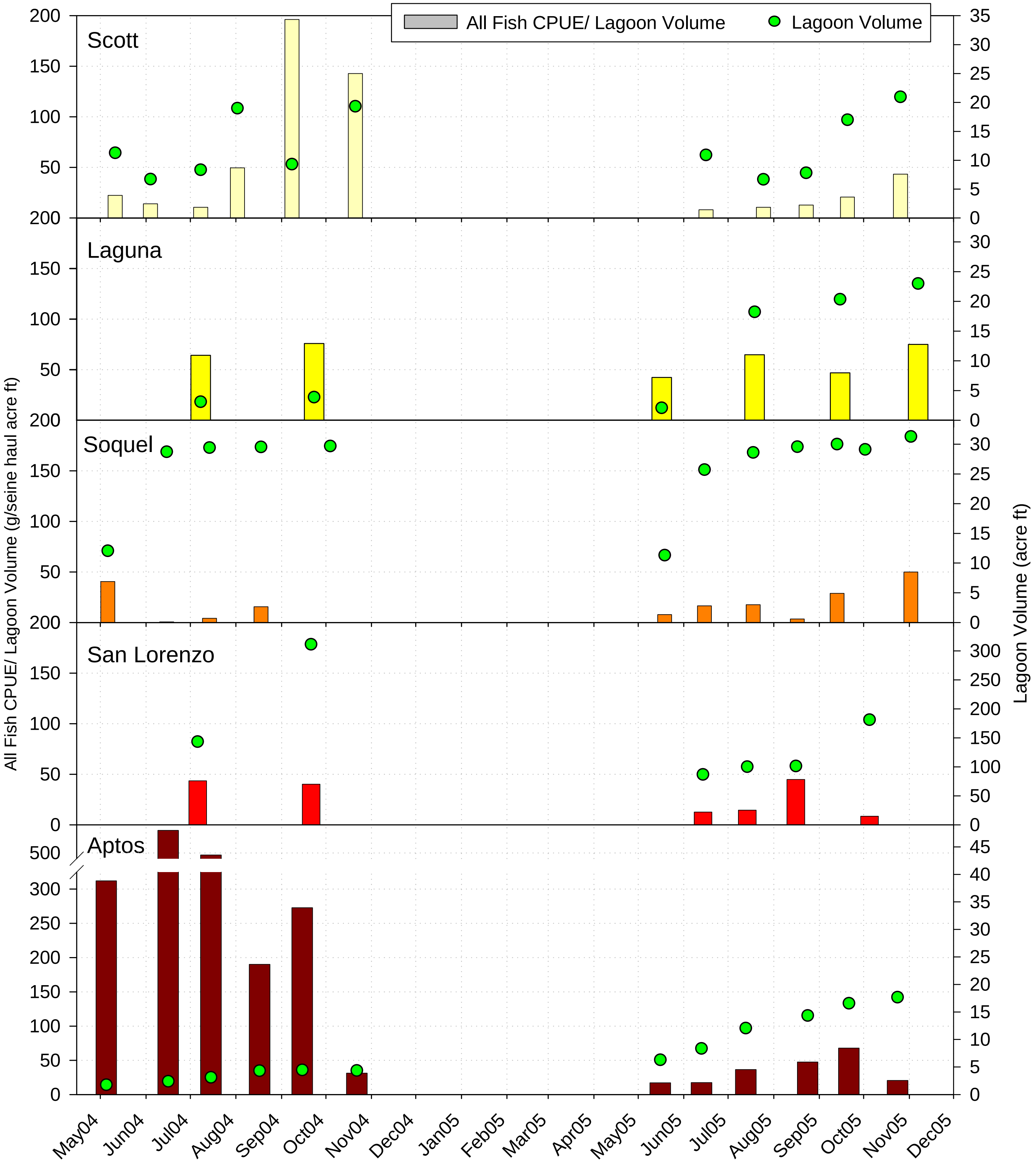


Total catch is normalized by lagoon volume. Lagoon volume (shown as green circles) is calculated as the average for the four days before and including the lagoon sampling day . Note that the scale for Fish Catch Biomass/Lagoon Volume is much larger for Aptos, and the Lagoon Volume scale is much larger for San Lorenzo.

TOTAL FISH CATCH BY LAGOON VOLUME

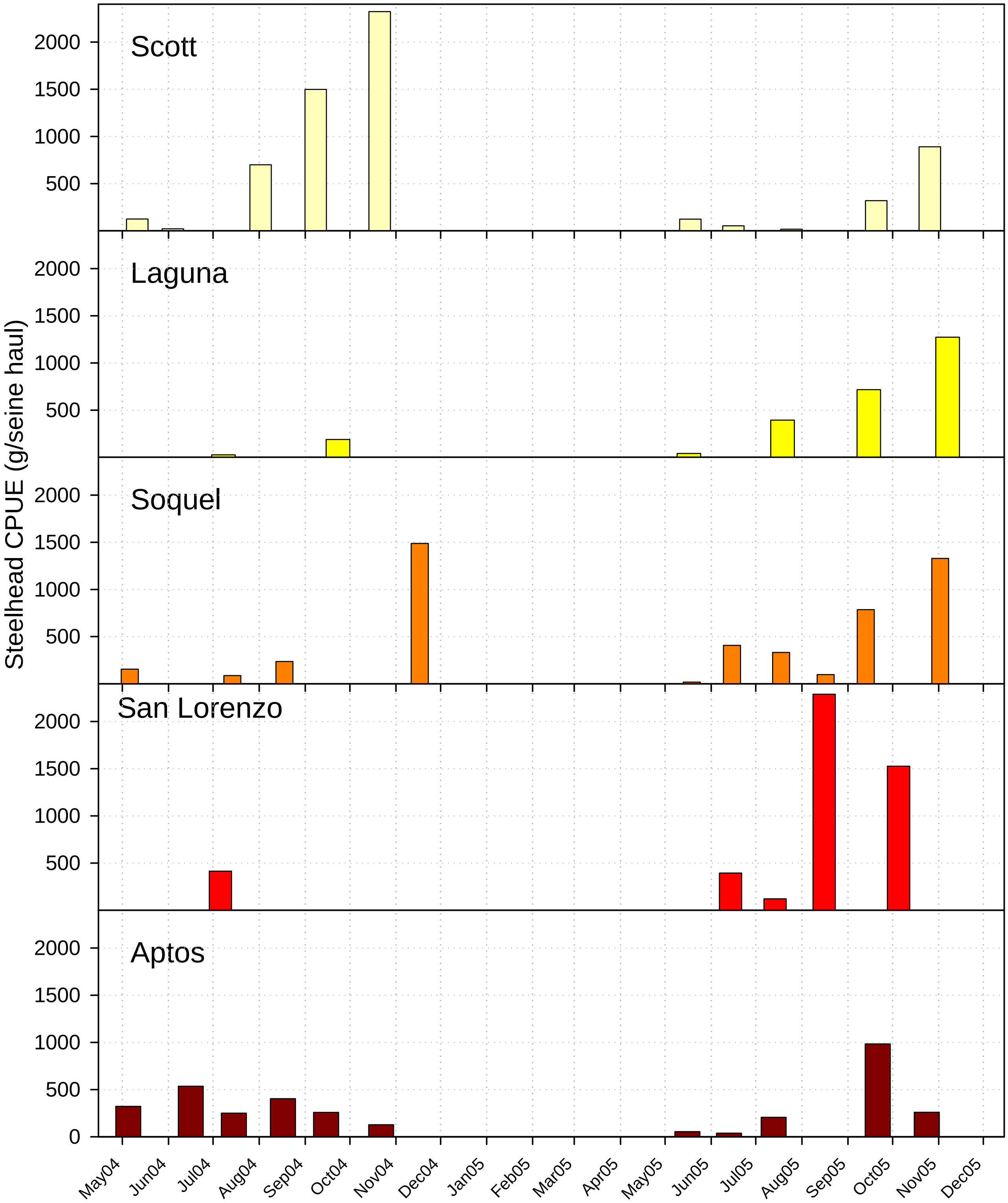
FIGURE 12.24



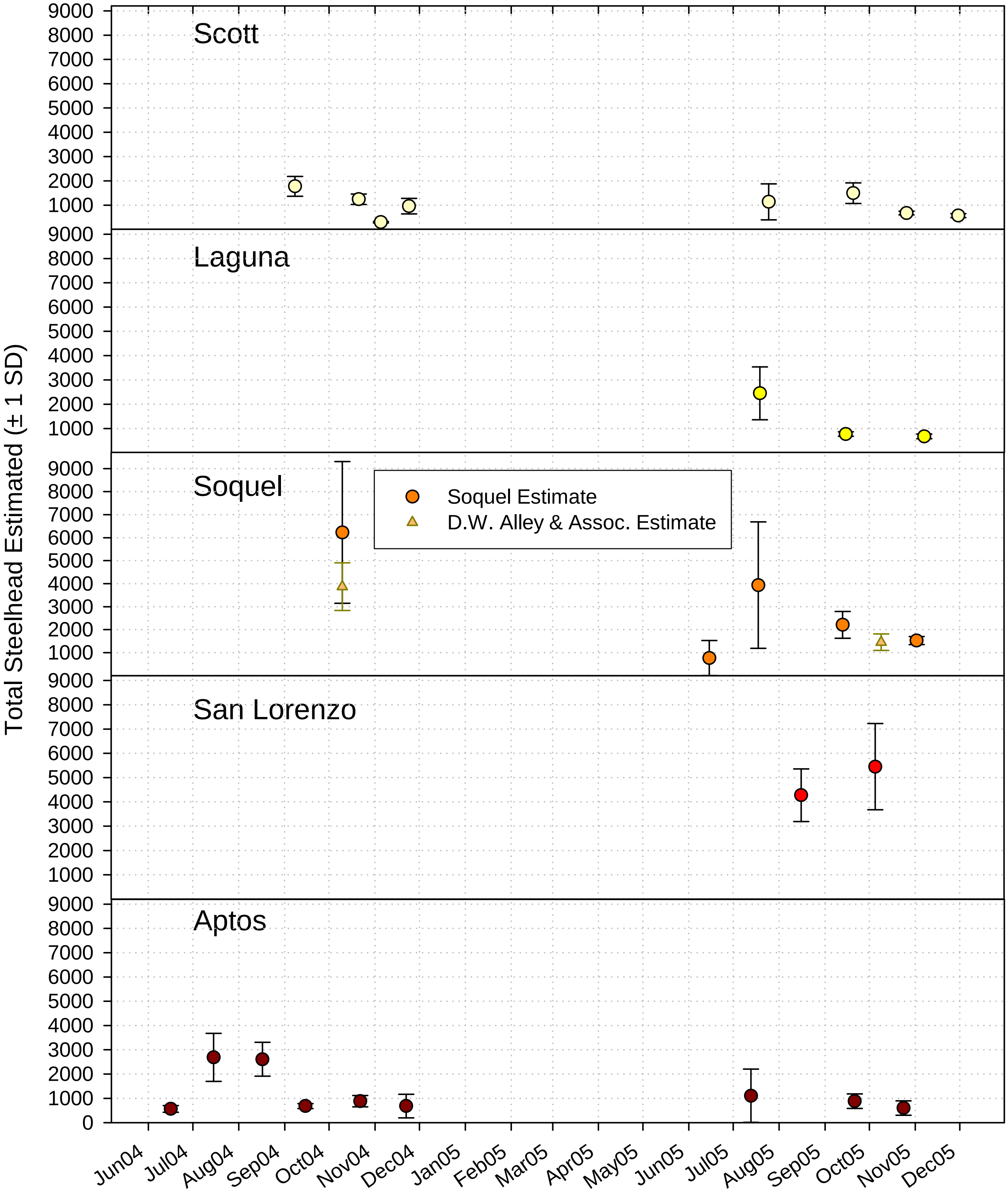
Total catch is normalized by number of seine hauls and lagoon volume for each sampling day. Lagoon volume is shown as green circles. Note that the scale for CPUE/Lagoon Volume for Aptos is much larger than the others, and the Lagoon Volume scale is larger for San Lorenzo.

ALL FISH CPUE BY LAGOON VOLUME

FIGURE 12.25



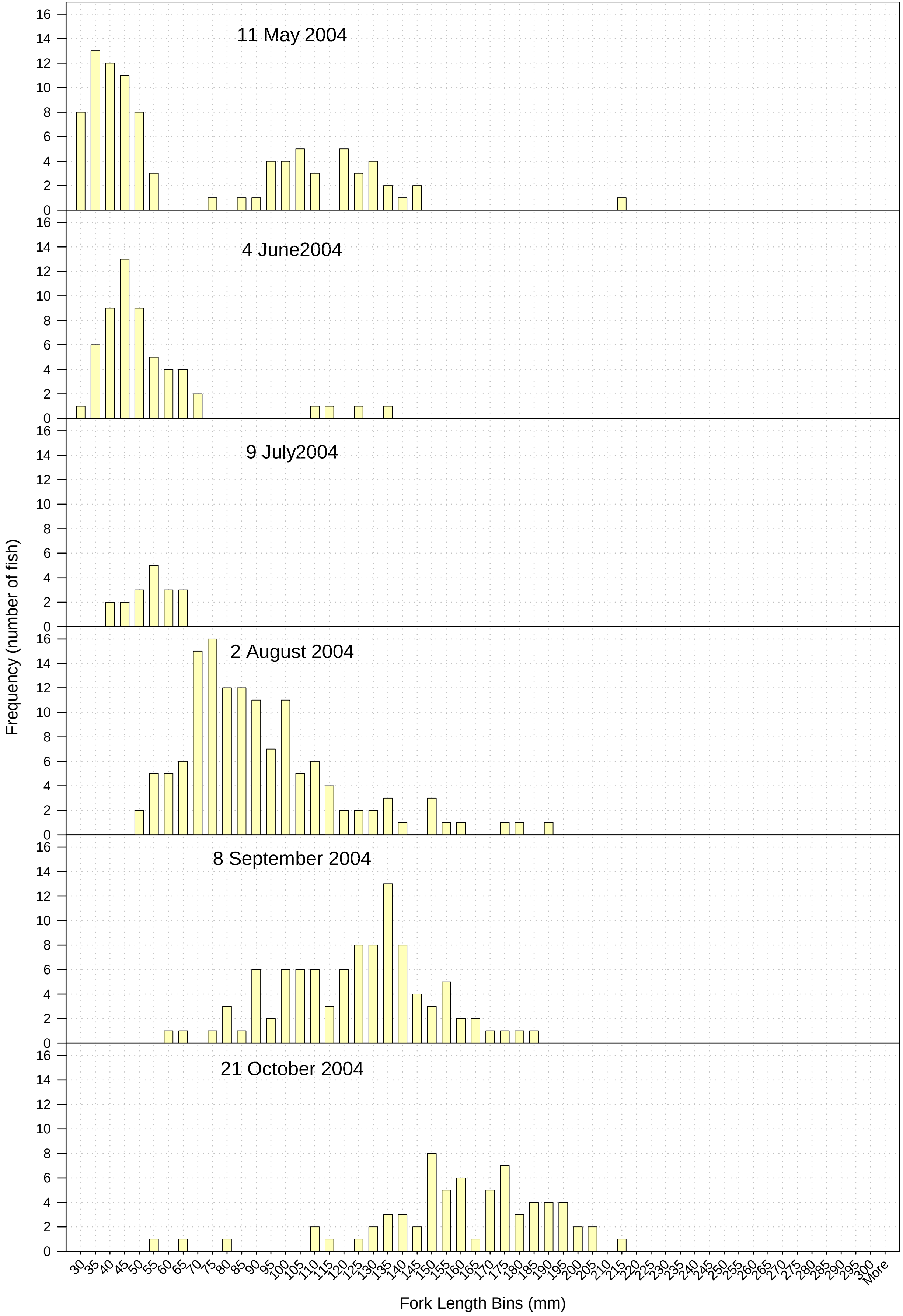
Catch per unit effort (CPUE) for steelhead is expressed as total mass of steelhead caught divided by number of seine hauls on each sampling day.



Population sizes were estimated using a mark-recapture calculation. By knowing the number of steelhead previously marked, the number of steelhead caught and the number of recaptures on a specific date, total populations ± 1SD were calculated (Note: Error bars for D.W. Alley & Associates estimates denote ± 1 standard error). Because determining population size was not the primary goal of this study, the lagoons were sampled as frequently as every month at best, and less frequently in Laguna and San Lorenzo (see sampling calendar for exact sampling schedule). Due to the relatively long time period between sampling, population sizes may be overestimated.

STEELHEAD POPULATION ESTIMATES

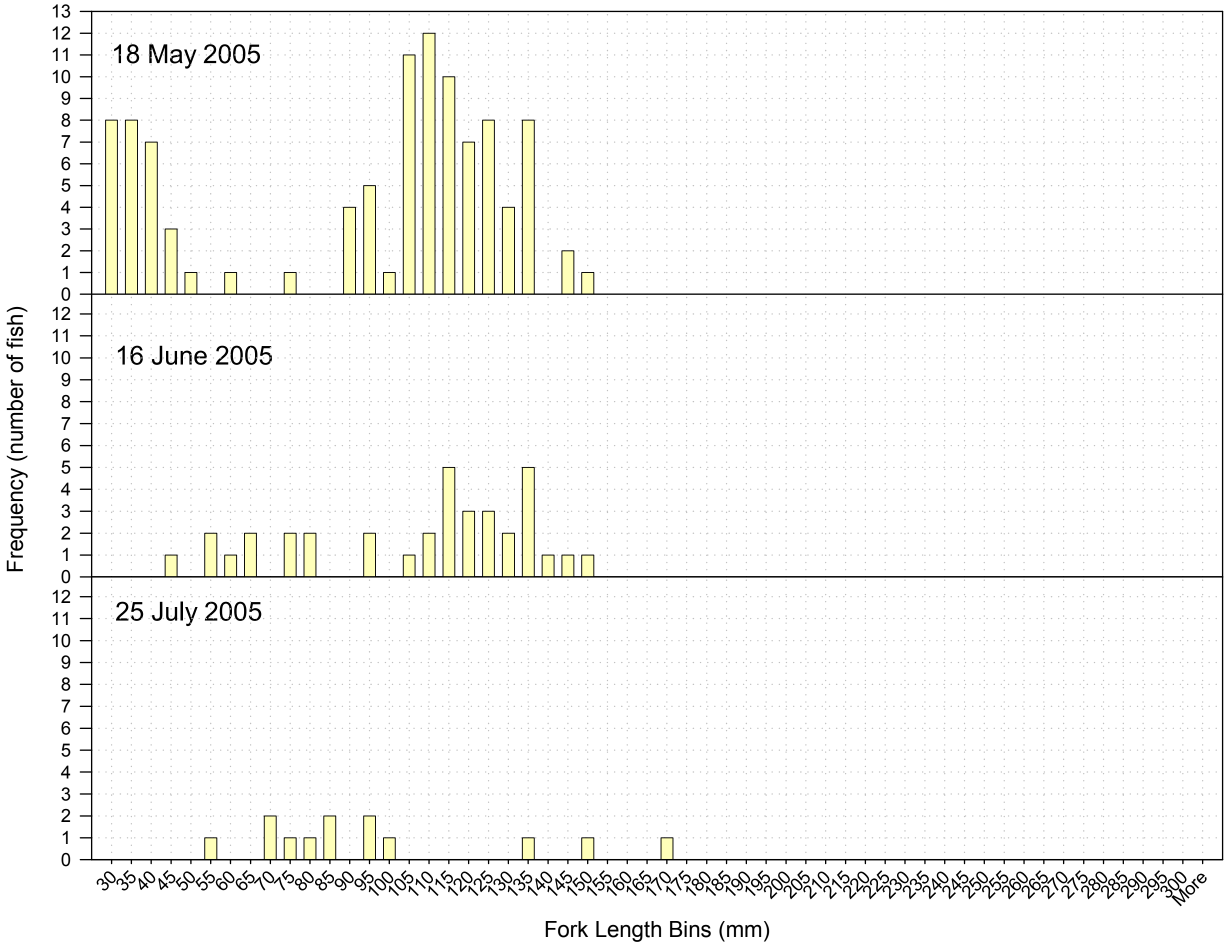
FIGURE 12.27



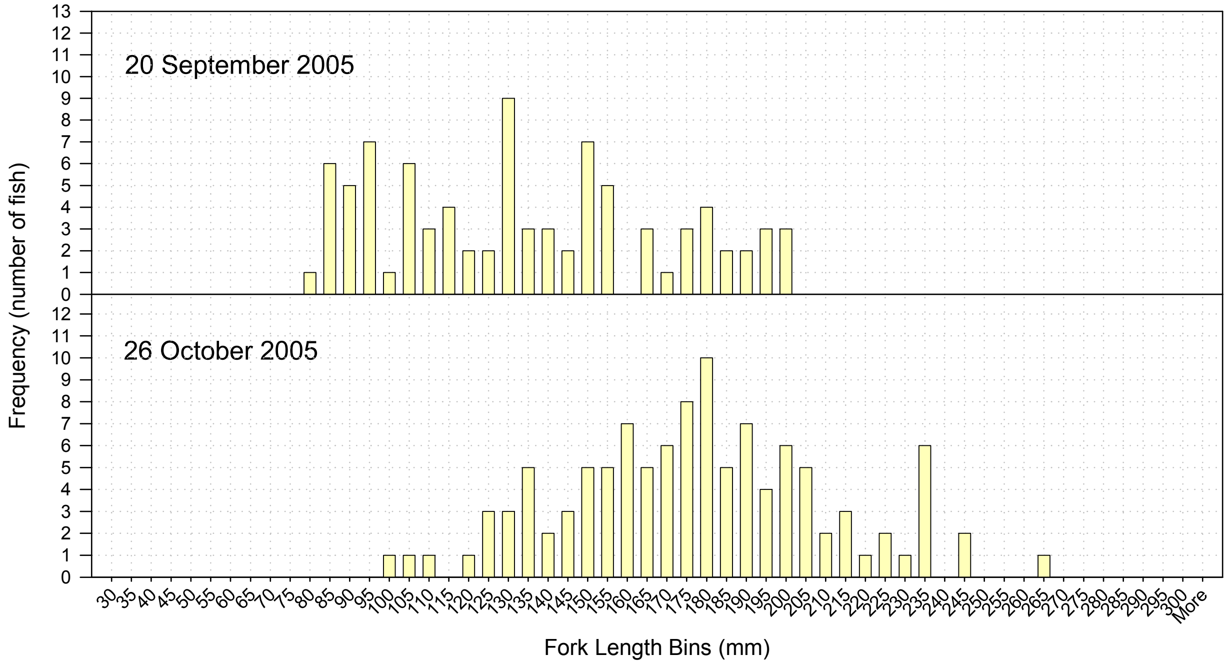
Numbers of steelhead are shown at each 5mm fork length bin for each sampling date.
Notice the appearance/disappearance of different age classes at different times of the year.

SCOTT 2004 STEELHEAD LENGTH - FREQUENCY HISTOGRAMS

FIGURE 12.28

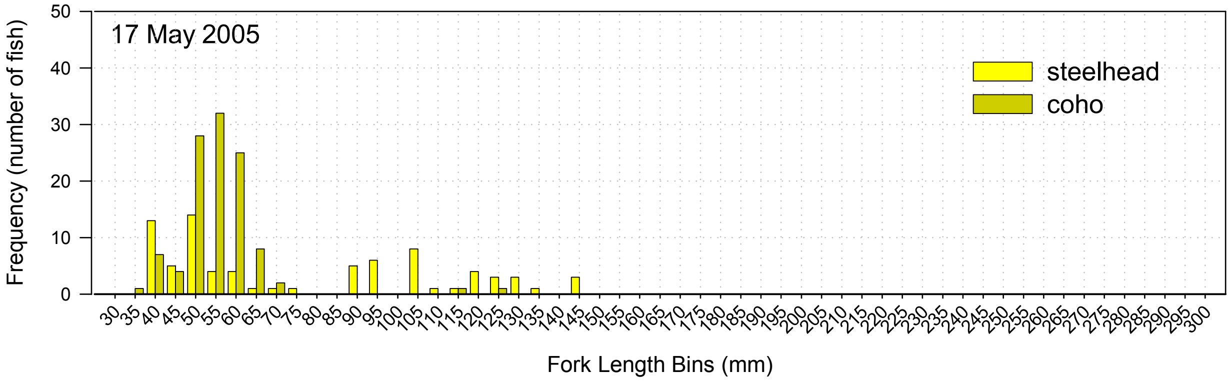


Numbers of steelhead are shown at each 5mm fork length bin for each sampling date.
Notice the appearance/disappearance of different age classes at different times of the year.

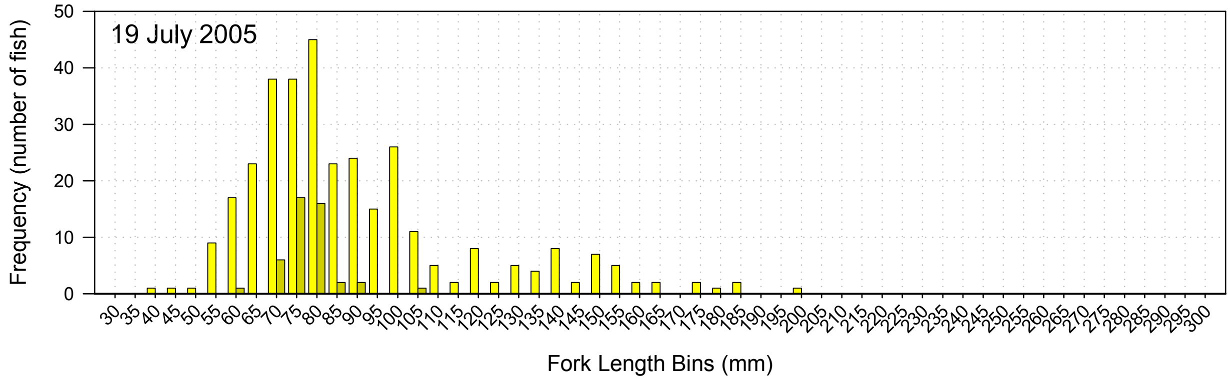


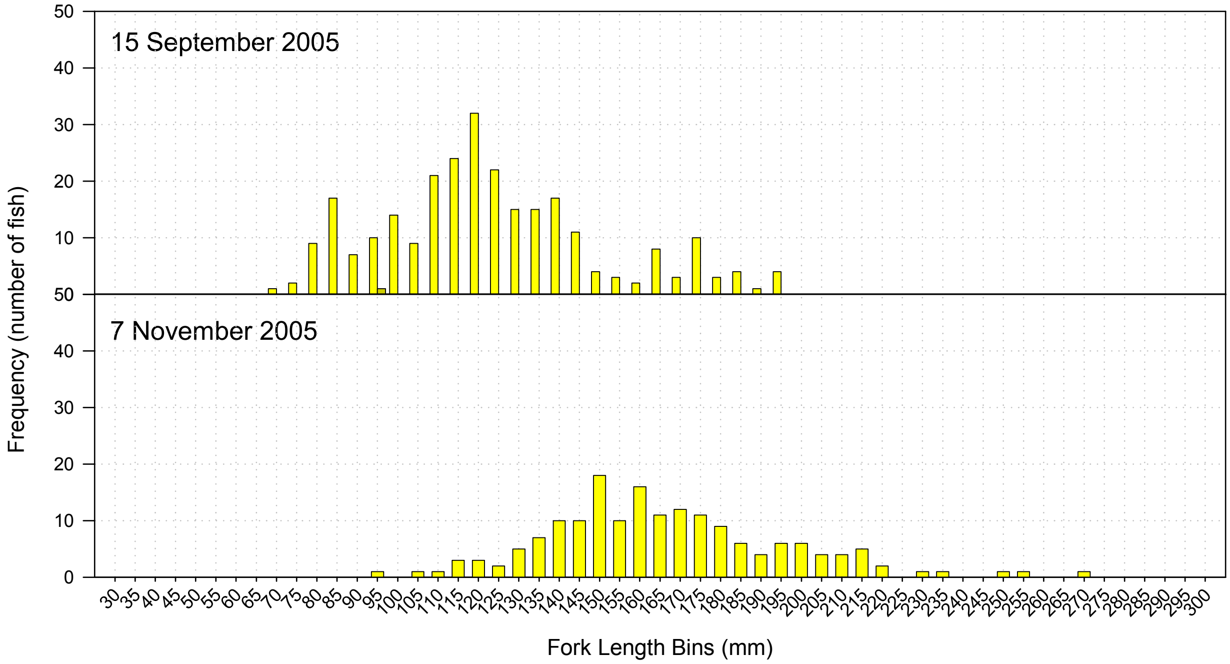
SCOTT 2005 STEELHEAD LENGTH - FREQUENCY HISTOGRAMS

FIGURE 12.29



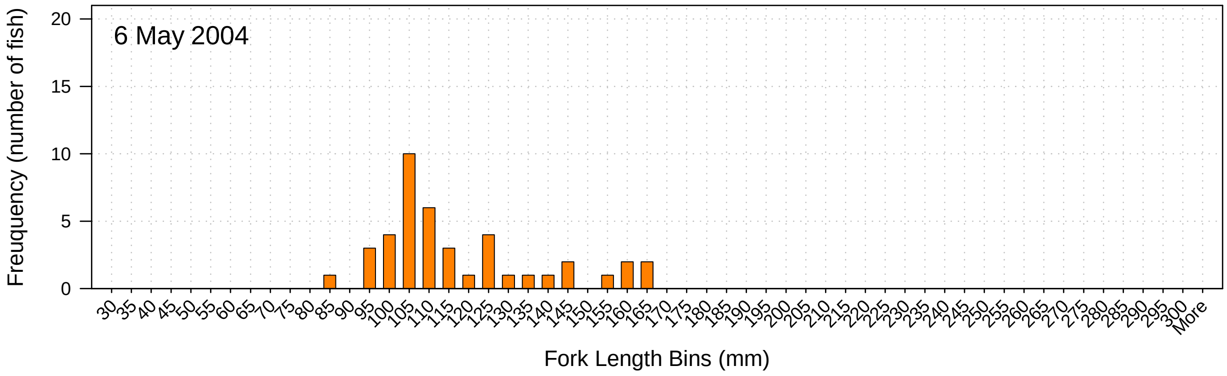
Numbers of steelhead are shown at each 5mm fork length bin for each sampling date.
Notice the appearance/disappearance of different age classes at different times of the year.



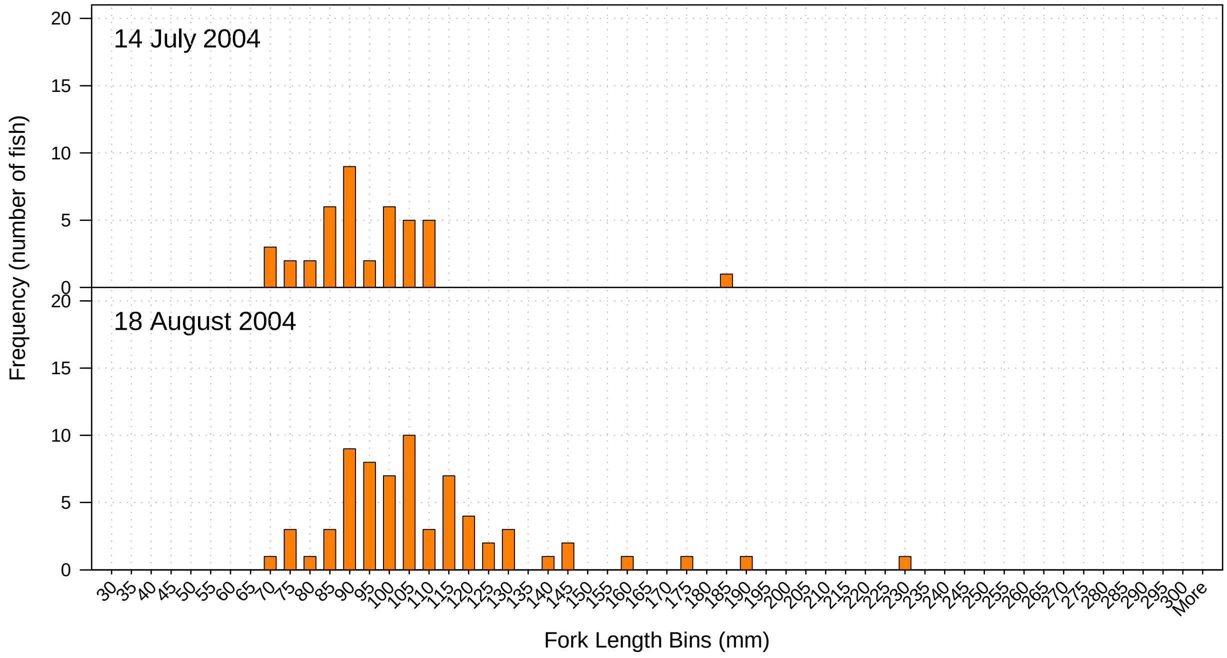


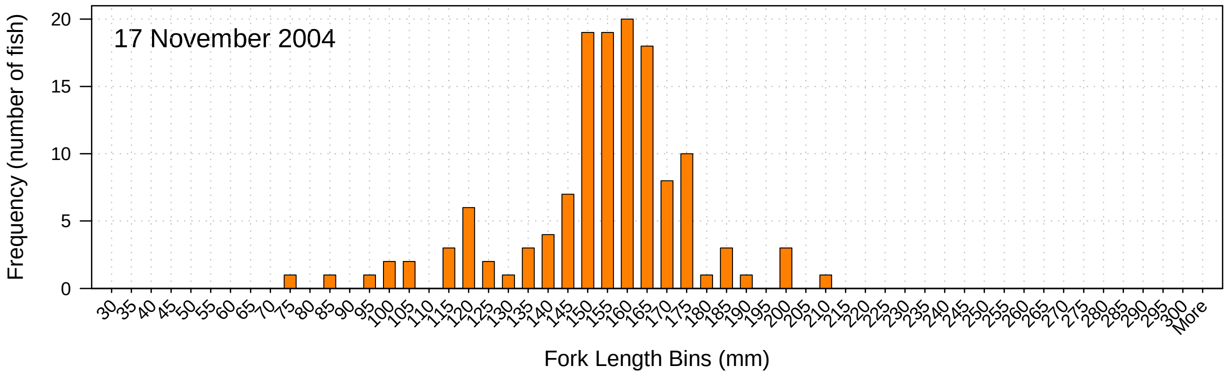
LAGUNA 2005 STEELHEAD AND COHO
LENGTH - FREQUENCY HISTOGRAMS

FIGURE 12.30



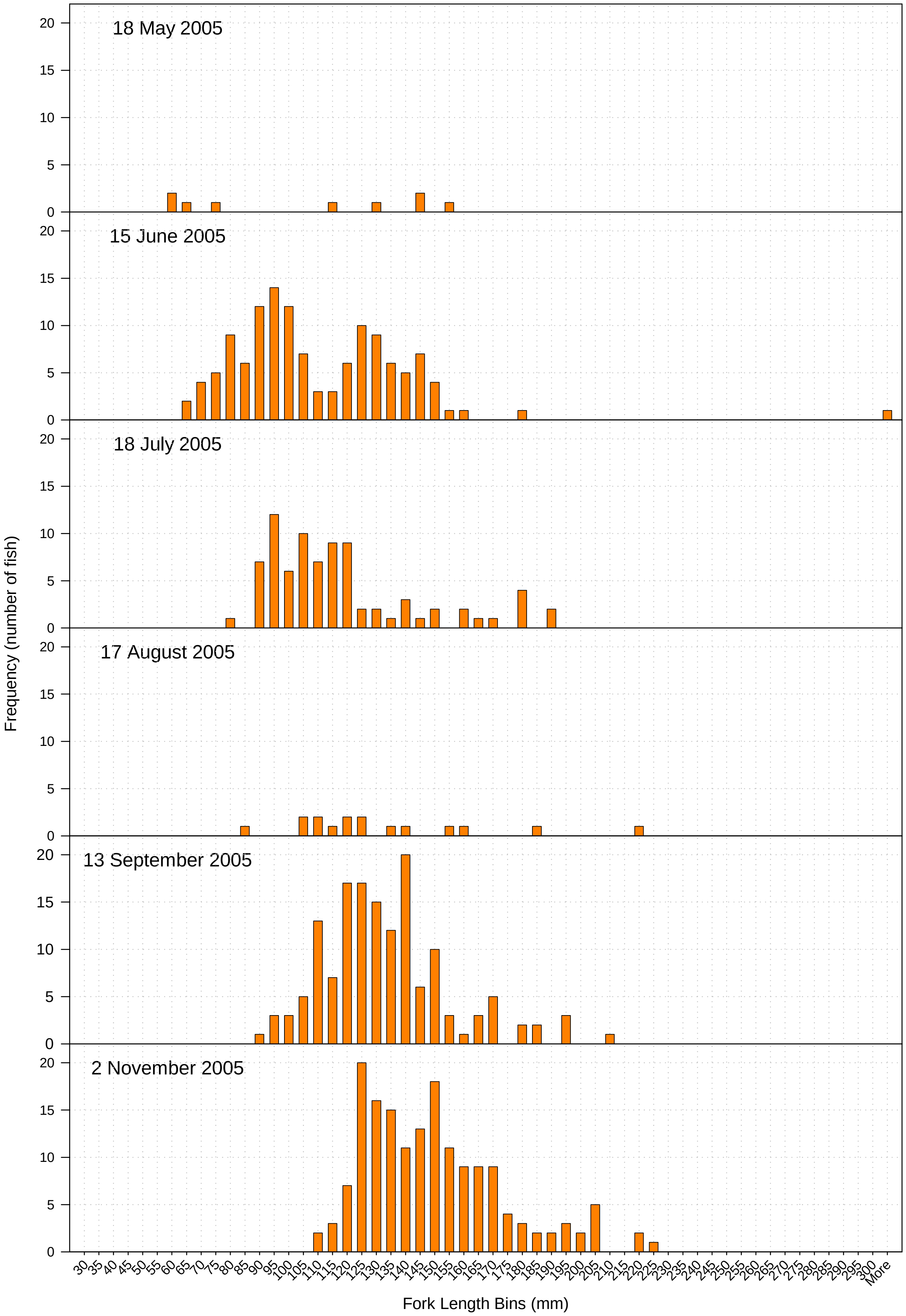
Numbers of steelhead are shown at each 5mm fork length bin for each sampling date.
Notice the appearance/disappearance of different age classes at different times of the year.





SOQUEL 2004 STEELHEAD LENGTH - FREQUENCY HISTOGRAMS

FIGURE 12.31



Numbers of steelhead are shown at each 5mm fork length bin for each sampling date.
Notice the appearance/disappearance of different age classes at different times of the year.

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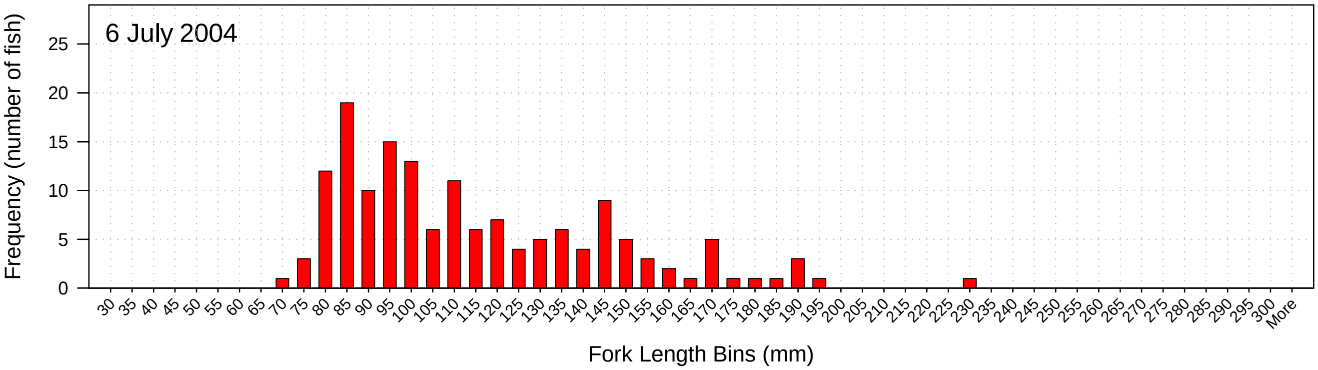
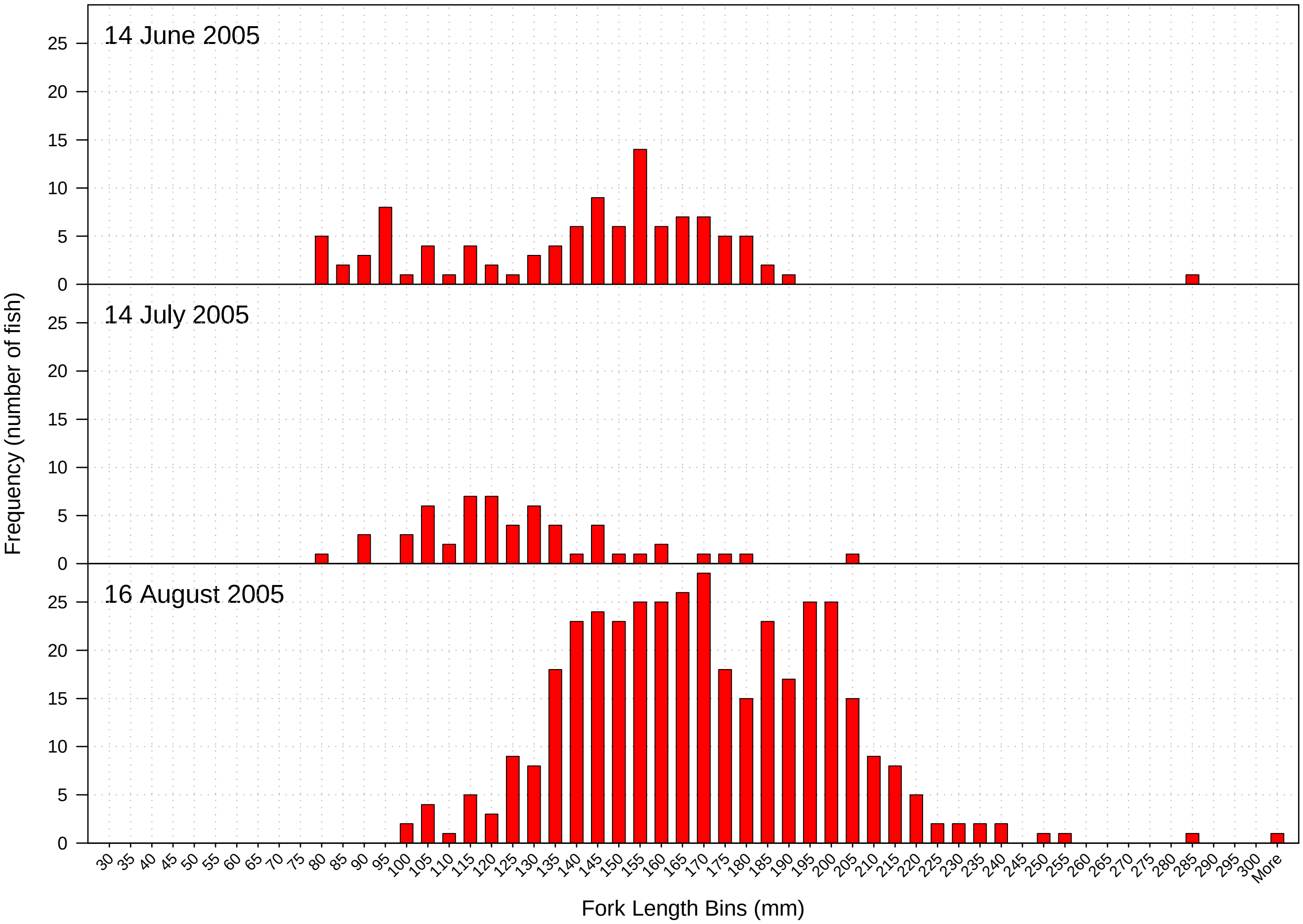
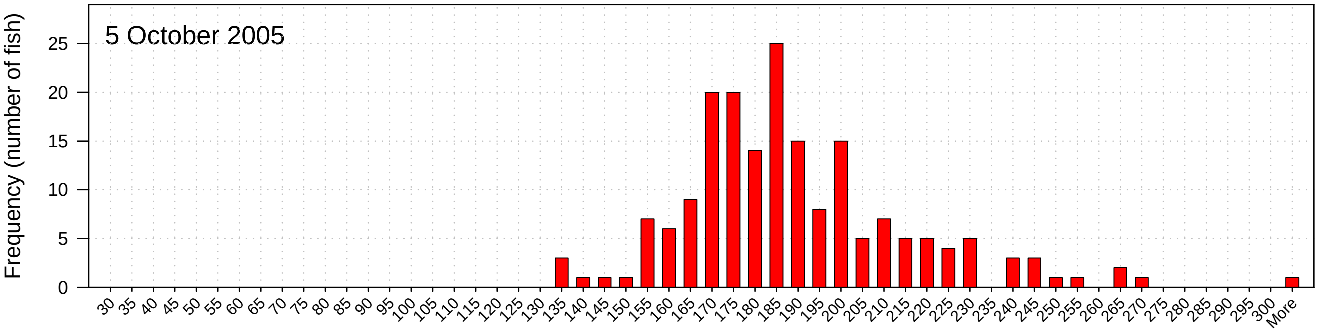
SOQUEL 2005 STEELHEAD LENGTH - FREQUENCY HISTOGRAMS

FIGURE 12.32



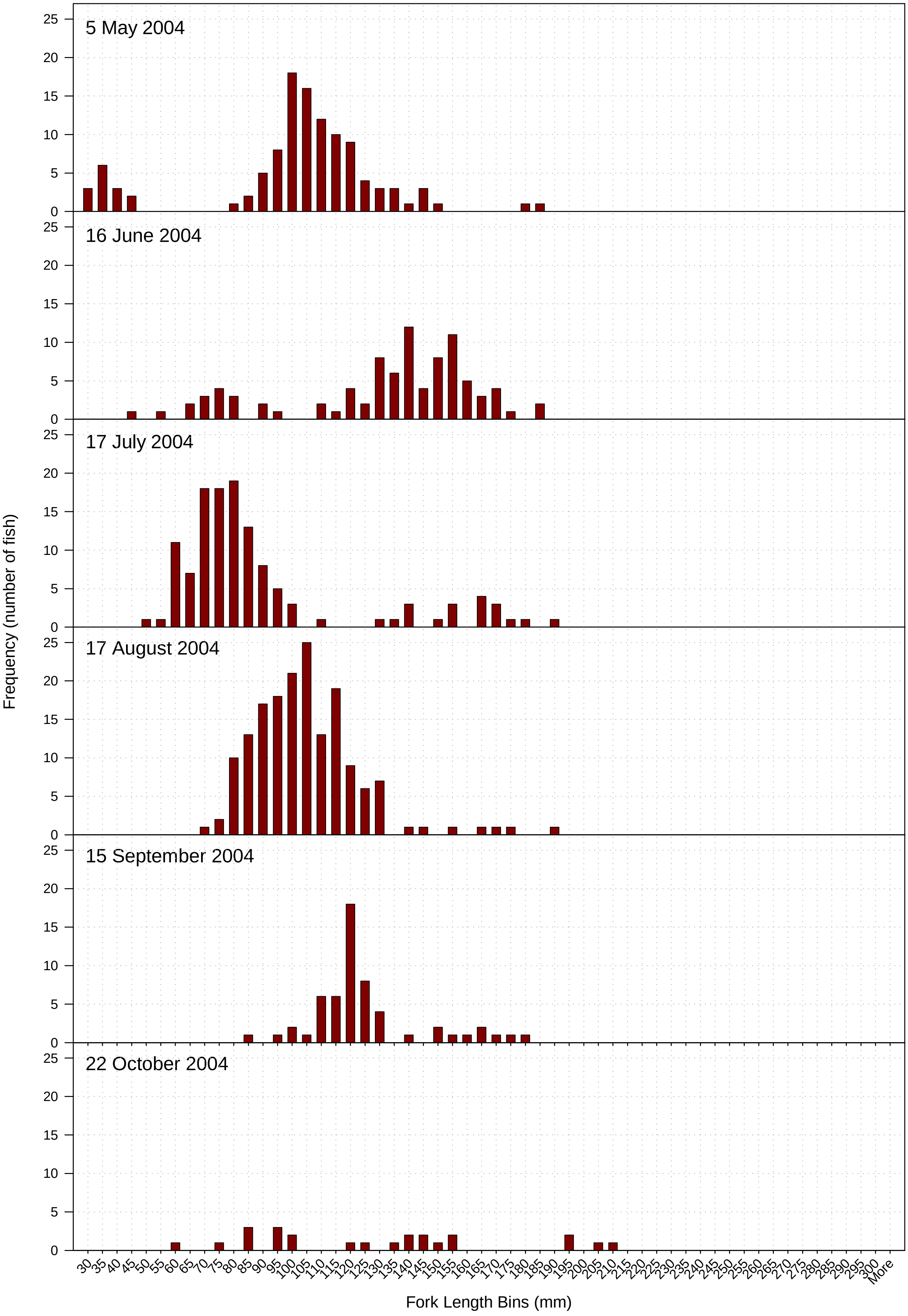


Numbers of steelhead are shown at each 5mm fork length bin for each sampling date.
Notice the appearance/disappearance of different age classes at different times of the year.



SAN LORENZO 2004 AND 2005
STEELHEAD LENGTH - FREQUENCY HISTOGRAMS

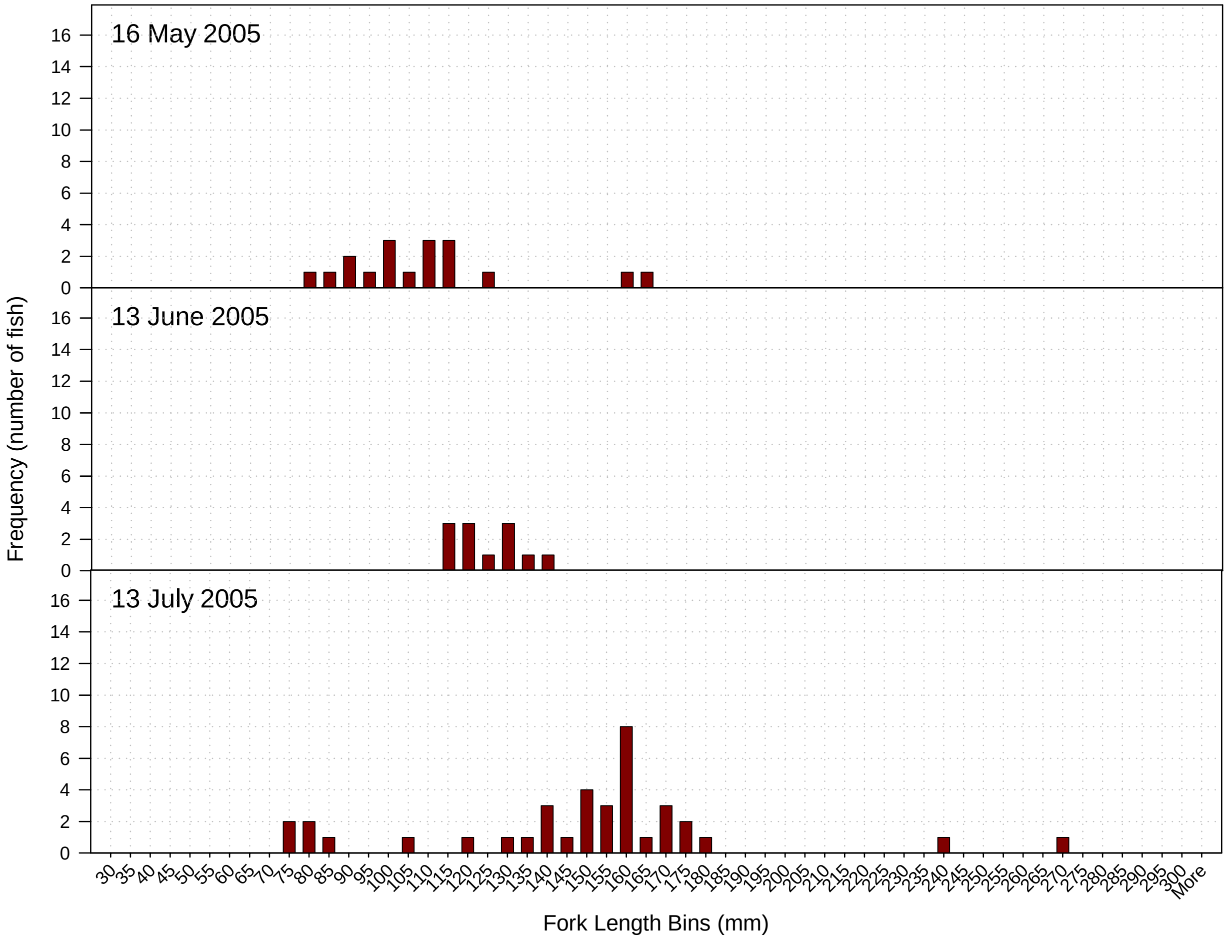
FIGURE 12.33



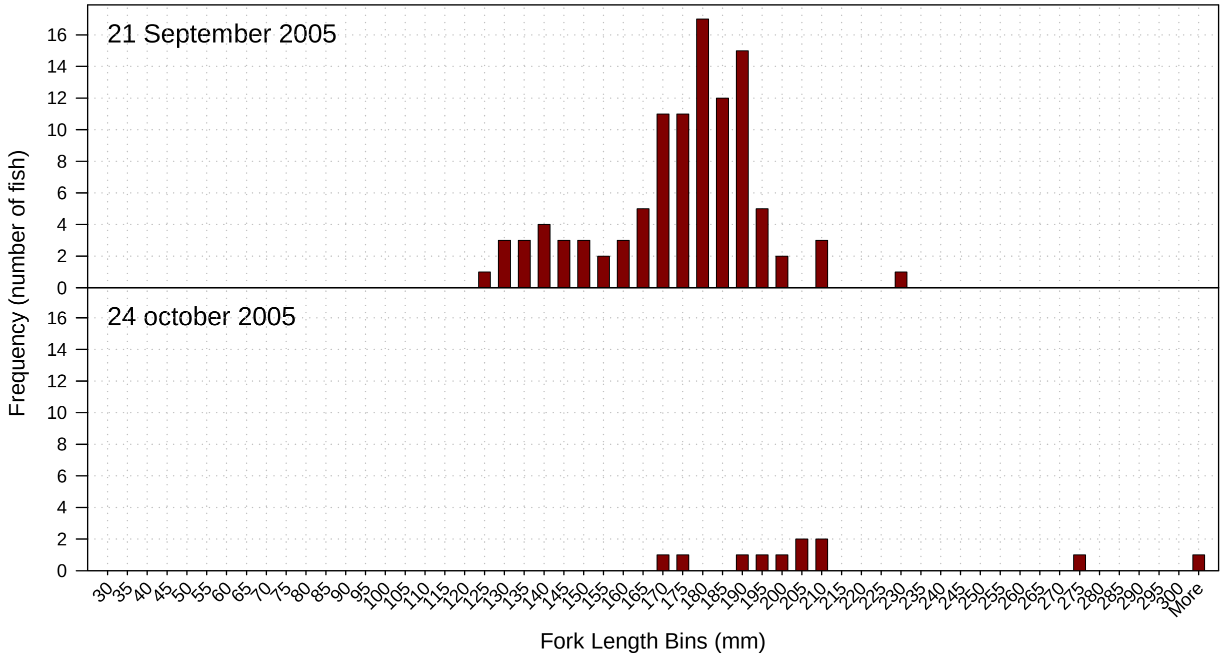
Numbers of steelhead are shown at each 5mm fork length bin for each sampling date.
Notice the appearance/disappearance of different age classes at different times of the year.

APTOS 2004 STEELHEAD LENGTH - FREQUENCY HISTOGRAMS

FIGURE 12.34

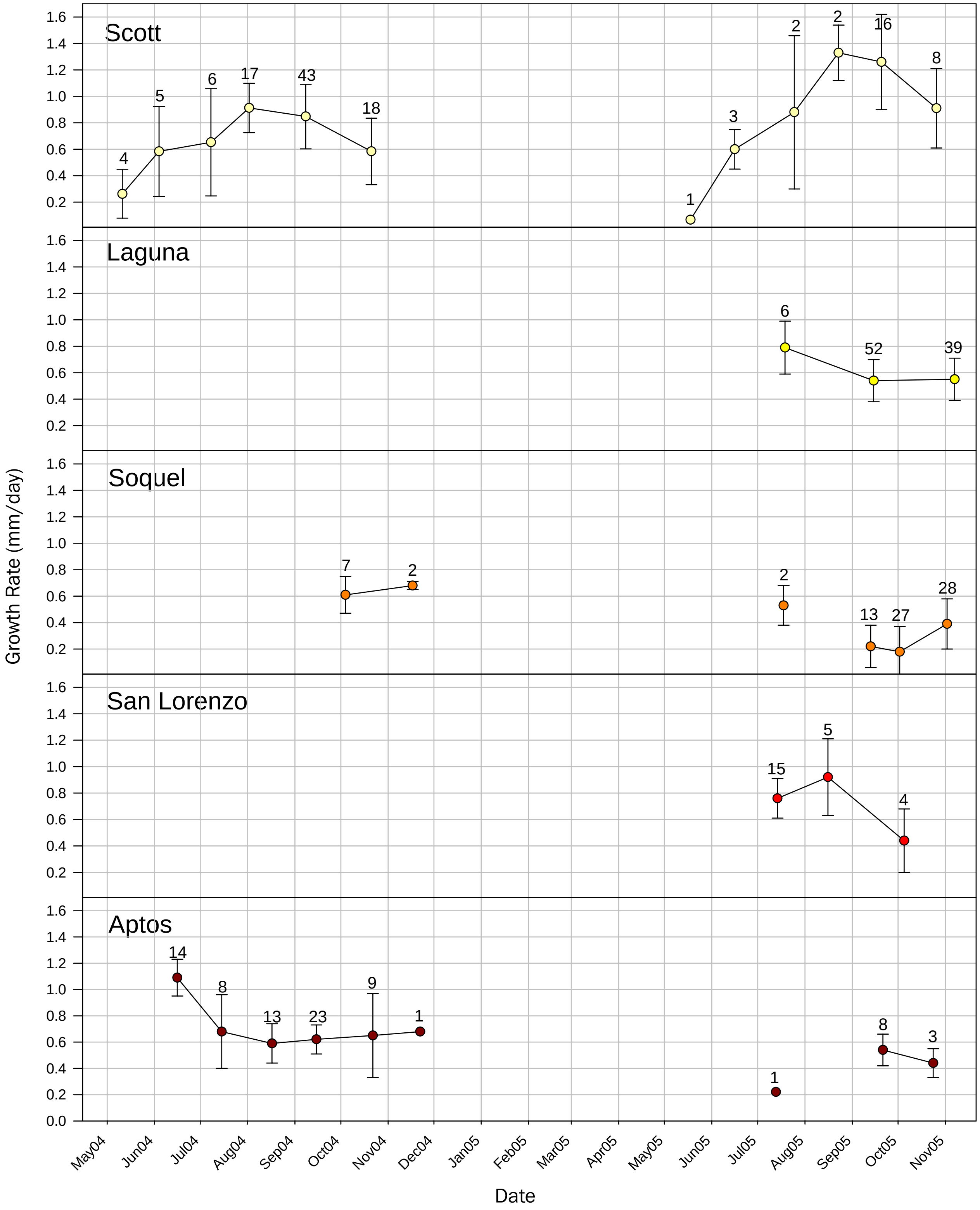


Numbers of steelhead are shown at each 5mm fork length bin for each sampling date.
Notice the appearance/disappearance of different age classes at different times of the year.



APTOS 2005 STEELHEAD LENGTH - FREQUENCY HISTOGRAMS

FIGURE 12.35



Numbers in each graph represent the sample size used to calculate growth rates.

STEELHEAD GROWTH RATES

FIGURE 12.36

13. Existing Santa Cruz Lagoon Management

Regular restoration and management of the seasonal lagoon systems are not the dedicated responsibility of any one particular resource management agency in Santa Cruz County; several agencies have permit authority over activities proposed in these systems. Depending on the concern, such as water quality, flood control, and/or public safety or access, local agencies may take occasional actions to manage these issues within the lagoon areas. State agencies with mandated responsibilities for resource protection in lagoon systems include the California Department of Fish and Game and California Coastal Commission. Federal agencies with mandates for protecting lagoon habitats for endangered species include the U.S. Fish and Wildlife Service and NOAA Fisheries.

The perception by neighbors and the general public of the Santa Cruz County lagoon systems is one of a nuisance due to odor, constriction of beach access, and water quality degradation. In general, most community members and the public are unaware of the importance of lagoons as fisheries habitat. This was clearly evident on CLEAP fish sampling days when people commonly asked about the lagoons and the fish being sampled. Many expressed that they did not know lagoons were important to fish health. This may partially explain why each of the lagoons assessed by CLEAP is currently compromised by illegal breaching at the hands of the public.

Historically, these lagoons were also breached by different public agencies for various reasons, including water quality concerns, public safety and flood protection. However, with the listing of coho salmon and steelhead in the mid-1990s, increased permitting and resource management concerns put an end to most agency breaching requests.

The following is a brief discussion of the types of management actions that currently occur in the systems assessed by CLEAP.

SCOTT CREEK LAGOON

Scott Creek Lagoon is located on property owned by Santa Cruz County and California Polytechnic State University Swanton Pacific Ranch. The lagoon has no active management plan at this time and is not actively managed by either landowner or any other resource management agency. The landowners remain interested partners in potential future restoration at the lagoon. Scott Creek Lagoon is vulnerable to illegal breaching and enforcement remains sporadic due to its remote location.

LAGUNA CREEK LAGOON

Laguna Creek Lagoon had been in private ownership and was transferred to federal and then state ownership with the Coast Dairies property acquisition. The lagoon has no active management plan nor is there an entity that conducts management actions currently. California Department of Parks and Recreation is the current owner of the property and has expressed an interest in developing resource management and enhancement projects for the lagoon. Similar to Scott Lagoon, Laguna Creek Lagoon is vulnerable to illegal breaching and its remote location makes enforcement difficult.

SOQUEL CREEK LAGOON

Soquel Creek Lagoon was chosen for further study because it has an active management program. The management of the lagoon is conducted by the City of Capitola Public Works Department. The city recently completed an update of its 1990 Soquel Creek Management Plan, completing the Soquel Creek Lagoon Management and Enhancement Plan Update in June 2004.

For over 50 years the Soquel Creek Lagoon has been artificially closed before Memorial Day weekend by constructing a sandbar across the mouth of the creek to facilitate the hosting of the annual Begonia Festival and to provide habitat for endangered fish species. The 1990 Soquel Creek Management Plan was developed to provide adequate environmental protection and enable issuance of future permits associated with sandbar construction and the Begonia Festival (Alley 2004). The 1990 Management Plan specified how to construct the sandbar, when to make the flume passable for steelhead migration, and how to breach the sandbar in the fall to prevent flooding. The Plan prescribed how to maximize survival of smolting steelhead, provided guidelines to protect young steelhead using the lagoon as nursery habitat, and made recommendations on improving water quality and conducting public education actions.

After actively managing the lagoon for over 10 years utilizing the recommendations in the 1990 plan, the City of Capitola wished to update the plan with new management techniques. The intent of the Plan Update was to focus attention on the value of the lagoon and its surrounding riparian corridor with renewed efforts to manage activities that impact the lagoon (Alley 2004). The 2004 update includes a number of new policies and actions focusing on fishery issues, bacterial count reduction in the lagoon and beach, management with a watershed perspective, streambank restoration, instream flow, water quality and public education. The artificial closure of the lagoon will continue under the new management plan as well. Other actions, such as “experimental habitats”, will be installed in the lagoon to provide escape cover. Monitoring of various management and restoration actions is also encouraged in the plan update.

Specifically, the 2004 plan includes policies and actions addressing the following priorities:

- Fish habitat restoration/protection
- Riparian vegetation enhancement
- Sandbar construction activities
- Lagoon management
- Emergency sandbar breaching
- Sediment reduction
- Summer water temperature reduction
- Nonpoint source pollution reduction
- Instream flow protection

SAN LORENZO RIVER LAGOON

The San Lorenzo River Lagoon is managed according to a plan completed in January 2002 by the City of Santa Cruz. The Lower San Lorenzo River and Lagoon Management Plan is part of the San Lorenzo Urban River Plan (2003) and provides specific recommendations for restoration actions to improve fish and wildlife habitat. However, actions are only conducted when funding is available and the City does not participate in any annual actions, except for flood control-related vegetation management in the area of the river between Soquel Avenue and Highway One.

Prior to the plan update in 2002, there was the 1989 San Lorenzo River Enhancement Plan that laid the groundwork for the management and habitat enhancement of the San Lorenzo River from 1989 to 2000. The 1989 Plan was developed in response to the revised U.S. Army Corps of Engineers plan to abandon maintenance dredging in the flood control channel and improve flood capacity by raising the levees in downtown Santa Cruz. The 1989 Plan included recommendations for riparian restoration on the streambanks, lagoon management to provide fisheries habitat, and operations and maintenance refinements for vegetation and sediment management within the flood control channel area of the river.

Improvements associated with the 1989 Plan include installation of new storm drains, abandonment of basements in downtown buildings to alleviate flooding when the lagoon is in a closed condition, and the ceasing of sandbar breaching in 1995.

In reviewing the issues associated with lagoon health during the preparation of the 2002 plan, the city identified several resource constraints that needed to be addressed, including:

- Current channel geomorphic conditions,
- Limiting factors for maintaining habitat for endangered species, and
- Chemical, physical and biological conditions that may affect water quality and habitat for endangered species.

Most pressing was developing a plan that would reflect projected flood elevations and channel conditions after the U.S. Army Corps of Engineers levee upgrade project in 1993-2003. The 2002 Plan therefore focused on management prescriptions that would enhance conditions for anadromous fish and terrestrial species, maintain adequate flood capacity to convey 100-year flow events, adaptively manage the system, and provide for monitoring of river and species conditions.

The 2002 Plan includes three management recommendations and three restoration recommendations:

- Management Recommendation 1: Develop annual vegetation and sediment management plan for flood control maintenance.
- Management Recommendation 2: Continue scientific analysis of summer lagoon water level management.
- Management Recommendation 3: Establish a flow standard for inflow into the lagoon and maintenance of a low flow channel.
- Restoration Recommendation 1: Enhance streambed aquatic cover and substrate in estuarine and transitional reaches.
- Restoration Recommendation 2: Enhance riverbank shoreline habitat in transitional and estuarine reaches.
- Restoration Recommendation 3: Enhance riverbank shoreline and riparian corridor vegetation.

The 2002 Plan also includes an ecological monitoring program and discusses the benefits of expanding the floodplain area of the river to achieve greater geomorphic and hydrologic function in the system.

APTOS CREEK LAGOON

Aptos Creek Lagoon forms on California Department of Parks and Recreation property at Seacliff State Beach. Historically, the lagoon has been breached to address water quality concerns of residents and beach users. These breaches were conducted by the Department of Parks and Recreation with permits, through an MOU with the California Department of Fish and Game, and were monitored by fisheries biologists. California Department of Parks and Recreation does not currently have an MOU for breaching Aptos Creek Lagoon and is interested in longer term solutions to managing this resource. Additionally, illegal breaching by the public has been an ongoing management concern for Aptos Creek due to its proximity to popular beaches and conflicts with water quality and high bacteria levels in the lagoon.

14. Existing Conditions and Enhancement Recommendations

Below we summarize the key physical, chemical and biological observations in each lagoon. The discussions are not intended to be exhaustive, but rather to highlight the existing conditions of each CLEAP lagoon as it relates to our understanding of lagoon function, seasonal changes within each lagoon, and site comparisons. Based on the site-specific data, observations and the results of stressor and indicator testing, the primary limitations assumed to cause biological stress in each lagoon are discussed. In some instances we provide conceptual preliminary enhancement recommendations that target actions that may alleviate identified stressors.

NORTH COAST LAGOONS

Scott Lagoon

In most instances, conditions in Scott Lagoon represent the least impacted of the unmanaged lagoons. While the lagoon is currently 16% of its original size, the watershed land use impacts and inflowing nitrogen levels are relatively low. Highway One dissects the lagoon approximately 1500ft from the shore zone and abruptly defines the transition from the beach sand environment to the marsh/lagoon habitat. The hydrologic connection between the lagoon and the ocean is limited to a 120ft opening beneath the highway. There is minimal hydrologic access to the adjacent floodplain and marsh due to levee presence. Channel incision over time may have exacerbated this hydrologic disconnection. When the sandbar forms the water levels increase with little change in lagoon surface area. Inundation of the adjacent floodplain has only been observed following winter rain events prior to sandbar breach. The combined confinement of the lagoon and the location of the Highway One bridge opening have resulted in over 30% of the summer lagoon area existing on top of beach sand. As discussed in detail in Section 11, Lagoon Water Budgets, observations and data suggest that surface water (water above ground) retention may limit Scott Lagoon habitat quality during below average precipitation years.

Scott Lagoon in November of 2003, following the first winter rains but prior to the sandbar breach. Notice the Highway One disection of the lagoon.

The most important contribution from Scott Lagoon towards our understanding of lagoon function is the comparison of habitat conditions and associated biological responses between the Scott Main Lagoon and the Scott Side Channel. Both the Scott Main Lagoon and the Scott Side Channel are subjected to the exact same inflowing freshwater source from the upper watershed, with the same relatively low DIN concentrations. We attribute the observed susceptibility to eutrophication, water quality degradation and associated biological differences of the Side Channel and Main Channel to the distinct morphologies of these two components of Scott Lagoon.

The Scott Main Channel is a relatively wider channel than the Scott Side Channel, allowing subtle water movement and exchange in all directions during sandbar closure. The main channel surface waters are exposed to coastal winds and surface water mixing is visible during windy conditions. Average spot wind measurements in the main channel were consistently above 5 mph. Scott Main Channel surface water temperatures peaked in August and rarely exceeded 22^{o}C in 2004 and 20^{o}C in 2005. Throughout the sampling season the channel substrate grain size decreases downstream, transitioning from cobble at station SC5 to sand at SC1 (Figure 11.3 and Table 11.2). The bed of the main channel is well flushed during winter rain events, allowing efficient removal of organic material and debris that accumulated on the bottom during the previous low circulation (lagoon) conditions.

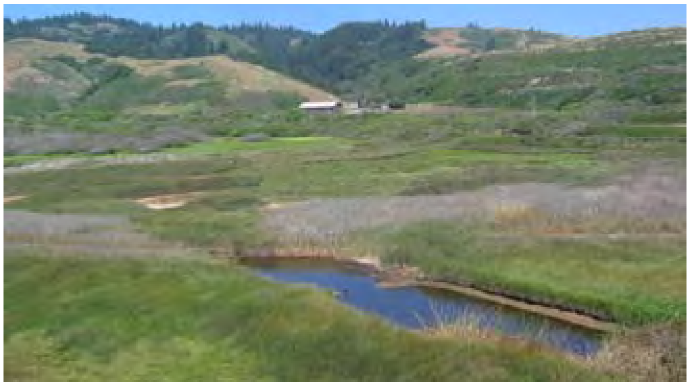
In comparison, the Scott Side Channel is oriented perpendicular to the main channel, having been formed by a failure in the north bank levee. We estimate the Side Channel is 30ft wide, 120ft long and an average of 6ft deep when the summer lagoon exists. There is an elevation sill at the failed levee that partially restricts the hydrologic connection between the Main and Side Channels, essentially limiting the horizontal movement of the bottom waters of the Scott Side Channel in all directions. The channel substrate is consistently fine-grained black organic material, including observations in April/May (Table 11.2). The Side Channel is well protected from the coastal winds by both the elevated road barrier at Highway One and perimeter emergent vegetation. Spot wind measurements exceeded 1 mph on only one occasion (n= 12). Surface water temperatures in the side channel (SC3) were, on average, 3-4°C higher than SC1 and 5°C greater than SC2 at Highway One (Figures 11.42-43).

Within Scott Side Channel during closed conditions Aug 2004 when lagoon volume is high (left) and in May 2005 during low tide conditions. (right)

The surface water (Figure 11.52), bottom water (Figure 11.53) and vertical profile (Figures 11.42-43) graphics illustrate significant water quality differences between the Side and Main Channels within Scott Lagoon. 2005 secchi depth monitoring indicates that the Scott Side Channel visibility was typically less than 1/2 of the total water column (Figure 12.2). Surface water chlorophyll concentrations reach over 100ug/L in August 2005 and bottom water NH_4^+ values were consistently > 10uM (Figure 11.53). The elevated ammonia levels suggest increased recycling of nitrogen supply from the sediments to the surface waters. The vertical profile results indicate the Side Channel is slightly deeper and often possesses bottom water DO levels < 2mg/L. On many LSDs, the Side Channel water column was stratified with respect to salinity and/or temperature, however repressed DO levels were observed on May 18, 2005 when no stratification was present. Density stratification was observed in locations of the Scott Main Channel in October and November of both sampling seasons without concurrent repressed DO levels.

The Scott Side Channel morphology is the key difference making it more susceptible to eutrophication than the main channel of Scott Lagoon. The lack of channel bed scour and removal of organic detritus during storm events, the poor water mixing and exchange during lagoon closure, and the elevated water temperatures are all expected to contribute to this susceptibility.

These physical and chemical conditions set the stage for the biological community. Biological conditions at the base of the food chain within the Scott Main Channel have higher biological diversity values and support a higher density of desirable species than the Side Channel. Separate phytoplankton community sampling was conducted in the Scott Side Channel in 2005 (Figure 12.5), indicating a very distinct community from the Main Channel. Scott Main Lagoon was characterized by a diverse collection (>10) of diatom species with relatively consistent biovolume values throughout the season (Figure 12.6). When dominated by diatoms, the Side Channel consisted of only 3-4 species. Two large cryptomonad and dinoflagellate blooms were observed in Scott Side Channel with sample biovolume exceeding all other site observations (>10,000 um^3/L).



The Scott Side Channel is a dead-end, relatively deep, incised channel with little hydrologic connection to its floodplain or the Main Channel, taken May 2004.

Phytoplankton diversity consistently increased as the summer lagoon conditions persisted and chlorophyll and phytoplankton biovolumes levels were relatively low in comparison to other lagoons. In August 2005, the zooplankton biomass in the Side Channel was 3.5 times the biomass in the shallow central zone of Scott Lagoon. The seasonal trends of community distribution and absolute zooplankton biomass were comparable, with a greater density of copepods observed in the Side Channel (Figure 12.10-11) and communities dominated by harpacticoids (a benthic zooplankton) were common in the Main Channel. The littoral sweeps of the Scott Side Channel benthic invertebrate sampling contained similar invertebrate abundances to the Main Channel sampling, consisting primarily of spiders, isopods and amphipods. However, the benthic grab sampling in the Scott Side Channel was consistently nearly devoid of organisms (Figure 12.17).

Scott and Laguna Lagoons contain a small complement of fish species compared to other CLEAP lagoons (Figure 12.21). How these fish utilized the various habitats within Scott Lagoon changed throughout the CLEAP study. Not only were there fish in the Side and Main channels, but fish were often captured in the large beach pools that expand in size as the duration of closure persists, even though the beach pools are an exposed sandy bottom water mass with no cover. Because the beach pools were ephemeral in nature, they were not as well-studied as the Side and Main Channels of Scott Lagoon (basic vertical profile data is available).

Scott Lagoon fish catch in 2004 was characterized by very high numbers of threespine sticklebacks throughout the sampling year. Sticklebacks are considered one of the more tolerant fish observed in the lagoons, able to withstand a wide range of salinities, temperatures and DO levels. While numbers of the other common species peaked at different times of the year, stickleback populations remained strong throughout the sampling season, with a peak catch (1306) in September 2004. In 2005, stickleback abundance was much lower and peak catch (219) occurred in late July 2005 (Figure 12.22).

Tidewater gobies were captured on all LSDs in Scott except August 2004, although peaks in catch numbers occurred at different times of the year during this study. In 2004, highest catch of tidewater gobies (30) occurred in early June, when the majority of these fish were captured in the Side Channel prior to sand bar formations. In 2005, peak goby catch (130) was near the end of September. Because of their presence on nearly every sampling date, we can assume that the gobies were present in August 2004, just not captured. Temperatures in Scott Lagoon in August 2004 were much higher in the main channel than on the other LSDs in 2004 (Figure 11.42), and the tidewater gobies may have been able to seek a cooler temperature refuge in a location that was not sampled.

Staghorn sculpins were captured in low numbers from June through September in both 2004 and 2005. Prickly sculpins, in contrast, had an even but low presence (0 to 9 per LSD) in catches in 2004, but peak catch numbers in July and August 2005 were 318 and 258 respectively. The majority of the prickly sculpins in these large catches were small fish with mean fork lengths of 35mm in July and 50mm in August 2005. Starry flounder were captured in July and October of 2004 and July, August and October of 2005 in very low numbers (1-3 fish). These fish were all juveniles with fork lengths ranging from 50-94mm.

Coho salmon juveniles were captured in Scott Lagoon on one LSD (16 June 2005) during macrotidal conditions. Only three coho were captured (fork length range: 51-58 mm), and all were in the Side Channel. Conditions in the Side Channel in June 2005 were unusual in that there was no salinity stratification resulting in a very consistent temperature (15°C) in the water column from the surface to the bottom, significantly warmer than the water in the Main Channel (Figure 11.43). Coho were not captured again in Scott Lagoon, indicating that while conditions in the lagoon may be important for coho as they pass through and out to sea, the lagoon is most likely not being utilized as long-term habitat for this species.

Catch of juvenile steelhead was highly variable throughout the CLEAP study. Highest numbers of steelhead were captured in 2004 shortly after the sandbar closure. In August 2004 almost 600 juvenile steelhead were captured and nearly 80% of these were found in the north and south beach pools (north and south of the exit of Scott Creek under Highway One). The majority of these fish were YOY (see Figure 12.28), ranging from 46 – 187mm fork length (mean=89mm). In 2005, catch numbers were lower than 2004, with the highest catch (112) occurring in October 2005, and all were captured in the Main Channel. In June 2005, the same date that coho were captured in Scott Side Channel, all steelhead captured were also in the Side Channel. Recall that conditions in the Side Channel on this date were unusual in that there was no temperature, salinity or DO stratification. During macrotidal conditions the Side Channel may provide refuge from the extreme water level variations associated with daily tidal changes. One month later, only one steelhead was caught in the Side Channel and all others were found in the beach pools. By July 2005 the Side Channel waters were 3° higher than the Main Channel and bottom water oxygen was beginning to decline (Figure 11.43). The smallest steelhead catch of 2 fish (23 August 2005), occurred when water quality throughout the lagoon was relatively poor (highly stratified salinity, temperature and DO), and water in the north beach pool was stratified with low DO (<5mg/L and lower) throughout the water column. Under these conditions, fish are most likely moving upstream to cooler more oxygenated stretches of the creek. The majority of juvenile steelhead captured in 2004 were caught in the beach pools/channels, whereas those captured in 2005 were more evenly spread between the beach, Side and Main channels. This is most likely due to the relatively early sandbar closure in 2004 creating more habitat in the beach pools for fish to utilize. Alternatively, the earlier sandbar closure in 2004 may have trapped a larger population of steelhead that may have otherwise moved out to sea, although the majority this movement is thought to occur earlier in the year.

Black spot disease, a parasitic infestation caused by a neascus-type trematode (family Diplostomidea) showed up in relatively low numbers in Scott Lagoon compared to the more urban lagoons. Black spot was quantified during 2005. Grading of none, light (less than 5 spots), medium (between 5 and

10 spots) and heavy (greater than 10 spots) was used. Table 14.1 shows the prevalence of diseased fish (from light to heavy infestations). There are few studies of the effects of black spot on salmonids, but a recent study of coho salmon in coastal Oregon streams suggests that higher temperatures may increase the susceptibility of fish to the parasites (Cairns et al 2005). Other stressors could certainly exacerbate how well fish can resist disease. How this ultimately affects survival and growth has yet to be established, but may be an important factor to consider.

Table 14.1. Frequency of black spot disease occurrence on fish in Scott Lagoon during 2005.

May	June	July	August	September	October
13%	22%	15%	0%	16%	23%

Steelhead age classes were estimated by looking at patterns of length-frequency histograms rather than analyzing scales. Fish referred to as “1+” in this report may be older, but that cannot be determined until scales are analyzed. When considering which age classes of steelhead utilize the lagoon, it is useful to compare catches from the month of May in both 2004 and 2005 (Figures 12.28-29). In 2004, the total steelhead catch is dominated by high numbers of very small YOY (26-53mm fork length), with a small proportion of age 1+ fish (73-142mm fork length) captured. In contrast, the catch in May 2005 is dominated by age 1+ fish (71-150mm), with fewer YOY (27-56mm fork length). It seems reasonable to assume that the 2004 YOY class was a stronger year class and one year later (as 1+ fish) these were the steelhead dominating the 2005 lagoon population. It is unclear as to whether the steelhead population in the lagoon mirrors the age class composition upstream. It is also unknown whether these two year classes respond to different environmental cues with each class moving to the lagoon under different conditions.

Growth rates of juvenile steelhead in Scott Lagoon were very high, with rates peaking in the warmest months of August and September in both 2004 and 2005 (Figure 12.36). In 2004, steelhead growth was fastest at 0.91± 0.19mm/day (mean ± 1SD) in August. In 2005, steelhead growth was fastest in September at 1.33 ± 0.21mm/day. Whether these growth rates are directly indicative of high quality habitat in the lagoon remains uncertain. The high mobility of fish allows them to move in response to changes in environmental conditions or to find food. Salmonids are able to forage for short periods in areas that may not have ideal water quality but may have particularly dense food resources (such as the littoral areas of the Scott Side Channel or the beach pools), intermittently moving back into refuges of better water quality.

Seining for fish in August 2005 in Scott Lagoon.

Laguna Lagoon

Similar to Scott Lagoon, we expect a primary limitation of Laguna Lagoon is reduced surface water residence times in the summer lagoon during average to dry years. A detailed discussion of the lagoon water budget and associated preliminary conceptual enhancement recommendations are provided following the review of the existing data and observations conducted within Laguna Lagoon.

The morphology of Laguna Lagoon was significantly modified in the early 1900's to accommodate agricultural cultivation in the historic marsh area. The North Coast Railroad earthen dam defines the eastern border and the Pacific Ocean borders the marsh to the west. The lagoon channel was straightened, leveed, and relocated along the northern Santa Cruz mudstone bluff to maximize the surface area for agricultural activities. Visual observations suggest the elevation of the main channel of Laguna Lagoon is incised as much as 4-6 feet below the elevation of the historic marsh. A small failure in the eastern levee has created a hydrologically constricted open pond in the remnant marsh area. The primary water source of this open pond (Station LA3.5) is the small (3ft wide) breach in the levee, filling the pond during high lagoon water elevations and draining the pond when the water surface elevation of the lagoon is below the elevation of the open pond.

A low tide in May 2005 disconnects the main channel (foreground) from the open pond.

Laguna Lagoon is the only CLEAP site without a bridge or flood control structure restricting the cross-sectional area near the mouth of the lagoon. The lack of a constriction near the mouth facilitates the creation of a stable sandbar earlier in the season than at the other lagoons. Laguna Lagoon had the greatest frequency of complete closure for all lagoons, averaging over 84% of the total number of days between May and October (Figure 11.8).

The 7.8 mi^2 watershed is home to slightly over 1,000 people, all on septic service. Laguna Lagoon average inflow DIN and SRP concentrations from May through September samplings were 6.76mg/L and 1.18mg/L, respectively. Using the product of discharge and tributary concentrations, the daily DIN and SRP loading average for the same time span were 0.29kg/day and 0.10kg/day, respectively. DIN concentrations in Laguna Creek were 50% greater on average in the dry months of 2005 compared to 2004. Compared to the other CLEAP lagoons, the seasonal loading of DIN to Laguna Lagoon is low. Surface water DIN and SRP values in the lagoon are consistently low, < 5uM and < 2uM respectively.

Comparisons of 2004 and 2005 lagoon conditions suggest lack of lagoon water volume was the primary factor limiting habitat quality in relatively dry 2004. Coupling the available YSI data with vertical profiles, the shallow lagoon in 2004 did convert to a freshwater column during the summer closure, but the average lagoon water depth was only 1.2ft. Morning water temperatures reached seasonal maximums (18-20°C) in August and DO profiles prior to the first fall rain event were homogenous with concentrations typically > 3mg/L (Figure 11.44).

A series of rain events in mid-October 2004 significantly increased water volumes for 5 days prior to the sandbar breach on October 23, 2004. Despite the significant dilution by an 80% increase in water volume with fresh rain and stream water, DO, ORP and pH simultaneously crashed as result of the storm and breach turbulence (Figure 11.34). We suspect the inclement water quality conditions were caused by the mobilization and suspension of partially decomposed organic matter (and associated reduced chemical compounds) that had accumulated in the lagoon. This episodic water quality decline occurred during the breach despite the homogenous water column with respect to salinity and DO during closure.

In 2005 precipitation totals were slightly above average and water availability did not limit aquatic habitat availability. Laguna Lagoon main channel surface water temperatures peaked in early August and rarely exceeded 21ºC (Figure 11.35). Partial sandbar development transitioned circulation in Laguna to microtidal conditions by mid-May 2005, with complete sandbar closure occurring on July 5, 2005. Four instances of saline waters overtopping the sandbar were observed at Laguna Lagoon (Figure 11.35), the timing of which corresponded to elevated coastal swells and were coincident with salinity spikes at Scott Lagoon (Figure 11.33). Each saline water introduction was marked by an increase in bottom water temperatures, reaching maximum values greater than 25ºC. In August, the first occurrence of DO below 1mg/L was observed and the levels remained low for 4 consecutive days. Bottom water salinity at this time was 1.2ppt. The second and third compromised DO conditions were concurrent with saline water introductions, with the most dramatic occurring over a 3-week period beginning in mid-September 2005. Coincidently, a significant phytoplankton/macroalgae bloom persisted through the middle of September 2005, introducing a large amount of organic matter to the lagoon. The increased organic matter loading increased the biological oxygen demand (BOD) by respiring bacteria and the salinity stratification reduced the available oxygen supply in the bottom waters of Laguna Lagoon in September 2005, resulting in the sustained low DO, low pH and low ORP values were observed during late September early October.

Comparing the 2005 Scott and Laguna water quality data, bottom water warming trends are coincident with saltwater intrusion, yet the dissolved oxygen concentrations responded variably. While our chlorophyll time series are not complete for either lagoon, we suspect that the existing supply of organic matter in the system has a large influence on the DO response. Scott Creek DO levels were observed to be sustained below < 2mg/L for more than 24hrs on only one occasion in 2004 (Figure 11.32). In Laguna 2005, DO levels (both daily averages and daily minimums) continue to decline throughout the season as the organic matter accumulated in the system. Saline introductions exacerbate these conditions by stratifying the water column and limiting the readily available supply of oxygen to the respiring bacteria in the benthos. The organic accumulation continues throughout the year resulting in a layer of organic detritus at the base of the channel. When the lagoon is breached, the turbulence and mixing of this organic material is suspended into the water column, significantly impairing water quality. As in 2004, the breach of Laguna 2005 is characterized by 4 days of persistent low DO, reduced ORP and low pH conditions (Figure 11.35).

Limited chemical and biological sampling occurred in the shallow open pond area, due to access, deep mud and other difficulties. A total of 6 vertical profiles were conducted in the open pond over the study, each indicating less than 1m of water, temperature stratification and anoxic bottom waters. The substrate of the open pond was consistently fine black organic matter. The exception being August-October 2004 when the pond dried completely (see photo Figure 11.21).

The dominant primary producer community in Laguna Lagoon shifted from an SAV Potamogeton community in 2004 to macroalgae Ulva dominance in 2005 (Figures 12.1-2). Site observations on

September 15, 2005 coincided with a visual Ulva bloom. An 8-hr increase of over 7,000um^3/L of chlorophyte cells as observed in the afternoon phytoplankton sample at station LA3 (Figure 12.6) further substantiates the dominance of algae. This bloom was also captured by the YSI instrumentation, spurring a subsequent decline in bottom water quality (Figure 11.35).

Macroalgae *Ulva* bloom during fish seining at Laguna Lagoon September 2005.

The exact cause of these inter-annual differences in primary producer community is unknown. Since primary producers are limited by nutrients and light, we compared the conditions that control the availability of each resource between 2004 and 2005. The DIN concentrations and loads introduced to Laguna were nearly double in 2005, though still consistently low relative to the urban lagoons. The average depth of the water column was 3.2ft in 2005 compared to 1.2ft in 2004, perhaps limiting light to the benthic growing SAV community as the phytoplankton community developed in the spring. In a deeper aquatic system, primary producers in the surface water (phytoplankton and macroalgae) are able to outcompete the benthic growing SAV community for light (Duarte 1995). The rapid growth of phytoplankton and macroalgae further reduces the light availability to the sediment-rooted SAV. We suspect the combination of slight increases in available DIN in the spring, coupled with the deeper water column in 2005, influenced the variations of the dominant primary producer in Laguna Lagoon.

The zooplankton community in 2004 was composed of relatively larger cells and displayed a consistent Simpson Index of Diversity greater than 0.6 (Figure 12.8). The zooplankton community remained relatively diverse throughout the entire season on 2005, with a slight community shift observed between September and November. Seasonal peaks in zooplankton biomass occurred in late 2004 and relatively early in 2005 (Figures 12.8 and 12.11), shortly following sandbar closure. The community compositions of each of the zooplankton peaks were also different, shifting from well-sized copepods in 2004 to relatively small sized community of rotifers and copepods in July 2005 (Figures 12.7, 12.9-10 and 12.12).

A balanced mix of amphipods and isopods are the most common invertebrates in the Laguna invertebrate community (Figure 12.13), but lagoon composites had consistent moderate to high diversity and abundance values relative to other lagoons. The downstream benthos sampling by the benthic grab technique indicated consistent presence of moderate invertebrate abundances, species diversity and potential fish food (Figure 12.17-18).

Fisheries sampling in Laguna was not consistent between 2004 and 2005, with only 2 samples in 2004 versus 4 in 2005. Not only were the sampling schedules different across the two years, but sampling techniques were as well. Hagar Environmental Sciences sampled Laguna during 2004 and used seines and electrofishing in an effort to sample the complete fish community. In 2005, the NMFS team used the same technique as in the other CLEAP lagoons (beach seine). In 2005 some sampling occurred before the sandbar closure, while all samples in 2004 were after sandbar closure.

The fish community in Laguna 2004 was characterized by very high numbers of tidewater gobies (>1000) and threespine sticklebacks (>450). Because these are small fish, the total mass of catch was relatively low (Figure 12.22). Other species present in 2004 (see Figure 12.21) included prickly sculpin, staghorn sculpin and juvenile steelhead, all in low numbers (<40 individuals). No starry flounders were caught in Laguna during 2004. Only 12 steelhead were captured in July 2004, and they were from two age classes YOY (59-79mm fork length) and 1+ (142-168mm fork length). In September 2004, 20 juvenile steelhead were captured, ranging from 93 to 229mm in fork length. No coho were captured in Laguna in 2004.

Fish catches in 2005 were very different from 2004. This may be due to increased water flow and larger lagoon volumes in 2005 (and associated physical and biological consequences). Again, there were high numbers of sticklebacks (432 in May 2005, peaking at 4,434 in July 2005). Tidewater goby numbers remained relatively low until November when over 1,000 individuals were caught. Staghorn sculpin, prickly sculpin and starry flounder were present in numbers <54 (Figure 12.22).

The salmonid catch was significantly different in 2005 compared to 2004. There was no documentation of previous coho presence in Laguna (Spence et al. 2005), although there had been anecdotal evidence of coho historically. During the first sampling in May 2005, while the creek mouth was still open, 78 juvenile steelhead (YOY and 1+, fork lengths: 37- 144mm) (Figure 12.30) and 178 coho (YOY and 1+, fork lengths: 35-121mm) were caught. While the creek mouth is still open, one could presume that the 1+ coho and steelhead were emigrating to sea, but the YOYs had most likely moved into the lagoon to take advantage of the habitat and food resources there. By July 2005, steelhead catch increased to the yearly peak of 330 (fork lengths: 40-198mm) and the coho catch declined to 44 individuals (fork lengths: 58-90mm). The decline in numbers of coho and the narrowing of the range in fork lengths may reflect numerous things: 1) larger smolts emigrated to sea, 2) fish grew, 3) smaller fish may have had higher rates of mortality, and 4) (unlikely) larger fish had higher rates of mortality. Increased numbers of steelhead in July are mirrored in the highest abundance of benthic invertebrates as well, dominated by copepods, isopods and amphipods, all decent fish food. While the water was stratified in July 2005, there still was significant volume, temperature was <17ºC and well-oxygenated. By September 2005, only one coho was caught, and steelhead numbers declined to 268. The disappearance of coho between July and September implies that either the lagoon habitat was unsuitable for coho and the fish died, or the habitat was unsuitable and the fish moved back upstream to cooler riparian stretches (they were unable to migrate to sea due to sandbar closure). We are unable to discern these two scenarios at this point. By November, steelhead numbers were still strong at 172 in the catch (recall that stickleback and tidewater goby catches were very large in November 2005 with >1000 gobies and >2750 sticklebacks).

Juvenile steelhead growth rates were calculated and population size was estimated from recaptures in 2005 (Figure 12.36). A total of 158 steelhead were tagged with PIT tags. Growth rates were stronger early in the summer at ~0.8mm/day (n=6). By September and November, growth rates were still rapid, but had dropped to just over 0.5mm/day (n=52 and 39 respectively). Interestingly, the highest growth rates occurred when the numbers of steelhead were greatest in our catch (July 2005), and as steelhead numbers declined, growth rates did also. Population estimates of juvenile steelhead in the lagoon (Figure 12.27) ranged from a high of 2,449 in July to a low of 675 by November 2005.

Steelhead YOY on top
Coho YOY on bottom
Laguna Lagoon May 2005

Juvenile steelhead in Laguna showed the lowest frequency of black spot disease out of all of the CLEAP lagoons (Table 14.2). Whether this is due to exceptional health of these fish or some other factor which would affect the life history of the parasite cannot be determined from this study.

Table 14.2. Frequency of black spot disease occurrence on fish in Laguna Lagoon during 2005.

May	July	September	November
3%	0%	0%	0%

The most marked evidence of the effects of precipitation totals and timing of annual rainfall were observed at Laguna Lagoon. Below average rainfall in 2004, coupled with minimal spring precipitation, significantly reduced the late summer streamflow in Laguna Creek. Surface water discharge in Laguna Creek steadily declined from approximately 1cfs in May to below 0.1cfs by September during the wetter 2005. In 2004, September discharge was estimated to be 0.01cfs. Average July water depths varied from 1.2ft in 2004 to 3.2ft in 2005. Photographs included on Figures 11.21-22 compare the Laguna area of inundation in August of both study years, reflecting the average summer lagoon water volume differences of 6ac-ft in 2004 versus 20ac-ft in 2005.

Comparisons of lagoon volumes during the two water years suggest Laguna Lagoon surface water habitat is susceptible to below average precipitation years. When the lagoon is closed the only significant source of water is from Laguna Creek inflow. Laguna Creek stream volumes are inherently low due to the small contributing watershed. On an absolute scale, Laguna Creek streamflow discharge is the lowest of all CLEAP tributaries, reaching a near 0.01cfs in September 2004. Laguna Creek is the smallest watershed in CLEAP, with a contributing area of only 7.8mi^2, over 20mi^2 smaller than the other north coast watershed of Scott Creek. The well-utilized rational method (Q= CIA, Dunne and Leopold 1986) is a hydrologic calculation to estimate peak discharge based on watershed area (A), rainfall intensity (I) and the fraction of precipitation, on average, that reaches the surface water stream as overland flow (C). Assuming land use is similar in Scott and Laguna Watersheds, a quick comparison of the expected peak discharge for any given storm is directly proportional to the watershed area. The ratio of Laguna to Scott watershed area is 0.26 or 26%. The average ratio of Laguna Creek discharge to Scott Creek discharge from May to October is 0.18 or 18%. While a very rough comparison, Laguna Creek stream volumes only deviate from the expected flows differences compared to Scott Creek by 10% or less, presumably due to upstream water removals.

Laguna Lagoon
Sept 15, 2005

North Coast Lagoons Enhancement Recommendations

With the exception of the hydrologically-restricted areas in both lagoons, the general water quality of the main portions Laguna and Scott Lagoons is better than the unmanaged urban lagoons, San Lorenzo and Aptos. While water diversions may be reducing surface water inflow to the lagoon areas, the future of successful natural resource enhancement is to create innovative solutions that improve ecological function given the inherent anthropogenic stressors.

We suggest that one primary limitation on ecological health of the North Coast Lagoons is the reduced residence time of surface water in the closed lagoon during below average precipitation years. In this situation, “surface water” refers to the volume of water that exists above ground, not merely the surface water layer of the water column as discussed in the water quality sections. The loss of lagoon surface water during closed summer conditions, as observed in 2004 (Figures 11.19 and 11.21), is exacerbated by the current morphologic configurations of these systems that do not maximize the hydraulic residence times of surface waters. While the biological conditions, including anadromous fish populations, are relatively good compared to the more impaired urban conditions observed in Aptos and San Lorenzo Lagoon, the obsolete flood control within the historic marsh areas provides an excellent opportunity to eliminate some of the existing physical constraints and improve the systems’ ability to retain the surface water supplied from the tributaries.

Three main characteristics of the existing morphologies of Scott and Laguna Lagoons may contribute to greater than necessary surface water loss during summer inundation. First, the channels of the lagoon are straighter and shorter than the natural channel. A shorter channel has the same elevation change from the top of the marsh to ocean over less distance, thus increasing channel slope. Increased slope inherently lowers the elevation of the channel bed; this process is called incision. Current elevations of the main channels are likely 4-6 ft lower than the low-flow lagoon channel prior to human modifications. Straight, incised channels directly reduce the elevation of the adjacent groundwater table, reducing adjacent soil moisture and potentially resulting in die-offs of riparian vegetation (Figure 11.1) (Leopold et al 1992, Fetter 1994).

Second, the shorter length of the existing channels in Scott and Laguna have smaller total channel wetted perimeters and marsh contact areas relative to the longer, meandering channel assumed in more natural conditions. A longer channel would influence a greater area of the groundwater table, resulting in a greater spatial distribution of conditions, as depicted in panels A and B of Figure 11.1. The combination of these two characteristics (lower groundwater table due to lagoon channel incision and less surface area of channel influence on the shallow groundwater due to lagoon channelization and straightening) likely results in an earlier seasonal transition from a “gaining” channel (net flux of water from groundwater to surface water in lagoon) to a “losing” channel (net flux from surface water to groundwater table). Opportunities to increase the shallow groundwater table will likely result in the retention of more water above ground for a longer duration in the dry season than would a repressed water table.

Finally, the existing lagoon configurations have resulted in a significant fraction of both Scott and Laguna lagoon channels being in contact with the beach sand berm. The permeability of beach sand is 4 orders of magnitude greater (i.e. 10^4) than the hydraulic conductivity of organic marsh deposits. The configuration of the lagoon parallel to the beach berm subjects it to higher surface water seepage rates than necessary.

The obsolete flood control structures surrounding both Scott and Laguna create an opportunity to enhance the natural morphologic function. Physical enhancement objectives for straightened, incised stream channels include reconnection of the stream with its floodplain by increasing the frequency and duration of overbank flow (Rosgen 1996). In order to accomplish this goal, the stream grade (i.e. channel bed elevation) and length of the channel are increased by reestablishing meander patterns and reducing the cross-sectional area of the low flow channel. As seasonal groundwater elevations increase due to floodplain recharge, riparian vegetation is able to persist longer into the dry seasons. The same surface water/groundwater hydrologic concepts should be true for these coastal lagoon settings.

We recommend the general enhancement approach in the North Coast CLEAP lagoons should focus on physical modifications that will reduce dry season surface water infiltration from the lagoons. Design components should:

- increase meander and length of the low flow channel,
- encourage point bar development, sediment deposition on the floodplain and a less homogenous lagoon cross-section,
- eliminate hydrologically isolated locations, such as the Scott Side Channel and the open pond at Laguna Lagoon,
- increase the hydraulic interaction of the main lagoon with the surrounding marsh during winter storm events and summer inundation,
- increase the elevation of low flow channel bed, thereby increasing the surrounding groundwater table during the dry months,
- reduce the fraction of the lagoon in direct contact with the beach berm by eliminating channel constraints such as levees, and
- increase physical complexity to increase the diversity of distinct niches used by specific aquatic organisms. Physical complexity of an aquatic system will directly increase the potential for biotic diversity.

The enhancement should be designed with features that would remove existing morphologic constraints and encourage flows to gradually reestablish a channel meander pattern through the historic marsh area. The extremely variable hydrology and sediment transport characteristics of a lagoon make an over-engineered lagoon design ill-advised. Rather, construction costs would be minimized with the intent that the subsequent event flows would naturally reconfigure the lagoon.

Using Laguna Lagoon as an example, an increase in bed elevation of the existing main channel could be accomplished by the placement of grade control features made of natural material in the existing channel and the removal of the earthen levees. The grade controls would gradually induce sediment deposition and increase the elevation of the lagoon bed, as well as the length of the low flow channel over time. Removal of the existing levees and a gradual sloping of the eastern banks would allow the lagoon hydrologic freedom during winter storm events to inundate and transport sediment to portions of the historic marsh and gradually reestablish a more natural channel configuration.

A second conceptual alternative at Laguna is to redirect the main channel at the upper portion of the lagoon toward the historic marsh and open pond area (Figure 14.1). Again, complete channel construction is ill-advised in such a dynamic system. Rather simple site manipulations to induce the direction of the low flow channel could be constructed to initiate flow patterns, but construction costs and efforts should be minimized. Levee material could be placed and compacted to fill the existing channel.

The cross-sectional schematic (Figure 14.1) illustrates the increases in channel grade (elevation of the channel bed) and channel complexity by the reestablishment of meanders and associated sediment sorting and overbank flow dynamics. Relocation of the low flow channel in a more central lagoon location on the historic marsh would increase the spatial connection between the surface water lagoon and the local shallow groundwater. The relocation of the lagoon low flow channel through the historic marsh deposits will directly reduce the fraction of the lagoon adjacent to the coastal sand deposits, limiting unnecessary surface water loss through the highly permeable beach sand. Figure 14.1 is intended to be merely conceptual to document the potential direction of enhancement opportunities and does not include site-specific hydrologic or geomorphic calculations that would be necessary to develop appropriate channel cross-sectional area, elevation of channel grade, meander frequency, etc. should the enhancement approach follow these recommendations.

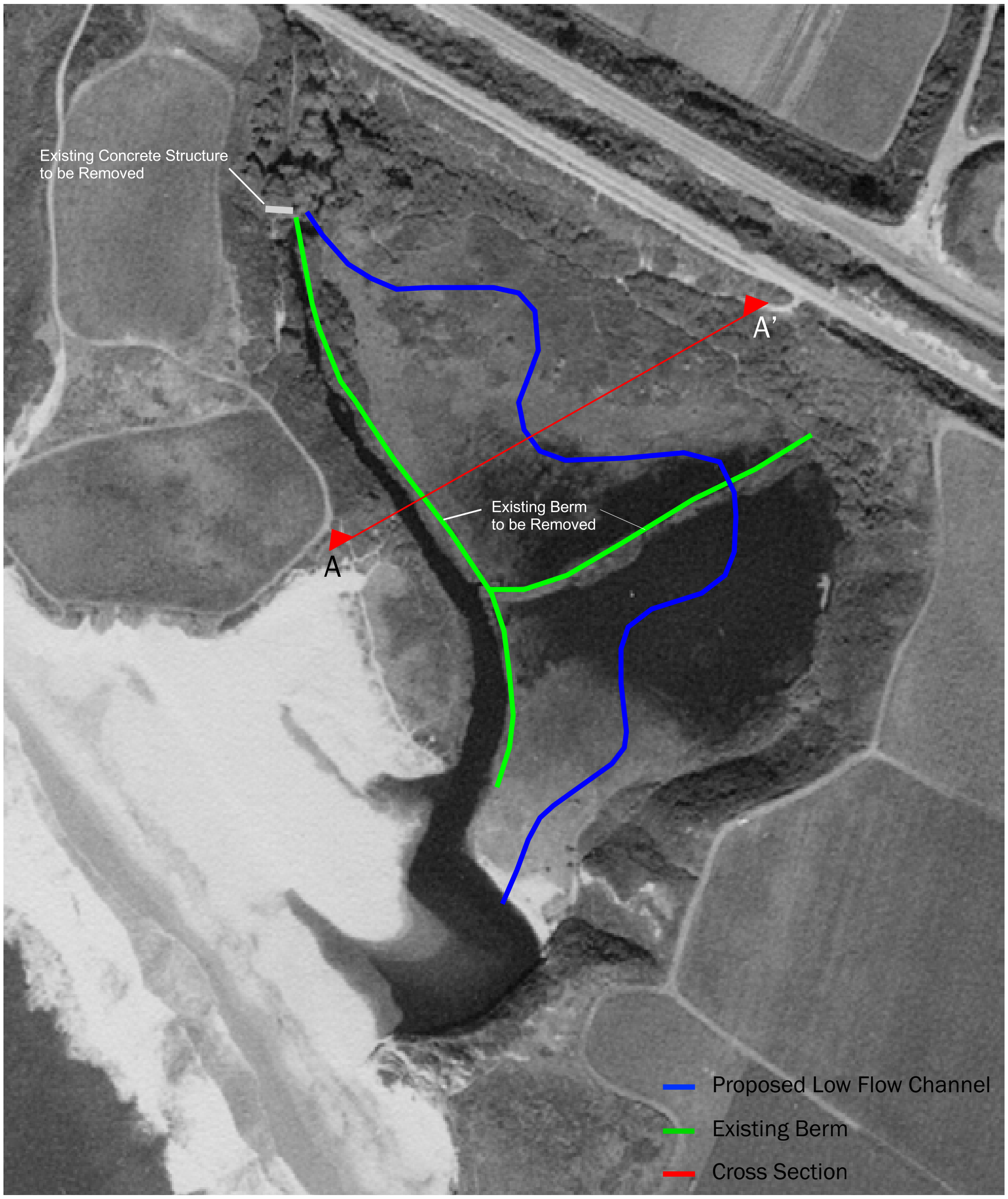
The general design concepts presented above apply to the recommended enhancement approach to Scott Lagoon as well. However, any enhancement efforts planned for Scott Lagoon should proceed in tight collaboration with CalTrans and the design of a new Highway One Bridge. The hydrologic restriction created by the existing bridge limits the restoration opportunities available at the site. Ideally, the new bridge design would allow a 4 to 5-fold increase in the cross-sectional area of the lagoon environment beneath the bridge span. This would reduce the hydraulic constriction beneath the bridge and assist with gradually increasing the channel bed elevation and natural dynamic physical processes of Scott Lagoon. An expanded bridge opening would also facilitate a more natural transition from the vegetated lagoon to the coastal beach.

Future recommendations to facilitate the enhancement process for Scott and Laguna Lagoons include:

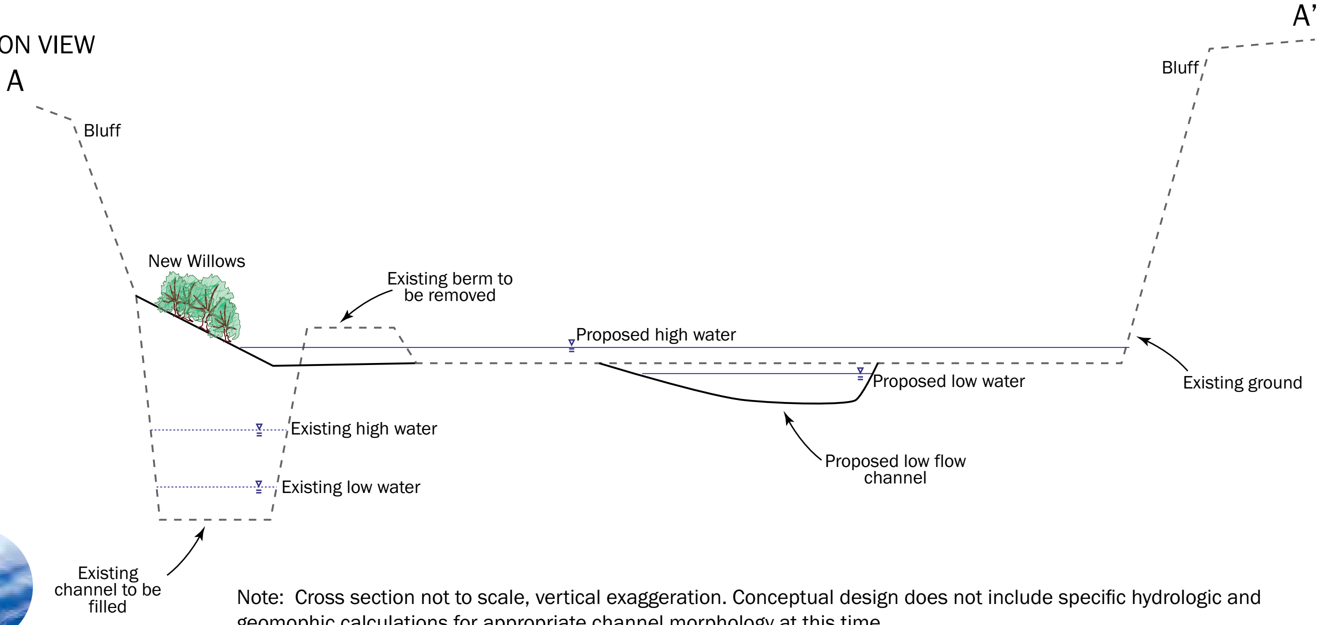
1. Scott Lagoon Enhancement
    - 1a. Develop channel reconfiguration alternatives in tight collaboration with CalTrans Highway One Bridge redesign approach.
    - 1b. Evaluate opportunities and constraints of each alternative.
    - 1c. Select preferred alternative and develop design plans, secure permits and construction plans.
    - 1d. Construct and implement enhancement.

2. Scott Lagoon Performance Monitoring
    - 2a. Identify and implement CLEAP parameters for continued monitoring pre and post project to evaluate enhancement performance and focus long-term monitoring. Focused post project monitoring should continue at least 5 yrs following implementation.

PLANVIEW



CROSS-SECTION VIEW



Note: Cross section not to scale, vertical exaggeration. Conceptual design does not include specific hydrologic and geomophic calculations for appropriate channel morphology at this time.

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CONCEPTUAL DESIGN FOR LAGUNA CREEK
LAGOON ENHANCEMENT

FIGURE 14.1

  - 2b. Investigate lagoon surface water/groundwater hydrogeology for pre and post project monitoring to demonstrate changes in lagoon shallow groundwater elevations as a result of enhancement efforts. Identify any additional non-CLEAP parameters that would directly evaluate enhancement project performance.
  - 2c. Provide adaptive management feedback for additional modifications/enhancement based on site-specific observations and enhancement performance 2-5 years following implementation of 1d above.

3. Laguna Lagoon Enhancement
  - 3a. Develop channel reconfiguration alternatives in more detail.
  - 3b. Evaluate opportunities and constraints of each alternative.
  - 3c. Select preferred alternative and develop design plans, secure permits and construction plans.
  - 3d. Construct and implement enhancement.

4. Laguna Lagoon Performance Monitoring
  - 4a. Identify and implement CLEAP parameters for continued monitoring pre and post project to evaluate enhancement performance and focus long-term monitoring. Focused post project monitoring should continue at least 5 yrs following implementation.
  - 4b. Investigate lagoon surface water/groundwater hydrogeology for pre and post project monitoring to demonstrate changes in lagoon shallow groundwater elevations as a result of enhancement efforts. Identify any additional non-CLEAP parameters that would directly evaluate enhancement project performance.
  - 4c. Provide adaptive management feedback for additional modifications/enhancement based on site-specific observations and enhancement performance 2-5 years following implementation of 3c above.

URBAN LAGOONS

Soquel Lagoon: Managed Control

Soquel Lagoon was included in CLEAP as a managed control to provide information on the response of an urban lagoon to summer water level management. The management of Soquel Lagoon is conducted in accordance with the Soquel Creek Lagoon Management and Enhancement Update Plan (2004). Observations and data collected at Soquel Lagoon suggest that the existing management strategy is satisfying both coastal water quality protection during the summer months and meeting ecological beneficial uses. The water level management of Soquel Lagoon is successful because of the lagoon's combination of low DIN loading, relatively low solar exposure and the management commitment to eliminate density stratification at the time of closure. The other two urban lagoons investigated, San Lorenzo and Aptos, have significantly greater DIN inflowing loads, as well as greater susceptibility to heat retention and solar exposure. Simple water level management of these two systems may not be advisable without additional enhancement components that would further reduce their susceptibility to eutrophication.

We can learn from the combination of lagoon and watershed characteristics that appear to make the existing management strategy successful to improve the ecological beneficial uses for this particular lagoon. Active water level management includes manual removal of organic detritus and saline water prior to May closure each year. A permanent cement flume maintains the water level in Soquel Lagoon at 6.0 MSL (Figures 11.36-37), thus eliminating the water storage limitations of the other flood-controlled lagoons, San Lorenzo and Aptos. The lagoon is manually breached prior to each fall rain event. The assisted conversion of the lagoon to freshwater and the water level maintenance appear to be a successful management strategy for Soquel Lagoon.

Permanent cement flume at Soquel Lagoon. Photo on left taken during lagoon closure, looking from beach upstream to lagoon. Flume can be seen in foreground, to the left of the posted sign.

Dating back as far as the early 1900's, the sandbar presence and water level in Soquel Lagoon has been managed, initially for recreational purposes and today for lagoon ecological and beach water quality benefits. Historically, a large corrugated metal pipe (CMP) was buried in the sand berm to allow drainage of the surface water to the coastal ocean. As human development expanded in Capitola, sewage was routed directly to Soquel Creek, impairing the summer lagoon water quality. In order to preserve Soquel Lagoon as a desirable recreational destination, the development of a community waste management infrastructure was undertaken (Swift 2004).

Circa 1930 photo of Capitola and Soquel Lagoon. The lagoon water levels are maintained by a CMP buried in the sand berm, slightly visible in the lagoon and at the edge of the beach. (Courtesy of Capitola Historical Museum)

Soquel Lagoon is located in the densely urbanized City of Capitola (Figure 11.7) and the beach and shops at Soquel Lagoon remain popular tourist destinations. The urban population remains dense until east of Soquel Drive in Soquel, CA. The upper watershed of Soquel Creek is rural residential development, serviced by septic, with a small amount of agricultural land use. The septic density of the contributing watershed is moderate (175 people/mi^2) relative to the other urban CLEAP lagoons (Table 11.1). Flood control for the lower 1/4 mile of Soquel Creek is a priority. The morphology of the lagoon is a straight, trapezoidal channel with a relatively flat uniform bottom and vertical retaining walls defining the width of the channel and lagoon. Homes and businesses are located adjacent to the lagoon banks. Many buildings in the riparian corridor are raised to reduce property damage during winter flood events.

Businesses lining the banks of Soquel Lagoon.

Soquel Lagoon average inflow DIN and SRP concentrations from May through September samplings were 3.65mg/L and 2.05mg/L, respectively. The SRP loading values were comparable to levels observed at other urban tributaries. Using the product of discharge and tributary concentrations, the daily DIN and SRP loading average for the same time periods were 1.17kg/day and 1.33kg/day, respectively. Compared to the other CLEAP lagoons, the seasonal loading of DIN (the limiting nutrient) to Soquel Lagoon is low. Surface water DIN and SRP values are consistently low, < 5uM and < 4uM respectively.

All observations during closed conditions indicated Soquel Lagoon is a freshwater column. Water quality observations indicated stable and homogenous ancillary water quality parameters (Figures 11.36-37). The lagoon area upstream of Stockton Avenue has a very dense riparian corridor, making Soquel Lagoon relatively less exposed to solar radiation than the other CLEAP lagoons and surface water temperatures remained below 22^{o}C for much of the season. Daily dissolved oxygen fluctuates around 8mg/L and ORP remains constant for the duration of the monitoring. Breach events show slight reductions in DO and pH, though ORP levels appeared unaffected.

Primary producer biovolume and community structure appeared stable during most observations, not exhibiting the presence of excessive phytoplankton or macroalgae blooms as observed in other urban lagoons. Using species diversity as an indicator of habitat health, the Soquel Lagoon phytoplankton community in 2004 was typically below 0.5 and biovolume was relatively low (Figure 12.4). The moderate presence of both SAV and macroalgae in 2004 suggested a well-balanced primary producer community (Figure 12.1). In 2005 the SAV cover was much less than the previous season, but the phytoplankton community remained in low abundance and stable over 2005 observations. 2005 species diversity values of the phytoplankton community in most instances were at, or above, the community diversity metrics observed in Scott and Laguna Lagoons (Figure 12.6).

The zooplankton community observed in Soquel had a relatively lower biomass, particularly in 2005 when Soquel Lagoon zooplankton was an order of magnitude below other lagoons (Figure 12.11). The high diversity and relative stability of the other Soquel Lagoon trophic structures (primary producers, benthic invertebrates and fish) suggests the zooplankton community may not play a significant role in the Soquel Lagoon food chain. The benthic invertebrates in 2005 showed relatively comparable total lagoon abundance values to other lagoons, with consistently elevated diversity values above 0.5 (Figures 12.13-14). The 2005 Soquel benthos invertebrate abundances near the lagoon mouth were lower than the single 2004 observation, but the numbers are comparable to less impacted sites (Scott and Laguna) and diversity values remained stable over the season (Figure 12.17). The freshwater column, dense riparian cover and stable lagoon water quality likely supported the most frequent observations of intolerant invertebrate species (Table 12.7) compared to all other lagoons.

Above: Soquel Lagoon during macro-tidal conditions
Right: Manual lagoon closure

Steelhead have been monitored in Soquel Lagoon for 15 years by D. W. Alley and Associates (Alley 1993-2005). This monitoring is in accordance with the management of the sandbar closure and breaching and includes a one-time population estimate using a tag-recapture protocol over the course of two successive weekends in early October. The 15 years of data have provided valuable information on yearly trends and cycles, as well as effects of droughts and heavy storm flows on steelhead and other species. The goal of the CLEAP study was to gain fisheries information on a finer time scale before and during lagoon closure, so sampling occurred approximately on a monthly basis and in cooperation with the October sampling by D. W. Alley and Associates. This allowed for fluctuations in species composition to be observed across the seasons. With steelhead being tagged throughout the study, recaptured fish provided valuable data on individual growth rates and allowed for estimations of population size from summer through fall.

The fish captured in Soquel were similar across 2004 and 2005 (Figure 12.21) except for the presence of near shore fish (topsmelt and bay pipefish) in 2004 before the sandbar was put in place. Otherwise, the complement of fish was simple with catches dominated by sticklebacks, steelhead, staghorn sculpin, prickly sculpin, and starry flounder (Figure 12.21). Sacramento suckers were also caught both years in Soquel Lagoon. Tidewater Gobies were not captured in either 2004 or 2005 at Soquel Lagoon. Coho salmon were not caught in Soquel Lagoon, although there are references to their historical presence (Spence et al. 2005).

Before sandbar closure in 2004, fish catch was relatively small, but dominated by sticklebacks in number and topsmelt in mass (Figure 12.22). Forty-one juvenile steelhead, age 1+ and perhaps 2+ but no YOY, were also caught (Figure 12.31). In the first sampling in 2004 after manual sandbar closure in mid-June, catch numbers dropped to only 26 fish total (3 steelhead, 2 staghorn sculpin, 15 starry flounder and 6 sticklebacks). A visual survey was completed on the same day and numerous fish (juvenile steelhead and Sacramento suckers) were observed to be under the restaurants, inaccessible by our seining efforts. During July and August 2004, numbers of staghorn sculpins, prickly sculpins, starry flounders and sticklebacks remained relatively constant, with catches dominated by thousands of sticklebacks. Steelhead numbers increased slightly from the low catch in June to 40 and 60 individuals in July and August, respectively, until the final sampling in 2004 when 136 steelhead were captured in November.

Again, in 2005 we were able to sample before and after sandbar closure and found a very different pattern from 2004. Before closure, catch was small with only 139 sticklebacks, a few starry flounders, prickly sculpins and three adult Sacramento suckers. Juvenile steelhead catch was only nine individuals. We then sampled within a week of manual closure of the lagoon and had a sizeable steelhead catch of 128 fish that were age YOY and 1+ (Figure 12.32). Very few other fish (sticklebacks and starry flounders) were caught at this time. Throughout the rest of the 2005 sampling season, stickleback numbers fluctuated but increased at the end of the year to over 1,000. Steelhead catch was low in May and August 2005, but also increased towards the end of the year to 167.

Growth rates of steelhead were significantly higher in 2004 compared to 2005 (Figure 12.36). Steelhead recaptures were not strong in 2004, so individual growth rates were calculated only in October and November, averaging over 0.6mm/day. Using these few recaptures, we estimated the steelhead population in the lagoon to be 6,225, which is within one standard deviation of D. W. Alley and Associates 2004 estimate of 3,869 (Figure 12.27). This was Alley's highest population estimate in 15 years, so it is surprising to see such high growth rates during a time when competition was likely for food from the high numbers of conspecifics. During 2005 there was much more success at recapturing tagged fish, making the growth rate calculations and population size estimates more reliable and cover a longer time frame. There is quite a bit of variation in population size estimates early in the year, which may be reflective in changes in the steelhead population in the lagoon during this time or could be an artifact of relatively few recaptures early in 2005. By September, the number of recaptures increased, and population estimates look more reliable, but much lower than in 2004 (1,400-2,000 in 2005 vs. 6,225 in 2004) (Figure 12.27). With this lower population size, one might expect higher growth rates due to decreased competition, but in fact growth rates were lower in 2005 (Figure 12.36).

Juvenile streelhead from Soquel Lagoon had relatively high levels of black spot disease. Table 14.3 shows the frequency of black spot (light through heavy infestations) for fish during 2005. These numbers are higher than those from the North Coast lagoons.

Table 14.3. Frequency of black spot disease occurrence on fish in Soquel Lagoon during 2005.

May	June	July	August	September	October
33%	36%	70%	100%	97%	81%

Light infestation of black spot disease, as seen on a steelhead captured during CLEAP fish monitoring in 2005.

San Lorenzo Lagoon

San Lorenzo Lagoon is located in the center of the City of Santa Cruz, discharging to the Monterey Bay at Main Beach and the Santa Cruz Beach Boardwalk. The recreational pressures at this Lagoon are high (see far left color photo on report cover). Due to potential liability issues, the City of Santa Cruz has not actively managed the San Lorenzo Lagoon water levels or sandbar dynamics. The oldest land use map of the San Lorenzo Lagoon (1853) indicates the lagoon in its present location, but with a greater channel cross-sectional area and associated access to its floodplain and marsh (Figure 11.10). Since 1853, the surface area of the San Lorenzo Lagoon has been further constricted by the South Pacific railroad trestle 700ft from the Bay, in addition to various road crossings, extensive floodplain development and an ACOE flood control project. The San Lorenzo River remains under strict ACOE flood control, with the most recent levee improvements competed in 2003. The lagoon area oceanward of the last roadway bridge (Riverside Drive) is extremely exposed, devoid of any vegetation and its substrate is homogenous beach sand. Annual vegetation management in the active channel is conducted each fall between Highway 1 and the Laurel Street bridge to maintain flood capacity while preserving some channel complexity and sediment retention (San Lorenzo River Enhancement Plan 2003). The lower lagoon and associated tributaries are densely urban and populated as illustrated in Figures 11.12 and 11.14. The upper watershed of the San Lorenzo River is a dense rural residential land use serviced by septic systems, with a septic density of 269 people/mi^2.

San Lorenzo River Watershed is the largest of all evaluated for CLEAP at 135.9 mi^2 (Table 11.1), and thus surface water discharge to San Lorenzo Lagoon is significantly greater than the other lagoons' freshwater tributaries. San Lorenzo River steadily declines from approximately 20-30 cfs in May to 3-4 cfs by September. Branciforte Creek has a much smaller watershed than the San Lorenzo River and is assumed to contribute less than 10% of total freshwater volumes to the summer lagoon.

San Lorenzo River average inflow DIN and SRP concentrations from May through September samplings were 19.5mg/L and 2.56mg/L, respectively. Branciforte Creek was sampled for nutrient loads in the early spring and during the first rain events. During summer conditions, Branciforte Creek backwaters as a result of elevated water levels in the San Lorenzo Lagoon, making sampling of tributary conditions unrepresentative. Using the product of discharge and tributary concentrations, the daily DIN and SRP loading average for the same time periods were 16.2kg/day and 4.41kg/day, respectively. Compared to the other CLEAP lagoons, the seasonal loading of DIN (the limiting nutrient) to San Lorenzo Lagoon is high. Surface water DIN values were consistently elevated, with many samples exceeding 10uM. In most instances the SRP lagoon concentrations were below 4uM, but project peak values exceeding 10uM were observed in the Upper San Lorenzo Lagoon.

The historic San Lorenzo Lagoon surface area has been reduced by over 80%, dramatically simplifying the morphologic complexity of the Lower San Lorenzo Lagoon. The necessity of flood control has eliminated the adjacent low lying marsh habitat that would typically be inundated during winter runoff and summer lagoon conditions. San Lorenzo Lagoon from Riverside Drive oceanward (identified as the Lower San Lorenzo Lagoon in CLEAP) is the physical interface between the salt and freshwater environment. In Scott and Laguna Lagoons, this transition zone is characterized by emergent vegetation and a gravel substrate. The Lower San Lorenzo River is a highly exposed, confined channel with dramatic daily water level variations when tidal connection to the coastal ocean is present. Following sandbar formation, the storage capacity of the Lower Lagoon limits the duration of sustained lagoon formation until the early fall when inflow volumes reach an annual minimum. As the season progresses and the sandbar becomes more stable as much as 15-20% of the lagoon can be characterized as brackish warm water overlying beach sand.

As mentioned throughout this report, one main limitation of the 2-yrs of CLEAP observations is the difficulty in constraining the inherent inter-annual variability within each of these lagoons systems. In addition to natural variations, the City of Santa Cruz implemented a bank-stabilization effort during the CLEAP monitoring during 2004. The bank stabilization was conducted along the right bank (viewing downstream) between CLEAP stations SL6-SL5 (Figure 11.9) The project included flood wall reconstruction, bank willow planting and placement of instream log structures to create in channel pool habitat and complexity. During construction a portable dam structure was installed in the active channel and the restoration area was constantly dewatered by active water pumping. Biological monitoring and active fish removal from the within the confines of the portable dam area were a priority. The presence of the portable dam, the continued water pumping, and other associated in stream restoration activities likely had an effect on the water quality and biological conditions observed within the San Lorenzo Lagoon during 2004. During the sandbar formation and Lagoon closure in September 2004, the high water surface elevations caused the portable dam to fail, ceasing restoration construction activities. The manual breach of the San Lorenzo Lagoon on September 21, 2004 was conducted to reduce lagoon water elevations at the restoration site, and ensure construction could be completed. The specific effects on the existing CLEAP data are difficult to constrain, but continued water quality and biological monitoring within San Lorenzo Lagoon may later illuminate these effects.

San Lorenzo River bank restoration project upstream of Riverside Bridge.

left: May 14, 2004 during portable dam construction
right: June 18, 2004

The water quality in San Lorenzo Lagoon was typically poorer during reduced circulation conditions (micro tidal and/or closed), possessing the stressor values indicative of impaired conditions in most instances. High solar exposure, elevated DIN inputs and anomalously deep lagoon locations are all assumed to contribute to the poor water quality. The density stratification persisted during each reduced circulation regime observed (Figure 11.2) and was typically coincident with low DO and elevated chlorophyll levels. Visual observations suggest dense macroalgae blooms are common from Laurel Bridge to the railroad trestle and SAV species are absent from the San Lorenzo Lagoon.

In 2004, the San Lorenzo Lagoon closed two times (Figure 11.38). The initial closure in mid-July was sustained for 6 days prior to a breach. Immediately following closure bottom water temperatures increased and DO, pH and ORP all significantly declined. The continuous water quality records indicate daily DO fluctuations around 4mg/L despite bottom water temperatures above 20ºC. During this closure, bottom water and surface water salinity never dropped below 8ppt. Following the second closure the sandbar remained until a permitted manual breach was conducted on September 21, 2004. The breach was conducted to facilitate completion of the bank restoration construction efforts at Riverside Bridge. Significant blooms of dinoflagellates were observed during this closure, indicating episodic conditions that select for a very simplified food source at the base of the food chain (Figures 12.3-4). The zooplankton community in early September 2004 also exhibited an impaired community, dominated by a large number of a very small copepod cells (Figures 12.7 and 12.9). September 2004 was the only sustained closure of San Lorenzo Lagoon observed over the CLEAP observations.

The manual breach gradually reestablished a microtidal condition within the lagoon and, based on the time series of water quality data, slightly improved the daily DO average values to 6mg/L. Macrotidal circulation was reestablished following the winter rains in late October 2004, and this was the only natural sandbar breach that did not result in concurrent observations of DO, pH and ORP reductions. The improved lagoon water quality during the complete fall breach of 2004 during the winter storms may in part have been due to the gradual transition of the lagoon system to increased circulation. In contrast, episodic draining of a lagoon system where a large amount of organic matter has accumulated at the sediment water interface appears to result in degraded water quality as observed by coincidental low DO, pH and ORP values during lagoon draining. This poor water quality is likely the result of water column turbulence that causes fine-particle suspension and mixing of reduced chemical species (i.e. ammonia and hydrogen sulfide) into the water column. Again, the enhancement approach challenge is not to implement annual manual lagoon breach events, but rather develop enhancement components that reduce the organic matter accumulation rates at the sediment water interface during the summer season, and/or physical components that reduce the lagoon water effluent flow rates during a natural breach event.

San Lorenzo Lagoon was characterized by microtidal circulation conditions in 2005 (Figure 11.39). Similar to 2003 morphology, the lagoon established an intermittent connection with the coastal ocean approximately 1000ft westward along Main Beach. The lagoon water budget was characterized by relatively slow filling from inflowing surface waters and periodic outflow events when water levels exceeded the sandbar elevation. While the patterns are irregular, these hydrologic cycles repeated every 3 days on average. The water quality in 2005 in Lower San Lorenzo Lagoon from mid-August to mid-November was characterized by depressed DO (typically < 5mg/L), pH and ORP levels. Daily variations are extremely muted in the DO and pH records during this time. The manufacturers of YSI probes warn that dissolved oxygen readings can become erratic in the sustained presence of hydrogen sulfide. Simple field Hach kit test did not detect H_2S above 0.1mg/L during the October 5, 2005 site visit, but the analytical accuracy of these kits is questionable. A pungent “rotten egg” odor in bottom water samples was noted by field personnel. Bottom water NH_4^+ concentrations exceeded 5uM (Figure 11.53), further supporting oxygen stressed conditions. The dominant substrate at the stations in the Lower San Lorenzo Lagoon transitioned from beach sand in May to organic detritus by late summer each year (Table 11.2).

While we only had one benthic sampling effort in 2004, the benthic invertebrate abundance in the benthos was extremely low following the manual breach of the lagoon. July and August 2005, just prior to the circulation transition to a microtidal system (Figure 11.18), the invertebrate abundance in the downstream San Lorenzo benthos was dominated by corophium (the highest observed abundance over the course of the project (Figure 12.16-17)). The subsequent samplings resulted in the benthic invertebrate abundance sequentially declining by 50% each observation (Figure 12.17). The littoral sweep samplings suggests that the abundance of the invertebrate communities along the periphery of the Lower San Lorenzo Lagoon remains more stable over the duration of the summer with the Simpson Diversity value averaging 0.6. The mysid population observed in the shallow shores of the July and August 2005 Lagoon were 18-20 mm, 3 times larger than the mysids observed in other lagoons. These mysids are expected to be an excellent food source for the juvenile salmonids (Martin 1995).

San Lorenzo Lagoon mouth during microtidal conditions (Oct 2005)

Lower San Lorenzo Lagoon view toward Monterey Bay (Aug 2005)

Juvenile steelhead monitoring has been conducted in the San Lorenzo watershed since 1994 (Alley *et al*. 2002 and Harvey *et al.* 2003). These studies focused on the mainstem and the many of the tributaries of the San Lorenzo, but did not include the stretch most important to the CLEAP study, the lagoon. San Lorenzo Lagoon, like Laguna, was sampled by Hagar Environmental Sciences in 2004 and the NMFS team in 2005. Sampling in 2004 was complicated by the enhancement project that shored up and improved the riverbank upstream of the Riverside Bridge. During this construction, a dam was built to exclude water, so pumps were constantly running and fish were moved from the construction zone to the alternate channel. This most likely had an effect on the fish communities that commonly live in that stretch of the lagoon, however the highest species richness was found in San Lorenzo during July 2004 (Figure 12.19). The majority of those species are near shore fish that may aggregate in the relative shelter of the Monterey Bay and probably moved into the lagoon with the incoming tides or large swells (Figure 12.21). Because San Lorenzo remained open to the ocean throughout most of both years, there was a large influence on total catch by these near shore fish (note the very large catches of topsmelt, Figure 12.22). Juvenile steelhead were found in San Lorenzo during both 2004 and 2005, but no coho salmon juveniles were found in the lagoon either year (although juvenile coho were found upstream in 2005, D. W. Alley, pers. comm.). Tidewater gobies were found during 2004 (and were moved during the dam construction), but not 2005. Stickleback densities were very low in San Lorenzo compared to all other CLEAP lagoons.

Steelhead catches were variable, but peak catch occurred in July of both years (154 fish in 2004 and 396 in 2005). Because of the very low steelhead catch during the second sampling in 2004, there were no estimates of population size or growth rates for that year. In 2005, however, we had better luck and were able to estimate population size (Figure 12.27) and growth rates (Figure 12.36). Population sizes were estimated at 4,277 in August and 5,452 in October 2005. These population estimates are surprisingly low considering the significantly larger volume in San Lorenzo compared to the other lagoons (Figures 11.19-11.28). This larger volume should provide greater habitat for more fish in San Lorenzo. One possible explanation for our low estimates is that we sampled in distinct sites along the length of the lagoon, so the total volume that we sampled in San Lorenzo is significantly less than the total volume of the lagoon. These population estimates suggest that steelhead in San Lorenzo have strong site fidelity and our tagged population was not being “diluted” by moving into regions of the lagoon that we did not seine (this movement would result in fewer recaptures and a larger population estimate).

As stated previously, steelhead growth rates were calculated only for 2005. Growth rates were relatively high in San Lorenzo in July and August 2005, 0.76 and 0.92mm/day respectively. These rates dropped later in the fall to 0.44mm/day in October. These growth rates are actually quite consistent across the whole season, indicating that habitat quality and food availability are adequate and competition from conspecifics may not be a significant factor.

Steelhead caught in the San Lorenzo Lagoon were large, and their age classes may be difficult to determine without analyzing a subsample of scales (scales were collected but have not been analyzed to date). Small YOY steelhead (<65mm) were never caught in San Lorenzo lagoon (they were caught in all other CLEAP lagoons at least during one sampling year). A dramatic demonstration of how different year/age classes utilize the different lagoons occurs when one compares the steelhead catch in Scott Lagoon in July 2004 (fork lengths: 37-65mm, Figure 12.28) to the San Lorenzo catch in July 2004 (fork lengths: 67-226mm, Figure 12.33). Fish residing in these two different lagoons during the same time period (sampling in Scott occurred 3 days after the San Lorenzo sampling day) are comprised of significantly different size classes.

San Lorenzo, like Soquel, was one of the lagoons where many steelhead were infected with black spot disease. Harvey et al. (2003) note the presence of the black spot disease at the most downstream sampling site (close to the lagoon) and at other locations scattered along the mainstem and certain tributaries. Table 14.4 shows the prevalence of diseased fish (light to heavy infestations combined). These numbers are for the most part lower than those in Soquel (Table 14.3), but higher than all other lagoons. What makes fish in Soquel and San Lorenzo more susceptible to this parasite is unknown at this time and could range from factors affecting the steelhead themselves to factors affecting the other hosts of the parasite, which could result in higher concentrations of the trematode in the water.

Table 14.4. Frequency of black spot disease occurrence on fish in San Lorenzo Lagoon.

July 04	June 05	July 05	Aug 05	Oct 05
53%	42%	21%	24%	34%

Aptos Lagoon

The lower portion of Aptos Lagoon is confined by 25ft vertical concrete walls for over 350ft, creating a channel/lagoon approximately 80ft wide. A pedestrian bridge is located 500ft from the ocean, representing the transition from a cement box channel to the beach sand environment. East of the cement channel are earthen levees with dense willow development and residential encroachment. Prior to development, the area of possible lagoon inundation of Aptos Lagoon spanned between the two sandstone bluffs (Figure 11.13). By 1928 the Rio Del Mar Area was subdivided and the Aptos Lagoon was channelized in its current location (Figure 11.14).

Aptos and Valencia Creeks are the main tributaries draining into Aptos Lagoon. The majority of Aptos Creek Watershed is undeveloped as part of Nisene Marks State Park. Valencia Creek Watershed is mostly rural residential development serviced by septic. The different land use distributions in Valencia Creek versus Aptos Creek have a significant impact on the associated nutrient concentrations, with Valencia Creek typically containing the highest DIN concentrations and Aptos Creek near the lowest levels observed in all CLEAP tributaries. Surface water discharge in Aptos and Valencia Creeks steadily decline from a combined discharge of approximately 5cfs in May to 1cfs by September.

Aptos Lagoon average inflow DIN and SRP concentrations from May through September samplings were 31.6 and 3.95mg/L, respectively. Compared to the other CLEAP lagoons, the seasonal loading of DIN (the limiting nutrient) to Aptos Lagoon is high. Surface water DIN values in the lagoon are consistently moderate to high, with DIN values ranging from 4uM - 15uM. Surface water SRP values in the lagoon are high relative to the other lagoons, typically greater than 3uM.

Views of Aptos Creek Lagoon. Left taken from pedestrian bridge, looking upstream at the flood-controlled, concrete channel. Photo right taken from bluff, looking at the lagoon mouth during macro-tidal conditions.

San Lorenzo and Aptos Lagoons are the most impacted (by human activities) lagoon systems evaluated for CLEAP (Table 7.2). The associated modifications to these systems as a result of flood control necessity and nutrient loading from upstream land uses limit the biogeochemical function of these lagoons. Similar to San Lorenzo, the lower Aptos Lagoon is significantly constrained, simplified and exposed. Aptos Lagoon did not experience a sustained closure in 2004 beyond 6 days (Figure 11.40), in part due to unauthorized manual breaches by local residents concerned about the lagoon water quality (personal communication with residents). Very poor water quality conditions were observed in late July 2004 and repressed DO levels (< 3mg/L) in Aptos Lagoon were common. Aptos Lagoon during the critical months in 2005 was typically microtidal with one sustained sandbar closure. While the continuous depth record suggests the sandbar was intact, numerous incidents of salinity increases were recorded by the bottom water instrument. DO, pH and ORP records indicated three specific instances where water quality was compromised in the lagoon during 2005 (Figure 11.41). The seasonal variability and absolute extremes of repressed DO, pH and ORP over the course of CLEAP were the most dramatic in Aptos Lagoon in 2005.

Similar to San Lorenzo, the biological indicator values from Aptos Lagoon typically represented impaired conditions. The primary producer community is dominated by dense macroalgae mats and phytoplankton blooms. The substrate of the lagoon transitions from sand in April to a black fine-grained organic substrate by early fall (Table 11.2). The bottom water disturbance caused by the act of fish seining in the fall resulted in a black water column and detectable odors of “rotten eggs”, suggesting the presence of hydrogen sulfide.

Average species diversity values of phytoplankton during summer and fall in Aptos Lagoon were below 0.3 (Figures 12.4 and 12.6). The biovolume observations of phytoplankton as measured during LSD and by the automated instrumentation suggest bloom-and-crash cycles from spring to fall. Large phytoplankton blooms were dominated by either chlorophytes or dinoflagellates species. The seasonal average and annual peak zooplankton biomass was consistently the highest of all lagoons. However, zooplankton bloom events consisted of relatively larger sized organisms in comparison to the conditions when biomass was low. The lagoon composite of the benthic invertebrate sampling (Figure 12.13-14) indicate a moderately diverse benthic community with comparable abundances to other lagoons. However, the downstream benthic grab results indicate the lower Aptos Lagoon is nearly devoid of benthic organisms with severely low diversity values (Figure 12.17). The upstream benthic monitoring station (Figure 11.12, AP5) is subjected to the same inflowing nutrient loads than the downstream station and the channel morphology is a similar trapezoid (AP2). The most obvious difference between the upstream and downstream stations is the riparian cover and the natural vegetation on the lagoon banks. The extreme exposure of the downstream station to solar radiation is exacerbated by the trapping of heat by the cement walls. The seasonal instability of the biological community is responding to the poor water quality, elevated nutrient loads and extreme susceptibility of the lower Aptos Lagoon to eutrophication.

Fish catches in Aptos were very different between 2004 and 2005. 2004 was characterized by very large numbers of sticklebacks and large juvenile steelhead catches, while 2005 had considerably smaller total catches with many juvenile starry flounder showing up in the early summer (Figure 12.22). The peak starry flounder catch in Aptos occurred the day before the peak starry flounder catch in San Lorenzo (13 and 14 June 2005). Aptos catches had a small complement of fish with the occasional visitor from near shore (topsmelt, bay pipefish and redtail surfperch). Topsmelt were a significant fraction of total catch in June and July 2004 and July and August 2005. Tidewater gobies were found in Aptos in both years in relatively small numbers. Coho salmon were not found in Aptos Lagoon, although anecdotal references place coho there and it was classified as having a high likelihood of coho presence by Spence et al. (2005).

Aptos consistently had the highest fish catch density (g/acre ft) of all of the CLEAP lagoons in 2004 (Figures 12.24-25). Steelhead catch was much larger in 2004, and there were sufficient recaptures to estimate population sizes (Figure 12.27). Population estimates for 2004 suggest a large population with values over 2,600 in August and September, dropping to around 700 towards the end of 2004. In contrast, steelhead catch was relatively small in 2005 and there were fewer recaptures, thus fewer opportunities to estimate population size. 2005 populations were estimated to be between 600 and 1,000 fish. While these are low numbers, they are comparable to Scott and Laguna population estimates for the same time period.

During 2004, it is easy to determine which age classes are utilizing the lagoon (Figure 12.34). Early in the year, YOYs, 1+ and even 2+ are present, and the 1+ year class seems to dominate the population (see May 2004). As time progresses and fish grow, by August the population is now dominated by the much larger YOYs, and there are very few 1+ left, most having gone to sea.

Growth rates of juvenile steelhead were very high early in 2004, over 1mm/day in June (Figure 12.36). This rate is close to the high growth rates found in Scott Lagoon during August of 2005. Growth rates fell to around 0.6mm/day and remained there for the rest of 2004. This is considered very strong growth. Due to the lack of recaptures in 2005, growth rates could only be calculated for 3 months. In all three months of 2005, growth rates were slower than during any month in 2004 (Figure 12.36).

Aptos lagoon steelhead showed evidence of black spot infestation, as quantified in 2005. Proportions of infested fish are shown in Table 14.5. While there were occasional incidences of black spot infestations on steelhead in the North Coast lagoons, it is significant to note that the highest prevalence of black spot disease was in the more urban lagoons.

Table 14.5. Frequency of black spot disease occurrence on fish in Aptos Lagoon during CLEAP monitoring.

May 05	June 05	July 05	Aug 05	Sept 05	Oct 05
22%	0%	24%	0%	28%	45%

Urban Lagoon Enhancement Recommendations

Soquel Lagoon

Soquel Lagoon is actively managed by the City of Capitola as described throughout the CLEAP report. The inclusion of Soquel Lagoon into the CLEAP efforts provided physical, chemical and biological data on a managed control lagoon. One opportunity for further enhancement of Soquel Lagoon is the physical simplicity of the trapezoidal cross-section lagoon channel. Opportunities to improve channel complexity, sediment sorting, and in-stream habitat niches may improve the ecological sustainability of this system. Greater physical variability within the lagoon could be accomplished with strategically placed instream wood structures to encourage a more focused low flow channel and sediment sorting during non-lagoon and storm flow conditions. Potential impacts to the existing Soquel Lagoon Management Plan associated with establishing a low flow channel within the confines of the current trapezoid shaped channel would have to be considered. The increased physical cross-sectional variability created by a more defined low-flow channel and instream log structures would increase the effort necessary to effectively remove organic matter and oceanic detritus during the manual spring closure.

San Lorenzo Lagoon

The imperative need to maintain flood protection for the surrounding City of Santa Cruz limits the immediate opportunities for physical enhancement to improve habitat complexity. Community efforts should continue to explore possibilities to reclaim the Santa Cruz Boardwalk Parking Lot and expand the surface area of the lagoon. The installation of additional log habitat enhancement structures like those recently placed upstream of Riverside Drive would improve the complexity of the lagoon substrate and potentially increase refuge for aquatic species (San Lorenzo Urban River Plan 2003).

Long-term source control of DIN should also be a priority in the San Lorenzo River Watershed. Management strategies to ensure upgrades of aging septic systems should be explored. Routine sewer system maintenance should be a priority. Public awareness and education about best management practices (BMPs) with respect to fertilizer applications, car washing, dog waste, etc. will also collectively reduce DIN loads from urban areas.

Given existing flood control constraints, we recommend that the San Lorenzo Lagoon be used as an educational laboratory to increase the community awareness of lagoons. The development of a Santa Cruz public elementary school curriculum would engage local residents with lagoon enhancement and utilize volunteer energy to test the feasibility and benefit of annual SAV and emergent vegetation planting in the channel bed of the Lower San Lorenzo Lagoon.

From a lagoon function perspective, the objectives of an annual channel revegetation effort in the Lower Lagoon would focus on the direct reduction of available DIN to the fast-growing primary producer community. All planting would occur in the channel substrate of the Lower Lagoon during low tide conditions in April and May each year. No planting would occur on the channel banks. A preferred list of potential herbaceous, SAV and emergent floral species would be developed and selection would focus on fast-growing, shallow-rooted species, tolerant of brackish conditions, and native to California marsh systems. SAV and emergent plants are expected to grow and fix DIN throughout the critical lagoon season, reducing the available DIN for phytoplankton and macroalgae. The plants would also provide instream shade and habitat for resident organisms. The location of the plantings in the active channel of the San Lorenzo River mouth would result in winter flows annually removing and transporting the organic material out of the lagoon each winter.

San Lorenzo Lagoon looking
downstream from Riverside Bridge
Site for potential community channel
SAV planting project.

A collection of Santa Cruz elementary schools would be equipped with on-site nurseries to cultivate the plants each year. An applied science curriculum would be developed to educate children and their families about coastal lagoon function and all of the associated physical, chemical and biological components of these valuable systems. The schools and volunteers would provide the labor necessary to replant the base of the lagoon each spring. A simple monitoring program to document enhancement success would be developed for implementation by the children and volunteers to refine planting techniques and species selection, observe influence on other primary producer communities, and conduct any other monitoring that would directly feed the adaptive management of this program. If successful, similar programs could be implemented in other flood-controlled, eutrophic lagoons.

Aptos Lagoon

Similar to San Lorenzo Lagoon, the two primary components impairing the ecological function of Aptos Lagoon are assumed to be poor water quality and lack of morphologic complexity. The susceptibility of Aptos Lagoon to eutrophication is due to extremely high DIN availability, high solar exposure, and lack of a slow-growing primary producer community to reduce organic matter loading. Long-term source control efforts to minimize the Valencia Creek DIN concentrations should be a priority. Management strategies that encourage replacement of degraded residential septic systems and commitments to urban sewer line maintenance will collectively reduce the DIN loads to the Aptos Lagoon.

While flood control remains a priority in Aptos Lagoon, potential opportunities may exist to widen the existing lagoon cross-section and replace the vertical cement walls with terraced earthen banks that can support emergent and riparian vegetation. Figure 14.2 is a conceptual plan view and cross section of a potential physical enhancement approach for Aptos Lagoon. The proposed cross-sectional area of the lagoon is slightly wider than existing conditions and terraced banks would provide planting opportunities of wetland and riparian flora. The engineering designs would preserve the existing hydraulic capacity of the channel, ensuring the same level of existing flood protection. The placement of alternating rock groins perpendicular to the flow path through the lagoon would promote the development of a meandering low flow channel and sediment grain size sorting. The terraced cross section and rock groin structures would significantly increase hydraulic variability during a range of winter flow volumes and result in greater morphologic complexity of the summer lagoon. The downstream extent of the channel groins could be placed to encourage the mouth development predictably to the North, onto Department of Parks and Recreation property each year. The current unpredictability of the lagoon mouth and area of inundation on the beach creates recreational management limitations for the beachgoers and limits human access to the ocean.

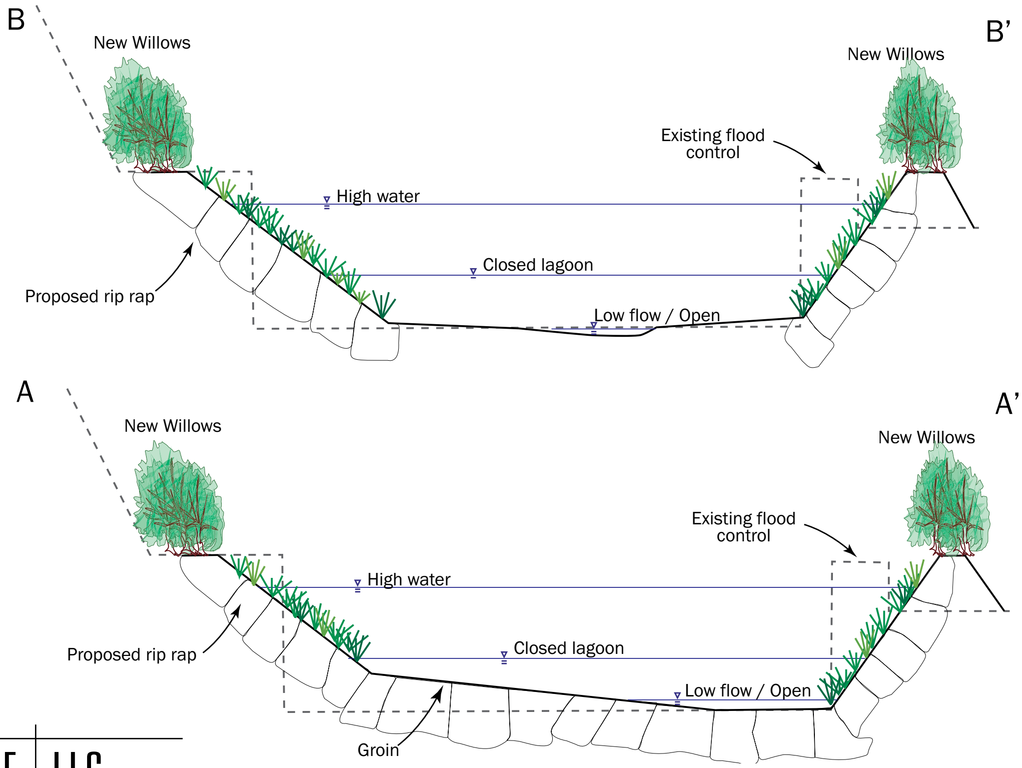
The replacement of the 25ft vertical cement walls with natural materials will soften the lagoon habitat and dramatically increase the terrestrial riparian ecology adjacent to the lagoon. The summer heat retention of a more native landscape would be significantly lower than a cement hardscape, thereby reducing the susceptibility of Aptos Lagoon to eutrophication and associated water quality impacts. However, the extent to which morphologic and exposure modifications will alter water quality is significantly limited by the existing nutrient loading to the lagoon. Progressive DIN source control efforts will gradually improve the water quality benefit of such a modification.

Future recommendations to facilitate the enhancement process for Santa Cruz County urban lagoons:

1. Long-term enhancement efforts should focus on land acquisition opportunities to expand the surface area of constricted flood controlled lagoons.
2. Long-term urban lagoon enhancement should focus on continued efforts to reduce non-point source loading of nitrogen and phosphorous.
3. Septic systems, leaky sewer systems, animal waste and agricultural activities are coincidently sources of indicator bacteria of human health concerns as well as nutrients. Additional evaluations of existing long-term nutrient and bacterial monitoring may identify useful correlations between elevated nutrient, eutrophic conditions in local lagoons and incidents of elevated bacterial counts.

PLANVIEW

CROSS-SECTION VIEW



Note: Cross section not to scale, vertical exaggeration

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CONCEPTUAL DESIGN FOR APTOS CREEK LAGOON ENHANCEMENT

FIGURE 14.2

4. Educational programs should be developed to better inform and involve the local community on the ecological value of lagoons, lagoon function, the effects of breaching on the lagoon, and the perceived water quality concerns to the nearshore beaches.
5. Lagoon specific enhancement opportunities should focus on increasing physical complexity within urban lagoons. Complexity includes variability in cross-sectional morphology, variability in channel substrate sorting, channel bed roughness variations, riparian cover and other components inherent in more naturalized aquatic systems that will provide an array of habitat niche characteristics for which the biological community can utilize.
6. Lagoon specific enhancement opportunities that reduce the susceptibility of urban lagoons to eutrophication and associated poor water quality conditions. The enhancement opportunities should be self-sustaining alternatives that will require little annual maintenance and focus on assisting these lagoon systems to establish a new sustainable equilibrium given inevitable human induced constraints.

Future recommendations to facilitate the enhancement process for San Lorenzo and Aptos Lagoons:

7. San Lorenzo Lagoon Educational Outreach
    - 7a. Identify educational and community stakeholders for channel revegetation program.
    - 7b. Develop details of channel revegetation program including species selection, cultivation techniques and logistics, curriculum requirements, performance monitoring parameters, etc.
    - 7c. Provide adaptive management feedback for additional modifications to annual planting program based on site-specific observations and enhancement performance 2-5 years following implementation.
8. Aptos Lagoon Enhancement
    - 8a. Acquire access to adjacent property bordering Aptos Lagoon.
    - 8b. Develop channel reconfiguration alternatives in more detail, including HEC-RAS model to evaluate effects of enhancement alternatives on flood conveyance.
    - 8c. Evaluate opportunities and constraints of alternatives.
    - 8d. Select preferred alternative and develop 100% design, secure permits and construction plans.
    - 8e. Construct and implement enhancement.
9. Aptos Lagoon Performance Monitoring
    - 9a. Identify and implement CLEAP parameters for continued monitoring pre and post project to evaluate enhancement performance and focus long-term monitoring. Focused post project monitoring should continue at least 5 yrs following implementation.
    - 9b. Identify priority functional parameters to be improved by enhancement design and collect pre-project data if any of the parameters were not collected during CLEAP.
    - 9c. Provide adaptive management feedback for additional modifications/enhancement based on site-specific observations and enhancement performance 2-5 years following implementation of 8e above.

Future recommendations to evaluate collective upstream enhancement efforts:

The location of the lagoons at the terminus of the watershed provides an opportunity for long-term evaluations of the collective success watershed enhancement effort have on the health of the aquatic system as a whole. Below we provide some conceptual recommendations for cost-effective long-term monitoring within specific lagoon systems with upcoming restoration efforts in the contributing watershed.

10. Monthly DIN and SRP loading, as quantified by CLEAP, should continue to be monitored. Successful enhancement efforts to reduce nutrient sources should result in a decrease in the monthly and annual nutrient loading to the lagoons over time. The reporting and evaluations of nutrient loads must account for, and consider, the interannual hydrologic variability and other processes influencing nutrient loads. Refining and extending the long-term nutrient loading data set of the Santa Cruz County Environmental Health Department would be a cost effective approach.
11. Sediment source reductions is a common objective of many future upstream enhancement and restoration projects in Santa Cruz County. The establishment and maintenance of continuous turbidity monitoring stations at the stream/lagoon interface would allow the development of long-term data set of sediment loading to the lagoon system. The continuous turbidity station would include an automated turbidity probe, intermittent suspended sediment sampling to establish a turbidity/total suspended sediment concentration rating curve, and continuous stream discharge in order to create a continuous time series of suspended sediment delivered to a lagoon. If upstream efforts are successful, long-term observations should display a reduction in the event and annual suspended sediment loads emanating from the watershed. Effective sediment reduction efforts should also increase the dominant grain size of the suspended sediment load over the long-term and components of the monitoring can evaluate grain size distribution as well. In order for these efforts to be effective at quantifying changes in sediment loading, the program must implemented in the near future with the goal of being an on-going monitoring program. A long-term sediment loading data-set will be necessary to extrapolate short-term variability from long-term sediment reductions.

15. Future Lagoon Evaluation Recommendations

The details of future monitoring plans in specific Coastal California lagoons will be unique and driven by the objectives of each evaluation effort. However, CLEAP has provided tools to refine future evaluations that may range from wide-scale rapid bioassessments of coastal lagoons to lagoon-specific evaluations designed to quantify the performance of various enhancement actions.

DOCUMENTATION OF METHODS

CLEAP has developed and documented all field data instrumentation, collection and monitoring techniques utilized to improve our understanding of coastal lagoon function (Sections 8 and 9). Detailed examples of data reduction and graphical presentations are also provided (Sections 10 and 11). Future lagoon physical, chemical and biological datasets can be collected with the direct intent of quantitative comparisons with CLEAP lagoon conditions.

STRESSORS

The observed physical and chemical conditions across lagoons were utilized to develop metrics (quantitative expressions) of static and dynamic stressors. Stressors were deemed ‘successful’ if they displayed a range of values across CLEAP observations and possessed a statistically significant correlation (p-value < 0.01) to biological indicators, and the correlation was not heavily influenced by outlier values. The successful stressor have been identified as components of lagoon systems that have an influence on habitat quality.

The successful stressors identified by CLEAP can be used to:

- refine future lagoon evaluations by targeting components of these systems that are directly relevant to ecological health.
- monitor these conditions pre- and post-enhancement to quantify changes of the stressor in a specific lagoon over time.

Below we recommend a number of cost-effective parameters to quantify stress based on the value of the data and the relative cost/data point. Each can be quantified by simple one-time field observations.

- Static stressors as presented in Table 10.1.
- Tributary DIN concentrations in July/August.
- Percent of lagoon where channel substrate is dominated by fine grained organic material in April, indicative of locations where winter hydraulic flushing is restricted. Depth of organic layer at sediment interface could also be measured at lagoon sampling stations.
- Percent of lagoon that appears to be hydrologically restricted relative to other locations within the lagoon.
- Dominant lagoon substrate grain size in late summer/early fall.
- Seasonal lagoon inundation area evaluations to determine if lagoon volume is limiting aquatic habitat during late summer/early fall. Does lagoon volume appear to be significantly below recent high water marks?
- Density stratification stability in late summer/early fall.
- Bottom water dissolved oxygen, pH and ORP levels during biological observations (late summer/early fall).
- In all instances, the circulation regime of the lagoon during biological/water column observations should be determined and considered during data evaluations.

There are likely other physical and/or chemical conditions that stress and/or impair the ecological health of a lagoon that were not identified during the CLEAP efforts. In addition, the most influential conditions limiting lagoon health is likely different for different lagoons. Future efforts should continue to address lagoon function as a process and refine a list of the most common stressors that have an influence on ecological sustainablity in coastal lagoons.

BIOLOGICAL INDICATORS

The CLEAP efforts have expanded our knowledge of existing biological communities for primary producers, secondary producers, benthic invertebrates and fish within Central California coastal lagoons. Conditions across lagoons with varying degrees of human impacts were used to identify specific components of each trophic level that best respond to a range of physical and chemical conditions. Future ecological evaluations within California lagoons can utilize this biological knowledge and 'successful' biological indicator list to select parameters for study.

- Cost-effective evaluations of a lagoon's primary producer community should focus upon the relative dominance of SAV, macroalgae and phytoplankton during reduced circulation conditions.
- Phytoplankton community dynamics, including species diversity, particular species dominance, taxa density and others, displayed a predictable response to specific lagoon stressors, showing promise as a biological indicator. Phytoplankton enumerations do require analysis by a trained taxonomist.
- While the taxonomy from brackish lagoon systems remains incomplete, the benthic invertebrate sampling and enumeration techniques employed for CLEAP were relatively cost-effective and provided a number of promising biological indicator metrics. The benthic invertebrate community near the mouth of the lagoons showed the greatest correlation across lagoons in response to the lagoon stressor values.
- There were no direct correlations between lagoon stressors and the sensitive fish species (i.e. steelhead, coho salmon and tidewater goby). Because fish are relatively long-lived, they can integrate conditions over the time frame of years, as well as seasons. The limited data of the CLEAP study (only 2 years) makes large-scale patterns within the fish data difficult to tease out. Future studies can use the CLEAP data as a starting point, and with increased amounts of data, aspects of the salmonid data (growth, populations numbers, age class composition) may develop into important new biological indicators.
- At a bare minimum, fisheries monitoring of restoration or enhancement projects should focus on enumeration of species present, counting numbers of individuals and determining locations within the lagoon that fish are utilizing (i.e., Are they inhabiting and/or feeding within the enhanced portion of the lagoon, or are they avoiding it?). Fisheries monitoring is expensive, whether paying for manpower or autonomous monitoring equipment. Ideally, fisheries monitoring would involve tracking of numerous individuals, allowing information on residence times within particular portions of the lagoon to be discovered, and over time, growth rates to be calculated. This could take the form of numerous PIT-tagged fish moving within a lagoon equipped with in-stream PIT-tag antennae (autonomous monitoring stations located at important sites throughout the lagoon) that would archive fish movement between locations of interest. These monitoring stations are expensive to install initially and require maintenance by a technician familiar with the equipment, however they would provide vast amounts of data with

constant monitoring of fish movements. Alternatively, a study like CLEAP could be useful, where PIT-tagged individuals are recaptured at various locations within the lagoon, thus showing site utilization (only at certain points in time), and the recaptures would provide growth rate data. The cost-benefit analysis of the type and quantity of fisheries data must be considered carefully.

BASELINE DATA OF CLEAP LAGOONS

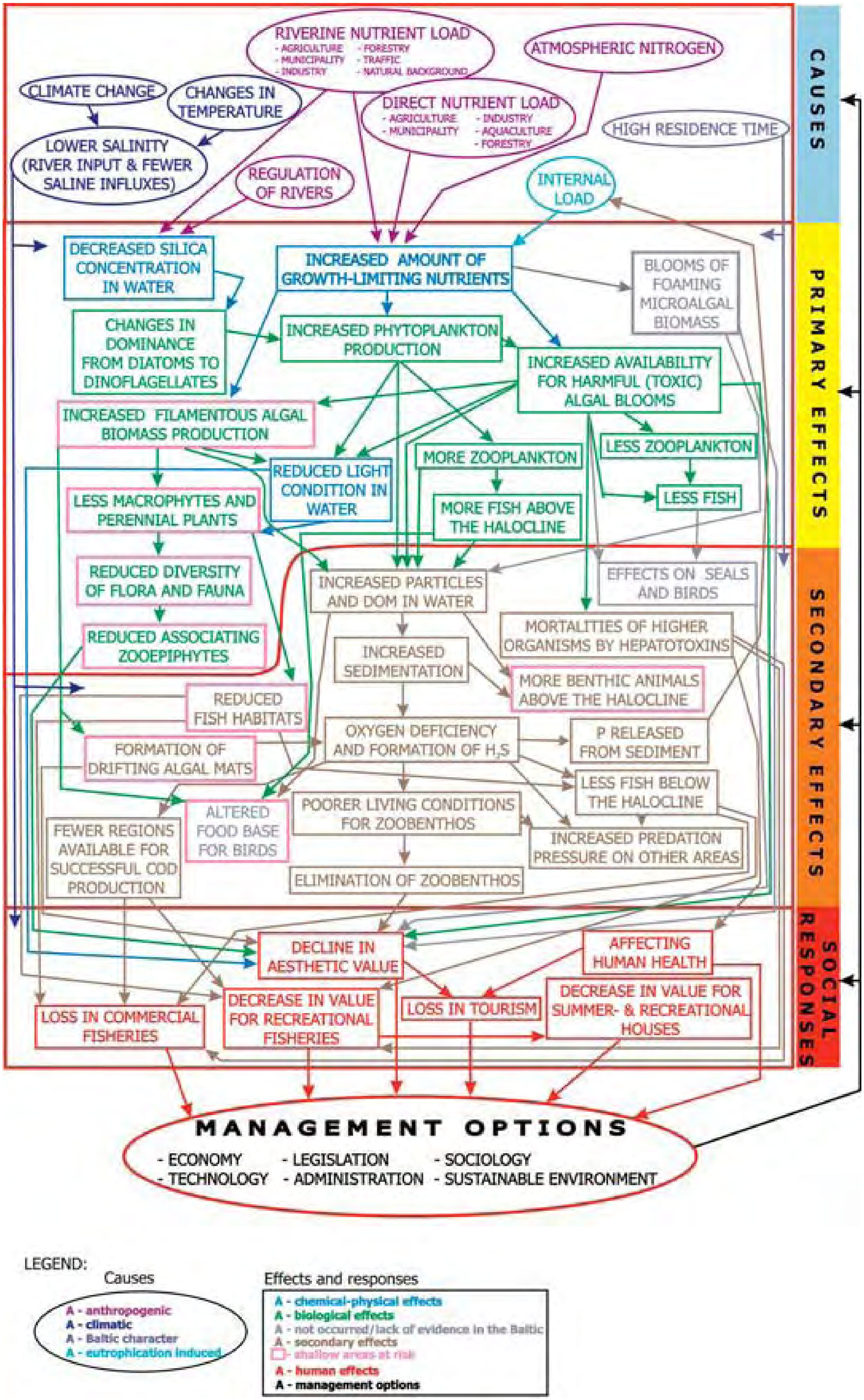
CLEAP has created an extensive baseline dataset of five lagoons in Santa Cruz County that is digitally available from the Santa Cruz County Resource Conservation District (entitled CLEAP_DATA.mdb). The selected CLEAP lagoons were resource management priority sites that satisfied the scientific needs of a range of habitat conditions. Each of the CLEAP lagoons has a high likelihood of future enhancement actions either in the contributing watershed or within the lagoon itself to meet flood control, recreational and/or ecological beneficial uses. As management issues arise and future resource enhancement efforts occur, the CLEAP database and calculated stressor and indicator values will be an invaluable resource. Performance evaluations of enhancement efforts can quantify changes in stressors and biological indicator values. Each monitoring plan will be specifically designed to address the objectives of future evaluations, but we have provided priorities of future CLEAP lagoon evaluations based on preliminary recommendations of enhancement alternatives for each lagoon (Section 14).

REGIONAL ASSESSMENTS OF COASTAL LAGOONS

The CLEAP efforts can assist with refining the approach, terminology and goals of future California Coastal lagoon assessments. As broader assessments are developed and implemented to determine the relative health and to identify limiting factors for ecological function of lagoon systems, the CLEAP approach, data collection protocols and findings will be useful. CLEAP lessons learned and approach can be incorporated into future regional bioassessment, or development of an index of biological integrity, or the newly developed California Rapid Assessment Method (CRAM) for coastal wetlands. Integrating the science of lagoon function into the future coastal lagoon enhancement approach will improve our ability to implement changes that will directly address the symptoms of lagoon impairment, while working within the inevitable human stressors.

INTEGRATION OF SCIENCE AND ENHANCEMENT

Management of natural aquatic systems must balance social, economic, recreational, and ecological needs. The interdisciplinary approach to lagoon management will increase the collective effectiveness of enhancement and management actions. The iterative process of adaptive management includes increasing the communication between scientists, resource managers and the public. The ecological complexity of lagoons makes a communication of the science to managers and the general public difficult in a simplified manner. Stakeholders of the eutrophic Baltic Sea developed a conceptual management tool to illustrate possible relations and pathways between natural science and the socioeconomy in a user friendly way (Lundberg 2005). The conceptual management tool is presented as Figure 15.1, and while it may look overwhelming, each factor (and the effects it may have on other factors) is presented clearly. While the specific responses to eutrophication in Coastal California Lagoons do not specifically follow the observations and key issues associated in the Baltic Sea, this flow chart illustrates the complexity of the eutrophication process and the potential relationships between science, public and management. The future of Central California lagoon management should continue to encourage cooperation between the fields of natural sciences, natural resource managers and the general public to improve the ecological value of these unique ecosystems.



CONCEPTUAL MODEL OF MANAGEMENT AND SCIENCE INTEGRATION

FIGURE 15.1

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