ELKHORN SLOUGH NATIONAL ESTUARINE RESEARCH RESERVE

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

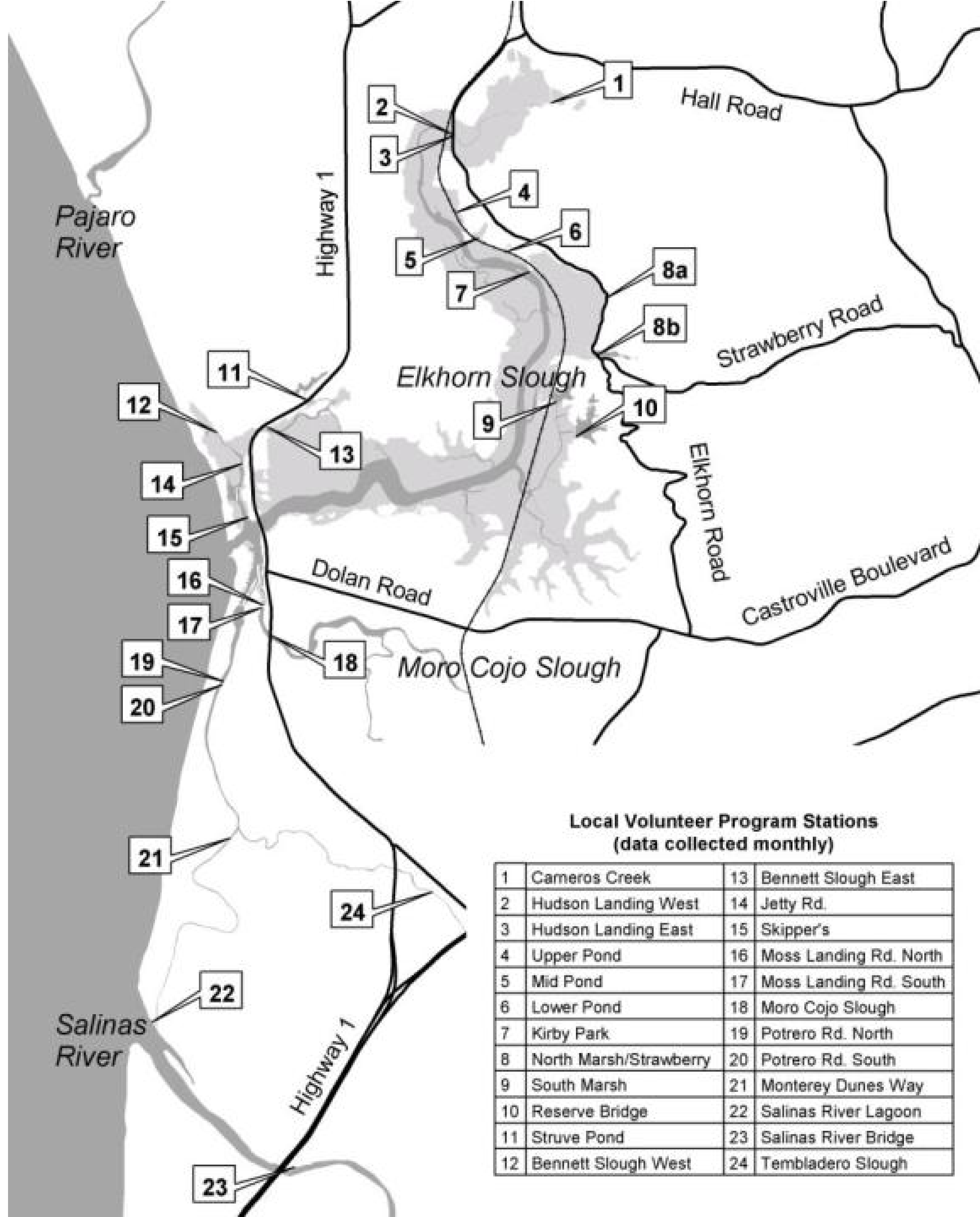
TAKE HOME MESSAGES

ESNERR Water Quality Monitoring

ESNERR WQ Monitoring Programs

Volunteer Program

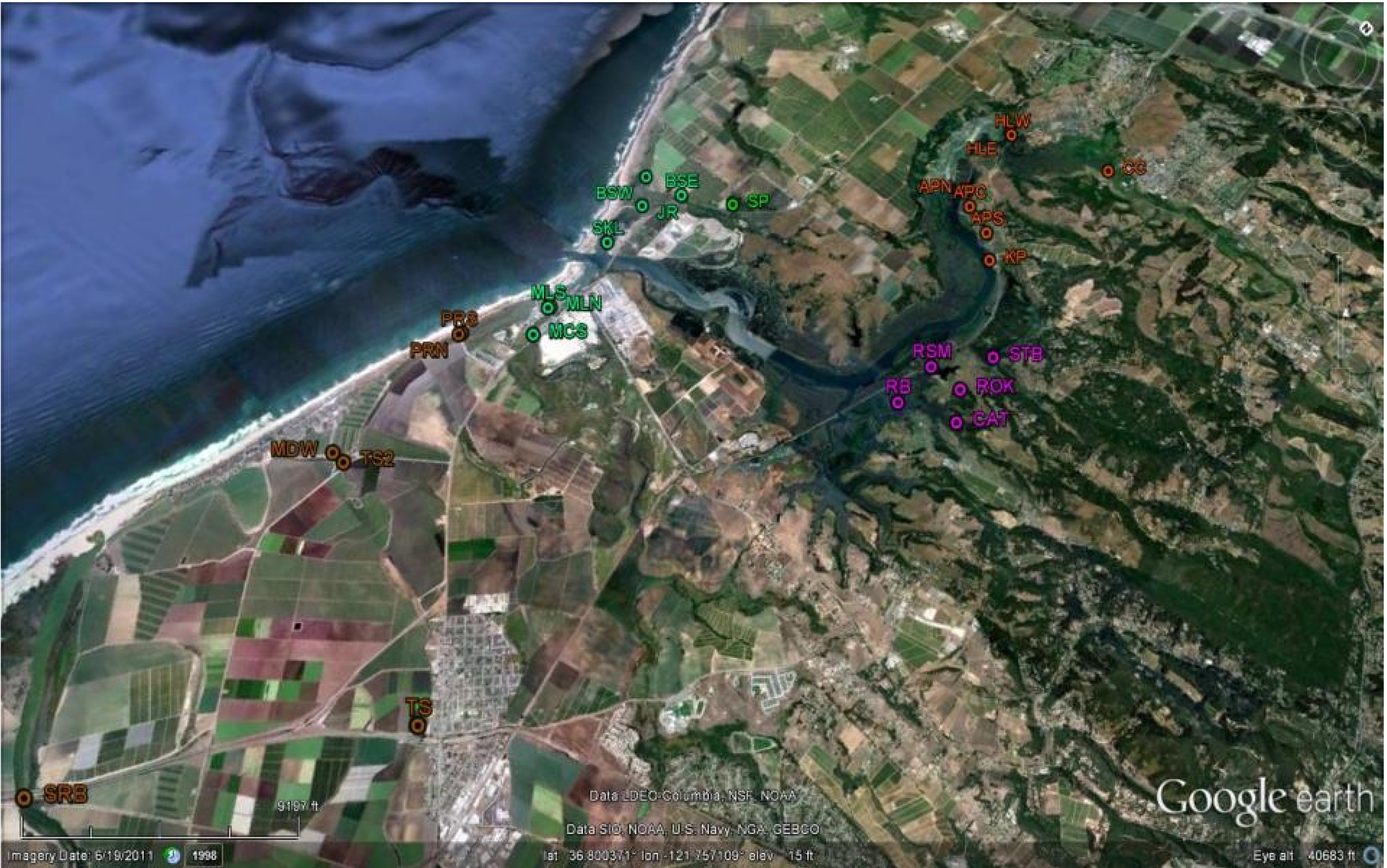
- Great <u>spatial</u> coverage (24 stations)
- Monthly sampling
- Very long time series (since 1989)
- Physical Parameters and nutrients



Local Volunteer Program Stations (data collected monthly)

1	Cameros 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

WQ Monitoring Program-Volunteer Sites



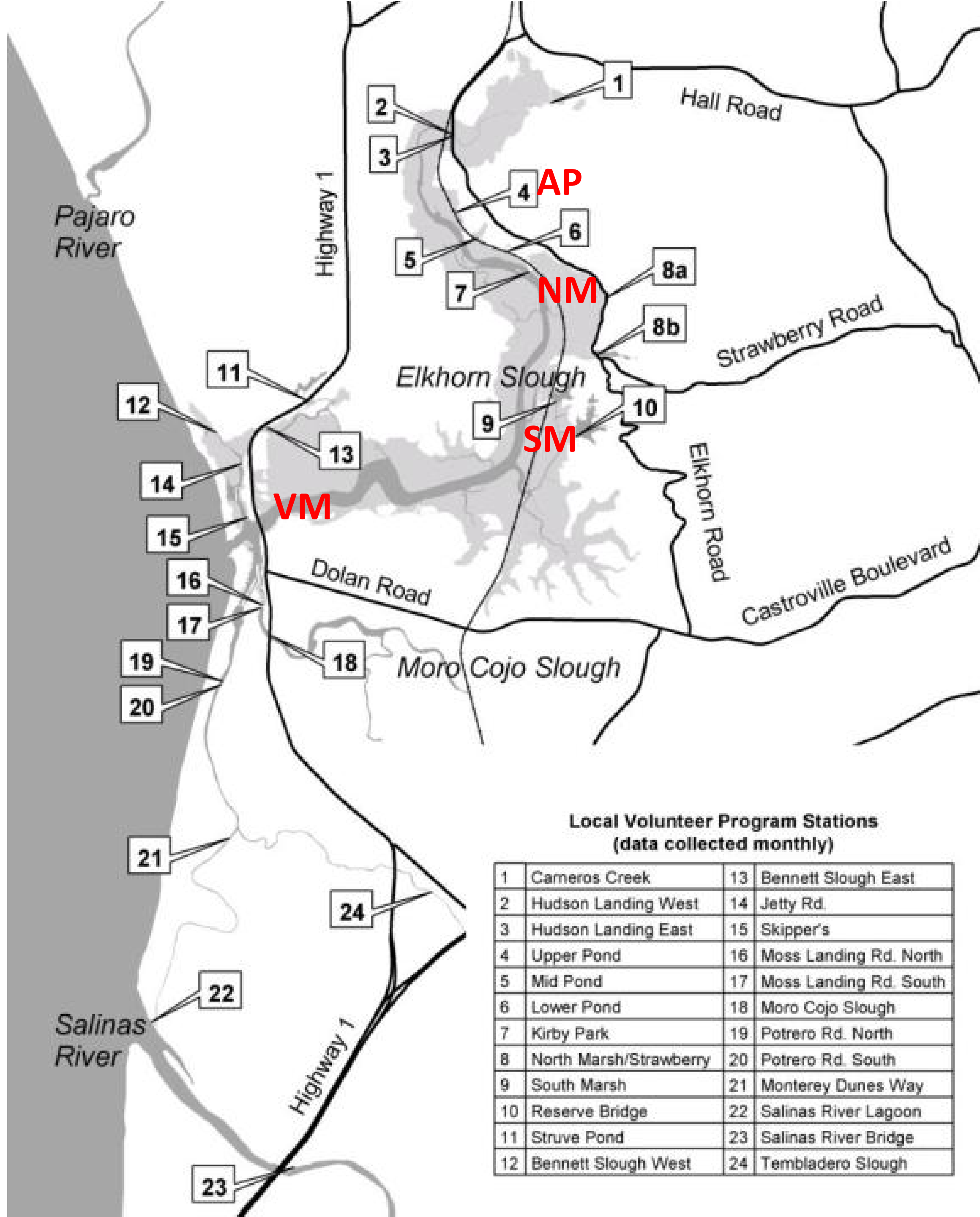
ESNERR WQ Monitoring Programs

Volunteer Program

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

NERR Program

- Great <u>temporal</u> coverage (every 15 min!)
- 4 stations
- Since 1995



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NERR system-wide monitoring program

WQ data collected consistently at four stations at 28 NERR sites

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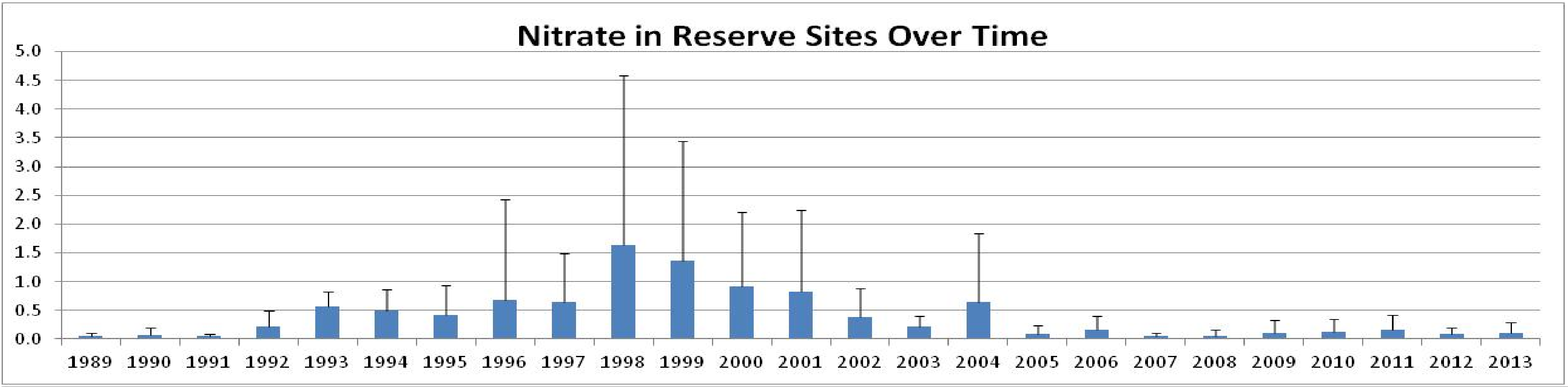
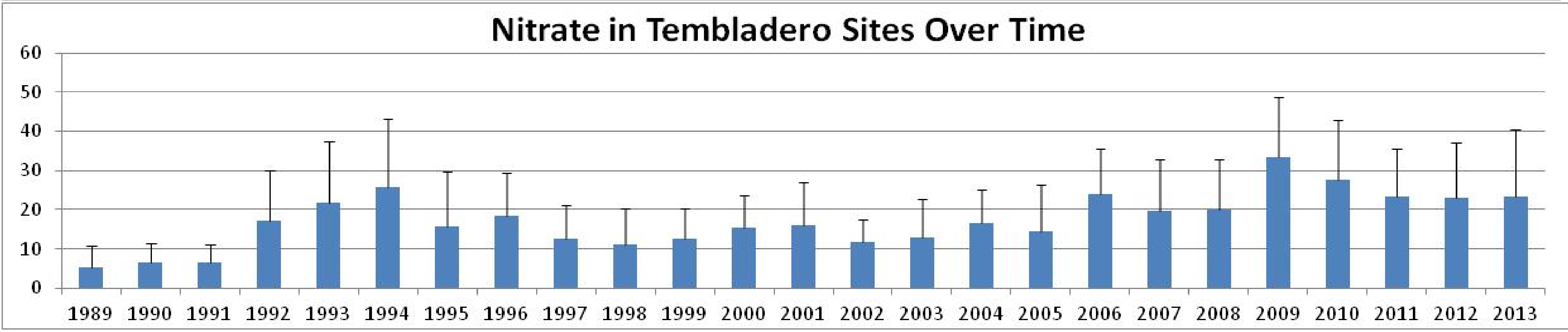
TAKE HOME MESSAGES

NUTRIENT POLLUTION VARIES BY REGION AND OVER TIME

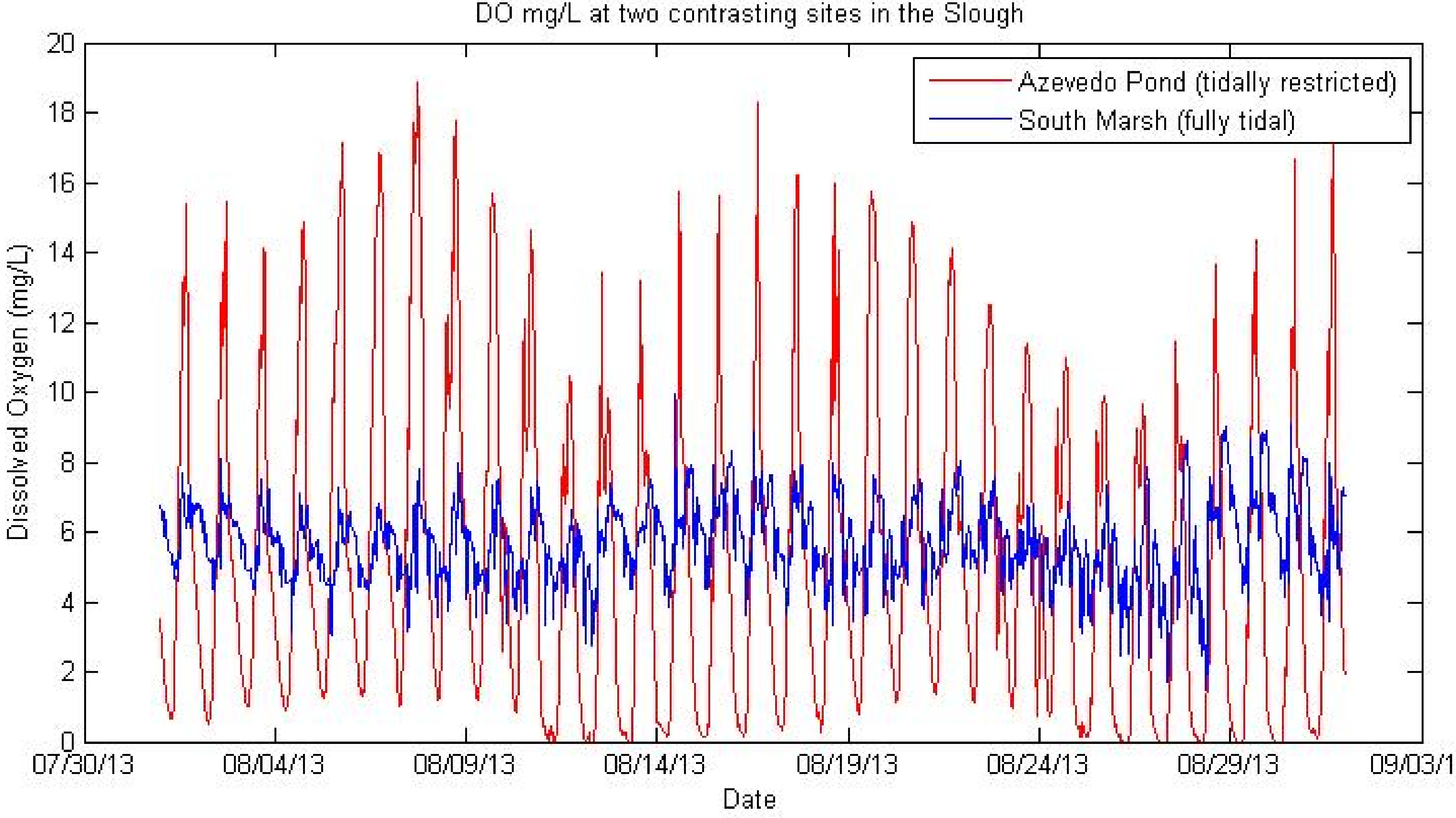




- Nitrates appear to undergo cycles of low vs. high years
- Nitrates are highest in Tembladero Slough sites (note variable scale bar across panels, 1mg/L is threshold)
- No clear trends over time at Tembladero but have stayed low in Reserve sites

[From monthly volunteer data]

EXAMPLE OF DAILY HYPERVENTILATION THAT OCCURS IN TIDALLY RESTRICTED SITES



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TAKE HOME MESSAGES

Estuaries and Coasts
DOI 10.1007/s12237-010-9276-3

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

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

Received: 29 June 2009 / Revised: 9 August 2009 / Accepted: 6 February 2010

Abstract Coastal managers and policy-makers are concerned with tracking improvements to 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 NO_3, NH_3, and PO_4 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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1700 Elkhorn Road,
Watsonville, CA 95076, USA
e-mail: agee108@gmail.com

A. K. Gee
Institute of Marine Sciences,
University of California at Santa Cruz,
Santa Cruz, CA 95064, USA

K. Wasson
Department of Ecology and Evolutionary Biology,
University of California at Santa Cruz,
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 (Flegal 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

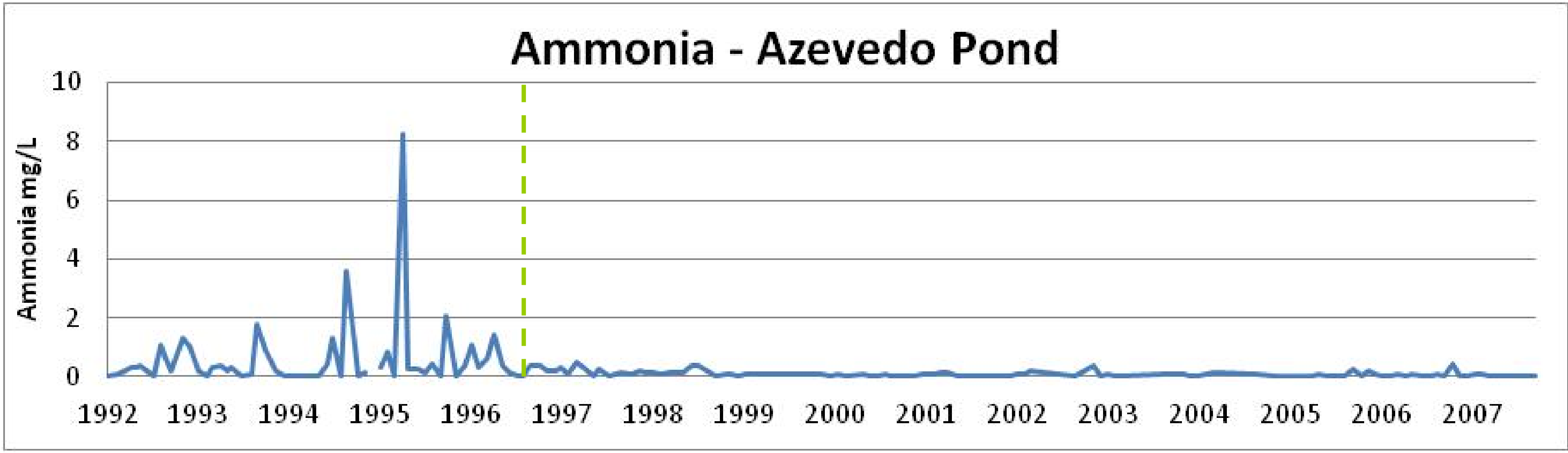
Data split at 1997

Restoration largely complete

All $p < 0.05$ for all three nutrients

Significant difference

NITRATE, AMMONIA AND PHOSPHATE ALL DECREASE AFTER RESTORATION



Gee et al. 2010

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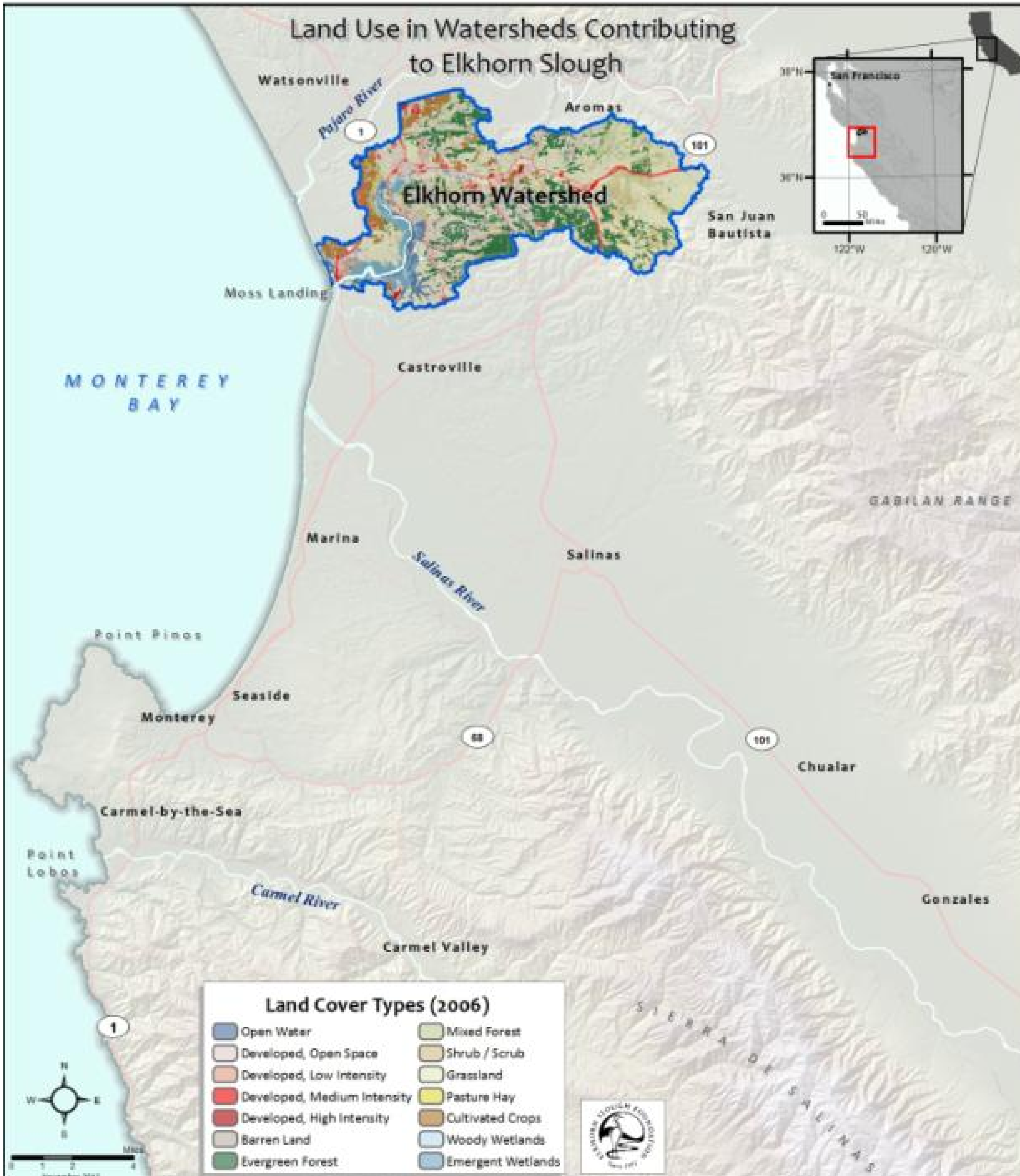
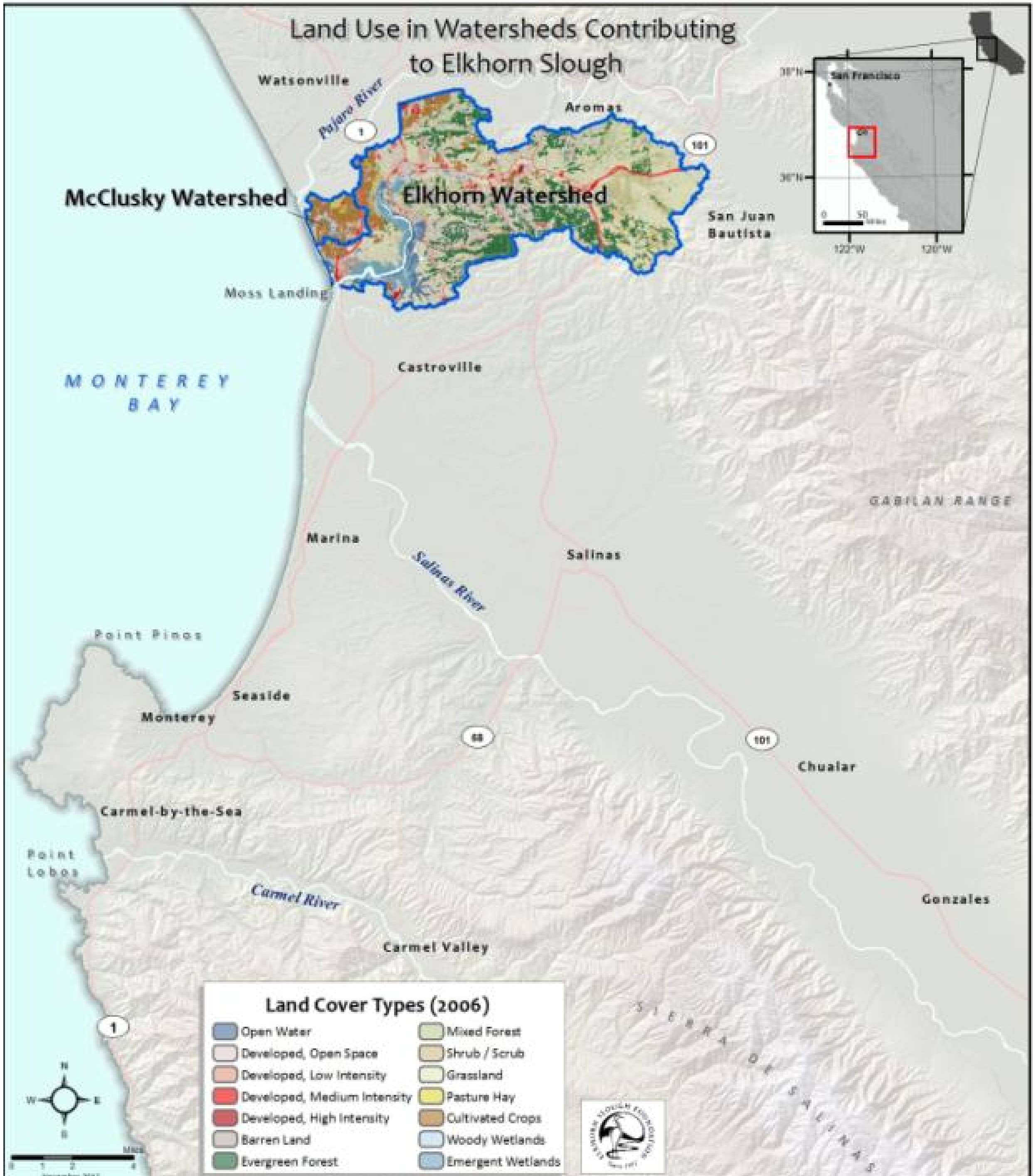

Land Use in Watersheds Contributing
to Elkhorn Slough
Elkhorn Watershed
Watsonville
Pajaro River
Aromas
San Juan
Bautista
Moss Landing
Castroville
MONTEREY
BAY
GABILAN RANGE
Marina
Salinas River
Salinas
Point Pinos
Seaside
Monterey
Chualar
Carmel-by-the-Sea
Point
Lobos
Carmel River
Carmel Valley
Gonzales
SIERRA DE SALINAS
San Francisco
38°N
36°N
122°W
120°W
1
101
68
Land Cover Types (2006)
Open Water
Developed, Open Space
Developed, Low Intensity
Developed, Medium Intensity
Developed, High Intensity
Barren Land
Evergreen Forest
Mixed Forest
Shrub / Scrub
Grassland
Pasture Hay
Cultivated Crops
Woody Wetlands
Emergent Wetlands
N
S
E
W
Miles
November 2013



Land Use in Watersheds Contributing to Elkhorn Slough
McClusky Watershed
Elkhorn Watershed
Watsonville
Pajaro River
Aromas
San Juan Bautista
Moss Landing
MONTEREY BAY
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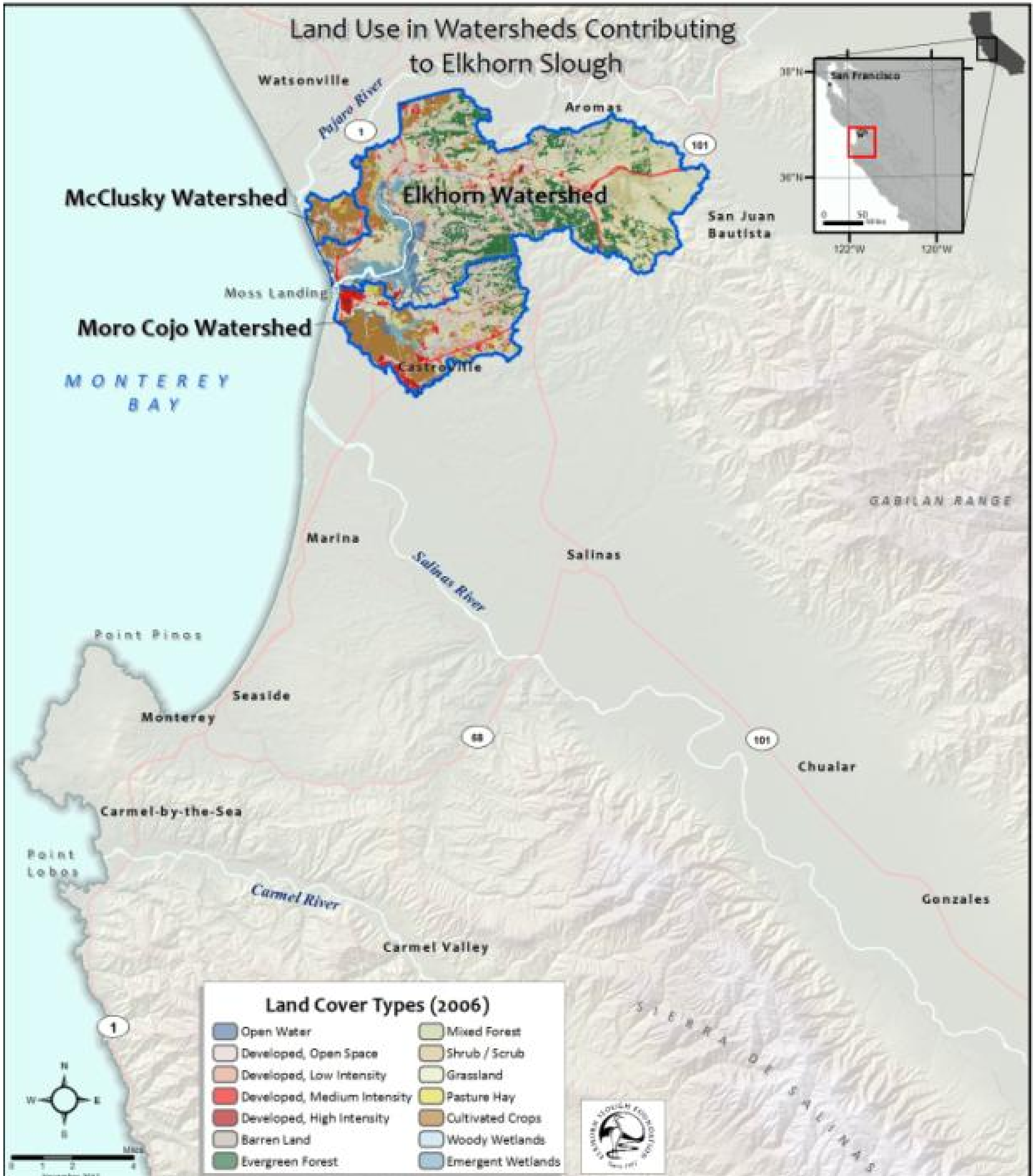
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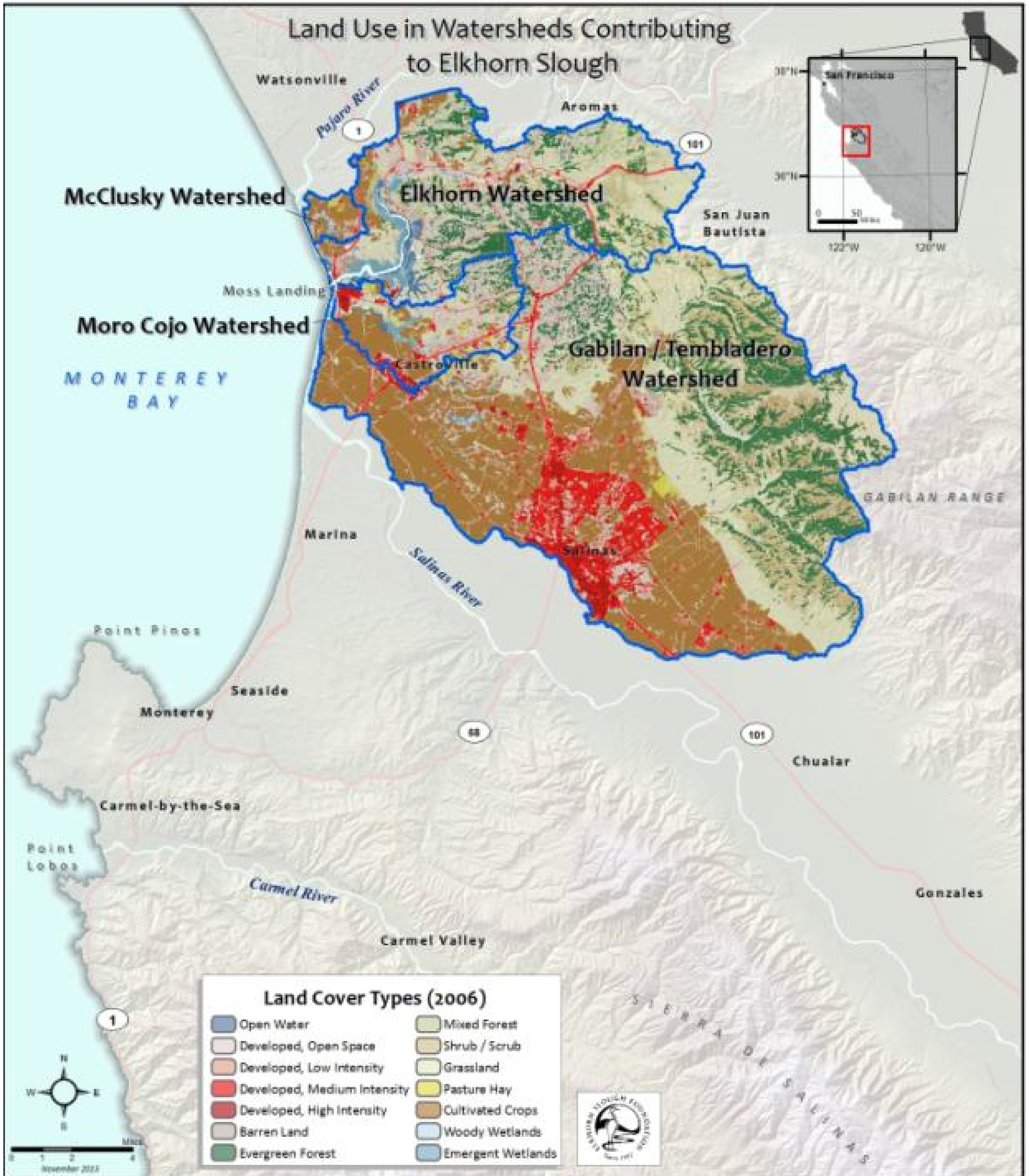

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120°W
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MONTEREY
BAY
GABILAN
RANGE
Salinas
Monterey
Total Watershed Area
2,252,074 ac
Salinas River
Carmel River
Soledad
Greenfield
King City
Salinas Watershed
Paso Robles
Atascadero
Morro Bay
San Luis Obispo
Grover City
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N
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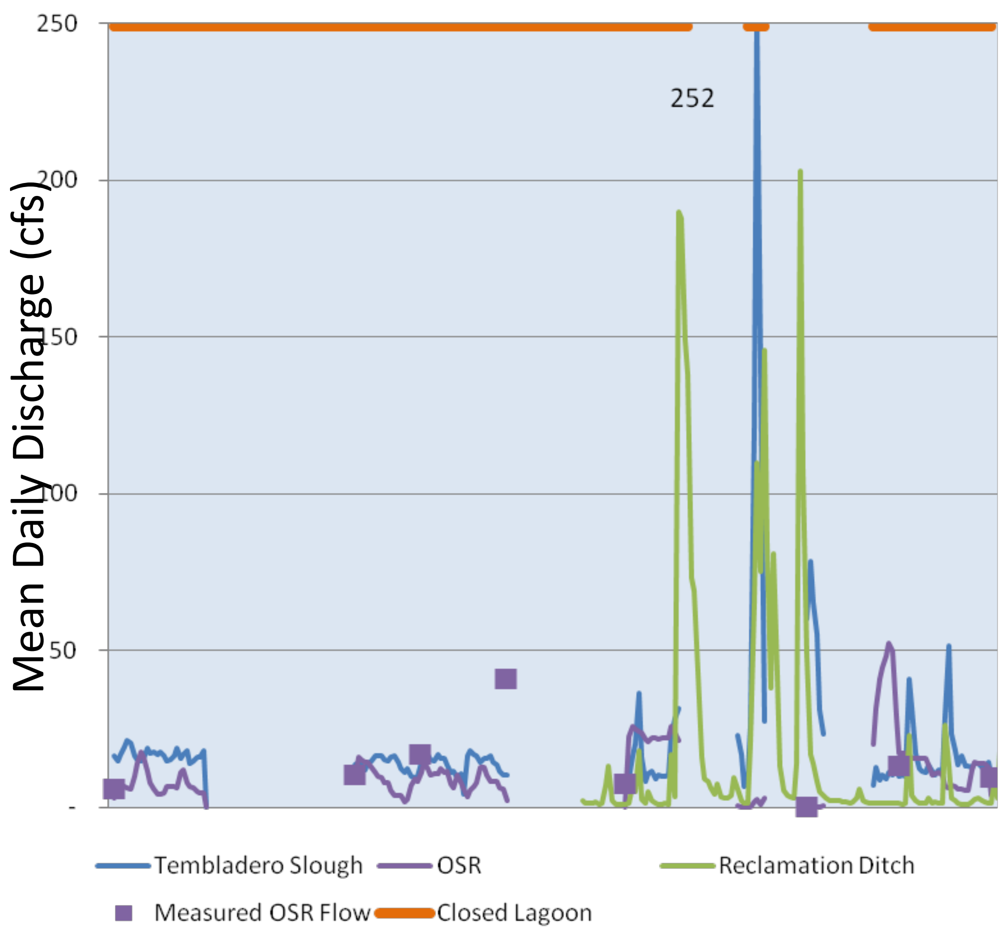
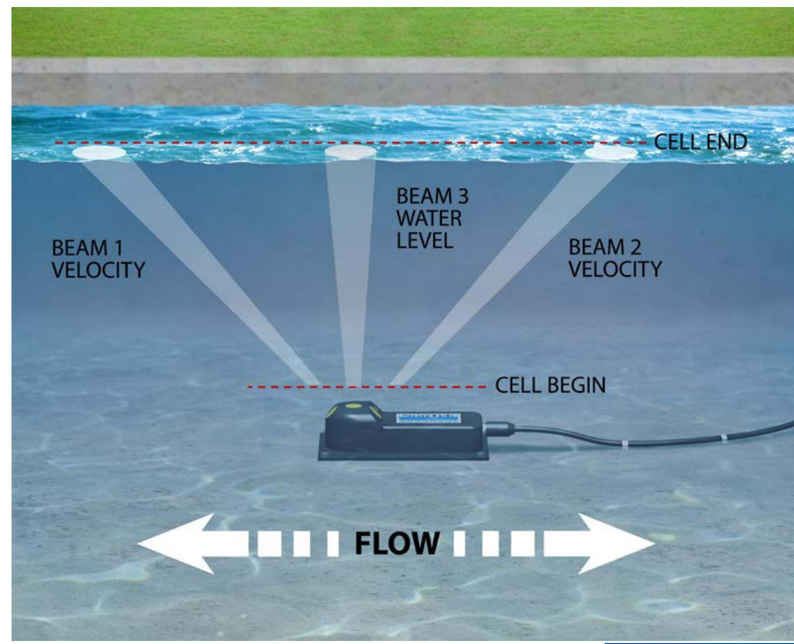
CALCULATING NUTRIENT LOADS AND SOURCES

ESNERR is taking measurements now in various key tributaries

Measuring flow





SonTek
YSI incorporated

ROAD MAP

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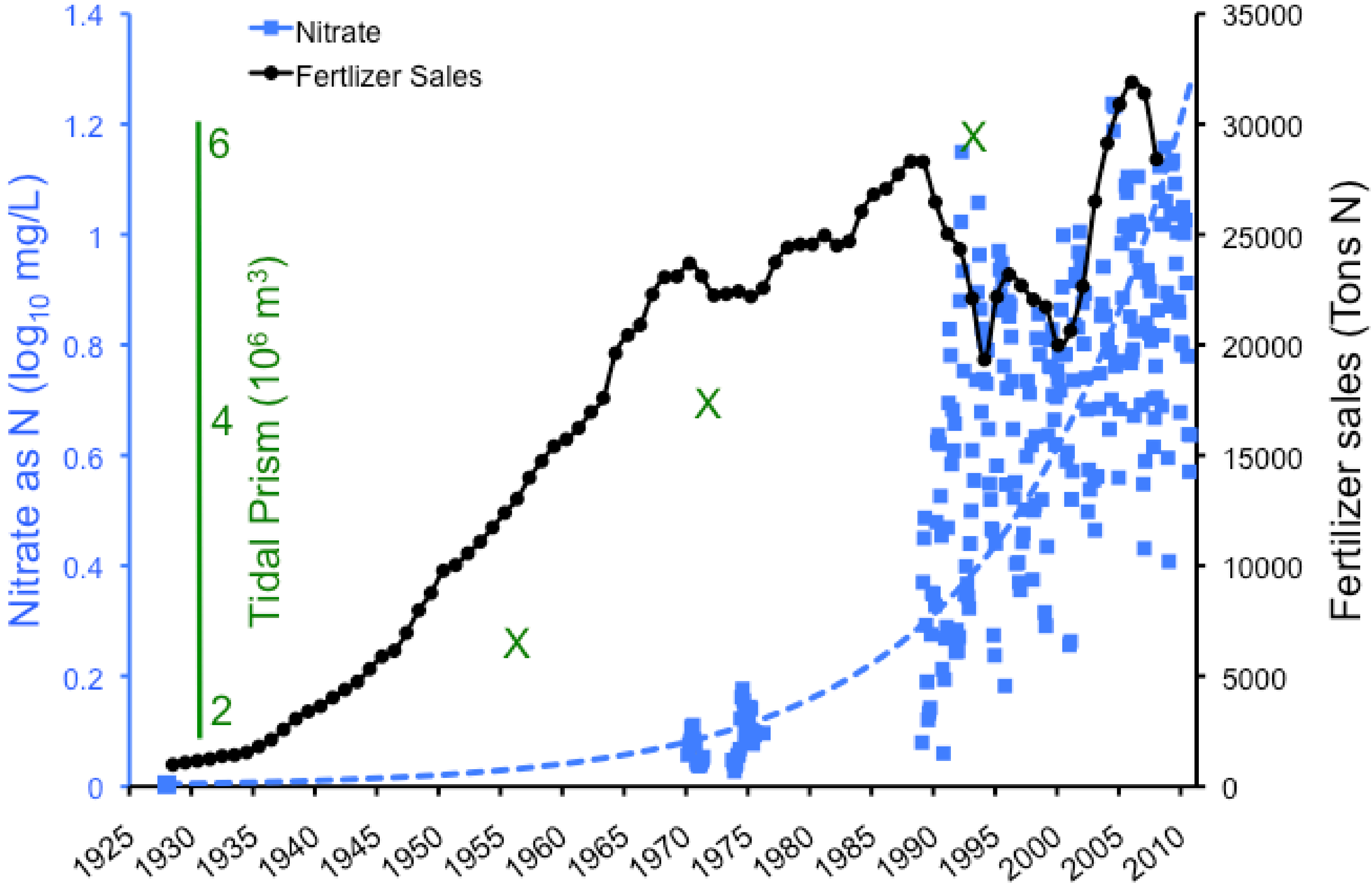
TAKE HOME MESSAGES

Long term nutrient trends



Hughes et al. (2012) *TNC Report*

ECOLOGICAL EFFECTS

OF NUTRIENT-LOADING ON ELKHORN SLOUGH

Vol. ■ ■
doi: 10.3354/meps09295

MARINE ECOLOGY PROGRESS SERIES
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Identifying factors that influence expression of eutrophication in a central California estuary

Brent B. Hughes[1,2,*], John C. Haskins[1], Kerstin Wasson[1,2], Elizabeth Watson[1,3]

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[2]Department of Ecology and Evolutionary Biology, University of California Santa Cruz, Santa Cruz, California 95064, USA
[3]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 · *Ulva* · Chl *a*

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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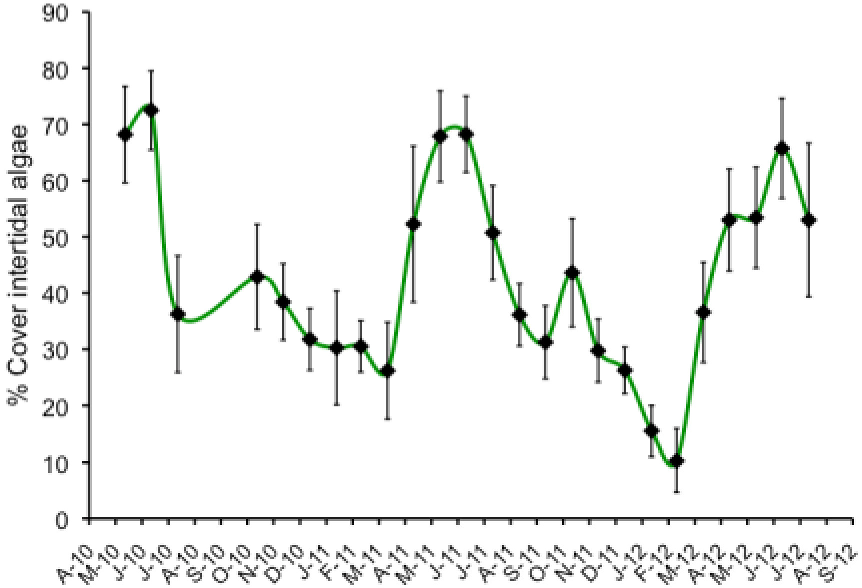
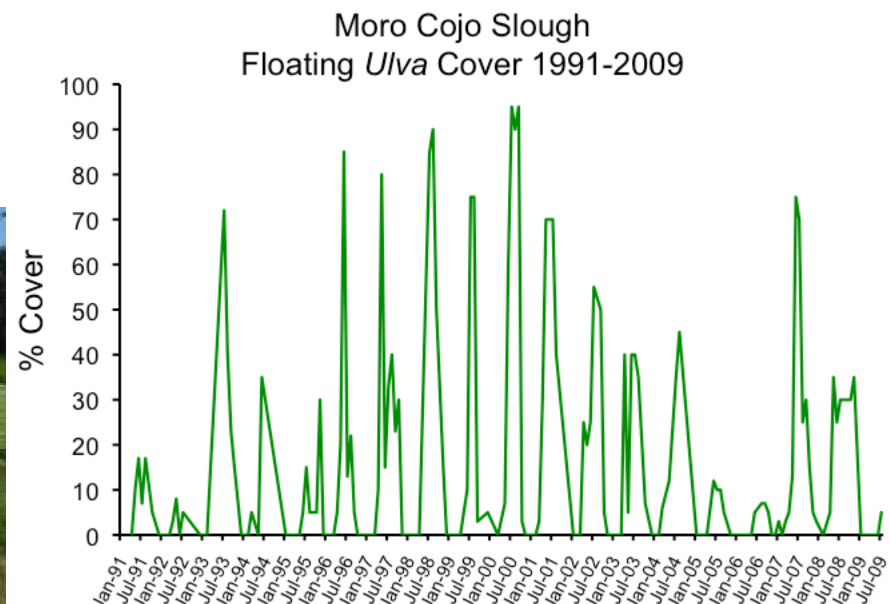
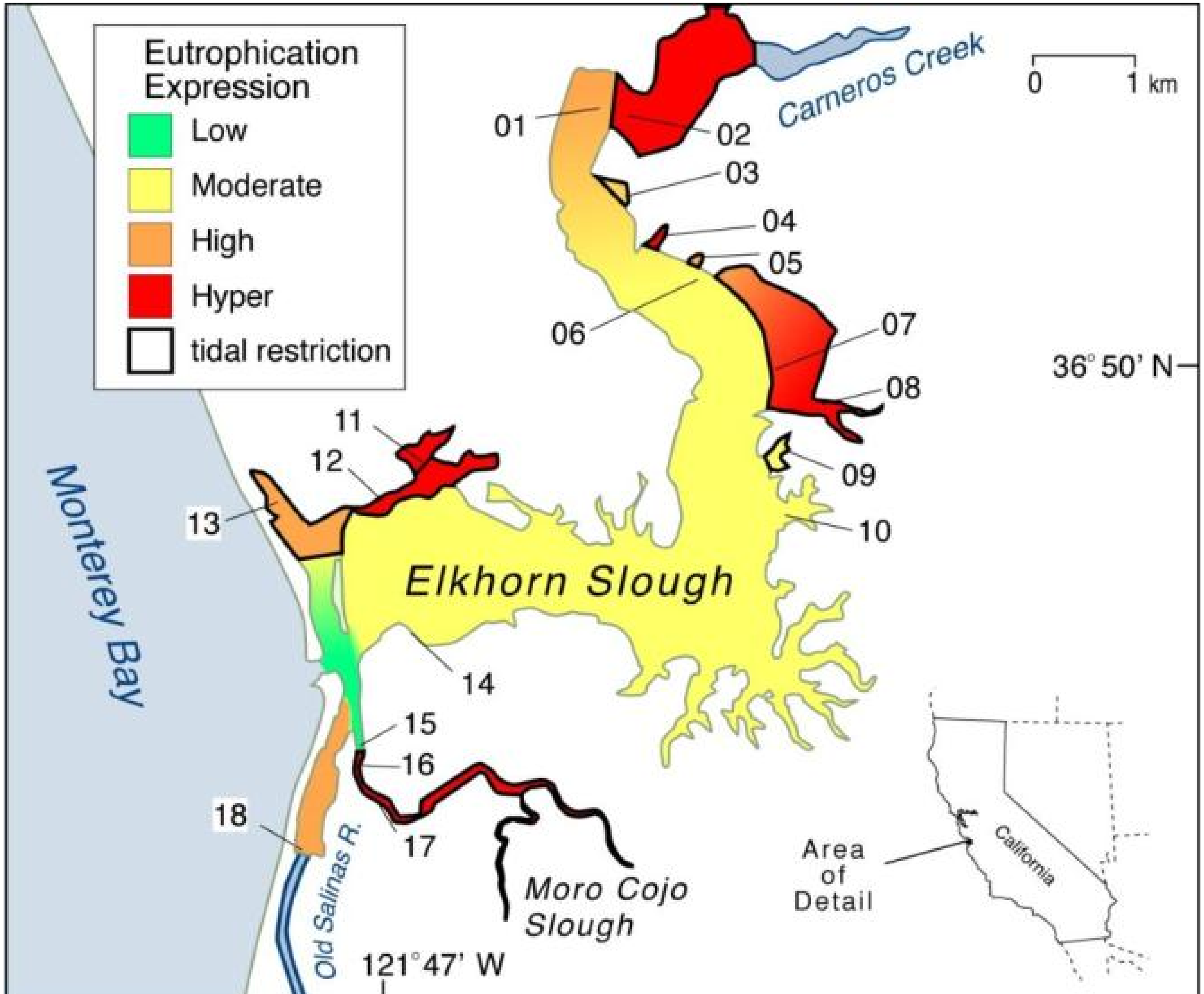
Nutrients grow lots of ephemeral macroalgae



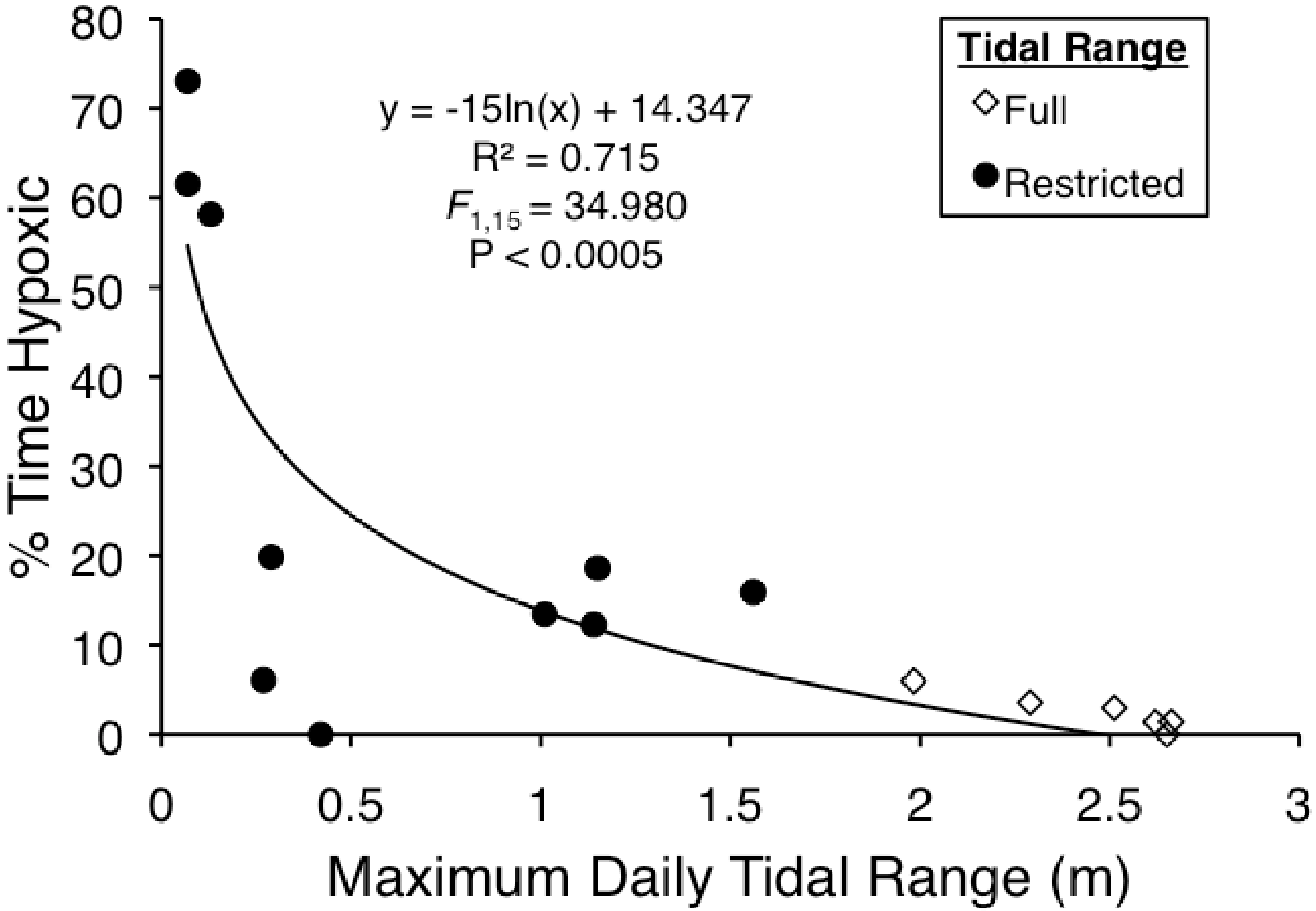


High Variability in Eutrophication Expression, with Moderately Eutrophic Conditions most common



Hughes et al. (2011) *MEPS*

Tidal range explains patterns in hypoxia



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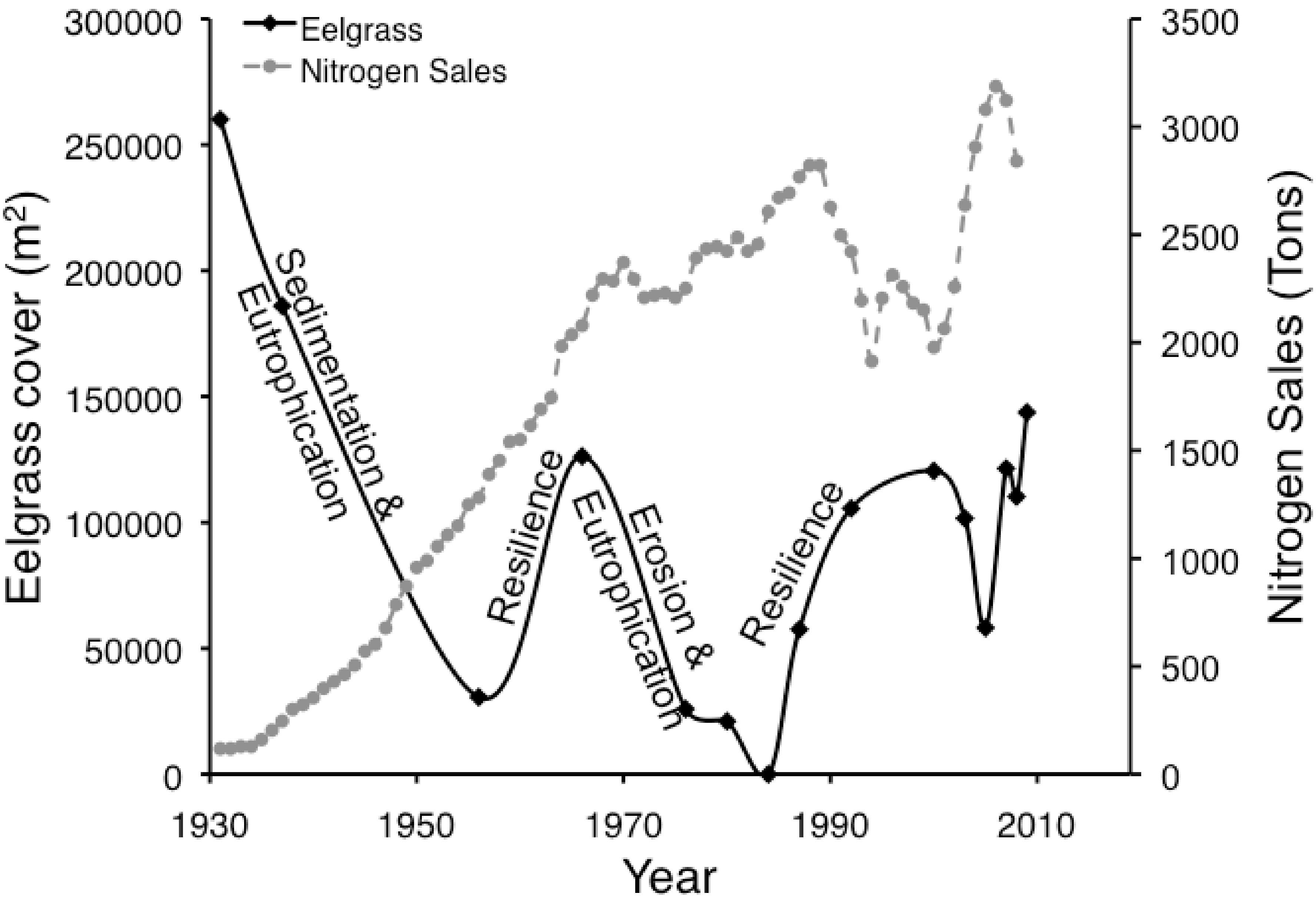
Seagrass unstable over the last century



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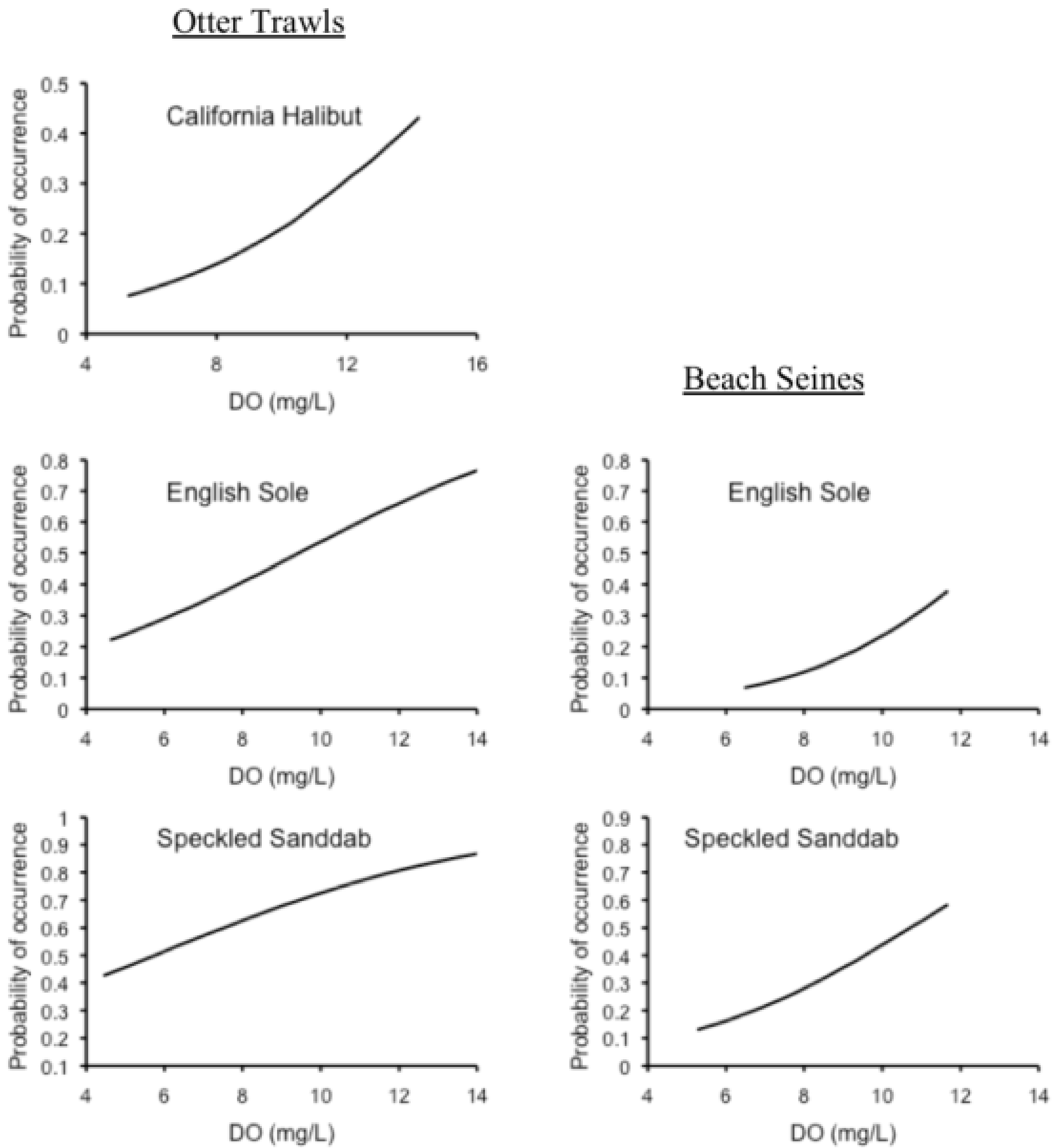
Hypoxia effects on flatfish species



Hughes et al. (2012) *TNC Report*

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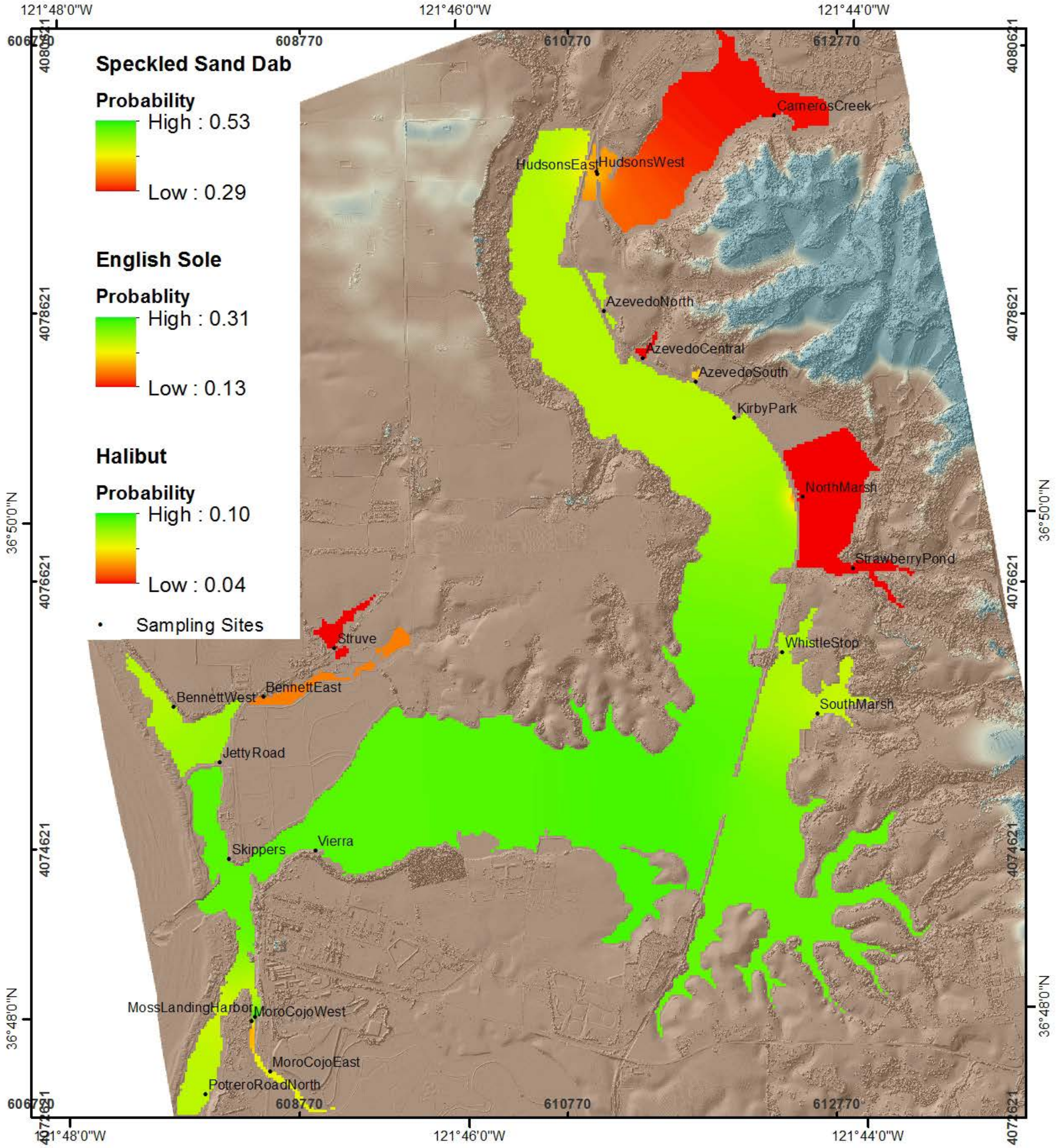
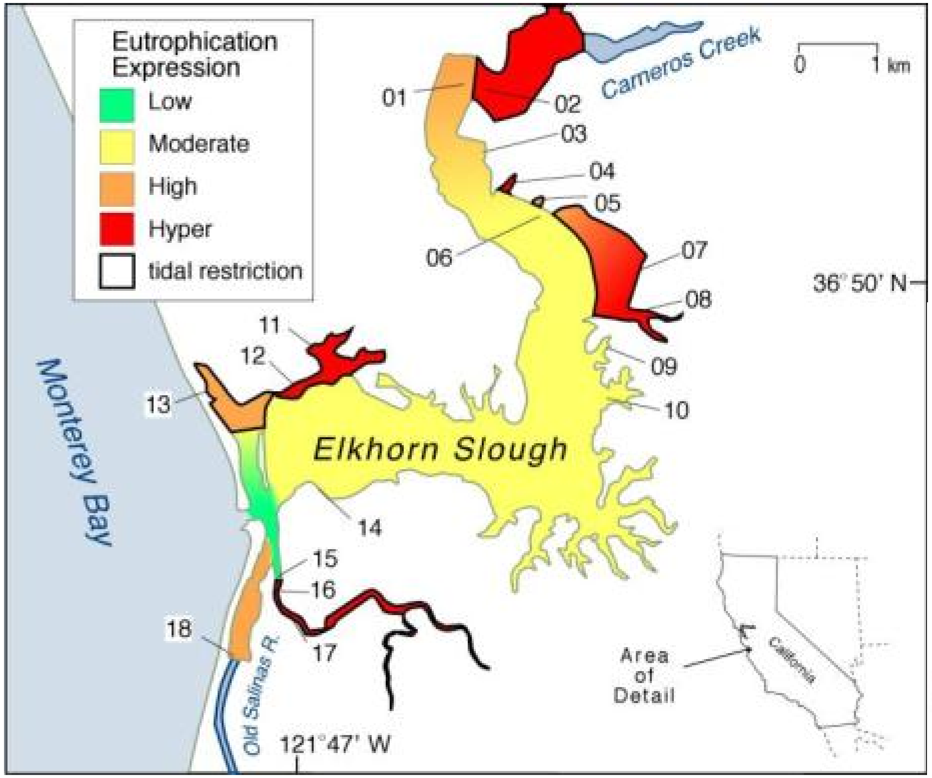
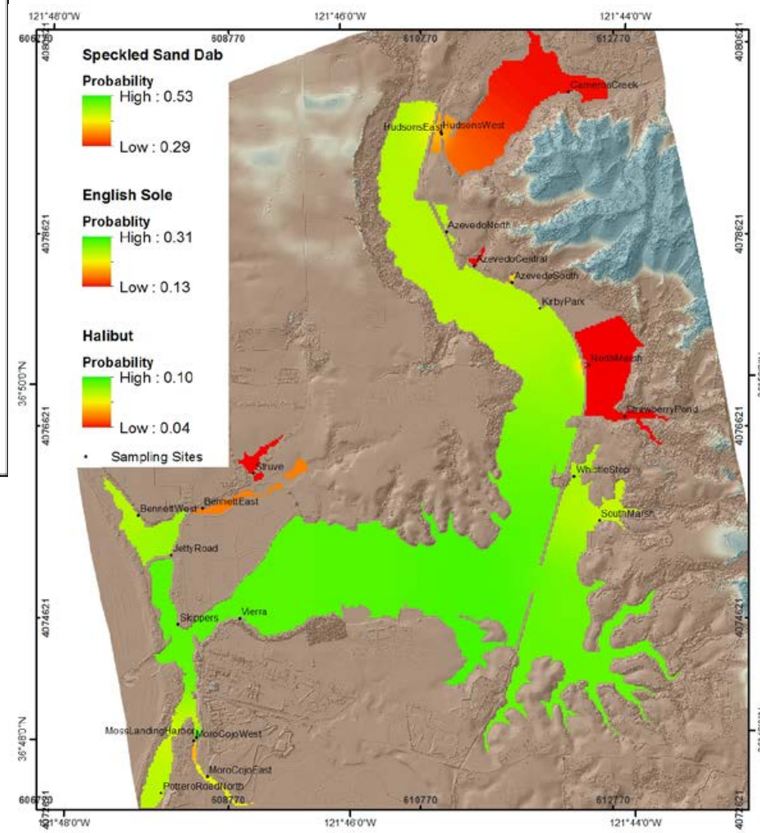


Hughes et al. (2012) *TNC Report*

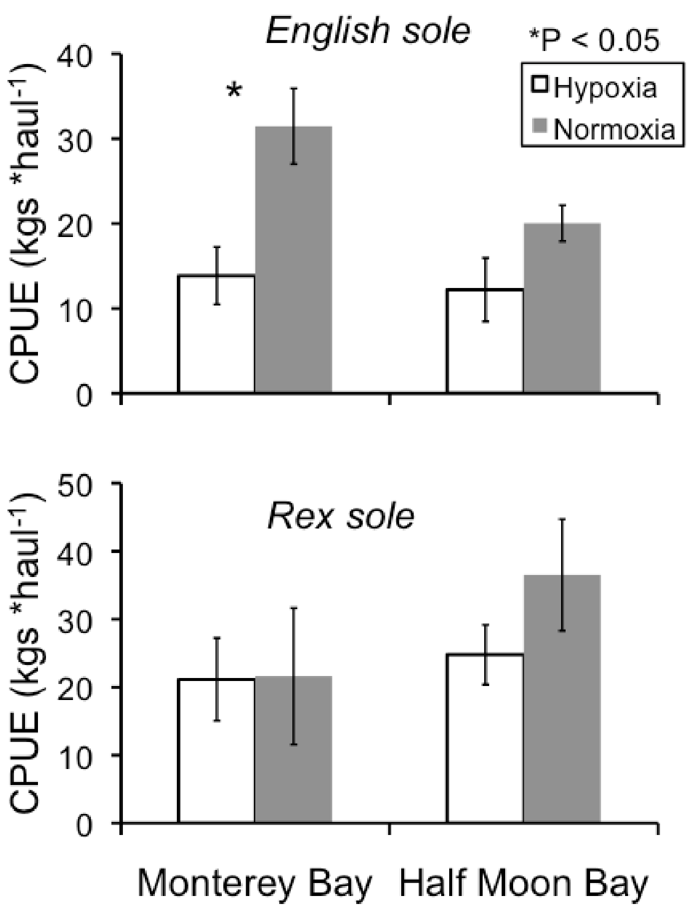
Spatial modeling consistent with eutrophic patterns

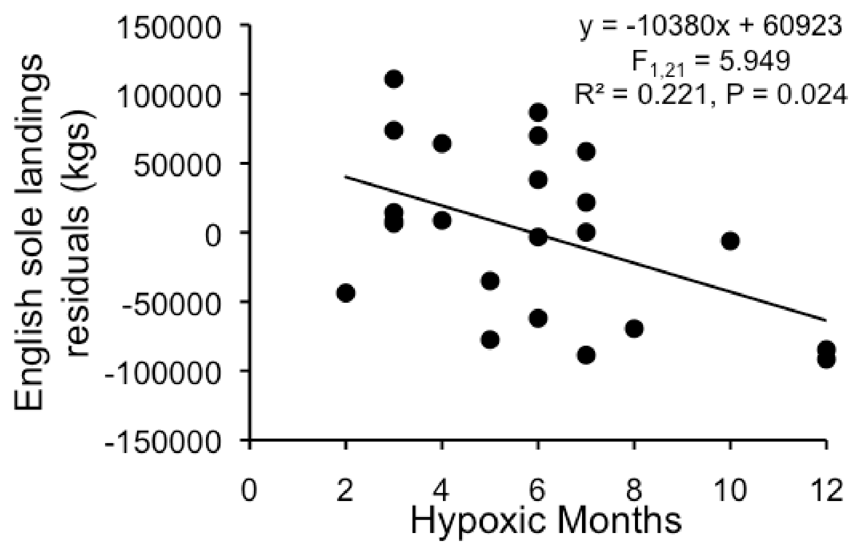




Hughes et al. (2012) *TNC Report*

Hypoxia effects on the offshore stocks & fishery





Hughes et al. (2013) *in prep*

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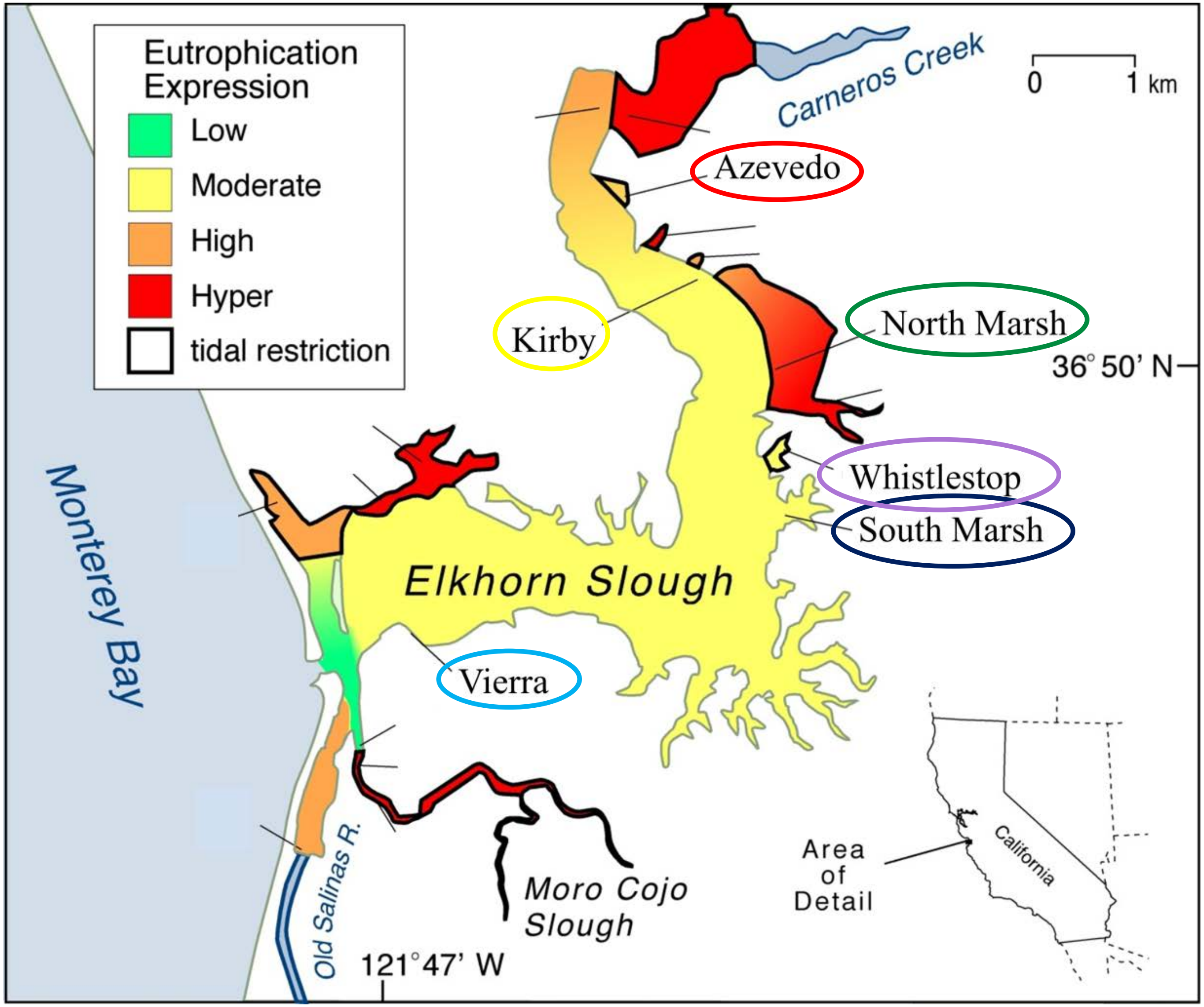
How do fish respond to water quality at different sites?



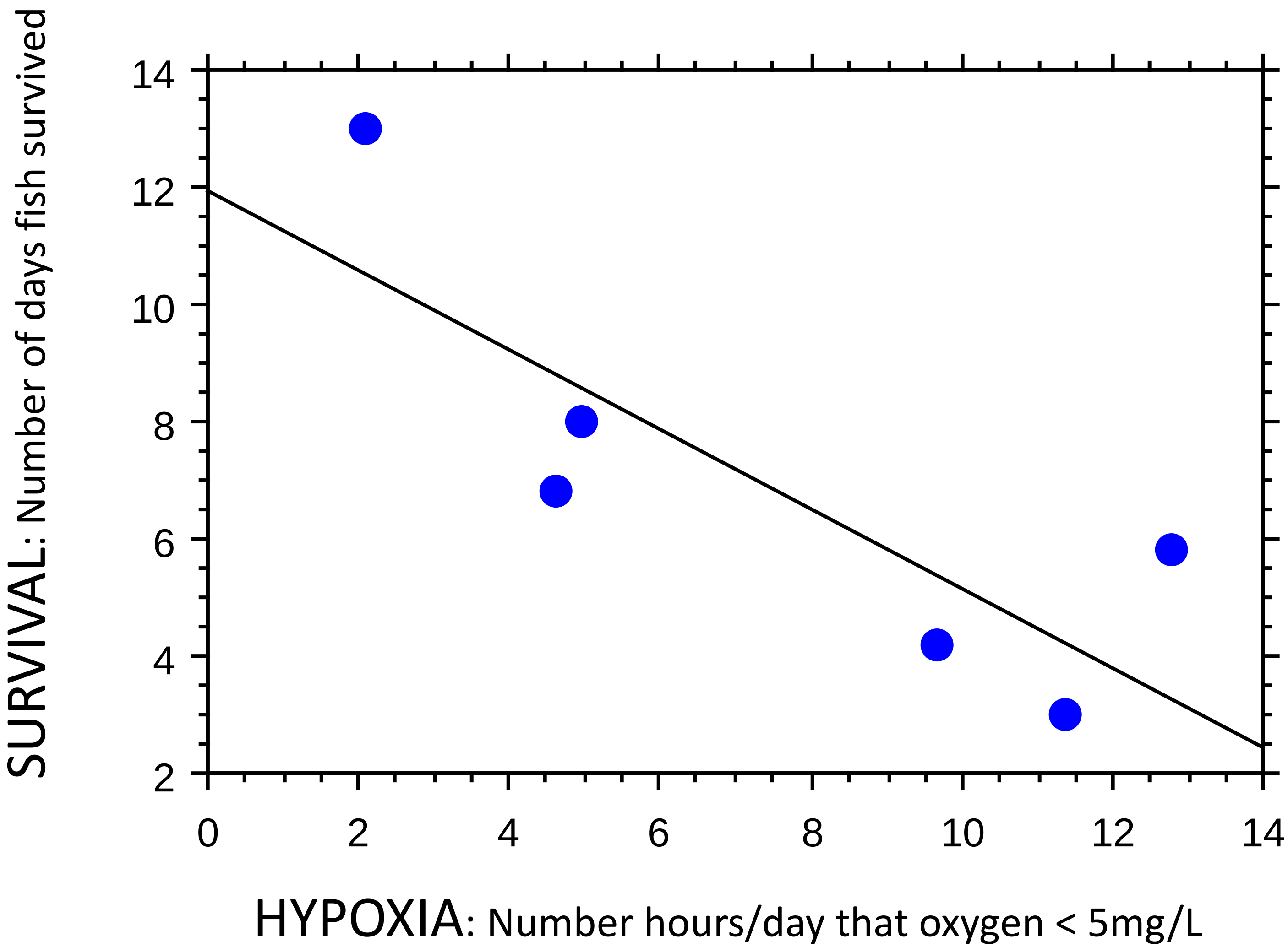
Caging Experiment




- 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

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

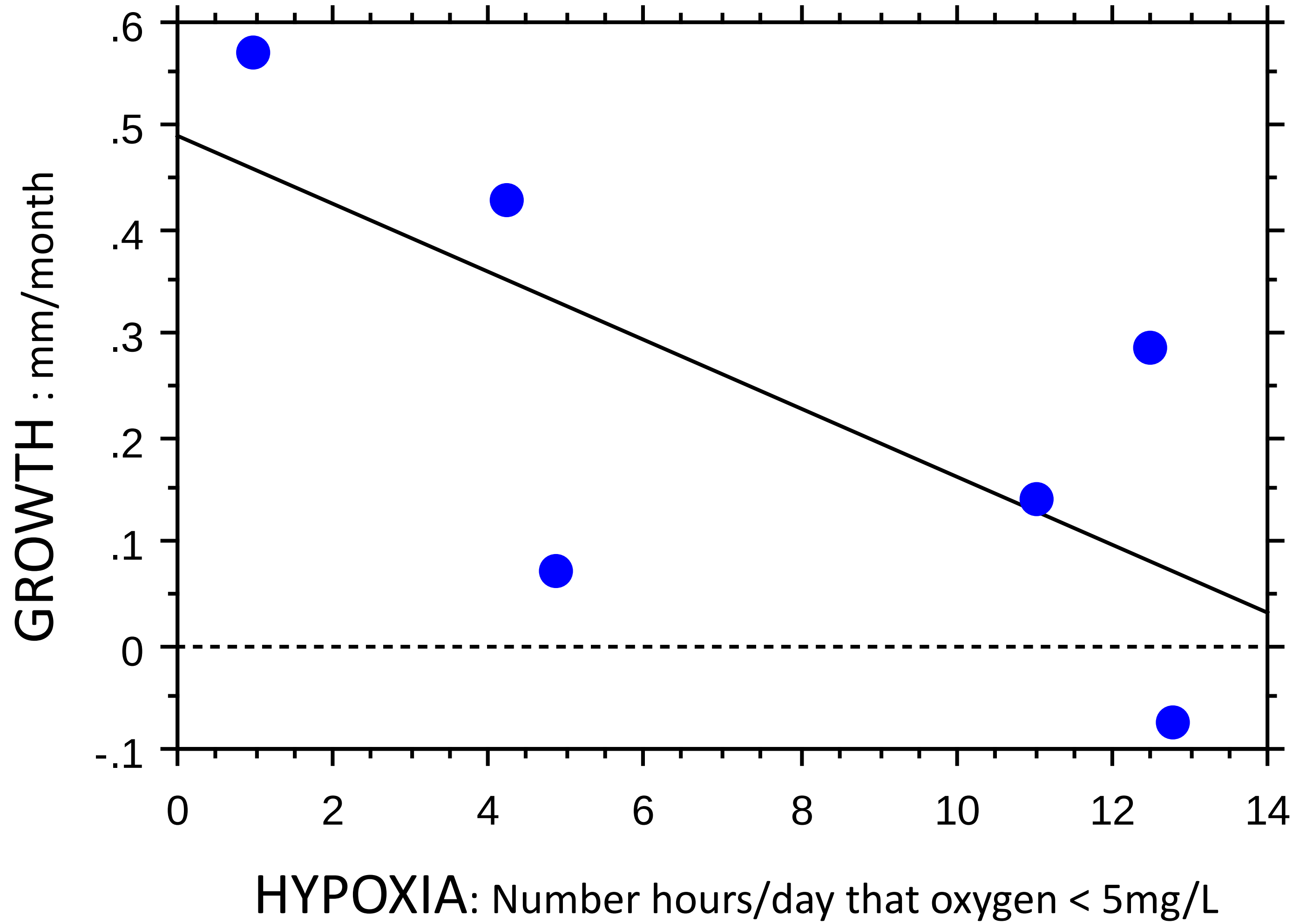
Caging Experiment



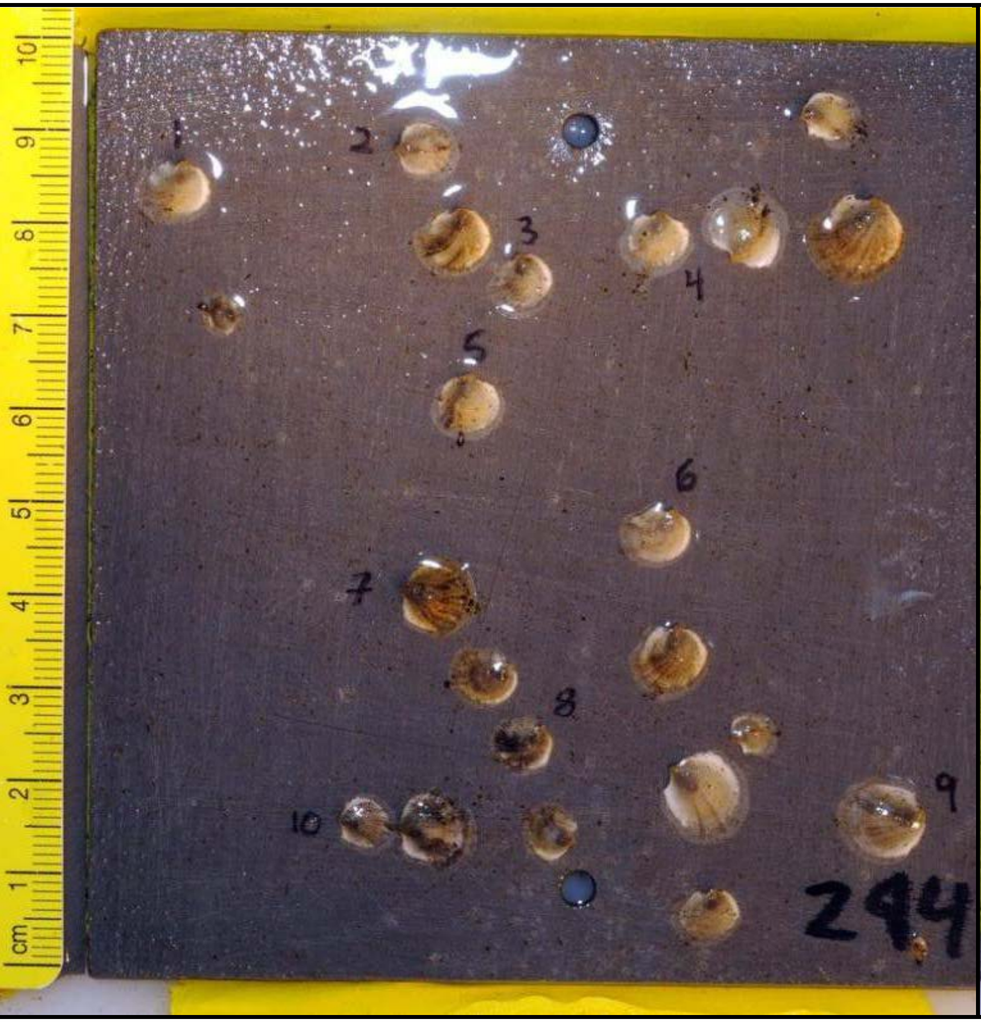

- Olympia oysters used as highly tolerant indicator species
- Cages deployed next to water quality sondes

HYPOXIA SLOWS OYSTER GROWTH

Water quality is inappropriate for shellfish growth in some wetlands



Lab Experiments:
low oxygen slows growth



Normal oxygen

Low oxygen

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ORIGINAL PAPER

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 in 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 fouled 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

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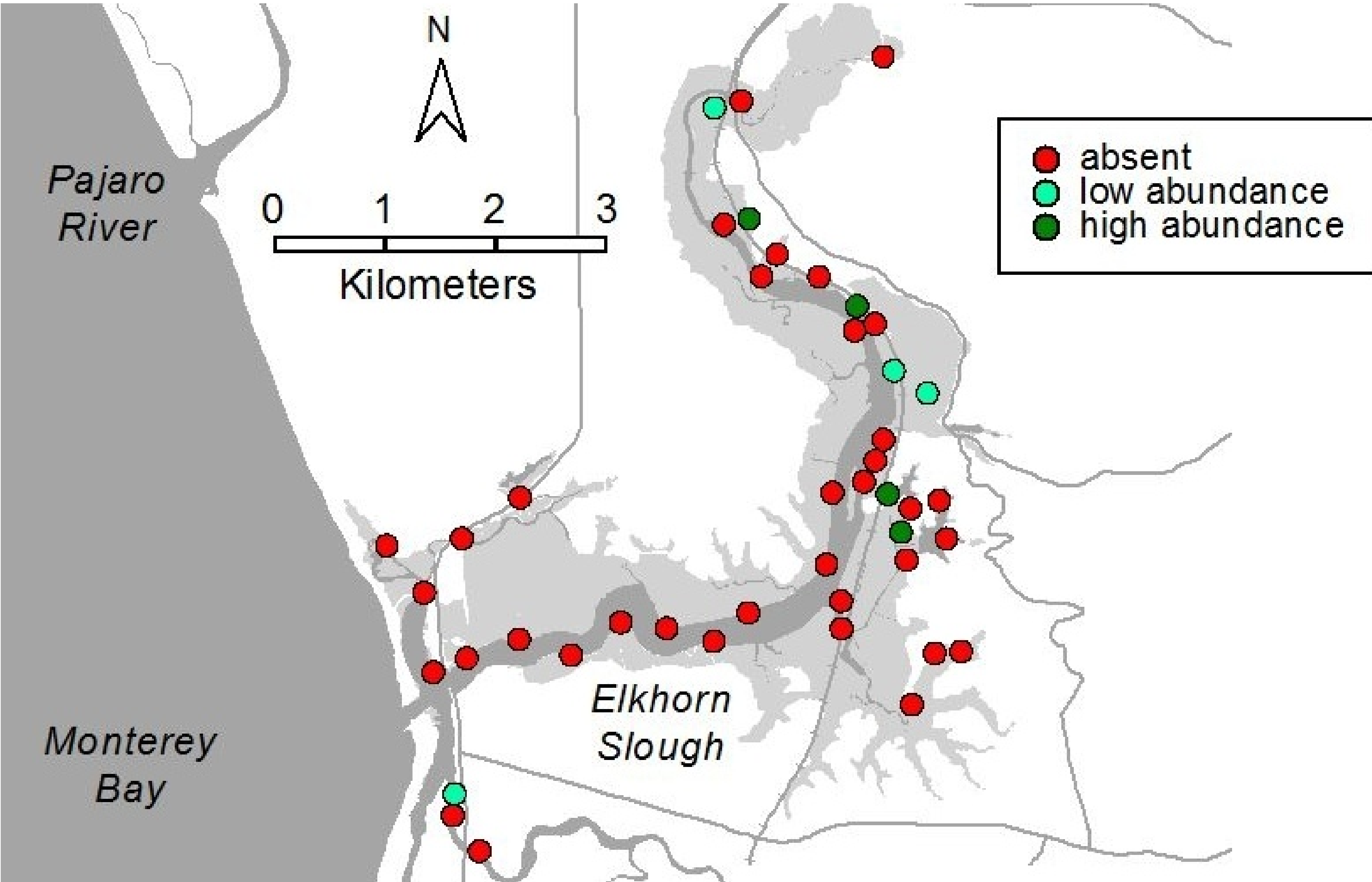
Introduction

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; Coen 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 (Salafsky 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 Grosholz 2006; NOAA Restoration Center 2007; Trimble et al. 2009). A

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

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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

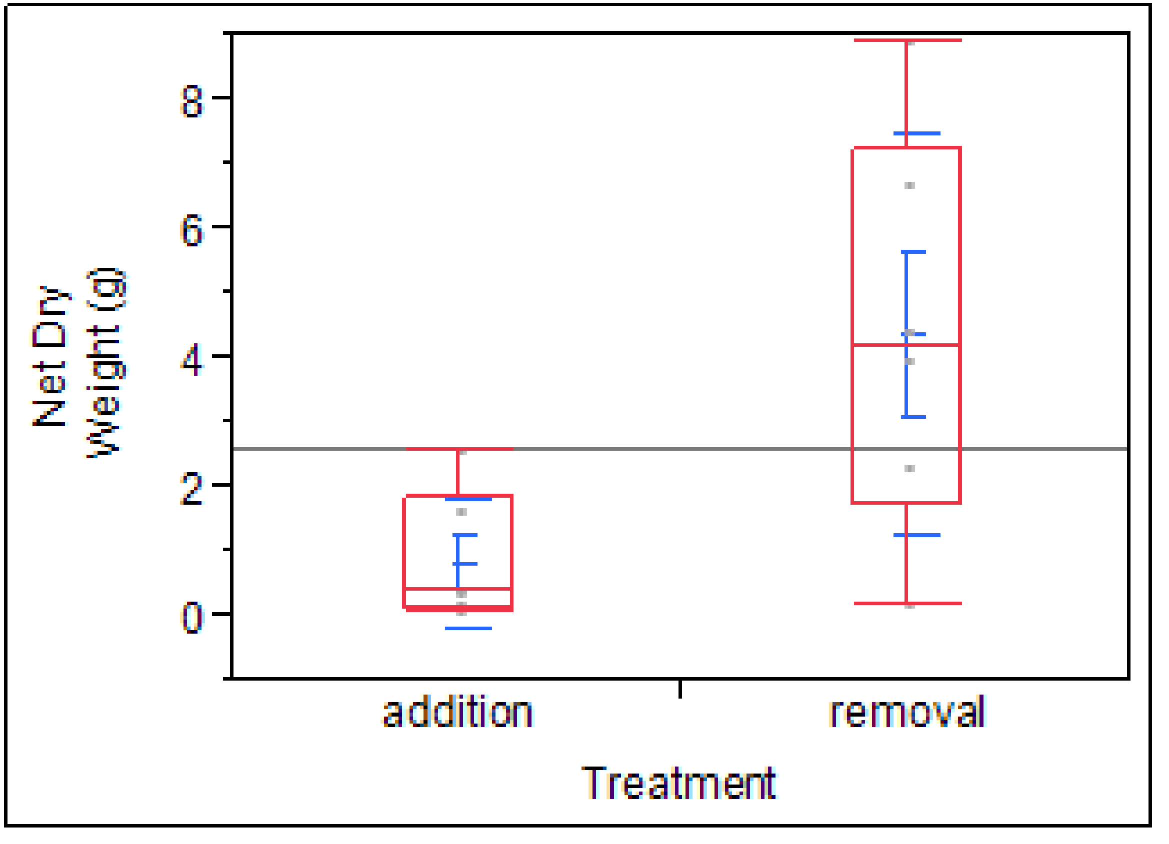
Negative impacts of algal cover

Picklweed <u>before</u> being covered by ulva

Picklweed <u>after</u> 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