YEAR 4 ANNUAL REPORT

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Title: Pacific Estuarine Ecosystem Indicator Research (PEEIR) Consortium: Modeling & Integration Component
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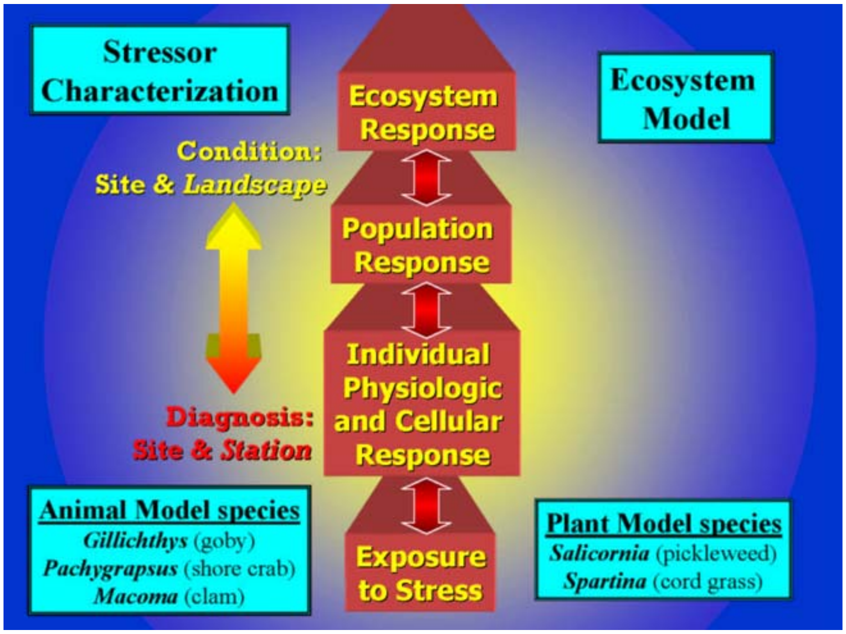
Research Category: EaGLE Program
Project Period: March 1, 2001 to February 28, 2006

RESEARCH OBJECTIVES:

The goal of the Center is to develop new indicators of estuarine wetland health in marsh plants and animals, so that corrective management of our nation's wetlands can be implemented before it is too late, difficult, or prohibitively expensive. The research spans all levels of the biological hierarchy from strands of DNA to populations to the landscape, and involves ecotoxicologists, ecologists, biochemists, microbiologists, and remote sensing experts. Research is being conducted at three sites in Tomales and San Francisco Bays in northern California, and three sites in southern California, across gradients of pollution impact from heavy metals, organic compounds, and excess nutrients.

Indicator species have been developed for surveys in west coast wetlands (Figure 1). Utilizing the shore crab (*Pachygrapsus crasssipes*), the mudsucker fish (*Gillichthys mirabilis*), and wetland plants including cordgrass (*Spartina* spp.) and pickleweed (*Salicornia virginica*), we have developed survey and census methodologies as well as numerous physiologic techniques. For plants, we have integrated techniques as variable as use of AVIRIS overflight images, plant physiology, and contaminant data. In animal models, we have refined numerous physiologic assays, perfected transplant techniques and validated otolith rings in fish for calibration of field data to population modeling. These animal models and our resulting compendia of techniques can eventually be used by numerous monitoring groups in the western United States to assess wetland health.

Figure 1. PEEIR Conceptual Model



Analytical chemistry and toxicity testing are often viewed as inadequate techniques to assess effects of contaminants on resident aquatic species. Evaluation of physiologic responses called biomarkers can be used to discern sublethal effects in resident species, but there is little consensus on how this general approach should be implemented in coastal monitoring. For example, at our most contaminated site indicators of ovarian tumors and apoptotic cells in liver (indicator of contaminant stress) are significantly elevated in the mudsucker fish (*Gillichthys mirabilis*), and these same fish exhibit more variable growth rates than were observed at other sampling locations. In some locales, we observe high rates of endocrine disruption. We envision that a suite of biomarker techniques will be recommended for monitoring applications and this will be useful to managers in discerning whether contaminants cause negative effects on the condition of wetland flora and fauna. Hence, management interventions will not be based on extrapolation from toxicity tests and chemical analysis data but on actual analysis of effects in marsh species.

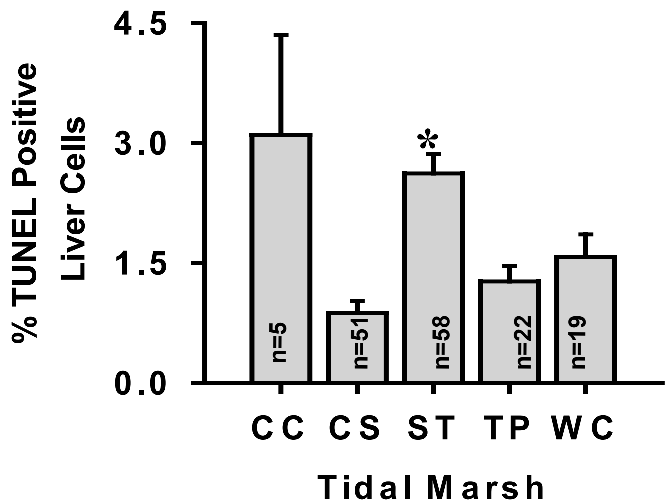
PROGRESS SUMMARY

Indicator Integration Overview

The PEEIR program will result in three levels of products. The **first level** is the development of new methodologies or simple indicators that can be used to assess effects of and exposure to pollutants in United States estuaries. Examples of specific methods are provided in the component reports but include a new and more efficient biochemical assay to assess endocrine disruption in fish, that can be widely applied. A second example, is a method to assess the levels of bioavailable metals in wetland plants that allows us to bypass extrapolations made to predict, rather than directly assess, metal availability in contaminated sediments. A third example, is the development of nitrogen isotope techniques to assess nutrient enrichment in wetland sites in a more informative way than using transient measurements of dissolved inorganic nitrogen.

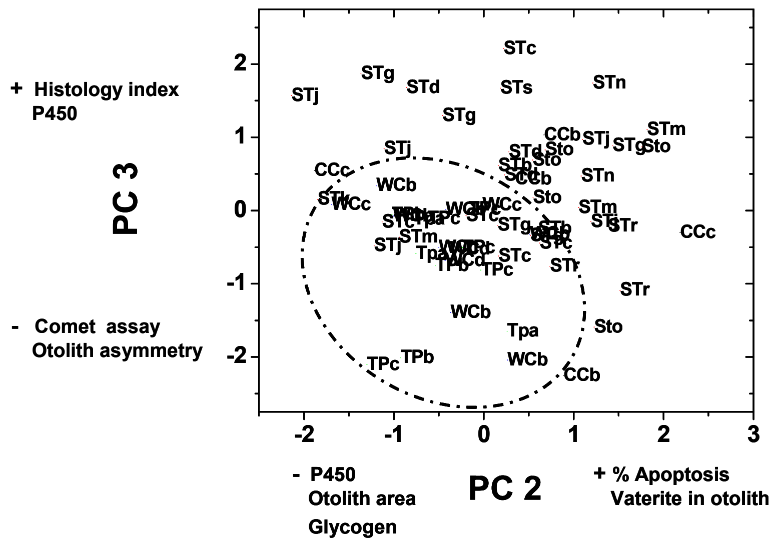
Our **second level** of products is the development of aggregated indicators that bring together multiple measurements of stress and exposure and considers their interrelationships using statistical techniques. An example provided in the BRC and EIC component reports, related to our fish indicators species, outlines how the spatial distribution of biomarker responses at multiple sites have been analyzed individually and in combination. For example, the frequency of apoptosis in liver of fish collected in 2003 was significantly different among sites (Figure 2), with the most contaminated site (Stege Marsh) exhibiting the highest incidence. Hence, this technique may be a useful "early warning" indicator of contaminant stress.

Figure 2.



However, greater scope of inference can be attained when multiple biomarkers are considered and related to fish condition. When Principal Components Analysis (PCA) is used to evaluate the interrelationships among multiple datasets (Figure 3) at these same sites, apoptosis can be related to other biomarker responses and measurements linked to fish growth and condition.

Figure 3.



Analysis of linked indicators in individual fish in PCA also allows apparent outliers (such as the one very high apoptosis response at the China Camp site, Figure 2) to be evaluated more critically. Ultimately, proportions of fish in different health categories can be discerned and associated with multiple contaminant stressors. Portfolios will be derived using the most informative markers emerging from the statistical analysis. This approach is novel because it links biomarker responses to growth rates and fish condition using body morphometrics and growth increments measured in otoliths. For fish, these findings and additional data are now being used to parameterize population models. For crab, interrelationships between numerous measures of reproductive output and multiple exposure routes have also been analyzed using multivariate statistics, and we will recommend a portfolio of indicators that relates crab reproductive success to contaminant exposure (see EIC component report). Similar integration efforts for microbe, plant and clam indicators are maturing rapidly (see EIC, BBC component reports).

Within our second level of products is an extensive modeling effort to validate and extend the utility of the indicators we develop. Progress of the modeling team is described below. In brief, the work is significant because it allows us to evaluate the significance of responses in individual fish to populations of fish (size structure and dynamics). This is what managers care the most about; yet options for relating effects on individuals to populations have been limited to date.

Our **third level** of accomplishment is demonstration that a portfolio concept can be transferable and applied in management. In brief, the PEEIR consortium advocates the development of integrated portfolios using indicator species selected for various habitat types. We are in the process of finalizing our demonstration of this concept for saltmarsh systems but contend that the general approach is transferable to other habitat types. In our research, a portfolio of techniques in resident species was cost effective and we elucidated significant detrimental effects in marsh sites where toxicity tests predicted minor impacts.

The ultimate value of our center program funding, and hence the value of integrated science, is the demonstration of this portfolio concept-- which could not have been accomplished with single investigator research. This approach will be valuable in management because effects are assessed directly on native species and the error associated with numerous extrapolations of routine ecological risk assessment are eliminated. In addition, the approach may save costs associated with expensive regulatory controls on single chemicals. It is vital that effects of complex mixtures, including hundreds of emerging contaminants, be assessed in combination. Single-chemical restrictions will not be practical. In short, we must continue to develop techniques that allow us to simply ask the fish whether several decades of environmental controls have been enough. Then we can prioritize the greatest problems. Our final report will provide recommendations on a stepwise process for national implementation of such an approach.

The types of outputs that will be submitted to EPA at the conclusion of our work are: manuscripts, a website with "indicator pages" that translate the technical manuscripts into a one-page format that will facilitate implementation, and a final report summarizing the above material and listing talks and outreach. This year a major effort for the Director was organization of three technical sessions at national and regional conferences. Talks from these meetings are listed in the component reports. We are accelerating outreach efforts throughout the coming year and focusing on manuscripts and integration with other EaGLes centers. The text below describes progress on technical work funded in the Administration and Integration Component (AIC) and the component reports describe the detailed technical progress throughout the PEEIR consortium.

Modeling Work Group Summary

The main advances during the year were:

- Completion of manuscript describing new method for estimating parameters in dynamic energy budget models from size trajectory data.
- Initiation of work on dynamic energy budget model for mudsuckers, PEEIR's primary fish indicator species.
- Further analysis of model describing dynamics of nitrogen isotope ratios.
- Initiation of major effort using ordination analysis to identify patterns in indicator measurements and to guide the development of aggregative measures of organism condition.

The rationale for using dynamic energy budget (DEB) models has been described in previous reports, and much of this year's effort was devoted to completion of previous projects and manuscript preparation. Briefly, DEB models describe the acquisition by organisms of energy from food and its utilization for growth, development, maintenance, reproduction, and avoiding mortality. Modifications of the models can be used to describe the flow of elemental matter (key to the work on stable isotope ratios), and bioaccumulation of contaminants. With additional information on mortality, DEB models are a key component of a population model.

PEEIR's planned applications of DEB models required developing new methodology, and that phase of the work is largely complete. One distinctive challenge was to find a method for estimating DEB model parameters from measurements on fish otoliths. For this work we added stochastic variation to the traditional (deterministic) DEB model, the result being a system of stochastic differential equations in which one of the state variables (the energy reserve) is unobservable. There is no analytical solution to the probability density of size at given age, so we use a numerical non-linear state-space method to calculate the likelihood. This method is general enough to apply to other stochastic differential equation models. We assessed the estimability of parameters in the individual growth model, and analyzed size trajectory data from delta smelt (*Hypomesus transpacificus*). We expect this method to become an important tool in ecological studies as computers become faster, as the models that we deal with become more complex, and as the data that we collect become more detailed.

We started work on a DEB-based population model for mudsuckers, one of the integrative studies promised by PEEIR. This model complements statistical analyses of biomarkers in muduckers described elsewhere in this report. The statistical approach uses data on a large number of biomarkers to ask "what are the fish telling us about habitat quality?" The DEB modeling aims to determine the relationship between the biomarkers and endpoints involving fish population dynamics. The following endpoints were selected for the modeling:

- *Population size structure* – an integrated measure of growth and survival
- *Lifetime reproductive success* – a commonly used integrated measure of individual performance
- *Long term population growth rate* - a commonly used integrated measure of population viability
- *Short term population growth rate* - measures population's <u>immediate</u> response to environmental perturbations.

Knowledge of mortality rates is important for the population model. Thus, in parallel with the model development, we completed a rigorous analysis of mark recapture data on mudsuckers. The results demonstrated that confidence intervals might be substantially narrowed by obtaining further data in spring and summer 2005. This is in progress.

As discussed in previous reports, PEEIR has gathered data on the proportions of stable isotopes of nitrogen in all our marshes (Page and collaborators). These have immediate value for empirical characterizations of habitat, but they also relate directly to ecological processes, notably trophic interactions. These processes are dynamic, so interpretation commonly requires special assumptions, for example assuming that some dynamic equilibrium is attained within the organism. We aim to use DEB models, and thereby obtain more powerful methodology for interpreting stable isotope data. Our model characterizes variations in the proportion of rare isotopes in an individual organism to fluctuations in food quantity and in the isotopic composition of the food. The model presented some unanticipated mathematical problems; these are now resolved and a MS is in preparation.

The final new integrative activity in year 4 was an intense effort on statistical analysis with two objectives. The first used ordination analyses in a search for pattern in the many measurements gathered by PEEIR investigators. Although the primary thrust of PEEIR's approach emphasizes the importance of physical, chemical and biological processes, identification of patterns and correlations is an essential component. Work completed to date includes studies relating microbial community properties to chemical information, and an investigation of correlations between trematode communities and other indicators. The second objective is to develop aggregative measures of the conditions of some focal organisms (fish and crabs). This work is in progress.

The top priority over the coming year is the completion of manuscripts. These include those discussed in previous reports that are now near completion, as well as those discussed above. Work still to be completed includes the mudsucker model and further analysis of statistical measures of organism condition.

Data Management Summary

By July 2005, the data management effort has archived about 85% of the datasets, with 15% still undergoing revision and not yet centrally archived. We have finished approximately 20% of the metadata files, which will accompany the data files when they are uploaded to the permanent repository. We are on track to complete all the metadata by the end of summer, though there will be revisions until the end of the Program. Finally, we are working with the other members of the EaGLe data committee to ensure that the metadata files are formatted according to standards, and that both the data and metadata will be archived securely after the Program ends.

The data effort is also continuing to support the internal data needs of the Program. We have developed a downloadable ARC Map geodatabase of the study sites with much of the point data from sampling; this will be updated as it is useful to integration projects. The data repository continues to be used by the Program researchers and too serve as the upstream piece in the data plan. Finally, the data manager has helped to coordinate some multidisciplinary mapping projects. An important example of this is serving as an interface between teams doing remote sensing, ecology and metal bioavailability, and the geomorphology work group. Extensive interaction has been required to finalize tidal datum as well as basic tidal statistics and to validate lidar data to be used by the remote sensing team.

Archival Data Workgroup Summary

This year, Anitra Pawley, Ph.D. of the Bay Institute has worked extensively on a review of emerging wetland indicators for San Francisco Bay wetlands. The project illustrates the broad range of indicators being investigated and/or developed for the Bay region and a regional context for the wetland products being developed as a result of PEEIR. The shear number of measurements and indicators and the variety proposed suggests that some time is needed before there is agreement on what indicators should be routinely measured in San Francisco Bay tidal marshes. Despite this, there is some convergence in the measurements used for evaluating tidal marsh health, restoration progress and even contaminant effects. Tidal marsh habitat extent estimates have been used successfully as public-level communication tools. Rapid assessment techniques to evaluate marsh sites are being developed and tested; representative indicator species that include invertebrate, fish and bird taxa have been studied, resulting in some tangible indicators for evaluating marshes; and several diagnostic tools such as plant exudates and parasites are showing promise as a means to depict specific trends in marsh use and levels of impacts.

The benthic paper entitled, " Developing Benthic Coastal Indicators and Indexes at Regional Scales: Thirty Years Since Pearson and Rosenberg " summarizes the status of estuarine and coastal benthic indicator studies since the late 1970's is now close to completion as we rewrite the draft for submission. The results were reviewed in last year's previous final report.

Remote Sensing Progress Under NASA Funding

This year's accomplishments include analysis of airborne hyperspectral (AVIRIS) data and lidar data for each site and comparison of these to field measurements. The land cover classification of the AVIRIS data to create vegetation maps for each of the wetlands is in the last stages of completion. We cannot consistently separate all species classes we want to identify in these wetlands based solely on spectral differences. We are currently examining whether including elevation (derived from the lidar imagery) can be used to improve the land cover classification. Physiological indexes, using spectral bands related to pigments, water and dry plant matter (cellulose, lignin, etc.) in the AVIRIS data have been completed for all of the sites. The land cover (classification) and condition (determined from the physiological indexes) maps will allow us to compare sites and determine if there are remotely sensed indicators of wetland condition and/or health that can be used in a monitoring program.

Linking the field-collected plant data to our field measured spectra and to the physiological indices was not successful for either the 2002 or the 2004 data sets. Correlating the physiological indices to biomass data (both % green or total biomass) showed low correlations (highest $r^2 = 0.28$ using the SARVI index). In previous studies (e.g., Epiphano et al. 1995, Zhang et al. 1997, Sanderson et al., 1998) significantly higher correlations between the physiological indices and field data were observed and the lack of correlation here is attributed to both the sample size (10cm x 10 cm) and sampling method used in this study. The small area of the field samples make them unrepresentative of the spatial scale of the AVIRIS pixels. Since field biomass and spectra were not collected at precisely the same locations, a similar sampling effect is attributed to the lack of correlation. We are investigating whether we can use the regression equations of Zhang (collected at the mouth of Petaluma Creek) to substitute a maximum biomass for maximum index value (since all methods show linear relationships) as a way to quantify the biomass variability within and between wetlands.

Striping was seen in the lidar data in overlapping flightlines. This indicates errors in the lidar data that could be due to systematic offsets related to the original calibration of the data or measurement errors due the instrument design (e.g., height differences between the center and the edge of the swath of the image), or some other cause. We began lidar analysis by evaluating the precision and accuracy of the data (Rosso et al., 2005). At the PEEIR sites, the lidar point data were initially processed into raster images with 1 meter horizontal resolution to create a digital elevation map for determining the channel network and inundation period. This resolution was chosen to limit the data volume and averaged out most of the systematic flightline differences but was found to be too coarse and missed some of the smaller channels. We have since tested 20 cm and 50 cm resolution and both appear to capture the full extent of the channel network that can be seen in high spatial resolution aerial photos and we are currently re-analyzing the channel network using a 50 cm horizontal scale. Following this, we will use the lidar elevation data in the AVIRIS classifier after co-registering them with the AVIRIS pixels and creating two layers for the classifier (mean elevation and standard deviation) for each AVIRIS pixel.

PUBLICATIONS & PRESENTATIONS:

Technical publications for Director Anderson's laboratory are listed in the BRC component report. As stated above, a major accomplishment of this year was organization of three technical sessions at: the national meeting of the Society of Environmental Toxicology and Chemistry (SETAC), the Northern California Regional meeting of SETAC and the semi-annual science conference of the California Bay Delta Authority (CBDA, previously known as CALFED). These talks are presented in the component reports.

Publications:

Fujiwara, M., Kendall, B. E. and Nisbet, R. M. 2004. Growth autocorrelation and animal size variation. *Ecology Letters* **7**:106-113.

Gurney, W. S. C. and Nisbet, R. M. 2004. Resource allocation, hyperphagia and compensatory growth. *Bulletin of Mathematical Biology* **66**:1731-1753.

Masami Fujiwara, Bruce E. Kendall, Roger M. Nisbet, and William A. Bennett (in press) Analysis of size trajectory data using an energetic-based growth model. *Ecology*.

Presentations:

Roger M. Nisbet. "Ecological Indicators". Invited lecture as Pacific Institute for Mathematical Sciences Distinguished Visitor, *University of Alberta*, October 2004.

Roger M. Nisbet. "Use of dynamic energy budget models to relate sublethal responses to population responses". Society of Environmental Toxicology & Chemistry. Portland, November 2004.

Masami Fujiwara, Bruce E. Kendall, Roger M. Nisbet, William A. Bennett, Wendy Rose. Models relating physiological indicators to population dynamics at multiple spatial scales (2005 ESA Abstract).

Susan L. Anderson, Andrew J. Brooks, Gary N. Cherr, Richard M. Higashi, Roger M. Nisbet, Susan L. Ustin and Scott Carr. Complementing the Eco-Risk paradigm: Indicators of exposure and effect in saltmarsh species. Society of Environmental Toxicology and Chemistry. Portland, November, 2004.

Susan L. Anderson, Andrew J. Brooks, Gary N. Cherr, Richard M. Higashi, Roger M. Nisbet, Susan L. Ustin and Scott Carr. Integrating indicators of exposure and effect in

saltmarsh species. California Bay Delta Authority Semi-Annual Science Conference. Sacramento, September, 2004.

Susan L. Ustin, Mui Lay, and Lin Li, Remote sensing of wetland conditions in West Coast salt marshes, International Symposium on Optical Science and Technology, SPIE 49th Annual Meeting, August, 2004.

PUBLIC AND AGENCY OUTREACH

Two briefings to San Francisco Bay Regional Water Quality Control Board Staff on contaminant effects in Stege Marsh and implications for long term management of the site

Briefing with landowners at Stege Marsh (UC Berkeley and Zeneca Agrochemical) regarding PEEIR data and implications for site restoration

Telephone updates with USEPA Region IX staff (Dr. Bobbye Smith) and California EPA staff (Dr. Barbara Washburn) regarding PEEIR progress and applicability to management

Technical briefing for Chevron consultants on how PEEIR data inform restoration of Carpinteria saltmarsh

Interactions with Southern California Coastal Water Research Project (SCWRP) including postdoctoral intern (Dr. Wendy Rose) and collaborative tech transfer discussions on pathogens in wetlands and sediment quality management issues in southern California.

Successive meetings and contacts with Steve Ritchie, lead for the extensive south San Francisco Bay salt marsh restoration program regarding toxicant effects and the role of the PEEIR approach

Briefing of California Coastal Commission authorities by Drs. Cherr and Higashi regarding value of PEEIR approach for various Bay-Delta restoration efforts

Participation in CBDA forum on facilitating integrated science in the San Francisco Bay.

SUPPLEMENTAL KEYWORDS watersheds, estuaries, ecological effects, bioavailability, ecosystem indicators, aquatic, integrated assessment, EPA Region IX

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Epiphanio, C. N., and Huete, A. (1995) Dependence of NDVI and SAVI on Sun/Sensor Geometry and Its Effect on fAPAR Relationships in Alfalfa, Remote Sensing of. Environment. 51:351-360

Rosso, P. H., Ustin, S. L. and Hastings, A. 2005. Use of lidar to study marsh dynamics in San Francisco Bay. Submitted to Remote Sensing of Environment (in revision).

Sanderson, E.W., Zhang, M., Ustin, S.L., and Rejmankova, E. 1998. Geostatistical scaling of canopy water content in a California salt marsh. Landscape Ecology 13:79-92.

Zhang, M. Ustin, S. L., Rejmankova, E., Sanderson, E. (1997) Monitoring Pacific Coast Salt Marshes Using Remote Sensing, Ecological Applications. 7:1039-1053.