The Decline of Pelagic Fishes in the San Francisco Estuary: An Update

Dr. Ted Sommer

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IEP Pelagic Organism Decline Management Team
POD Management Team

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# POD Principal Investigators

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- **US Bureau of Reclamation**
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- **US Fish and Wildlife Service**
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- **US Geological Survey**
  - Joseph Simi, Cathy Ruhl, Pete Smith

- **UC Davis**
  - Bill Bennett, Swee Teh, Inge Werner, David Ostrach, Frank Loge

- **SF State University**
  - Wim Kimmerer, John Durand

- **SF Estuary Institute**
  - Daniel Oros, Geoff Siemering, Jennifer Hayworth

- **Consultant**
  - Bryan Manly, BJ Miller
Inshore Habitat  Pelagic Habitat

Figure from L. Grimaldo
Abundance Levels Are Highly Variable

Source: Kimmerer and Nobriga (2005); Sommer et al. (In Review)
The Pelagic Organism Decline

Source: Kimmerer and Nobriga (2005); Sommer et al. (In Review)
Historically Flow Has Helped Predict Fish Abundance

Adapted from Kimmerer (2002)

longfin smelt

$\log \text{abundance}$ vs. $\log \text{outflow}$

$r^2 = 0.765$

striped bass

$\log \text{abundance}$ vs. $\log \text{outflow}$

$r^2 = 0.463$
Invasive Species Shifted These Relationships

Adapted from Kimmerer (2002)

Log abundance vs. Log outflow for longfin smelt and striped bass. The graph shows a positive correlation for longfin smelt with $r^2 = 0.639$ and a non-significant correlation for striped bass (Not sig.).
POD Has Further Shifted Abundance-Outflow Relationships

Adapted from Kimmerer (2002)
POD: What We Know Now

Caveats

- Synthesis is from POD MT, not all PIs.
POD: What We Know Now

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- Synthesis is from POD MT, not all PIs.
- New results = unpolished story.
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*Caveats*

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- New results = unpolished story.
- The story will change...probably a lot.
- Most results have not been written up.
- Very few results have been peer-reviewed.
- The management implications of this effort are therefore unclear.
FISH ABUNDANCE

PHYSICAL & CHEMICAL FISH HABITAT

TOP-DOWN

LOSS

PARENTS

Prior Fish Abundance

FISH ABUNDANCE

FOOD

BOTTOM-UP

HOME

FOOD
The ‘Big Three’ Questions

• Did anything change at the same time as the Pelagic Organism Decline?

• How and why did these factors change?

• Did these factors affect populations of pelagic organisms?
## Quick Answers

<table>
<thead>
<tr>
<th></th>
<th>Change with POD?</th>
<th>Mechanism?</th>
<th>Population Impact?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stock</td>
<td>Yes</td>
<td>????</td>
<td>Yes</td>
</tr>
<tr>
<td>Habitat</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Food</td>
<td>Some</td>
<td>Some</td>
<td>Yes</td>
</tr>
<tr>
<td>Mortality</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>
Prior Abundance → Present Abundance
Stock - Recruitment Effects

• Extremely low stocks
Stock - Recruitment Effects

- Extremely low stocks.
- Environmental variables strongly affect recruitment
FISH ABUNDANCE

PHYSICAL & CHEMICAL FISH HABITAT

Temperature
Turbidity
Salinity
Contaminants
Disease
Toxic algae
Fall “habitat quality” has deteriorated

Source: Feyrer et al. (CJFAS, In press)
Fall “habitat quality” has deteriorated

Fall EQ + Fall Abundance predicts juvenile production
Fall habitat quality decreased as salinity intruded.

Source: Feyrer et al. (In press)
Summer habitat changes affect regional delta smelt catches.

Source: Nobriga et al. (In review)
Salinity variation also affects clams

Source: Marc Vaysierres and others (DWR)
Other habitat stressors

- Bioassays showed little effect (<5 %) in 2005 or 2006.
- <15% adult delta smelt impaired
- 100 % of young striped bass show multiple infections

Source: Inge Werner, Swee Teh, and Dave Ostrach (UCD)
TOP-DOWN

FISH ABUNDANCE
TOP-DOWN

Water Diversions  Predation

FISH ABUNDANCE
Winter Salvage of Delta Smelt (Nov-Mar)

Source: IEP (2005)
Increased winter exports

Low San Joaquin River flow

Source: Simi and others (USGS)
Increased winter exports  

Low San Joaquin River flow

**Entrainment**
Increase in winter salvage.
Negative Old & Middle River Flows Apparently Increase Adult Delta Smelt Entrainment

\[ y = -4 \times 10^{-05}x + 0.7265 \]

\[ R^2 = 0.309 \]

0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8

\(-10000\)
\(-5000\)
0
5000
10000
15000

Delta Smelt
SWP & CVP Salvage (log count)

Combined Old & Middle River Flow (cfs)

\[ r^2 = 0.31, \ p<0.05 \]

Mean Values for December-March
1993-2005

Source: Adapted from Pete Smith (USGS)
Negative Old & Middle River Flows Seem to Have Similar Effects on Striped Bass & Longfin Smelt Entrainment

Mean Values for indicated periods
1993-2005

Source: L. Grimaldo, DWR
Fall delta smelt index

Summer delta smelt index

Old & Middle River flows

In Log-Linear Modeling Over 1981-2004, Monthly or Semi-Monthly Exports or O&M River Flows Individually Explain No More Than 1.5% Of The Variation In Fall Catches

Source: Bryan Manly and Mike Chotkowski (USBR)
Bennett Hypothesis:  
*Not All Smelt Are Created Equal*

Larger/older females:
- Have higher fecundity.
- Spawn early and repeatedly.
- Produce larger offspring that have higher fitness.
- Are more subject to water project effects.
Evidence of Fish Predation Effects

Log (threadfin shad mortality)

Only POD year

Log (striped bass abundance)
There Also May Be Substantial Inshore Predation for Some Species
FISH ABUNDANCE

Food availability

Food quality

BOTTOM-UP

Food availability

Food quality

FISH ABUNDANCE
Phytoplankton

- Chlorophyll levels very low compared to other estuaries
- Long term declines, especially in Suisun Bay
- But: No evidence of a recent decline in the Delta

Zooplankton (fish food species)

- Long term declines throughout the system
- Recent declines in Suisun Bay
- “Waves” of species invasions
Phytoplankton Primary Production

... is related to Fisheries Yields in many Marine Systems (Nixon 1988)

Fisheries Yield = 0.011 * Phytoplankton Production^{1.55}
Phytoplankton Primary Production

... in Estuaries is typically very HIGH
Phytoplankton Primary Production

... in Estuaries is typically very HIGH

Source: S. Nixon, 1988
Phytoplankton Primary Production

... in the Delta & Suisun Bay is usually very LOW

Sources: A. Jassby (UCD), J. Cloern (USGS), IEP data
Phytoplankton Primary Production

... in the Delta & Suisun Bay is usually very LOW

... and has DECLINED since the 1970s

1970s: ~100 g m⁻² yr⁻¹

1990s: <50 g m⁻² yr⁻¹

Sources: A. Jassby (UCD), J. Cloern (USGS), IEP data
Phytoplankton Primary Production

... CRASHED in Suisun Bay right after the 1987 *Corbula* invasion

Source: J. Cloern (USGS), IEP data
Phytoplankton Primary Production

... CRASHED in Suisun Bay right after the Corbula invasion

Sources: A. Jassby (UCD), J. Cloern (USGS), IEP data
BUT:
Phytoplankton Primary Production

... during the POD years is slightly up in the Delta & Suisun Bay.

Sources: A. Jassby (UCD), J. Cloern (USGS), IEP data
Phytoplankton Primary Production

... during the POD years is slightly UP in the Delta & Suisun Bay.

Quality???

Sources: A. Jassby (UCD), J. Cloern (USGS), IEP data
Zooplankton: Waves of Invasions and Declines

Example: Chipps Island
Zooplankton Species Invade in “Waves”

Adult copepods at Chipps Island, yearly averages with 5-year moving average lines

Source: A. Mueller-Solger (DWR), IEP data
Zooplankton Species Invade in "Waves"

Adult copepods at Chipps Island, yearly averages with 5-year moving average lines
Zooplankton species invade in “Waves”

Adult copepods at Chipps Island, yearly averages with 5-year moving average lines.
Zooplankton Species Invade in “Waves”

Calanoid Copepods (CB net count/m³)

- 18??: Eurytemora affinis
- 1978: Sinocalanus doerri
- 1988: Pseudodiaptomus forbesi
- 1993/1994: Acartiella sinensis

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Limnoithona tetraspina

Calanoid Copepods (CB net count/m³)
Limnoithona tetraspina (Pump count/m³)
Zooplankton Species Invade in "Waves"

Adult copepods at Chipps Island, yearly averages with 5-year moving average lines.

Good Fish Food

LOW!!! LOW!!!

Zooplankton Species Invade in "Waves"
Zooplankton Species Invade in “Waves”

Adult copepods at Chipps Island, yearly averages with 5-year moving average lines

High!!!
Important Fish Food Species have Declined

**Eurytemora affinis** declined at almost all IEP stations

**Pseudodiaptomus forbesi** declined in Suisun Bay & the Confluence

Trends significant at $p<0.05$, *Seasonal Kendall Test*

Source: A. Mueller-Solger, DWR
P. forbesi & E. affinis Abundance in Suisun Bay is Affected by Upstream Subsidies and Clam Grazing

Corbula amurensis

P. forbesi

Suisun Bay

Sacramento River

San Joaquin River

Adapted from John Durand (SFSU)
P. forbesi & E. affinis Abundance in Suisun Bay is Affected by Upstream Subsidies and Clam Grazing

Adapted from John Durand (SFSU)
Overlap with Food Species Helps Predict Adult Delta Smelt Recruitment

Source: BJ Miller
Reduced Food Availability Affects Abundance-Outflow Relationships

Adapted from Kimmerer (2002)
Fish Abundance

Physical & Chemical Fish Habitat

Temperature
Turbidity
Salinity
Contaminants
Disease
Toxic algae

Prior Fish Abundance

Fish Abundance

TOP-DOWN

Water Diversions
Predation

Food availability
Food quality

BOTTOM-UP
Summer

- Reduced Food in LSZ
- Increased Predation Loss (?)
- Clams and Limnoithona
- Improved Survival
- Late Growth Start

Fall

- Reduced Outflow
- Reduced Habitat Area
- Reduced Size & Egg Supply
- High Entrainment of Adults and Early Larvae
- Decreased Number Survive to 2 Years Old

Spring

- VAMP

Winter

- Jan-Mar Exports
**Summer**
- Reduced Food in LSZ
- Increased Intra-Specific Competition/Predation
- Impaired Offspring

**Fall**
- Reduced Habitat Area
- Disease/Intersex/Lesions

**Winter**
- Ocean Conditions
- Disease

**High Variability in Annual Survival**
- Only Largest And Healthiest Survive First Winter
- Increased Entrainment

**Reduced Outflow**
- Seasonal Food
- Winter Exports

**Clams and Limnoithona**
- Maternal Contaminants
Summer

Water Quantity
Food Supply
Salvage

Reduced Survival From Larvae To Young-Of-Year

Fall

Food Supply?
Water Quality?

Survival of Young-Of-Year to Age-2+

Spring

Reduced Larval Abundance

Winter

Water Quantity
Salvage
Predator Abundance?

High Entrainment Loss of Adults and Larvae

Dec-Mar Exports

Stock-recruit?
Summer

Reduced Survival From Larvae To Young-Of-Year

Food Supply? Water Quality? Salvage?

Reduced Larval Abundance

Spring

Fall

Poor Survival of Young-Of-Year to Age-0

Food Supply? Water Quality? Salvage?

Winter

Adult Mortality

Stock-recruit?

Predator Abundance Salvage?

Food Supply
2006-2007 POD Studies

- 2006 Budget $3.7 + million
- 60 study components
Prior Abundance

PRESENT ABUNDANCE

- Fish and Zooplankton Surveys (DFG)
- Gear Efficiency Studies (DFG)
- Pelagic Fish Population and Egg Supply Estimates (DFG/USFWS)
- Threadfin Shad Population Dynamics (DWR)
- Statistical Analyses of Fish Abundance Trends (USBR/Manly)
- Delta Smelt Growth and Survival (UCD)
- Delta Smelt Stock Structure (UCD)
- Trends in Apparent Growth Rates (DFG)
- Fall and Summer Habitat Trends (DWR)
- Temporal and Spatial Changes in Habitat (EPA)
- Trends in Aquatic Weeds (UCD)
- Effects of Aquatic Weeds on Turbidity (USGS)
- Bioassays (UCD)
- Fish Pathology (UCD, USFWS)
- Climate Effects (USGS)
- Hydrologic Changes (USGS)
- Microcystis Studies (DWR)
- Salinity Effects on Clams (SFSU)
TOP-DOWN

FISH ABUNDANCE

- Effect of Fish Behavior on Entrainment Risk (DWR)
- Effects of Hydrodynamics on Fish Salvage Trends (USGS)
- Particle Tracking Simulations of Entrainment (DWR)
- Statistical Analyses of Salvage Data (DWR, USBR, Manly)
- Power Plant Studies (Mirant, Tenera, Hanson)
- Salvage History (DFG, USBR)
- Modeling Striped Bass Predation in the Estuary (DWR/DFG)
- Phytoplankton Trends (UCD)
- Zooplankton Trends (DWR)
- Zooplankton Community Structure (SFSU)
- Sources of Food Web Disruption (SFSU/UCD)
- Changes in Benthic Biomass and Abundance (DWR)
- Fish Diet and Condition (DFG)
- Food Match/Mismatch (DFG)
Synthesis: Next Steps

- Delta smelt life cycle and individual-based models
  Bill Bennett UCD; Wim Kimmerer SFSU; Kenny Rose, LSU

- Striped bass life cycle, individual-based, and dose-response models
  Frank Loge UCD; Kenny Rose, LSU

- Statistical analysis of environmental effects on pelagic fish abundance
  Bryan Manly, Consultant: Mike Chotkowski, USBR

- Synthesis and evaluation
  National Center for Environmental Analysis and Synthesis (NCEAS), UCSB
• Neutral location, setting, facilities, equipment, and staff to support focused synthetic work

• >400 projects conducted by more than 3700 participants (~45% non-academic)

• >1200 publications in respected, peer-reviewed journals

• In top 1% of 38,000 scientific institutions in citations in ecology
POD Work Team
- Hypotheses
- Needs/questions
- Logistic limits

Existing data

New data

POD/“local” points of contact

NCEAS Parent Team

University Seminars
Working Groups
Data Infrastructure
Parent Team Members

Fish Health - Daniel Schlenk, UC Riverside

Fish Population Modeling - Julian Dodson, Universite Laval

Geospatial Statistics - Dave Krolich, ECorp

Ecosystem Modeling - George Jackson, Texas A&M

Estuarine Hydrodynamics - Dave Jewett, US EPA
POD Timeline for Review

- Project Work Teams (Continuous)
- Peer-Reviewed Publications (Continuous)
- Presentations at Major Meetings
  - American Fisheries Society National Meeting (Sep 2007)
  - State of the Estuary Conference (Oct 2007)
- Completion of Study Elements
  (Fall 2007-2008)
- POD/NCEAS Synthesis Report I (Late 2007)
- Review by CALFED Science (Late 2007)
Planning
-e.g. Pelagic Fish Action Plan,
Delta Vision,
CALFED, BDCP,
SDIP, DRMS, IEP...

Operations
-e.g. Delta Smelt Working Group,
Water Operations Management Team,
Data Assessment Team...

POD Investigations
Studies, Review, Synthesis, Presentations, Publications
Questions?