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Monitoring of Seagrass, Marsh Plants, and Macroalgae in Elkhorn Slough

Sherry Palacios

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S. Palacios was invited to prepare this document as a part of her duties as a NOAA Graduate Research Fellow at the Elkhorn Slough National Estuarine Research Reserve.

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AUTHOR AFFLIATION
At the time the report was prepared, Sherry Palacios was a graduate student at Moss Landing Marine Laboratories, Moss Landing, CA 95039.

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The mission of the Elkhorn Slough Foundation and the Elkhorn Slough National Estuarine Research Reserve is conservation of estuarine ecosystems and watersheds, with particular emphasis on Elkhorn Slough, a small estuary in central California. Both organizations practice science-based management, and strongly support applied conservation research as a tool for improving coastal decision-making and management. The Elkhorn Slough Technical Report Series is a means for archiving and disseminating data sets, curricula, research findings or other information that would be useful to coastal managers, educators, and researchers, yet are unlikely to be published in the primary literature.

Monitoring aquatic vegetation in Elkhorn Slough: an introduction

The Elkhorn Slough is a dynamic marine and fresh water environment that supports submerged and emergent aquatic vegetation. The taxa reviewed here include seagrasses, marsh plants, and macroalgae. This review does not include phytoplankton or animal communities associated with aquatic vegetation. The goal of this paper is to summarize previous monitoring efforts in the slough, to review monitoring efforts from other research programs, and to establish a rigorous monitoring plan for the future to be undertaken by the Elkhorn Slough National Estuarine Research Reserve (ESNERR). This review does not include restoration efforts.

Taxa

Common species of aquatic vegetation present in the Elkhorn Slough (Zimmerman and Caffrey in press), and selected factors that may stress their populations:

	Species	Stressor
Seagrasses –	*Zostera marina*	Low light conditions
Marsh Plants –	*Salicornia virginica* *Frankenia salina* *Distichlis spicata* *Jaumea carnosa*	Burial, desiccation or flooding- all marsh plants
Macroalgae –	*Ulva* sp. *Enteromorpha* sp. *Derbesia marina* *Gracilaria* sp. *Griffithsia* sp. *Polysiphonia* sp. *Porphyra* sp.	Nutrient loading – all algae

Background: aquatic vegetation and stressors

Eelgrass (*Zostera marina*), pickleweed (*Salicornia virginica*), and two mat forming algae (*Enteromorpha* and *Ulva* sp.) are the most abundant and best studied macroscopic, photosynthetic species present in the Elkhorn Slough.

Plants of the species *Zostera marina* are intolerant of severe light limitation (less than 3% surface irradiance) (Beer 1989, Duarte 1991) and will perish if exposed to these conditions for more than three days (Alcoverro et al. 1999, Smith et al. 1988, Zimmerman et al. 1991, Zimmerman et al. 1995). Plants of this species are most successful in shallow clear water (Keller and Harris 1966). Poor water quality due to high concentrations of suspended solids and chlorophyll from nuisance algal blooms is often the cause of light limitation and eelgrass habitat loss.

Marsh plants are sensitive to changes in elevation and hydrodynamics. Burial and changes in hydrodynamics have destroyed much of the emergent vegetation habitat in the San Francisco Bay estuary (Morris and Tomasko 1993). In the Elkhorn Slough, tidal erosion is the greatest stressor, resulting in marsh plain subsidence and strong currents, Trampling and changes in marsh elevation due to tectonic activity also influence the distribution and abundance of marsh plants (Lowe 1999, Woolfolk 1999). Upper marsh species are threatened by human disturbance and invasive plants at the marsh-upland ecotone (K. Wasson, pers. com.).

Macroalgae occur naturally in the Elkhorn Slough. However, in the Upper Slough, persistent blooms of the green alga *Enteromorpha* sp. occur filtering out light, preventing submerged aquatic vegetation from surviving. These algal blooms are not well understood, but nutrient input is the likely cause. Historically, nitrate levels (the limiting nutrient in this type of system) were approximately 0.5 μM in the Slough. Today, due to residential and agricultural lands of the watershed draining into the Slough, nitrate levels range from 30μM in the main channel up to 1000μM in the old Salinas River channel (Caffrey in press). All of the above "stressors" can occur naturally, but have been exacerbated in this and many estuarine environments as a result of human impact.

Past and Current Monitoring and Trends

No comprehensive long-term monitoring program for aquatic vegetation has been carried out at Elkhorn Slough. However, there have been snapshot surveys, and other monitoring relevant to vegetation.

Eelgrass distribution has periodically been examined by R. Zimmerman and colleagues (MLML). Most recently, Zimmerman and S. Palacios carried out an extensive survey of *Zostera marina* distribution in 2001.

Dr. John Oliver and colleagues (Moss Landing Marine Laboratories = MLML) conducted extensive survey work on salt marsh plants during the 1970s and early 1980s. Most of the work examined plant succession dynamics and competition. Included in this body of work was a map library (available through ESNERR or MLML) that may be useful for future mapping efforts to use as historical data (Oliver and Schwartz 1988).

Marsh-upland ecotone dynamics are being monitored at 60 stations around the Slough by K. Wasson and A. Woolfolk (ESNERR), who are tracking shifts in ecotone elevation, width, and species composition. Extent and density of pickleweed marshes around the Slough have been surveyed by J. Oliver, T. Lowe (Lowe 199), and others at MLML. E. Van Dyke (ESNERR) is tracing marsh boundaries and density over time using historical maps and photographs.

Eutrophication, a process in which nutrient enrichment stimulates algal growth, has been monitored since September 1988 with a twenty-four station monitoring effort coordinated by ESNERR. At these stations, temperature, salinity, dissolved oxygen, pH, turbidity, nitrate, ammonium, and phosphate are measured. Nitrate, phosphate, and turbidity are useful variables to use as indicators to predict eutrophication events and the subsequent effects on submerged aquatic vegetation (SAV) and macroalgae. NOAA lists the Elkhorn Slough as a high impact waterway with regard to eutrophication (Bricker et al. 1999). The ESNERR is in need of a long-term monitoring plan for aquatic vegetation. By monitoring the system, resource managers will be able to predict and prevent nuisance algal blooms and loss of SAVs.

Best Monitoring Methods

The goal of monitoring is to establish a baseline dataset of biological and physical variables (e.g., biomass, nutrient concentrations, temperature) and to measure changes in these variables in an environment over time. The approach to monitoring any environment is complex because many factors can confound data readings and obscure the causes of change in a system. Ecological monitoring can be as complex as monitoring the weather. One way to deal with this is to collect large quantities of data of many physical and biological variables. The most successful estuarine vegetation monitoring efforts use a combined approach of mapping and *in situ* measurements of ecological indicators such as: species present, water quality, photosynthetically available radiation (PAR), nutrient concentrations, and diel dissolved oxygen concentrations (Monroe and Kelly 1992, Morris and Tomasko 1993, Neckles 1993, Short 1992). By monitoring a diverse array of variables, researchers may be able to protect estuarine vegetative habitats from destruction or unnatural bloom conditions.

A long term monitoring project can be costly in terms of field survey time and analysis time. Many studies at other sites exist for the monitoring and restoration of seagrass and marsh plant populations in estuarine environments. These studies use varying methods to determine the state of the estuary and can be grouped into two categories: The layered approach and the snapshot survey. It is necessary to design a monitoring plan that is appropriate for a particular site and for the species of interest. These approaches are summarized here and the appropriate components of each will be melded in the section: Recommendations for Future Monitoring.

The Layered Approach

The workshops: Submerged Aquatic Vegetation Initiative and Photosynthetically Active Radiation conducted in 1992 and 1993 (Morris and Tomasko 1993) reviewed several monitoring programs and developed a plan for a successful monitoring approach for SAVs that can also be applied to emergent vegetation and macroalgae. This four-part layered approach is as follows.

1. Establish estuary-wide status and trends using aerial mapping with ground-truthing.
2. Establish status and trends in target areas using low altitude imagery with extensive and detailed (species level identification) ground-truthing.
3. Establish status and trends at selected specific sites using fixed permanent transects with quantitative monitoring, at specific time of year, of distribution, abundance, and condition of vegetation.
4. Establish site-specific relationships to water quality parameters (e.g., turbidity, chlorophyll concentration). Describe the water quality vs. underwater PAR relationship and PAR vs. seagrass distribution relationship.

Employing all of the layers would give scientists and resource managers a thorough understanding of the state of the vegetation in the estuarine environment. This can be costly, and using a few of the layers instead of all of them can still provide valuable information about an environment. Many of the monitoring studies on SAVs and marsh plants use some, but not all of the layers mentioned above.

Two excellent site summaries on estuary status, The Ecology of the Great Bay Estuary of New Hampshire and Maine: an Estuarine Profile and Bibliography (Short 1992) and the San Francisco Estuary Project: State of the Estuary (Monroe and Kelly 1992) were published in the last ten years. These reviews provide a site summary of geology, hydrochemistry, water flow, nutrients, dissolved oxygen, pollution, and biomass abundances. Both reviews map vegetation in the estuaries and discuss trends in distribution and abundance of marsh plants and SAVs. Each of the reviews also discusses human impacts on water transparency and chlorophyll levels and draws relationships of these variables to primary productivity in the system. Neither summary uses layer 2 from the list above (target area – low altitude imagery with ground-truthing), yet the condition of the estuary in each summary is clear using the other layers.

These reviews also outline suggestions for management and monitoring. The San Francisco Estuary Project proposes that in order for any regional monitoring program to be successful, all stakeholders must develop and adopt the management plan and that the plan must have adequate long-term financial support (Monroe and Kelly 1992). The stakeholders in this case are dischargers, scientists, environmental groups, and regulators. Without consensus and financial support, the monitoring and management plan will likely fail. The Great Bay Estuary review goes on to propose mitigation and restoration of eelgrass and salt marsh habitats. Through monitoring, it was determined that these habitats were lost due to the eelgrass wasting disease, eutrophication, dredging, and backfilling. Efforts to restore eelgrass habitat by transplanting were successful, however attempts to restore the marsh plant, *Spartina alterniflora*, failed. With a formal monitoring plan, it is possible for scientists and resource managers to study changes in the estuarine environment, and when possible, prevent destruction of vegetation habitat, propose restoration plans, and monitor the success of restoration.

Snapshot Survey

This type of survey examines the condition of an estuary on a one-time basis. These surveys are helpful, however, not appropriate for a monitoring plan, because they do not capture long term variability in the ecosystem. Using studies such as these to make management decisions is risky and ill advised. Nevertheless, these studies are not without merit. Several elegantly designed ones exist and if continued over time, would be excellent aids to management. Lack of long-term funding often prevents these studies from occurring on an annual basis.

The Padilla Bay National Estuarine Research Reserve published two excellent surveys of the distribution of eelgrass, macroalgae, and the invasive cordgrass, *Spartina alterniflora* (Bulthuis 1991, Riggs 1992). Each study was conducted during one summer. The cordgrass study measured densities along permanent transects and created distribution maps from these. The seagrass and macroalgae study used digital color aerial imagery to map seagrass and macroalgae coverage in the bay. These images were ground truthed in the field. If these two studies were continued on an annual basis, measuring plant abundances and distributions at the same time of year, then they would be useful as a long term monitoring plan.

Recently, the Elkhorn Slough National Estuarine Research Reserve was a study site for using hyperspectral imaging (Siciliano and Potts 2001). A hyperspectral remote sensing imager installed on an airplane flew over the study site and collected light reflected from the Earth's surface. This type of imaging captures surface reflectances in very narrow bands (5-10nm) along the electromagnetic spectrum. The wavelengths of interest lie within the visible spectrum (400-700nm) and into the infrared. The visible spectrum reflectances are useful for distinguishing both submerged and emergent vegetation and the infrared is useful for only the emergent vegetation. Reflectances of pure samples of plants were then used to create a library of species-specific spectral end members, which were used to classify the vegetation in the flyover images. This new imagery technology can be used to determine physiological status of terrestrial plants and to determine nutrient inputs into an estuarine environment (Los Huertos 2001). Terrestrial plants of the same species will reflect different energy wavelengths depending on the level of nutrient input (Los Huertos 2001, Siciliano and Potts 2001). When its cost decreases, this technology will be useful to quickly assess the distribution, abundance, and health of estuarine vegetation.

Snapshot surveys are useful for beginning a long term monitoring plan when one presently does not exist. They are also useful for incorporating fresh monitoring ideas into programs that have existed for many years. These types of surveys are effective to understand the species present in an estuarine ecosystem at one point in time, but should not be used alone for management decisions.

Recommendations for Future Monitoring

The Elkhorn Slough National Estuarine Research Reserve is in a position to develop a long term monitoring plan now that would help in managing this coastal resource in the years to come. Designing and implementing a monitoring plan can be time consuming and costly, therefore, it is necessary to prioritize the monitoring effort to have the greatest benefit for the Slough. The layered approach outlined by the SAVI-PAR workshops is likely the most thorough and conclusive for use by the ESNERR to monitor seagrasses, marsh plants, and macroalgae. In this section, I have modified this approach to fit into three categories of funding: a. Bare minimum – no funding, 50-100 hours/year of volunteer time, b. Mid-level—one-half time research technician plus volunteer time of bare minimum, and c. High-level—bare minimum and mid-level plus outside funding. The goal is to design a program that produces meaningful results at any level, regardless of funding.

Bare Minimum

The bare minimum approach would incorporate two layers of the multi-layer approach: fixed permanent transects with quantitative measurements and establishment of a relationship between PAR and water quality. It would employ annual field surveys of fixed transects and analysis of the twenty-four water-monitoring stations. The monitoring station survey would be modified to include PAR measurements, which can be taken using a Li-Cor field PAR collector. The annual surveys would be conducted at the same time of year at the same tidal cycle and would use an "army" of docents to measure plant distribution and abundance.

Ideally, five transects total for marsh plant distributions would be distributed in the Upper Slough near Kirby Park, in the Middle Slough on the grounds of the ESNERR, and in the Lower Slough due east of Seal Bend. These locations would roughly correspond to the transect lines in Lowe (1999). Each 20 meter transect would be used to measure plant species present, or bare substrate in cases where plants are not present. Fixed quadrats measuring species percent cover would be used and a repeated measures ANOVA employed for testing among year variability. The five transect measurements for eelgrass and algae monitoring would be conducted by boat and would be located at 50 meters east of the Highway 1 Bridge, Seal Bend, ESNERR, Kirby Park, and one site north of Kirby Park to be determined. The boat transect would be conducted at the low tide from shore to shore. Presence or absence of eelgrass and algae (noting algal species) would be measured by observers in the boat along the transect. The docents would be broken up into teams and sent into the field with team leaders. At least two boats would be needed to survey the Lower and Upper Slough. Volunteer assistance could also be used to enter the field data and to maintain the databases. The transect line and water quality data would then be available to monitor long term, annual variability in submerged and emergent aquatic vegetation in the Slough.

Questions Addressed:

1. What are long term trends in temperature, salinity, dissolved oxygen, turbidity, pH, and some macro-nutrients (NO_3, NH_3, PO_4)?
2. Is there a relationship between nutrients and macroalgae abundance and distribution in the Elkhorn Slough?

3. What aquatic vegetation is present in the Elkhorn Slough?
4. How are land use changes in the watershed affecting water quality?

Mid-Level

The mid level funding study would incorporate three of the layers of the combined approach: low-level aerial imagery and ground truthing, fixed transects with quantitative measurements, and relationship between water quality and PAR. This monitoring program would use the methods of the bare minimum approach with the addition of low altitude imagery using a new technology known as Kite Aerial Photography (KAP) (Benton 2001, Gary Thurmond, pers. comm.). MBARI is presently experimenting with this technology and would be a resource to either volunteer manpower and equipment, or to contract out these services. Using KAP technology with a digital color camera, images of the Elkhorn Slough would be captured as close to the date of the transect measurements as possible. These photos would be georeferenced by the part time technician and resampled for distortion. The transect data would serve as the ground truth data. Like the transect surveys, this imagery would be captured annually to generate a long-term data set of vegetation distribution and abundance in the Slough.

Questions Addressed (in addition to Bare Minimum):
1. What are long term trends in erosion?
2. What are long term trends in vegetation cover, density, soil wetness, and mudflat extents?
3. What are the long term trends of ecological change and succession in the restored marsh areas of the Elkhorn Slough?
4. What are continuing changes in the Elkhorn Slough compared to historical data in the map library (e.g. patterns of deposition and erosion)?

High-Level

The high-level approach would incorporate all layers of the combined approach plus include collaboration with policy makers to create a whole watershed plan for monitoring and protecting the coastal waterways of the Elkhorn Slough. Funding sources for this project include the Conserving California Landscapes Initiative of the Packard Foundation, NOAA's Benthic Habitat Mapping project (funding for geographic locations varies from year to year), the Monterey Bay National Marine Sanctuary, and NASA. These are only a few sources; others exist. The monitoring plan for this level of funding would incorporate fixed transects with quantitative measurements, measurements of *in situ* visible spectrum light energy (using a HOBILabs HydroRad instead of the Li-Cor PAR meter) to develop relationships between water quality and primary productivity, low altitude imagery with ground truthing using KAP technology, and system-wide trends using over flight imagery using the hyperspectral remote sensing technology on board the HyMap airplanes. These surveys, conducted annually would provide a complete understanding of the abundance, distribution, and physiological state of the vegetation of the Elkhorn Slough. Funding would be used to purchase over-flight time and to pay for a full time technician, trained to use ArcView and the hyperspectral data analysis software ENVI, to analyze the KAP and over flight data. The results from the surveys, if the over flights include the entire watershed, would be useful for county planners and the agriculture industry. Collaboration with these entities would create funding opportunities from granting agencies that fund integrated approaches to managing coastal systems.

Questions Addressed (In addition to above):
1. What is the physiological condition of terrestrial and aquatic vegetation?
2. Can the community work together to monitor inputs into the Elkhorn Slough?

The primary producers of the Elkhorn Slough, including seagrasses, marsh plants, and macroalgae form the basis of the food web in this dynamic system. Scientists and resource managers must monitor and preserve these taxa to ensure the stability and longevity of Slough ecosystems. The ESNERR has the opportunity to develop a rigorous monitoring program to assess the "health" of the ecosystem. The aim of this review is to open a dialog on what the monitoring priorities are for the Elkhorn Slough, and what approach is best suited to addressing these priorities.

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