Effects of Invasive Species on Native Populations of Aquatic Organisms in the San Francisco Bay-Delta and Freshwater Tributaries: A Review

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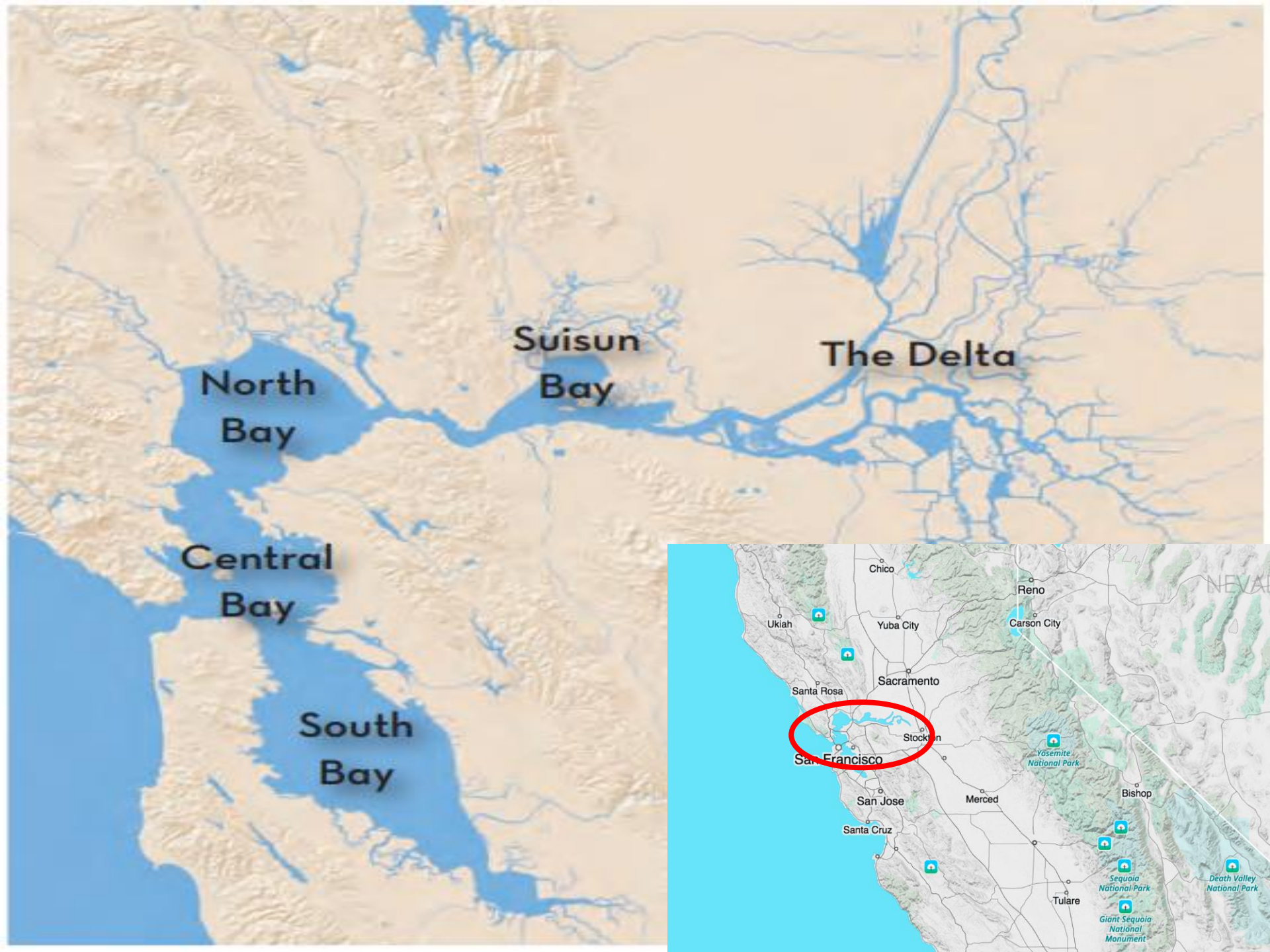
Compliance Services International

International Conference on Aquatic Invasive Species

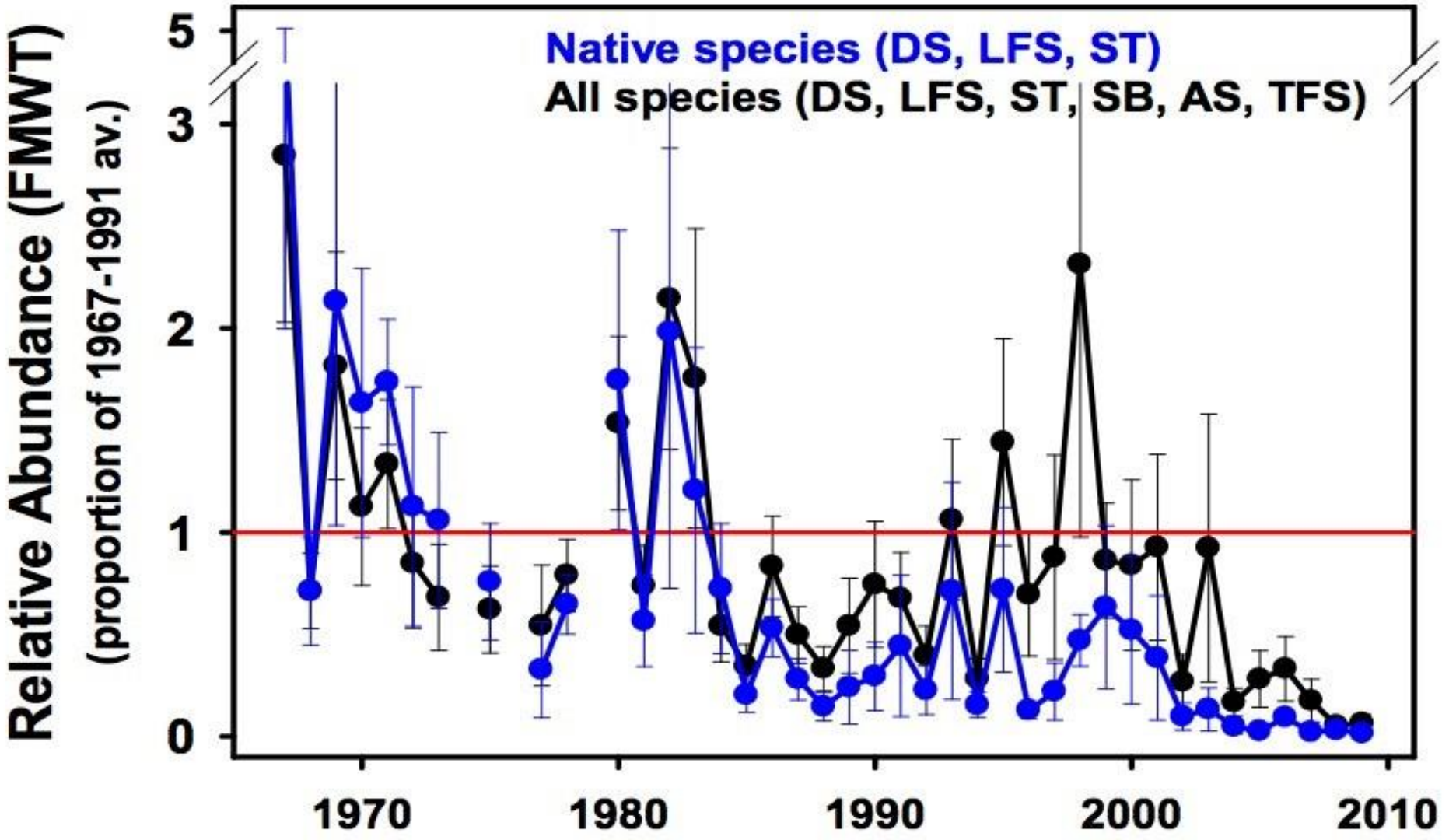

North Bay
Suisun Bay
The Delta
Central Bay
South Bay
Chico
Reno
Ukiah
Yuba City
Carson City
Sacramento
Santa Rosa
Stockton
San Francisco
Yosemite National Park
San Jose
Merced
Bishop
Santa Cruz
Tulare
Sequoia National Park
Death Valley National Park
Giant Sequoia National Monument

San Francisco (SF) Bay-Delta

- Sacramento and San Joaquin Rivers carries runoff from 40% of California's surface area
- One of the largest estuaries in the Western U.S. (1,100 sq. miles)
- Sacramento-San Joaquin watershed: 9 of 10 largest rivers dammed
- State and regional water projects seasonally export 65% of flow
- Supports 7.5 million people via water diversions and agricultural production
- Significant population declines in native aquatic species (including pelagic organisms)

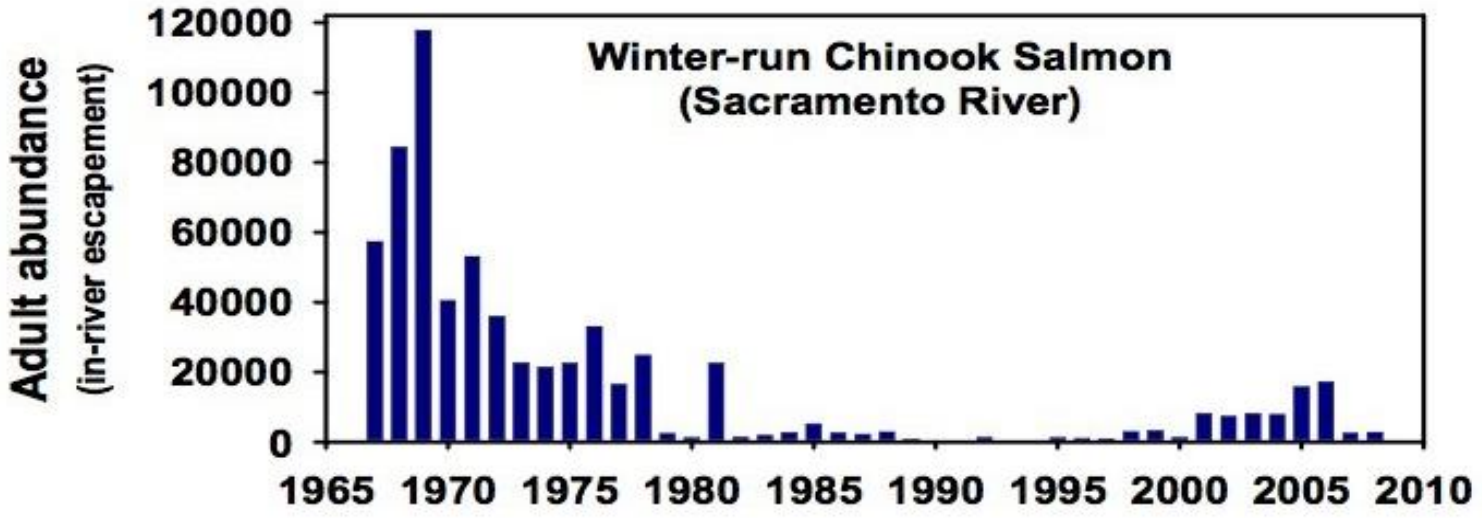
Pelagic Delta fish populations have collapsed

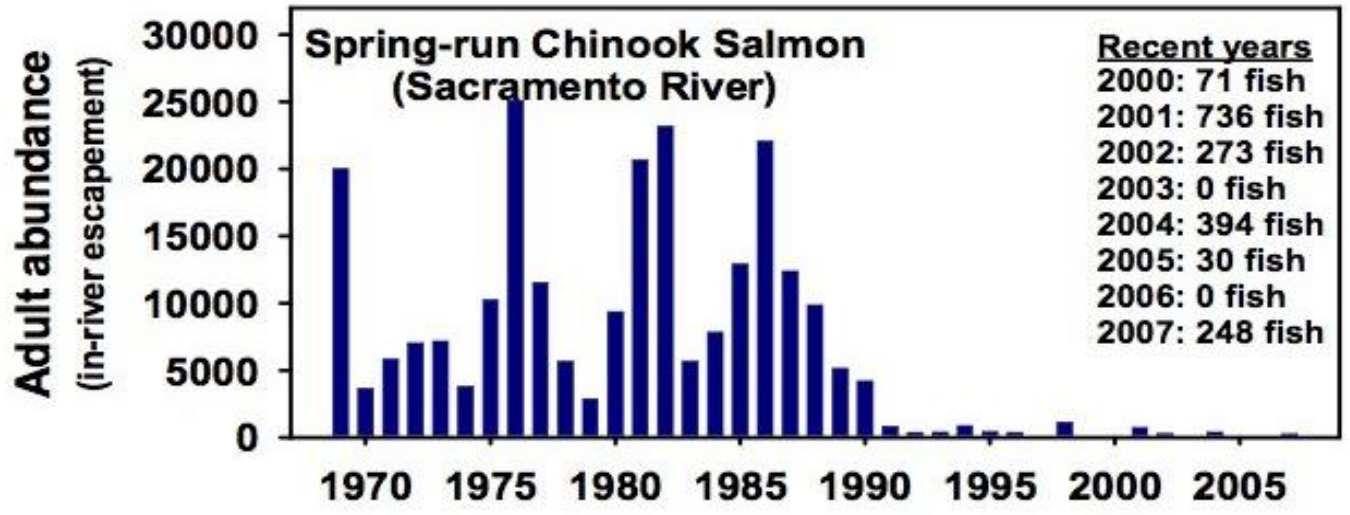
Delta smelt and longfin smelt at high risk of extinction



Bay Institute of San Francisco

Declining Salmon: Sacramento River





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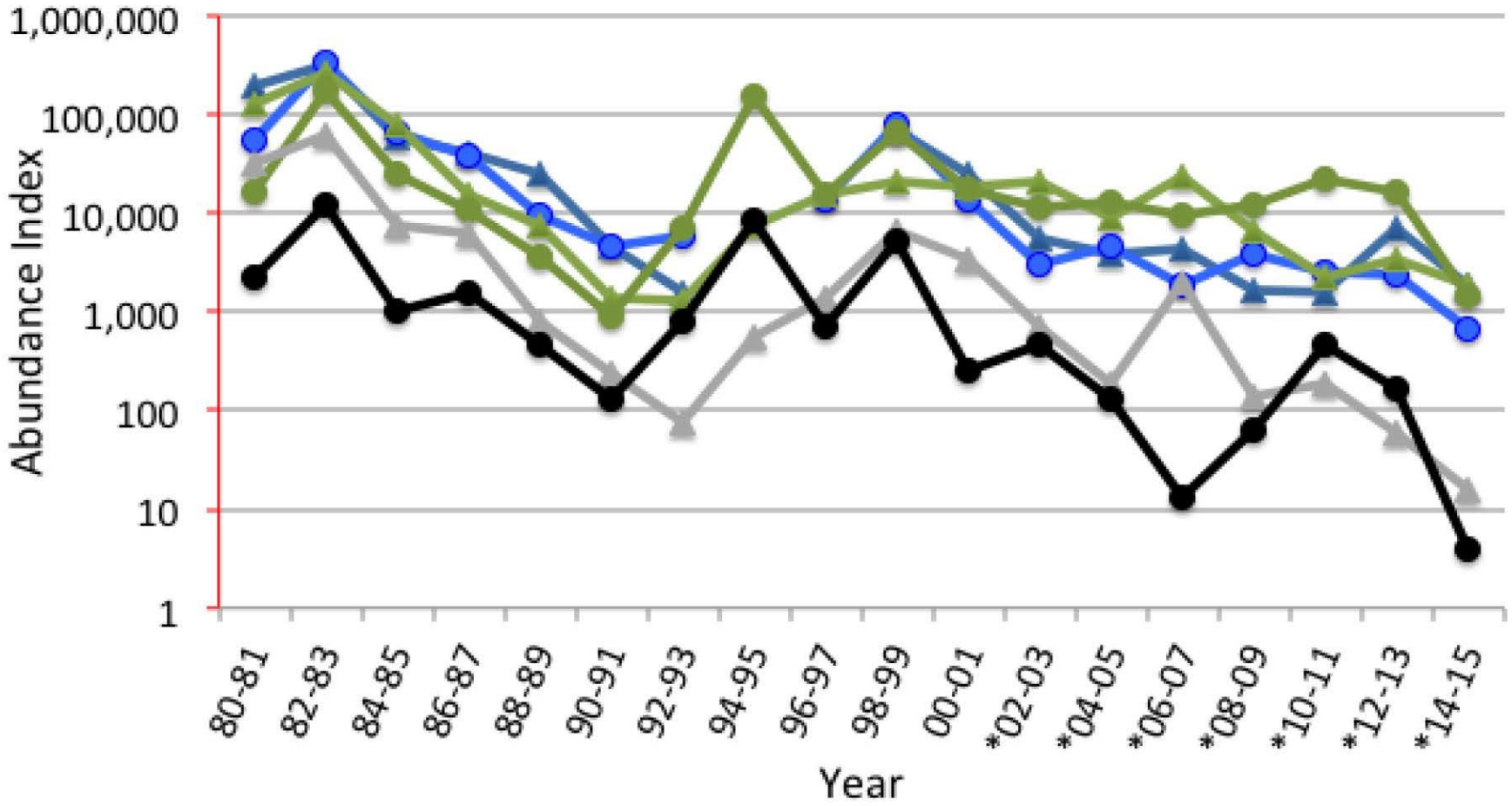
Declining Smelt: SF Bay-Delta



FMWT
>99% decline

Bay Otter Trawl
=96% decline

Bay Midwater Trawl
=98% decline

SF Bay-Delta Invasions

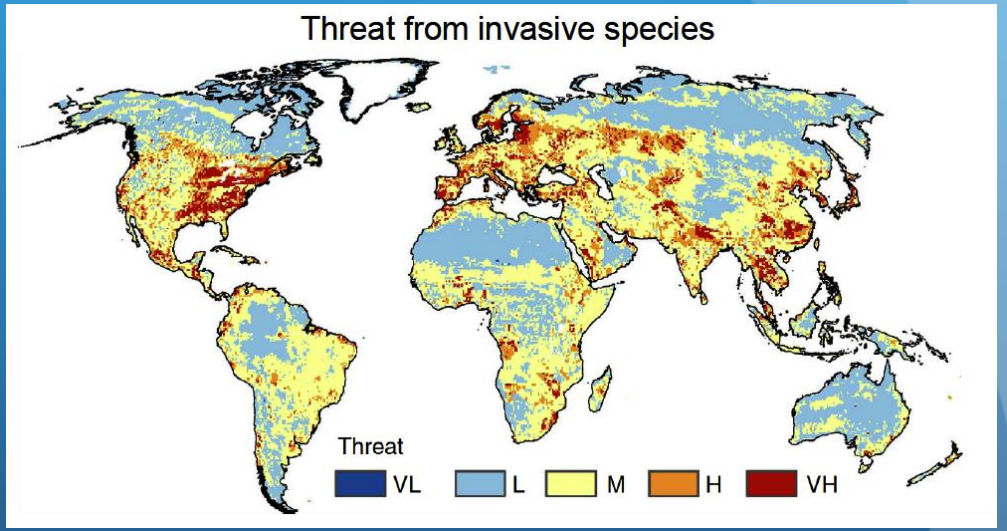
- Estimated that 97% of individuals and 99% of the biomass of some communities are introduced species
- The rate of invasion continues to increase, while a new species was introduced every 14 weeks from 1961 to 1995
- In 1995, there were 212 confirmed introduced species and 123 cryptogenic species, with possibly many more unconfirmed
- Introduced species are present at every trophic level

Asian clams. Photo: Crown Copyright 2009 - GB Non-Native Species Secretariat

Cohen and Carlton 1995

Biological Factors of Successful Invasions

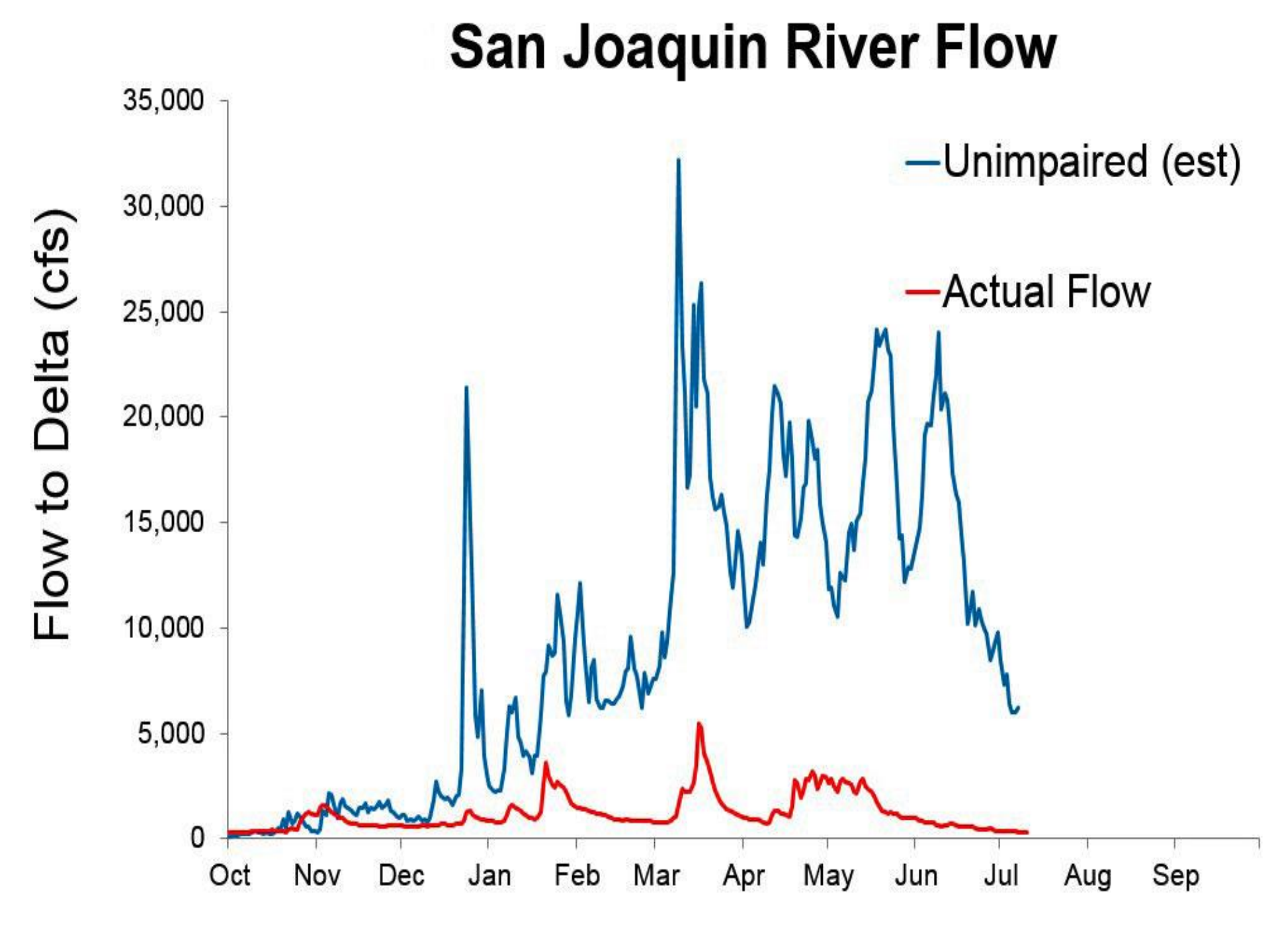
- Habitat disturbances
- Phenotypic plasticity
- Trophic adaptability
- Taxonomic distinctness
- Competition
- Food web dynamics



Invasion Success: Habitat Disturbances

- A highly disturbed aquatic system enables colonization by more species
- Waters that are dammed, diverted, or modified, creating reservoirs and consistent flows are most susceptible to invasions
  - Similar habitat characteristics over broad geographic areas lead to invasions
- Fluctuations in hydrology (flows) and water quality makes it difficult for colonization of invasive species
- Postulated invasion resistance by CA native species related to habitat is attributed to two factors:
  - Introduced fishes cannot adapt to fluctuating water flows
  - Introduced species cannot break established assemblages with strong biotic interactions (resources and space limited)

Moyle and Light 1996; Stachowicz et al. 1999; Moyle 1986; Arthington et al. 1990; Gido and Brown 1990


San Joaquin River Flow
Flow to Delta (cfs)
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
Unimpaired (est)
Actual Flow
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep

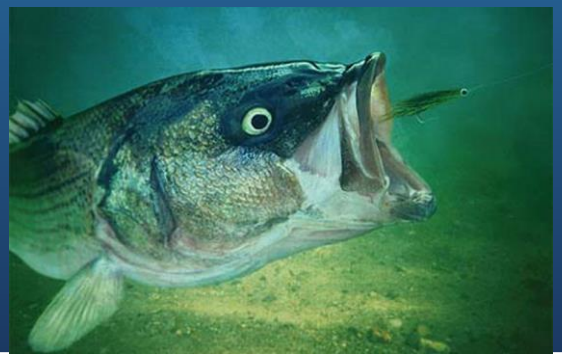
Invasion Success: Phenotypic Plasticity

- Defined: ability to change behavior, life history, or morphology during an individual's lifetime to match changing environment conditions
- Successful invaders can drive the selection of the most adaptive traits of native predators
  - Native predators may change morphologically to be more capable of consuming introduced prey
- Consequence: switching from native to exotic prey can affect growth and body condition
- Invasive species often possess higher phenotypic plasticity than native species

Nussey et al. 2005; Carlsson et al. 2009; Davidson et al. 2011

Invasion Success: Trophic Adaptability

- Defined: ability to change diet depending on food availability
- Example in SF Bay-Delta:
  - Delta smelt and larval striped bass switched to preying on non-native copepods when native species were replaced
  - Consequence: reduced reproductive capacity of young striped bass and smelt



Gerking 1994; Moyle et al. 1992; Meng & Orsi 1993; Kimmerer et al. 2000; Norbriga & Feyrer 2008

Invasion Success: Taxonomic Distinctness

- Defined: a measure of functional diversity (niche/role in community)
  - Species with similar life history characteristics considered functionally equivalent
- Invasive species that are taxonomically distinct may be more successful
  - Less likely to encounter prey or predators adapted to them
- Impact of invasive species in communities can be explained by prior experience with functionally similar species
- Introduced prey that are taxonomically distinct have characteristics that enables them to overcome defenses adapted for native predators

Ricciardi & Atkinson 2004; Diamond & Case 1986; Agrawal & Kotanen 2003

Invasion Success: Competition

- A competitive advantage of an introduced species may lead to its establishment
  - Ex. Resource extraction efficiency
- Key attributes in competition that determine success:
  - Broad physiological tolerances to environmental conditions
  - Broad feeding habits
  - Diverse life history traits
- Example in SF Bay-Delta:
  - Japanese mud snail has outcompeted the California horn snail due to more proficient resource conversion efficiency

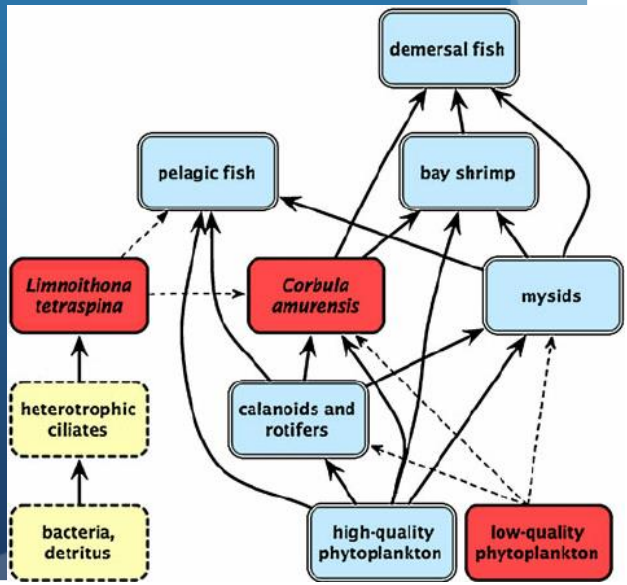
Herbold & Moyle 1986; Byers 2000; Arthington & Mitchell, 1986; Bruton, 1986; Lodge, 1993; Williamson & Fitter, 1996; Ricciardi & Rasmussen, 1998; Rosecchi, Thomas & Crivelli, 2001; Koehn, 2004


Japanese mud snail


CA horn snail

Invasion Effects on Food Web Dynamics

- Arrival of new aquatic organisms may alter interactions among trophic levels, resulting in changes in biological structure and health
- Examples (2) in SF Bay-Delta:
  - Microcystis aeruginosa
    - Consumption while foraging result in lethal and sublethal effects to fish and birds
    - Outcompete phytoplankton
  - Replacement of native copepods and mysids
    - Changes in nutritional value of prey
    - Changes in zooplankton biomass
    - Poor growth and survival of native predators not equipped to feed upon introduced species (delta smelt, threadfin shad, etc…)



Winder and Jassby 2011; Lehman & Waller 2003; Carmichael 1995; Lehman et al. 2005; Winder & Jassby 2011; Moyle 2002; Kimmerer 2006

Transformation of an Estuary: Overbite Clam (*Corbula amurensis*)

A Case Review

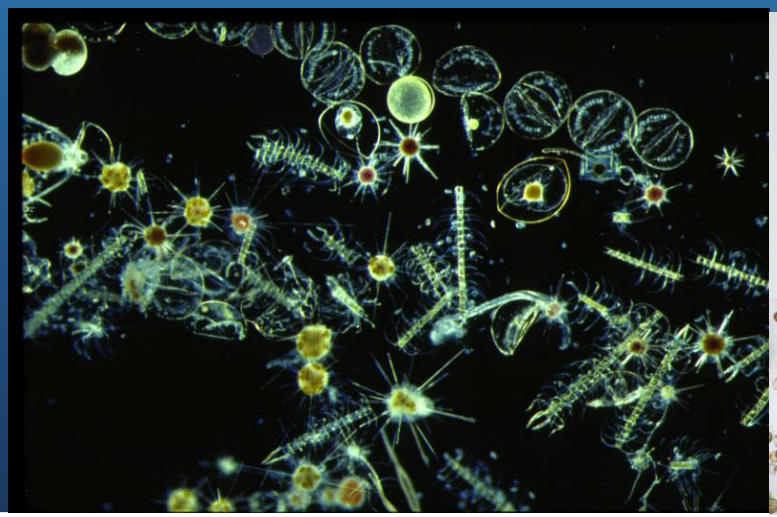
Overbite Clam

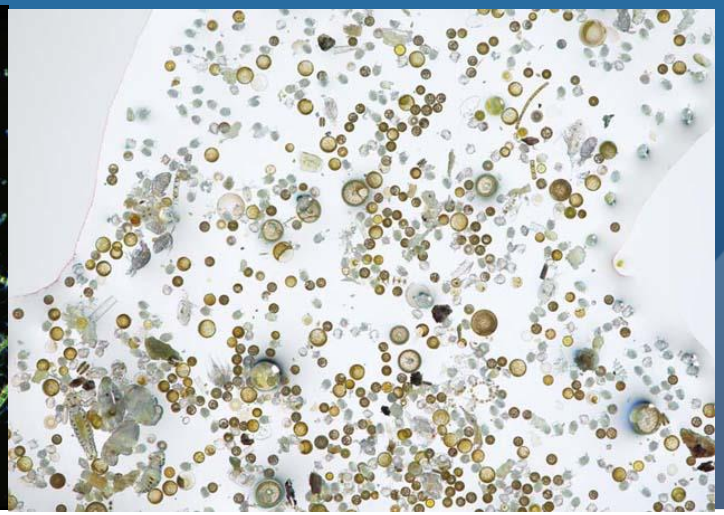
- Discovered in 1986
- Native to rivers and estuaries in East Asia
- Introduced via ship ballast water
- Tolerant to wide range of salinities and varied diet
- 1988 SF Bay: dominant organism in benthic community
  - Comprised 95% of total abundance and biomass
  - 16,000 individuals per square meter

Carlton et al. 1990; Nichols et al. 1990; Chauvaud et al. 2003; Nicolini and Penry 2000

Overbite Clam: A Trophic Cascade

- Phytoplankton:
  - Overbite clam filtration rate is about twice the growth rate of phytoplankton
  - Phytoplankton declined and shifted from diatom-based community to chlorophytes, flagellates, and cyanobacteria
  - Following colonization, mean phytoplankton biomass declined from >20 to <2 mg/m^3 chlorophyll a
  - Food limitations to higher trophic levels (i.e. zooplankton)





Lehman 2000; Apline and Cloern 1992; Jassby et al. 2002; Thompson 2005; Orsi & Mecum 1996; Kimmerer 2006

Overbite Clam: A Trophic Cascade

- Zooplankton
  - Reductions in phytoplankton biomass have been followed by a decline in zooplankton, including native copepods and mysids
  - The zooplankton community has moved from one dominated by mysids, rotifers, and calanoid copepods to one dominated by non-native copepods
  - 1970s to 1990s, average biomass change:
    - Calanoid copepods: 14 to 4 µg/L carbon
    - Rotifers: 10 to 1 µg/L carbon
    - Cladocerans: 1.2 to 0.2 µg/L carbon

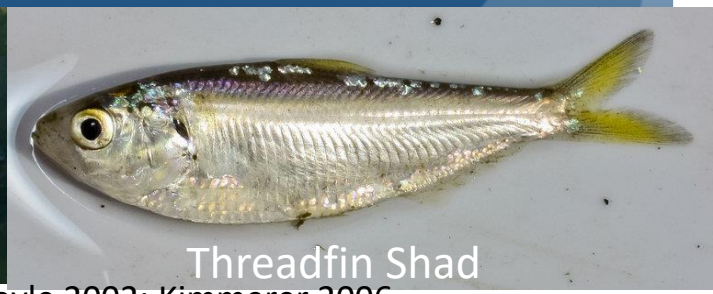
Winder & Jassby 2012; Orsi & Mecum 1996; Kimmerer 2006

Overbite Clam: A Trophic Cascade

- Fish
  - Several SF Bay-Delta fish (smelt, salmonids, shad) depend on copepods, mysids, cladocerans, and insect larvae
  - Loss of zooplankton and replacement of native species with introduced species has led to changes in prey abundance and nutritional content leading to reduced growth and survival
  - Long-term fish declines have coincided with declines in phytoplankton and zooplankton production
- Cascade eventually affects terrestrial organisms dependent on aquatic species


Delta Smelt

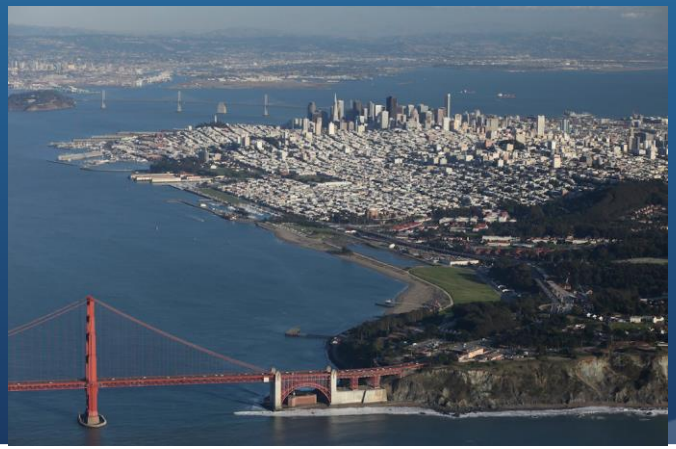

Chinook Salmon


Threadfin Shad

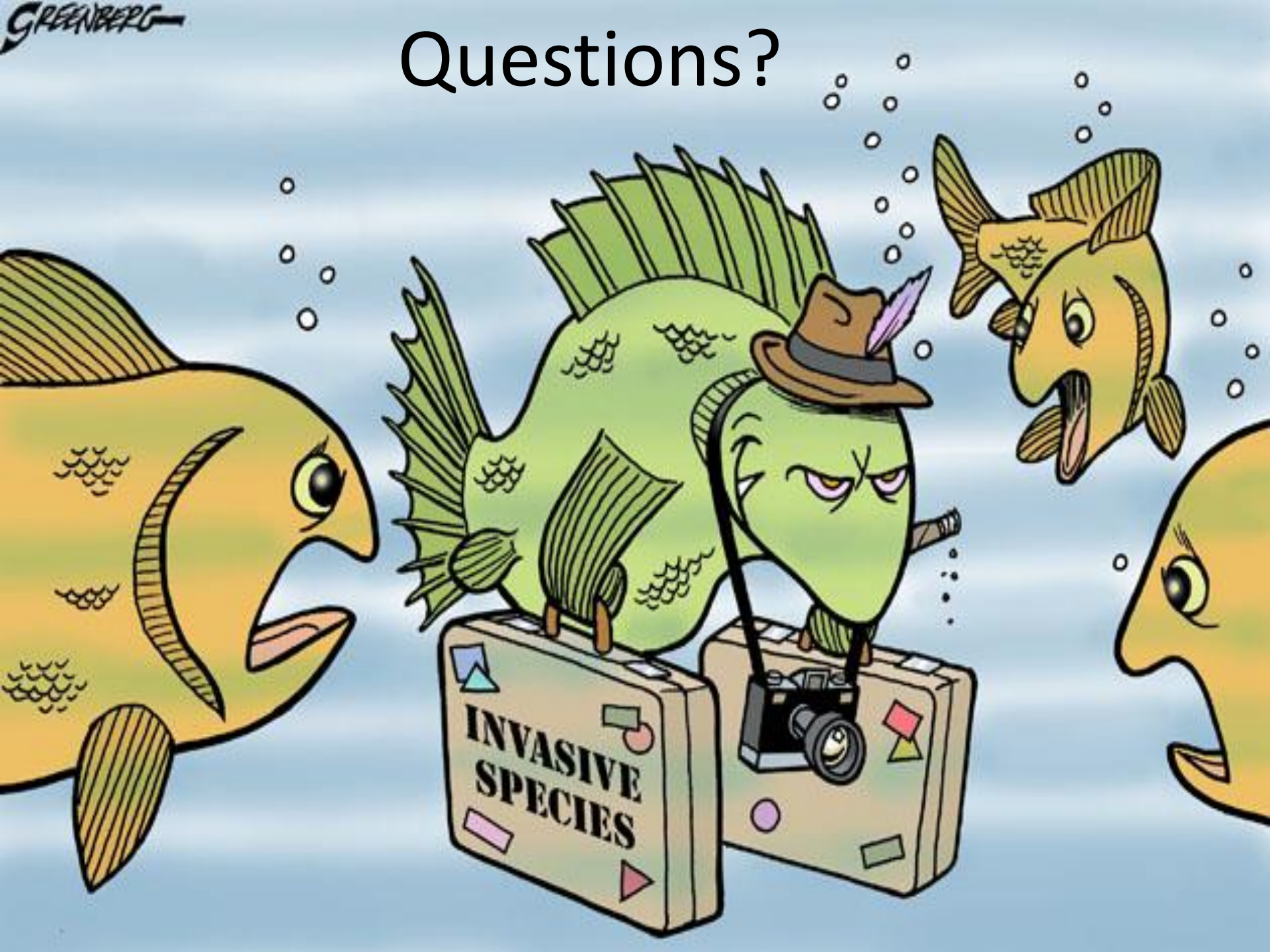
Nobriga 2002; Kjelson & Raquel 1982; Hobbs et al. 2006; Moyle et al. 1992; Moyle 2002; Kimmerer 2006

Conclusions

- SF Bay-Delta is highly modified from natural state
- Native species have innate defenses against invasive species, albeit with limited capacity
- Homogenization of the environment and habitat disturbances increase invasion success
- Invasive species are a significant cause of pelagic organism decline in SF Bay-Delta

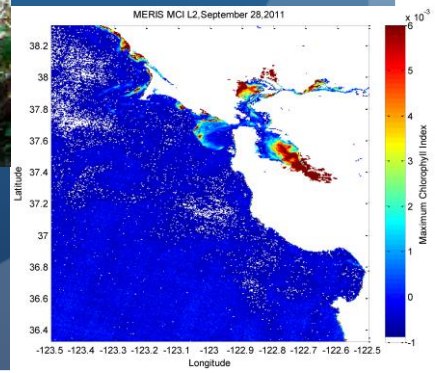


Questions?



Factors in SF Bay-Delta Species Declines

- **Invasive species**
- Hydrology
- Diversions
- Dams
- Habitat modification
- Harvesting
- Harmful algal blooms
- Toxicants
- Climate change (drought, water quality)



Cohen and Carlton 1995

Sources of Invasive Species

- Several anthropogenic vectors:
  - Ballast water and solid waste
  - Hull fouling
  - Intentional release for stock enhancements
  - Aquaculture systems
  - Discarded fishing gear, packing materials, & plastic debris
  - Release of transgenic species
  - Movement of species through dam locks
  - Accidental or intentional release
  - Snorkeling and scuba gear

Carlton 2001