


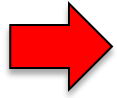
# ELKHORN SLOUGH NATIONAL ESTUARINE RESEARCH RESERVE

An aerial photograph of the Elkhorn Slough National Estuarine Research Reserve. The image shows a large, winding body of water (the slough) flowing through a landscape of agricultural fields and wetlands. In the background, a small town with a prominent church steeple is visible near the ocean. The foreground is dominated by the intricate, winding channels of the slough, which are surrounded by dark, marshy land. The sky is clear and blue.

Long-term water quality monitoring  
and eutrophication research

# ROAD MAP

## **WATER QUALITY MONITORING AND TRENDS**



- ESNERR water quality monitoring
- Examples of spatial and temporal trends from monitoring
- Local WQ improvement due to restoration
- Nutrient sources and loads: new perspectives

## **EFFECTS OF NUTRIENT LOADING ON THE ESTUARY**

- Eutrophication assessment of the estuary
- Ecological studies of negative effects of eutrophication
  - Eelgrass
  - Fish
  - Oysters
  - Salt marsh

## **TAKE HOME MESSAGES**



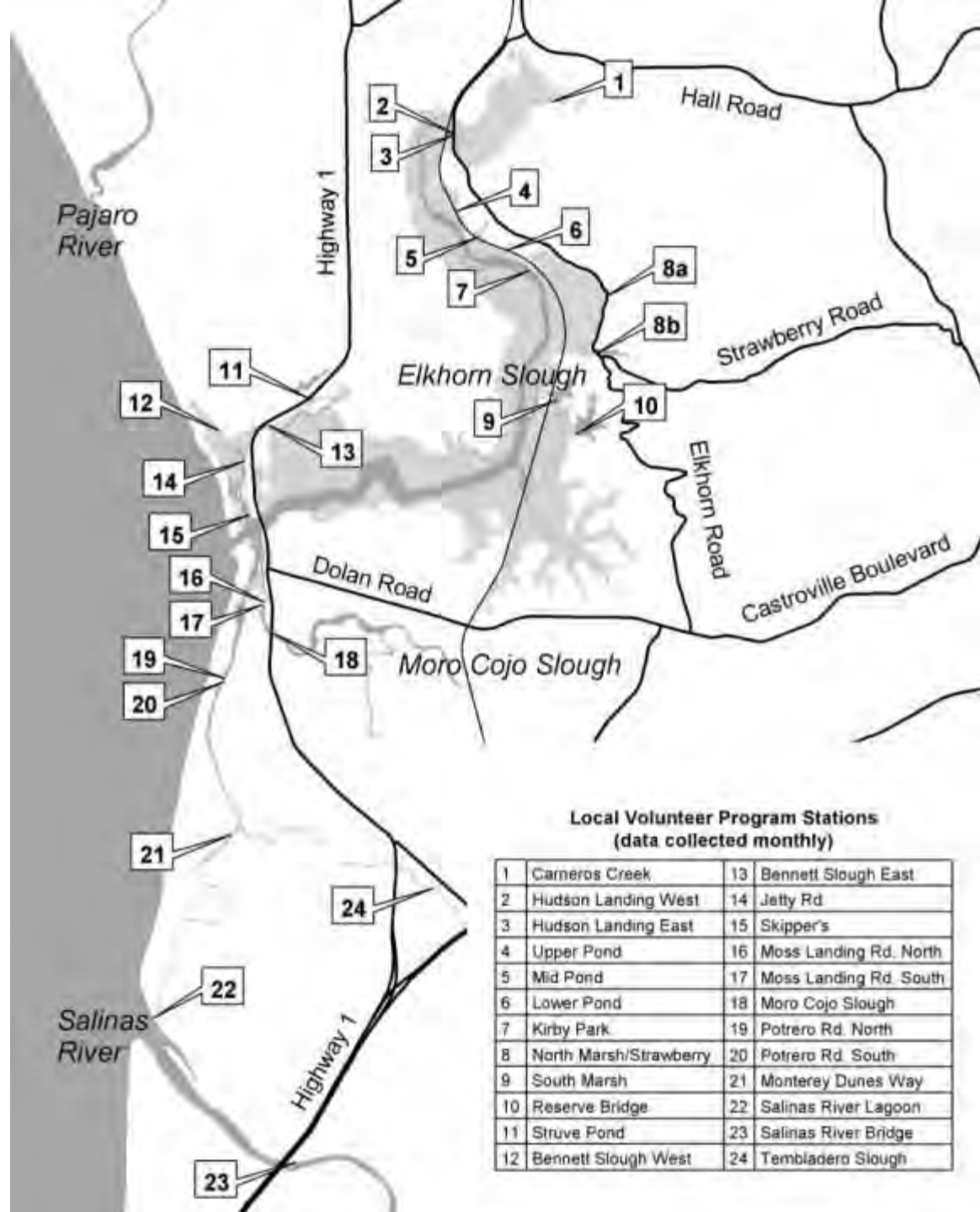
# ESNERR Water Quality Monitoring



# ESNERR WQ Monitoring Programs

## Volunteer Program

- Great spatial coverage (24 stations)
- Monthly sampling
- Very long time series (since 1989)
- Physical Parameters and nutrients





# WQ Monitoring Program-Volunteer Sites



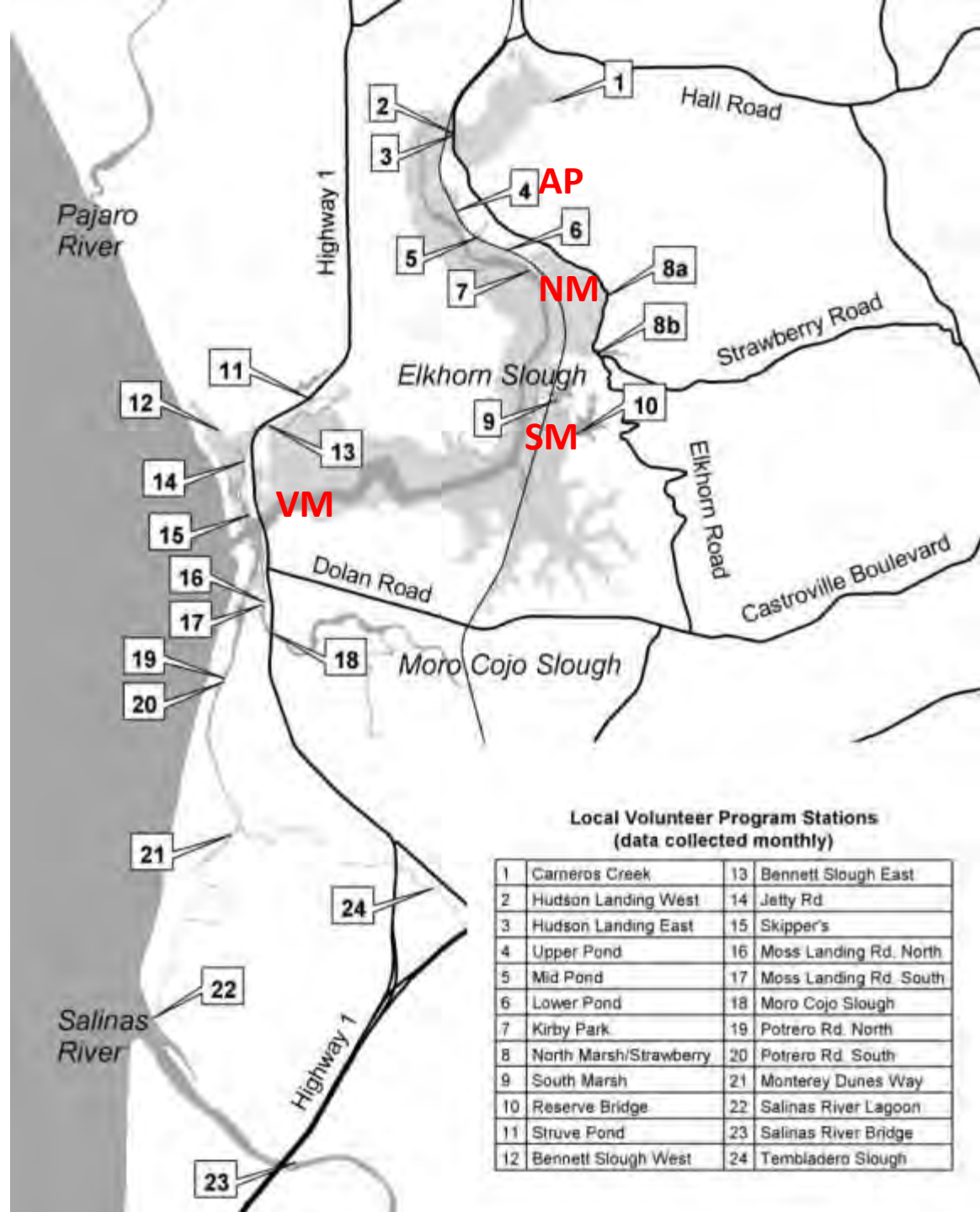
# ESNERR WQ Monitoring Programs

## Volunteer Program

- Great spatial coverage (24 stations)
- Monthly sampling
- Very long time series (since 1989)
- Physical Parameters and nutrients

## NERR Program

- Great temporal coverage (every 15 min!)
- 4 stations
- Since 1995



Local Volunteer Program Stations  
(data collected monthly)

1	Carneros Creek	13	Bennett Slough East
2	Hudson Landing West	14	Jetty Rd
3	Hudson Landing East	15	Skipper's
4	Upper Pond	16	Moss Landing Rd. North
5	Mid Pond	17	Moss Landing Rd. South
6	Lower Pond	18	Moro Cojo Slough
7	Kirby Park	19	Potrero Rd. North
8	North Marsh/Strawberry	20	Potrero Rd. South
9	South Marsh	21	Monterey Dunes Way
10	Reserve Bridge	22	Salinas River Lagoon
11	Struve Pond	23	Salinas River Bridge
12	Bennett Slough West	24	Tembladero Slough



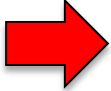
# NERR system-wide monitoring program

WQ data collected consistently at four stations at 28 NERR sites



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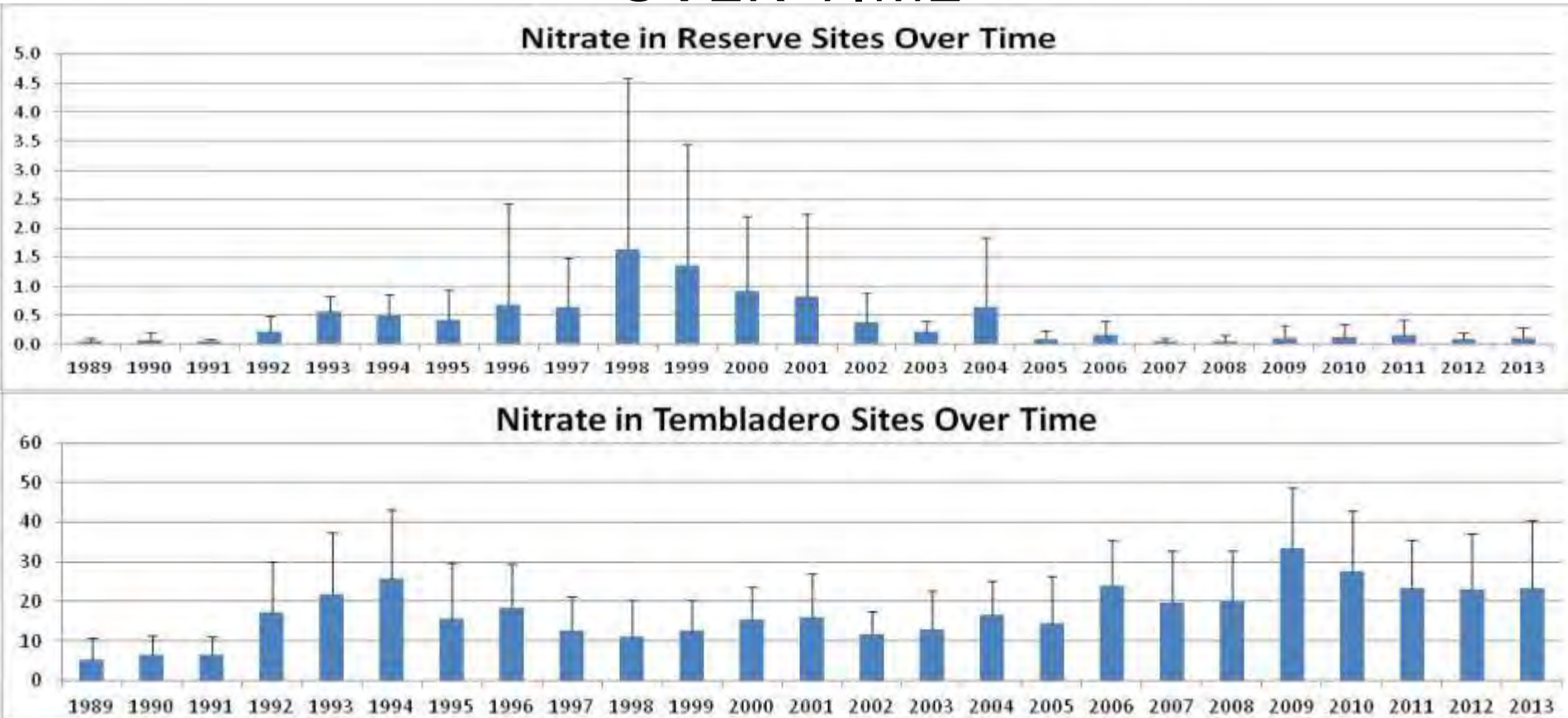
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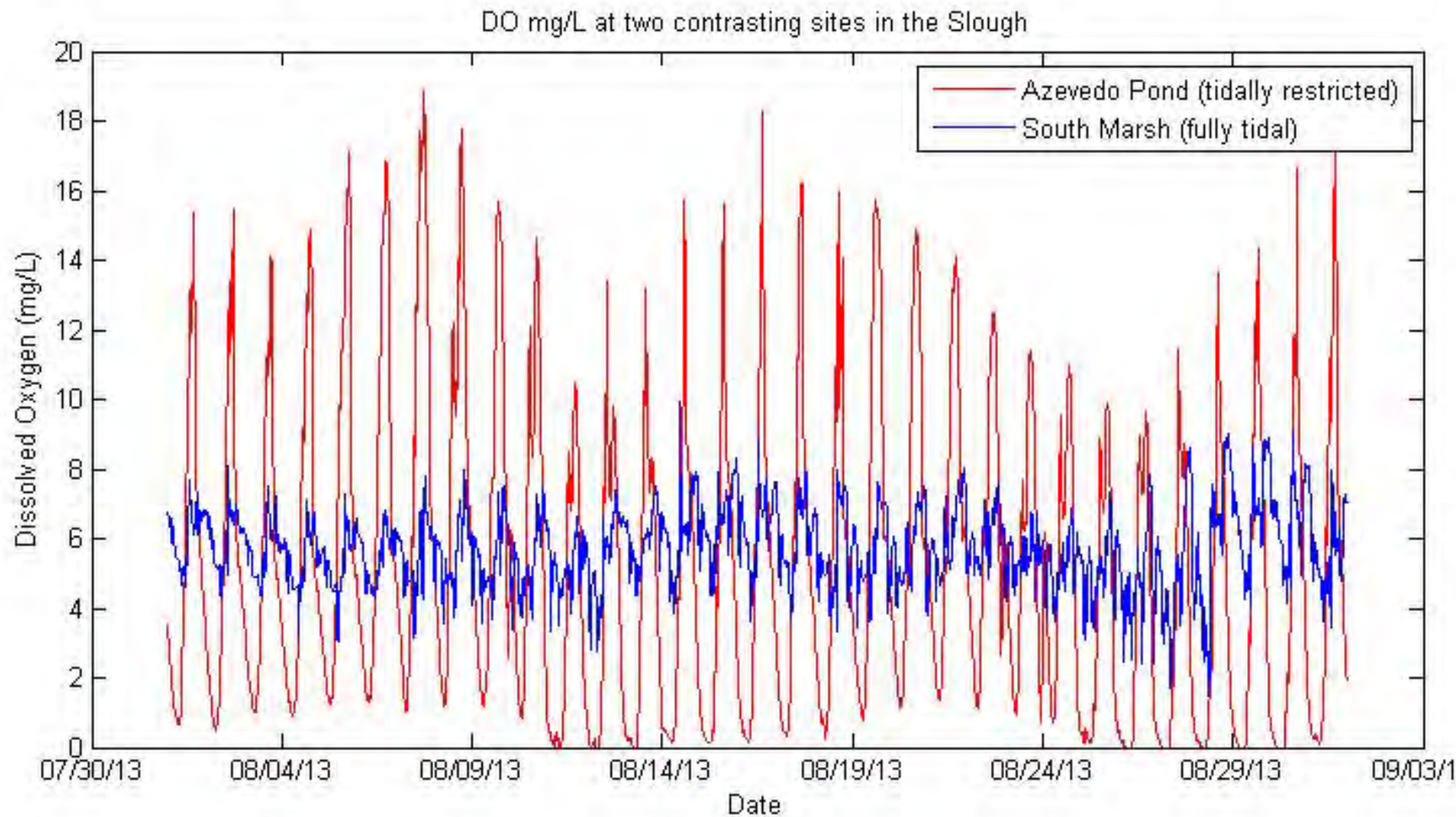


# NUTRIENT POLLUTION VARIES BY REGION AND OVER TIME



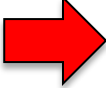
- Nitrates appear to undergo cycles of low vs. high years
  - Nitrates are highest in Tembladero Slough sites (note variable scale bar across panels, 1mg/L is threshold)
  - No clear trends over time at Tembladero but have stayed low in Reserve sites
- [From monthly volunteer data]

# EXAMPLE OF DAILY HYPERVENTILATION THAT OCCURS IN TIDALLY RESTRICTED SITES



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## **TAKE HOME MESSAGES**



## Signatures of Restoration and Management Changes in the Water Quality of a Central California Estuary

Allison K. Gee · Kerstin Wasson · Susan L. Shaw ·  
John Haskins

Received: 29 June 2009 / Revised: 9 August 2009 / Accepted: 6 February 2010  
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**Abstract** Coastal managers and policy-makers are concerned with tracking improvements in water quality linked to management changes. Long-term water quality data acquired from two wetland areas in the upper reaches of the Elkhorn Slough estuary in central California were analyzed for signatures of land restoration or water control structure management. Post-restoration averaged  $\text{NO}_3^-$ ,  $\text{NH}_4^+$ , and  $\text{PO}_4^{3-}$  concentrations were 50–70% less than before-restoration concentrations. Assessment of watershed-scale effects revealed that proximity of restoration to sampling locations had almost as strong an effect on water quality as the percentage of land restored relative to watershed size. Results also suggest that restoration of even 1% of an agriculturally intensive watershed such as that of the Elkhorn Slough may result in improvements to water quality. Finally, results indicate that tide gate function can dominate water quality in managed wetlands and must be carefully tracked and managed in the context of estuarine conservation targets.

**Keywords** Restoration · Water quality · Nutrient loading · Tide gate management · Eutrophication

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Santa Cruz, CA 95064, USA

### Introduction

Recent global demographic studies have found as much as 78% of the world population to live within 50 km of sea level, with population densities expected to intensify in urban centers located along coast lines worldwide (Small and Nicholls 2003; Cohen 2003). Following release of the historic WHO demographic study in 1968 predicting that 80% of the world's human population would live within 20 km of the coast by the beginning of the twenty-first century, concern dramatically increased over estuarine health. This is reflected in a multitude of studies published around the world in the last four decades focusing on declining estuarine water quality and increasing contaminants from urban, industrial, and agricultural sources (Cohen et al. 1997). Researchers in estuaries surrounded by urban centers such as the San Francisco Bay, the *urban estuary* (Conomos 1979), have developed robust and detailed monitoring programs to focus on a suite of point and nonpoint source industrial and urban pollutants to evaluate water quality and associated impacts to humans and wild life, e.g., San Francisco Estuary Institute (SFEI) Regional Monitoring Program (RMP) for Trace Substances (JLEGAL 2000). The nearby Elkhorn Slough estuary south of San Francisco Bay might more appropriately be called the *agricultural estuary*, since 24% of its watershed is in agricultural cultivation. Runoff into the slough from agricultural activities has grown each decade following the upsurge of intensive agriculture along the Central California coast post-World War II (Caffrey et al. 2002a). In the 1970s, Elkhorn Slough nutrient concentrations were lower than those found in South San Francisco Bay and were similar to those measured in neighboring Tomales Bay, CA, USA (Smith and Hollibaugh 1997). Two decades later, ammonium and nitrate concentrations in the slough

# BEFORE RESTORATION





# AFTER RESTORATION





# Nutrient Concentrations decrease after restoration

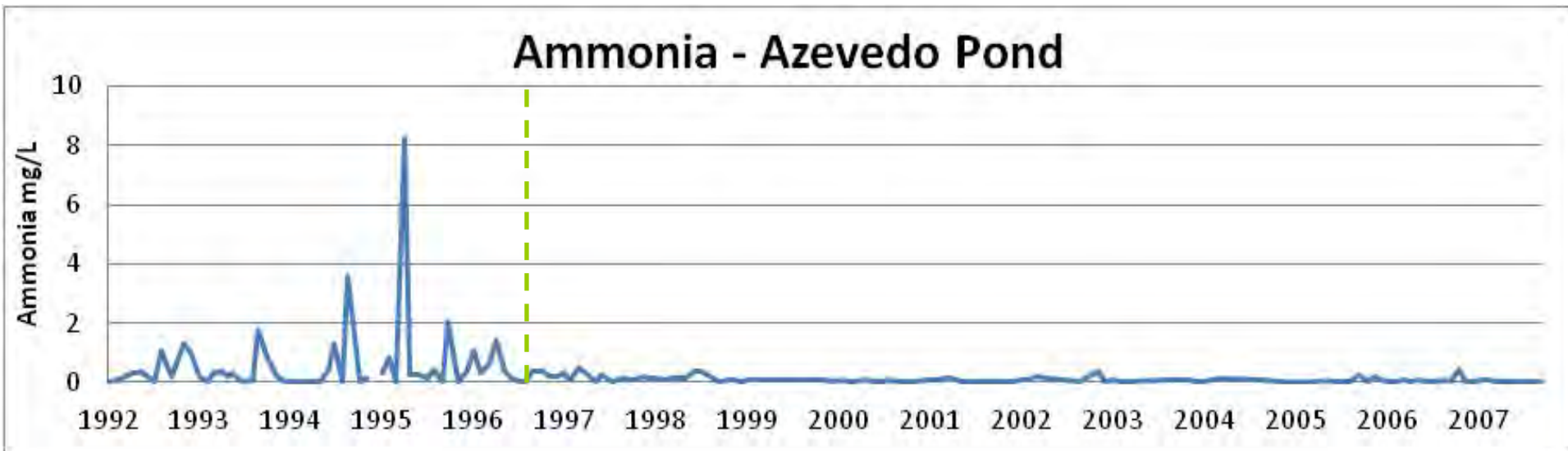
Data split at 1997

Restoration largely complete

All  $p < 0.05$  for all three nutrients

Significant difference

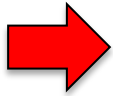
NITRATE, AMMONIA AND PHOSPHATE ALL DECREASE AFTER RESTORATION



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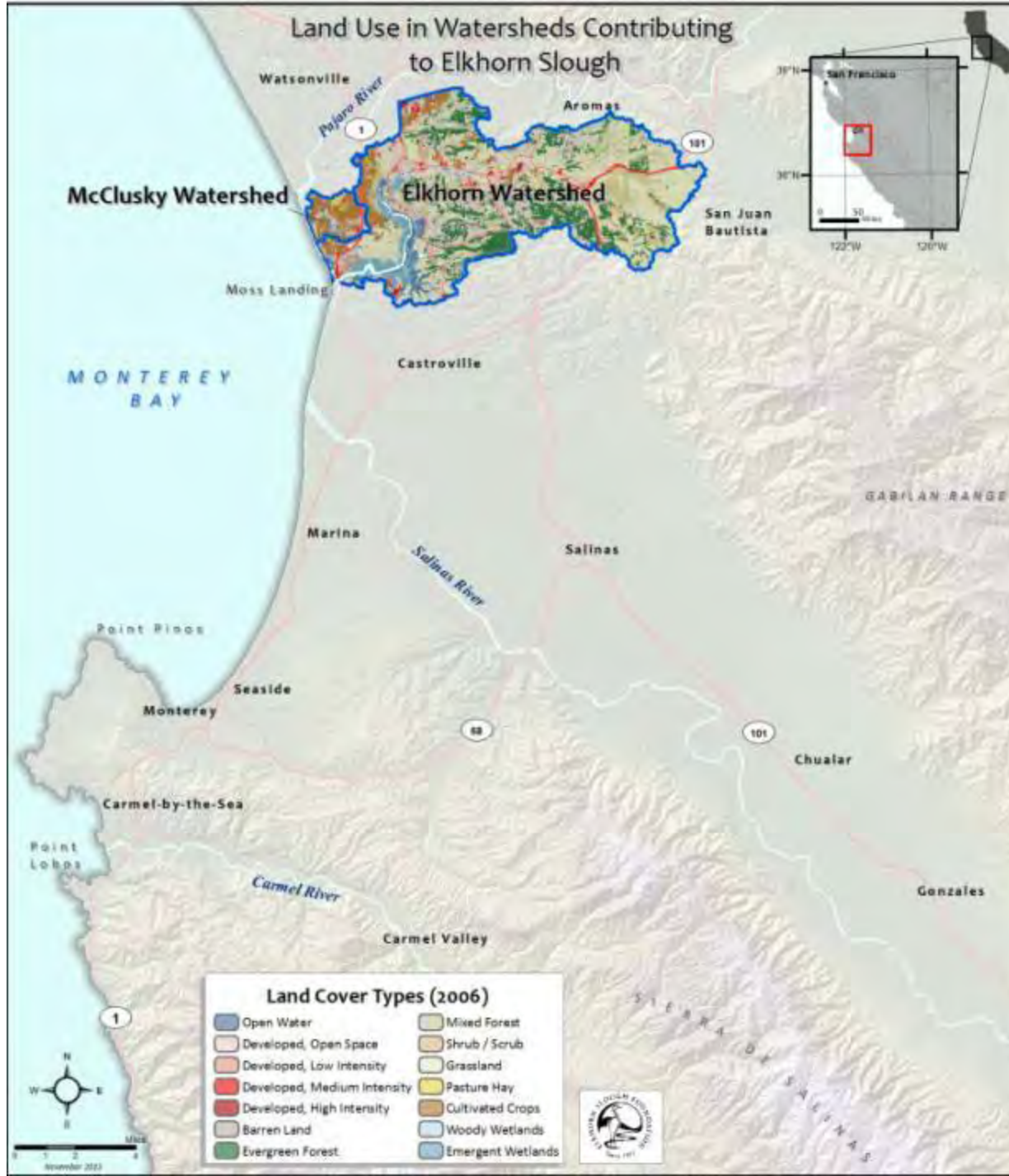
## **TAKE HOME MESSAGES**

# Land Use in Watersheds Contributing to Elkhorn Slough

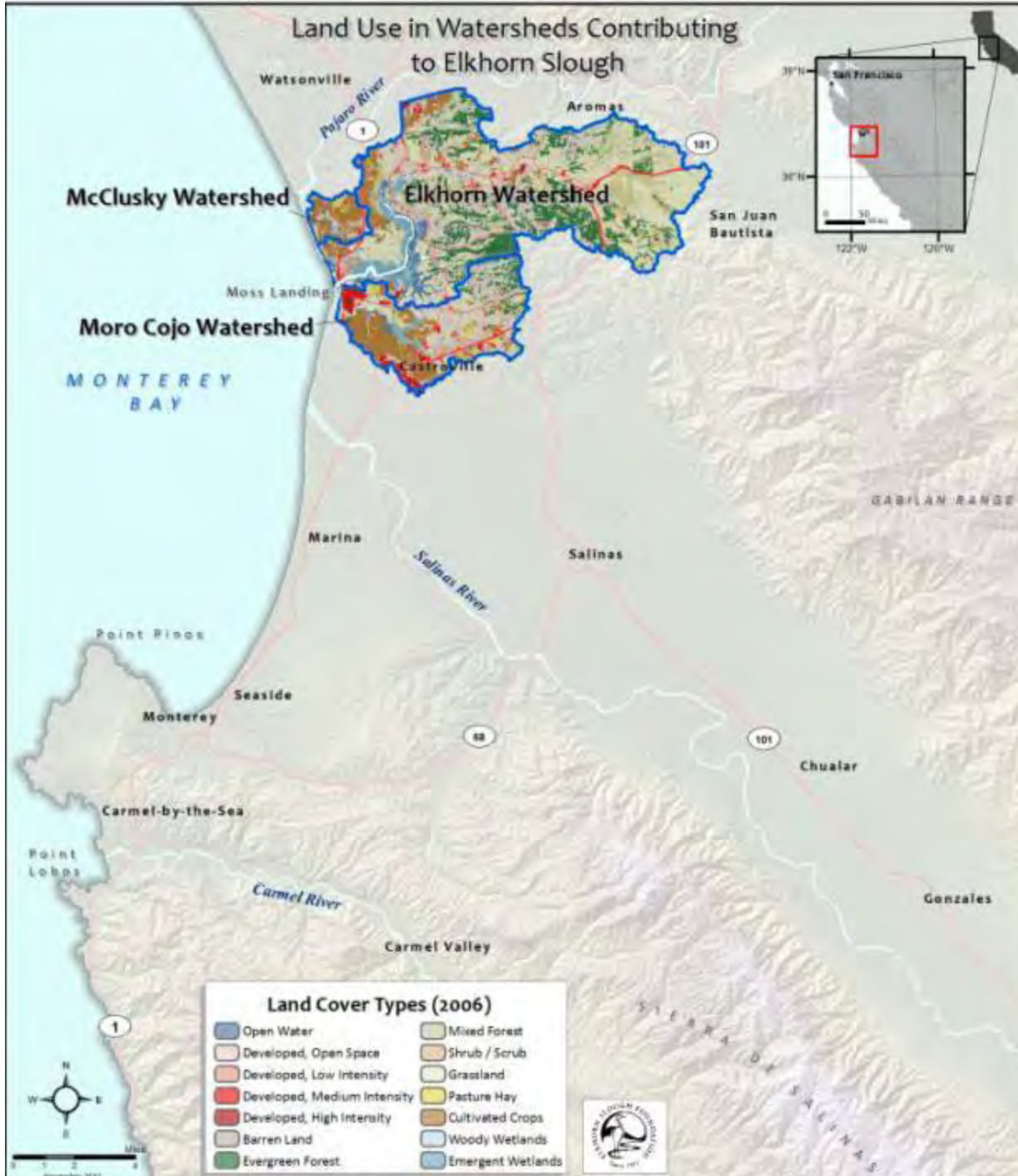




# Land Use in Watersheds Contributing to Elkhorn Slough

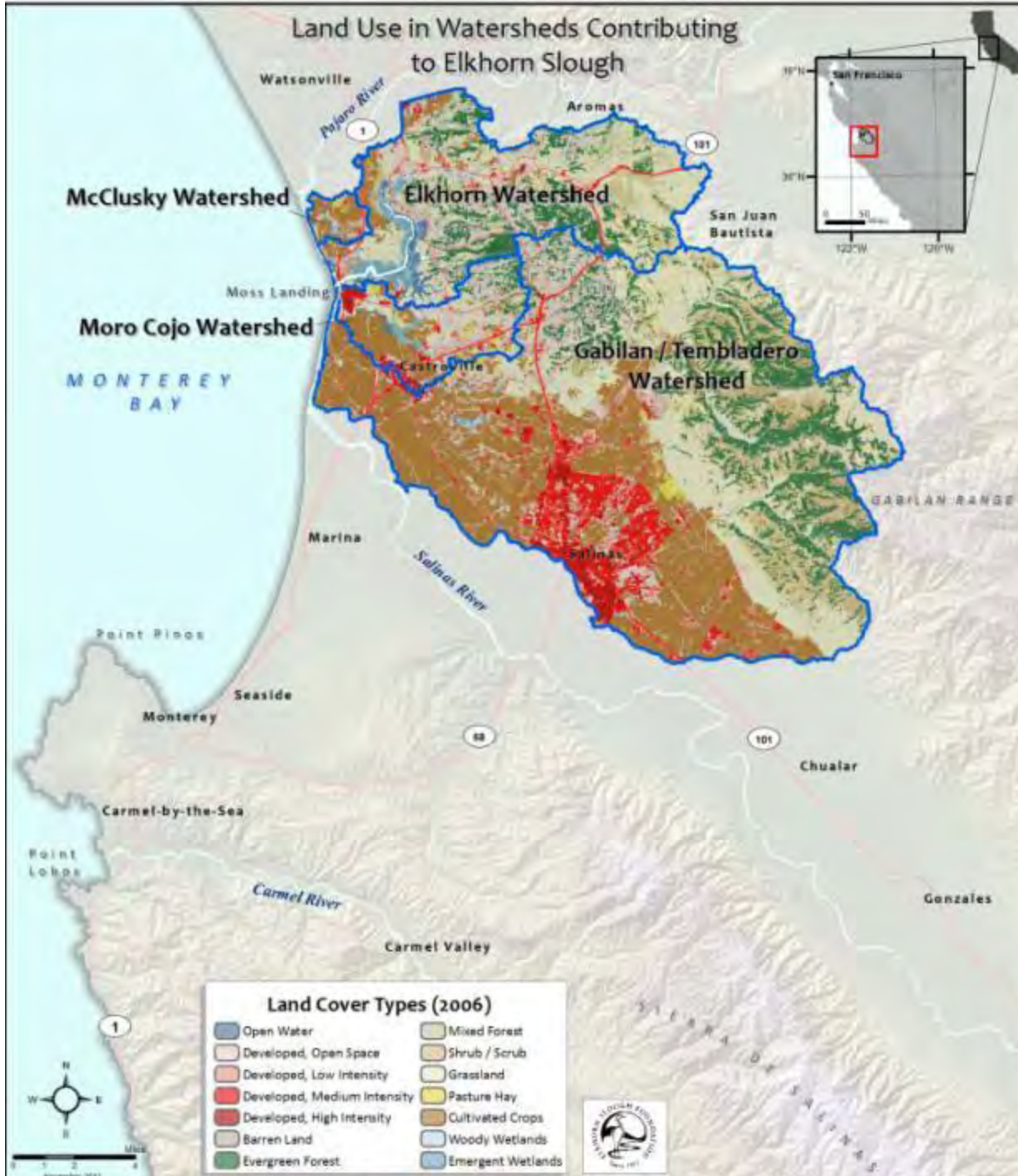


# Land Use in Watersheds Contributing to Elkhorn Slough





# Land Use in Watersheds Contributing to Elkhorn Slough





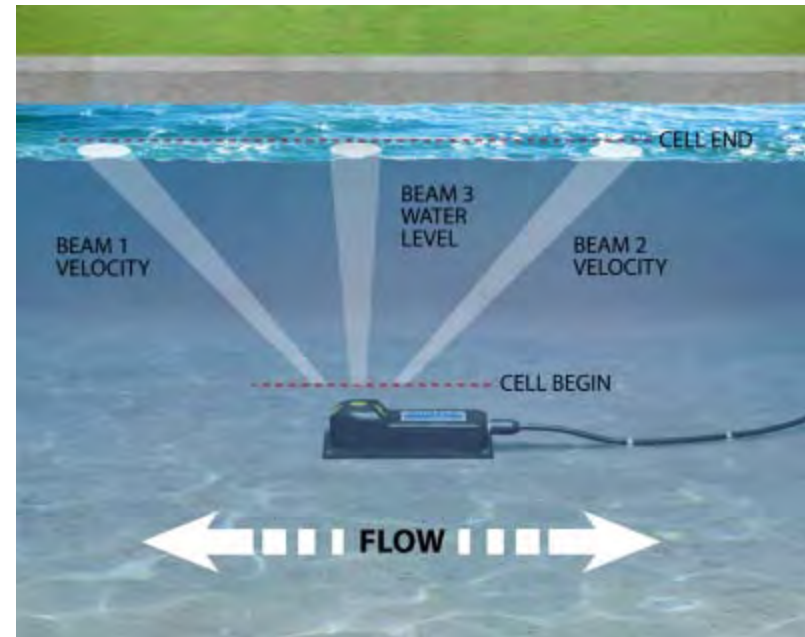
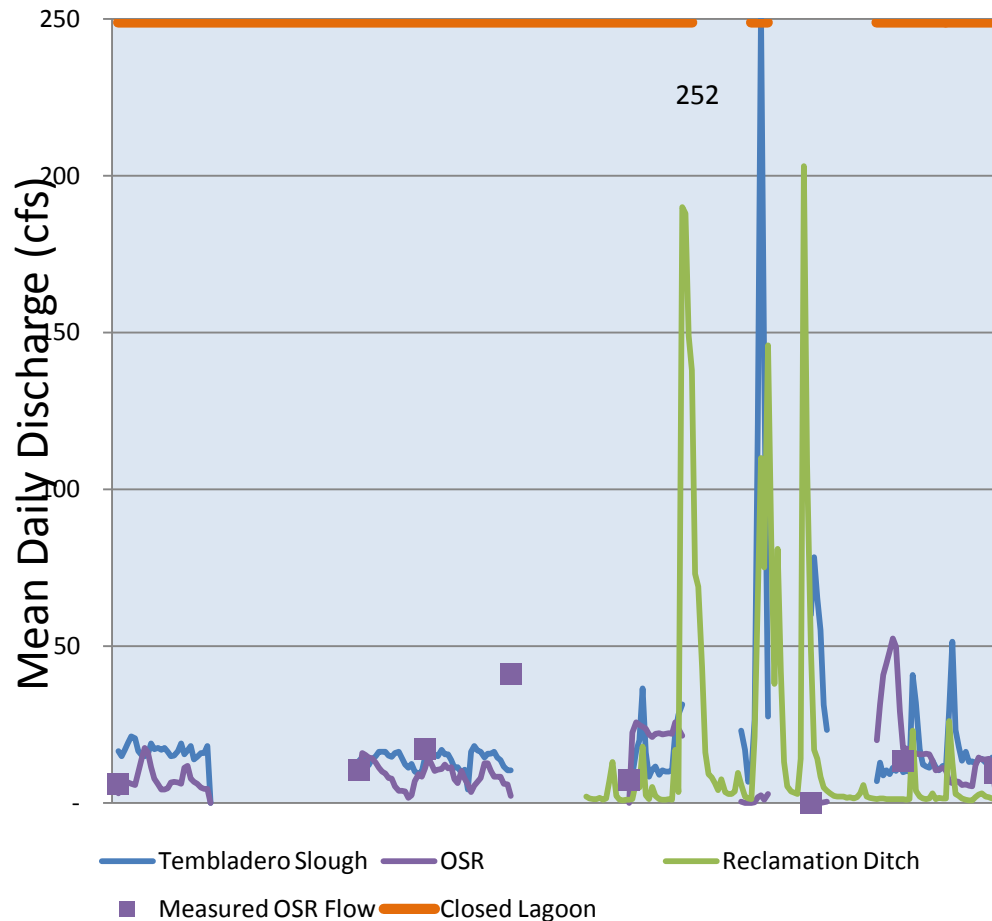
# Land Use in Watersheds Contributing to Elkhorn Slough



# CALCULATING NUTRIENT LOADS AND SOURCES

ESNERR is taking measurements now in various key tributaries

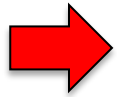
## Measuring flow



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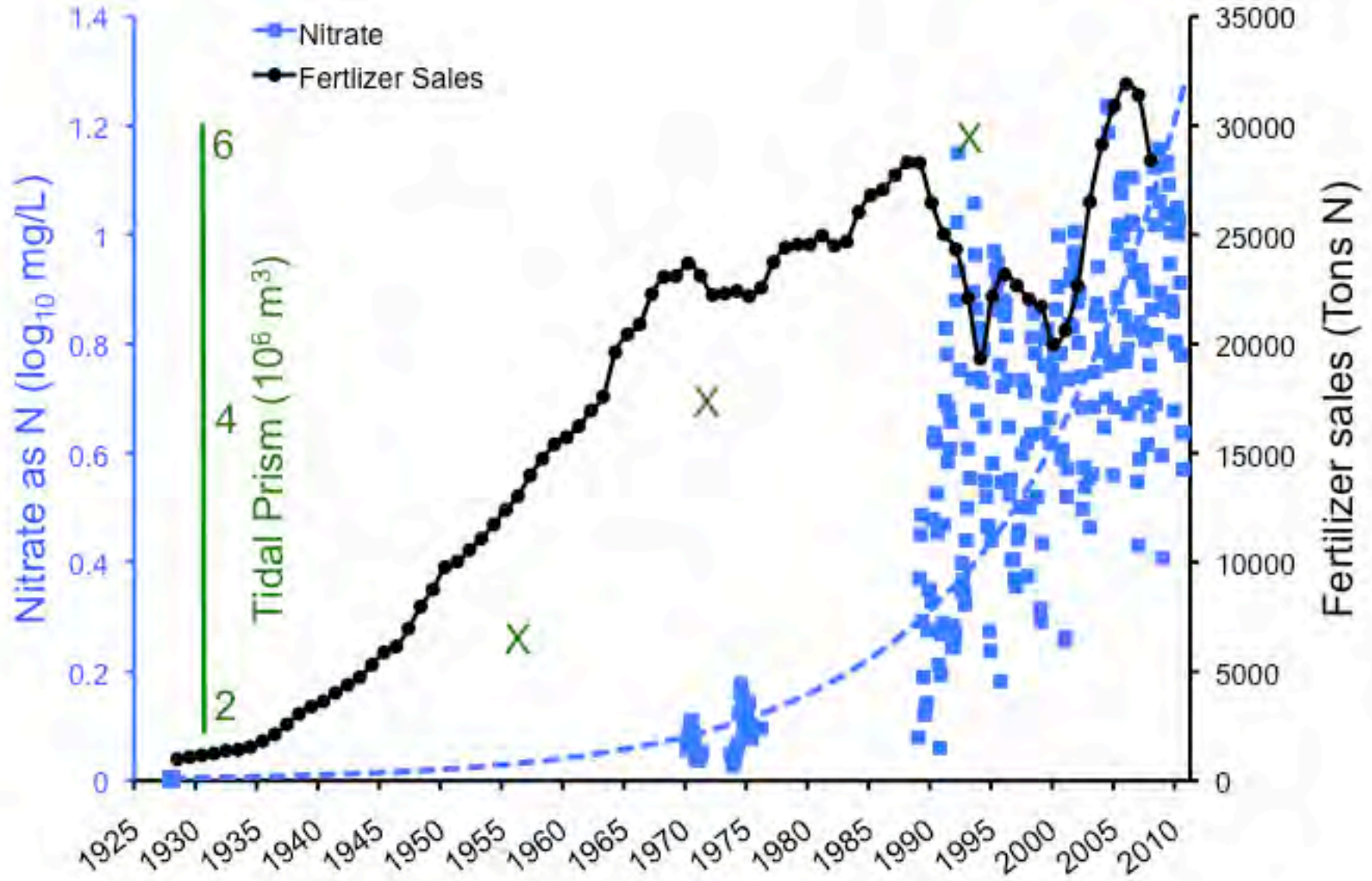
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## **TAKE HOME MESSAGES**



# Long term nutrient trends



# **ECOLOGICAL EFFECTS**

## **OF NUTRIENT-LOADING ON ELKHORN SLOUGH**





# Identifying factors that influence expression of eutrophication in a central California estuary

Brent B. Hughes<sup>1,2,\*</sup>, John C. Haskins<sup>1</sup>, Kerstin Wasson<sup>1,2</sup>, Elizabeth Watson<sup>1,3</sup>

<sup>1</sup>Elkhorn Slough National Estuarine Research Reserve, Watsonville, California 95076, USA

<sup>2</sup>Department of Ecology and Evolutionary Biology, University of California Santa Cruz, Santa Cruz, California 95064, USA

<sup>3</sup>ORD-NHEERL, Atlantic Ecology Division, US Environmental Protection Agency, Narragansett, Rhode Island 02882, USA

**ABSTRACT:** Coastal eutrophication models have proposed that various environmental conditions can serve as filters mediating the effects of nutrient loading on coastal ecosystems. Variation in such filters due to natural or anthropogenic causes can potentially lead to varied responses in overall eutrophication expression as well as in individual eutrophication indicators. In this study, we sought to identify factors that affect eutrophication expression at contrasting sites within one nutrient-loaded estuary in central California. We developed and applied a eutrophication expression index to 18 sites in the Elkhorn Slough estuary and then used principal components analysis of environmental drivers (nutrients) and filters to determine how they relate to overall eutrophication expression as well as to individual eutrophication indicators. We also examined the relationship between one key filter, tidal range, and eutrophication indicators. Elkhorn Slough was determined to be a moderately eutrophic estuary, with individual sites varying from being low to **hypereutrophic**. **Eutrophication expression** was explained mostly by tidal range, depth, temperature, salinity, distance to estuary mouth, and turbidity, but not by nutrient concentrations. Tidal range in particular correlated strongly with most eutrophication indicators. Sites with artificially dampened tidal range through water control structures were more eutrophic than sites with full tidal exchange. Results from this study emphasize the importance of filters in mediating the negative ecological effects of eutrophication. Coastal managers can decrease eutrophication expression at a local scale by managing for filters (e.g. increasing tidal exchange to managed wetlands), complementing efforts to reduce eutrophication at a regional scale by decreasing nutrient loading.

**KEY WORDS:** Eutrophication · Elkhorn Slough · Hypoxia · Environmental filters · Tidal range · *Ulv*a · Chl *a*

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## INTRODUCTION

Over the last 70 yr, the addition of nitrogen to the earth's surface has doubled, mainly due to the production of industrial nitrogen for fertilizer (Vitousek et al. 1997, Gruber & Galloway 2008, Schlesinger 2009). This has caused eutrophication via sustained delivery of anthropogenic nutrients to surface waters. Defined as an increase in the rate of organic

world faces today (Nixon 1995, Howarth et al. 2000, National Research Council 2000, Smith & Schindler 2009). Eutrophication can lead to algal blooms, hypoxia events, decreases in biodiversity, and even dead zones, all of which can fundamentally change an ecosystem and its ecologic function (Cloern 2001, Diaz 2001, Diaz & Rosenberg 2008).

The earliest studies of eutrophication focused on lakes, where nutrient additions often trigger direct

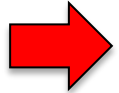


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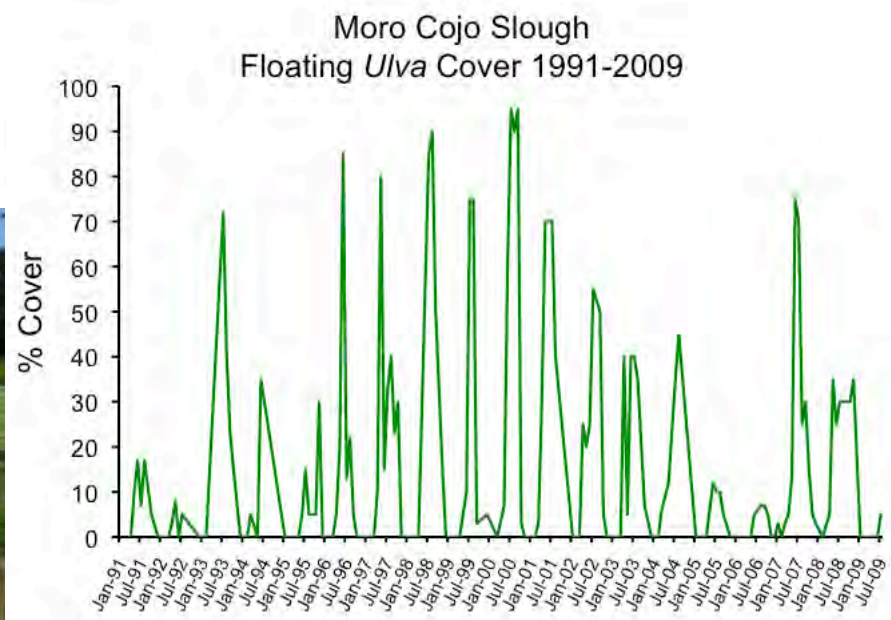
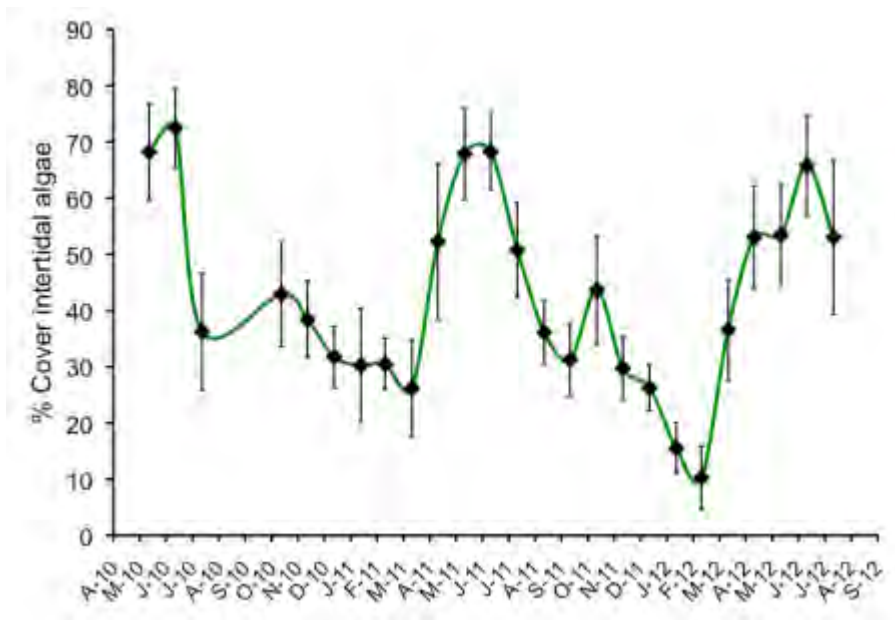
## **EFFECTS OF NUTRIENT LOADING ON THE ESTUARY**



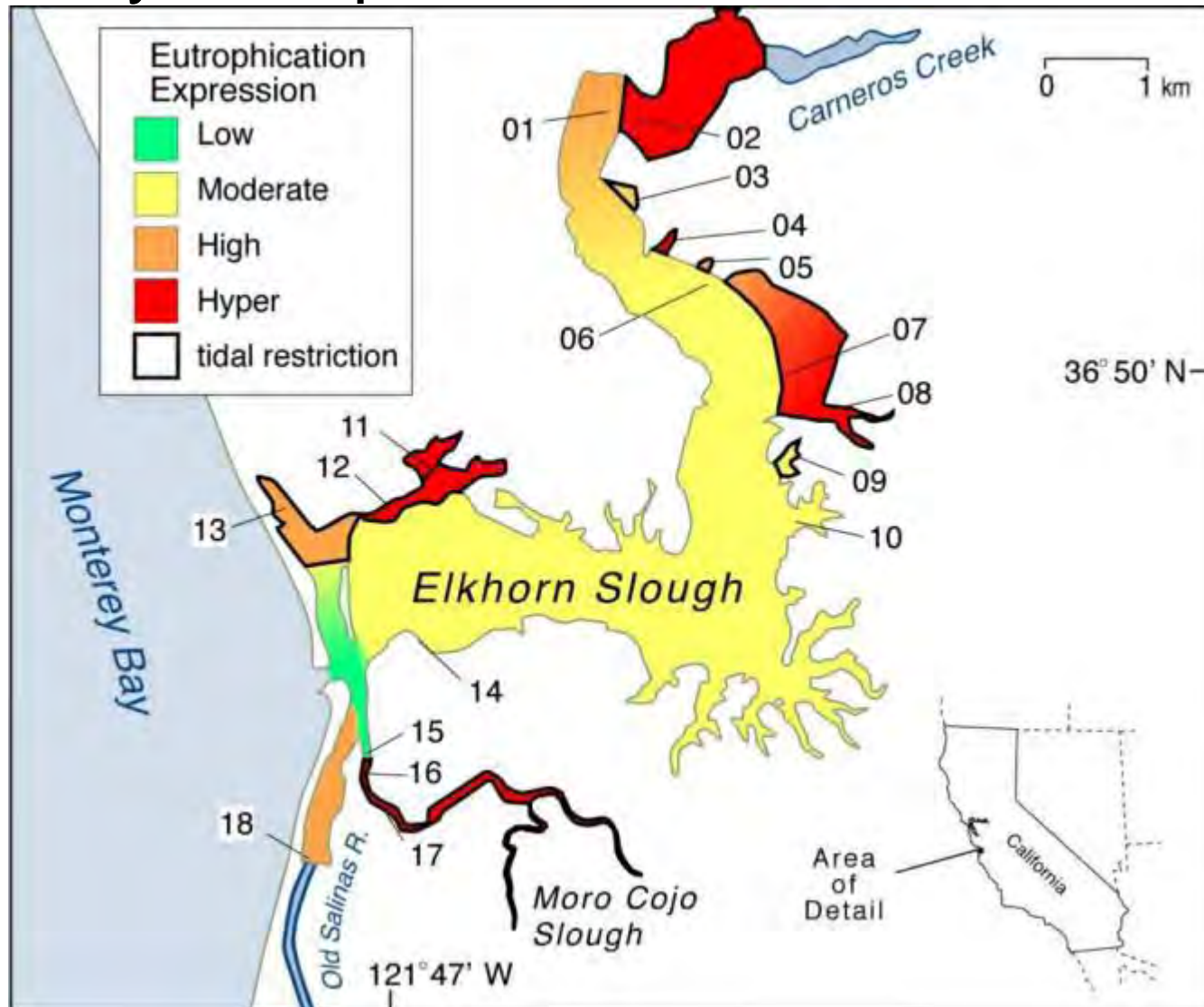
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## **TAKE HOME MESSAGES**

# Nutrients grow lots of ephemeral macroalgae



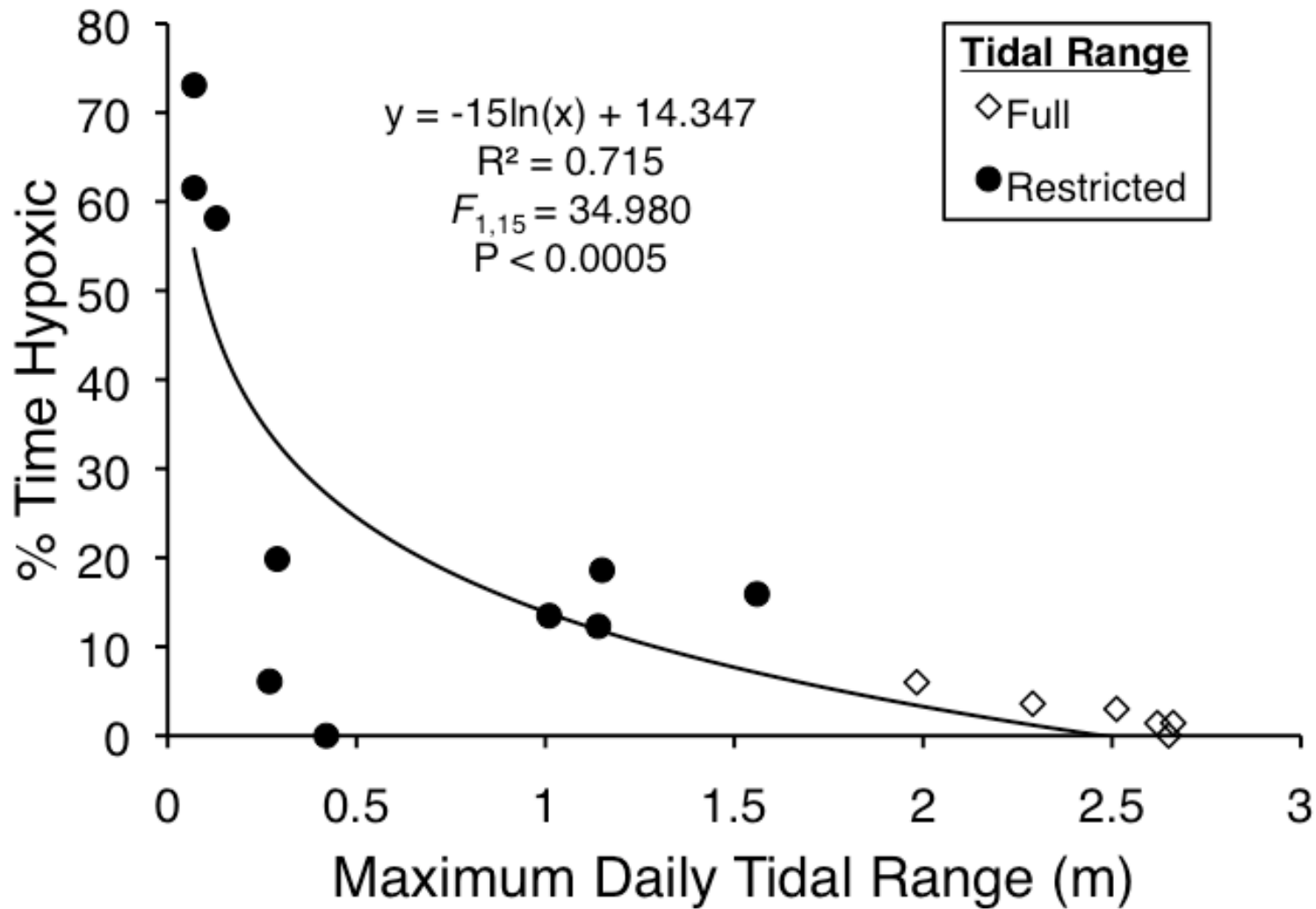
# High Variability in Eutrophication Expression, with Moderately Eutrophic Conditions most common



Hughes et al. (2011) *MEPS*



# Tidal range explains patterns in hypoxia



Hughes et al. (2011) *MEPS*

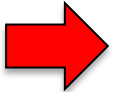
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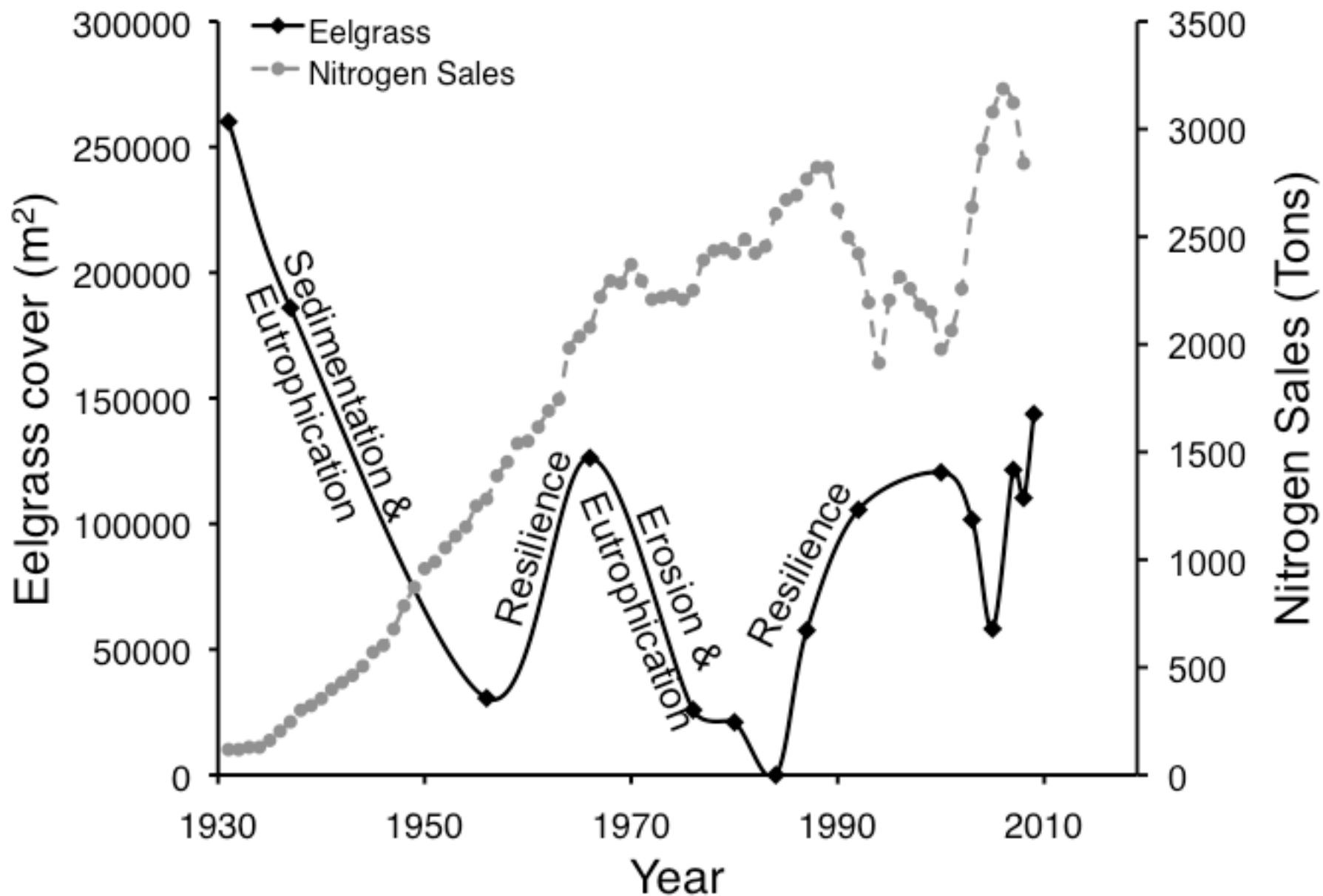
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## **TAKE HOME MESSAGES**

# Seagrass unstable over the last century






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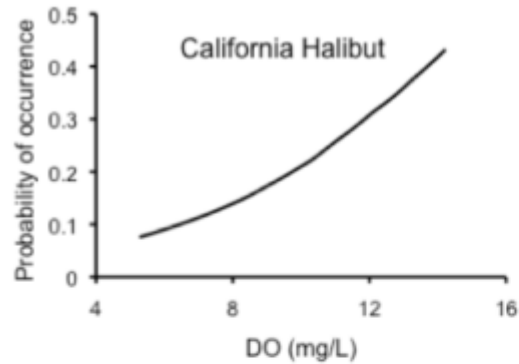
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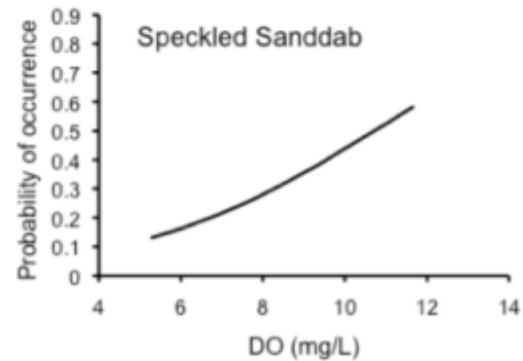
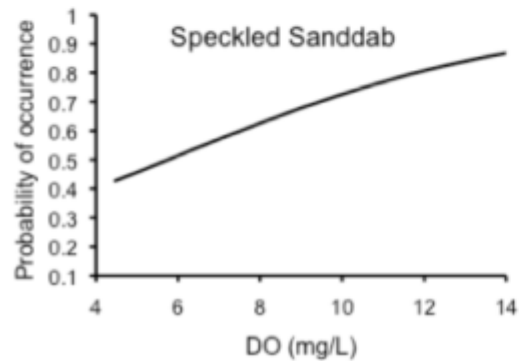
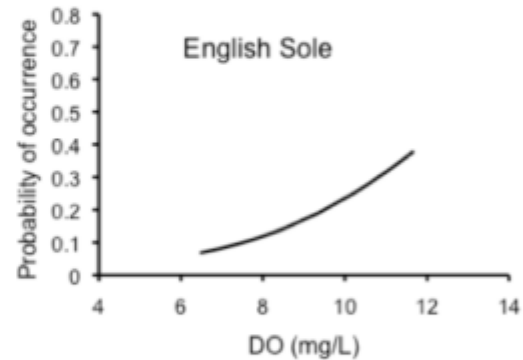
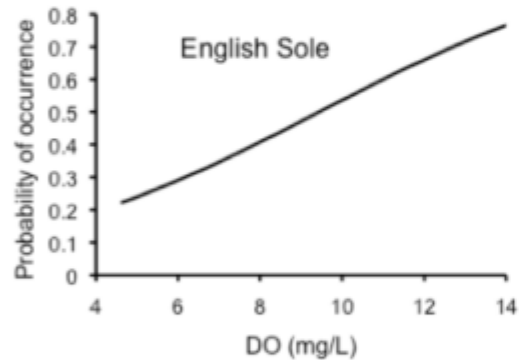
## **TAKE HOME MESSAGES**

# Hypoxia effects on flatfish species

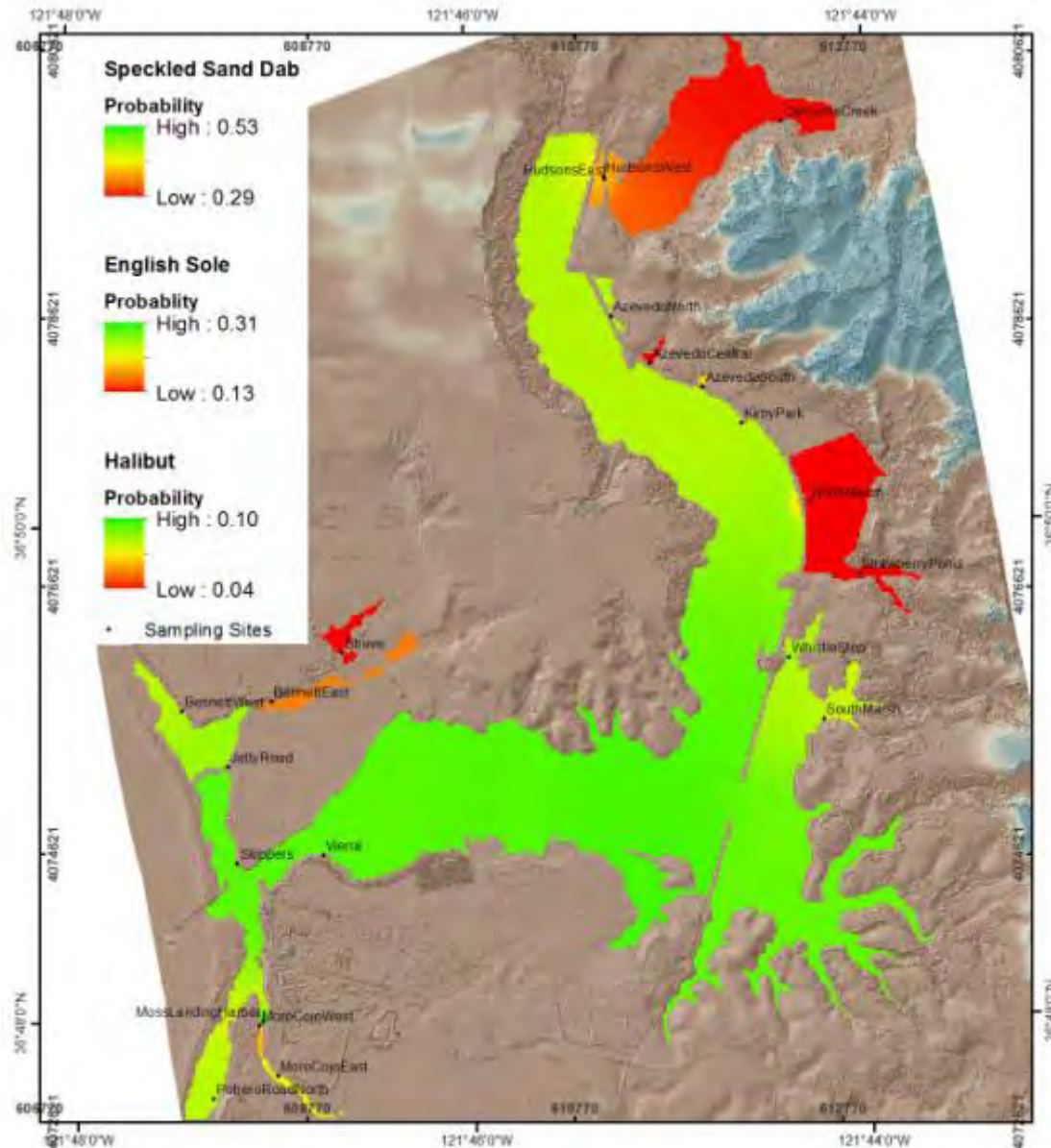
## Otter Trawls



## Beach Seines

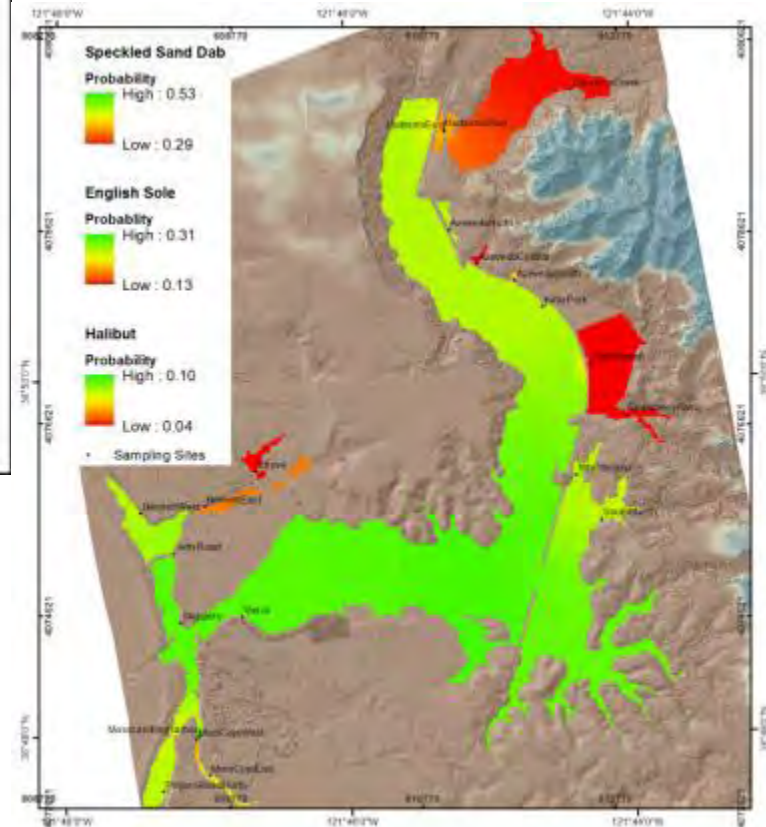
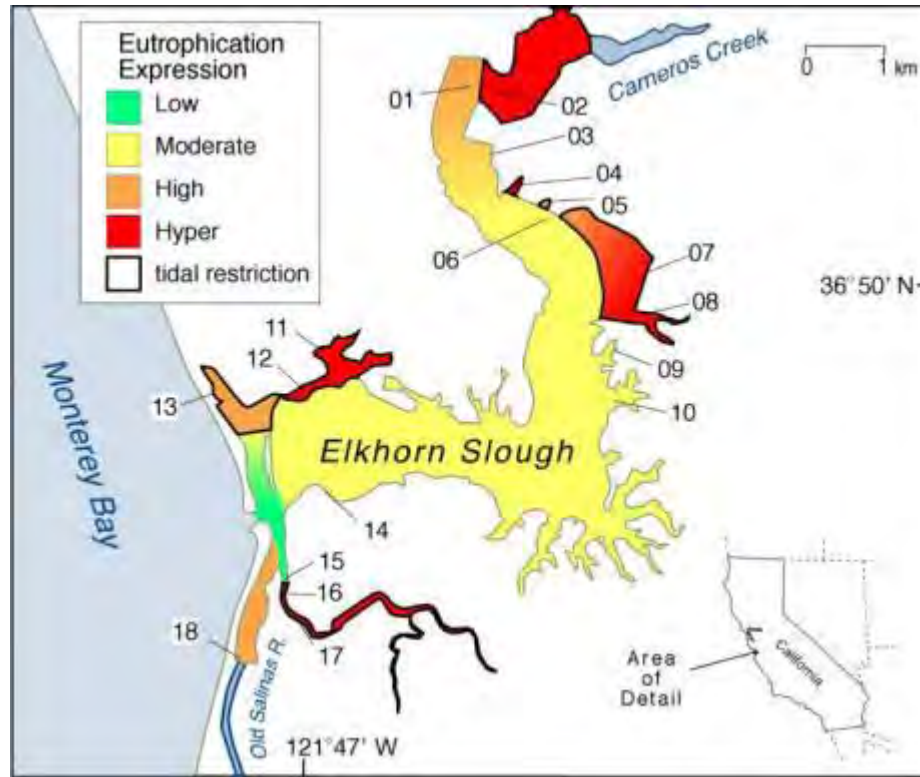


# Hypoxia effects on flatfish species

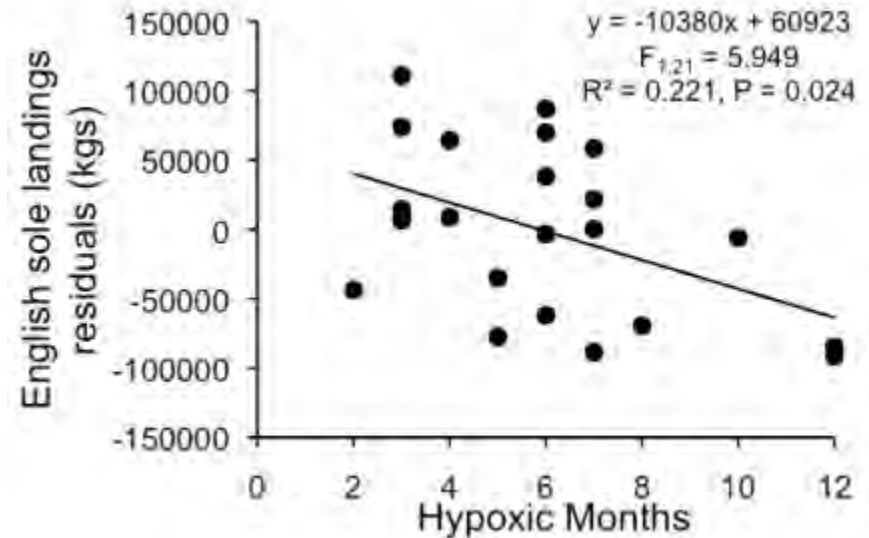
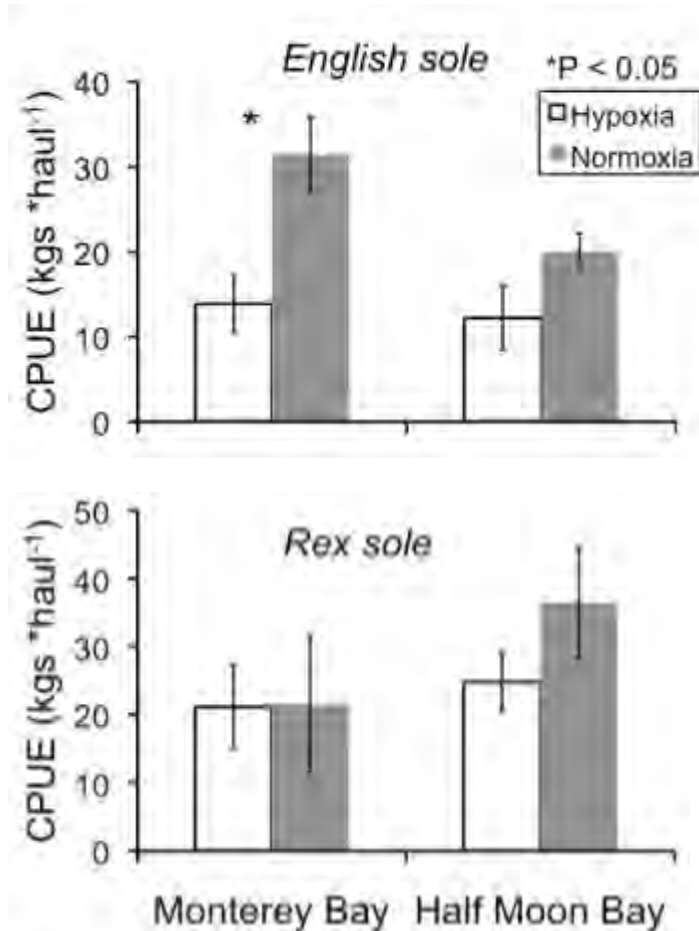




# Spatial modeling consistent with eutrophic patterns



# Hypoxia effects on the offshore stocks & fishery




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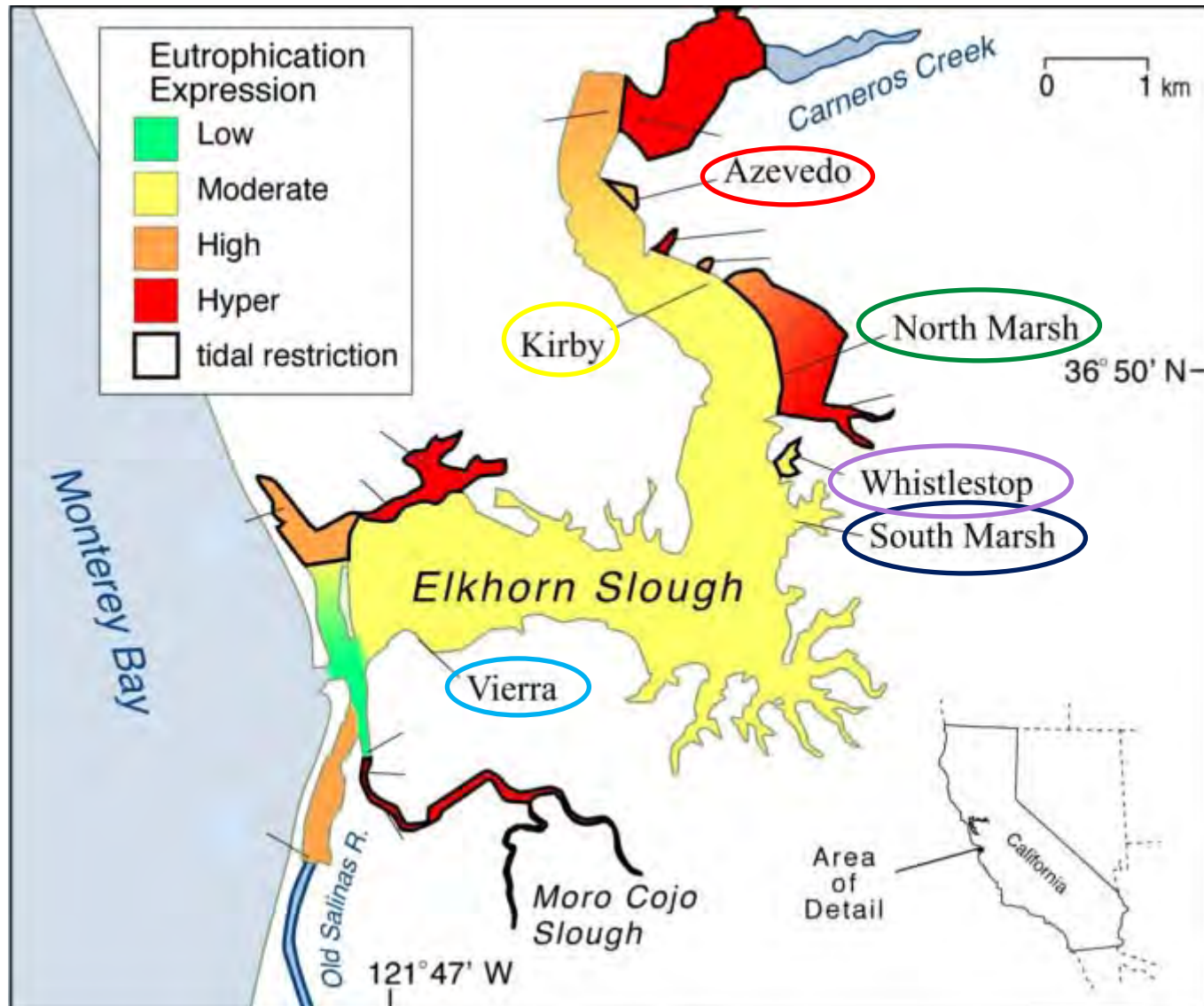
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## **TAKE HOME MESSAGES**



# How do fish respond to water quality at different sites?



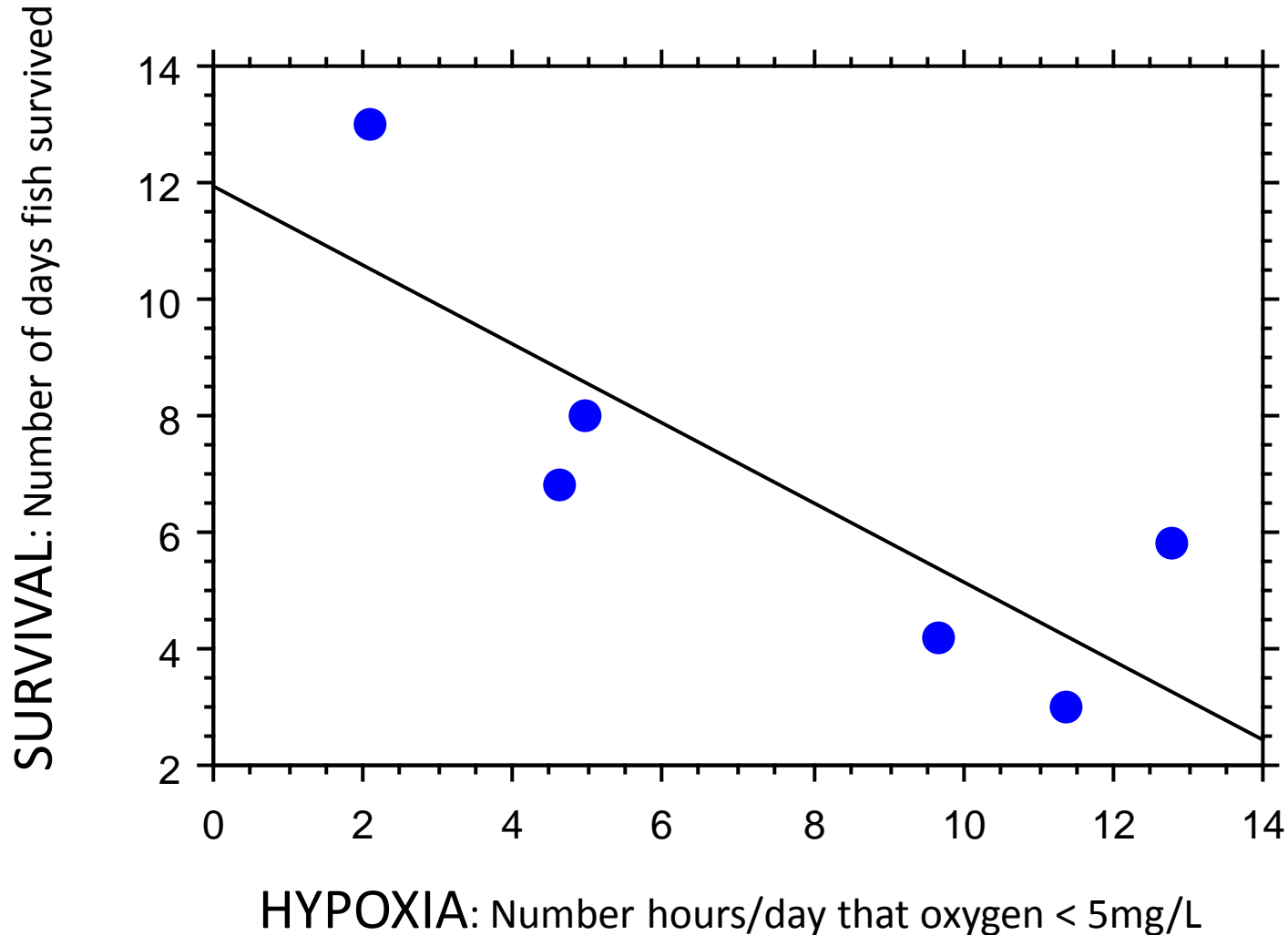
# Caging Experiment



- Staghorn sculpin used as highly tolerant indicator species
- Cages deployed next to water quality sondes

# HYPOXIA KILLS FISH

Water quality is inappropriate for fish survival at some wetlands





# Making poor water quality issues tangible through indicator species




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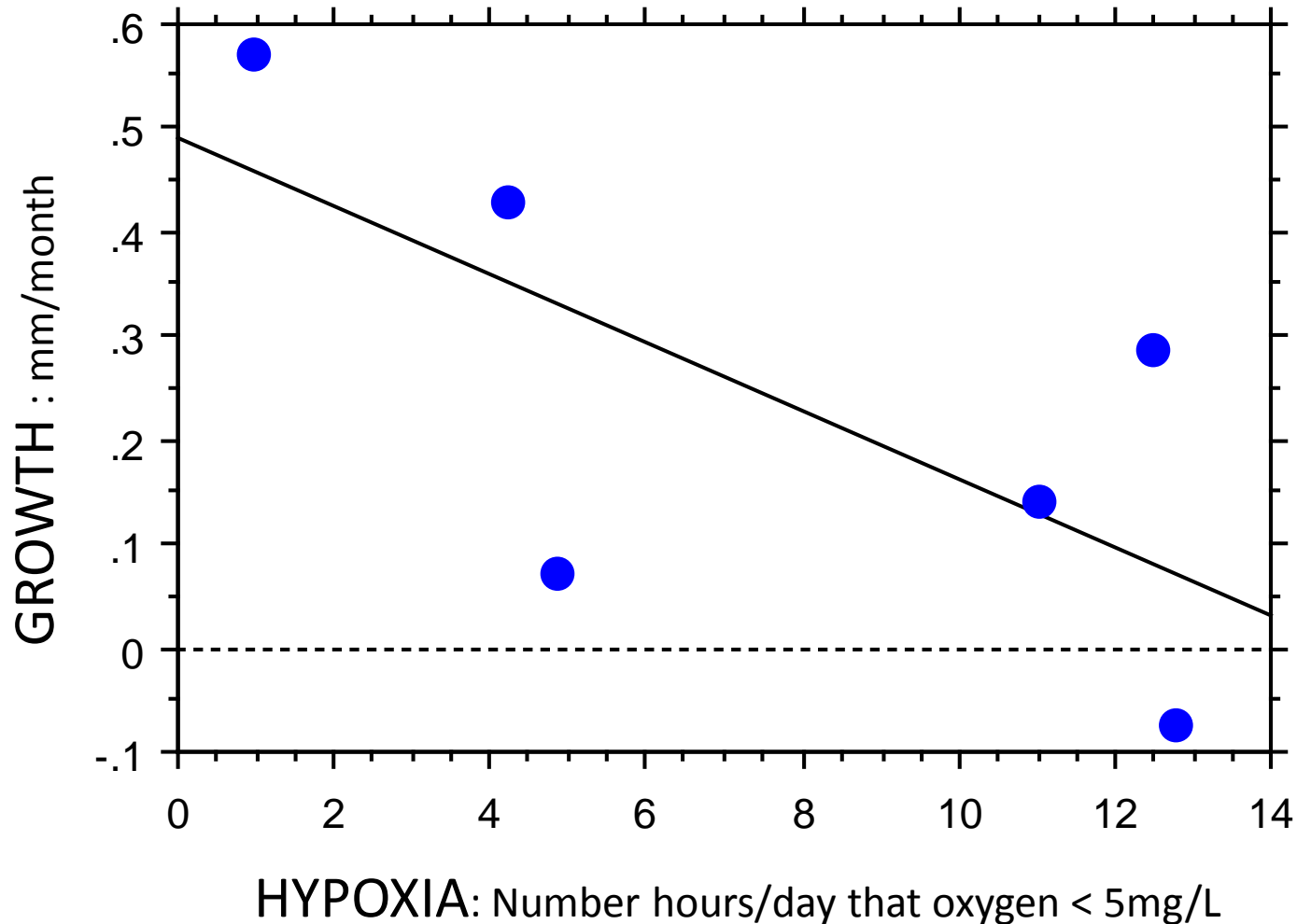


- Olympia oysters used as highly tolerant indicator species
- Cages deployed next to water quality sondes



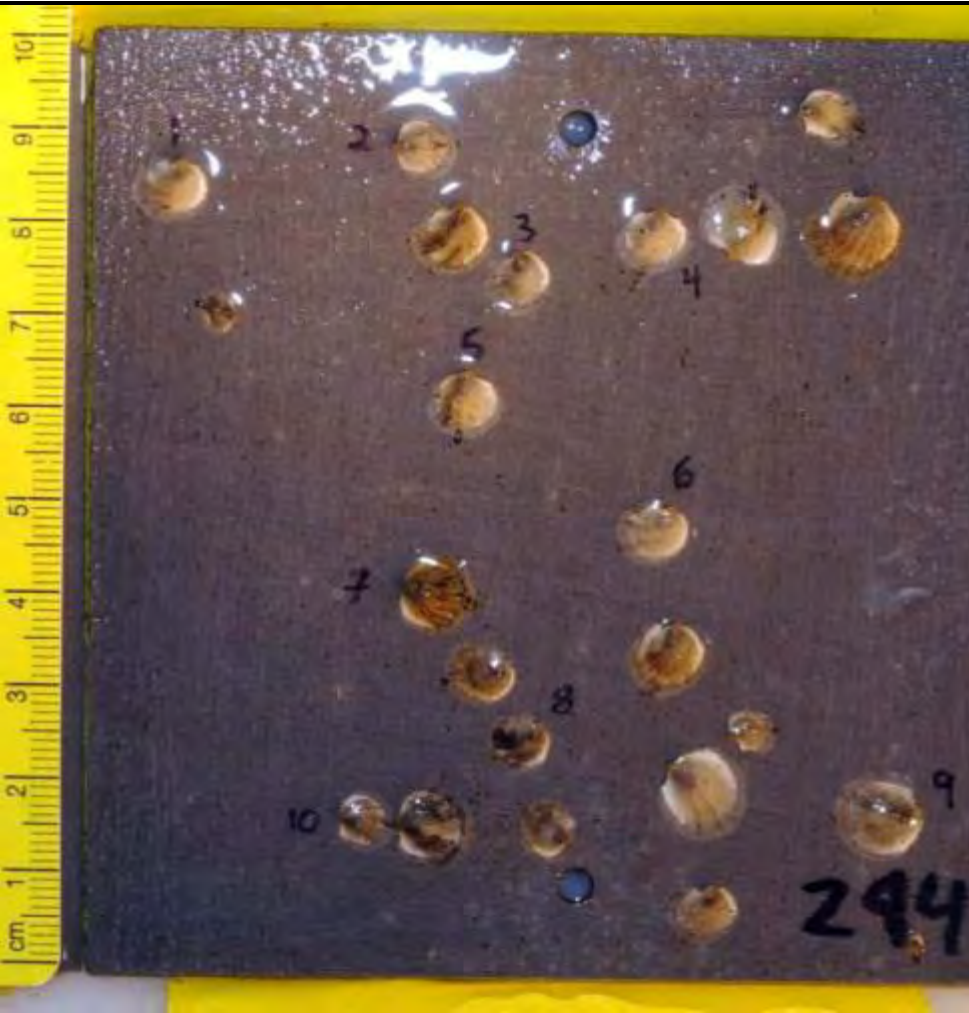
# HYPOXIA SLOWS OYSTER GROWTH

Water quality is inappropriate for shellfish growth in some wetlands



# Lab Experiments:

## low oxygen slows growth



Normal oxygen



Low oxygen



## Informing Olympia Oyster Restoration: Evaluation of Factors That Limit Populations in a California Estuary

Kerstin Wasson

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**Abstract** The goal of this investigation was to inform restoration strategies by determining which factors are most important to limiting Olympia oyster (*Ostrea lurida*) distribution and abundance at a Pacific coast estuary, Elkhorn Slough in central California, where Olympia oysters are currently extremely rare but were formerly abundant. An array of mensurative experiments and correlative analyses were used to examine the role of potential limiting factors. Absence of oysters was associated with symptoms of eutrophication, including elevated nutrient concentrations and turbidity. Oysters were also absent from all sites where water control structures resulted in minimal tidal exchange. Predation and competition did not appear to play a major role in surveyed oyster populations above Mean Lower Low Water but at lower elevations oysters were heavily foaled by non-native species. In most sites oysters were found only on large artificial substrates; survival on small natural hard substrates was apparently precluded by burial by fine sediments. Restoring more natural ecosystem processes by reducing nutrient and sediment inputs, increasing tidal exchange to areas behind water control structures, and preventing establishment of new non-native species would benefit Olympia oysters as well as support broader ecosystem-based management goals.

**Keywords** Ecosystem-based management · Elkhorn Slough · *Ostrea lurida* · Water quality

### Introduction

Bivalve shellfish restoration initiatives have become increasingly common in coastal habitats in recent decades because of increasing community awareness of declines in shellfish and their importance for ecosystem integrity, and as a result of increased funding (Brumbaugh et al. 2006). In estuarine ecosystems, oysters in particular have been the focus of conservation and restoration efforts. Oyster reefs have declined worldwide as a result of human exploitation and habitat alteration (Kirby 2004), and so have the ecosystem services they provide, ranging from commercial and recreational shellfish harvest by humans, provision of feeding habitat and refuge for fish and other invertebrates, and improvement of water quality through suspension-feeding activities (Brumbaugh et al. 2006; Côté et al. 2007).

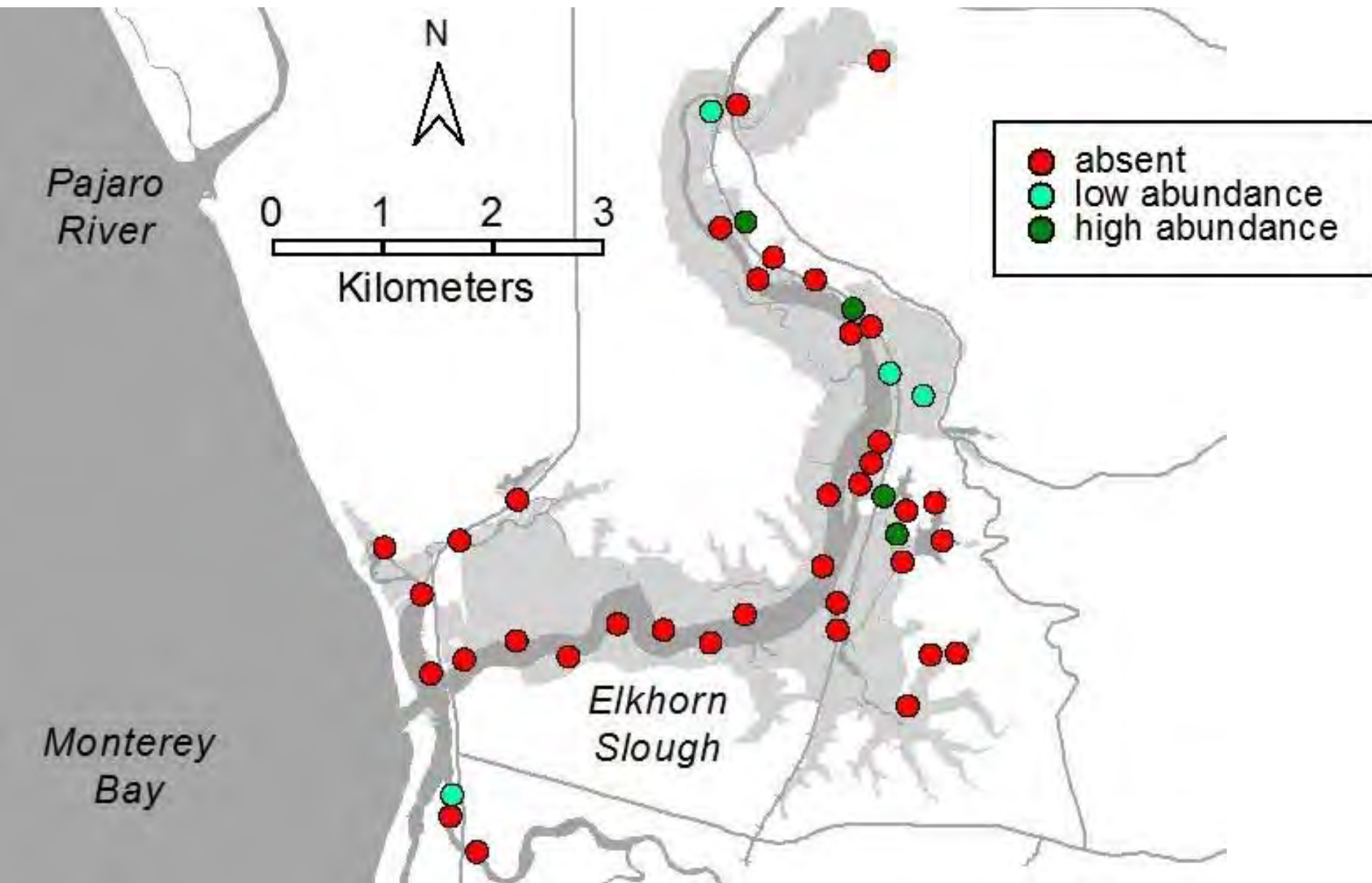
Successful conservation and restoration depend on sound ecological frameworks, and an understanding of the mechanisms limiting distribution and abundance is necessary in order to protect and enhance a species that has declined (Salačický et al. 2002). Many mechanisms have contributed to oyster declines globally, including overharvest, water quality degradation, habitat loss, and disease (Kirby 2004; Brumbaugh et al. 2006). Some oyster species, such as the Eastern oyster (*Crassostrea virginica*), have been intensively studied for decades, and ecological knowledge is supporting restoration efforts (Luckenbach et al. 1999). Even so, better links could be forged between ecological monitoring and restoration planning (Breitburg et al. 2000; Mann and Powell 2007).

The native oyster of the Pacific coast of the United States, the Olympia oyster (*Ostrea lurida*), has been the subject of relatively few ecological investigations (Baker 1995; Cook et al. 2000; Kimbro and Grossholtz 2006; NOAA Restoration Center 2007; Trimble et al. 2009). A

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# OYSTERS ABSENT FROM MANY WETLANDS WHERE THEY WERE HISTORICALLY PRESENT



# EUTROPHICATION AND OYSTERS



Oysters absent from sites with highest nutrients, chlorophyll and turbidity



# TIDAL RESTRICTION



Oysters absent from 14/17 sites with water control structures



Only the harbor and  
main Elkhorn Channel  
have full tidal  
exchange

More than 50% of the  
historic estuary is  
behind water control  
structures




# ROAD MAP

## **WATER QUALITY MONITORING AND TRENDS**

- ESNERR water quality monitoring
- Examples of spatial and temporal trends from monitoring
- Local WQ improvement due to restoration
- Nutrient sources and loads: new perspectives

## **EFFECTS OF NUTRIENT LOADING ON THE ESTUARY**

- Eutrophication assessment of the estuary
- Ecological studies of negative effects of eutrophication
  - Eelgrass
  - Fish
  - Oysters
  -  – Salt marsh

## **TAKE HOME MESSAGES**

# EUTROPHICATION AND SALT MARSH DIEBACK





# MARSH DROWNING

## Our marshes are sinking

- Subsidence measured at our monitoring stations

## Eutrophication may be culprit

- Studies elsewhere have shown faster decomposition, less organic deposition by roots in nutrient loaded vs. control sites
- We have measured high decomposition rates in our marshes, much higher than Morro Bay





# Field experiments examining algae effects



# Negative impacts of algal cover

Picklweed before being covered by ulva

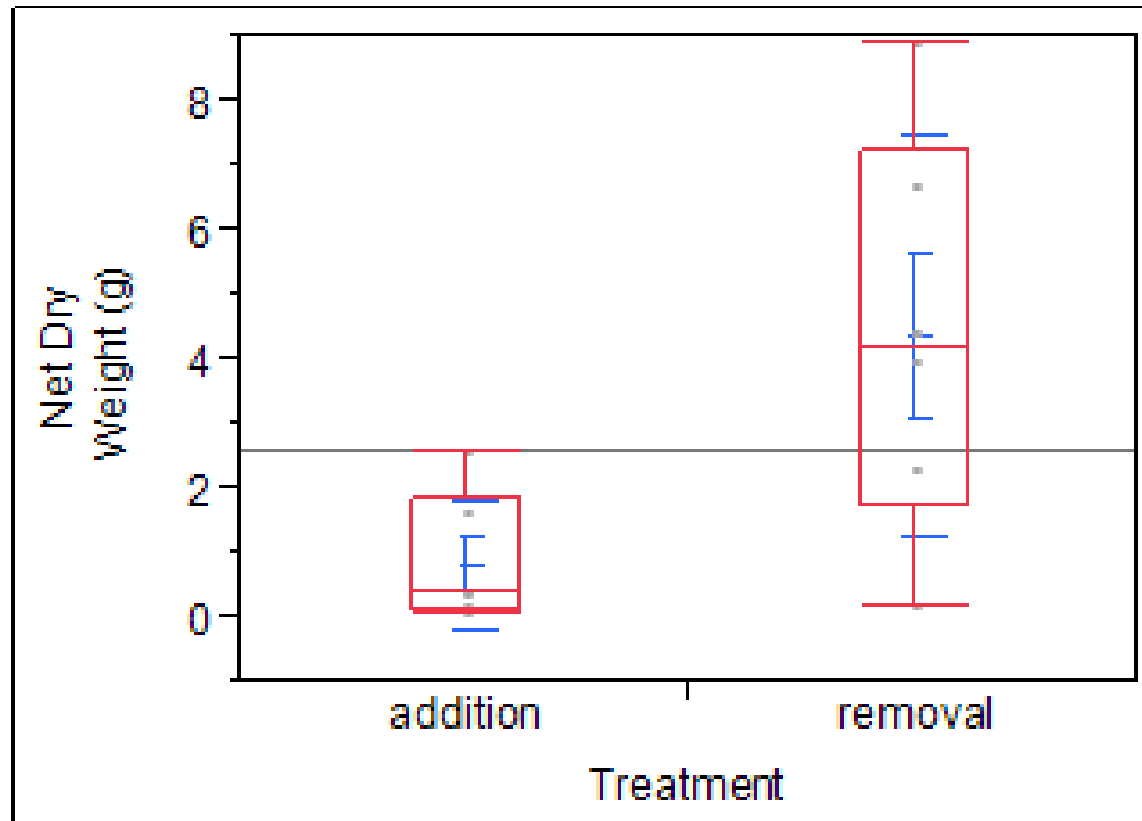


Picklweed after being covered by ulva



# Negative impacts of algal cover on salt marsh

Biomass of pickleweed much higher in algal removal treatment





# Algal mats may contribute to marsh loss at edge





# Eutrophication/marsh studies in progress...





Loss of marsh sustainability in the face of sea level rise may be one of the biggest ecosystem effects of eutrophication



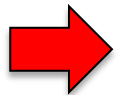
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## **TAKE HOME MESSAGES**



# Take home messages

- **ESNERR has lots of data relevant to water quality issues**
  - We're glad to make the data available: raw data, analyses, summary reports – whatever is useful
- **Our monitoring has revealed decades of high nutrients, with no general improvement over time**
  - However local upland and buffer restoration efforts have local benefits
- **We have demonstrated significant negative effects of nutrient-loading**
  - Strong evidence for eutrophication problems including diurnal hypoxia, extensive algal production and decreased eelgrass, oyster and fish habitat
  - On-going work suggests eutrophication may also contribute significantly to the extensive salt marsh loss observed in the estuary
- **There are clear spatial patterns to eutrophication**
  - Highest nutrient concentrations are found in the lower estuarine complex (Salinas Lagoon, old Salinas channel, Tembladero Slough)
  - The worst eutrophication is in the 50% of the estuary behind water control structures, and upper Elkhorn Slough which has a long residence time
- **Decreased nutrient loading would support greater ecological health of the estuary**
  - Benefits would include increased production of eelgrass, fish and oysters