Identifying Economic Indicators for Ecosystem-Based Management:

A Case Study in the Elkhorn Slough

A Capstone Project

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Abstract

In America and across the world, the use of ecosystem-based management is increasing. One of the primary challenges faced in using this method of management is the integration of economic data and environmental information. This report explores the use of a new tool for integrating economic data, ecosystem-based economic indicators, in a case study of Elkhorn Slough National Estuarine Research Reserve, an estuarine environment located in Monterey County, CA. Research and literature reviews were used to detail the economic activities of the area, in order to identify possible indicators, criteria for evaluating the indicators, and potential sources of indicator data. After evaluating ten candidate datasets, four datasets were collected: 1) the cost of dredging the slough to Moss Landing Harbor, 2) the volume of dredged material removed by the United States Army Corps of Engineers, 3) the weight of fish landed by commercial fishers in the Moss Landing area, and 4) the number commercial passenger fishing vessel participants. These datasets were used to establish a baseline of relevant economic activity and to explore trends in these economic activities over time. The economic indicators were then compared with ecological indicators from similar time periods. The comparisons were used to assess whether changes in economic activity could be correlated to changes in ecological conditions. Visual observation revealed possible links between 1) the average annual turbidity and volume of dredged material removed by the United States Army Corps of Engineers, 2) annual maximum turbidity value and the cost of dredging to Moss Landing Harbor, 3) the annual frequency of hypoxic conditions and the weight of fish landed by commercial fishers in the Moss Landing area, and 4) the annual frequency of hypoxic conditions and the number of commercial passenger fishing vessel participants. Although preliminary in nature, conclusions indicate that ecosystem-based economic indicators will help the managers of the Elkhorn Slough National Estuarine Research Reserve to establish baselines of economic activity and to predict changes in this activity as a result of an ecological policy change.

Introduction

Environmental resource managers utilizing ecosystem-based methodologies must identify ways to integrate economic data into decision-making processes when considering policy actions or restoration options. This project seeks to identify, collect, and evaluate economic indicator data as a way to make better decisions for ecosystem-based management in the Elkhorn Slough.

> *Ecosystem Based Management is an integrated approach to management that considers the entire ecosystem, including humans. The goal of EBM is to maintain an ecosystem in a healthy, productive and resilient condition so that it can provide the services humans want and need.* (McCloud et al 2005)

On March 21, 2005 more than 200 academic scientists and policy experts released the above statement in an attempt to define ecosystem-based management (EBM) in the scientific and political communities. As natural resource managers and institutions increased the use of ecosystem-based methods across the globe, a clear definition of the process became imperative (Slocombe 1998). In the United States, the growing popularity of EBM is underlined by the inclusion of the methodology in the strategic goals of the National Oceanographic and Atmospheric Administration (NOAA), the agency responsible for the stewardship of coastal and marine environments (NOAA 2006). In its 2003-2008 Strategic Plan, one of NOAA's four primary goals is to "Protect, restore, and manage the use of coastal and ocean resources through EBM" (NOAA 2003). The Pew Oceans Commission and the United States Commission on Ocean Policy cite EBM as a necessary addition to the nation's ocean and coastal management strategies (POC 2003, USCOP 2004). In addition, private institutions and non-profit groups have invested funds to study and develop tools that will be used in ecosystem-based methodologies. While the Scientific Consensus Statement on Marine EBM, may help elucidate the definition, it remains unclear how to best develop, implement, and monitor EBM.

One of the largest challenges is the integration of economic data into the methodology. While policymakers recognize the need for economic data and agree that economic information should pay an important part in the development and implementation processes of management efforts (Hammer et al, 2003), a comprehensive process by which economic and ecological information can be combined is lacking. Traditionally, data detailing economic activities has not played a central role in EBM efforts (EPA, 2002). The economic data used in EBM were limited to economic valuations of environmental goods and services. Economic valuations provide only a snapshot of the economic activity that takes place within a given area at a specific point in time (Pendleton, 2006). Thus, historically economic data collection in environmental management attributes value to the natural resources in question or estimates the value of a specific ecosystem at some point (Limburg et al, 2002).

While some ecosystem valuation studies provide rough estimates of the overall value of an ecosystem, no matter how extensive an ecosystem valuation study is, it is not appropriate for tracking changes over time (Pendleton, 2006). It is, however, the *changes* in economic activity due to environmental fluctuations that are most informative to managers when considering the potential outcomes of ecosystem-based restoration options. Economic information collected over time, referred to in this report as *time-series* data, accomplishes several important goals:

1. It establishes a baseline of economic activity that depends on the ecosystem health of the environment in question.
2. It allows managers to track how ecosystem-dependent activities vary as a result of changes in ecosystem health.
3. It allows analysts to combine ecological and economic data to form a model for predicting how changes in ecosystem health translate into fluctuations in the local economy based on the relationships visible in past datasets.
4. It reflects the stream of economic activity that may potentially be affected by ecosystems by detailing the types of economic activities that are dependent on ecological resources.

(Pendleton 2006; Kildow 2006)

Due to these valuable contributions today's resource managers and policymakers seek to integrate economic time-series data with environmental information. One way to combine economic and ecological data involves the use of *economic indicators*. An economic indicator is a value that represents an action in an economy. The indicators are assumed representative of the total economic activity that takes place in the area of investigation and allow analysis of economic trends as well as predictions of future performance. These measures are currently used at the global, national, regional, state, and local levels. Common examples of economic indicators include gross domestic product, employment rates, and retail sales.

The use of *ecosystem-based economic indicators* offers an integrated approach to the valuation of ecosystems and has the added ability to model future changes (Pendleton, 2006). An ecosystem-based economic indicator is one that can be associated with ecological data for the same time period, and thereby links ecosystem health with the performance levels of specific economic activities. Ecosystem-based economic indicators must be easily measured, clearly interpreted, and defendable when questioned. With respect to wetland or estuarine systems, ecosystem-based economic indicators may include recreational uses, such as the number of recreational fishing trips, or commercial industry data, such as the cost of dredging-related activities.

The Elkhorn Slough as a Case Study

To investigate the role of economic indicators in EBM this report focuses on the Elkhorn Slough National Estuarine Research Reserve (ESNERR). The managing agencies of ESNERR are considering several restoration options that would serve to advance the goals of their EBM objectives. It is assumed in this report that all restoration options are part of a comprehensive EBM plan and represent manifestations of the methodology.

The ESNERR contracted the National Ocean Economics Program (NOEP) to complete a socio-economic assessment of the Elkhorn Slough area. One portion of the NOEP project is to estimate the economic changes due to potential changes in the physical environment of the Elkhorn Slough caused by restoration activities. This Capstone project is a preliminary study to determine if a methodology built around ecosystem-based economic indicators can provide accurate information and enhance the ESNERR managers' decision-making process.

The identification of ecosystem-based economic indicators provides managing agencies with rigorous evidence of the potential links between economic and ecological communities. Establishing these connections is the first step in developing an improved valuation research method that will allow the estimation of economic impacts from ecological changes. With this information, future NOEP work will estimate the economic impacts and present likely ranges of economic changes to ESNERR. ESNERR will then consider these impacts when evaluating the recommended scientific and engineering options.

The ESNERR is located within the Elkhorn Slough, adjacent to Monterey Bay, California. The reserve encompasses the largest tract of tidal salt marsh in California outside of the San Francisco and Tomales Bays (Caffrey 2002). An ecological jewel located in the center of the Monterey Bay Coastline, this estuary houses a diverse group of plants and animals, including more than 340 species of birds (Caffrey 2002). The unique conditions of the Elkhorn Slough also create an ideal area for many commercially important fish species for some portion or all of their lives (Caffrey & Zabin 2003). These species are referred to in this document as *slough-dependent species* and include northern anchovy, pacific herring, sole, rockfish, surfperch, elasmobranches, sanddabs, lingcod, cabezon, and starry flounder.

For more than 8,000 years, humans have utilized the natural resources of the Elkhorn Slough to support and enhance their livelihood (Caffrey & Zabin 2003). Today the slough continues to support numerous market economic enterprises, such as commercial fishing, recreation and leisure activities, research and educational institutions, and agriculture. The estuarine habitat of the Elkhorn Slough also provides essential ecosystem goods (such as living aquatic resources) and services to the communities in the area (Caffrey and Zabin 2003). Examples of the ecosystem services include protection from extreme weather events, nutrient cycling, and dilution of harmful pollutants. While some of these goods or services are captured in the market economy, others are not. The non-market value of ecosystem goods and services are vital to the issue of restoration within the Elkhorn Slough, but this value will not be addressed in this report.

The slough ecosystem has suffered from the direct withdrawal or overuse of resources, but it is the indirect effects of human economic activity that now pose the greatest threats (Caffrey & Zabin 2002). The Elkhorn Slough is an environment undergoing metamorphosis. The changes compromise its sustainability as a wetland. Past anthropogenic modifications to the slough, or in the areas surrounding it, have dramatically altered the ecosystem. The construction of the Southern Pacific Railroad, diking and draining of wetland areas by farmers, diversion of the Salinas River, agricultural activities, residential development, groundwater overdraft, and introduction of non-native species have all contributed to the alteration of the Elkhorn Slough estuarine ecosystems (Caffrey & Zabin 2002).

The largest single event that created lasting effects within the slough was the rerouting of its entrance into the Monterey Bay. In 1946, a direct channel was cut between the mouth of the slough and Monterey Bay to create the modern day Moss Landing Harbor (Caffrey & Zabin 2002). This action, coupled with the previously mentioned anthropogenic alterations, triggered a series of unforeseen changes in the physical characteristics and biotic communities of the Elkhorn Slough:

1. Tidal currents in the main channel of the slough dramatically increased causing the area to switch to an erosional rather than depositional environment.
2. Increased tidal scour resulted in the conversion of marshes to mudflats where macroalgae replaced pickleweed as the primary producer.
3. Changes in the distribution and abundance of invertebrate species and possible extinction of local phoronid worm species.
4. Reduction in the diversity of fish species throughout the slough, particularly in the side branches of the estuary.
5. Increased flow converted the lower slough to a more marine environment that is more favorable to large marine mammal species.
6. Increased tidal scour increased mudflat environments and provided shorebirds with greater feeding area, but less roosting area critical for migratory species.

(Caffrey & Zabin 2002)

In an attempt to quantify and study the changes brought about by these modifications to the slough, the ESNERR convened a Tidal Wetland Planning Scientific and Advisory Team (TWP Team). The panel of experts was formed to identify current trends, estimate future conditions, explore potential restoration options, and offer predictions for proposed physical changes. This Capstone project seeks to aid in the decision-making process by exploring a new methodology the team could use to examine past relationships between economic activity and ecological change in the Elkhorn Slough and use these relationships to estimate the likely effects of the potential restoration options on the area's economic activities.

The TWP Team, has reached consensus that under current trend conditions the main channel of the Elkhorn Slough and surrounding tidal creeks will continue to become deeper and wider as the result of tidal erosion (TWP Team 2005). Predictions also estimate that this change will be accompanied by losses of salt marsh habitat and subsequent conversion to mudflat environments. In October of 2005, the TWP Team, in collaboration with local experts, generated five primary restoration options that would serve to retard or reverse the tidal erosion and the loss of salt marsh. Each of these five options is further divided into sub-components that may or may not be adopted. It is important to note these options are not finalized proposals, but represent potential alternatives to be considered by the TWP Team. Prior work completed by Erik Edmonds, a member of the NOEP project, detailed the restoration alternatives and is presented here in its original format.

Restoration Options:

Large Scale Alternatives – near the mouth of Elkhorn Slough

Option A. This first potential restoration option starts with adding a sill(s) or some other kind of water control structure (**A1**) under the current opening of the Highway 1 bridge (which is high enough to decrease the tidal prism) to reduce tidal erosion and marsh loss in the system. The goal of reducing the tidal prism is to replicate the dimensions of the Elkhorn Slough mouth and channel. The next action would be to add backfill behind those structures or have series of water control structures (**A2**) replicating a graded slope in the subtidal channel so there would be less of a hydraulic jump over the structure. Then the next action would be to add sediment/fill (**A3**) to raise the elevation of subsided areas to restore intertidal marsh areas. This action could also coincide with adding sediment/fill (**A4**) to subtidal creeks that have scoured to restore them to appropriate levels. It is believed that in the long term, it would be ideal to reestablish a more permanent sediment supply (a river that connected near the mouth of Elkhorn Slough from the south that drains a much larger watershed was diverted in 1908) that would help sustain marsh levels and once areas behind the water control structures are restored to appropriate elevations, they could be reconnected with the main channel.

Option B. This second potential restoration option starts with installing a dam or lock and a dam (**B1**) under the current opening of the Highway 1 Bridge and create new channel and mouth (**B2**) with a smaller cross-sectional area (more shallow) entering Monterey Bay near Bennett Slough. There are currently variations of this idea that include diagonal dams to reduce the length of a newly constructed channel. The idea is to restore characteristics such as dimensions, sinuosity, and location of the mouth. Then the next action would be to add sediment/fill (**B3**) to raise the elevation of subsided areas to restore intertidal marsh areas. This action could also coincide with adding sediment/fill (**B4**) to subtidal creeks that have scoured to restore them to appropriate levels. These two actions are the same as in **Option A**. Also like **Option A**, in the long term, it would be ideal to reestablish a more permanent sediment supply (a river that connected near the mouth of Elkhorn Slough from the South that drains a much larger watershed was diverted in 1908) that would help sustain marsh levels and once areas behind the water control structures are restored to appropriate elevations, they could be reconnected with the main channel.

Medium Scale Alternatives – Parsons Slough/South Marsh

Option C. This potential restoration option begins with adding water control structures (**C1**) under the current opening of the railroad bridge at the mouth of Parson Slough (above mean lower low water - MLLW) to reduce the tidal prism of the entire Elkhorn Slough system. This could slow tidal erosion and marsh loss in the lower Elkhorn Slough. Then over time, the next action would be to add sediment/fill (**C2**) to raise the elevation of subsided areas to restore intertidal marsh areas and add sediment/fill (**C3**) to subtidal creeks that have scoured to restore them to appropriate depth. It is believed that in the long term, if this area can be restored to appropriate elevations to support tidal marsh/creek habitats and if a large-scale option to reduce the tidal prism at the mouth of Elkhorn Slough is completed, then this area could be reconnected to the system. This potential restoration option could be implemented whether or not a large-scale alternative at the mouth of Elkhorn Slough but could be used as part of a multiphase restoration plan.

Small Scale Alternatives

Option D. This potential restoration option beings with adding sediment/fill (**D1**) to subsided marsh areas (North Marsh, Estrada Marsh) east of the railroad tracks that are behind tide gates (above MLLW) to restore marsh and tidal creek habitats. The next action would be to alter the water control structure (**D2**) in order to improve drainage and maximize water quality.

Option E. This potential restoration option involves changing the water control structure (**E1**) (i.e. decrease the number of culverts) under the road between Bennett Slough and North Harbor to reduce tidal erosion. What is important to note is even though these two small scale options would probably not significantly reduce the tidal prism and reduce tidal erosion and marsh loss in the main areas of Elkhorn Slough, they could serve as good projects to demonstrate successful restoration techniques in the wetlands.

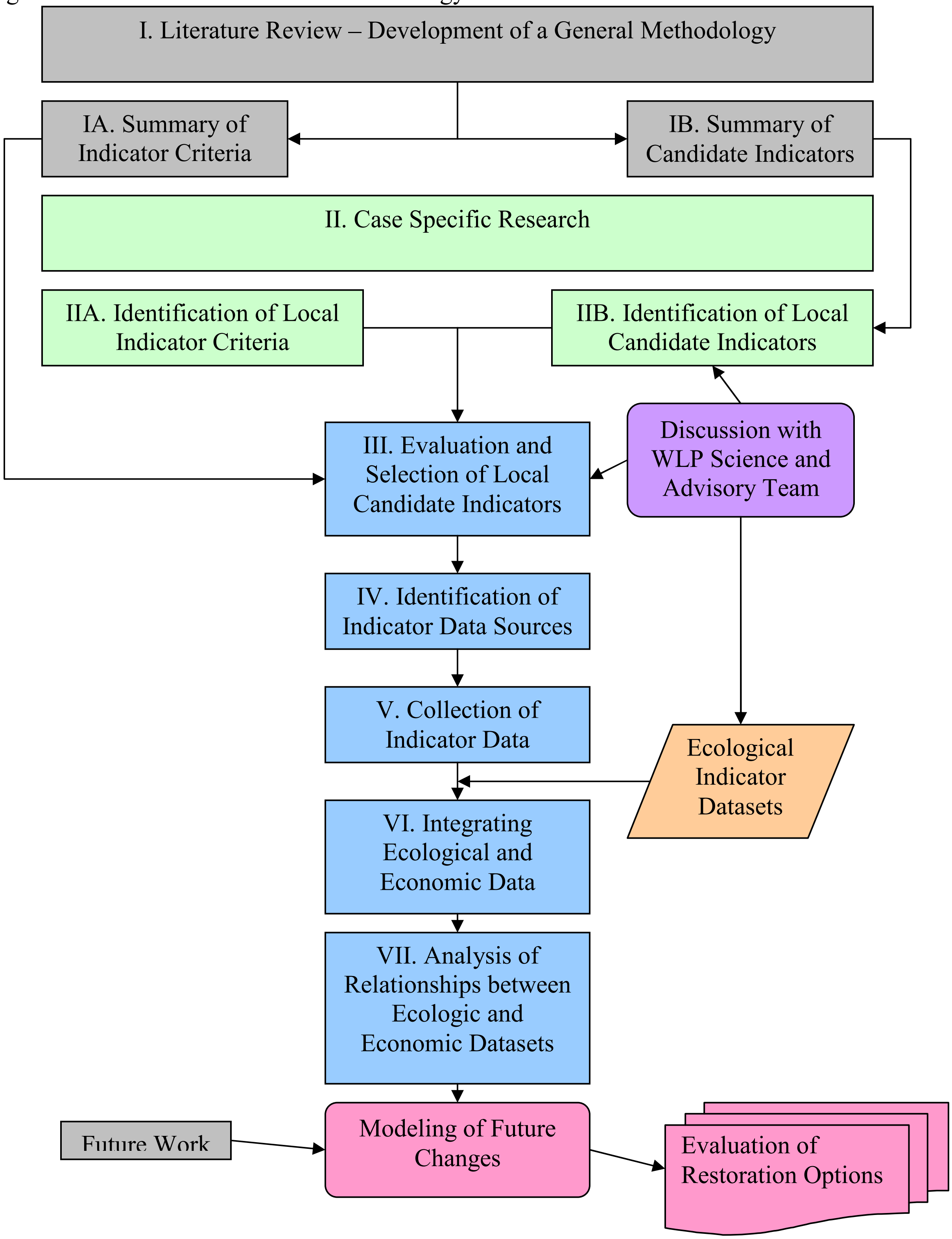
(Edmonds 2005)

Additional Implications

While natural resource managers recognize the need to integrate economic data into the ecosystem-based methodology, the tools that would allow for the effective and continued incorporation of such data do not currently exist. The use of ecosystem-based economic indicators in wetland valuation represents the cutting edge of scientific exploration and a solution to the integration of economic data. This groundbreaking approach to ecosystem appraisal deviates from the traditional valuation methodologies of market driven or non-market assessments such as contingent valuation, travel cost, hedonic pricing, or stated preference valuations. Similar investigations into the efficacy of ecosystem-based economic indicators are currently under way in other California areas such as Morro Bay and Santa Monica Bay. The ecosystem-based economic indicators that are identified in this case study may have partner indicators in other wetland areas. These common indicators would allow for comparison, correlation, and verification between the Elkhorn Slough and other estuarine ecosystems. A methodology that integrates economic data into the larger framework of EBM and has the added ability of estimating future economic changes, would be a powerful instrument for natural resource managers. The results of these studies will have broad reaching implications for EBM, serving to further advance the scope and efficacy of integrated management efforts.

Methods

Figure 1: Flow Chart of Research Methodology.



I. Literature Review – Development of a General Methodology:

To establish the historic use of economic and related socio-economic data in past decision-making methodologies, I conducted a comprehensive literature review of previous studies including published reports and journal articles from a variety of disciplines in the social and natural sciences. This review provided a foundation for understanding four important considerations in this case study:

1. Indicators that had been used in past studies
2. Role of economic indicators in past decision-making processes
3. Ability of indicators to inform policy
4. Key criteria by which indicators could be evaluated

The knowledge gained from the exploration contributed to the production of two key products that proved essential to the later stages of the indicator-selection process. These two products were:

I A. Summary of Candidate Indicators:

Generated by the review of 37 sources, this list of indicators represented those utilized or suggested in literature reviewed. This list served as a starting point for the examination of local datasets. The list was later expanded by the addition of supplementary candidate indicators not found during the initial review process, but uncovered during the case specific research (See: Case Specific Research below).

I B. Summary of Indicator Criteria:

I developed seven key criteria as a product of the literature review. The criteria were used to evaluate and assess the efficacy of potential indicators and ensure their continued effectiveness in monitoring economic activity.

1. Availability of economic data in the area: The sum of available economic data collected in the geographical area of interest.
2. Availability of ecological data in the area: Ecological datasets that closely parallel the scale and frequency of selected economic data.
3. Connection between economic and ecological data: The economic indicators chosen must be dependent in some manner on the condition of the ecosystem with which the economic indicators are being linked.
4. Indicators that can be measured within relevant boundaries and scale: Economic indicators must be quantifiable at an appropriate scale to reflect changes of the ecosystem.
5. Historical data record: Economic indicators that have an extensive historical data record provide the opportunity to analyze past changes in the economic activity of local economies related to changes in ecosystem health. In addition, the likely occurrence of time lags between changes in one variable and possible effects in the other variable makes longer datasets necessary.
6. Likelihood of continued collection/cost-effectiveness: The relative likelihood that data will continue to be collected and the comparative cost-efficiency to other similar datasets.
7. Rigorously collected and statistically sound: Data was collected in a manner to quantify the sum of economic activities, will withstand

scrutiny, and accurately represents the overall trends of the economic activity described.

II. Case Specific Research:

The second portion of the literature review was devoted to the specific economic activities that take place in the study region. In this focused literature review, I investigated the market economy of the Elkhorn Slough and greater Moss Landing communities. The research detailed the following four aspects of the area's economy:

1. The economic activities taking place in the area
2. The estimated importance of these activities to the overall economy of the area
3. The number of firms participating in each activity
4. The history and projected future of economic activities

This information proved important to many of the later phases of the case study (See: Evaluation of Indicators, Identification of Data Sources), but was intended to produce two primary products. These products appear below:

II A. Identification of Local Candidate Indicators:

In this step, I combined the local economic activities with the summary of candidate indicators from the more general literature review process and the input received from the ESNERR Tidal Wetland Planning Scientific and Advisory Team (TWP Team - See page 11). This compilation was composed of the 27 economic indicators, listed in alphabetical order, in Table 1.

Elkhorn Slough Area Candidate Indicators	
Candidate Indicator	**Explanation**
Bait Sales	Intended to capture the sale of live bait to local recreational fishers
Beach Visits	Number of visitors to Moss Landing State Beach
Birdwatching Gear Sales	Sale of supplies such as binoculars, guide books, or scopes
Birdwatching Tours	Private or group tours led by birding experts in the Elkhorn Slough area
Birdwatching Visits	Number of visitors to the Elkhorn Slough to view any bird species
Commercial Fish Catch	Commercial fishing activities in the area outside of the Elkhorn Slough
Dredging Activities	Sediment removed from Moss Landing Harbor Channel
Cost of Shoreline Maintenance	Moss Landing Harbor maintenance of shoreline structures bordering wetlands
Cost of Well-Drilling	Cost associated with the drilling of wells for domestic use in surrounding areas
Duck Hunting	Intended to capture economic activities associated with duck hunting in local area
Duke Energy Maintenance	Cost to power plant to maintain water-intake pipes free of biological impediments
ESNERR Attendance	Number of visitors to access ESNERR through the Visitor Center entrance
ESNERR Gift Shop Sales	Sale of books, art, gifts, or souvenirs from gift shop located in Visitor Center
Failure of Wells	The rate of wells experiencing failure in surrounding areas
Kayak Gear Sales	Sale of kayak related equipment in the local area
Kayak Rentals	Kayak rentals originating from local merchants
Mosquito Abatement	Cost to Monterey County of mosquito abatement activities in Moss Landing Area
Photography Tours	Tours of local area intended to provide photographic opportunities
Public Access Visitors	Intended to capture access to the Elkhorn Slough by alternate entrances
Railroad Maintenance	Cost to maintain railroad dike and bridge structures crossing slough wetlands
Real Estate Sales	Sale of local residential and commercial property
Recreational Fishing	Participation of recreational fisherman in or around the Elkhorn Slough
Research Activities	The economic contribution of research projects conducted in the Elkhorn Slough
RV Park	Economic activities of recreational vehicle campground located in Moss Landing
Sport Fishing	Chartered fishing boats originating from Moss Landing
Whale Watching	Privately operated whale watching tours
Wildlife Tours	Privately operated tours to view wildlife

Table 1: List of local candidate indicators and brief explanations.

II B. Identification of Local Indicator Criteria:

I also created several additional criteria specific to this study to evaluate the indicators. While these criteria do not necessarily qualify as characteristics of future indicators in more extensive studies, due to the scale and scope of this initial phase, they did play a role in indicator selection. These criteria were:

1. Data must be publishable: Data must be able to be used in documents that are made available to the general public. This excludes some types of proprietary financial data from local businesses firms.

2. Ease of data collection: Investigators must be able to collect in a relatively short time-frame and so must be currently available or easily obtained.
3. Cost of data acquisition: Data must be available for minimal or no cost, due to the constraints of budgetary limitations.

III. Evaluation and Selection of Indicators:

Pendleton and I then evaluated the 27 candidate indicators according to the criteria developed during the literature review and case-specific research. This evaluation process included extensive input from the TWP Team. Evaluations were completed during verbal and written planning sessions and in the form of round-table discussions with the TWP Team.

During the evaluation process, I prioritized the relative connection of the economic activities to the ecological health of the environments and the overall economic contribution to local economies. Pendleton and I assigned each indicator a priority level ranging from one to five, with one being the most relevant, and then evaluated the indicators based on the other six criteria from the general literature review and the three criteria from the case specific research.

Pendleton and I then generated a list that ranked the indicators according to each indicator's ability to fulfill the criteria and selected the top ten. While future studies may select a greater number of indicators, this project chose only ten for the purpose of manageability. The selected indicators and rankings appear in Table 3 below.

Priority of Selected Indicators	
Indicator	**Priority**
ESNERR Attendance	1
Kayak Rentals	2
Commerical Fishing	3
Recreation Fishing	4
Cost of Dredging	5
Duke Energy Maintenance	6
Beach Visits	7
Bait Sales	8
Ice Sales	9
Cost of Well Drilling	10

Table 3: List of selected ecosystem-based economic indicators and priority.

IV. Identification of Indicator Data Sources:

After selecting the ten indicators, I researched and explored the potential data sources for each. The previous investigation detailing the number of participating firms, the history, and the projected future of each of the economic activities (II) was essential to the identification of data sources. I expanded my knowledge of potential sources via research into city and county records, personal communication with firm operators, and by exploring the data.

V. Collection of Indicator Data from Sources:

Once I located data sources, the firm and/or institutions were contacted. Through communication, either in person or via written correspondence, I invited each of the firms to participate in the study. Of the firms and institutions contacted, five made data relating to four different candidate indicators available, within the allotted data collection period of three months. Each of the responding organizations' data sources required unique request procedures and special use considerations. A short synopsis of the request procedure and the information the dataset details are featured in Table 4.

Description of Indicator Data and Request Process		
Indicator	**Request Process**	**Details**
Commercial Fishing	Requested from CDFG, via online request process with guidance from organization employees.	Reported commercial landings of all fish species by all gear types in pounds for the 12 CDFG blocks (Appendix C) outside Moss Landing from 1990-2004
Cost of Dredging - MLH	Direct written communication with the Harbor Master and staff	Payments made for dredging related services by the Moss Landing Harbor District from 1999-2004
Volume Dredged - USACE	Was requested under the revised Freedom of Information Act of 2005 and communication was conducted via written correspondence	Volume (cubic yards) of material removed during dredging events from 1947-2002
Recreational Fishing	Requested from CDFG, via e-mail communication with guidance from organization employees.	Number of Commercial Passenger Fishing Vessel Participants originating in Moss Landing Harbor from 1990-2005

Table 4: Request process for data sources and the details provided by each dataset.

Ecological Indicator Datasets

Kerstin Wasson Ph.D. and I selected candidate ecological indicators to include in the analysis through short discussions and investigations into available data. Prior to the project Wasson created an informational matrix that detailed what data was available, for what years, and possible connections with economic data. Based upon this informational matrix, the ecological indicators were evaluated using the same criteria as were used in the economic assessment, with emphases placed on connections to economic activities and availability of a historical data record. The data selected for inclusion originated from two ongoing studies taking place within the Elkhorn Slough. These datasets and a brief description are described in Table 5.

Ecological Dataset Descriptions		
Dataset	**Description**	**Parameters**
Elkhorn Slough Monthly Volunteer Water Quality Monitoring Program	Established in 1988 this monthly water quality monitoring completed by trained volunteers samples 24 sites through the Elkhorn Slough.	Temperature, Salinity, DO, pH, Turbidity, Nitrate, Ammonium, and Dissolved Inorganic Phosphate
National Estuarine Research Reserve Water Quality Program	Data from the network of 26 National Estuarine reserves is measured continuously at 30 minute intervals and housed online. Within the Elkhorn Slough this data is collected at 5 sites.	Water Temperature, Specific Conductivity, Salinity, Percent DO Saturation, Dissolved Oxygen, Depth, pH, and Turbidity

Table 5: Description and parameters of ecological datasets

VI. Integrating Ecological and Economic Data:

The differing temporal aggregations represented in each dataset, did not allow for direct comparison of economic and ecological data. To correct for this, I reconfigured several of the datasets to allow for comparison. For example, in the case of MLH dredging-related costs the values were recorded with specific dates. These individual payments were combined to find the total yearly cost of dredging-related activities. Table 6 details the procedures used for each individual economic and ecological dataset during this process.

Reconfigurations Made to Datasets	
Dataset	**Procedure**
Economic	
MLH Dredging Cost	Reconfigured to represent annual cost of dredging
USACE Dredge Volume	Reconfigured to represent annual volume of material removed
Commercial Fishing	Reconfigured to represent yearly totals of all blocks included in
Recreational Fishing	No reconfiguration
Ecological	
Elkhorn Slough Monthly Volunteer Water Quality Monitoring Program	Reconfigured to represent annual averages or number of days variables exceeded specific levels for the Kirby Park site
National Estuarine Research Reserve Water Quality Program	Reconfigured to represent daily and monthly averages, as well as counts of days that variables exceeded specific levels.

Table 6: Datasets and the reconfigurations made to the original data forms for comparison.

VII. Analysis of Relationships between Ecological and Economic Datasets:

After pairing the datasets, I examined the data for abrupt changes and noted the overall trends between and within the time-series. The exploration of data focused primarily on identifying major shifts in the indicator variables or years that appeared to be extreme outliers. First, I graphed each economic time-series noting large changes and general trends over the period. I then repeated this process for the ecological time-series. Each economic dataset was then paired with a related ecological variable, per earlier exploration into the economic and ecological connections (III, Ecological Indicator Datasets). I graphed the coupled time-series on opposing vertical axis with relevant scales and the same horizontal axis. By doing so, I was able to compare changes in the different types of data over the same period. These graphs appear in the Results and Discussion section below.

Results and Discussion

While in many natural and social science papers these are distinct and separate sections, the presentation of results and discussion of the results appear together to accommodate the reader. The graphs of individual ecosystem-based economic indicators for the entire period over which data was available for each are presented first. These figures are intended to establish a baseline of economic activity and to show how it has changed over the period detailed. Under each of these charts appears a brief discussion of the trends observed and the variables that may explain fluctuations in the indicators. Next, each individual economic indicator is graphed simultaneously with an ecological variable for a common time period. These graphical analyses are included to examine major changes in economic indicators and explore whether previous or simultaneous changes can be detected in the ecological indicators. A brief discussion of the changes in economic indicators and the possible correlations to changes in ecological indicators is found with the comparison graphs.

Ecosystem-based Economic Indicators

United States Army Corps of Engineers (USACE) Dredging

The first dataset representing economic activity details the volume of sediment removed during dredging events in Moss Landing Harbor. The volumes of sediment removed from the harbor channel represent a significant economic expenditure, with the USACE spending $3.3 billion from 1947 to 2002 (USACE 2006). This time-series is displayed in Figure 1 below.

USACE dredging data is an effective ecosystem-based economic indicator because it quantifies the volume of sediment deposited in the Elkhorn Slough main channel as the result of changing sediment transport processes (primarily the increased tidal currents and rates of tidal scour). The changes in the sediment transport processes are principally the result of harbor mouth relocation in 1946. Measures of tidal current and the rate of tidal scour are key variables used by the Wetland Planning Team to predict the likely environmental effects of possible management actions. Thus, economic activities related to them are important to include in this assessment. In addition, these processes indirectly contribute to other important changes taking place, such as the conversion of marsh to mudflat or altered species distributions, also utilized by the Wetland Planning Team to estimate changes.

Figure 2 depicts a general decrease in the volume of sediment removed over the period. Tests for linearity indicate that there is no significant relationship between the amount of volume removed by the USACE and year variables (Linear Regression $F_{1,5}$= 3.327, R^2= .447, p=.146). Several large outliers in the dataset influence the linearity test statistics. From 1947 to 1978, approximately half of the 57 years, the cumulative level of dredged sediment accounts for 71% of total sediments removed. The frequency of dredging events increased from 1990 to 2002 with over one-third of the dredging events occurring from 1990 to 2002, but these years only account for 16% of the cumulative volume removed. While not depicted here, the cost of dredging activities also increased from 1990 to 2000 with the 16 % of cumulative volume responsible for 33% of cumulative costs.

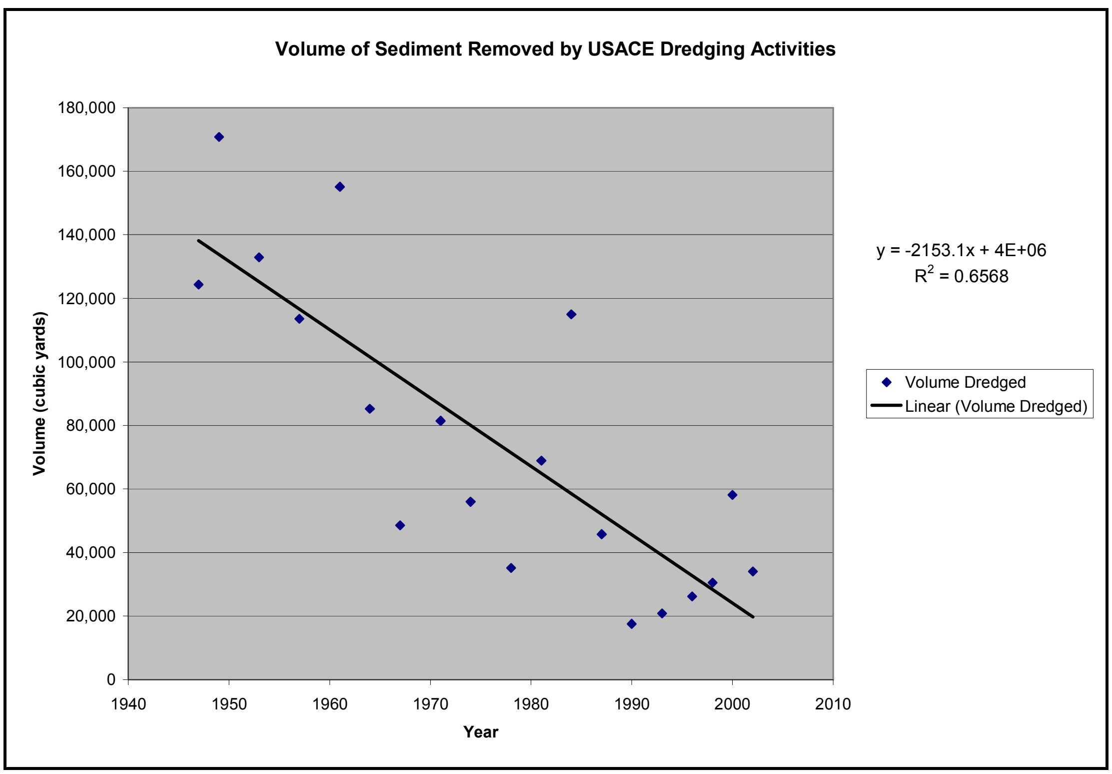


Figure 2: Time-series of USACE dredging volumes removed from Elkhorn Slough area from 1947 to 2002.

As illustrated by the graph, the USACE does not dredge every year. Research into the documents provided by the USACE revealed that Moss Landing, at least recently, is on a three-year dredging cycle. Annual sediment level surveys conducted by the USACE, may adjust the dredging schedule in the case of extreme or insufficient sediment levels in the harbor. Personal communication with USACE members further revealed that the timing of dredging events is also the result of numerous non-environmental variables. These variables can include:

- The amount of funding provided to the USACE for dredging events
- The completion of required sediment testing to decide if dredged sediment requires special disposal
- The status of permitted disposal sites (e.g.: open, full, or restricted)
- Navigation and safety considerations of dredging equipment
- New or existing regulatory controls

The extent to which these administrative variables affect the timing and scope of dredging events is unclear at this time and must be further researched to quantify the role of non-ecological variables.

Moss Landing Harbor (MLH) Dredging

The data in Figure 3 represent an alternate measure of dredging-related economic activity in the Elkhorn Slough area. This dataset details the cost to the MLH of dredging-related expenses from 1999 through 2005 in real U.S. dollars. MLH represents an important economic value to the Moss Landing area, with average annual expenditures of around $10 million from 1999 to 2001. Dredging activities account for variable percentages of this annual budget as illustrated by the values in Figure 3. MLH dredging is important to ensure the continuation of current economic activities, such as commercial fishing or vessel storage.

Just as with the USACE dataset, the values in Figure 3 represent an important connection to the changing sediment transport process within the Elkhorn Slough. Human influences and the natural processes that have resulted from those influences have altered the sediment transport process and changed the erosion/deposition balance of the ecosystems. The values depicted in Figure 3 may partially reflect these changes in sediment transport.

The data in Figure 3 spans a period of only six years. This short period over which the dataset was available makes trend observation difficult and weakens the statistical power of the results. There does not exist a significant linear relationship between the variable of year and the cost to MLH of dredging-related activities (Linear regression $F_{1,5}$= 2.170, R^2= .303, p=.201). The test statistics of linearity are greatly influenced by the large outlier of the year 2000 value. This value is larger than all others combined. The year 2000 value represents an increase of more than 2.3 million dollars from the previous and next highest expense year. Data detailing years before 1999 was not available at the time of collection, and thus it is hard to estimate the variance of the 2000 value from earlier years.

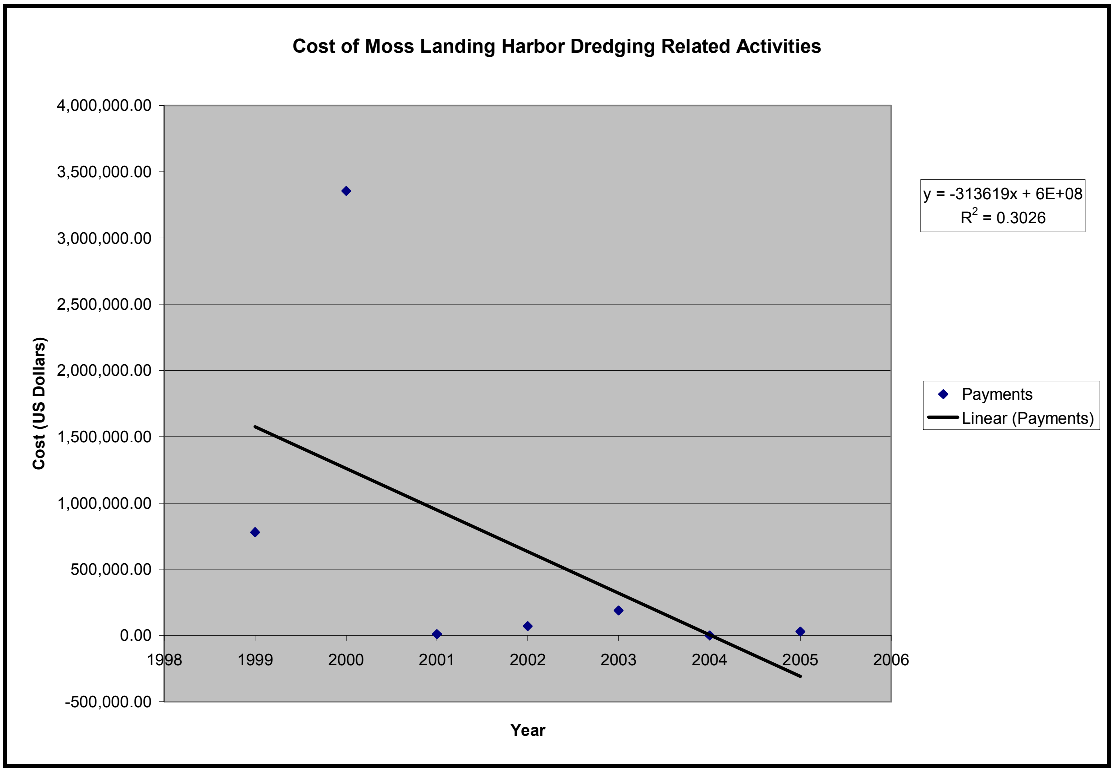


Figure 3: Time-series of Moss Landing Harbor payments for dredging related costs from 1999 to 2005.

Unlike the USACE dataset, which details the volume of sediment removed, the MLH data represents payments made for dredging-related activities or processes. These activities and processes include consulting fees, permitting procedures, environmental impact statements, the disposal of sediment, and the actual cost of dredging actions. Payments made during any one year may be for services rendered in prior years, or in preparation for future dredging-related activities. The dredging-related costs of MLH vary according to the similar administrative and fiscal variables as outlined by the USACE. Since the MLH is a smaller organization with a substantially smaller fiscal budget, it is more affected by these constraints.

Commercial Fishing

Figure 4 illustrates commercial fishery landings of Elkhorn Slough-dependent species (see page 8) for the years 1996 to 2005. The data includes all reported landings by commercial fishers of slough-dependent species caught within the 20 CDFG blocks as reported to the CDFG. Commercial fishing activity represents an important economic source to Moss Landing and the greater Monterey County areas. In 2003, the commercial fishing industry in Moss Landing included 125 resident and 175 non-resident fishing operations, seven resident and many non-resident fish buyers, as well as local or non-local businesses that provide goods and services to the industry (Dalton & Pomeroy 2003). Dalton and Pomeroy estimated the direct economic value of commercial fishing at MLH to be between $18 million and $25 million per year (2003).

The commercial fishing industry is important to include in this assessment because several commercially viable species depend on the slough as a nursery or spawning ground. The two dominant fisheries in the MLH area are the coastal pelagic species (CPS) and groundfish groups, both of which contain species dependent on Elkhorn Slough ecosystems. The coastal pelagic species group contains the market squid, pacific sardine, northern anchovy, and mackerel. The groundfish category includes flatfish, roundfish, and some rockfish species. Slough-dependent species in these two categories include the northern anchovy, english sole, cabezon, and sanddabs.

The populations of slough-dependent species fluctuate in response to environmental variables. These variables include dissolved oxygen concentrations, salinity, temperature, turbidity, and nutrient levels. Within the Elkhorn Slough, two monitoring programs continually measure these and other variables. Each of these monitoring programs has a time-series greater than ten years and thus is a strong candidate for trend identification and comparison with economic indicators.

Figure 4 displays a general increase in fish landings over time, but is greatly influenced by large outliers. Tests for linearity reveal there is not a significant linear relationship between the pounds of slough-dependent species landed and the year variables (Linear Regression $F_{1,8}$= 1.098, R^2= .121, p=.325). The lowest value during this period appears in 1998 with a catch of approximately 16.5 million pounds and the maximum value appears in 2005 with a catch exceeding 78.6 million pounds. The dominate portion of the slough-dependent species is composed of the northern anchovy; northern anchovy account for as little as 55% and as much as 97% of the slough-dependent fish species detailed below. For six out of the ten years northern anchovy accounted for over 90% of the landed weight of slough-dependent fish species.

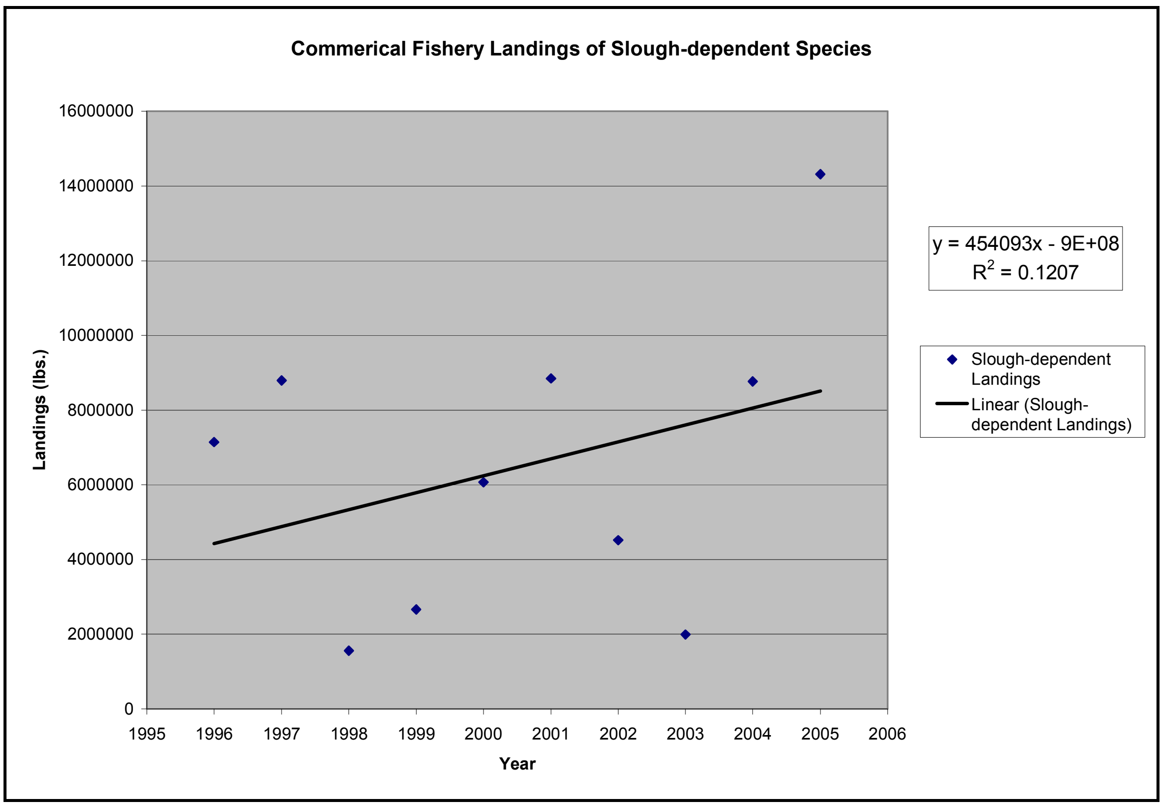


Figure 4: CDFG commercial fishery landings of slough-dependent species in the Elkhorn Slough area for the years 1996 to 2005.

One explanation of the changes observed in Figure 4 may be fluctuations of market values for fish species. While the landed values associated with the weights for these years were not collected for this project, per pound values do play an important role in fishery shifts. Changing values of a particular fish species will either increase or decrease the catch of that species relative to others. Dalton and Pomeroy note that increases in the value of CPS, particularly sardines, has heightened vessel revenues and encouraged Moss Landing commercial fishers to increase CPS landings (2003).

While sardines are not included in the slough-dependent species data above, the northern anchovy is included. As previously mentioned, the northern anchovy account for much of the slough-dependent species landed weights, averaging 86% of the total from 1996 to 2005. The National Ocean Economics Program (NOEP) keeps a database of landings and price/pound for counties in coastal states. In Monterey County in 1996, northern anchovy had a price/pound of $.05, with a landed weight of 7.8 million pounds. The price/pound increased in 1997 to $.06, with a landed weight of 8.5 million pounds. In 1998, the price fell to $.03, with a landed weight of 1.9 million pounds (NOEP 2006). The correlation of increased price/pound and the increased landing of northern anchovy reflect the rise and fall of the data in Figure 4. When prices climbed from 1996 to 1997 the landed weight of anchovy increased, and when prices declined from 1996 to 1998, the landed weight decreased. The 1999 and 2000 years, experienced increases in price/pound and the landed weight of northern anchovy, which also follow the patterns of increased landings in Figure 4 (NOEP 2006).

Another important influence on commercial fishery landings is the changing regulations of managing agencies. The commercial fisheries of the Moss Landing area are regulated by the Pacific Fishery Management Council (PFMC) on the federal level and the CDFG at the state level. Changes in policies of these managing institutions do affect the landings of the commercial fishing industry (Dalton & Pomeroy 2003). The northern anchovy is regulated primarily by state-level authorities under the regulations outlined in the Northern Anchovy Fishery Management Plan (NAFMP). While recent amendments to the NAFMP were made in 1998 and 2000, these changes did not significantly affect the take of northern anchovy, but were intended to manage other CPS species (Dalton & Pomeroy 2003).

Other slough-dependent species have experienced a greater effect of changing regulations. Sole, sanddab, cabezon, and lingcod fisheries are among those affected by changes to groundfish regulations over the past decade. At the federal level, the PFMC began actively managing groundfish populations in 1982, with the introduction of a limited entry program for the groundfish fishery in 1994 (Dalton & Pomeroy 2000). While the early efforts of the PFMC groundfish management were focused initially on protecting widow rockfish and hale, the policies have expanded to encompass over 80 species of fish (Dalton & Pomeroy 2000). Catch limits were imposed in 2000 when the West Coast groundfish fishery was declared a federal disaster. Subsequent restrictions in 2002 and 2003 limited further the take of groundfish species.

These changes as well as state-level efforts such as the Nearshore Fishery Management Act and the Nearshore Fishery Management Plan, have resulted in the decrease of landed weight in many species of groundfish. With respect to the Moss Landing fisheries, these species combined account for an average of 12% of the slough-dependent species. It is likely then, that regulatory changes in these fisheries also contribute to the changing values of slough-dependent species displayed in Figure 4.

Recreational Fishing

Figure 5 depicts the number of passengers on Commercial Passenger Fishing Vessels (CPFV) leaving from Moss Landing Harbor in 1990 through 2005. The values represent the number of individuals taking place in CPFV trips and not the number of trips originating from the port. The recreational fishing industry contributes value to the Moss Landing area by expenditures for fishing guide services, CPFV operations, or recreational fishery support services such as bait or tackle sales. There are three recreational fishing charter services, many vessel supply and support businesses, and approximately six fishing supply businesses (including bait, tackle, and ice sales). Recreational fishing does not take place only from CPFV vessels, but also from the jetties that line the harbor. Fishing off jetties does not require a fishing license and details on the number of participants has not been located.

Data describing some measure of recreational fishing activity is important to include in this assessment because of the economic contribution of the recreation and tourism industries to the Moss Landing economy. Several species of fish commonly caught during recreational fishing are slough-dependent species. Rockfish and flatfish rank in the top four categories of fish commonly landed by recreational anglers.

Figure 5 displays the number of CPFV participants has generally increased over time with several outliers appearing across the time-series. Linear regression reveals there is a strong linear relationship between the number of CPFV trips and the year variable ($F_{1,14}$= 53.082, R^2= .791, p>.001). The linear correlation coefficient of .79 is the highest value in all the economic indicator datasets. The minimum value takes place in 1991 with six participants and the peak value appears in the 2005 year, with 3947 participants.

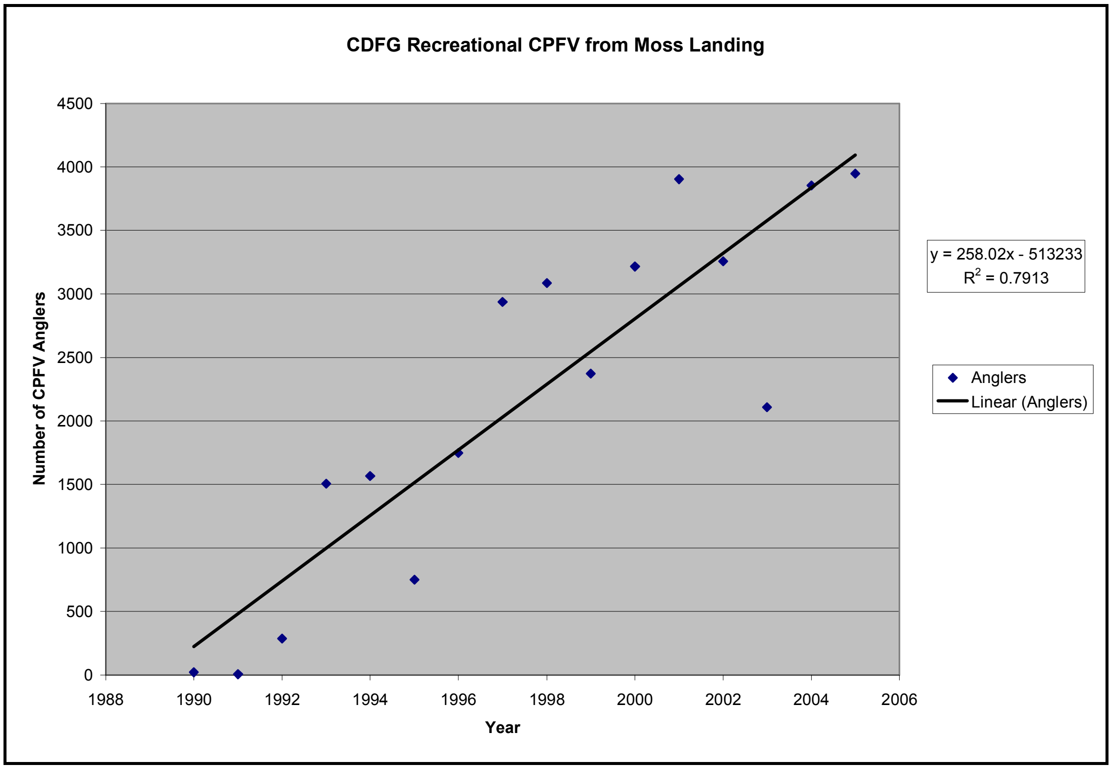


Figure 5: Time-series of CDFG recreational CPFV trips originating from Moss Landing Harbor in the years 1990 to 2005.

The Recreational fishing industry is also subject to regulation by state and federal authorities. The primary authority in the Moss Landing recreational fishing industry is the CDFG and its local offices. Several changes in recreationally important species in past years may account for shifts in the number of CPFV participants. As with the commercial fishing industry, the recreational groundfish fishery is closely regulated. The CDFG lists the following fish as protected under current groundfish regulations: leopard shark, cabezon, lingcod, sablefish, numerous species of rockfish, several species of sole, and the starry flounder. All of these fish are found within the waters of the Elkhorn Slough.

While it is known that these groundfish are currently protected, research did not uncover sources able to detail the history of changing regulations.

The method of survey used by the CDFG may also play a significant role in the shift in participants over time. While no data has yet been located relating to the method of CDFG data collection for this specific measure, changes were made to the methodology used to record the catch of CPFV vessels in early 2000 (CDFG 2004). The pattern of increase and the minimal 1991 and 1992 levels suggests that the frequency and thoroughness of CPFV data sampling may have increased in later years.

Ecosystem-based Economic Indicator and Environmental Indicator Comparisons

USACE Dredging and Turbidity

Figure 6 displays the volume of dredged material removed by the USACE on the left vertical axis and the maximum monthly turbidity measured by ESNERR water quality volunteers on the right vertical axis. The maximum monthly turbidity was calculated by taking the highest monthly value of turbidity for each year and is intended to act as a measure of extreme sediment loads carried in the water and/or large sediment transport events. While turbidity can be the product of a variety of factors, sediment loads contained in the water column are a major contributor of turbidity levels in estuarine environments (Ward & Trimble 2003). As mentioned in the section describing the USACE dataset time-series, the frequency of dredging events depends upon a variety of fiscal and administrative variables. However, as seen in Figure 6, these changes may also be correlated with high levels of turbidity. This correlation assumes that the amount of sediment can be at least partially quantified by the maximum monthly turbidity as calculated here.

This relationship is characterized by a time lag of approximately 1-2 years. This means the volume dredged in 1993 is not a direct result of increased levels of turbidity in 1993, but the years prior. The large dredging volumes observed in 1998 and 1999, could be an expression of the extreme turbidity measures in 1997 and 1998. Likewise, the volume of sediment removed by dredging in 2002 may have been necessary due to the 2000 and 2001 turbidity values.

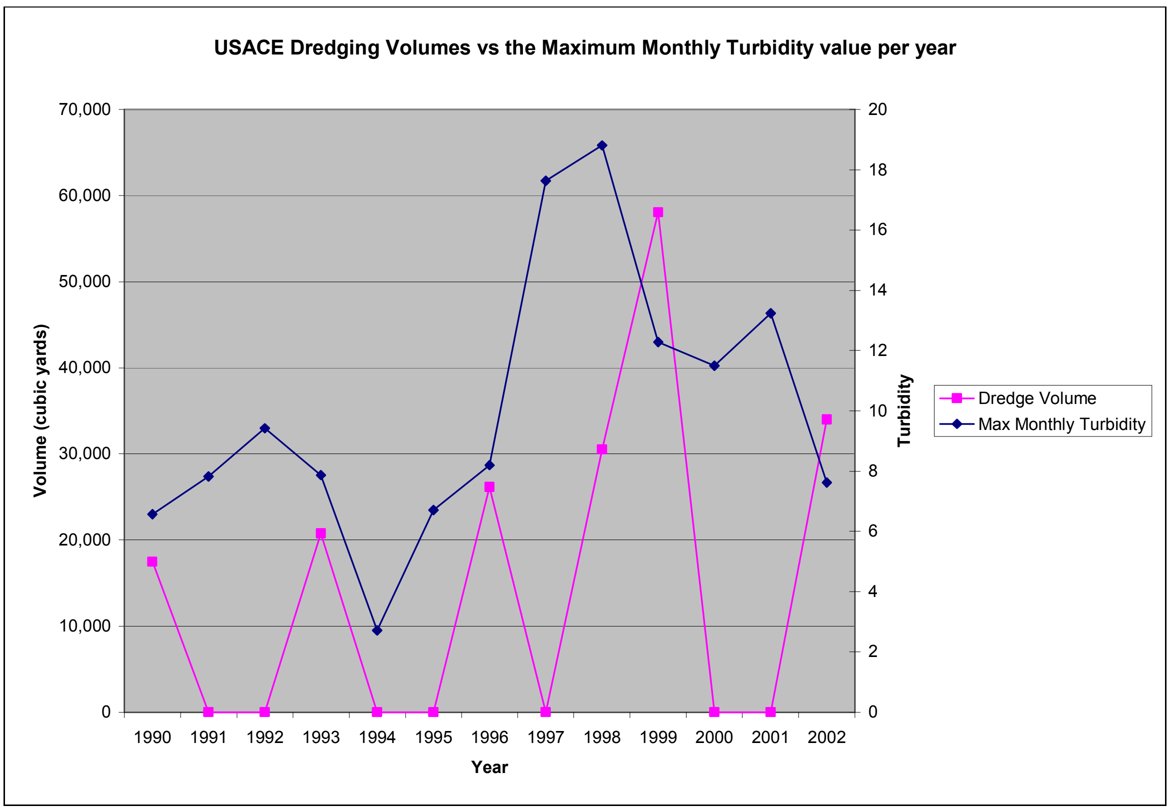


Figure 6: The volume dredged by the USACE in comparison to the maximum monthly turbidity per year from 1990 to 2002.

Moss Landing Harbor Dredging and Turbidity

Figure 7 is a graph of the MLH's dredging-related costs on the left vertical axis and the maximum turbidity value recorded by the NERR monitoring network annually on the right vertical axis. This dataset displays the total time-series available for maximum annual turbidity and the six years (1999-2004) of MLH dredging-related cost data. These measures are intended to represent a comparison between events of extreme turbidity and the cost of dredging over time. As discussed in the section detailing the MLH dredging cost dataset, this data represents payments made for dredging-related activities or processes. Payments made during any one year may be for services rendered in prior years or in preparation for future dredging-related activities. Just as in the case of the USACE dredging activities, administrative and fiscal variables play an important role in the timing and scale of dredging events.

Observation of Figure 7 suggests a correlation between increased turbidity and increased dredging-related costs. The elevated measures of maximum annual turbidity in 1997 and 1998 could be responsible for the increased dredging-related costs (assumed to relate directly to yearly dredging activities) in 2000. This correlation implies a 2-year time lag between increased levels of maximum annual turbidity and the MLH dredging-related costs. If this relationship is accurate, the smaller peak in maximum annual turbidity values in 2000 may also help explain the subsequent increase in dredging-related costs in 2002 from the prior 2 years.

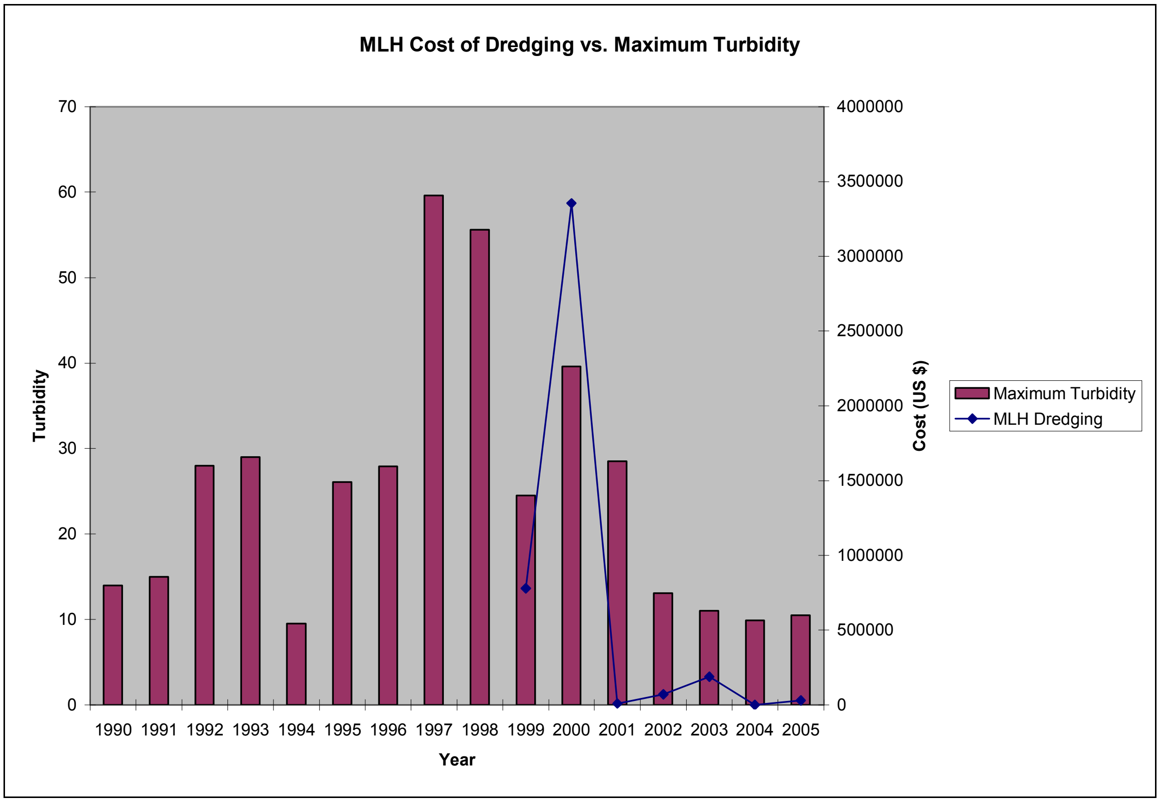


Figure 7: Shows the comparison of Moss Landing Harbor dredging related expenses in line form and the average maximum daily turbidity value per year in bars.

Commercial Fish Catch and Hypoxia

Figure 8 shows commercial catch of slough-dependent species on the left vertical axis and the number of days per year that slough waters demonstrated hypoxia (extended levels of oxygen depletion) on the right vertical axis. Changes in landings could be the product of the aforementioned regulatory changes or market fluctuations, but may also be partially attributed to changes in ecosystem conditions such as hypoxia (<3mg/l of dissolved oxygen). Juvenile fish species are likely to be sensitive to the availability of oxygen in estuarine waters (Taylor & Miller 2001). Figure 8 depicts the number of hypoxic events in the slough. Peaks in the number of hypoxic days/year immediately precede nadirs in landings for slough-dependent species. The high number of hypoxic days in 1995 could have triggered the death of fish larvae or juveniles that contributed to the lowered landings of fisheries in 1997; this pattern is repeated with the smaller peak of hypoxic days in 2000 and the decline of landed fish in 2002. As the number of hypoxic days stayed relatively low from the years of 1997 to 1999, the fish species dependent on the slough may have rebounded, possibly contributing to the increasing catch peaking in 2000.

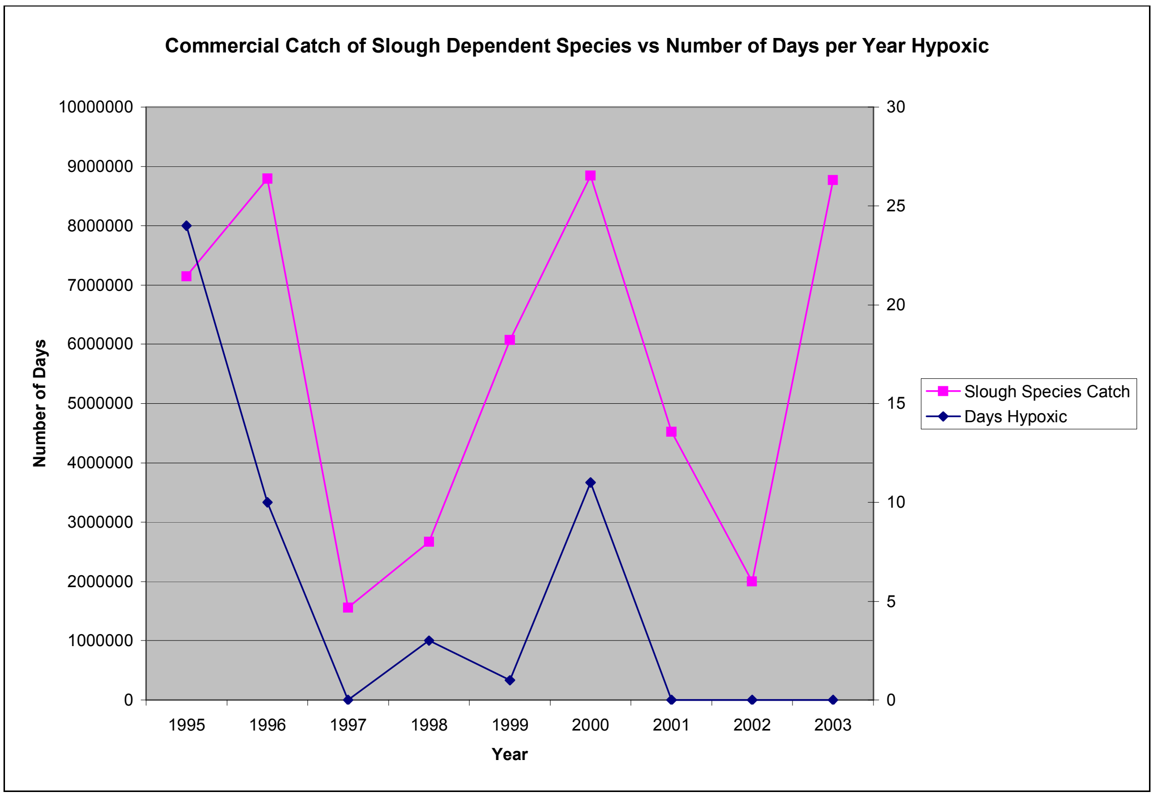


Figure 8: Commercial landings of slough-dependent species and the number of days hypoxic from 1995 through 2003

Recreational Fishing and Hypoxia

Figure 9 displays the number of people taking part in CPFV recreational fishing trips on the right vertical axis and the number of days the slough waters experienced hypoxia on the left vertical axis. CPFVs are not allowed inside ESNERR, but several species sought during recreational trips are considered slough-dependent species (rockfish, elasmobranches, etc). CPFV participation levels will change according to the earlier regulatory and annual variables mentioned in the recreational fishing section above, but may also be linked to the environmental health of the slough nursery.

One of these environmental conditions could be the number of hypoxic days experienced in slough waters. Any causal change in recreational participation caused by hypoxic conditions in the slough would likely display a significant time lag of several years. This relationship assumes that the number of CPFV participants would decrease if slough-dependent species' survival rates decreased with the increased frequency of hypoxic days. The peak value in number of annual hypoxic days occurs in 1996 and may be partially responsible for the diminished increase from 1998 to 1999, when compared to previous years. In addition, the peak hypoxia levels in 1996 may be correlated to the decreased participation rates in 1999. Likewise, the elevated levels of hypoxic days in 2001 may have played some role in the decreased participation levels of 2003. These reduced participation levels may be the result of recreational fishers observing decreased catch success due to diminished fish populations as the result of hypoxic events. However, the time lag observed may be too short a period of time for recreational fishers to notice the effects of the increased frequency of hypoxic events enough to impact their decision to take place in Moss Landing CPFV trips.

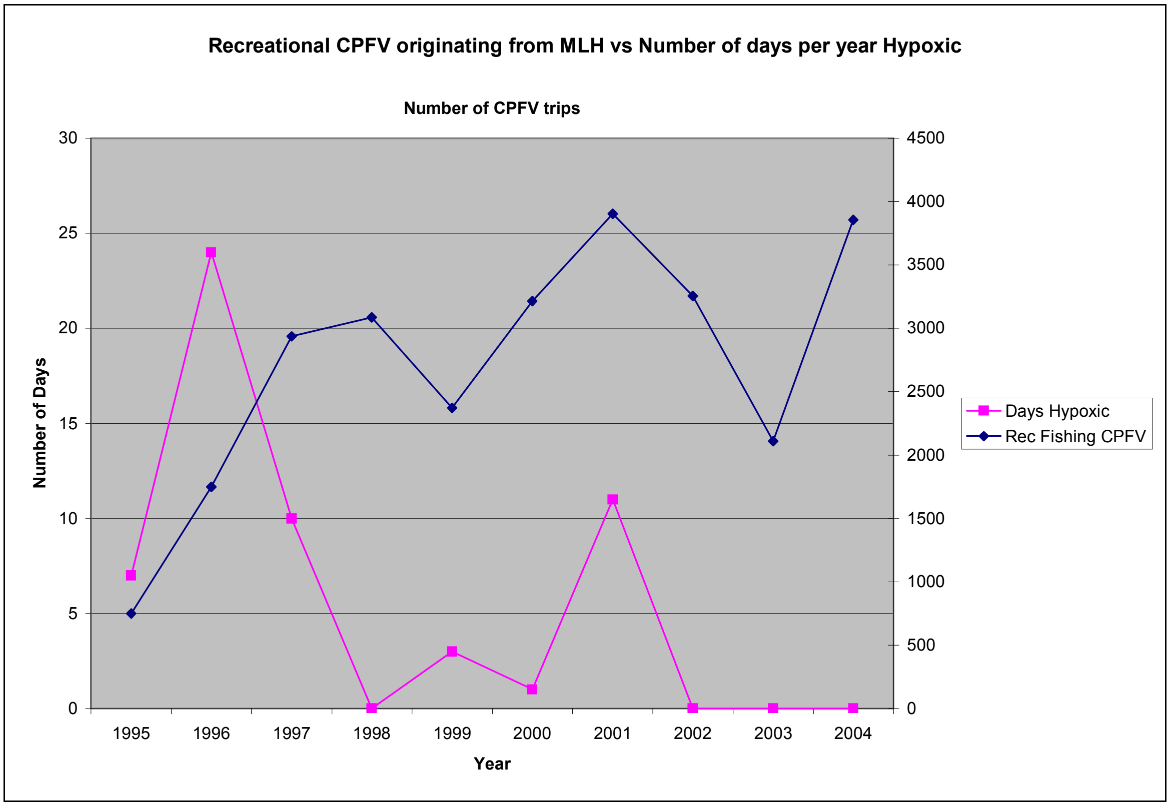


Figure 9: Shows the comparison of Moss Landing Harbor dredging related expenses on the left axis and the average maximum daily turbidity value per year on the rightmost axis.

Conclusions

This Capstone explored the use of ecosystem-based economic indicators in assessing EBM restoration options. This investigation researched, evaluated, and selected ecosystem-based economic indicators and then surveyed the indicators' potential to inform managers of the changes taking place in both economic and ecological systems. The specific ecosystem-based economic indicators chosen for review in this study were the volume of sediment removed by the USACE during dredging activities, the cost of dredging-related activities to the MLH, the pounds of slough-dependent species caught by commercial fishers, and the number of CPFV participants leaving from Moss Landing.

In particular, this report undertook four main objectives. Information gained about these objectives and reviews of key results are featured in this section. Resulting recommendations to the managers of the Elkhorn Slough are summarized in bullet form including caveats and limitations that require explanation. Finally, recommendations for future studies and additional work are purposed.

Summary of Objectives

This Capstone's first objective was to explore the idea that economic indicators can act as effective tools to better inform ecosystem managers. The results show that ecosystem-based economic indicators do offer important insight into the economics of a region by articulating the number and type of organizations participating in the area's economy. Case specific research revealed those businesses linked to ecosystems and thus offer a view of organizations that would be affected by changes in ecosystem management. Ecosystem-based economic indicators also serve to establish a baseline of economic activity and show the historical trends. This economic information is important to managers as they consider or implement new ecosystem management policies, and track how these changes alter the economic activity in the area. The information concerning the financial contributions of the commercial fishing industry and the large number of related businesses in the Moss Landing area is an excellent illustration of the need for this type of research. Any management decisions, which failed to consider the possible impacts of restoration alternatives on fishing, would be incomplete in assessing the cumulative impacts of such actions. This report demonstrates that ecosystem-based economic indicators can be used as an effective tool to inform ecosystem managers.

This Capstone's second objective was to determine whether economic and ecological data could be collected. The datasets gathered during this investigation clearly demonstrate that information detailing these areas is available and can be gathered. However, this lengthy and demanding process requires coordination and continued follow-up. Each data source had a unique request procedure and many required special considerations before use. Often, upon collection, data required reconfiguration before its application to this project. The USACE dredging volumes dataset is an example of the difficult request procedure. Not only did it require an extensive request process, but dialogue with USACE personnel to understand the values provided was also necessary. No changes to the USACE data were needed to compare the values with the ecological variable of maximum monthly turbidity, but the process of selecting and calculating data for this ecological counterpart did require time and research. All of these procedures, as documented in the Methods section, are important information for managers to consider before selecting candidate indicators. The data gathered for this project illustrates economic and ecological indicators can be collected.

This Capstone's third objective was to establish whether economic and ecological data could be integrated in order to identify the impacts of environmental change on economic activities. Figures 6-9 show the integration of economic and ecological indicators. These correlative graphs demonstrate that datasets can be merged to generate a time-series of economic and ecological trends. Changes in economic activity are the result of administrative and/or fiscal variables, as described in the Ecosystem-based Economic Indicators section of the Results, but can also be linked to changes in ecological indicators. The relationships between the turbidity levels and dredging volumes or costs, as well as relationships between hypoxic conditions and fish catch demonstrate possible links between economic and ecological systems. The integration of economic and ecological datasets can help to identify impacts of environmental change on economic activities.

This Capstone's final objective was to explore whether natural resource managers can use the relationships between economic and ecological indicators to predict changes in economic activities that may result from management actions or policies. For this process to take place, ecosystem managers first need to estimate the ecological effects of proposed physical changes driven by management objectives. In the case of the Elkhorn Slough, the TWP Team has already offered an introductory assessment of the likely outcomes from each of the proposed restoration alternatives. Quantifying ranges of likely effects associated with the options must be added to this initial step. Then, the relationships mentioned in the above paragraph, such as the one between turbidity levels and the cost of dredging, could be computed through statistical analysis and used to predict limits of likely economic effects based upon the ranges of estimated ecological changes for each restoration option (See Appendix A). While the enumeration of statistical relationships between economic and ecological datasets was beyond the scope of this investigation, future work by NOEP will directly address this analysis.

Recommendations

Based on the information found in this case study, the author recommends the following actions to the managers of the Elkhorn Slough:

- Use ecosystem-based economic indicators, alone or in combination with other valuation tools, to better integrate economic data into EBM plans or restoration actions.
- Perform additional research into the availability of economic and ecological indicators.
- Work with community partners to establish relationships that would increase the participation of public agencies and private firms in the data collection process.
- Use the relationships between ecological and economic indicators to estimate the likely effects of ecological changes driven by new management policies on ecosystem-based economic activities.
- Encourage other estuarine areas to undertake similar studies defining economic activities and selecting important indicators to compile a compendium of economic indicators that might may connected with ecosystem changes.

Data Limitations

The data and conclusions reached in this report must be viewed with an understanding of the limitations or caveats associated with the data as it appears here. In many cases, datasets were reconfigured from original form into annual totals, averages, or counts to allow for comparison of ecological and economic datasets. These actions decrease the accuracy of data and limit the ability of analyses to detect events with large variation from normal levels. Other measures, such as the maximum annual turbidity, assess only extreme values and may not accurately reflect the annual average conditions of an indicator. Ecological indicator data derived from the Elkhorn Slough Volunteer

Monthly Water Quality Monitoring Program represent only values collected at the Kirby Park testing site. Ecological indicator data originating from the National Estuarine Research Reserve Water Quality Program detail only the site located at the South Marsh monitoring site. These single-site measures may not accurately indicate levels elsewhere in the slough. In addition, any proposed relationships suggested in this investigation are based solely on visual inspection of comparison graphs and do not represent statistical analyses.

Future Work

This investigation represents a pilot study into the use of ecosystem-based economic indicators. Continuing work by the NOEP and Principal Investigators Judith Kildow Ph.D. and Linwood Pendleton Ph.D., will further advance the understanding of this new methodology and its role in EBM. The continued investigation will build upon the lessons learned in this initial phase, and refine the methodology for natural resource managers.

Similar investigations into economic indicators are currently under way in other California estuaries. The economic indicators that are identified in this case study may have partner indicators in other wetland areas that would encourage comparison, correlation, and verification among the Elkhorn Slough and other estuarine ecosystems. Cooperation among the managers of these estuaries and other natural resource administrators will advance the development of improved tools for the multidisciplinary integration of information.

Ecosystem Based Management is an integrated approach to management that considers the entire ecosystem, including humans. The goal of EBM is to maintain an ecosystem in a healthy, productive and resilient condition so that it can provide the services humans want and need. (McCloud et al 2005)

The increased utilization of EBM across the globe has inspired the search for tools that can better inform ecosystem managers. This Capstone project worked to explore the efficacy of ecosystem-based economic indicators. Ecosystem-based economic indicators can be used to better integrate economic and ecological data and provide a more comprehensive view of the entire ecosystems including humans. While this study is preliminary, the lessons learned serve to advance the understanding of the advantages and limitations of this new methodology and will better guide future developments. It is through the investigation and development of tools like this groundbreaking approach to ecosystem valuation that the science of EBM can more effectively maintain ecosystems that are healthy, productive, and resilient.

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Appendix A – A Note about NOEP Future Development

While beyond the scope of this Capstone, future work by NOEP will offer estimates of the likely economic implications of each of the restoration options proposed for the Elkhorn Slough. These predictions are important as Elkhorn Slough managers consider the cumulative effects on all components of the ecosystem, consistent with the principles of EBM. Preliminary work completed by the TWP Team has initiated the evaluation of potential physical changes. As these estimates are refined and further investigated, managers will be able to more accurately predict the physical effects to slough ecosystems resulting from restoration options. Based on the changes to physical environments, NOEP will offer estimates as to what economic activities will be affected by each restoration option.

One example of the usefulness of this process can be seen in the estimation of economic effects resulting from adoption of option **A**. Option **A** is composed of four parts and consists of adding a water control structure(s) beneath the Highway 1 Bridge **(A1)** and then the addition of sediment to surrounding areas in order to simulate previous marsh conditions (**A2-A4**).

The introduction of a water control structure that is high enough to decrease the tidal prism may have implications for watercraft such as kayaks or research vessels. While the structure is intended to be only temporary, the time required to achieve the desired results is not expressly stated. Even temporary closure of the connection between the lower slough and the ESNERR reserve could result in significant loss of revenues to kayak rental shops and guided boat tours.

Options **A2-A4** each involve the addition of sediment to slough ecosystems. These actions are intended to replicate a graded slope above the bridge **(A2)**, elevate subsided areas to restore intertidal marshes **(A3)**, and restore appropriate sediment levels to adjacent tidal creeks **(A4)**. Through hydrological transport processes much of this sediment could be quickly displaced, deposited in the slough main channel or into the Monterey Bay. Subsequent additions may experience increased residence time as marsh plants colonize the area and the roots retain substrate. The time necessary for this colonization to take place as well as the overall efficacy of this process in specific areas is uncertain. However, it is very likely that at least some portion of these sediments will be deposited into the slough main channel or harbor areas resulting in the need for increased dredging scope and frequency. As detailed in this Capstone dredging activities are essential to maintain the commercial viability of the Moss Landing Harbor and represent significant economic expenditures to the Moss Landing Harbor Authority and the United States Army Corps of Engineers.

While this example is simple and lacks rigorous evidence to support the proposed economic implications, it does serve as an illustration of the unintended effects restoration options may have on area economies. It is presented here only to underline the complexity of the decisions that face the natural resource managers and to reinforce the need for effective tools that can predict economic ramifications of changing ecological policies.