Fisheries Resources: A Technical Assessment of Available Scientific Information

State Water Resources Control Board
Phase II Comprehensive Review of the Bay-Delta Plan

Workshop 2: Fisheries Resources

October 1-3, 2012

Submitted by: State Water Contractors, Inc.
San Luis & Delta-Mendota Water Authority

Review: Ecological Change

- Food Web
- Physical Landscape
- Water Temperature
- Turbidity
- Changes in Water Flows

The Management Challenge

Today’s Science Presentation

- **Salmon**
- Pelagic Fish

Salmon Presentation Outline

- Relationships between flow and salmon survival
  - Dr. Chuck Hanson
- Integration of scientific information and decisionmaking
  - Steve Cramer

Next up:

Dr. Chuck Hanson, Hanson Environmental

Dr. Steve Cramer, Cramer Fish Sciences

Salmon technical presentation

Fisheries Resources: A Technical Assessment of Available Scientific Information Regarding Salmonids

State Water Resources Control Board

Phase II Comprehensive Review of the Bay-Delta Plan

Workshop 2: Fisheries Resources

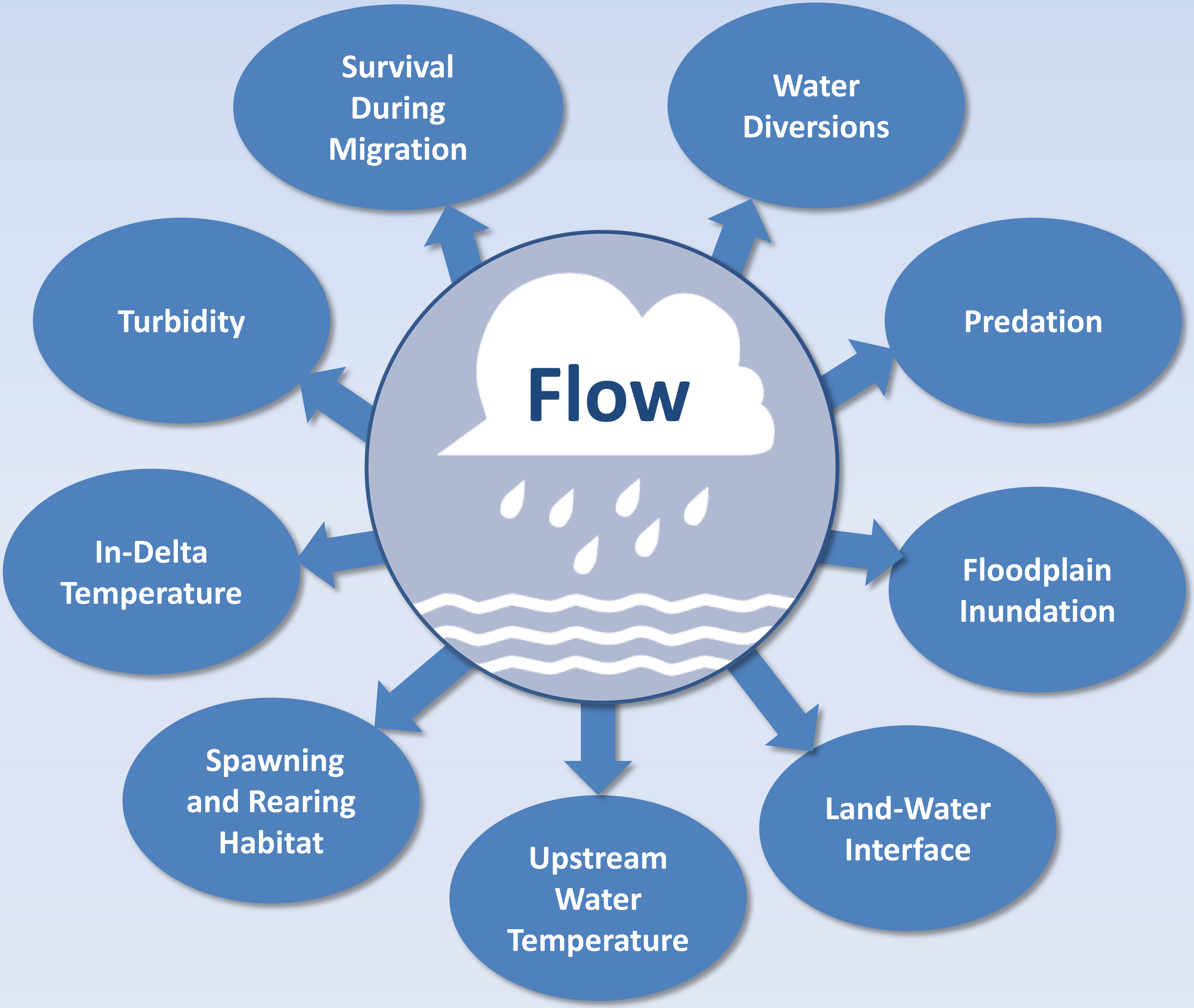
October 1-3, 2012

Objective: Provide a scientific basis for identifying potential recommendations based on opportunities and constraints of alternative management strategies.

Submitted by:
State Water Contractors, Inc.
San Luis & Delta-Mendota Water Authority

Presentation Organization

- Flow Functions and Reservoir Releases
- Stressors
- River Flow and Survival
- River Flow and Juvenile Migration Rates
- Water Temperature Management
- Effect of Exports on Survival
- Tidal Hydrodynamics and Flow
- Ocean Conditions
- Lifecycle Models
- Summary



Flow

Survival During Migration

Water Diversions

Turbidity

Predation

In-Delta Temperature

Floodplain Inundation

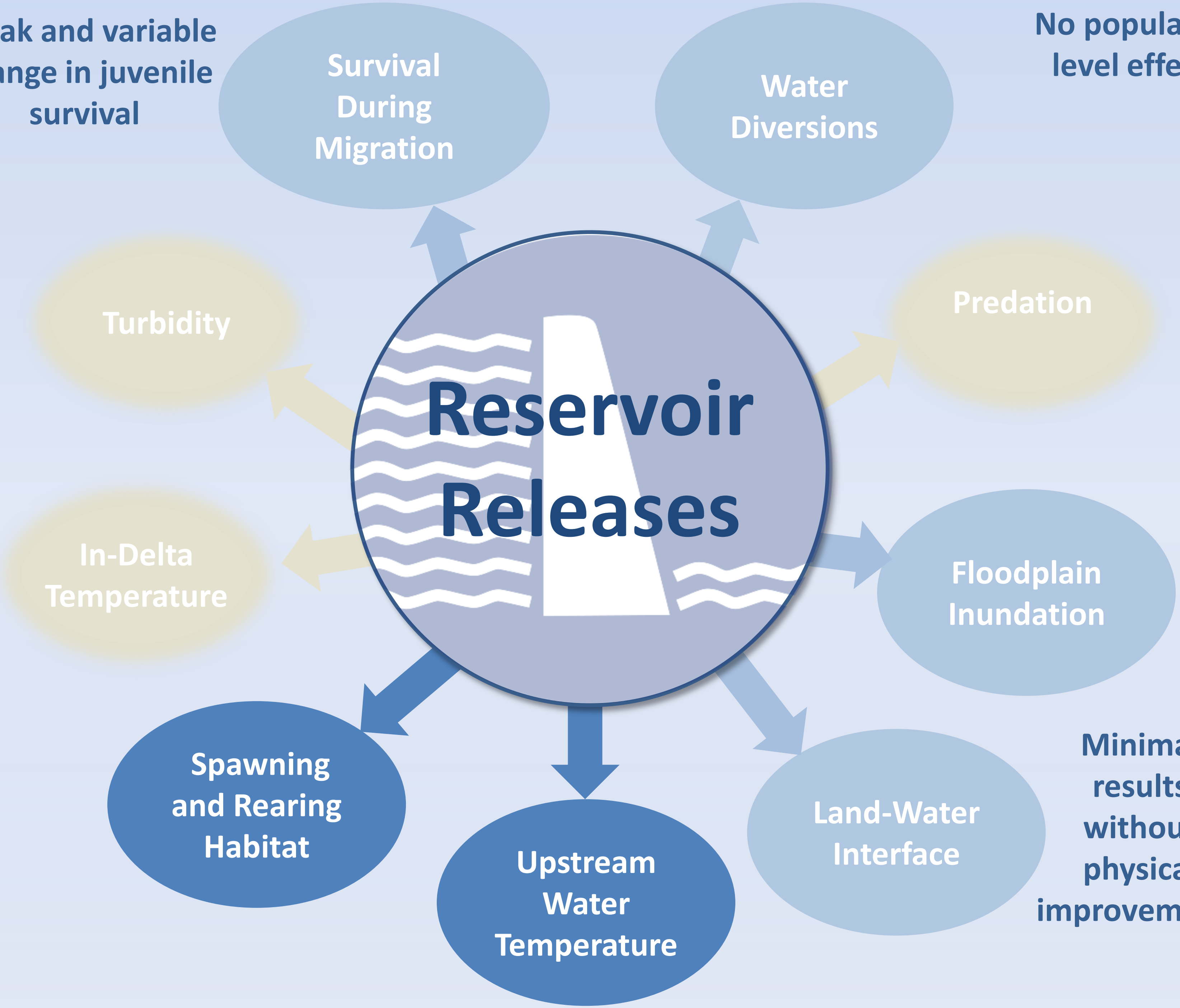
Spawning and Rearing Habitat

Upstream Water Temperature

Land-Water Interface

Weak and variable change in juvenile survival

No population level effects

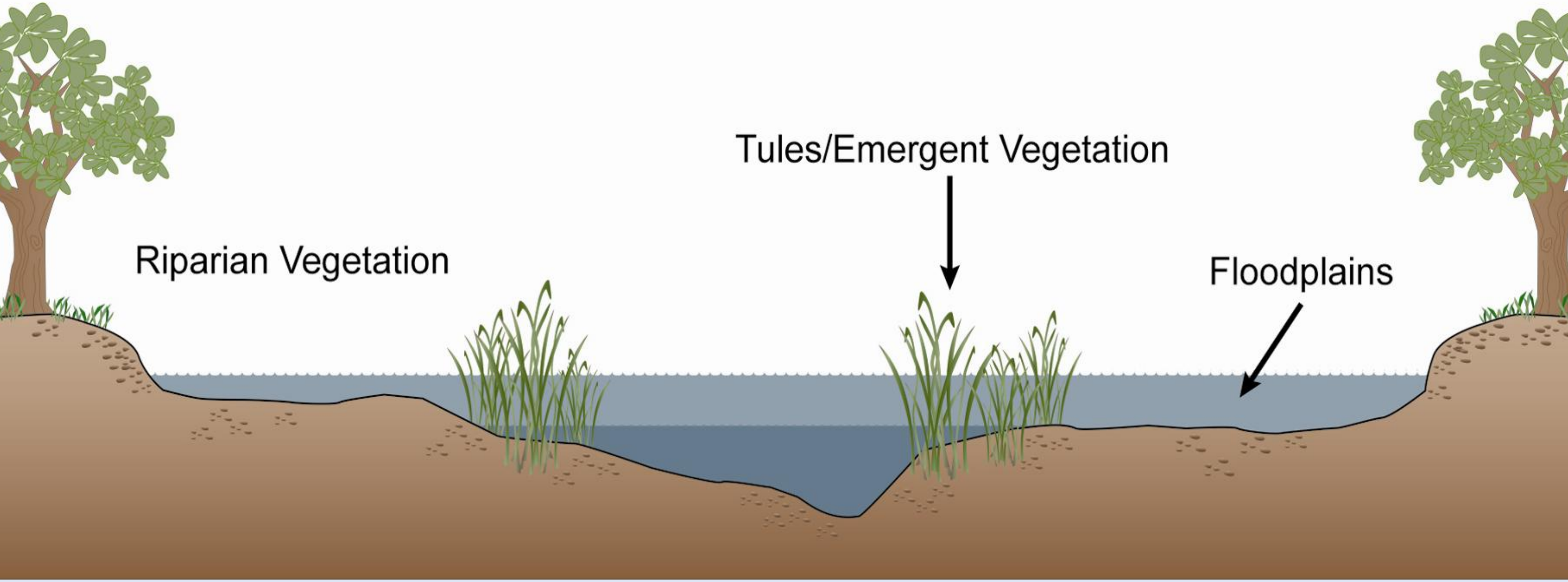


Reservoir Releases

- Survival During Migration
- Water Diversions
- Predation
- Floodplain Inundation
- Land-Water Interface
- Upstream Water Temperature
- Spawning and Rearing Habitat
- In-Delta Temperature
- Turbidity

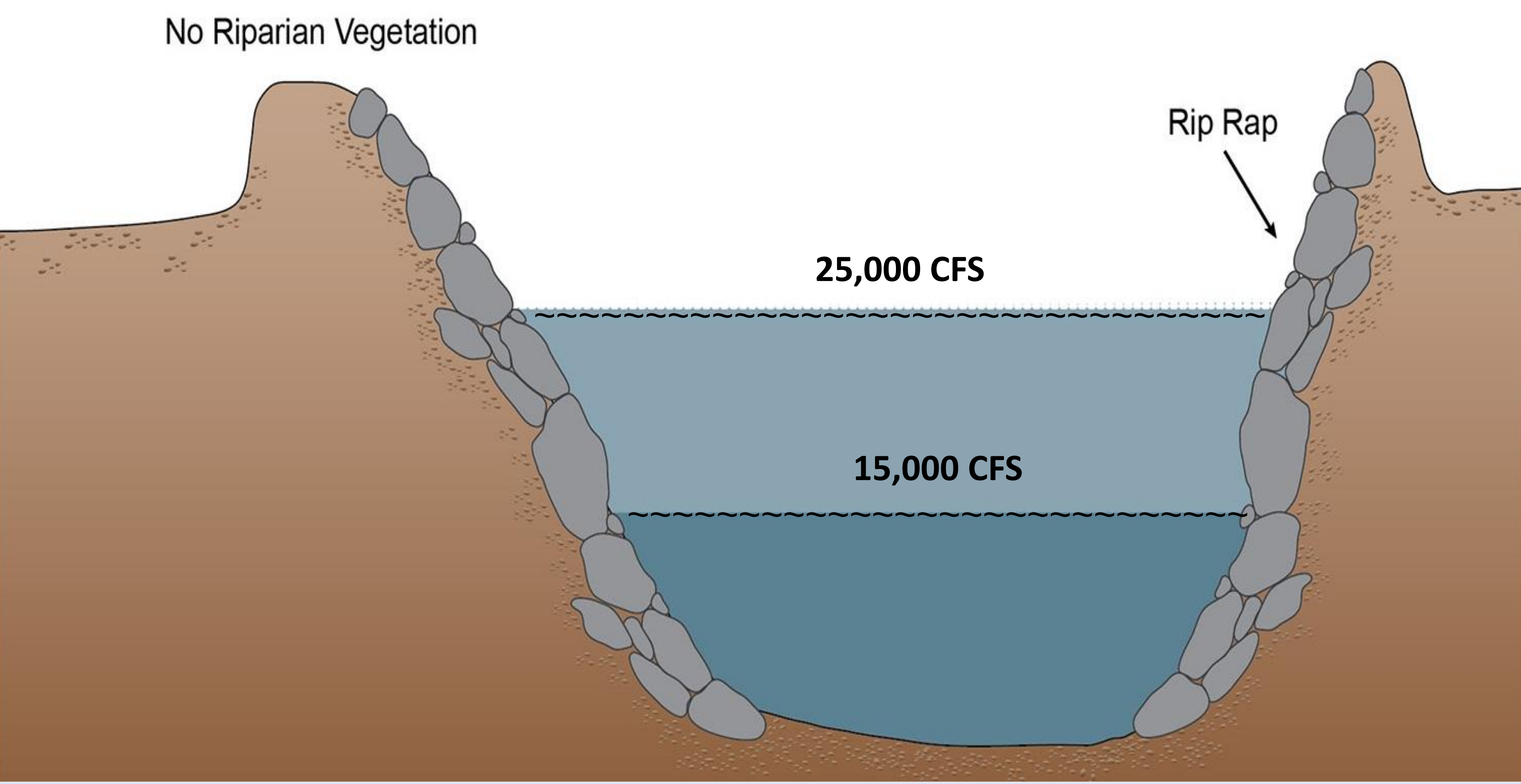
Minimal results without physical improvements

Changes in habitat can be a function of changes in river flow



Cross section through a natural (historic) Sacramento River channel showing the change in habitat as a function of changes in river flow.

Flow functions are diminished in altered channel

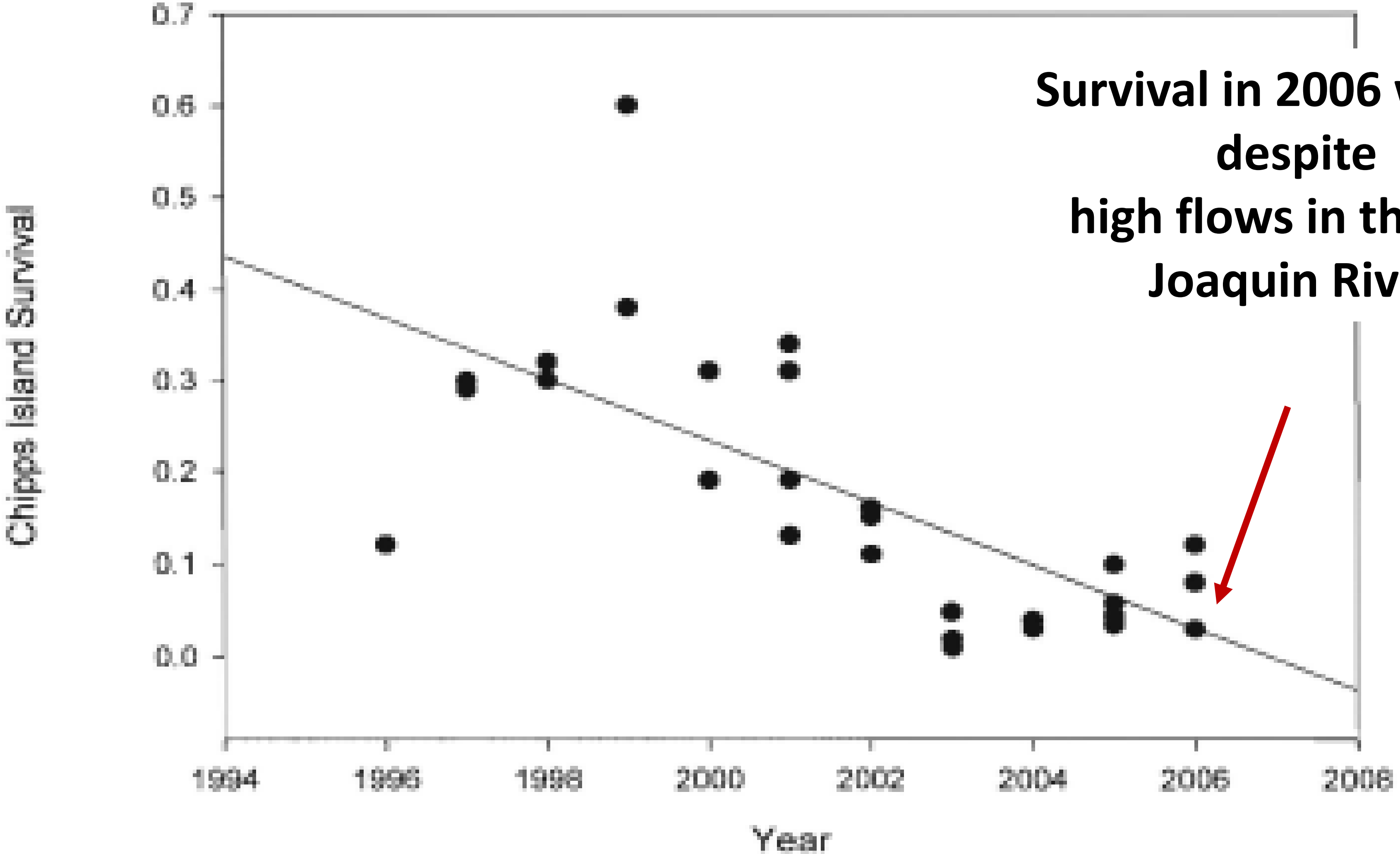


Cross-section through a channelized reach of the Sacramento River showing change in habitat as a function of changes in river flow.

Multiple interacting variables affect salmonid populations

- Predation
- Water temperature
- Quality of spawning and rearing habitat
- Water diversions
- Channelization
- Reduced access to floodplains and wetlands
- Ocean rearing conditions
- Ocean harvest

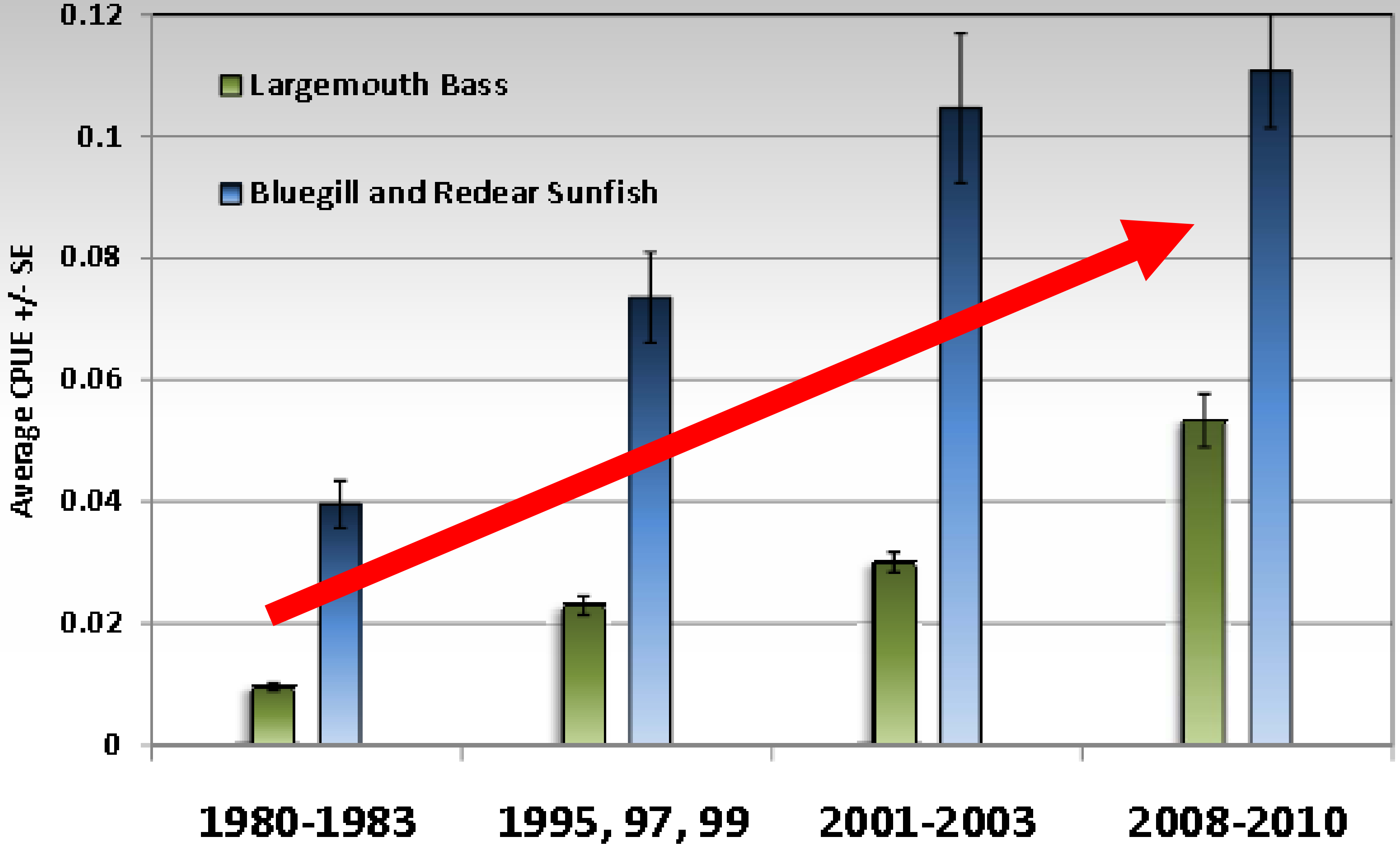
Survival of juvenile San Joaquin River fall-run salmon has declined substantially in recent years



Survival in 2006 was 5% despite high flows in the San Joaquin River

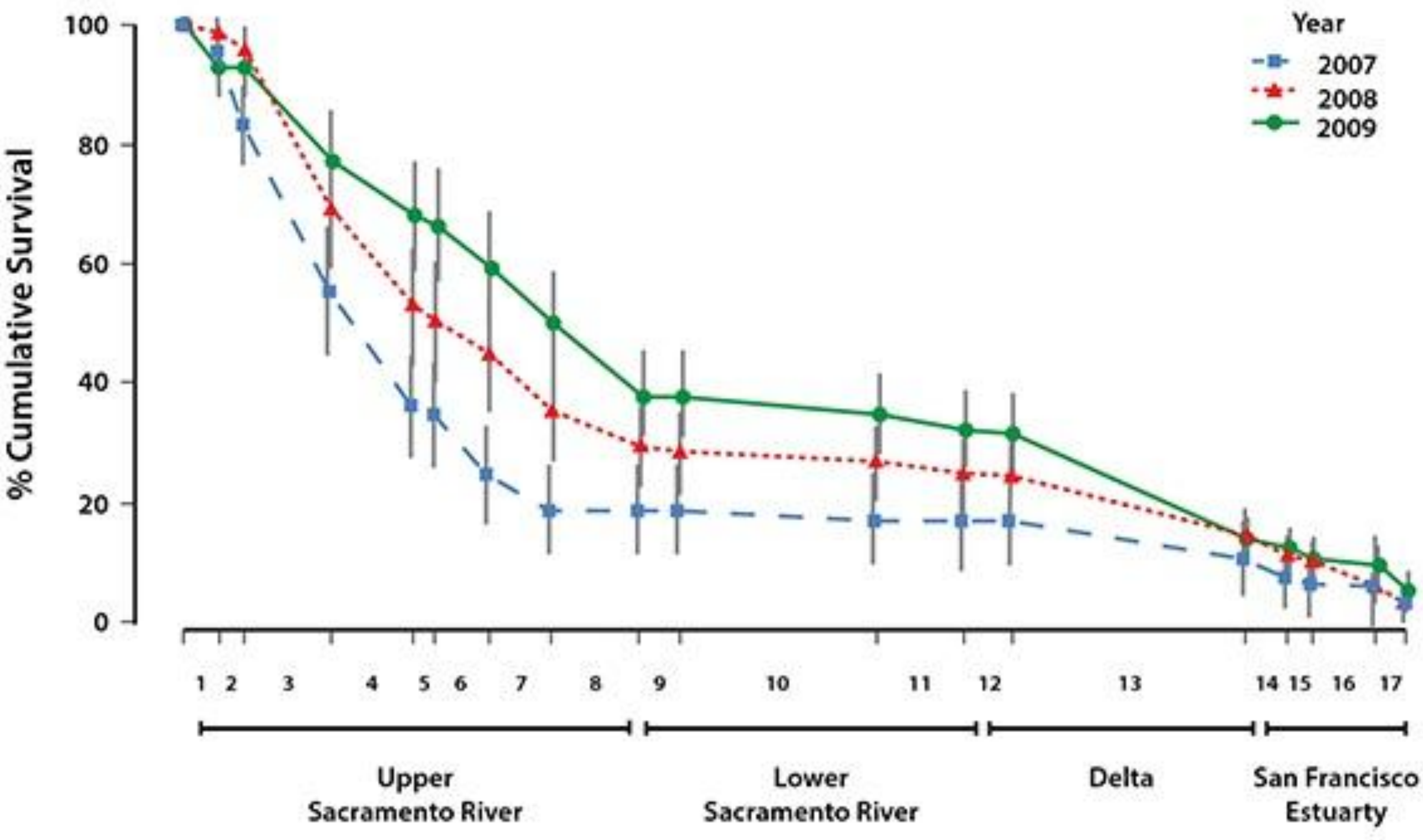
Data from VAMP studies: SJRGA 2006

Abundance of non-native predators has increased substantially in recent years in the Delta



Source: Conrad et al. 2010a

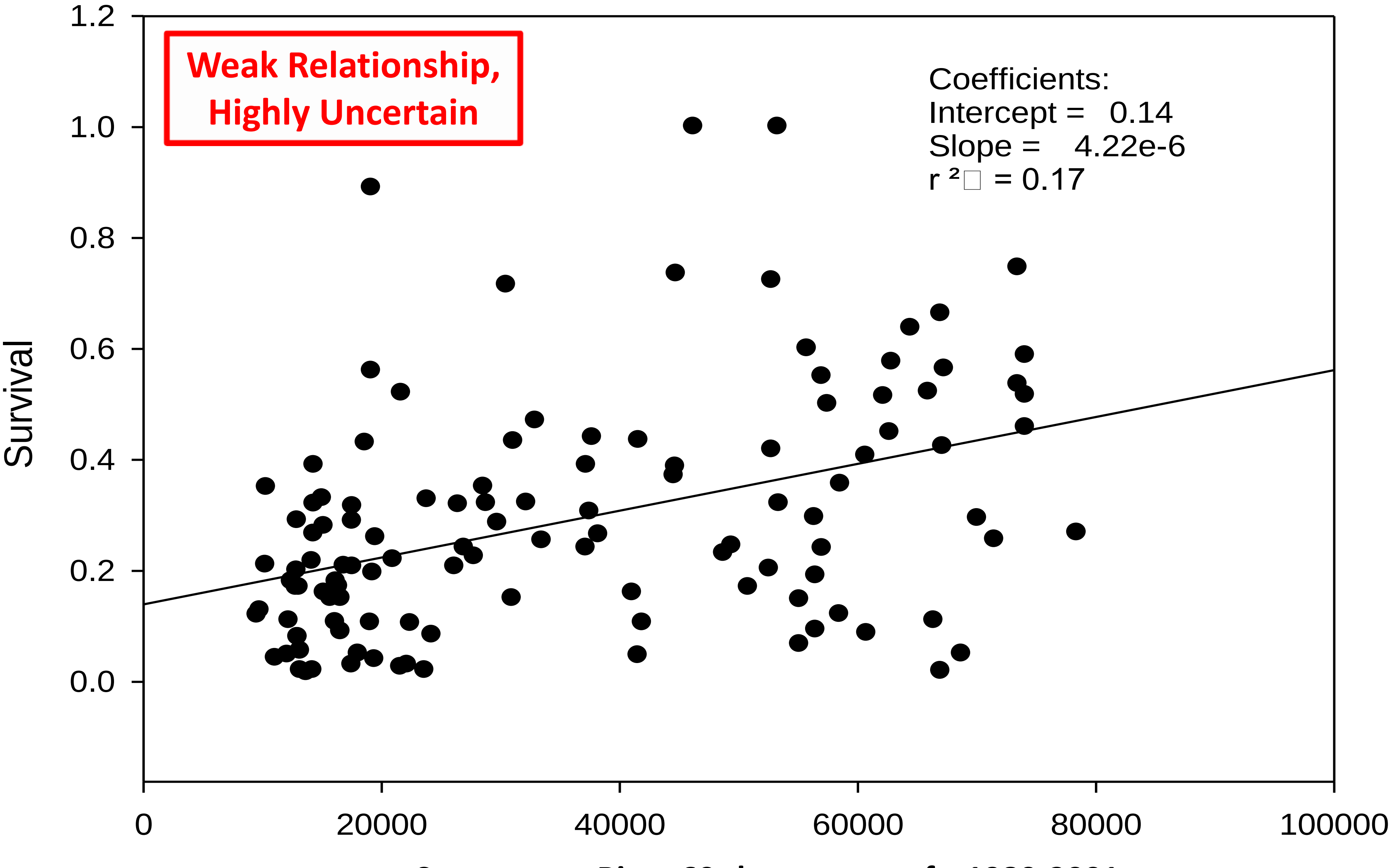
Mortality rates of juvenile Chinook salmon are high



Source: Michel 2010

Reach

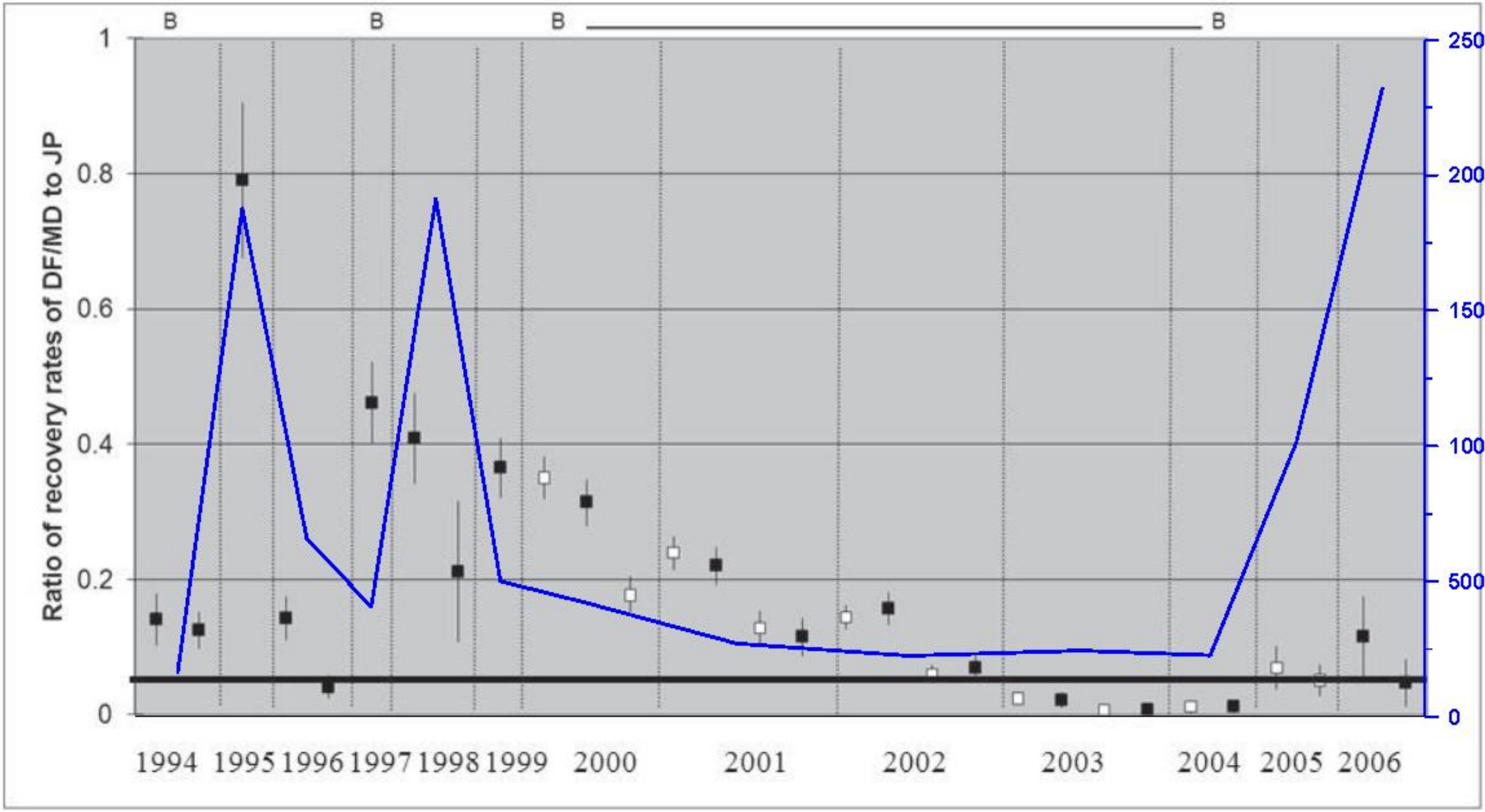
Juvenile salmon survival is weakly correlated with Sacramento River flow



Weak Relationship, Highly Uncertain

Coefficients:
Intercept = 0.14
Slope = 4.22e-6
r ²□ = 0.17

Low survival in 2005 and 2006 in San Joaquin River was not related to flow



Estimates of smolt survival (+/- 2 Standard Errors) from Mossdale to Jersey Point during the VAMP between 1994 to 2006 using coded wire tagged fish. Years with the physical Head of Old River Barrier installed are denoted with B and are in 1994, 1997 and 2000-2004. The black line is the estimate of survival between Mossdale and Chipps Island in 2010 using acoustic tag technology and removing predator-type detections. (Brandes et al., 2008 and SJRG, 2011).

A poor relationship was observed between Sacramento River flow during juvenile migration in 2006 and 2009 and subsequent adult abundance

	2006	2009
Average January-May Sacramento River flow during juvenile migration	62,000 cfs	15,500 cfs
PFMC Estimated Adult Chinook salmon abundance 2.5 years later (assuming 3-year generation period)	53,000 adult salmon	819,000 adult salmon

Size and migration route effect juvenile salmon survival

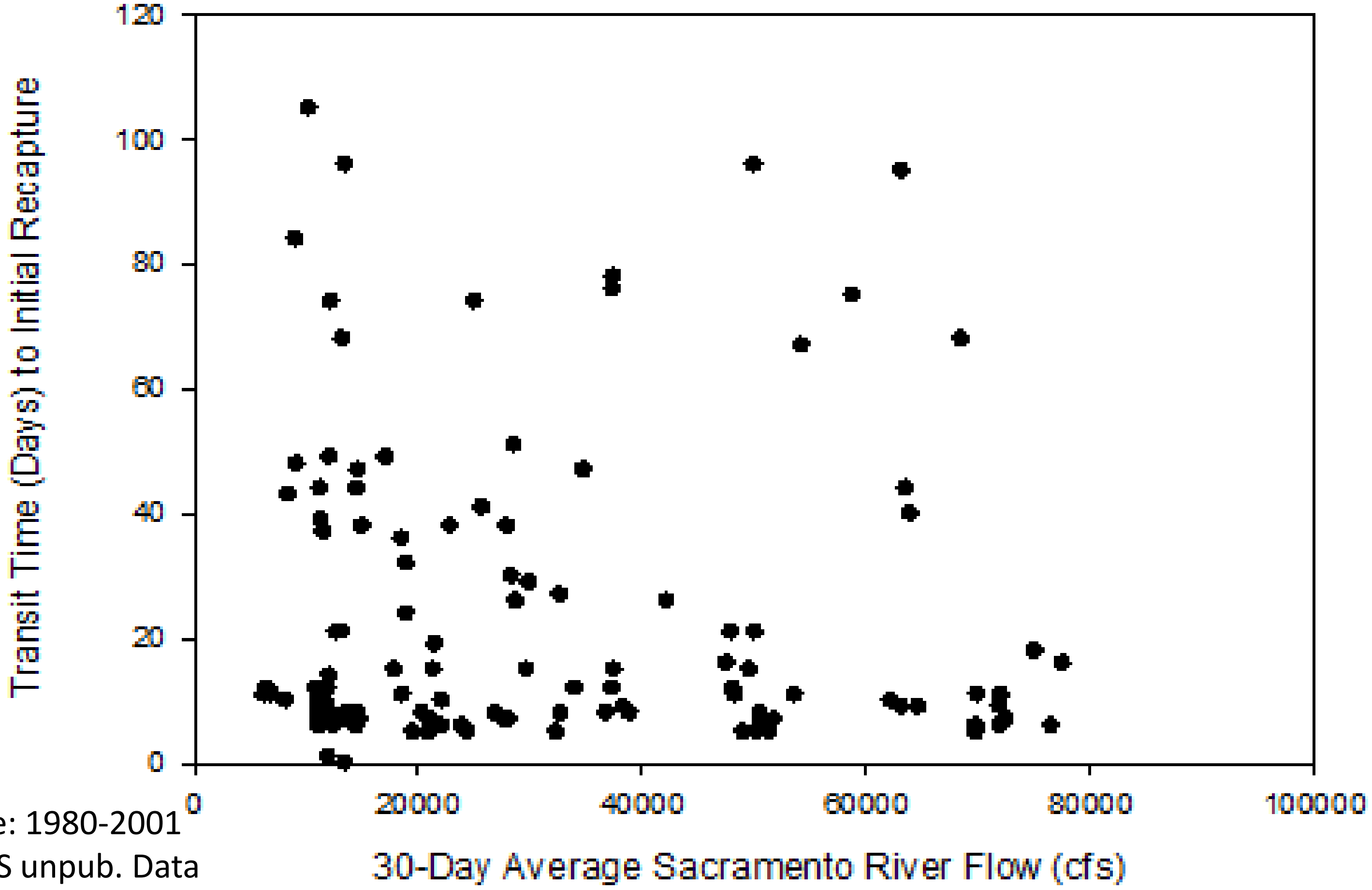
- Fish size has significant effect on juvenile salmon survival
- Survival rates are higher for Sacramento River and lower for migration via interior Delta
- Non-physical barriers appear to reduce juvenile salmonid migration into interior Delta

Significant salmonid research is underway

Ongoing research will:

- Improve understanding of juvenile reach-specific survival
- Improve understanding of effects of river flow and tides on migration route
- Reduce uncertainty from earlier studies

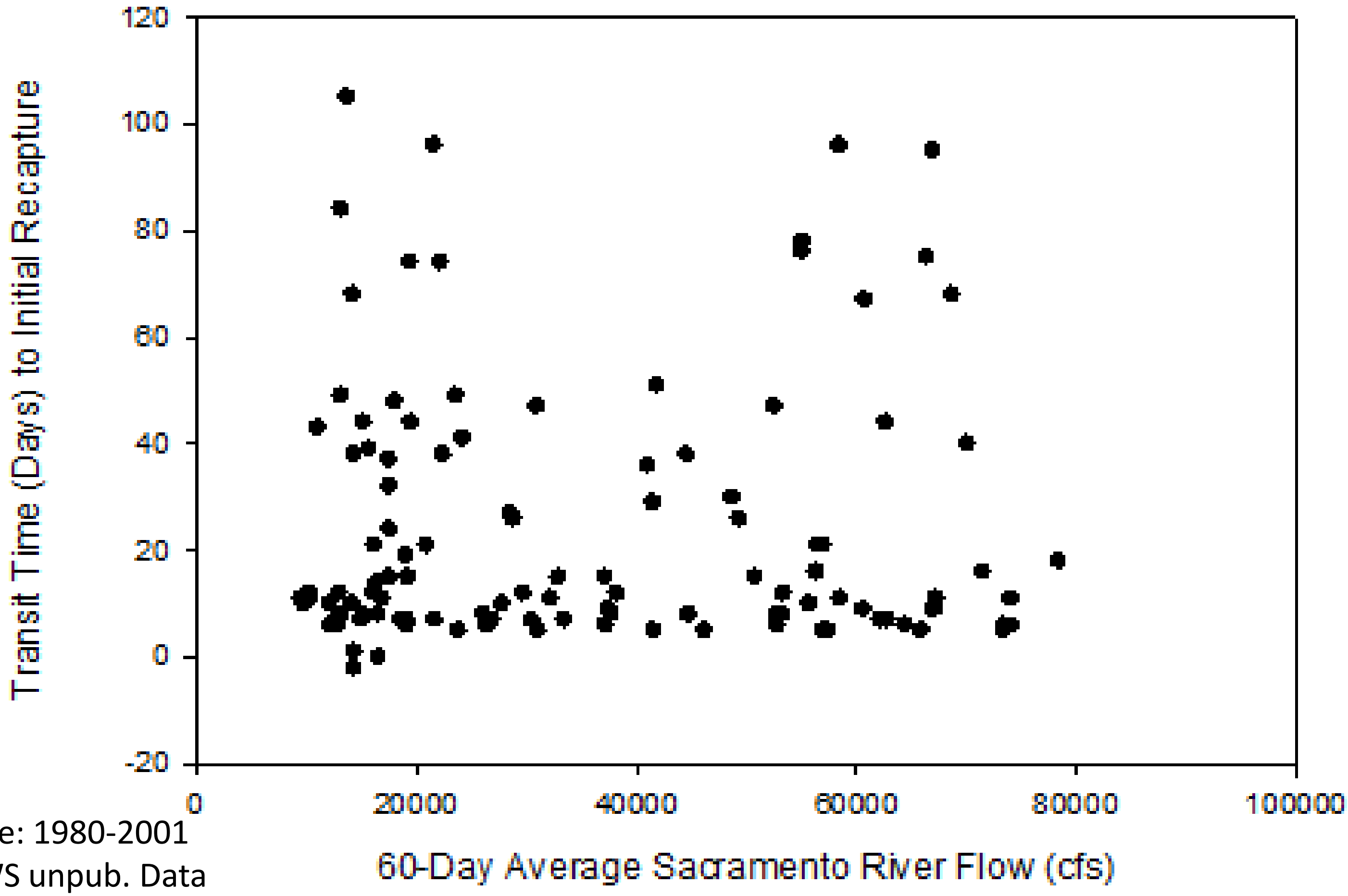
Juvenile salmon migration rate is independent of Sacramento river flow



Source: 1980-2001
USFWS unpub. Data

- ***Increased flow alone will not reduce duration of juvenile migration or vulnerability to predation***

Juvenile salmon migration rate is independent of Sacramento River flow



Source: 1980-2001
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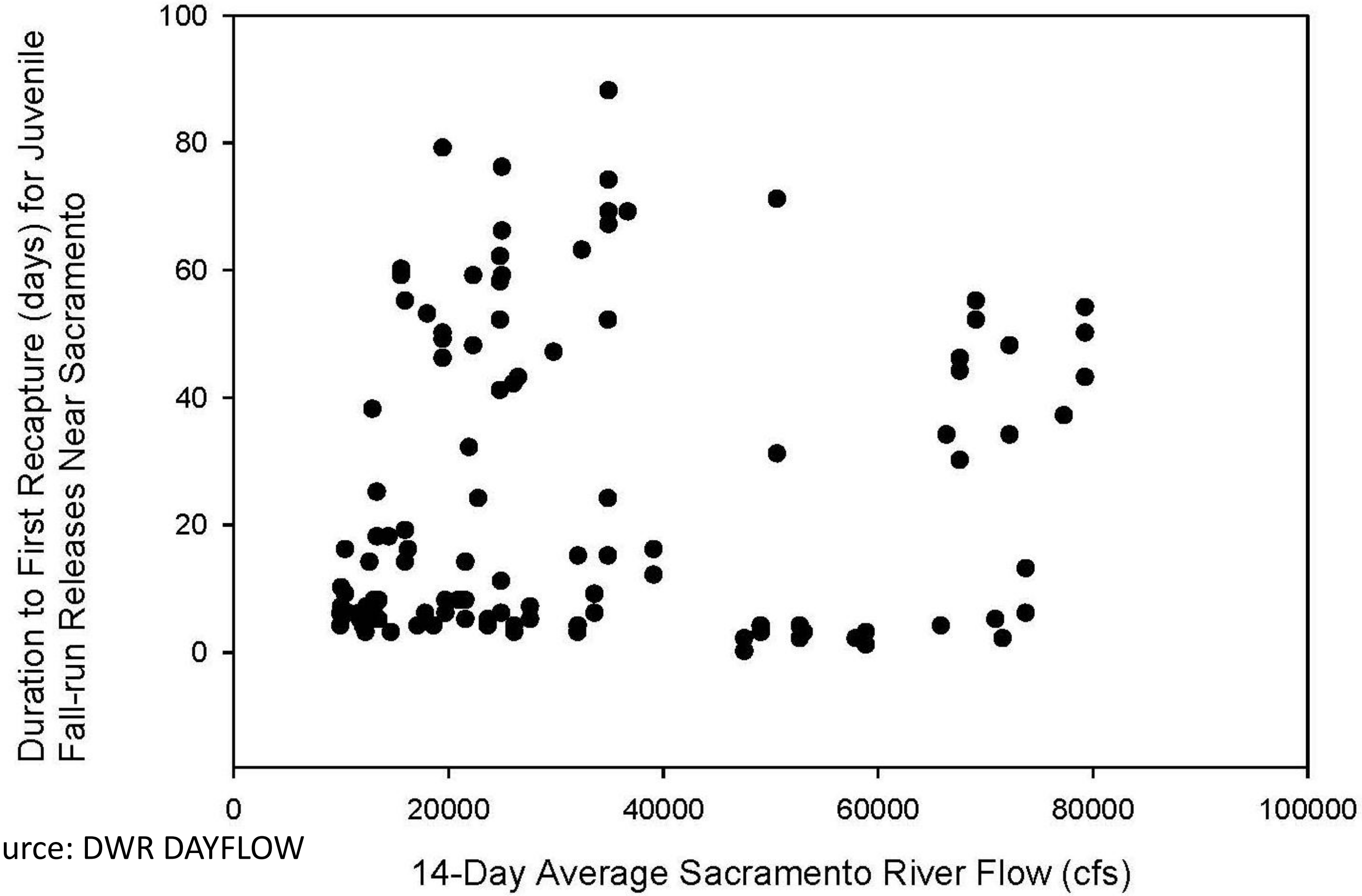
Juvenile salmon migration rate is independent of Sacramento River flow



Source: DWR DAYFLOW

- ***Increased flow alone will not reduce duration of juvenile migration or vulnerability to predation***

Water temperature management within reservoirs is critical to maintaining suitable spawning and rearing habitat

- Release of cold water from reservoirs maintains cool temperatures immediately downstream

- Water temperature increases downstream--eventually equilibrates with air temperature

- Reservoir releases have no effect on instream water temperatures for most of the lower reaches of the Sacramento and San Joaquin Rivers and the Delta.

Juvenile salmon survival through the Delta is independent of SWP/CVP export rate

- Survival largely independent of export:inflow ratio and OMR reverse flows.
- Salmon survival during Delta migration is not significantly related to SWP and CVP export rate.

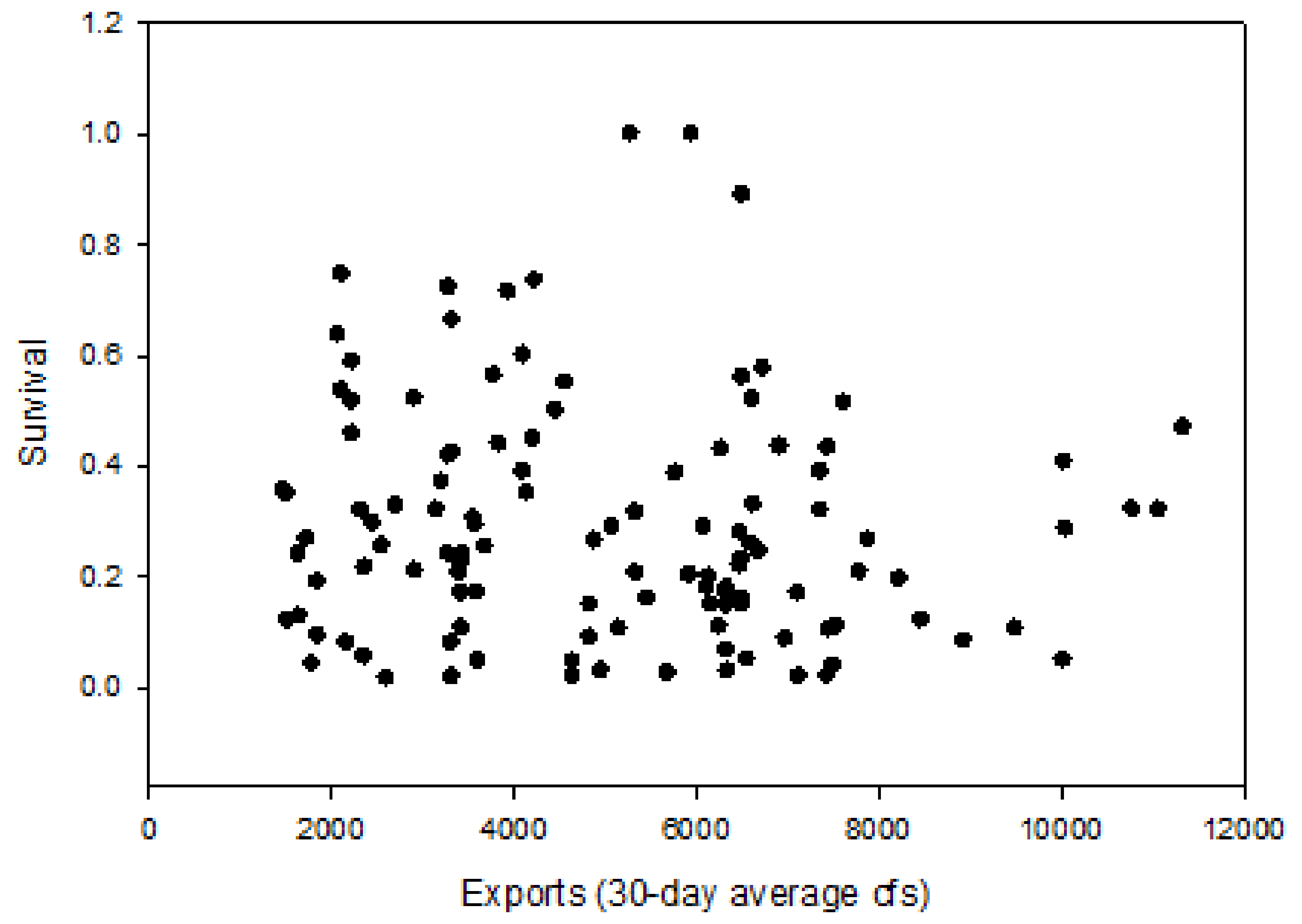
Salmon salvage at SWP-CVP facilities is extremely small percentage of juvenile outmigrants

1994-2007: 3.6 million tagged smolts

- Released in Battle Creek and Sacramento River upstream of the RBDD
- Juvenile Chinook salmon were marked with an adipose fin clip and coded wire tag
- Releases included fall-run, winter-run, spring-run, and late fall-run juvenile salmon

0.1% (0.0% to 0.5%) salvaged at SWP-CVP pumping plants

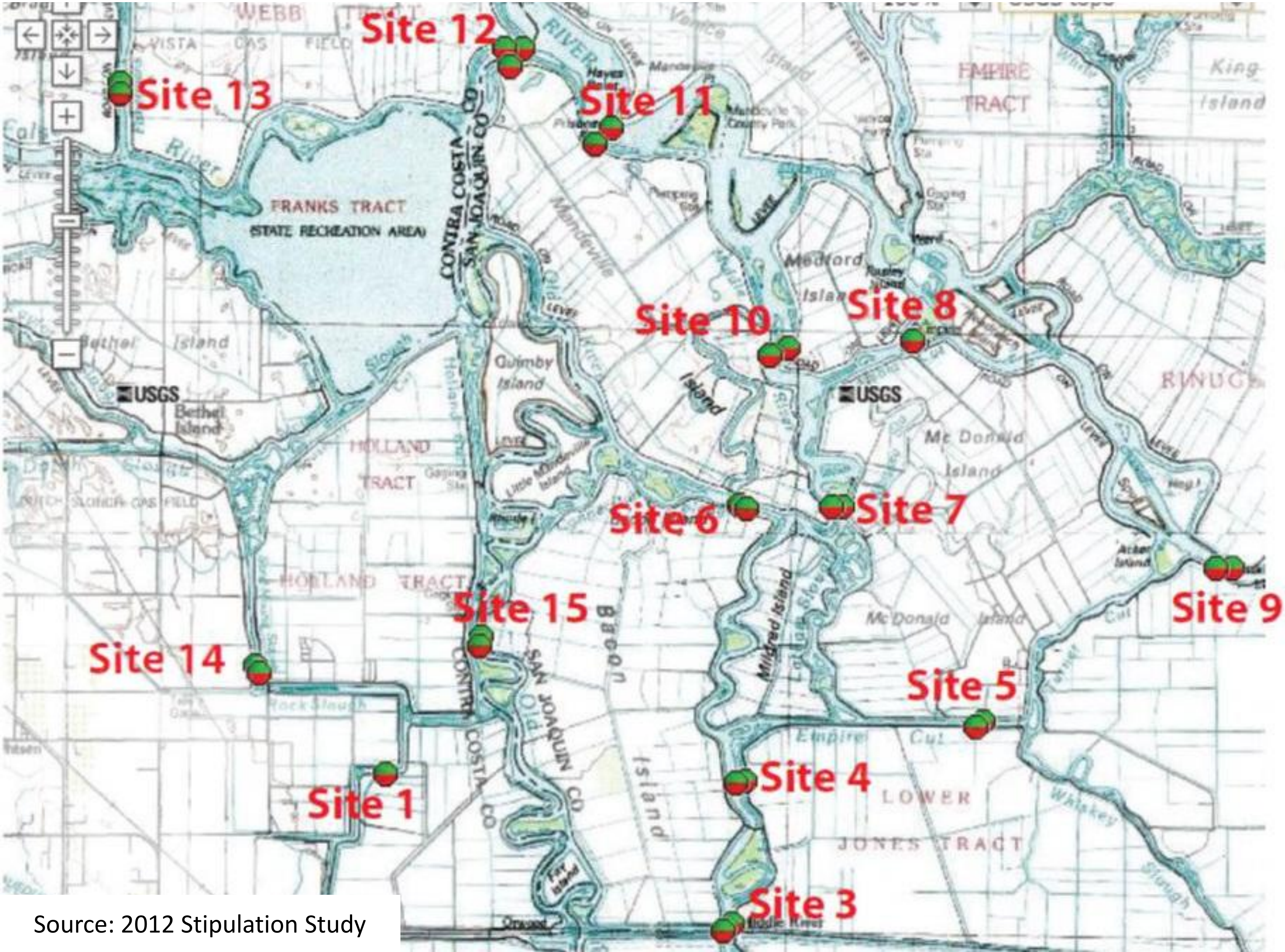
There is no relationship between smolt survival and SWP-CVP export rate



Tides dominate hydrodynamics in the Delta

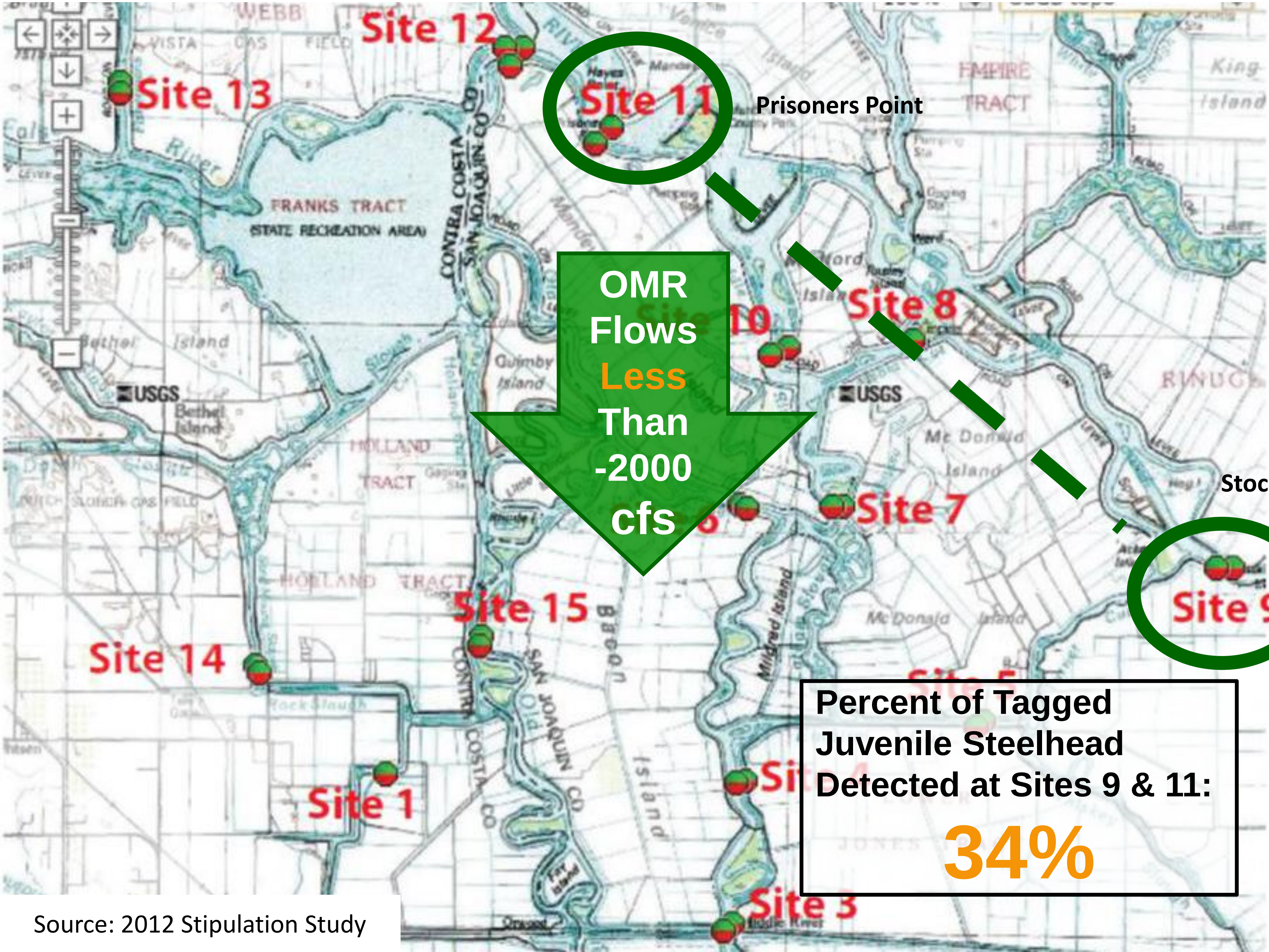
- Sub-daily tidal flows are a major factor affecting migration route selection
- Tidal flows overwhelm inflows in the western Delta (tidal flow frequently is approximately 10 times greater that Delta inflow)
- Increasing Delta inflow or outflows would not significantly affect salmonid migration rates

2012 Acoustic Tag Monitoring



Source: 2012 Stipulation Study

2012 Acoustic Tag Monitoring



Prisoners Point

Stockton

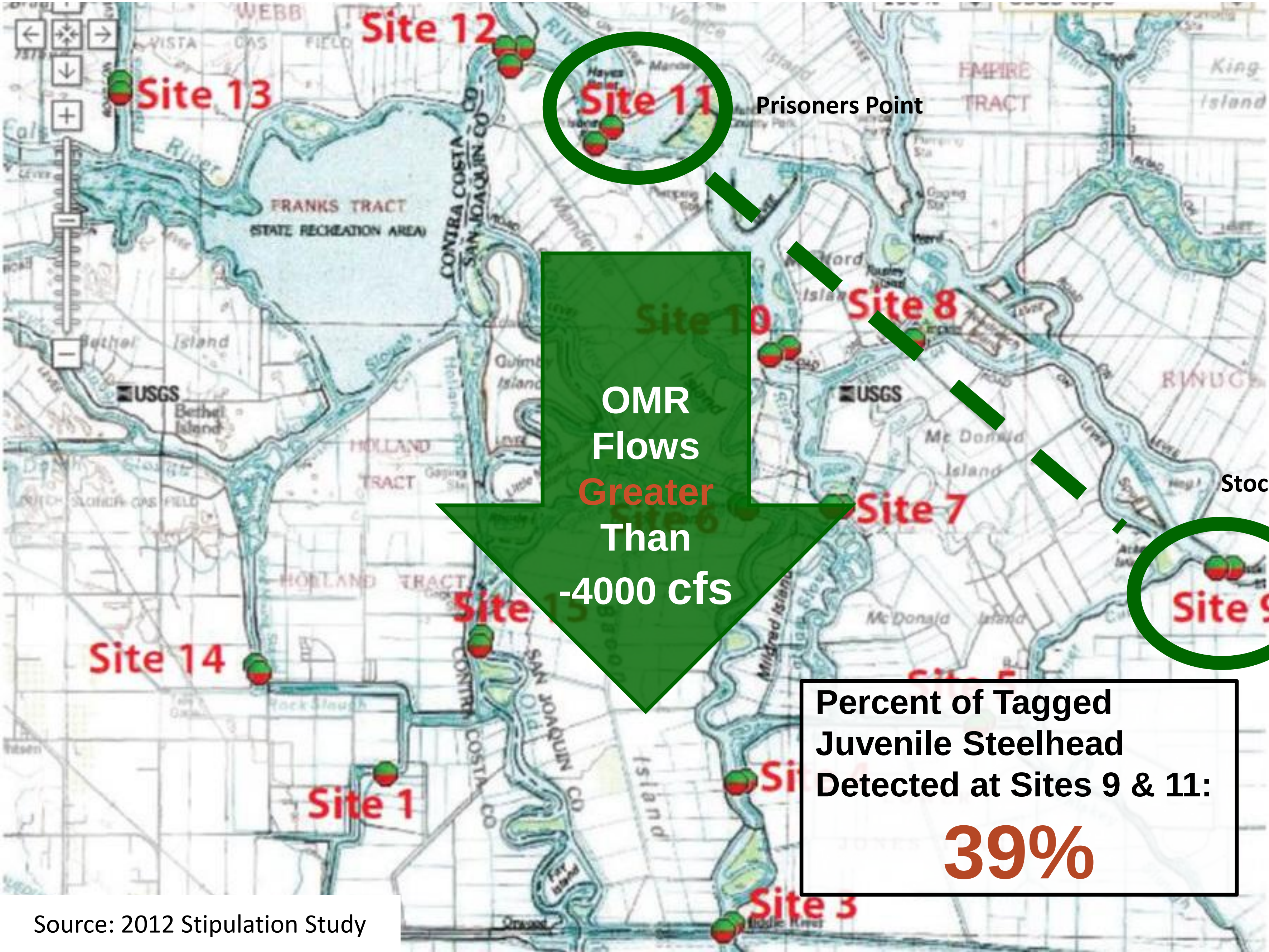
OMR Flows **Less** Than -2000 cfs

Percent of Tagged Juvenile Steelhead Detected at Sites 9 & 11:

34%

Source: 2012 Stipulation Study

2012 Acoustic Tag Monitoring



OMR Flows Greater Than -4000 cfs

Percent of Tagged Juvenile Steelhead Detected at Sites 9 & 11:

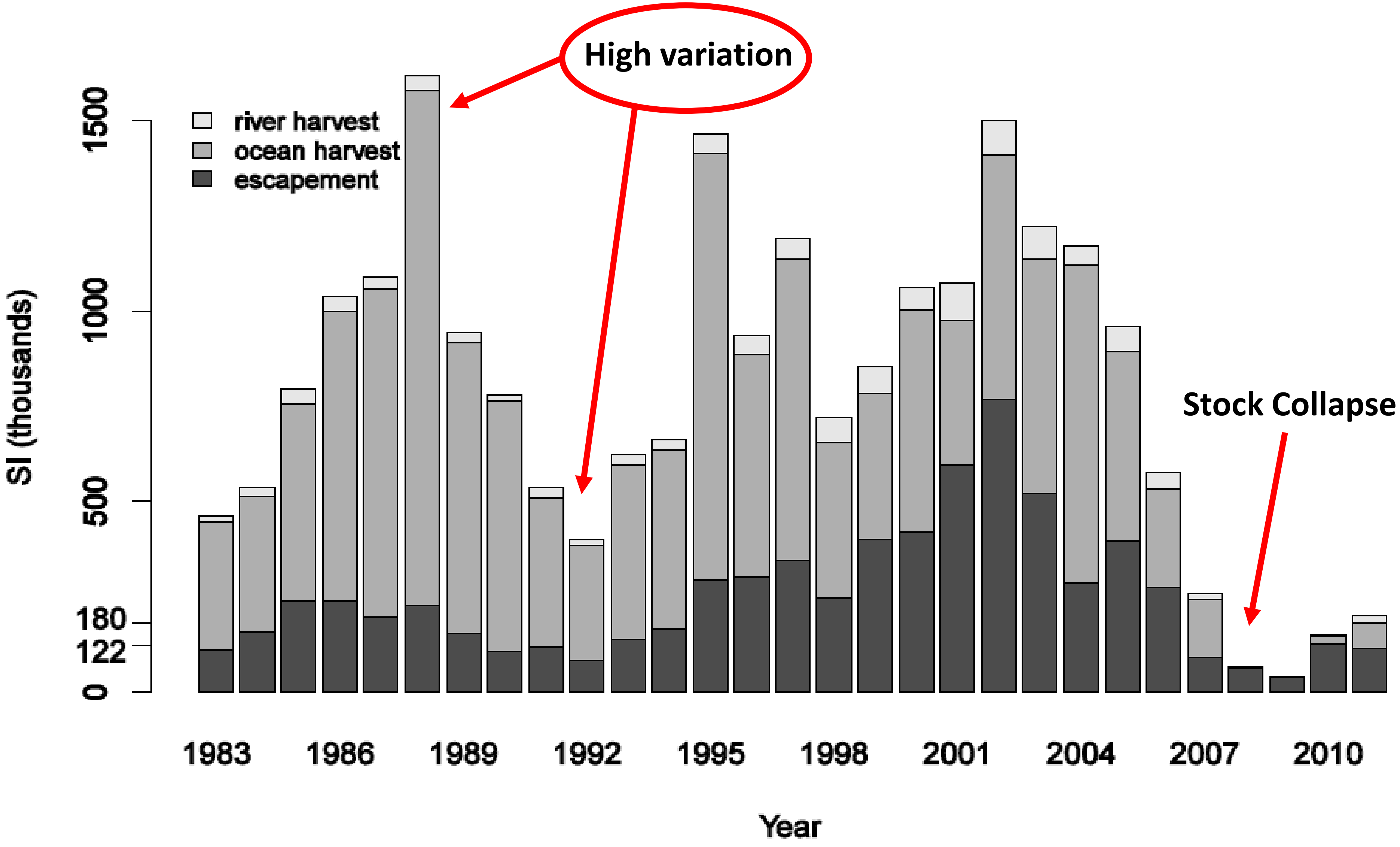
39%

Source: 2012 Stipulation Study

Integrating best available science:

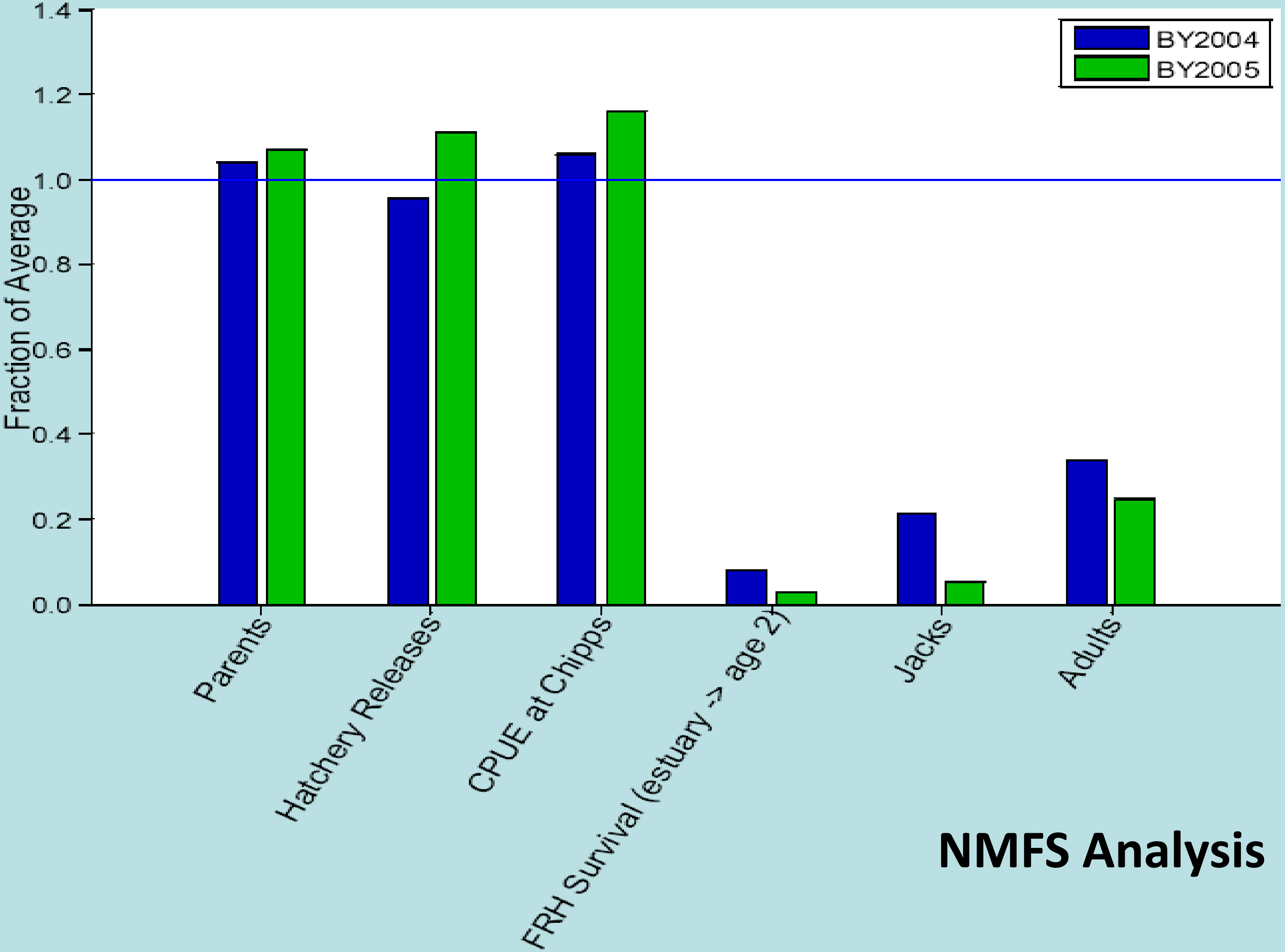
- Accounting for all the variables
- Discerning what matters most
- Discovering balanced solutions to competing needs

Sacramento Index (SI) of Fall Chinook Abundance



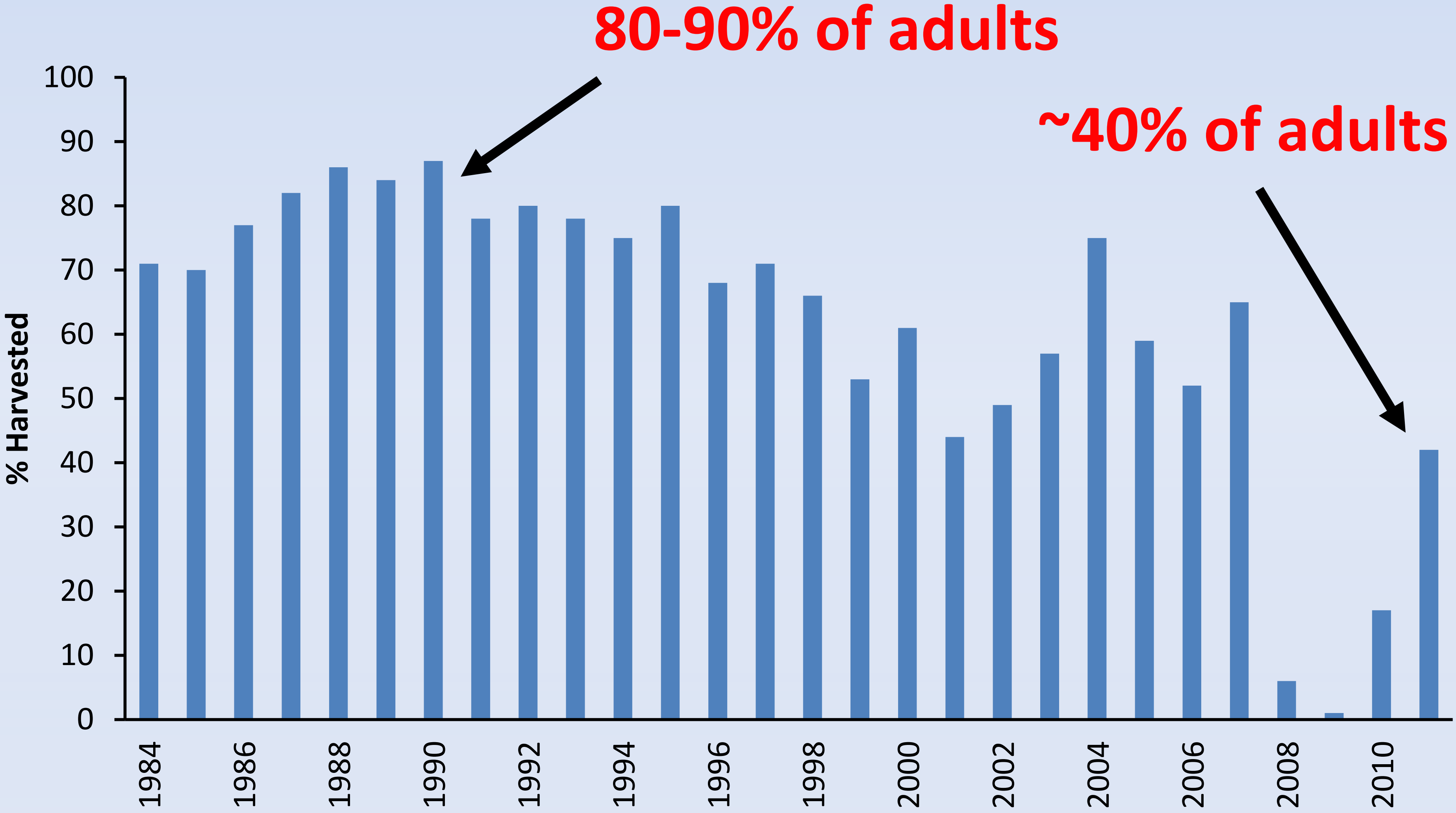
Source: Pacific Fisheries Management Council. 2012. Preseason report 1 for 2012 ocean salmon fishery regulations

Ocean factors caused collapse of Chinook runs in 2008-2009



NMFS Analysis

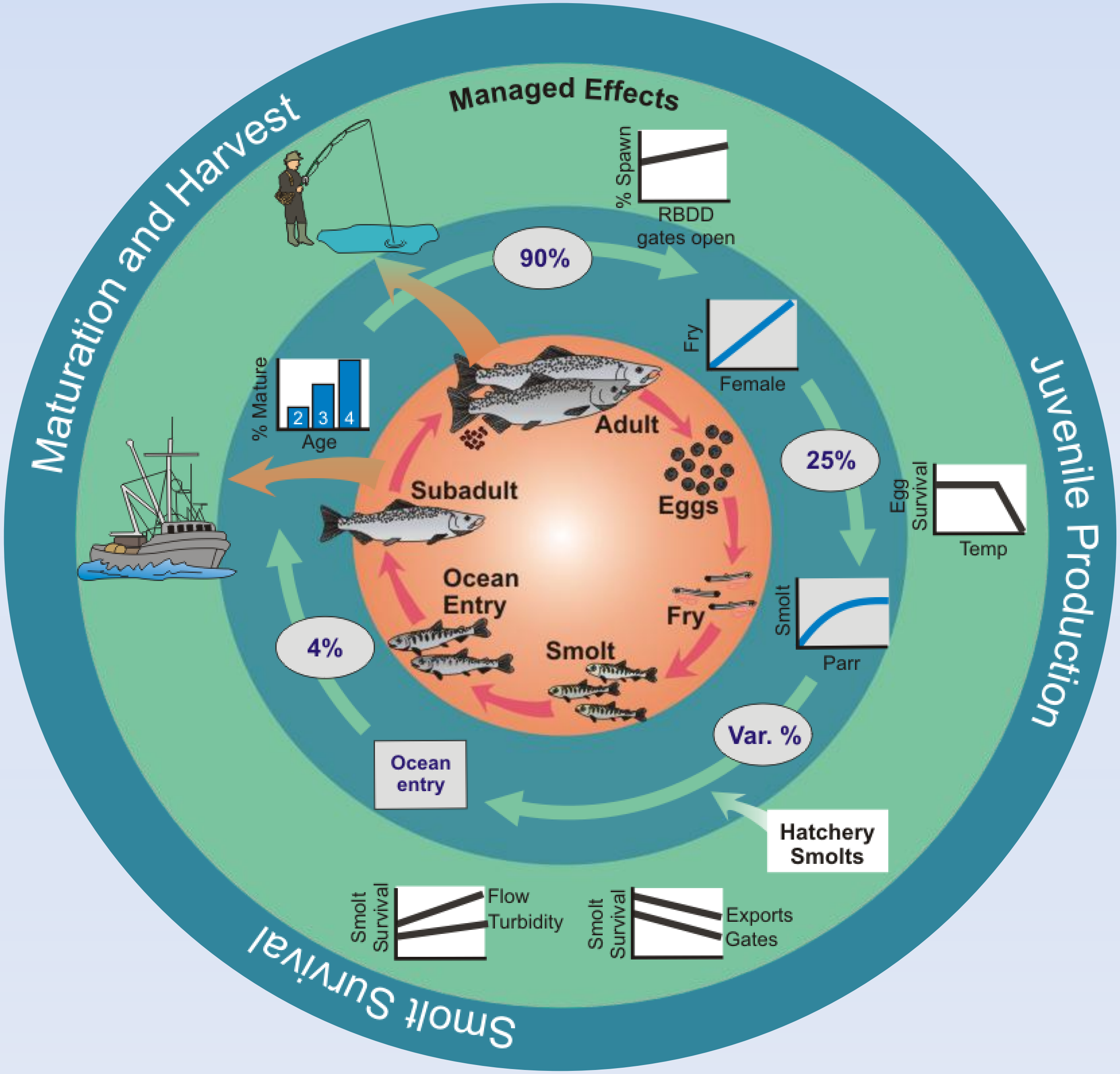
Ocean harvest has large impact

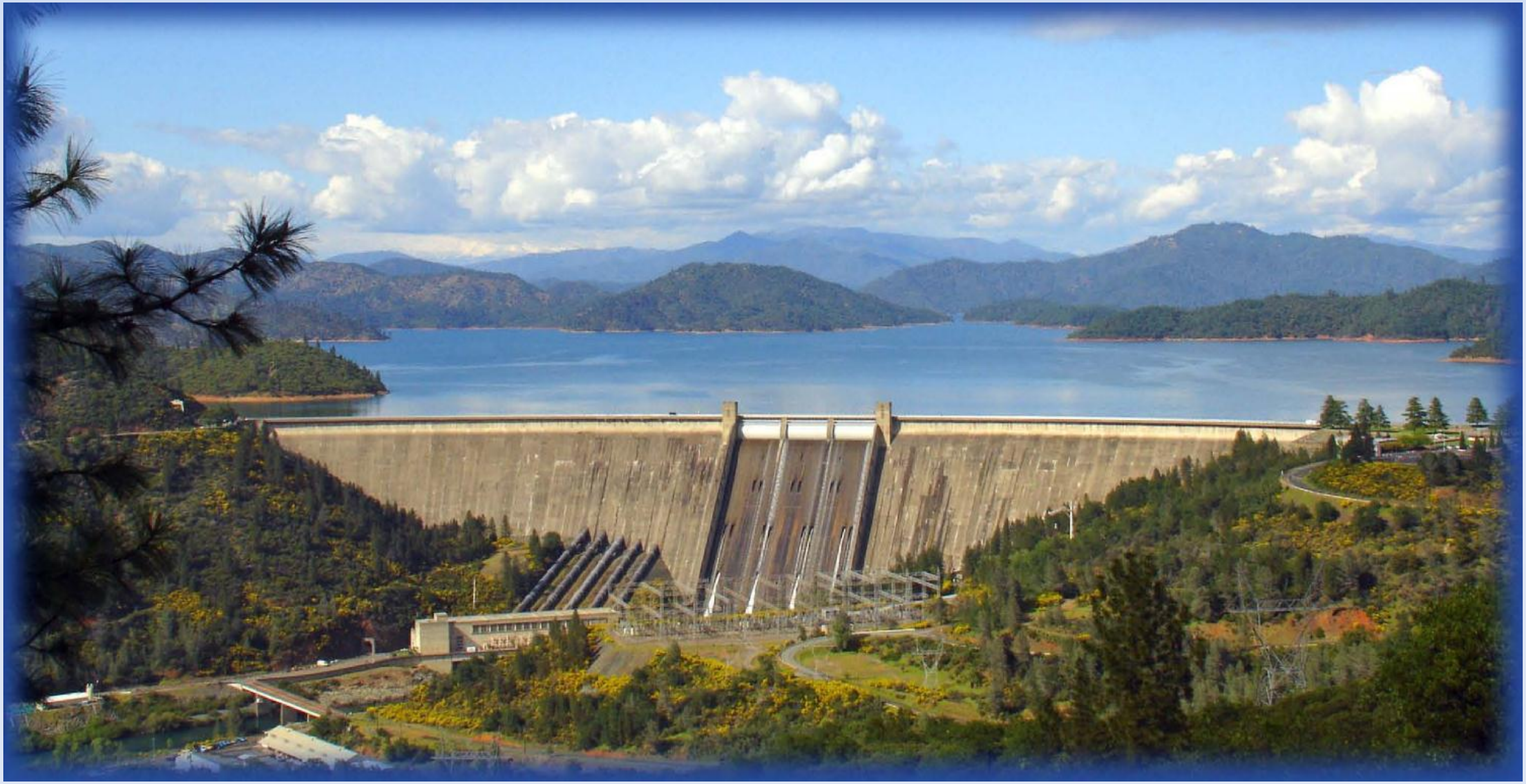


Source: PMFC 2012

CV Chinook Salmon

Application of lifecycle models





Finding science solutions:

- Rely on recent studies with best technologies
- Beware of correlated explanatory variables
- Accumulate factor effects across all life stages
- Express effects in adult equivalents
- Use temporally and spatially explicit life-cycle models to compare management scenarios

Summary:

SCIENTIFIC FINDINGS THAT SUPPORT RECOMMENDATIONS:

- Majority of natural flow functions cannot be replicated through reservoir releases
- Large changes in flow produce small, uncertain changes in juvenile survival
- Increases in flow may adversely impact reservoir cold water reserves and carryover storage
- Salmon survival largely independent of pumping rates at CVP/SWP Delta Facilities
- Ocean conditions, ocean harvest, and predation have large influences on survival and abundance of salmonids
- Juvenile salmon mortality of 75% or more upstream of the Delta is high compared to other large-river systems

RECOMMENDED FOCUS FOR STATE BOARD:

- Protect cold water pool to maintain suitable temperatures for spawning and rearing
- Support creation, restoration and conservation of floodplain and other habitats
- Support use of non-physical barriers and other mechanisms to decrease salmonid migration into the Interior Delta

Today's Science Presentation

- Salmon
- **Pelagic Fish**

Key Points for Delta smelt

- Life cycle modeling indicates that key drivers are food, temperature, and predation
- Nutrients are important drivers of food web productivity
- No statistical foundation supporting a relationship between X2 and Delta smelt abundance in any season
- Neither low salinity zone nor X2 define habitat
- Entrainment does not drive abundance. Operations sensitive to OMR and turbidity have successfully ended large entrainment events.

Key Points for Longfin Smelt

- There is no demonstrated mechanism to explain the longfin FMWT: X2 correlation.
- Even if outflow *per se* increased abundance, the increases would be very small.
- Many factors other than flows are correlated with longfin smelt abundance. The most plausible causal mechanism for longfin abundance is food supply and ultimately nutrient patterns.
- Different longfin surveys show different long-term abundance trajectories.

Pelagic Presentation Outline

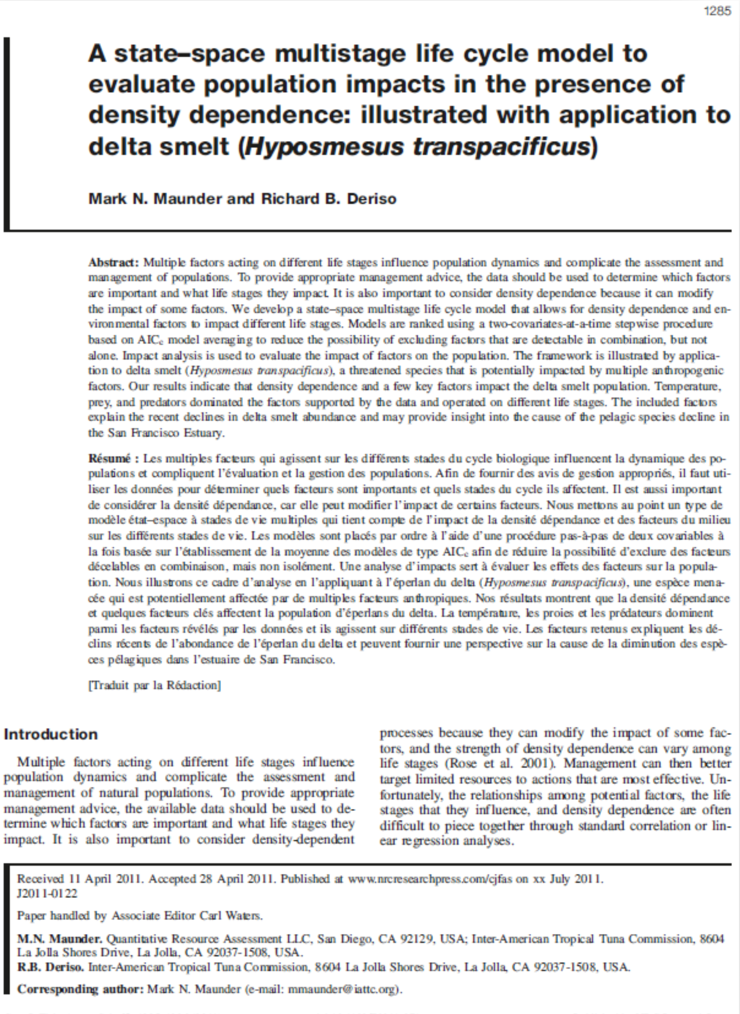
- Lifecycle Modeling; Entrainment
  - Dr. Richard Deriso
- Fall X2 and Delta smelt abundance
  - Dr. Noble Hendrix
- Outflow and Longfin smelt abundance
  - David Fullerton
- Ammonium inhibition and the foodweb
  - Dr. Richard Dugdale

Next up: Dr. Richard Deriso, IATTC

Life cycle model and delta smelt entrainment

Life Cycle Modeling

- A life cycle model is a common tool used to analyze species population decline
- Life cycle model results may provide essential information to future species management actions



A state–space multistage life cycle model to evaluate population impacts in the presence of density dependence: illustrated with application to delta smelt (*Hyposmesus transpacificus*)

Mark N. Maunder and Richard B. Deriso

Abstract: Multiple factors acting on different life stages influence population dynamics and complicate the assessment and management of populations. To provide appropriate management advice, the data should be used to determine which factors are important and what life stages they impact. It is also important to consider density dependence because it can modify the impact of some factors. We develop a state–space multistage life cycle model that allows for density dependence and environmental factors to impact different life stages. Models are ranked using a two-covariates-at-a-time stepwise procedure based on AIC_c model averaging to reduce the possibility of excluding factors that are detectable in combination, but not alone. Impact analysis is used to evaluate the impact of factors on the population. The framework is illustrated by application to delta smelt (*Hyposmesus transpacificus*), a threatened species that is potentially impacted by multiple anthropogenic factors. Our results indicate that density dependence and a few key factors impact the delta smelt population. Temperature, prey, and predators dominated the factors supported by the data and operated on different life stages. The included factors explain the recent declines in delta smelt abundance and may provide insight into the cause of the pelagic species decline in the San Francisco Estuary.

Résumé : Les multiples facteurs qui agissent sur les différents stades du cycle biologique influencent la dynamique des populations et compliquent l'évaluation et la gestion des populations. Afin de fournir des avis de gestion appropriés, il faut utiliser les données pour déterminer quels facteurs sont importants et quels stades du cycle ils affectent. Il est aussi important de considérer la densité dépendance, car elle peut modifier l'impact de certains facteurs. Nous mettons au point un type de modèle état–espace à stades de vie multiples qui tient compte de l'impact de la densité dépendance et des facteurs du milieu sur les différents stades de vie. Les modèles sont placés par ordre à l'aide d'une procédure pas-à-pas de deux covariables à la fois basée sur l'établissement de la moyenne des modèles de type AIC_c afin de réduire la possibilité d'exclure des facteurs décelables en combinaison, mais non isolément. Une analyse d'impacts sert à évaluer les effets des facteurs sur la population. Nous illustrons ce cadre d'analyse en l'appliquant à l'éperlan du delta (*Hyposmesus transpacificus*), une espèce menacée qui est potentiellement affectée par de multiples facteurs anthropiques. Nos résultats montrent que la densité dépendance et quelques facteurs clés affectent la population d'éperlans du delta. La température, les proies et les prédateurs dominent parmi les facteurs révélés par les données et ils agissent sur différents stades de vie. Les facteurs retenus expliquent les déclins récents de l'abondance de l'éperlan du delta et peuvent fournir une perspective sur la cause de la diminution des espèces pélagiques dans l'estuaire de San Francisco.

[Traduit par la Rédaction]

Introduction

Multiple factors acting on different life stages influence population dynamics and complicate the assessment and management of natural populations. To provide appropriate management advice, the available data should be used to determine which factors are important and what life stages they impact. It is also important to consider density-dependent processes because they can modify the impact of some factors, and the strength of density dependence can vary among life stages (Rose et al. 2001). Management can then better target limited resources to actions that are most effective. Unfortunately, the relationships among potential factors, the life stages that they influence, and density dependence are often difficult to piece together through standard correlation or linear regression analyses.

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Maunder & Deriso Life Cycle Model Specifics

- Represents all life cycle stages of smelt (larval, juvenile, adult) and how population abundance changes between stages
- Allows multiple factors or covariates to influence survival and stock-recruit relationships
- Data spans 1972-2010

Model Conclusions

- Food abundance, temperature, predator abundance, and density dependence are the most critical factors impacting the Delta smelt population
- Entrainment from water export operations is NOT an important factor impacting smelt population growth rate
- Fall X2 is NOT an important factor impacting smelt population growth rate
- Efforts should be focused on addressing environmental conditions affecting the species, such as food supply

Results of Recent Modeling Efforts

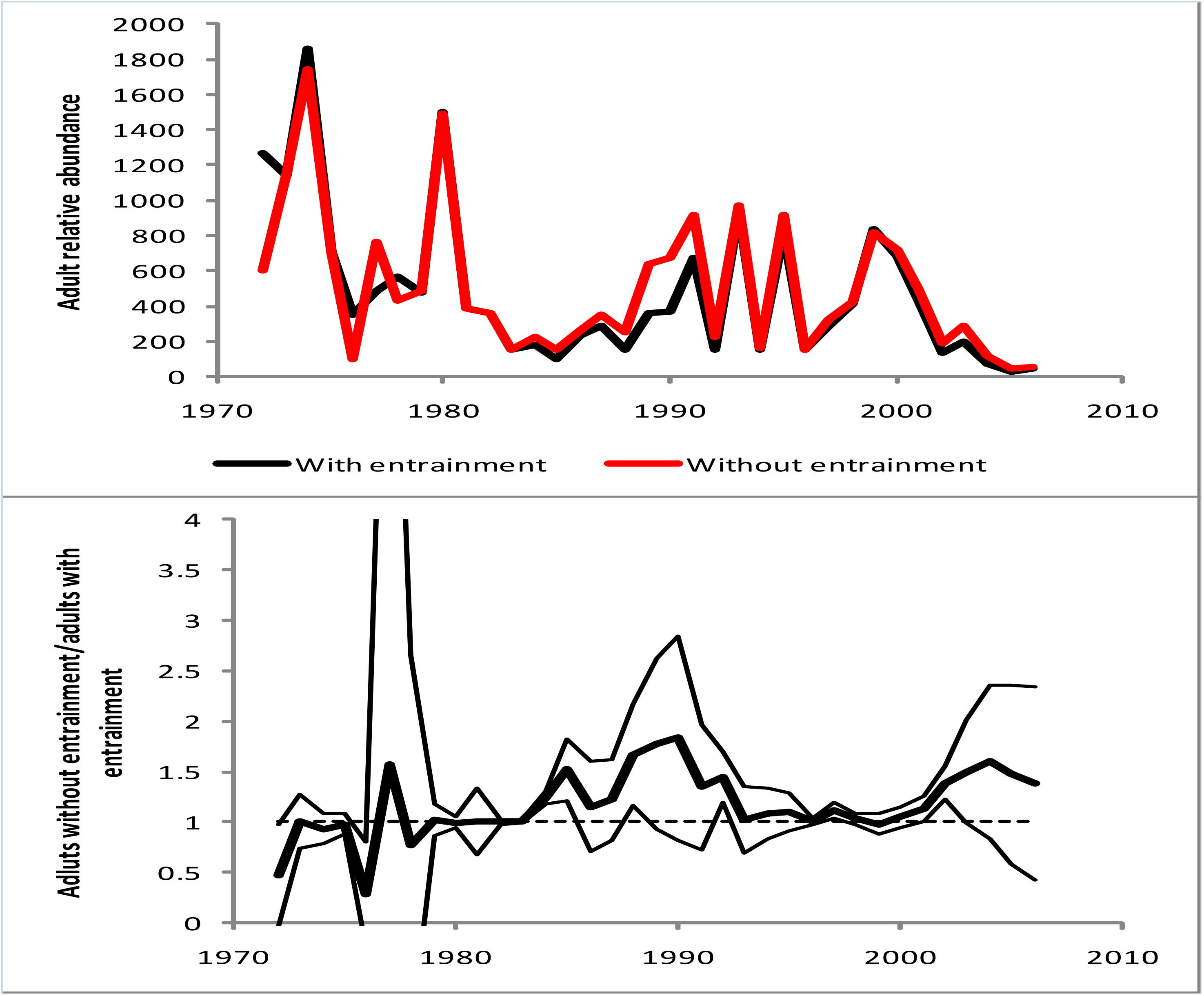
MacNally et al. (2010)	Thomson et al. (2010)	Maunder and Deriso (2011)	Miller et al. (2012)
Factors with statistically significant effects			
Predator abundance		Predator abundance	Predator abundance
Summer temperatures		***Water temperatures***	Water temperatures
		Prey density	***Prey density***
Duration of water temperatures suitable for spawning			
	Water clarity		
	Winter exports		

Bold italic = Strong effect
Regular = Weak effect

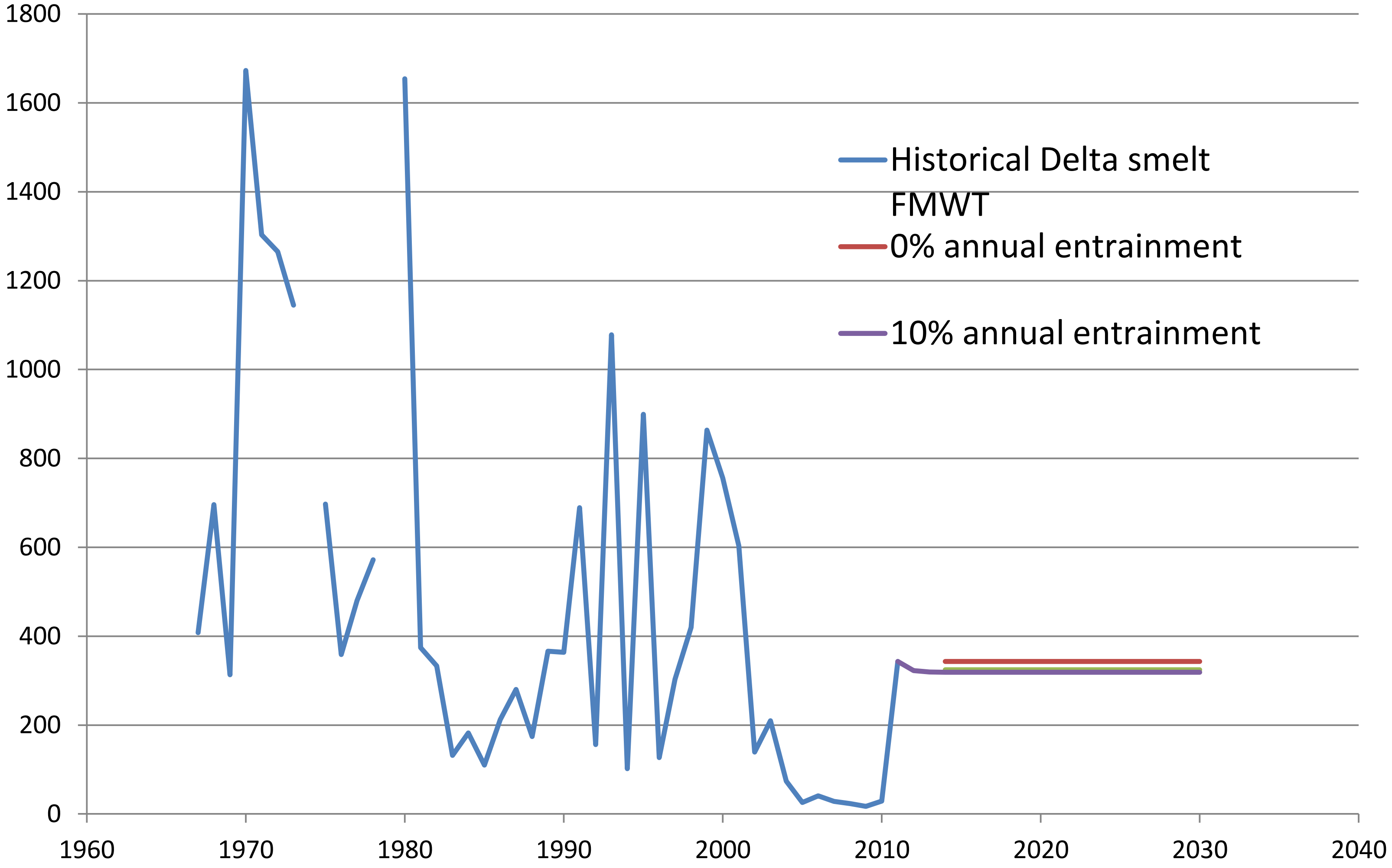
Results of Recent Modeling Efforts

MacNally et al. (2010)	Thomson et al. (2010)	Maunder and Deriso (2011)	Miller et al. (2012)
Factors without statistically significant effects			
Spring X2	Spring X2	Spring X2	Spring X2
Fall X2	Fall X2	Fall X2	Fall X2
		Juvenile entrainment	Juvenile entrainment
		Adult entrainment	Adult entrainment
Silverside abundance			
Water clarity			

Impact analysis: entrainment



Historical and Possible Future Steady State Delta Smelt FMWT Values

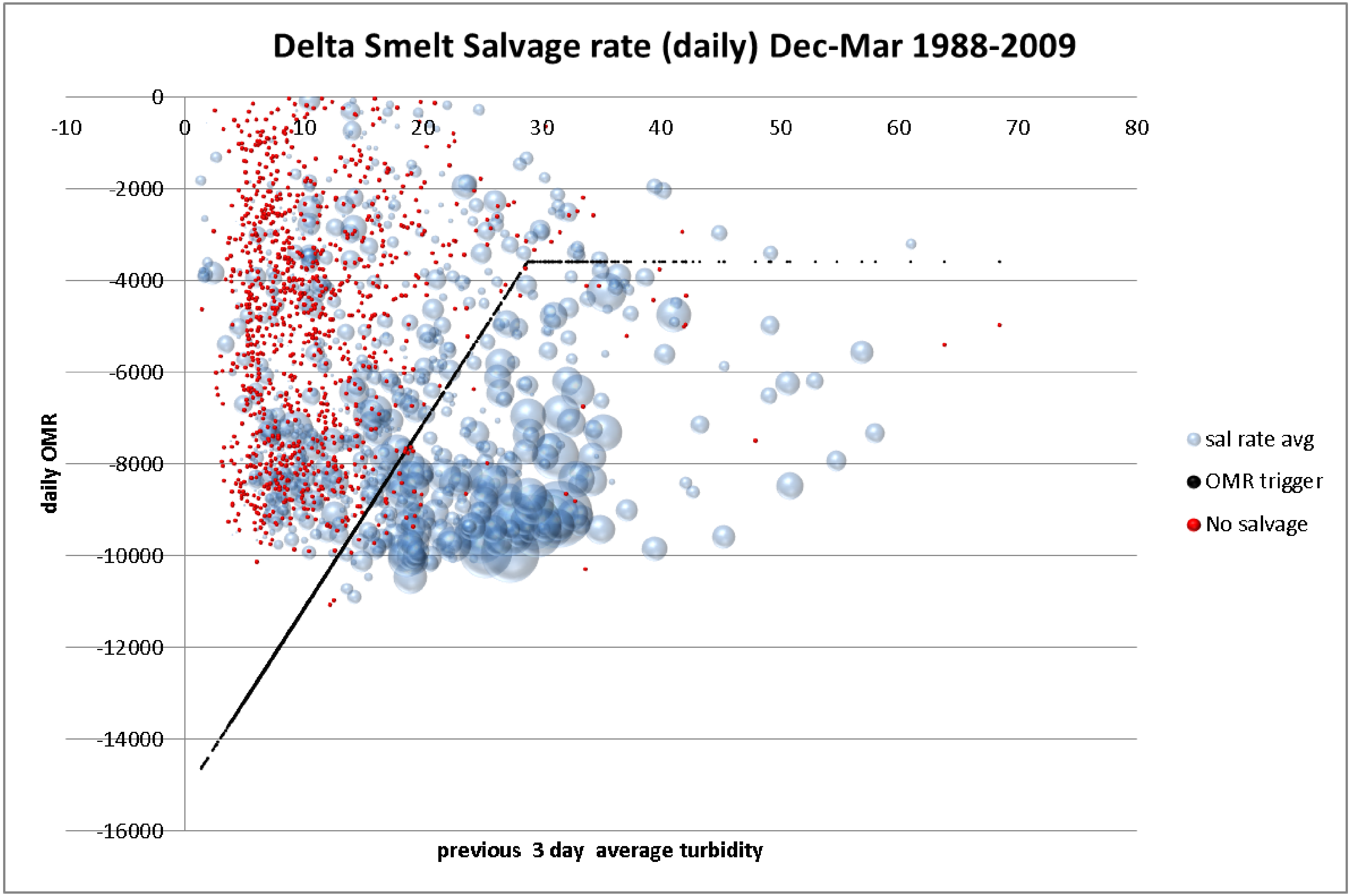


Management of Adult Smelt Entrainment

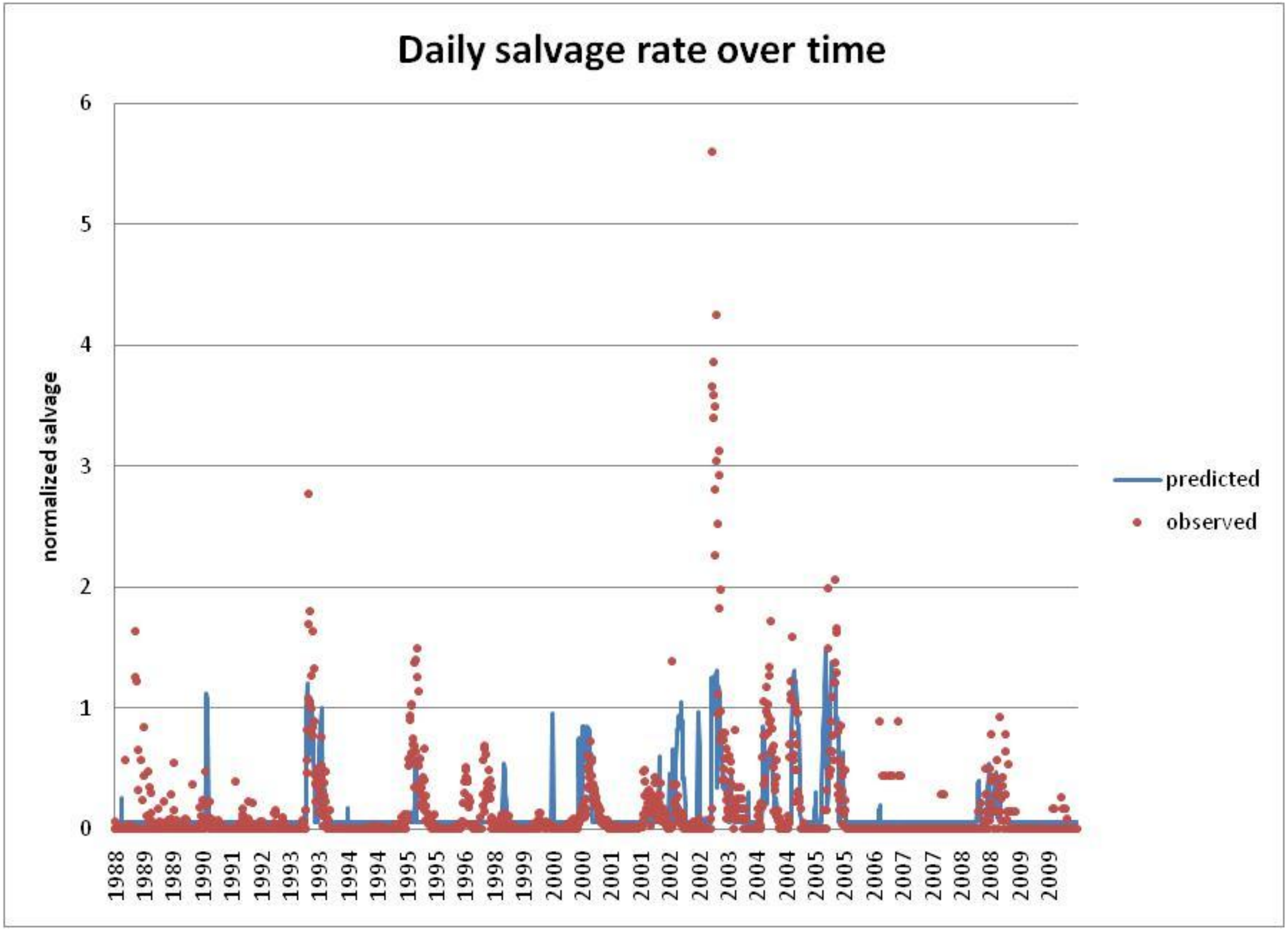
Turbidity Can be Used to Manage Entrainment

- Data show historic relationship between turbidity, OMR flow, and adult smelt entrainment
- Developed mathematical model as a function of turbidity at Clifton Court and OMR flow
- Model predicts adult salvage rates and when large entrainment events have occurred

Delta Smelt salvage rate as influenced by OMR and Clifton Court turbidity



Three-Day Turbidity OMR Model Predictions



Conclusions

- Entrainment does not appear to affect Delta smelt abundance patterns
- Entrainment levels are related to OMR and turbidity levels

Next up: Dr. Noble Hendrix, QEDA Consulting LLC

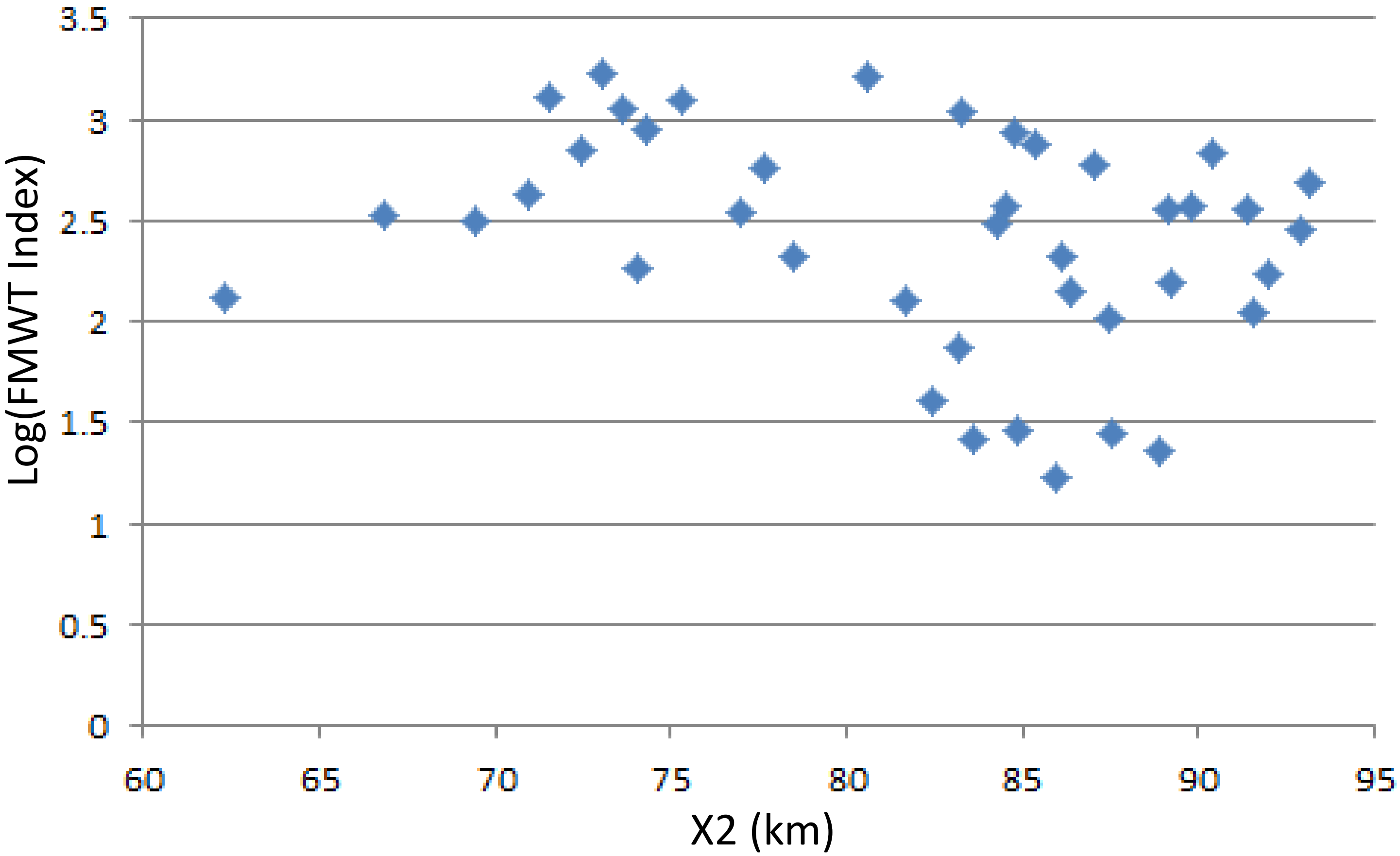
Delta smelt habitat and abundance

Fall X2 and Delta smelt abundance

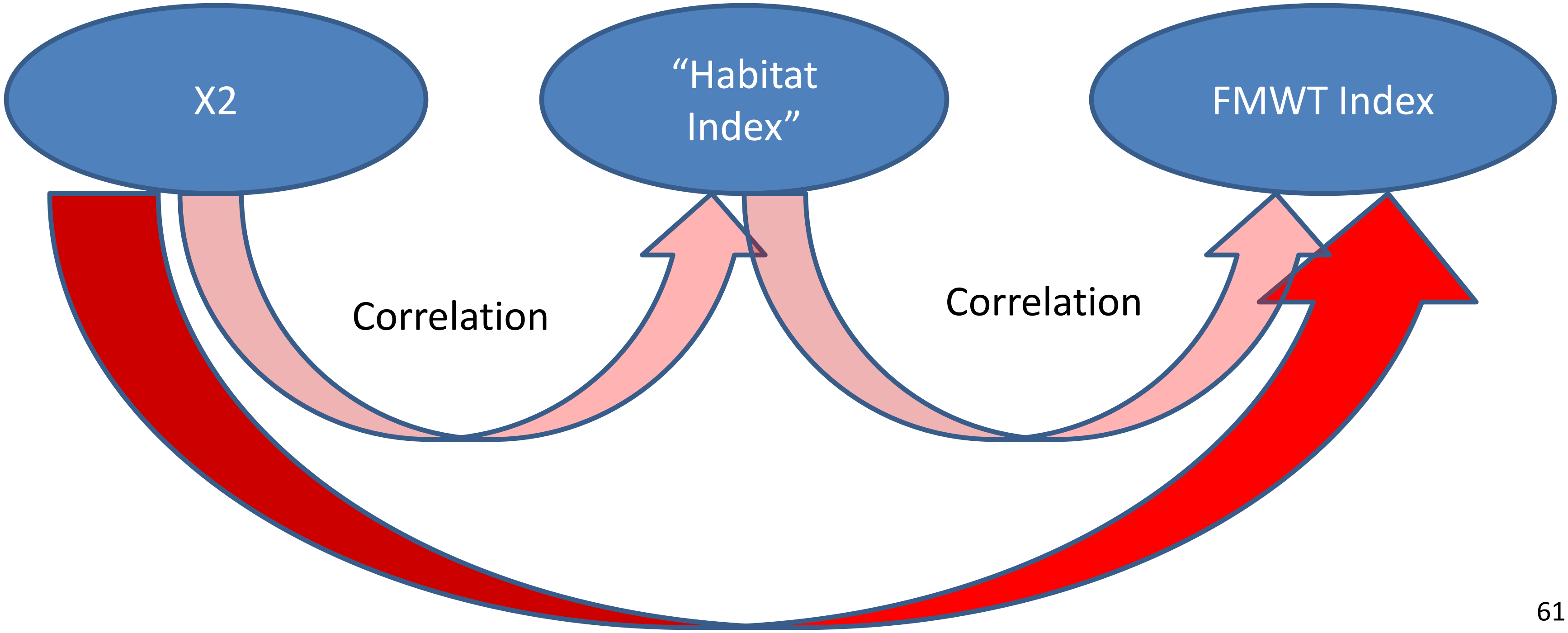
Dr. Noble Hendrix

QEDA Consulting, LLC
10/2/12

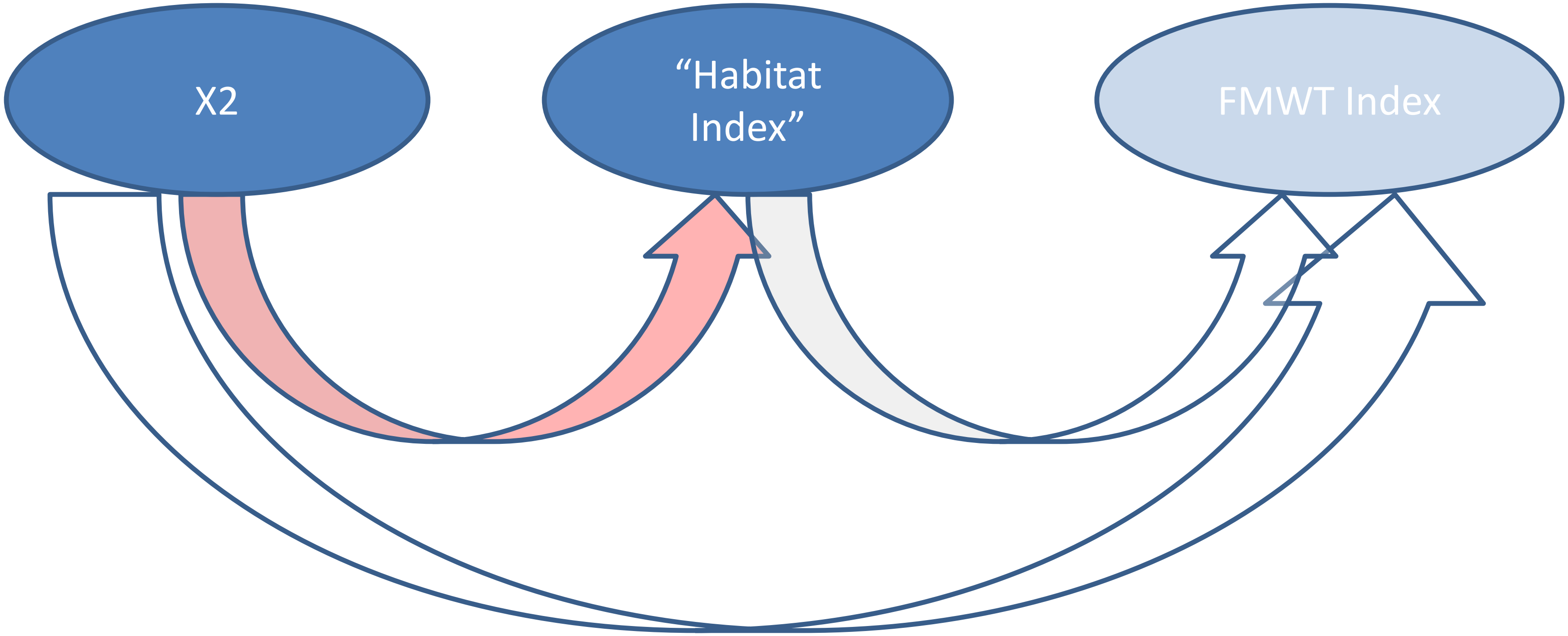
Correlation between delta smelt FMWT Index and Concurrent Fall X2



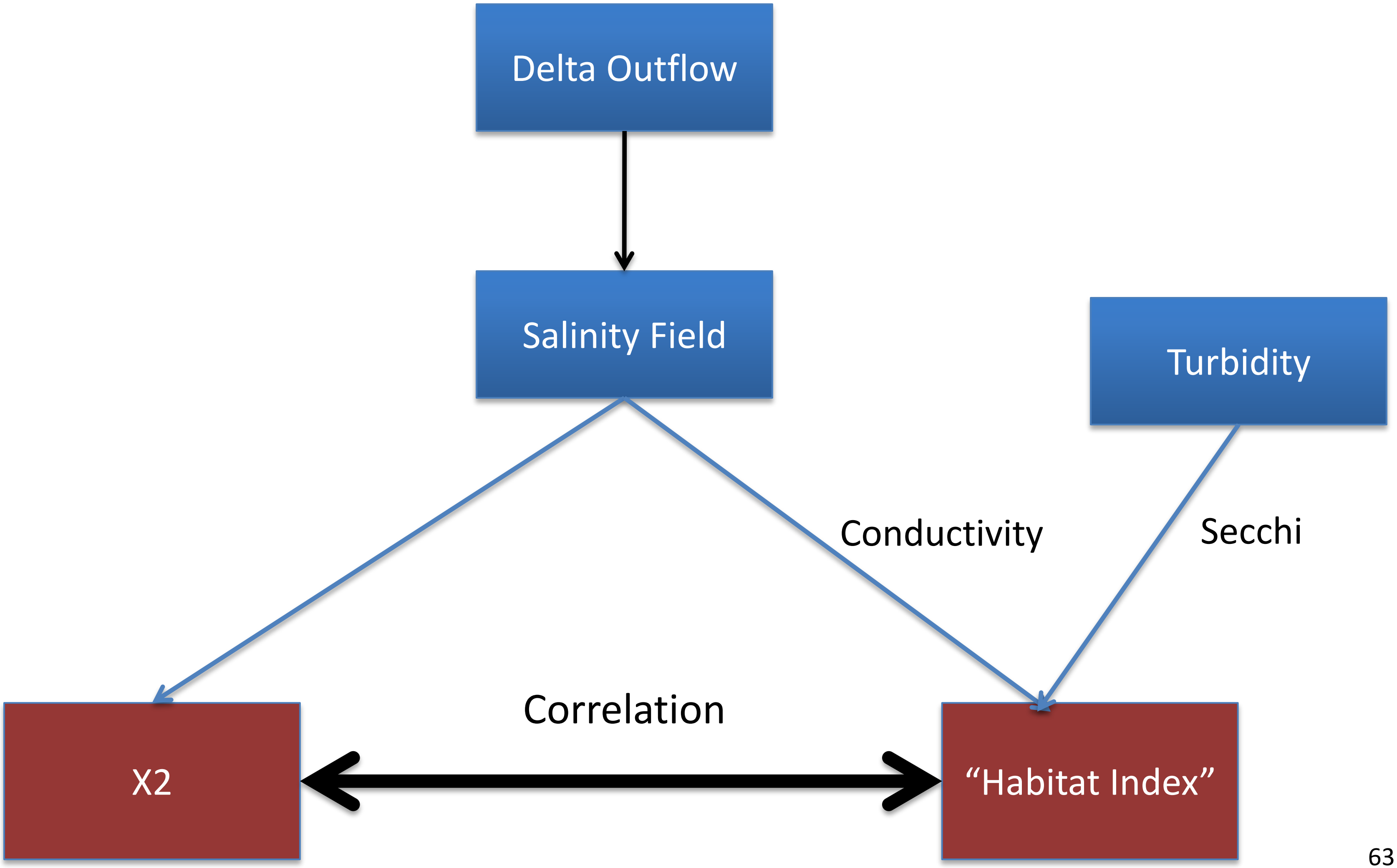
- Hypothesis of Feyrer et al. (2011):
  - X2 influences Delta smelt “Habitat Index”
  - Delta smelt “Habitat Index” influences Delta smelt abundance
  - Therefore, X2 influences Delta smelt abundance



X2 influences “Habitat Index”



Using two measures of salinity (X2 and EC) assures X2 will correlate with “Habitat Index”



Delta Outflow

Salinity Field

Turbidity

Conductivity

Secchi

Correlation

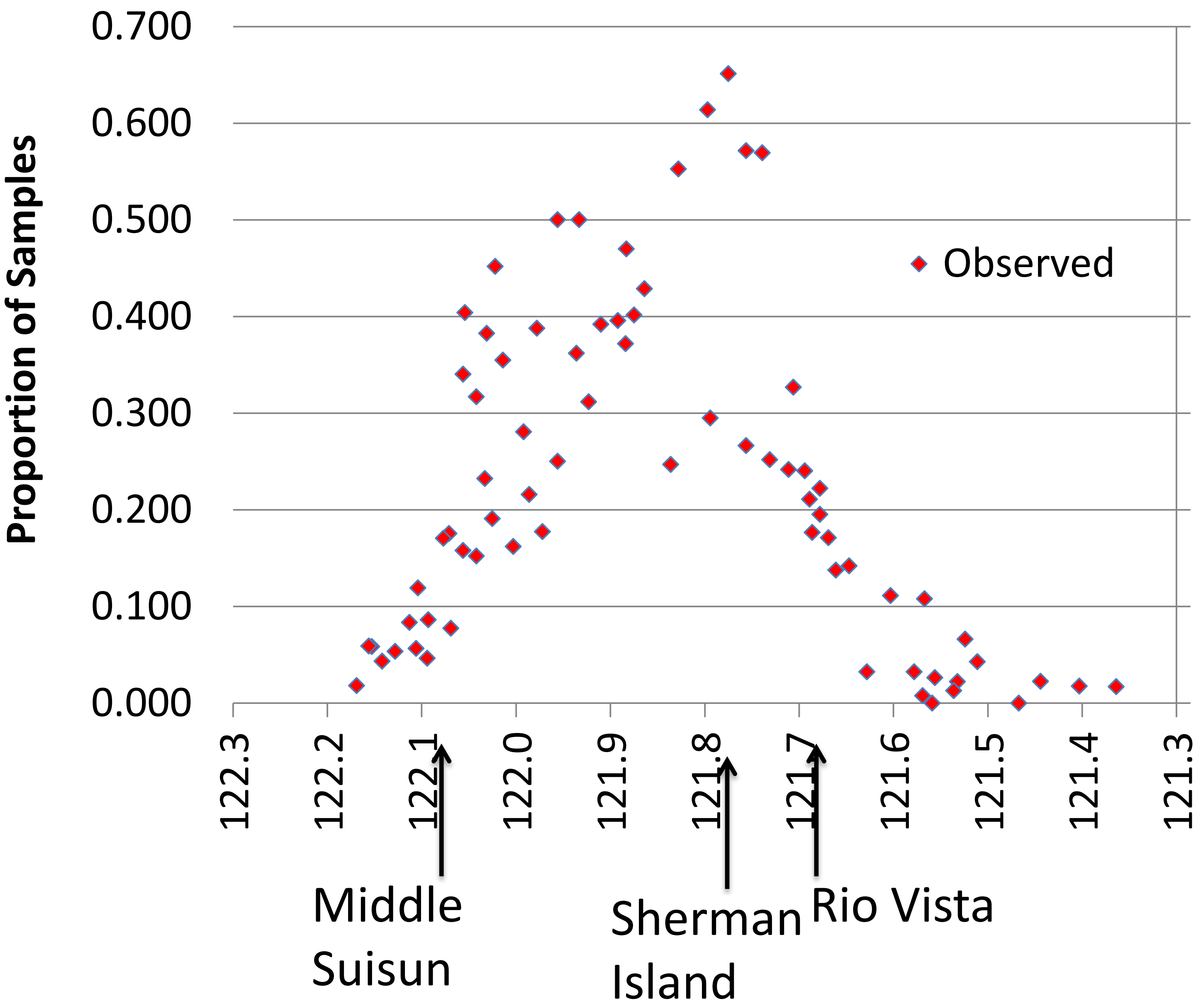
X2

“Habitat Index”

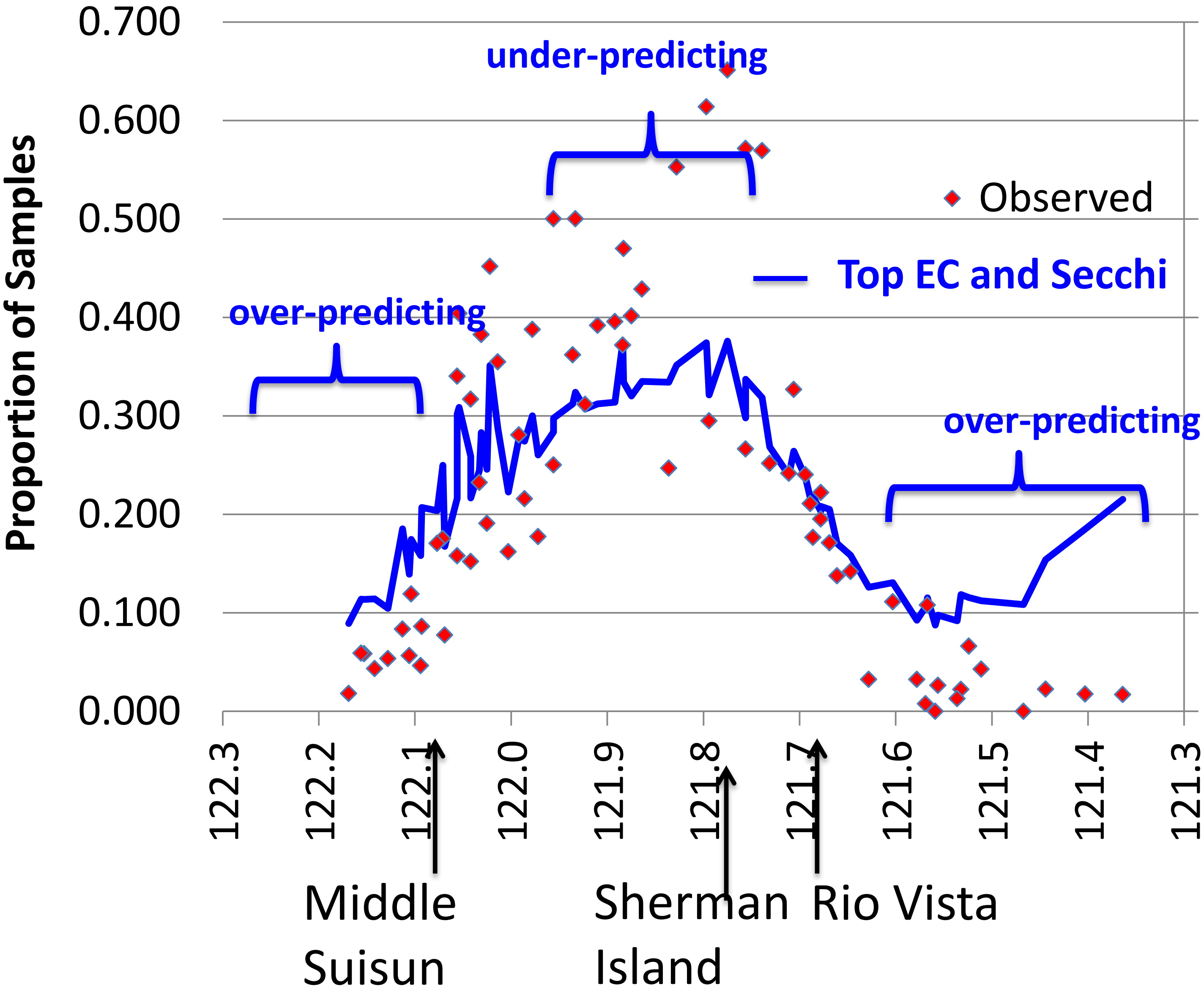
Other “Habitat Indices” fit the FMWT presence/absence data better

Model	% Variation explained	Correlation with X2
Top EC and Secchi	17.8%	-0.86
Longitude & Date	18.4%	-0.48

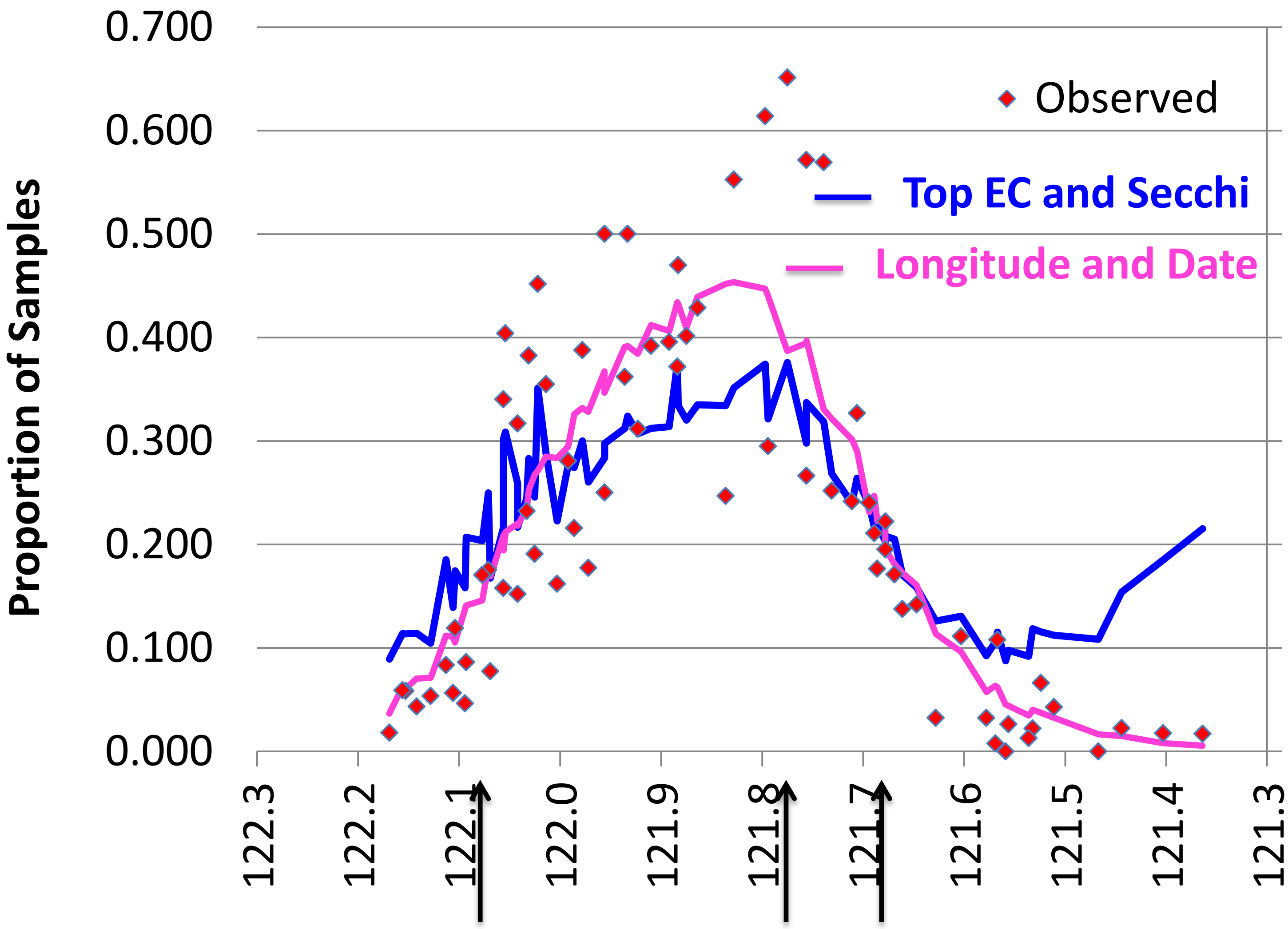
Proportion of samples with delta smelt



The “Habitat Index” does not fit well



Longitude model does better



Middle
Suisun

Sherman
Island

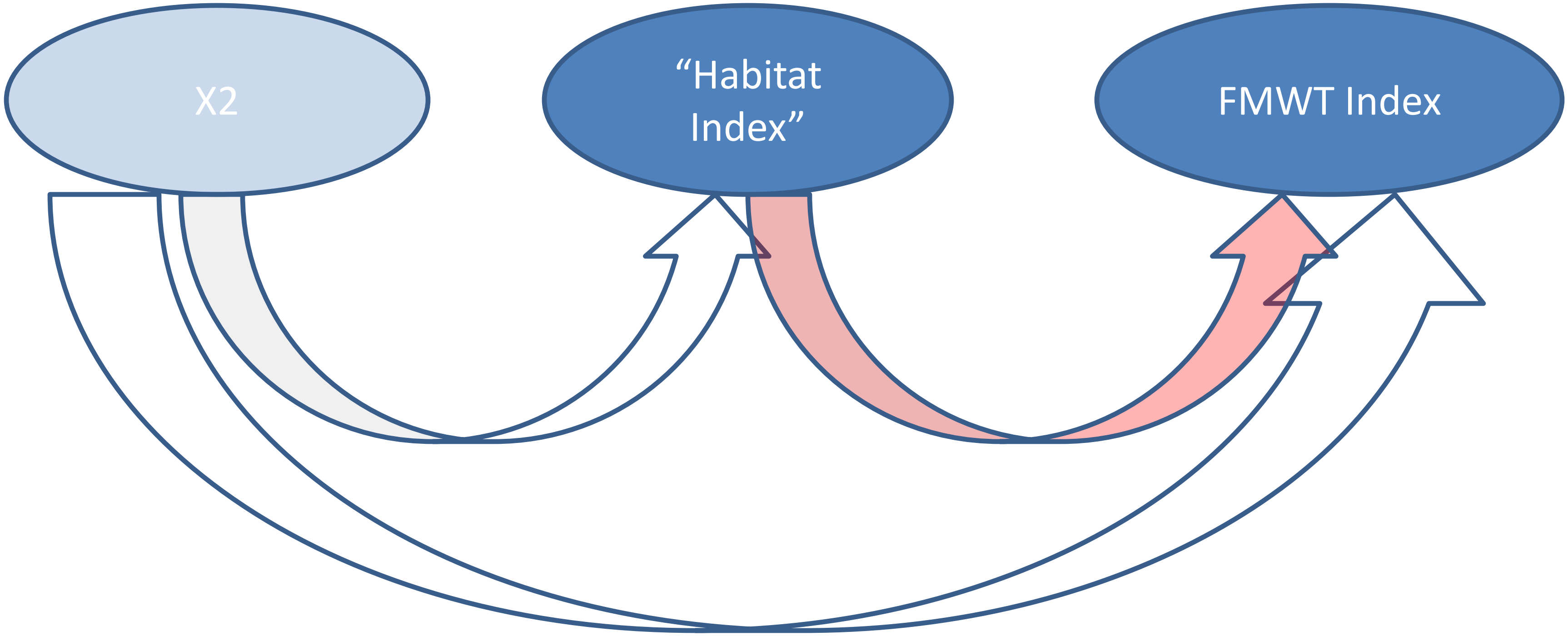
Rio Vista

Low Salinity Zone and Estuarine Habitat

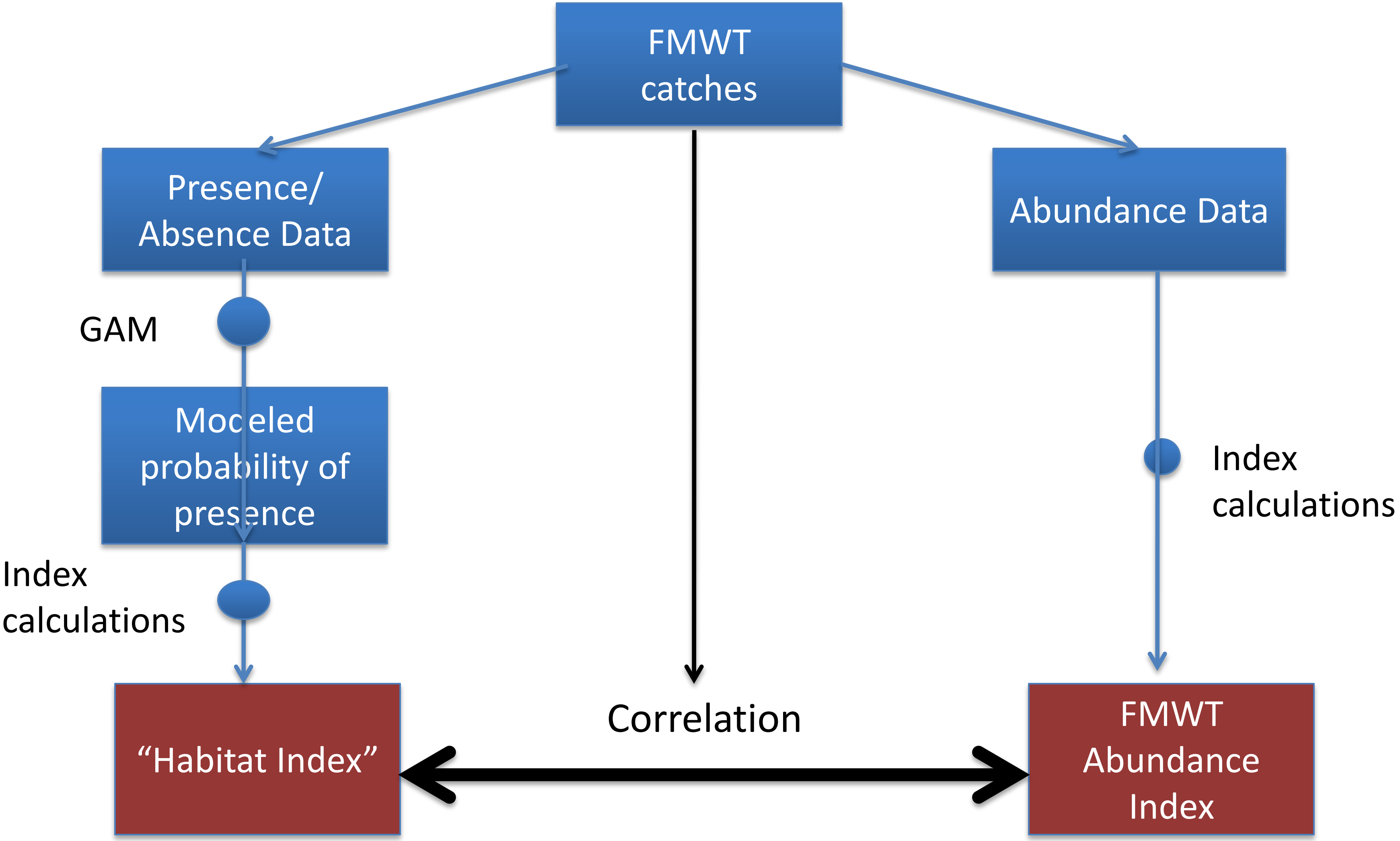
The low salinity zone (LSZ) is not equivalent to estuarine habitat. Estuarine habitat encompasses the range from 0 to 35 ppt salinity and the LSZ is just one part of the overall gradient. Other gradients and important aspects of habitat in this estuary include: salinity, temperature, turbidity, food supply, predation, connectivity, geometry, variability [in time and space].

- USEPA Technical Workshop Summary

“Habitat Index” influences abundance



Construction of two indices from the same catch data ensures correlation



FMWT catches

Presence/ Absence Data

Abundance Data

GAM

Modeled probability of presence

Index calculations

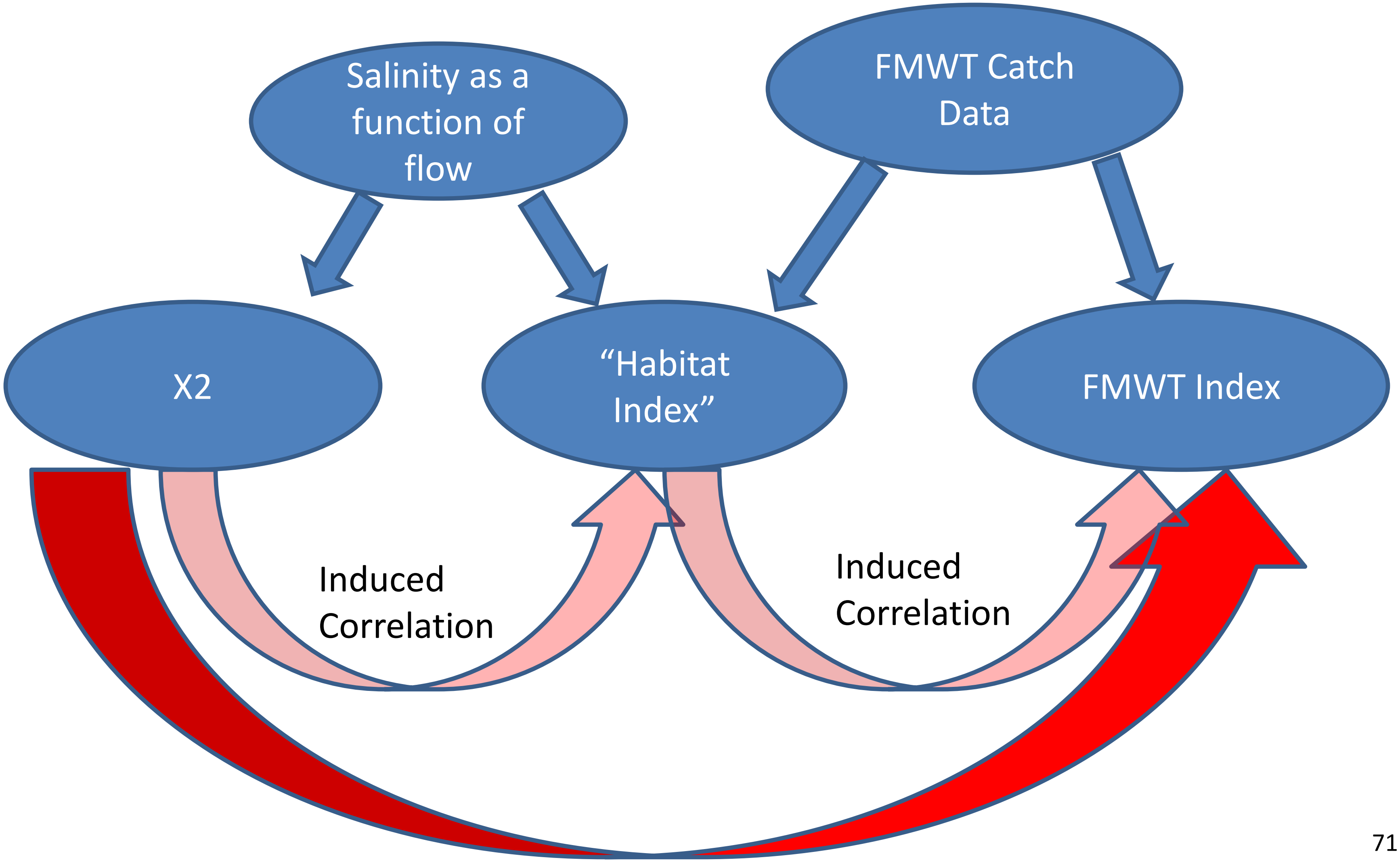
Index calculations

"Habitat Index"

Correlation

FMWT Abundance Index

Result: Chain of Induced Correlations



Salinity as a function of flow

FMWT Catch Data

X2

"Habitat Index"

FMWT Index

Induced Correlation

Induced Correlation

What USFWS Says About Induced Correlation

Feyrer et al. (2011) showed that despite being based on presence or absence of delta smelt, their resultant habitat index was correlated with the FMWT abundance index…

However, this is an expected outcome because delta smelt abundance and presence-absence are correlated. The point in showing this association was to demonstrate that although the linkage is variable and inherently based on a circular argument (because catch was used to define habitat suitability), there is nonetheless a correlation between the FMWT indices and the habitat indices, which are nonlinearly related to fall X2.

USFWS Workshop #1 page 46.

Conclusions

- The circularity means that comparing the “habitat index” to the FMWT abundance will be meaningless – the “habitat index” is essentially being compared to itself
- The “habitat index” should reflect the spatial patterns in observed smelt distribution

Next up: David Fullerton, MWD

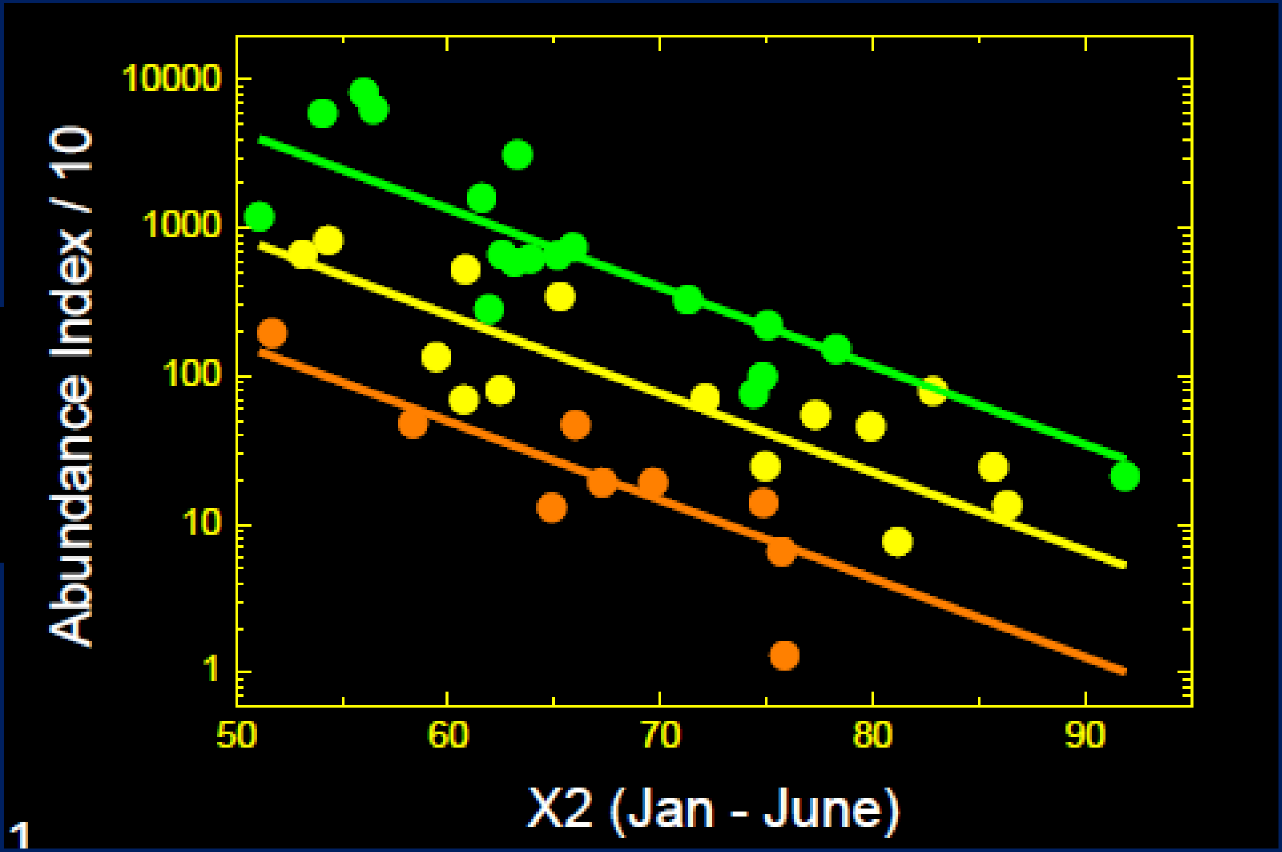
Longfin smelt

Longfin:X2 Relationship

1967 – 1987: Pre-clam

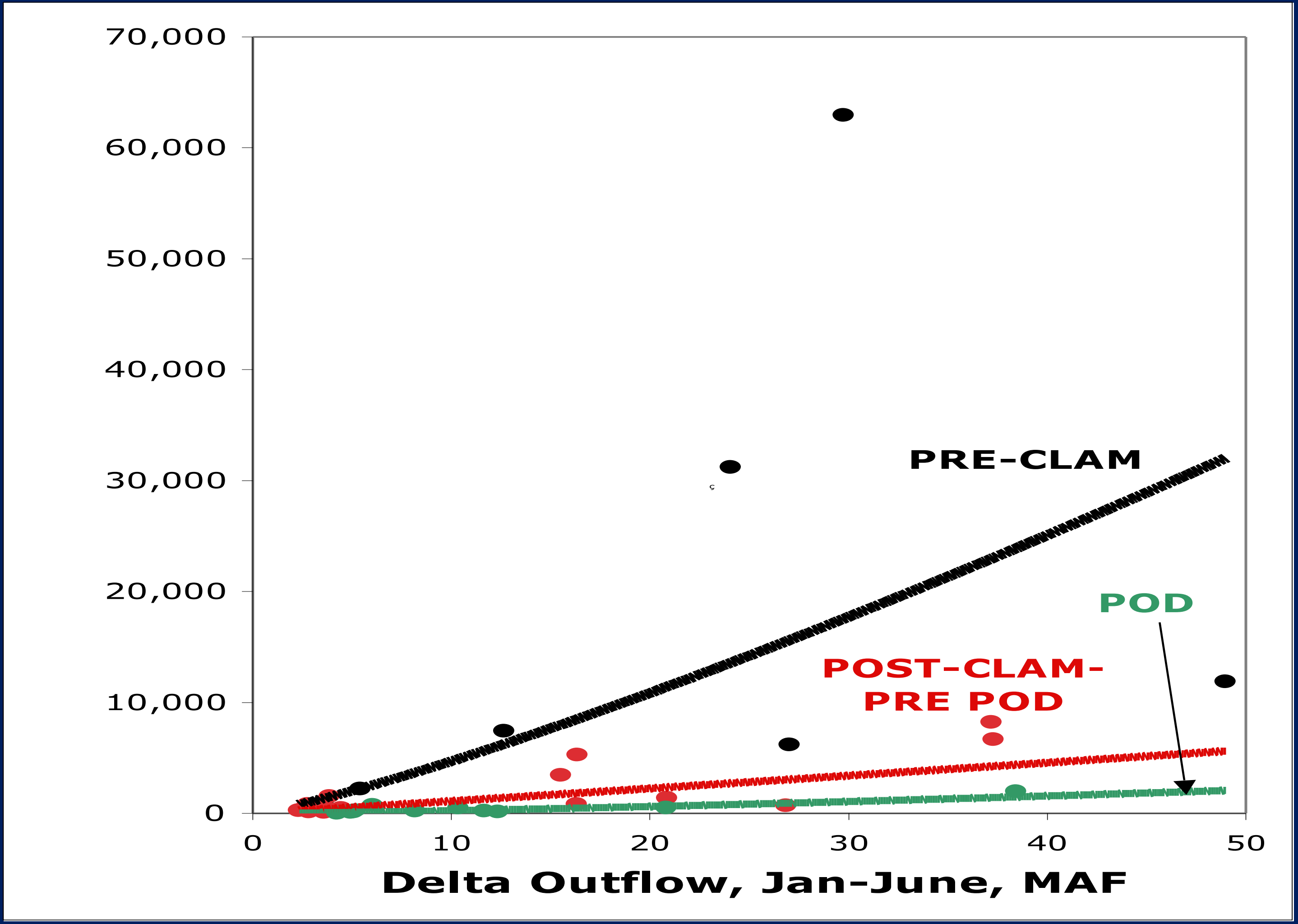
1988 – 2002: Post-clam

2003 – 2011: Post-POD



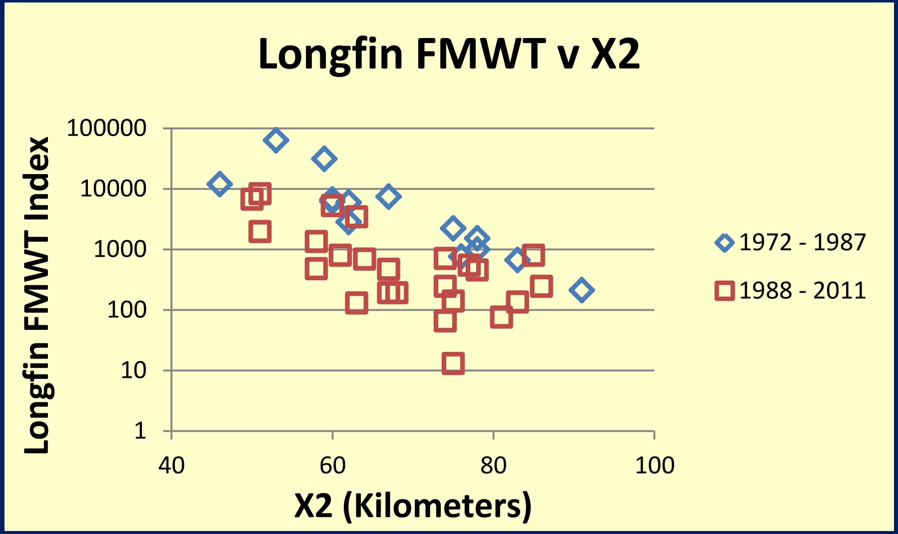
Expert Panel Presentation, Workshop 1

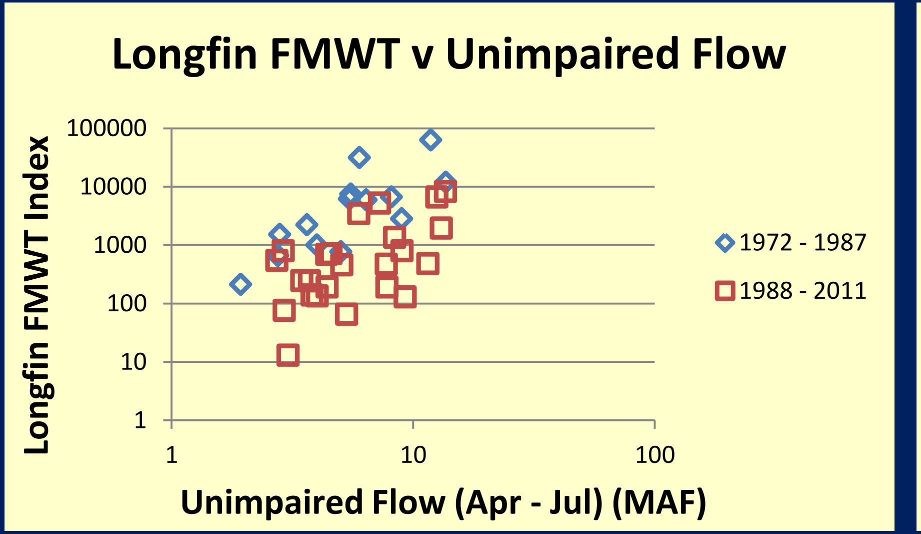
The FMWT: Flow relationship is now nearly flat

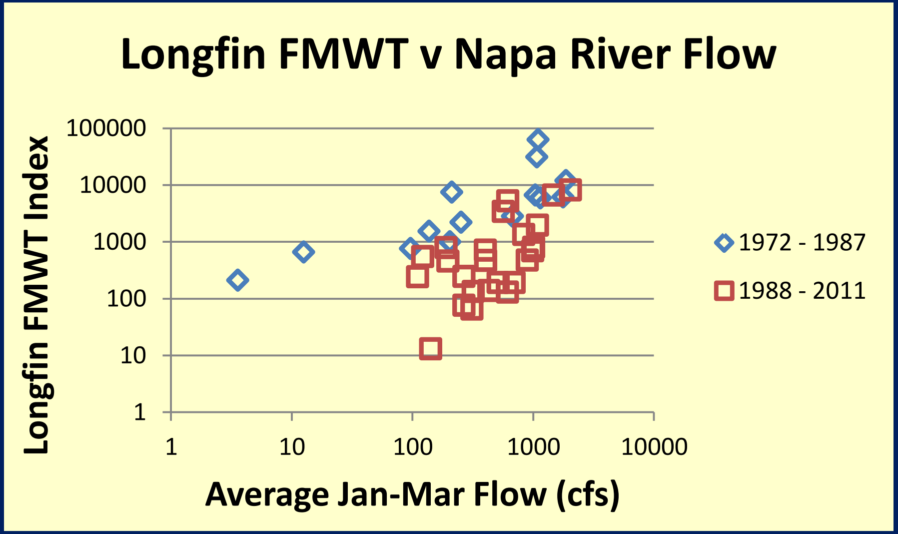


Source: FMWT Index and Dayflow

Flow:Abundance Relationships



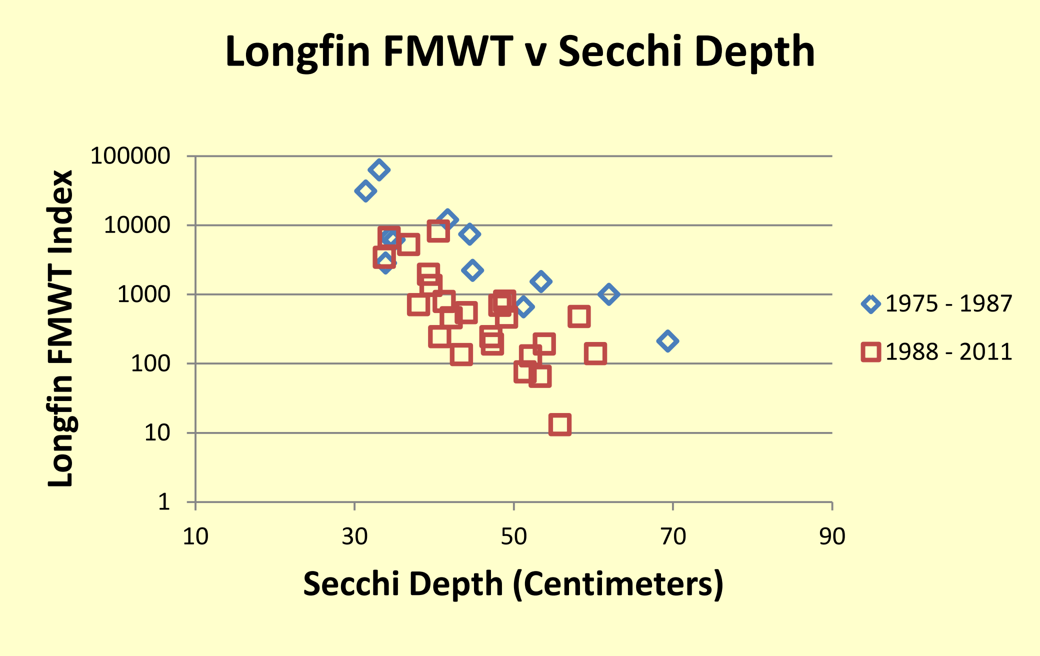


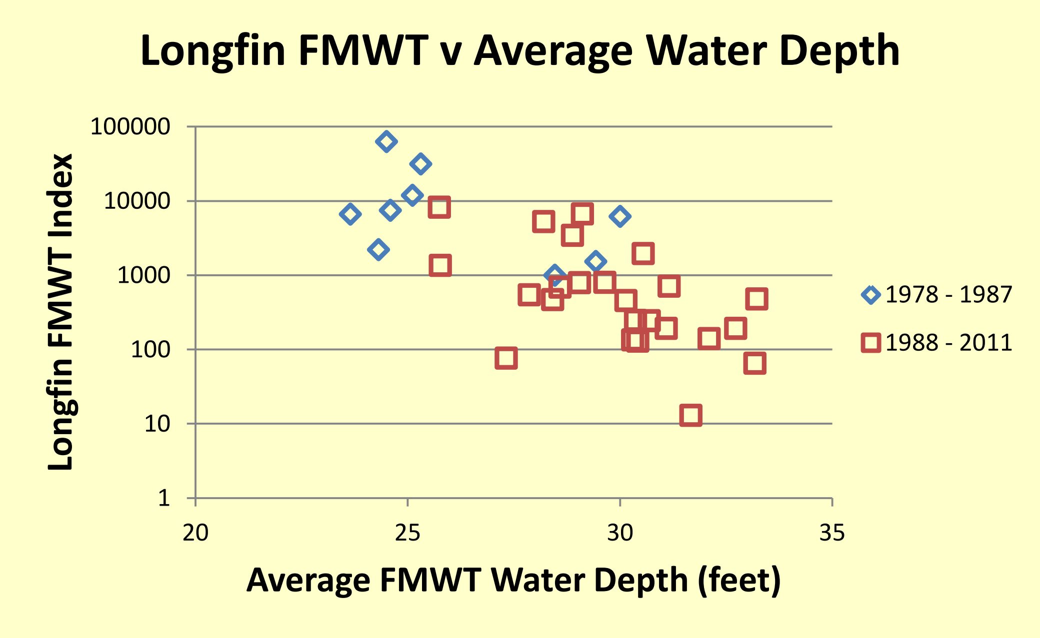


Source: DWR

Source: USGS

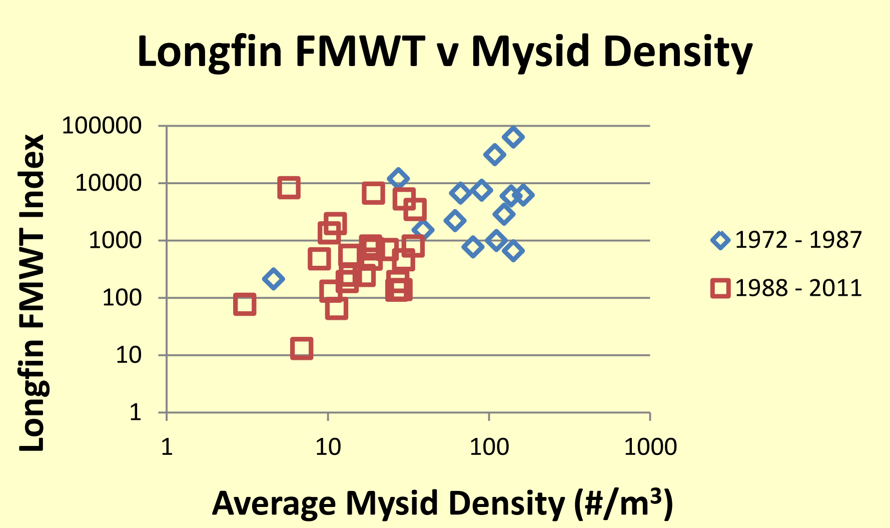
Water Depth, Secchi Depth :Abundance Relationships

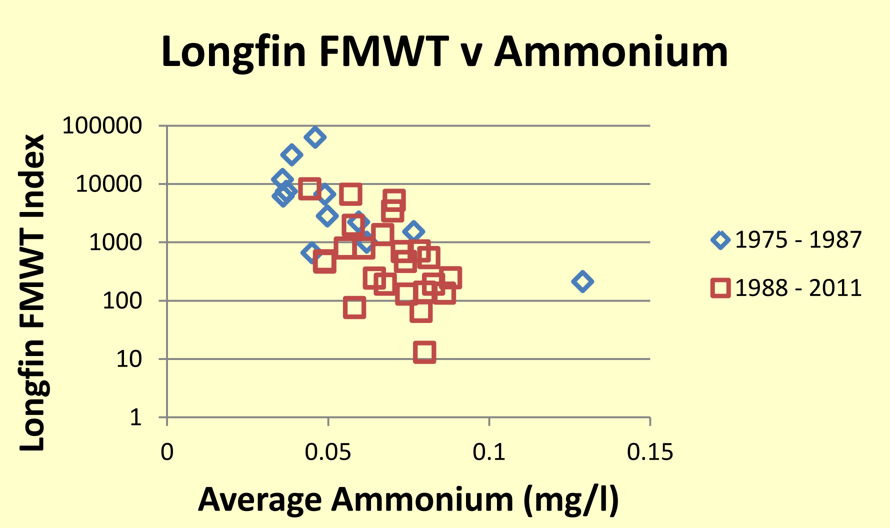


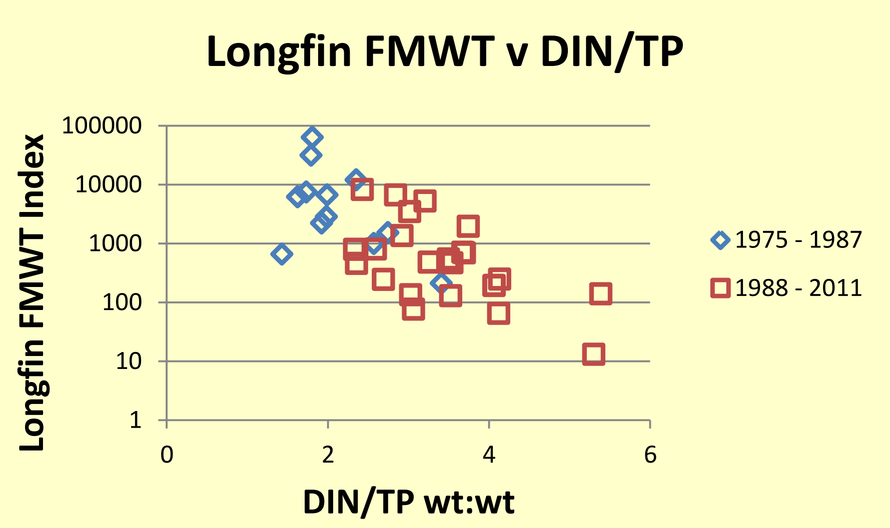


Source: EMP

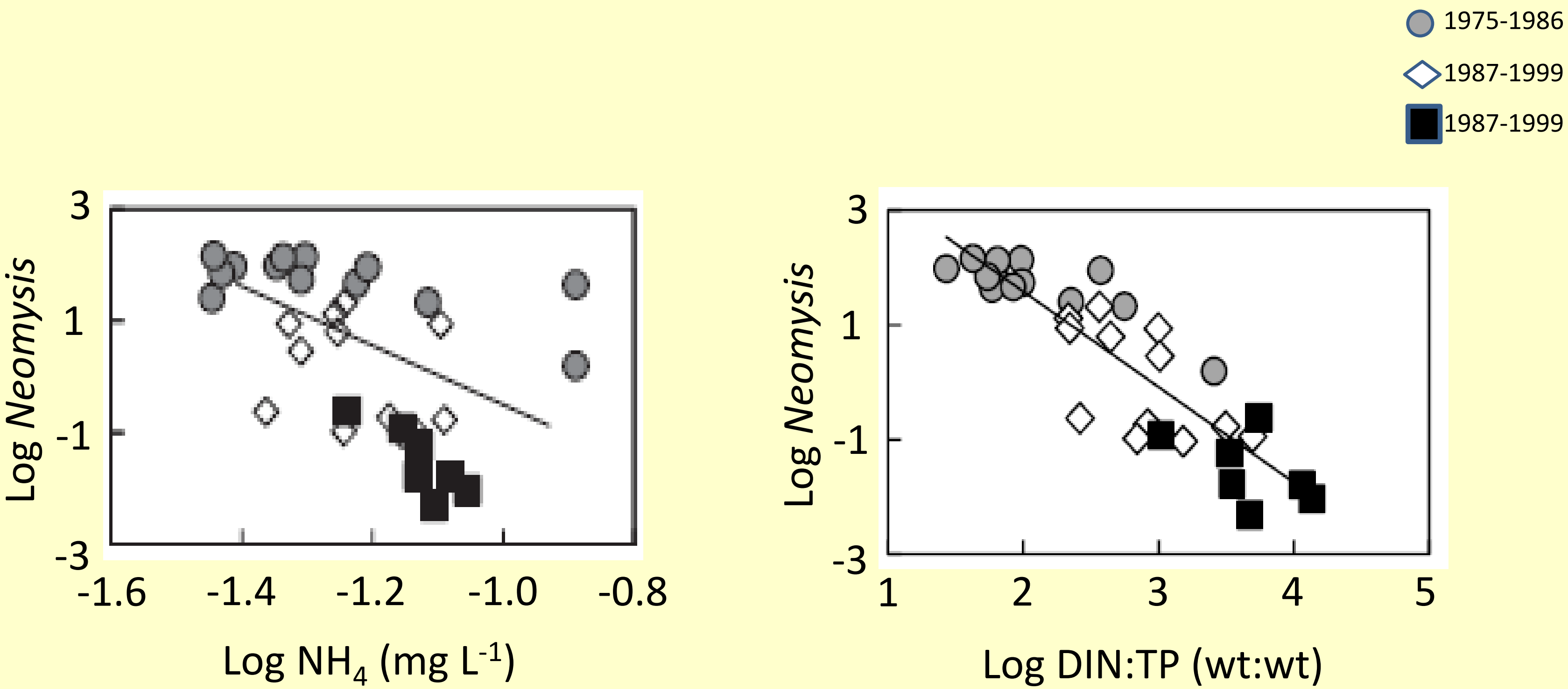
Nutrients/Food:Abundance Relationships



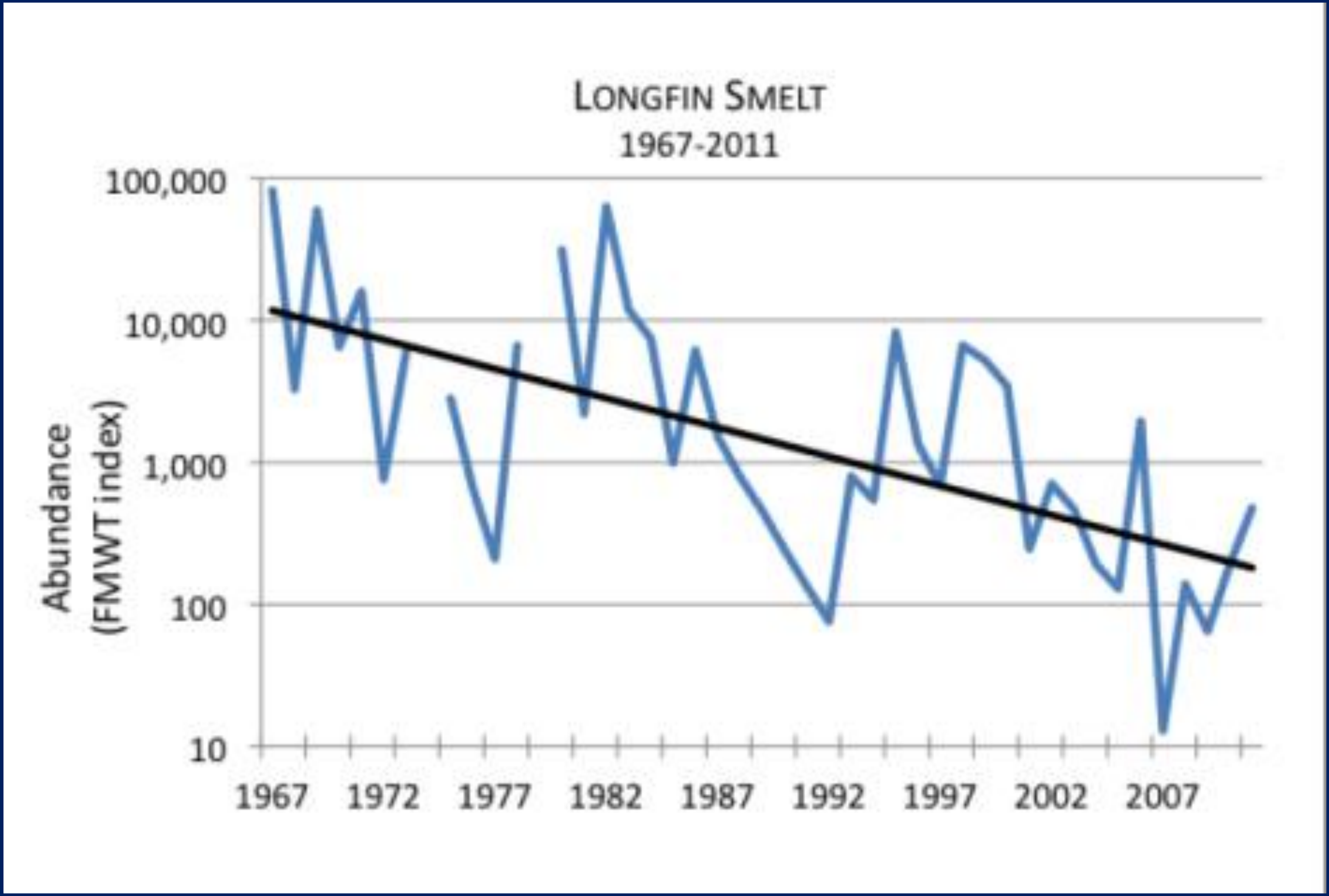




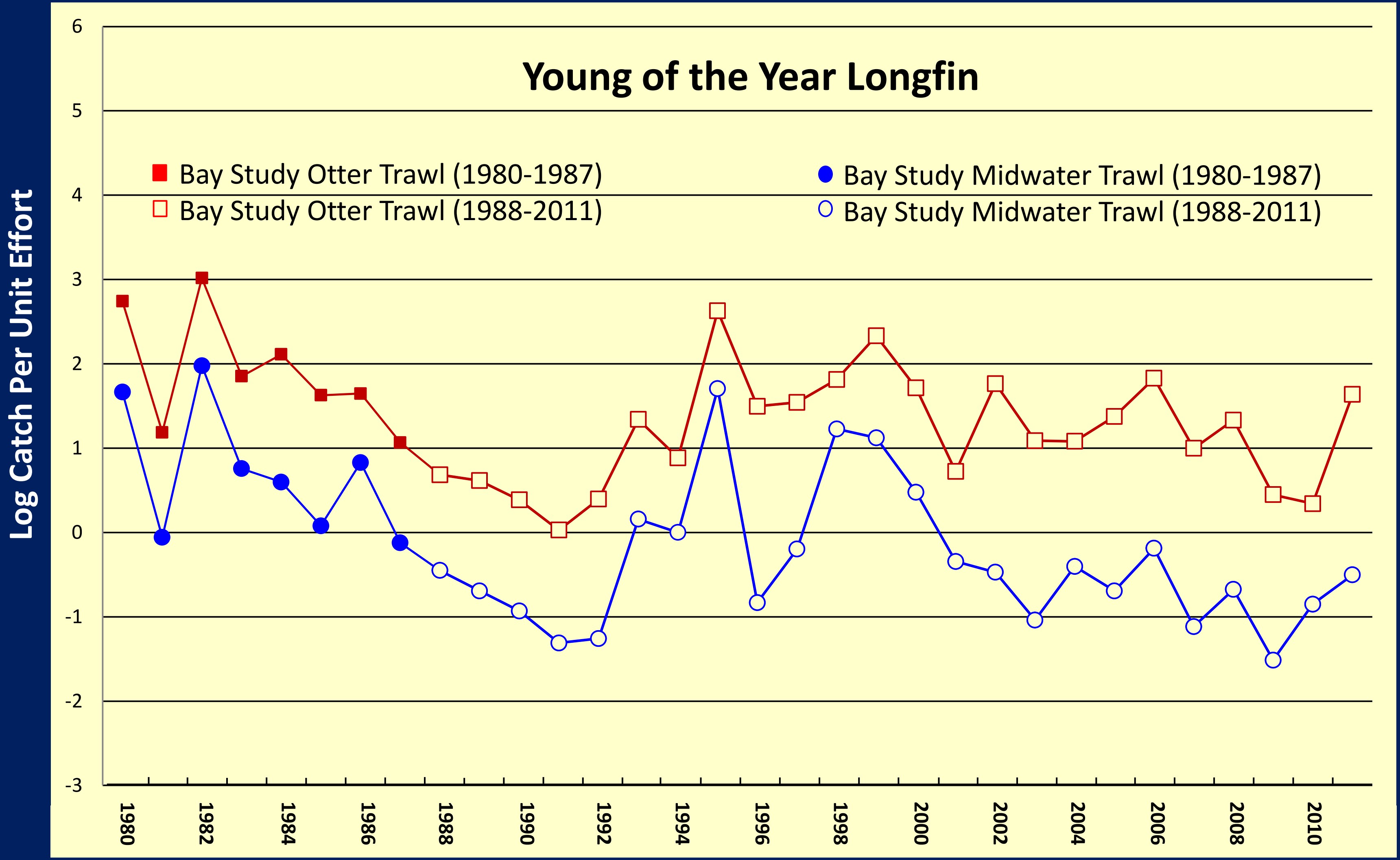
Nutrients:Abundance Relationships



From Glibert et al. (2011)



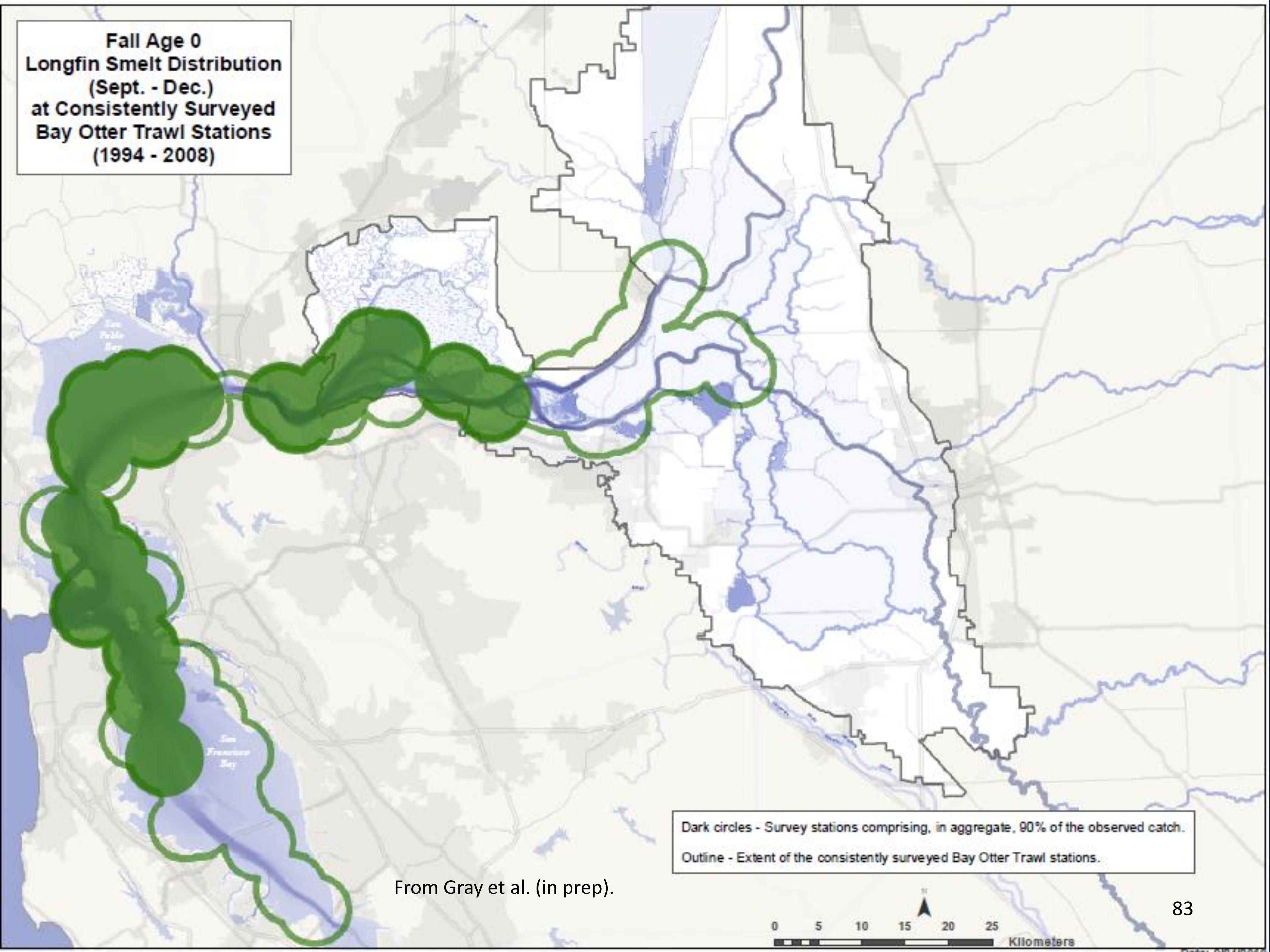
From Bay Institute presentation at Workshop 1, slide 7



Young of the Year Longfin

Source: DFG

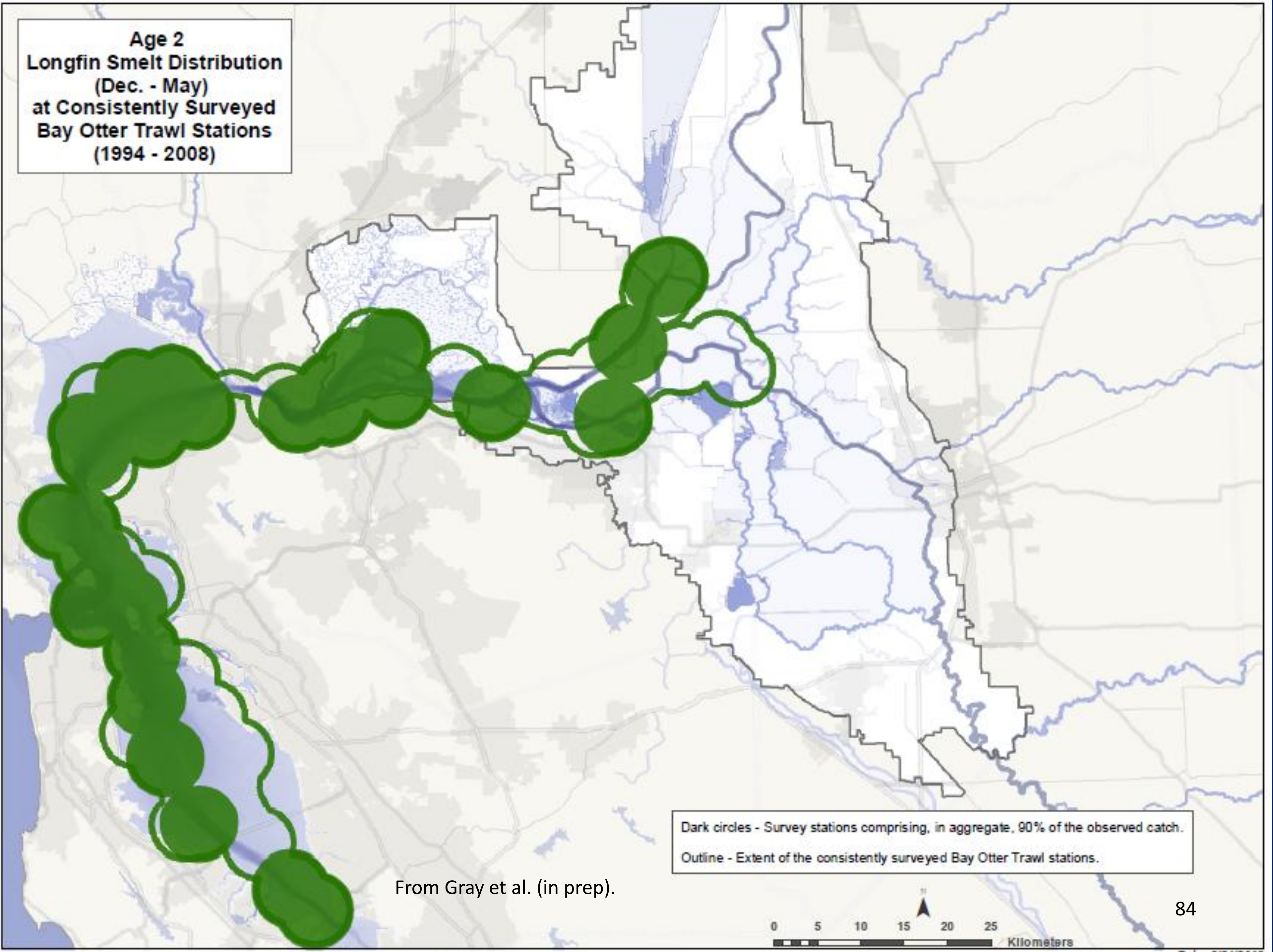
Fall Age 0 Longfin Smelt Distribution (Sept. - Dec.) at Consistently Surveyed Bay Otter Trawl Stations (1994 - 2008)



Dark circles - Survey stations comprising, in aggregate, 90% of the observed catch.

Outline - Extent of the consistently surveyed Bay Otter Trawl stations.

From Gray et al. (in prep).



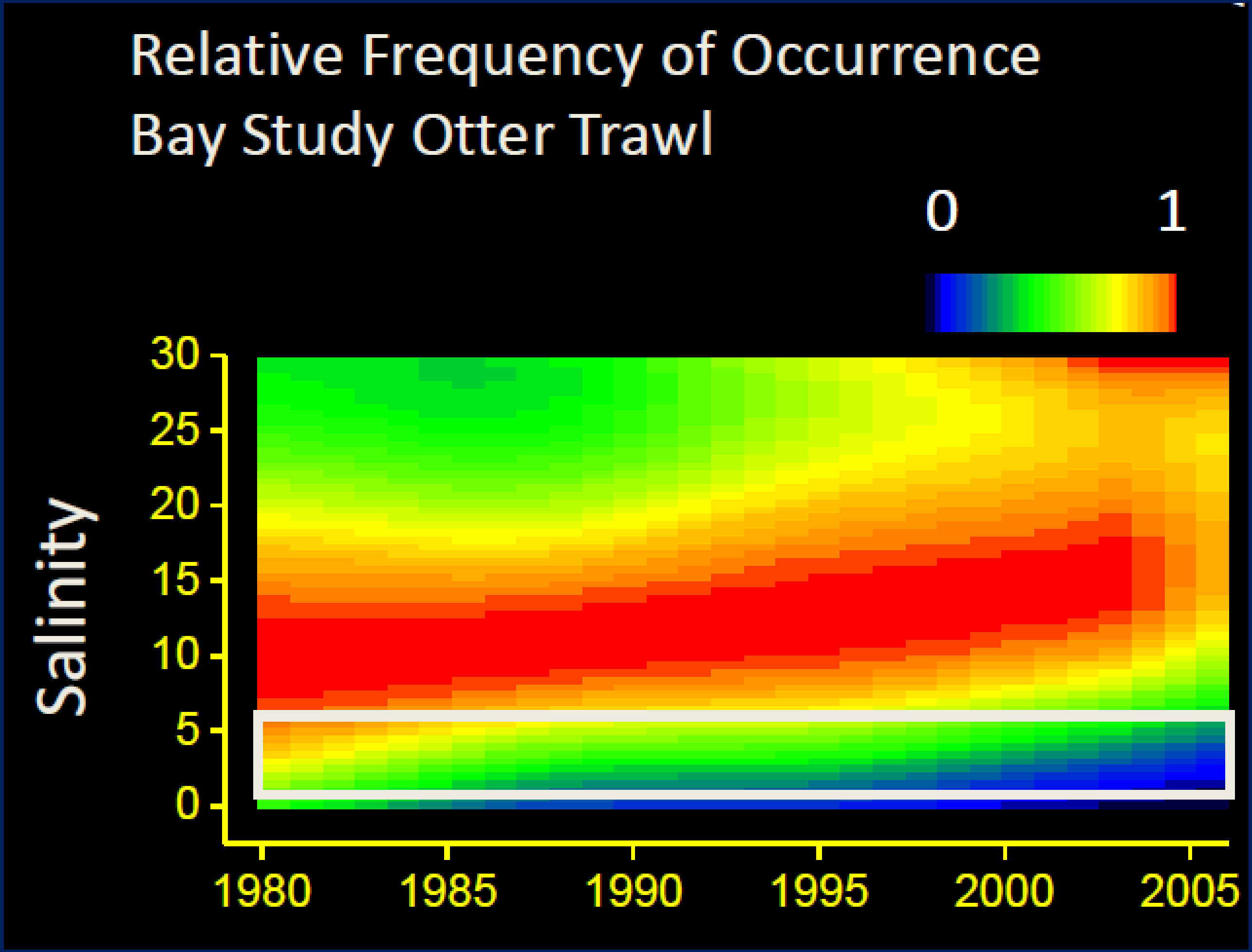
Age 2 Longfin Smelt Distribution (Dec. - May) at Consistently Surveyed Bay Otter Trawl Stations (1994 - 2008)

Dark circles - Survey stations comprising, in aggregate, 90% of the observed catch.

Outline - Extent of the consistently surveyed Bay Otter Trawl stations.

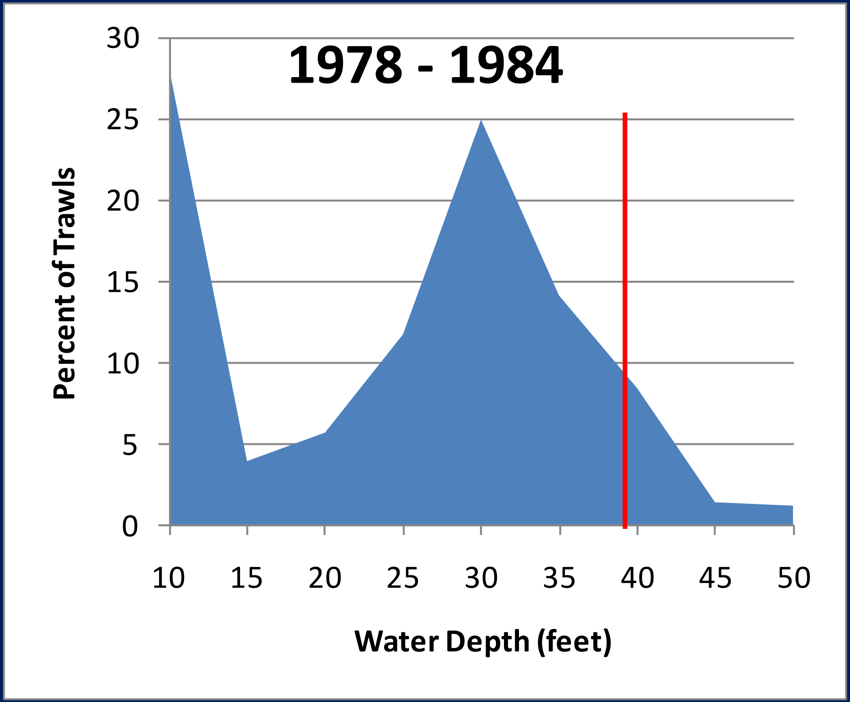
From Gray et al. (in prep).

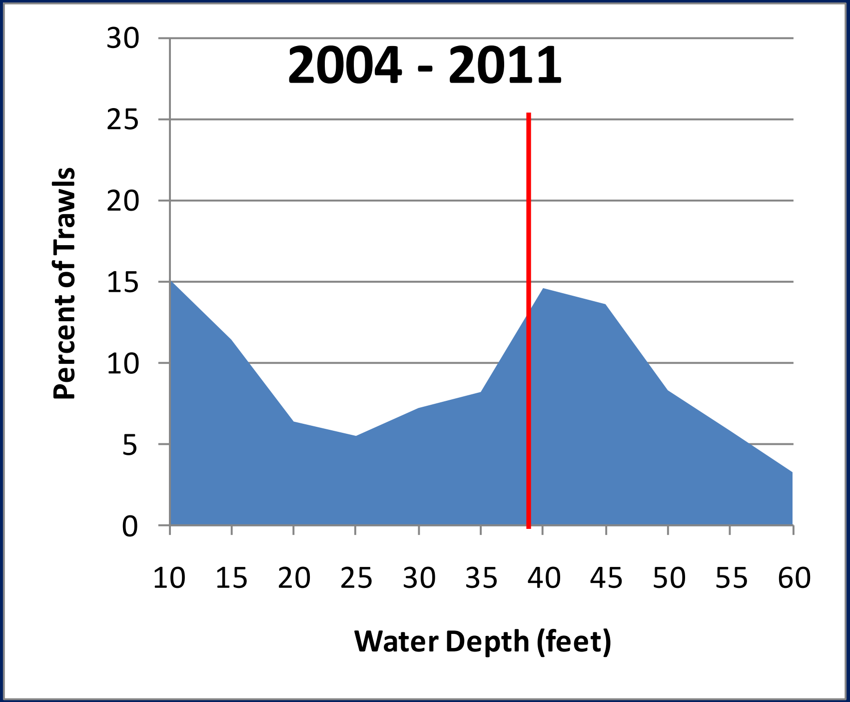
Shifts on Longfin Distribution over Time



From Kimmerer's presentation at Workshop 1, slide 20.

Water Depths Over Time in the FMWT





Source: FMWT dataset

Key Points for Longfin Smelt

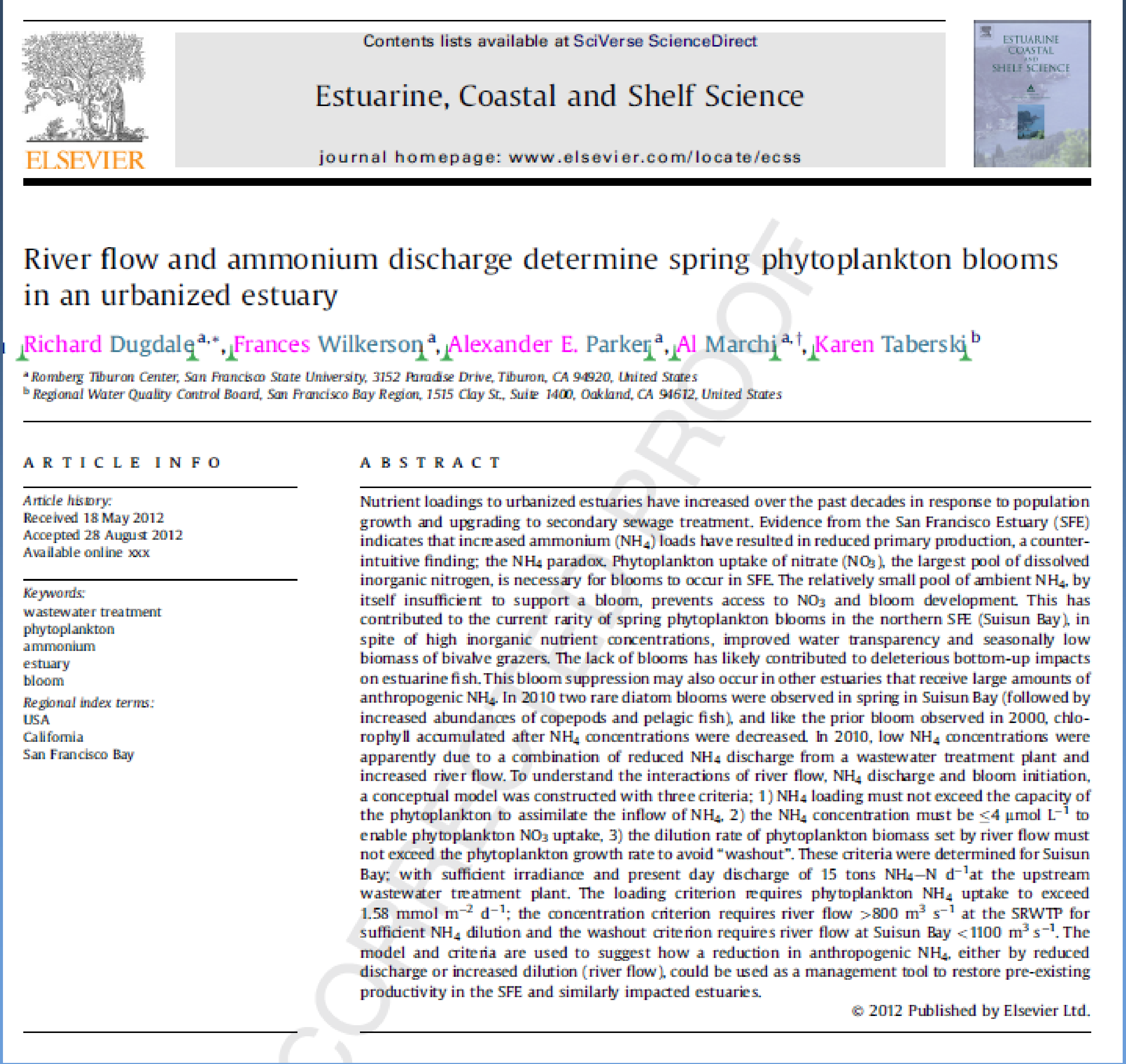
- There is no demonstrated mechanism to explain the longfin FMWT: X2 correlation.

- Even if outflow *per se* increased abundance, the increases would be very small.

- Many factors other than flows are correlated with longfin smelt abundance. The most plausible causal mechanism for longfin abundance is food supply and ultimately nutrient patterns.

- Different longfin surveys show different long-term abundance trajectories.

Next up: Dr. Richard Dugdale, SFSU



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River flow and ammonium discharge determine spring phytoplankton blooms in an urbanized estuary

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ABSTRACT

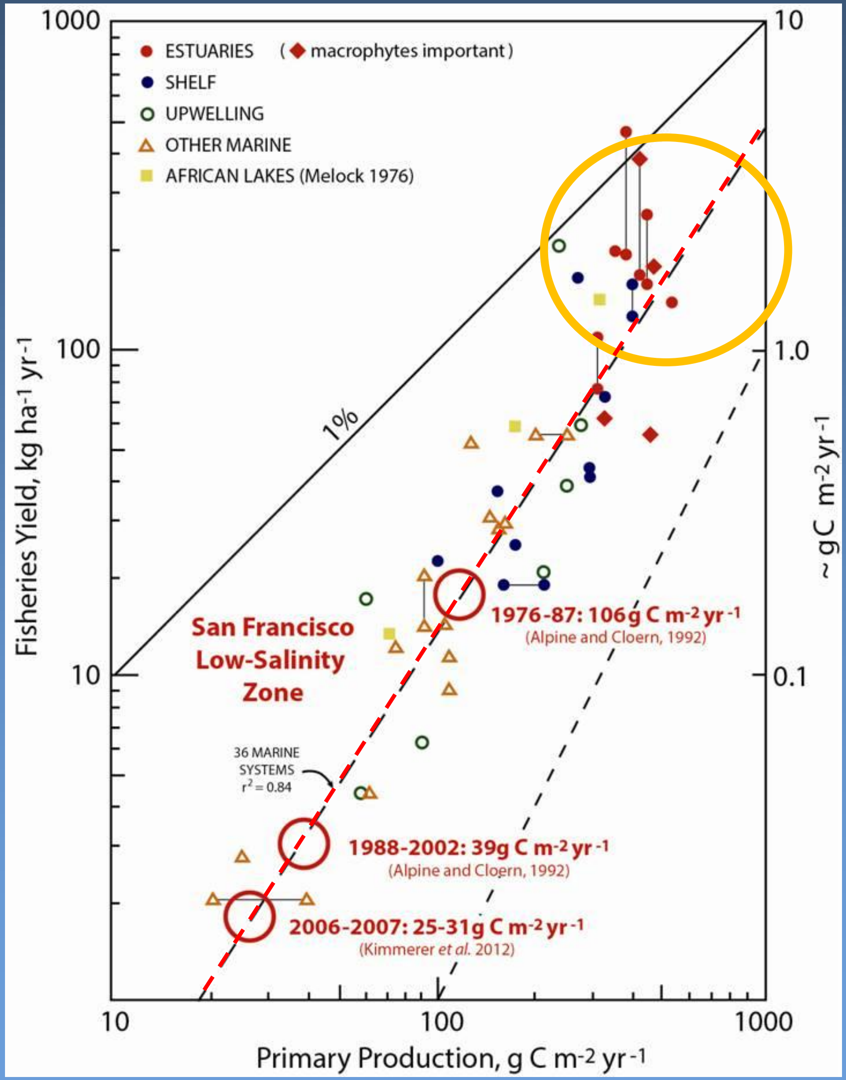
Nutrient loadings to urbanized estuaries have increased over the past decades in response to population growth and upgrading to secondary sewage treatment. Evidence from the San Francisco Estuary (SFE) indicates that increased ammonium (NH_4) loads have resulted in reduced primary production, a counter-intuitive finding; the NH_4 paradox. Phytoplankton uptake of nitrate (NO_3), the largest pool of dissolved inorganic nitrogen, is necessary for blooms to occur in SFE. The relatively small pool of ambient NH_4, by itself insufficient to support a bloom, prevents access to NO_3 and bloom development. This has contributed to the current rarity of spring phytoplankton blooms in the northern SFE (Suisun Bay), in spite of high inorganic nutrient concentrations, improved water transparency and seasonally low biomass of bivalve grazers. The lack of blooms has likely contributed to deleterious bottom-up impacts on estuarine fish. This bloom suppression may also occur in other estuaries that receive large amounts of anthropogenic NH_4. In 2010 two rare diatom blooms were observed in spring in Suisun Bay (followed by increased abundances of copepods and pelagic fish), and like the prior bloom observed in 2000, chlorophyll accumulated after NH_4 concentrations were decreased. In 2010, low NH_4 concentrations were apparently due to a combination of reduced NH_4 discharge from a wastewater treatment plant and increased river flow. To understand the interactions of river flow, NH_4 discharge and bloom initiation, a conceptual model was constructed with three criteria; 1) NH_4 loading must not exceed the capacity of the phytoplankton to assimilate the inflow of NH_4, 2) the NH_4 concentration must be ≤ 4 μmol L^{-1} to enable phytoplankton NO_3 uptake, 3) the dilution rate of phytoplankton biomass set by river flow must not exceed the phytoplankton growth rate to avoid "washout". These criteria were determined for Suisun Bay; with sufficient irradiance and present day discharge of 15 tons NH_4–N d^{-1}at the upstream wastewater treatment plant. The loading criterion requires phytoplankton NH_4 uptake to exceed 1.58 mmol m^{-2} d^{-1}; the concentration criterion requires river flow >800 m^3 s^{-1} at the SRWTP for sufficient NH_4 dilution and the washout criterion requires river flow at Suisun Bay <1100 m^3 s^{-1}. The model and criteria are used to suggest how a reduction in anthropogenic NH_4, either by reduced discharge or increased dilution (river flow), could be used as a management tool to restore pre-existing productivity in the SFE and similarly impacted estuaries.

Background: *The Ammonium Paradox*

Paradigm: Excess nutrient loads cause phytoplankton blooms (production) and may result in cultural eutrophication; degraded aesthetics, low DO, HABs.

Empirical evidence: In the northern SFE and other systems, excess NH_4 may result in low phytoplankton production; cultural oligotrophication, (decreased algal biomass and altered phytoplankton community).

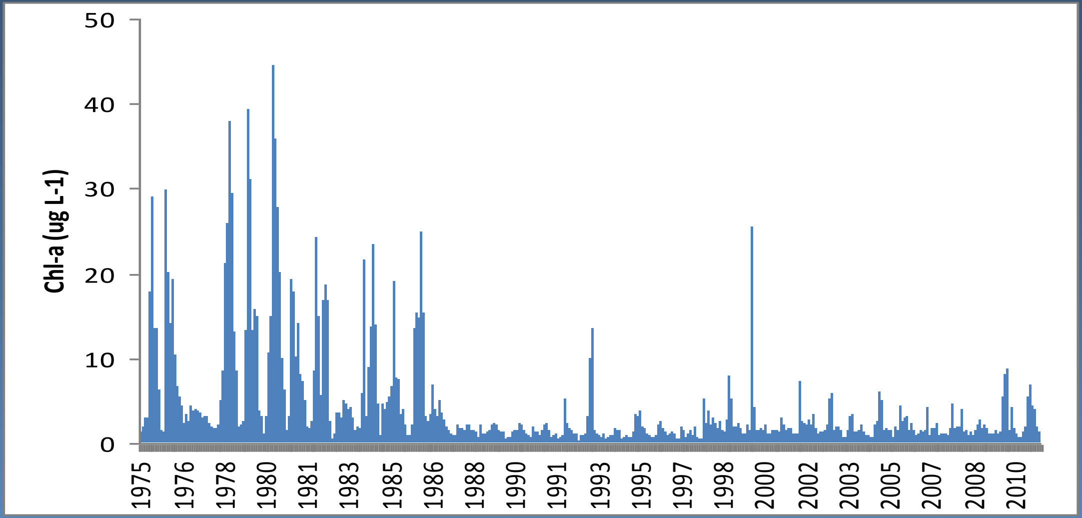
Background: *The Link Between Phytoplankton and Fish Yield*

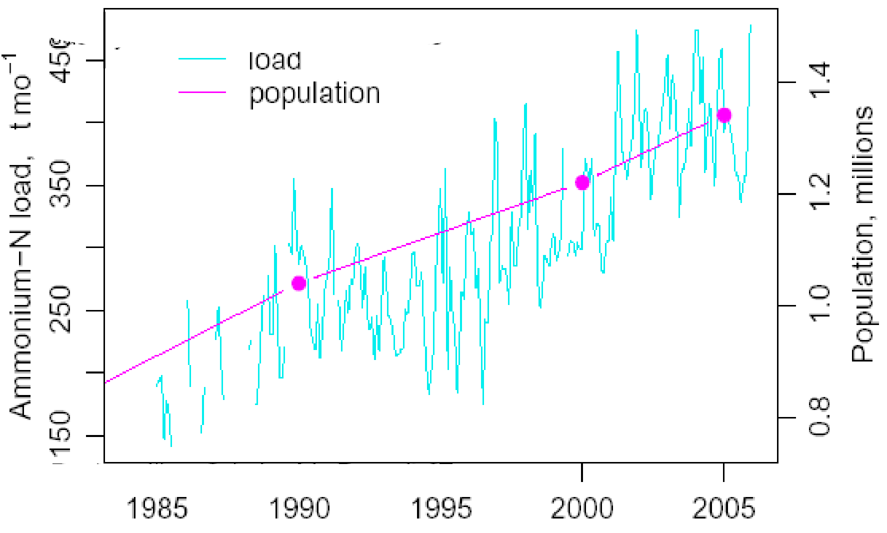


Background: *Long Term Trends in Ammonium and Phytoplankton*

Chl-a decline due to benthic grazing…

but decline predates clams.





Spring blooms in 2000 and 2010 cannot be explained by clams.

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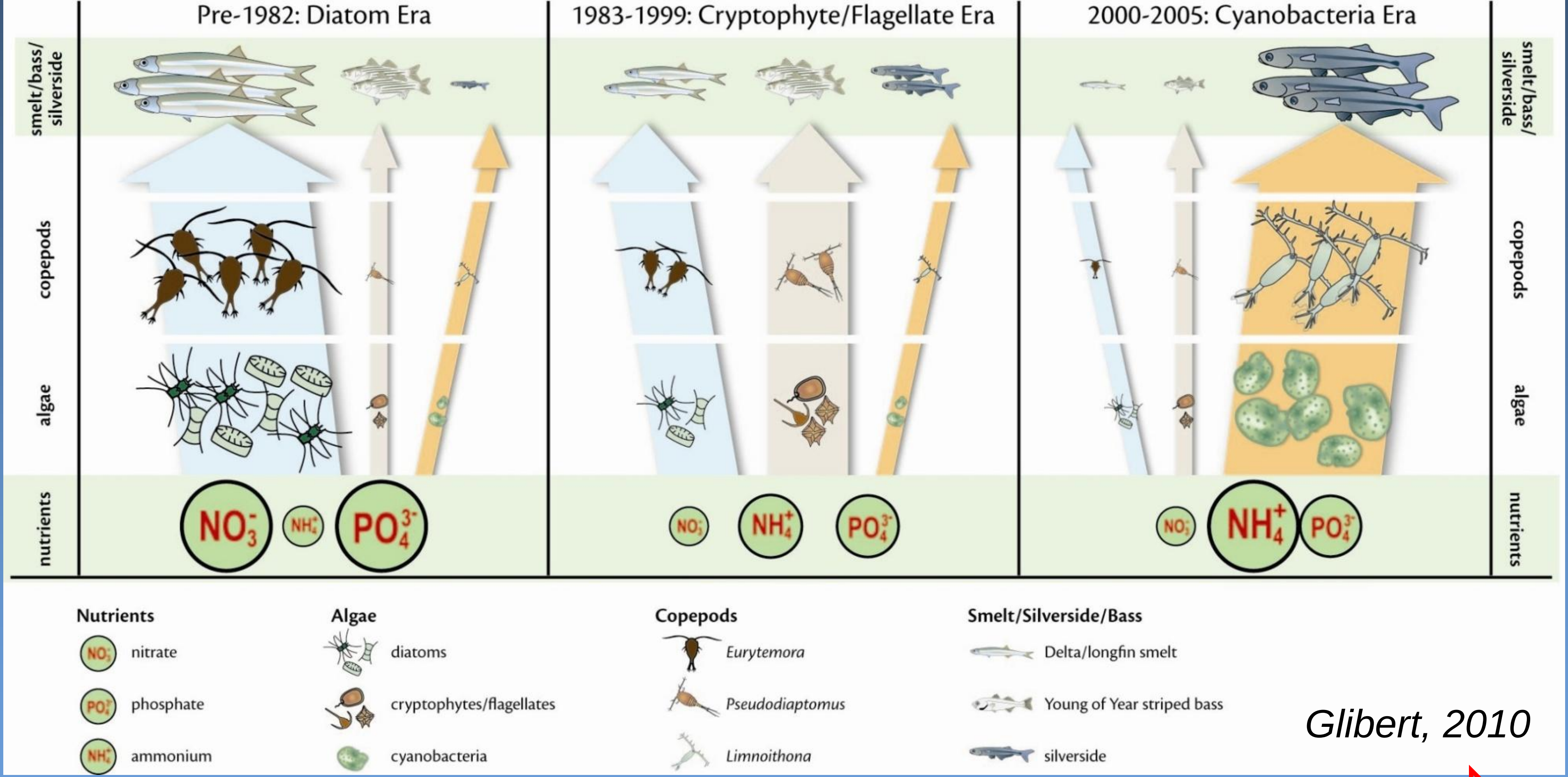
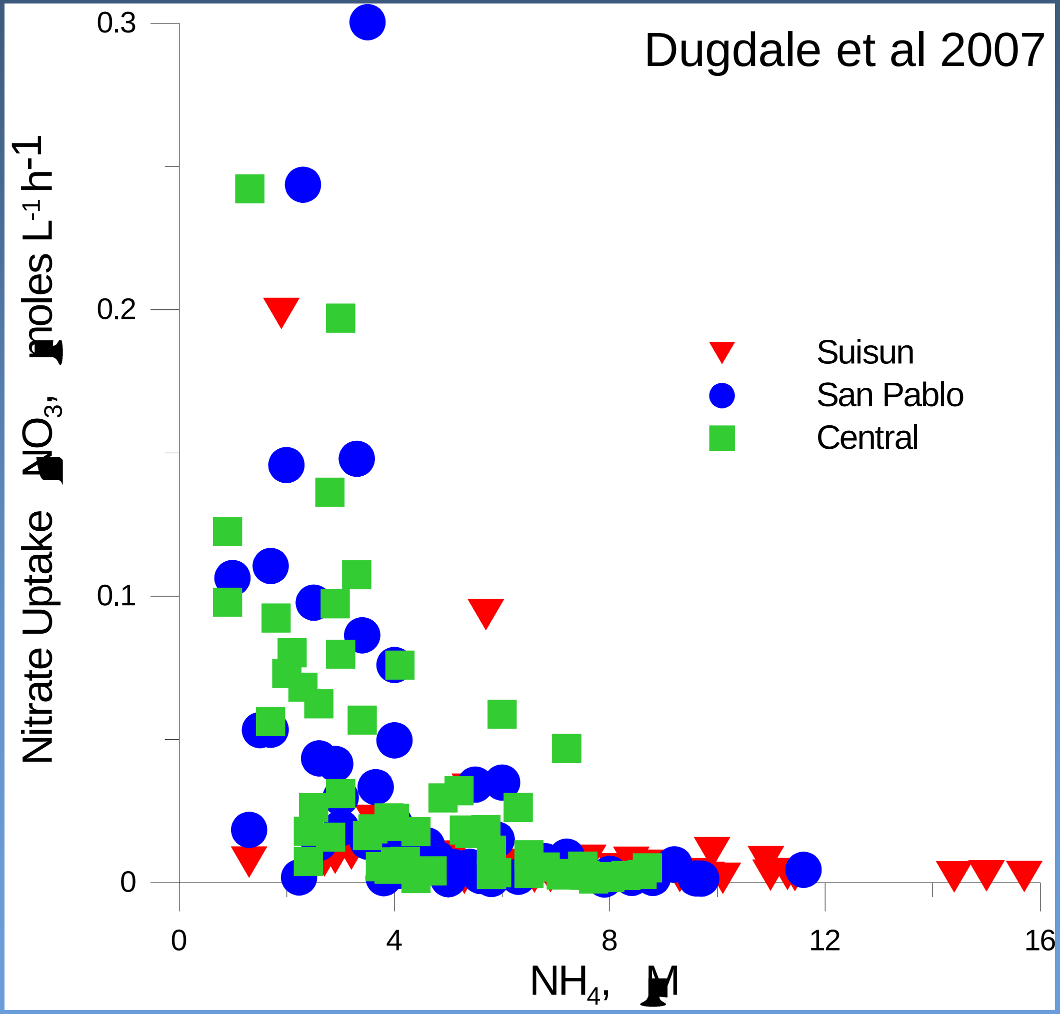
Background: *Nutrients Alter Foodwebs*



Glibert, 2010

Increasing contribution by NH_4

Background: *Ammonium Interferes with Phytoplankton Nitrate Physiology*

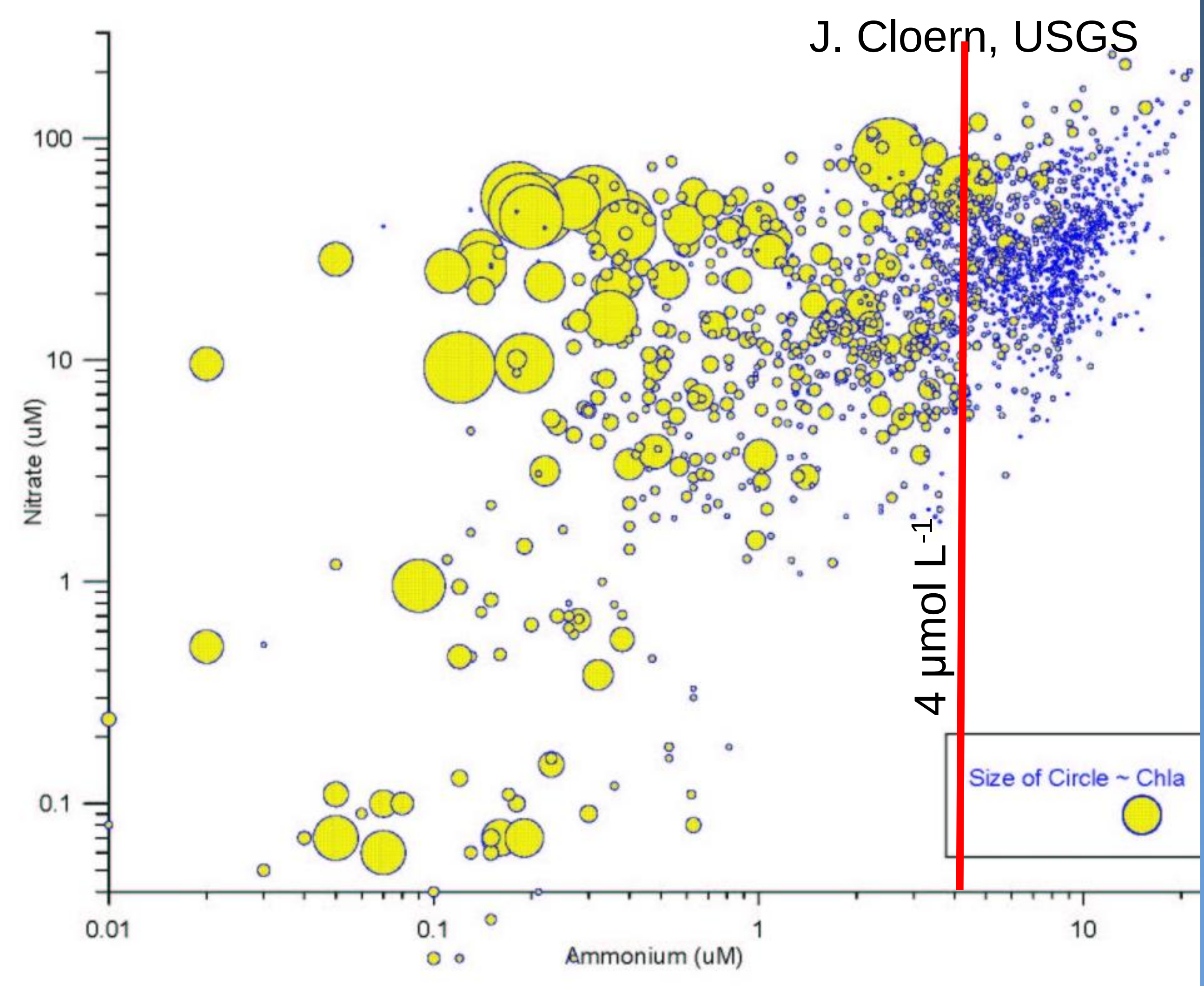


Dugdale et al 2007

NH_4 > 4μmol L^{-1} (0.056 mg L^{-1}) virtually ELIMINATES phytoplankton NO_3 uptake

NH_4 > 1μmol L^{-1} (0.014 mg L^{-1}) substantially REDUCES phytoplankton NO_3 uptake

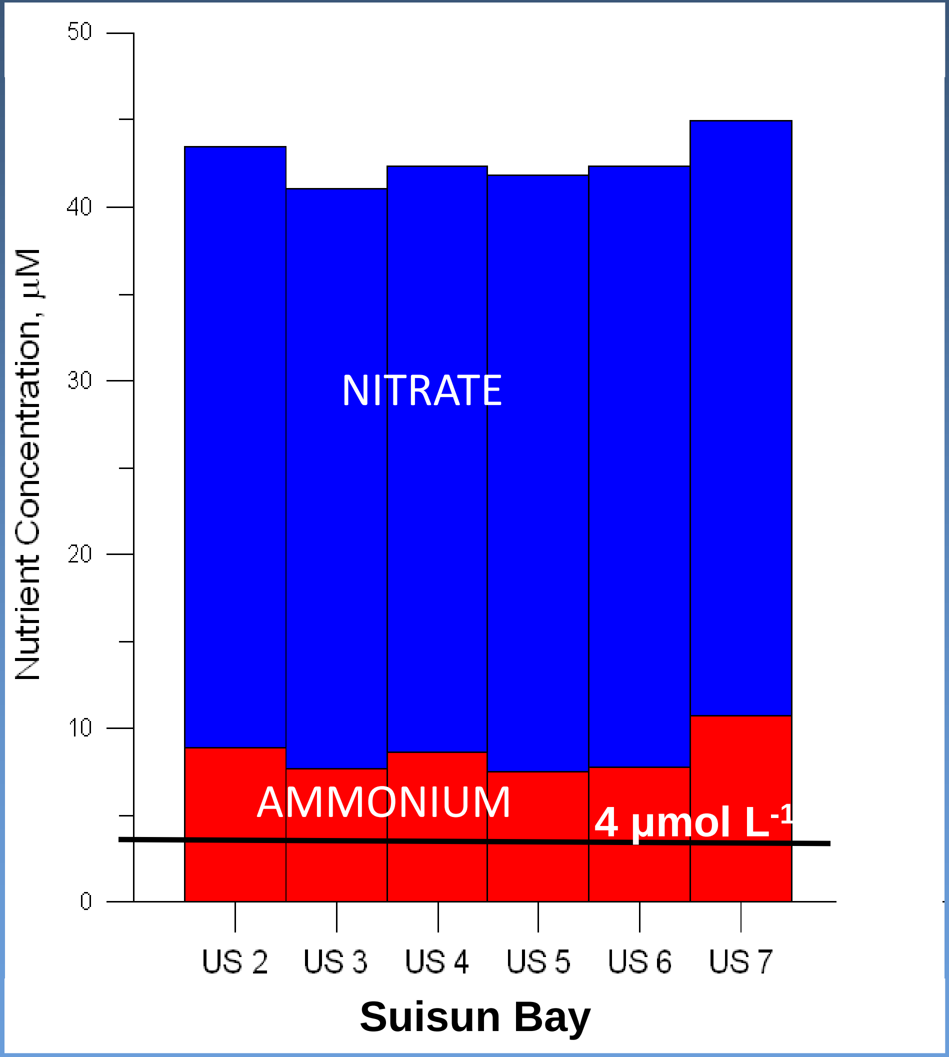
Background: Ammonium Reduces Phytoplankton Biomass



USGS monitoring shows that NH_4 >4µmol L^{-1} is not associated with chl-*a*.

Chl-*a* associated with low NH_4 and high NO_3.

Background: *Ammonium and Nitrate in the SFE*

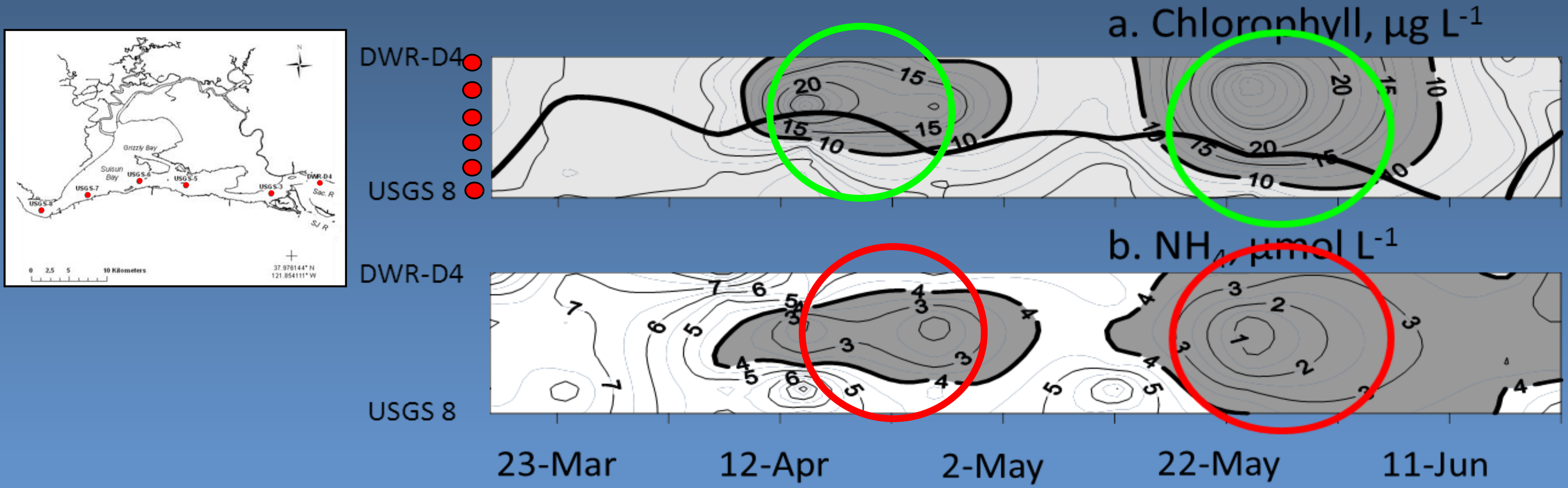


1 µmol N L^{-1} = 1µg chl-*a* L^{-1}

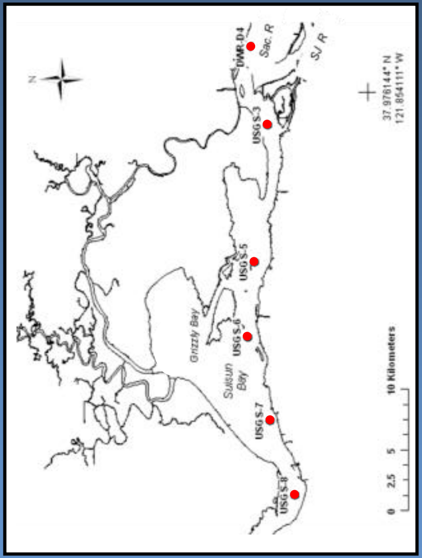
If phytoplankton use all N (e.g. in a culture flask) then the initial N conc. is predictive of the final chl-*a*

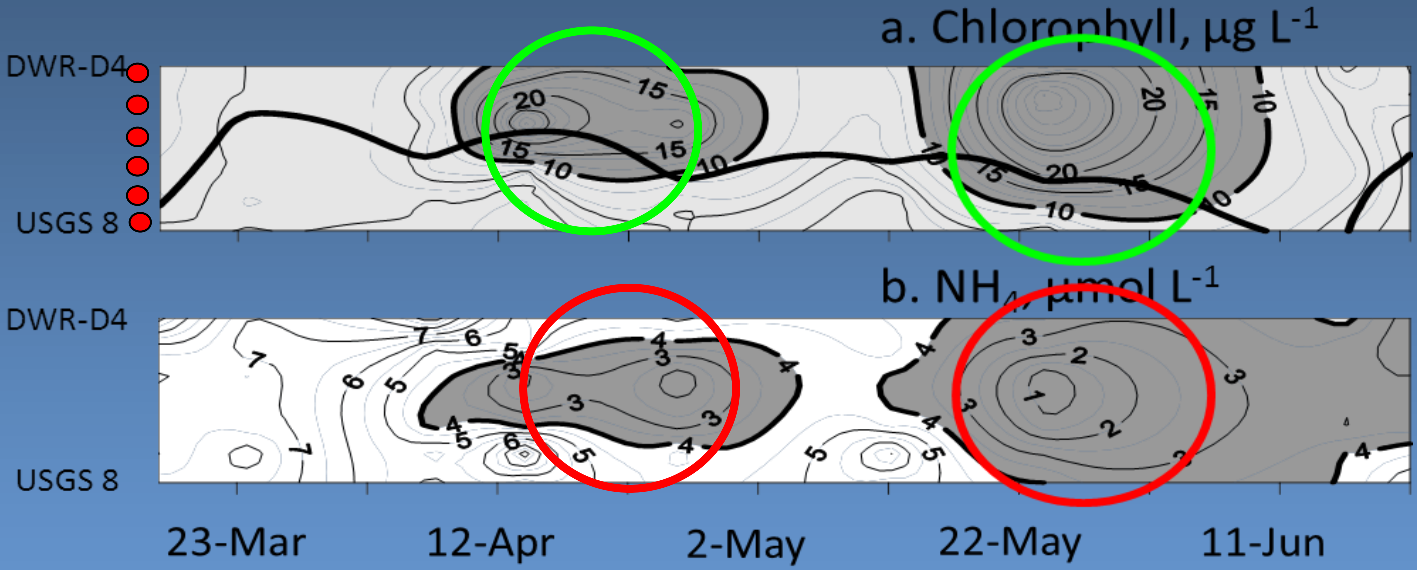
In the northern SFE NO_3 is the largest pool (ca. 75%) of nitrogen. Most N NOT used by phytoplankton

What Can Anomalous Blooms Tell Us About Controls on Phytoplankton Growth?



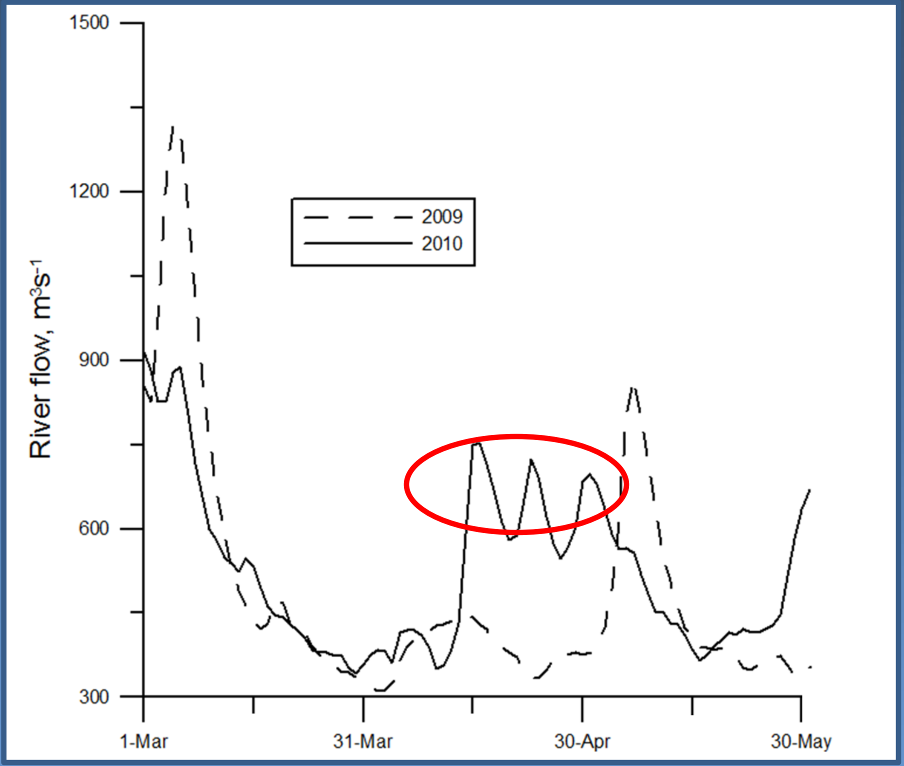
What Can Anomalous Blooms Tell Us About Controls on Phytoplankton Growth?





2010 phytoplankton bloom when $NH_4 < 4$ µmol L^{-1}

2010 vs. 2009: What Contributed to the Lower NH_4 in 2010?



April	Effluent Discharge, tons N d^{-1}
2009	15.54
2010	14.42

Conc. / Washout Criteria

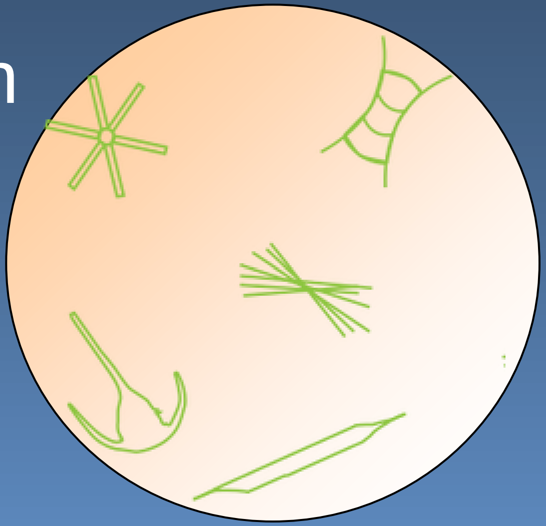
Flow rate 2010 was >50% compared to 2009

Loading Criteria

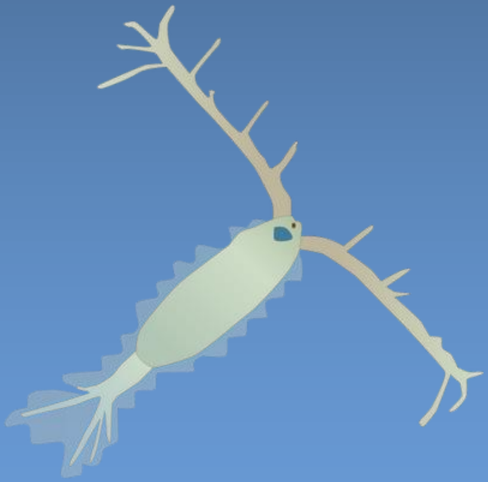
Decreased NH_4 discharge at WWTP in April 2010

Consequences of the 2010 Bloom on the Pelagic Food Web

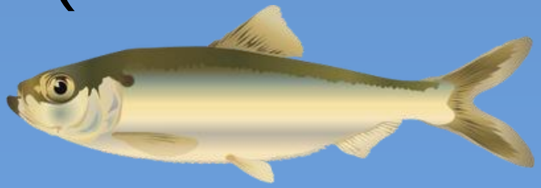
Phytoplankton increase 10-fold.



Zooplankton increase 9-fold over 2009



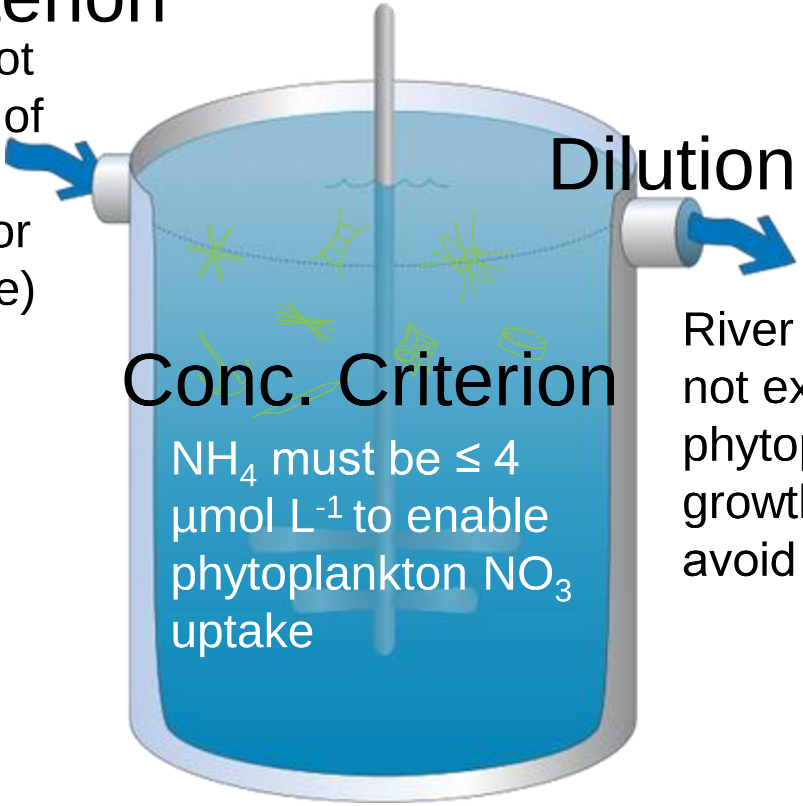
Delta smelt (70%) and longfin smelt (194%) increased (FMWT survey)



River Flow and NH_4 Discharge Control Spring Phytoplankton Blooms in the Northern SFE

Loading Criterion

NH_4 load must not exceed capacity of phytoplankton to assimilate NH_4 (or NH_4. will increase)



Conc. Criterion

NH_4 must be ≤ 4 µmol L^{-1} to enable phytoplankton NO_3 uptake

Dilution Criterion

River flow, must not exceed the phytoplankton growth rate to avoid “washout”.

Criteria Values for Suisun Bay with Present Day NH_4 Loading of 15 tons NH_4-N d^{-1}

1. *Loading Criterion* requires phytoplankton **NH_4 uptake > 1.58 mmol m^{-2} d^{-1} (unlikely) (Suisun uptake rates range from a mean of 0.88 to max of 2.02 mmol m^{-2} d^{-1})**

2. *Concentration Criterion* requires **river flow >825 m^3 s^{-1} (29,000 cfs)**

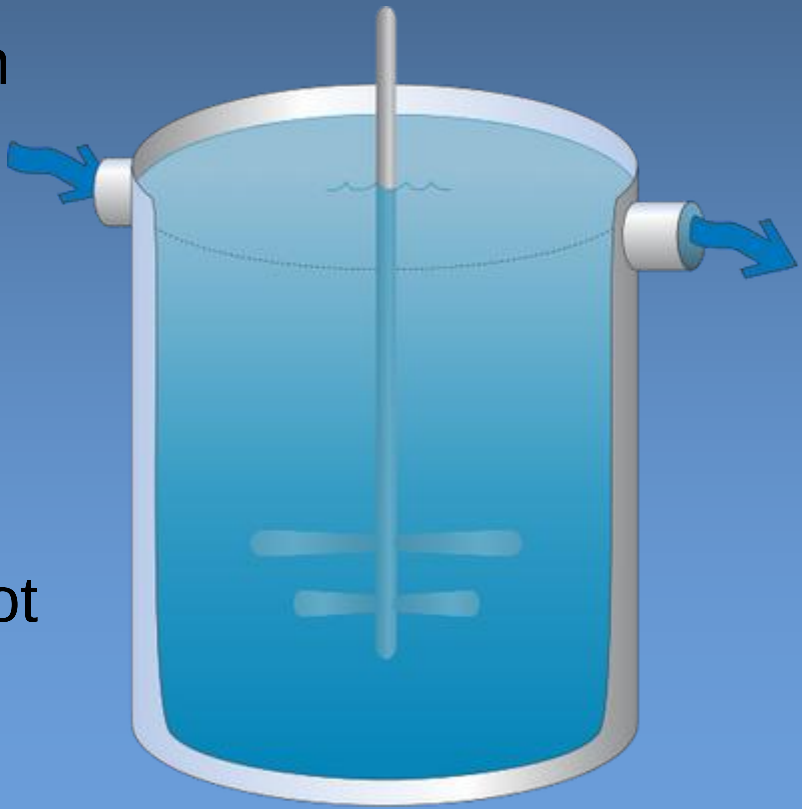
3. *Washout Criterion* requires **river flow at Suisun Bay <1100 m^3 s^{-1} (39,000 cfs)**

What Does this Mean for Managing Nutrients and Flow in the Estuary?

Based on the three criteria, the most effective management action is to ***reduce the NH_4 discharge:***

- This addresses the loading criterion and the concentration criterion (which increases the flow/nutrient "window") and both increase the probability of bloom formation.

- Increasing flow alone will improve ***Concentration Criterion*** but will not influence ***Loading Criterion and will quickly exceed the Washout Criterion***



END

Conclusions

- Salmon
- Delta smelt
- Longfin smelt