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4.5 PSP Cover Sheet (Attach to the front of each proposal)

Proposal Title: UNDERSTANDING TIDAL MARSH RESTORATION PROCESSES AND PATTERNS: VALIDATING AND EXTENDING THE "BREACH" CONCEPTUAL MODEL

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Amount of funding requested: $ 1,042,246 for 3.3 years

Indicate the Topic for which you are applying (check only one box).

- ☐ Fish Passage/Fish Screens
- ☒ Habitat Restoration
- ☐ Local Watershed Stewardship
- ☐ Water Quality
- ☐ Introduced Species
- ☐ Fish Management/Hatchery
- ☐ Environmental Education

Does the proposal address a specified Focused Action? X yes ____ no

What county or counties is the project located in? San Joaquin, Sacramento, Yolo, Contra Costa, Solano, Napa, Sonoma, Marin

Indicate the geographic area of your proposal (check only one box):

- ☐ Sacramento River Mainstem
- ☐ Sacramento Trib: ____
- ☐ San Joaquin River Mainstem
- ☐ San Joaquin Trib: ____
- ☐ Delta: ____
- ☐ East Side Trib: ____
- ☐ Suisun Marsh and Bay
- ☐ North Bay/South Bay: ____
- ☒ Landscape (entire Bay-Delta watershed)
- ☐ Other: ____

Indicate the primary species which the proposal addresses (check all that apply):

- ☒ San Joaquin and East-side Delta tributaries fall-run chinook salmon
- ☐ Winter-run chinook salmon
- ☒ Late-fall run chinook salmon
- ☒ Delta smelt
- ☒ Splittail
- ☐ Green sturgeon
- ☒ Migratory birds
- ☐ Other: ____
- ☐ Spring-run chinook salmon
- ☒ Fall-run chinook salmon
- ☐ Longfin smelt
- ☐ Steelhead trout
- ☐ Striped bass
- ☐ All chinook species
- ☐ All anadromous salmonids

Specify the ERP strategic objective and target (s) that the project addresses. Include page numbers from January 1999 version of ERP Volume I and II:

* Tidal emergent wetland (tidal perennial aquatic), delta slough, saline and fresh emergent and essential fish habitats; Vol. 1: 30-31, 111-116, 120-124, 160-163

* Ecological processes, Bay-Delta aquatic foodweb: Vol. 1; 95-101

Indicate the type of applicant (check only one box):

☐	State agency	☐	Federal agency
☐	Public/Non-profit joint venture	☐	Non-profit
☐	Local government/district	☐	Private party
☒	University	☐	Other: ______________

Indicate the type of project (check only one box):

☐	Planning	☐	Implementation
☐	Monitoring	☐	Education
☒	Research		

By signing below, the applicant declares the following:

1.) The truthfulness of all representations in their proposal;

2.) The individual signing the form is entitled to submit the application on behalf of the applicant (if the applicant is an entity or organization); and

3.) The person submitting the application has read and understood the conflict of interest and confidentiality discussion in the PSP (Section 2.4) and waives any and all rights to privacy and confidentiality of the proposal on behalf of the applicant, to the extent as provided in the Section.

CHARLES A. SIMENSTAD
Printed name of applicant

[signature]
Signature of applicant

DONALD W. ALLEN, DIRECTOR
GRANT AND CONTRACT SERVICES

[signature]

Understanding Tidal Marsh Restoration Processes and Patterns: Validating and Extending the "BREACH" Conceptual Model

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I. Executive Summary

Our interdisciplinary team of researchers proposes to build on and expand initial CALFED Category III-supported research in the Sacramento-San Joaquin Delta (Delta)[1] to address considerable uncertainty in predicting the outcome and ecological benefit of restoring shallow-water tidal habitat in three different regions of the Bay-Delta: the Delta, Suisun Bay, and San Pablo/North Bay. This team is composed of sedimentologists, hydrologists, geomorphologists, fisheries and avian biologists, and estuarine ecologists from the University of Washington, School of Fisheries' Wetland Ecosystem Team (UW-WET), University of New Orleans (UNO), Philip Williams & Associates (PWA), San Francisco State University-Romberg Tiburon Environmental Center (SFSU-RTC), Pt. Reyes Bird Observatory (PRBO) and the California Department of Water Resources-Interagency Ecological Program (DWR-IEP). Our intent in this proposed study is to extend and refine the emerging results of the BREACH approach to the other regions under consideration in the CALFED Ecosystem Restoration Plan (ERP).

In the present BREACH project, we are studying historically-restored and remnant natural wetland sites in the Delta to determine how far (if at all) they are along important 'functional equivalency trajectories' (Simenstad and Thom 1996) that will indicate progress toward the CALFED goal to "*rehabilitate the capacity of the Bay-Delta system to support, with minimal ongoing human intervention, natural aquatic and associated terrestrial biotic communities, in ways that favor native members of those communities*" (ERP Goal 2). Initial findings from these Delta studies suggest that restoration of emergent tidal-freshwater and brackish wetlands of the Delta is contingent upon the interaction of tidal and fluvial processes with vegetation communities that depend upon prior (e.g., subsidence) and initial (e.g., breach locations) conditions affecting the rate of emergent marsh colonization and expansion. Accordingly, biological communities that are associated with various habitat (e.g., water depth) and vegetative structure will dominate restoration sites through the duration of various successional stages. However, many factors influencing the rate and pattern of shallow water habitat restoration are significantly different between the Delta and other regions under consideration for restoration actions by CALFED. Differences in tidal regime, fluvial influence, suspended sediment sources, vegetation communities, exotic species and anthropogenic manipulations may result in significant divergences from our present understanding of restoration stages and endpoints originating from studies in the Delta. By identifying the corresponding biological communities and food webs associated with transitional restoration stages in the three regions of the Bay-Delta, we propose to use a refined and extended BREACH conceptual model to address emerging questions about shallow water restoration, such as:

1. *What is the timeframe of restoration to a natural shallow water habitat? What are the limiting factors?*
2. *What is the interaction between submerged aquatic vegetation (SAV) and emergent shallow water vegetation? Does SAV promote or inhibit the transition to an emergent marsh?*
3. *Do native species benefit from interim transitional stages in recovering breached-levee sites? Are nonindigenous fishes or concentrations of piscivorous birds detrimental to native fishes utilizing the site?*
4. *Do shallow water ecosystems contribute significantly, either as organic matter sources or intermediate pathways, to Bay-Delta food webs important to important species?*
5. *What are the ecological attributes of successful restoration?*

Thus, this proposal addresses both the feasibility of restoration of shallow water habitat, and differences inherent to different regions of the Bay-Delta continuum, as well as evaluates the contribution of that endpoint to the long-term recovery of fisheries and ecological integrity of the Bay-Delta. Our goals of the proposed refinement and expansion of the BREACH investigations are to: (1) systematically address the present status, rates, and patterns of tidal ecosystem restoration in recognizably different Bay-Delta ecosystems; (2) evaluate factors that promote rapid restoration of shallow-water habitat *versus* factors that have potentially inhibited natural rates and patterns of functional development; (3) evaluate the contribution of shallow water habitats to food webs supporting Bay-Delta ecosystems; and (4) assess the overall outcome of breached-levee restoration

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[1] See *http://weber.u.washington.edu/~calfed/calfed.htm*

in the different Bay-Delta regions and recommend optimum strategies and spatial distribution of future restoration initiatives. The focus of our sampling design and synthesis is a BREACH conceptual model that we have developed for restoration patterns, rates and processes in the Delta.

We will expand from the Delta to Suisun Bay-San Pablo/North Bay our BREACH approach of using the "natural experiment" of the diverse age distribution of selected breached-levee sites in a 'space-for-time substitution' to predict the patterns and rates (trajectories) of restoration that would be expected from levee breaching. In our initial CALFED studies in the Delta, we are systematically evaluating the rates and patterns of restoration, and determining sources of variability, in both naturally and artificially restored diked wetland sites of a broad spectrum of ages as compared to the reference sites. The overall objectives of the BREACH project are to: (1) Assess hydrological, geomorphological, biogeochemical and ecological indicators at diverse, differently-aged sites of formerly diked wetlands that have reverted to tidal inundation; (2) compare indices of fish and wildlife habitat quality of these naturally breached-dike sites to existing mitigation and restoration sites that were purposefully constructed by dike breaching or comparable restoration actions; and, (3) using the same indicators, compare the status of these restored wetlands to wetland function at natural reference marsh sites. This approach is integrated into a developing conceptual model (see Appendix A) that relates transitional phases in the development of shallow water habitat to the support of fish and wildlife.

In our expansion of the BREACH investigations, we will:

- Refine and extend applicability of BREACH conceptual model by (a) elucidating rates of transition between vegetated and non-vegetated habitats, and rates of transition from one floral community to another, and (b) adapting it for processes, conditions and floral/faunal communities in more saline regions of Bay-Delta.
- Prepare synthesis of patterns, rates and short-term and long-term endpoints of tidal marsh restoration predicted from refined conceptual model for breached-levee restoration along the Bay-Delta continuum.
- Assess food web contributions of restoring marshes to consumer organisms, in conjunction with collaborating existing/proposed CALFED studies.
- Disseminate intermediate and final results to the CALFED and regional wetland restoration community by organizing and/or participating in sessions in relevant conferences and/or organizing specific opportunities for interaction and discussion.

We will address these objectives in five tasks and associated subtasks distributed in three phases over 3.3 years:

(1) Refine conceptual model development for Delta (Phase I); a. conduct two BREACH workshops to design, modify and incorporate new data and other information into expanded conceptual model; present to IEP Project Work Team and other related scientific bodies for feedback; b. investigate subtidal accumulation processes; c. investigate marsh expansion processes, including interactions between tule and submerged aquatic vegetation; d. continue measurements of elevation change to refine rate estimates for Delta systems; e. as opportunity arises, incorporate additional/existing data to test model;

(2) Extend conceptual model development to Suisun Bay and San Pablo/North Bay (Phase I); a. inventory of "restoring" marsh and natural marsh reference sites; b. review of existing studies in Suisun March and San Pablo/North Bay marshes; c. select ~12 sites, including 7-8 restoring, 2-3 reference, 1-2 managed/seasonal/salt pond wetlands; d. conduct geomorphic assessment at all sites;

(3) Assess relationship of fish, macroinvertebrates, and avifauna to restoration status (Phase II); a. document seasonal fish community composition, life history and relative abundance; b. document seasonal macroinvertebrate community composition, life history and relative abundance; c. document seasonal avifauna composition, abundance and behavior;

(4) Evaluate food web and other ecosystem linkages (Phase III); a. conduct stable isotope analyses of representative consumer organisms; and, b. compare to conventional fish diet results.

(5) Prepare synthesis document and presentations (Phase III).

Our products are intended to provide critical information necessary to predict whether breached-dike restoration strategies proposed under CALFED would provide natural wetland functions to support tidal (shallow-water) aquatic habitat for other aquatic and terrestrial species of concern and rehabilitate a robust Bay-Delta food web.

II. Project Description

A. Proposed Scope of Work

Both the current and proposed extension of the BREACH research project are designed to address the identified need under the CALFED ERP to "rehabilitate natural processes in the Bay-Delta system to support, with minimal ongoing human intervention, natural aquatic and associated terrestrial biotic communities..." Our fundamental approach is to use the differential age distribution of selected breached-levee sites in a 'space-for-time substitution' to predict the patterns and rates (trajectories) of restoration that would be expected from levee breaching. In the current BREACH studies in the Delta, we are investigating historically-restored and remnant natural wetland sites to determine how far (if at all) they are along important functional equivalency trajectories (Simenstad and Thom 1996). Over two years, we are systematically evaluating the rates and patterns of restoration, and determining sources of variability, in both naturally and artificially restored diked wetland sites of a broad spectrum of ages as compared to the reference sites. Our primary synthesis product is a conceptual model of the patterns, rates and underlying processes that are involved in the evolution of breached-levee restoration sites (Figure 1). Although the initial BREACH research products are just emerging (an interim report will be available by early May), some of these interpretations are presented in the attached (Appendix A) posters (somewhat reduced) that the BREACH investigators have displayed and discussed at several Bay-Delta science and management meetings (1999 IEP Annual Meeting; 1999 State of the Estuary Conference). Basic information about BREACH is also available on the project's WWWsite[1].

This proposal is intended to address two aspects of the present BREACH project that have become readily apparent in our development of the BREACH conceptual model: (1) a lack of essential data in the Delta on rates of sub-tidal accumulation and the role of submerged aquatic vegetation on expansion of the tule marsh edge; and (2) how the BREACH conceptual model of site evolution applies in more saline regions of the Bay-Delta and implications for the Bay-Delta food web. The objectives of our expanded BREACH study are described in the Executive summary. Research tasks for obtaining the objectives are as follows (primary investigators indicated for each subtask):

Task 1: Refine conceptual model development for Delta (Phase I)

a. *conduct two BREACH workshops to present and receive feedback on the expanded conceptual model; present to IEP Project Work Team and other related scientific bodies for feedback*

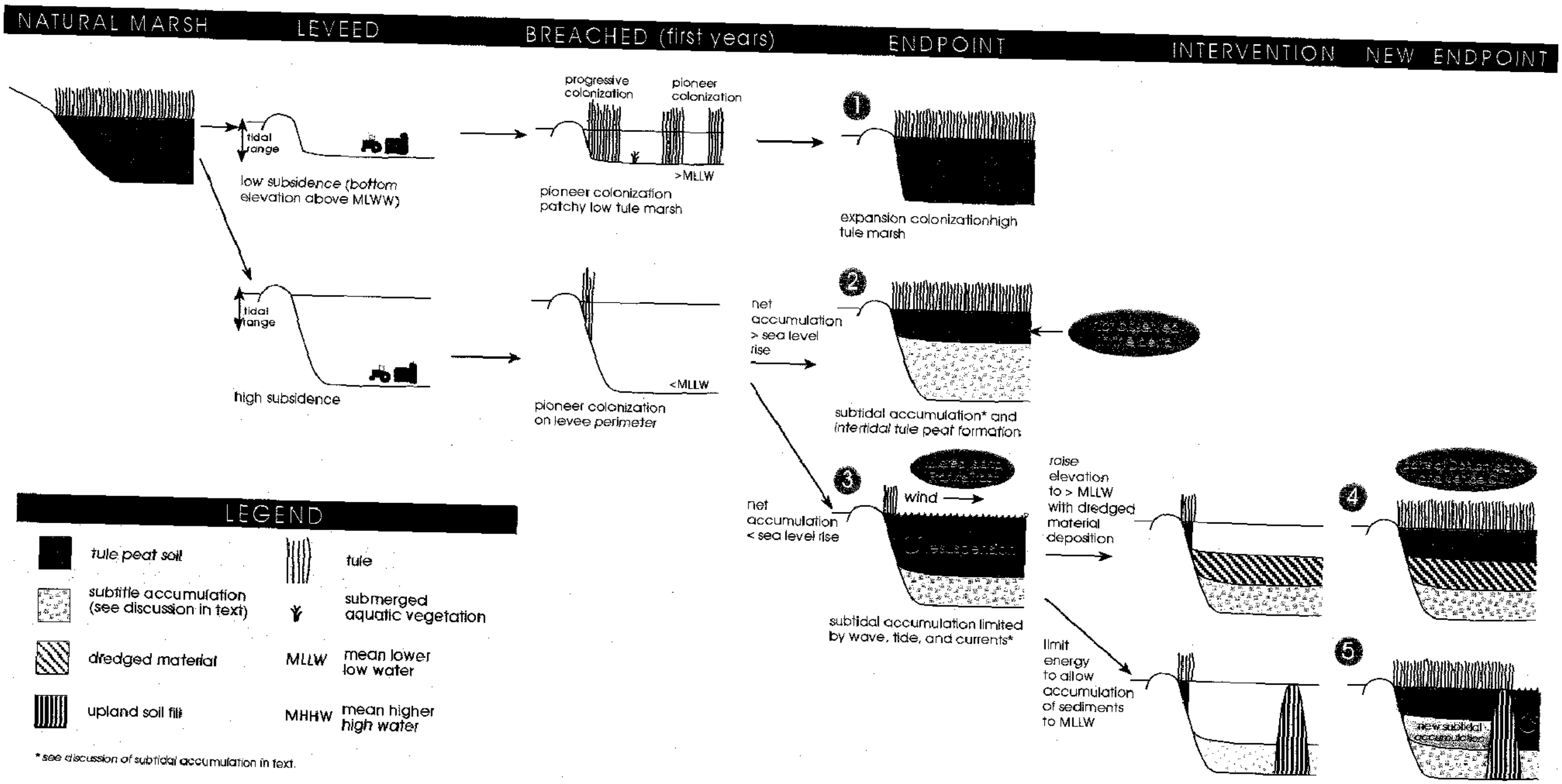
b. *investigate subtidal accumulation processes--PWA, UNO*

We have identified the importance of a minimum ground surface elevation (approximately 2 feet below mean lower low water) for the establishment of tule vegetation and restoration of marsh habitat through natural processes. Although we have been able to quantify the rates and mechanisms of site evolution that occur once this minimum "threshold" elevation is achieved, the rates and mechanisms of sub-tidal accumulation up to this minimum threshold are less well understood. Sub-tidal accumulation appears to be the slowest step in the natural restoration of breached-levee sites, and can prevent natural restoration altogether where rates of accumulation are slower than sea level rise. This study will characterize rates of sub-tidal accumulation in large, open water areas of the Delta, such as Franks Tract, Sherman Lake, and Mildred Island and identify the physical and vegetative factors that influence these rates. PWA and UNO will gather background data and conduct field studies to quantify rates of sub-tidal accumulation and to understand the relative roles of sediment supply, wind-wave action, submerged aquatic vegetation, salinity, ground elevation, and other factors on these rates.

c. *investigate marsh expansion processes, including interactions between tule and submerged aquatic vegetation (SAV)--PWA, UNO, UW/WET*

In shallow water areas, prograding tule marsh edges frequently juxtapose subtidal areas with SAV, such as *Egeria*. We will conduct studies to understand the interactions between tule and SAV, and particularly the transition from one type of shallow water habitat to another. We hypothesize that tule will ultimately prograde over SAV. UW, PWA, and UNO will conduct field studies to measure the expansion of marsh edge over time and to relate these changes to the presence or absence of SAV. In addition, cores in recently-colonized, "new"

Figure 1. BREACH conceptual model of alternative pathways and transitions,and underlying processes, in the restoration of shallow water habitats in the Sacramento-San Joaquin Delta.



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marsh will be collected and analyzed to identify the pre-colonization substrate. Potential new marsh study sites include portions of Sherman and Brown's Islands.

d. continue measurements of elevation change to refine rate estimates for Delta systems--UNO

On-going surveys of marsh surface elevation change and organic/inorganic accumulation at the BREACH sites in the Delta will be continued annually to improve the projected rates of marsh restoration used in the conceptual model.

e. as opportunity arises, incorporate additional/existing data as it becomes available to test model (e.g., Cache, Georgianna sloughs, Prospect, Twitchell, and Decker islands, etc.)--all including DWR, with UW/WET lead

Task 2: Extend conceptual model development to Suisun Bay and San Pablo/North Bay (Phase I)

a. inventory of "restoring" marsh and natural marsh reference sites--PWA, UW

PWA and UW will create an inventory of "restoring" marsh and natural marsh reference sites. Reference sites are areas of ancient natural marsh, several thousands of years old. Restoring sites are younger marsh sites, on the evolutionary trajectory to ancient marsh. Restoring marsh sites include breached-levee sites (accidentally breached and intentionally restored), managed marsh sites, and new marsh formed in the last 150 years by estuarine deposition. For each site, we will collect readily-available information to identify key site data such as: area, date(s) leveed, date(s) breached or restored, amount of subsidence prior to breaching, restoration actions taken, previous studies, current conditions, and management actions (particularly for managed marshes). We will review mapping of historical and existing wetlands (primarily SFEI mapping), review historical aerial photographs, conduct interviews with persons knowledgeable about the sites, and identify previous studies.

b. review of existing information on Suisun Bay and San Pablo/North Bay marshes(all)

UNO and PWA will review available hydrologic and geomorphic data and studies. PWA has in house data from marsh monitoring (channel geometry, marsh transect topography, water surface measurements, vegetation, etc.) at various San Francisco Bay sites collected over the past twenty years. We will review existing research (Grossinger 1995) documenting changes in tidal channel planform morphology with salinity. UW/WET and PWA will characterize vegetation community structure along estuarine gradients in the two extended study regions, relying particularly upon contemporary studies in Suisun Bay by UC-Davis. Fish and macroinvertebrate data from marsh and other shallow water habitats is relatively rare, but considerable unpublished data and knowledge resides in several agencies and institutions that have conducted sampling in Suisun Bay (P. Moyle, UC-Davis) and San Pablo Bay (C. Heib; CF&G). SFSU/RTC and UW/WET will compile and review these data to evaluate both the state of the knowledge about fish utilization of these shallow water marshes and channels as well as sampling methodology. PRBO has been conducting avian field studies in Suisun Marsh, San Pablo Bay and San Francisco Bay in tidal marsh habitat since 1996. Hence we are familiar with avian studies other than our own. Other studies include bird surveys at Sonoma Baylands and at Napa/Sonoma salt ponds. For this task, we will summarize findings from other studies (in the published and gray literature) as well as summarize our own findings most relevant to this project.

c. select sites for refined/expanded BREACH study

We will use the site inventory data (Task 1a) combined with selection criteria (availability of previous studies, access, logistics, etc.) to select a subset of approximately 12 sites for refined/expanded BREACH study. Site inventory and selection information will be made available to the CALFED community as an interim product. Potential study sites in Suisun Bay include restoring sites such as Ryer Island, Roe Island, Chipps Island, and Hill Slough West, and potential reference sites such as the undiked regions of Ryer Island and Rush Ranch. Potential study sites in the San Pablo/North Bay region include "restoring" marshes on the lower Petaluma River (e.g., Sonoma Baylands and Carl's marsh), Napa marsh sites (e.g., Pond 2A and White Slough), and others. Potential reference sites include natural Petaluma Marsh on west bank of Petaluma River and Sonoma Creek marshes and China Camp.

d. conduct geomorphic assessment at all sites

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- open water sedimentation—UNO, PWA

PWA will collect and analyze existing information regarding historical rates of open water (un-vegetated) sedimentation for the selected sites and regionally. PWA will conduct field studies to measure open water sedimentation rates at the selected study sites. PWA will conduct empirically-based and wave-theory-based analysis to characterize sedimentation as a function of sediment supply, salinity, and wind-wave resuspension.

- marshplain accumulation and elevation change – UNO

UNO will establish, at the selected study sites, stations for the measurements of marsh surface elevation change, marsh surface accretion, soil bulk density and organic matter content. These measurements will be made semi-annually during the project using the same protocols used in the current BREACH study, described above and in the Reed and Morrison poster in Appendix A.

- marsh elevations, channel and marsh geomorphology –PWA, UW/WET

PWA will collect field data and data from previous studies to characterize tidal channel shape, both in planform and cross-section, in Suisun and San Pablo Bays. This data will be used to assess the effects of vegetation, salinity, and tidal prism on channel shape.

- vegetation – UW/WET, PWA, UNO

UW, PWA, and UNO will analyze existing field data on initial vegetation colonization rates, plant types, elevations, and mechanisms. PWA will measure mudflat elevations for areas colonized by pioneer seedlings (isolated patches) and for areas colonized by expansion from an existing marsh edge. UW and UNO will identify vegetation types along marshplain elevation transects and tidal channel cross-sections.

Task 3: Assess relationship of fish, macroinvertebrates, and avifauna to restoration status (Phase II)

a. *document seasonal fish community composition, life history and relative abundance—SFSU/RTC*

SFSU/RTC, with assistance from UW/WET, will conduct sampling and experiments to characterize fish community composition, life history structure, and relative density of fishes occupying discrete shallow water habitats that reflect different stages of marsh restoration. Sampling will be specifically designed to sample different shallow water habitat strata and to generate density or other dimensioned data that can be scaled by different habitat strata metrics. Fish will be identified, their life history stage characterized, measured, and subsamples retained for further analysis (e.g., diet).

b. *document seasonal macroinvertebrate community composition, life history and relative abundance--UW/WET*

Coincident with the SFSU/RTC fish sampling, UW/WET will conduct quantitative sampling of benthic macroinvertebrates, zooplankton and fallout insects associated with the same shallow water habitat strata. Focus will be on capturing macroinvertebrates that are prominent prey items in the diets of dominant fishes, so we will have to be somewhat adaptable in terms of the targeted invertebrate communities. Techniques and sampling protocols developed for sampling in the Delta, as well as experience in many comparable studies in the Pacific Northwest, will ensure that we will be able to characterize these invertebrate communities associated with different stages (habitats) of restoring marshes.

c. *document seasonal avifauna composition, abundance and behavior--PRBO*

PRBO will quantify the use of tidal marsh habitat (reference, and restoration sites), and managed/seasonal wetlands by waterbirds and landbirds. We will determine species composition, abundance and habitat use (foraging, roosting, breeding) and how these vary: (1) Across sites. Here we will compare sites that vary in habitat type (e.g., mature tidal marsh, recently restored, seasonal wetland, etc.), and compare sites within a habitat type (within SPB and SM, and comparing these two areas with each other and with Delta sites); and, (2) over inter-annual and intra-annual (seasonal) variation in species composition, abundance and habitat use. For inter-annual comparisons we will compare results from the 2000 and 2001 field season, as well as data as available from earlier studies in SPB and SM conducted in 1996-1999. A limitation of earlier data is that, unlike this study, surveys focused on the breeding season (March – June) only.

An additional objective, as part of Task 3, will be to determine the habitat features and vegetation characteristics that are most important in explaining variation in species composition, abundance, and habitat use, by comparing sites with different, and similar, restoration status. Information on habitat and vegetation will be collected utilizing methods developed by by PRBO and others, which focus on bird-specific, relevant parameters.

Task 4: Evaluate food web and other ecosystem linkages (Phase III)

Representative species and life history stages of fishes retained from Task 3 sampling by SFSU/RTC will be quantitatively analyzed by UW/WET. Diet data will include numerical and gravimetric composition and frequency of occurrence, and the resulting Index of Relative Importance (IRI).

a. conduct stable isotope analyses of representative consumer organisms—UW/WET

Samples of indicator (e.g., representative feeding type; widely distributed) fishes and macroinvertebrates from the SFSU/RTC and UW/WET sampling will be retained for analysis of the stable isotopes of $\delta^{13}C$, $\delta^{15}N$, and $\delta^{34}S$. With comparison to the same isotope signatures of the most likely organic matter sources to the food web (e.g., riverine input, phytoplankton, benthic microalgae, SAV, emergent wetland vegetation) that will be obtained by another CALFED research project (J. Cloern, PI; see Linkages), we will use a multiple tracer mixing model (Lubetkin and Simenstad, submitted) to estimate the relative proportions of organic matter supporting these organisms through various food web pathways.

Task 5: Prepare synthesis document and presentations

Information and products from the proposed research will be disseminated regularly as they emerge. We will use a variety of media, including our BREACH WWWsite, an interim and a final technical report, presentations at regional Bay-Delta management forums, and publication in peer-reviewed scientific journals. Scientific papers will be presented at professional society meetings, IEP annual meetings, and the State of the Estuary conferences at various stages of our research.

B. Location/Geographic Boundaries of the Project

The present BREACH research sites (10 total) are distributed throughout the Delta (see Table 1 in BREACH poster, Appendix A and/or the BREACH WWWsite, "http://weber.u.washington.edu/~calfed/calfed.htm"). We propose to add approximately 12 sites in the Suisun Bay and San Pablo/North Bay regions. Potential study sites are described in Task 2c.

III. Ecological/Biological Benefits

A. Ecological/Biological Objectives--organized by objectives 1-4 above

Over 95% of the once-vast tidal-freshwater and brackish wetlands of the Sacramento-San Joaquin Delta have been leveed and removed from tidal and floodwater inundation. In Suisun Bay, 79% of the tidal marsh had disappeared, most of it behind levees, by 1988. Tidal wetland loss in San Pablo/North Bay is comparable (70%), although much of it was turned into agricultural bayland. One of the CALFED Bay/Delta Program's primary goals is to restore ecosystem health of the Bay-Delta. Restoration of a significant portion of these tidal wetlands by breaching levees of selected "reclaimed" islands is considered to be a potential step toward recovery of ecosystem integrity through rehabilitation of shallow water habitat. However, not unlike coastal restoration throughout the region and country, we know very little about the patterns, rates and even endpoints of breached-levee restoration in the Delta. There continues to be a high degree of *uncertainty* and *unpredictability* associated with reestablishing sustainable ecological functions in restored wetlands, such that: (1) direct measurement of function is difficult, if not impossible; (2) indirect or surrogate 'indicators' have not be developed or validated; and, (3) we don't know what independent factors promote rapid development of functions. Given the extensive changes in watershed structure and processes, complex management and manipulation of water, introductions of pollutants and non-indigenous species, and drastic declines in fish populations, there are many questions about the feasibility and practicality of restoration.

Based on our investigations in the Delta and our and other investigators' studies of marshes in Suisun Bay and San Pablo Bay, we hypothesize several significant differences among processes and biota along the Bay-Delta continuum that would influence the rates and patterns of shallow water habitat restoration. As salinity and tidal energy increase from the Delta toward the Golden Gate, the geomorphic processes driving the rates and endpoints of site evolution change. The resulting changes in structural habitat, in turn, effect the biological communities that use this habitat. We expect that the results of our study will document and describe the following trends in the geomorphic evolution of structural habitat (from the Delta, through Suisun Bay, to San Pablo Bay). Associated ecological implications are also discussed below.

- *Faster rates of evolution toward tidal marsh in "restoring" sites and increase in prevalence of tidal marsh as the likely endpoint of site evolution.*

Changes in sedimentation processes (flocculation, wind-wave re-suspension, currents, and sediment supply) will result in increased inorganic sedimentation rates, especially in subtidal areas. This will change the likely endpoint of site development from open water (in the Delta) to tidal marsh (in San Pablo Bay). Tidal marsh will tend to be the evolutionary endpoint in San Pablo Bay for all but the highest wave energy areas. Documentation of rates of sedimentation and how they vary across the selected study sites will provide insights into the mechanics of sedimentation and the controlling factors important to the evolution of tidal marsh restoration.

- *Increase in channel drainage density and more small channels.*

As halophytic vegetation becomes dominant in more saline parts of the Bay-Delta, the biogeomorphic processes controlling channel formation and maintenance will change. Changes in tidal energy and the elevation of the marsh plain will also influence channel formation, and thus the provision of important channel margin habitats. As this study will encompass many aspects of the biogeomorphic processes, the proposed studies will allow this component of marsh development to be encompassed in the conceptual model.

- Addition of intertidal mudflat as a new evolutionary endpoint

Changes in sediment deposition, sediment supply and wave and tidal energy, as well as differences in vegetative tolerance for inundation, will produce a sustainable intertidal flat environment in more saline parts of the Bay-Delta. This shallow water habitat component of the landscape may provide important substrate for macroinvertebrates adjacent to detritus exports from the marsh plain, and is observed to be a very prominent foraging area for shorebirds. In the winter, we hypothesize that shorebird distribution is limited by availability of exposed intertidal mudflats, specifically invertebrate prey found in the mudflats.

In addition, we hypothesize the following ecological responses to these varying hydrologic, geomorphic, and vegetation structure and processes:

- *Fish community structure is less dominated by exotic species in natural and mature restoring marshes than in young restoring sites and managed systems.*
- *Songbird breeding distribution in tidal marsh habitat (mature and restored) is limited by vegetation characteristics (e.g., height of shrubs serving as nest substrate).*
- *Shorebird distribution in winter is limited by availability of intertidal mudflats, specifically invertebrate prey found in the mudflats.*
- *The production of resident populations of consumer organisms is supported more by organic matter from shallow water emergent vegetation than from water column production or exogenous sources.*

B. Linkages

The proposed refinement and expansion of the BREACH project will promise both direct and indirect linkages to related CALFED research. One of the more directly related CALFED studies is the "Assessment of the Sacramento-San Joaquin River Delta as Habitat for Production of the Food Resources that Support Fish Recruitment" directed by Dr. James Cloern (USGS-Menlo Park, with collaborators M. Brett, E. Canuel, B.

Cole, A. Jassby, J. Koseff, S. Monismith and D. Müller-Navarra) that seeks to evaluate lower trophic structure and processes in the Bay-Delta. One critical linkage of this study is that Cloern *et al.* will be conducting multiple stable isotope analyses of organic matter sources produced within or imported into the Bay-Delta. This would provide essential information on the isotopic signature of organic matter entering Bay-Delta food webs and allow us to concentrate our analyses on the isotopic characterization of consumer organisms. Their study is also utilizing several of the current BREACH study sites, further enhancing the comparative power of the combined datasets. Similarly, our Task 4 investigations will be integrally linked to new CALFED Category III research on the Bay-Delta food web. This project, entitled "Assessment of the Impacts of Selenium on Restoration of the San Francisco Bay-Delta Ecosystem" (#98-2015000-00096; P-Is, Dr. Sam Luoma, USGS; Greg Cutter, Old Dominion Univ.; Nick Fisher, SUNY-Stony Brook; and David Hinton, UC-Davis), is designed to address the question of whether and why specific food web components preferentially bioaccumulate selenium, thereby providing a threat to some predators but not others in the system. They will be using stable isotopes to determine how concentrations of selenium in organisms at different trophic levels differ with water column and sediment concentrations. We have jointly agreed that, should the refined/expanded BREACH proposal be accepted, we will collaborate with both the J. Cloern CALFED study and this one to integrate the three stable isotope sampling designs and protocols and maximize what can be learned about trophic structure across the Bay-Delta. SFSU is also involved directly in this study, responsible for monthly sampling of mesozooplankton using vertical plankton net samples in San Pablo, Central and South Bays.

Our current BREACH research in the Delta is already collaborating closely with the on-going CALFED study of "The Effects of Wetland Restoration on the Production of Methyl Mercury in the San Francisco Bay-Delta System" being conducted by T. Suchanek, D. Slotton, B. Johnson, D. Nelson and S. Ayers at UC-Davis. This study of the potential risk of increased toxic methyl mercury release with breached-levee restoration involves joint investigations at several BREACH study sites and data sharing.

We will also investigate opportunistically the potential to link into existing/proposed CALFED restoration site studies in order to expand the breadth of our sample size and diversity of restoration site 'treatments,' especially at comparatively young sites. For example, one potential sites is the Twitchell/Sherman Island project (CALFED approved, in contracting). This project will yield "maximum" tule accretion rates (tule farming), which we can compare with our results. The new Georgianna Slough CALFED project and proposed Delta Meadows River Park project (both J. Hart, PI) also promise opportunities to complement our on-going BREACH investigations in the Delta.

The proposed project also links well with a new project in San Pablo Bay, led by UC Davis (Geoffrey Schladow, lead PI; with Inge Werner and Thomas Young), with PRBO (Nadav Nur PI), the San Francisco Estuary Institute (Bruce Thompson PI), and USGS-Sacramento (David Schoellhamer). The project, titled "CISNet San Pablo Bay Network of Environmental Stress Indicators," is funded for Sept. 1998 to December 2001 by EPA (sponsor agency) and NOAA. CISNet is the "Coastal Intensive Sites Network" which NOAA is establishing on all coasts of the United States (Atlantic, Pacific, Gulf), and San Pablo Bay will serve as one of the intensive sites in the network. The main objectives are to 1) develop and evaluate indicators of ecological health and 2) determine spatial and temporal variability in anthropogenic and natural stressors. The project involves a study of sedimentation and salinity, as well as evaluating contaminant loads in sediment and bioaccumulation of contaminants in benthic fauna (amphipods), fish and birds, and determining ecological impacts of such stressors. The CISNet project will complement our own proposed project very well, and we will endeavor to minimize any duplication. The geographical scope of the proposed project is more extensive than the CISNet project and the objectives and the ecological attributes assessed differ in the two projects. In particular, for the bird component, no funds are requested from CALFED that are already covered by the EPA-funded project. The proposed project will also link well with a recently established USGS project, led by David Schoellhamer and John Takekawa, which is studying biophysical and ecological characteristics of former salt ponds in San Pablo Bay, titled "Science Suppport for Wetland Restoraion in the Napa-Sonoma Salt Ponds, SF Bay Estuary."

C. System-Wide Ecosystem Benefits

The proposed research will provide critical information that will be important to assessing the long-term role of restoration of shallow water wetlands and other habitats in rehabilitating the integrity of the Bay-Delta ecosystem. We anticipate that the expanded and refined BREACH conceptual model will become a valuable tool in developing priorities and allocating restoration resources to maximize the contribution to the systems fish and wildlife and, ultimately, the Bay-Delta food web.

D. Compatibility with Non-Ecosystem Objectives

In addition to the implications for ecosystem restoration objectives, this proposal is related to several proposals to this solicitation that address drinking water quality issues, including B. Bergamaschi *et al.*'s (USGS, UG, MWD) "Dissolved Organic Carbon Release from Delta Wetlands: Amounts, Alterations, and Implications for Drinking Water Quality and the Delta Foodweb: Part I., and R. Fujii et al.'s (USGS, UNO) "Dissolved Organic Carbon Release from Delta Wetlands: Amounts, Alterations, and Implications for Drinking Water Quality and the Delta Foodweb: Part II-Fluxes and Loads from Tidal and Non-Tidal Wetlands and from Agricultural Operations." Both of these proposals will include study sites at current BREACH sites in the Delta and will utilize data generated from our study.

IV. Technical Feasibility and Timing

A. Proven Feasibility in Delta Implementation of BREACH

The scientific research team of the current BREACH project will remain the same, with the addition of the team from San Francisco State University, Romberg Tiberon Center for Environmental Studies, who will assume the primary role of fish investigations in the Suisun Bay and San Pablo/North Bay regions. This research team has proven it's ability to work together effectively, even under some of the more difficult field sampling conditions.

B. Phased Timing:

The project will be organized in three overlapping phases:

1. Phase I: Tasks 1 & 2, Refine and extend conceptual model
   <u>9/99-12/02</u>
   - continue selected Delta field work (monitoring) for 2.5 yr
   - inventory sites and evaluate extant literature
   - select sites
   - conduct geomorphic, hydrological and vegetation sampling for 1.5 yr (some monitoring up to 3 years, see tule-*Egeria* below)
2. Phase II: Task 3, Relationship of fish, macroinvertebrates, and avifauna to restoration status;
   <u>6/00-12/02</u>
   - pilot studies in summer 2000, full-scale seasonal (or more frequent, if necessary, e.g., fish) sampling fall 2000-summer 2001
3. Phase III: Tasks 4 & 5, Evaluate food web and other ecosystem linkages
   <u>1/01-12/02</u>
   - sample acquisition from Phase II, Task 3 sampling
   - sample processing
   - data analysis & interpretation
   - preparation, review and dissemination of synthesis document

V. Monitoring and Data Collection Methodology

A. Biological/Ecological Objectives

The biological/ecological objectives of our study are:

- identify the structure of fish, macroinvertebrate and avifauna communities that are associated with transitional stages in restoring shallow water habitats in the three Bay-Delta regions under study;
- determine whether any transitional states are detrimental to target fish and wildlife species; and,
- evaluate differences in the contribution of different restoration states to Bay-Delta food webs.

B. Monitoring Parameters and Data Collection Approach

In the present BREACH study, we are assessing indicators of wetland status and restoration patterns and rates at all or subsets (e.g., fish sampling only being conducted in East/Central Delta sites) of the ten sites (see Research Sites, Figure 1), in four primary habitat strata: 1) marsh plain; 2) emergent macrophyte shoreline margin; 3) submergent macrophyte; and 4) open water unvegetated. We propose to extend the same design and indicators of wetland status to the Susisun Bay and San Pablo/North Bay regions, including:

- Marsh elevation and accretion--UNO: SET/accretion stations will be installed at all new locations, including streamside/backmarsh and upstream/downstream where possible. Organic matter soil contributions will also be determined for all sites. Semi-annual sampling for 3 years.
- tule-*Egeria* interaction--PWA, UNO: PWA will establish multiple short elevation transects across tule-*Egeria* and tule-mudflat (no *Egeria*) margins. Transect locations will be selected to control for similar topography (elevations and slopes) and wave exposure. PWA will conduct semi-annual monitoring of changes in position of the tule/*Egeria* or tule/mudflat boundary and associated elevation changes. UNO will collect cores in areas of newly expanded tule marsh to characterize the type and relative abundance of organic material in the underlying substrate. Substrate composition will indicate the relative importance of SAV in raising site elevations for subsequent tule colonization. Measurements will be taken semi-annually for 3 years.
- Marsh and channel geomorphology, including GIS analysis of aerial photographs, with particular emphasis on tidal channel delineation--PWA, UW: PWA will survey marsh elevation transects and tidal channel cross sections for the selected study sites. In rapidly-evolving areas, PWA will perform repeat surveys annually for 3 years. Project bench marks and marsh plain elevation measurements will be established during an intensive survey "blitz" in summer 2000 using a high-resolution global positioning system (GPS). Geomorphological, sedimentological and vegetation sampling are focused in emergent marsh strata, while most ecological sampling is focused at the interface and adjacent (open water) habitats. Intensive field sampling will occur between Spring 2000 and Fall 2001, but routine seasonal sampling at our existing Delta sedimentation sites will begin in Fall 1999 and continue through Summer 2002.
- Marsh vegetation complexity and structure, based on GIS analysis of aerial photographs and *in situ* groundtruthing along marsh plane and shoreline transects: UW/WET and PWA will document marsh vegetation (e.g., emergent, woody, forbs) structure across marsh geomorphology gradients (across elevation gradients, perpendicular to channel edges) in conjunction with the GPS "blitz." Sampling transects and spot sample points will be chosen based on initial investigations of the sites' geomorphic features and aerial photograph interpretation of the distribution of vegetation assemblages.
- Benthic and epibenthic invertebrate populations, measured from 0.0024-m^2, 10-cm deep benthic cores; 0.21-m^2 insect fallout traps, 0.5-m dia., 333-μm zooplankton net vertical hauls and 1-m^2 horizontal tows (sample from fish egg and larvae samples, below), and epibenthos associated with SAV roots--UW/WET, SFSU-RTC
- Fish assemblage and life history structure and behavior in tidal channel drainage systems using: fyke nets deployed to sample fish emigrating from marsh through ebb tide, captured in 3.1-mm mesh fyke, shallow shoreline areas with emergent vegetation: 15-m x 1.5-m, 3.1-mm mesh beach seine depletion sampling in 15- and 30-m enclosures, shallow subtidal 1-3 m deep: 30-m x 3-m, 3.1-mm mesh purse seines, and 30-min

sets; fish egg and larvae net tows (variable distance/volume) with 1-m^2 opening, 2.5-m net)-- SFSU, UW/WET

- Avifauna ecology and behavior in vegetation and non-vegetated habitats--PRBO: Standardized point count surveys will be conducted by PRBO biologists, following methodology used in the BREACH I project. The protocol used will follow that outlined in Ralph *et al.* (1993), and is widely used throughout North America. These surveys consist of identifying all bird species, including number of individuals and behavioral category (foraging, flying, roosting, etc), which are detected within 50 m of a fixed point, as well as beyond 50 m, during a 5 minute period. Detections are both visual and auditory (relying on distinctive calls and songs). The surveys will be conducted in morning hours only, with point count "stations" spaced at least 200 m apart. Each site (marsh) will have at least 10 point count stations. The same protocol has been used in PRBO studies in riparian habitat (see, e.g., Nur *et al.* in press a). The data collected can be analyzed to determine species composition, relative (but not absolute) abundance, species richness, and species diversity; analytic methods are described in Nur *et al.* (in press b). These surveys will be used for all groups of birds (landbirds, waterbirds, waterfowl, birds of prey). They will be conducted during every season (breeding season, winter, spring migratory period, fall), and will be conducted for 2 full years (2000, 2001).

  Conjointly with bird surveys, PRBO biologists will collect information on vegetation and habitat characteristics within the same 50-m radius as the bird surveys (methods described in Ralph *et al.* 1993; example in Nur *et al.* in press a). The vegetation and habitat surveys will enable us to identify specific features that birds respond to, and that can be used as indicators of successful marsh restoration (success measured in terms of the avian community represented, with regard to the avian communities at reference sites). These habitat and vegetation variables are the proximal mechanisms by which birds respond, ultimately, to the biophysical processes acting on marsh and wetland sites.
- Food web linkages based on systematic fish diet analyses, generating Index of Relative Importance (IRI) data and stable isotope analyses--UW/WET, SFSU/RTC

Indicators of restoration patterns and rates will include:

- Sediment accretion rate and structural changes; seasonal Sediment Erosion Table (SET) and artificial horizon measurements; ^{210}Pb and ^{137}Cs dating of marsh sediment/peat cores
- Development of tidal channel geomorphology; GIS-based comparison of aerial photograph chronoseries
- Change in marsh vegetation assemblage structure and zonation
- GIS-based comparison of aerial photograph chronoseries
- Change in benthic invertebrate species diversity and assemblage structure, and age and trophic structure; analysis of invertebrate community and population structure
- Fish age structure and consumption, autochthonous/allochthonous food web linkages; analysis of fish community structure and food web associations with invertebrate prey resources

C. Data Evaluation Approach

Data and model analyses and interpretations will be subjected to the rigorous peer-review required for publication in international scientific journals, such as those cited above.

VI. Local Involvement

Local involvement will be fostered through interaction with various land owners and other stakeholders associated with candidate study sites. Explicit identification of these partners will depend upon the outcome of the site selection process (Phase I). We will explicitly work through the CALFED network to approach potential land owners and managers that are amenable to encouraging CALFED research on their property. This will be particularly important for sites such as managed/seasonal wetlands that will likely reside in the private domain.

VII. Cost

Total cost of the ~3.3 years of research is estimated to be $1,042,246 (Tables 1&2).

Table 1. Estimated allocation of project costs among tasks by budget category.

Task	Direct Labor Hours	Direct Salary and Benefits	Service Contracts	Material and Acquision Costs (supplies)	Miscellan-eous and Other Direct Costs	Overhand and Indirect Costs	Total Cost
Task 1	440.5	$10,639	$106,433	$925	$13,332	$10,302	$141,631
Task 2	424	$11,018	$182,943	$370	$14,095	$17,175	$225,601
Task 3	2,746.5	$56,145	$278,461	$925	$14,222	$29,774	$379,527
Task 4	249	$7,441	$7,546	$0	$45,938	$4,025	$64,950
Task 5	928	$29,293	$181,323	$1,480	$862	$17,579	$230,537
Total Costs	4,788	$114,536	$756,706	$3,700	$88,449	$78,855	$1,042,246

Table 2. Estimated allocation of project costs among tasks over the 13 quarters.

Task	9-12/99	1-3/00	4-6/00	7-9/00	10-12/00	1-3/01	4-6/01	7-9/01	10-12/01	1-3/02	4-6/02	7-9/02	10-12/02*	Total
Task 1	15,682	15,682	15,682	15,682	10,854	10,855	10,855	10,854	8,871	8,871	8,871	8,872	0	$141,631
Task 2	25,949	25,949	25,949	25,949	18,471	18,471	18,471	18,471	11,980	11,980	11,980	11,981	0	$225,601
Task 3	26,251	26,251	26,251	26,251	42,048	42,048	42,048	42,048	26,583	26,583	26,583	26,582	0	$379,527
Task 4	2,127	2,127	2,127	2,127	6,630	6,630	6,630	6,630	7,481	7,481	7,481	7,479	0	$64,950
Task 5	12,530	12,530	12,529	12,530	16,989	16,985	16,985	16,986	27,618	27,618	27,618	27,619	2,000	$230,537
Total	82,539	82,539	82,538	82,539	94,992	94,989	94,989	94,989	82,533	82,533	82,533	82,533	2,000	$1,042,246

* The last quarter is included in Year 3 in other budgets and descriptions of effort.

VIII. Cost Sharing

Salary support in the equivalent of $30,000 will be provided by the Interagency Ecological Program (DWR) to include the time devoted by Dr. Zachary Hymanson and Lenny Grimaldo to assisting with the BREACH conceptual model refinement and expansion.

In addition, The PWA cost estimate has been calculated using federal billing rates, which are lower than PWA's standard billing rates. The use of the lower billing rates results in an estimated project cost savings of $10,896, and this amount can be considered "matching funds" for the purposes of this proposal.

IX. Applicant Qualifications and Responsibilities

A. University of Washington, Wetland Ecosystem Team--coordination, macroinvertebrates, fish diet, and food web

Charles ("Si") Simenstad is an estuarine and coastal marine ecologist at the School of Fisheries, University of Washington, where is Coordinator of the Wetland Ecosystem Team. Since receiving his M.S. from the School of Fisheries at the University of Washington in 1971, he his has studied estuarine and coastal marine ecosystems throughout Puget Sound, the Washington coast, and Alaska for over twenty-seven years. Much of this research has focused on the functional role of estuarine and coastal habitats to support fish (especially juvenile Pacific salmon) and wildlife, and the associated ecological interactions that are responsible for enhancing populations of economically and ecologically-important fisheries resources. His research concerns

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primarily natural (e.g., basic) ecosystem-, community- and habitat-level interactions, with emphasis on predator-prey relationships, the sources, organization and flow of organic matter through food webs, and interaction between estuarine circulation and ecological processes. Recent research has integrated such ecosystem interactions with applied issues such as restoration, creation and enhancement of estuarine and coastal wetland ecosystems, and ecological approaches to evaluating the success of coastal wetland restoration at ecosystem scales. Recent, relevant publications include Simenstad and Thom (1996), Miller and Simenstad (1997) and Simenstad *et al.* (in revision).

B. UNO--sedimentation, conceptual model

Dr. Denise Reed received her Ph.D. in coastal geomorphology from the University of Cambridge in 1986. Her thesis work examined sediment transport in tidal salt marshes and since 1986 she has worked on coastal marsh studies in the United States. Her work has focussed in Louisiana where she was an Associate Professor at LUMCON until 1998. Her work there on the effects of levees and structures on tidal sedimentation processes has been of great interest to policy makers in coastal restoration. Dr. Reed has also received funding from NOAA, USGS and CALFED for work on marsh accretion and elevation change on the Atlantic and Pacific coasts of the US. Dr. Reed is presently as Associate Professor at the University of New Orleans. Recent relevant publications include Reed (1995), Cahoon et al. (1995) and Reed et al. (1997).

C. PWA--hydrology/geomorphology, conceptual model

Dr. Philip Williams, P.E., is President of Philip Williams & Associates, Ltd. Dr. Williams has completed hundreds of tidal, seasonal, and riparian wetland restoration plans and analyses, primarily in the San Francisco Bay-Estuary. Dr. Williams designed several of the first tidal wetland restorations in San Francisco Bay and has conducted long-term monitoring of many San Francisco Bay tidal wetlands over the past 20 years. His design credits include the recently-completed Sonoma Baylands tidal wetland restoration project in San Pablo Bay, which received the U.S. Army Corps of Engineers 1998 Civil Works Honor Award. Dr. Williams is Principal-in-Charge for the original CALFED BREACH project and the CALFED-funded Twitchell/Sherman Island "Learning Laboratory for Restoring Subsided Lands in the Delta" project. Dr. Williams has pioneered practical technical analyses of tidal marsh restoration and management, coastal wetland hydrology and hydraulics, flood and riparian management, harbor maintenance dredging, and the impacts of climate change.

Michelle Orr, M.S., Senior Associate, is a water resources engineer with experience in tidal wetland hydrology, geomorphology, and restoration design. Ms. Orr is PWA Project Manager for the original CALFED BREACH project, as well as the CALFED-funded Twitchell/Sherman Island "Learning Laboratory for Restoring Subsided Lands in the Delta" project. She is also managing the conceptual design development for tidal wetland restoration of the 900-acre Hamilton Army Airfield in northern San Pablo Bay and for tidal wetland restoration of a 100-acre former salt production pond in south San Francisco Bay.

D. SFSU/RTC--fish ecology and local logistics support

Dr. Stephen Bollens is Associate Professor, Department of Biology and Romberg Tiburon Center for Environmental Studies, and Assistant Dean, Office of Research and Sponsored Programs, San Francisco State University. He received his Ph.D. in Biological Oceanography from the University of Washington in 1990, and spent two years as a Postdoctoral Scholar ('90-92) and 4 years as Assistant Scientist ('92-'96) in the Biology Department, Woods Hole Oceanographic Institution. Dr. Bollens' research interests include behavioral ecology, population dynamics, and community ecology of zooplankton and fishes, and ecosystem dynamics of estuaries and coastal oceans. Recent field sites have included San Francisco Bay, Puget Sound, Georges Bank, the Bering Sea, the Arabian Sea, and the Antarctic Ocean, and have been supported by funding agencies including NSF, ONR, and NOAA. He is currently a member of the Interagency Ecological Program's Estuarine Ecology Team, the Romberg Tiburon Center's Board of Directors, and the Moss Landing Marine Laboratories Board of Governors. Several on-going and proposed research activities at SFSU-RTC will also benefit the proposed BREACH research. SFSU/RTC is in the final stages of being designated as the lead agency for a new San

Francisco Bay National Estuarine Research Reserve (NERR) comprising several sites between the South Bay and the Delta, including the potential reference site at China Camp in San Pablo Bay. Representative publications include Bollens and Frost (1989), Bollens *et al.* (1993) and Madin *et al.* (1996).

F. PRBO--avifauna ecology

Dr. Nadav Nur, is a Quantitative and Population Ecologist with the Point Reyes Bird Observatory (Stinson Beach, CA), where he has been a Senior Scientist since 1989. Dr. Nur will be responsible for all aspects of the avian component of the project, including: design of the study, supervision of field work, compilation of results, synthesis of results, and report-writing (with respect to the avian component). Dr. Nur earned an M.S. in Biostatistics from the University of Washington and a Ph.D. in Zoology from Duke University. He has been studying avian population biology for 20 years, and authored or co-authored 48 papers, published or in press, in peer-reviewed scientific journals and books. He is lead author on **A Statistical Guide to Data Analysis of Avian Population Monitoring Data**, which will be published in 1999. He has been lead investigator for several projects of the Point Reyes Bird Observatory, including population studies of riparian birds in Central Valley, CA, and since 1996, has been leading a study of songbirds utilizing tidal marsh habitat in the San Francisco Estuary, a study that was funded by the National Biological Service. He has served on two CALFED CMARP working groups, is a member of the state and national working groups for Partners in Flight, and serves on the Board of Directors of the Cooper Ornithological Society.

G. DWR--conceptual model

Mr. Zachary (Zach) Hymanson is a senior Environmental Specialist with the Department of Water Resources (DWR) Environmental Services Office, where he currently serves as chief of the Interagency Program Section. Prior to his current assignment in DWR, Mr. Hymanson was the chief biologist for the California Coastal Commission (1993-1997) and an Environmental Specialist in the Environmental Services Office, Water Quality Monitoring and Analysis Branch (1988-1992). Relevant experience includes: design and implementation of applied studies to understand the impacts human activities have on resident and anadromous fishes dependent on the Sacramento-San Joaquin Estuary, and extensive experience in impact analysis of biological systems. Mr. Hymanson received his Bachelor of Science in Biological Sciences from U.C. Davis in 1983, and his Master of Science in Marine Sciences from San Francisco State University in 1986.

DWR staff intend to participate in the development and refinement of the emerging BREACH conceptual model for shallow-water habitat in the Bay-Delta. This participation will be provided as a State agency match and will involve the review and synthesis of new information obtained through extension of the BREACH study. DWR staff will provide important local knowledge during the review of this information. DWR staff intend to participate in meetings of the BREACH study team to synthesize this information into a working conceptual model for shallow-water habitat. Finally, through the Interagency Ecological Program Shallow-water Habitat Project Work Team, DWR staff intend to serve as liaison between the BREACH study team and local/regional workers.

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XI. Appendices

A. BREACH posters

B. Investigator Vitae

Predicting the Evolution of Ecolo
Diked Wetlands in the Sacrame

C. Simenstad, J. Cordell, and J. Toft, Wetland Ecosystem Team, Scho
Philip Williams and Associates; D. Reed, University of New Orleans and L. G

Abstract

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Introduction

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CALFED Bay-Delta Program

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CALFED AGENCIES

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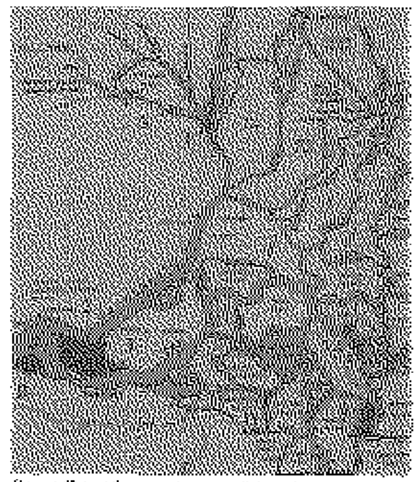

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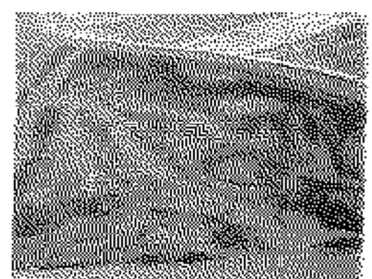

Figure 2. Aerial photograph of [illegible]

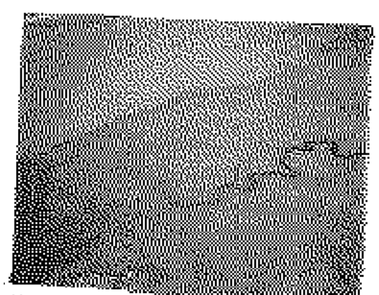

Figure 3. Aerial photograph of [illegible]

gical Functions from Restoration of nto River/San Joaquin River Delta

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Approach & Objectives

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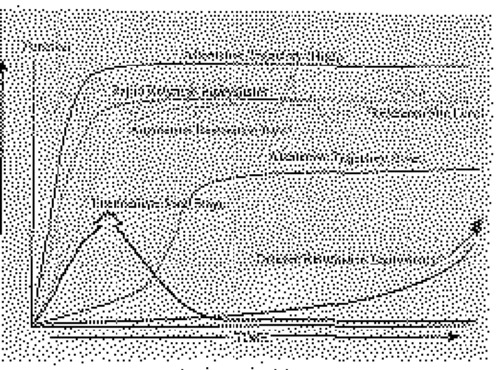

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Products

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Research Sites

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Methods

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Alternative Ecosystem Restoration Trajectories

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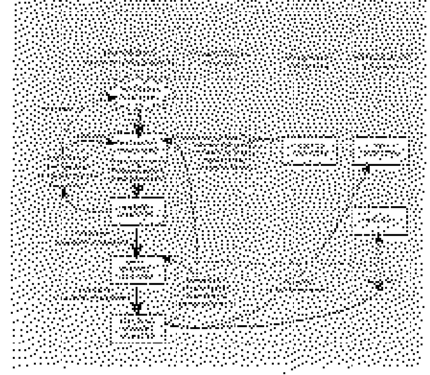

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References

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I-016175

A Conceptual Model of the Geomorphic Evolution of Freshwater Tidal Wetlands within Breached-Levee Sites in the Sacramento-San Joaquin Delta

Prepared by: Michelle Orr[1], Philip Williams[1] and Denise Reed[2]

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Abstract

This study presents a conceptual model of freshwater tidal wetland geomorphic evolution within breached-levee sites in the Sacramento-San Joaquin Delta. Breached-levee sites are former natural freshwater tidal wetland areas that were leveed in the past and have now reverted to tidal action. Some of these sites subsided up to 20 feet during the time they were leveed. Our examination of breached-levee sites in the Delta indicates that freshwater tidal marsh vegetation quickly colonizes bare ground at intertidal elevations (within several years). Vegetation establishment through natural processes on deeply subsided, sub-tidal areas takes significantly longer, on the order of several

Introduction

Over 95% of the 320,000 acres of historical freshwater tidal wetlands in the Sacramento-San Joaquin Delta have now been leveed. In the past few years, there has been a growing interest in restoring the ecological functions of large areas of the Delta by breaching levees and re-introducing tidal action. Since most of the potential restoration sites are significantly subsided, up to 20 feet in some areas, one of the major constraints associated with this type of restoration is re-building bed elevation faster than the rate of sea level rise. The conceptual model of tidal wetland geomorphic evolution presented in this poster can be applied in planning future Delta restoration efforts.

fauna studies. The information presented here is part of an ongoing study and will be refined as the study continues.

Approach

We examined the geomorphic evolution of six breached-levee sites and four natural reference sites in the Delta (Figure 1). Breached-levee sites are previously-leveed areas that have been re-flooded, either intentionally or accidentally. Reference sites are remnant portions of wetland that have never been leveed. We characterized the following hydrologic and geomorphic features at some or all of the sites:

- colonization, expansion, and erosion of marsh vegetation over

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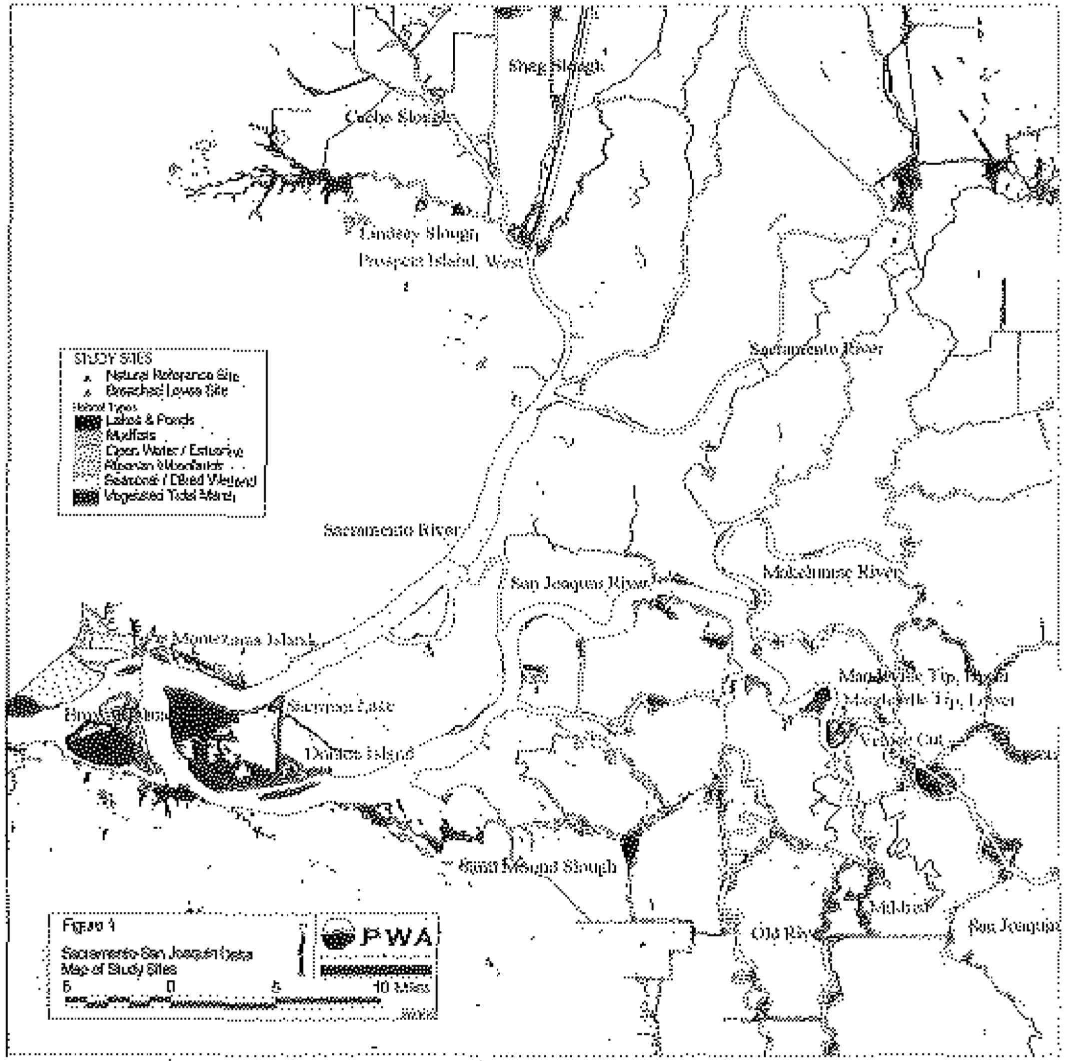
all. Artificial means of raising bed elevations, such as beneficial re-use of dredged materials, accelerates vegetation establishment and may be the only way to ensure restoration of vegetated marsh in deeply subsided sites.

larger study of breached-levee Delta wetlands with the University of Washington, California Department of Water Resources, and University of New Orleans that includes sedimentation, fish, invertebrates, and other flora and

- type and elevation of wetland vegetation
- tidal characteristics
- marsh plain elevation

Historical Evolution of the Natural Delta



The original extensive tidal marshplain evolved over the last 5,000 years by transgression -- expanding into lowland floodplain around the Delta perimeter in response to a rising sea level (Atwater *et al.*, 1979). The natural marshplain tends to be at approximately mean higher high water (Figure 2), and keeps pace with sea level rise through sedimentation and organic peat accumulation. Browns Island, the largest remaining natural marsh in the Delta, is shown in Figure 3.

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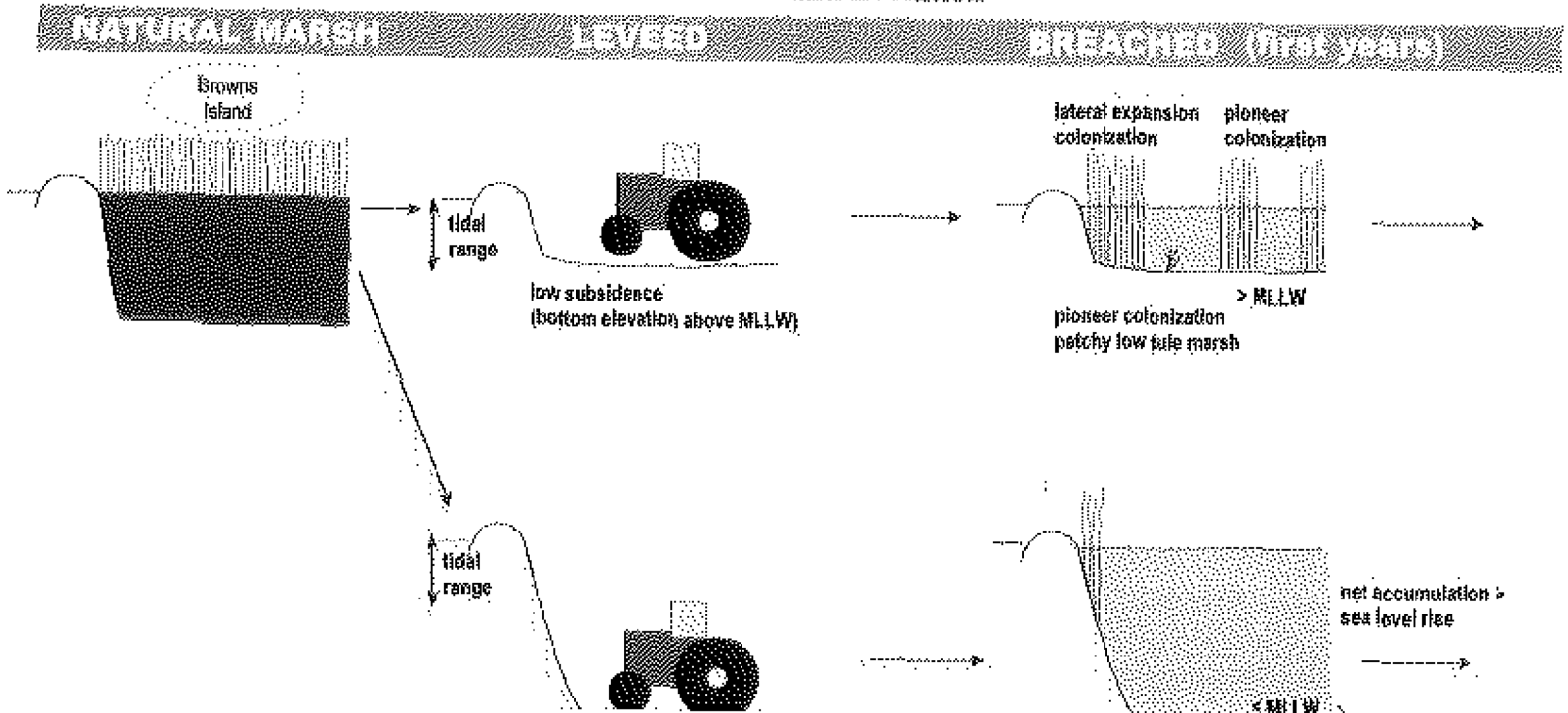
Evolution of Breached-Levee Sites in the Delta

Vegetation colonization of extensive subsided areas requires the build up of bed elevations through sedimentation until vegetation can establish. The conceptual model (Figure 2) predicts the following:

- *Once a leveed site is breached, marsh vegetation ("tule") establishes rapidly at intertidal* elevations (Figure 4).
- Once established, vegetation spreads to lower elevation areas (approximately two feet below mean lower low water) by lateral colonization from the initial patches. Lateral colonization proceeds at a slow pace (maximum of *5 to 10 feet* linear *feet/year*) and requires sheltered, low wave energy conditions.
- The presence of vegetation promotes subsequent accumulation of both organic and inorganic sediment, though at a relatively slow rate (approximately 0.02 to 0.04 feet/year [6 to 12 mm/year] above the rate of sea level rise).
- The rate of subtidal accumulation in open water areas is slow and may be less than the rate of sea level rise (Figure 5).
- *The use of fill*, such as dredged material, to raise site elevations results in rapid establishment of marsh vegetation at intertidal elevations (Figure 6).
- Where wave energy is sufficiently high (due to long fetch lengths, boat wakes, etc.), erosion and loss of marsh

figure 2 **Conceptual Model of Freshwater Tidal Wetland Evolution**



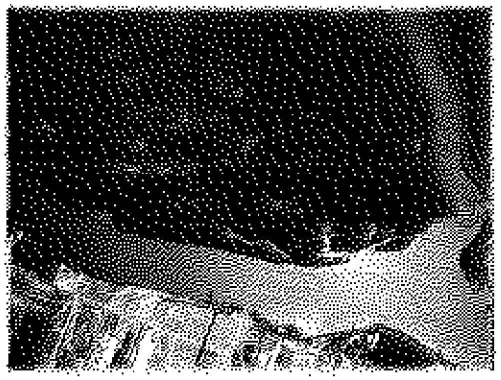


figure 3 **Browns Island**
Browns Island is the largest remaining natural tidal marsh in the Delta and the only site with an extensive branching channel network typical of the historical Delta. Although Browns Island is slightly brackish, it provides one of the best analogues of the Delta's historically vast areas of freshwater tidal marshes.

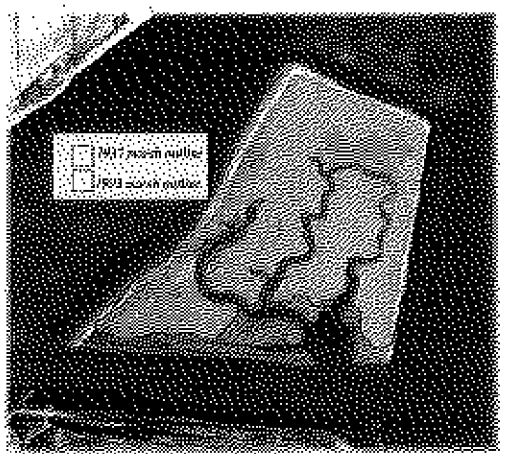


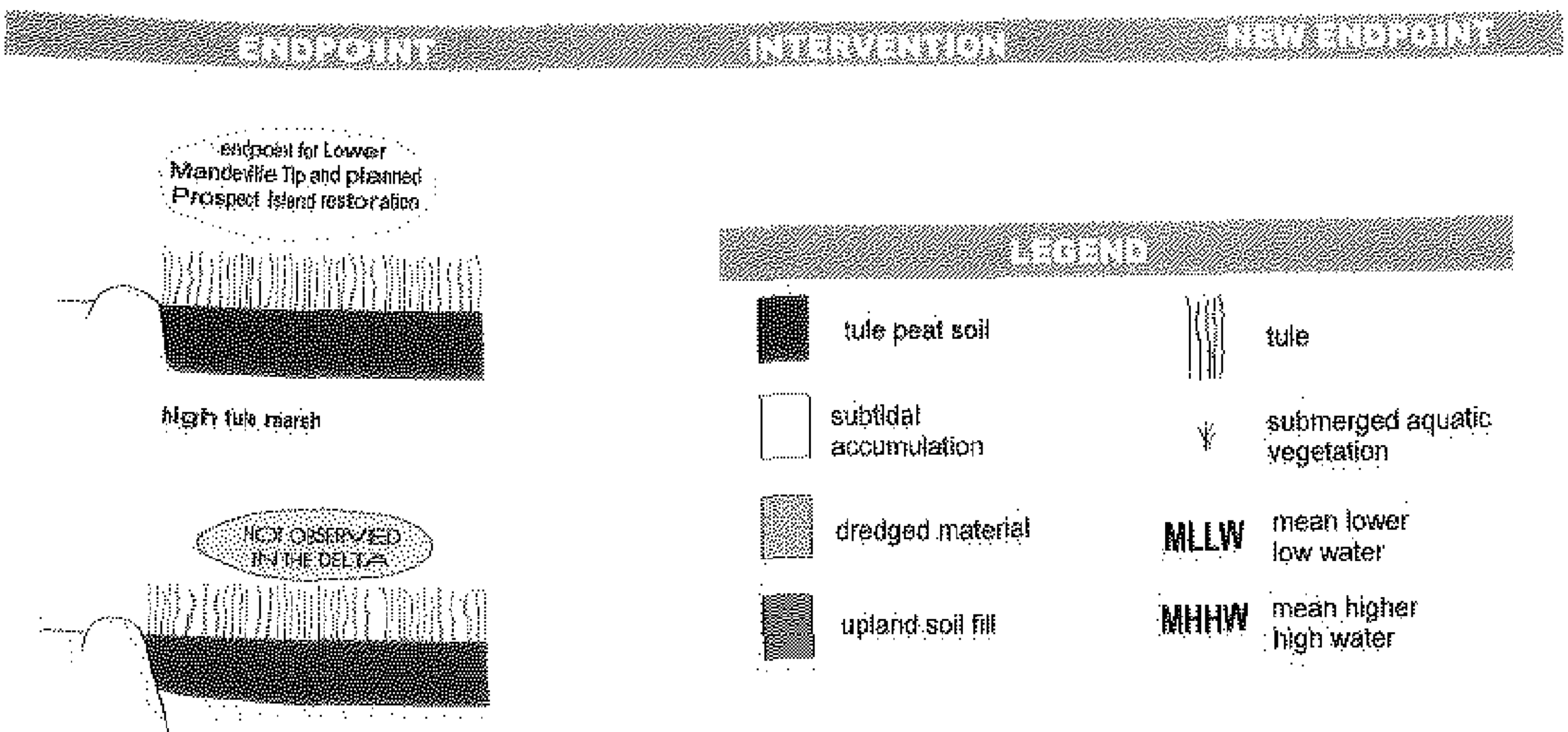
figure 4 **Lower Mandeville Tip**
Lower Mandeville Tip provides an example of rapid re-vegetation at a shallowly-subsided site following breaching. The majority of the site was at intertidal elevations when it breached in 1933. This aerial photograph, taken in 1937, shows nearly complete re-vegetation four years later. The photograph also shows significant erosion between 1937 and 1993 in the southern part of the site, where wave energy is high along the Stockton Deep Water Ship Channel.

figure 5 **Mildred Island.**
Mildred Island was a deeply-subsided site (approximately 16 feet below mean higher high water) when it breached in 1983. This 1993 infra-red photograph shows that limited perimeter vegetation (shown in red) established in the 10 years following breaching and that most of the site remains open water (shown in black).

Implications of the Conceptual Model for Restoration in the Sacramento-San Joaquin Delta

The conceptual model has the following implications for future Delta wetland restoration:

- **Shallowly-subsided sites.** Restoring tidal action to shallowly-subsided (intertidal) sites is expected to result in rapid re-establishment of a vegetated marshplain. Where the remnant channel system is intact, a natural network of drainage channels will also re-establish. Up to 100 to 200 years may be required to re-establish natural marshplain elevations at mean higher high water.
- **Deeply-subsided sites and natural sedimentation.** Natural sedimentation and organic accumulation cannot be relied upon to build marshplain elevations to intertidal elevations for the type of deeply-subsided, high wind fetch conditions typically encountered in the central Delta. Limiting wave action and wind-driven currents may be an effective way of speeding the rate of natural sedimentation, although this method is untested.
- **Deeply-subsided sites and beneficial reuse of dredge material.** Beneficial reuse of dredged material is a promising technique for restoring vegetated marsh to deeply-subsided sites. Creation of ecologically-valuable tidal channel habitat, however, requires special design consideration, such as grading during construction or creation of the appropriate conditions for natural tidal action to scour channels.



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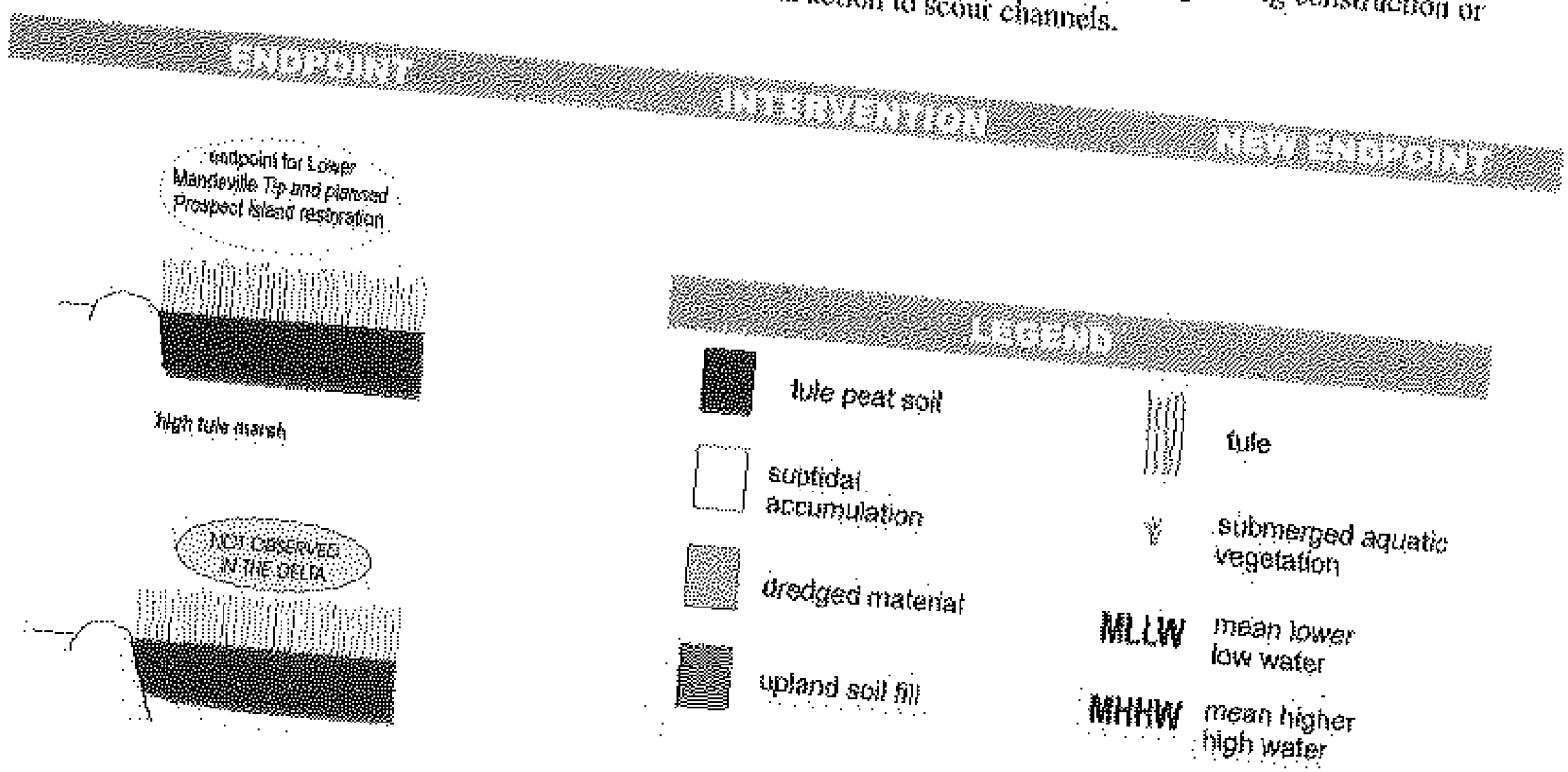
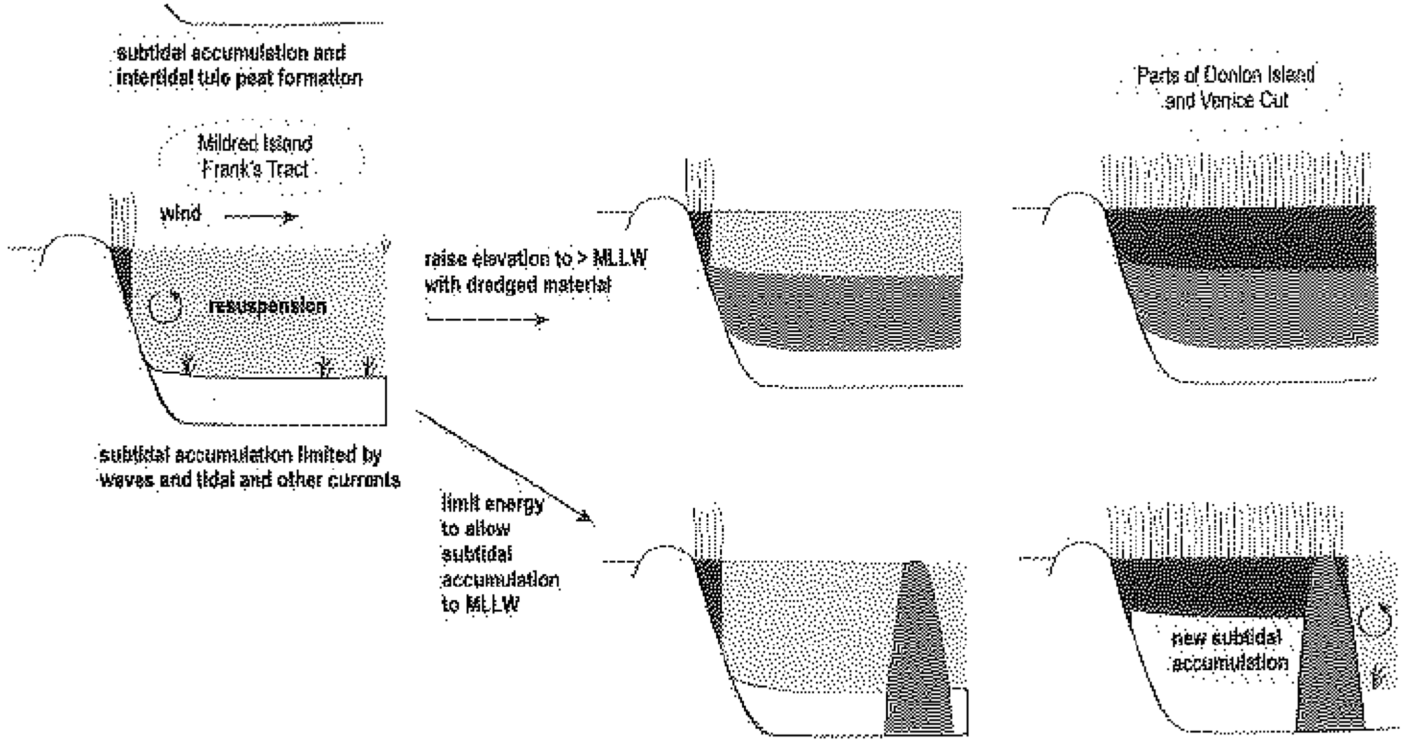
- **Deeply-subsided sites and beneficial reuse of dredge material.** Beneficial reuse of dredged material is a promising technique *for restoring vegetated marsh to deeply-subsided sites.* Creation of ecologically-valuable tidal channel habitat, *however, requires special design consideration, such as grading during construction or creation of the appropriate conditions for natural tidal action to scour channels.*





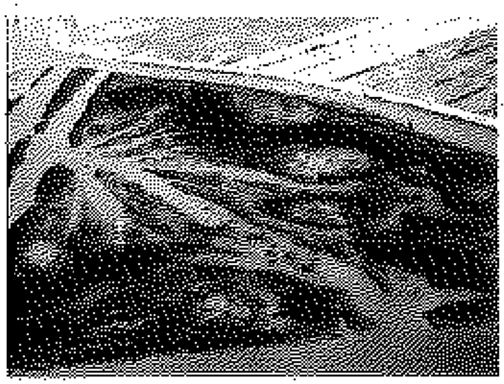


figure 6 **Donlon Island.**
Donlon Island is a breached-levee site that has been fully tidal since 1937. Nine dredged material islands were created at Donlon Island in 1985 as part of a beneficial re-use effort. Initial colonization of bare soil occurred rapidly for approximately the first two to three years, then slowed or stopped (USFWS and USACE 1990). This photograph was taken in 1997.

ACKNOWLEDGMENTS: *The research upon which this poster is based was funded by Category III. We wish to thank Charles Simenstad at the University of Washington for his assistance in developing the conceptual model and for providing graphics support for this poster and Michelle Stevens of the University of California at Davis for her vegetation expertise.*
REFERENCES: *U.S. Fish and Wildlife Service Sacramento (USFWS) and U.S. Army Corps of Engineers Sacramento District (USACE). 1990. Design and Biological Monitoring of Wetland and Riparian Habitats Created with Dredged Materials. Deep Water Ship Channel Monitoring Program.*

Contemporary Rates of Sedimentati[on in] Wetlands of the Sacramento-San Jo[aquin ...]

Denise J. Reed and Wendy Morrison, Department of Geology and Geog[...]

Introduction

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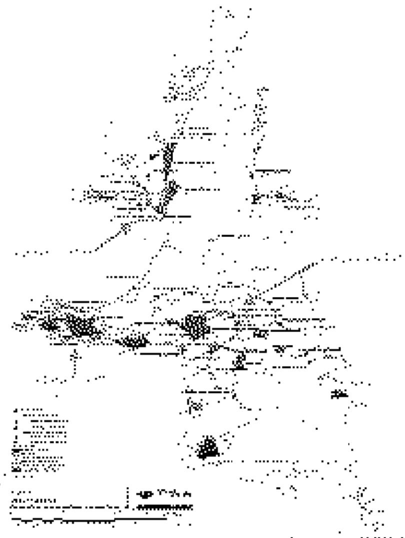

Sampling Design

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Methods

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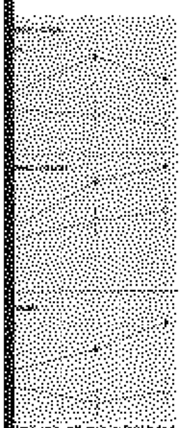
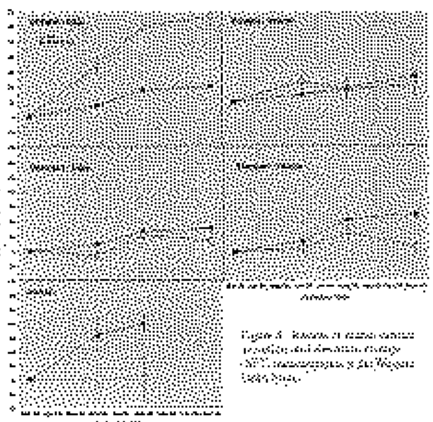
...ysics, University of New Orleans, New Orleans, Louisiana 70148

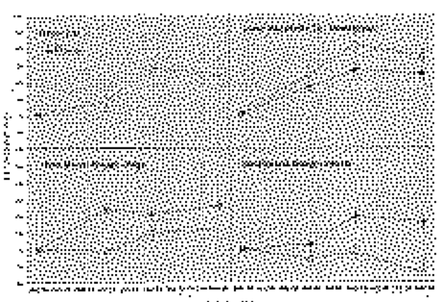
...ts—Northern Delta





Results—Western Delta

Results—Central Delta



Summary of Preliminary Results

Literature Cited

Acknowledgements

I-016184

THE EFFECT OF THE EXOTIC AQUATIC PLANT E[illegible] THE FISH/INVERTEBRATE FOOD WEB IN THE SA[illegible]

Jason Toft, Charles Simenstad, and Jeffery Cordell. Wetland Ec[illegible]

FIG. 1 *Eichhornia crassipes* (Water Hyacinth).

FIG. 3 Patch of *E. crassipes* along the marsh fringe.

ABSTRACT:

Eichhornia crassipes (Water Hyacinth) is a floating aquatic macrophyte that was introduced into the Sacramento/San Joaquin Delta region in the 1900's. *E. crassipes* is native to Brazil, and has a history of worldwide invasions. Its international prominence, detrimental economic impacts, and associated management challenges make it an important research focus. A common native plant that functionally occupies the same habitat as *E. crassipes* in the Delta is *Hydrocotyle umbellata* (Pennywort). Both plants are abundant in shallow water areas of the central Delta, although the Department of Boating and Waterways controls abundance of *E. crassipes* with chemical spraying of 2,4-D. The relative effect on community dynamics of *E. crassipes* as compared to its suitable native counterpart *H. umbellata* is unknown. It is expected that invertebrate taxa richness and density will be different between the two vegetation types, due to distinct physical and biological characteristics of the canopies.

As part of the BREACH research program (see BREACH poster) and in conjunction with collaborating DWR research on fish assemblages in shallow water habitat, we are investigating food web linkages between invertebrate prey associated with *E. crassipes* and *H. umbellata*. Additionally, we are measuring vegetation patch size and dissolved oxygen levels. Both plants have diverse invertebrate assemblages in their root masses, dominated by amphipods. Fish diet analyses show that these amphipods provide food for fish in the area. We are also characterizing the insects in the above-water canopy of the two plants, and the benthic invertebrate communities. Dissolved oxygen levels show a marked decrease underneath *E. crassipes*, as compared to underneath *H. umbellata* and nearby emergent vegetation.

INTRODUCTION:

The invasion of *E. crassipes* has caused a hotbed of controversy over issues of control and management. By the 1980's, its abundance became a hindrance to boat traffic. Chemical control of *E. crassipes* currently has an annual cost of approximately $1,000,000 (Pat Thalken, personal communication). Biological invasions such as *E. crassipes* have become widespread on a global level. Exotic species can alter the population dynamics and community structure of native ecosystems, and are primarily successful in disturbed habitats. This is especially important in the Sacramento/San Joaquin Delta, as the San Francisco Bay area is considered the major estuary in the United States most modified by human activity (Nichols et al. 1986), and may be the most invaded estuary in the world (Cohen and Carlton 1998).

Research elsewhere in the world has shown that the roots of *E. crassipes* can be important habitat for epibenthic macroinvertebrates, mainly amphipods (Gopal 1987). Floating aquatic vegetation (FAV) can also be beneficial as a nursery habitat for juvenile fishes, as well as many invertebrates. This is often dependent on patch size, as large patches of *E. crassipes* can cause low dissolved oxygen, high detritus production, and senescence of submerged vegetation (Gopal 1987). The effects of *E. crassipes* on community dynamics as compared to its native functional counterparts has not been studied in the Delta, and little is known elsewhere. The native [illegible] *Hydrocotyle umbellata* (Pennywort) functionally occupies the same niche as *E. crassipes* in the Delta. It is expected that invertebrate taxa richness and density will be different between the two vegetation types, due to changes in: (1) spatial complexity of vegetative structures (Figs. 1, 2, 3), (2) shading effects of dense canopies, (3) amount and location of plant biomass, (4) densities of vegetation patches, (5) plant detritus production rate, (6) growth rates, (7) dissolved oxygen levels, and (8) rates of evapotranspiration (Gopal 1987). Effects on the fish/invertebrate predator-prey food web are relatively unknown, and are of importance due to the prominence of FAV as a major element in this food web.

[illegible]ECTIVES:

[illegible] the assemblages of macroinvertebrates, [illegible] and terrestrial insects associated with *E. crassipes* and *H. umbellata*.

[illegible] the resident fish assemblages and food web pathways.

[illegible] physical measurements of dissolved oxygen and patch size.

METHODS:

Study Sites: We are studying 3 sites in the Delta, which are a subset of the 10 study sites involved in the BREACH research program (Fig. 4). Site A was sampled in June of 1998, and Sites B and C were sampled in August of 1998. All vegetation patches are located on the marsh fringe, and are medium in size. Length and width measurements of the FAV canopy are taken at each patch.

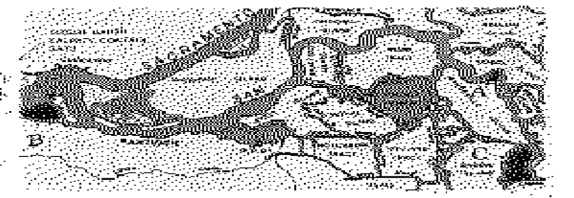


FIG. 4 Map of study sites.

Biological sampling:

(1) Epibenthic invertebrates living in the root masses of the vegetation are sampled by manually collecting plant samples. Macroinvertebrates are then separated from the collected root mass by rinsing the root mass into a bucket containing 10% ethanol. Canopy surface area is determined by correlating the number of leaves in each plant sample to the number of leaves in a 0.5 m² quadrat.

(2) Benthic invertebrates are sampled with a 2-inch diameter core to a depth of 10 cm. Sampling is also conducted at nearby emergent tule (*Scirpus* sp.) and riparian patches when present.

(3) Insect fallout traps are used to sample the terrestrial insects living in the vegetation canopies. These traps consist of a rectangular tray (55 cm x 38 cm) filled with soapy water. The trays are tethered to PVC poles at each site, allowing vertical movement with the tides. The trays are collected after 24 hours. Sampling is also conducted at nearby emergent tule (*Scirpus* sp.) and riparian patches when present.

(4) Seine-netting is used to sample fish underneath FAV. Although not presented in this report, the Department of Water Resources (DWR) also is sampling fish in shallow water areas adjacent to FAV using seine netting (see poster by Grimaldo et al.). Fish are saved for diet analyses. Prey items are ranked based on modified IRI (Index of Relative Importance) values. Diet overlap with invertebrates is calculated using the PSI (Percent Similarity Index), with a value of 100 showing complete overlap.

Physical Sampling: Measurements of dissolved oxygen and patch size are taken at each FAV patch.

RESULTS AND DISCUSSION:

Biological Sampling:

(1) Epibenthic Invertebrates in the Roots: The amphipods *Crangonyx floridanus*, *Hyalella azteca*, and *Gammarus daiberi*, and the isopod *Caecidotea racovitzai* are the most abundant taxa overall (Fig. 5; see Box A for a description of amphipods and isopods, many of which are introduced and/or first records for the Delta). Results are specific for each site, and signify differences in invertebrate communities between *E. crassipes* and *H. umbellata*. For example, at Site A the major species is the introduced *C. floridanus* at *E. crassipes*, and the native *H. azteca* at *H. umbellata*. Taxa richness and the Shannon-W[illegible] *umbellata* in June (Site A), but higher for *E. crassipes* in August (Sites B and C; Table 1). This correlates with the peak bloom of *H. umbellata* in June, and the peak bloom of *E. crassipes* in August.

(2) Benthic Invertebrates: Oligochaetes represent the most abundant taxa overall (Fig. 6). In June (Site A), taxa richness and the Shannon-Weiner Diversity Index are much higher for FAV than for emergent and riparian strata (Table 1). However, in August (Site B), taxa richness in *E. crassipes* is equal with that for the emergent strata, while *H. umbellata* still has high values. This is presumably due to the high plant detritus deposition rate associated with *E. crassipes*. Most of the additional taxa in the FAV represent fallout amphipods and isopods from the overlying root mass community.

(3) Terrestrial Insects in the Vegetation Canopy: Chironomidae and Collembola represent the most abundant taxa overall for June (Fig. 7). The abundance of Cicadellidae in *H. umbellata* patches is the major difference with *E. crassipes*. Measurements of taxa richness and the Shannon-Weiner Diversity Index are similar for FAV, and are both higher than emergent and riparian strata (Table 1).

(4) Fish: Numbers and average lengths for all fish captured in five seine-net samples underneath five patches of *E. crassipes* at Site C are as follows: 6 juvenile Bluegill (*Lepomis macrochirus*), 51.89 mm; 5 juvenile Bluegill (*Lepomis macrochirus*), 25.75 mm; 15 juvenile Largemouth Bass (*Micropterus salmoides*), [illegible]; 5 Rainwater Killifish (*Lucania parva*), [illegible] mm; [illegible] Largemouth Bass (*Micropterus salmoides*), 55.0 mm. All of these fish are non-native to the Delta. Other captures were included the crayfish *Procambarus clarkii* and the giant water bug *Belostomatidae*. Figure 8 illustrates a representative IRI for *Lepomis macrochirus*, a PSI value of 64.30 with prey invertebrates in the root mass, feeding mainly on the amphipods, isopods, zygoptera nymphs, and chironomidae larvae in the overlying root mass. The remainder of the prey is planktonic copepods, cladocerans, and ostracods. Site C was the only site sampled in this manner, as the water was too deep at all other sites. However, sampling by DWR in shallow water areas adjacent to the FAV patches has produced additional fish data. Diet analyses of these fish illustrates similar trends in prey foraging.

Physical Sampling: At site B dissolved oxygen levels are significantly lower underneath both FAV patches than at emergent strata, with *E. crassipes* having a slightly lower value than *H. umbellata* (Fig. 9). At site C, *E. crassipes* has a lower value than emergent strata, but *H. umbellata* has a much higher value. This could again be due to the high plant detritus deposition rate associated with *E. crassipes*. Average FAV patch size for all sites was 39.26 m², except for the *H. umbellata* patches at Site A, which occurred along the marsh edge and did not have a strictly defined boundary.

THE EFFECT OF THE EXOTIC AQUATIC PLANT

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THE FISH/INVERTEBRATE FOOD WEB IN THE SA

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OBJECTIVES:

(1) Characterize the assemblages of macroinvertebrates in the roots, benthic macroinvertebrates, and terrestrial insects associated with *E. crassipes* and *H. umbellata*.
(2) Characterize the resident fish assemblages and food web pathways.
(3) Characterize physical measurements of dissolved oxygen and patch size.

METHODS:

Study Sites We are studying 3 sites in the Delta, which are a subset of the 10 study sites involved in the BREACH research program (Fig. 4). Site A was sampled in June of 1998, and Sites B and C were sampled in August of 1998. All vegetation patches are located on the marsh fringe, and are medium in size. Length and width measurements of the FAV canopy are taken at each patch.

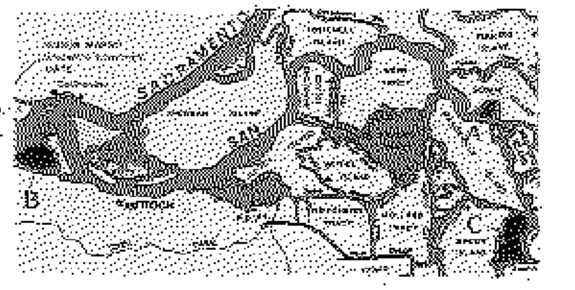

FIG. 4 Map of study sites.

Biological sampling
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RESULTS AND DISCUSSION:

Biological Sampling
(1) Epibenthic Invertebrates in the Roots: The amphipods *Crangonyx floridanus*, *Hyalella azteca*, and *Gammarus daiberi*, and the isopod *Caecidotea racovitzai* are the most abundant taxa overall (Fig. 5; see Box A for a description of amphipods and isopods, many of which are introduced and/or first records for the Delta). Results are specific for each site, and signify differences in invertebrate communities between *E. crassipes* and *H. umbellata*. For example, at Site A the major species is the introduced *C. floridanus* at *E. crassipes*, and the native *H. azteca* at *H. umbellata*. Taxa richness and the Shannon-Weiner Diversity Index are higher for *H. umbellata* in June (Site A), but higher for *E. crassipes* in August (Sites B and C; Table 1). This correlates with the peak bloom of *H. umbellata* in June, and the peak bloom of *E. crassipes* in August.
(2) Benthic Invertebrates: Oligochaetes represent the most abundant taxa overall (Fig. 6). In June (Site A), taxa richness and the Shannon-Weiner Diversity Index are much higher for FAV than for emergent and riparian strata (Table 1). However, in August (Site B), taxa richness in *E. crassipes* is equal with that for the emergent strata, while *H. umbellata* still has high values. This is presumably due to the high plant detritus deposition rate associated with *E. crassipes*. Most of the additional taxa in the FAV represent fall-out amphipods and isopods from the overlying root mass community.
(3) Terrestrial Insects in the Vegetation Canopy: Chironomidae and Collembola represent the most abundant taxa overall for June (Fig. 7). The abundance of Cicadellidae in *H. umbellata* patches is the major difference with *E. crassipes*. Measurements of taxa richness and the Shannon-Weiner Diversity Index are similar for FAV, and are both higher than emergent and riparian strata (Table 1).
(4) Fish: Numbers and average lengths for all fish captured in five seine net samples underneath five separate patches of *E. crassipes* at site C are as follows: 6 juvenile Bluegill (*Lepomis macrochirus*), 75.83 mm; 24 small juvenile Bluegill (*Lepomis macrochirus*), 25.25 mm; 18 juvenile Largemouth Bass (*Micropterus salmoides*), 51.89 mm; 5 Rainwater killifish (*Lucania parva*), 28.80; and 2 Brown Bullhead (*Ictalurus nebulosus*), 35.0 mm. All of these fish are non-native to the Delta. Other common taxa included the crayfish *Procambarus clarkii* and the giant water bug *Belostomatidae*. Figure 8 illustrates a representative IRI for *Lepomis macrochirus*. A PSI value of 64.36 with prey invertebrates in the root mass shows that these fish are feeding mainly on the amphipods, isopods, zygoptera nymphs, and chironomidae larvae in the overlying root mass. The remainder of the prey is planktonic copepods, cladocerans, and ostracods. Site C was the only site sampled in this manner, as the water was too deep at all other sites. However, sampling by DWR in shallow water areas adjacent to the FAV patches has produced additional fish data. Diet analyses on these samples illustrates similar trends in prey foraging.
Physical Sampling At site B dissolved oxygen levels are significantly lower underneath both FAV patches than at emergent strata, with *E. crassipes* having a slightly lower value than *H. umbellata* (Fig. 9). At site C, *E. crassipes* has a lower value than emergent strata, but *H. umbellata* has a much higher value. This could again be due to the high plant detritus deposition rate associated with *E. crassipes*. Average FAV patch area for all sites was 30.26 m^2, except for the *H. umbellata* patches at Site A, which meandered along the marsh edge and did not have a strictly defined boundary.

THE EFFECT OF THE EXOTIC AQUATIC PLANT *E.*
THE FISH/INVERTEBRATE FOOD WEB IN THE SA(

Jason Toft, Charles Simenstad, and Jeffery Cordell. Wetland Ec(

FIG. 1 *Eichhornia crassipes*. Water Hyacinth.

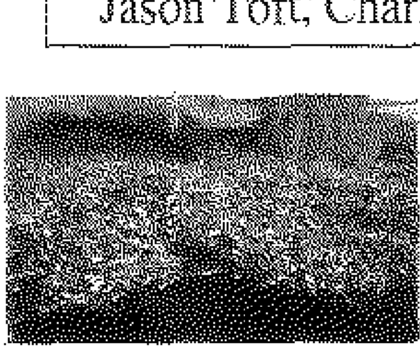

FIG. 3 Patch of *E. crassipes* along the marsh fringe.

ABSTRACT:

Eichhornia crassipes (Water Hyacinth) is a floating aquatic macrophyte that was introduced into the Sacramento/San Joaquin Delta region in the 1940's. *E. crassipes* is native to Brazil, and has a history of worldwide invasions. Its international prominence, detrimental ecological impacts, and associated management challenges makes it an important research focus. A common native plant that functionally occupies the same habitat as *E. crassipes* in the Delta is *Hydrocotyle umbellata* (Pennywort). Both plants are abundant in shallow water areas of the central Delta, although the Department of Boating and Waterways controls abundance of *E. crassipes* with chemical spraying of 2,4-D. The relative effect on community dynamics of *E. crassipes* as compared to its suitable native counterpart *H. umbellata* is unknown. It is expected that invertebrate taxa richness and density will be different between the two vegetation types, due to distinct physical and biological characteristics of the canopies.

As part of the BREACH research program (see BREACH poster) and in conjunction with collaborating DWR research on fish assemblages in shallow water habitat, we are investigating food web linkages between invertebrate prey associated with *E. crassipes* and *H. umbellata*. Additionally, we are measuring vegetation patch size and dissolved oxygen levels. Both plants have diverse invertebrate assemblages in their root masses, dominated by amphipods. Fish diet analyses show that these amphipods provide food for fish in the area. We are also characterizing the insects in the above-water canopy of the two plants, and the benthic invertebrate communities. Dissolved oxygen levels show a marked decrease underneath *E. crassipes*, as compared to underneath *H. umbellata* and next to emergent vegetation.

INTRODUCTION:

The invasion of *E. crassipes* has caused a myriad of controversy over issues of control and management. By the 1980's, its abundance became a hindrance to boat traffic. Chemical control of *E. crassipes* currently has an annual cost of approximately $1,000,000 (Pat Thalken, personal communication). Biological invaders such as *E. crassipes* have become widespread on a global level. Exotic species can alter the population dynamics and community structure of native ecosystems, and are primarily successful in disturbed habitats. This is especially important in the Sacramento/San Joaquin Delta, as the San Francisco Bay area is considered the major estuary in the United States most modified by human activity (Nichols et al. 1986), and may be the most invaded estuary in the world (Cohen and Carlton 1998).

Research elsewhere in the world has shown that the roots of *E. crassipes* can be important habitat for epibenthic macroinvertebrates, mainly amphipods (Gopal 1987). Floating aquatic vegetation (FAV) can also be beneficial as a nursery habitat for juvenile fishes, as well as many invertebrates. This is often dependent on patch size, as large patches of *E. crassipes* can cause low dissolved oxygen, high detritus production, and senescence of submerged vegetation (Gopal 1987). The effects of *E. crassipes* on community dynamics as compared to its native functional counterparts has not been studied in the Delta, and little examined elsewhere. The native *Hydrocotyle umbellata* (Pennywort) functionally occupies the same habitat as *E. crassipes* in the Delta. It is expected that invertebrate taxa richness and density will be different between the two vegetation types, due to changes in: (1) spatial complexity of the vegetative structures (Figs. 1, 2, 3), (2) shading effects of dense canopies, (3) amount and location of plant biomass, (4) densities of vegetation patches, (5) plant detritus deposition rate, (6) growth rates, (7) dissolved oxygen levels, and (8) rates of evapotranspiration (Gopal 1987). Effects on the fish/invertebrate predator-prey food web are particularly unknown, and are of importance due to the prominence of FAV as a major habitat zone in this food web.

OBJECTIVES:

(1) Characterize the assemblages of invertebrates in the roots, benthic macroinvertebrates, and terrestrial insects associated with *E. crassipes* and *H. umbellata*.
(2) Characterize the resident fish assemblages and food web pathways.
(3) Characterize physical measurements of dissolved oxygen and patch size.

METHODS:

Study Sites We are studying 3 sites in the Delta, which are a subset of the 40 study sites involved in the BREACH research program (Fig. 4). Site A was sampled in June of 1998, and Sites B and C were sampled in August of 1998. All vegetation patches are located on the marsh fringe, and are medium in size. Length and width measurements of the FAV canopy are taken at each patch.

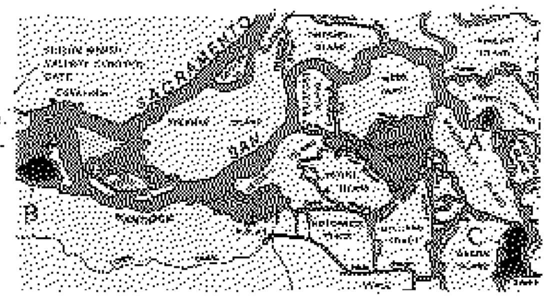

FIG. 4 Map of study sites.

Biological Sampling

(1) Epibenthic invertebrates living in the root masses of the vegetation are sampled by manually collecting plant samples. Macroinvertebrates are then separated from the collected root mass by immersing the root mass into a bucket containing 10% ethanol. Canopy surface area is determined by correlating the number of leaves in each plant sample to the number of leaves in a 0.5 m² quadrat.
(2) Benthic invertebrates are sampled with a 2-inch diameter core to a depth of 10 cm. Sampling is also conducted at nearby emergent tule (*Scirpus* sp.) and riparian patches when present.
(3) Insect fallout traps are used to sample the terrestrial insects living in the vegetation canopies. These traps consist of a rectangular tray (55-cm x 30-cm) filled with soapy water. The trays are tethered to PVC poles at each site, allowing vertical movement with the tides. The trays are collected after 24 hours. Sampling is also conducted at nearby emergent tule (*Scirpus* sp.) and riparian patches when present.
(4) Seine netting is used to sample fish underneath FAV. Although not presented in this report, the Department of Water Resources (DWR) also is sampling fish in shallow water areas adjacent to FAV using seine netting (see poster by Grimaldo et al.). Fish are saved for diet analyses. Prey items are ranked based on modified IRI (Index of Relative Importance) values. Diet overlap with invertebrates is calculated using the PSI (Percent Similarity Index), with a value of 100 showing complete overlap.
Physical Sampling Measurements of dissolved oxygen and patch size are taken at each FAV patch.

RESULTS AND DISCUSSION:

Biological Sampling

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...CHHORNIA CRASSIPES (WATER HYACINTH) ON ...RAMENTO/SAN JOAQUIN DELTA, CALIFORNIA

...ystem Team, University of Washington, Seattle, WA 98195.

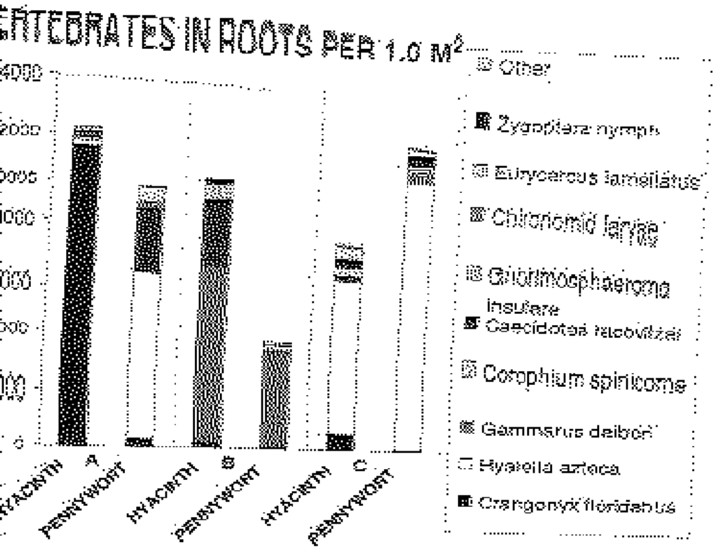


FIG. 5 Density of root invertebrates at Sites A, B, and C (n=5).

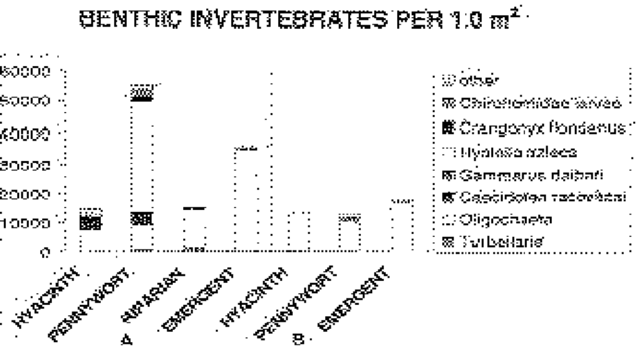


FIG. 6 Density of benthic invertebrates at Sites A and B (n=5)

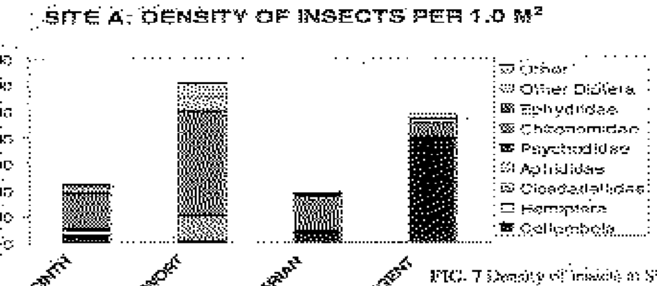


FIG. 7 Density of insects at Site A(n=5 for hyacinth and emergent, n=4 for pennywort and riparian).

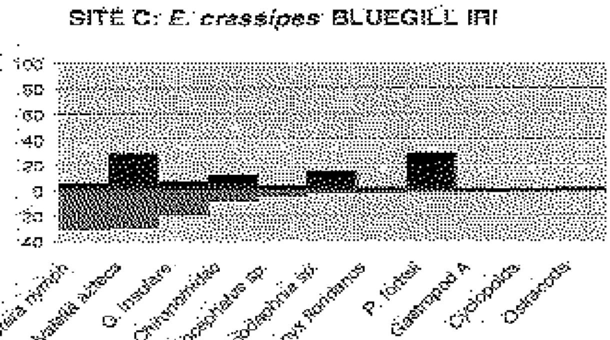


Fig. 8 IRI of Bluegill fish prey. Yellow triangles represent % frequency of occurrence.

	TAXA RICHNESS	SHANNON-WEINER DIVERSITY INDEX
ROOT INVERTEBRATES		
Hyacinth A	26	1.04
Pennywort A	29	2.34
Hyacinth B	20	1.65
Pennywort B	16	1.18
Hyacinth C	21	2.00
Pennywort C	20	1.02
INSECTS		
Hyacinth A	24	2.24
Pennywort A	25	2.12
Emergent A	18	1.14
Riparian A	18	1.7
BENTHIC INVERTEBRATES		
Hyacinth A	16	2.61
Pennywort A	13	1.92
Emergent A	7	0.25
Riparian A	8	0.89
Hyacinth B	5	0.26
Pennywort B	12	1.47
Emergent B	4	0.31

TABLE 1 Measurements of taxa richness and the Shannon-Weiner Diversity Index for representative invertebrate sampling.

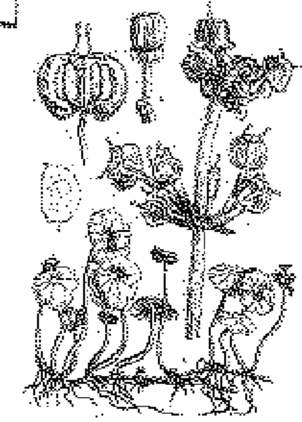


FIG. 2 *Hydrocotyle umbellata*, Pennywort.

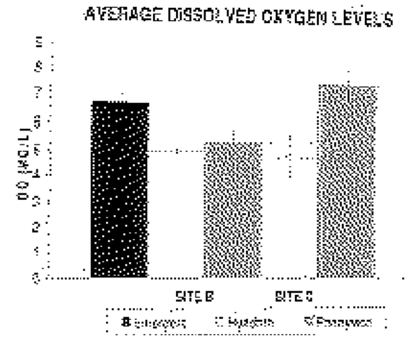
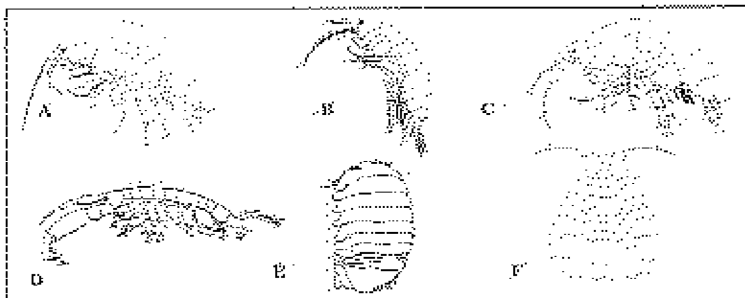


FIG. 9 Average dissolved oxygen levels (mg/l) in Sites B and C for emergent strata (n=3) and FAV strata (n=5)



BOX A: Sampled amphipods (A-D) and isopods (E-F). A. *Crangonyx floridanus*, first record in the Delta, introduced? B. *Gammarus daiberi*, introduced. C. *Hyalella azteca*, native. D. *Corophium spinicorne*, native. E. *Gnorimosphaeroma insulare*, native. F. *Caecidotea racovitzai*, first record in the Delta, introduced? And *Caecidotea* sp. A, first record in the Delta, characteristic of *Caecidotea kitgendorfii* from Asia, introduced?

CONCLUSION:

It is apparent that *E. crassipes* has had a remarkable impact on nearshore habitats in the Sacramento/San Joaquin Delta, as well as many other areas throughout the world. The invertebrate communities associated with *E. crassipes* are often unique from the native *H. umbellata*. The invertebrates living in the root mass serve as prey for resident non-native fish. These root mass invertebrates consist mostly of amphipods and isopods, many of which are introduced. It is open to speculation whether some of these crustaceans may have arrived into the Delta via the roots of *E. crassipes*. All fish sampled underneath canopies of *E. crassipes* were juveniles, so it appears that fish use *E. crassipes* as both a refuge habitat and food resource. *E. crassipes* can have a detrimental effect on the underlying benthic community as compared to *H. umbellata*, due to high plant detritus deposition rate and low dissolved oxygen levels. Congruent with the high monetary value placed on controlling the spread of *E. crassipes*, such preliminary findings warrant more research on the role of *E. crassipes* in the nearshore community.

REFERENCES:

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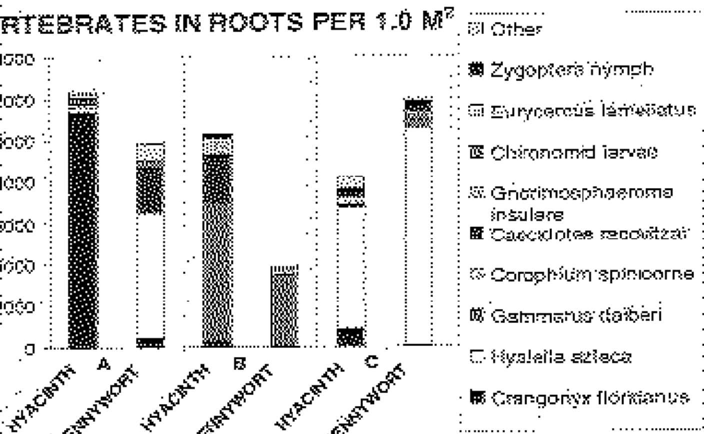

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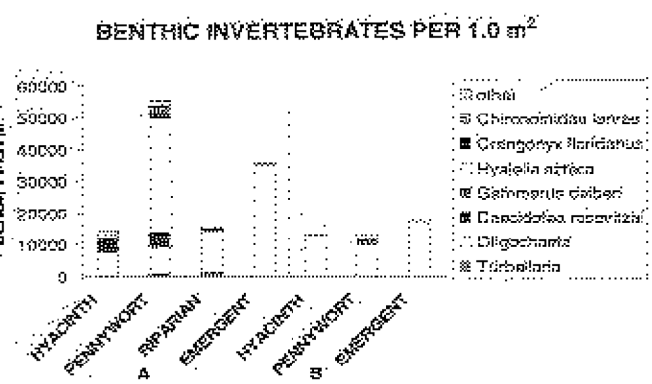

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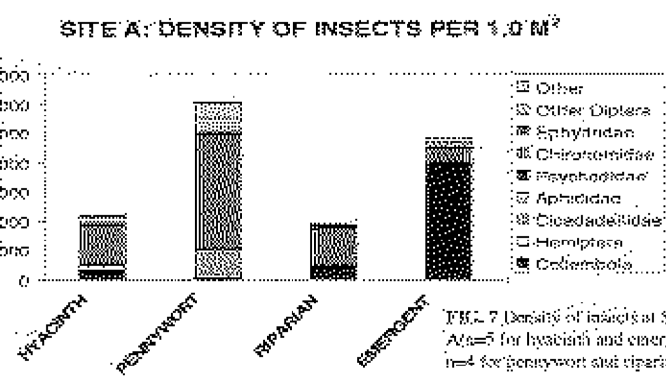

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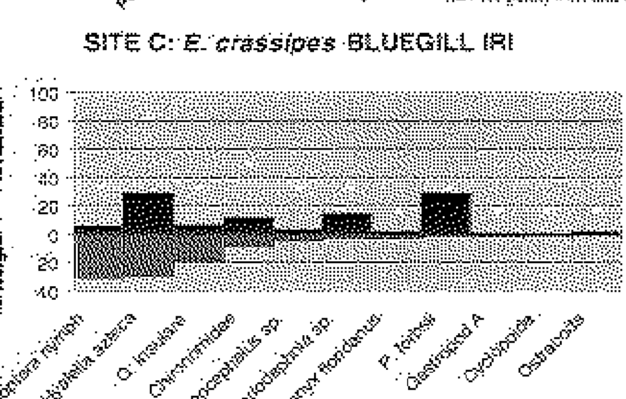

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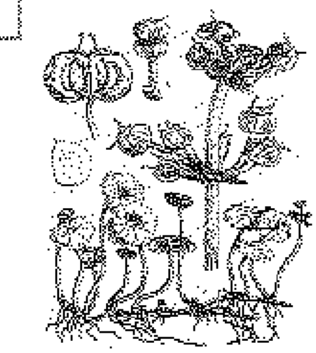

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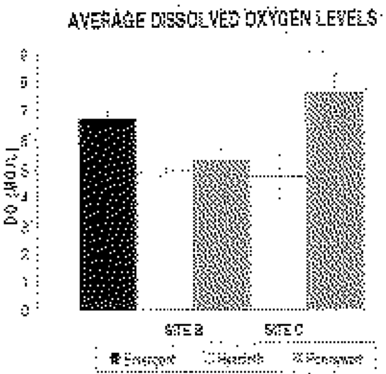

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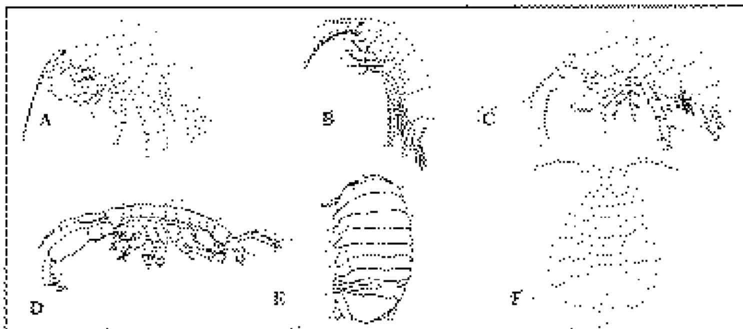

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