



Brown University

Elkhorn Slough Tidal Wetland Project

A Case Study of Estuarine Ecosystem-Based Management

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About the Study

Recognizing the declining health of the world's oceans, policymakers, managers and scientists have called for expanded efforts at ecosystem-based management in marine and coastal systems (MEBM). In many places in North America and around the world, collaborative, adaptive planning and management processes have developed to enable scientists, managers and stakeholders to move beyond management of single species and single user groups to incorporate complexity, consider larger scales and longer timeframes, and incorporate measures of ecosystem integrity.

The David and Lucile Packard Foundation invested in the development of science to support management in a number of initiatives in California, Mexico and the Western Pacific. The Foundation also recognized the need to capture the lessons from the experiences at these initiatives as well as the many other places that are trying to move toward an ecosystem-based management approach. Accordingly, they provided grant support to research teams at the University of Michigan and Brown and Duke Universities to develop rich case studies of MEBM, documenting the approaches and their accomplishments, and analyzing the challenges the efforts faced and the factors that have promoted progress. Ultimately, the projects seek to provide lessons that can improve the practice of MEBM.

This document contains one of the complete case studies. Others can be accessed through the project website, which can be reached at: *www.snre.umich.edu/ecomgt/mebm*.

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Introduction

Elkhorn Slough is one of California's premier coastal wetlands, known for its ecological capital and growing nature-based tourism industry. The slough and surrounding watershed are critical habitats for more than two dozen rare, threatened or endangered species, and they have been designated key conservation assets by local, state and national entities. The area also sustains year-round crop production and harbors several world-class marine science research institutions (Scharffenberger, 1999).

The slough and its important marsh habitats are threatened by accelerating tidal erosion, inordinate nutrient inputs, and limited solutions to these problems (Silberstein, 2005). Human alterations of the estuary and watershed's hydrological dynamics have caused over 1,000 acres (4 km^2) (approximately 50%) of the slough's salt marshes to be lost since 1870, and the conversion of the estuary from salt marsh to mudflats is accelerating.

In 2004, recognizing the urgency of the situation, the Elkhorn Slough National Estuarine Research Reserve (NERR) initiated a two-year strategic planning process to develop restoration strategies with potential to reduce tidal scour and reverse loss of rare salt marsh habitats. The planning process led to the Elkhorn Slough Tidal Wetland Project (TWP), an effort to conserve and restore estuarine habitats in Elkhorn Slough through an integrated approach supported by the local community and relevant stakeholders. To accomplish the TWP's goal, NERR staff enlisted over a hundred stakeholders representing government and resource management agencies, scientific institutions, environmental groups, economic and other interests to participate, and together these participants developed four potential restoration strategies.

Over the past several years, TWP working groups have been investigating the slough's hydrology, nutrient and sediment dynamics, biological communities and socio-economic values, and the political and financial feasibility of each restoration alternative. The results of these studies were integrated to make predictions for future conditions of the slough under each alternative strategy. In June 2009, project team members decided to proceed with a smaller restoration project at the mouth of the Parsons Slough complex, a component of Elkhorn Slough. A low sill will be constructed to reduce tidal prism in Parsons Slough, and impacts on erosion rates, water quality, wildlife and marsh habitats will be monitored over time to evaluate efficacy and facilitate adaptive management of the structure. This project will restore a section of Elkhorn Slough while serving as a learning experience for the project team.

Ecosystem Characteristics and Stressors

Ecological Context

Among the largest expanses of tidal salt marsh remaining in the state of California today, Elkhorn Slough is a special ecosystem (Silberstein, 2005). In conjunction with its surrounding watershed, the area encompasses diverse habitats and associated wildlife (Silberstein, 2005). The slough itself is a 2,690 acre (10.9 km^2) body of water that extends 7 miles (11.3 km) inland from Monterey Bay in central California, approximately 100 miles (161 km) south of San Francisco (Figure 1) (Silberstein & Campbell, 1989). Not far from the mouth of the slough, the Monterey Submarine Canyon unfurls; one of the deepest and most productive oceanic features off the California coast (Scharffenberger, 1999).

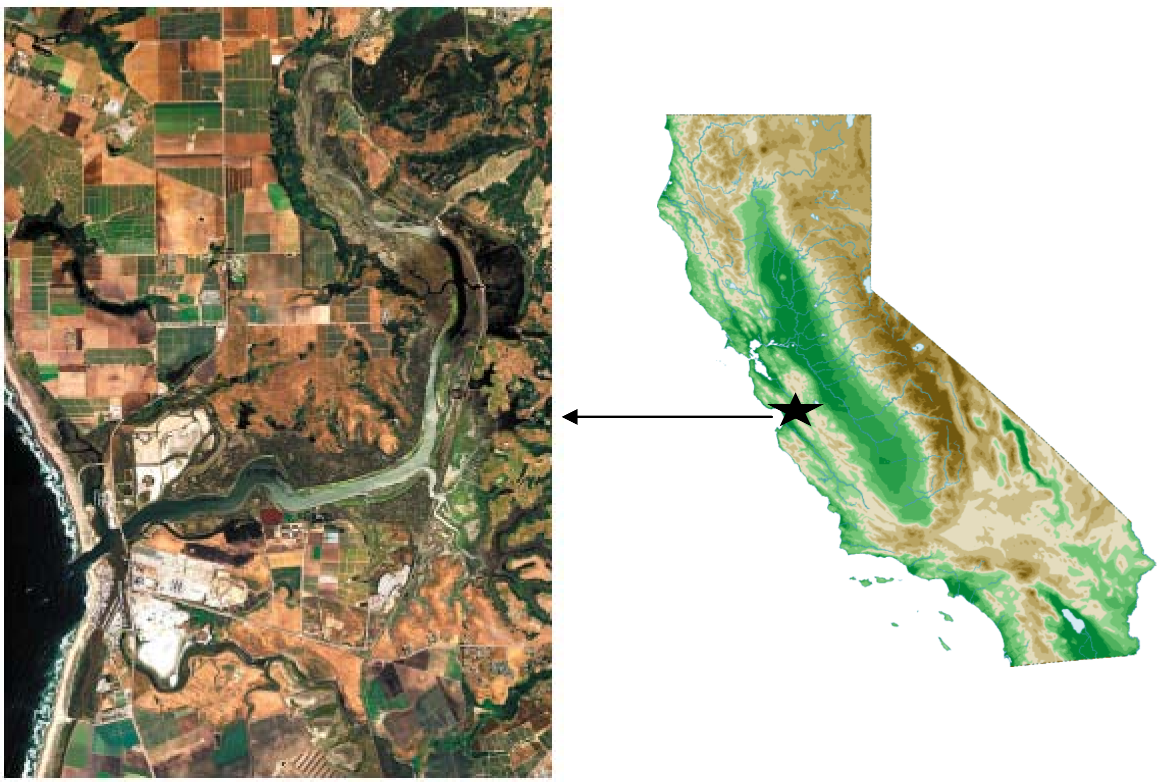

Figure 1: Aerial image (left) is of Elkhorn Slough showing Monterey Bay, to the west, on the left-hand side. Map (right) shows the location of Elkhorn Slough in California (California-Map.org; 2005 NAIP Orthos; Elkhorn Slough Tidal Wetland Project Team [ESTWP Team], 2007).

Although Elkhorn Slough is a full-time slough[1], it is only an estuary[2] in winter months when precipitation causes the Carneros Creek to overflow with runoff from the upper Elkhorn Valley, which flows downhill and empties into the slough, diluting the slough's inland waters (Silberstein & Campbell, 1989). It is comprised of approximately 796 acres (3.2 km^2) (29.5%) of intertidal salt marsh and tidal creeks that are inhabited by species such as the California black rail (*Laterallus jamaicensis coturniculus*), great egret (*Casmerodius albus*), and arrow goby (*Clevelandia ios*); 1,605 acres (6.5 km^2) (59.6%) of intertidal mudflats that provide critical habitat for gaper clams (*Tresus nuttali*) and feeding grounds for animals such as the marbled godwit (*Limosa fedoa*), southern sea otter (*Enhyra lutris nereis*), sharks and rays; and 293 acres (1.2 km^2) (10.9%) of subtidal channels and tidal creeks that are occupied by such species as the bat ray (*Myliobatis califonica*), shiner surfperch (*Cymatogaster aggregate*) and double-crested cormorant (*Phalacrocorax auritus*) (Figure 2) (ESTWP Team, 2007; "Setting Goals for Elkhorn Slough," 2008).

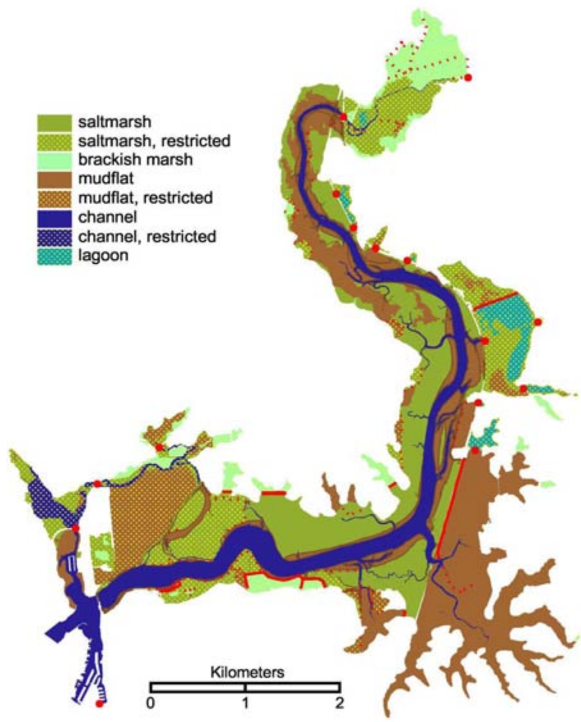

Figure 2: Illustration showing the distribution of habitat types/conservation targets in Elkhorn Slough (Peichel, 2007a).

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[1] A *slough* is "a narrow, winding waterway edged with marshy and muddy ground. It can be salt water or fresh, open to the sea or apart from it. A slough is a type of *wetland*, a broader category that includes all types of land-plus-water environments" (Silberstein and Campbell, 1989).

[2] "An *estuary* is a protected embayment with freshwater inflow from its land end and tidal exchange on its seaward side, where fresh and salt water mix. In simplest terms, it's an inlet where a river meets the sea" (Silberstein and Campbell, 1989).

The wetland environments of Elkhorn Slough provide food, shelter, breeding and nursery grounds, migratory stopovers and other important habitat resources to more than 780 species of resident and transient wildlife species, including over 135 aquatic birds species, 550 marine invertebrate species and 102 fish species (ESTWP Team, 2007). A disproportionate number of rare, threatened or endangered species are also found here, including the southern sea otter, tidewater goby (*Eucyclogobius newberryi*), southwest pond turtle (*Actinemys marmorata pallida*), California tiger salamander (*Ambystoma californiense*), California red-legged frog (*Rana aurora draytonii*) and Santa Cruz long-toed salamander (*Ambystoma macrodactylum croceum*) (Caffrey, Brown, Tyler, & Silberstein, 2002; Silberstein, 2005; "Setting Goals for Elkhorn Slough," 2008). In addition to providing important habitats to diverse species, the slough acts as filter and sink for sediment and pollution from upland agriculture and residential activities, but not without consequences (Scharffenberger, 1999).

The watershed encompassing Elkhorn Slough and nearby Moro Cojo Slough covers approximately 30,292 acres (122.6 km^2). It is comprised of a series of largely intact sand dunes that buffer parts of the estuary from the ocean, grasslands and the Elkhorn Highlands, which are covered in dense coast live oak woodlands and maritime chaparral on its north and south facing slopes, respectively. The coast live oak woodlands and maritime chaparral are often found in an ecological mosaic and are considered priorities for protection (Scharffenberger, 1999). Maritime chaparral itself is rare in California, and in the Elkhorn Highlands the biological community is comprised of a unique aggregation of plants exclusive to this ecosystem (Scharffenberger, 1999). These upland areas are inhabited by an array of species that include red-shouldered hawks (*Buteo lineatus*), white-tailed kites (*Elanus leucurus*), northern harriers (*Circus cyaneus*) and black-tailed deer (*Odocoileus hemionus columbianus*).

The Elkhorn Slough area has been recognized locally, regionally and nationally for its ecological significance. The National Oceanic and Atmospheric Administration (NOAA) designated the slough a National Estuarine Research Reserve (NERR), and the slough is part of the Monterey Bay National Marine Sanctuary (MBNMS) (Silberstein, 2005). The California Department of Fish and Game declared part of the slough a State Ecological Reserve and part a Wildlife Management Area (Silberstein, 2005). Other acknowledgments include its inclusion on the National Audubon Society's list of Globally Important Bird Areas and its classification as a Western Hemisphere Shorebird Reserve by the Manomet Bird Observatory. At the county level, Elkhorn Slough has been designated a Scenic Waterway (Scharffenberger, 1999). Furthermore, large investments in land have been made by the Elkhorn Slough Foundation and The Nature Conservancy as they have strategically acquired over 3,500 acres (14.2 km^2) of the watershed for conservation purposes (Silberstein, 2005).

Social and Economic Context

The land surrounding Elkhorn Slough is largely undeveloped, comprised mostly of agricultural plots and properties purchased for conservation purposes. Today, a quarter of the land surrounding the estuary is in cultivated agriculture, 10% of the which is planted with strawberries that contribute significantly to the state's strawberry crop (approximately 10% of the state's production) (Scharffenberger, 1999). These farms are an important component of the local and county economy, but are sources of sedimentation and excessive nutrient inputs in the slough (Scharffenberger, 1999). Year-round production of strawberries, cut flowers and artichokes is made possible by the area's Mediterranean climate, which is moderated by summer fog, and deep well-drained, sandy soils (Scharffenberger, 1999).

In the last three decades, over 7,000 acres (28.3 km^2) of the watershed have been protected through strategic land acquisitions, primarily by the Elkhorn Slough Foundation (ESF) who owns 2,538 acres (10.3 km^2) and manages 1,057 acres (4.3 km^2) of The Nature Conservancy's land and ESF easements (ElkhornSlough.org, 2009). A majority of this protected land is within or adjacent to the slough (Scharffenberger, 1999). Additional protected areas in the watershed are owned by the California Department of Fish and Game (DFG) and the NERR. Remaining land is owned by the Moss Landing harbor district, Monterey County, California Department of Parks and Recreation and private land owners. While approximately only 10% of the watershed consists of residential lots, there has been a growing trend recently in conversion of land for residential housing (Silberstein, 2005).

Despite being relatively undeveloped, the watershed hosts diverse human uses. The Moss Landing Harbor, located at the entrance of the slough, is one of the most active fishing ports in the state and is heavily used by the local commercial and recreational fishing communities (Silberstein, 2005). Over the course of the last decade, the slough has also become an increasingly popular destination for recreational activities such as boating, birding, kayaking and other forms of wildlife viewing (Silberstein, 2005). Several world-class marine science and coastal research institutions are located in and around the slough as well, including the Monterey Bay Aquarium Research Institute (MBARI), Moss Landing Marine Laboratories (MLML), University of California at Santa Cruz (UCSC), Hopkins Marine Lab of Stanford University, California State University in Monterey Bay (CSUMB) and the Elkhorn Slough National Estuarine Research Reserve (NERR). In addition, several transportation corridors intersect the slough, including three highways and a main north-south coastal railroad, and the largest electricity-generating power plant in California is located at the slough's mouth (Scharffenberger, 2002; Silberstein, 2005).

Land and Resource Management in Elkhorn Slough

Land and resources in Elkhorn Slough are primarily managed by three entities: the NERR, ESF, and DFG. In 1979, the slough was adopted into the National Estuarine Research Reserve program administered by National Oceanic and Atmospheric Administration (NOAA). It is one of twenty-seven NERRs in the United States that serve as living field laboratories for long-term estuarine research, environmental monitoring, education and stewardship (Elkhorn Slough National Estuarine Research Reserve [NERR], n.d.). The Elkhorn Slough NERR is owned and managed by DFG in partnership with NOAA and ESF (ElkhornSlough.org, n.d. a). The reserve itself covers 1,439 acres (5.8 km^2) and contains a visitors' center and numerous hiking trails, and it is a hub for scientific research activities (National Oceanic and Atmospheric Administration [NOAA], n.d.).

The Elkhorn Slough Foundation is a non-profit member-supported organization created in 1982 "to conserve and restore Elkhorn Slough and its watershed" (Elkhorn Slough Foundation [ESF], n.d.). It seeks to advance education, research and conservation in the area. As a conservation strategy, the ESF acquired the conservation properties discussed previously, which consist of some of the most pristine and degraded lands in the watershed. This dual strategy has enabled the ESF to preserve healthy areas while simultaneously restoring lands that were intensively farmed in the past and had significant impacts on the health of the slough. Taking some of the steep hillside farms out of production has reduced the amount of sediment and pollution entering the slough, and by leasing some of their land back to farmers with better land management practices, the ESF is provided with a source of revenue and is able to ensure a link between the organization and surrounding agricultural community (Resource Manager[3], personal communication, September 2009). In addition to managing land, the ESF administers funding to the NERR, contracts consultants for the NERR, engages the public in educational activities and coordinates volunteer and monitoring programs in the area (Silberstein, 2005).

The California Department of Fish and Game is the state agency responsible for managing "California's diverse fish, wildlife, and plant resources, and the habitat upon which they depend, for their ecological values and for their use and enjoyment by the public" (California Department of Fish and Game [DFG], n.d. 1). At Elkhorn Slough, the DFG is responsible for overseeing activities and operations throughout the NERR, permitting and ensuring compliance with state and federal regulatory requirements, including the California Endangered Species Act, California's Wetlands Conservation Policy, Clean Water Act – Section 404(b) and Rivers and Harbors Act – Section 10, among others (ESTWP Team, 2007).

Ecosystem Threats

As a result of human activities, the future of the Elkhorn Slough ecosystem is in jeopardy. The two biggest threats to the estuary are:

(1) Loss and conversion of marsh habitat as a result of past human alterations of tidal influence and hydrology; and

(2) Contamination and sedimentation of marshes due to uncontrolled runoff from cultivated fields. (Silberstein, 2005)

While these "two problems are not the only threats to Elkhorn Slough ecosystems, they have had the largest impacts on the estuary and are the key problems" being addressed by the EBM initiative (Silberstein, 2005). Other environmental issues in Elkhorn Slough include destruction and fragmentation of maritime chaparral habitat caused by residential development and depletion of groundwater reservoirs from excessive pumping for agricultural irrigation (Scharffenberger, 1999).

[3] To protect the identity of interviewees, names have been removed and replaced with titles that indicate their general role in the project.

Elkhorn Slough is considered one of the most threatened ecosystems in California because of the magnitude of its tidal erosion problem with 90% of the historic salt marsh area predicted to disappear by 2050 if no action is taken (Dahl, 1990; Macdonald, 1990; San Francisco Bay Joint Venture [SFBJV], 2001; Zedler, 1996). Tidal creeks widened between 7 and 40 feet (2 and 12 m) between 1931 and 2001, and current bank erosion rates are on the magnitude of approximately 1.6 feet (0.5 m) per year. Since 1870, more than 1,200 acres (4.9 km^2) (approximately 50%) of the marsh plain has been lost (Figure 3): 1,000 acres (4 km^2) diked and drained, and 200 acres (0.8 km^2) of interior marsh dieback (Figure 4) (Peichel, 2007a; Peichel, 2007b; "Setting Goals for Elkhorn Slough," 2008).

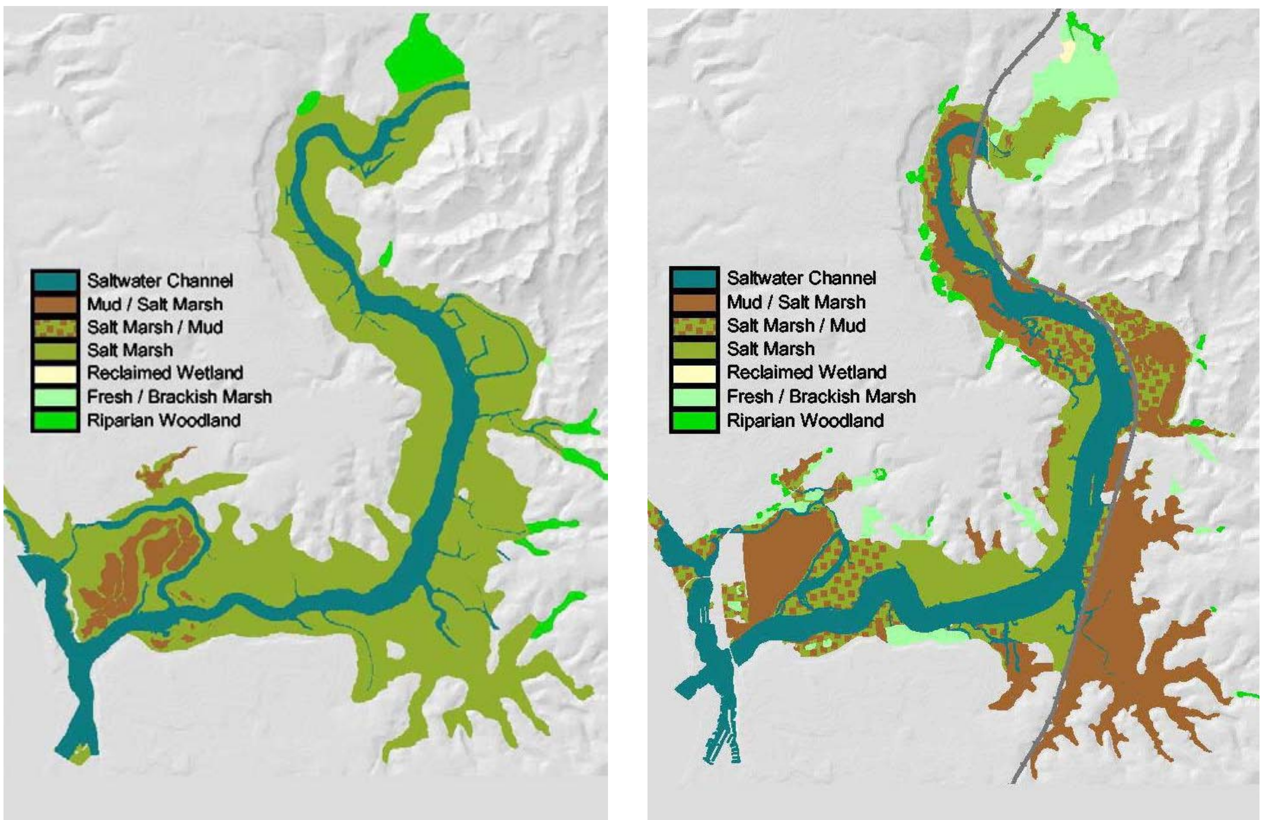

Figure 3: Illustration of habitat changes resulting from salt marsh habitat loss between 1870 (on left) and 2000 (on right) (Peichel, 2007a).

Elkhorn Slough's habitat loss issue has been attributed to alterations of tidal flow and sediment supply, which have been traced back to the first half of the twentieth century, a period of significant change in the area. In 1947, the mouth of the estuary was relocated for the construction of the Moss Landing Harbor (Figure 5). It was moved from its original position north of the estuary's main channel to its current location, which is directly in line with the harbor (Peichel, 2007b). In the process, large sand dunes that historically sheltered the estuary from the ocean were removed. As a result, the estuary's channel has deepened and its tidal prism tripled since 1956 (ESTWP Team, 2007). Consequently, outgoing tides have sped up, causing increasing sediment loss (i.e. tidal scour) and drowning of marsh habitats (ESTWP Team, 2007).

Figure 4: Aerial images showing interior marsh dieback in the northern section of Elkhorn Slough between 1931 (left) and 2005 (right). Along the channel, the darker gray areas in the left image indicate healthy marsh vegetation and the whitish areas in the right image indicate loss of marsh vegetation (Peichel, 2007a).

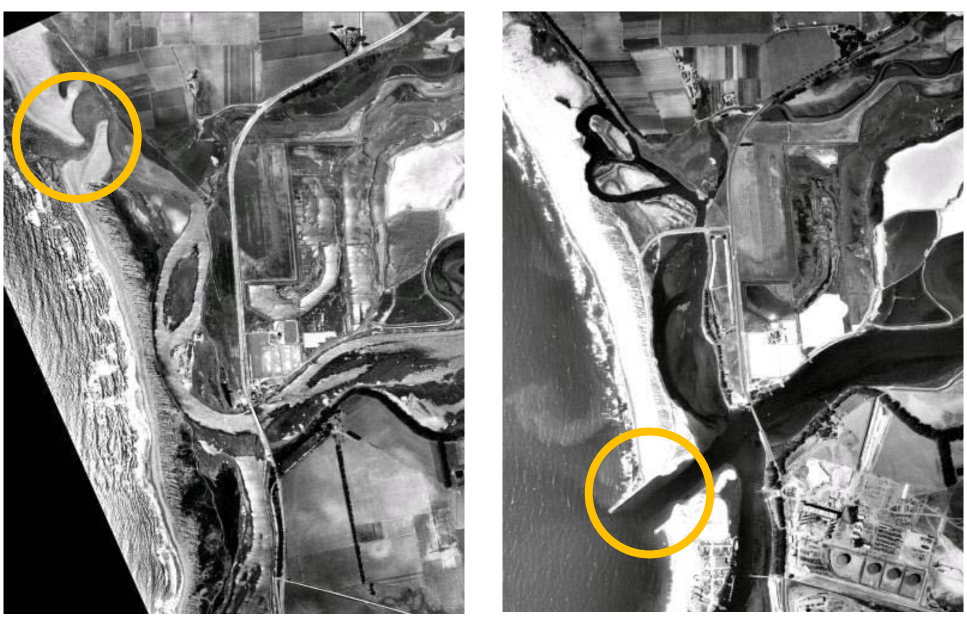

Figure 5: Aerial images showing the location of the mouth of Elkhorn Slough before (1931, left) and after (1949, right) the 1947 construction of the Moss Landing Harbor. The orange circles indicate where the estuary enters Monterey Bay (on the left-hand side of the images) (Peichel, 2007a).

The issue is complicated further by the reduction of riverine sediments entering the slough (Peichel, 2007a). The diversion and connection of upland rivers, particularly the Salinas River around 1909**,** for agricultural purposes has reduced downstream flow of fine sediment that traditionally replenished the estuarine plain. Decreasing elevations from tectonic causes or groundwater overdraft first documented in the 1930s, levee erosion and sea-level rise have also contributed to marsh loss (ESTWP Team, 2007; "Setting Goals for Elkhorn Slough," 2008; Peichel, 2007c).

Run-off from upland areas of the watershed is responsible for the slough's pollution problem. In particular, cultivation of steep hillsides around the slough leads to sediment erosion and run-off of fertilizers and pesticides into the wetland. In addition, in 2004 it was discovered a significant proportion of the pollution in Elkhorn Slough originates from the Salinas River Valley south of Elkhorn Slough, which is also in heavy agricultural production. Nitrogen-enriched water from the Salinas River Valley flows into the Moss Landing Harbor area before entering the slough on incoming tides. An amount "the equivalent of about a dump trunk worth of fertilizer coming into Elkhorn Slough every two days" (Scientist, personal communication, September 2009). Water quality is also poor in a third of the slough's habitats that are behind water control structures, which limit circulation and lead to low dissolved oxygen levels (ESTWP Team, 2007).

EBM Initiative

Evolution of the Tidal Wetland Project

There is a history of environmental initiatives in the Elkhorn Slough watershed. Beginning in the 1980s, the slough was designated an ecological asset by federal and state agencies. At this time, strategic land acquisitions were made for conservation purposes by the Elkhorn Slough Foundation, The Nature Conservancy, and others. In the 1990s, erosion and nutrient runoff from steep hillside farms adjacent to the slough became a top priority, which led the US Department of Agriculture (USDA) and the ESF to conduct community outreach and education campaigns to increase awareness of better land use practices amongst farmers and the visiting public. Together with Sustainable Conservation, the USDA and ESF developed a program to create one-stop regulatory permitting packages that facilitated farmers' voluntary implementation of conservation measures on their land.

In 1999, efforts were made to characterize the nature and degree of threats to the Elkhorn Slough ecosystem. The David and Lucile Packard Foundation awarded funding to The Nature Conservancy to develop a conservation plan for the slough, the Elkhorn Slough Watershed Conservation Plan. Through a process that involved more than two dozen stakeholders, a plan was drafted, which identified coastal marsh habitat, among other things, as a critical resource within the watershed, and it identified loss and conversion of marsh habitat, and contamination and sedimentation of remaining marshes, as major threats to the ecosystem (Silberstein, 2005). This plan was reviewed through the state clearinghouse and later adopted by the California

Coastal Conservancy and Coastal Commission to direct future conservation activities in the area (Silberstein, 2005).

In 2002, staff at the NERR acknowledged the scale and complexity of the slough's environmental issues and the need for coordinated input and action from scientific experts, resource managers and community members. Building on past efforts to preserve and restore the ecosystem, the NERR and partners wrote a proposal to the NOAA Coastal Impact Assistance Program for resources needed to initiate a stakeholder-driven science-based process that would develop a coherent and comprehensive vision for the slough and address the spectrum of threats impacting the wetland, including habitat loss, pollution, colonization of invasive species, recreational uses and hydrological alterations (Scientist, personal communication, September 2009). While the proposal was approved, its budget was significantly scaled back from several million dollars to approximately $2-300,000. As a result, NERR staff scaled the project down and chose to prioritize and address the threats they perceived to be the most urgent and unaddressed, and that were within their capacity to mitigate given existing resources. They chose to focus on tidal scour and loss of salt marsh habitat.

In 2004, with funding from NOAA's Coastal Impact Assistance Program, the NERR initiated the Tidal Wetland Planning Process to develop a Tidal Wetland Plan to "identify hydrological strategies to address tidal erosion and marsh loss" (Silberstein, 2005). This is considered the first phase of what is now known as the Elkhorn Slough Tidal Wetland Project (TWP) (Peichel, 2007c).

Over a hundred coastal resource managers, representatives from regulatory agencies, scientists, key conservation organizations and other select stakeholders participated in this strategic planning process, which aimed to gain a better understanding of the ecosystem, decide on management activities to pursue based on their potential to combat the erosion and habitat loss issues and remedy natural processes that maintain the health of the ecosystem while simultaneously reducing negative impacts on areas of high quality wildlife habitat (West Coast Ecosystem Based Management Network [West Coast EBM], n.d.). A Strategic Planning Team was organized among participants to provide a consensus statement "outlining the goals for the conservation and restoration of estuarine habitats," and to serve as the effort's decision-making body (Silberstein, 2005). The planning process ultimately produced conceptual models of the ecosystem and identified several management actions with potential to reverse, or at least contain, the extent of ecosystem degradation (West Coast EBM, n.d.).

Interest in approaching restoration of Elkhorn Slough with an ecosystem-level perspective developed organically within the NERR and Tidal Wetland Planning Process. While deliberating over restoration alternatives, new scientific findings and discussions among project participants generated concerns about possible negative consequences of altering tidal flow in the estuary, particularly for nutrient dynamics and water quality, which would have ecosystem-wide impacts (Silberstein, 2005). By approaching the restoration process in a holistic manner that takes into account the impacts of restoration activities on target and non-target species and habitats, and human uses, the project team believed they could develop strategies to halt degradation of important habitats, and replenish critical areas and ecosystem functions, in a manner that would be supported by all key stakeholders (Silberstein, 2005).

In October 2005, the Director of the ESF submitted a proposal to The David and Lucile Packard Foundation for funding to implement the Tidal Wetland Project (TWP). The purpose of the TWP was to evaluate relative effectiveness and feasibility of the restoration alternatives identified through the Tidal Wetland Planning Process and begin implementation of one or more of these strategies using an EBM approach (Silberstein, 2005; Peichel, 2007b; Peichel, 2007c). In early 2006, following approval for funding, the second phase of the initiative began.

Tidal Wetland Project Goals and Objectives

The vision statement for the project put forth by the Strategic Planning Team states, "We envision a mosaic of estuarine communities of historic precedence that are sustained by natural tidal, fluvial, sedimentary, and biological processes in the Elkhorn Slough Watershed as a legacy for future generations" (ESTWP Team, 2007). The project's overarching goal is "to conserve and restore sustainable estuarine habitats in the Elkhorn Slough watershed through the application of an ecosystem-based management approach "(Silberstein, 2005; ESTWP Team, 2007). Overall, the TWP seeks to enhance understanding of different conservation strategies and select preferred actions to achieve its vision for Elkhorn Slough (Silberstein, 2005). While currently focused on estuarine habitats, the project boundaries also encompass the surrounding watershed and project activities take into account the reciprocal influences of the watershed and coastal ocean on the conditions of the slough (ESTWP Team, 2007).

Seventeen planning principles were articulated by the Strategic Planning Team during the Tidal Wetland Planning Process to guide decision-making for the TWP. These include:

- Consider the broadest range of possible approaches to achieve the goals and objectives.
- Accommodate boating, farming, transportation, recreation and other human uses necessary to support people in the region.
- Incorporate the needs of special estuarine conservation targets such as estuarine-dependent species, state- and federally-listed species, migratory species and formerly dominant species.
- Give priority to actions that focus on protecting estuarine habitats most rapidly being lost both locally and in the region.
- Mitigate or avoid the negative impacts and consider the positive impacts of management strategies to neighboring landowners.
- Support projects that improve water quality for estuarine habitats and humans.
- Take into account present natural and cultural constraints and future geomorphological and climatic conditions (i.e., sea level rise) in selecting restoration strategies.

- Consider how restoration and management strategies might be tested and implemented through pilot projects and reversible steps.

- Take advantage of opportunities for short-term pilot and demonstration projects that answer research questions most relevant to adaptively managing the resource.

- To the extent possible, find solutions that minimize the long-term cost of on-going maintenance required to sustain ecological services of habitats or the natural processes that control them.

- Maintain flexibility so that the planning process and potential strategies can be adaptively managed in the future.

- Recognize that the geographic scope is variable depending on estuarine processes, so different scales need to be considered.

- Keep a watershed perspective. Consider the conservation and management efforts of adjoining upland and stream habitats.

- Document the major assumptions of all restoration designs and determine if the project seems reasonable to accomplish the goals.

- Learn from the successes and failures of similar projects that have been implemented and favor management strategies with high rates of success.

- Collaborate and stay informed about other planning processes in the area without disrupting those efforts.

- Aim for more aesthetically-pleasing structures when large-scale projects are designed. (ESTWP Team, 2007)

In 2007, the TWP Strategic Plan was completed, which provided a description of the ecosystem, its threats and overview of each of the restoration options to reduce erosion and habitat loss in Elkhorn Slough (Figure 6). The plan also refined the Tidal Wetland Project's broad goal into three more-focused goals and objectives. These include:

(1) Conserve the existing highest quality estuarine habitats and native biodiversity by aiming for a more natural rate of habitat change by significantly reducing the rate of:

  (a) Salt marsh conversion to other habitat types;

  (b) Subtidal channel erosion;

  (c) Loss of soft sediment from mudflat and subtidal channel habitats; and

  (d) Tidal creek conversion to other habitat types.

(2) Restore and enhance the estuarine habitats of Elkhorn Slough. Aim for the natural distribution, extent and quality of Elkhorn Slough habitats with special emphasis on habitats with the highest loss rates by striving to increase the extents of:

   (a) Salt marsh habitats, including the natural distribution and abundance of tidal creeks, panes, vegetated plains and wetland/upland transitional areas;

   (b) Tidal brackish marsh habitats, including the natural distribution and abundance of tidal creeks, panes, vegetated plains and wetland/upland transitional areas;

   (c) Freshwater/saltwater natural transition gradients and connectivity; and

   (d) High quality soft sediment in mudflat and subtidal channel habitats.

(3) Restore and enhance the natural processes (hydrologic and geomorphologic) of Elkhorn Slough and its watershed to sustain a more stable and resilient estuarine system. Emphasize the roles of natural sources, transport, circulation, filtration and storage of water and sediment by taking actions to:

   (a) Attain a more appropriate tidal influence by reducing the tidal prism in undiked areas;

   (b) Restore appropriate levels of tidal exchange to former tidal areas that have no tidal connection or a very restricted tidal exchange if it will not exacerbate habitat erosion and salt marsh loss in other areas; and

   (c) Re-establish or augment the supply of suitable sediment to increase the elevations and resiliency of subsided marsh areas. (ESTWP Team, 2007)

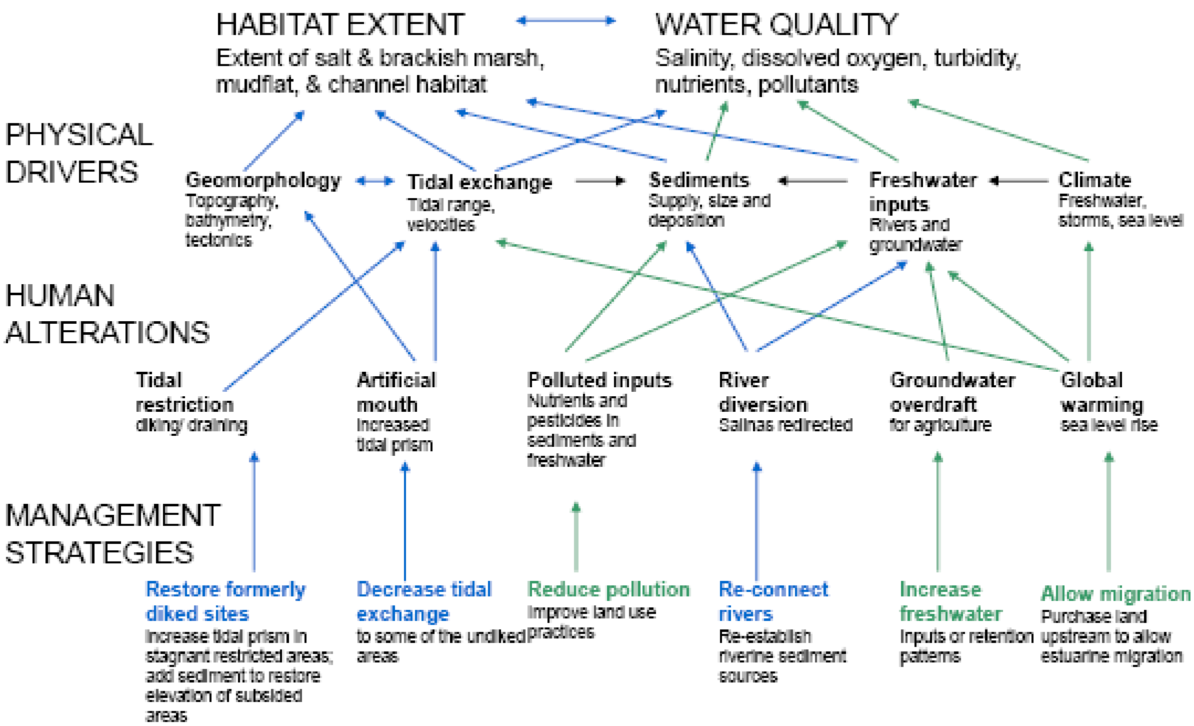

Figure 6: Diagram of the TWP's main focus and understanding of ecosystem (Peichel, 2007a).

Project Structure

The Tidal Wetland Project is managed by staff at the NERR in partnership with the Strategic Planning Team and Science Panel from the Tidal Wetland Project Planning Process (Figure 7). Core EBM project team members include the Tidal Wetland Project Coordinator from the NERR, NERR Research Coordinator, NERR Reserve Manager (from DFG), NERR Geographical Ecologist, Executive Director of the ESF, a scientist and a policy analyst from the MBARI, and Director of Ocean and Coastal Policy at the Nicholas School of the Environment at Duke University (formerly the Director of the Coastal Ocean Values Center of the Ocean Foundation (Silberstein, 2005; Largay, 2009). NERR staff members assigned to the Tidal Wetland Project oversee the project's organization and implementation, and serve as liaisons between the reserve, the TWP's institutional participants, subcontractors and other stakeholders (Silberstein, 2005).

The Strategic Planning Team is the primary decision-making body for the project. It is comprised of representatives from regulatory and resource management agencies, conservation organizations, scientists, local government officials, marine-focused strategic planners, social scientists, landowners and harbor and boasting interests (Silberstein, 2005). In all, the group represents federal, state, local, nonprofit, academic and corporate interests ("Setting Goals for Elkhorn Slough," 2008). They meet every two to four months and were previously responsible for overseeing the strategic planning process and the production of the Tidal Wetland Project Strategic Plan (2007). This group also is responsible for developing criteria for habitat goals for the estuary, attending or jointly holding meetings with the Science Panel, providing input on background materials and evaluating and prioritizing management strategies (ElkhornSlough.org, n.d. b).

The SPT is the decision-making body for the TWP, but it serves more of an advisory role to the TWP participants with jurisdiction over land and resources in the area. While TWP participants that own land in the estuary or surrounding watershed can make decisions to implement restoration options on their land, other participants merely provide input and recommendations. Specifically, plans to be implemented within the NERR (e.g., Parsons Slough) or ESF land, fall under the purview of the DFG or ESF, respectively; however, restoration alternatives two and three, which require large construction efforts at the mouth of the slough and on nearby properties do not. This complicates the TWP's ability to undertake such efforts.

The Science Panel reviews scientific information and provides the Strategic Planning Team with guidance on technical matters ("Setting Goals for Elkhorn Slough," 2008). This group is comprised of a broad spectrum of disciplinary and interdisciplinary experts who are knowledgeable of biological, ecological, hydrodynamic, geological and physiochemical processes, some of whom have previous experience with estuarine restoration (Silberstein, 2005). In all, this group includes more than 80 individuals ("Setting Goals for Elkhorn Slough," 2008). They are responsible for compiling research results, identifying important habitats and hydrological issues, suggesting restoration alternatives for different scales, developing and making recommendations regarding potential restoration strategies, ensuring activities are monitored and management is adaptive (ElkhornSlough.org, n.d. c). As a whole, the Science Panel meets two to four times every two years; however, smaller working groups meet on a more regular basis to accomplish specific tasks (ElkhornSlough.org, n.d. c). Project leaders conducting studies of the slough's hydrodynamic, sediment and nutrient dynamics meet every four months to provide updates on activities and discuss integration of their findings (Silberstein, 2005; Peichel, 2007c).

Working groups comprised of members of the Strategic Planning Team and Science Panel have been convened on the following topics: ecology, outreach, monitoring, hydrodynamics, conceptual modeling, modeling advising (the Modeling Advisory Team), historical ecology, ecosystem-based management and the Parsons Slough project (Figure 7) (Peichel, 2007a). At the time writing, these working groups are being reorganized and new groups are in the process of being established to address emerging needs. Preliminary results of the working groups' efforts are presented to coastal decision-makers, scientists, agency representatives and community members once or twice a year at TWP meetings (Silberstein, 2005). Other important players in the EBM effort include the Elkhorn Slough Foundation and various contracted institutions and consultants. MBARI, CSUMB, and other entities are involved through subcontracts (Silberstein, 2005). In addition, NERR Docents, local community members, and peer reviewers participate (Silberstein, 2005).

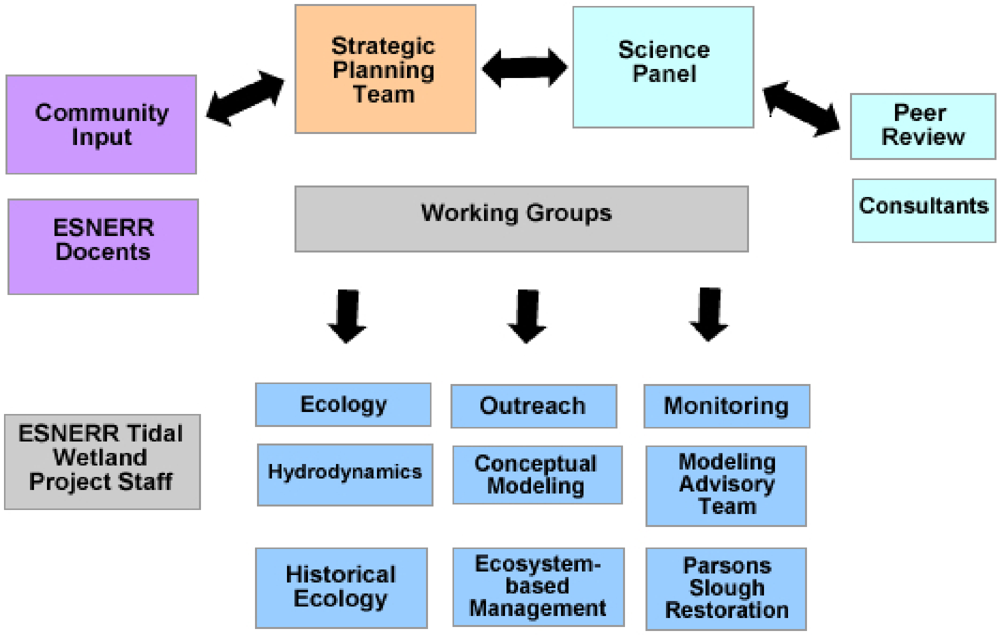

Figure 7: Diagram of Elkhorn Slough Tidal Wetland Project organizational structure (ElkhornSlough.org, n.d. d).

Strategies and Tools

Consideration of Alternative Actions

To select the best strategy for habitat restoration, four alternative projects ideas were developed simultaneously, which provided stakeholders with options and allowed the project team to weigh benefits, drawbacks, and tradeoffs of each approach. The first option was a "no action" approach, which would expectedly result in continued deepening and widening of the estuary's main channel and loss of salt marsh habitat. This strategy is primarily serving as point of reference for other strategies (Philip Williams and Associates, Ltd. [PWA], 2008). The second restoration option is to create a new ocean inlet for the estuary near the location of the mouth circa 1943 (Figure 8) (PWA, 2008). This may be accomplished by constructing a connecting channel between the main channel of the slough and a flood-tide shoal located near what is today known as Lower Bennett Slough, and a new Highway 1 bridge would need to be built along with a full tidal barrier at the existing mouth of the slough between the Moss Landing Harbor and the main channel of the wetland (Brennan, May, Danmeier, Crooks, & Haltiner, 2008; PWA, 2008). The third alternative is the construction of either a low sill (i.e., partial tidal barrier) (1.4 m below Mean Lower Low Water (MLLW)) or a high sill (0.1 m below MLLW) under the Highway 1 bridge, thereby reducing the size of the slough's mouth (Figure 9) (PWA, 2008). The fourth strategy is to implement a restoration project within the Parsons Slough complex of Elkhorn Slough that could involve re-establishment of the sediment supply and/or construction of sill at the entrance to Parsons Slough, which will reduce tidal scour from the Parsons Slough and South Marsh areas of the slough (Figure 10) (Peichel, 2007c; PWA, 2008;

"Setting Goals for Elkhorn Slough," 2008). Re-establishing sediment supply to the estuary is also being considered as an option for restoring salt marsh habitats, but given current resources, the logistical challenges of delivering sediment to the system and the magnitude of sediment needed to be effective, this option is not being actively pursued at this time. Sediment sources considered include the submarine canyon in Monterey Bay, dredged material from the Moss Landing harbor, channel excavation and byproduct dust from a nearby quarry (PWA, 2008; Scientist, personal communication, September 2009).

Each strategy was explored, and descriptions of each one and its expected outcomes were presented to TWP participants and the public. Each alternative was also considered in light of climate change and sea-level rise to evaluate the potential for long-term success or failure (Tidal Wetland Project [TWP], 2008). While the potential restoration strategies were deliberated, pilot restoration projects were conducted as experiments to test the feasibility of a subset of tactics (ESTWP Team, 2007). One such pilot project involved establishing a sediment fence to assess the practicality of using sediment additions to restore the elevation of the marsh and encourage plant growth (ESTWP Team, 2007).

Figure 8: Image of the mouth of Elkhorn Slough, indicating the second restoration option (i.e., to create a new ocean inlet) in light blue. Monterey Bay, to the west, is shown in dark blue on the left side of the image (Google Earth; Largay, 2009).

Figure 9: Image of the mouth of Elkhorn Slough, indicating the third restoration option (i.e., construction of a sill at the Highway 1 bridge) circled in white. Monterey Bay, to the west, is shown in dark blue on the left side of the image (Google Earth; Largay, 2009).

Figure 10: Image of the Parsons Slough complex, indicating the fourth restoration option (i.e., a Parsons Slough sill). The main channel of Elkhorn Slough is shown in the upper left corner (Google Earth; "The Tidal Wetland Project and the Proposed Parsons Slough Restoration Project at the Elkhorn Slough National Estuarine Research Reserve," n.d.).

Investigation of Similar Cases

The project team investigated estuarine restoration projects in places addressing similar threats, which enabled them to learn from related initiatives. Case studies were selected based on criteria that ensured lessons learned regarding policy and legal considerations were applicable to Elkhorn Slough's circumstances. Selection criteria included estuary size, location, characteristics of the surrounding population (abundance, nature, rural/urban), similarity of restoration issues, cost of restoration activities, complexity and number of jurisdictions and similarity of economic activities in the area (Kildow & Pendleton, 2007; Peichel, 2007b). Estuaries on the west coast were then input into a matrix that detailed which cases met the selection criteria (Peichel, 2007d). Through this activity, the planning team was able to identify key approaches and elements of short- and long-term success (Peichel, 2007b). The most relevant case studies, including Bolsa Chica, Napa/Sonoma Marsh and Morro Bay, were complied into a literature review and made available online[4] (Peichel, 2007b; Kildow, Pendleton, Norris, Rome, and Chan, 2008).

The following lessons were gleaned with regards to estuary restoration efforts:

(1) There can be challenges coordinating with the US Army Corps of Engineers due to unanticipated cost increases, lengthy assessment processes and uncertainties with federal budgeting.

(2) Assessments should be handled internally.

(3) It is more productive to rely on consultants.

(4) It is best to guarantee comprehensive engineering options that have been individualized in advance.

(5) Although it may be difficult, strategically coordinating financial resources with the permitting process is necessary to avoid delays. (Kildow et al., 2008)

It was also realized that similarly-sized restoration projects have needed political and economic support at both the federal and state level and usually require funding from multiple public and private sources (PWA, 2008).

Using Locally-Derived Data to Inform Predictions

The multi-stakeholder project team conducted physical, biological and socio-economic studies to enhance their understanding of the ecosystem and inform predictions for future conditions of the slough under each restoration scenario. Time-series data helped project team members estimate baseline conditions within the slough and understand change (Kildow & Pendleton,

[4] http://www.elkhornslough.org/tidalwetland/research.htm

2007). Abiotic features such as hydrology, sediments and nutrients were studied using a Land/Ocean Biogeochemical Observatory (LOBO) network of chemical sensors, sediment elevation tables (SETs), and tide stations. Pollen analysis enabled a better understanding of historic vegetation communities, and marsh sediment cores made it possible to determine the age of Elkhorn Slough marshes and rates of sedimentation processes in different areas (ESTWP Team, 2007). These data informed a baseline understanding of the slough as well as the development of a hydrodynamic model of the ecosystem that was run for each of the alternative restoration strategies. Model outputs provided predictions of future conditions under each restoration scenario.

Pilot Project Implementation and Adaptive Management

In 2009, the project team decided to move forward with the fourth restoration alternative (a Parsons Slough project) as it is the most politically and financially feasible given current circumstances, and it can serve as learning experience for future larger-scale projects such as a sill at the Highway 1 bridge. A low sill will be built at the mouth of the Parson Slough complex to reduce tidal scour in Elkhorn Slough from the Parsons Slough complex and the Harbor while having a minimal affect on habitats in Parsons Slough and allowing fish and wildlife to swim across ("Parsons Slough Sill," n.d.). In addition, the sill will be under water and will not be obvious to kayakers, NERR visitors and others enjoying the area ("Parsons Slough Sill," n.d.). As it is currently designed, the sill will only affect extreme spring tides that are responsible for the greatest tidal erosion while leaving normal typical tides unchanged and impact of the structure can be reversed if needed ("Parsons Slough Sill," n.d.; PWA, 2008). Designs and cost estimates have been drafted for the project and in November 2009 a preliminary plan outlining the project's purpose and objectives, existing conditions, proposed project elements, and construction and operation details was produced and made available for public review on the NERR website (www.elkhornslough.org) (Duck Unlimited, Dixon Marine Services, and URS, 2009). Biological communities will be studied and monitored over time along with water quality, marsh habitats and erosion rates to facilitate evaluation of this strategy (Largay & McCarthy, 2009). Subsequent data will then be combined with input from scientific advisors and the community, and provided to project team members and other managers to inform evaluation discussions and future plans (ESTWP Team, 2007; Largay & McCarthy, 2009).

Public Consultations

To inform the public about the TWP, its impetus and objectives, and to allow stakeholders to provide input on potential restoration strategies, the TWP team has held several community meetings and field tours of the slough.

Use of Visuals to Convey Complex Ideas

To convey complex ideas and explain the ecology of the estuary and potential restoration options to non-technical audiences, conceptual models, Geographic Information System (GIS) maps, and diagrams were used during TWP Strategic Planning Team meetings and public meetings. GIS maps and conceptual models were generated for each restoration concept and presented at project meetings to ensure everyone understood and could visualize the details of each strategy (Peichel, 2007d). Diagrams were generated for a number of uses, including to display the likely major mechanisms of marsh loss and changes within the slough, the organizational structure and features of the permit system (e.g., relevant legal and regulatory processes that would need to be addressed with any of the restoration alternatives) and the jurisdictional system of agencies with authority within the NERR (Peichel, 2007d; Kildow et al., 2008; TWP, 2008a).

Internet as a Communication Tool

The internet and NERR's website are used to share information and products generated by TWP team members, which helps ensure management transparency and allows community members to provide input. Numerous project documents are accessible through the NERR website, including strategic plans, meeting minutes, agendas, presentations and the literature review of case studies from other west coast estuary restoration efforts, and key indicator species reports are available through this portal. The website has also been used to collect survey data regarding use patterns, economic expenditures, demography of users, users' perceptions of the state of the slough and attendance (Peichel, 2007d). Data from tide stations and the Land/Ocean Biogeochemical Observatory network were also made available through the website. Furthermore, the public is informed of TWP progress, and working partnerships and relationships formed through the TWP process are sustained, through monthly project bulletins sent via email to over 600 people.

Marine Protected Areas

To facilitate conservation of key resources, three marine protected areas (MPAs) were established in and around Elkhorn Slough in 2007 as part of California's Marine Life Protection Act Initiative, which is creating a state-wide network of MPAs in fulfillment of the Marine Life Protection Act (1999) (Figure 11). The MPAs in and around Elkhorn Slough were established along with 27 other MPA's in the central coast region as part of the MLPA initiative, not the TWP. The Elkhorn Slough State Marine Reserve (SMR) includes the waters below mean high tide within Elkhorn Slough lying east of longitude 121° 46.40' W and south of latitude 36° 50.50' N, and within this area take of all living marine resources is forbidden (DFG, n.d. b). Within the Elkhorn Slough State Marine Conservation Area (SMCA), which includes the waters below mean high tide within Elkhorn Slough east of the Highway 1 Bridge and west of longitude 121° 46.40' W, take of all living marine resources is prohibited with the exception of recreationally collected finfish by hook-and-line and clams (DFG, n.d. b). Clams are only allowed to be taken on the north shore of the slough in the area adjacent to the Moss Landing State Wildlife Area (DFG, n.d. b). Lastly, there is a State Marine Reserve (SMR) within the Moro Cojo Slough below mean high tide and east of the Highway 1 Bridge and west of the Southern Pacific Railroad tracks crossing (DFG, n.d. b). Within this area any take of living marine resources is prohibited (DFG, n.d. b).

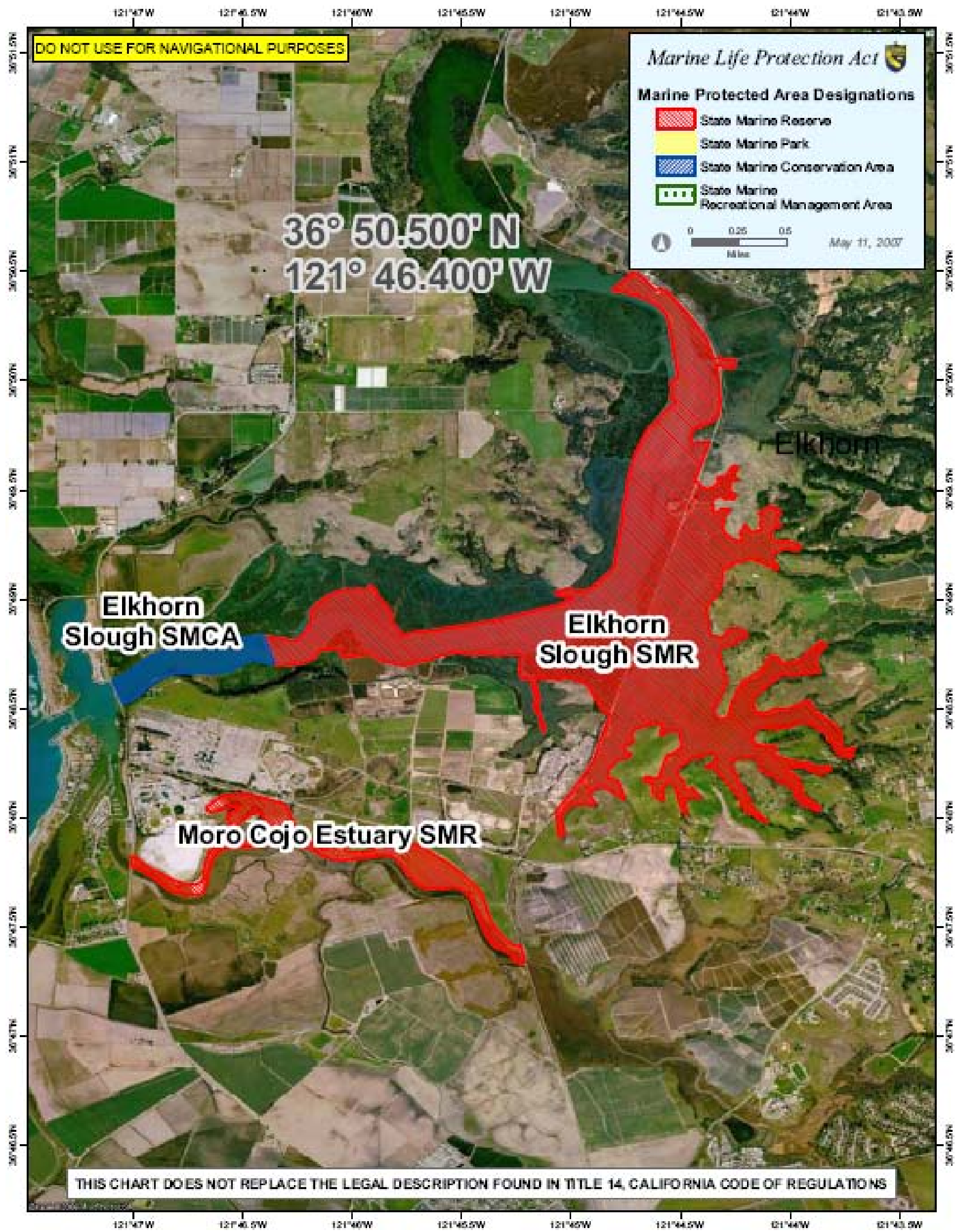

Figure 11: Marine Protected Area designations in Elkhorn Slough (DFG, n.d b, DFG, n.d. b).

Decision-Support Tools

The TWP has made minimal use of decision-making tools such as the Miradi Adaptive Management software tool, the Nature Conservancy's 5s Framework for Conservation Management, or any of the Geographic Information System-based systematic conservation planning tools. Project team members felt many of these tools required too large an investment of time to learn (Scientist, personal communication, September 2009). Other participants thought these tools were too limited for the TWP's needs or the tools were introduced too far into the TWP process to be useful.

Role of Science

Natural Science

Natural scientific knowledge and methods have dominated the effort in Elkhorn Slough. Scientific experiments, environmental sampling devices, and modeling have enabled a more complete and thorough understanding of ecosystem dynamics to be obtained, and the knowledge gained through these endeavors has informed discussions regarding restoration alternatives.

To guide selection of the most promising restoration strategies, the project team carried out several specific tasks that addressed key gaps in their understanding of the ecosystem, which are critical for making informed decisions. An overview of the process follows: First, the project team developed means to predict changes in tidal hydrology and sediment dynamics (Peichel, 2007c). Then, interactions between nutrient dynamics and hydrology were investigated (Peichel, 2007c). From here, it was important to understand interactions between wetland elevation, hydrology and sediment within marsh habitats in order for scientists to develop sediment budgets in the slough and assess the potential of each strategy to restore lost habitat. The results of these various studies were integrated into a hydrodynamic, sediment and nutrient model, which allows the project team to predict future conditions in the slough's habitats. Ecosystem boundaries were reexamined based on new information on inputs from outside previously delineated watershed boundaries. Also, water quality monitoring efforts were expanded and a mechanism for institutionalizing this monitoring program was developed to facilitate later adaptive management. Responses of biological indicators were correlated with hydrologic regime changes, and ecological resources, processes and services were mapped. In conjunction with these activities, an analysis was conducted of the legal and political context. Using the data and knowledge produced through these efforts, each of the restoration strategies is undergoing a technical evaluation process that takes into account predictions of outcomes and discussions regarding tradeoffs between reduced tidal erosion, habitat changes, water quality conditions, wildlife populations, socio-economic factors and political and financial feasibility (Peichel, 2007b).

Specifically, time-series data for hydrology, sediments and nutrients helped scientists affiliated with the TWP estimate baseline conditions in the slough and understand change (Kildow & Pendleton, 2007). These important abiotic features are being measured and monitored with devices such as the LOBO sensors network, sediment elevation tables (SETs), and tide stations. The network of LOBO moorings established throughout the estuary, the Moss Landing Harbor, and Monterey Bay is providing a system of autonomous observing stations that use *in situ* chemical sensors to measure nutrients such as nitrate, ammonium and phosphate. The network, operated by MBARI, also measures water quality parameters, including salinity, temperature and current speeds, and produces real-time observations that enable researchers to better understand nutrient dynamics and interactions between these dynamics and water quality in the slough. With these data combined, managers are able to assess chemical fluctuations and processes taking place in the coastal ocean, estuary and watershed.

The LOBO monitoring network has been collecting data for over five years now and has enabled researchers to determine rates and likely sources of nutrients within and beyond the ecosystem (Peichel, 2007b). It was this network that identified incoming tides enriched with large amounts of nitrogen from run-off in the Salinas River Valley as a major contributor to Elkhorn Slough's extraordinary nitrogen load, mentioned earlier. In addition, through the LOBO network, Elkhorn Slough has been identified as a consumer of nitrate; hence, it is providing a valuable ecosystem service. Furthermore, results show annual mean nitrate in the slough is closely linked with annual rainfall, which explains its large inter-annual fluctuations (Brookes, 2008a).

Sediment Elevation Tables (SETs) were set up in several parts of the estuary by NERR staff to determine spatial differences in the rate and extent of marsh loss and help managers better understand sediment sources (ESTWP Team, 2007). Areas where potential restoration activities may occur and wetland areas that receive muted tidal flows are being monitored (ESTWP Team, 2007). The data produced by the SETs in combination with feldspar markers helped generate an understanding of shallow subsistence, which informed development of a sediment budget for the estuary that includes sediment demands and fluvial supply (Peichel, 2007b; PWA, 2008). From this data, the project team was able to conclude each of the proposed restoration strategies would halt or reduce sediment losses due to tidal scour, but a new supply of sediment is needed to offset the sediment loss ratio (PWA, 2008).

Tide stations were also established by NERR staff in coordination with NOAA to help elucidate mechanisms of marsh loss resulting from changes in tidal level. This information complements work being done on water quality and sediment dynamics, guiding decisions regarding future restoration efforts (ESTWP Team, 2007).

To elucidate historical changes in and around the slough, scientists affiliated with the TWP conducted pollen analyses and took marsh sediment cores, which helped them determine the composition of historic vegetation communities, age of Elkhorn Slough marshes and rates of sedimentation processes in different areas, respectively (ESTWP Team, 2007).

To compare pre- and post-harbor conditions and predict future changes resulting from various restoration scenarios, a hydrodynamic model of the ecosystem was developed, then calibrated and validated to water level, tide and current data, as previously mentioned (ESTWP Team, 2007). Outputs produced by the model included estimates of tidal prism, tidal asymmetry and tidal inundation characteristics (Peichel, 2007b). After first running the model for the "no action" alterative for zero, ten and fifty years, the model was then run for each alternative restoration strategy, producing predictions for hydrodynamic, geomorphic and habitat changes (Peichel, 2007b). The modeling results demonstrated the rate of sediment loss from the slough would naturally diminish under the "no action" strategy; however, it would possibly take more than fifty years and would cause extensive marsh loss over that time period as the estuary converted from tidal salt marsh to shallow mudflats (Brookes, 2008a). The model also indicated flatfish would be a beneficiary of the natural conversion to mudflats (Brookes, 2008a). Further, the model predicted the new ocean inlet (alternative two) and the high sill at the Highway 1 bridge (alternative three) projects would be most effective at reducing sediment losses from the slough, but none of the four alternatives would replenish the sediment supply (Brookes, 2008a). In addition, the model suggested the new ocean inlet may lead to increased red tides in Monterey Bay because the slough currently consumes excessive chlorophyll from the bay and the new inlet would inhibit this function (Brookes, 2008a).

The model is not without limitations. It does not address bank and wave erosion, the channel width at the entrance, continuation of erosion and increasing velocity, among other things (Brookes, 2008b). In the future, the project team plans to improve the model such that it can address these dynamics and include ecosystem processes and roles within a larger scale context as well as predict impacts of sea level rise (ESTWP Team, 2007).

A scientist affiliated with the project explains that while some EBM advocates claim enough science has been done in most systems to take action, this was not the case in Elkhorn Slough. Further research discovered additional contributors to the problem; the major cause of salt marsh habitat loss was not fully understood at the time the proposal was written:

> We went in thinking we understood the problem and it's solution. When we wrote the Packard proposal we were like, "The harbor is the big evil villain, and we just need to reverse its effects." As a result of having more people studying it we realized actually it's not clear that that's why our salt marshes are dying. The thing that motivated us was salt marsh loss, and only by bringing in lots of outside wisdom did we realize it might actually be the diversion of the Salinas River [...] or it might be the marsh sinking due to groundwater overdraft from agriculture [...] or agricultural nutrients can actually lead to subsidence. So, fixing the harbor mouth won't necessarily fix our salt marsh. [...] Even in this small, fairly well-studied system, we did not actually know enough yet to manage it. (Scientist)

Social Science

Social science has played a lesser role in the TWP than natural science and has consisted of participation of an economist and a policy analyst. With the intention of implementing estuarine restoration within an ecosystem-based management framework, the TWP sought to understand interactions between ecological components of the ecosystem and the socio-economic context in which restoration strategies would be implemented. The economist was engaged to analyze the socio-economic values of Elkhorn Slough and how these values and human uses might be affected by each of the habitat loss reduction strategies. While he was unable to come up with accurate predictions of economic impacts of each restoration strategy due to limited understanding of how ecological elements would respond and an absence of baseline data for human uses of the slough, it was possible to get a sense of what draws people to the slough and identify the areas that they use as well as areas for further study. Overall, the economic research indicates alterations to the slough could influence the local economy through habitat changes; locale connectivity; changes in sediment delivery, erosion, and accretion; and changes in water quality (Kildow & Pendleton, 2010).

In addition, an in-depth analysis of the political feasibility of each restoration strategy was conducted, and applicable laws and regulations were investigated (ESTWP Team, 2007). An interesting discovery made during these analyses was the absence of an identifiable entity with legal oversight and accountability for the whole area being considered for the new ocean inlet and Highway 1 sill restoration options (Kildow & Pendleton, 2010). Multiple land owners and regulators possess authority within the scope of these alternatives, which pose obstacles to their implementation. It has yet to be decided whether a new entity should be created or if a Memorandum of Understanding among relevant bodies should be pursued to overcome this limitation (Kildow & Pendleton, 2010). This realization contributed to the decision to move forward with the Parsons Slough restoration project in the interim because it will take place solely on land owned and managed by DFG.

Knowledge Gaps

Technical and scientific knowledge gaps were primarily identified during the Tidal Wetland Planning Process as project team members deliberated on the area's threats, desired outcomes, possible solutions and potentially negative consequences of management actions. Early on, the following information gaps were identified:

(1) Spatial patterns of marsh loss and the roles played by tidal range and duration, and inundation frequency;

(2) Factors leading to anoxic conditions in subsurface marsh sediment, which was resulting in vegetation dieback, and whether or not tidal inundation and/or poor drainage were the causes;

(3) Sources (e.g., marine, terrestrial and fluvial) and quantities of sediments needed and whether sediment additions would be sustainable;

(4) Historical conditions of the slough, including historical sedimentation quantities and rates, past tidal range conditions and previous vegetation patterns and habitat characteristics;

(5) Functions biogeochemical processes play in the estuary and the role of plants and infaunal species;

(6) Climate change scenarios and the expected effects of minimum and maximum sea-level rise on each strategy;

(7) Whether or not adding or containing sediment behind temporary structures would be a practical or effective way to restore marsh habitat;

(8) How ecological communities would change over time from their status before the project(s), during the project(s), and eventually after the project(s) were completed;

(9) Economic value of the slough and the political context, including the jurisdictional framework, individual agency/legislative requirements applicable to the various

restoration projects, characteristics of major users and their interests, relevant policy issues, and what lessons could be learned from restoration projects carried out elsewhere. (Kildow & Pendleton, 2007)

Currently, most, if not all, of these gaps have been addressed through natural and social scientific research; however, new questions continuously emerge. As the results of research are analyzed and integrated, new research questions arise. As one scientist observed, "At the end of [scientific] papers are always requests to do more research."

Impacts

Over the last several years, progress has been made towards attaining a better understanding of the Elkhorn Slough ecosystem and implementing measures to restore and conserve rare marsh habitats. Project team members and the community have come together to discuss and plan for the future of the slough, significant amounts of data have been produced and yielded a more thorough understanding of ecosystem dynamics, a decision was made to proceed with the construction of a low sill at the entrance to the Parsons Slough complex, and the TWP has joined other EBM initiatives in creating an EBM network for the west coast. In addition, knowledge gained regarding the implementation of EBM is being shared with others through a variety of venues.

Diverse Stakeholder Engagement

A common feature of EBM is the formation of an integrated stakeholder group and pursuit of collaborative partnerships and working relationships among diverse ecosystem actors and community interests. The Tidal Wetland Project has achieved this through the formation of its Strategic Planning Team and interactions between the Strategic Planning Team, Science Panel and participants of community meetings. Since 2004, there have been more than five community meetings or walking tours in and around Elkhorn Slough, fourteen joint Strategic Planning Team and Science Panel meetings or field trips, two Science Panel meetings, three Science Panel working group meetings, and five Strategic Planning Team meetings. Joint meetings of project leaders, the Strategic Planning Team and Science Panel have allowed principal investigators to share progress updates, discuss management decisions and how to best integrate research results and project outcomes. Among the valuable products of these interactions has been the integration of diverse disciplinary research results, which have enhanced understanding of interactions and interconnections of ecosystem components and features (e.g., tidal cycles and nutrient loads; tidal restriction, water quality and wildlife populations). The community meetings have provided opportunities to solicit input from various perspectives and engage representatives of different interests.

Enhanced Understanding and Information Sharing

A more comprehensive understanding of ecosystem dynamics and the sociopolitical context in which the project is operating has been gained through intensive efforts to study the area. In addition to the insights and advancements discussed previously, data were gathered with respect to the concentration of fecal coliform bacteria and other pollutants in the estuary; weather conditions (i.e., precipitation, temperature, humidity); habitat requirements, baseline distribution and abundance of key species (i.e., eelgrass, pickleweed, oysters, large clams, flatfish, sea otters, mudflat worms, and shorebirds); and the local economy, including commercial fishing activities, park attendance, harbor activity (i.e., dredging, lease and parking revenue), and boating activity (i.e., slip rentals and live-aboard fees). These data have yielded a more complete picture of the status and function of the slough, and this information will serve to establish baseline conditions against which future conditions can be compared. A resource manager affiliated with the TWP describes the improved understanding of the ecosystem attained via these efforts:

> Our understanding about the tidal marshes shifted dramatically. […] I think we did learn a lot of surprising things: the relationship between sediment supply and marsh loss; the narrow tolerance of water quality and the relationship between tidal flushing and water quality. […] Maybe [some of that] was intuitive, but [the scientist's] work showed us how finely balanced that can be.

Data and project documents are available to the public and other interested persons via the NERR website. For example, there are over five years of real-time LOBO data available and several publications produced by TWP team members regarding the state of the ecosystem and potential restoration strategies are now available. There are also planning documents, scientific documents about changes in the slough, fact sheets, presentations, maps and diagrams, monthly email bulletins and other research documents available on the Tidal Wetland Project page of the NERR website.

Parsons Slough Project

As previously discussed, project team members agreed to move forward with the fourth restoration option, a Parsons Slough restoration project on land owned and managed by the NERR and DFG, for the time being. In November 2009, a preliminary project description was produced outlining the project as it is currently conceptualized (described above).

West Coast EBM Network

Elkhorn Slough has also joined other west coast EBM initiatives in forming a network to strengthen their initiatives and enhance their effectiveness. In 2008, following discussions between The David and Lucile Packard Foundation, Surfrider Foundation, Ocean Foundation, and the NOAA Coastal Services Center, the West Coast EBM Network was created (Hansen, 2009). There was an evident need to associate and align the six EBM efforts supported by these organizations on the west coast (i.e., the San Juan Initiative in Washington, Port Orford Ocean Resource Team in Oregon, Humboldt Bay Initiative in northern California, Elkhorn Slough Tidal Wetland Project and San Luis Obispo Science and Ecosystem Alliance in central California, and Ventura River Ecosystem Project in southern California) (Hansen, 2009). The goals of the network are twofold: to develop a learning system involving EBM topic teams, training opportunities, and a compilation of best practices; and to establish a presence of EBM in coastal management policy discussions within state, regional, and federal activities (Hansen, 2009).

The member EBM efforts have met three times during 2008 and 2009 (Hansen, 2009). The creation of the West Coast EBM Network will help ensure continuing support for and recognition of EBM initiatives on the west coast.

Other Accomplishments

The Elkhorn Slough Tidal Wetland Project is having an impact beyond the boundaries the ecosystem as well. The TWP team has publicized their experiences and expertise through various venues, providing others with an example of how to approach estuary restoration in a more holistic manner. For example, community meetings were advertised through press releases to notify the public of the TWP, several articles were published about the project in newspapers, and the story was covered on the radio. An overview of the work going on at Elkhorn Slough was also presented to The Nature Conservancy's all marine staff in Monterey, at the US Geological Survey's Coastal Processes Group meeting, at the Communication Partnership for Science and the Sea (COMPASS) meeting in Portland, to the Central Coast Regional Water Quality Control Board staff, to the US Fish and Wildlife Service National Coastal Program staff , and to other EBM practitioners at The Packard Foundation's Regional Initiatives meeting in 2007.

Challenges

While the TWP has made significant progress in its first few years, interviews with project partners and analysis of project documents have elucidated several issues, which have impeded progress. For instance, the complexity of wetland ecosystems and of ecosystem-based management administrative activities has made the TWP a challenging endeavor. Project team members have also struggled with balancing tradeoffs between ecological objectives and dealing with uncertainty. The integration of natural and social science data has been difficult as well, and the constraints imposed by limited, unreliable grant funding have restricted the TWP's ability to address issues such as water quality, ensure project activities will be sustained in the long-term and capitalize on other opportunities when they present themselves.

Complexity

Complexity is a challenge manifested in two ways within the context of the TWP: ecosystem complexity and administrative complexity associated with taking an ecosystem-based approach. Wetlands are inherently complex because they contain terrestrial and aquatic habitats, are influenced by fresh and salt water inputs, and experience variable conditions across tidal cycles and seasons. The environmental threats to Elkhorn Slough are equally complex and require multiple solutions. For example, marsh habitat loss in the slough is exacerbated by at least three factors: hydrological changes that have accelerated tidal erosion, sinking sediment elevations that drown salt marsh, and sediment-starvation from river diversions that have prevented natural replenishment of the estuarine plain.

Administratively, EBM poses a challenge as efforts must be made to engage a spectrum of stakeholders who represent different interests, objectives, skills, expertise and levels of commitment. In addition, activities of different stakeholders are being conducted over variable timelines, so contributions of input, data and resources are sometimes out of sync. Furthermore, knowledge provided by participants is constantly evolving, which makes integration across stakeholders difficult. The process itself also changes. As a project partner explains:

> I think the biggest challenge is the complexity is huge. […] There's a lot of moving parts that are moving simultaneously to operate a good EBM project. […] You're kind of saying, "Okay, think of everything […] and talk to everyone, but don't talk to the wrong people at the wrong time." […] Keeping multiple needs met who […] meet at different time frames is really challenging, and there's a ton of administration to track and manage this. […] [It is] a constantly moving, changing process. […] It changes and so you have to constantly be changing with it and restructuring your process. […] The ecological processes that are in play are complex […] and each one of those things has its own set of data and monitoring and speculation and policy and engineering and each affects the other. […] and that's not even layering in the human aspects of it. […] I think that's one of the most challenging parts – is not just doing it – […] it's managing it and then communicating it.

A scientist affiliated with the TWP also observed the challenge of maintaining communication among participants:

> Getting all the stakeholders involved in this landscape engaged in the process is one challenge. Even within the agency we have people who aren't able to maintain those relationships. […] Faces involved in a long process leave – it takes maintaining communication to develop a realistic strategy.

While the confluence of scientific activity in and around the slough has been beneficial, another scientist describes the challenges of having so many experts engaged:

> [The number of scientists per capita] makes the process more complicated actually. […] I think a more authoritarian decision-making structure would be more efficient, but I don't know that it would be better. […] Because of our high density of ecologists per square meter there's lot of disagreement about what should be done in any one place and that causes friction which interferes with making progress on more substantive issues.

Such an initiative is also complicated by confusion over the definition of EBM and what exactly such an approach entails. As demonstrated by a scientist affiliated with the TWP:

> I'm like, "We don't really know what EBM means for us." […] It's difficult because with the TWP we're addressing some specific issues and I think we're trying to take an EBM approach to addressing them. […] Is EBM the approach that you should use for a specific environmental problem or is EBM […] the means to a solution or is it a solution in and of itself.

Balancing Tradeoffs

Further challenges have arisen as the TWP has sought to address tradeoffs between different ecosystem targets and objectives. Key considerations raised at project team meetings include: Which state of the ecosystem should be valued, and which component(s) of the ecosystem is the project prioritizing? For example, should scenarios preferred by TWP participants who obviously value estuarine habitats be selected or should the project team be making decisions in line with the general community's interest, which may favor additional marine recreation opportunities. Also, the current conversion of estuarine habitat from tidal marsh to mudflats benefits species such as shorebirds and flatfish, both of which have special significance in the ecosystem as protected wildlife and economic resources, respectively. In contrast, however, marsh is a rare, but important habitat on the west coast, which makes it valuable. Two scientists affiliated with the TWP explain:

> One of the biggest problems we're facing is - okay, so we want to protect and restore salt marsh, but that means losing some stuff - and the goals didn't quite get to that point. What are we willing to lose?
>
> [Evaluating tradeoffs] slows us down. […] Something's optimized by any scenario […]. Figuring out the right balance between historic function, current function, threatened species, species that birdwatchers like, means that you can't just instantly go do something. You really have to weigh a lot of tradeoffs and come up with decision-making processes for weighing them.

Another scientist affiliated with the TWP provides an example:

> A fundamental source of disagreement is fresh water. Estuaries are rare in CA and many are highly disturbed – some of the rarest habitats in the state are brackish water. Other habitats are rarer like still-water marine habitats. […] There are so many different uses that people get out of our little estuary. Some people think [the goal] should be preservation of existing habitat, while other people argue that the most important thing is to bring the estuary back to a historic state. Disagreements range from what is an acceptable risk to what historical ecological states are.

For the time being, activities that can be accomplished without dealing with this issue are being pursued:

> There are a number of things to do that don't require us to be able to answer that question. We've been working around it ever since we started. (Scientist)

As the TWP team has decided to move forward with the Parsons Slough project, other tradeoffs have emerged. The construction of a sill at the entrance of the complex will reduce tidal flow and could increase resident times for water, leading to hypoxic conditions inland from the sill. Such conditions are detrimental to many species of wildlife and can decrease the area's aesthetic qualities; therefore, there is a tradeoff between reducing tidal scour and maintaining water quality, which has implications for the rest of the system. Mechanisms are not in place to efficiently evaluate these options and make decisions. These issues are still being negotiated.

Dealing with Uncertainty

Lack of data on which to base management decisions is a common management problem - one that EBM seeks to address through acknowledgement of uncertainty and adaptive management. While Elkhorn Slough is relatively data-rich, knowledge gaps remain because there are limited resources for conducting additional research, there is pervasive natural variability in estuarine ecosystems that makes it difficult to recognize patterns and establish baselines, most existing data has been collected for only short periods of time, and there is limited understanding of how climate change will impact management strategies in the future. Such uncertainty complicates discussions of tradeoffs and selection of management actions. A resource manager participating in the TWP describes this problem and the TWP's strategy to address these issues through applied studies:

> There are a lot of uncertainties associated with how a system functions and how it will react. […] Something like sea level rise is a good example. We know it will have an impact, but don't know how much. We're supposed to plan a project that is self-sustaining, but it's hard to predict impacts of these events. Also things like changing tidal dynamics. In restricting the channel with fill, there will be unknown effects on lots of things. We need to take an ecosystem-perspective to accommodate those concerns, but we need to figure out how to address risks without a more certain outcome of the action. In ES, we're actually trying to address some of those uncertainties through applied studies – to test some of those uncertainties.

A scientist acknowledges:

> We are modeling and designing projects for what we think is going to happen, but in the face of climate change it's unclear.

Participants are also hesitant to establish thresholds for adaptive management because they feel they still do not understand the system well enough to make these decisions. There are also problems with existing data. For example, kayaking data was only provided by one company, potentially biasing analyses of economic value. There are also discrepancies between harbor dredging records and NERR attendance revenue data for years prior to 2002 were incomplete or non-existent.

Integrating Natural and Social Science

Social scientific considerations of the political context and economic activities in and around Elkhorn Slough made important contributions to the TWP; however, the integration of these findings with the natural scientific findings has been a challenge for TWP participants. Efficient mechanisms for integration of different knowledge sources and types of data are not yet in place:

> There has not been a way to integrate the multidisciplinary information. So, EBM is supposed to be interdisciplinary, one would hope, it's not there yet. […] You can do EBM and you fill it with all the disciplines, but how you use the information from all the disciplines to make sure that they're all considered appropriately [is a challenge]. (Subcontractor)

To date, the TWP's integration of disparate types of knowledge has entailed extensive communication between project leads from different disciplines, conceptual models showing the relationships between the disciplines and conceptual models showing the linkages specifically between their work.

The divide between different disciplines is reinforced by specialized expertise and insufficient communication across specialties. A scientist participating in the TWP observed:

> I see a big gap that's difficult to get over. I'll hear questions about, "What are the social science and economics people doing? What is their role in their project," but then when the [social science] reports […] come out, then the technical people say, "Well, that's not my forte, I don't want to review that. People with more familiarity with that should." So it's reinforcing that gap that the two sides aren't communicating very well.

There is also a challenge associated with the timing of integration. For instance, within the TWP, the social, political and economic analyses were conducted in a much shorter time-frame than some of the scientific studies. For the results o be integrated, consideration needed to be given to due dates of deliverables such that the natural scientific research could be completed in time to inform socio-economic and political analyses, which was not the case. Furthermore, social scientific expertise is underrepresented at the NERR; therefore, outside help is often solicited for such investigations and to ensure socio-economic factors are taken into consideration (Scientist, personal communication, September 2009; Resource Manager).

Lack of Authority

Although some of the TWP participants have authority over land within the project area, it was discovered during the political analysis that no single entity has the authority to authorize the construction of a new ocean inlet or sill at the Highway 1 bridge because these projects extend across multiple ownership and jurisdictional boundaries. As a result, restoration options may be limited to TWP participants' properties and large scale efforts may not be feasible, which reduces opportunities to restore marsh habitats in Elkhorn Slough. As a resource manager affiliated with the TWP observed:

> Wetlands are not easy to build and construct in. […] We need to work with existing infrastructure and land uses and of course can only directly affect what is directly within the project and owned lands. But a lot of the issues are outside our boundaries – inputs from outlying areas, loss of sediment from those streams.

For the time being, restoration activities will be carried out in the Parsons Slough complex, which is owned and managed by the DFG.

If project team members choose to move forward with a larger scale approach in the future, seventeen major laws and provisions must be complied with, including standards for planning and development projects, requirements for Environmental Impact Statements (EIS), water quality requirements, stipulations to protect endangered species and their habitats, and approval from local property owners and regulators to implement projects or conduct research across property or jurisdictional boundaries (Kildow et al., 2008). For example, at a local level, strategies that would involve a sill at the Highway 1 bridge or relocation of the mouth of the slough fall under the jurisdiction of transportation related laws, thus, requiring permits and compliance with additional rules related to interference with the nearby bridge (Kildow et al., 2008). In addition, the California State Department of Transportation requires encroachment permits for activities occurring in a right of way (Kildow et al., 2008). To construct a new bridge or modify the existing one to accommodate the sill would need approval by the U.S. Coast Guard, as well as require a Rivers and Harbors Act Section 10 ACE permit (Kildow et al., 2008). There are also environmental impact related requirements, among others. Fulfilling these requirements and obtaining relevant permits can prolong implementation and, thus, prolong achievement of project objectives. To streamline the process, the TWP has been engaging representatives of various relevant agencies from the onset such that applicable regulations are considered early in the planning process (ESTWP Team, 2007).

Funding Constraints

Improvement of ecosystem conditions will depend on the TWP's ability to acquire additional, sustainable funding. Funding constraints have required the TWP to prioritize its activities and focus on the issue of tidal erosion and salt marsh habitat loss for the time being, but the ecosystem is being bombarded by other threats that the project team does not have the resources to address at this time. A scientist affiliated with the TWP explains this while discussing the initial proposal to NOAA's Coastal Impact Assistant Program in 2002:

> We wrote a grant to start a big stakeholder science-based project to come up with a coherent vision of what we want to manage the slough for. Originally, we'd hoped that that could cover all sorts of threats and solutions from pollution to invasive species to recreational uses to these hydrological alterations and somehow have this multi-ring circus that has teams tackling all of that at once […] because they inform each other and influence each other. But, we'd applied for […] over a million dollars and they gave us two or three hundred thousand, and so we scaled it back to dealing with what seemed like the most urgent and intractable threat - or the one that we most need different groups for - and really the most unmet need in the estuary, which is dealing with the hydrological alterations. […] So, that was our focus for the first grant, and partway through that we got Packard money to continue it.

For the NERR to tackle other related ecosystem threats in the future, additional funding will need to be obtained. One scientist highlights the way funding limitations hinder their ability to tackle multiple issues:

> Funding is the most major [challenge]. I'd say, in that we could do a bunch of things tomorrow if we had a large staff with large budgets to do them. A lot of the big problems

> are well enough understood and have solutions that could be agreed upon by the stakeholders that could be implemented. […] If we had unlimited budgets we could solve a lot of the big problems.

As a resource manager affiliated with the TWP phrases it:

> We're just as limited as our creativity to bring in funds and get the work done – we're just limited by our capacity.

Some stakeholders involved in the TWP recognize this as a long-term process. While the other issues are being pushed to the side for the current project, they will be addressed in the future. The current phase is only the top priority at this point in time:

> In a triage […] we have small grants with small teams of staff to work on something at a particular time. […] The phase the TWP is in for this decade is very much trying to deal with issues related to the harbor, of having too much tidal energy for that artificial harbor entrance […] and wanting to decrease that. That [is] the most urgent bleeding in the patient or whatever. That's our primary focus, but I know sometimes in some of the documents it says that *is* the goal of TWP, and I would still say that the bigger goal is overall ecosystem health, and that's the one thing we can tackle right now. (Resource Manager)

Furthermore, continuing restoration projects and monitoring their impacts, sustaining community involvement activities, and supporting staff hired to manage various related projects will all require a sustainable funding mechanism over the coming years.

Another funding-related challenge is timing, having the resources in place to capitalize on opportunities when they present themselves. For example:

> The town of Watsonville […] is doing a flood management project planning process right now. They want to build levies around the town – it goes underwater every 10-20 years. […] And we could take their river and flood flows. We could have it flow into Elkhorn Slough, give us a ton of mud, protect their town […]. […] It's an Army Corps of Engineers project. They have all of these meetings […]. If you want to influence that you have to be there every meeting, hounding them, providing them with data, making it happen. […] We don't have the resources to do that concurrent with all this other stuff. […] There's a great opportunity there, but we don't have the bandwidth to advance it even if it is a great idea that is a win-win for a bunch of people. […] And the way these things are funded – if you have a good idea, you won't be able to hire someone to do it until a year and a half out – probably two years considering that the call for proposals is usually six months out. The whole grant process is a very slow animal. What I view as the greatest challenge is having the people to do what needs to be done. (Scientist)

Facilitating Factors

As indicated in interviews and among project documents, the Tidal Wetland Project in Elkhorn Slough has been facilitated by five key factors: a history of multi-objective management, the small-scale of the ecosystem, the presence of several distinguished marine science institutions in the area, EMB-promoting legislation at the state level and grant funding.

History of Multi-Objective Management

Estuary management has a history of being multi-objective. Prior to being called EBM, managers in and around Elkhorn Slough have been focused a variety of ecosystem topics, including water quality, recreational opportunities, nursery areas for fish and habitats for endangered species, to name a few. In addition, estuaries are utilized by diverse stakeholders for a spectrum of activities. Wetlands are also visibly influenced by adjacent habitats, receiving freshwater input and run-off from surrounding watersheds and exchanging tides with the ocean. For these reasons, there is a pre-existing framework for multi-objective management, consideration of human influences, and understanding of interactions between systems at this site. In many regards, EBM has been occurring at Elkhorn Slough for years without the label:

> Estuaries have always had these multiple conservation targets or ecosystem services […] that people are managing for, and clearly multiple threats from much more widespread habitat loss than you get for open marine systems. [...] Anyone who's been working with management of estuaries in the last fifty years has already had to do some degree of EBM in terms of thinking of multiple targets. […] It doesn't seem like it was such a paradigm shift for estuaries. […] And that the multiple human stakeholder groups have always wanted to do different things with estuaries. It's the most fertile farmland. It's often in river deltas. It's a great place to put power plants because of intakes. There's good fishing. They're beautiful places for recreation. [...] Estuaries have been such a hub of human interaction with the natural environment, and so again that's like a natural fit. That may make it harder on some levels because everyone wants to use the estuary for a different function, but it means again that you're sort of predisposed to working out compromises between different human user groups. (Scientist)

Small Scale

The small scale of the Elkhorn Slough ecosystem has made the TWP manageable relative to projects in larger estuaries such as the San Francisco Bay area. Having to engage fewer stakeholders and being able to involve participants with a history of interaction and an intimate knowledge of the area has made easier to come to consensus on ecosystem threats and project priorities. A scientist participating in the TWP made this observation:

> Having a small system where we all know each other and we all know the different field sites or whatever is probably helpful; a useful scale to work at.

Local Marine Science Research Institutions

The TWP has also benefitted from its proximity to several world-class marine science research institutions, including the Monterey Bay Aquarium Research Institute, the Moss Landing Marine Labs, the University of California at Santa Cruz, the Hopkins Marine Lab of Stanford University, the California State University in Monterey Bay and the Elkhorn Slough National Estuarine Research Reserve. By the time the TWP was initiated, there was already a vested interest among scientists in the area in the status of the slough as they have been studying this ecosystem for decades. Consequently, the area is also relatively data-rich, and these scientists, of which there are benthic ecologists, fish biologists, marine mammologists, ornithologists, chemists, geologists and hydrologists, possess beneficial knowledge of the ecosystem and relevant expertise and skill sets for further study of the system. They have contributed significantly to discussions regarding the health of the slough, restoration strategies and potential outcomes. Furthermore, many of these scientists are familiar with one another and have a history of working together, which has contributed to the productivity of the TWP working groups. As some of the TWP participants have observed:

> There are probably more ecologists per square meter than a lot of other places – we have lots of data here.
>
> It also helps that we're in the middle of some of […] a network of some of the best research institutions around, so we've got a ton of excellent scientists and grad students around us. I think we're in an excellent location in terms of getting expert input and research projects done out here.
>
> Having so many research institutions surrounding us is a huge help to the science-based aspect of it. While some of our fellow reserves that are in Mississippi or something, and the nearest university is a three hour drive away, they just can't weigh tradeoffs in as thoughtful a way because no one's studying them.
>
> I think having this Monterey research crescent will help - all these great universities like Moss Landing, Santa Cruz, Hopkins, California State University in Monterey Bay. There's a lot of state-of-the-art researchers looking towards that, and having the Packard Foundation here and MBARI. I think that's kind of what has helped a lot as well. […] There's a lot of environmental concern in the area. There are a lot of research organizations here. There's a lot of regulatory oversight.

State Legislation

The interest of regulatory agencies to become involved in this initiative on a voluntary basis was likely facilitated by the state's proactive attitude towards holistic marine management. In the past decade, the state government in California has led the country in passing legal mandates to protect marine resources, and one of the first pieces of state legislation that encouraged holistic marine resource management was the 1998 Marine Life Management Act (MLMA). This act aimed to conserve marine ecosystems, sustain and restore fisheries, and ensure the long-term health of fishing communities (Sutton, 2005). At the time, it embodied some of the most advanced fisheries management concepts in the country and it demonstrated the shift in management foci from single species to ecosystems (The David and Lucile Packard Foundation [Packard], 2008). Also, the state legislature passed the Marine Life Protection Act (MLPA) in 1999. This piece of legislation entailed an unprecedented requirement to develop a statewide network of marine protected areas to preserve the natural richness and abundance of marine life as well as the complexity, organization and integrity of marine ecosystems off the California coast (Sutton, 2005; Packard, 2008).

In 2004, Governor Schwarzenegger signed the California Ocean Protection Act (COPA), which requires the state to think about ecosystem-level dynamics when considering management decisions related to coastal and ocean resources (Packard, 2008). Rather than managing single species or resources, COPA again placed priority on the ecosystem and focused on protection, conservation and restoration at this level (Sutton, 2005). In coordination with COPA, Governor Schwarzenegger created the Ocean Protection Council (OPC) with the general mission to improve the protection and management of California's ocean and coastal resources. The OPC is a cabinet-level, multi-agency entity responsible for ensuring state policies are consistent with the principles of ecosystem-based management (Packard, 2008). It is charged with coordinating the state's agencies and laws responsible for protecting and enhancing ocean resources.

Since its establishment, the OPC has distinguished itself as a vehicle for agency reform, primarily through its development of a Science Advisory Council as well as some other measures (Packard, 2008). The OPC is also responsible for implementing the Governor's Ocean Action Pan that was released in October 2004 (Packard, 2008). The Action Plan recommends the development of EBM programs to help reach broad conservation, restoration and sustainability goals (Packard, 2008). COPA also established the Ocean Protection Trust Fund, which allocates funds for the Ocean Protection Council and was worth $26 million in 2005 (Sutton, 2005). These legislative mandates have potentially generated interest among government employees in integrated marine management initiatives.

Also occurring in 2004, after failure of two initial attempts to establish the statewide network of MPAs required by the 1999 MLPA, the Marine Life Protection Act Initiative was launched. This private-public partnership between the California Natural Resources Agency, California Department of Fish and Game and the Resources Legacy Fund Foundation is facilitating a collaborative process that is engaging a diverse mixture of stakeholders in the development of proposals for the state's network of MPAs. The first of four regions to take part in this MLPA process was the central coast region and members of the TWP participated. A scientist affiliated with another EBM initiative in central California summarized the EBM-friendly atmosphere in California as follows:

> I mean California's doing a lot of EBM activities. I mean all the marine reserves that are being implemented – that's spatial management – one tool within EBM. I think that we have some of our highest level governing bodies like the Ocean Protection Council whose mission is […] integrating jurisdictions and a focus on science for policy decisions and so on .[…] They have a major influence in this state.

In 2006, the West Coast Governors' Agreement on Ocean Health was signed by the governors of California, Washington and Oregon. Through this agreement, the west coast states pledged to cooperate with one another in their efforts to fulfill federal policies and embark upon common activities such as ocean and coastal research (Packard, 2008). Two years later, in 2008, an action plan for implementation of the West Coast Governors' Agreement on Ocean Health was developed, providing a practical outline for fulfilling the agreement. The action plan reflects the Ocean Protection Council's strategic plan and the recommendations for marine ecosystem management described by the Pew Oceans Commission and the US Commission on Ocean Policy reports (Packard, 2008).

Grant Funding

As mentioned previously, the Elkhorn Slough TWP was catalyzed by grant funding. An initial NOAA Coastal Impact Assistance Program grant awarded to the California Department of Fish and Game and the University of California in Santa Cruz provided the financial resources that enabled the TWP to hire a project coordinator, establish a project team, develop research summaries to assist planning efforts and identify and begin to meet with key stakeholders. The David and Lucile Packard Foundation and Resources Legacy Fund Foundation provided an additional three years of funding in 2006 to support project activities that resulted in agreement among TWP participants to pursue the Parsons Slough restoration project. In November 2006, the TWP was awarded another two and a half years of funding from an Environmental Protection Agency Wetland Protection Development Grant and a state Coastal Conservancy grant to develop the wetland restoration project for Parsons Slough. Federal stimulus funds were also acquired to support the Parsons Slough project. These grants have enabled the NERR to engage in more holistic management by funding efforts to build the necessary organizational structure and facilitating the processes needed to integrate stakeholders and scientific investigations, and address multiple ecosystem objectives.

Lessons Learned

Through the TWP process, project team members have learned several lessons regarding EBM implementation.

It is important to have a coordinating agency and local research capacity.

It is important to have a non-profit or coordinating agency established as the nucleus of the effort, and having local scientific capacity to thoroughly study the area is critical.

Bureaucrats facilitate implementation.

While scientific involvement is essential, having a process driven by scientists can be difficult since many prefer to avoid advocacy and risk. Implementation of the TWP has been facilitated by hiring bureaucrats.

Acknowledge uncertainty.

Being upfront about uncertainty is important to ensure stakeholders are not surprised by unexpected outcomes, which could compromise trust.

Some research should precede other research.

Nome natural science should be completed prior to economic and policy analyses. While initiating both natural and social scientific studies simultaneously enabled the TWP multi-disciplinary team to learn from each other, the social scientists found that their research on environmental services and policy considerations would have been bolstered if the ecological data had been collected beforehand. Relatedly, high uncertainty associated with ecological data can make valuation and quantification of ecosystem services difficult.

Personality is important.

The personalities of participants greatly influence the trajectory and dynamics of the effort. Participants with strong opinions and loud voices may be more influential in directing the initiative's focus. Further, a diplomatic leader that respects each stakeholder and validates their concerns facilitates the process by enhancing legitimacy, and having a close-knit group of people who are already committed to the place ensures dedication to the project and likelihood of continued interactions.

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