The X_2 Relationships:

What they are

Where they came from

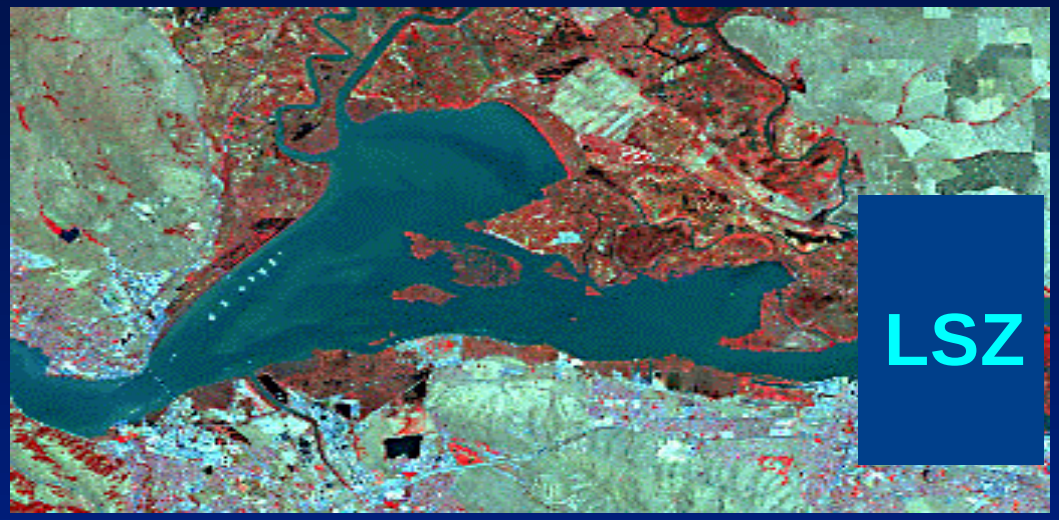
Why we should care

How they might work

Future steps

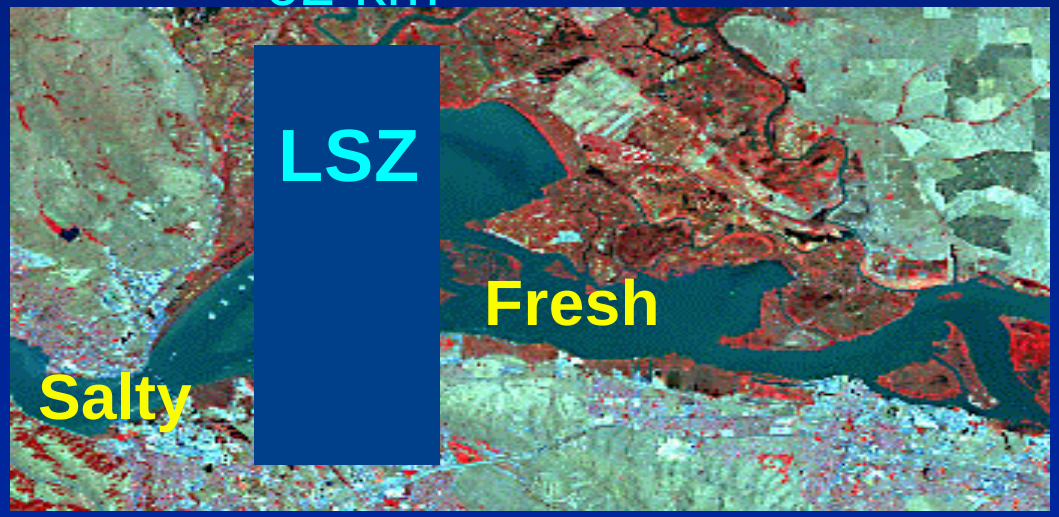
Wim Kimmerer
Romberg Tiburon Center for Environmental Studies
San Francisco State University

Flow moves Low-Salinity Zone



X_2 → 89 km

→ 62 km



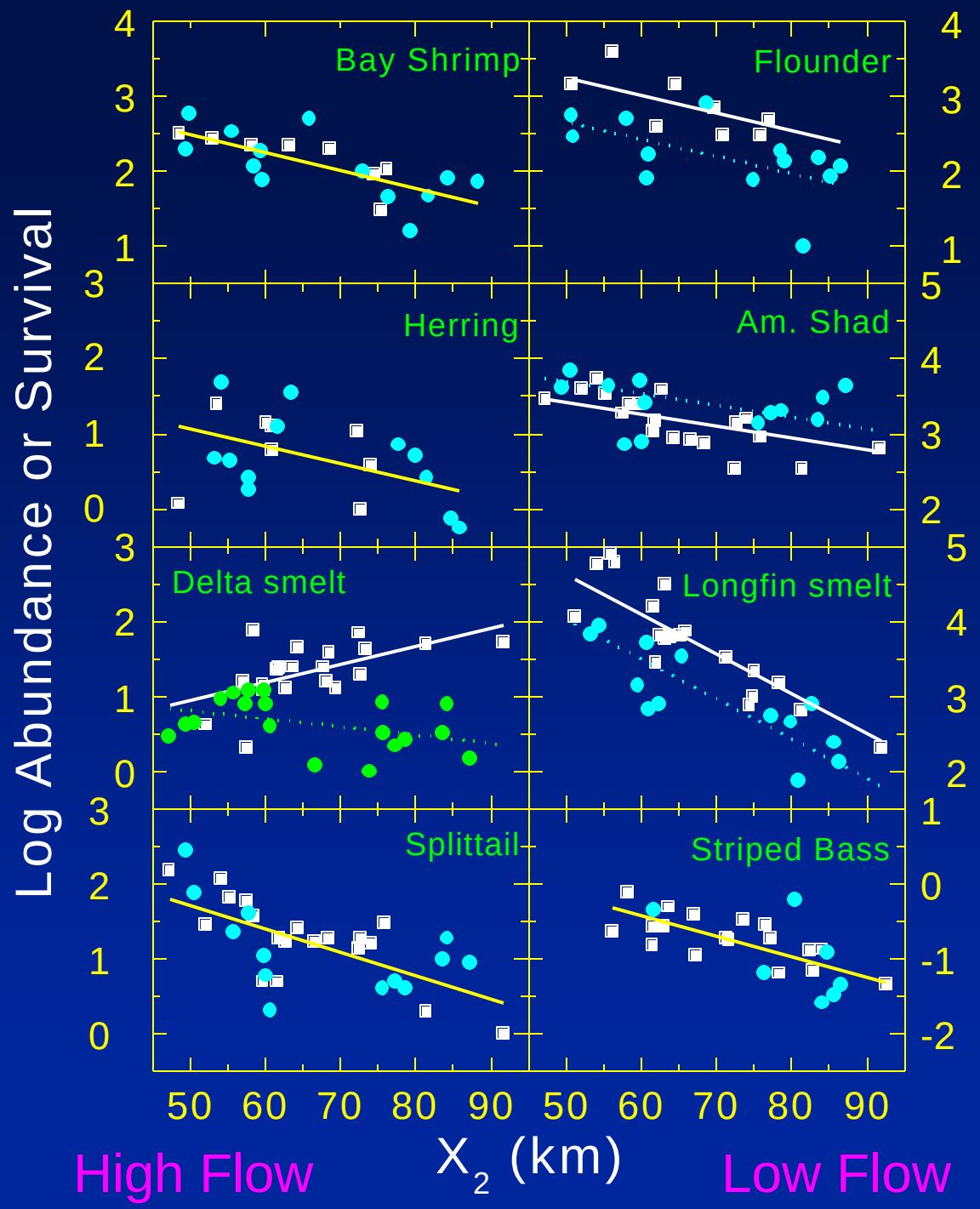
Suisun Bay Delta

← 100 $m^3 s^{-1}$

Freshwater Flow

← 1000 $m^3 s^{-1}$

Relationships Between Freshwater Flow and Biological Populations



1967-87

1988-2000

1982-2000 (DS)

All Years

Source:
Kimmerer 2003 MEPS

X2 :
Basis, Structure, and History

Bruce Herbold
USEPA

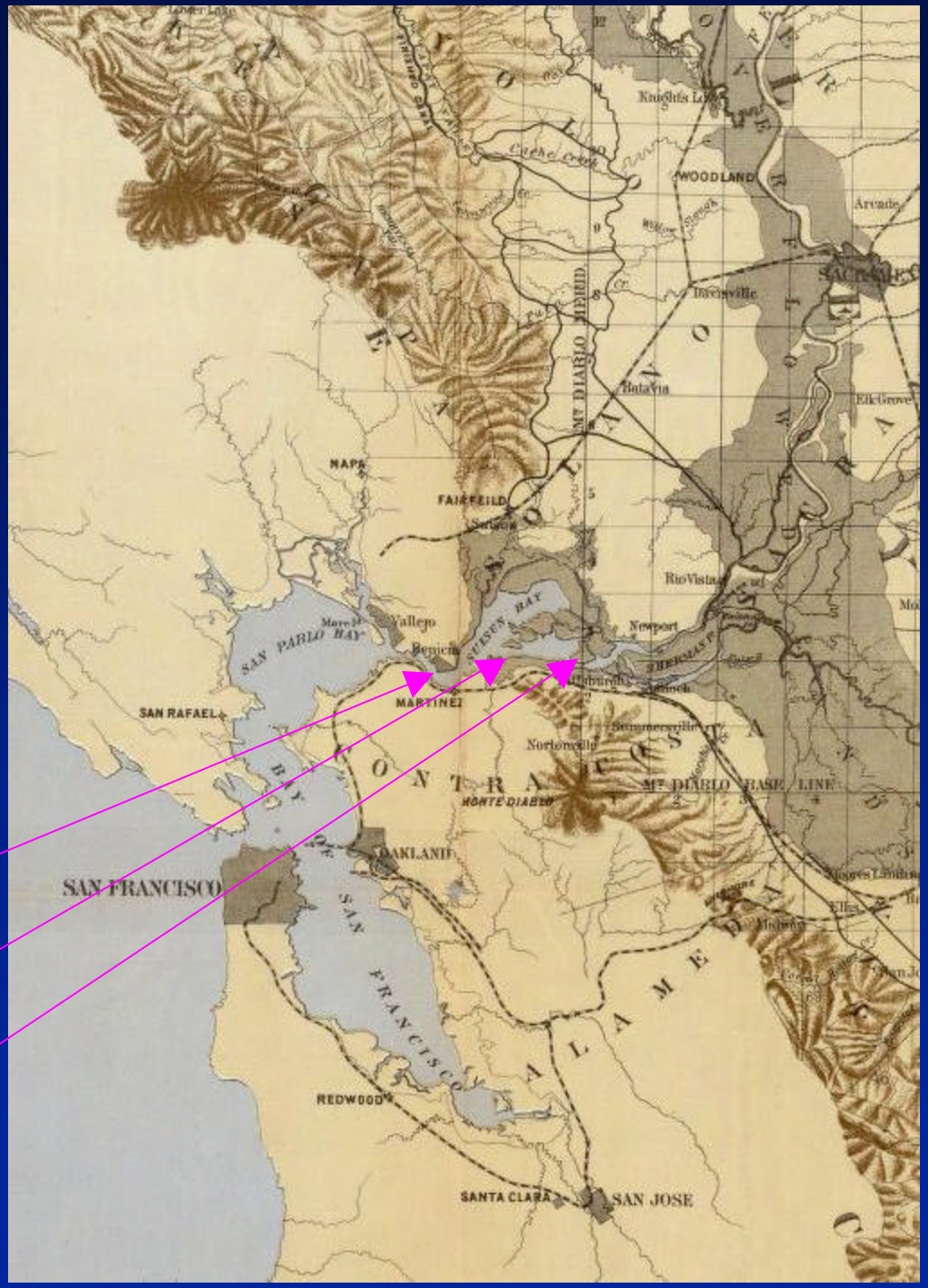
USGS
science for a changing world
PG&E

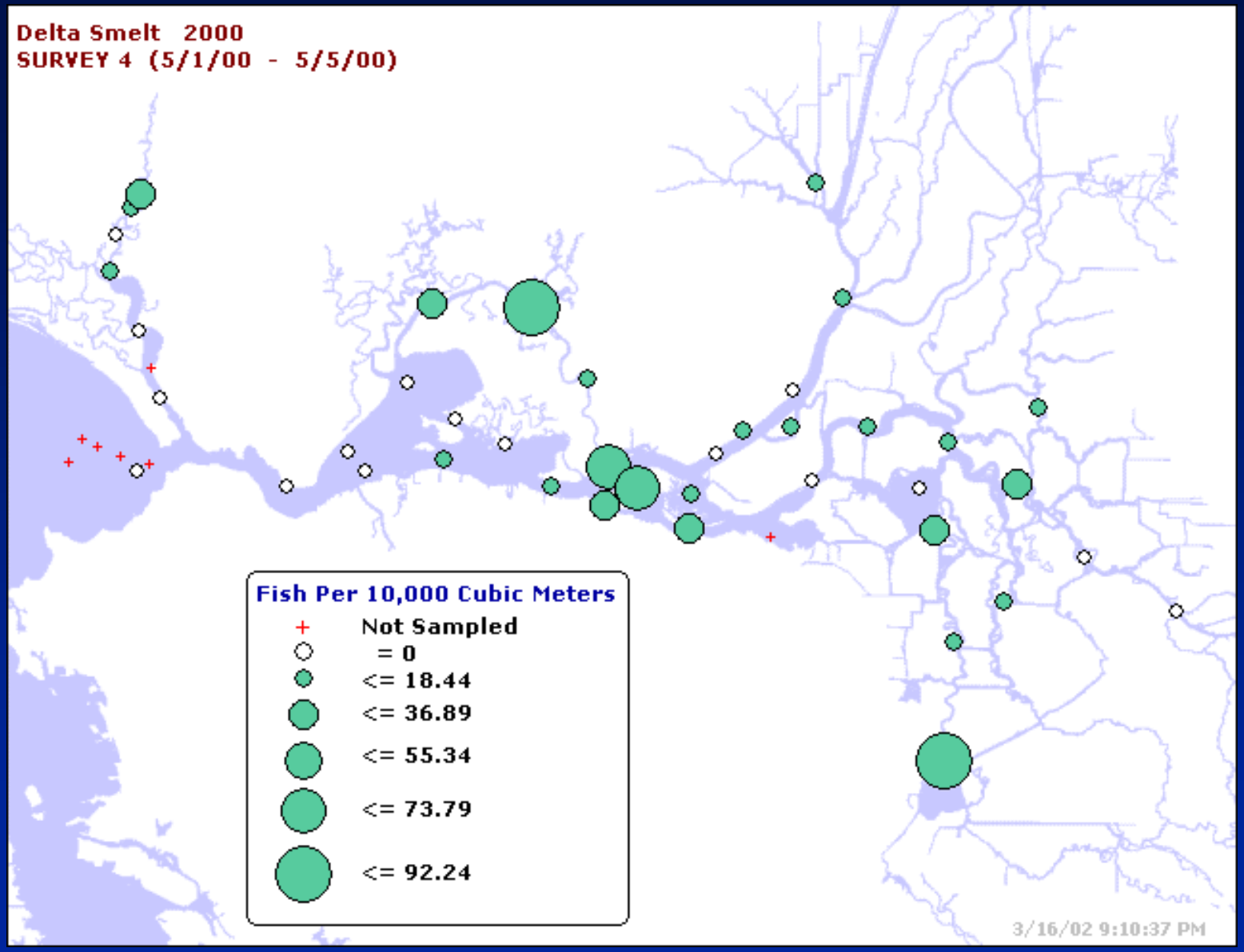
X2=

55 km

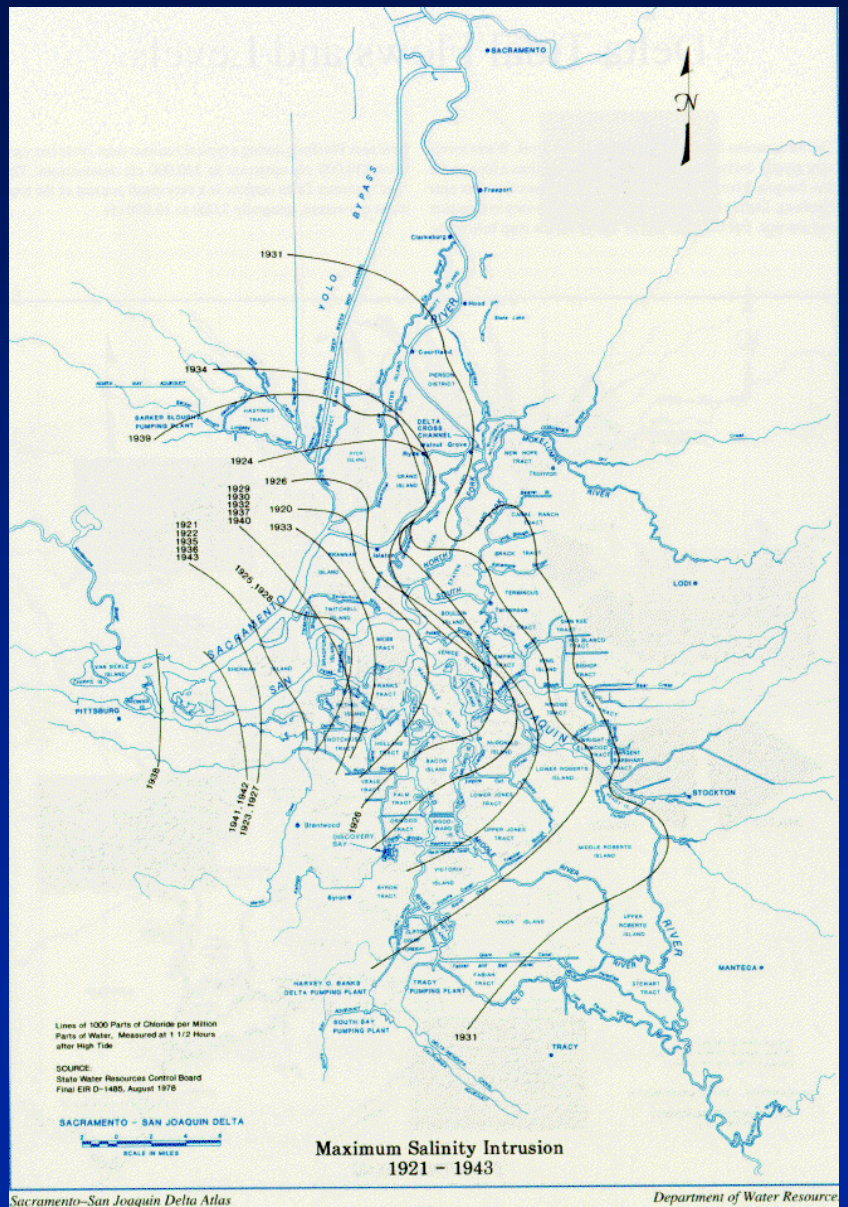
65 km

75 km



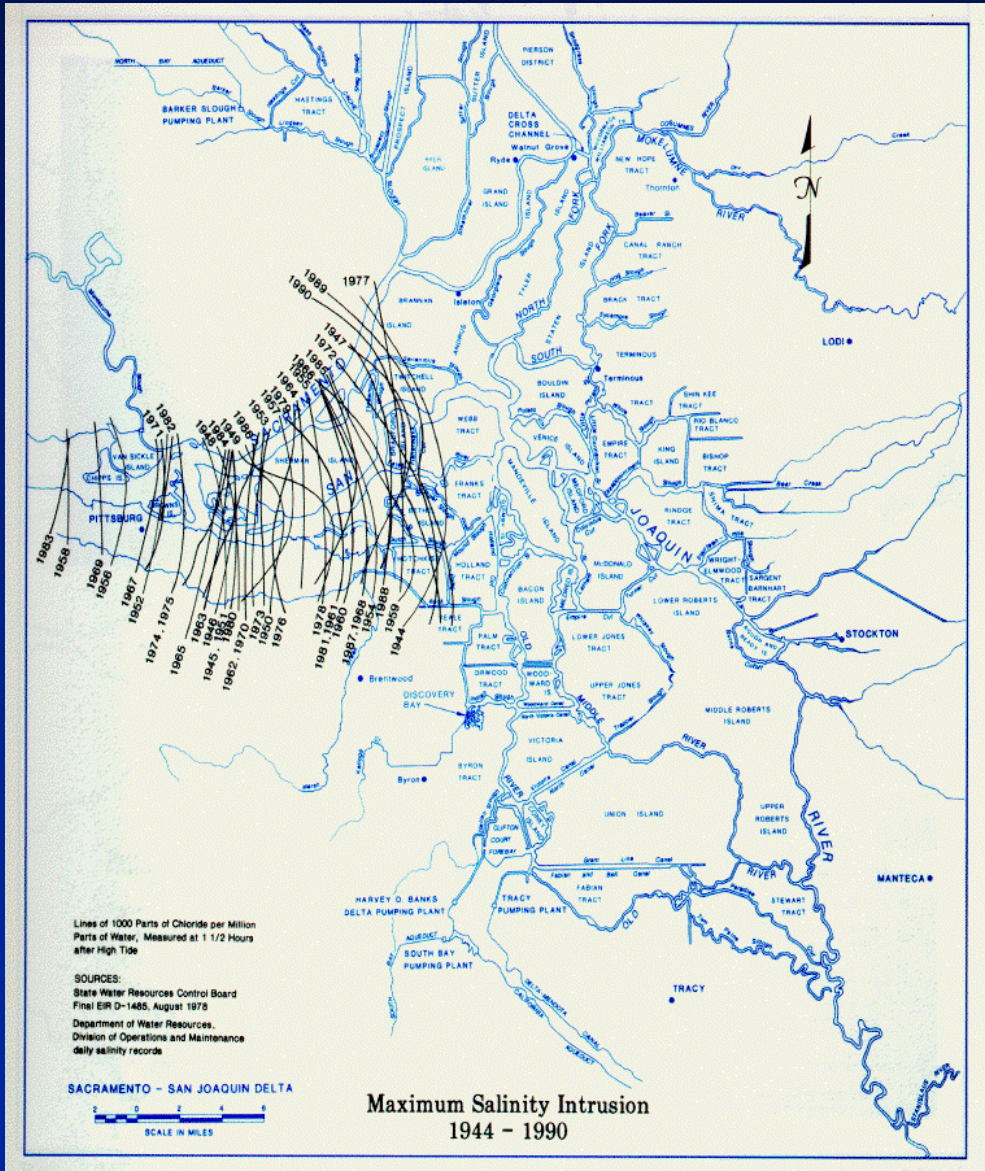

Delta Smelt 2000
SURVEY 4 (5/1/00 - 5/5/00)
Fish Per 10,000 Cubic Meters
Not Sampled
= 0
<= 18.44
<= 36.89
<= 55.34
<= 73.79
<= 92.24
3/16/02 9:10:37 PM

Summertime Salinity Intrusion 1921-1943



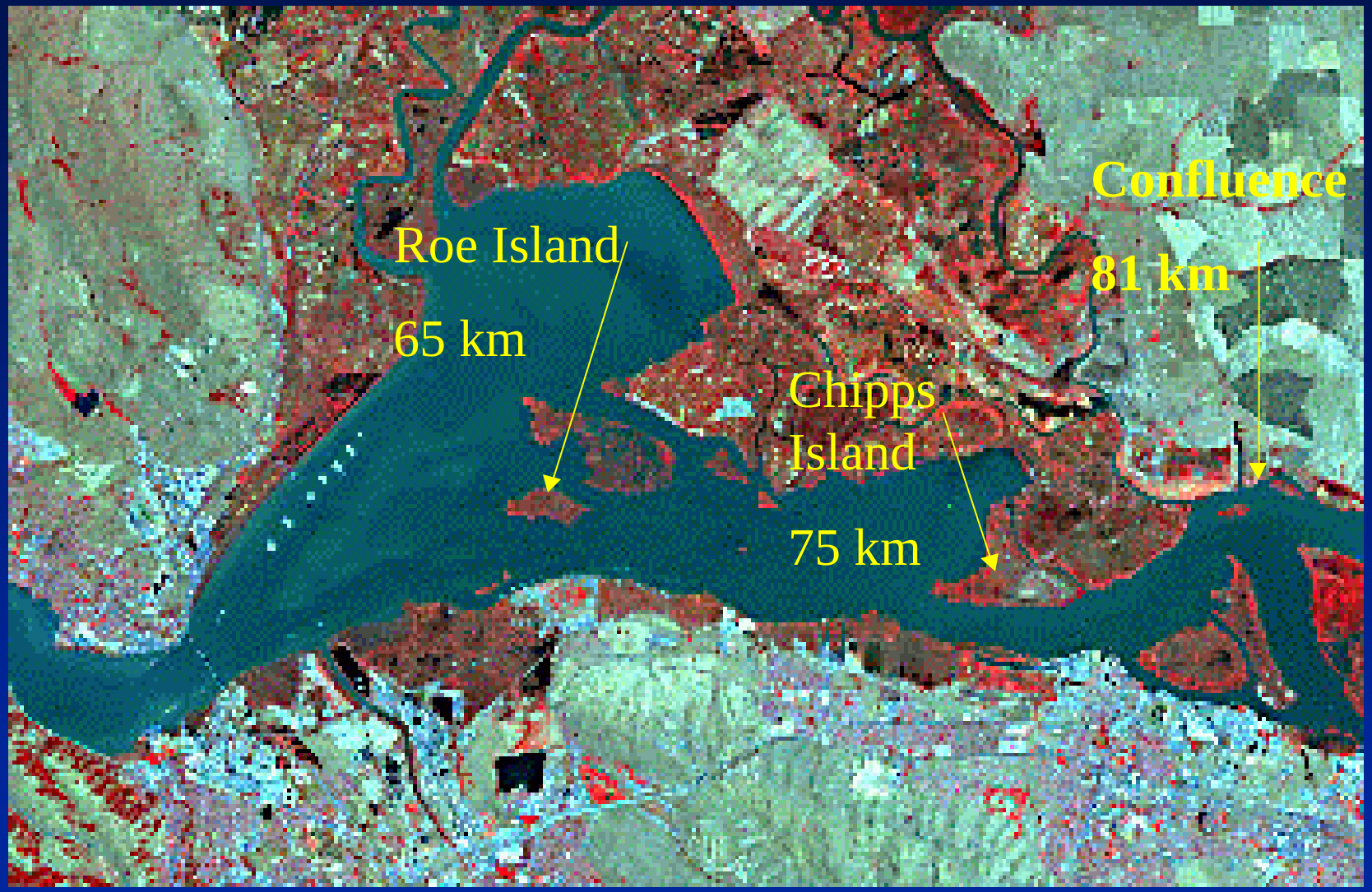
Select from the following
Map Views
Major Rivers
State Projects
Federal Projects
Local Projects
All Water Projects
Redding
Sacramento
San
Francisco
Fresno
Los
Angeles
San
Diego

Summertime Salinity Intrusion 1944-1990

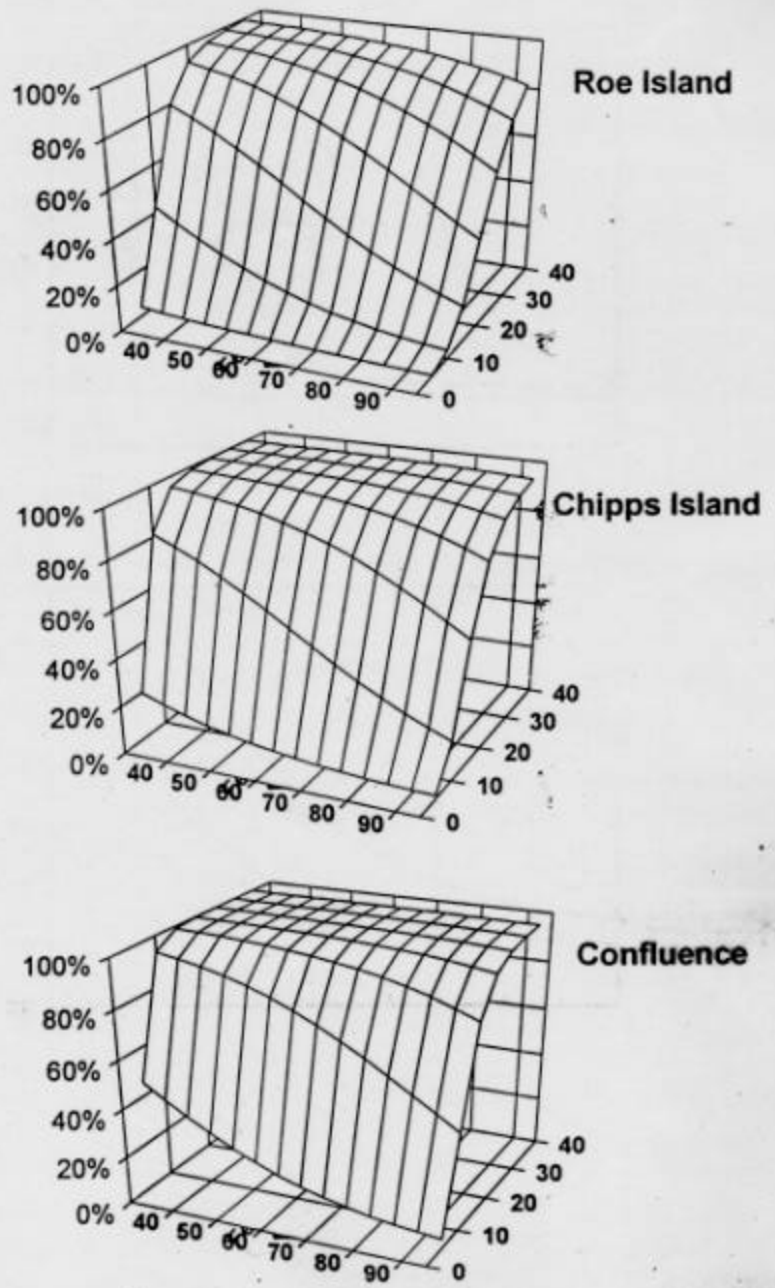


Average Springtime X2

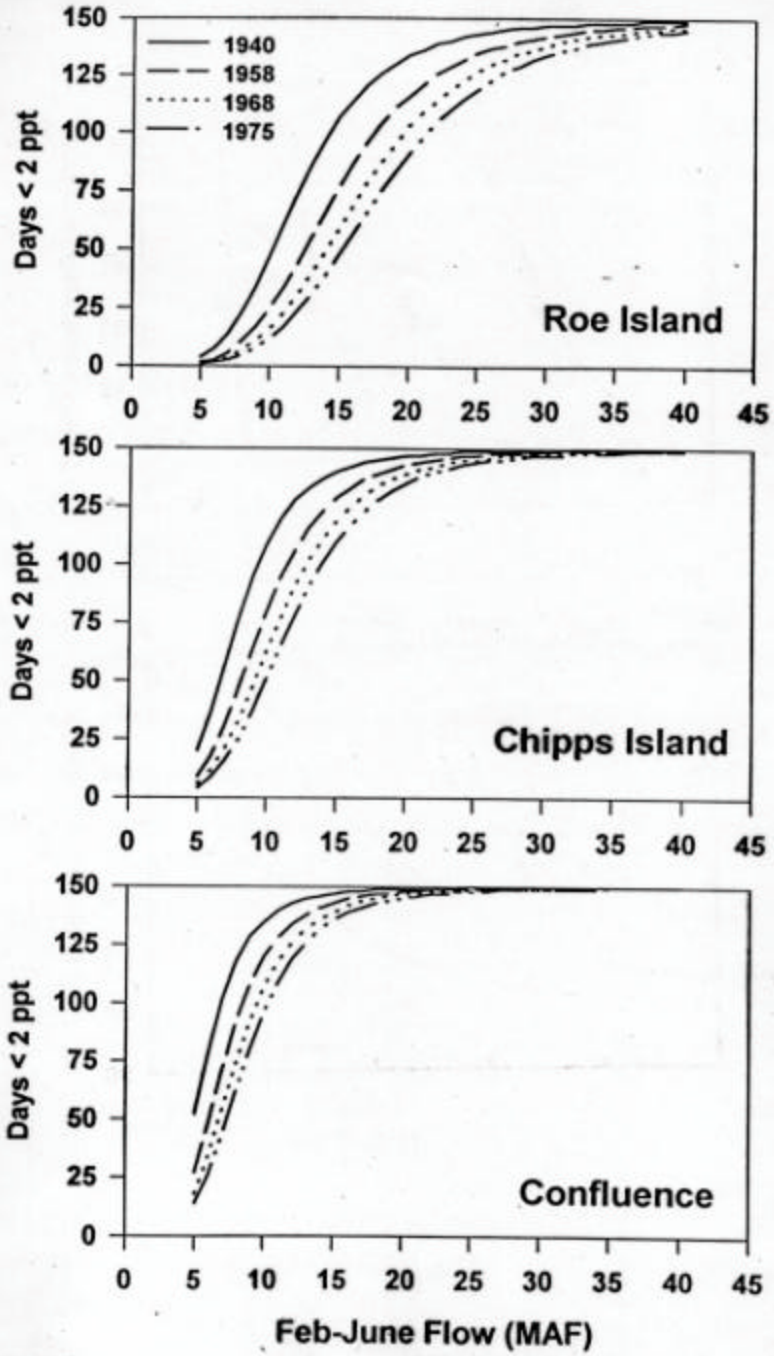
	Critical	Dry	Below	Above	Wet
1930-45	76	67	58	54	51
1946-55		69	63	61	56
1956-65		72	69	66	56
1966-75			73	62	59
1976-85	87	77	69	60	55
1986-95	83	79		61	56

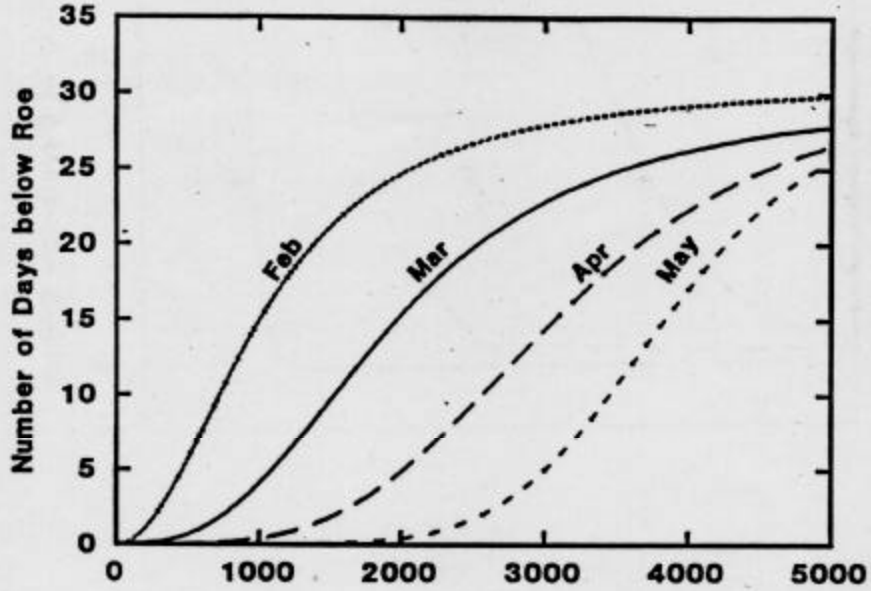

Confluence
81 km
Roe Island
65 km
Chipps
Island
75 km

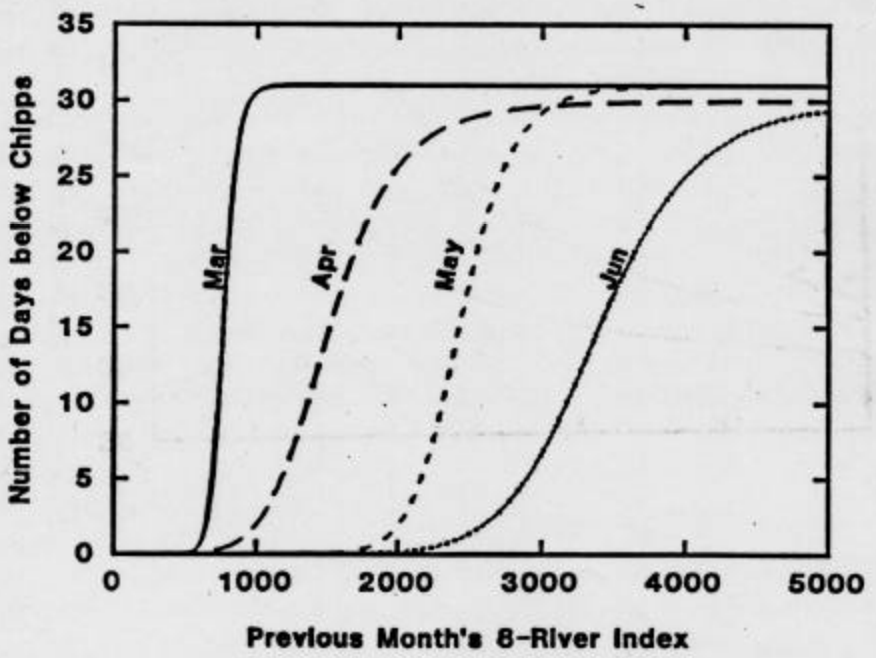
Predicted percent days < 2 ppt showing effects of year and flow



Predicted days < 2 ppt vs. unconstrained flow for 4 reference years




Number of Days below Roe
35
30
25
20
15
10
5
0
0
1000
2000
3000
4000
5000
Feb
Mar
Apr
May

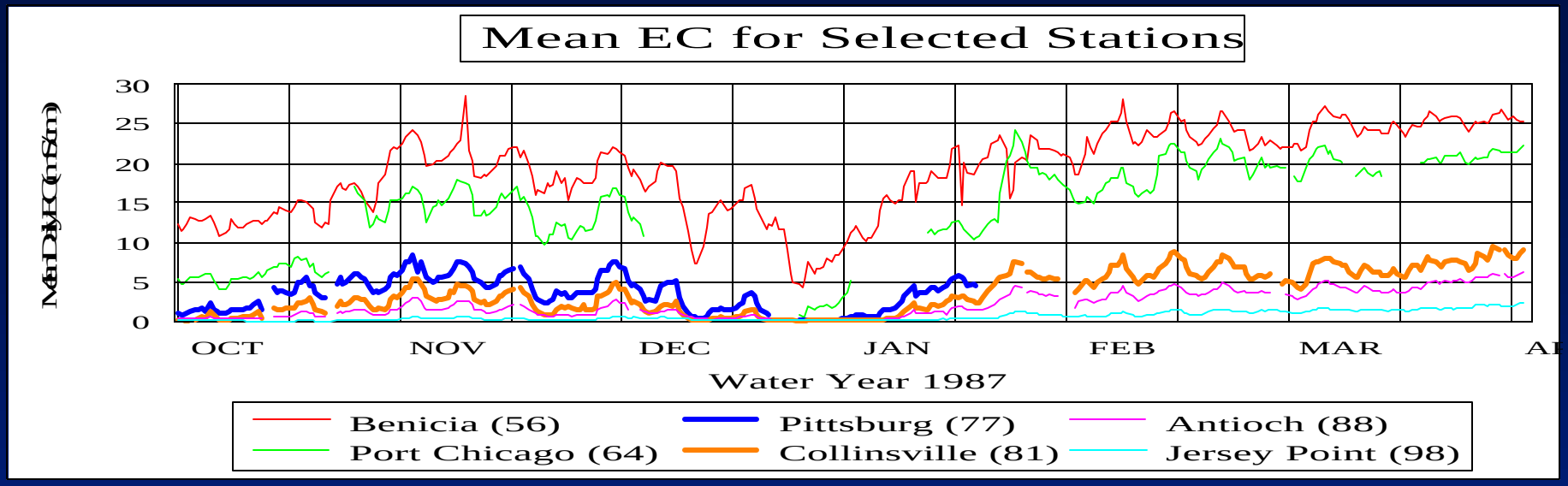

Number of Days below Chipps
35
30
25
20
15
10
5
0
0
1000
2000
3000
4000
5000
Mar
Apr
May
Jun
Previous Month's 6-River Index

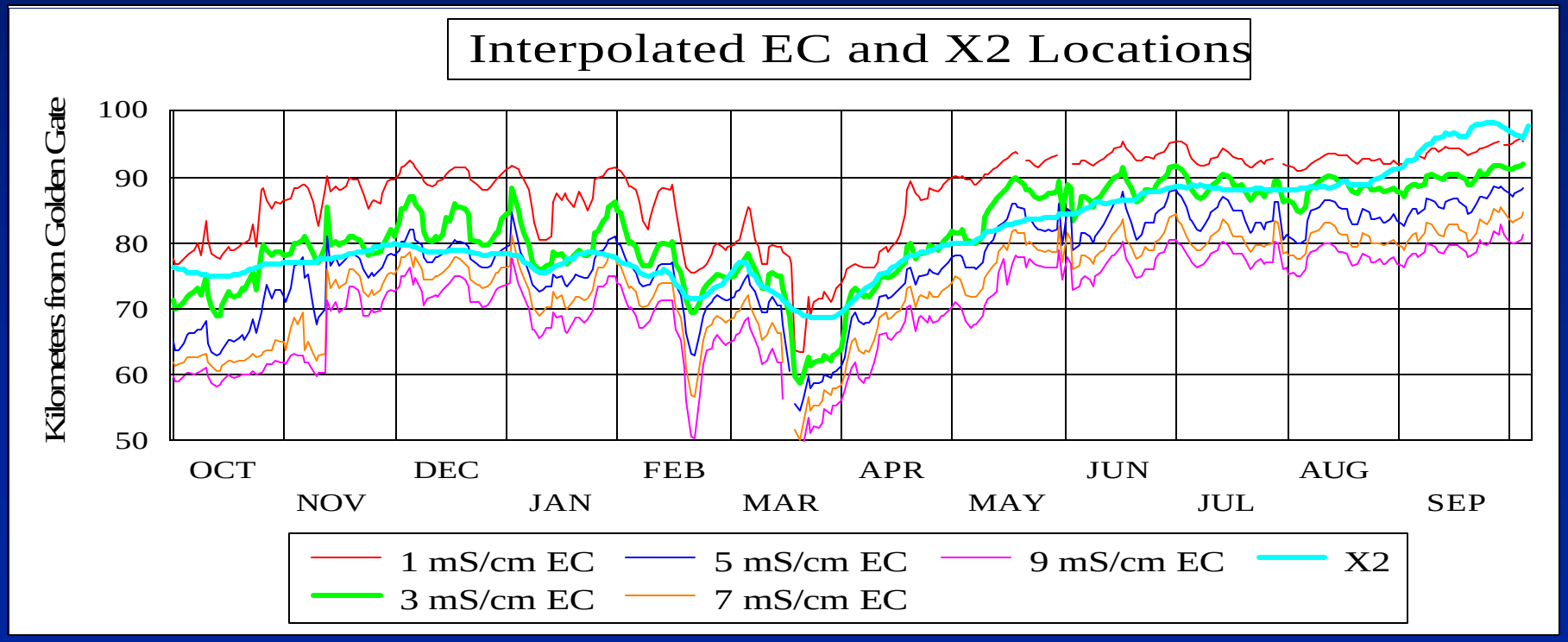
Examples

- Take previous month's 8 River Index
  - Say 2.5 MAF in March
    - Must be met at confluence for 30 days of April
    - X2 must be met at Chipps Island for 29 days
    - 8 Roe Island days, if last 2 weeks of April had X2 west of Roe
  - Say 2.5 MAF in April
    - At confluence for 31days in May
    - X2 at Chipps Island for 11 days
    - 1 Roe Island day, if triggered

History

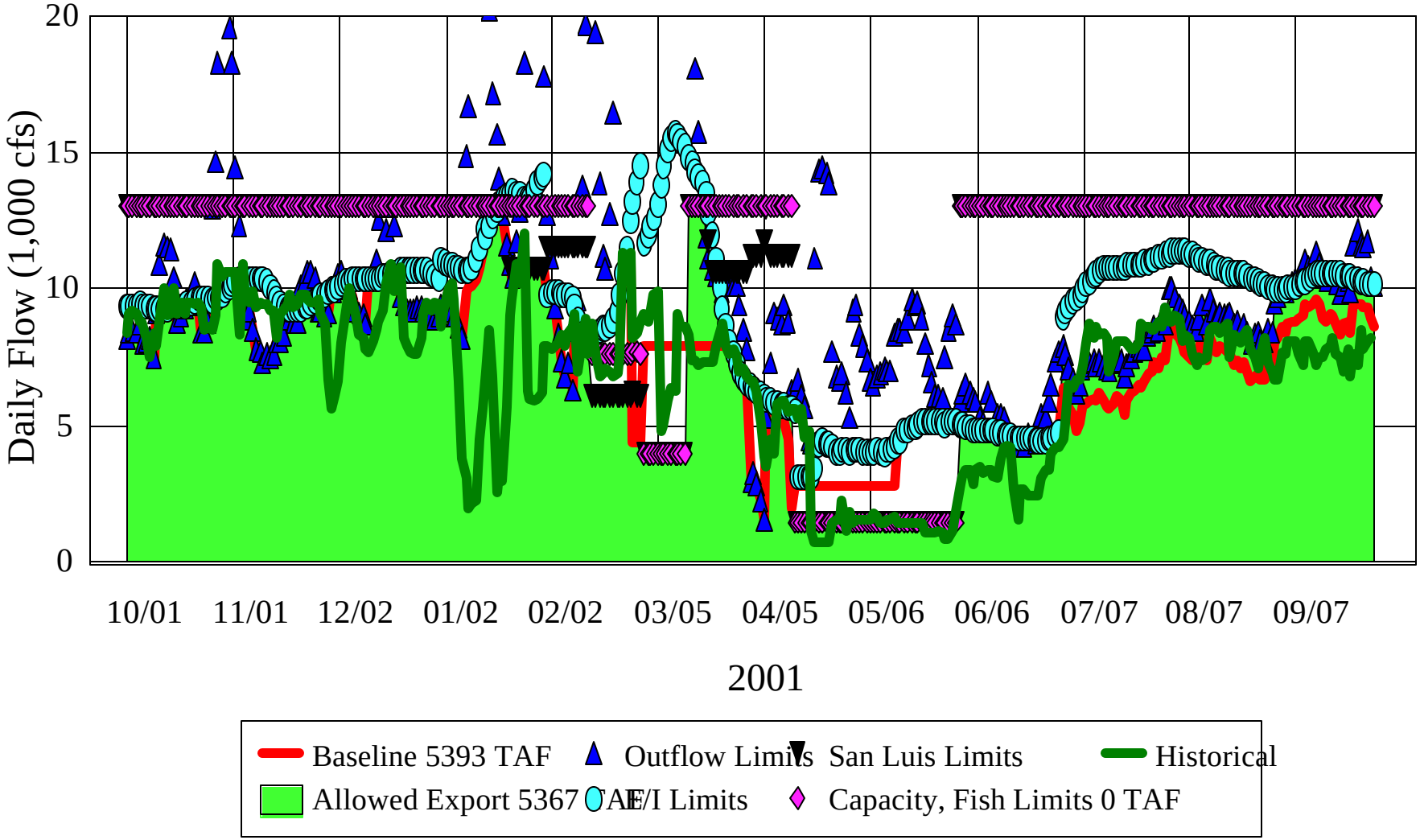
- No outflow requirement
- EPA disapproves and so…
- Estuary Project brings in academia
- X2 recommended
- EPA works with Club Fed and BDMF
- CUWA supports (at 1971.5 level)
- EPA and SWRCB adopt

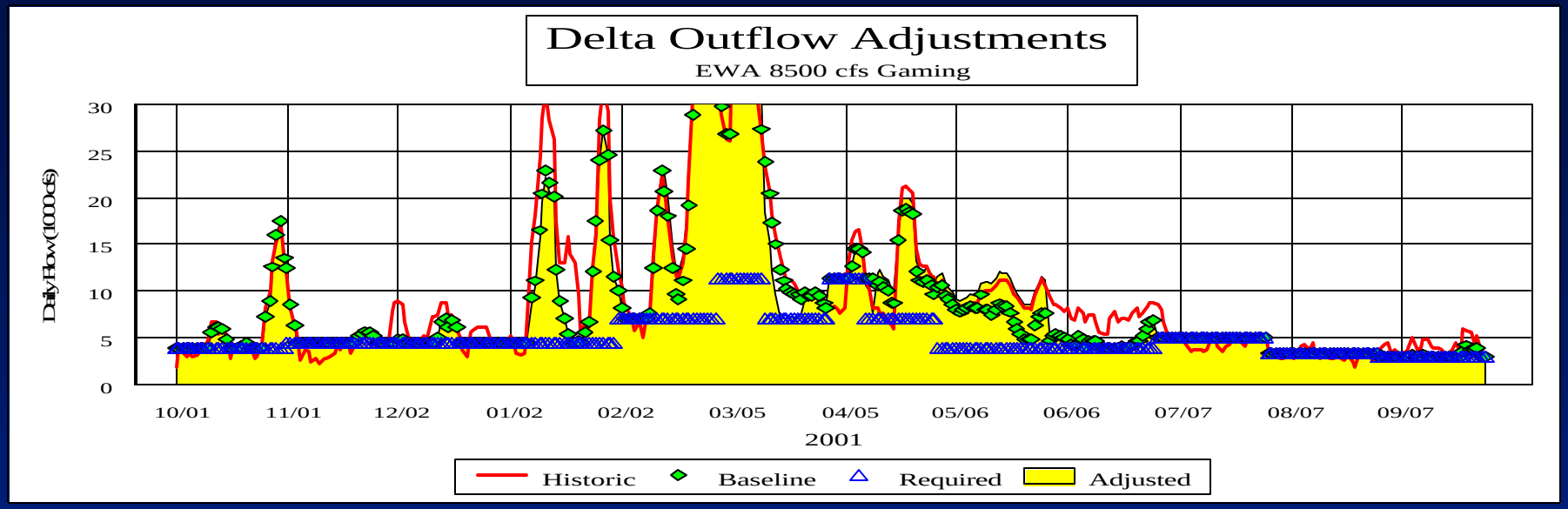

Mean EC for Selected Stations
30
25
20
15
10
5
0
OCT
NOV
DEC
JAN
FEB
MAR
Water Year 1987
Benicia (56)
Port Chicago (64)
Pittsburg (77)
Collinsville (81)
Antioch (88)
Jersey Point (98)

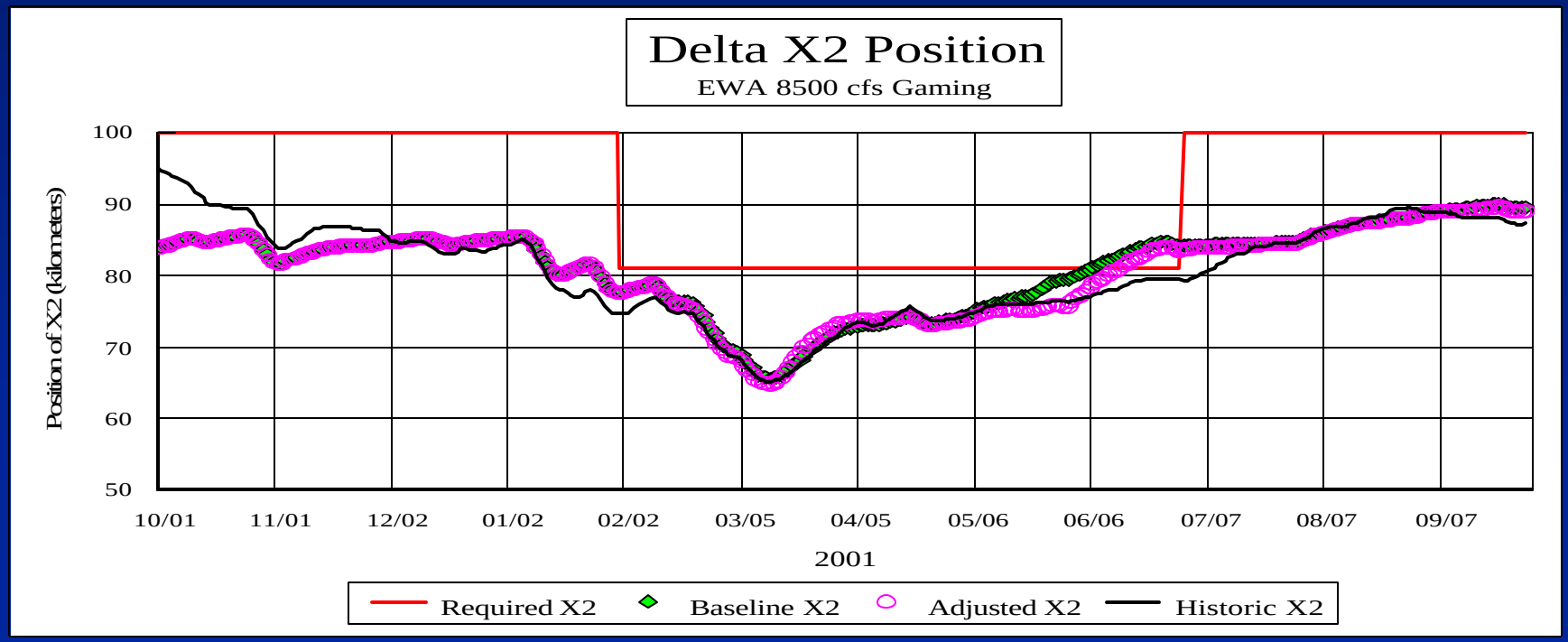

Interpolated EC and X2 Locations
Kilometers from Golden Gate
100
90
80
70
60
50
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
1 mS/cm EC
3 mS/cm EC
5 mS/cm EC
7 mS/cm EC
9 mS/cm EC
X2

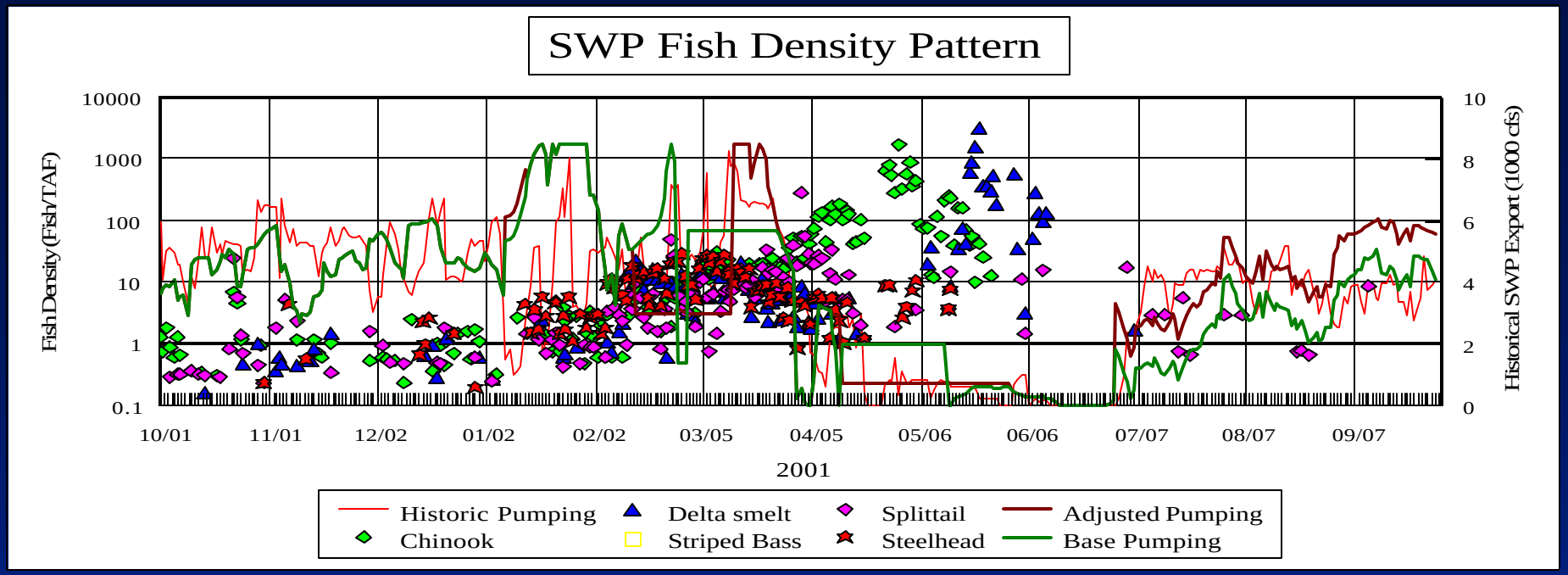
Delta Export Limits

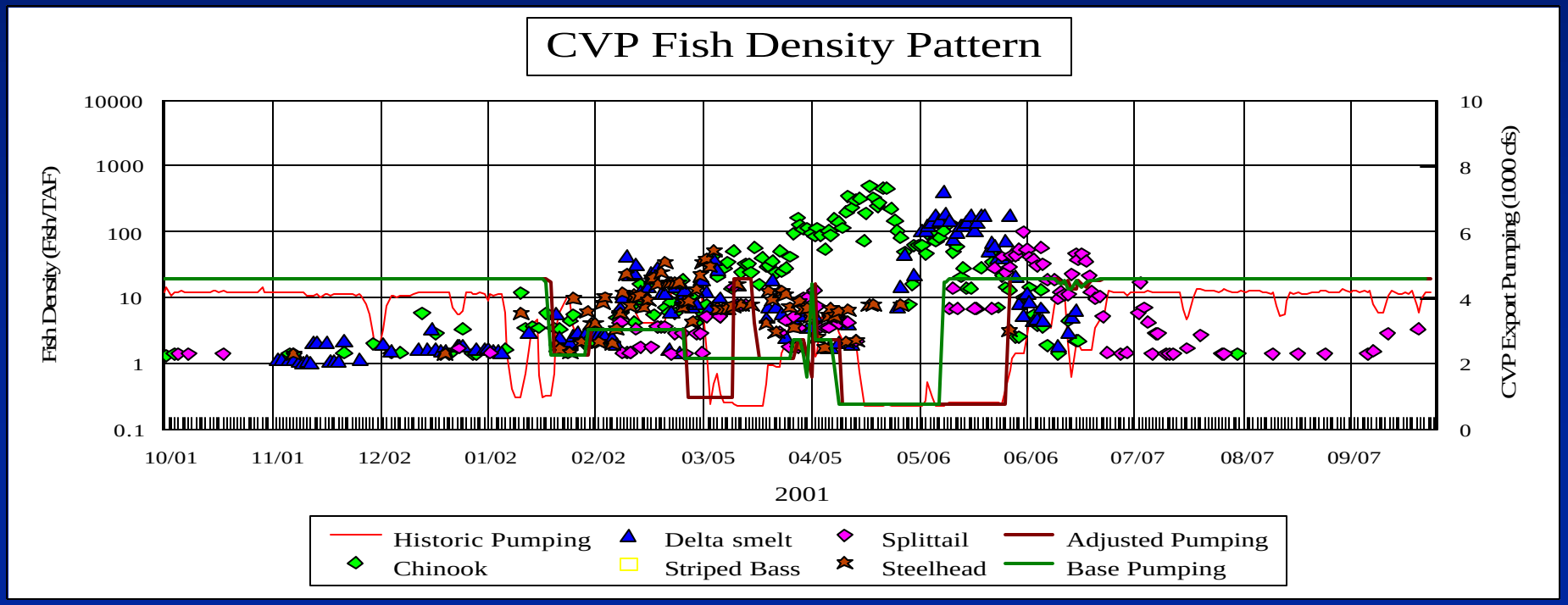
EWA 8500 cfs Gaming




Delta Outflow Adjustments
EWA 8500 cfs Gaming
Daily Flow (1000 cfs)
30
25
20
15
10
5
0
10/01
11/01
12/02
01/02
02/02
03/05
04/05
05/06
06/06
07/07
08/07
09/07
2001
Historic
Baseline
Required
Adjusted

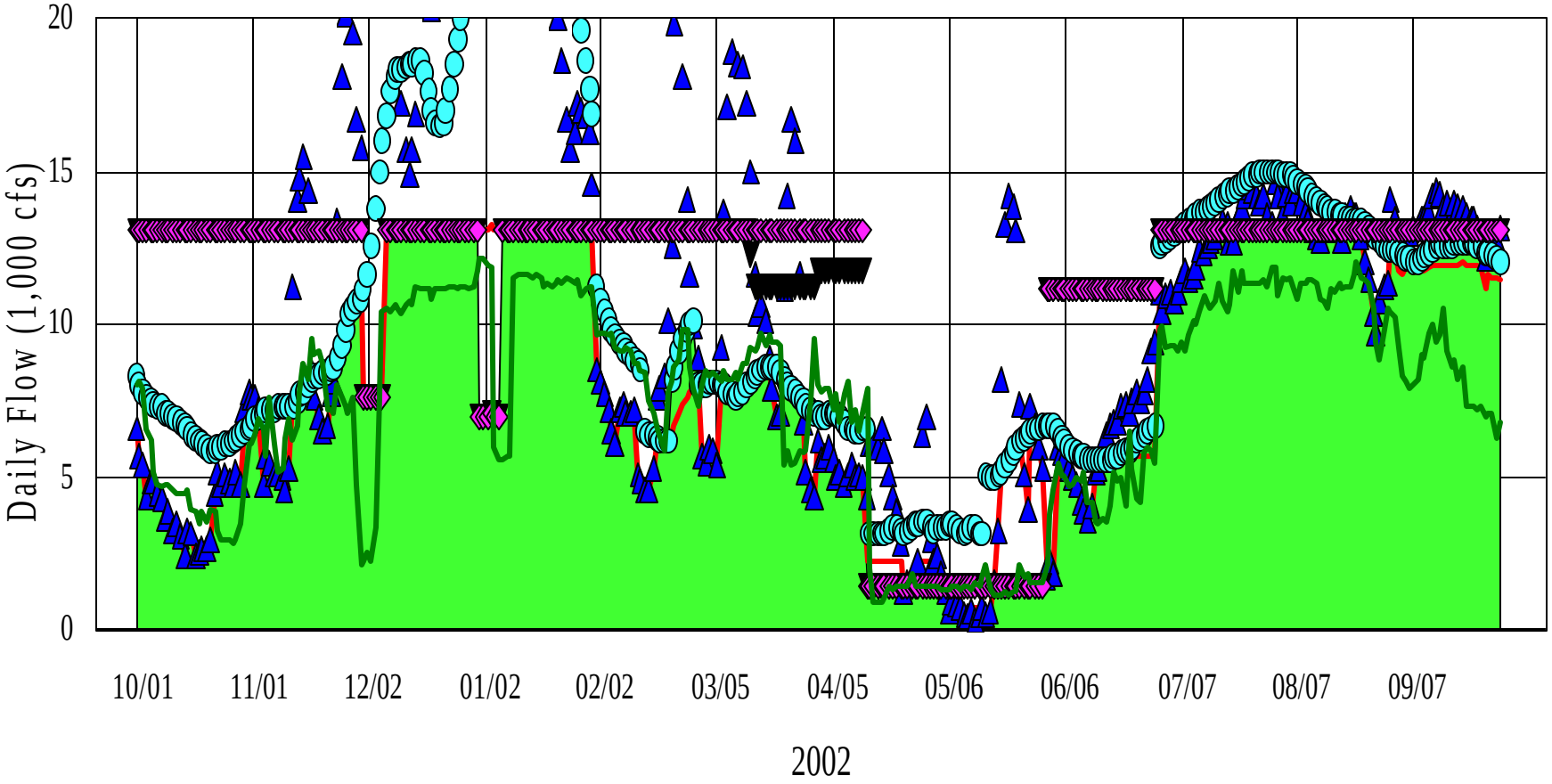

Delta X2 Position
EWA 8500 cfs Gaming
Position of X2 (kilometers)
100
90
80
70
60
50
10/01
11/01
12/02
01/02
02/02
03/05
04/05
05/06
06/06
07/07
08/07
09/07
2001
Required X2
Baseline X2
Adjusted X2
Historic X2

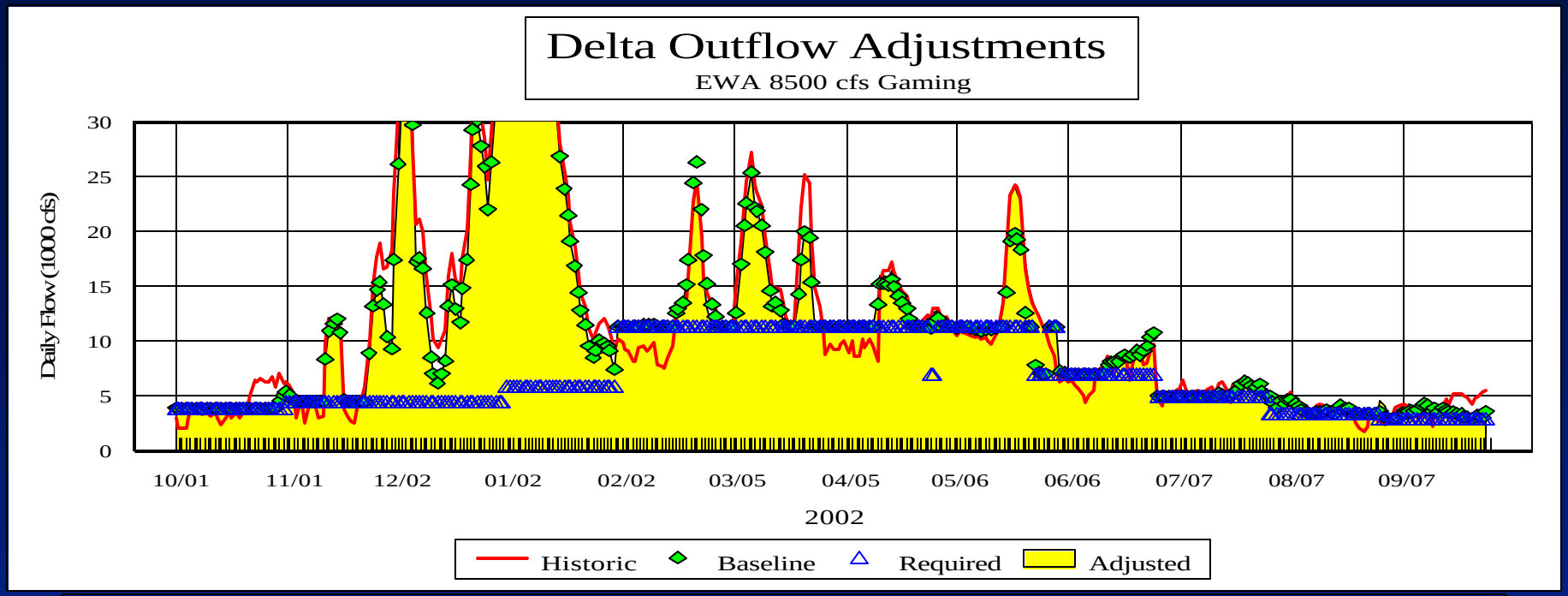

SWP Fish Density Pattern
Fish Density (Fish/TAF)
10000
1000
100
10
1
0.1
Historical SWP Export (1000 cfs)
10
8
6
4
2
0
10/01
11/01
12/02
01/02
02/02
03/05
04/05
05/06
06/06
07/07
08/07
09/07
2001
Historic Pumping
Delta smelt
Splittail
Adjusted Pumping
Chinook
Striped Bass
Steelhead
Base Pumping

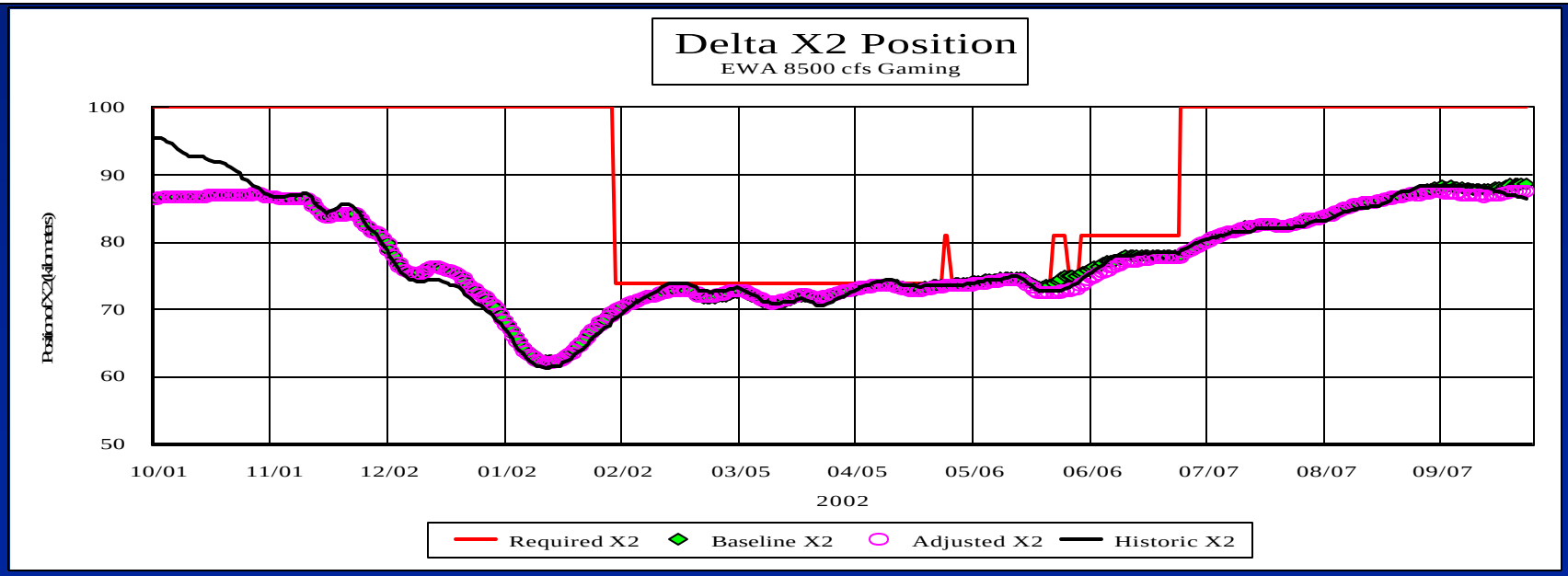

CVP Fish Density Pattern
Fish Density (Fish/TAF)
10000
1000
100
10
1
0.1
CVP Export Pumping (1000 cfs)
10
8
6
4
2
0
10/01
11/01
12/02
01/02
02/02
03/05
04/05
05/06
06/06
07/07
08/07
09/07
2001
Historic Pumping
Delta smelt
Splittail
Adjusted Pumping
Chinook
Striped Bass
Steelhead
Base Pumping

Delta Export Limits

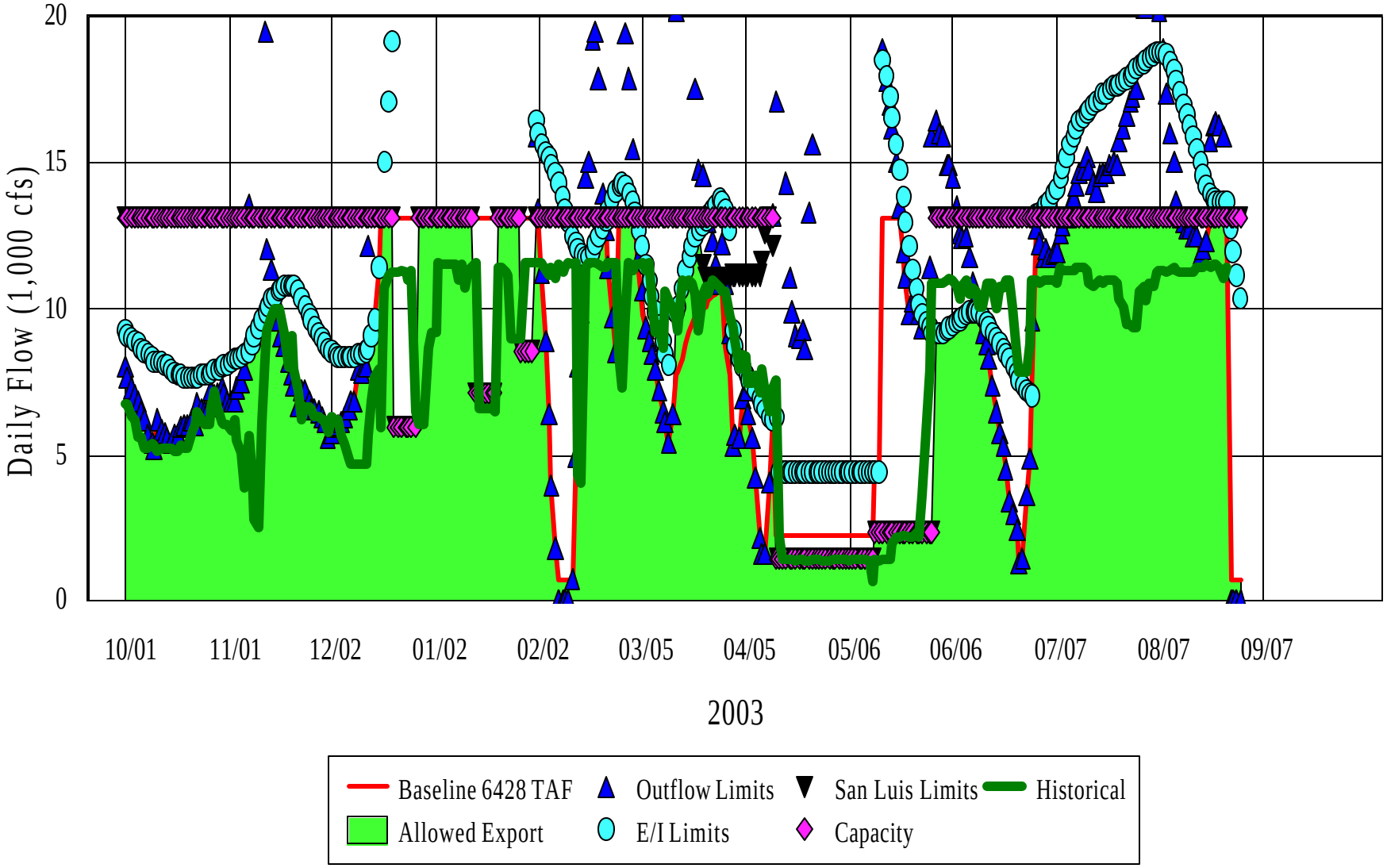
EWA 8500 cfs Gaming

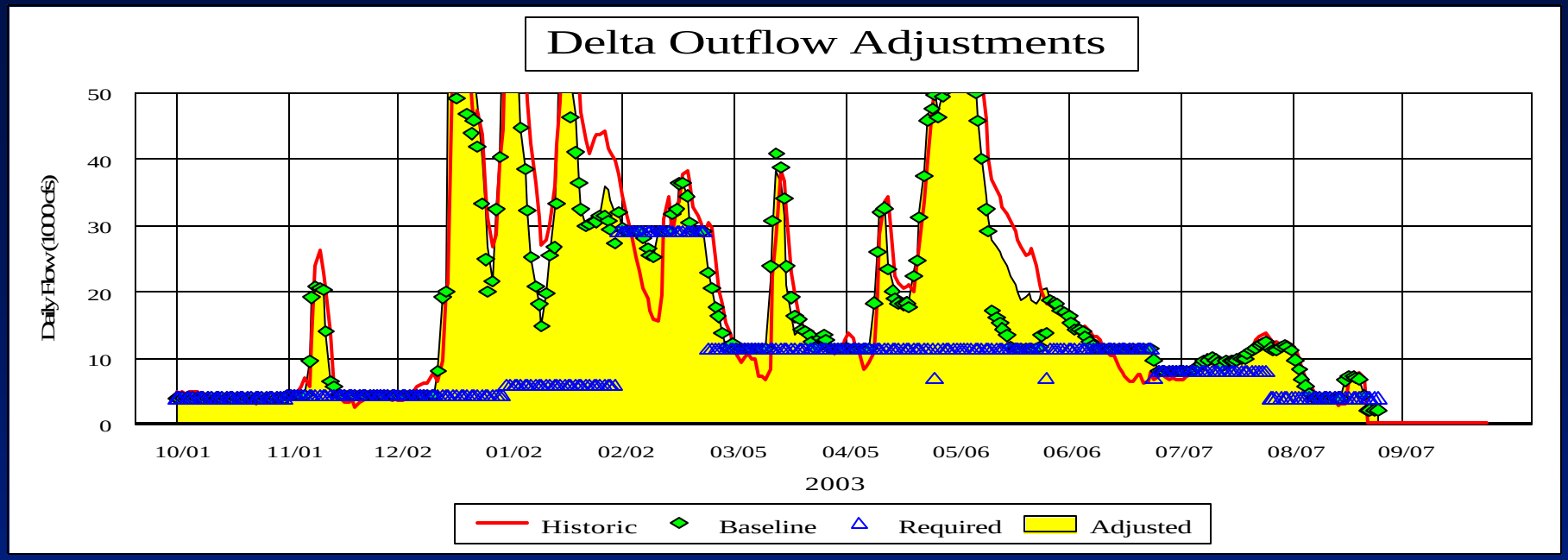


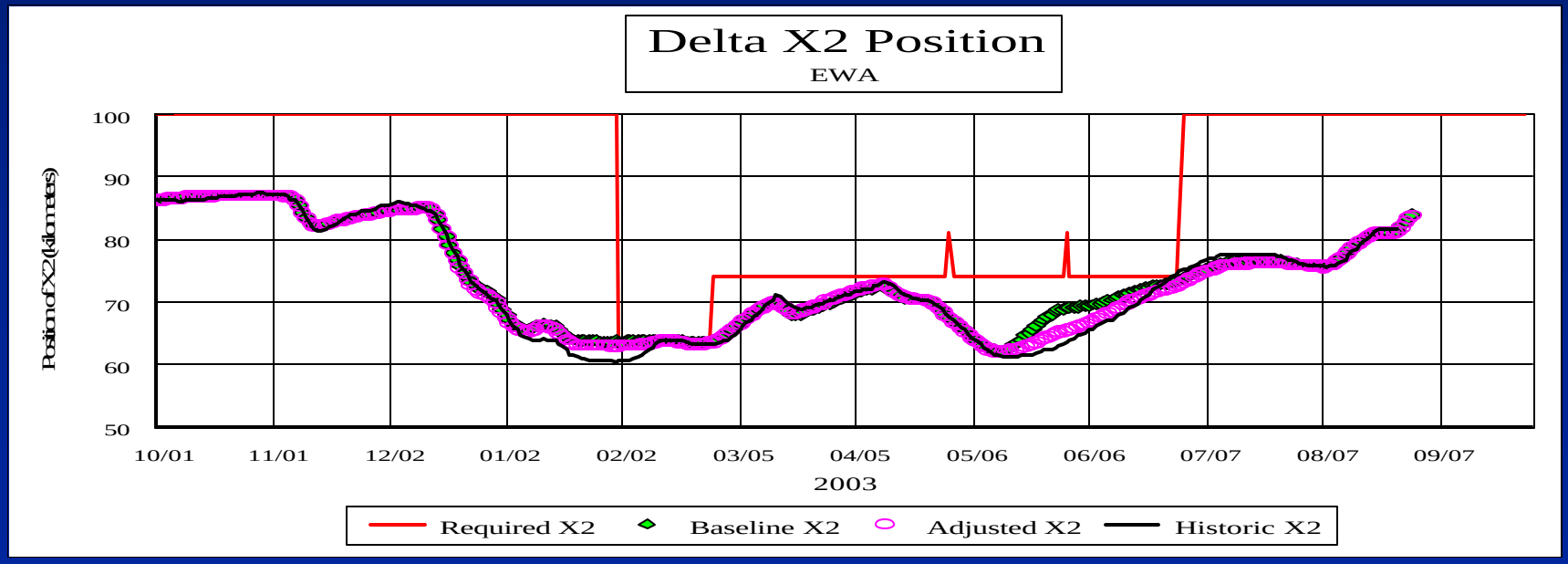

Delta Outflow Adjustments
EWA 8500 cfs Gaming
Daily Flow (1000 cfs)
30
25
20
15
10
5
0
10/01
11/01
12/02
01/02
02/02
03/05
04/05
05/06
06/06
07/07
08/07
09/07
2002
Historic
Baseline
Required
Adjusted


Delta X2 Position
EWA 8500 cfs Gaming
100
90
80
70
60
50
10/01
11/01
12/02
01/02
02/02
03/05
04/05
05/06
06/06
07/07
08/07
09/07
2002
Required X2
Baseline X2
Adjusted X2
Historic X2

Delta Export Limits




Delta Outflow Adjustments
Daily Flow (1000 cfs)
50
40
30
20
10
0
10/01
11/01
12/02
01/02
02/02
03/05
04/05
05/06
06/06
07/07
08/07
09/07
2003
Historic
Baseline
Required
Adjusted


Delta X2 Position
EWA
Position of X2 (kilometers)
100
90
80
70
60
50
10/01
11/01
12/02
01/02
02/02
03/05
04/05
05/06
06/06
07/07
08/07
09/07
2003
Required X2
Baseline X2
Adjusted X2
Historic X2

All-New, Completely Updated Edition of the #1 NATIONAL BESTSELLER

Not quite

Everything you always wanted to know about

X_2 and hydrodynamics*

Explained by

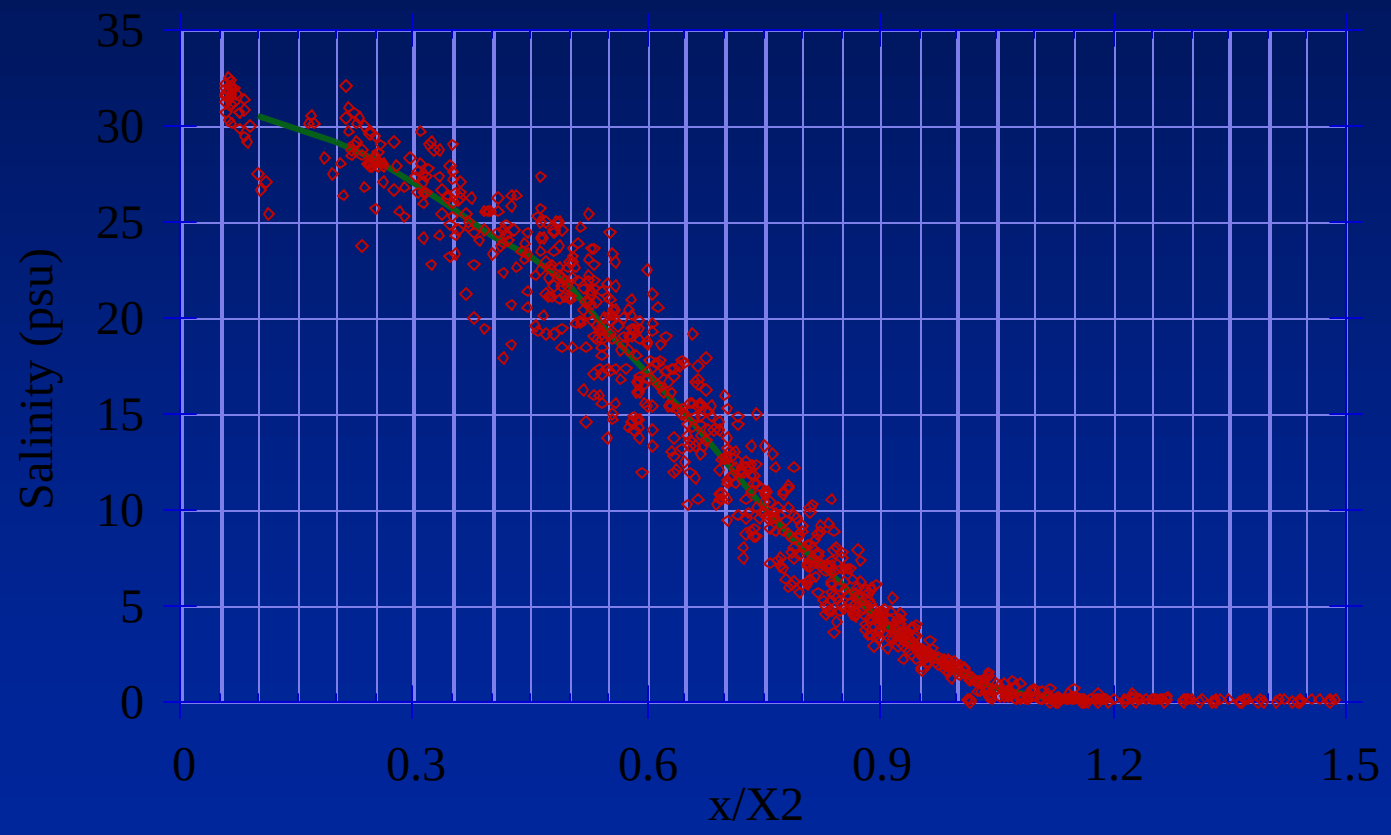
STEPHEN MONISMITH

* BUT WERE AFRAID TO ASK™

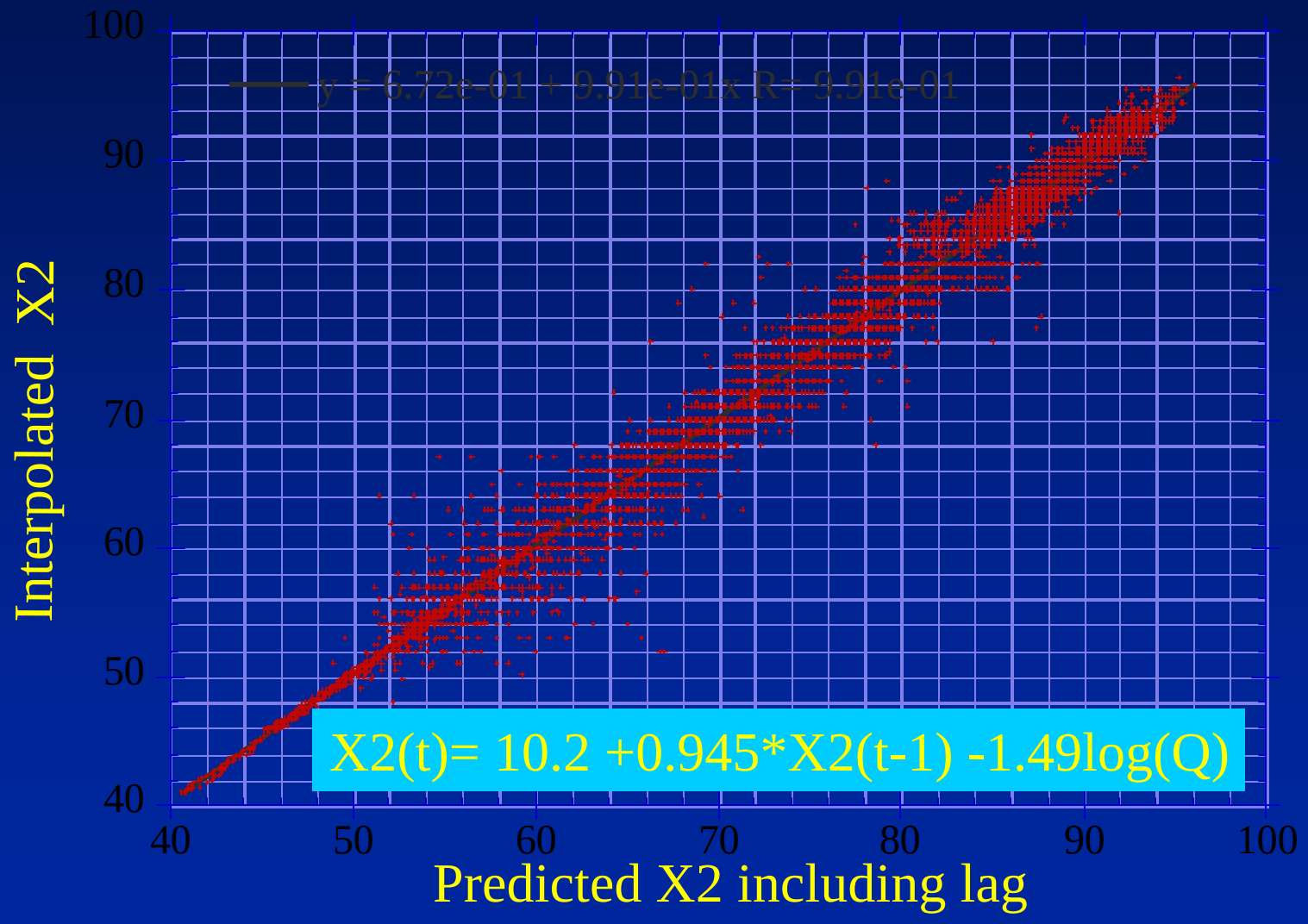
Collaboration w. Mark Stacey and Jon Burau

Salinity Field Structure

(data from J. Cloern, USGS)



Prediction of X2 (Jassby equation)



Estuarine Salt Balance: Steady flows

Basic idea: Upstream salt flux due to dispersion balances downstream salt flux by advection:

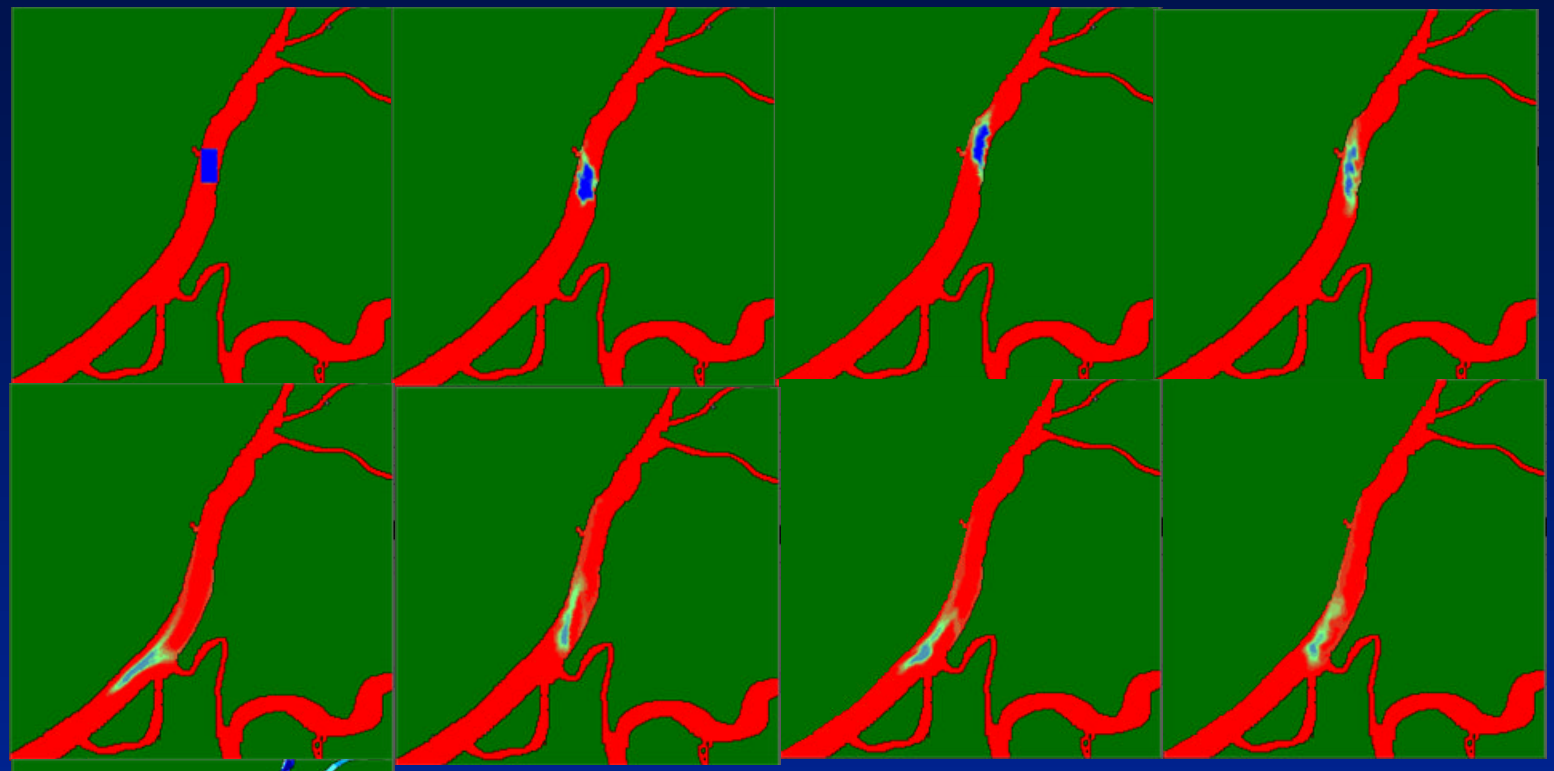
$$-Q\langle \bar{S} \rangle = K_x(x)A(x)\frac{d\langle \bar{S} \rangle}{dx}$$

Freshwater flow pushes salt out

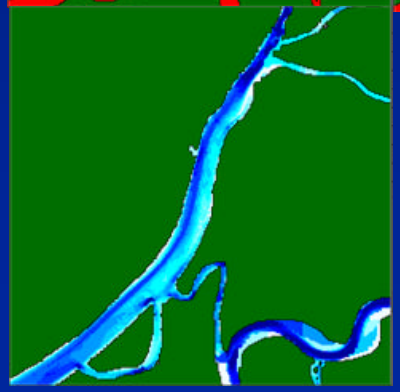
Dispersion (variety of mechanisms) transports salt upstream

x = distance along axis of estuary
Q = Downstream flow (m^3/s)
A(x) = Cross-sectional area (m^2)
K(x) = Dispersion coefficient (m^2/s)

Dispersion of a patch in the Sacramento River

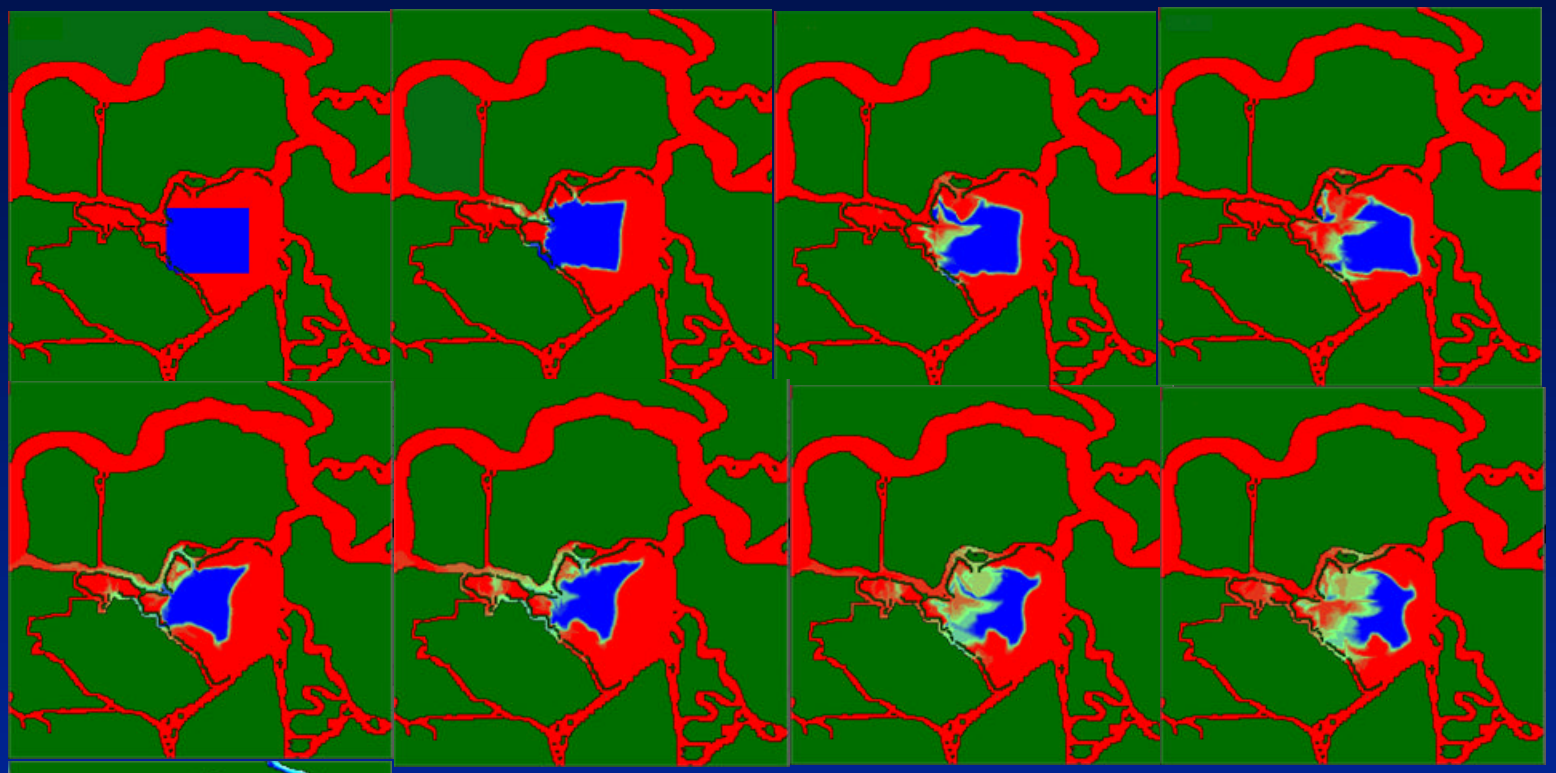


Calculations by N. Monsen



Local bathymetry

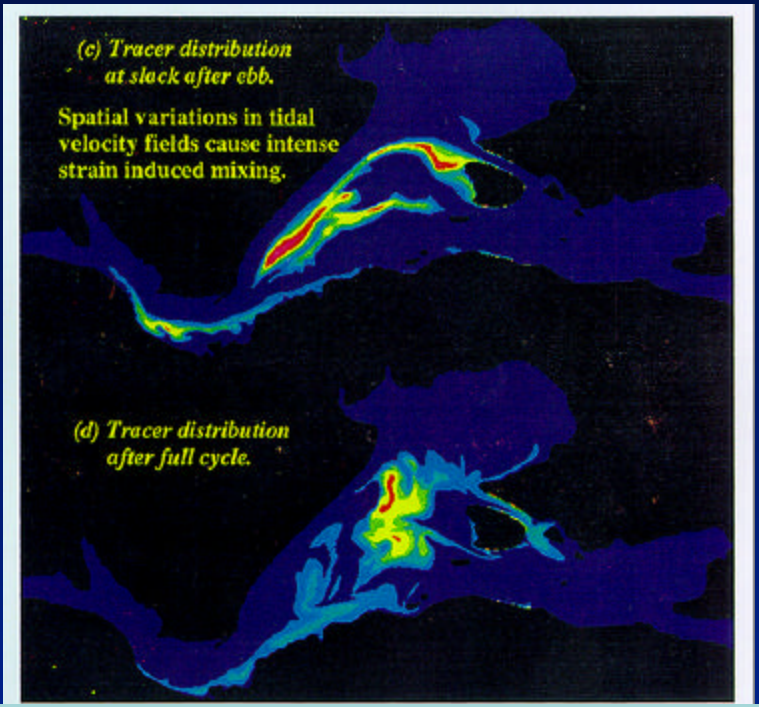
Tidal dispersion in Franks Tract



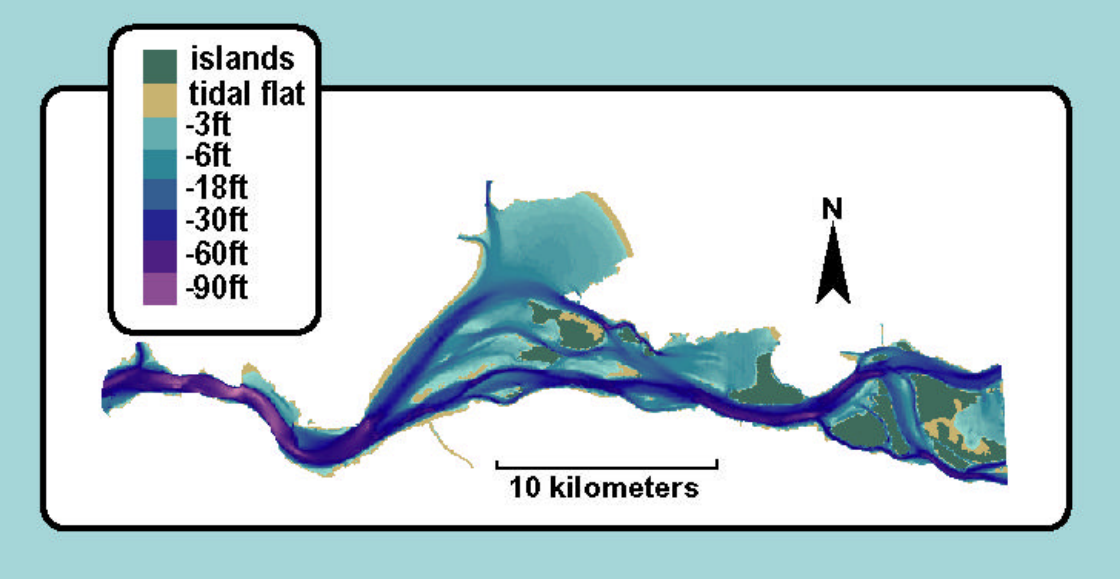
Calculations by N. Monsen

Local bathymetry

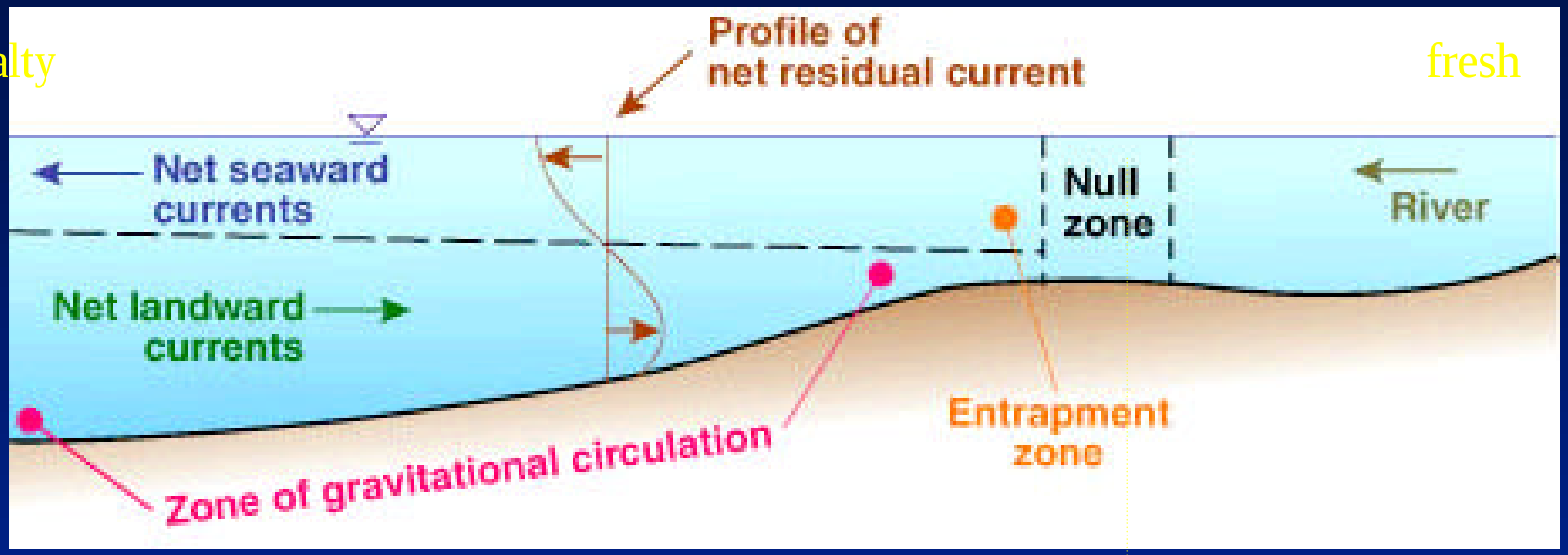
Tidal mixing in Suisun Bay

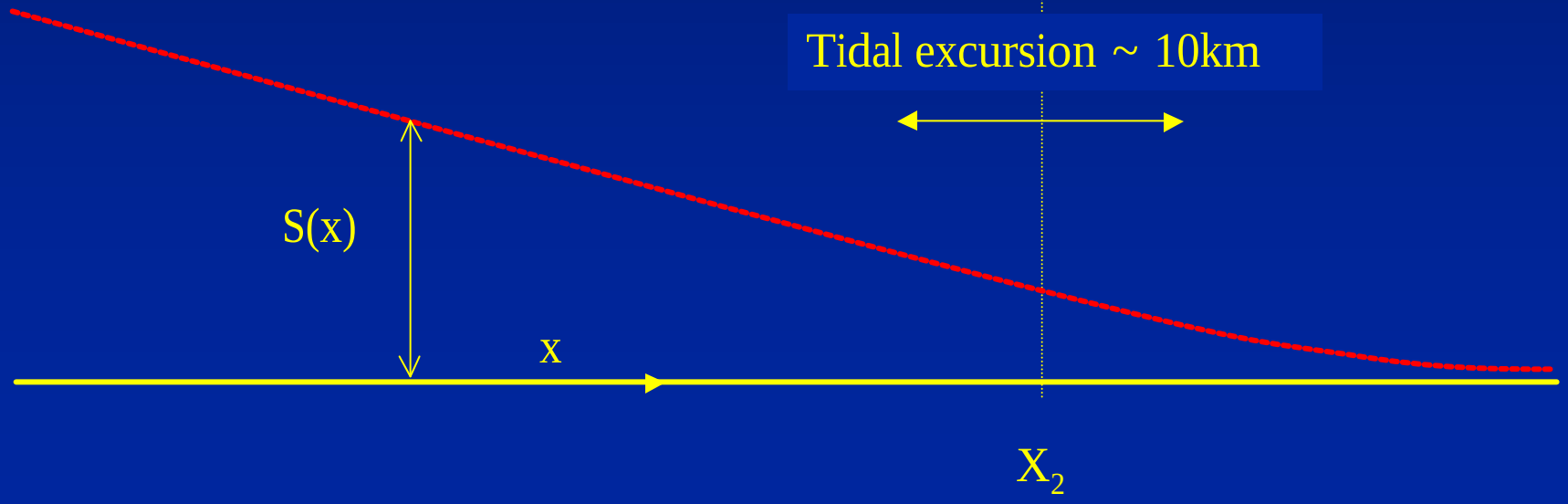


Dispersion via tidal shear in Suisun Bay (2D calculations by Jon Burau)

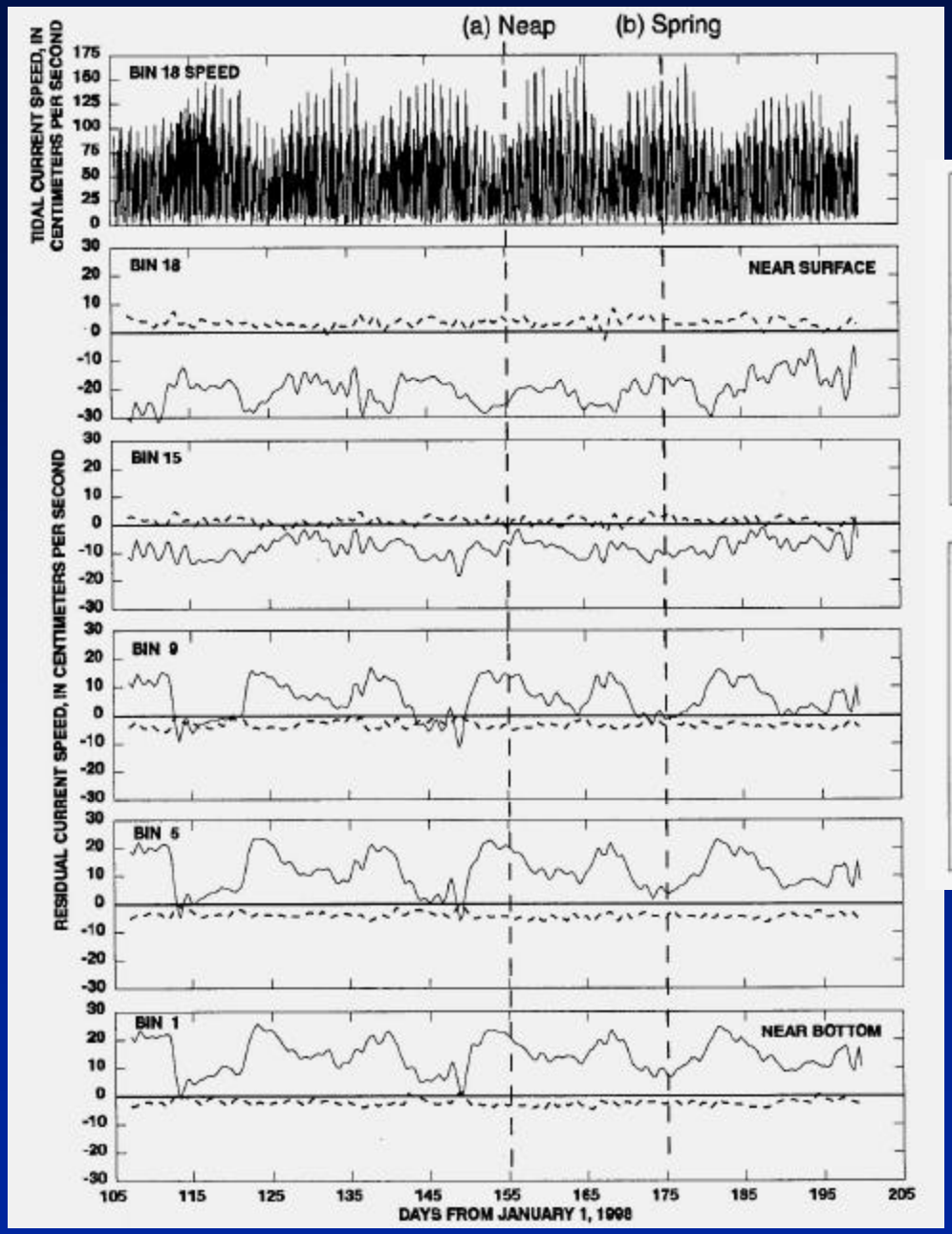


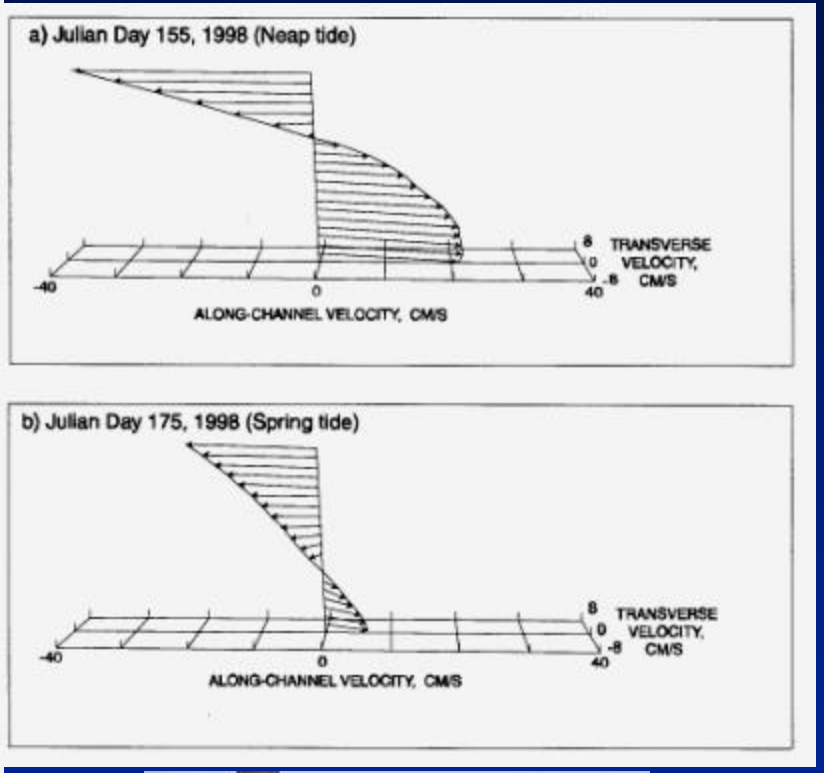
Gravitational circulation (traditional)



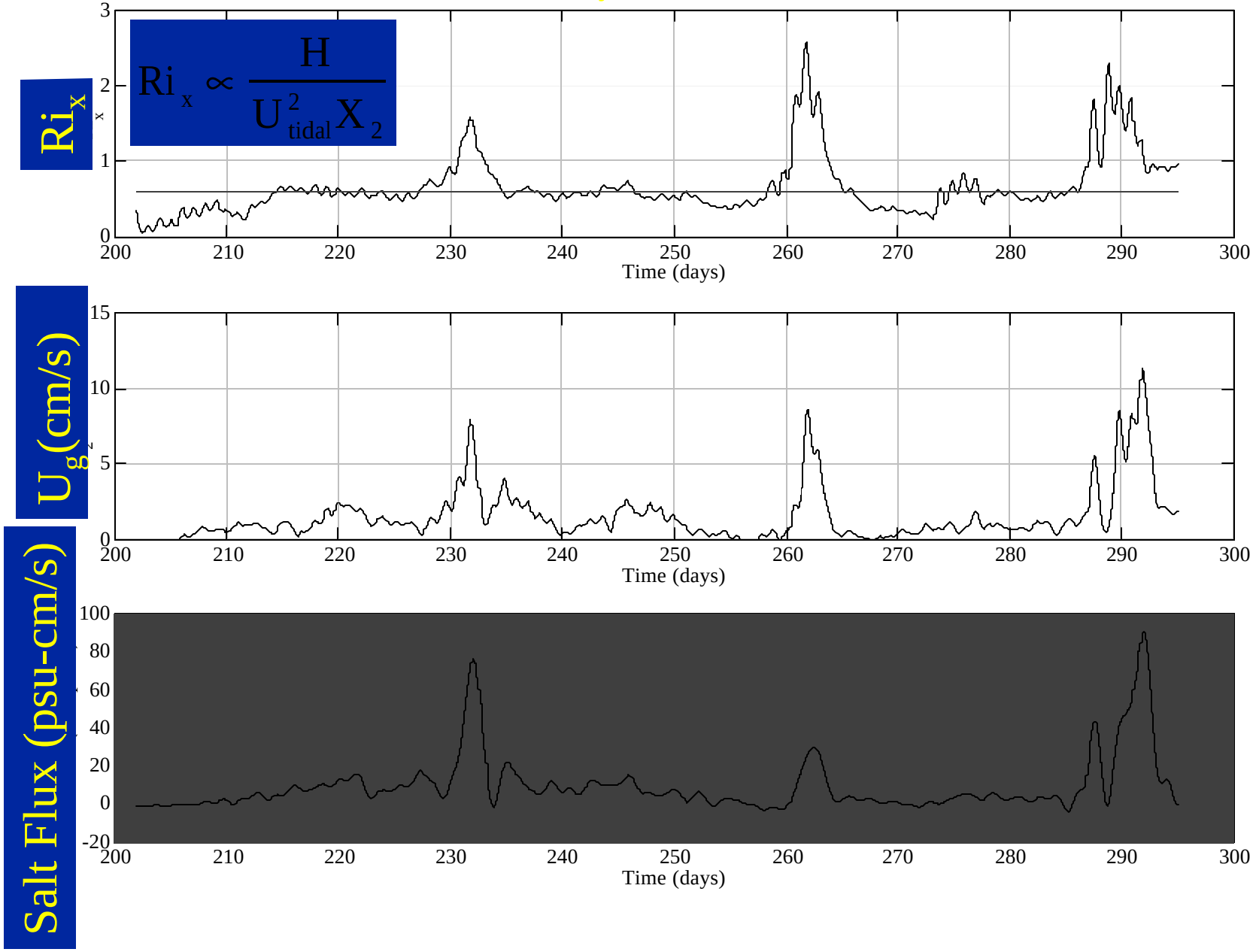


ADCP in channel near Richmond Bridge

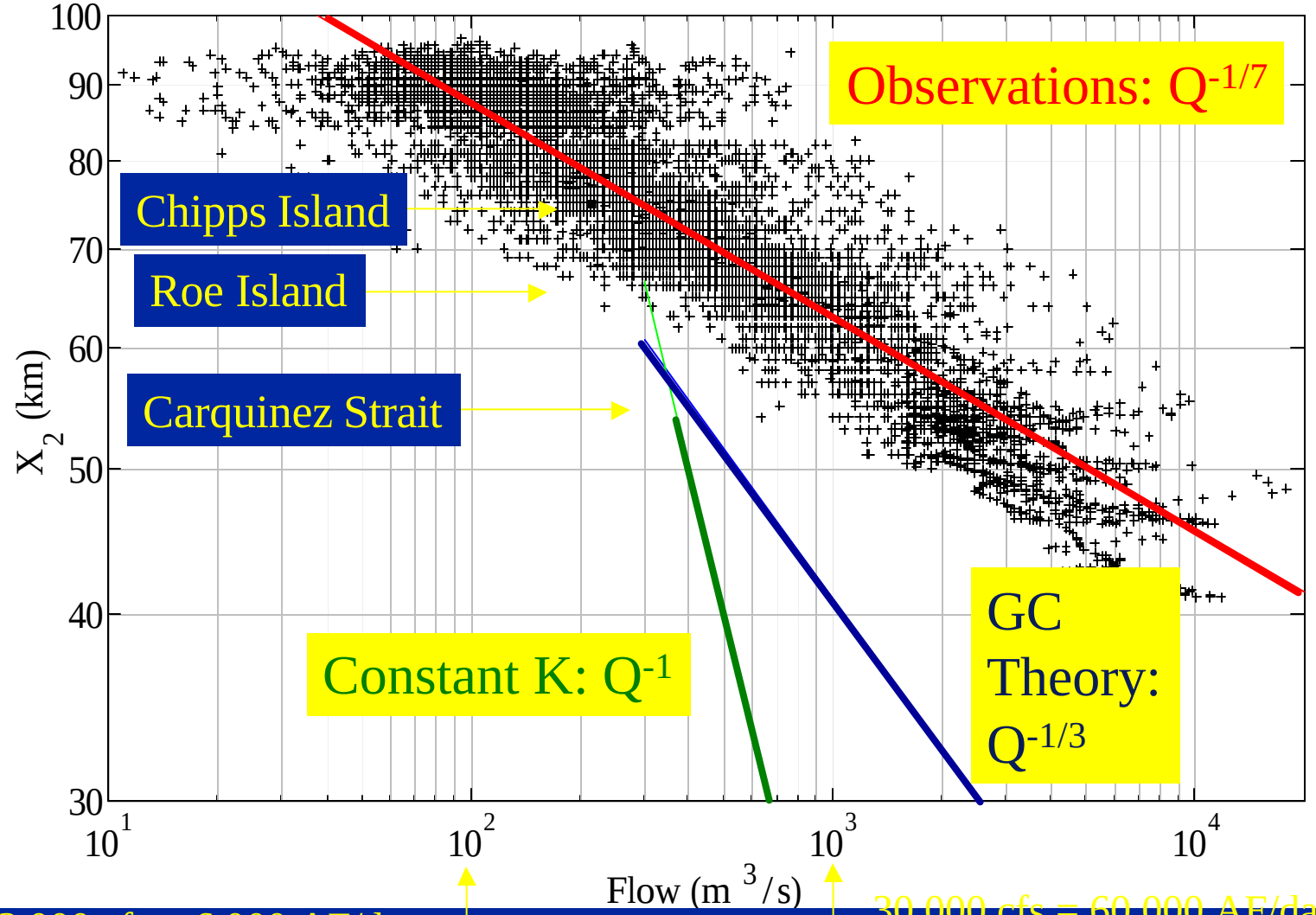




Salt flux and stability in Susiun Cut 1995



Source: Monismith et al J. Phys. Ocean. 32(11): 3003-3019, 2002



3,000 cfs = 6,000 AF/day

30,000 cfs = 60,000 AF/day

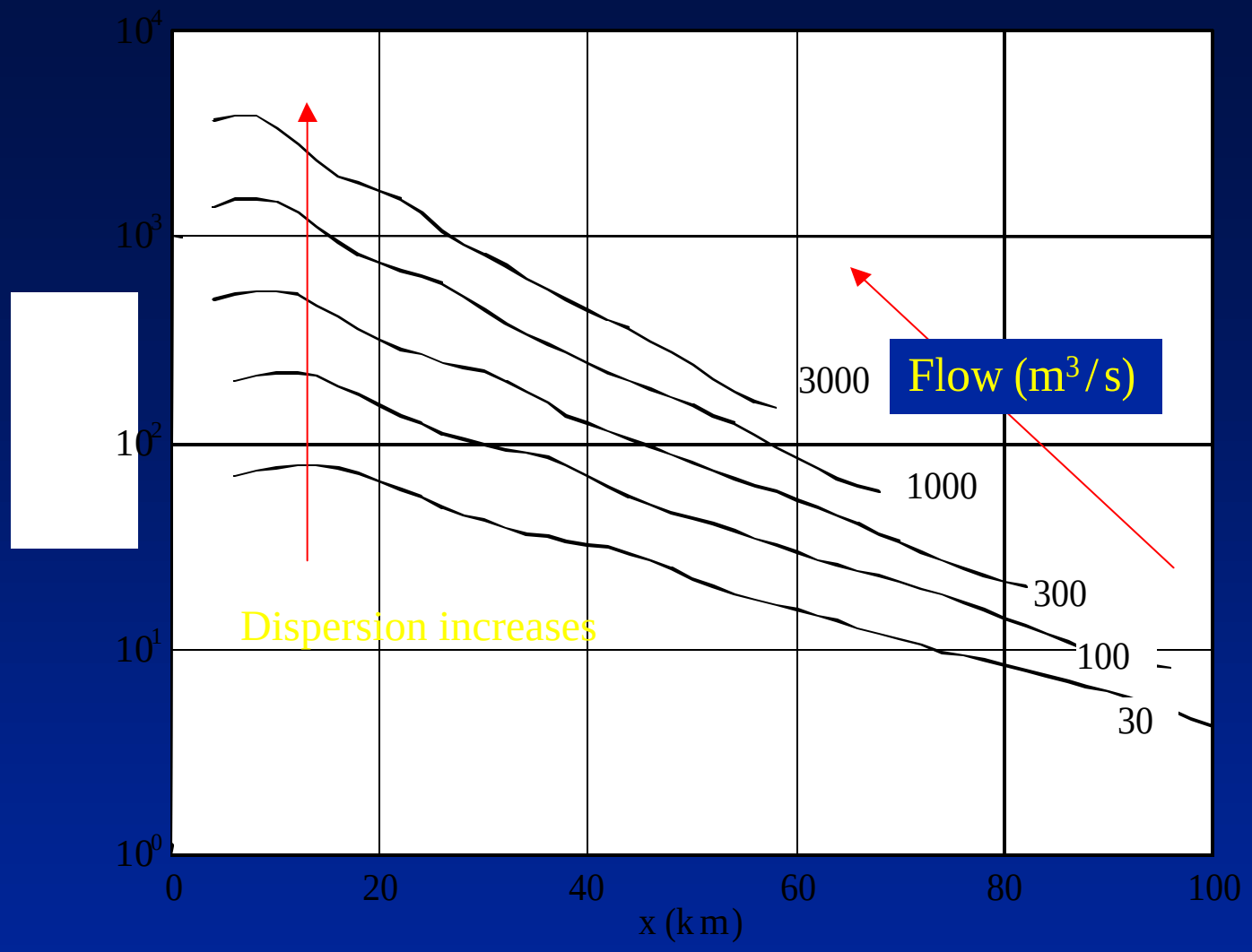
Position of X_2 determines:

- Location of given salinity ranges
- Strength of gravitational circulation
- Strength of vertical density variation

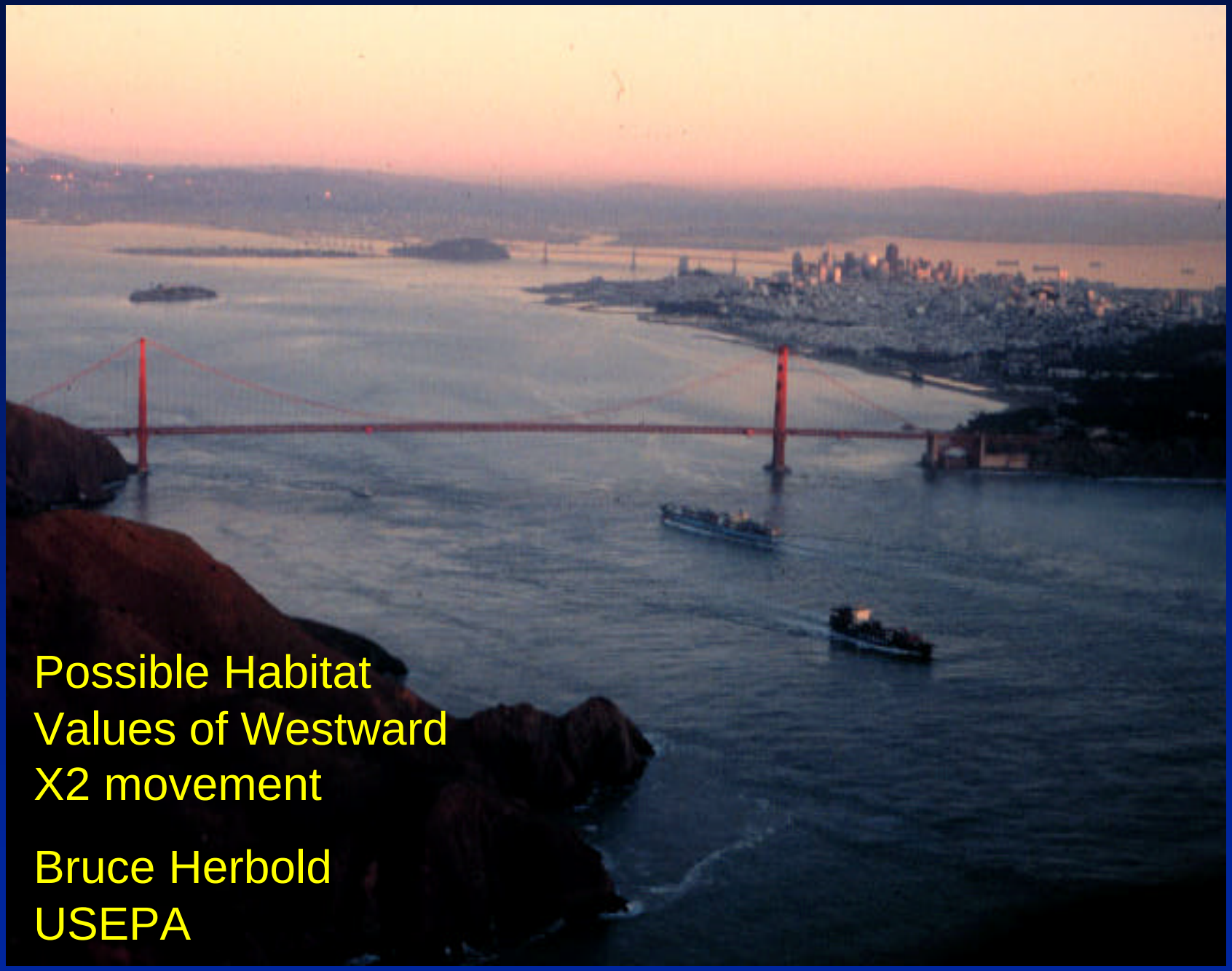
All of these mean basic differences in physics and transport up and downstream of X_2, and as X_2 moves downstream

Water ops: “Resilience” of salt field means that as Q increases dQ/dX_2 decreases - flow control of X_2 weakens

4 7:32



Dispersion - largely due to gravitational circulation -changes with Q

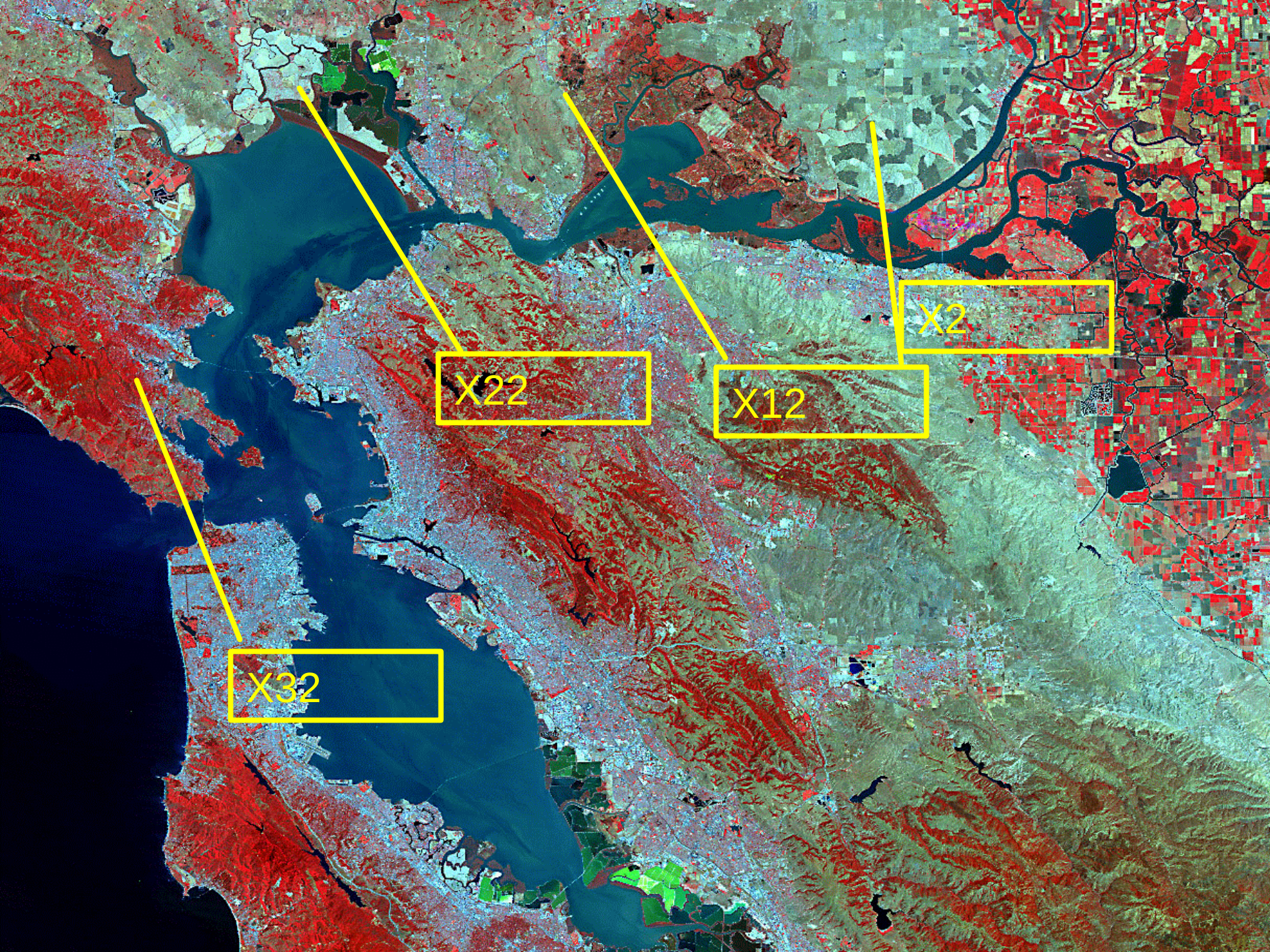


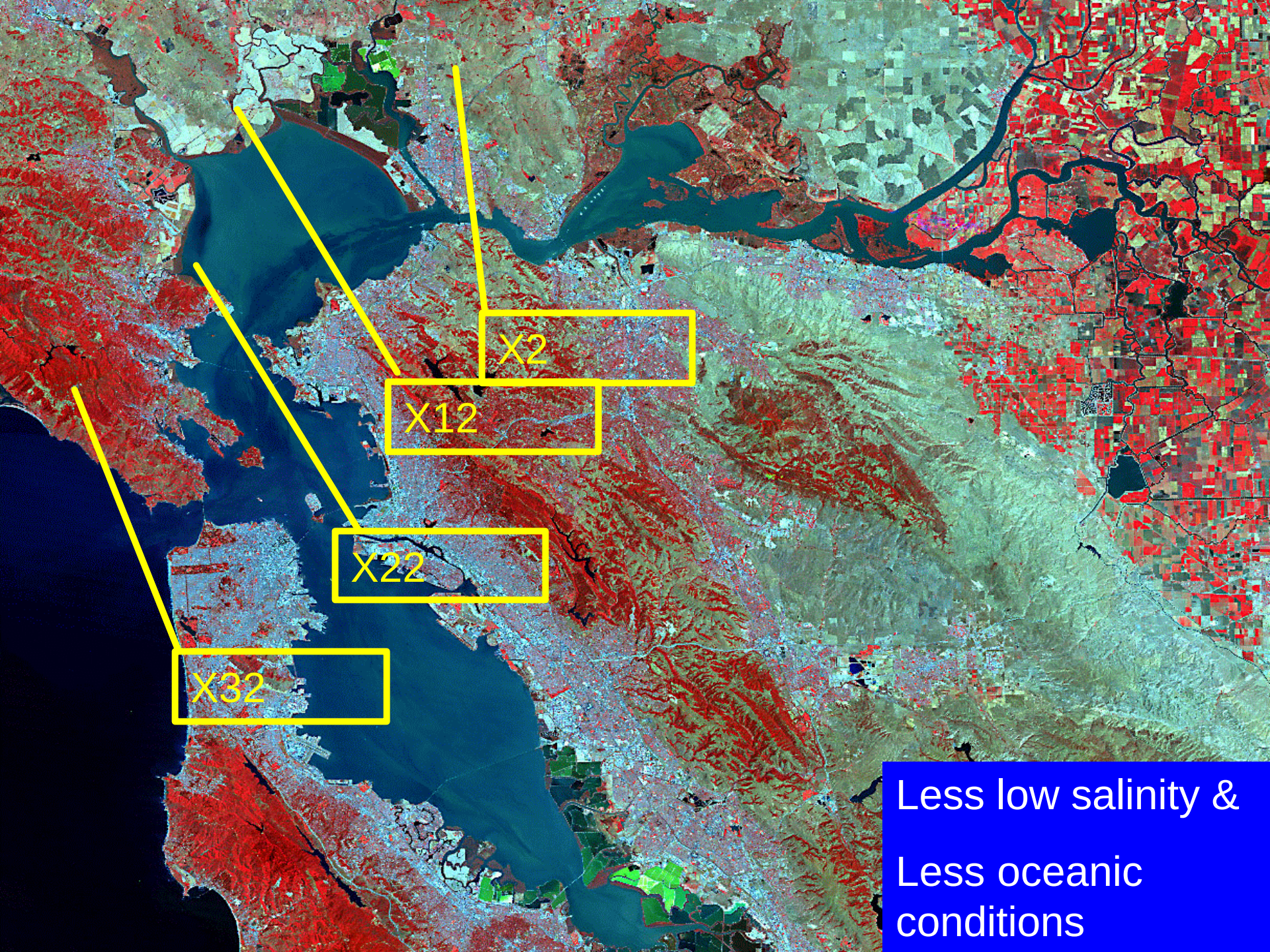
Possible Habitat Values of Westward X2 movement

Bruce Herbold
USEPA

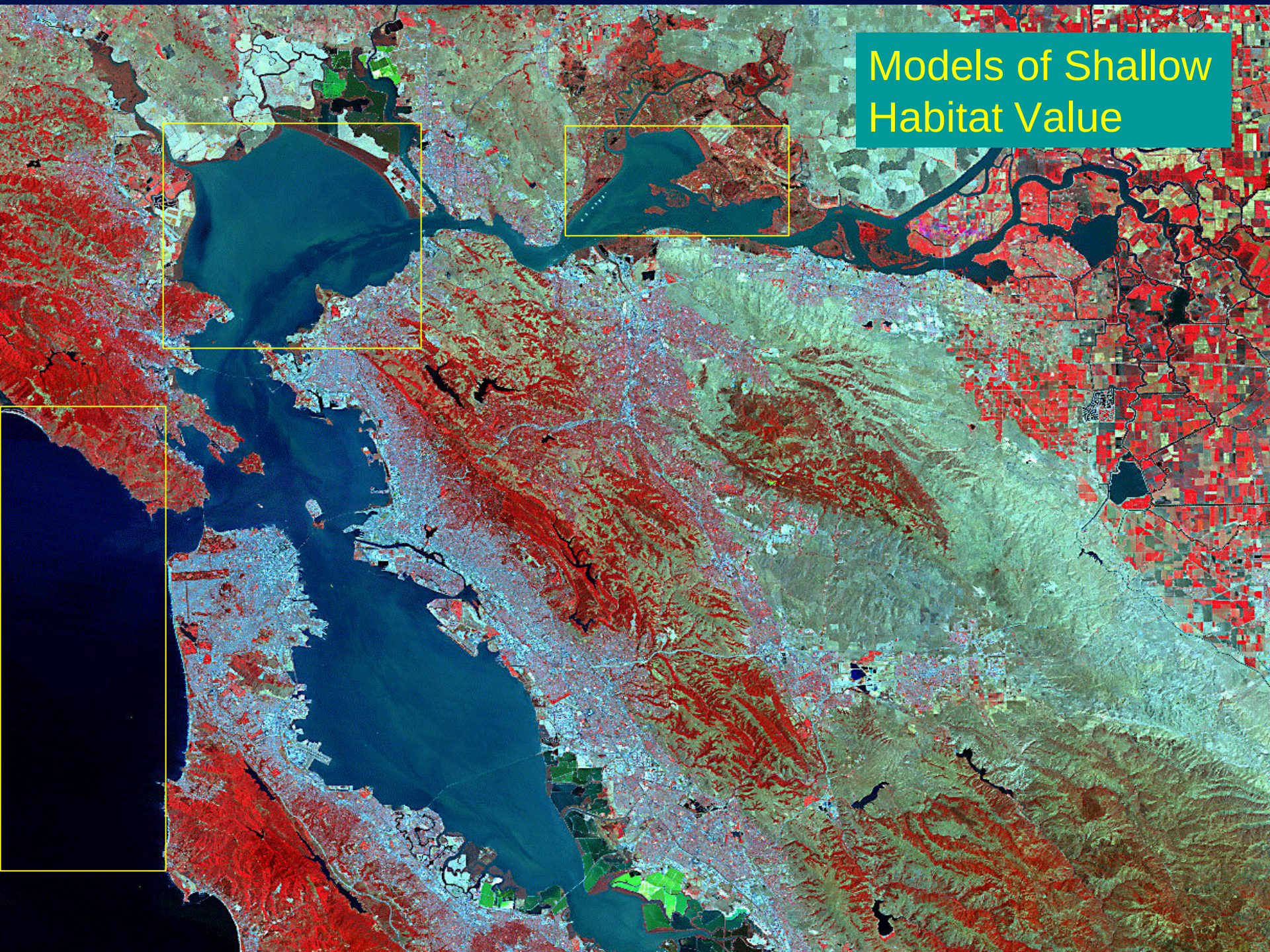
Species of interest

- Species whose abundance has apparently increased when X2 decined
  - Longfin smelt
  - Crangon
  - Mysis
  - Striper survival
  - Starry flounder
  - Delta smelt*
- No apparent population level impact of X2
  - Bay/arrow goby
  - English sole
  - Top/jacksmelt
  - Embiotocids
  - White croaker
  - Staghorn sculpin

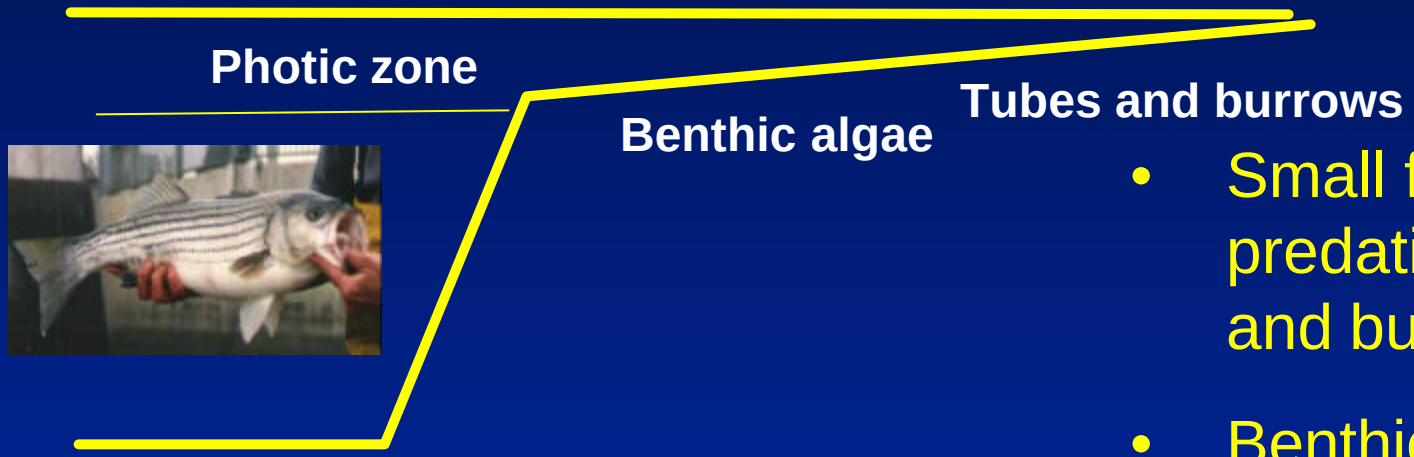

X22
X12
X2
X32


X2
X12
X22
X32
Less low salinity &
Less oceanic conditions

Models of Shallow Habitat Value

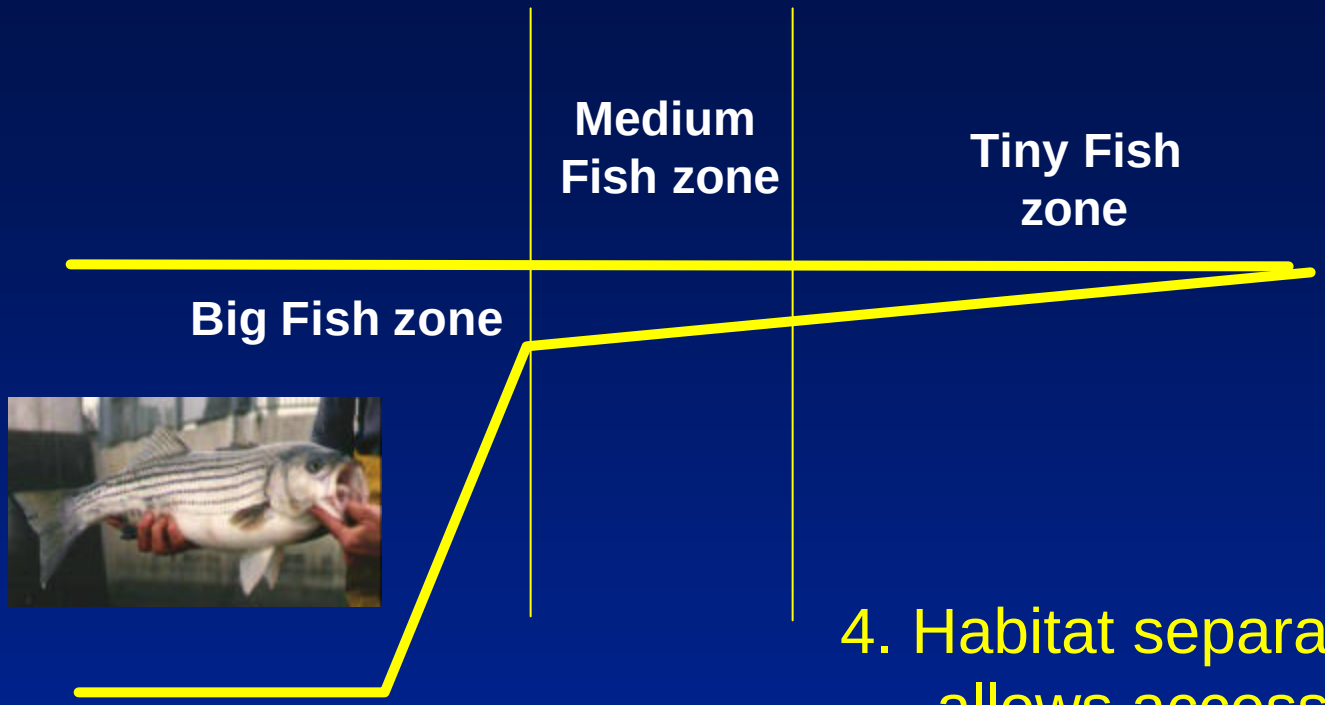


Models of shallow habitat values



- Small fish escape predation in shallows and burrows
- Benthic algal community supports high prey densities
- Small fish distributed over wide area reduces predator effectiveness

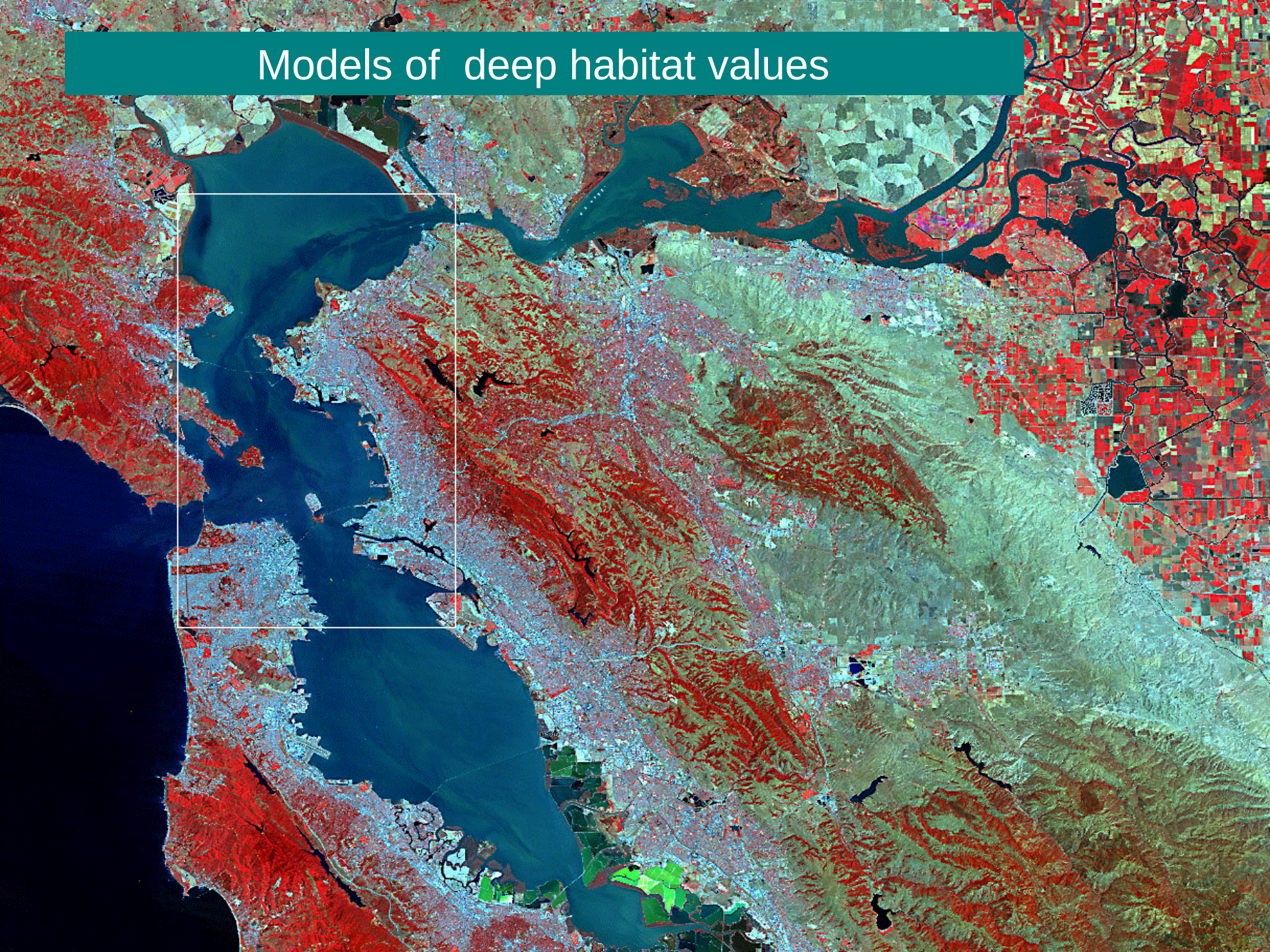
Models of shallow habitat values



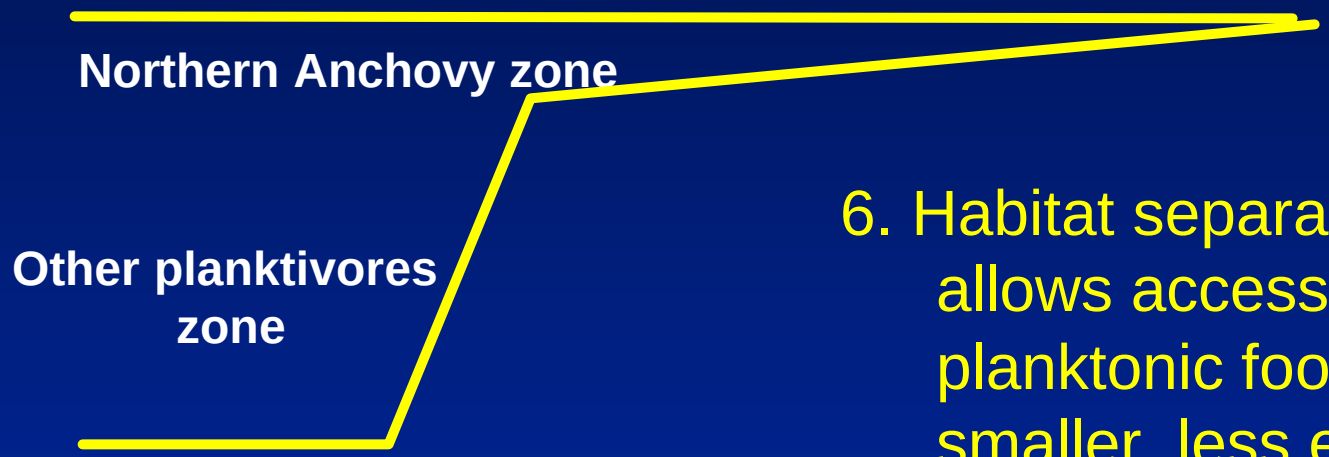
4. Habitat separation allows access to planktonic food by smaller, less efficient foragers

5. Low tides expose medium size fish to maximum predation

Models of deep habitat values



Models of deep habitat values

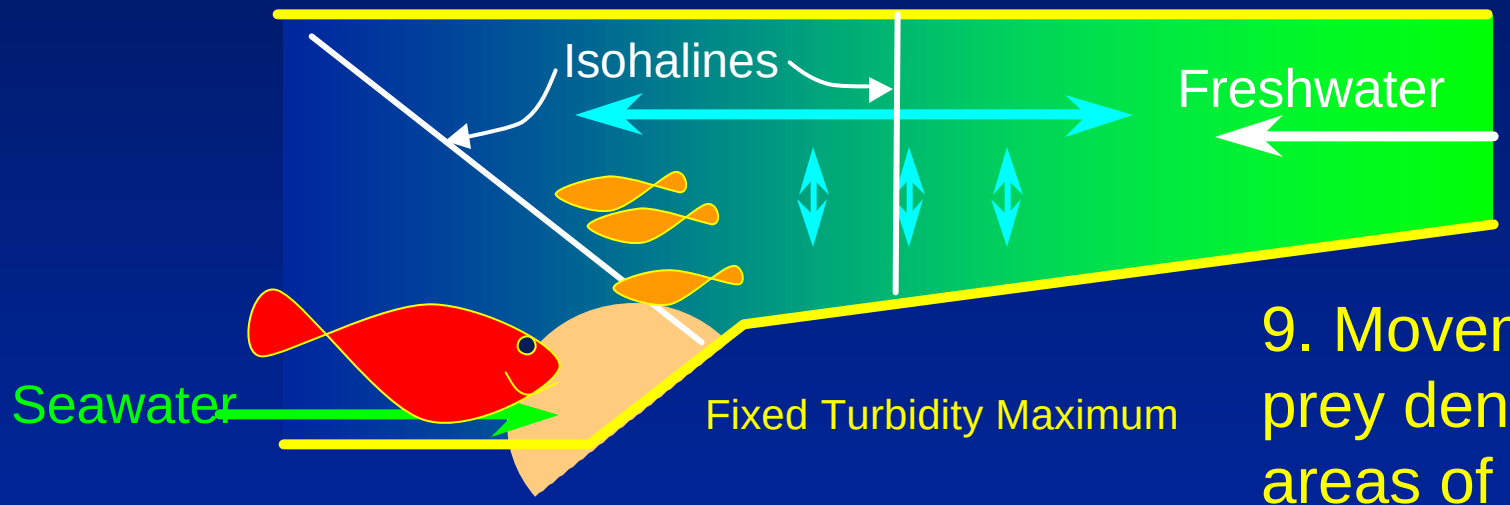


6. Habitat separation allows access to planktonic food by smaller, less efficient foragers

7. Reduces risk from visual predators

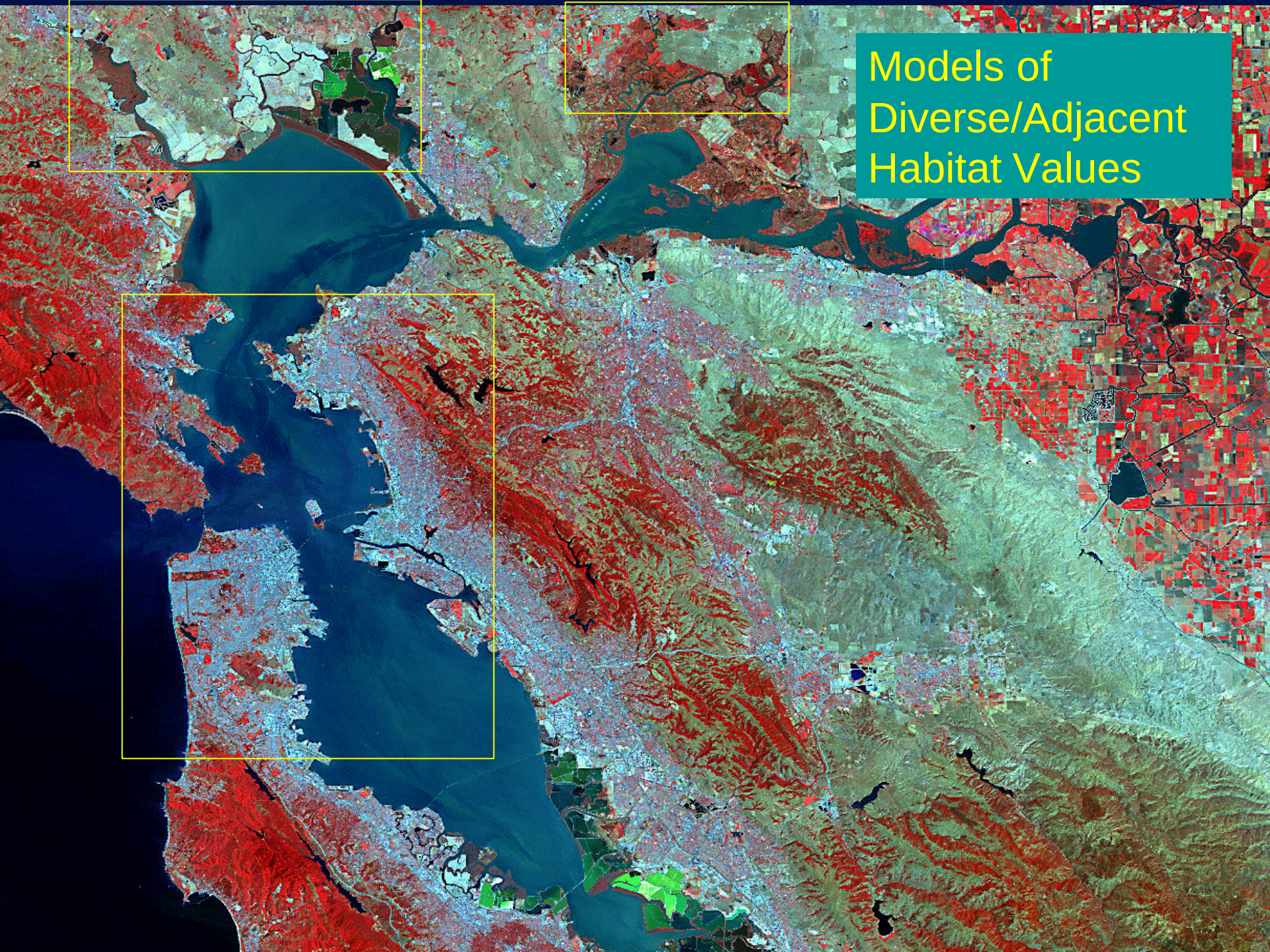
8. Thermal refuge

Models of Deep habitat values

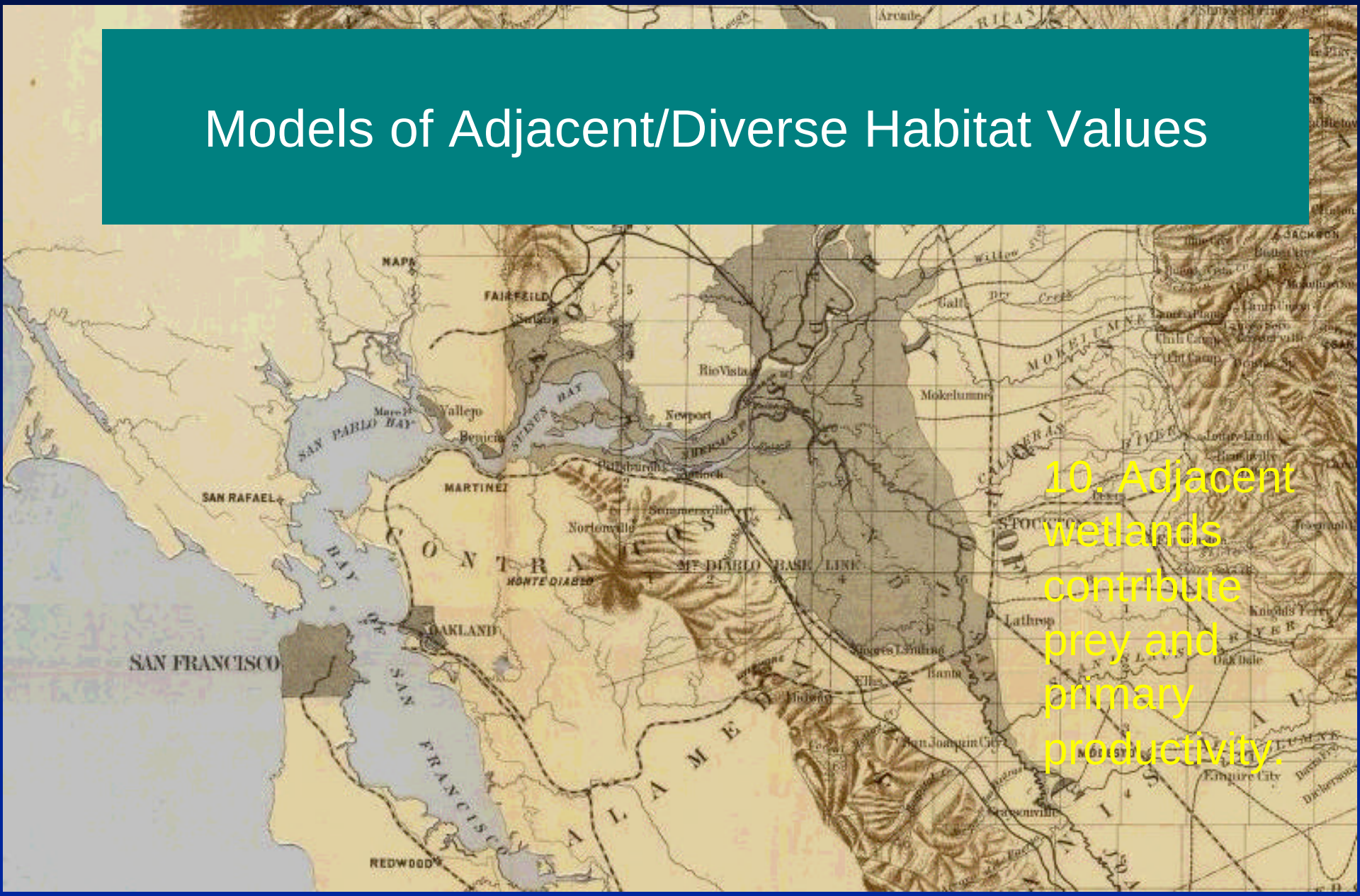


9. Movement of prey densities into areas of shears and gravitational flows enhance predation

Models of Diverse/Adjacent Habitat Values



Models of Adjacent/Diverse Habitat Values



10. Adjacent wetlands contribute prey and primary productivity.

Models of LSZ Habitat Expansion

11. Turbidity reduces visual predator effectiveness.

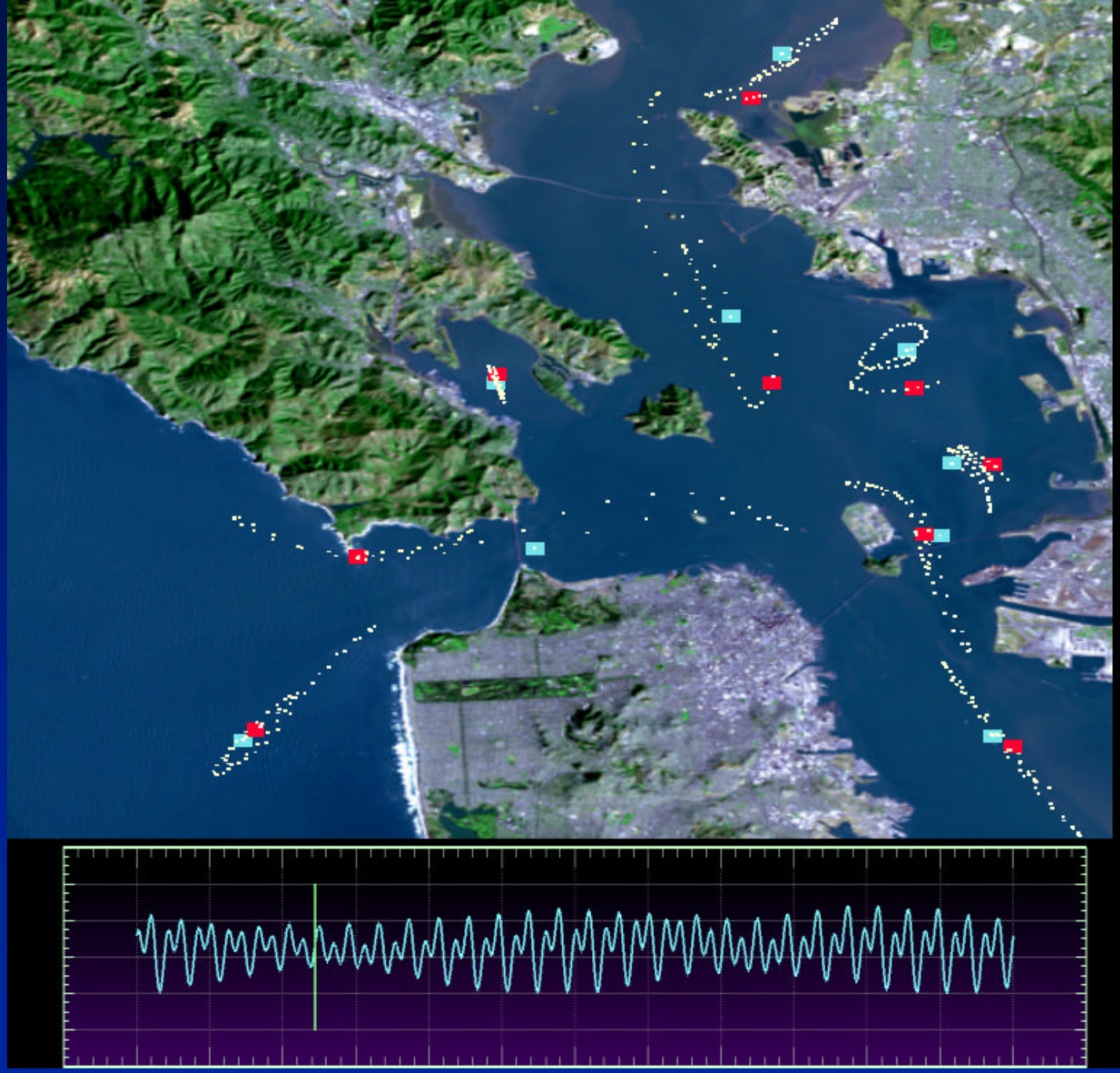
12. Complex morphology captures low salinities between X2 and western delta

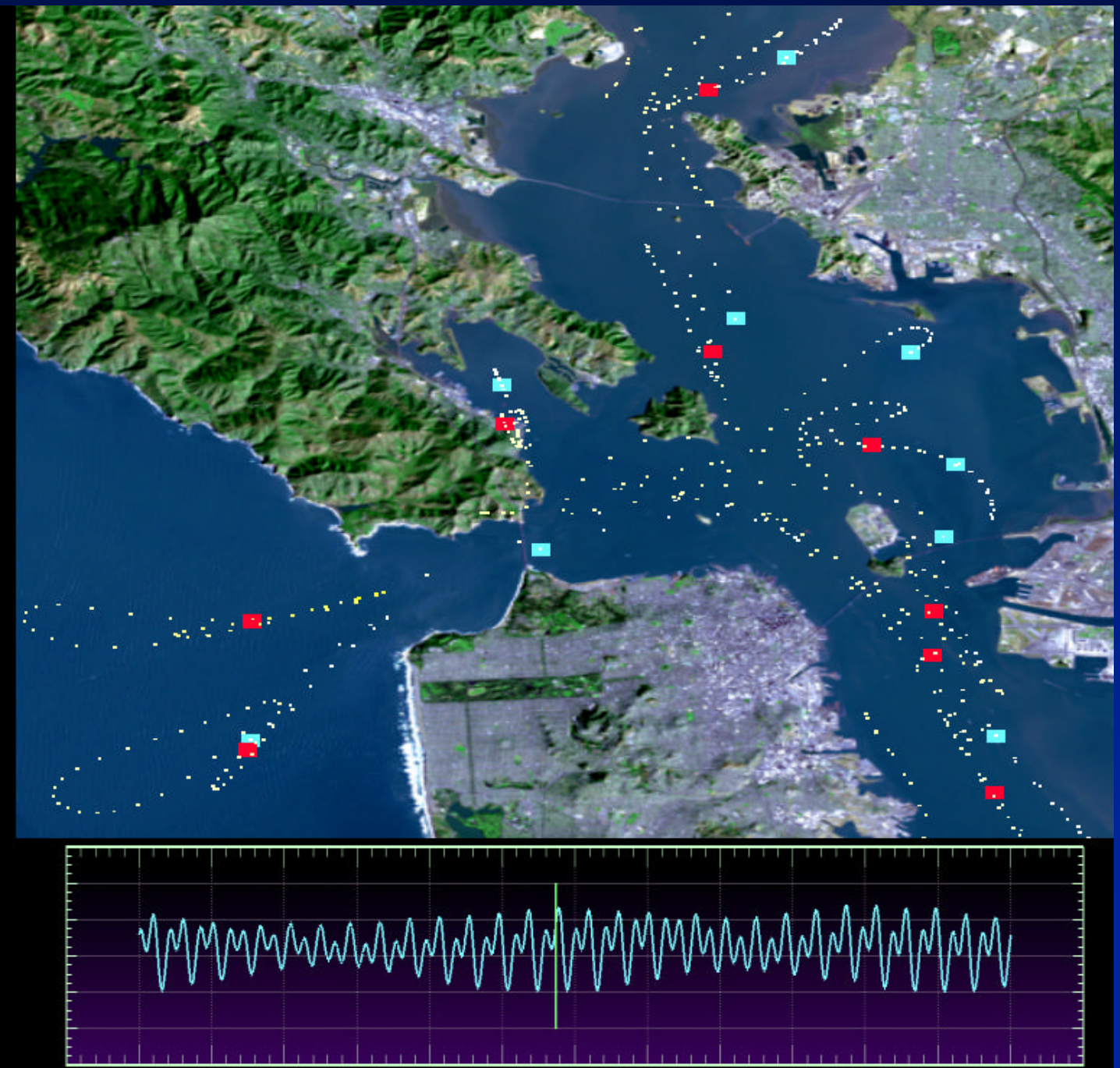
Models of Greater Habitat Connectivity Value

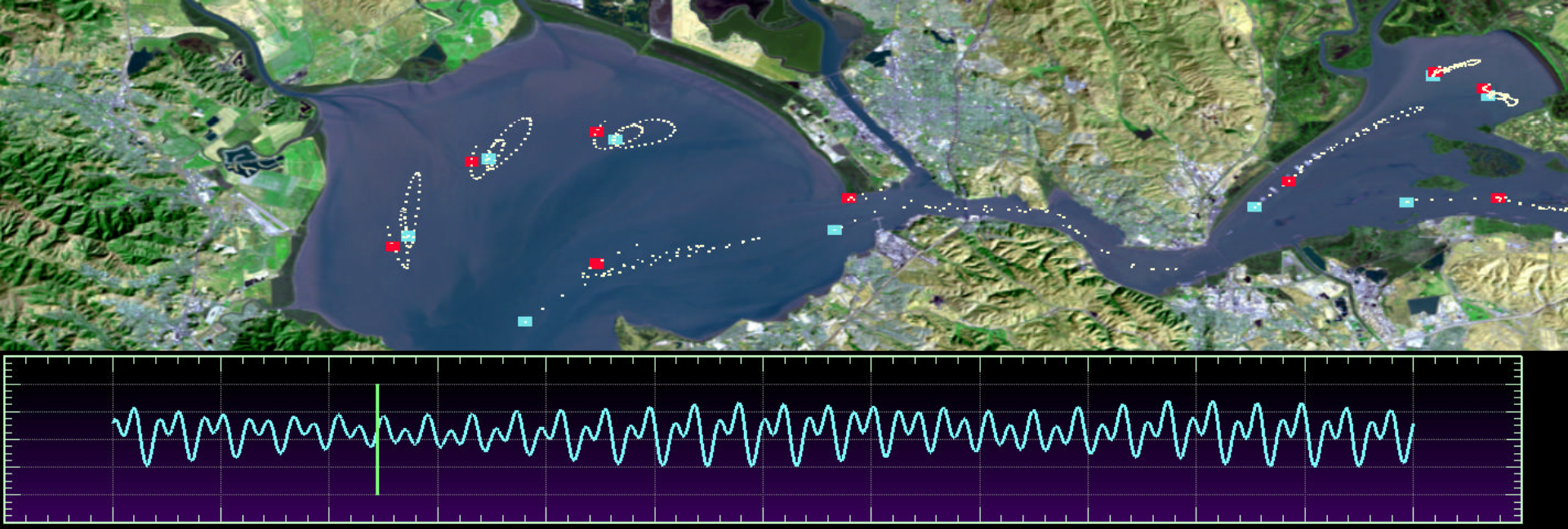
13. Different life stages find best habitats.

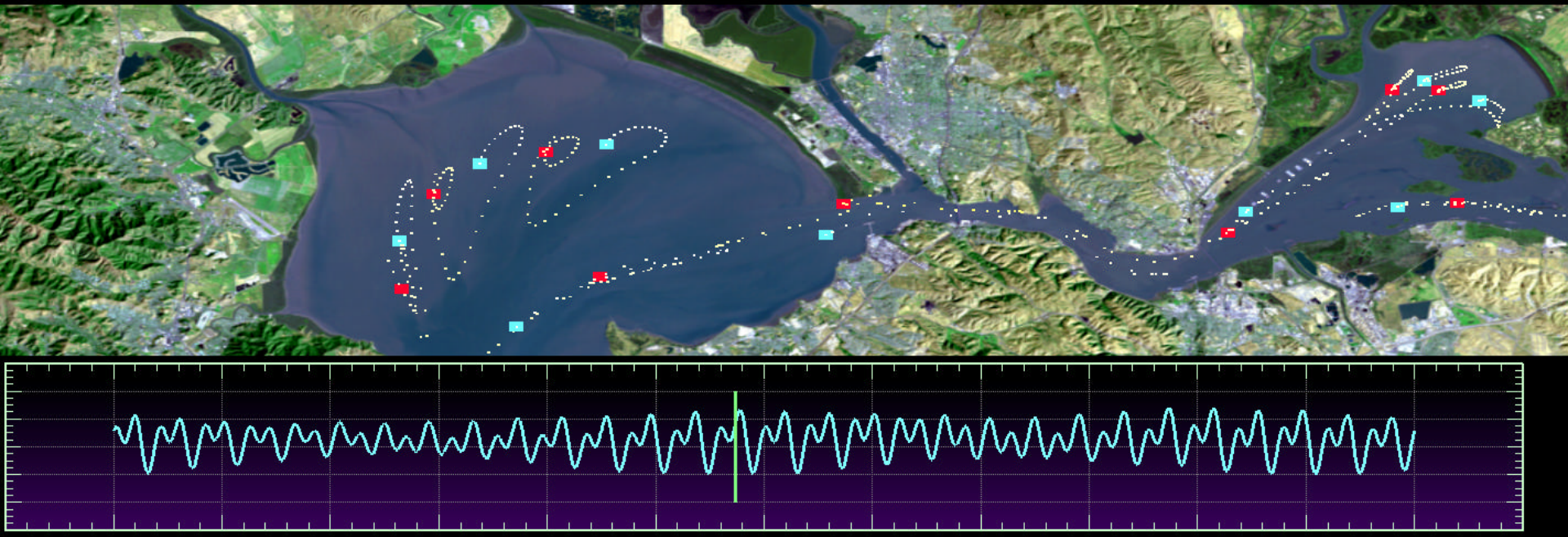
14. Offshore productivity available.

15. Greater tidal excursions distribute individuals into better habitats. (more winners)





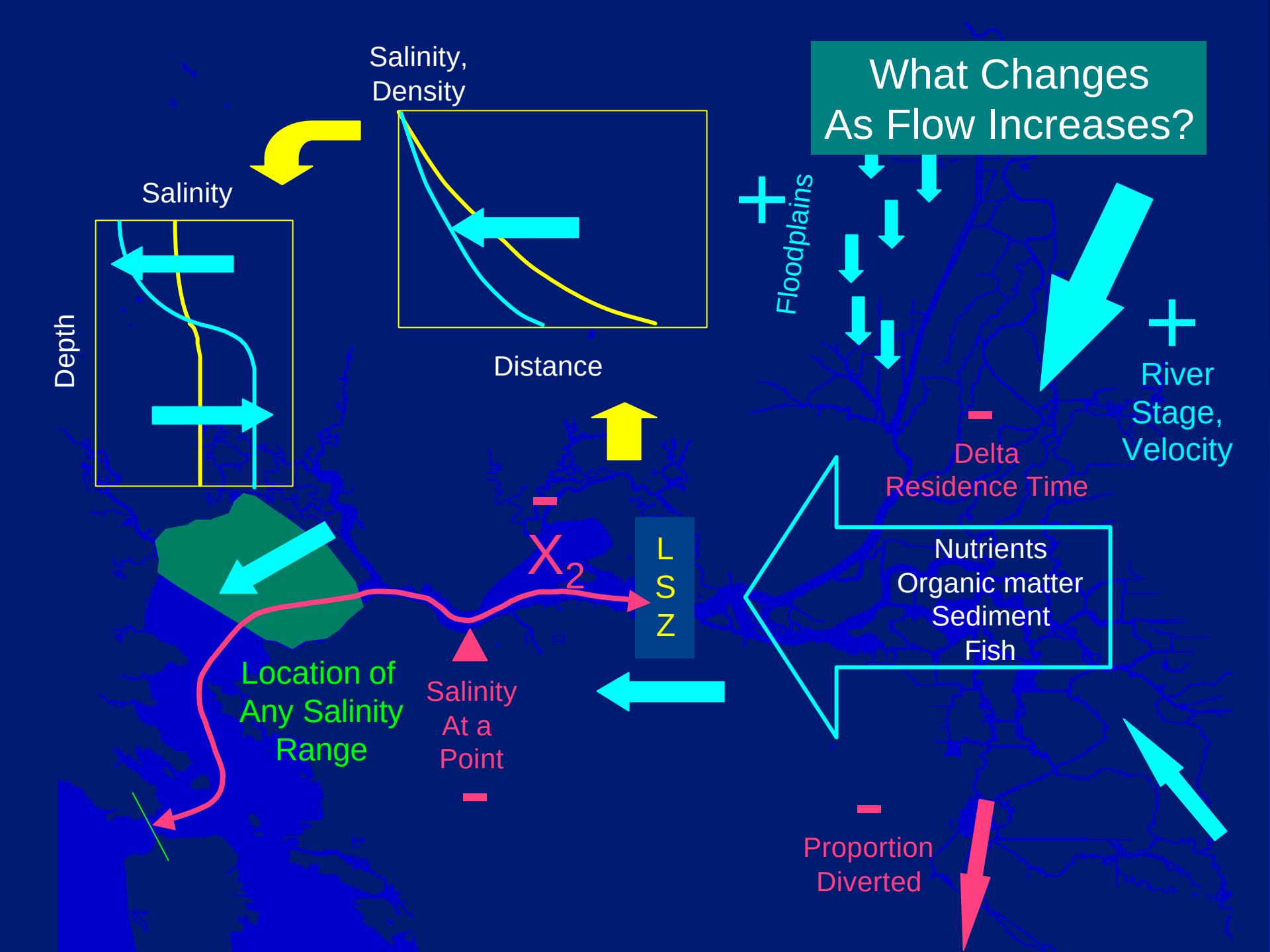




Models of Habitat Values: Summary

Mechanism	Which species?
I. Shallow access	Gobies, jack/topsmelt, Crangon, Croaker, LFS, DS, Mysids, flatfish Yearling SB
II. Deep access	Mysids, LFS, SB, Croaker, Jacksmelt
III. Adjacent Habitat Access	Mysids, Embiotocids, Croakers, Sby, SF, Crangon, Staghorn, Gobies
IV. LSZ Expansion	LFS, DS, SB, Mysids, Top/Jacksmelt, Crangon
V. Habitat conectivity	Croakers, SB, top/jacksmelt, LFS, Embiotocids, flatfish, gobies

What Changes As Flow Increases?



Species

	CF	PH	SF	WS	AS	SB	LF	DS	ST	CS	NM
Spawning Habitat Space		○		•	●	○	•	●	○	○	
Spawning Habitat Access				•	◎	○			○	○	
Co-occurrence of Food		●		•	•	●	●	●	●	•	•
Rearing Habitat Space	○	●	●	●	●	○	○	●	●	•	•
Predation Avoidance: Turbidity		•			•	○	•	•	•	○	●
Predation Avoidance: Shallow	•	•	•						•	○	
Predation Avoidance: Encounter	•						•	●	•	•	
Reduced Entrainment (CVP-SWP)			•	○	○	○	○	○	•	○	○
Reduced Entrainment (PG&E)	•		•		○	○	●	●	•	○	•
Reduced Entrainment (Agricultural)			•		•	○	•	●	•	•	•
Toxic Dilution	•	•	•	•	•	○	•	•	●	•	•
Transport	•			○	○	○	○	•	•		
Gravitational Circulation Strength	●	○	●			●	●	●			●
Entrapment Zone Residence Time						●	●	●			●
Temperature (As affected by flow)					•	•				○	•
Strong Migratory Cues	•	•	•	●	○	•			•	○	
Higher Production of Food	•	•			●	●	●	●	•		●

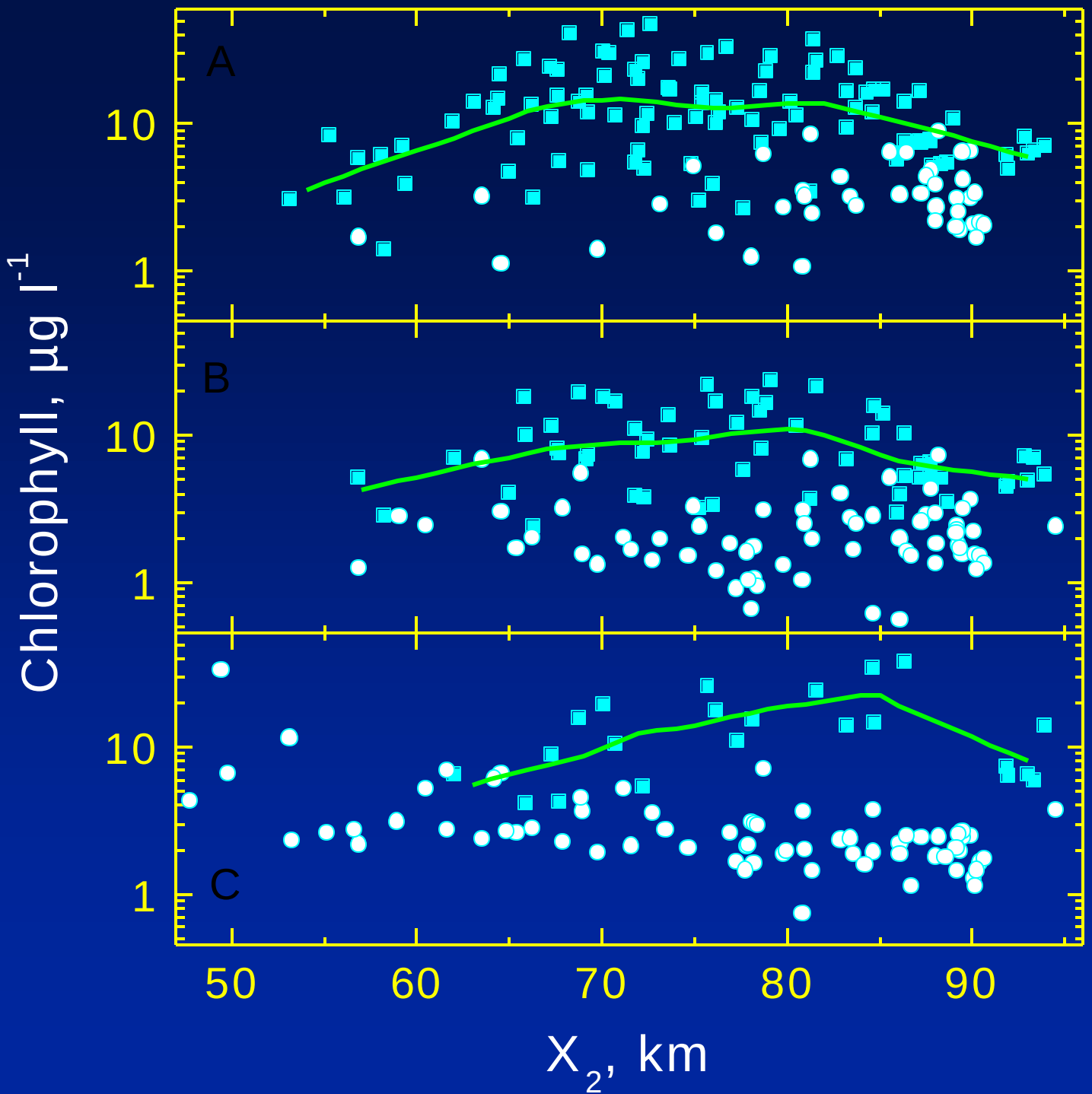
Relative Uncertainty

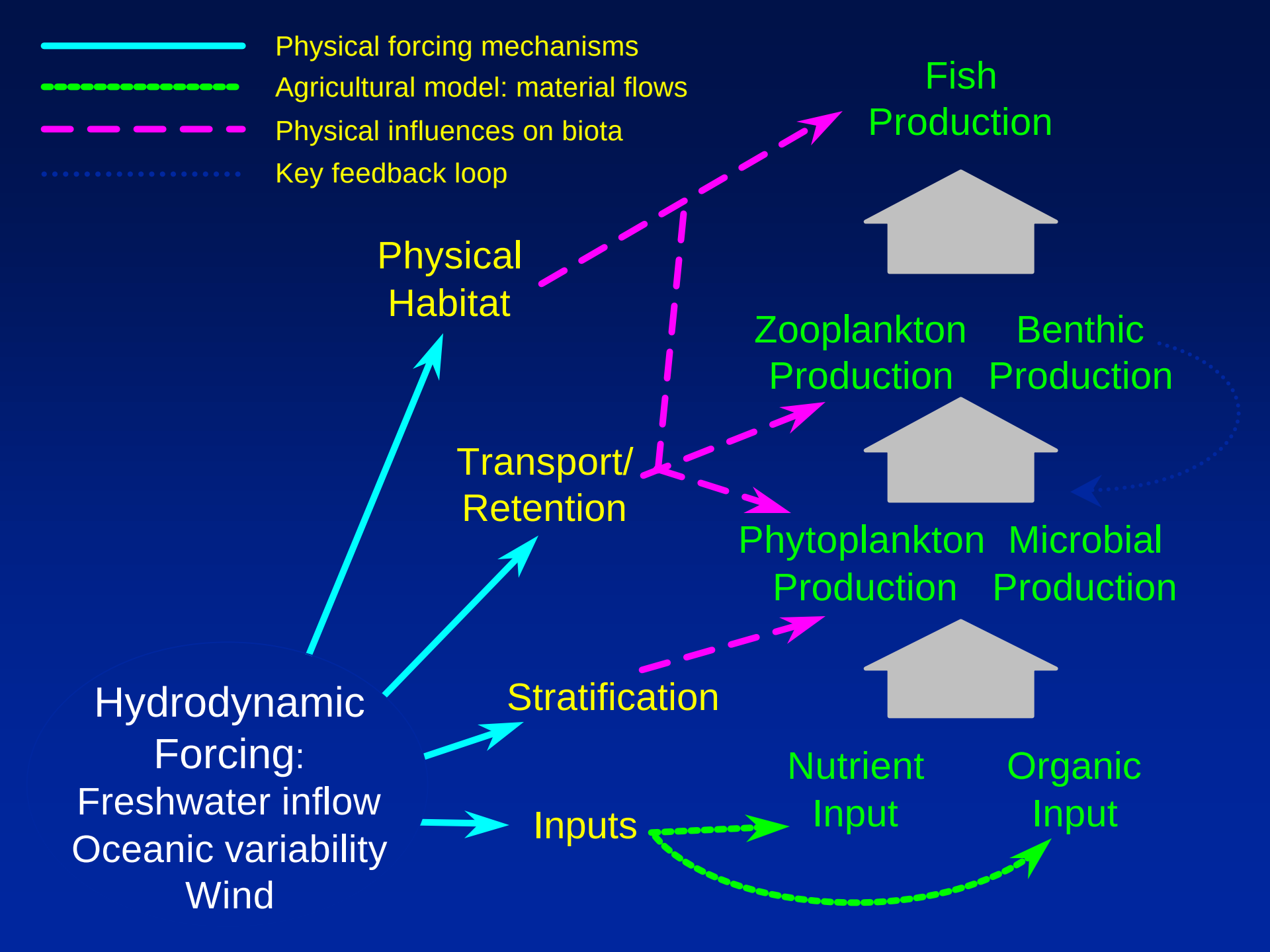
- • Higher
- ○ Lower

Importance

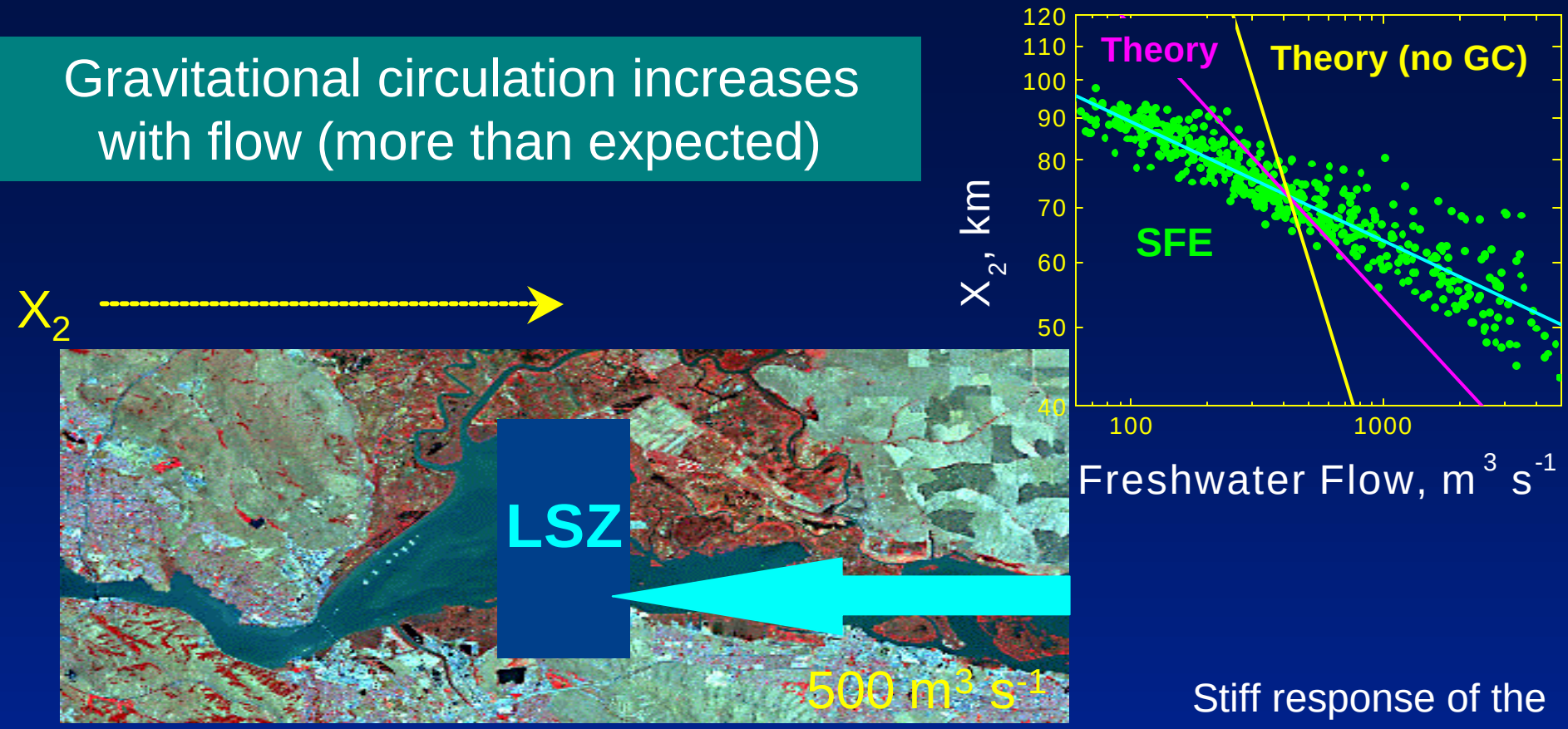
- ● High
- • Low

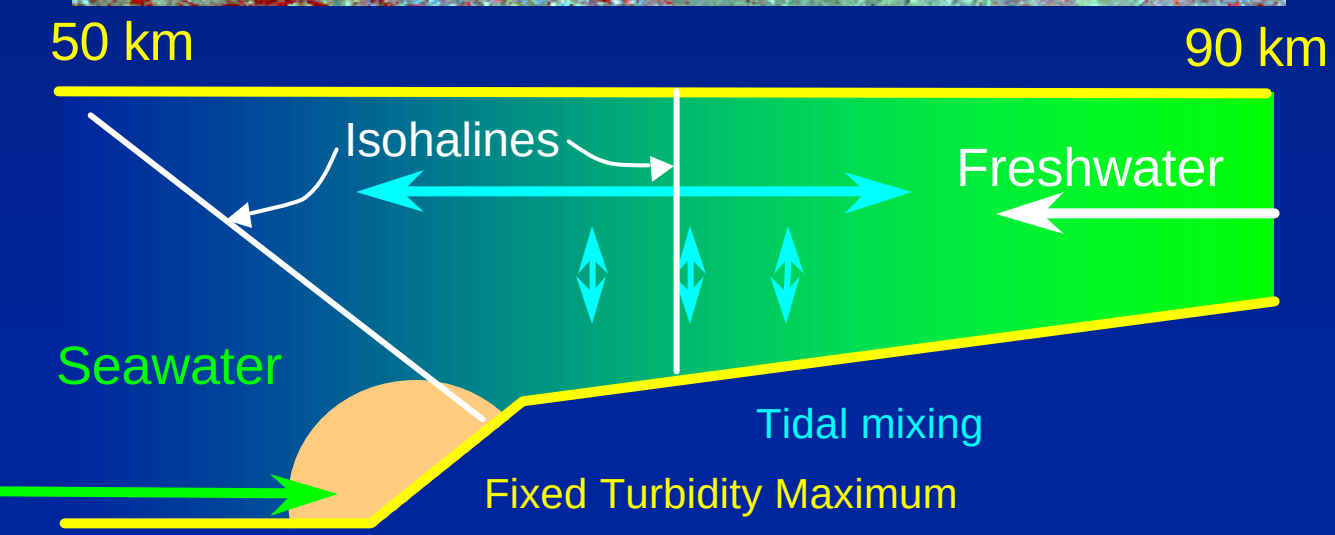
● Upstream Effect


A
B
C
10
1
10
1
10
1
Chlorophyll, µg l-1
50
60
70
80
90
X2, km


Physical forcing mechanisms
Agricultural model: material flows
Physical influences on biota
Key feedback loop
Fish Production
Physical Habitat
Zooplankton Production
Benthic Production
Transport/ Retention
Phytoplankton Production
Microbial Production
Stratification
Hydrodynamic Forcing:
Freshwater inflow
Oceanic variability
Wind
Inputs
Nutrient Input
Organic Input

Gravitational circulation increases with flow (more than expected)

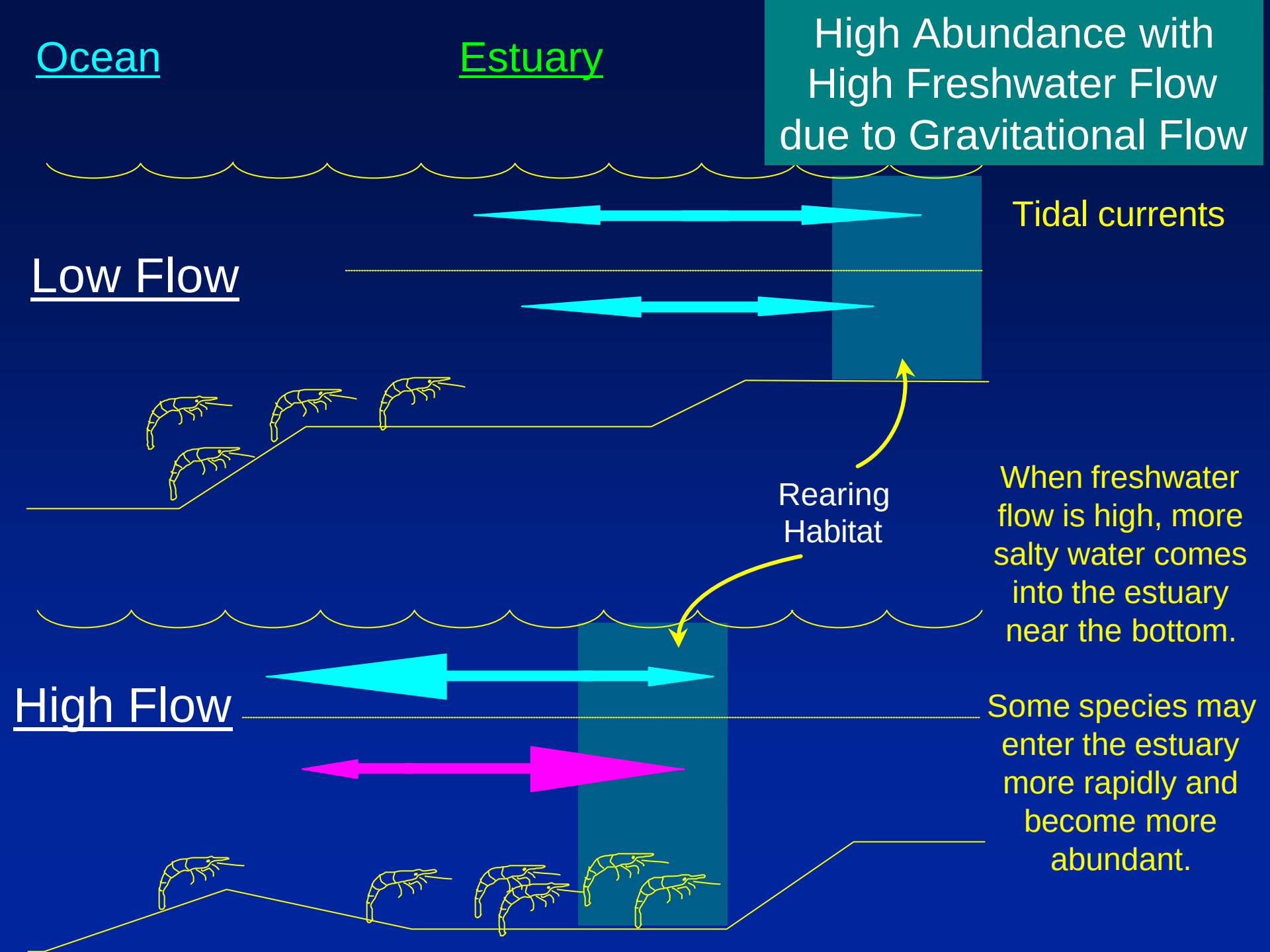




Stiff response of the salt field indicates gravitational circulation in deeper channels.

Source:
Monismith et al. 2002

High Abundance with High Freshwater Flow due to Gravitational Flow



Investigations into X_2:

Entrapment zone and related studies (1994-96)

Modeling

Developing research plan

Investigating monitoring data