Session Title: Marine and Estuarine Fisheries: Research, Conservation, and Management in a Changing Climate.

Session Moderator: Cynthia LeDoux-Bloom, Staff Scientist, Dept. of Water Resources

Abstract:
California has the largest human population in the United States with 90% living within 15 miles of coast. Subsequent large-scale development has decreased and altered the aquatic habitat available to marine and estuarine dependent fish species to the extent that some fisheries are closed (e.g. Chinook salmon) while others are in decline (e.g. Striped bass). Californian's burgeoning human population depends on water exported from the Sacramento-San Joaquin watersheds usually pumped from the San Francisco Estuary, the largest estuary on the west coast. Water exports significantly change the flow regimes and tidal mechanisms within the San Francisco Estuary and near-shore coastal waters. Fluxes in both the marine and estuarine habitat quality has contributed to the listing of several estuarine dependent fish species (e.g. delta smelt, coho salmon, and green sturgeon) by state and federal agencies.

Anticipated future climate change has driven research, modeling, and forecasting efforts to detect and predict changes in fish populations, distributions, and assemblages resulting in new management strategies and policies. Presentations in this session glimpse into the future by linking current marine and estuarine fisheries research, conservation and management efforts with climate change.

Presentations:

1. Climatic and anthropogenic factors affecting the marine and estuarine environments.
   Joseph Merz, Ph.D., Cramer Fish Sciences, 600 NW Fariss Rd., Gresham, OR 97030. jmerz@fishsciences.net

2. Variation in response of Pacific salmon to environmental variability
   Louis W. Botsford, Ph.D., Department of Wildlife, Fish and Conservation Biology, University of California, One Shields Avenue, Davis, CA 95616. lwbotsford@ucdavis.edu

3. Forecasting returns of coho and Chinook salmon in the northern California Current: a role for high-frequency long term observations.
   William Peterson, Ph.D., NOAA-Fisheries, Northwest Fisheries Science Center, Hatfield Marine Science Center, Newport, OR 97365. bill.peterson@noaa.gov

4. Modeling the Effects of Future Freshwater Flow on the Abiotic Habitat of an Imperiled Estuarine Fish.
   Frederick Feyrer, Applied Science Branch, U.S. Bureau of Reclamation, 2800 Cottage Way, Sacramento, CA 95825. ffeyrer@mp.usbr.gov

5. Ecological Response to Climate-Change Induced Water Temperature Changes in the Sacramento-San Joaquin Delta
   Wayne Wagner, Department of Civil and Environmental Engineering, 760 Davis Hall, University of California, Berkeley, CA 94720-1710. waynestock19@hotmail.com

6. What Resource Managers and Researchers Need in Planning for Climate Change?
   Russell J. Bellmer, Ph.D., Coordinator Coho Recovery Plan, Fisheries Branch, California Department of Fish & Game, Sacramento, CA 95811. rbellmer@dfg.ca.gov

Sat Bio
Dr. Joseph Merz

Joe is a principal scientist with Cramer Fish Sciences and a Research Associate with the UC Santa Cruz. He has also worked as an environmental studies lecturer for the California State University System and as a natural resources lecturer at the University of California Extension. He has had a lifelong obsession with the aquatic environment, culminating into a 19-year career as a fisheries ecologist emphasizing study of anthropogenic effects on California salmonid streams.
Please welcome Dr. Merz

Dr. Louis Botsford
Loo is a professor of population biology at UC Davis, where he also completed his Ph.D. He was the valedictorian of Fort Bragg High School, my home town.
His chief research interests include use of age-and size-specific population models in analysis of population dynamics and management.
Please welcome Dr. Botsford.
*

Dr. Bill Peterson
Bill is a Senior Scientist at NOAA's NWFSC's Newport Field Station in Oregon, an adjunct professor of oceanography at the College of Oceanographic and Atmospheric Sciences at Oregon State University, and serves on several Ph.D. committees and advises graduate students. Bill's chief research interest include the effects of climate variability and change on zooplankton and pelagic fish populations, particularly juvenile salmonids, in the Northern California Current region. He also leads an active research program on the biology and ecology of euphausiids.
Please welcome Dr. Peterson.

Fred Feyer
Fred Feyer is a former Department of Water Resources and current US Bureau of Reclaimation Fishery scientist. He completed his bachelor's at UC Davis and masters at Sac State. Fred is one of the most highly published agency scientists in California, and lucky for me, an avid striped bass fisherman. Please welcome Fred.

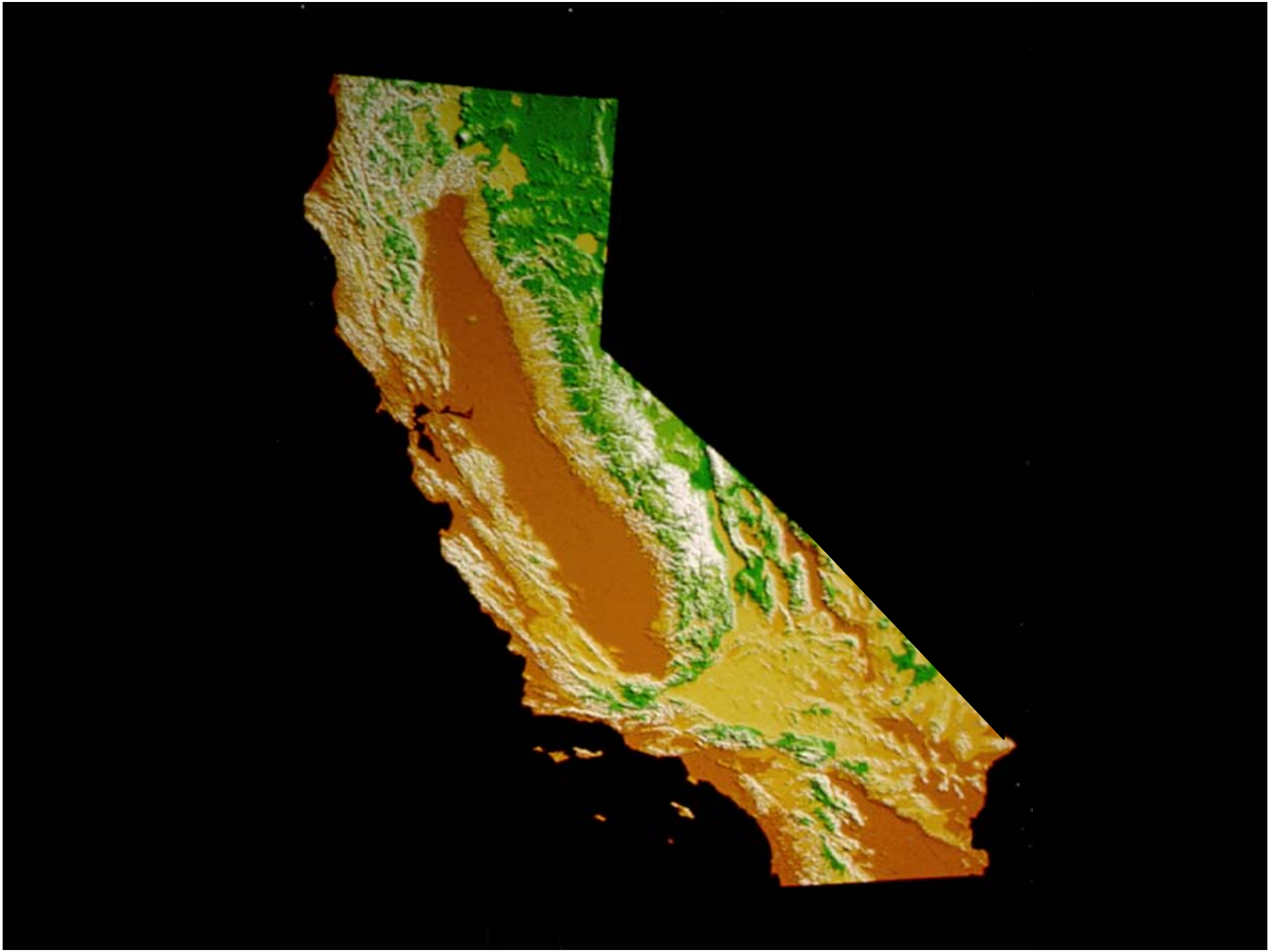
Wayne Wagner
Wayne is a former High school math teacher from New Orleans. He is currently a Ph.D. student under the amazing Dr. Mark Stacey at UC Berkeley focusing on physical processes in estuaries and ecosystem response. Please Welcome Wayne.

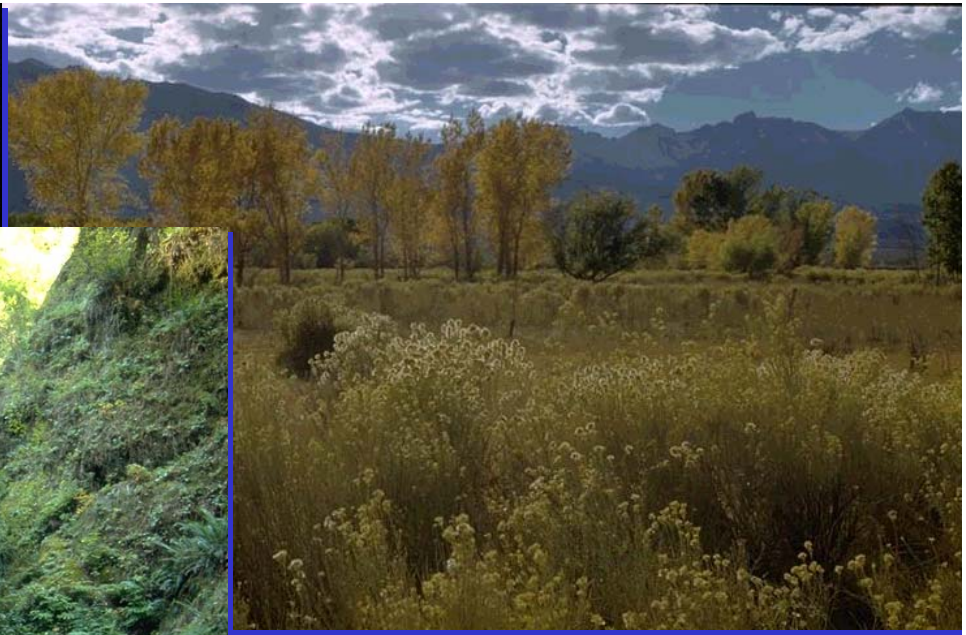
Dr. Russ Bellmer

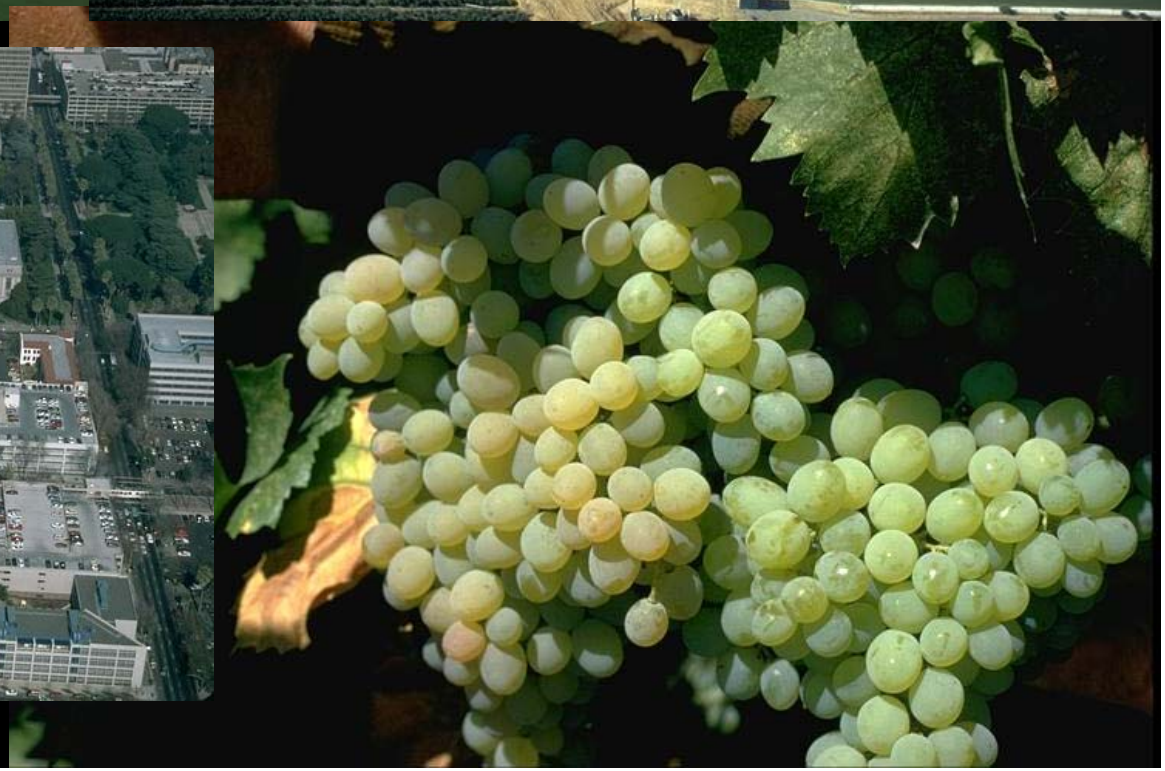
Russ is currently a Scientist with the California Department of Fish & Game. He holds a Ph.D. in Marine Ecology. He has been involved nationwide in numerous fish and coastal resource activities, including applied ecological research, fisheries habitat restoration project implementation, marine non-native invasive species issues, and Natural Resource Damage Assessment case activities. He is a past President of the American Fisheries Society California-Nevada Chapter. Please welcome Dr. Belmer.

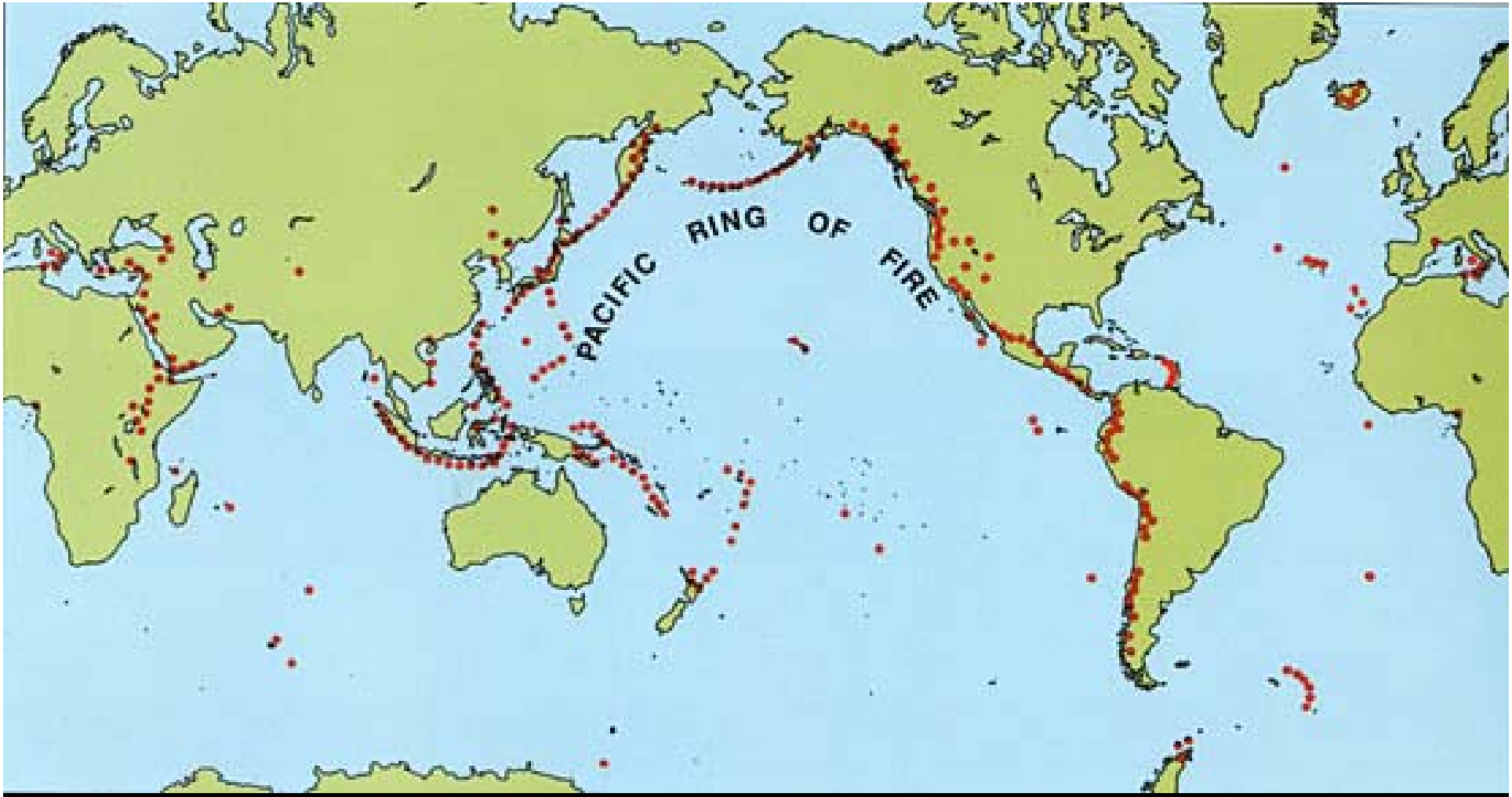
Climatic and Anthropogenic Factors Affecting the Marine and Estuarine Environments

Joseph E. Merz, Ph.D.
Cramer Fish Sciences and University of California Santa Cruz







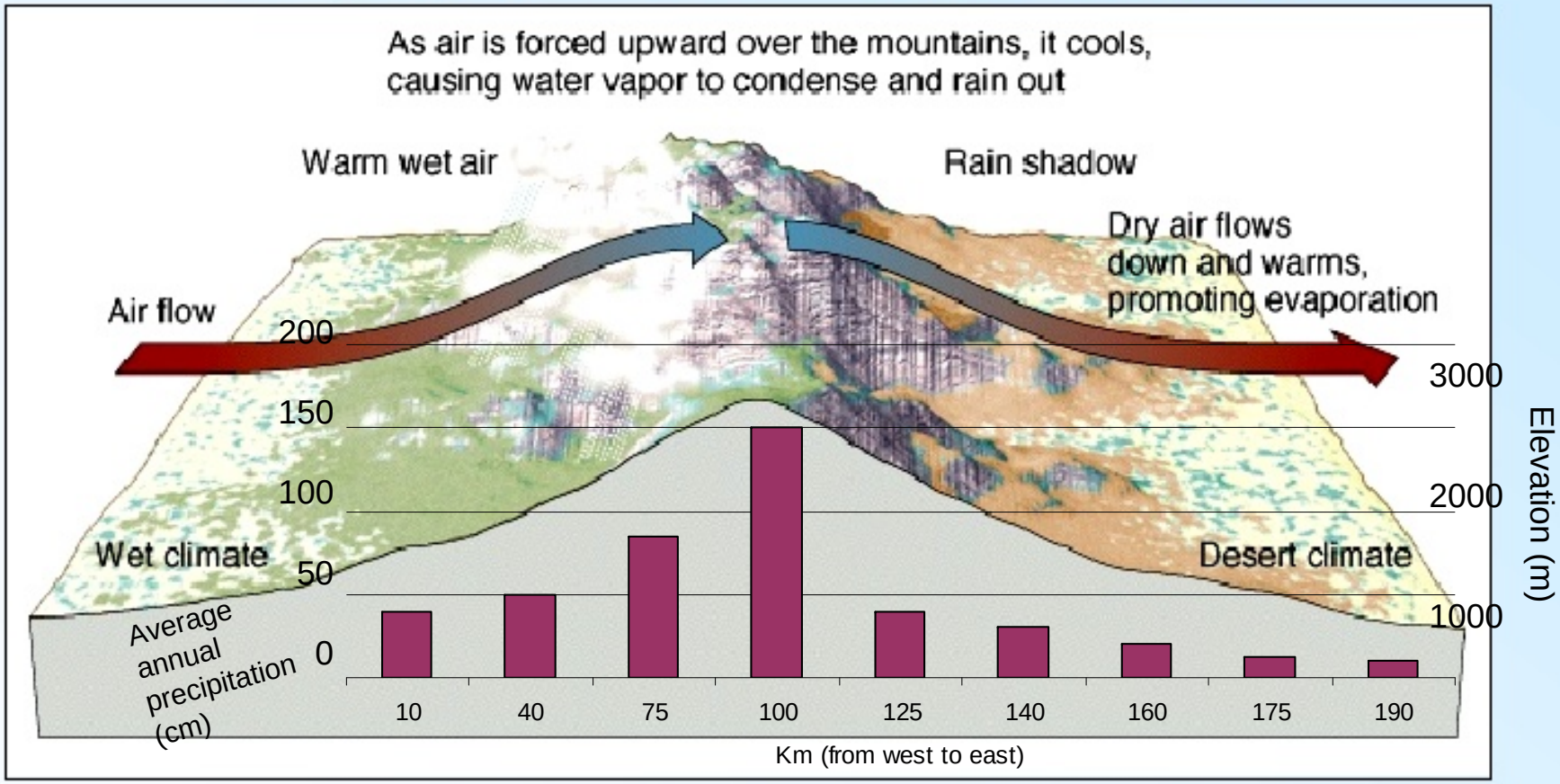


The Pacific Ring of Fire is perhaps one of the most volcanically active places on Earth. Each red dots indicates an active volcano.

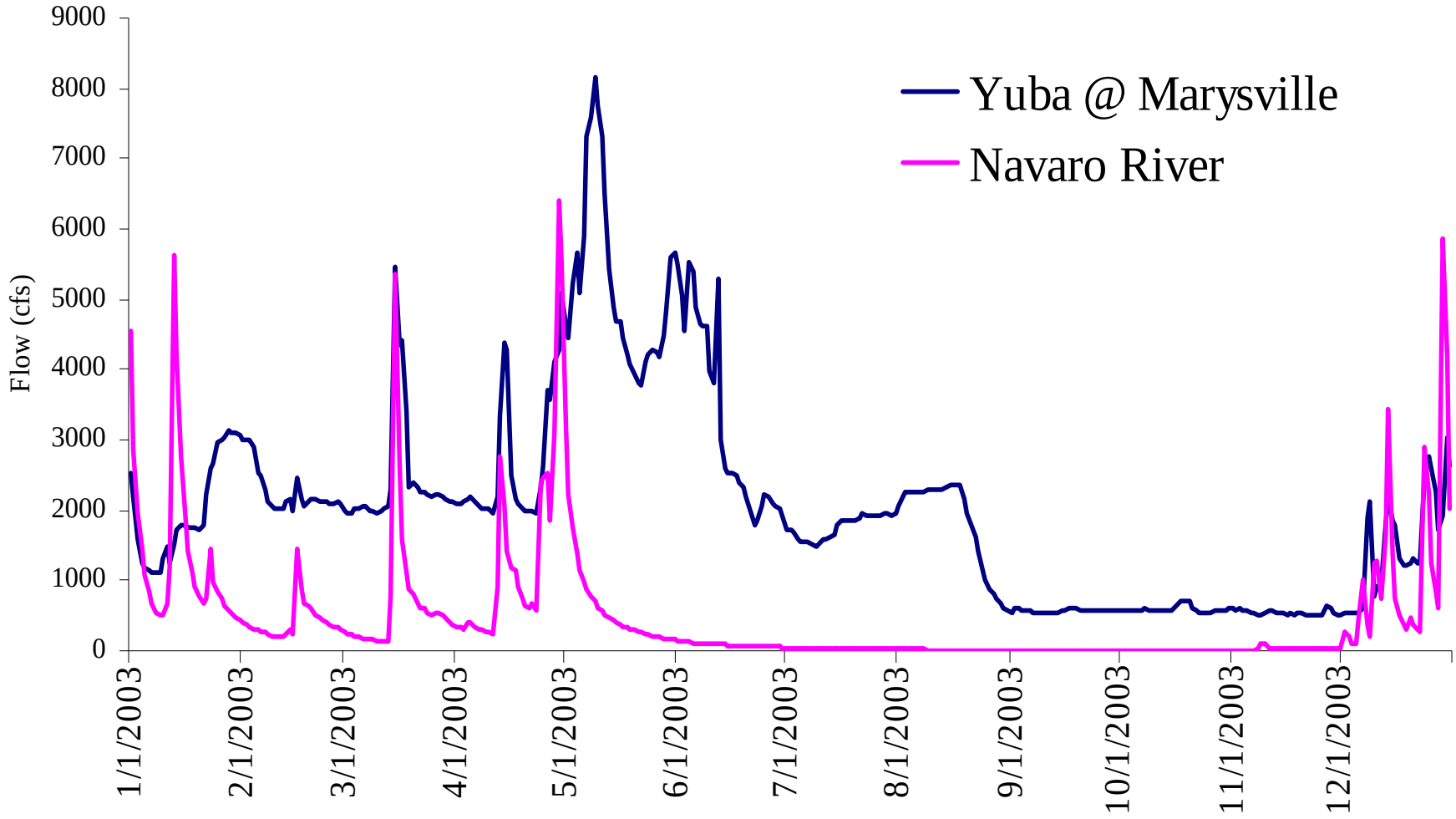
Movement of continental plates creates and releases large amounts of energy and develops an extremely diverse topography along the Pacific coast.

Without large wall of granite to capture a variety of precipitation, Mediterranean climate would be similar to middle Italy or southern France

Orographic effect - Rain Shadow

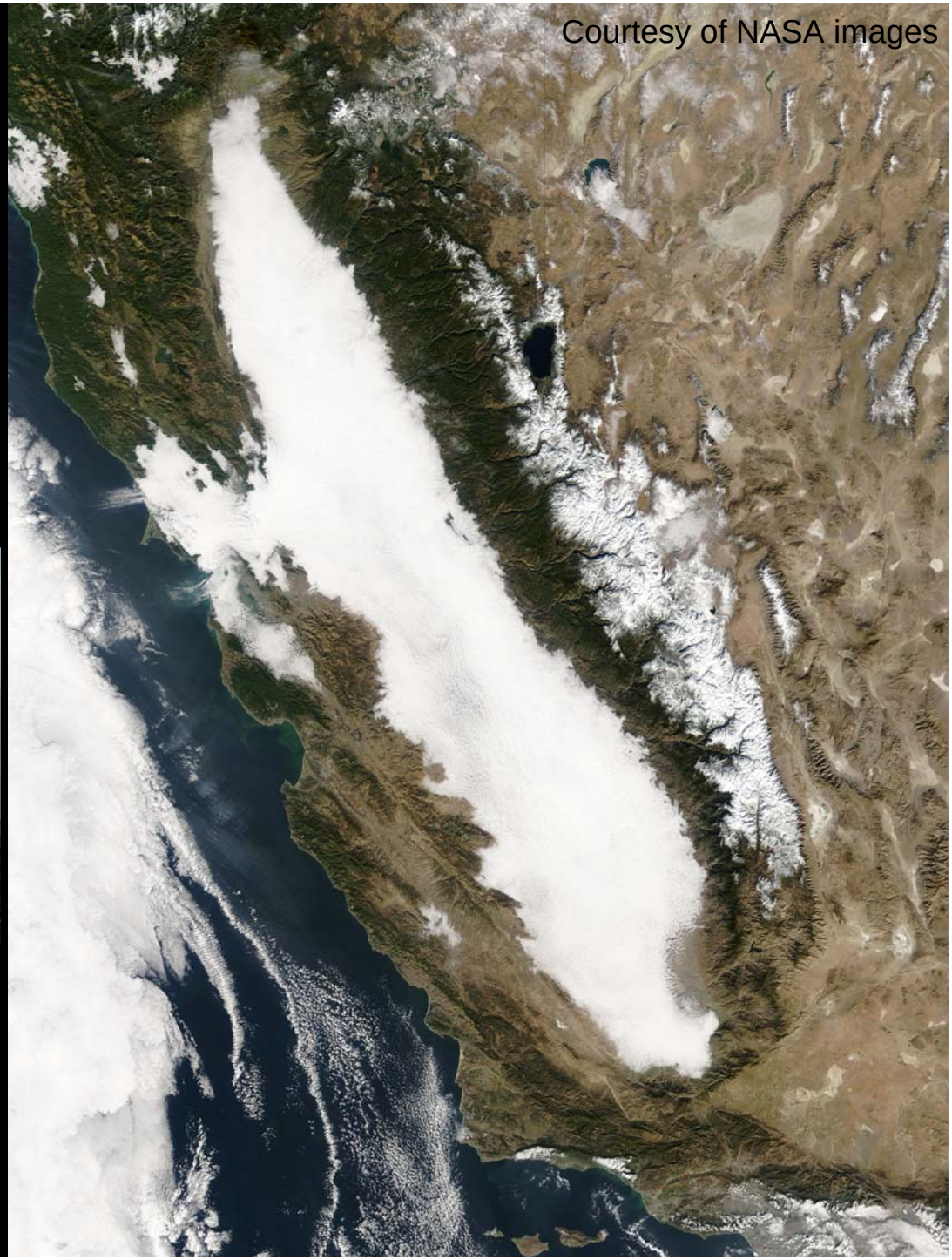


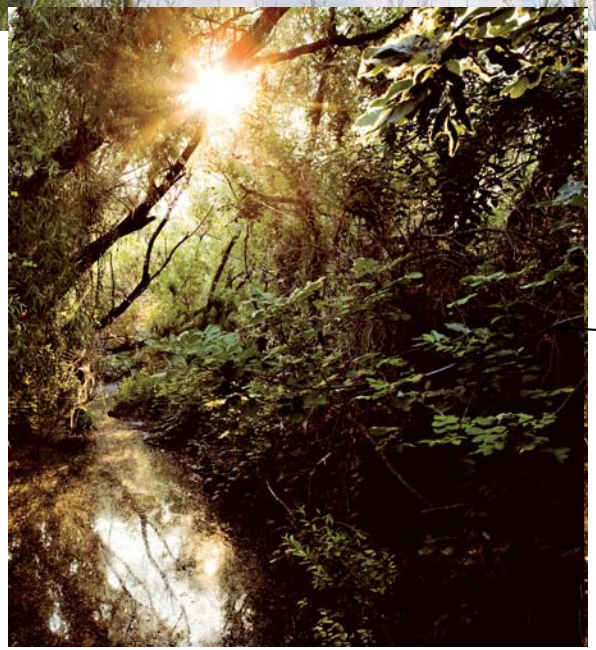
The water resources of California depend heavily on snowpack to store part of the wintertime precipitation into the drier summer months.

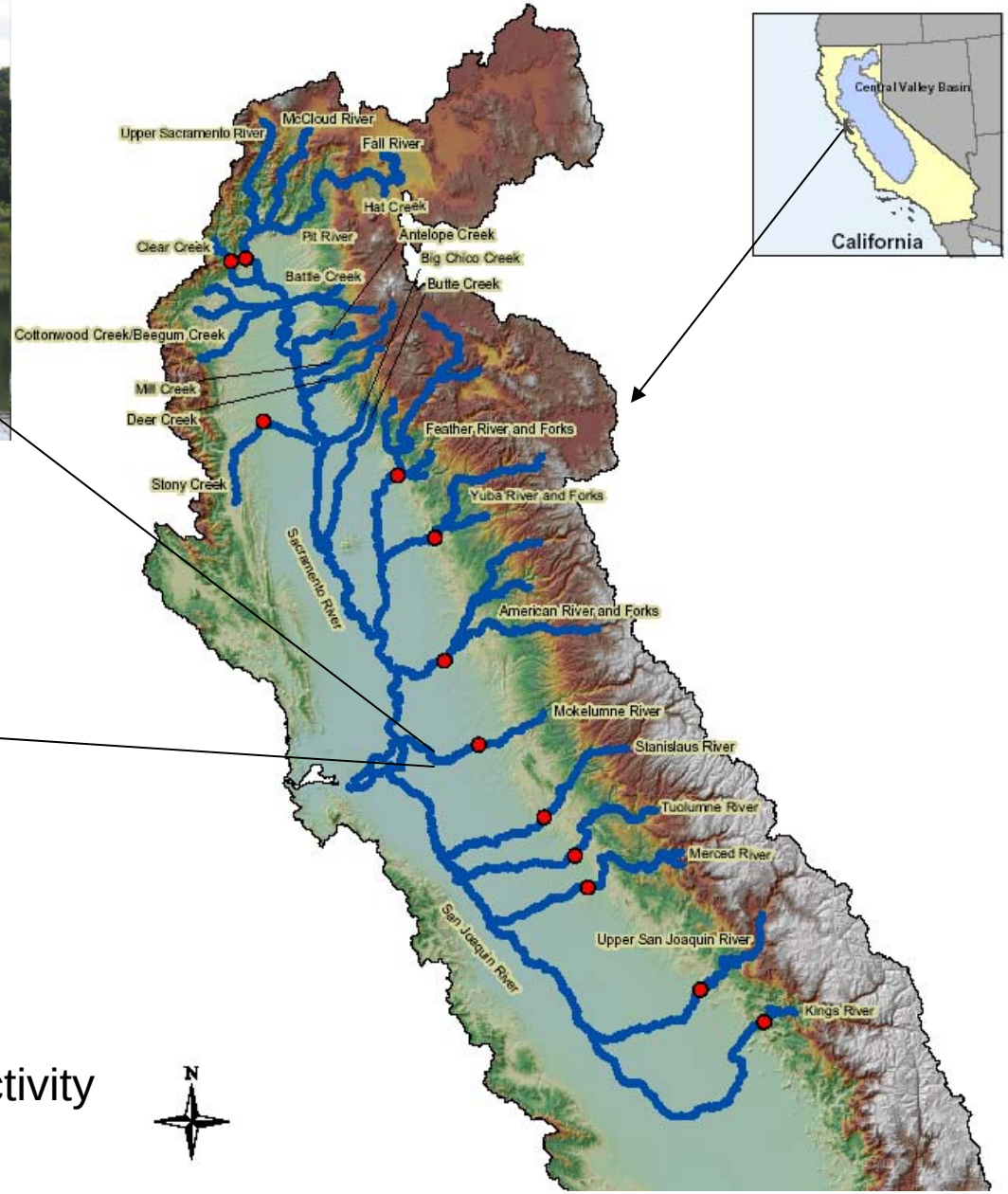


Many streams have a predictable period when the hydrograph transports coarse sediment. This is often a result of seasonal as well as “type” of precipitation (e.g. snow or rain).

cool, foggy winters







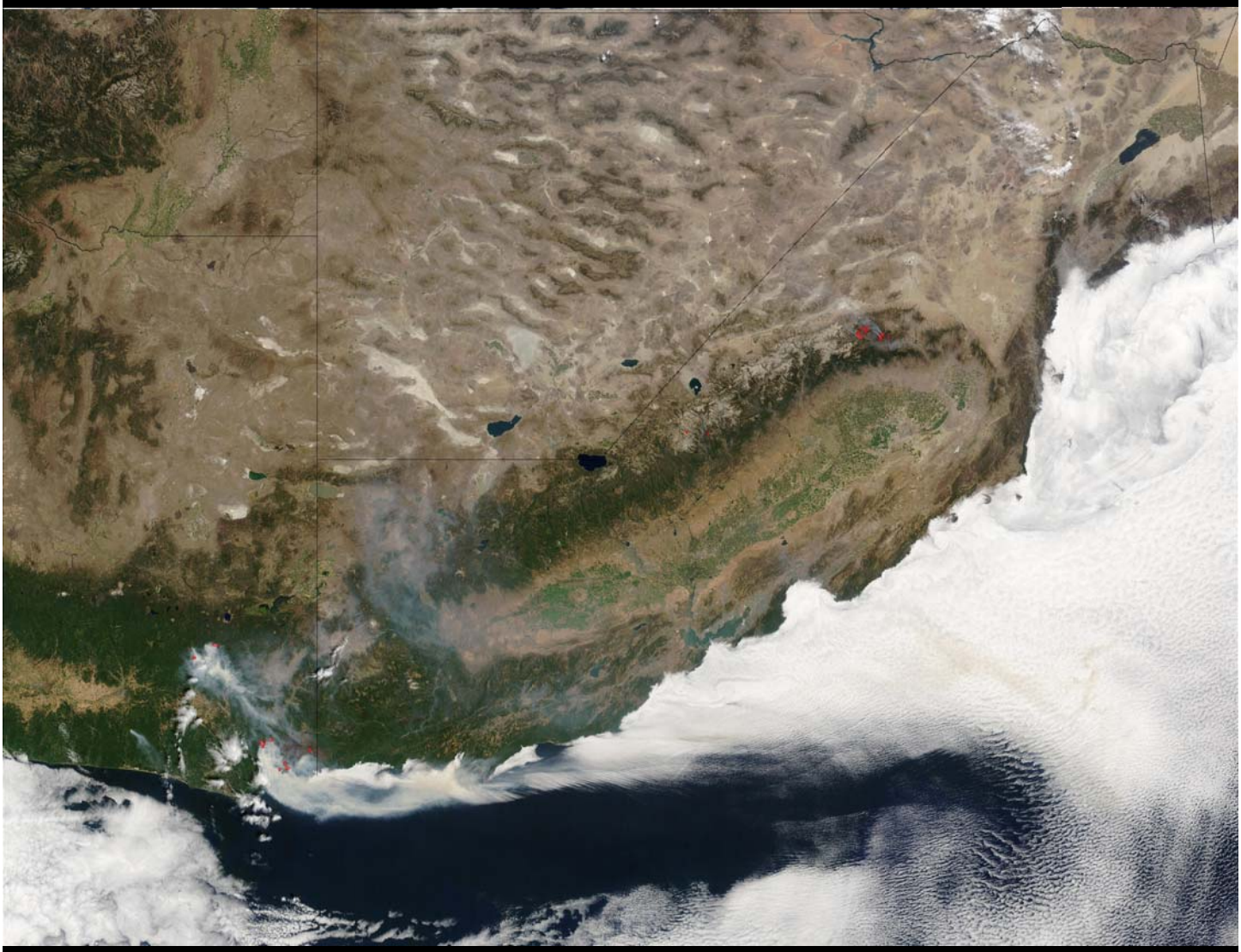
Seasonal flood pulse drives productivity of the Central Valley

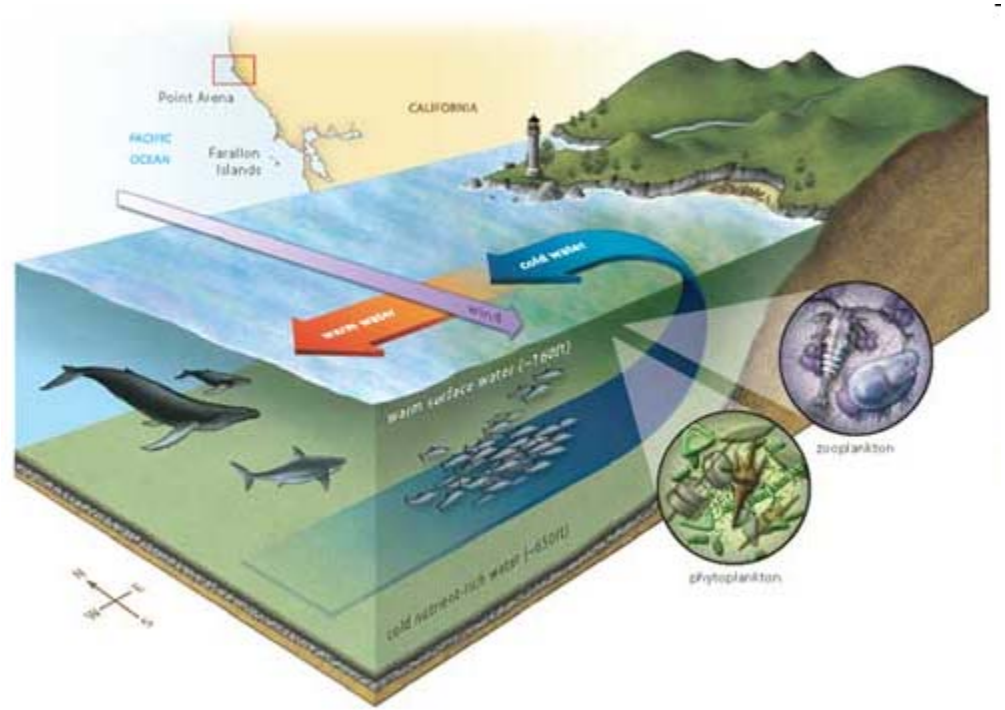
Tectonic Estuary

San Francisco Bay

- *Formed by subsidence of land from tectonic activity*
- *Ocean moves in as surface elevation drops*

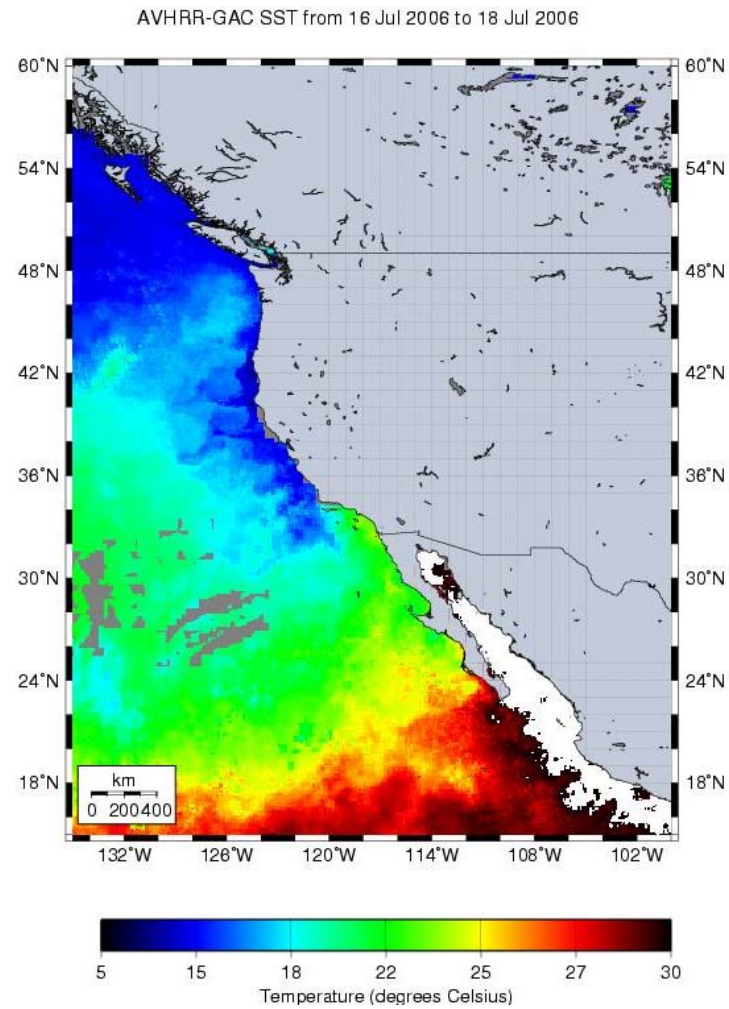
DROUGHT
OFFICER



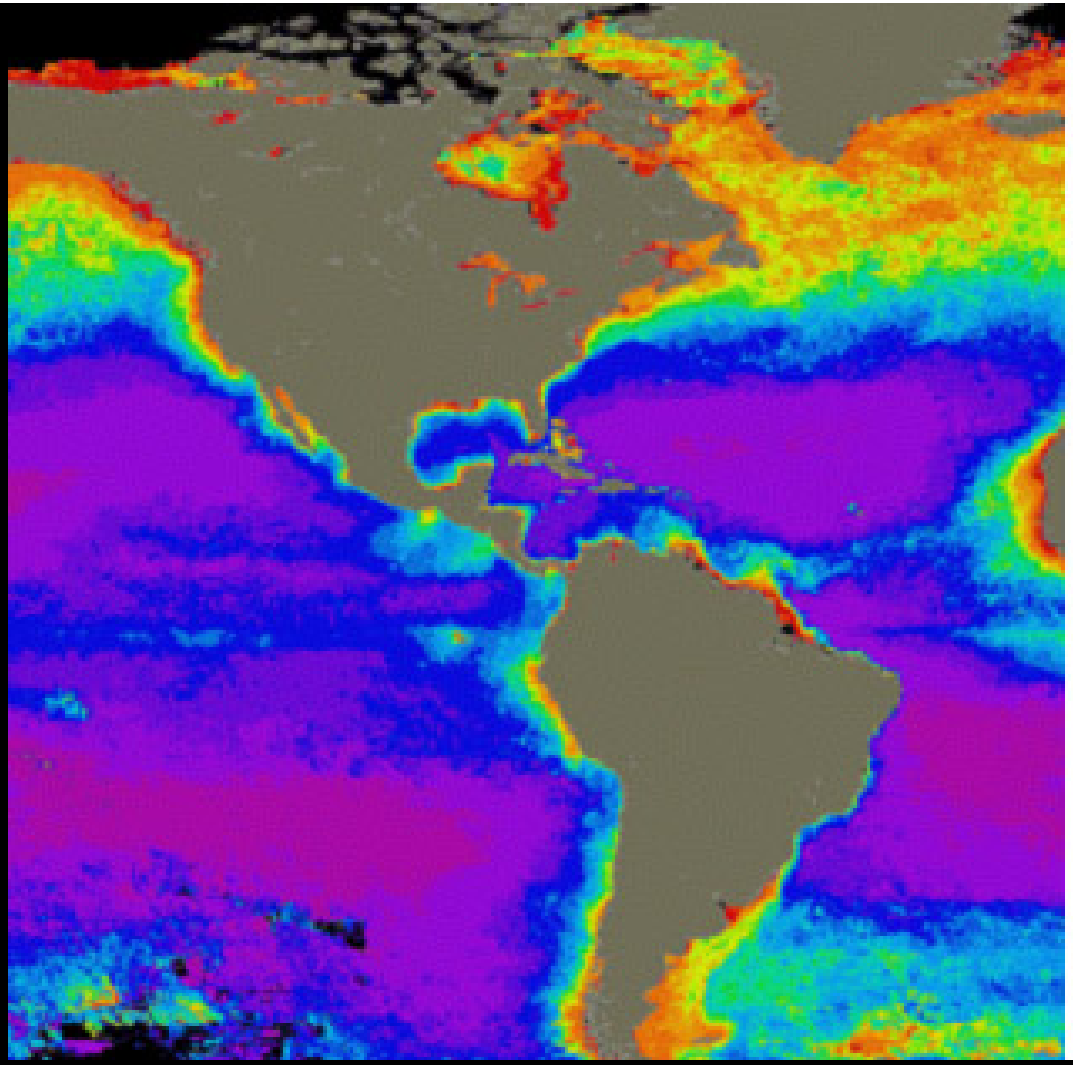


Left: Schematic diagram showing equatorward winds along the California coast (purple arrow) push water offshore (red arrow), leading to upwelling of colder water along the coast (blue arrow) shown in the figure on the right above. The cold water not only influences the atmosphere, but it also carries nutrients that increase the productivity of the area.

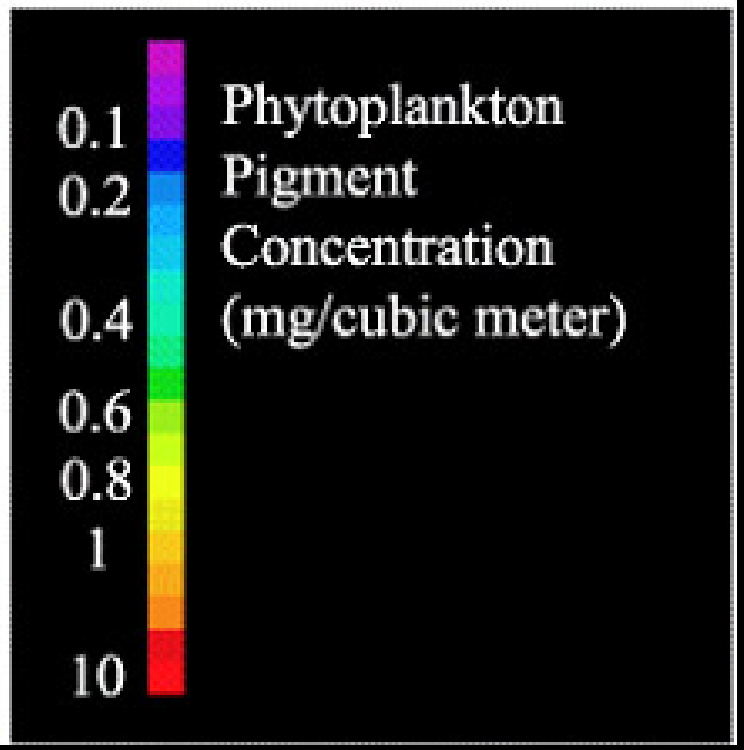
From Bay Nature: A Moveable Feast: The Ups and Downs of Coastal Upwelling. Drawing by Fiona Morris.



Right: Sea-surface temperature along the US west coast on 16-18 July 2006 measured by the Advanced High Resolution Radiometer AVHRR on the NOAA polar-orbiting, meteorological satellites. The cold (blue) areas are upwelled water caused by north winds offshore of the coast. Click on the image for a zoom with color scale.
From NOAA CoastWatch.



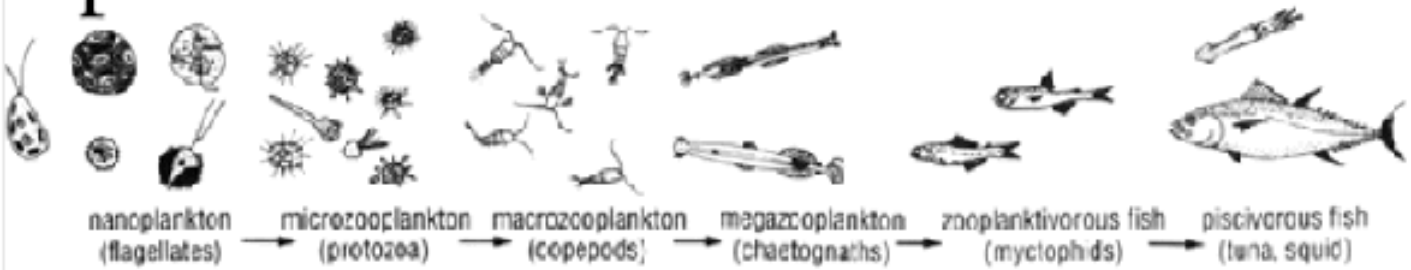
Composite satellite image since 1978 depicting phytoplankton concentration along North & South America. The image key is in units of milligrams of phytoplankton pigment per cubic meter of seawater. Note how high populations of plankton correspond to areas where coastal upwelling is strong, like the Peruvian coast and the Pacific Northwest. (From: NASA)



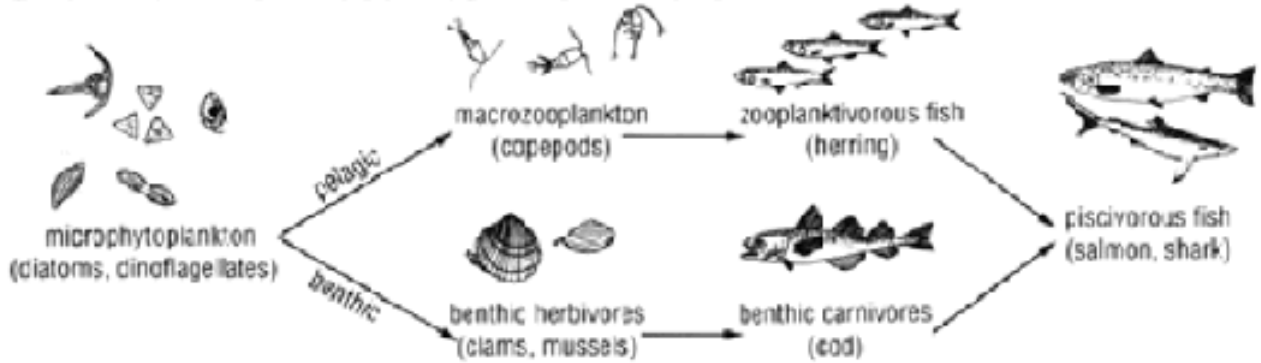
All organic material sinks to the bottom eventually and the upper water column would be pretty much a non-productive area if it weren't for upwellings.

In fact, off the coast of California, the North Pacific currents, in combination with upwelling caused by winds out of the north, bring cold nutrient waters to surface near shore, producing one of the most abundant fisheries on Earth.

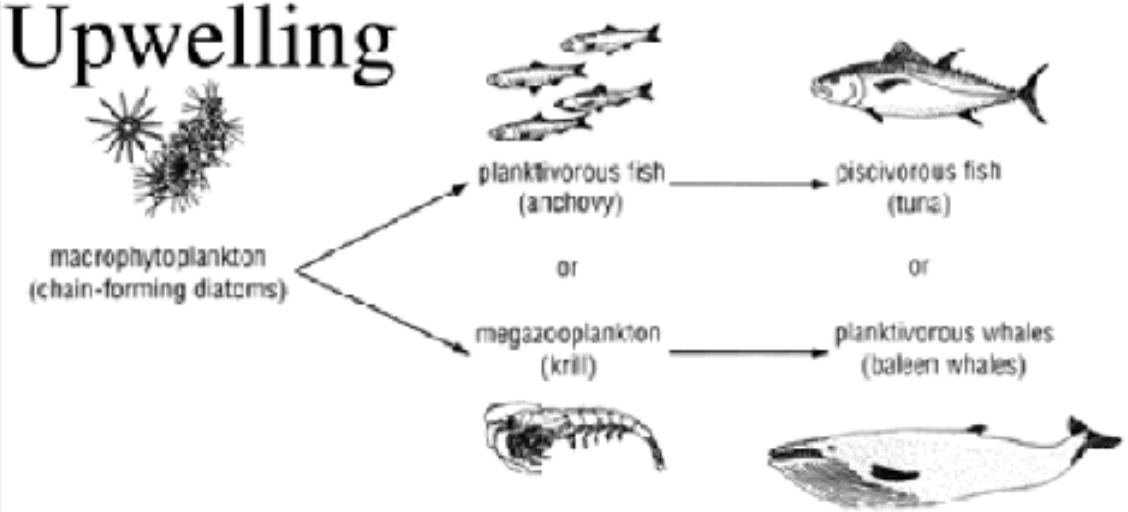
Open ocean



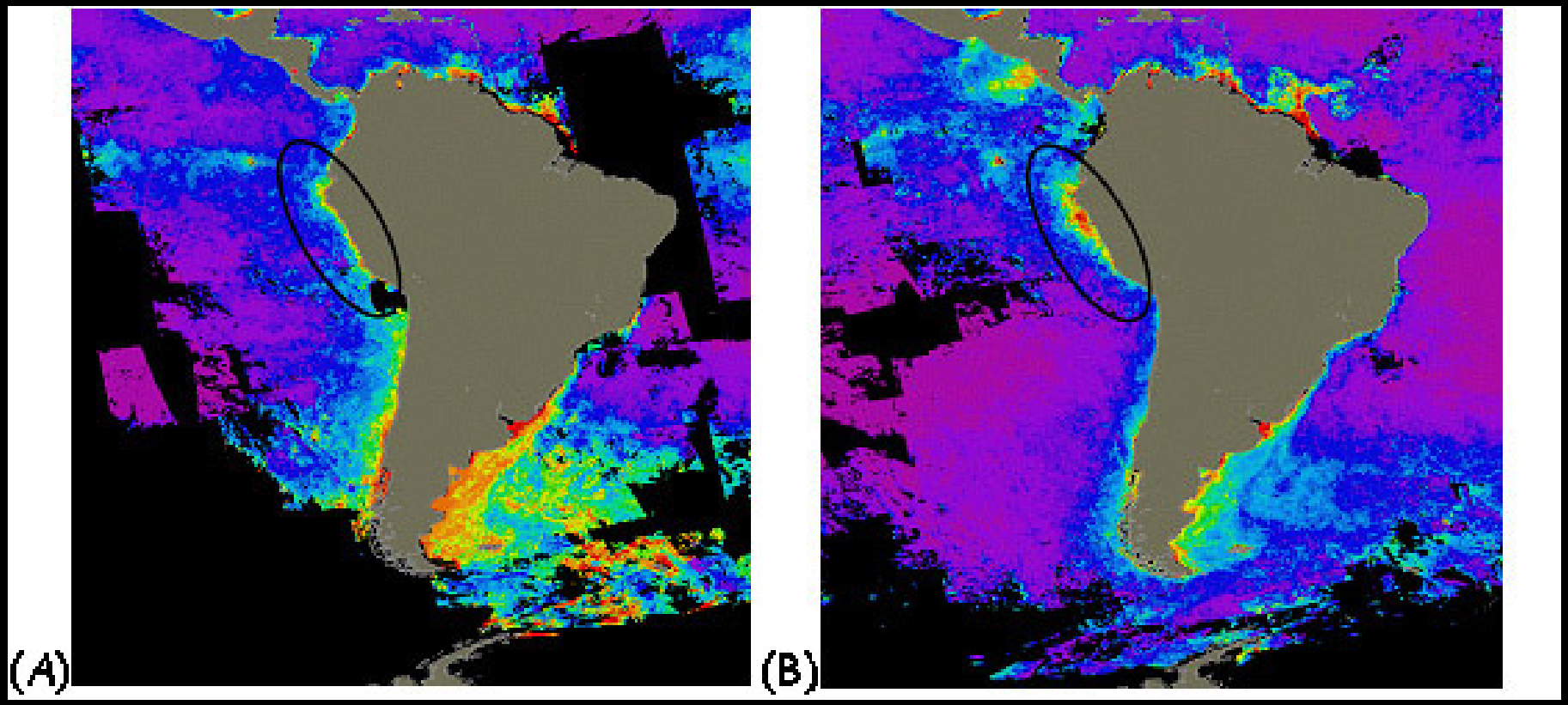
Continental Shelves



Upwelling

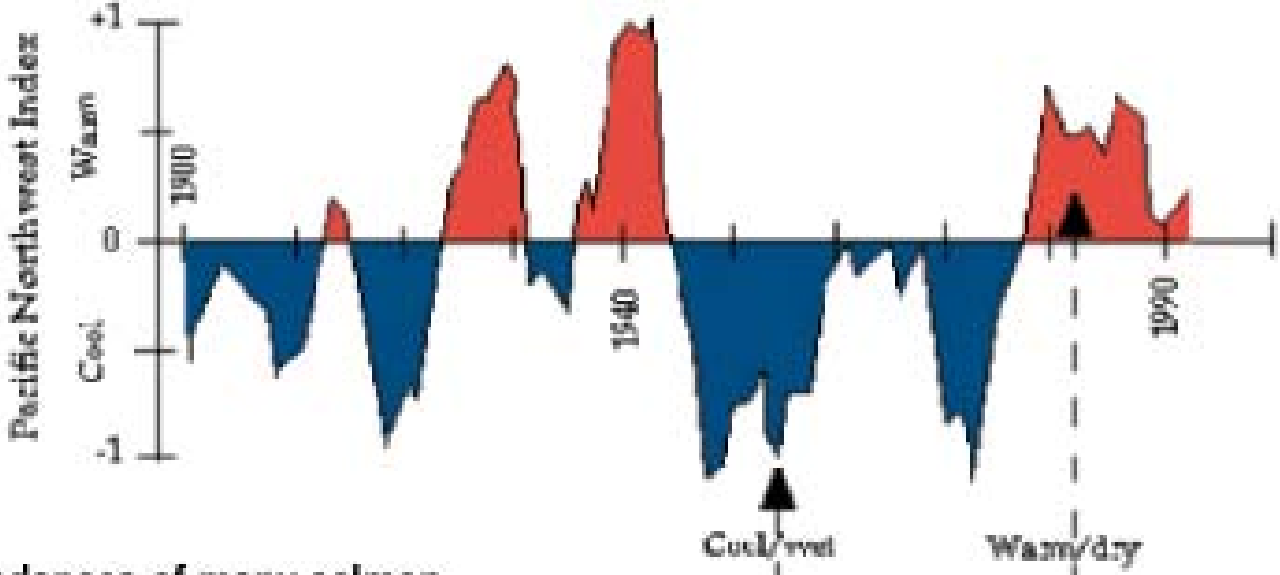


Remember the currents off the Pacific Coast creating upwellings that provide nutrients? There are seasonal processes like El Nino that can influence this.

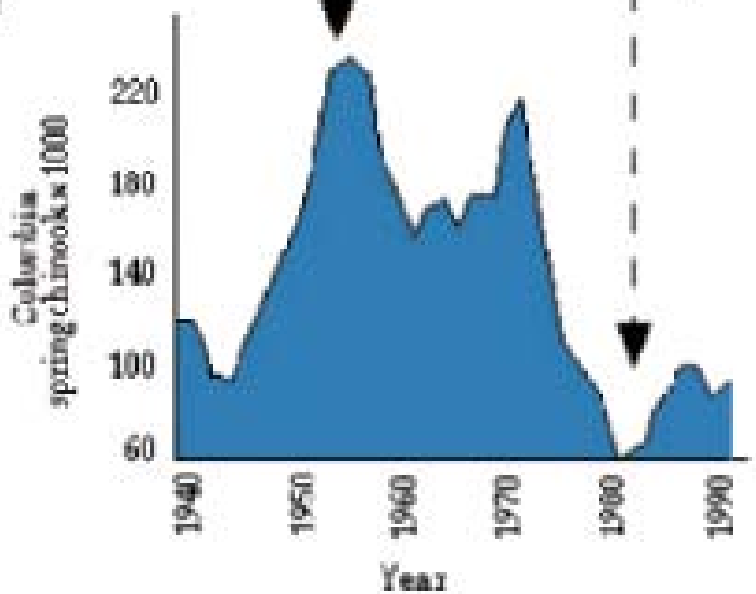


A comparison of phytoplankton concentration during upwelling periods off the coast of Peru: (A) 1983, a severe El Niño and (B) 1985, a non-El Niño period. Note how much smaller the bloom (circled) is during El Niño conditions, when nutrient upwelling ceases. The color key needed to read the phytoplankton concentrations is the same as that in the above satellite image. (From: NASA)

Observed Effects of Climate Variability on Salmon



Abundances of many salmon stocks closely track inter-decadal climate variation since 1940. Upper Columbia bright spring Chinook are abundant when the Pacific Northwest Index (one measure of decadal climate variation) is negative. Both are 5-year moving averages.



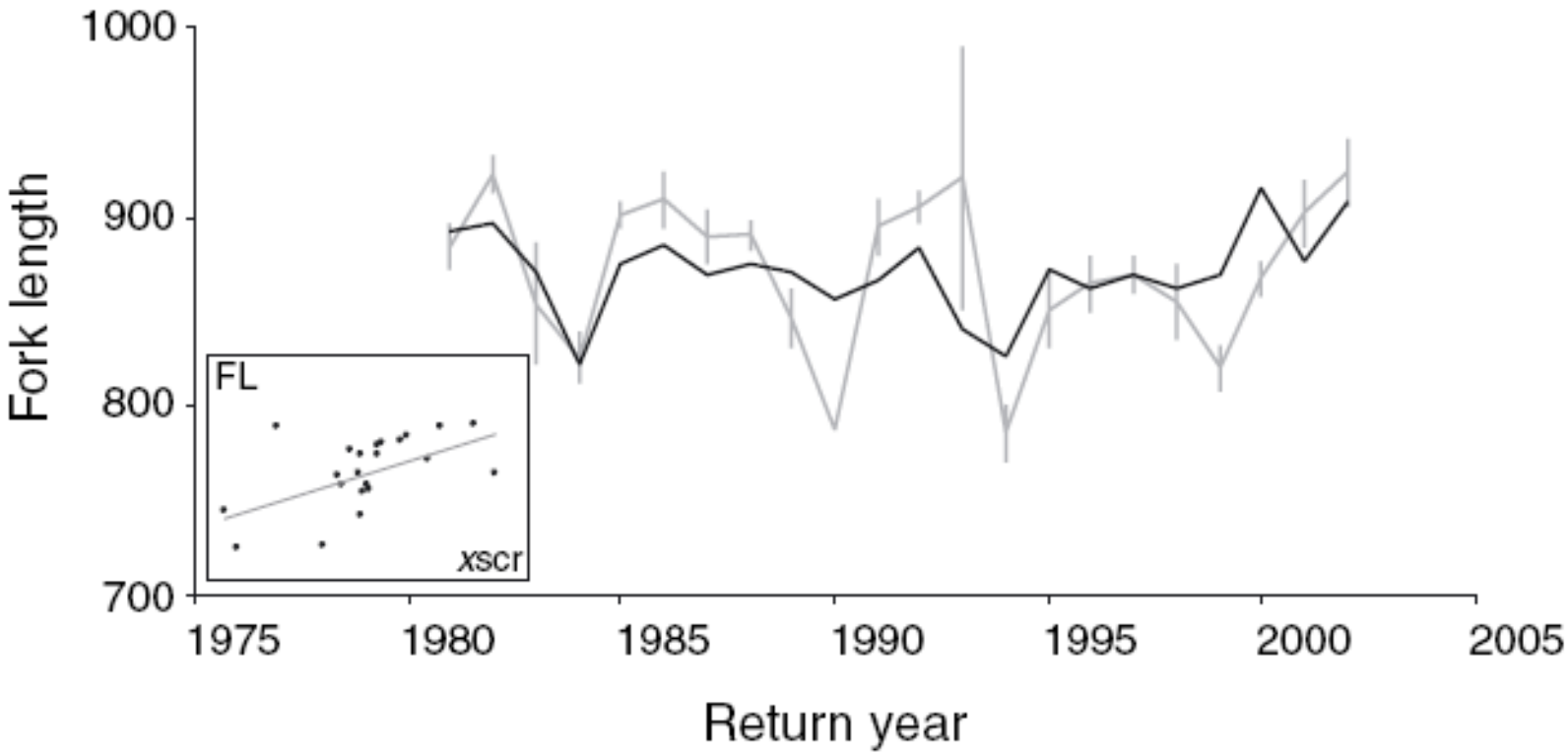


Table 2. Seven environmental variables used to characterize the oceanic environment between Cape Mendocino and Cape Blanco off shore to 125°W (Fig. 1) were collected from various sources for the years 1977–2002.

Variable description	Variable identifier
Easterly pseudo-wind stress*	EPseudo
Northerly pseudo-wind stress*†	NPseudo
Non-directional wind speed; scalar wind speed*	Scalar
Upwelling‡	Upwelling
Curl†‡§	Curl
Sea surface temperature*	SST
Sea level height¶**	SLH

Figure 11. Shown is the fit of average fork lengths (FL) of returning three ocean-winter fish with environmental data from the spring before the last winter at sea using partial least squares regression displayed across the time series & as an inset scatter plot showing the fit of the data to the first latent variable (xscr). Gray time series show the observed average fork lengths (±1 standard error) of three oceanwinter fish across the return years for which there were data, & black time series show the predicted average FL from the partial least squares regression. The inset scatter plot shows the observed average FL of three oceanwinter fish fit with the first latent variable and, within the inset, the gray line represents the fitted relationship of observed data to the first latent variable. (Wells, Grimes, Waldvogel 2007).

Many aquatic organisms have life histories adapted to seasonal events in the environment (Phenology).

Phenology plays a critical role in the California Current System (CCS), in which ecosystem productivity and structure is driven largely by the seasonal cycle of coastal upwelling.

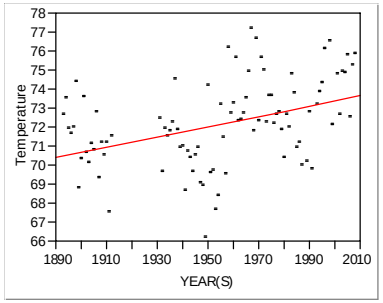
The impact of an anomalous seasonal cycle such as delayed onset of coastal upwelling (Schwing et al., 2006), can result in:

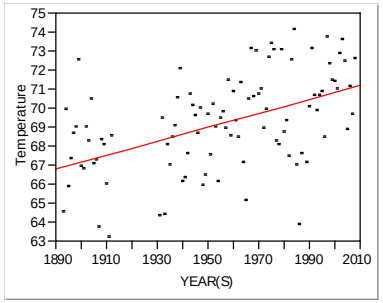
- anomalously warm sea surface temperatures (Kosro et al., 2006; Pierce et al., 2006),
- low surface chlorophyll levels (Thomas and Brickley, 2006),
- spatial redistribution of zooplankton species (Mackas et al., 2006),
- low rockfish recruitment and lack of forage species (Brodeur et al., 2006),
- total breeding failure of dominant planktivorous marine birds (Sydeman et al., 2006), and
- changes in California sea lion foraging strategies (Wiese et al.,2006).

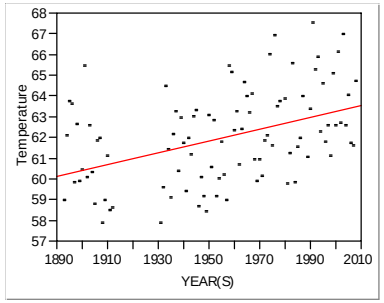
Photos courtesy of Monterey Bay Aquarium Research Institute

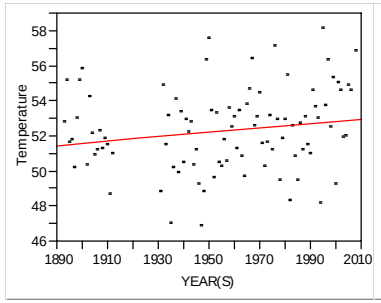
Climate Change and Anthropogenic Effects on These Processes

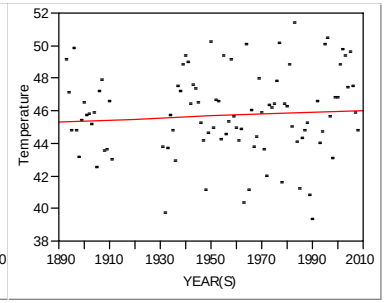
Changes in Air Temperature From 1890 to 2008 Lodi CA











August September October November December

Mean monthly air temperature recorded at Lodi, CA 1890 to 2008

- Almost an 4° F air temperature change during august over past 118 years
- In contrast, an insignificant temperature change in December

Global Warming Threatens Spawning and Rearing Habitat for Spring-Run Chinook Salmon in California's Central Valley

- Habitat at risk if August water temperature increases 3.6°F
- Habitat at risk if August water temperature increases 7.2°F
- Habitat unavailable due to existing dams

0 25 50 Miles

Map produced by the National Wildlife Federation based on Yates et al. ("Climate Warming, Water Storage, and Chinook Salmon in California's Sacramento Valley," *Climatic Change*, accepted February 2008).

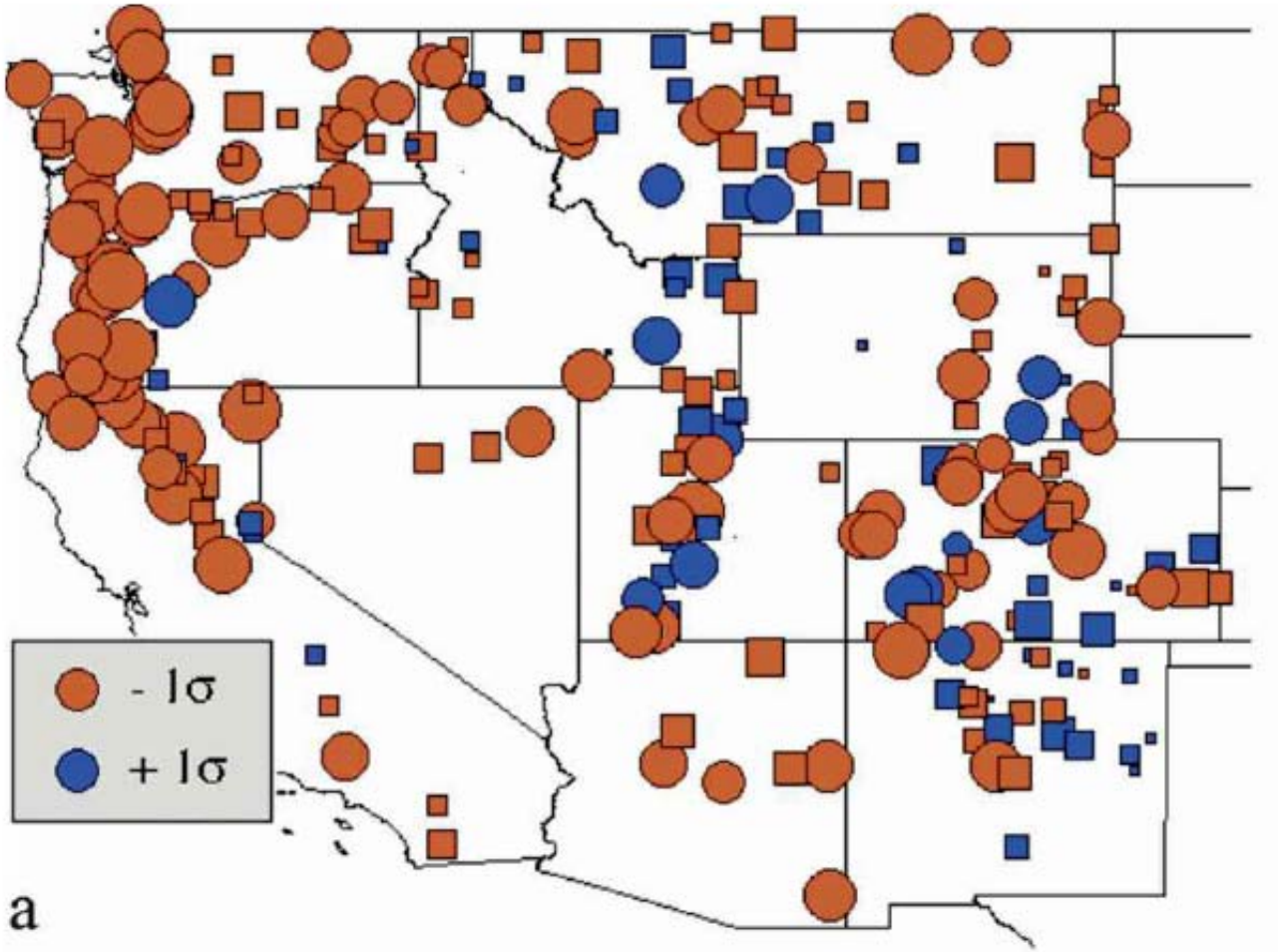
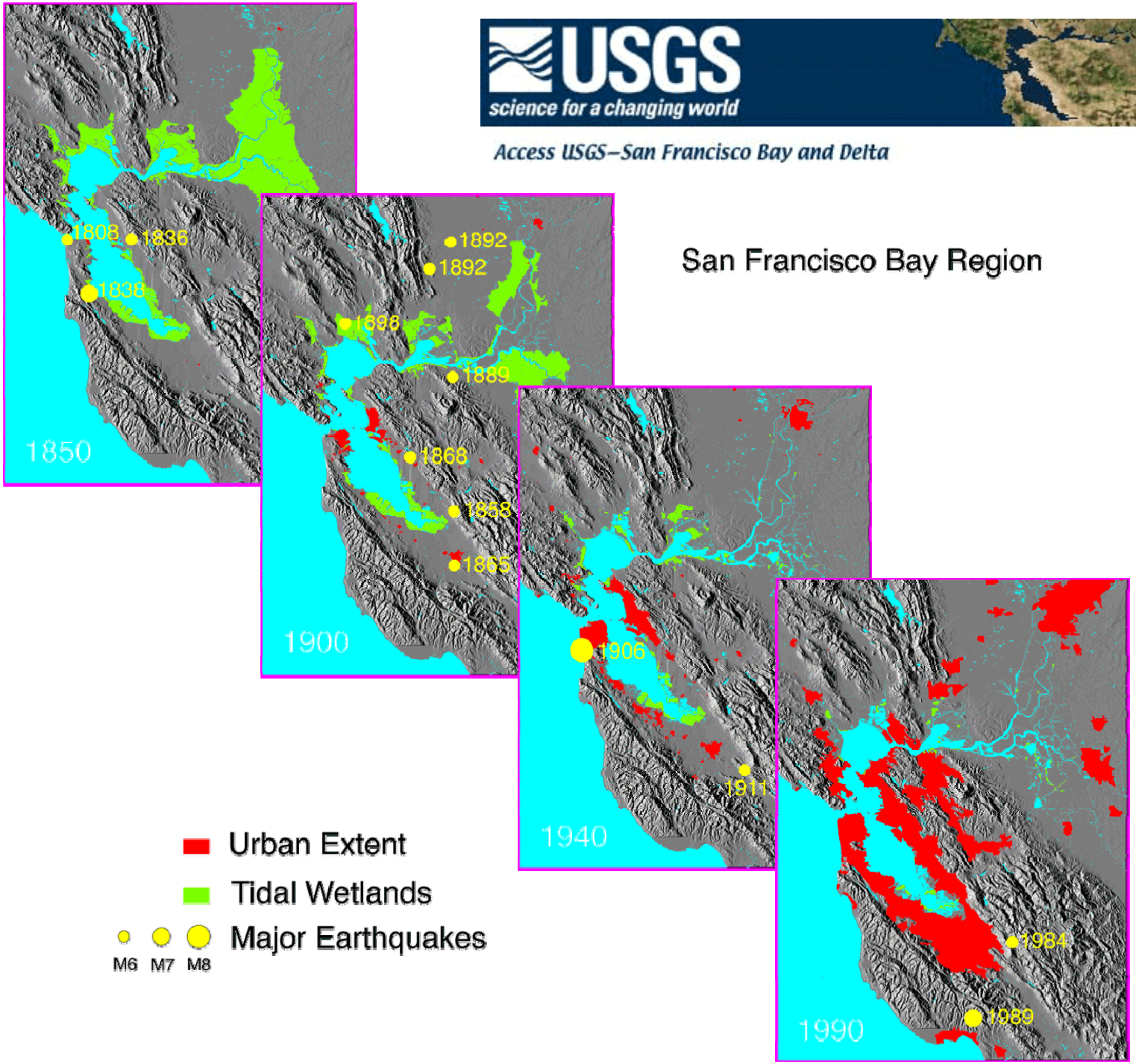


FIG. 1. Trends in fraction of winter (Nov–Mar) precipitation falling on snowy days (SFE/P), 1949–2004: red indicates decreasing snowfall fractions; symbol radius is proportional to study period changes, measured in standard deviations of the detrended time series as indicated; circles indicate high trend significance ($p < 0.05$), and squares indicate lower trend significance (Knolwes et al. 2006).

Trends toward reduced SNOW/RAIN ratios were most pronounced in March regionwide and in January near the West Coast, corresponding to widespread warming in these months.

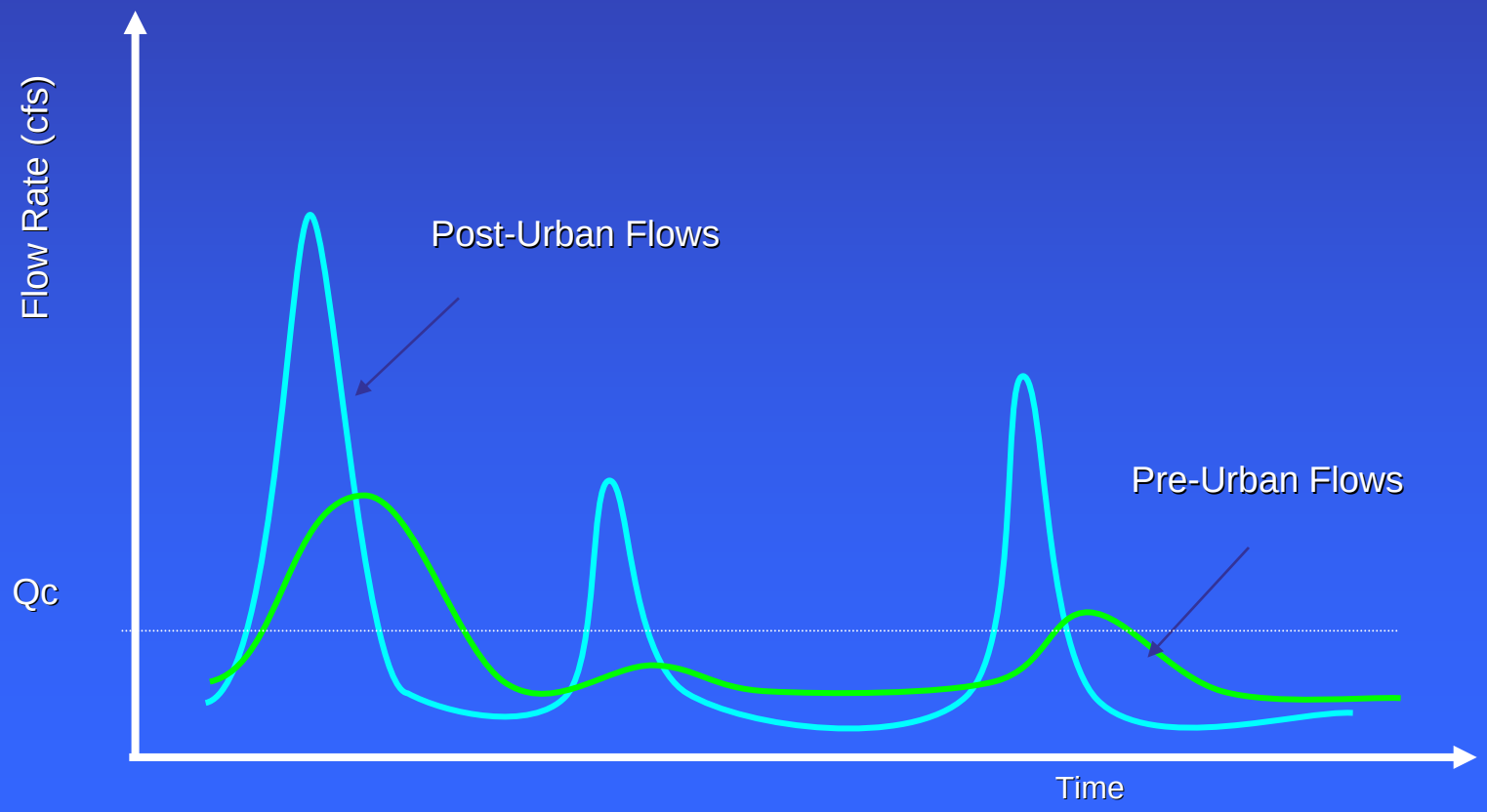
USGS
science for a changing world

Access USGS–San Francisco Bay and Delta



Hydromodification refers to the effects of urbanization on stormwater runoff and stream flows. As natural surfaces are paved, covered by structures, and compacted, less rainwater infiltrates into the ground. Urbanization also increases the connectivity of paved surfaces and the storm drain system: roof downspouts, curbs, streets, and drainage pipes all flow directly to storm drains, which discharge directly to streams. So, not only does *more* water flow to creeks, but the pavement and storm drains *speed the delivery* of the runoff into the creeks.

(Qc is the flow rate at which bed and bank material begins to erode.)



Pre-Development vs. Post-Development Hydrographs ***for Santa Clara Valley from GeoSyntec Consultants***

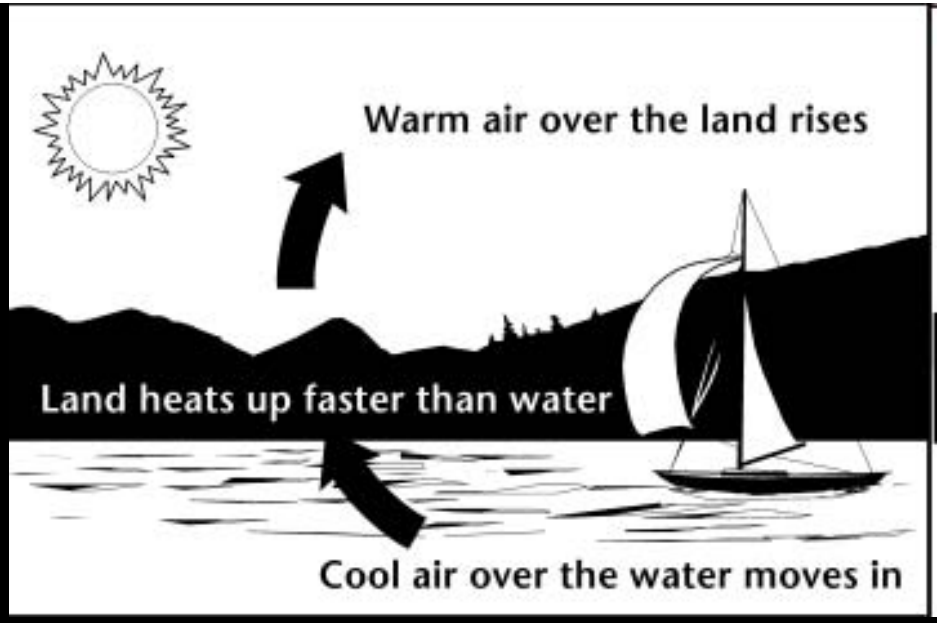
1946
1963 construction of Camanche Dam

Snyder et al. (2007) : Modeling scenarios suggest future wind strength increase along California coast may have far reaching effects:
land temperatures are increasing at a faster rate than ocean temperatures, and this thermal gradient is driving increased winds.

increases in wind speeds of up to 2 meters per second, which is a large change in relation to current average wind speeds of about 5 meters per second.

One effect of these increased winds may be earlier and more intense upwelling of cold water along the coast.

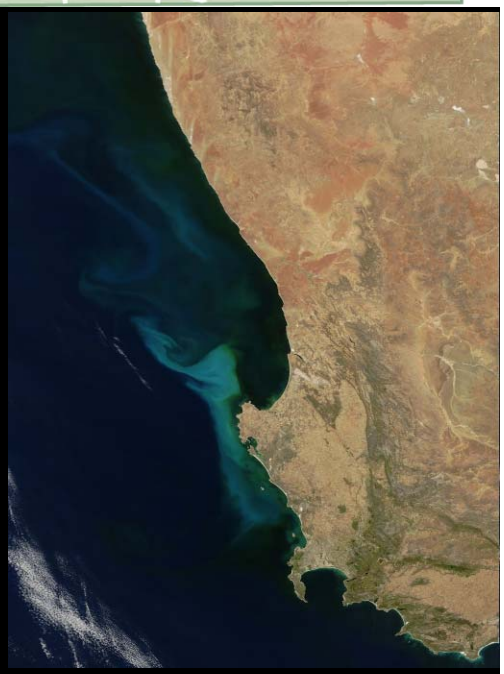
An enhanced sea breeze during the warm months of the year has a cooling effect along the coast. Such a cooling trend could have many ramifications, particularly for coastal species adapted to seasonal changes in temperatures and fog.



While upwelling is generally a good thing, bringing up nutrient-rich deep water to support thriving coastal ecosystems, researchers think too much upwelling may be causing the massive "dead zone" that has begun to appear with alarming regularity off the Oregon coast.

Intense upwelling driven by stronger, more persistent winds stimulates excessive growth of phytoplankton (microscopic algae), which ultimately sink to the bottom and decompose, sucking oxygen out of the bottom waters.

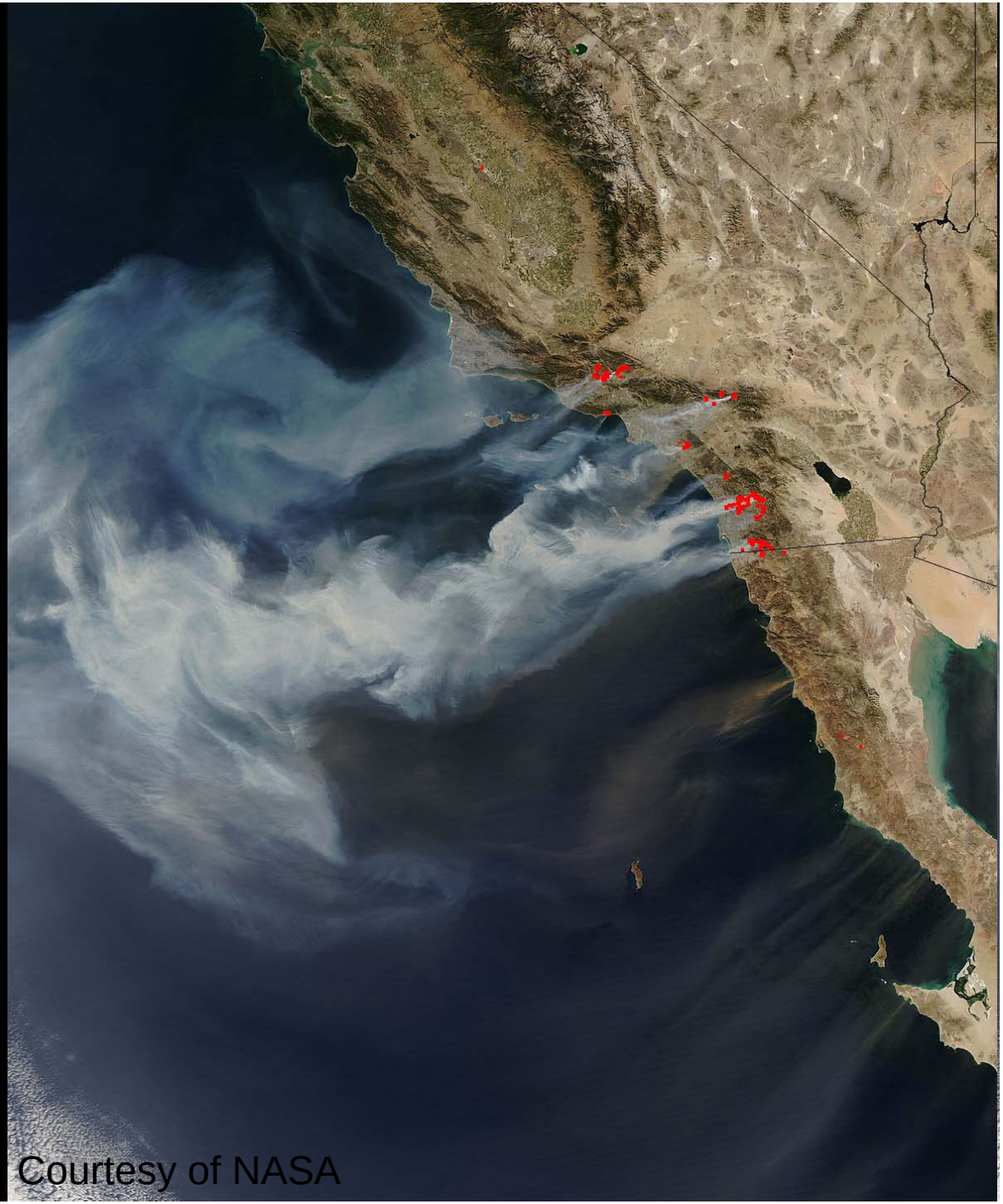
Dungeness crabs washed ashore at Cape Perpetua as the ocean off Oregon experienced "dead zone" conditions in the summer of 2004.



Deadly plume off of South Africa coast

Strong winds can also create:
extremely hazardous fire conditions, as was seen last fall in Southern California.

Greater fire incidences within inland waterways will have far-reaching effects on watershed health.



Courtesy of NASA

Greater opportunities may arise to harness wind power

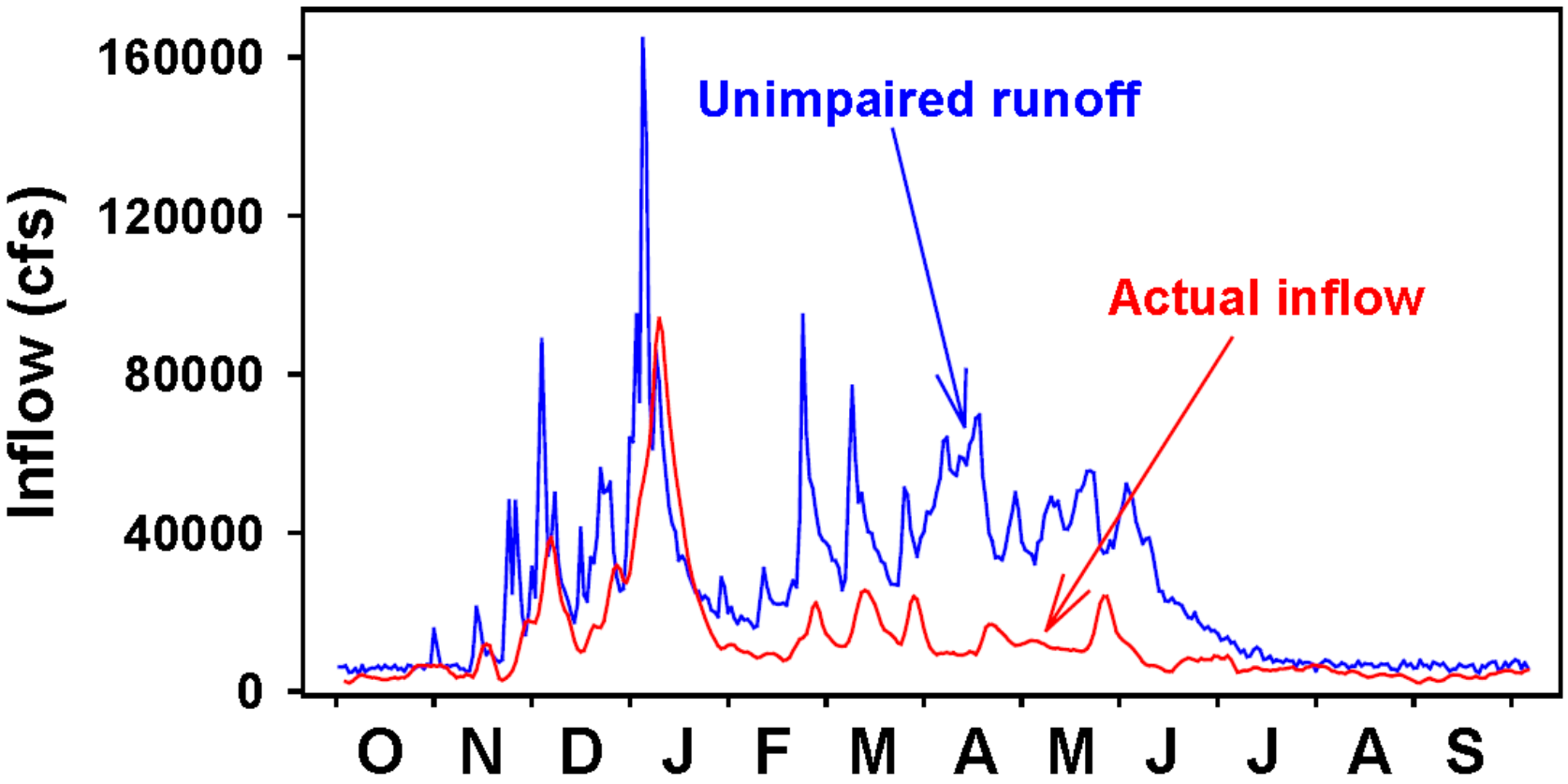


Figure 1. The amounts and timing of freshwater inflow to the Bay have been altered by upstream dams and water diversions. The blue line shows unimpaired runoff from the ten largest rivers of the Sacramento-San Joaquin watershed. The red line shows the actual pattern of freshwater inflow to the Bay from the watershed (taken from Bay Institute 2003).

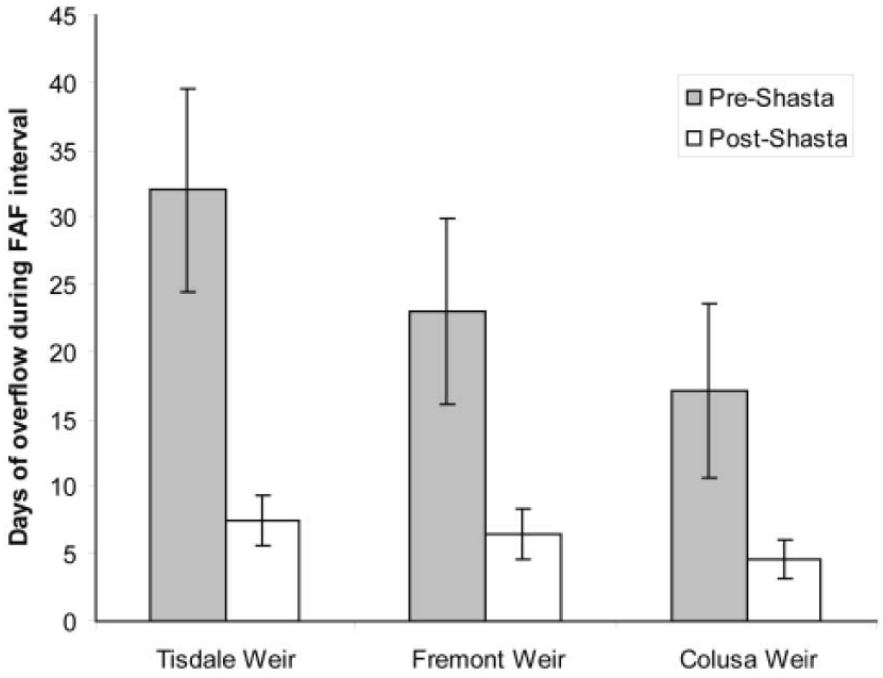


Figure 10 Days of overflow of Tisdale Weir into Sutter Bypass and Fremont Weir into Yolo Bypass, pre-Shasta and post-Shasta, within the FAF interval (March 15 – May 15) (Williams et al. 2009).

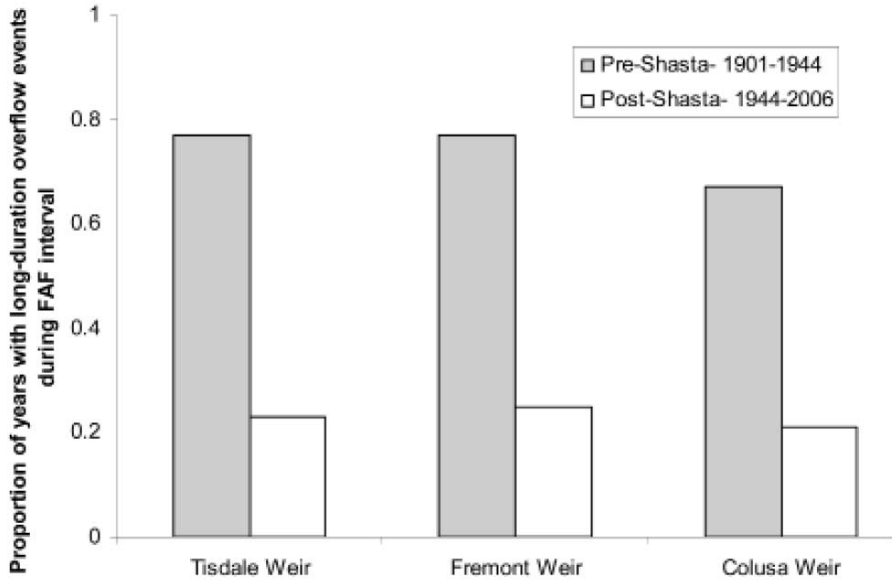


Figure 11. Proportion of years with overflow events of seven days or longer of Tisdale Weir into Sutter Bypass and Fremont Weir into Yolo Bypass, pre-Shasta and post-Shasta, within the FAF interval (March 15 – May 15) (Williams et al. 2009).

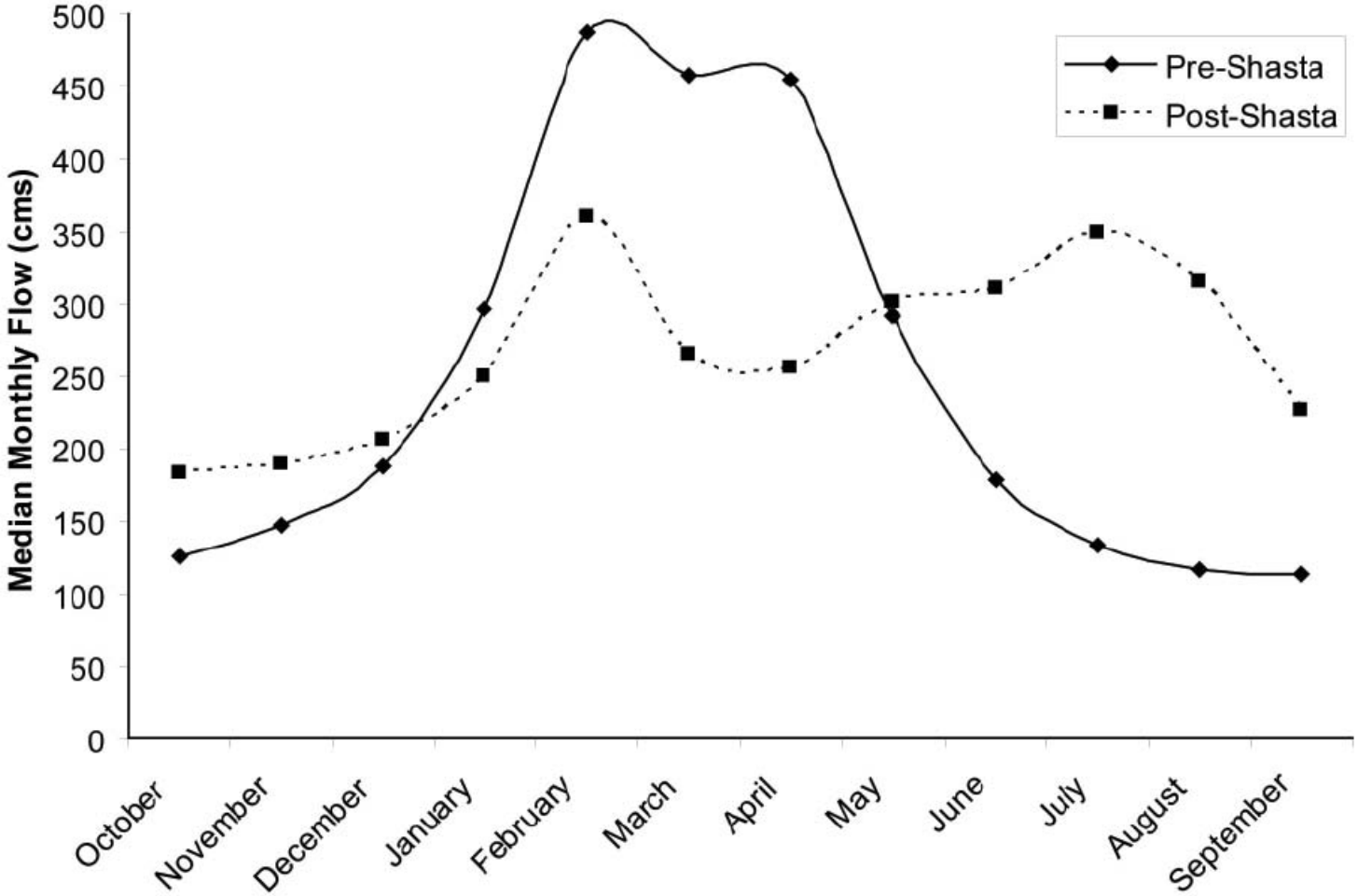


Figure X Monthly median flow values, pre-Shasta and post-Shasta, at the USGS gauge at Red Bluff. Median flows have been considerably reduced during winter and spring, due to reservoir storage and regulation, and increased during summer for irrigation and water supply deliveries (Williams et al. 2009).

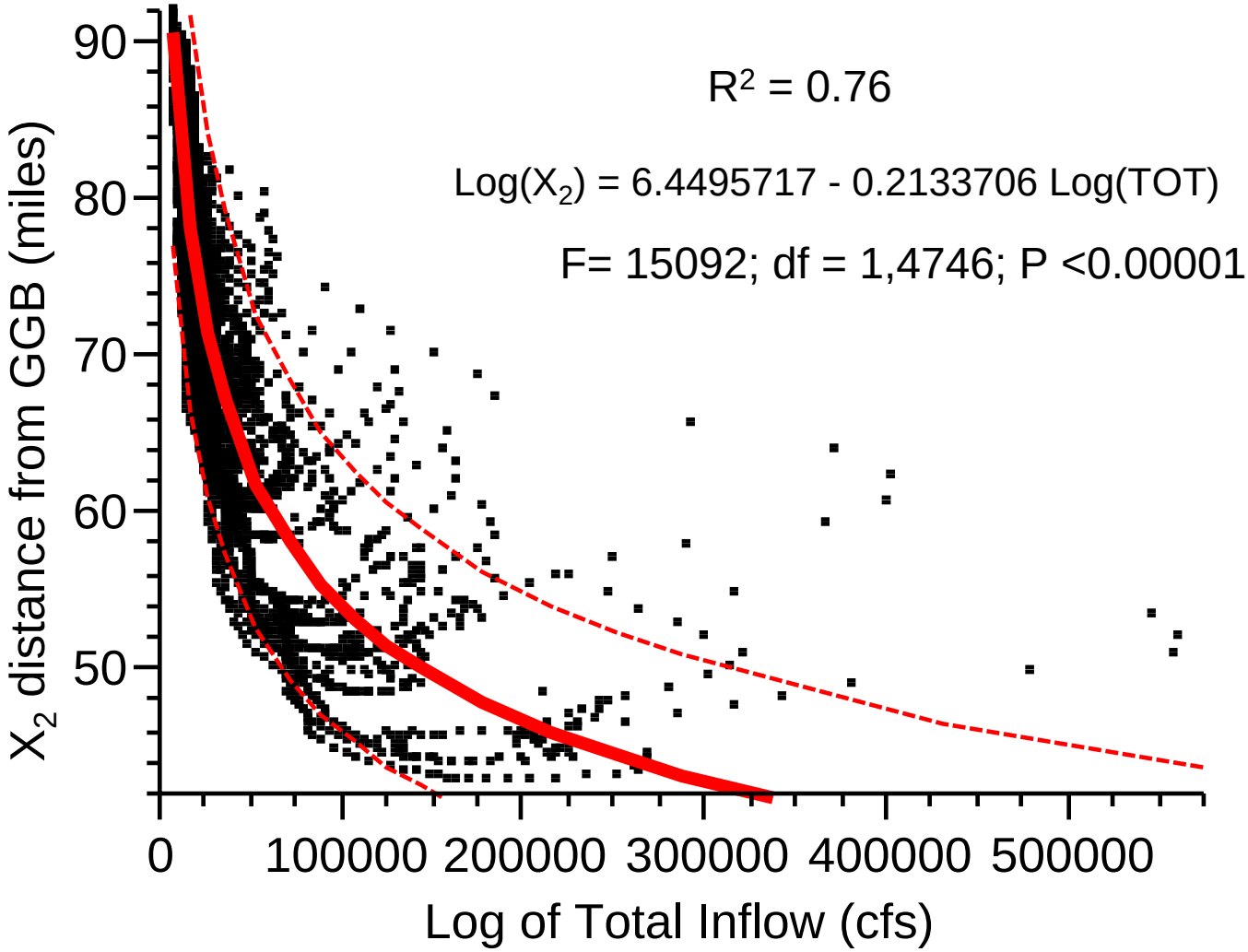


Figure X. The relationship between Total Delta inflow and the location of X_2, 1997 – 2008.

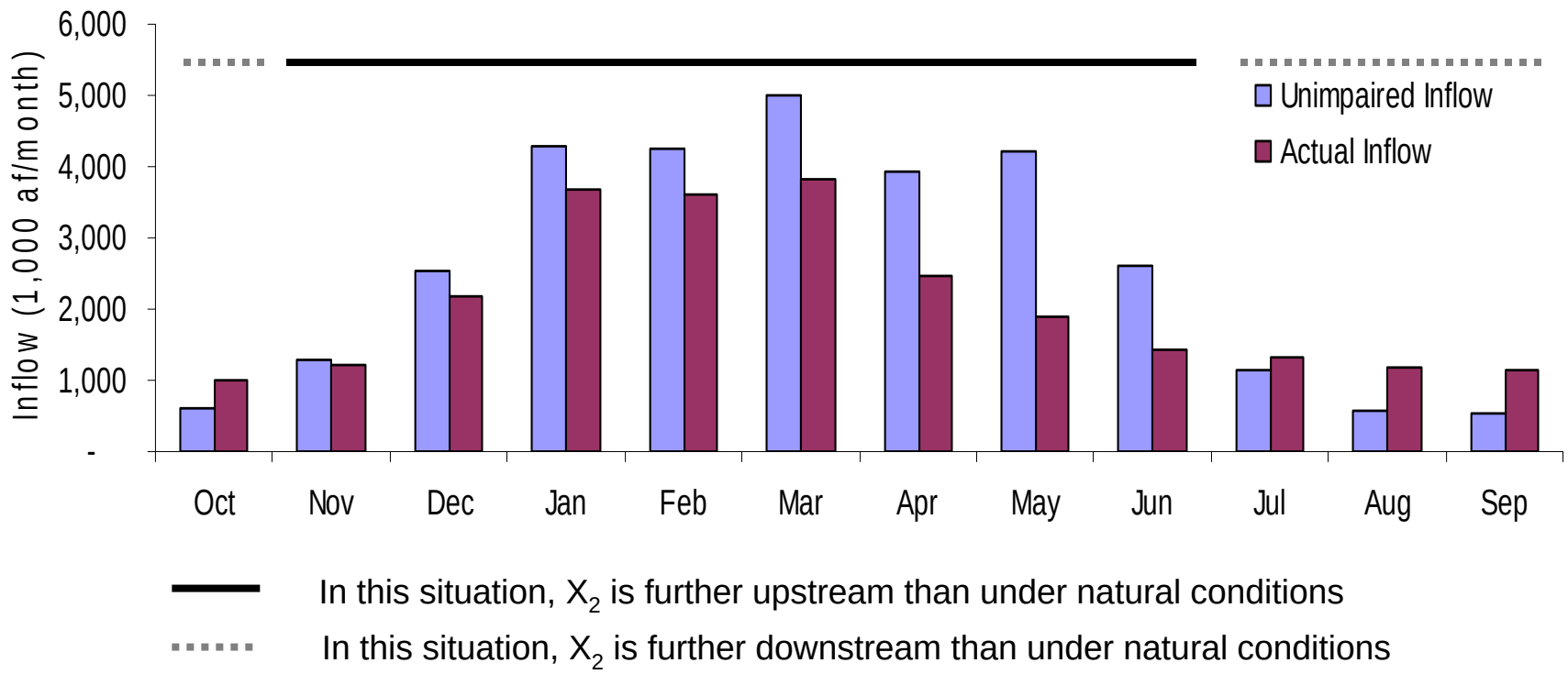


Figure 4. Unimpaired versus actual inflow for the period 1997 -2008; Sacramento-San Joaquin Delta.

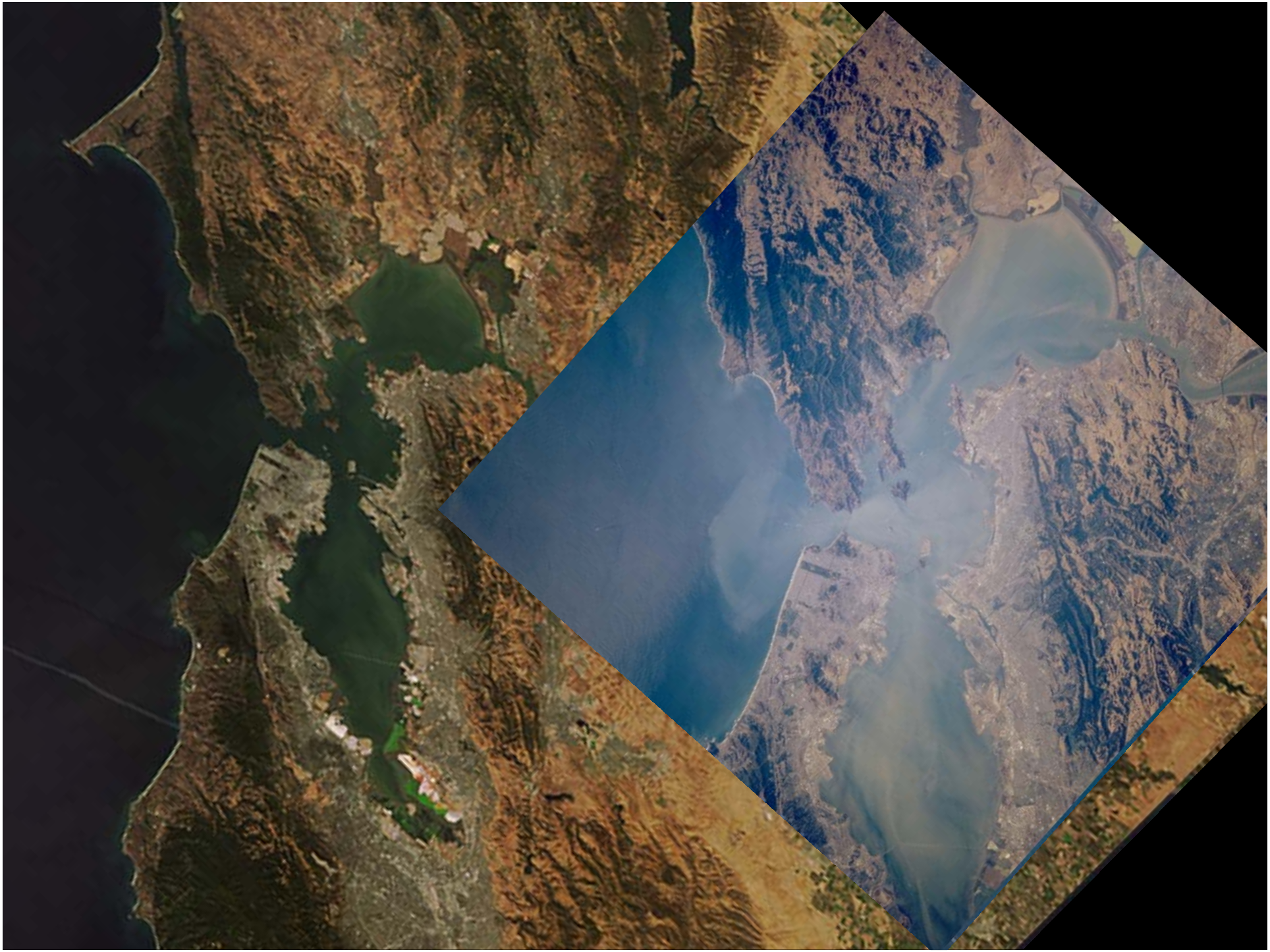
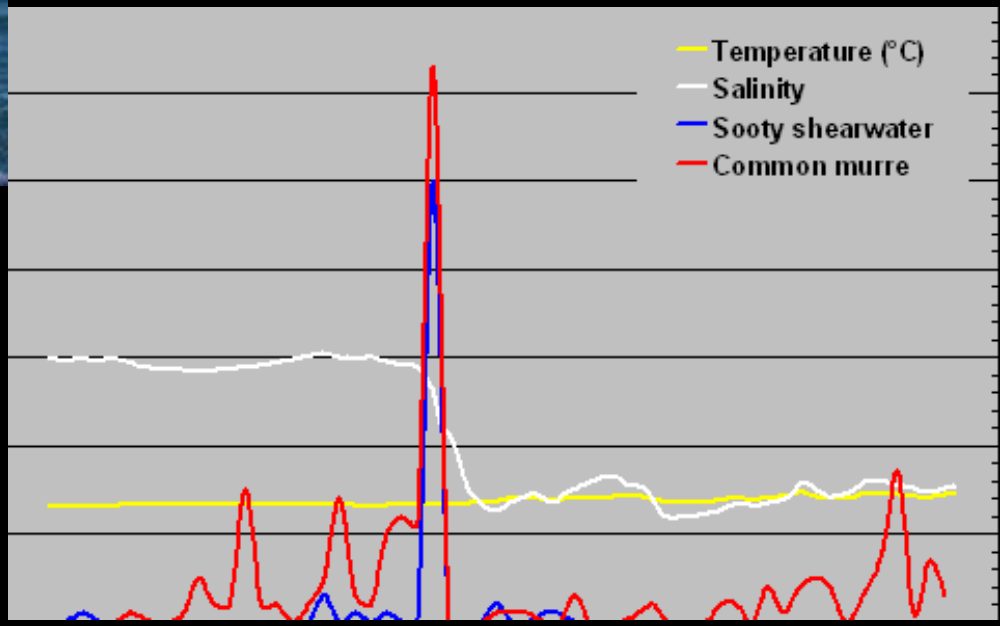


Photo of sardine schools (dark patches) around a commercial purse seine fishing vessel from the NOAA Twin Otter during LIDAR aerial surveys within the Columbia plume. (photo courtesy of Northwest Fisheries Science Center)

Example of what the Columbia River plume front looks like. At certain phases of the tide, the boundary between the river and ocean water is visible as a long foam line between brownish water from the river and more grayish or bluish water from the ocean. All juvenile salmon exiting the Columbia River must pass through this boundary to enter the ocean.

(photos and data courtesy of Northwest Fisheries Science Center)

Common murre and sooty shearwater



Example of a seabird aggregation at the Columbia River plume front. The largest red and blue peaks (in the center of the graph) indicate the highest numbers of birds counted along a 27 kilometer transect. Greatest predator numbers occur at the plume front, the area where salinity (white line) changes abruptly from about 15 to 30. The plume front is the boundary between two water types: the ocean and the Columbia River.

Two distinct issues are affecting the estuary and coastal ecology of California. I state two but they are clearly linked:

- Climate Change
  - Warmer temperatures over California
  - Change in precipitation
    - Less precipitation
    - More rain, less snow
  - Stronger winds – Land temperature increasing faster than ocean; Jet stream cycle fluctuations
  - More persistent winds
  - Winds at different time
- Direct Anthropogenic effects
  - Stream Regulation
  - Watershed development
    - Loss of wetlands
    - Hydromodification - effects of urbanization on runoff and stream flows
- Other issues
  - Invasive species
  - Management masking events – e.g. artificially propagated fish can mask declines in natural populations caused by a lack of suitable habitat.
  - Water quality

Variation in species response to environmental variability and climate change: salmon and cod as examples

Louis W. Botsford[1], Lee Worden[1], Michael J. Fogarty[2], Francis Juanes[3], Alan Hastings[1], Steven Teo[1], Matt Holland[1], Will White[1], and Hui-Yu Wang[3]

[1] University of California, Davis

[2] National Marine Fisheries Service, Woods Hole

[3]University of Massachusetts, Amherst

Question: How will fish population dynamics respond to climate change

Salmon, cod as examples

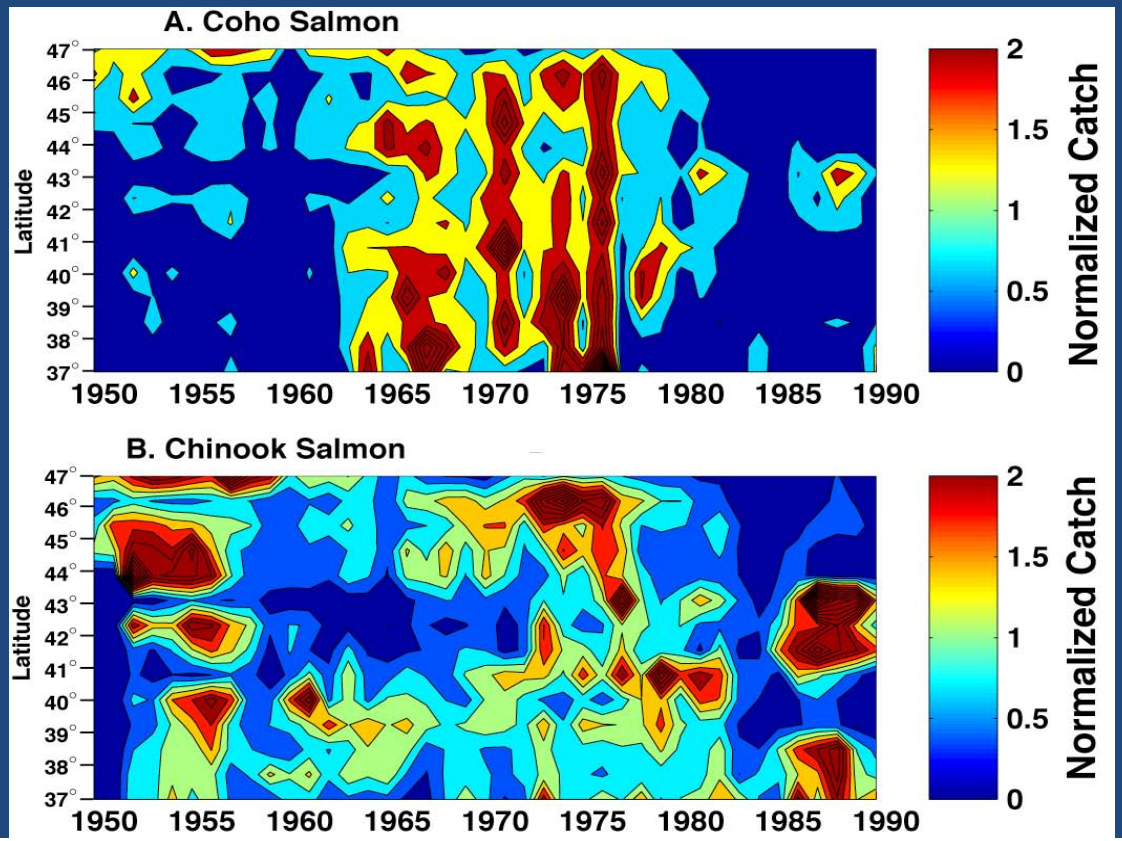
California Current salmon

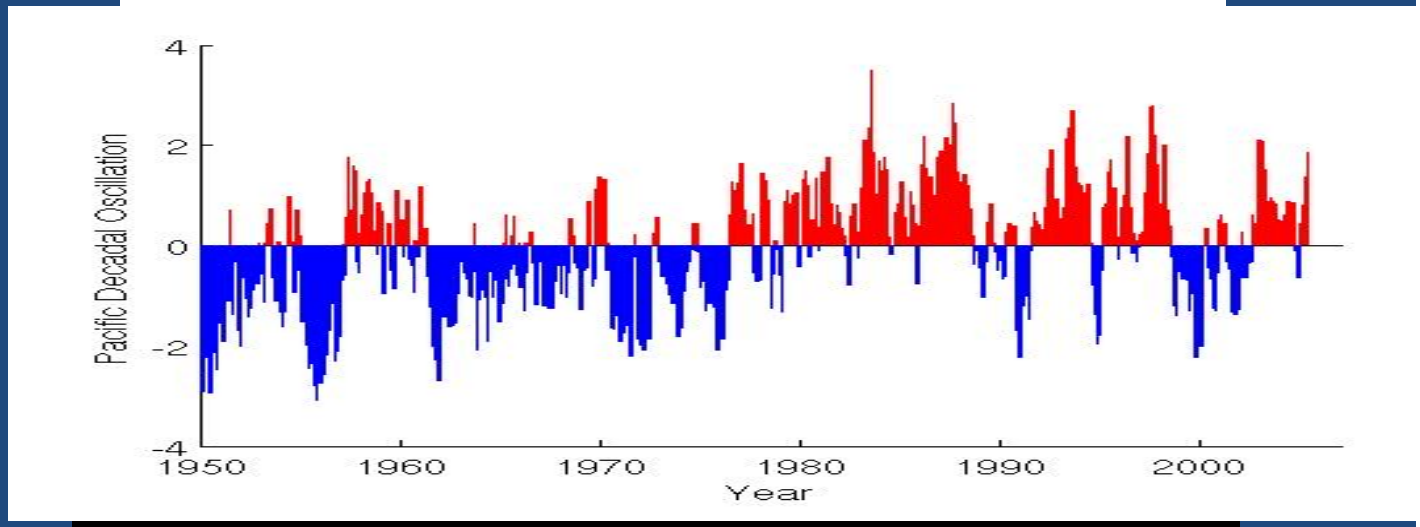
Both coho and chinook salmon respond to ENSO

Coho salmon collapsed coastwide mid-1970s

Chinook salmon did not

Same time as change in PDO index





Question: How? (population dynamics)

Caused by changes/ variability in individual growth rate?

OR survival rate? At what age(s)?

Observations same in abundance, recruitment, spawners?

Do long term changes in survival (e.g., fishing, climate) matter?

Why did coho decline coastwide, not chinook?

What is the contribution of population dynamics?

Answer: Analysis of age structured model with density-dependent recruitment (Beverton-Holt)

$$\vec{x}(t) = F(\vec{x}(t-1), t) = \begin{pmatrix} R(P(t)) \\ s(t)\, x_1(t-1) \\ s(t)\, x_2(t-1) \\ \vdots \\ s(t)\, x_{n-3}(t-1) \\ (1-\delta_e(t))\, s(t)\, x_{n-2}(t-1) \\ \delta_l(t)\, s(t)\, x_{n-1}(t-1) \end{pmatrix}$$

Age vector

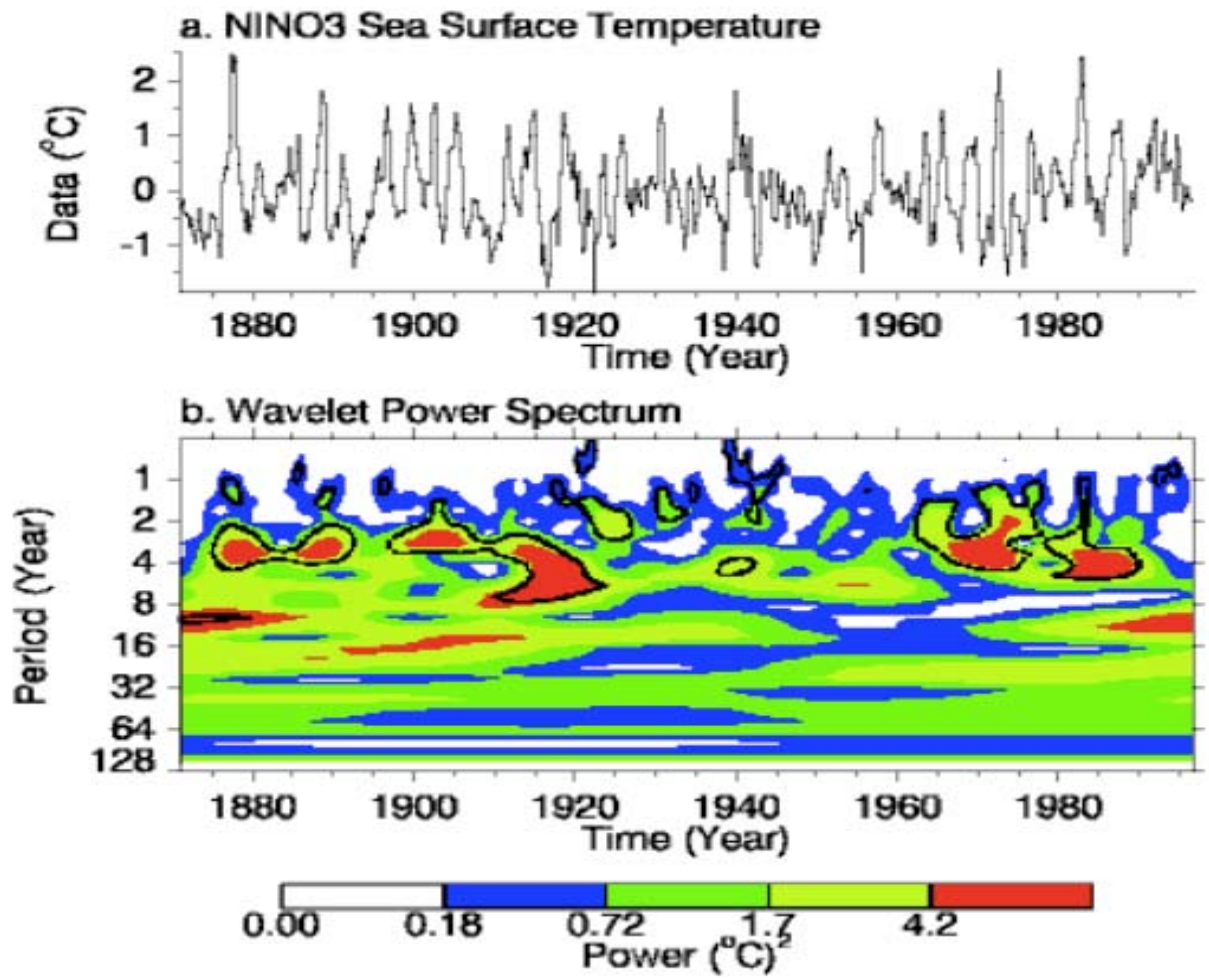
$$R(P(t)) = \frac{\alpha P(t)}{1+\beta P(t)}$$

$$P(t) = (\delta_e(t)\, x_{n-2}(t-1) + (1-\delta_l(t))\, x_{n-1}(t-1) + x_n(t-1))$$

Pacific salmon model, e.g., chinook and coho

Answers expressed in terms of sensitivity to time scales of variability , i.e., spectral response to changing climate

Example: changing spectrum of ENSO, 1870-1997



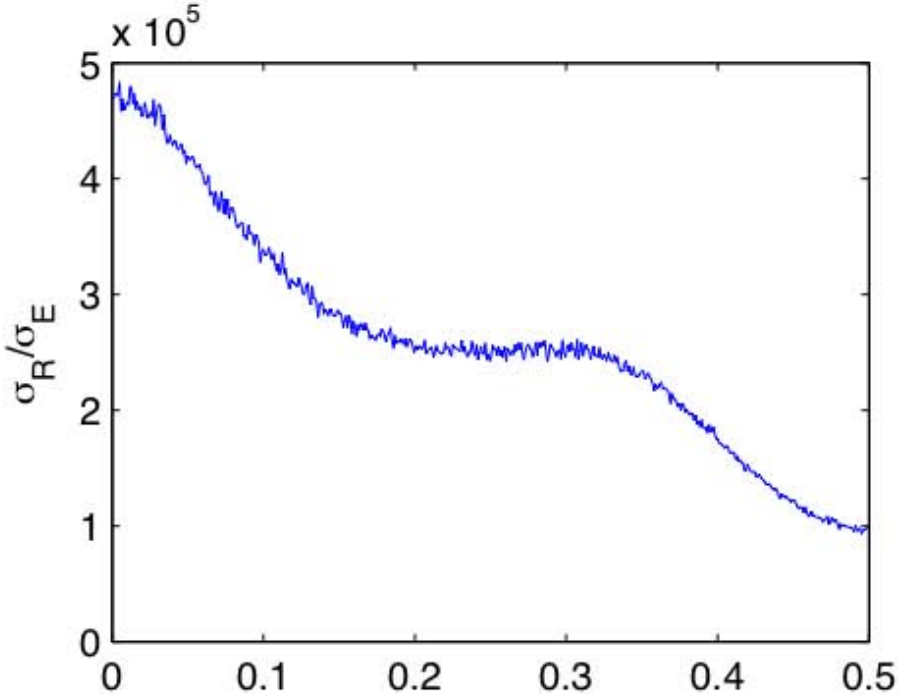
Torrence and Compo (1998)

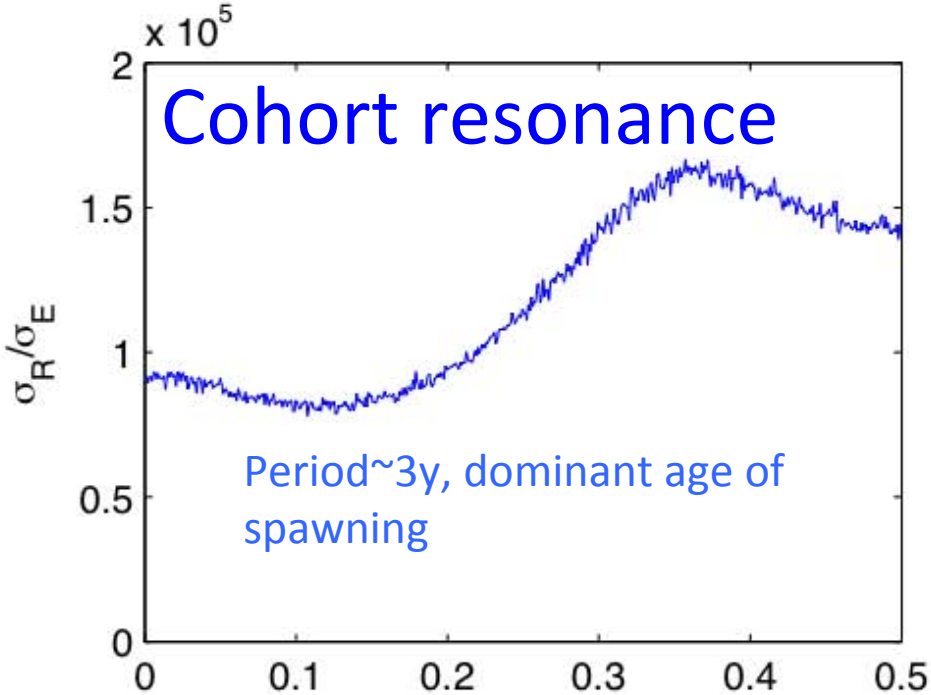
Answer to: Does point of action make a difference?

Sensitivity of coho salmon recruitment to time scales of variability in the environment:

Varying ocean survival

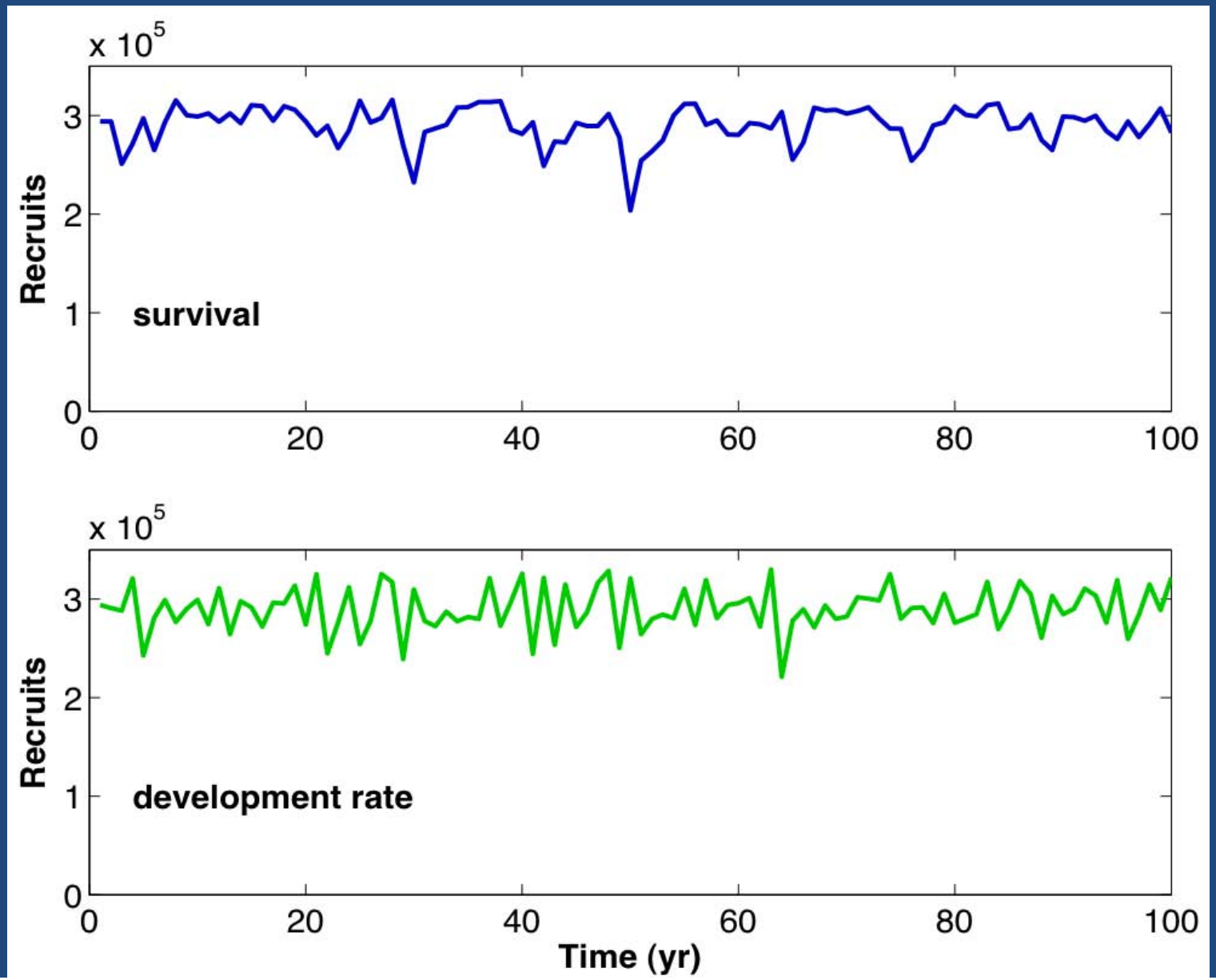
Varying growth or development rate





frequency (y^{-1})

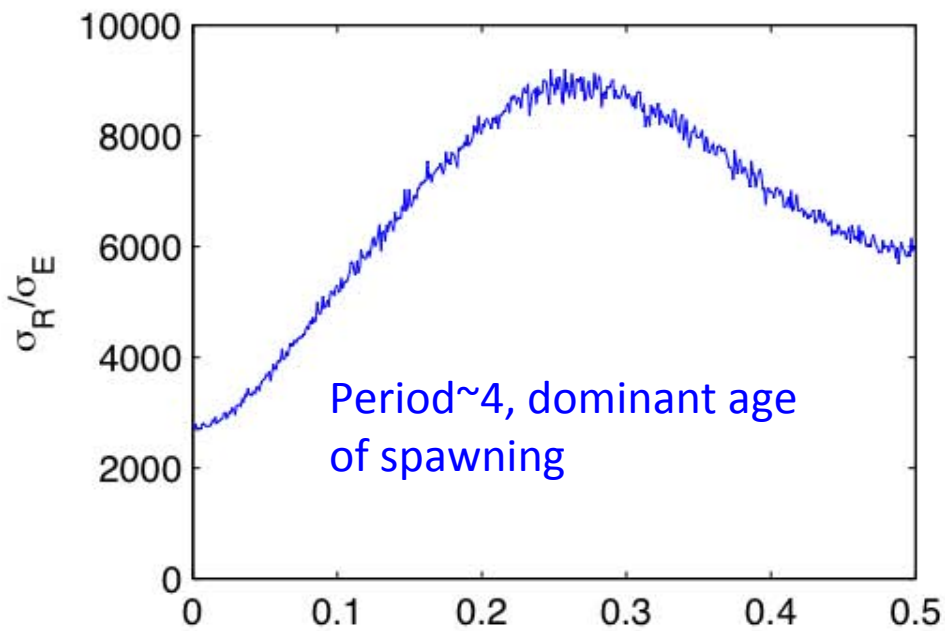
Time series: varying survival vs. growth rate (white noise)



Answer to: Does result depend on mode of observation (e.g., recruitment, abundance, catch)?

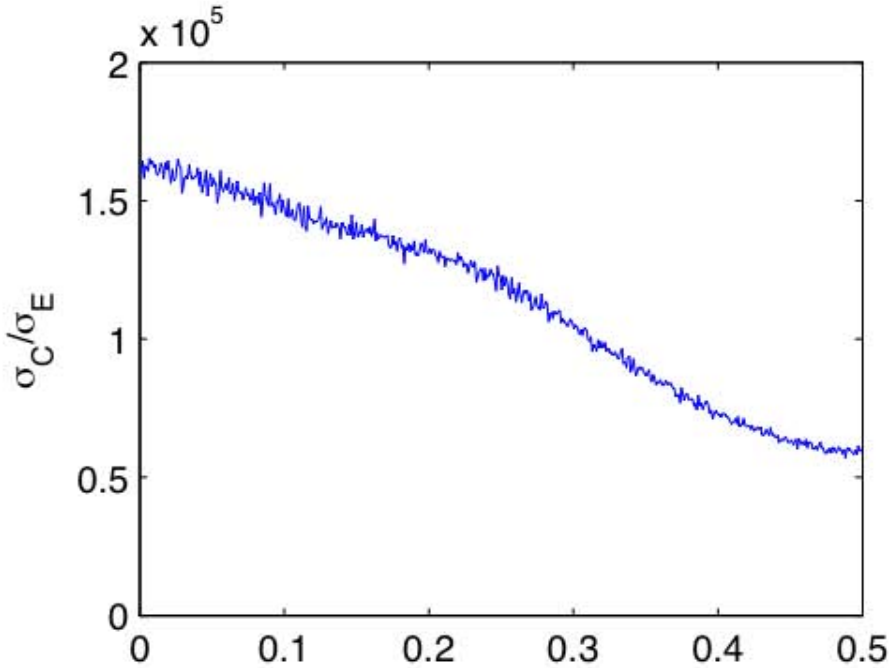
Example: CCS chinook salmon, variable growth rate

Observing: Recruitment



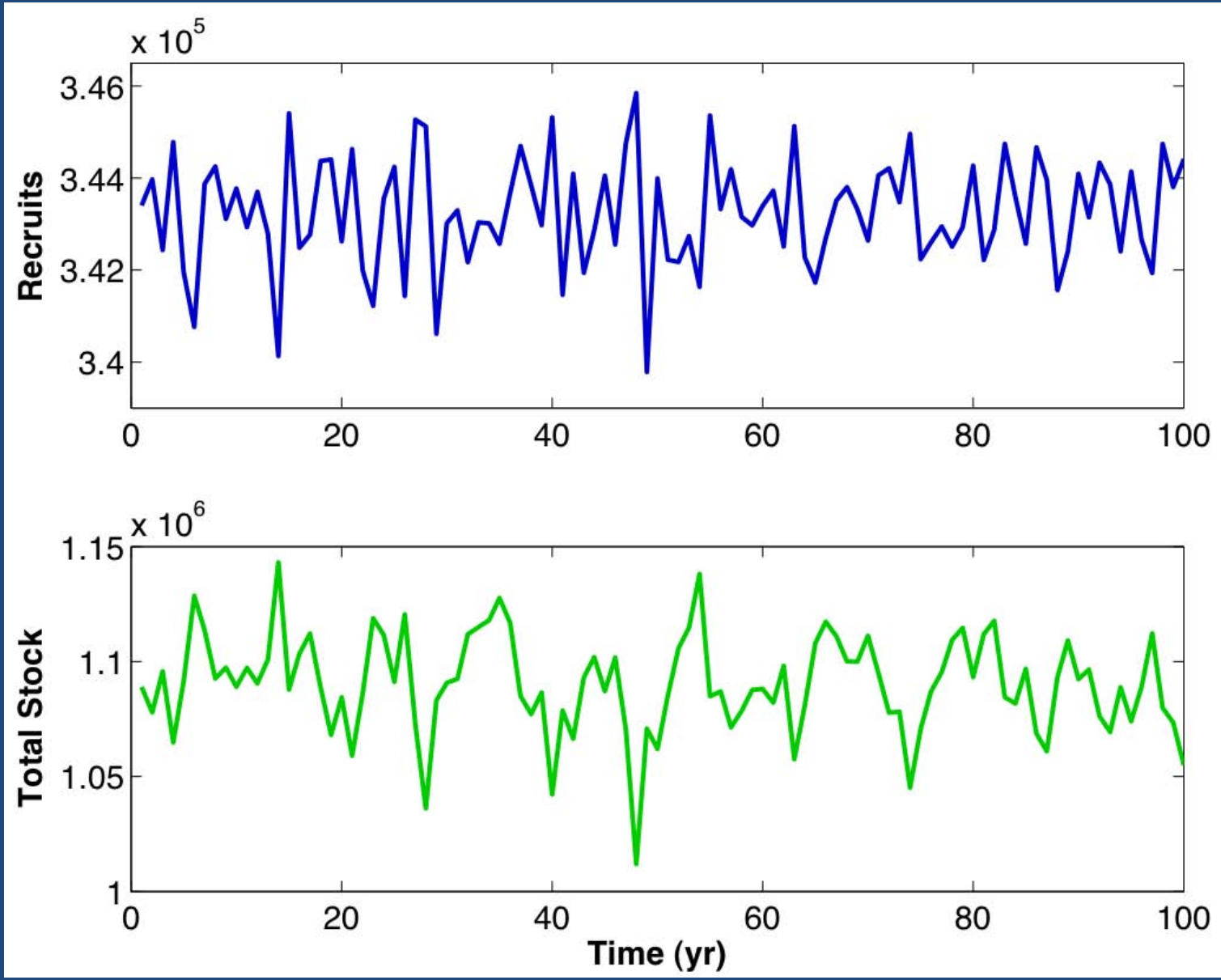
Cohort resonance

Abundance



frequency (y^{-1})

Time series: Observation of recruitment vs. abundance.
(white noise driving growth rate)



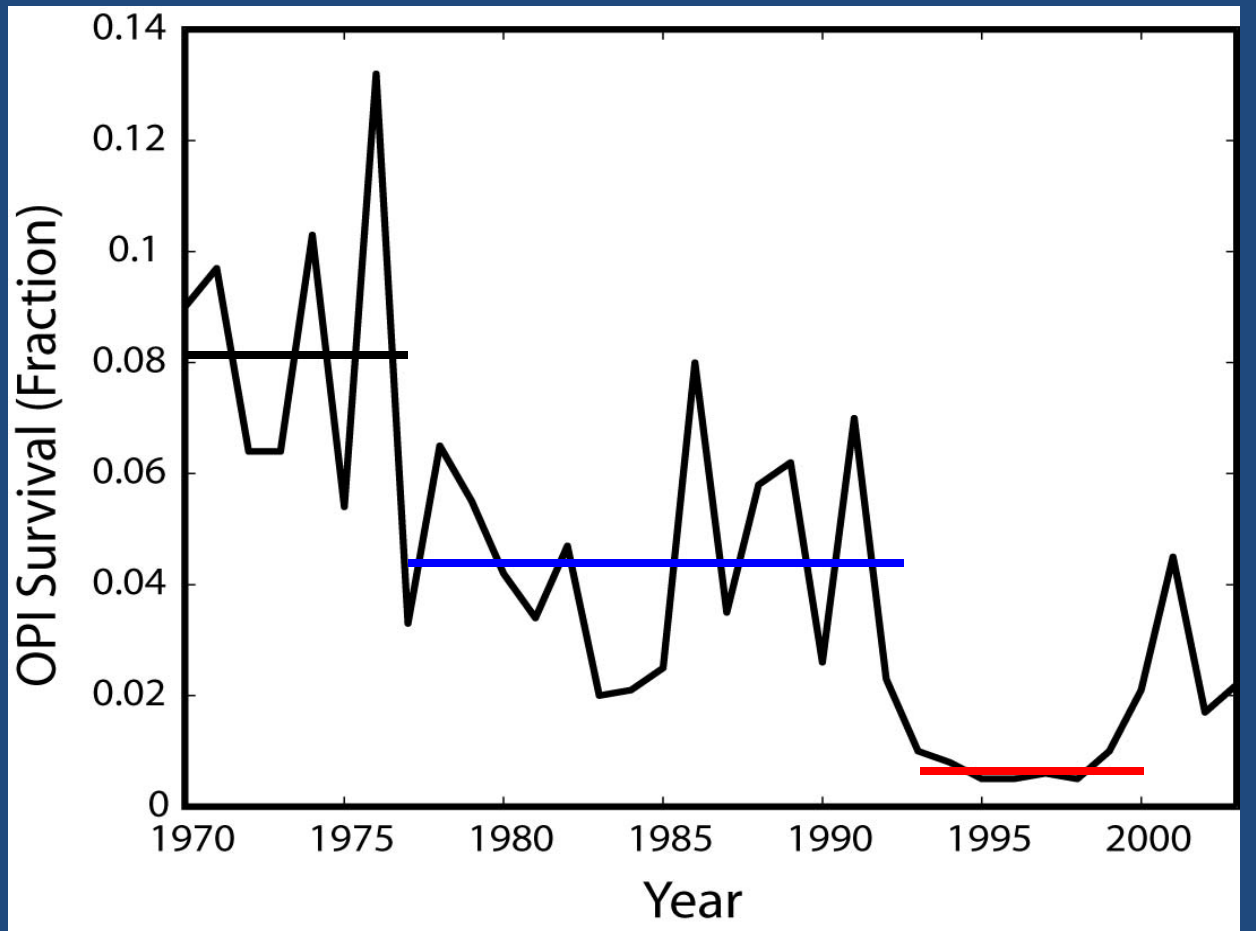
Answer to: What are effects of long-term decline in survival (e.g., fishing, climate)?

1. Equilibrium declines, could collapse
2. More sensitive to interannual variability

Example:

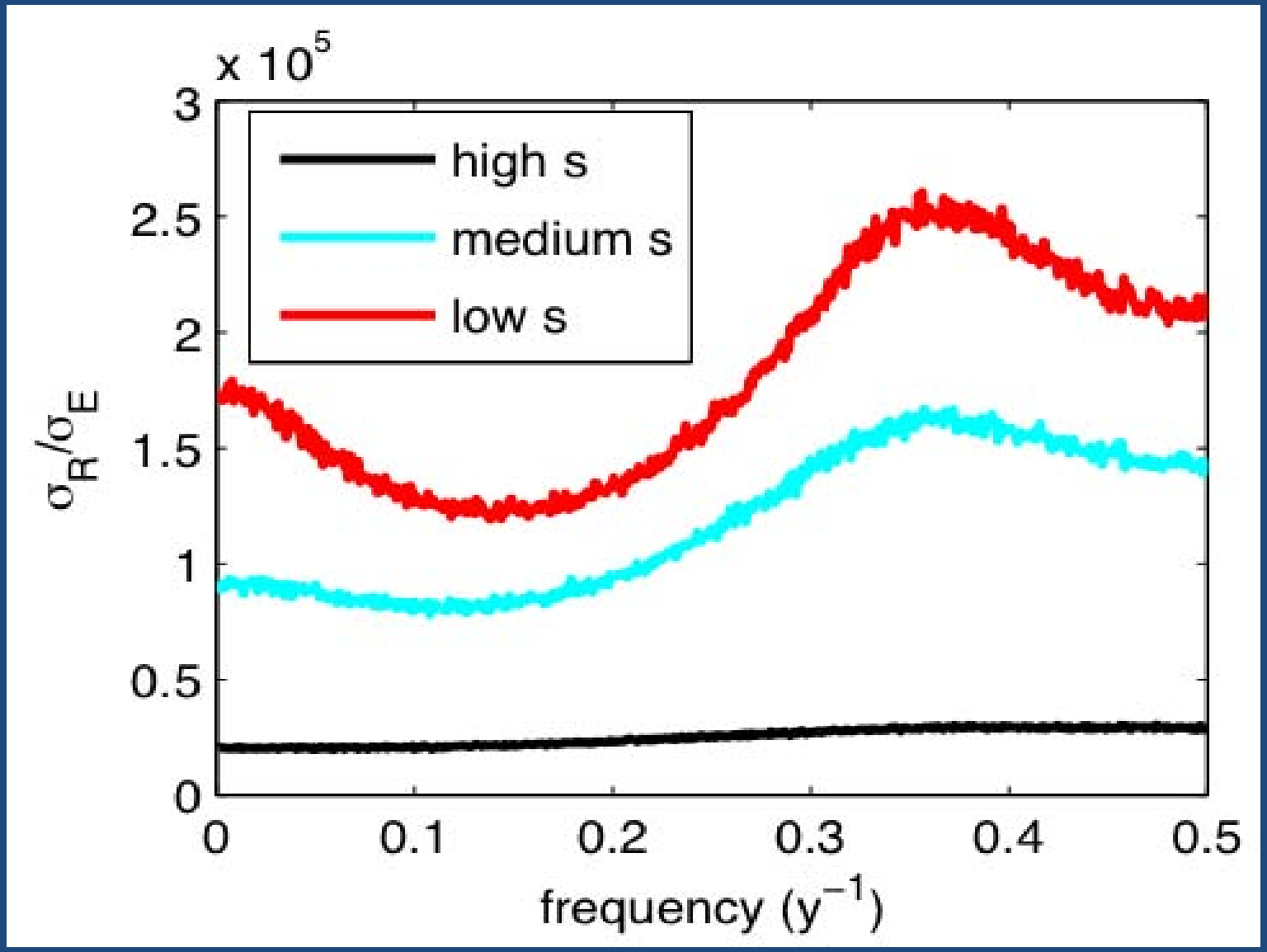
CCS coho salmon

Fishing and climate-induced decline

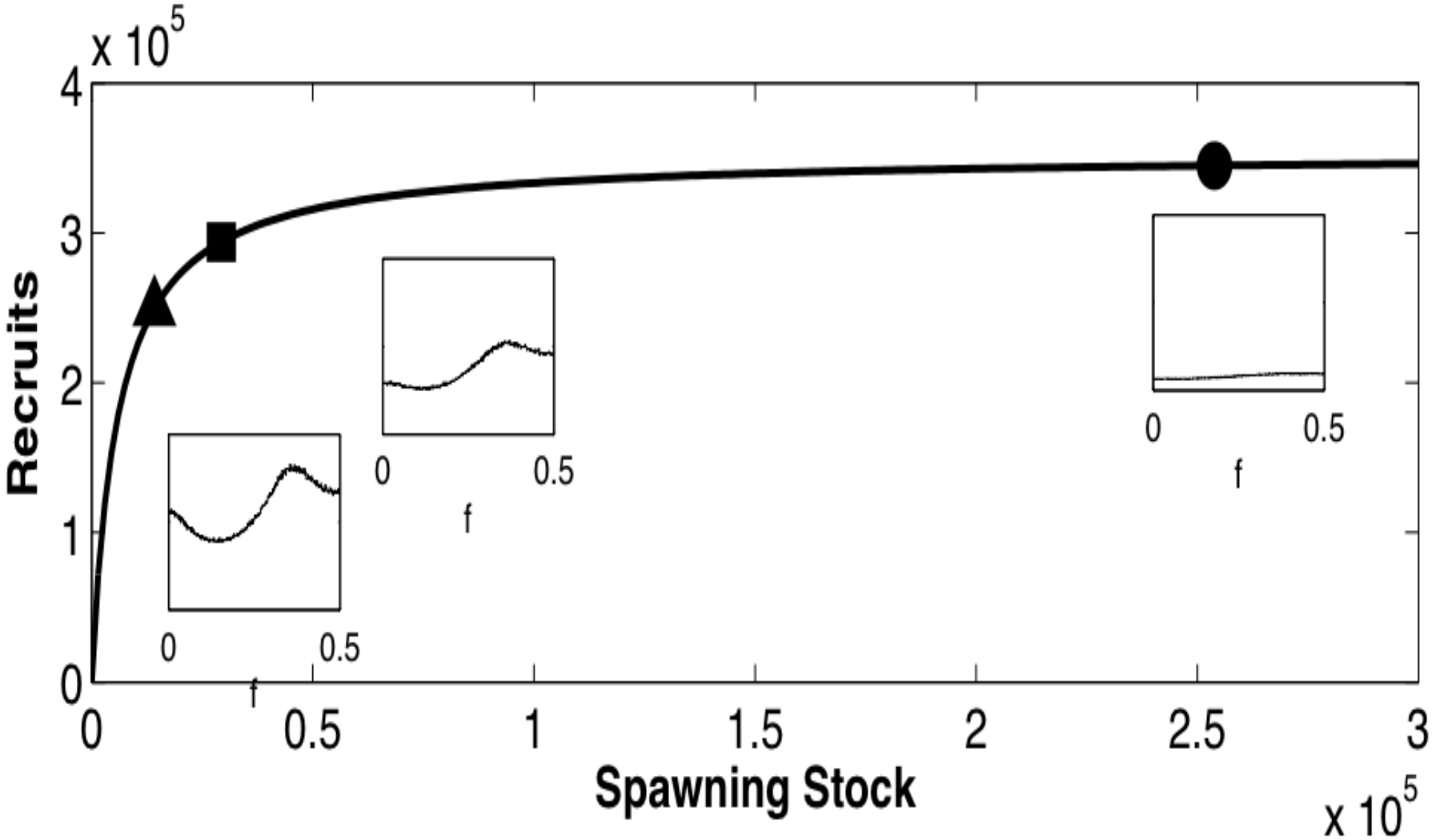


CCS Coho salmon with different ocean survivals, and time varying growth rate (white noise)

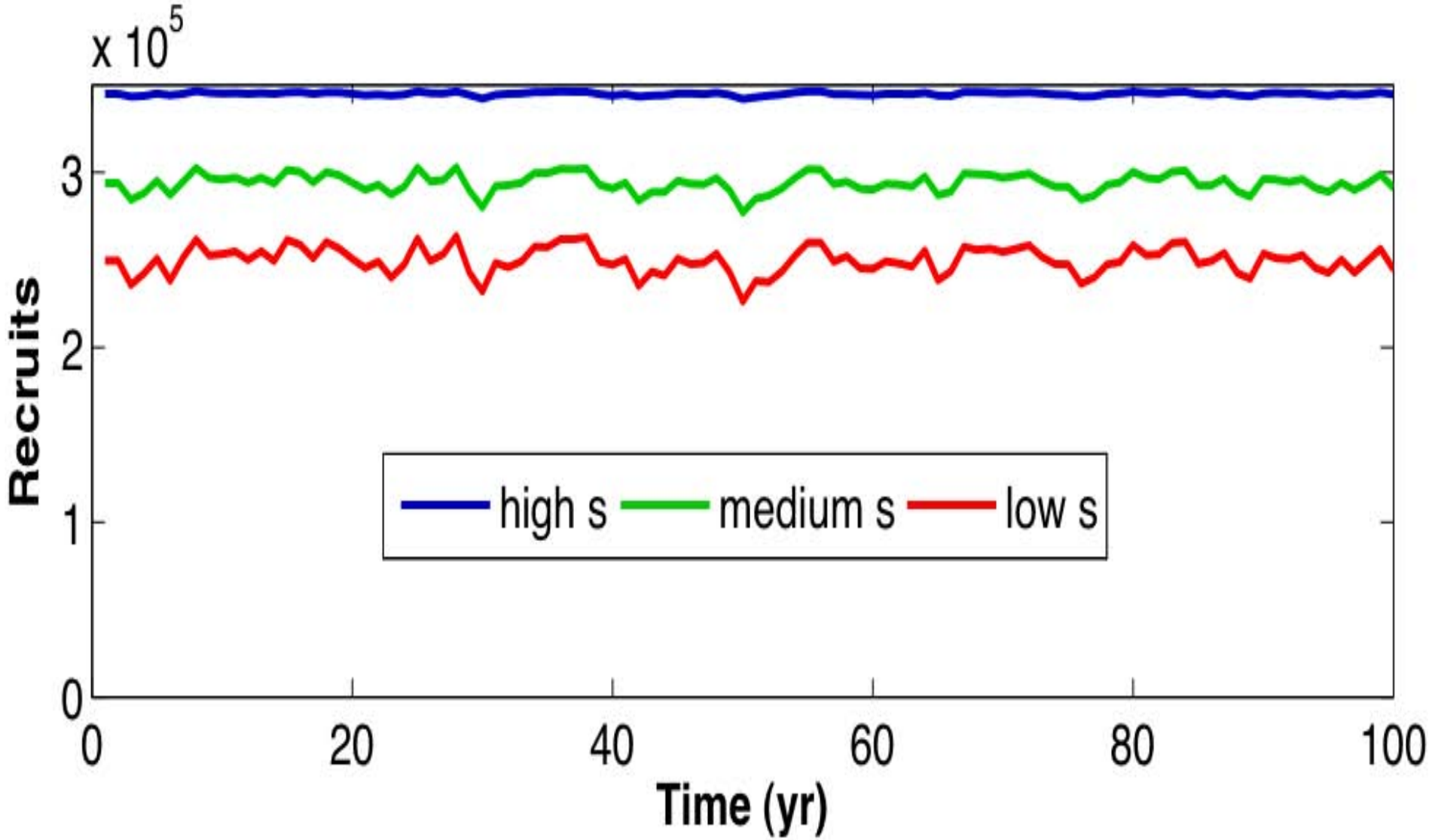
Variability about equilibrium



Changes in equilibrium and frequency response, as long-term survival changes



Time series of coho salmon at different constant ocean survivals, and time varying growth rate (white noise).

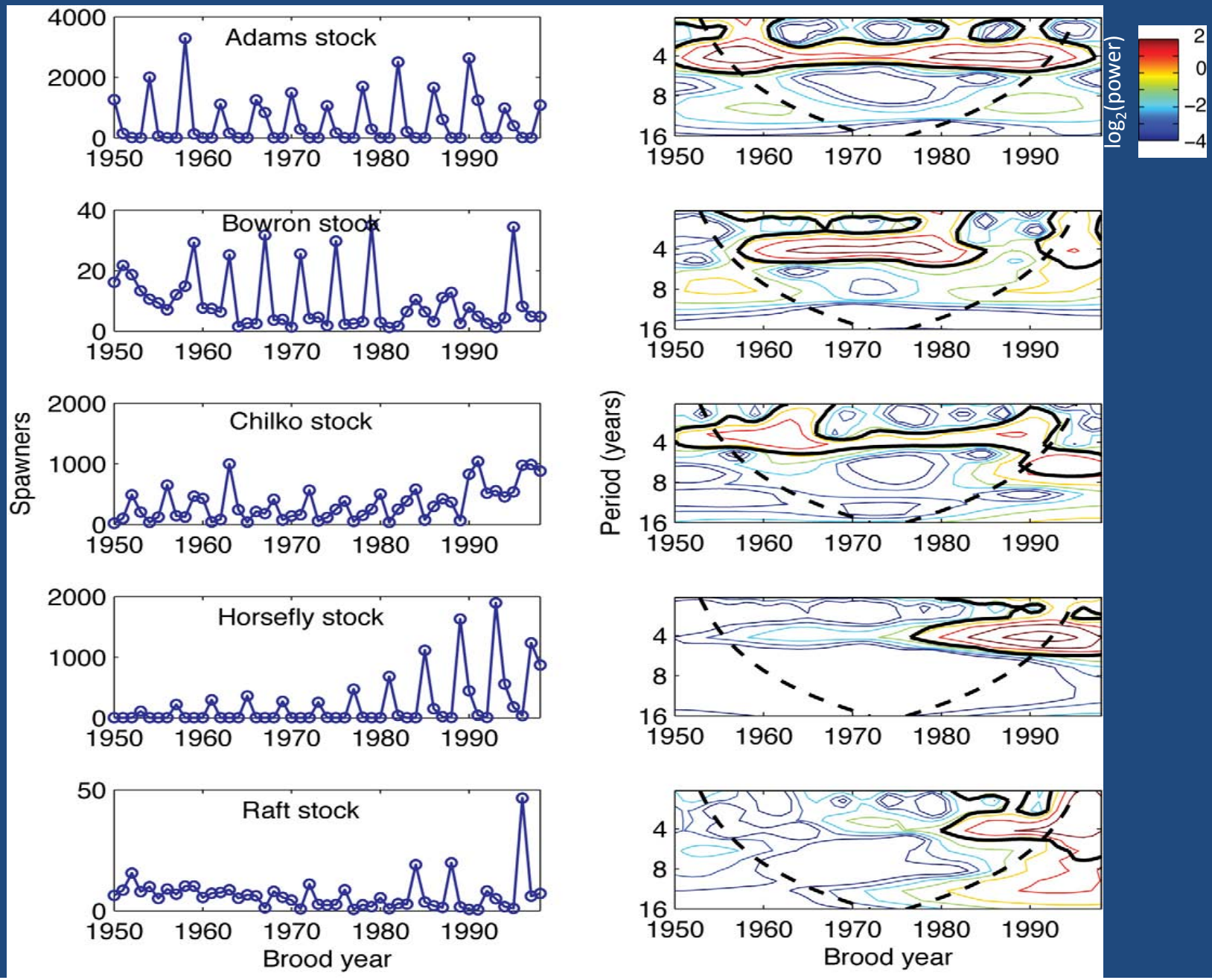


Applications:

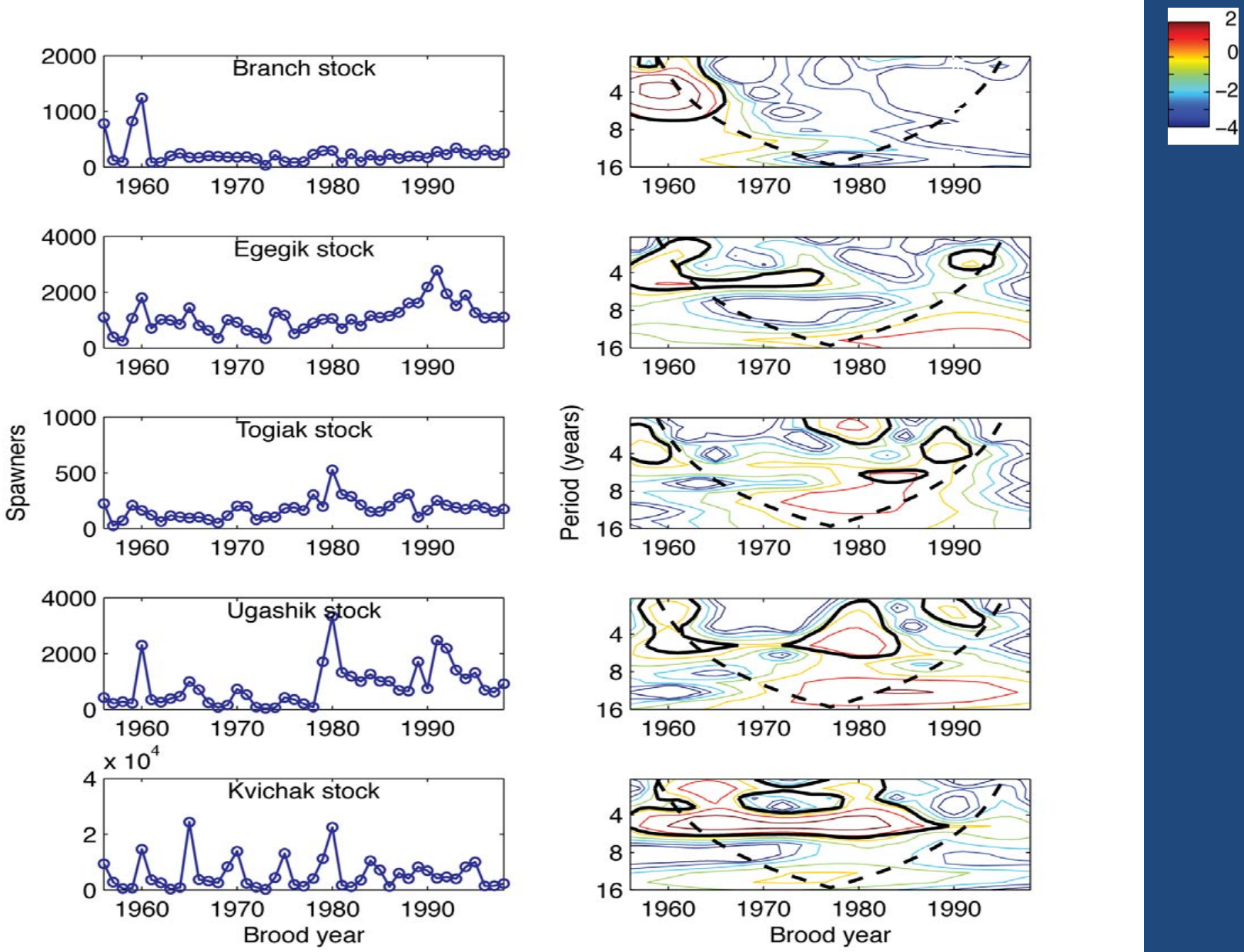
1. sockeye salmon in Pacific
2. Atlantic cod

Fraser River sockeye (cycles common, period 4)

Cyclic dominance



Bristol Bay sockeye (cycles rare, period 5)



What causes cycles, period?

- Cycles at low survival, equilibrium and narrow spawning age distribution
- Period = age of dominant spawning

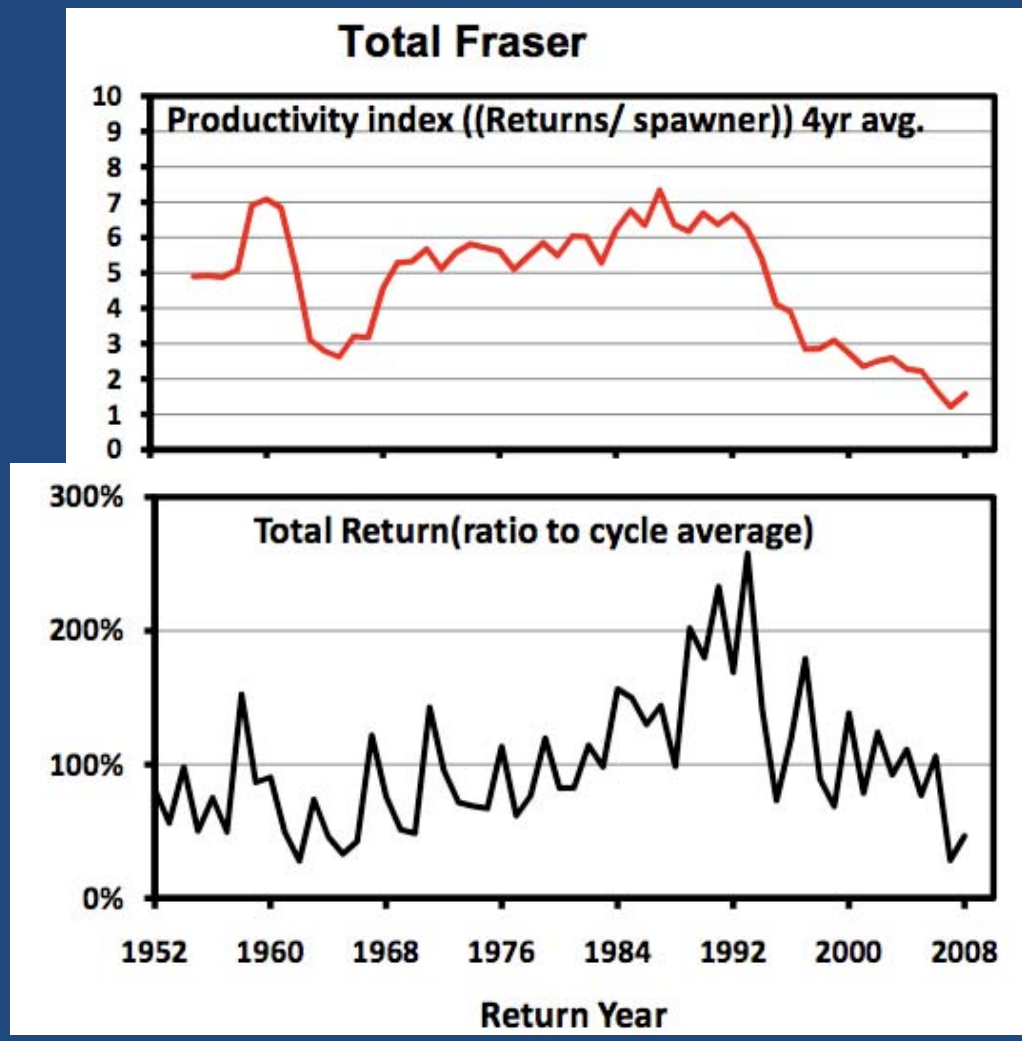
Can age structured model with DDR cause “cyclic dominance”?

Yes, at low survival with variability in both survival and spawning age distribution.

Practical application

- Some sockeye salmon populations declining

Are cycles an indicator of sensitivity of equilibrium to ocean survival?

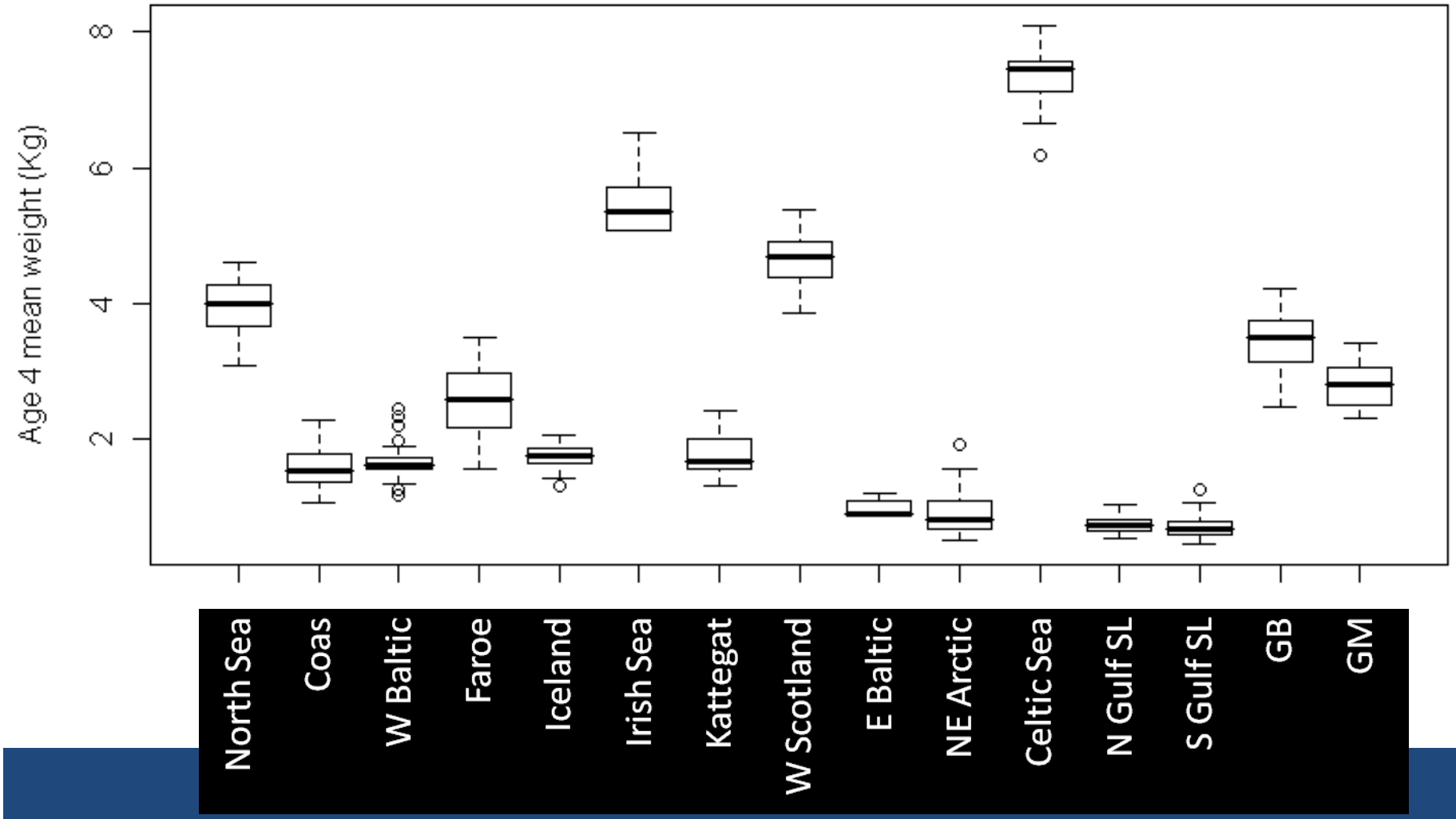


Mike Lapointe

Atlantic cod variability in life history

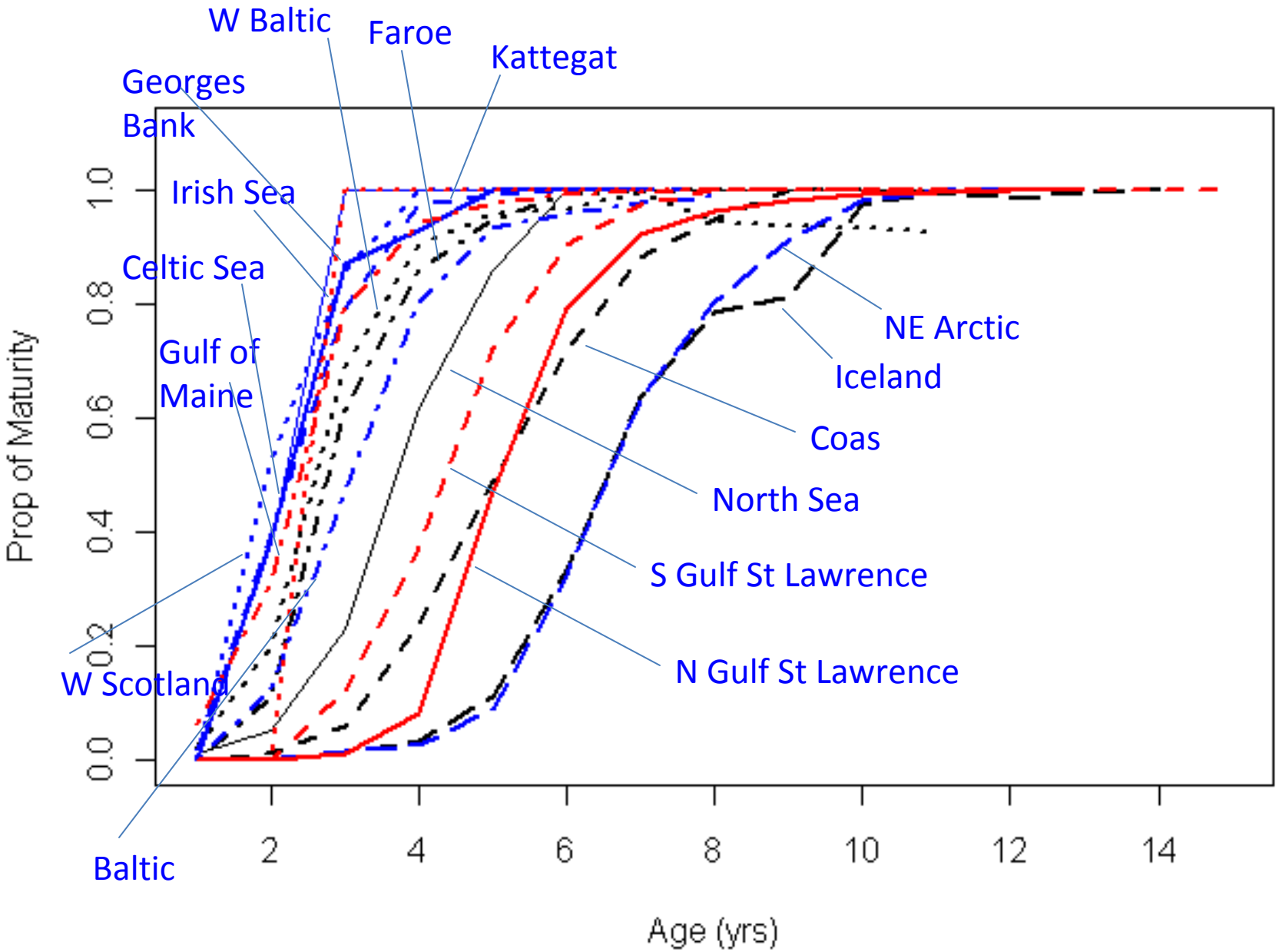
- Effect of life history on equilibrium
- Effect of life history on response to variability

Growth rate varies with location



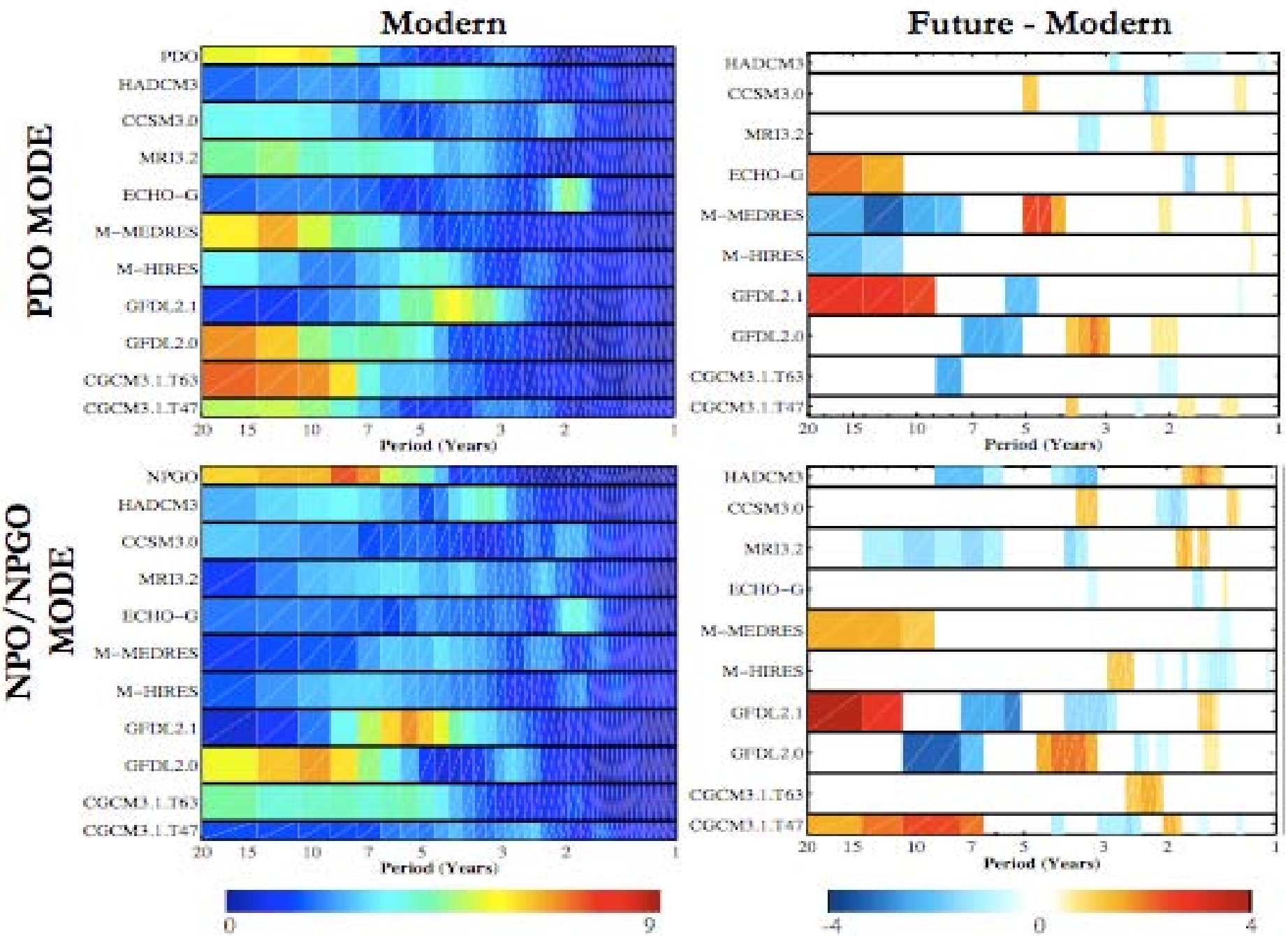
Weight-at-age estimated from catch data; each box represents a time series of data of a stock

Spatial variation in maturation schedules



The future

- Explore ENSO, PDO, NPGO and other predictions from GCMs.

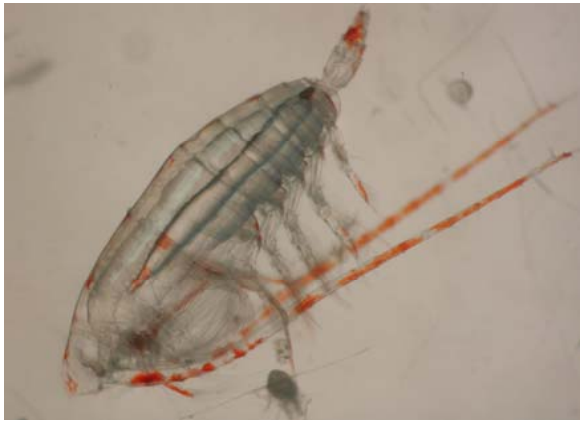


Furtado and Di Lorenzo (EPOC 2008)

Thank You

Forecasting returns of coho and Chinook salmon in the Northern California Current: a role for high-frequency long-term observations

Bill Peterson, Senior Scientist
NOAA Fisheries
Hatfield Marine Science Center
Newport Oregon



- See www.nwfsc.noaa.gov, "Ocean Index Tools"

Some First Principles

- Common perception is that salmon leave the rivers and enter a black box (the ocean) and magically (and luckily) they return after being away for a year or two (or more).
- Rates of return from the ocean are quite variable among years, and results are often filled with many surprises.
- After 14 years of research we think we have worked out what it is about ocean conditions that leads to variable returns.
- And, we have gone boldly where others have gone before, and think that we can forecast returns of salmon to rivers at least in a qualitative manner

What are we doing to learn about climate change, marine ecosystems and salmon?

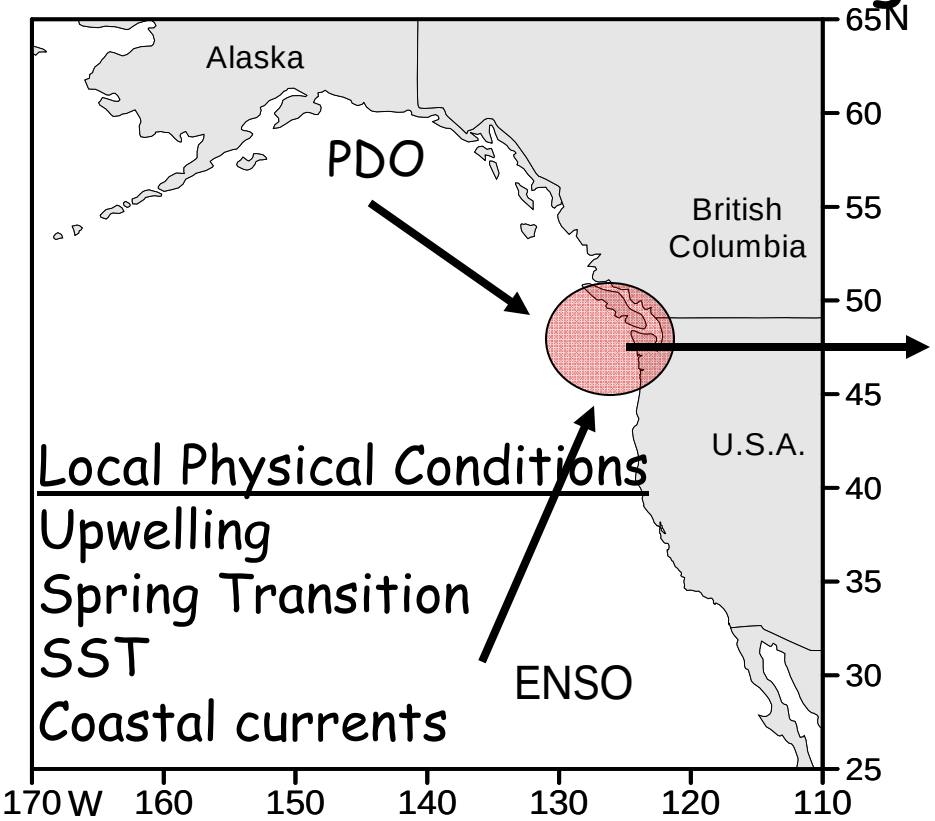
- Making lots of observations, at sea
- Working with computer models/modelers at Oregon State University, Georgia Tech and Princeton Univ.
- Meet with watershed managers, Columbia River power managers, fisheries managers, teachers and the general public, to educate them, through talks and our web-page, on how ocean conditions might affect living marine resources.

•See www.nwfsc.noaa.gov, “Ocean Index Tools”

We are contributing to salmon management by studying the ocean phase of their life history and by developing management advice based on a suite of physical, biological and ecological indicators

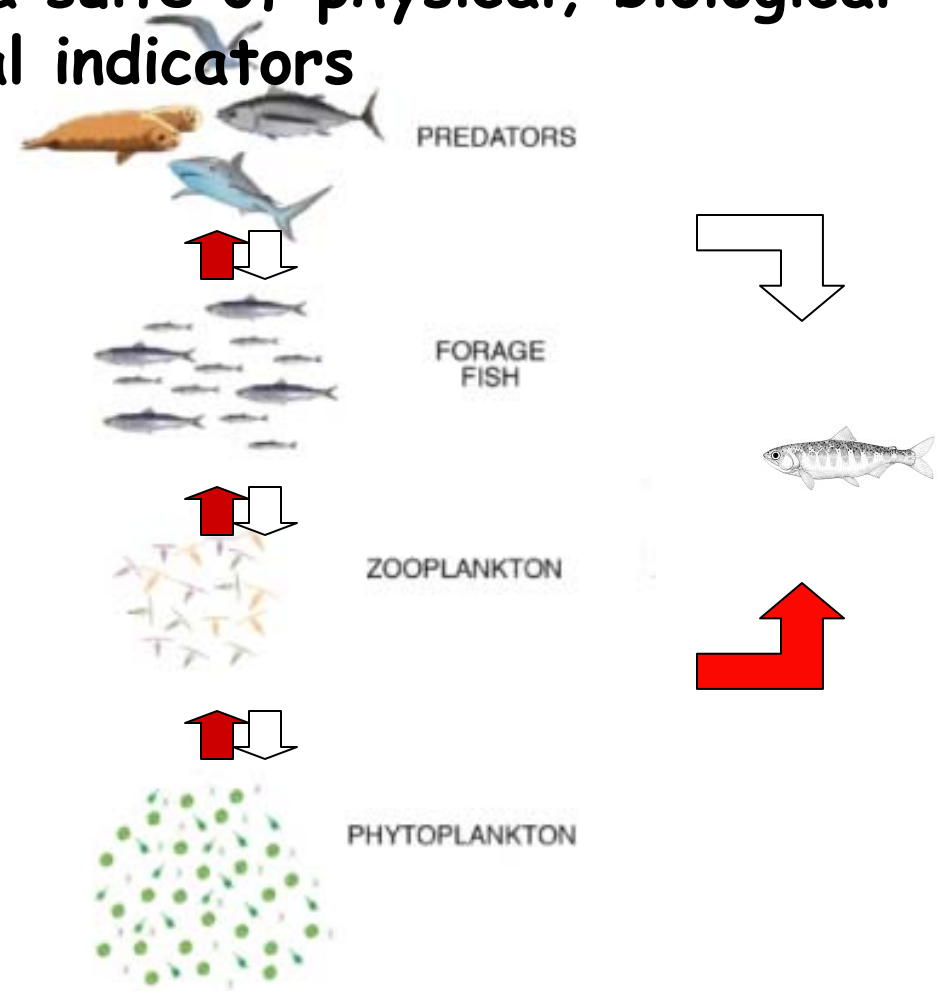
Today I will speak about changes in the food chain

Large scale forces acting at the local scale can influence biological processes important for salmon



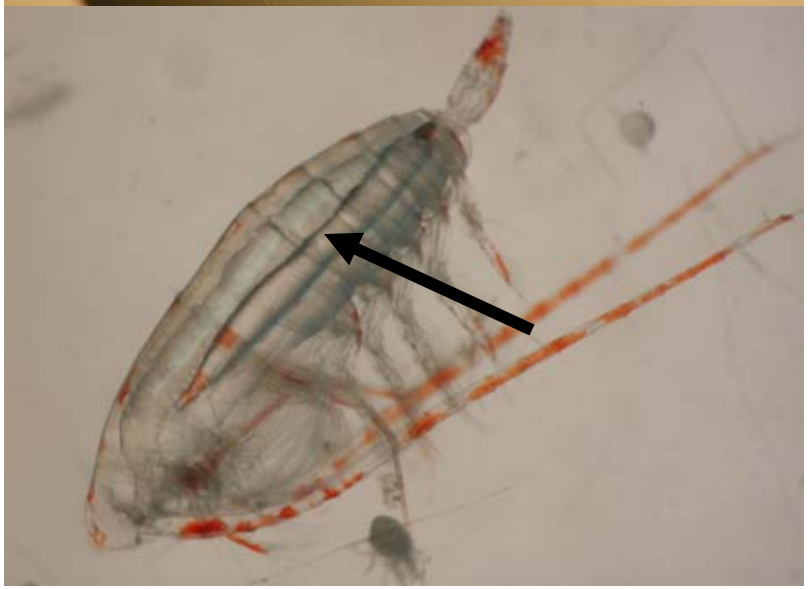
Local Physical Conditions
Upwelling
Spring Transition
SST
Coastal currents

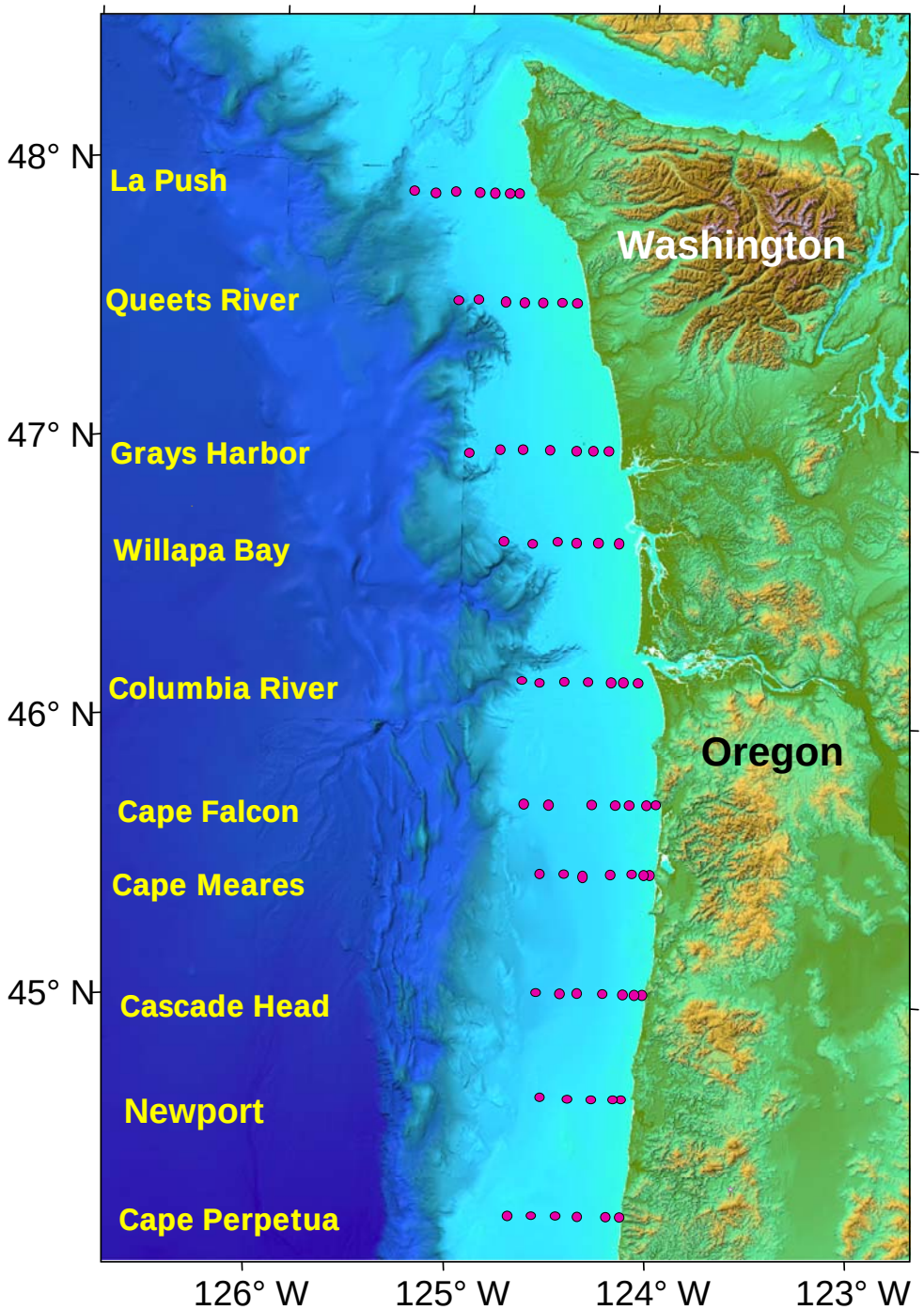
Approach
1. Develop time series
2. Relate to salmon through simple bivariate analyses



Local Biological Conditions

Here are some images of two types of plankton, copepods and krill, that play key roles in a salmon's food web





Observations

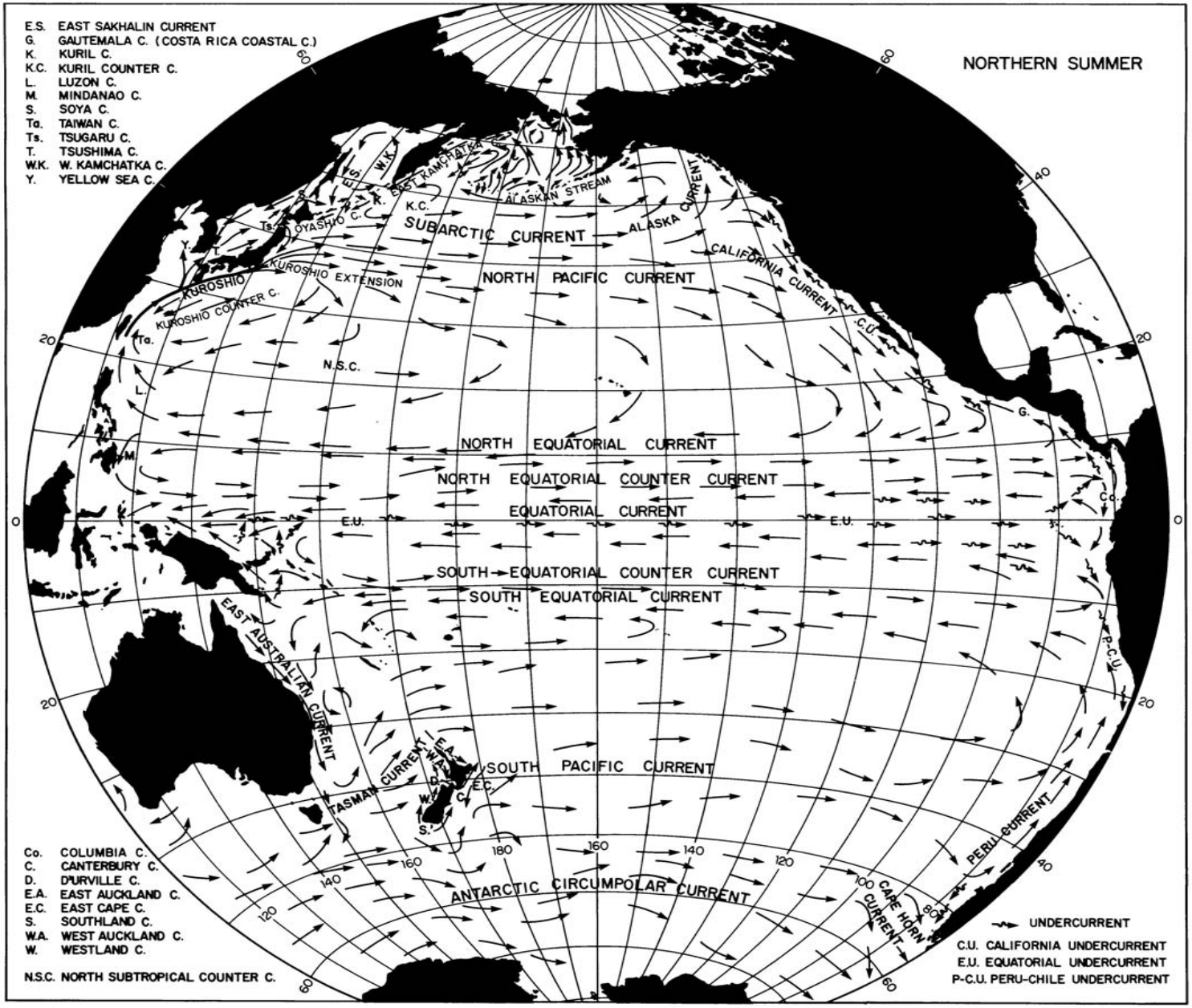
- Newport Line biweekly sampling since 1996 (15th year)
- Juvenile salmon sampling in June and September since 1998 (13th year)
- Historical data:
  - hydrography, 1960s;
  - plankton, 1969-1973; 1983, 1990-1992
  - juvenile salmon, 1981-1985

Four factors affect plankton, food chains, pelagic fish and the growth and survival of salmon in the northern California Current

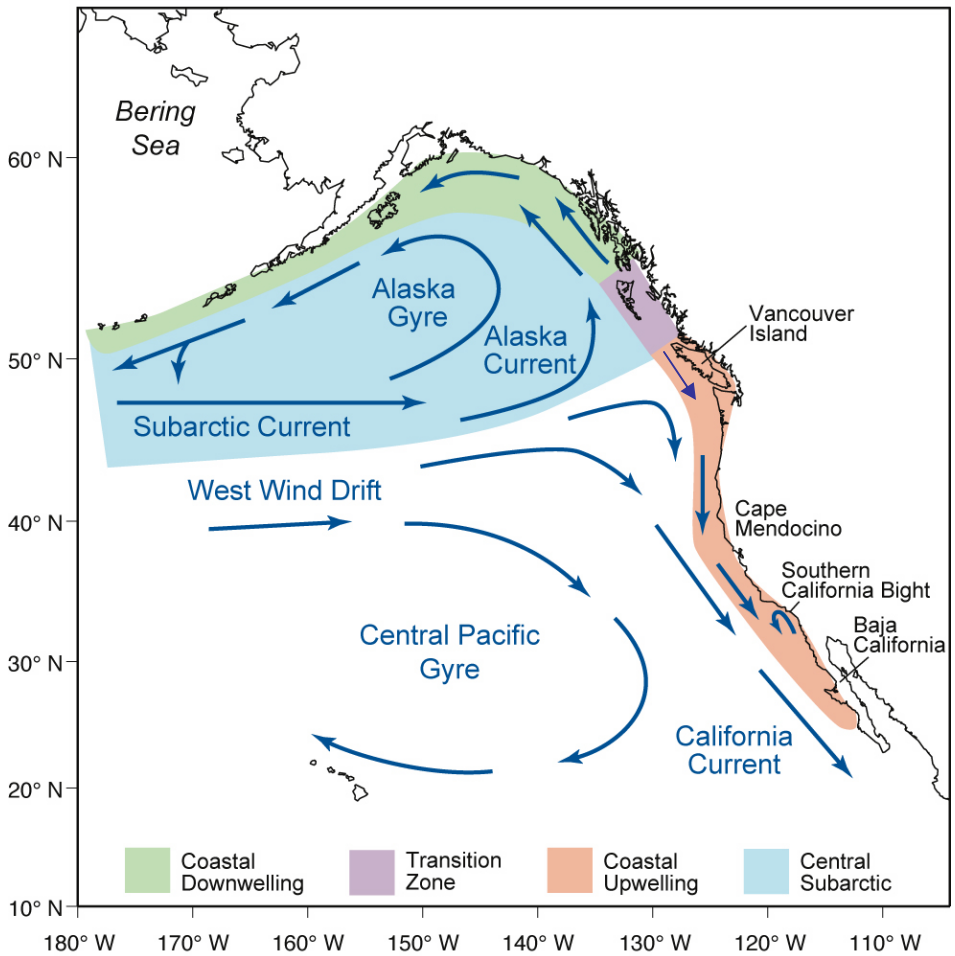
- Large-scale circulation patterns and the kinds of water that feed the California current
- Seasonal reversal of coastal currents: southward in summer – northward in winter
- Coastal Upwelling
- Phase of the Pacific Decadal Oscillation (PDO)

Everything is on the the web
at: http://www.nwfsc.noaa.gov
"Ocean Index Tools"

Oceanography 101



Circulation off the Pacific Northwest

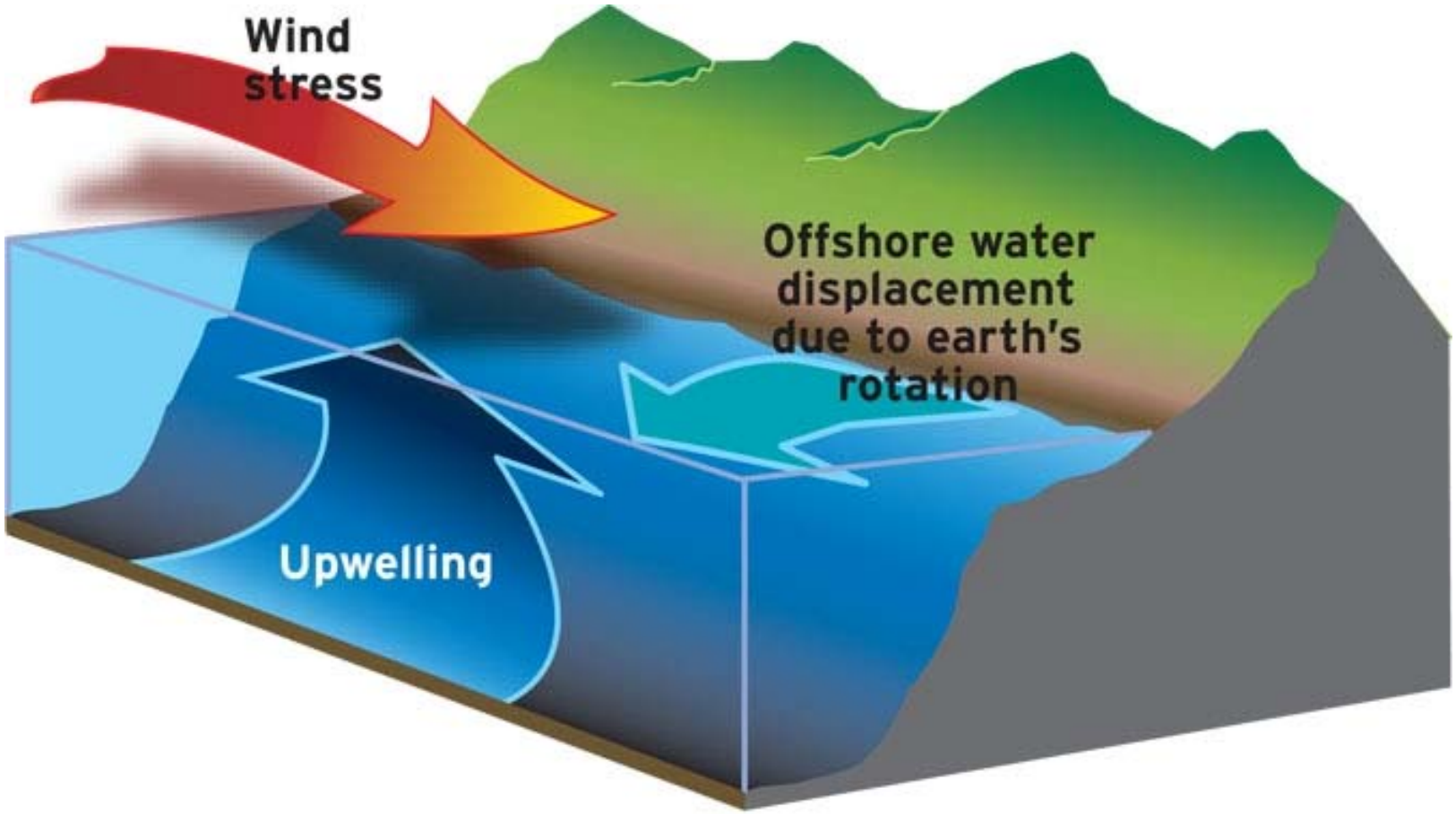


Subarctic Current brings cold water and northern species to the N. California Current;

The West Wind Drift brings subtropical water and subtropical species to the N. California Current

Therefore, ecosystem structure is affected by the source waters which feed the California Current.

Local winds drive currents and cause upwelling along the coasts of Washington, Oregon and California



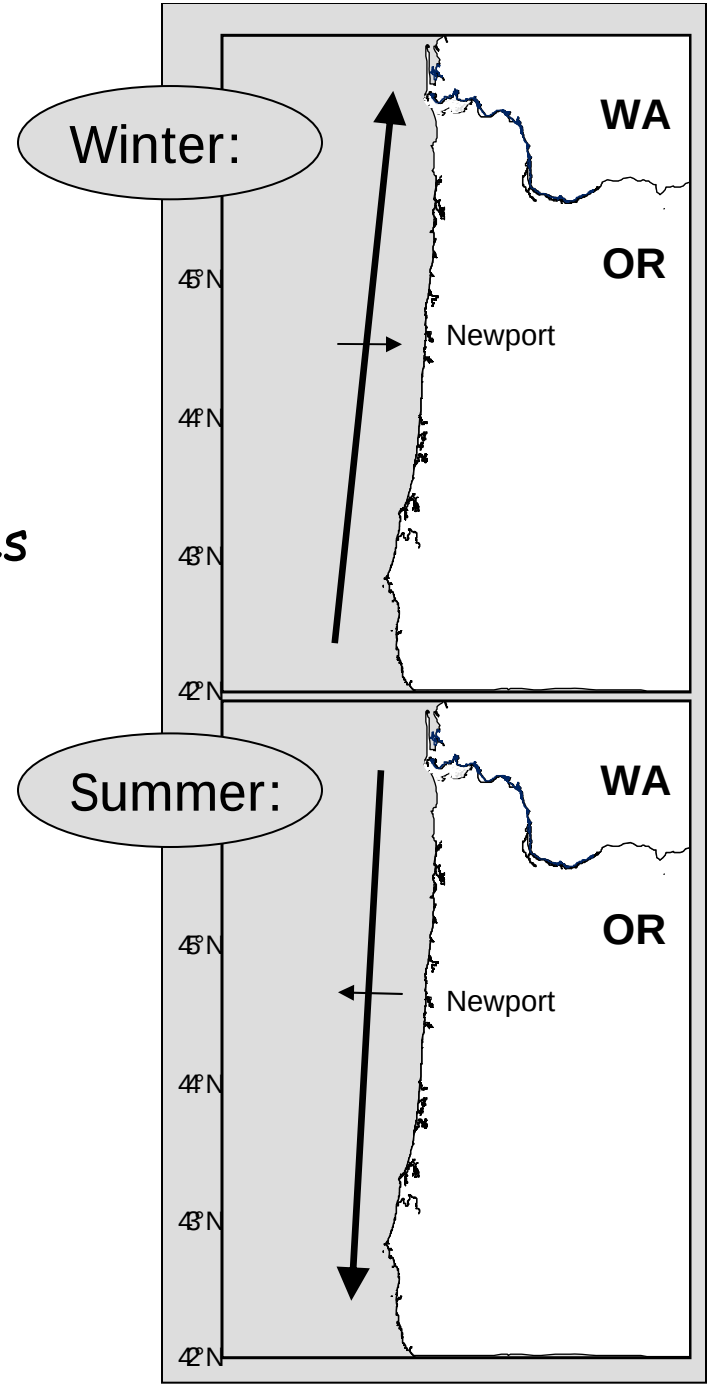
Winds and current structure off coastal Oregon:

- Winter:
  - Winds from the South
  - Downwelling
  - Poleward-flowing Davidson Current
  - Subtropical and southern plankton species transported northward & onshore
  - Many fish spawn at this time

- **Spring Transition in April/May**

- Summer:
  - Strong winds from the North
  - Coastal upwelling
  - Equatorward alongshore transport
  - Boreal/northern species transported southward

- **Fall Transition in October**

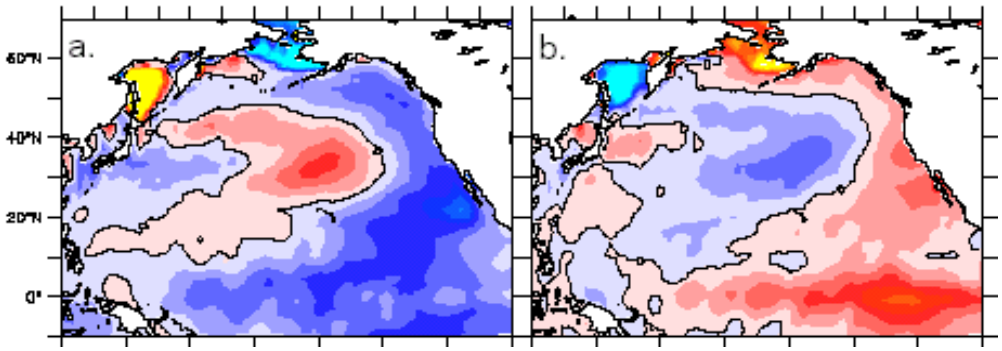


PDO & SST

The PDO has two phases, resulting from the direction from which winds blow in winter.

The SST anomaly patterns shown on the right results from basin scale winds: W'ly and NW'ly [negative phase] and SW'ly [positive phase]

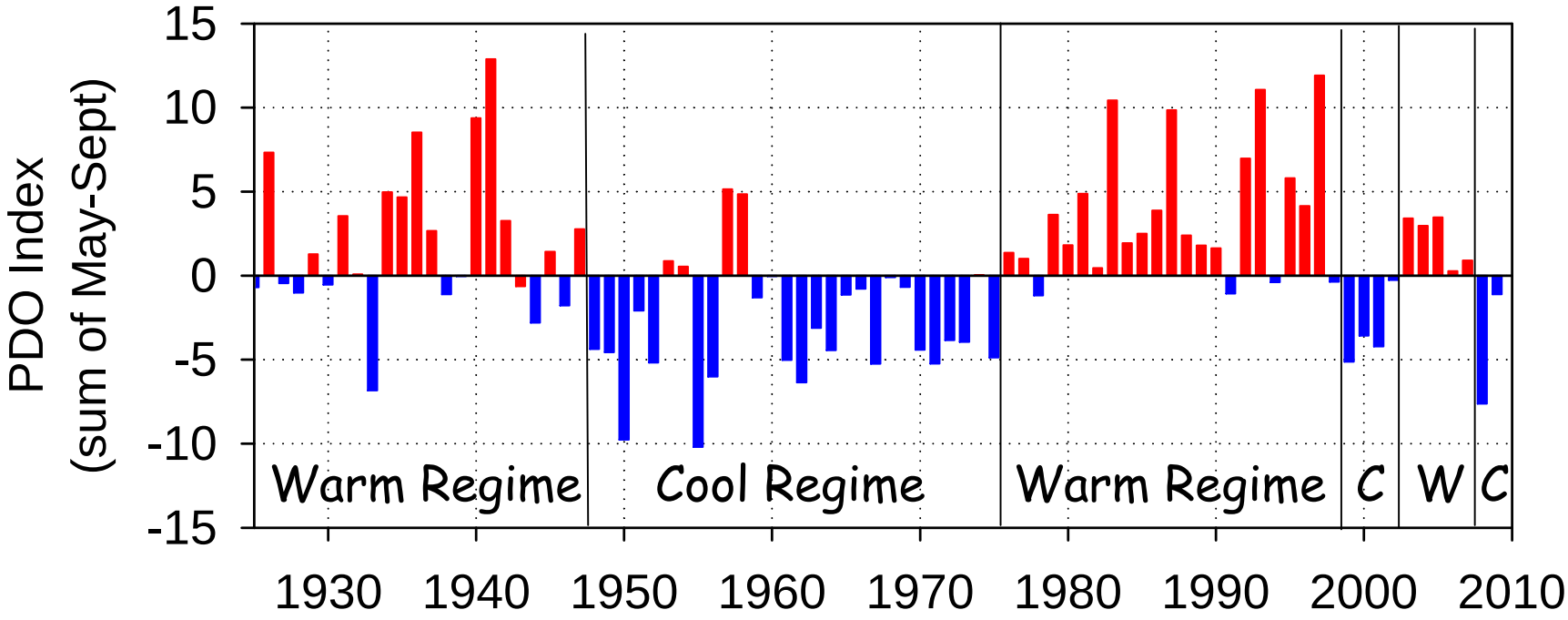
Westerlies dominated last winter (07-08) and now this winter.



Negative Phase	Positive Phase
1948-1976	1925-1947
1998-2002	1976-1998
2006-	2003-2006

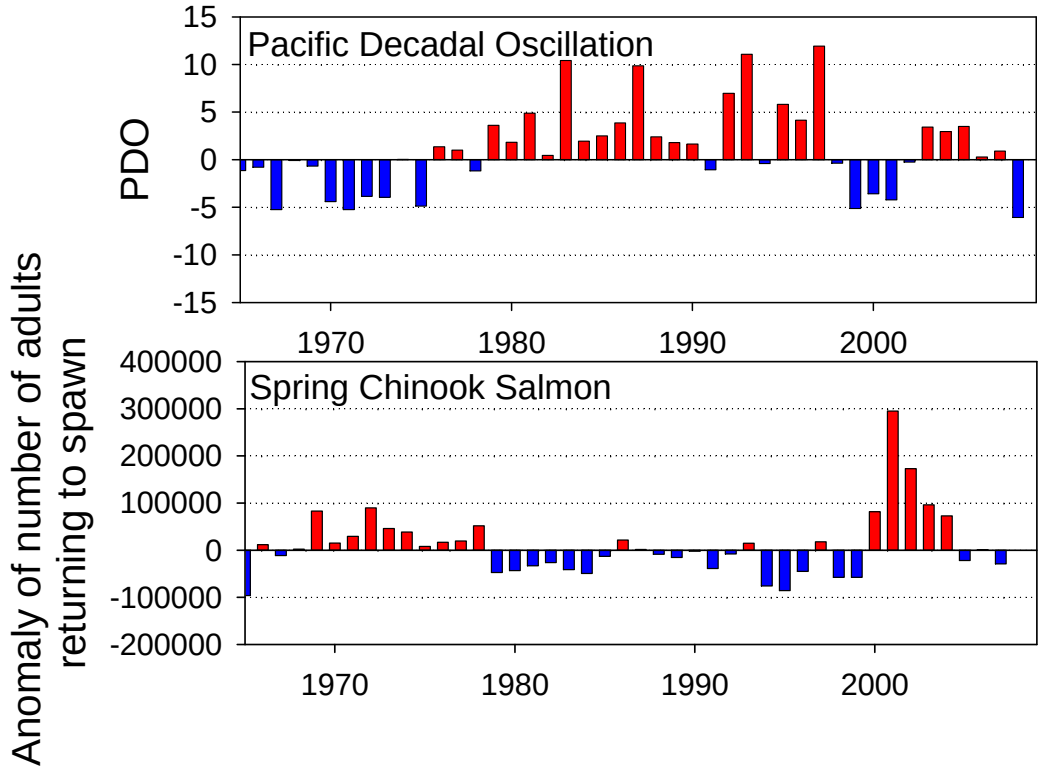
Blue is anomalously cold
Red is anomalously warm
Neutral PDO means there Is no pattern.

PDO: May-Sep Average, 1925-2009



- From 1925-1998, PDO shifted every 20-30 years. Some refer to these as "salmon" regimes (cool) and "sardine" regimes (warm).
- However, we have had two shifts of four years duration recently: 1999-2002 and 2003-2006, and another shift in late 2007, thus we have a natural experiment to test the affects of PDO on marine food chains and salmon populations.
- Note 2008: most negative PDO since 1950s!!

PDO and salmon



- Spring Chinook salmon counts at Bonneville Dam track the PDO. HUGE RETURNS of fish in 2001-2003 surprised everyone.

- PROGNOSIS: negative PDO is good for salmon; positive PDO not good.

Contrasting Communities

- **Negative PDO = "cold-water" copepod species.** These are dominants in Bering Sea, coastal GOA, coastal northern California Current
  - *Pseudocalanus mimus, Calanus marshallae, Acartia longiremis*
- **Positive PDO = "warm-water" copepods.** These are common in the Southern California Current neritic and offshore NCC waters
  - *Clausocalanus spp., Ctenocalanus vanus, Paracalanus parvus, Mesocalanus tenuicornis, Calocalanus styliremis*

Based on Peterson and Keister (2003)

Comparisons in size and chemical composition

- **Warm-water taxa** - (from offshore OR) are **small** in size and have limited high energy wax ester lipid depots

- **Cold-water taxa** – (boreal coastal species) are **large** and store **wax esters** as an over-wintering strategy

Therefore, significantly different food chains may result from climate shifts;

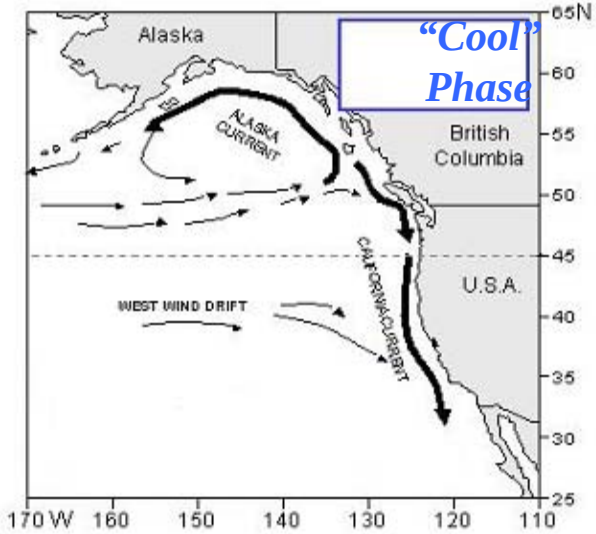
A working mechanistic hypothesis: source waters. . .

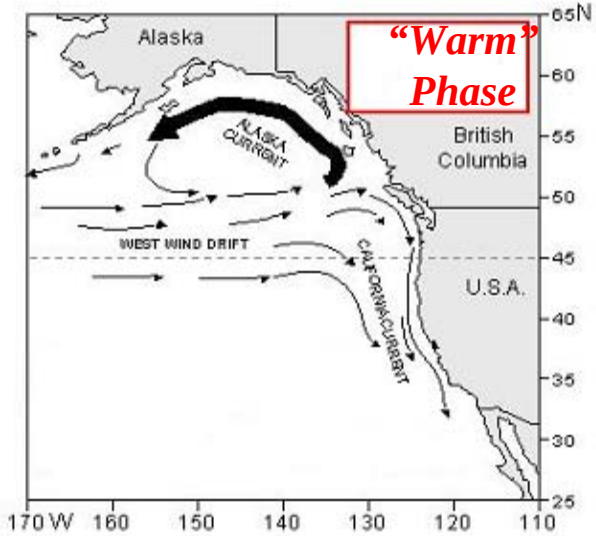
Cool Phase →

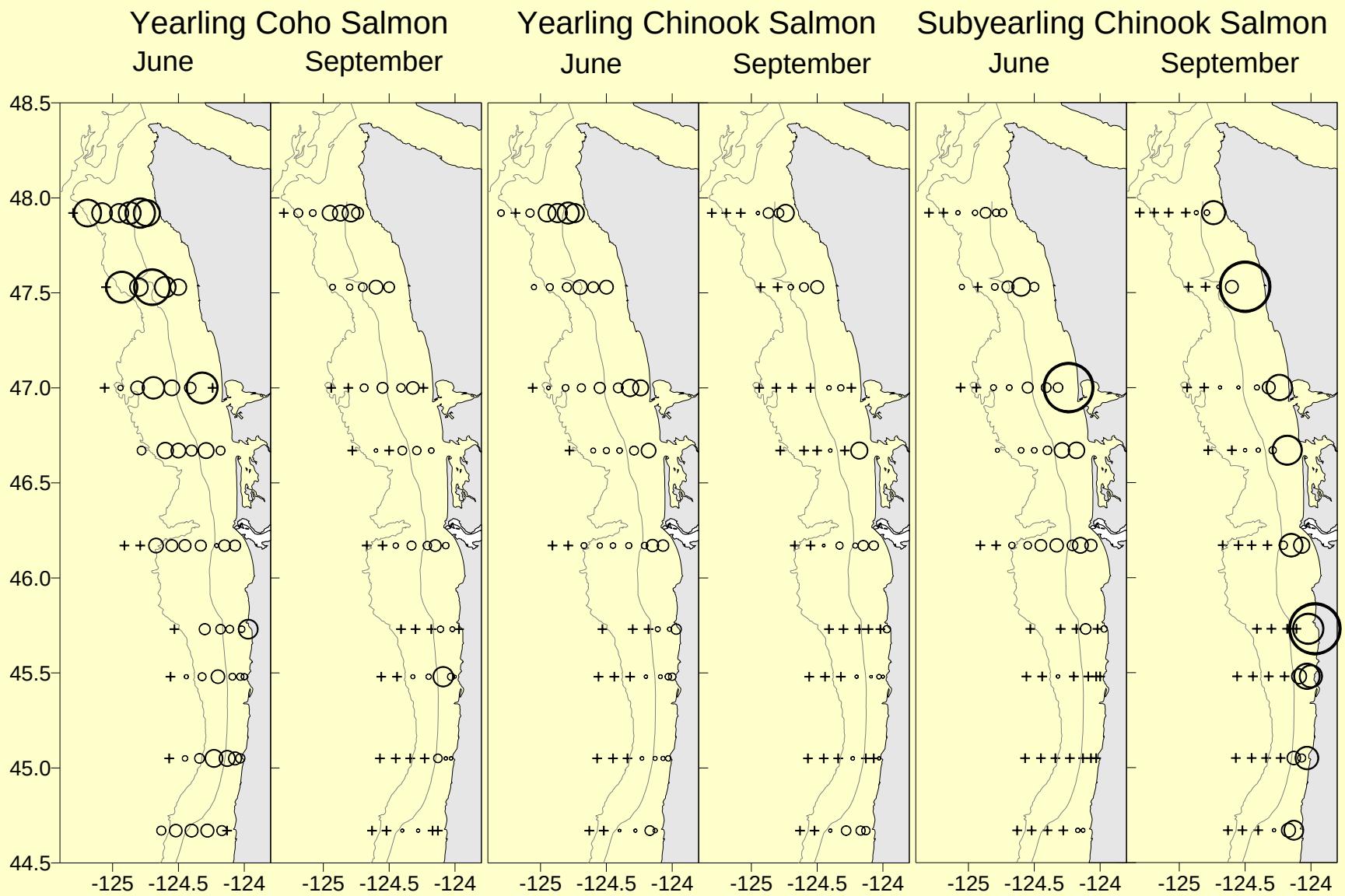
Transport of boreal coastal copepods into NCC from Gulf of Alaska

Warm Phase →

Transport of sub-tropical copepods into NCC from Transition Zone offshore






Yearling Coho Salmon
June
September
Yearling Chinook Salmon
June
September
Subyearling Chinook Salmon
June
September
48.5
48.0
47.5
47.0
46.5
46.0
45.5
45.0
44.5
-125
-124.5
-124

Forecasting -- since we know that juvenile salmonids live in continental shelf waters, we use indices relevant to shelf waters

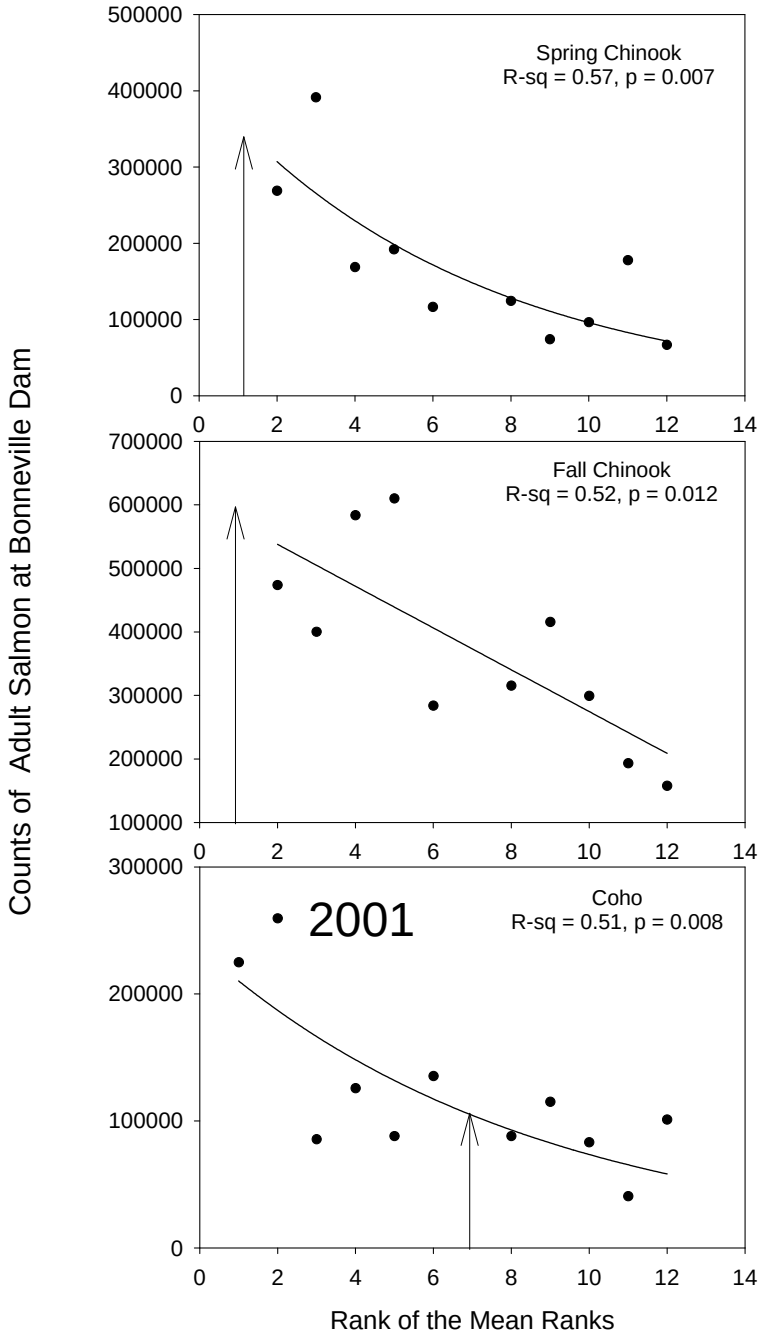
- Basin scale indicators
  - PDO
  - MEI
- Local indicators
  - SST
  - Upwelling
  - Date of spring transition
  - Length of upwelling season
- Biological indicators
  - Copepod biodiversity
  - N. copepod biomass anomaly
  - Copepod Community Structure
  - Catches of spring Chinook in June
  - Catches of coho in September

Values of ocean condition parameters used in forecasting

		1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
PDO (December-March)		5.07	-1.75	-4.17	1.86	-1.73	7.45	1.85	2.44	1.94	-0.17	-3.06	-5.41
PDO (Sum May-September)		0.9	-5.54	-3.23	-2.95	-0.47	3.42	2.21	3.94	0.28	0.18	-6.08	-1.11
SST 46050	deg C	13.70	13.14	12.54	12.56	12.30	12.92	14.59	13.43	12.60	13.88	12.5	13.02
SST NH 05 Winter Before	deg C	12.11	10.52	10.26	10.31	10.01	10.81	11.32	11.07	10.92	9.96	9.03	9.63
Physical Spring Trans Log	Day of Year	105	91	72	61	80	112	110	145	112	74	89	82
Upwelling Anomaly (April-May)		-14	19	-36	2	-12	-34	-27	-55	-14	9	0	-5
Length of upwelling seasc	days	191	205	208	173	218	168	178	132	194	200	180	201
Copepod richness	no. of speci	5.49	-2.46	-3.03	-0.41	-0.72	1.52	0.57	5.02	3.67	-0.39	-0.53	-0.35
Northern Copepod Bioma	log biomass	-1.97	0.084	0.717	0.486	0.834	-0.08	0.262	-1.74	0.163	0.617	0.87	0.662
Biological Transition	Day of Year	187	119	96	129	120	156	131	206	150	81	63	83
Copepod Community stru	X-axis ordir	0.726	-0.82	-0.82	-0.78	-0.98	-0.18	-0.14	0.541	0.15	-0.66	-0.96	-0.8
June-Chinook Catches	fish per km	0.26	1.27	1.04	0.44	0.85	0.63	0.42	0.13	0.69	0.86	2.55	1.00
Sept-Coho Catches	fish per km	0.11	1.12	1.27	0.47	0.98	0.29	0.07	0.03	0.16	0.15	0.27	0.01

Stoplight Chart

Environmental Variables	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
PDO (December-March)	11	5	2	8	4	12	7	10	9	6	3	1
PDO (May-September)	9	2	3	4	6	11	10	12	8	7	1	5
SST at 46050 (May-Sept)	10	8	4	5	1	6	12	9	2	11	3	7
SST winter before going to sea	12	7	5	6	4	8	11	10	9	3	1	2
Physical Spring Trans (Logerwell)	8	7	2	1	4	10	9	12	10	3	6	5
Upwelling (Apr-May)	7	1	11	3	6	10	9	12	7	2	4	5
Length of upwelling season	7	3	2	10	1	11	9	12	6	5	8	4
Copepod richness	12	2	1	5	3	9	8	11	10	6	4	7
N.Copepod Anomaly	12	9	3	6	2	10	7	11	8	5	1	4
Biological Transition	11	5	4	7	6	10	8	12	9	2	1	3
Copepod Community structure	12	3	4	6	1	8	9	11	10	7	2	5
June-Chinook Catches	11	2	3	9	6	8	10	12	7	5	1	4
Sept-Coho Catches	9	2	1	4	3	5	10	11	7	8	6	12
Mean of Ranks of Environmental Da	10.1	4.3	3.5	5.7	3.6	9.1	9.2	11.2	7.8	5.4	3.2	4.9
RANK of the mean rank	11	3	2	5	4	9	10	12	8	6	1	7



A simple approach to forecasting

- Regression of salmon counts at Bonneville Dam with the rank of all variables combined
- Chinook that went to sea in 2008 will return next year at near record numbers (record was 604,200 in 2003 (fall) and 414,628 in 2001 (spring)
- Of the Coho that went to sea in 2008, 224,592 were counted at Bonneville Dam
- Coho that went to sea in 2009 are expected to only reach about half that value.

A chain of events (in a perfect year)

	Negative	Positive
• Changes in basin-scale winds lead to sign changes in PDO		
• SST changes as do water types off Oregon	Cold/salty	Warm/fresh
• Spring transition	Early	Late
• Upwelling season	Long	Short
• Zooplankton species	Cold species	Warm species
• Food Chain	Lipid-rich	Lipid-deplete
• Forage Fish	Many	Few
• Juvenile salmonids	Many	Few

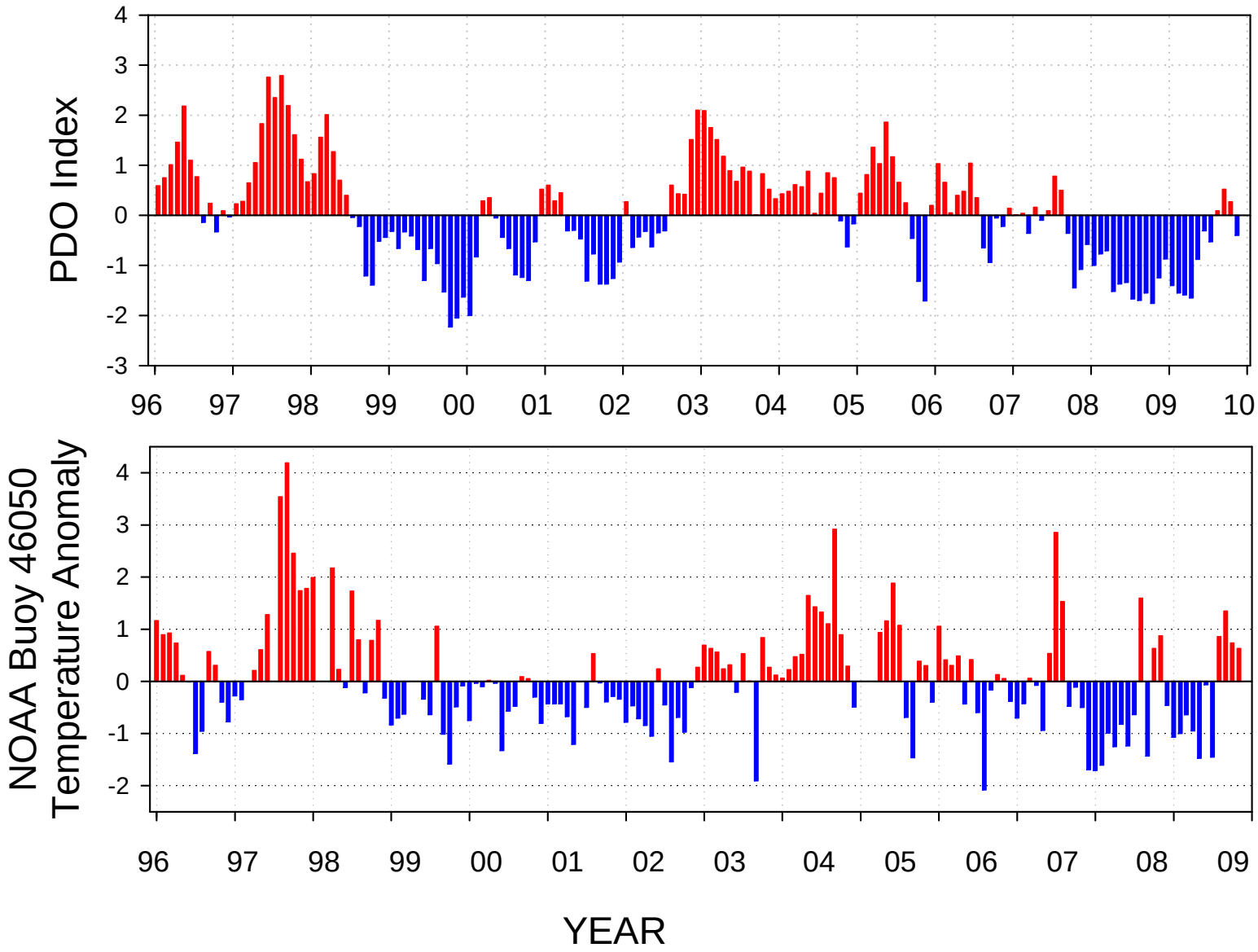
But time lags can complicate interpretations!

Acknowledgements

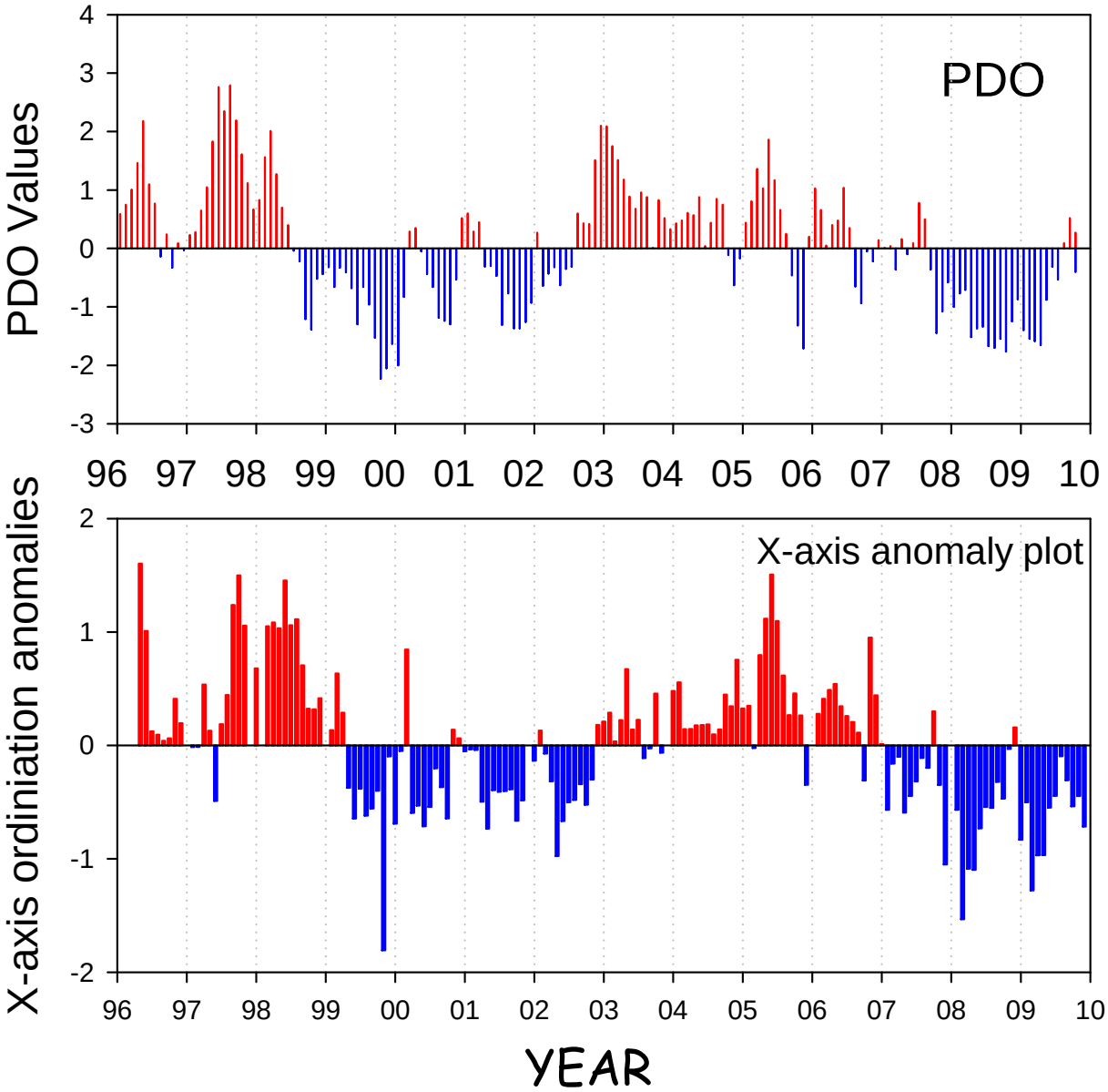
- Bonneville Power Administration
- U.S.GLOBEC Program (NOAA/NSF)
- Stock Assessment Improvement Program (SAIP-NOAA)
- Fisheries and the Environment (FATE-NOAA)
- National Science Foundation
- Office of Naval Research
- NASA

- See www.nwfsc.noaa.gov, "Ocean Index Tools"

PDO and SST off the Oregon coast



PDO and Plankton off the Oregon coast



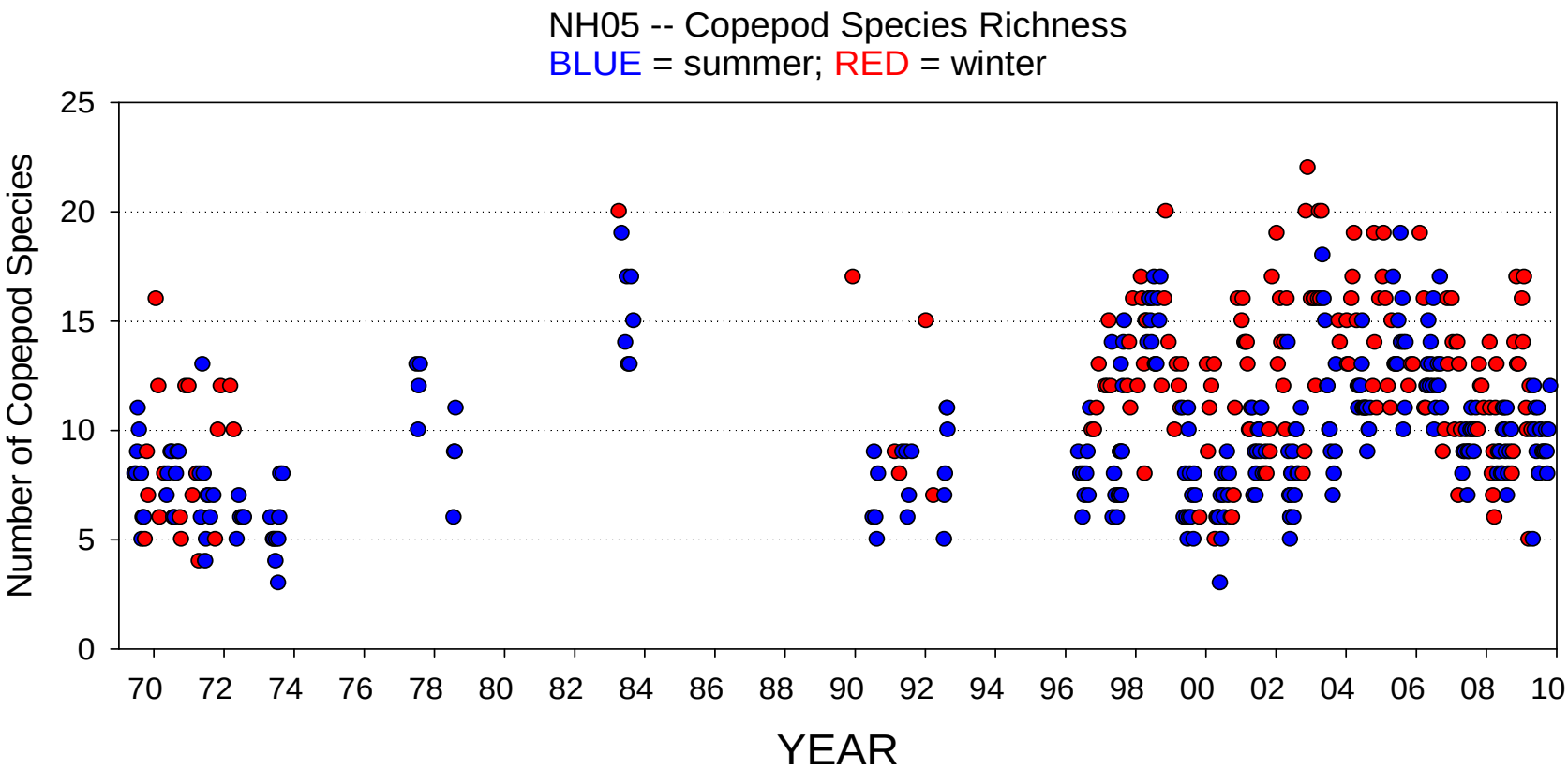
Warm water community

Cold water community

Changes in marine food chains

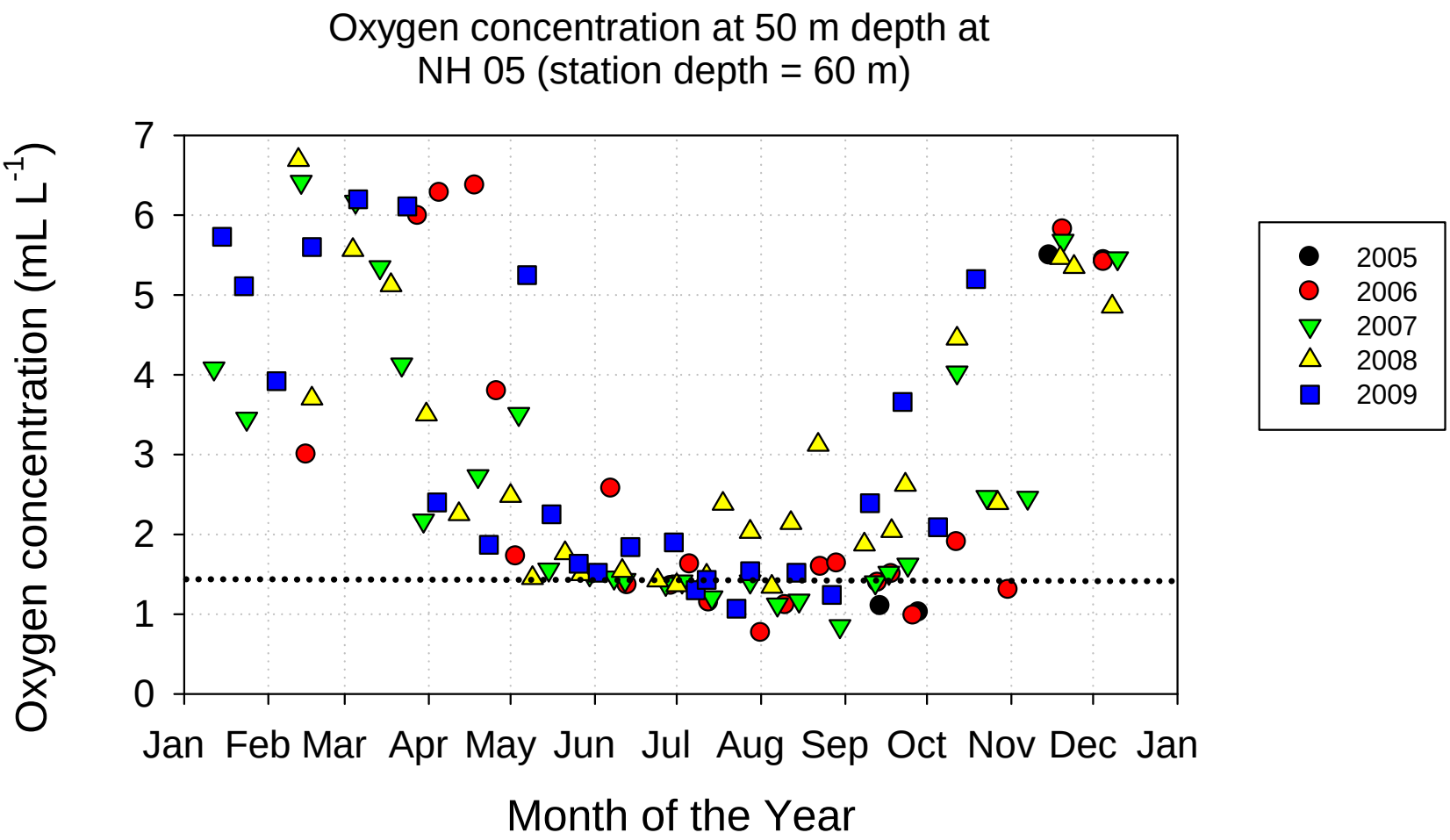
Photo taken just outside Ucluelet near Tofino BC…
Published in <www.westcoaster.ca>

Are we seeing any indication of changes in copepods over the past 40 years?



- 69-73 = 6.68 species
- 96-08 = 10.24 species
- Despite recent cold ocean conditions we still see high species richness.

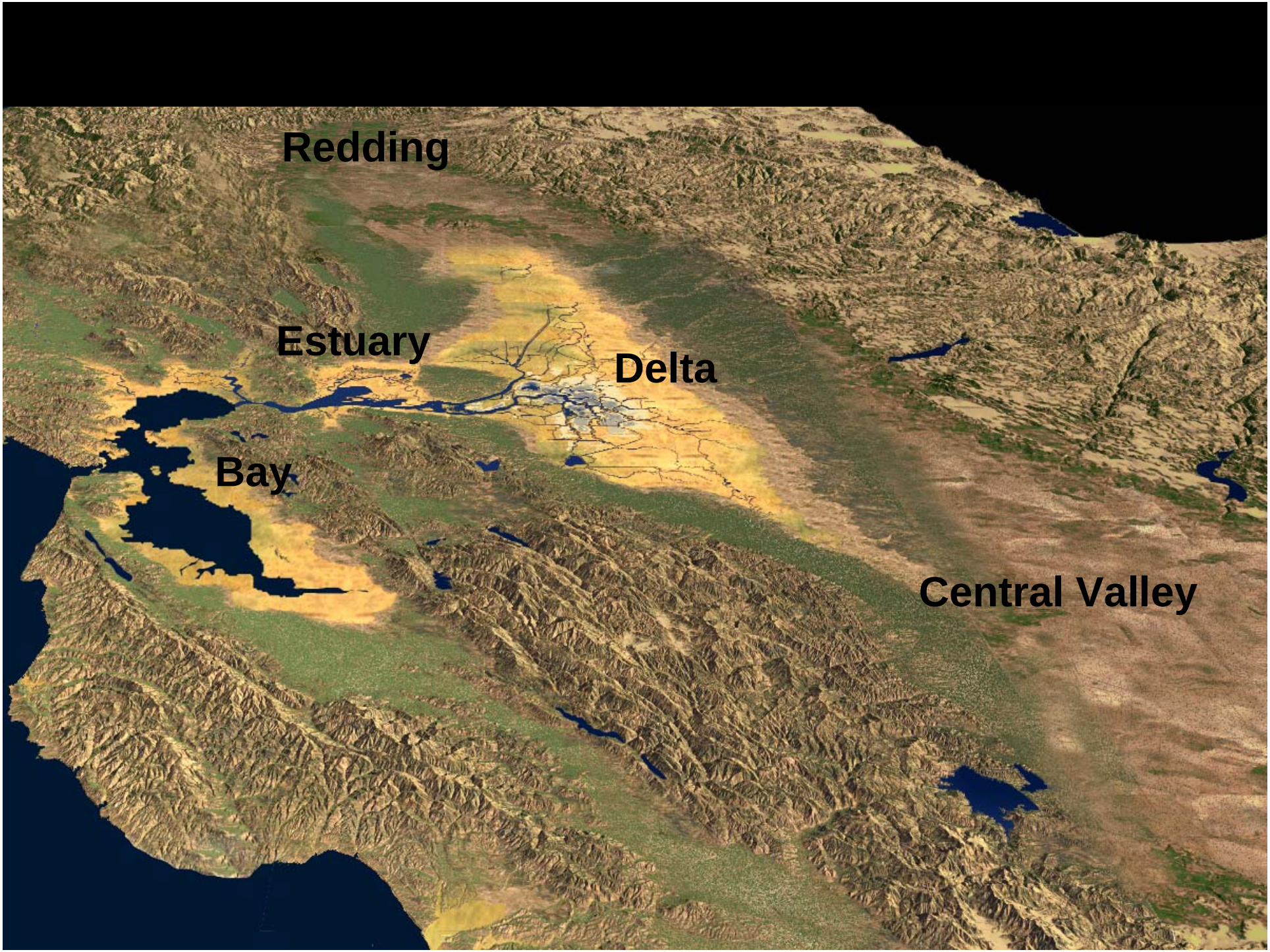
Oxygen concentrations at a mid-shelf station off Newport

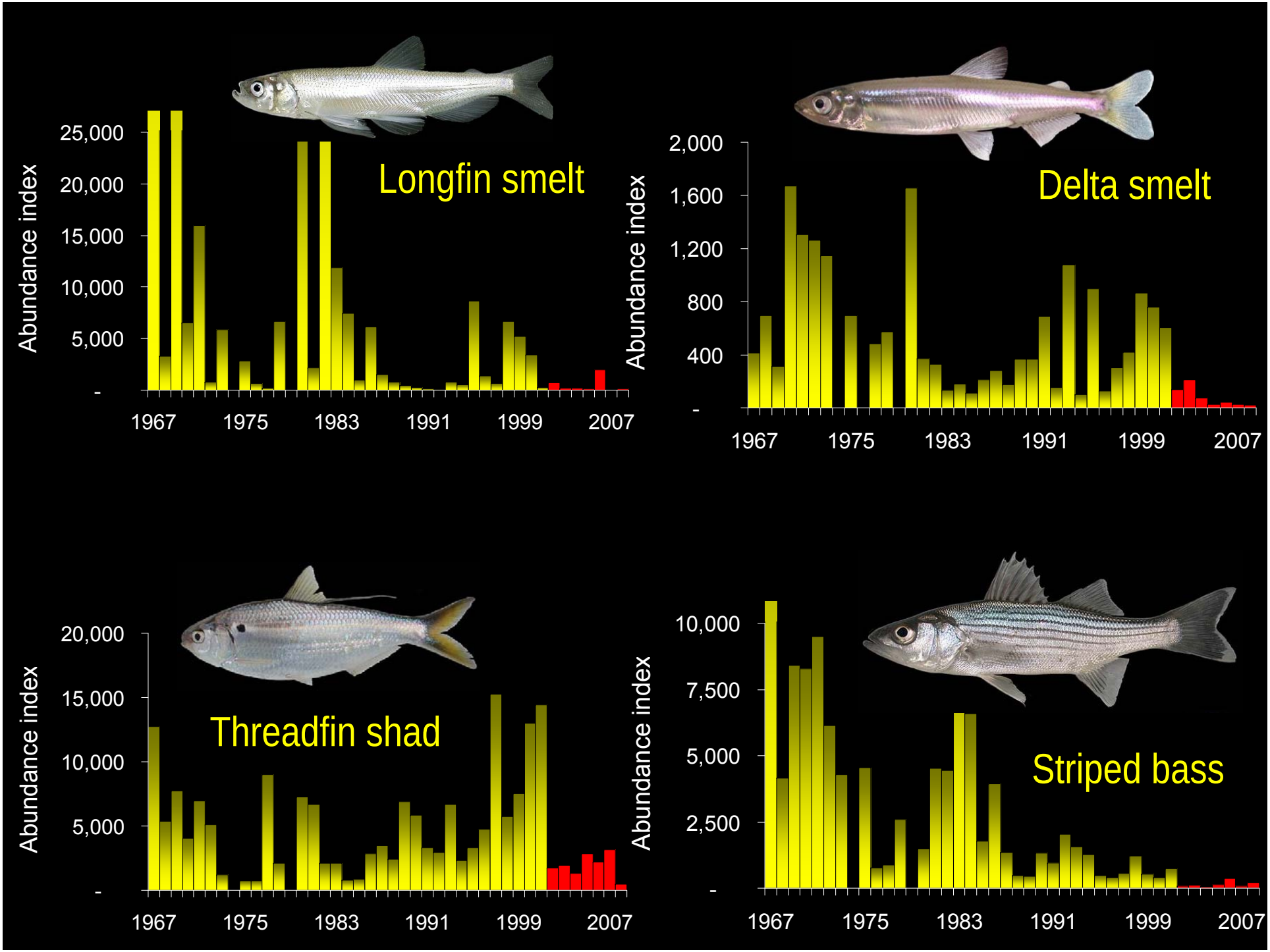


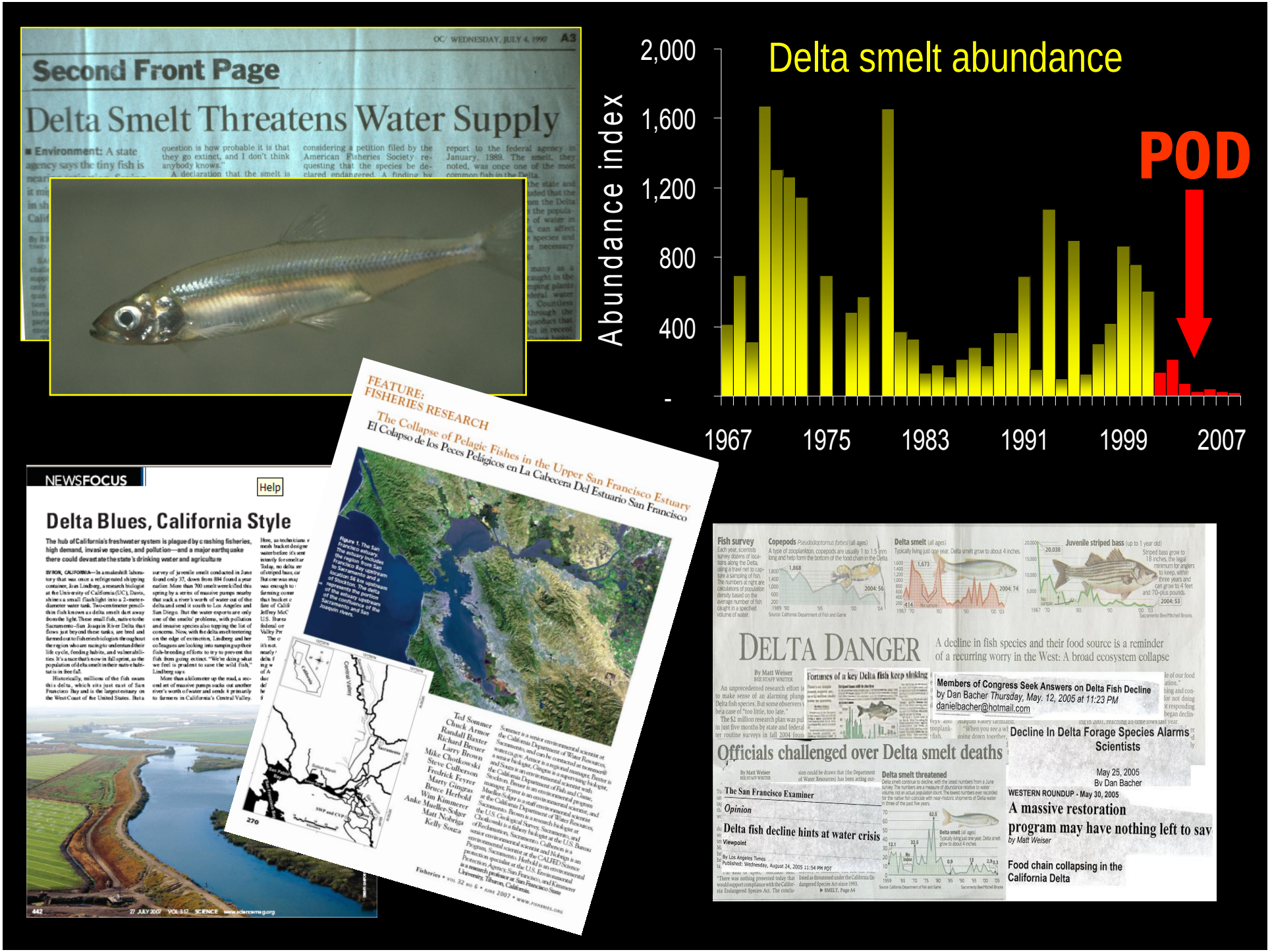
Modeling the Effects of Future Outflow on the Abiotic Habitat of an Imperiled Estuarine Fish

Fred Feyrer, US Bureau of Reclamation
Ken Newman, US Fish and Wildlife Service
Matt Nobriga, CA Department of Fish and Game
Ted Sommer, CA Department of Water Resources

Delta smelt *Hypomesus transpacificus*


Redding
Estuary
Delta
Bay
Central Valley


Longfin smelt
Abundance index
25,000
20,000
15,000
10,000
5,000
-
1967
1975
1983
1991
1999
2007
Delta smelt
Abundance index
2,000
1,600
1,200
800
400
-
1967
1975
1983
1991
1999
2007
Threadfin shad
Abundance index
20,000
15,000
10,000
5,000
-
1967
1975
1983
1991
1999
2007
Striped bass
Abundance index
10,000
7,500
5,000
2,500
-
1967
1975
1983
1991
1999
2007

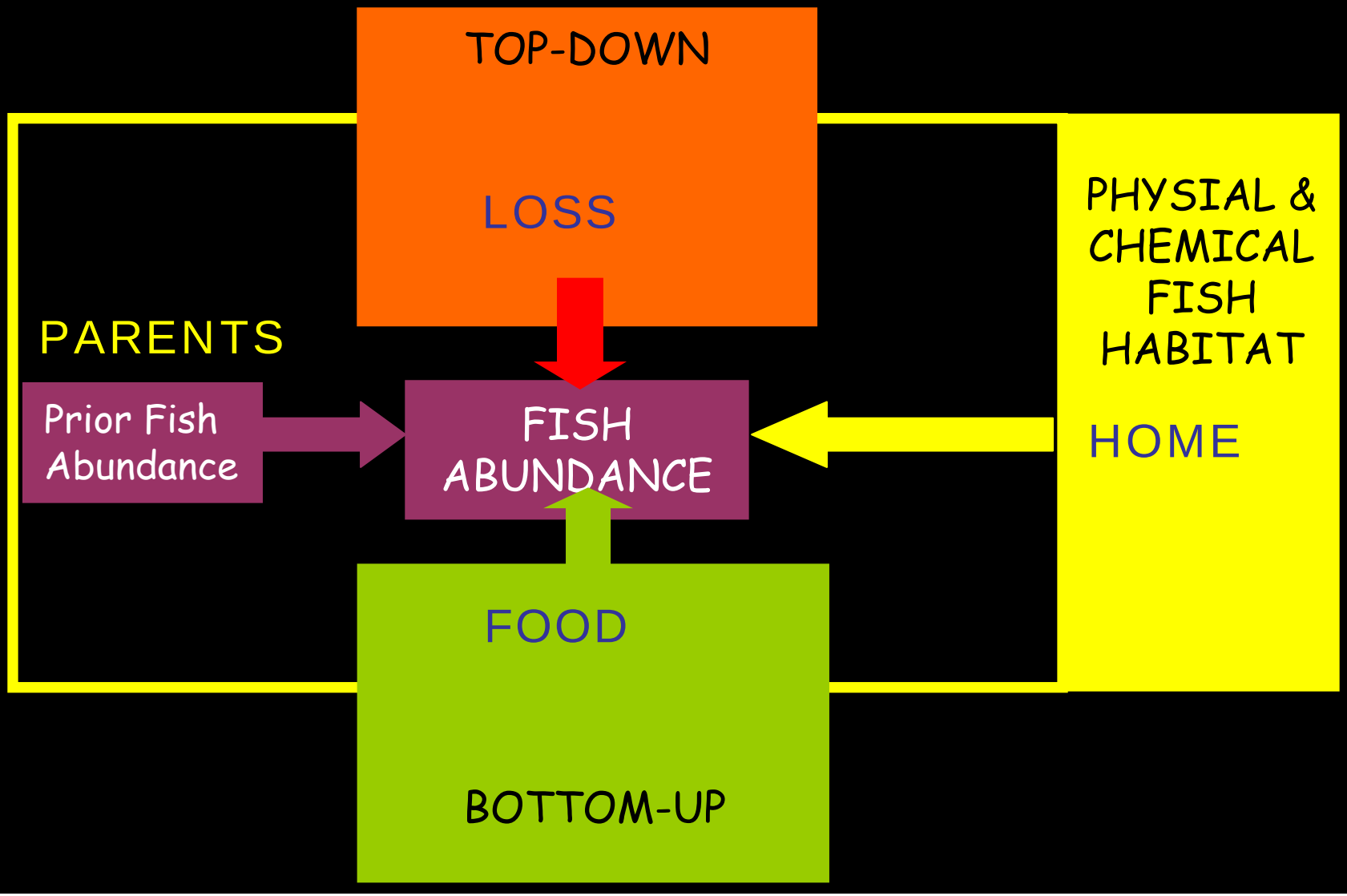


Delta smelt abundance
Abundance index
2,000
1,600
1,200
800
400
-
1967
1975
1983
1991
1999
2007
POD
OC/ WEDNESDAY, JULY 4, 1990 A3
Second Front Page
Delta Smelt Threatens Water Supply
FEATURE: FISHERIES RESEARCH
The Collapse of Pelagic Fishes in the Upper San Francisco Estuary
El Colapso de los Peces Pelágicos en La Cabecera Del Estuario San Francisco
NEWSFOCUS
Help
Delta Blues, California Style
DELTA DANGER
A decline in fish species and their food source is a reminder of a recurring worry in the West: A broad ecosystem collapse
Members of Congress Seek Answers on Delta Fish Decline
by Dan Bacher Thursday, May. 12, 2005 at 11:23 PM
danielbacher@hotmail.com
Officials challenged over Delta smelt deaths
The San Francisco Examiner
Opinion
Delta fish decline hints at water crisis
Viewpoint
Decline In Delta Forage Species Alarms Scientists
May 25, 2005
By Dan Bacher
WESTERN ROUNDUP - May 30, 2005
A massive restoration program may have nothing left to sav
by Matt Weiser
Food chain collapsing in the California Delta

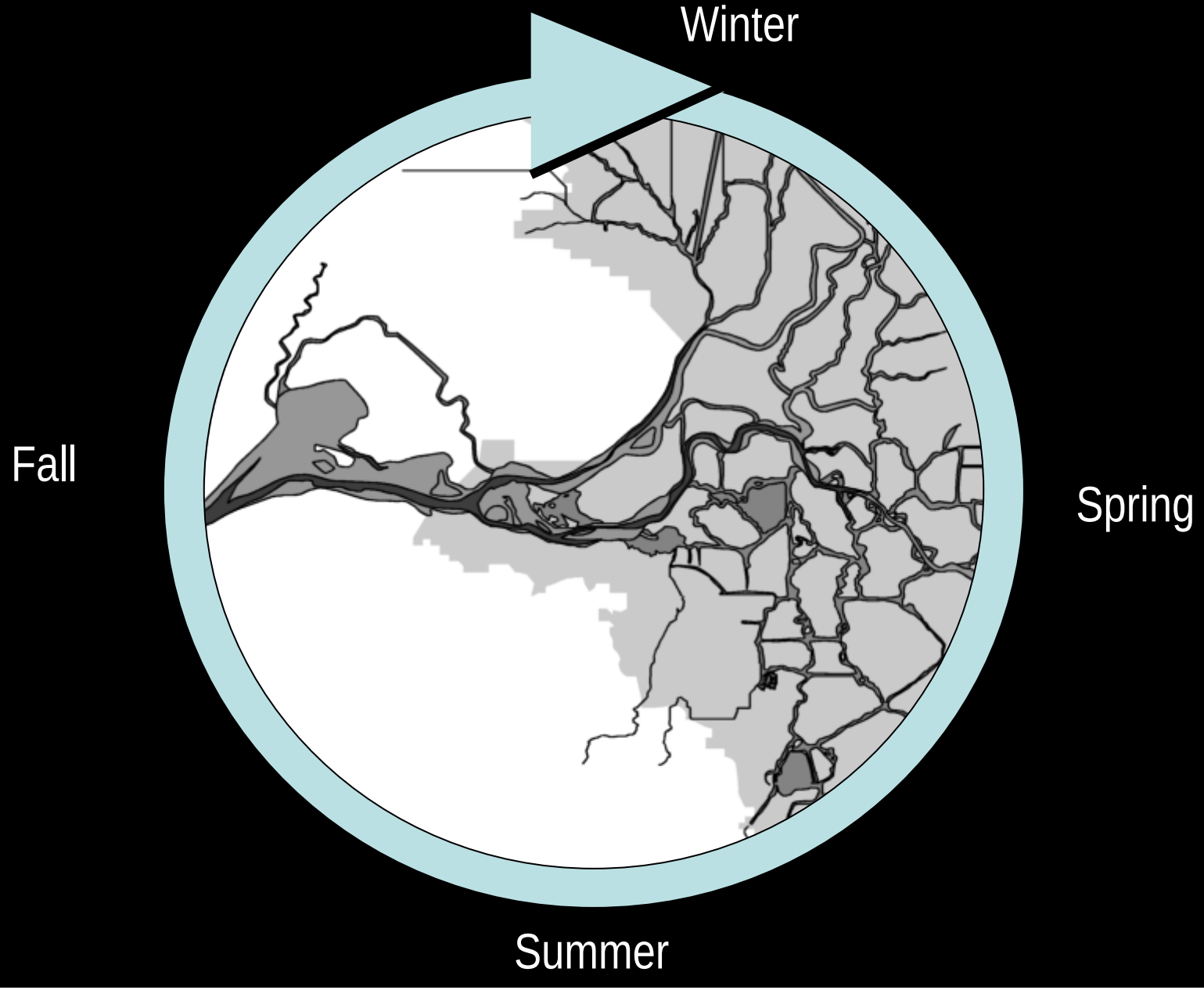
- 500,000 people live around the estuary
- 25 million people depend on the water

  (SF Bay area, Los Angeles, San Diego)
- Supports $US 30 billion to economy

POD Study Conceptual Model

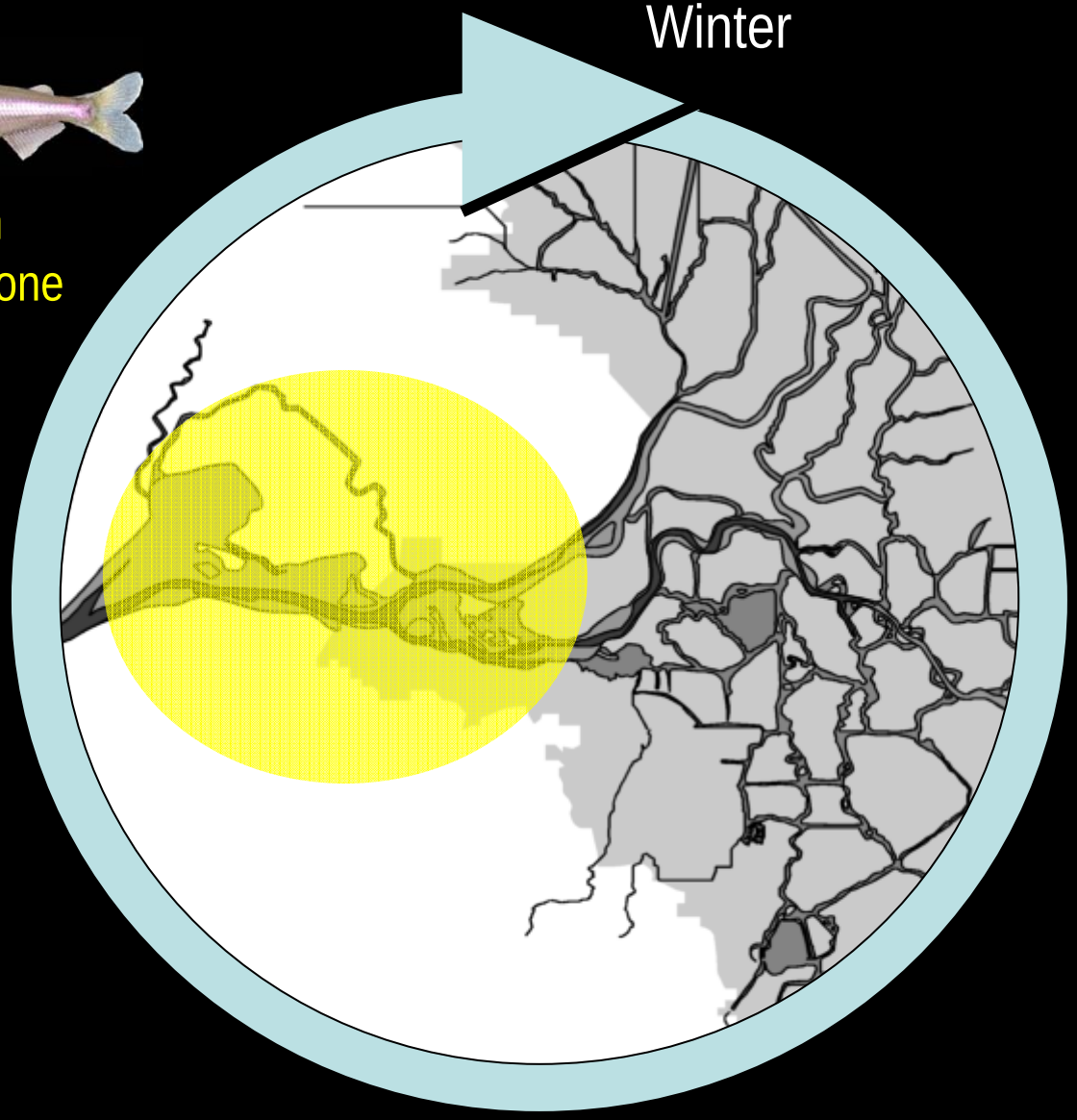


(Greatly) Generalized Delta Smelt Life Cycle

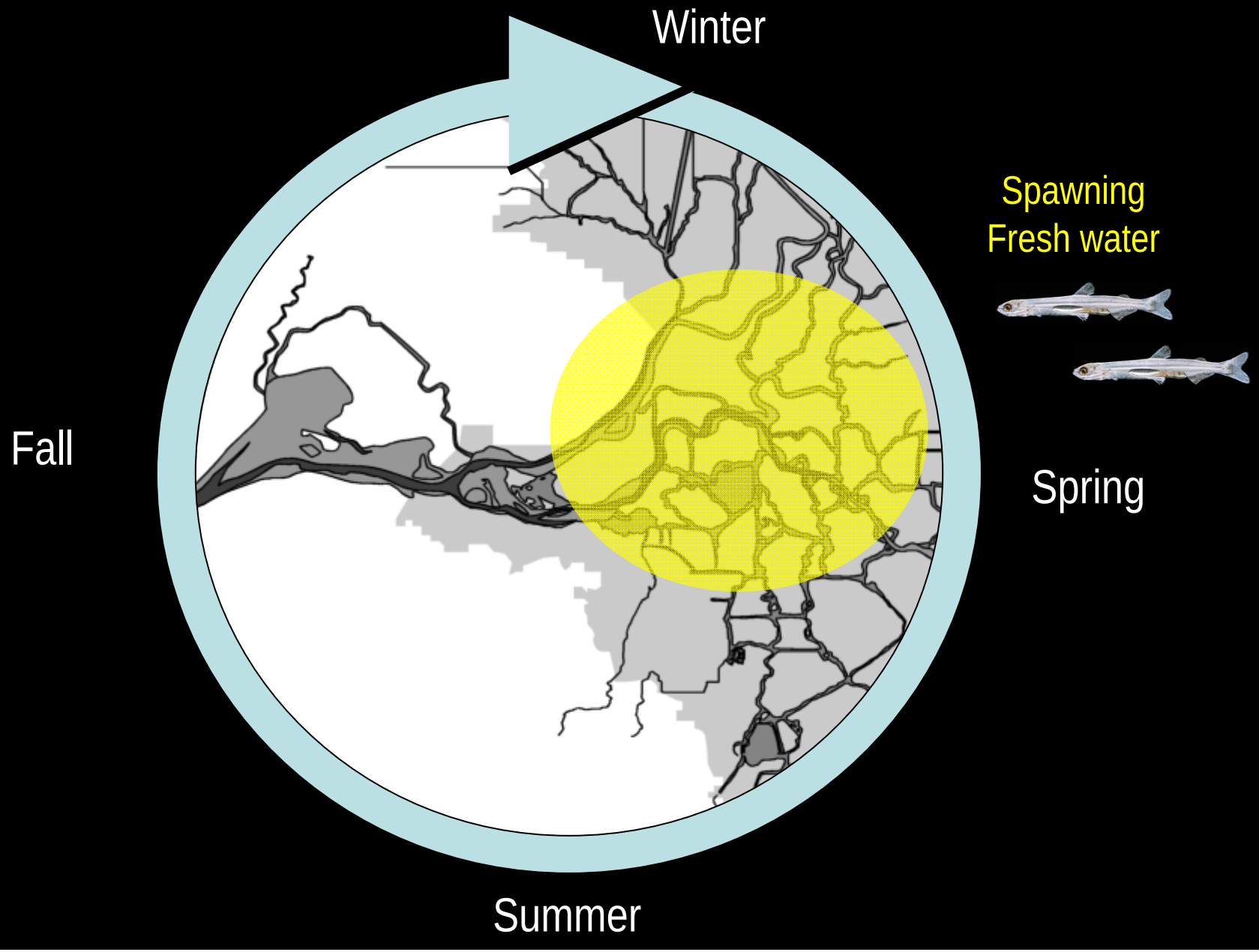


(Greatly) Generalized Delta Smelt Life Cycle

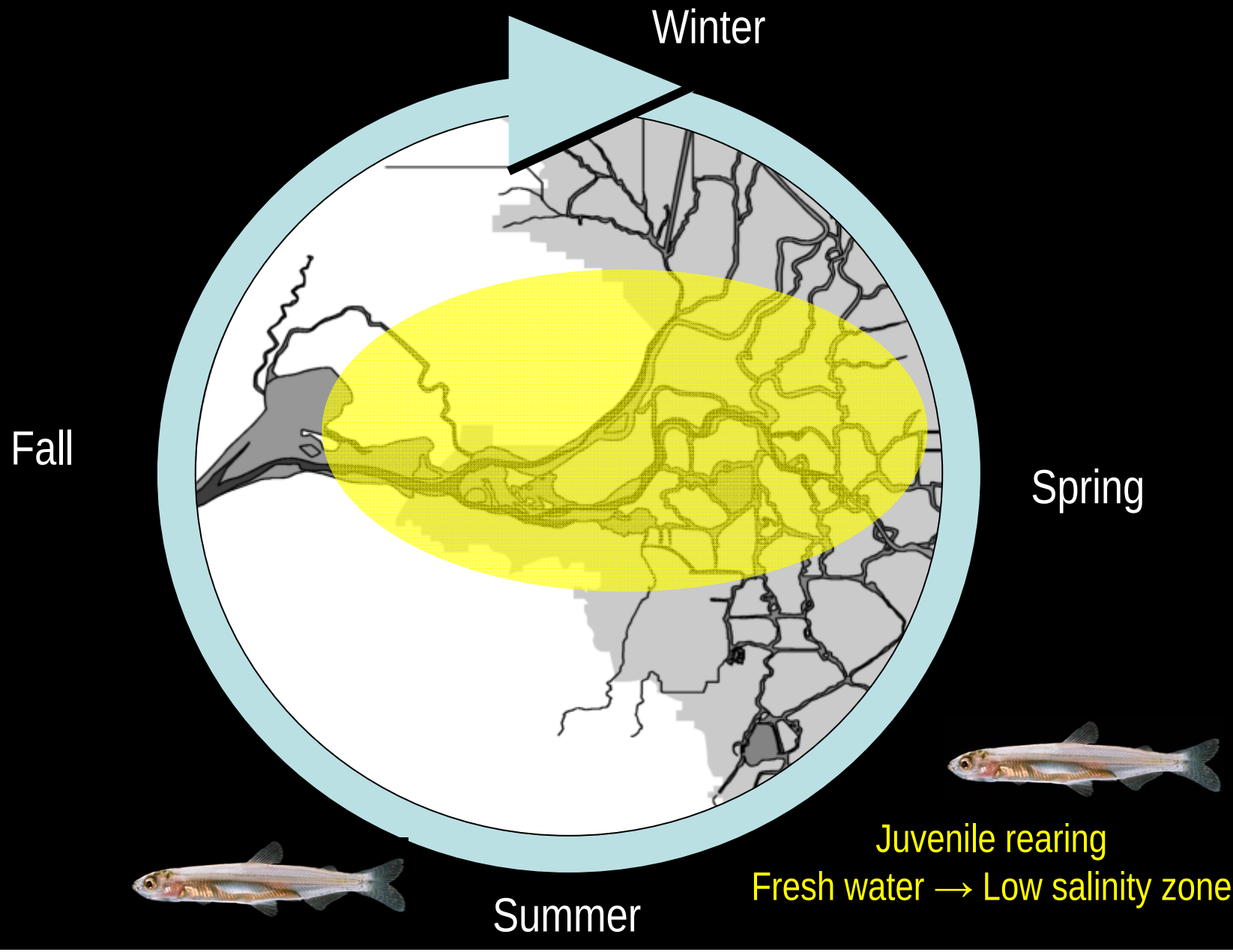
Maturation
Low salinity zone



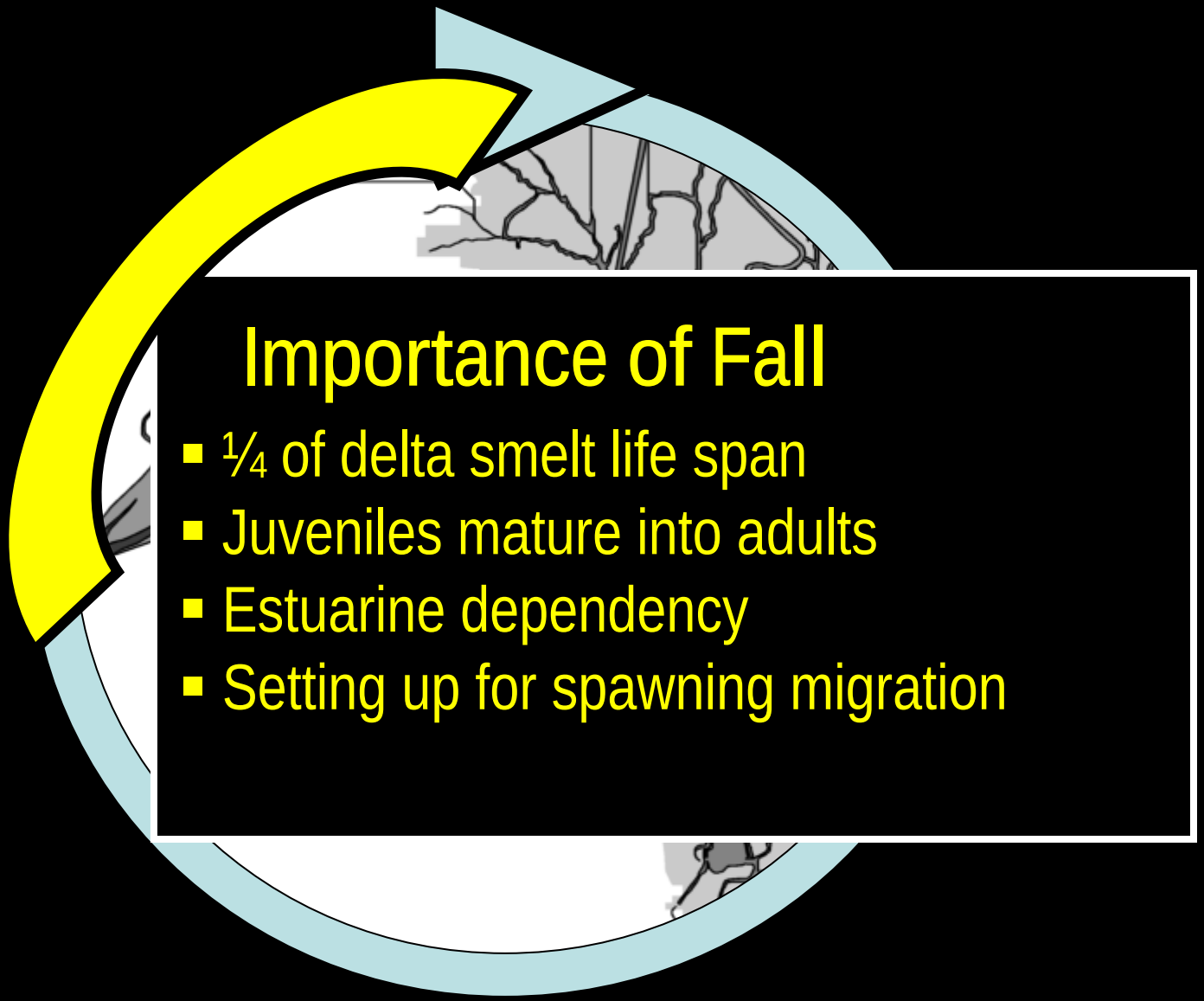
(Greatly) Generalized Delta Smelt Life Cycle



(Greatly) Generalized Delta Smelt Life Cycle



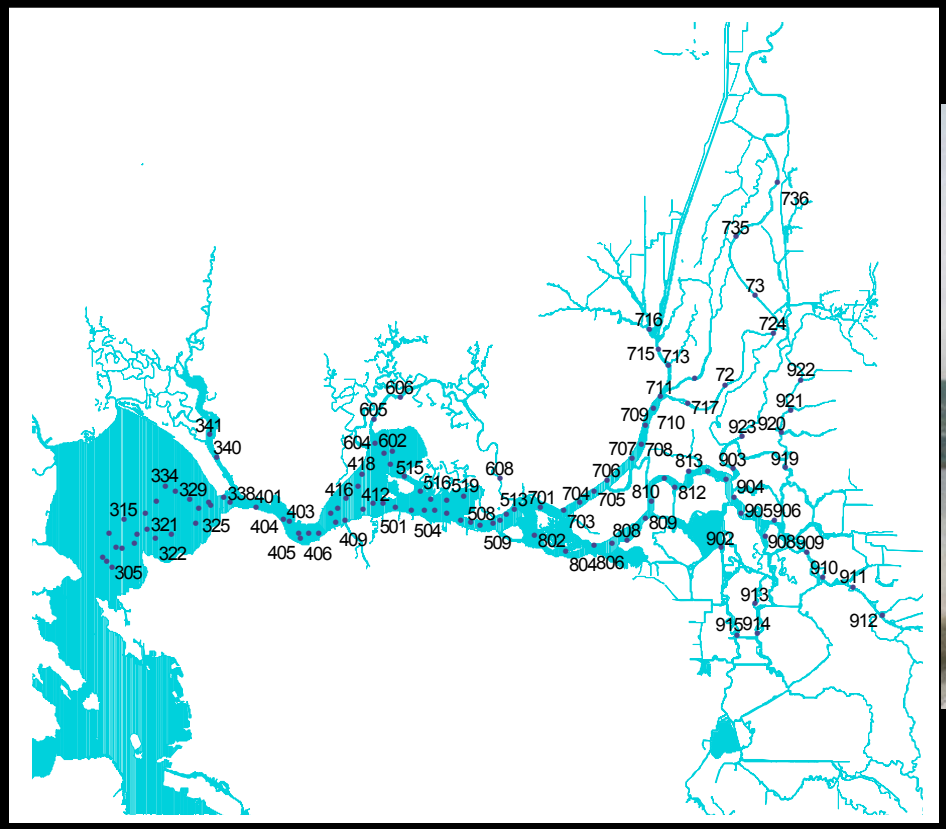
(Greatly) Generalized Delta Smelt Life Cycle



Importance of Fall

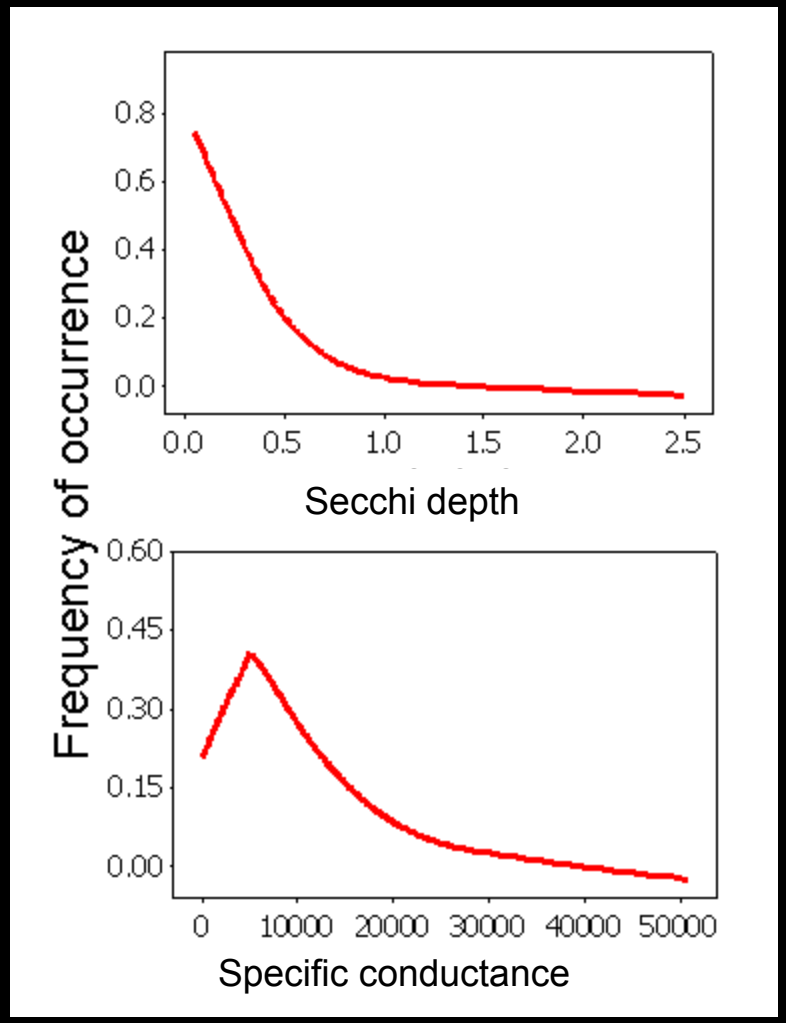
- ¼ of delta smelt life span
- Juveniles mature into adults
- Estuarine dependency
- Setting up for spawning migration

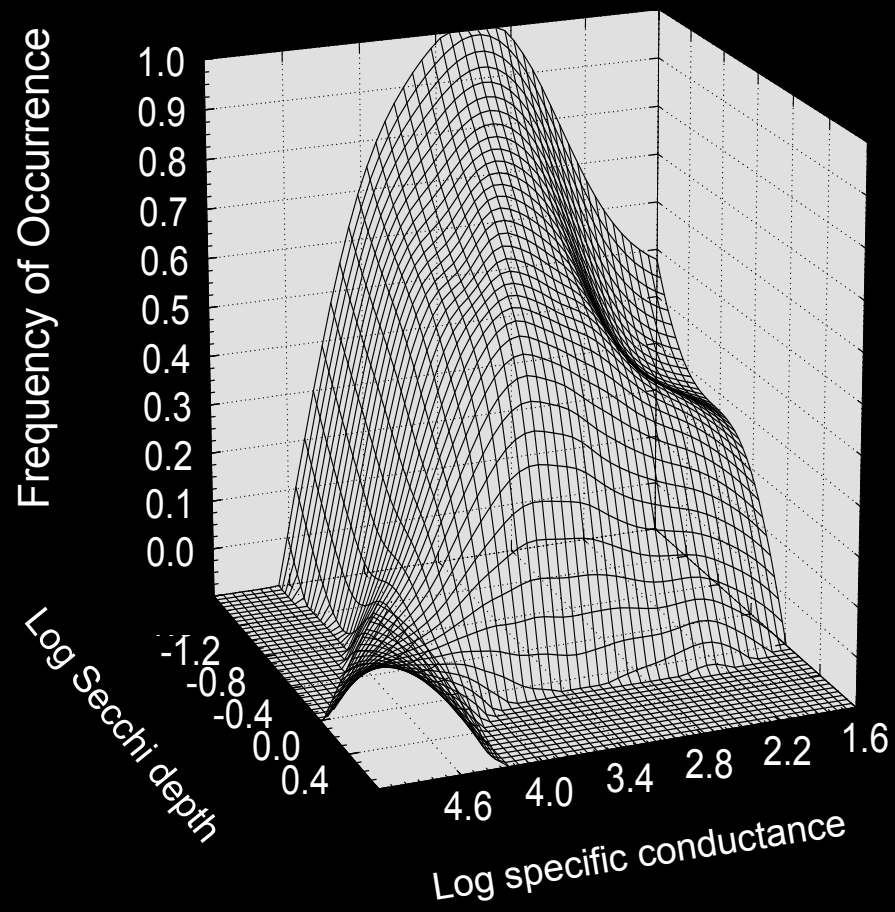
Fall Midwater Trawl Survey



1967 – present
100+ stations sampled 4x, September-December
water temperature, specific conductance, Secchi depth

Abiotic Habitat of Delta Smelt

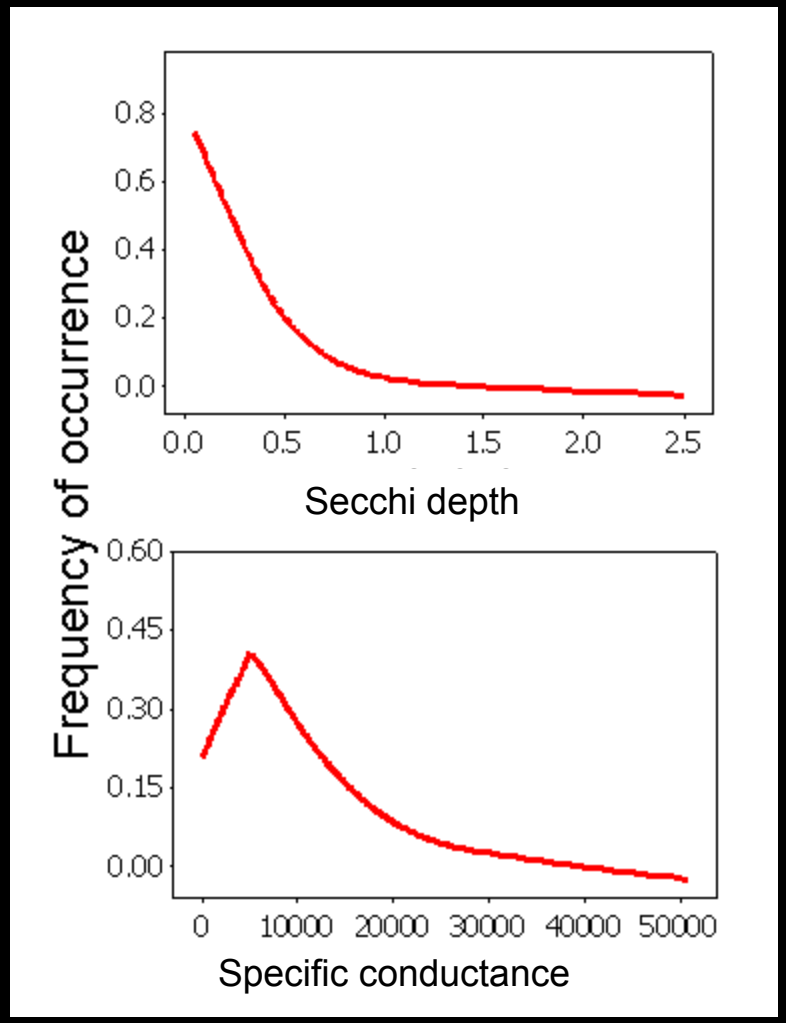


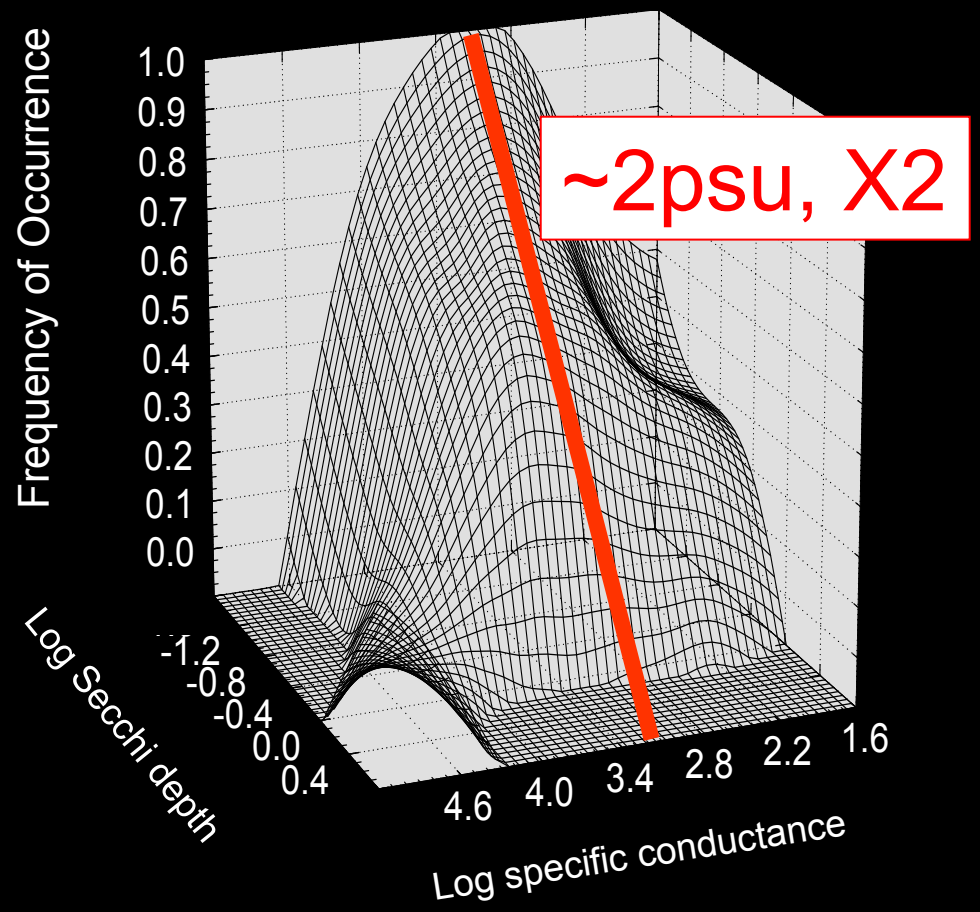


Generalized Additive Modeling

Fall Midwater Trawl Survey: 1967 – present
N > 10,000 observations

Abiotic Habitat of Delta Smelt

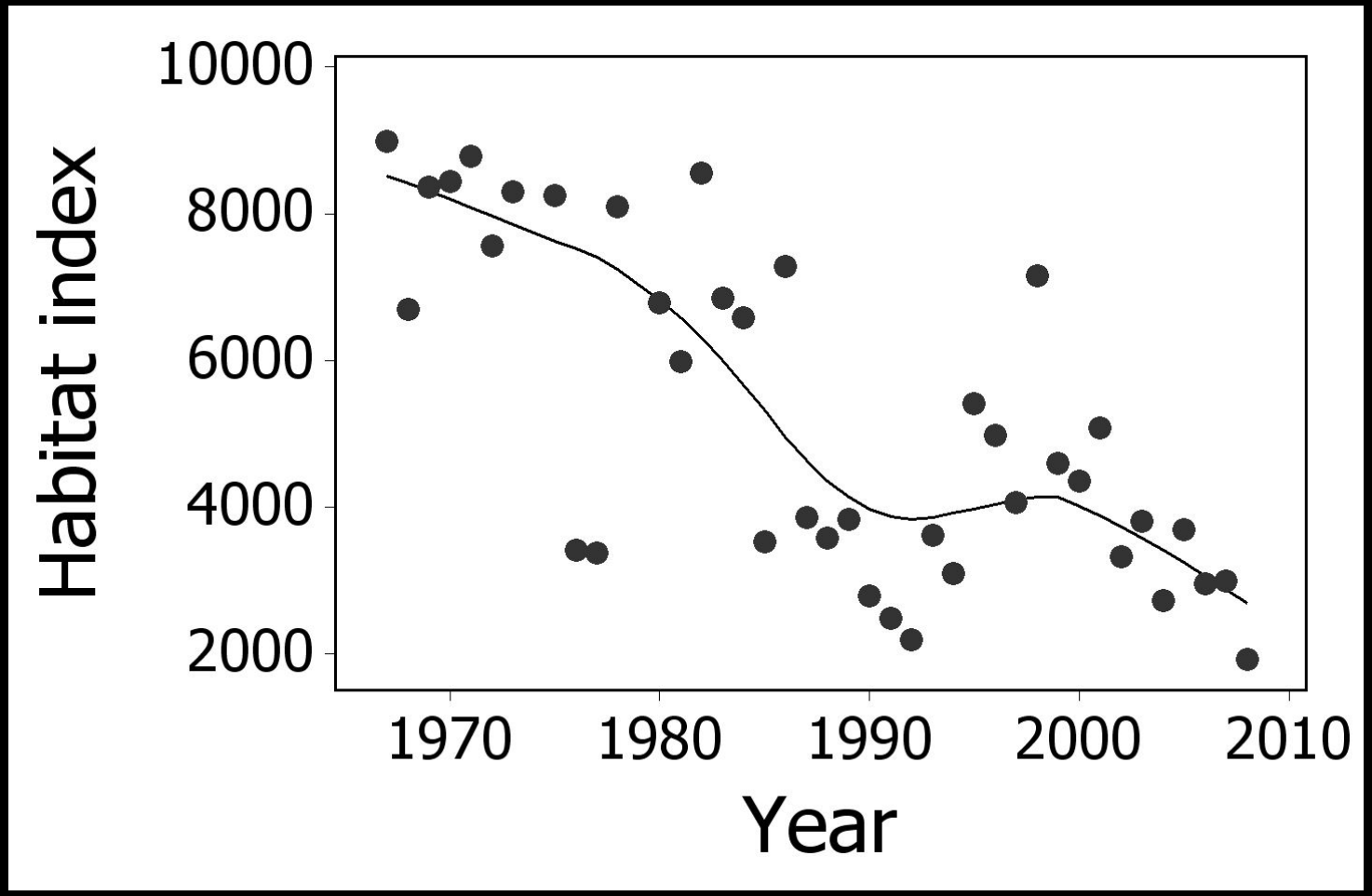




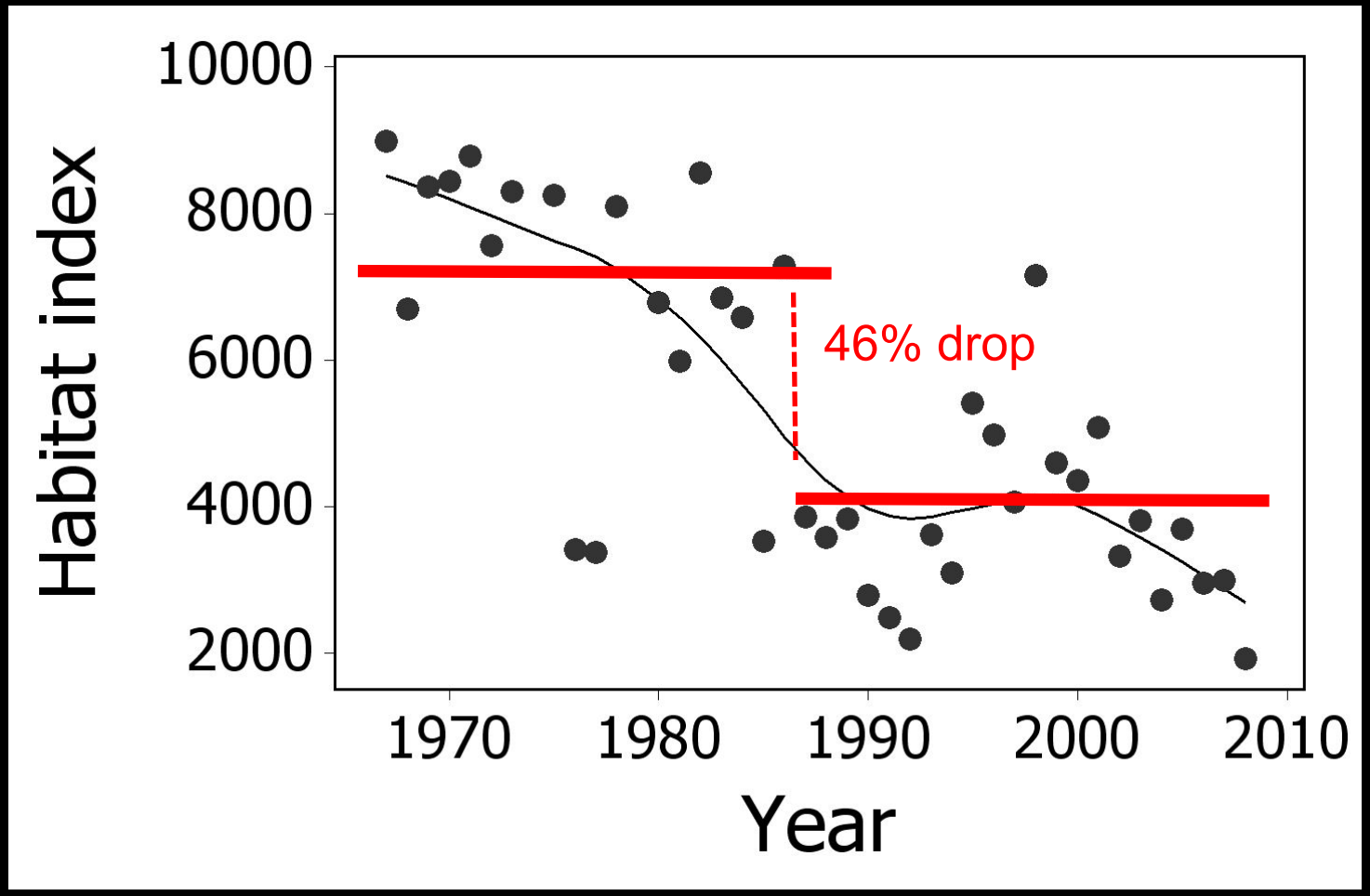
Generalized Additive Modeling

Fall Midwater Trawl Survey: 1967 – present
N > 10,000 observations

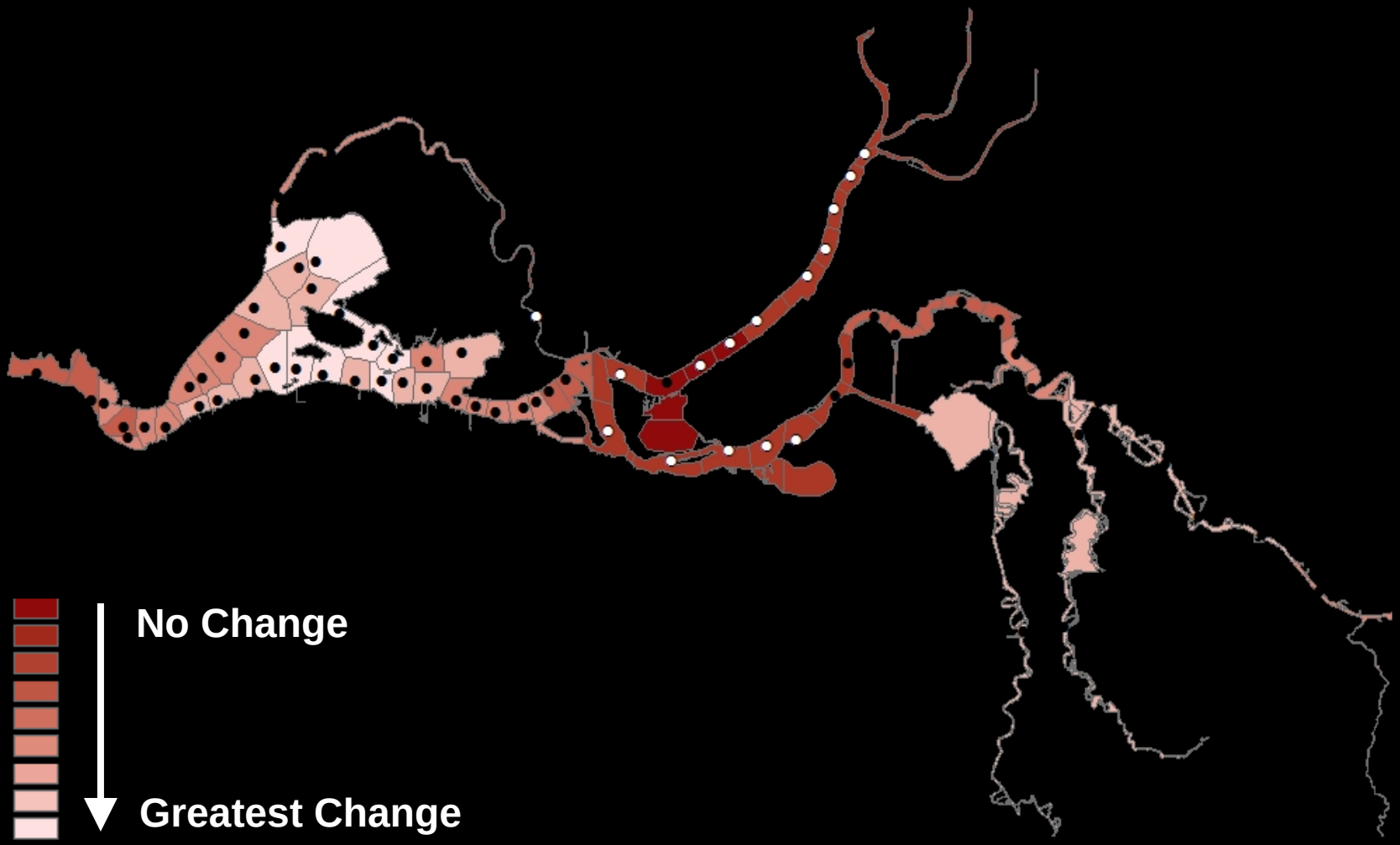
Long-term Habitat Trend – not good!



Long-term Habitat Trend – not good!

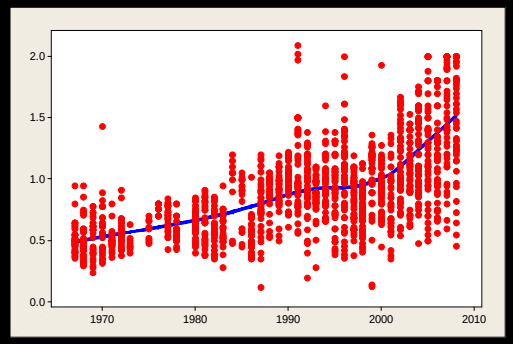


Spatio-Temporal Patterns of Habitat Change

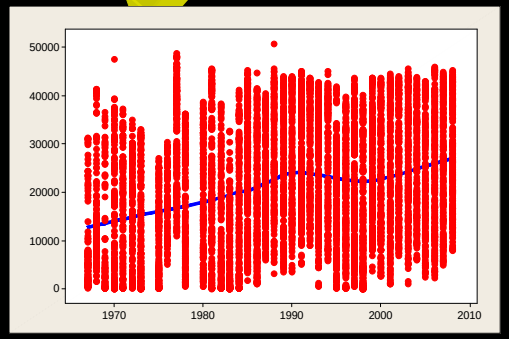


Feyrer, Nobriga, Sommer. 2007 .CJFAS

Spatio-Temporal Patterns

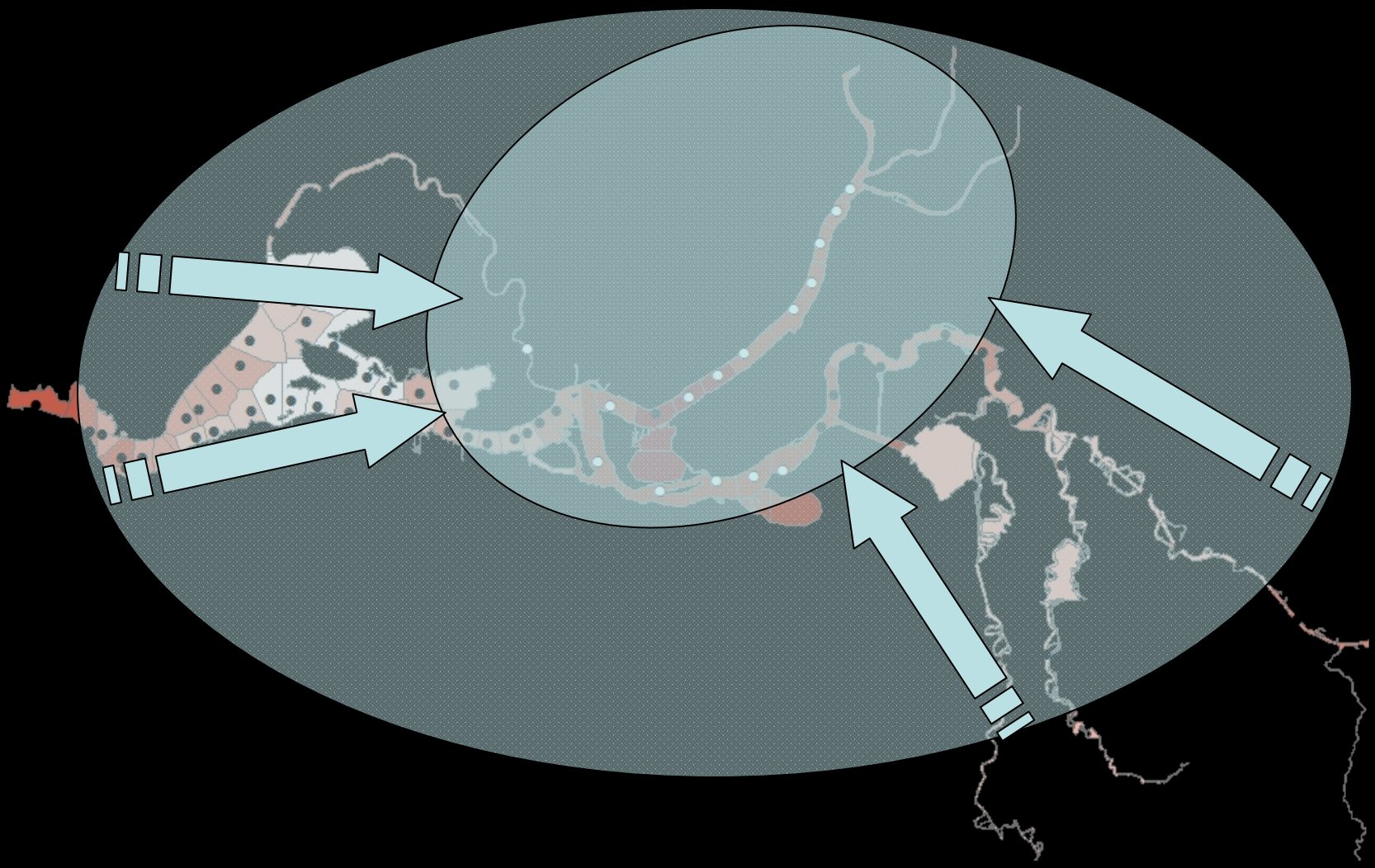


Increasingly clear

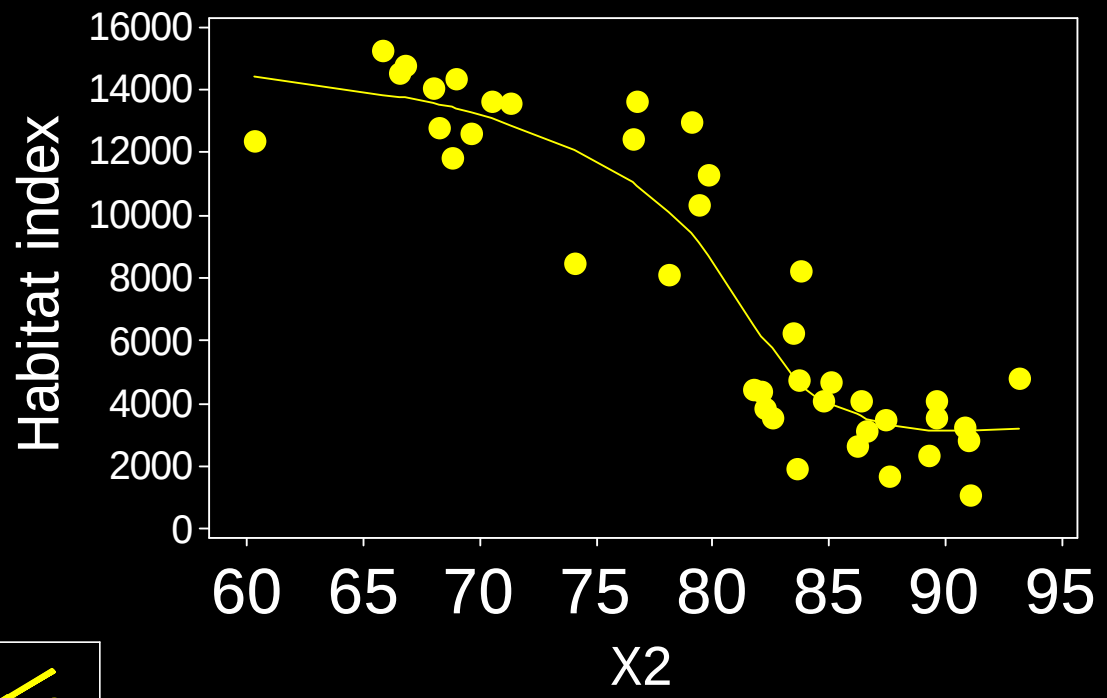


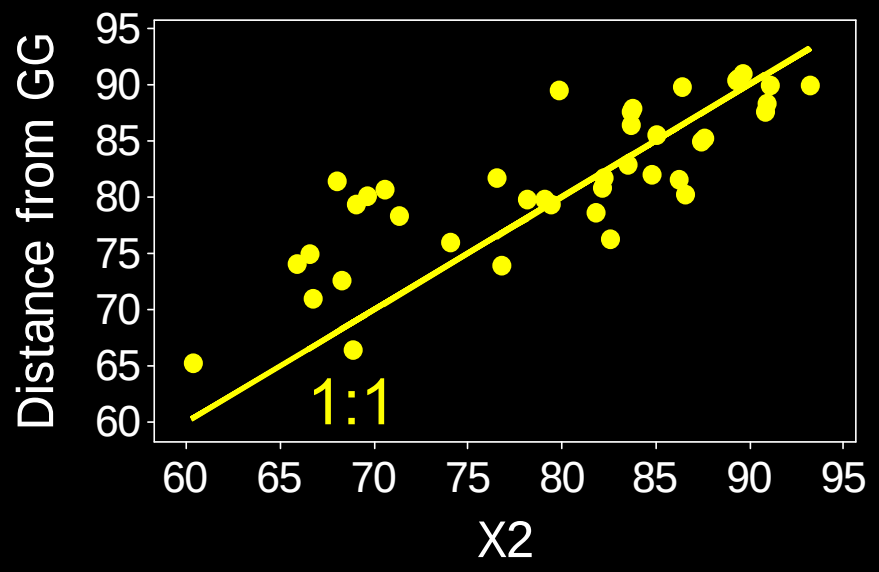
Increasingly salty

Constriction of Habitat Space

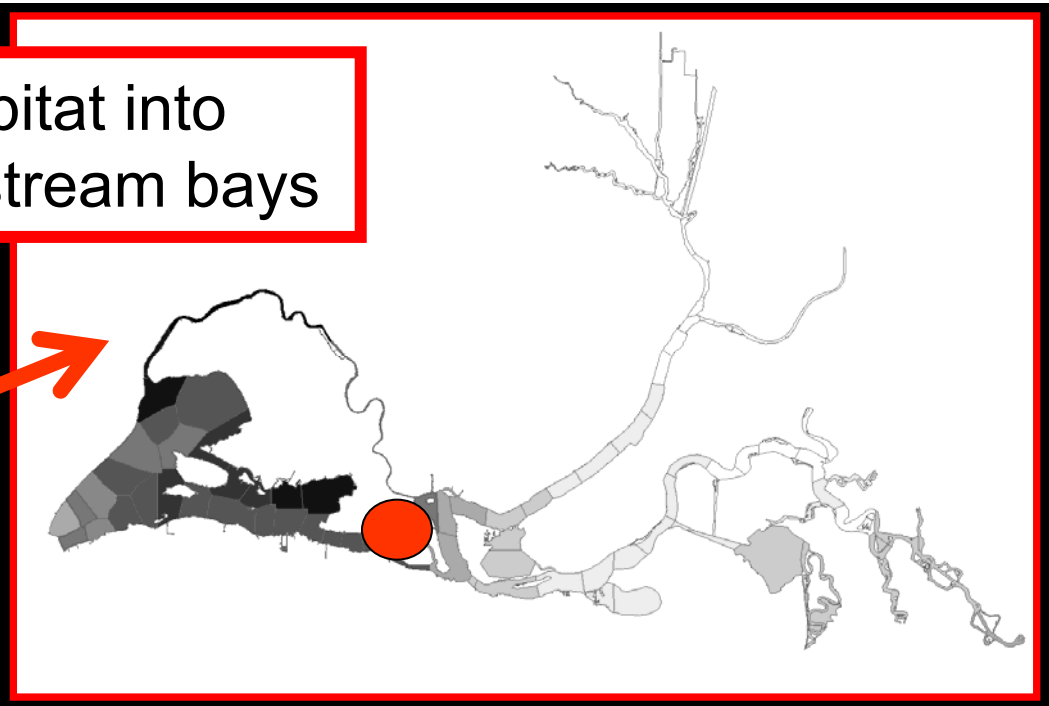


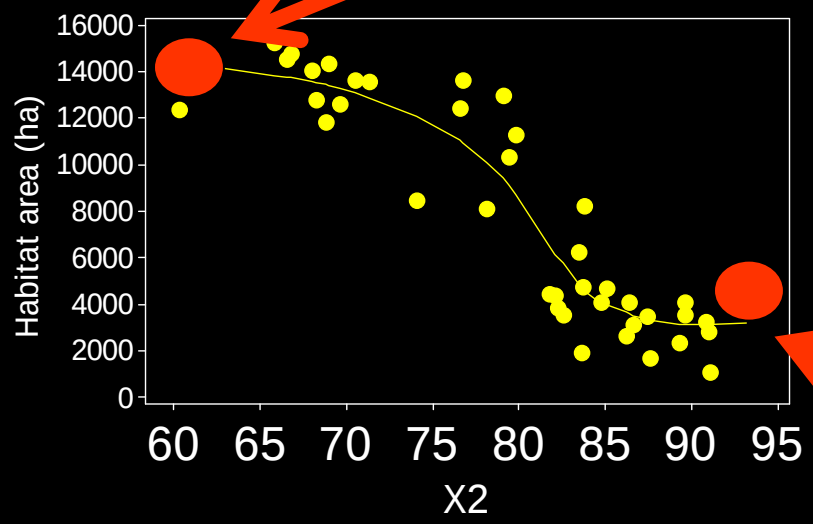
X2 Affects Abiotic Habitat and Distribution





Low X2 ***expands*** habitat into broad shallow downstream bays





High X2 ***restricts*** habitat to narrow upstream channels

Modeling Future Scenarios

Modeled X2

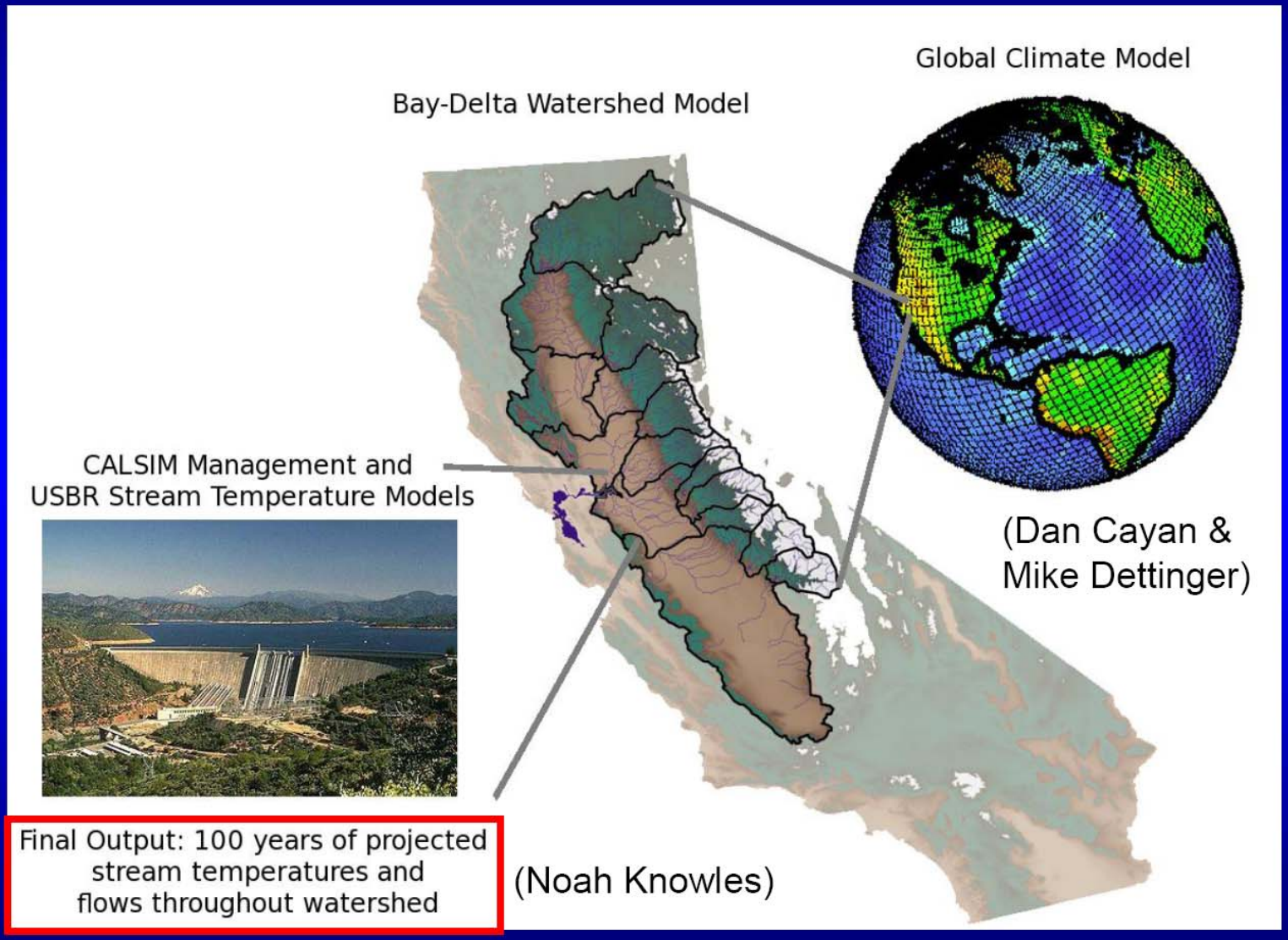
↓

X2-habitat relationship

↓

Predicted future habitat

Model Hierarchy for CASCaDE Watershed Modeling



Slide from Larry Brown, Plenary Session

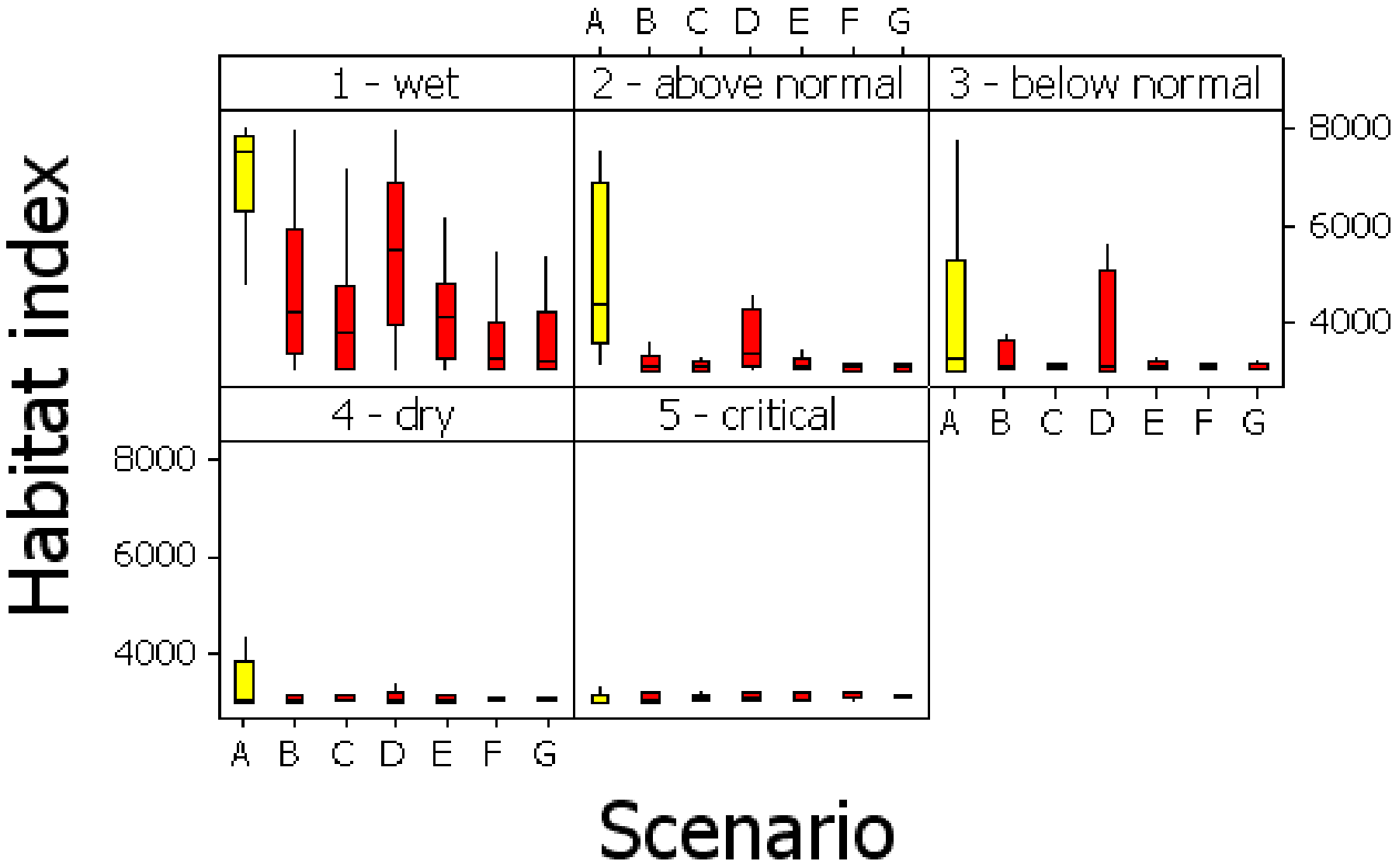
Modeled Future Scenarios

Study	Water demand	Climate change relative to the present
A	2005 (present day scenario)	n/a
B	2030	n/a
C	2030	0.3-meter increase in sea level
D	2030	Wetter and warmer
E	2030	Wetter and warmer still
F	2030	Drier and warmer
G	2030	Drier and warmer still

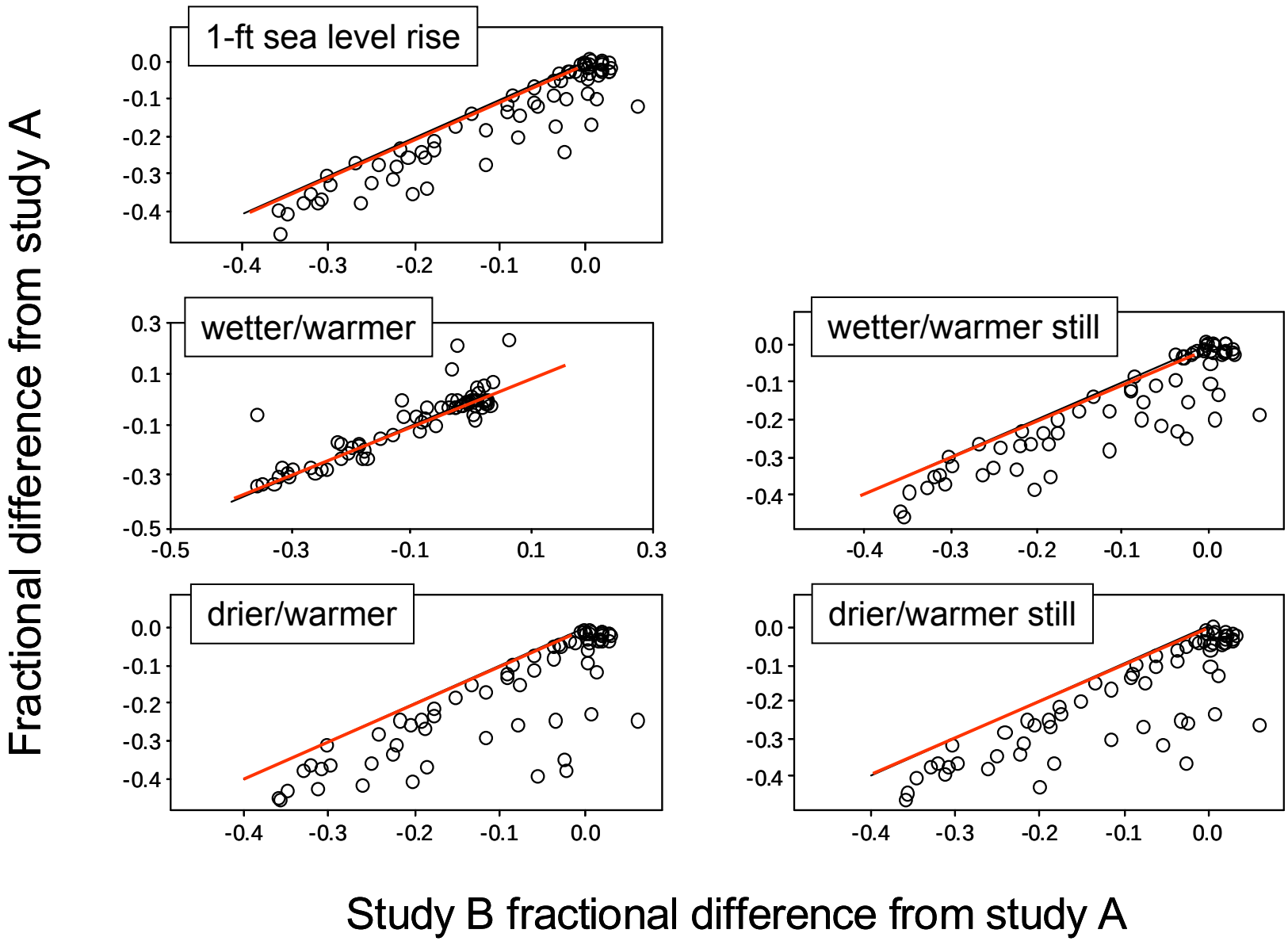
Output generated by CALSIM II – statewide water planning tool

Source:
Brekke, L. 2008. Sensitivity of future Central Valley Project and State Water Project operations to potential climate change and associated sea level rise. Appendix R of OCAP BA on the continued long-term operations of the CVP and SWP.

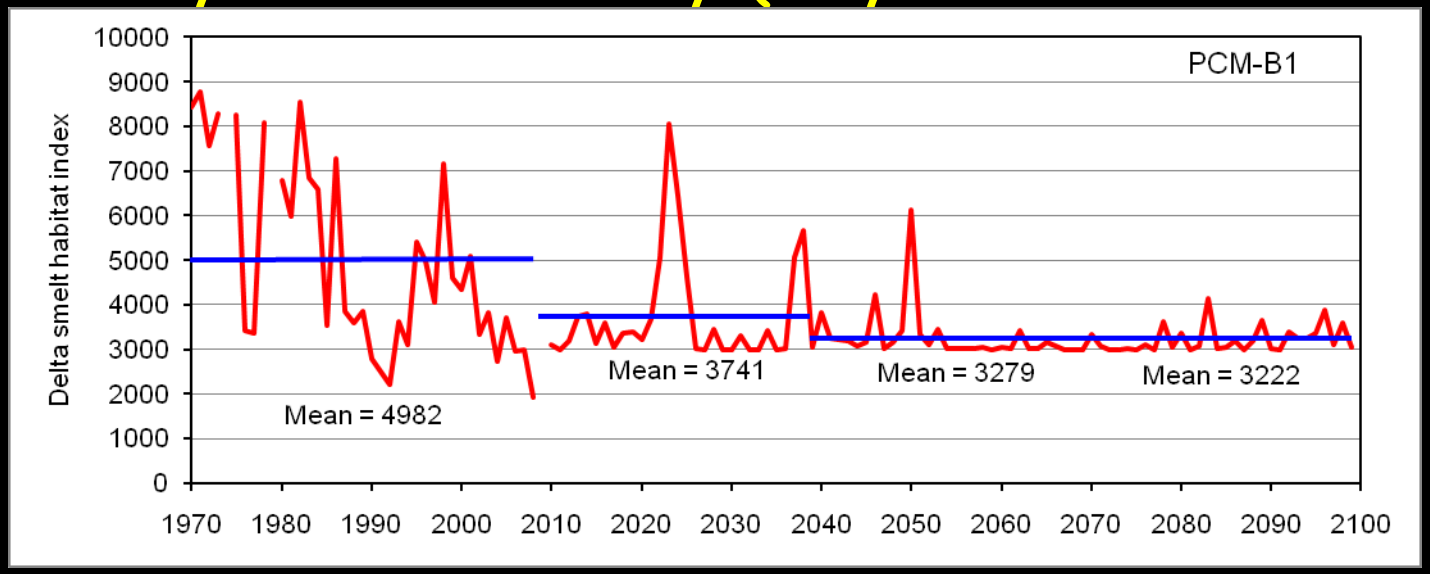
Potentially Large Decreases in Abiotic Habitat

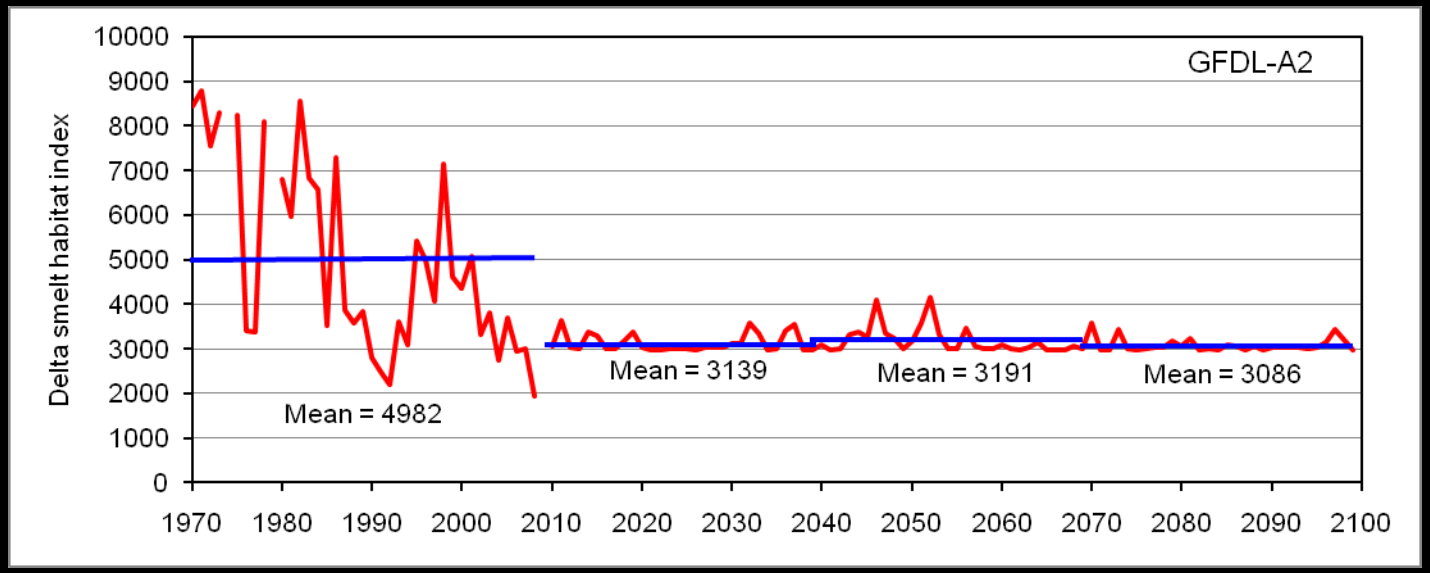


Climate Change Exacerbates Water Demand



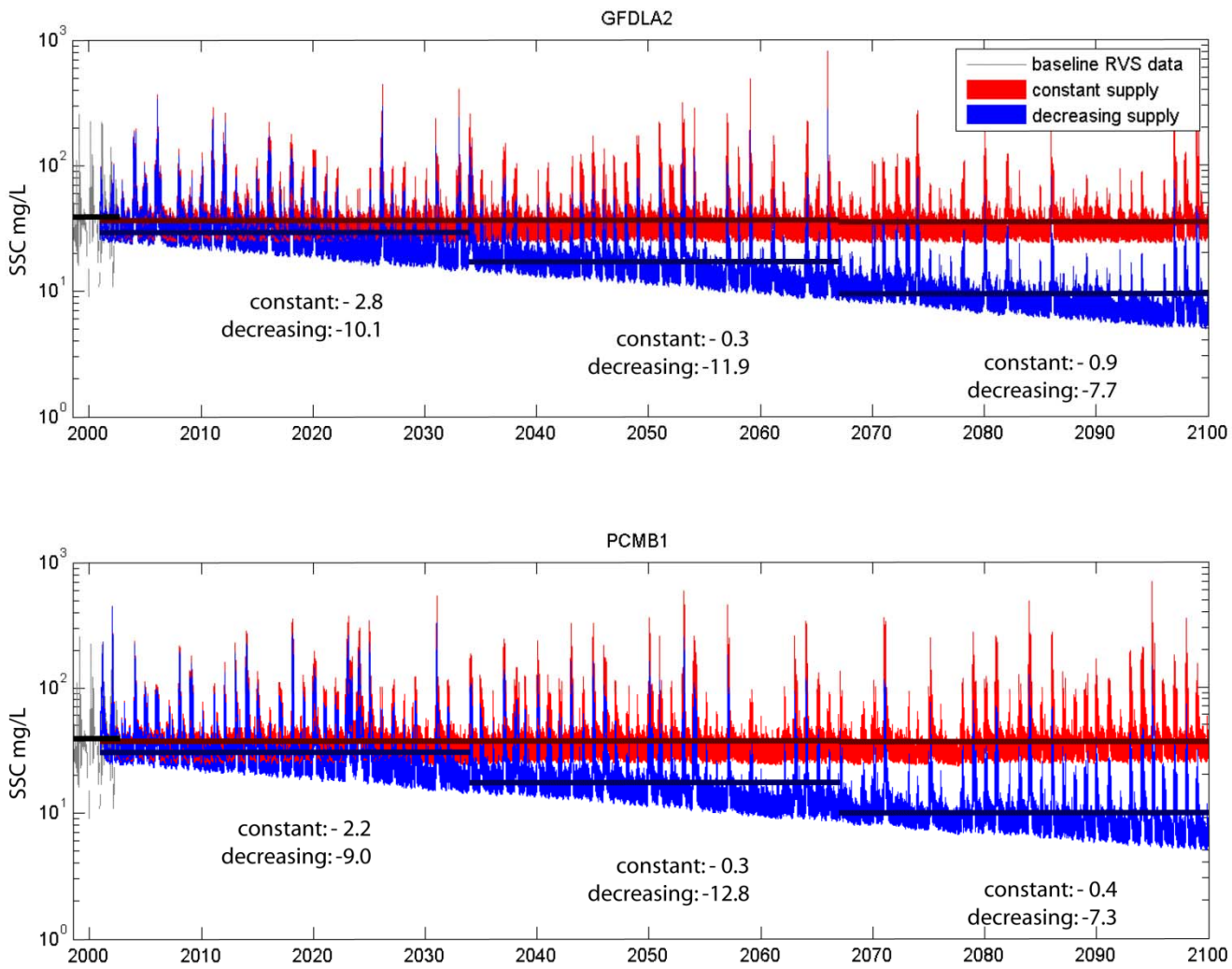
Habitat Index for Fall Delta Smelt as Defined by Salinity and Turbidity (Feyrer et al. in review)





Slide from Larry Brown, Plenary Session

The Delta is clearing



(Morgan and Schoellhamer, unpublished data)

Slide from Larry Brown, Plenary Session

Summary

- Future development and climate change pose a potentially serious threat to the habitat of estuarine biota such as delta smelt.

- Scenarios NOT predictions!

Ecologic Response to Climate-Change Induced Water Temperature Changes in the Sacramento-San Joaquin Delta

March 13, 2010

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[1]Department of Civil and Environmental Engineering, UC Berkeley

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drwilliambowen@hotm

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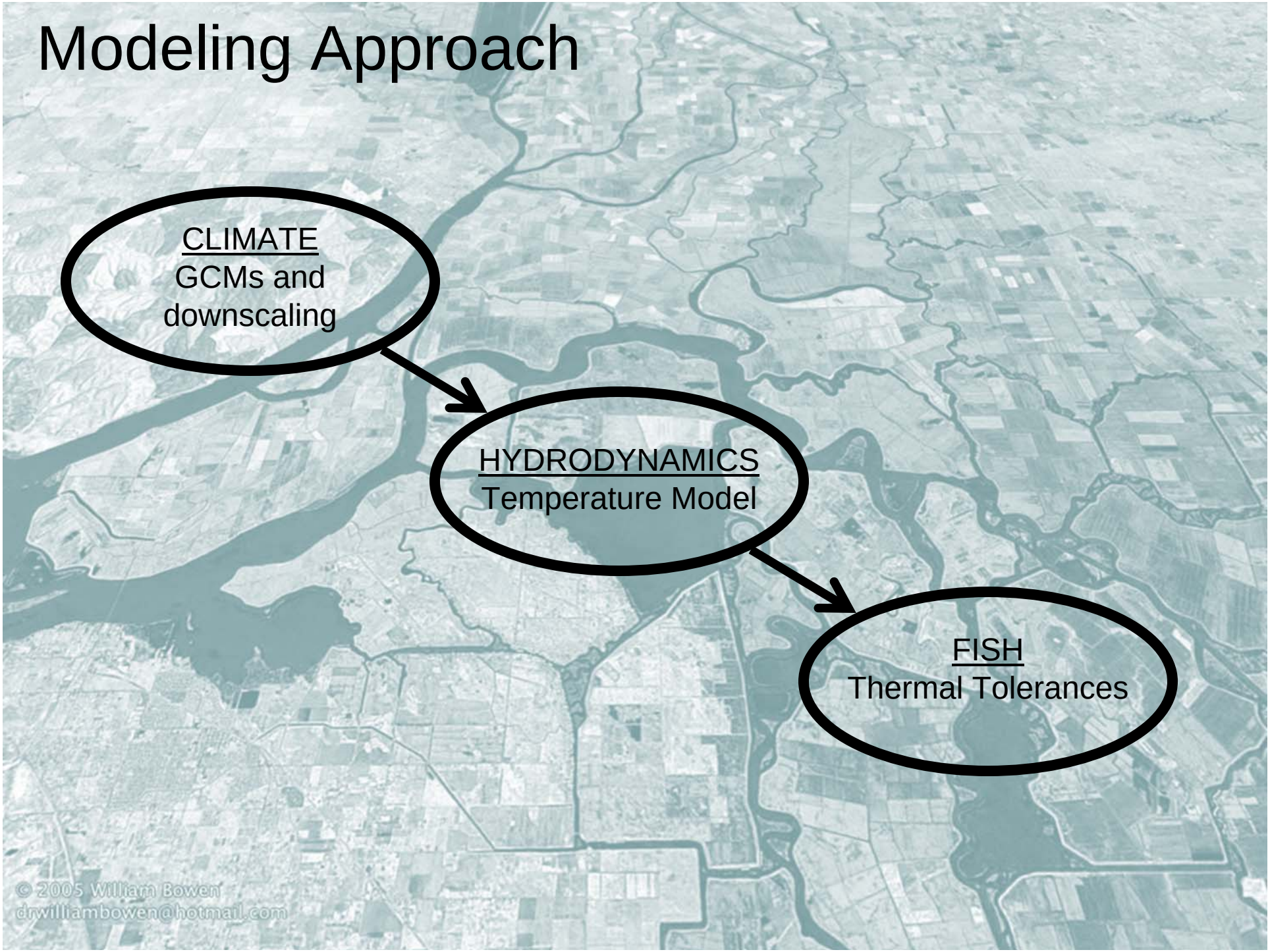
Motivation

- San Francisco Bay-Delta's ecological and water stress
- Forcing on the system will continue to change in the coming century
- Water temperature modeling and the Delta ecosystem

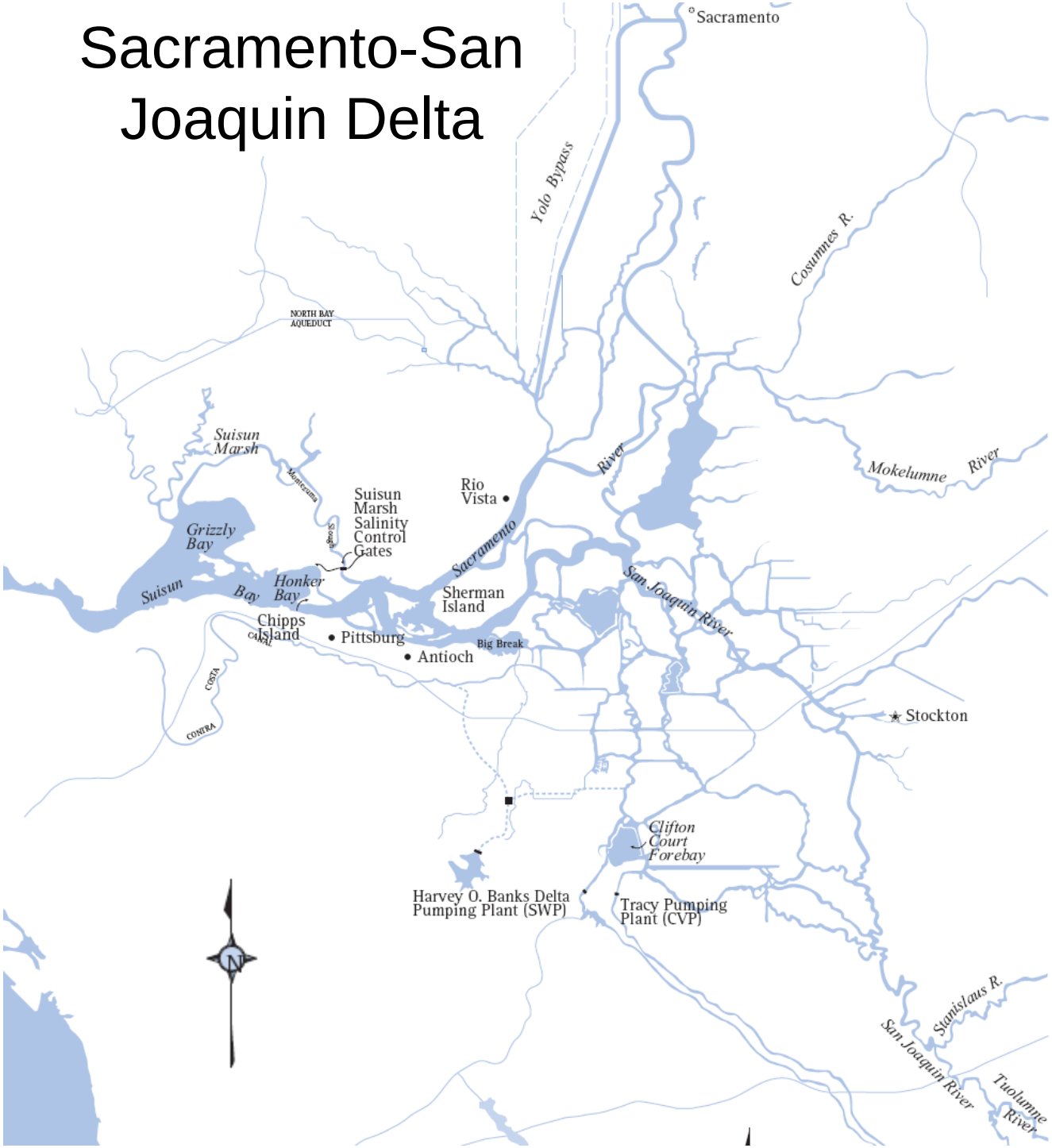
Modeling Approach

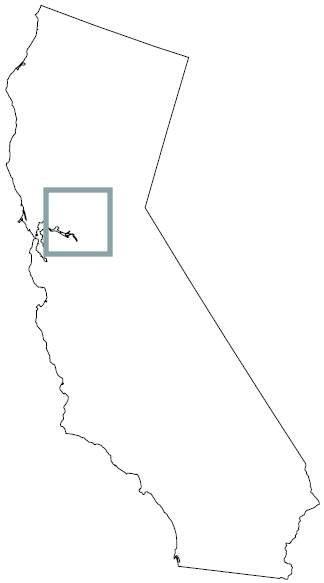


Overview

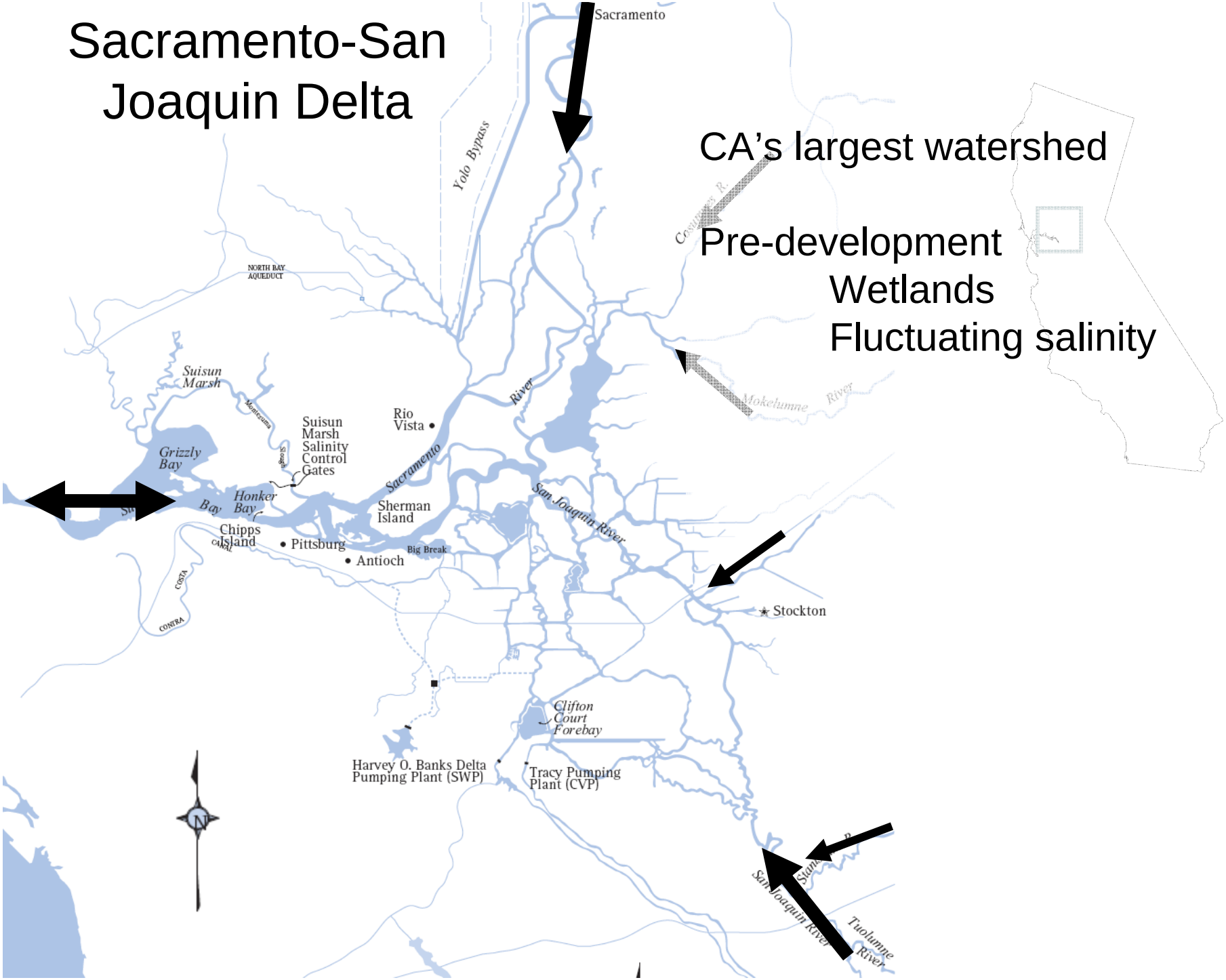
- Study site and data sources
- Water temperature model
- Downscaled climate data and forecasts
- Ecological implications
- Smaller scale

Sacramento-San Joaquin Delta





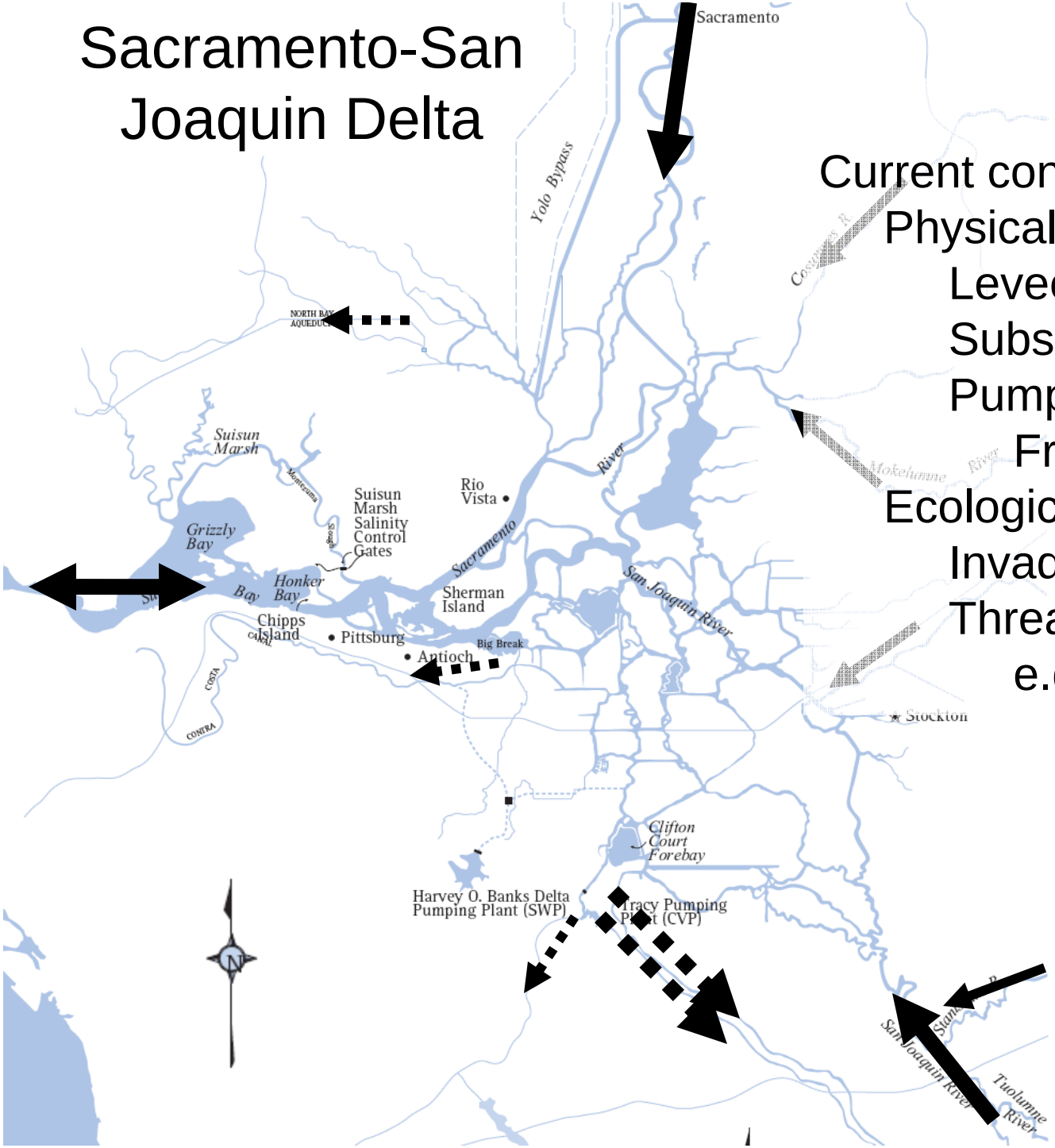
Sacramento-San Joaquin Delta



CA's largest watershed

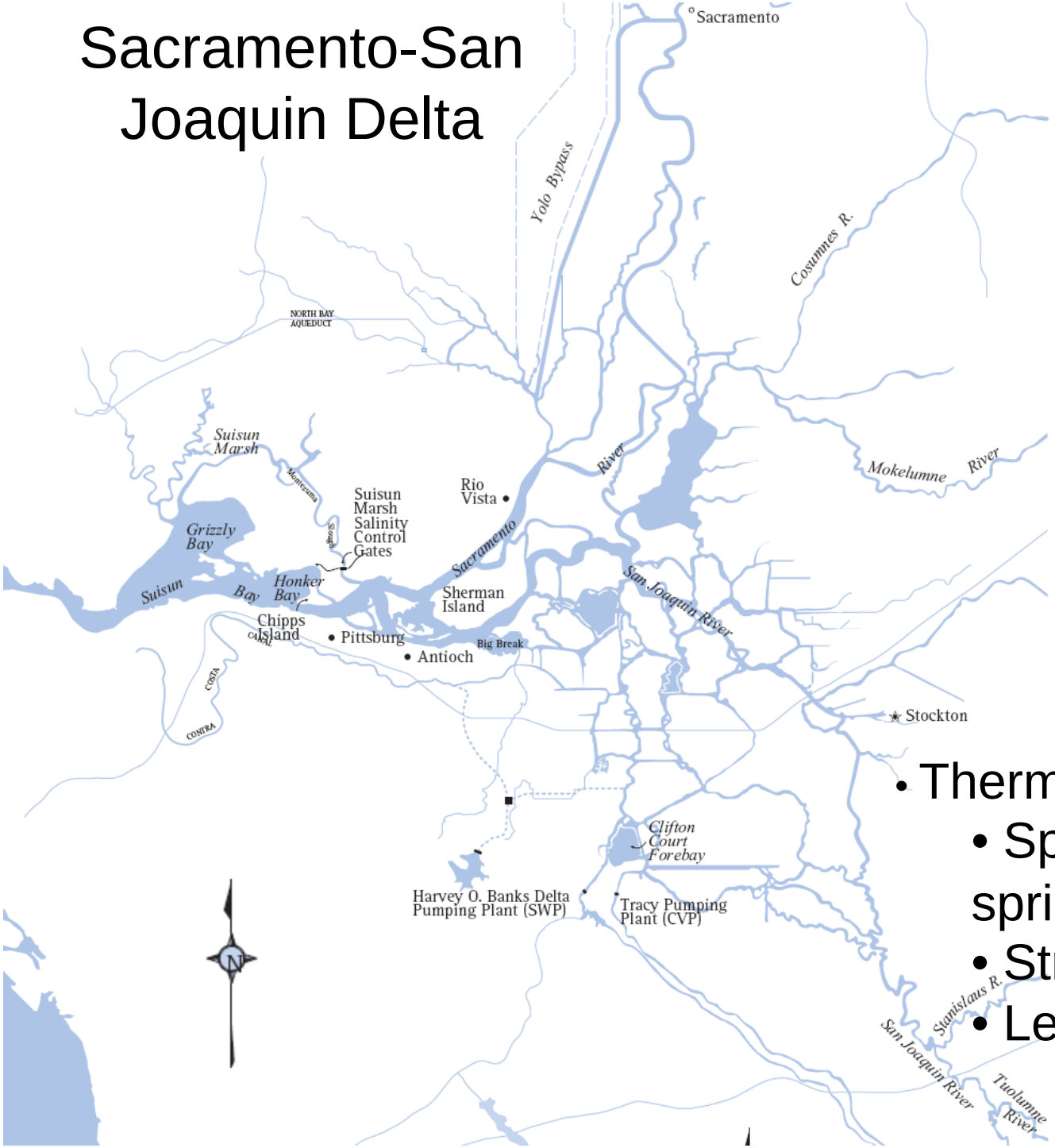
Pre-development
- Wetlands
- Fluctuating salinity

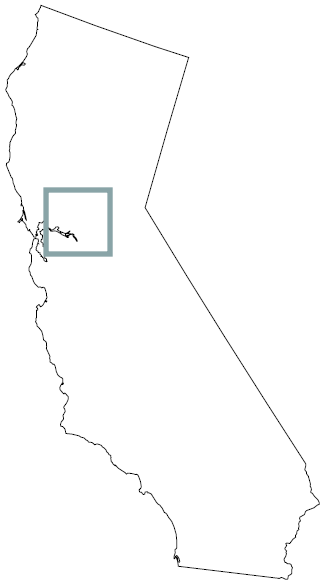
Sacramento-San Joaquin Delta



Current conditions
- Physically altered
  - Levees
  - Subsidence
  - Pumps
    - Freshwater maintained
- Ecologically altered
  - Invaded ecosystem
  - Threatened native species
    - e.g. Delta smelt

Sacramento-San Joaquin Delta

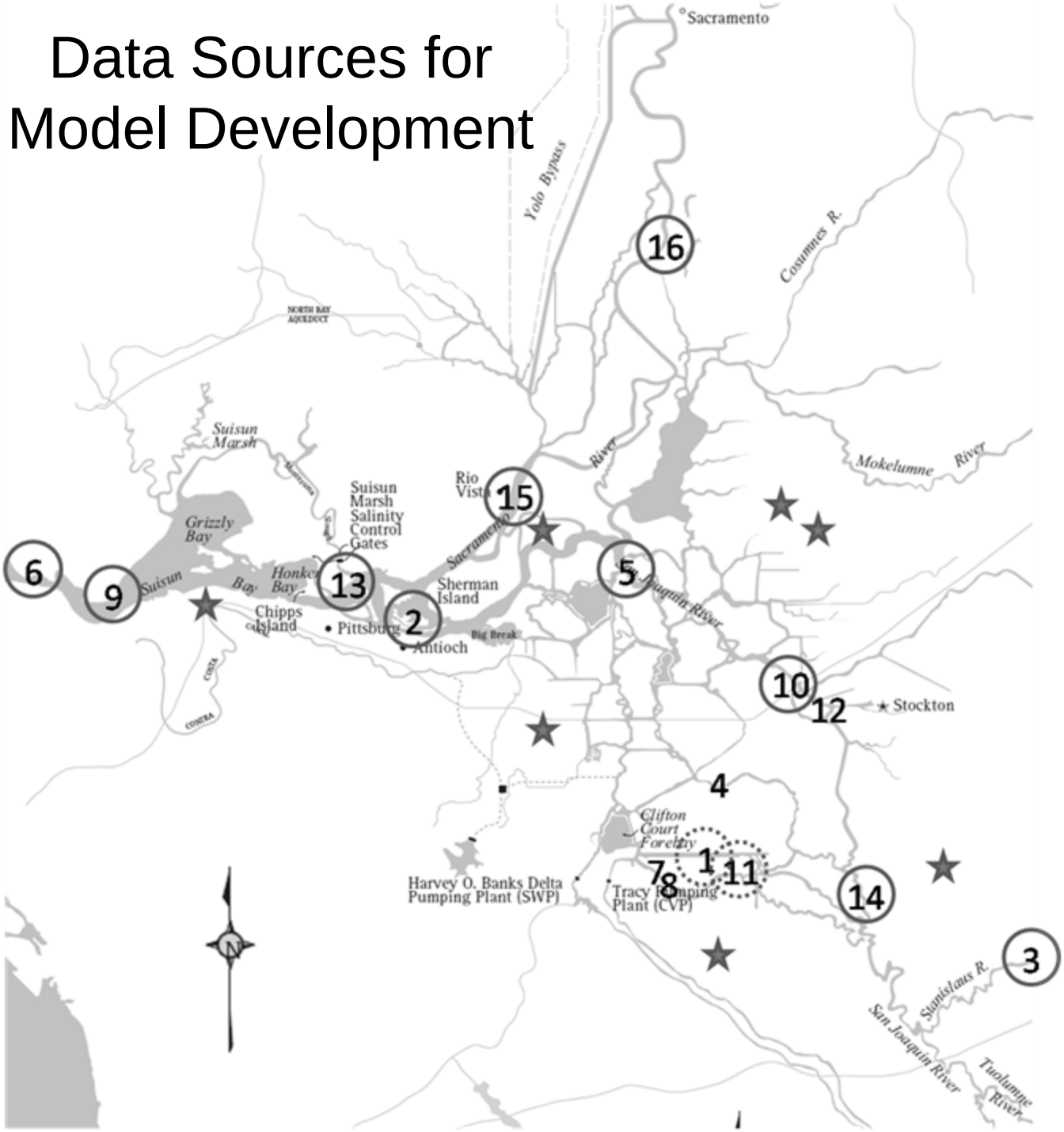




Delta smelt

- Thermal tolerances
  - Spawn in 15-20ºC in spring
  - Stress over 20ºC
  - Lethal over 25ºC

Data Sources for Model Development



- o IEP
  - Water temperature
- o CIMIS
  - Insolation
  - Air temperature

Water Temperature Model

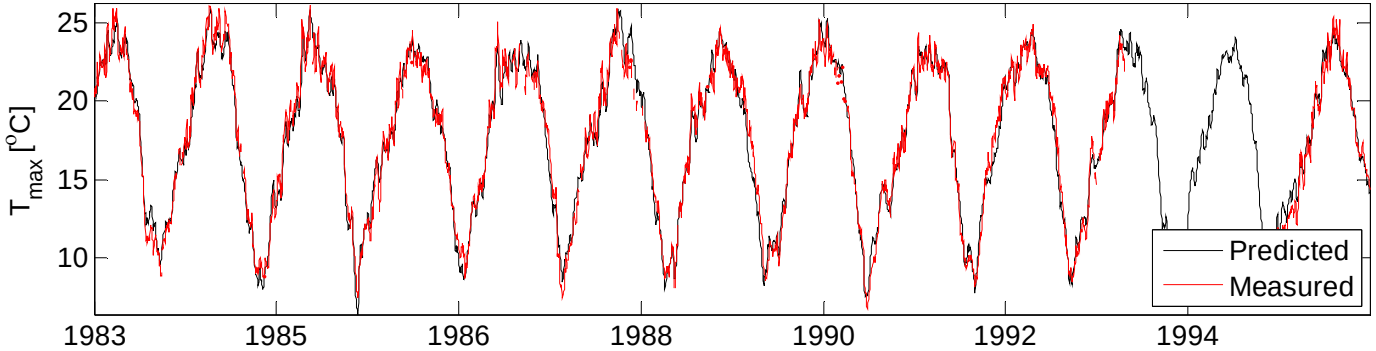
- Pure Statistic Model
  - Mulitple linear regression at each location

$$T_{water}(t) = b_0 + b_1 T_{water}(t-1) + b_2 T_{air}(t) + b_3 r(t)$$

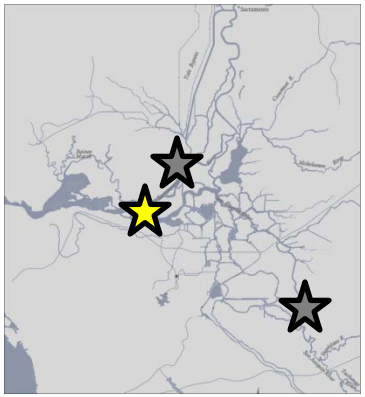
  - T_{air} refers to average of daily max and min
  - Can be used to predict $T_{w,max}$, $T_{w,avg}$, $T_{w,min}$
- Data split for calibration/verification
  - Calibrate with first half for b_0, b_1, b_2, b_3
  - Initialize second half w/ measured data

Water Temperature Model

Calibration r^2 = .977

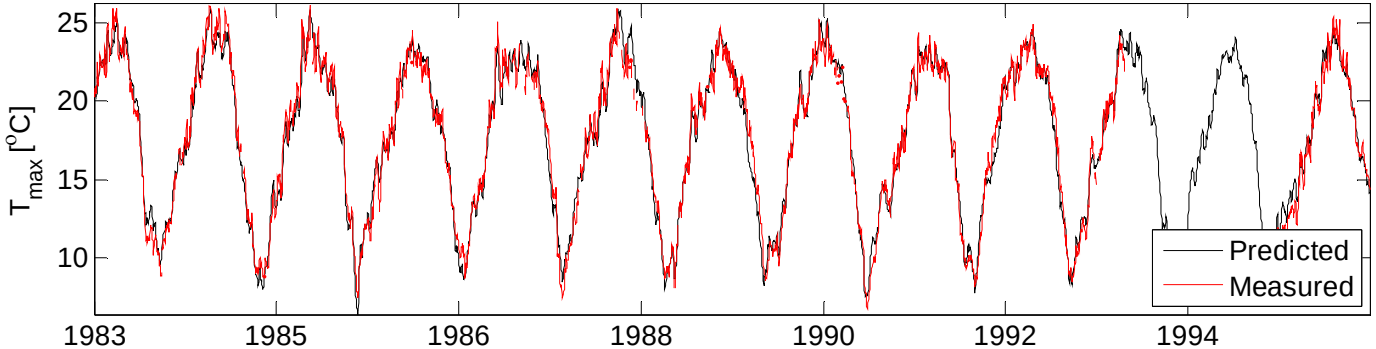


- Projections at Antioch
  - Top panel: Calibration period (defines 4 parameters)

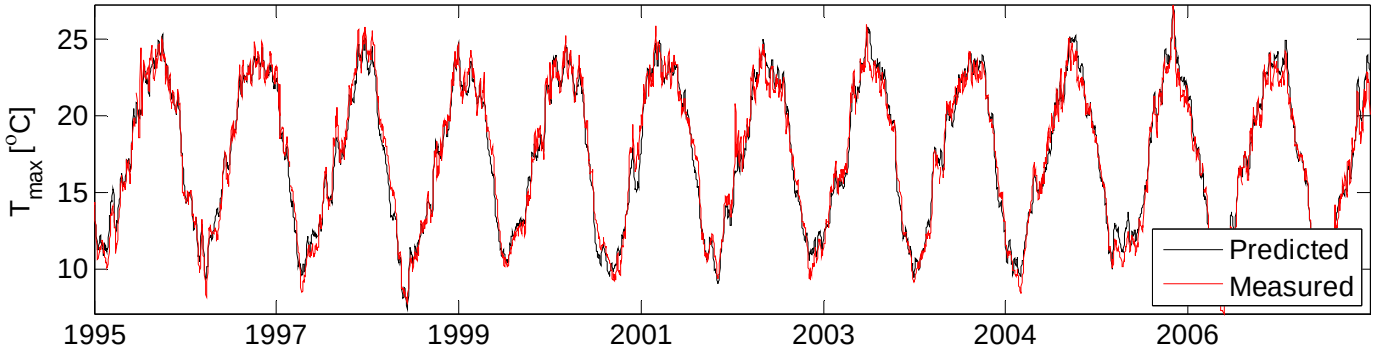


Water Temperature Model

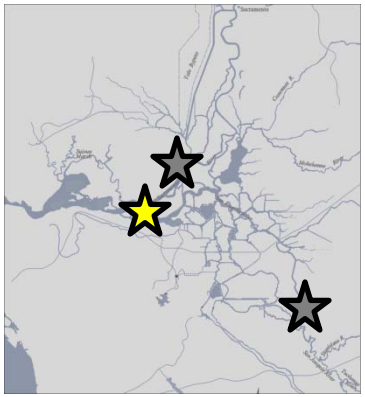
Calibration r^2 = .977



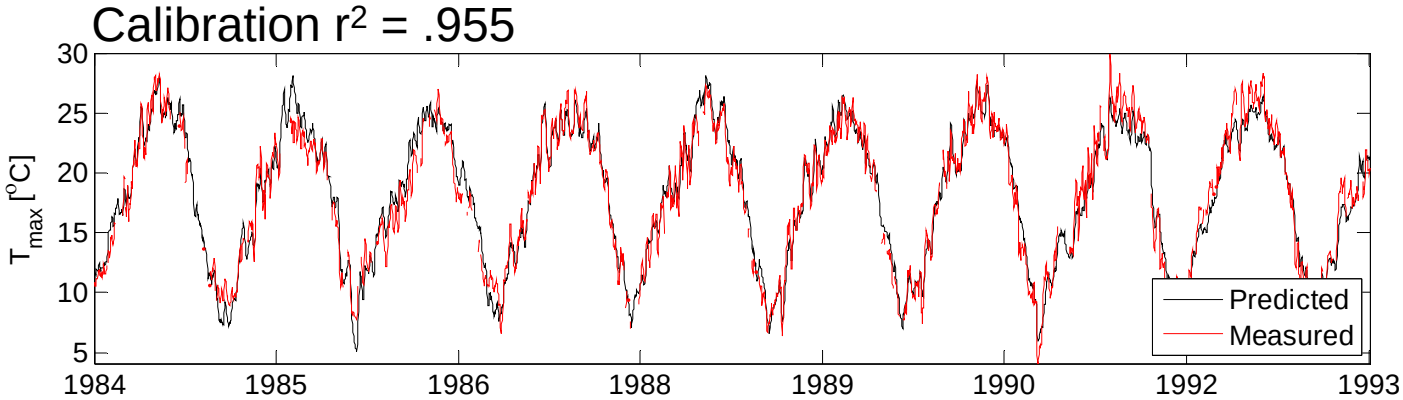
Verification r^2 = .974

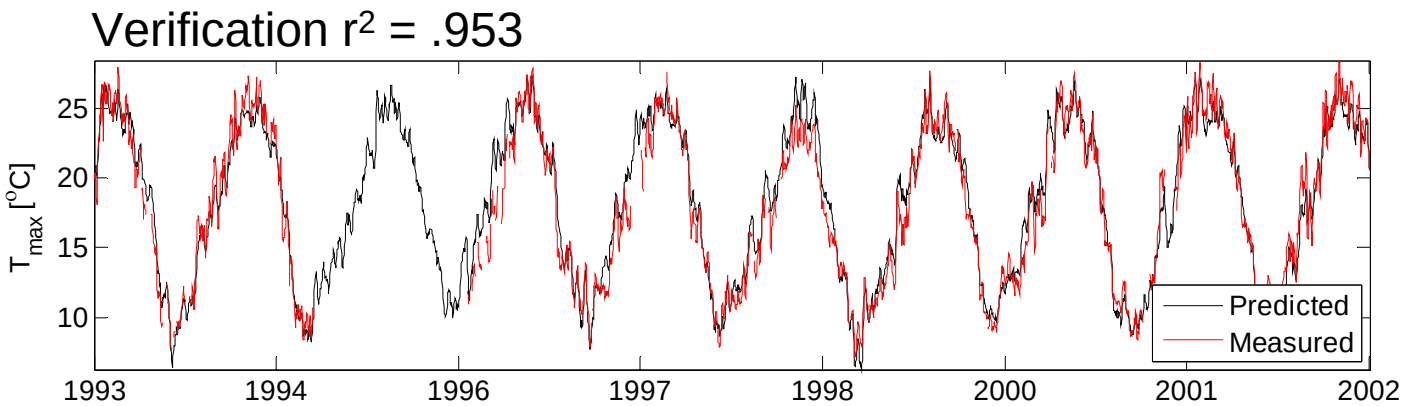


- Projections at Antioch
  - Top panel: Calibration period (defines 4 parameters)
  - Bottom panel: Unconstrained calculation to test model performance.

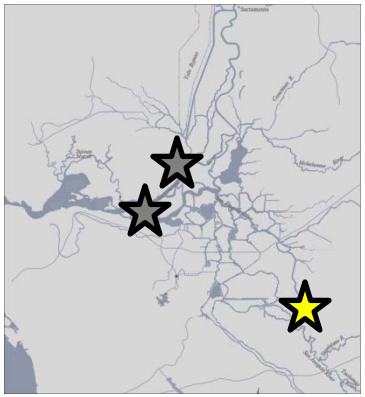


Water Temperature Model



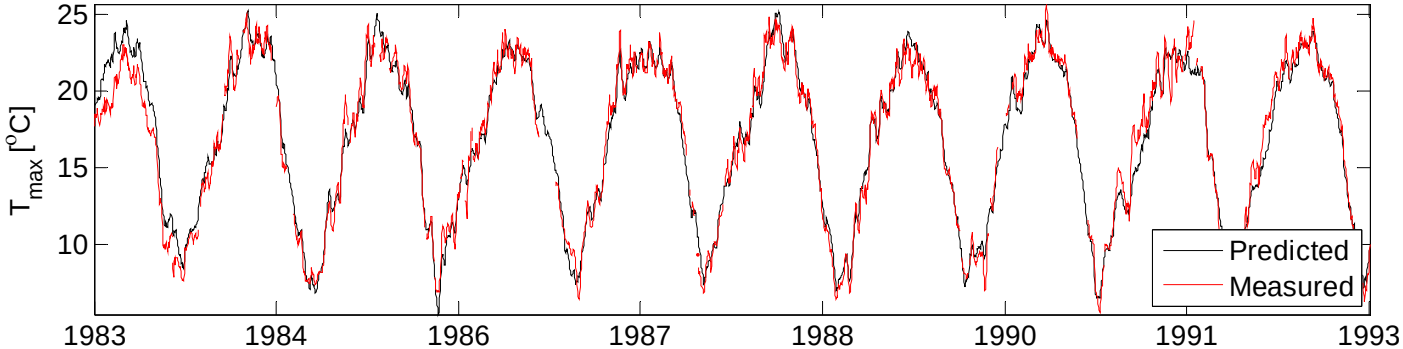


- Projections at Mossdale (SJ River)
  - The model displays high predictive skill, but measurements lag model during warming periods.

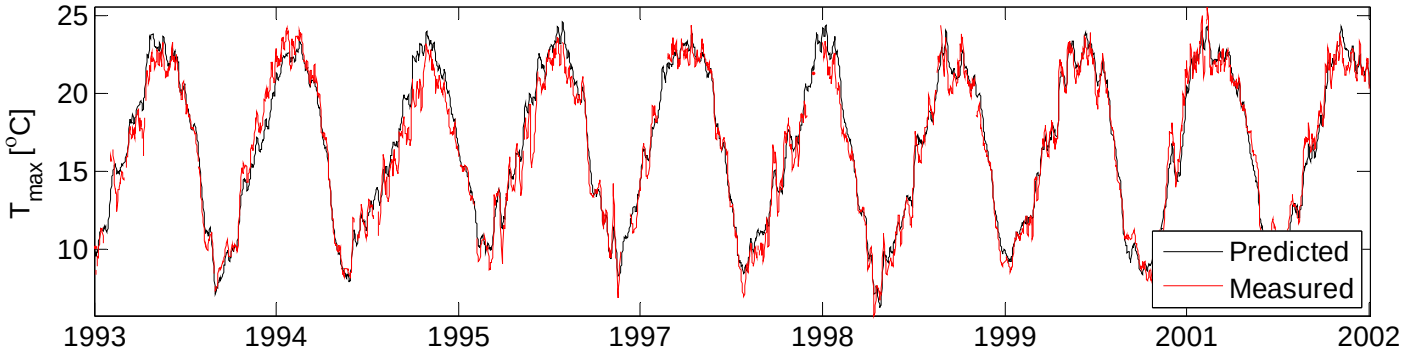


Water Temperature Model

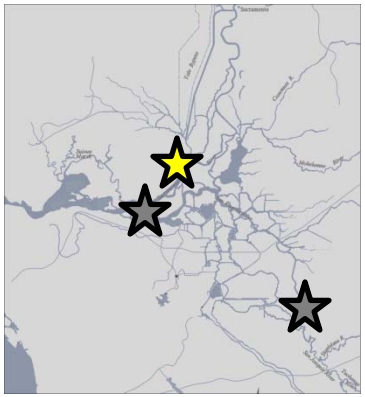
Calibration r^2 = .969



Verification r^2 = .966

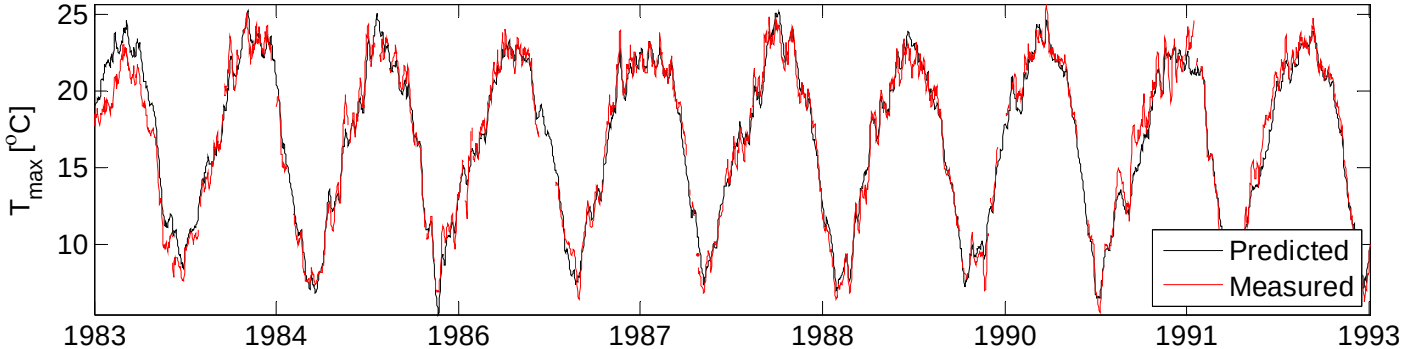


- Projections at Rio Vista (Sacramento River)
  - The model displays high predictive skill with respect to the yearly cycle and yearly maximums in the northern Delta.

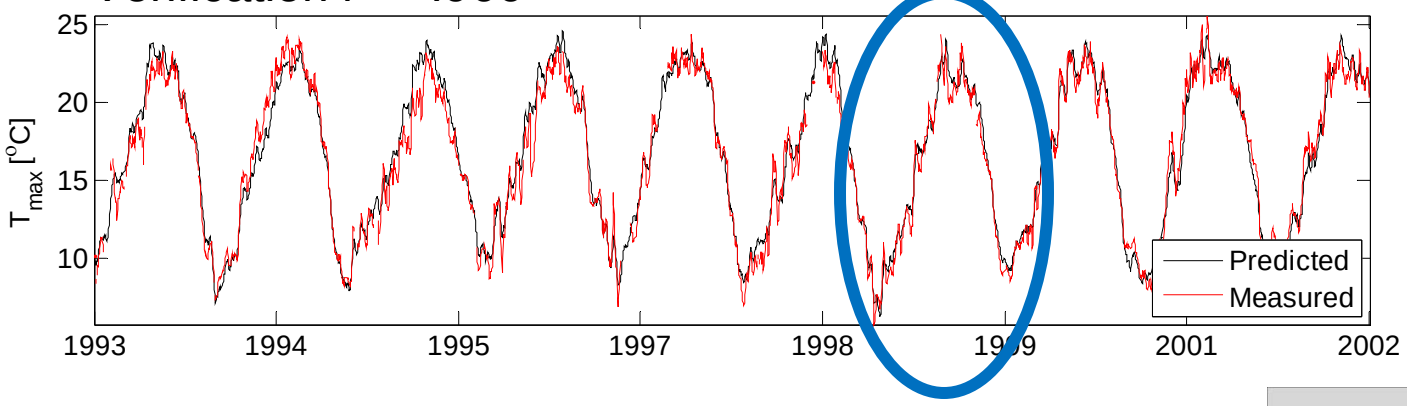


Water Temperature Model

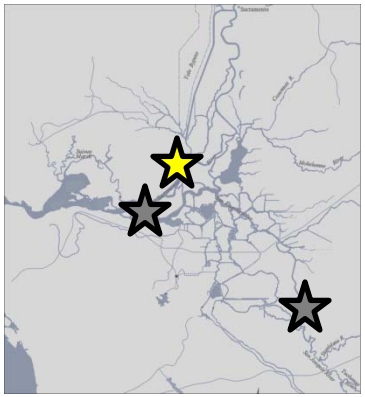
Calibration r^2 = .969



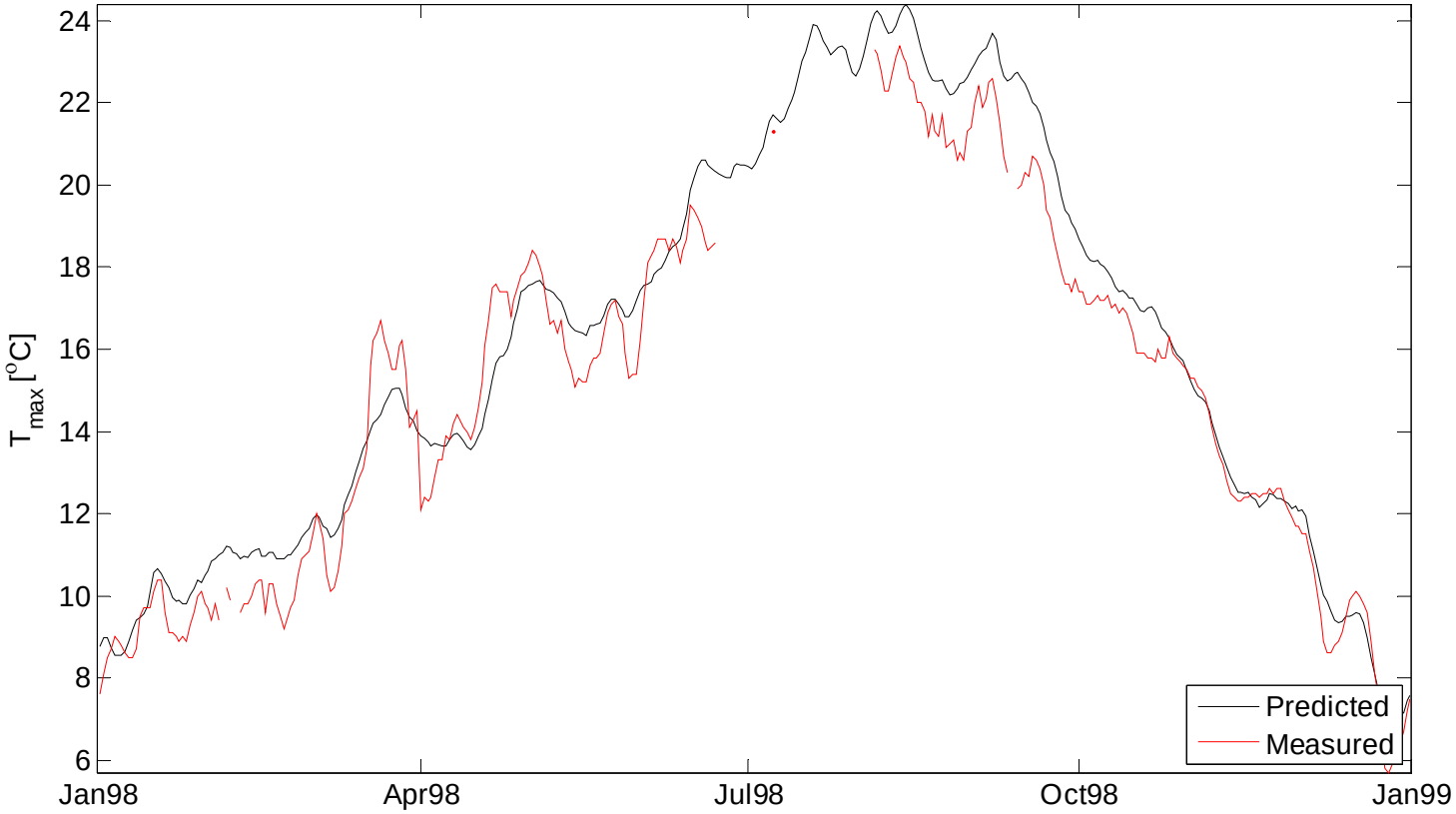
Verification r^2 = .966



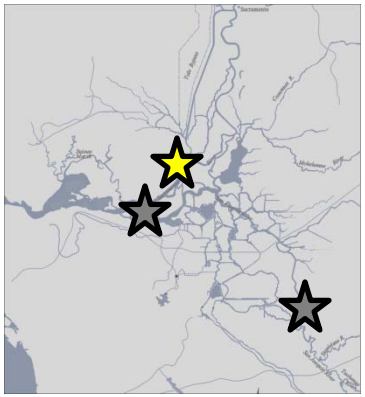
- Projections at Rio Vista (Sacramento River)
  - Note finer scale comparisons.



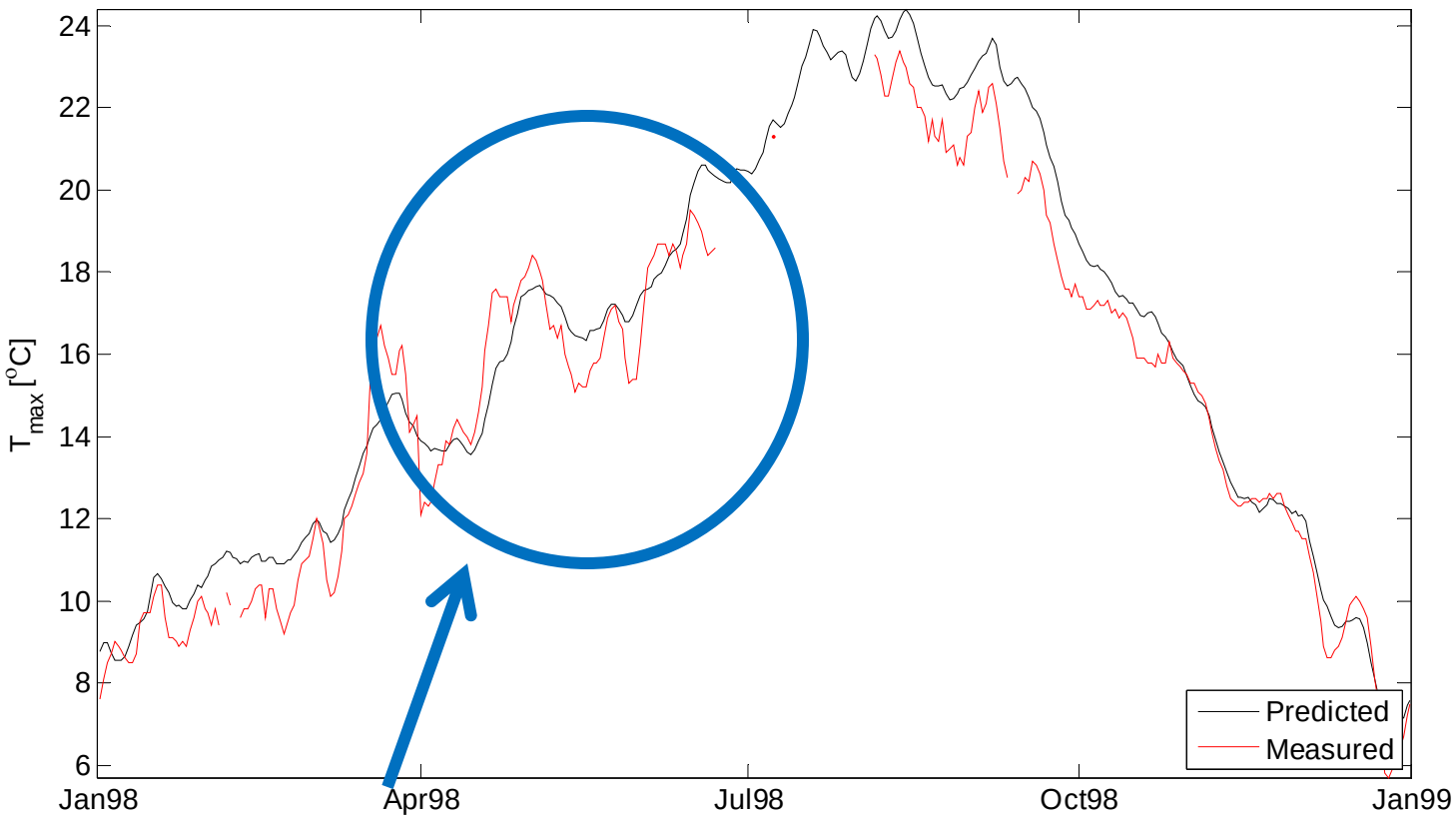
Water Temperature Model



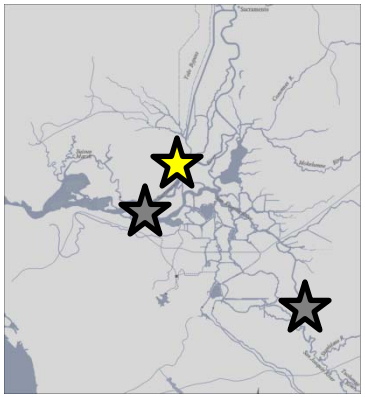
- Measurements lead model during cooling periods.



Water Temperature Model



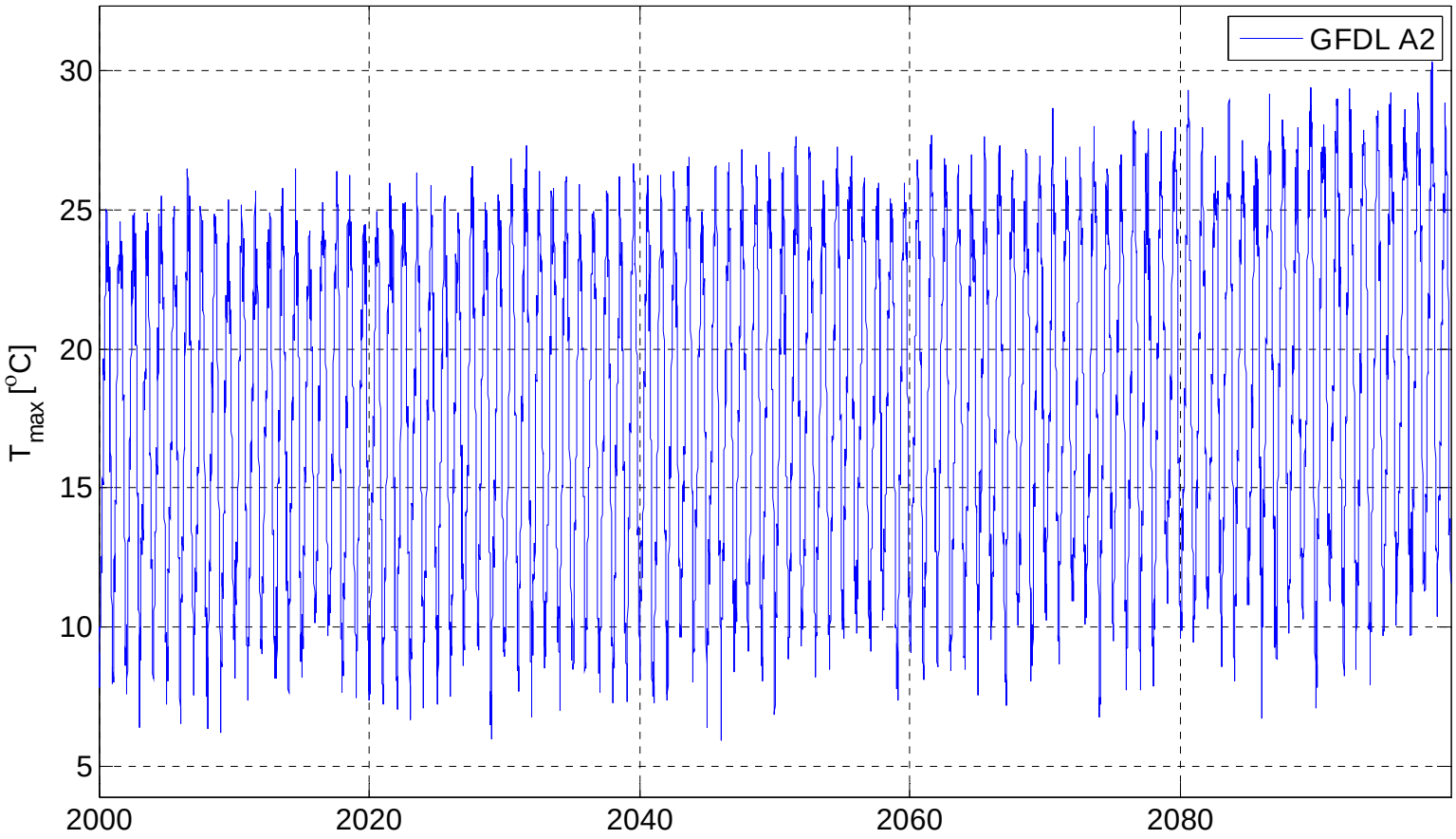
- Measurements lead model during cooling periods.
- Model reproduces temperature fluctuations on weekly timescales



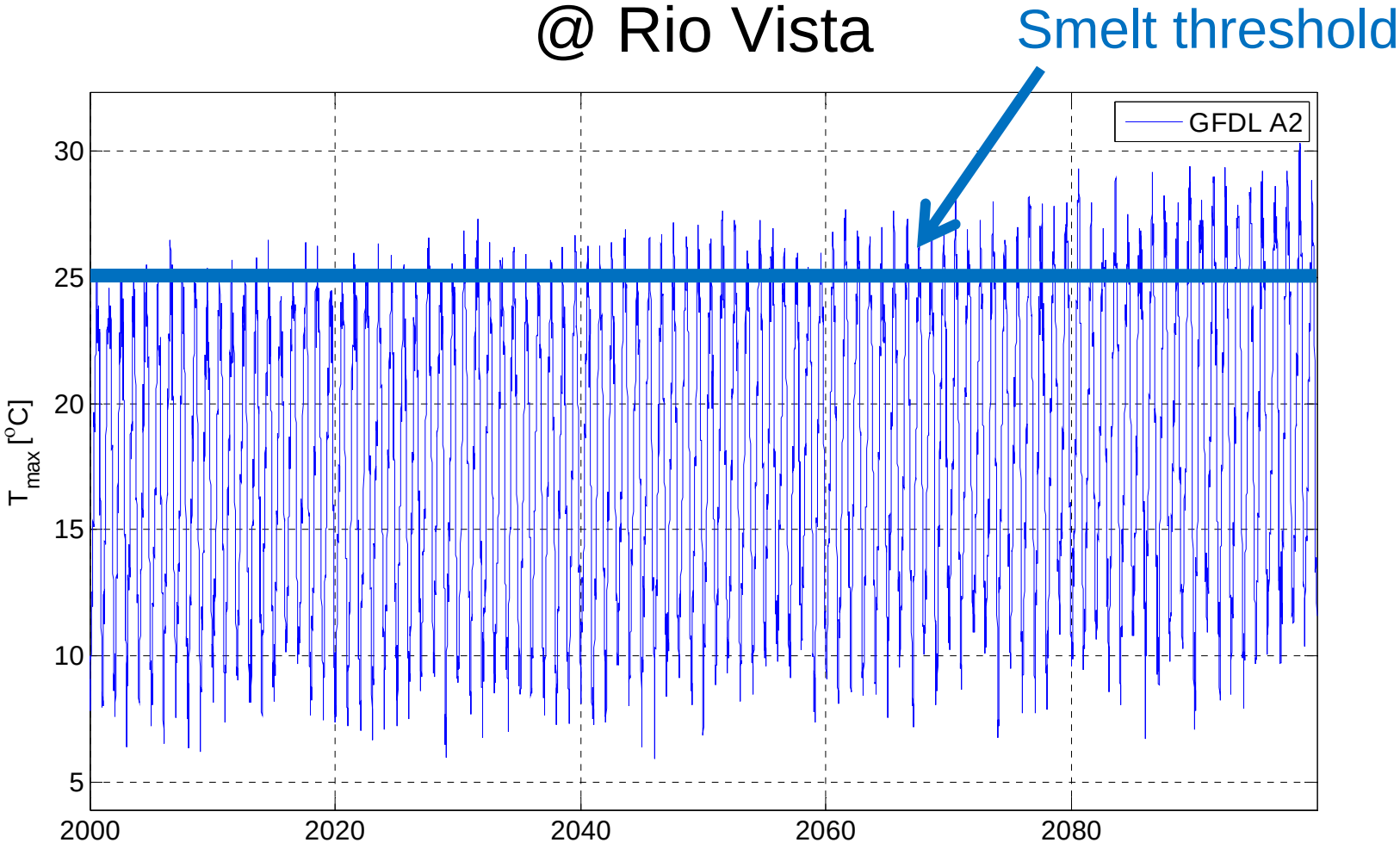
Water Temperature Projections

- Statistical model
  - Verification r^2 >0.95 provided enough calibration data.
  - Timing off seasonally in some locations.
- Projection
  - Calibrate with full dataset.
  - Initialize with measured water temperature.
  - Force with downscaled GCM data for 4 scenarios .

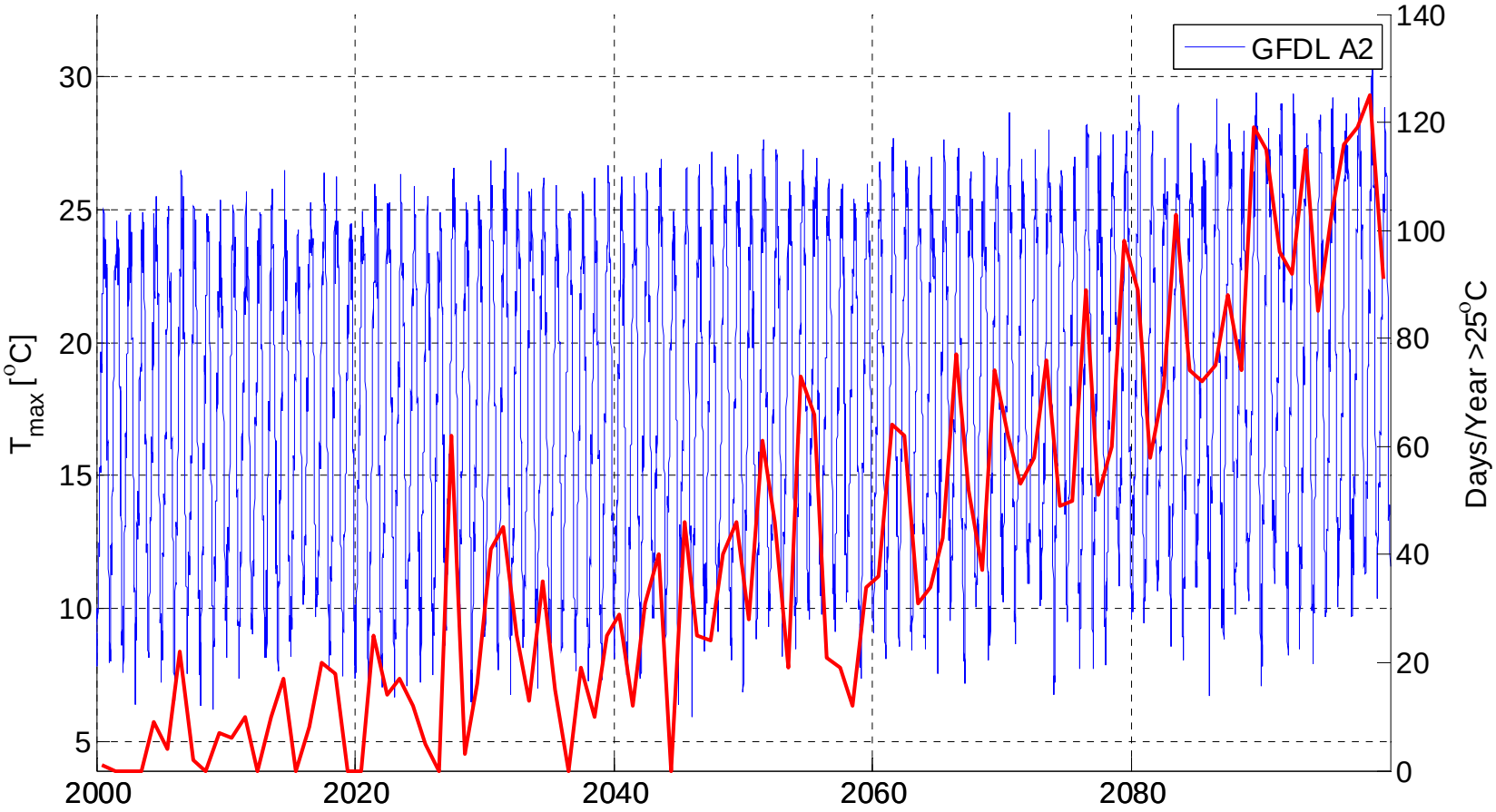
Water Temperature Projections @ Rio Vista



Ecological Implications @ Rio Vista

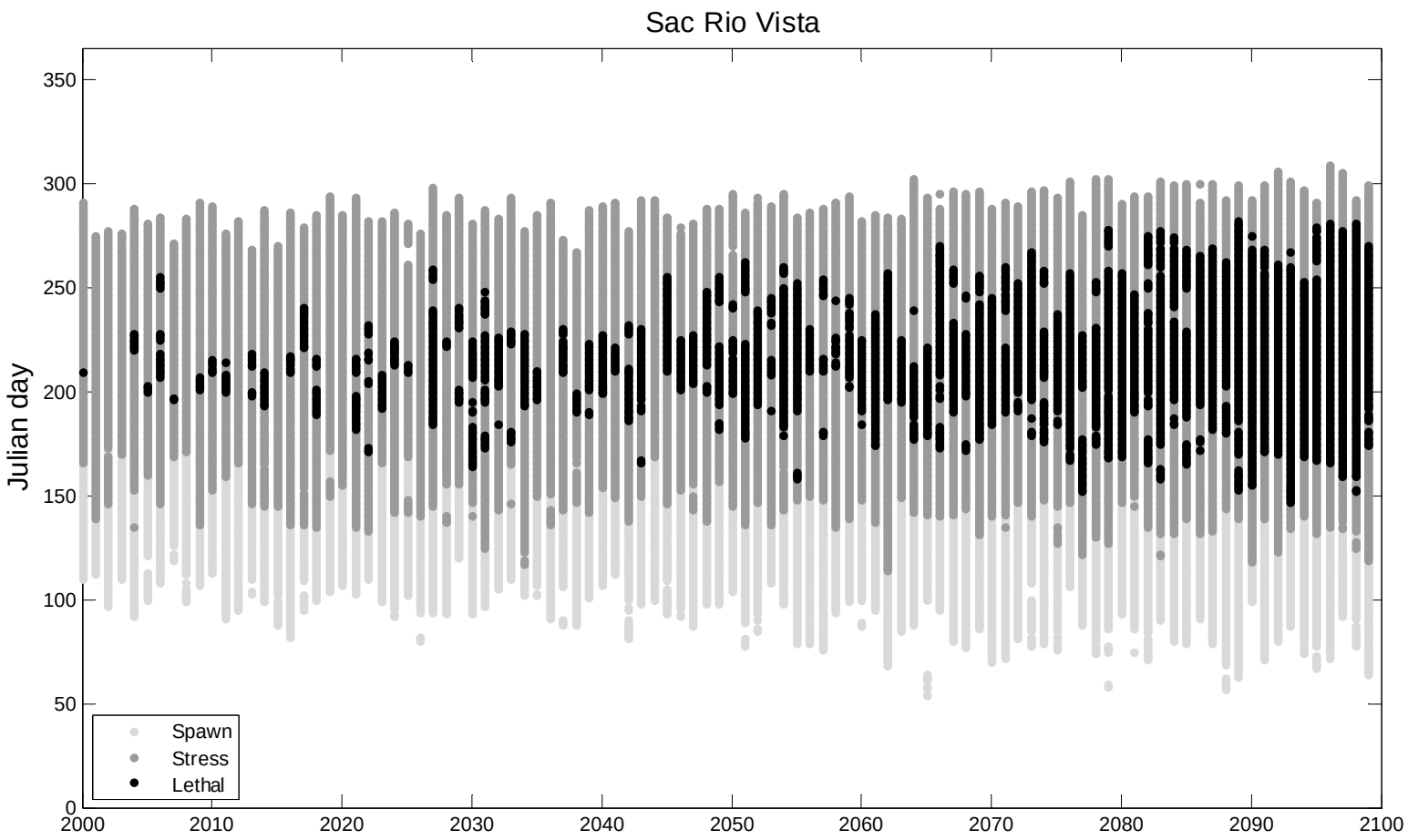


Ecological Implications

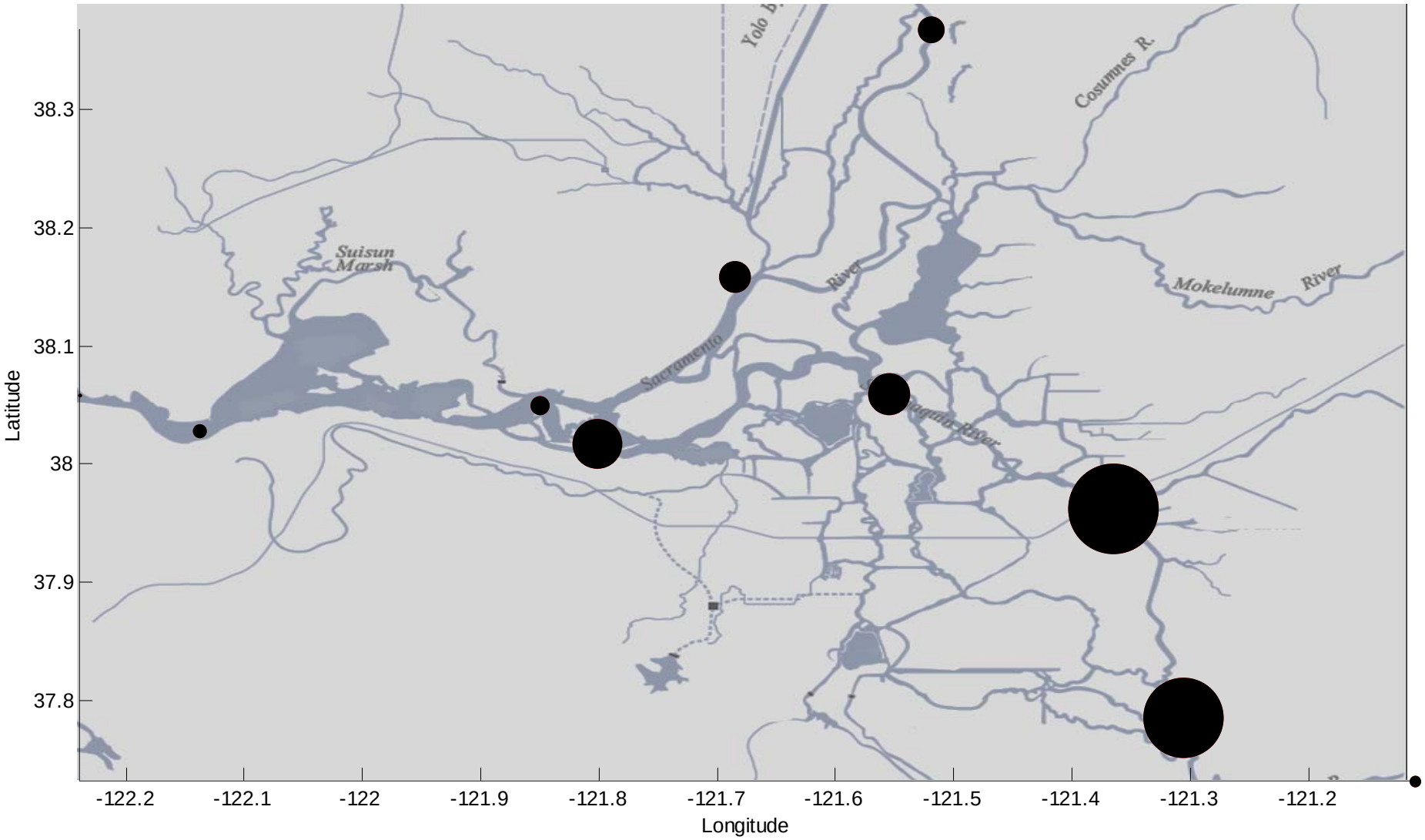


- Dramatic increase in the number of days exceeding 25^{0}C under this scenario at Rio Vista.

Ecological Implications

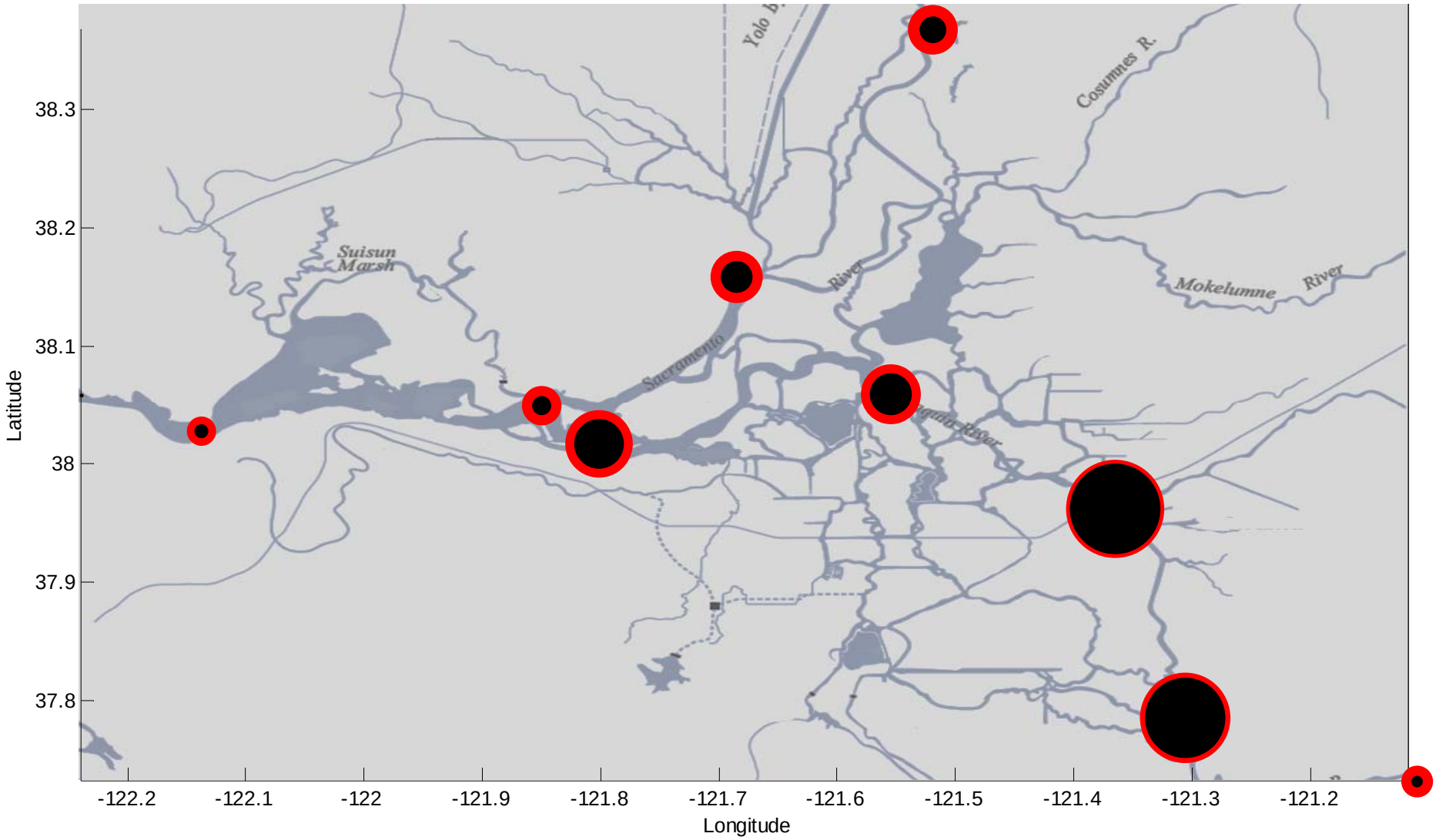


Projections (2010 - 2030)



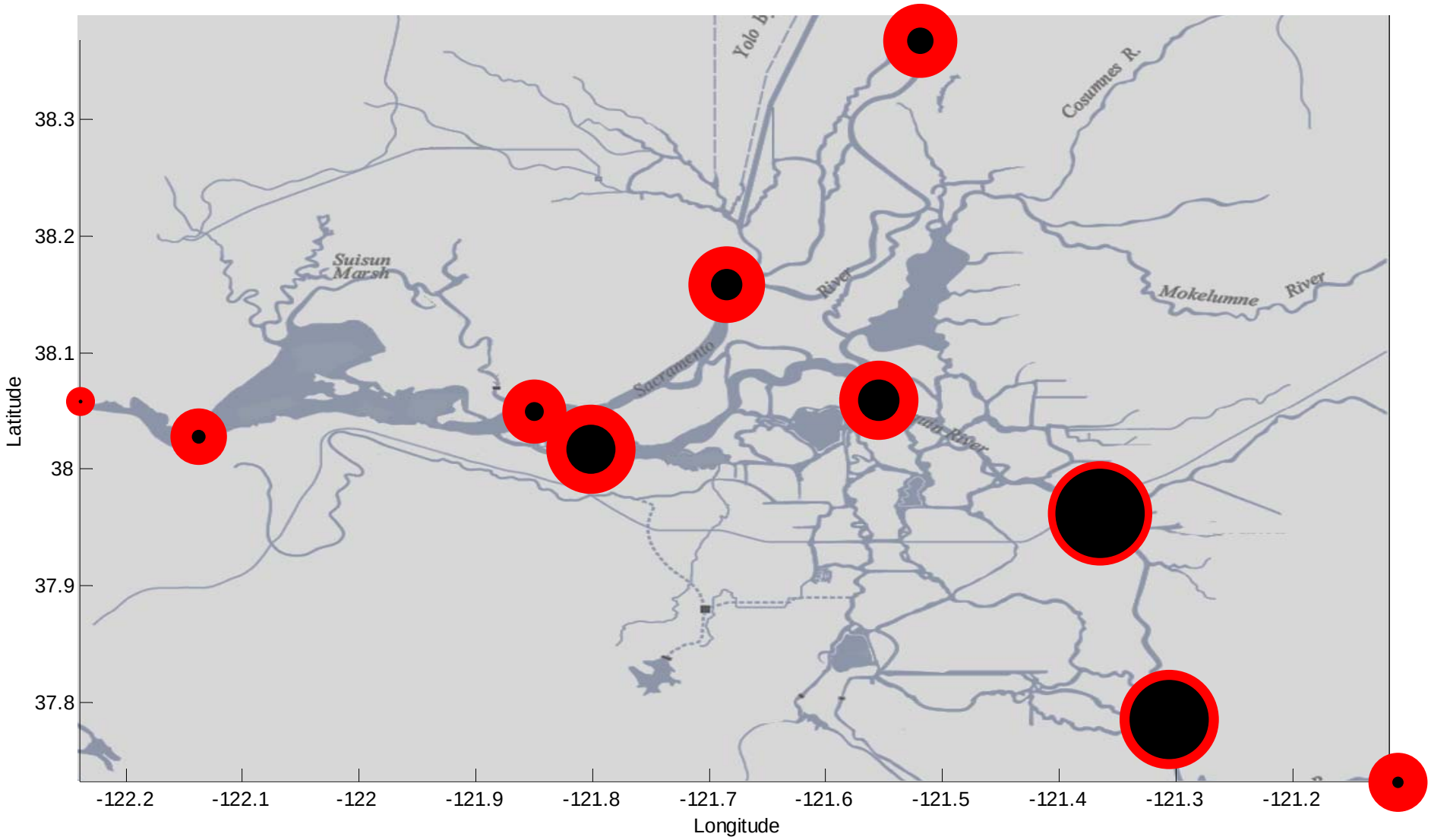
Dot size is proportional to the average number of days per year in exceedence of 25^{0}C at each location under GFDL A2 forcing.

Projections (2040 - 2060)



Dot size is proportional to the average number of days per year in exceedence of 25^{0}C at each location under GFDL A2 forcing.

Projections (2070 - 2090)



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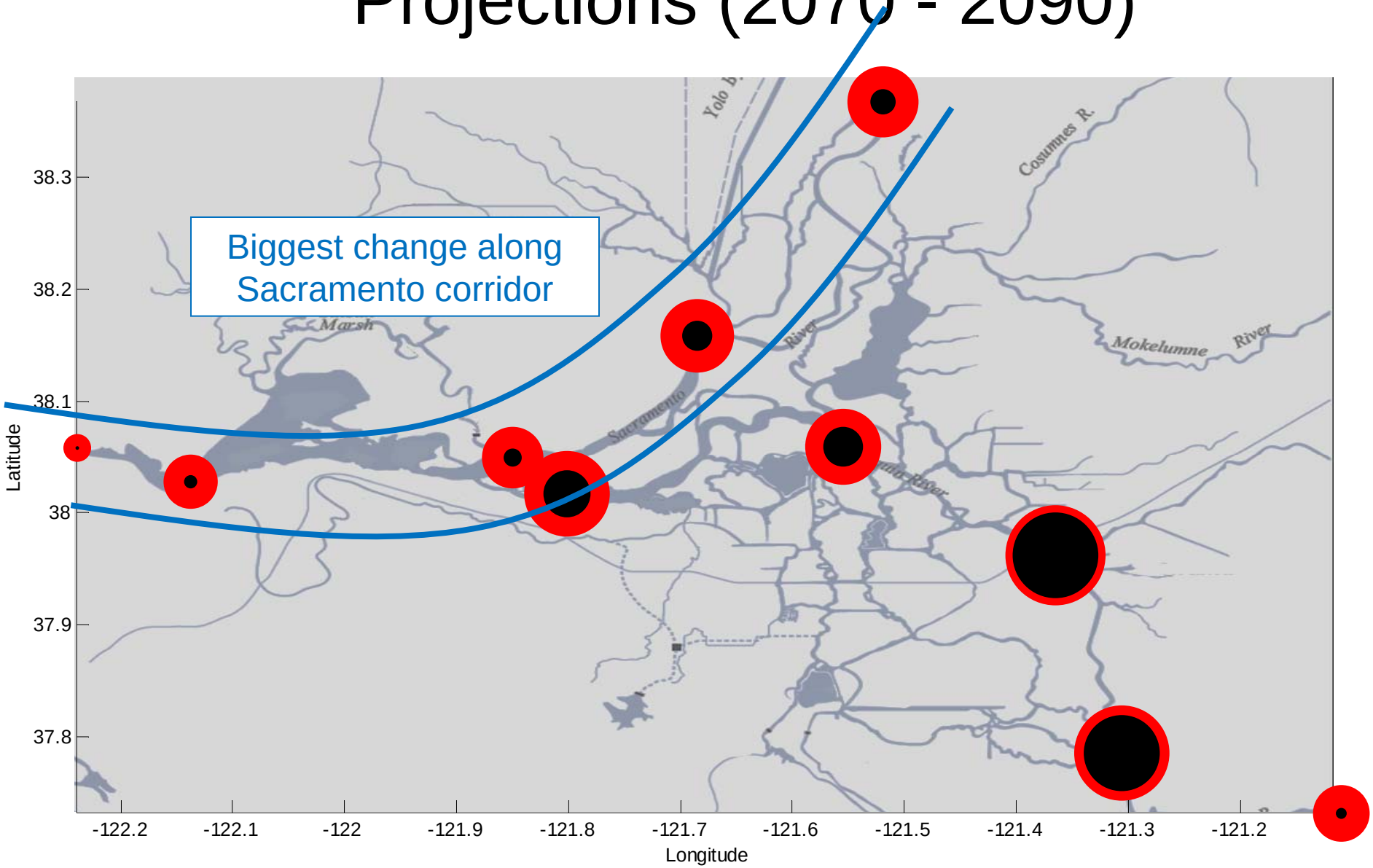
Projections (2070 - 2090)



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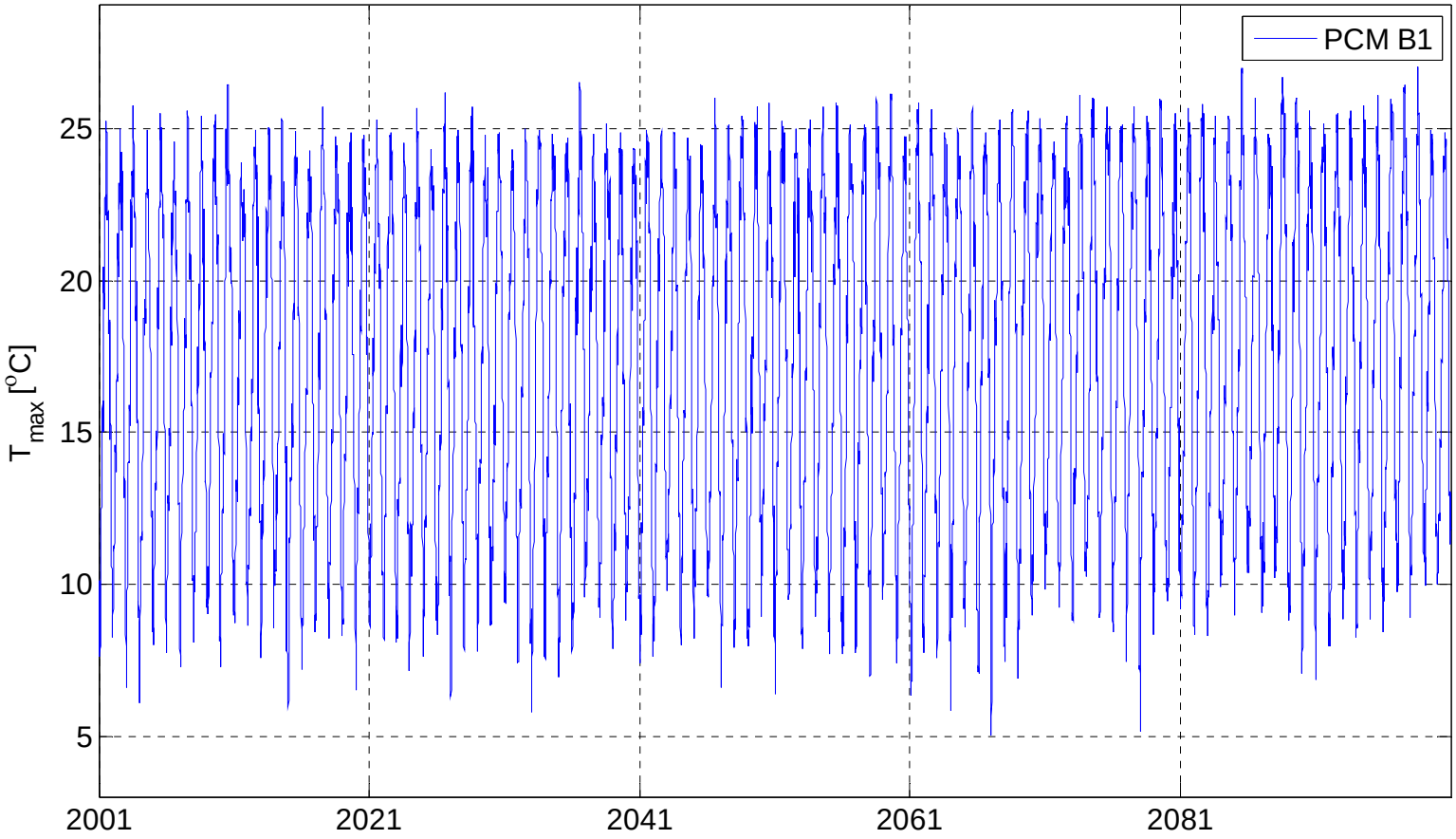
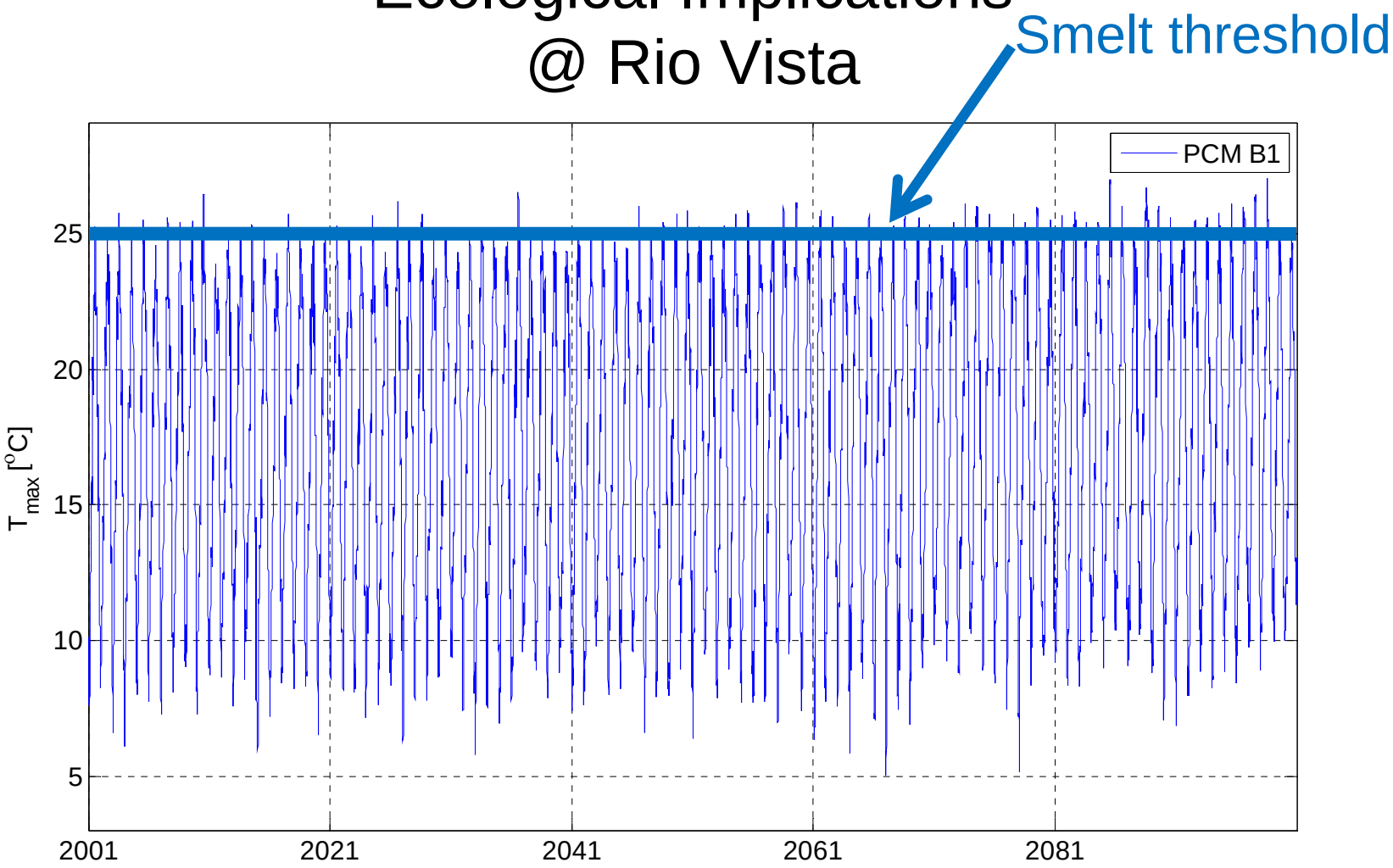
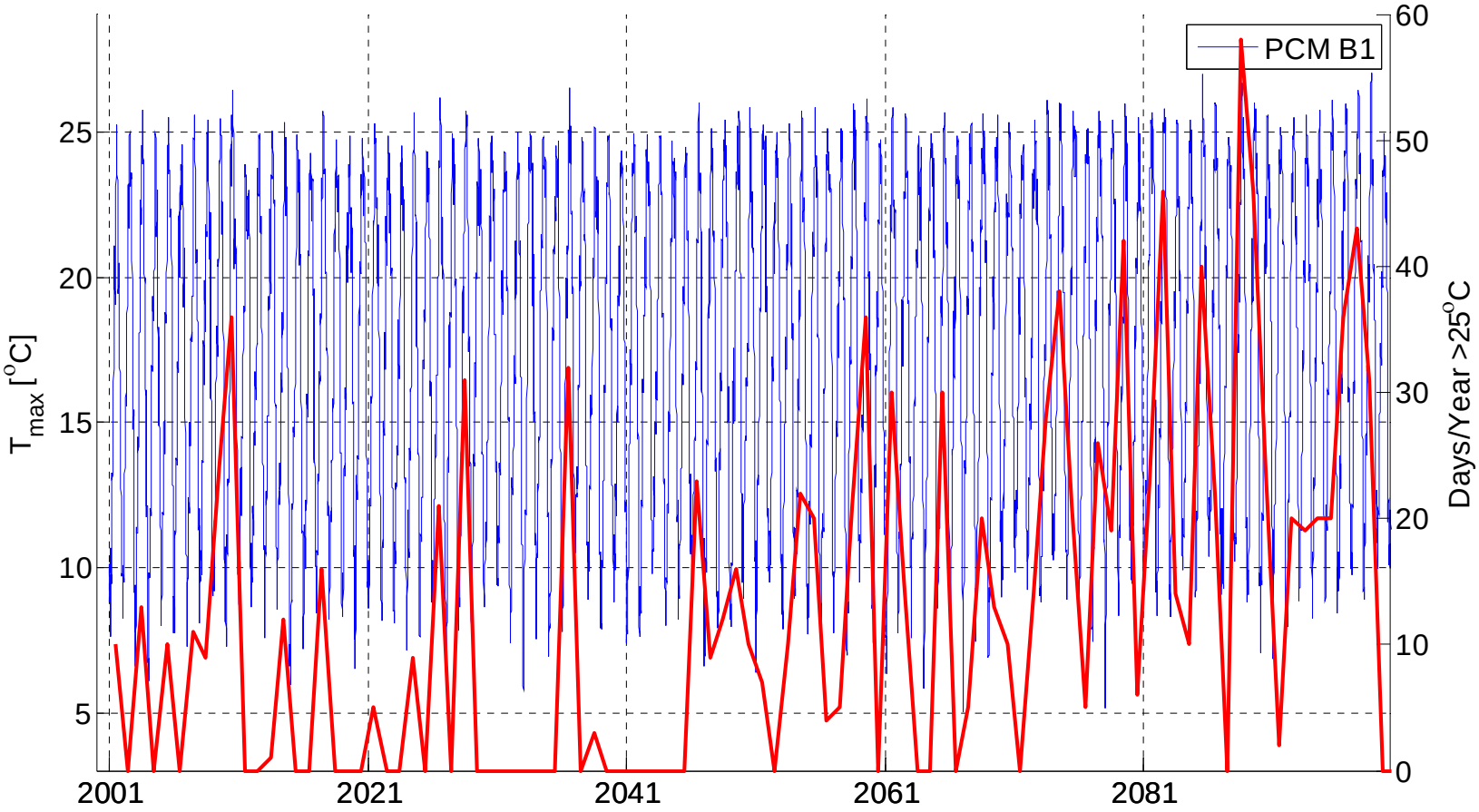
Water Temperature Projections @ Rio Vista



Ecological Implications @ Rio Vista

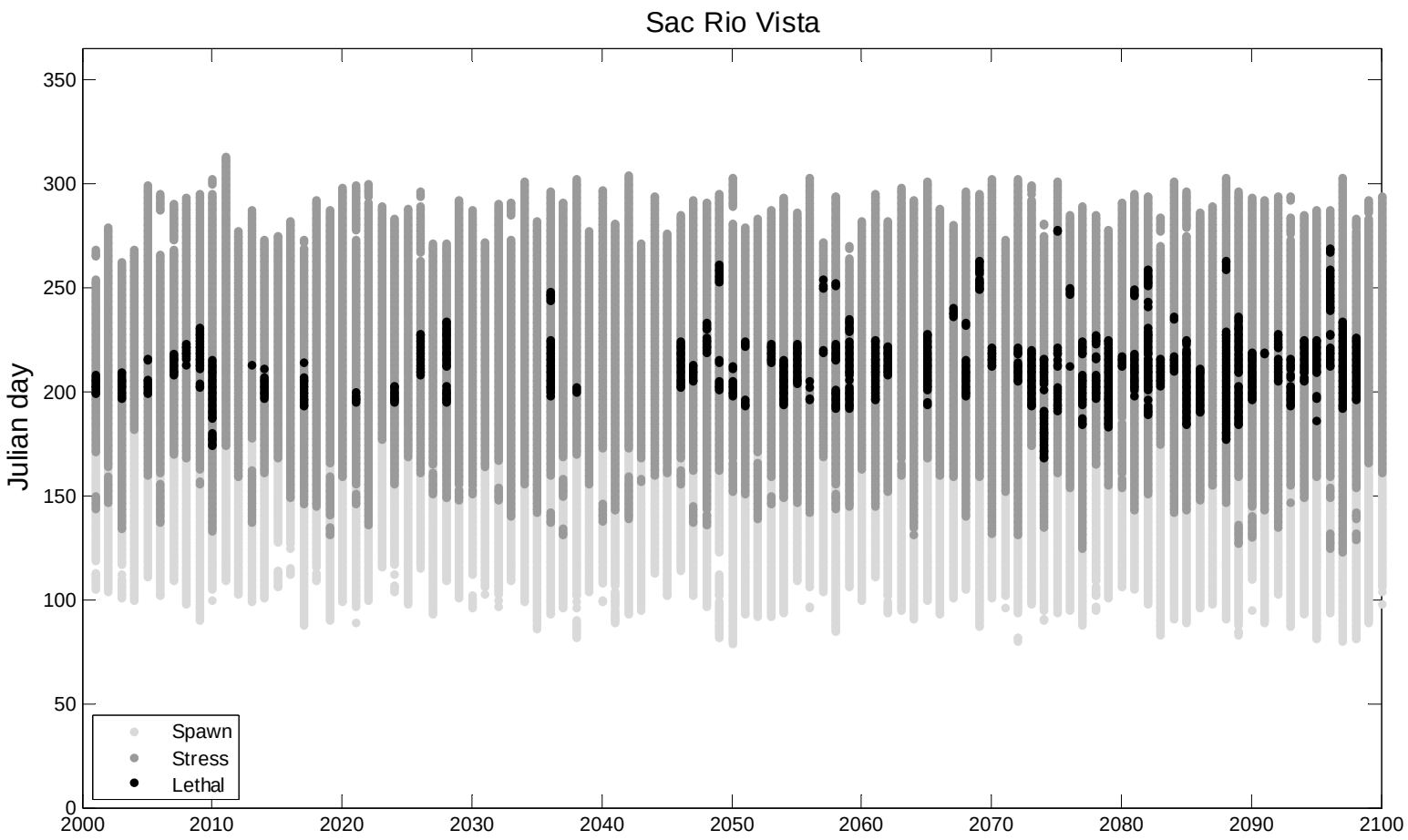


Ecological Implications

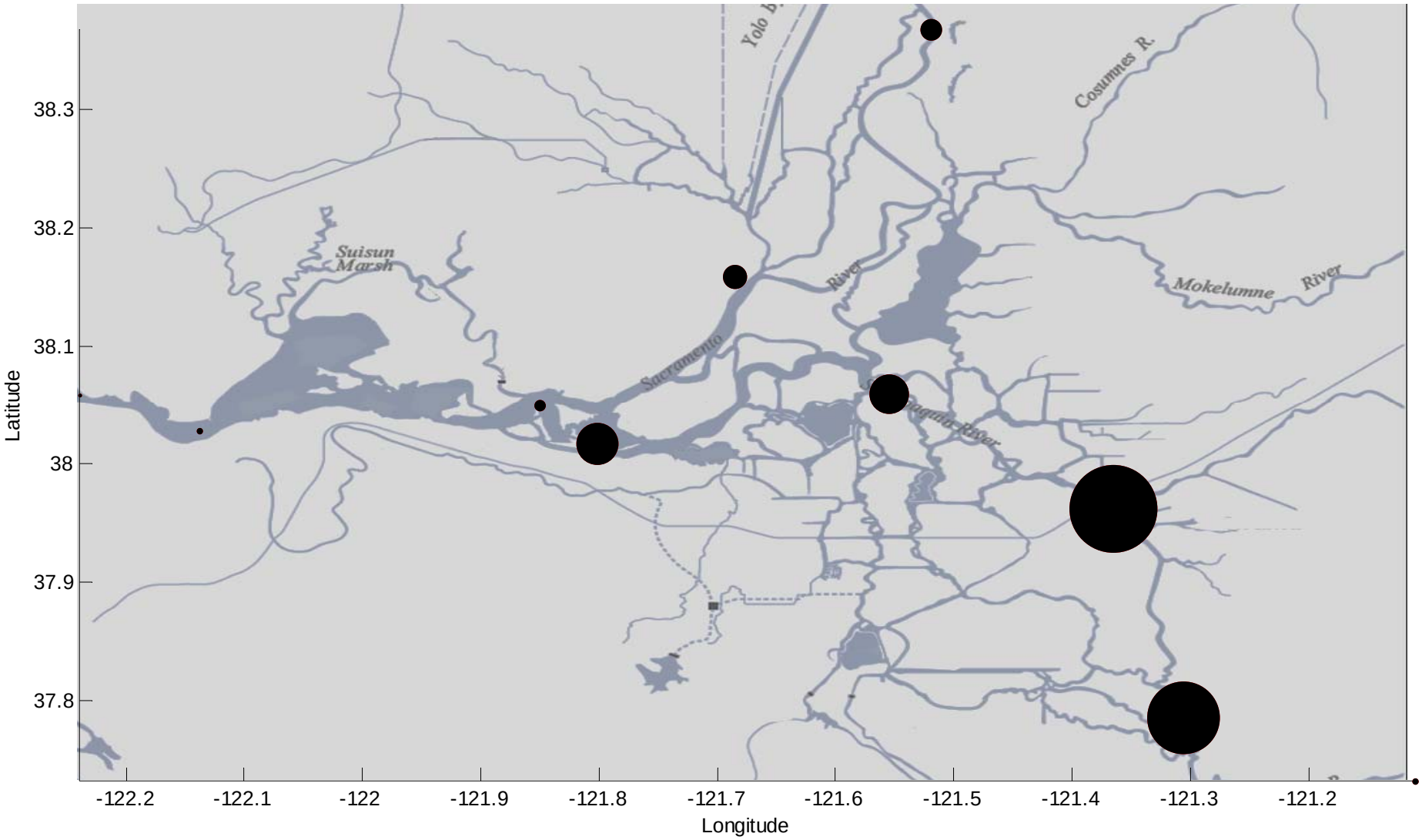


- Increase in the number of days exceeding 25^{0}C under this scenario at Rio Vista.

Ecological Implications

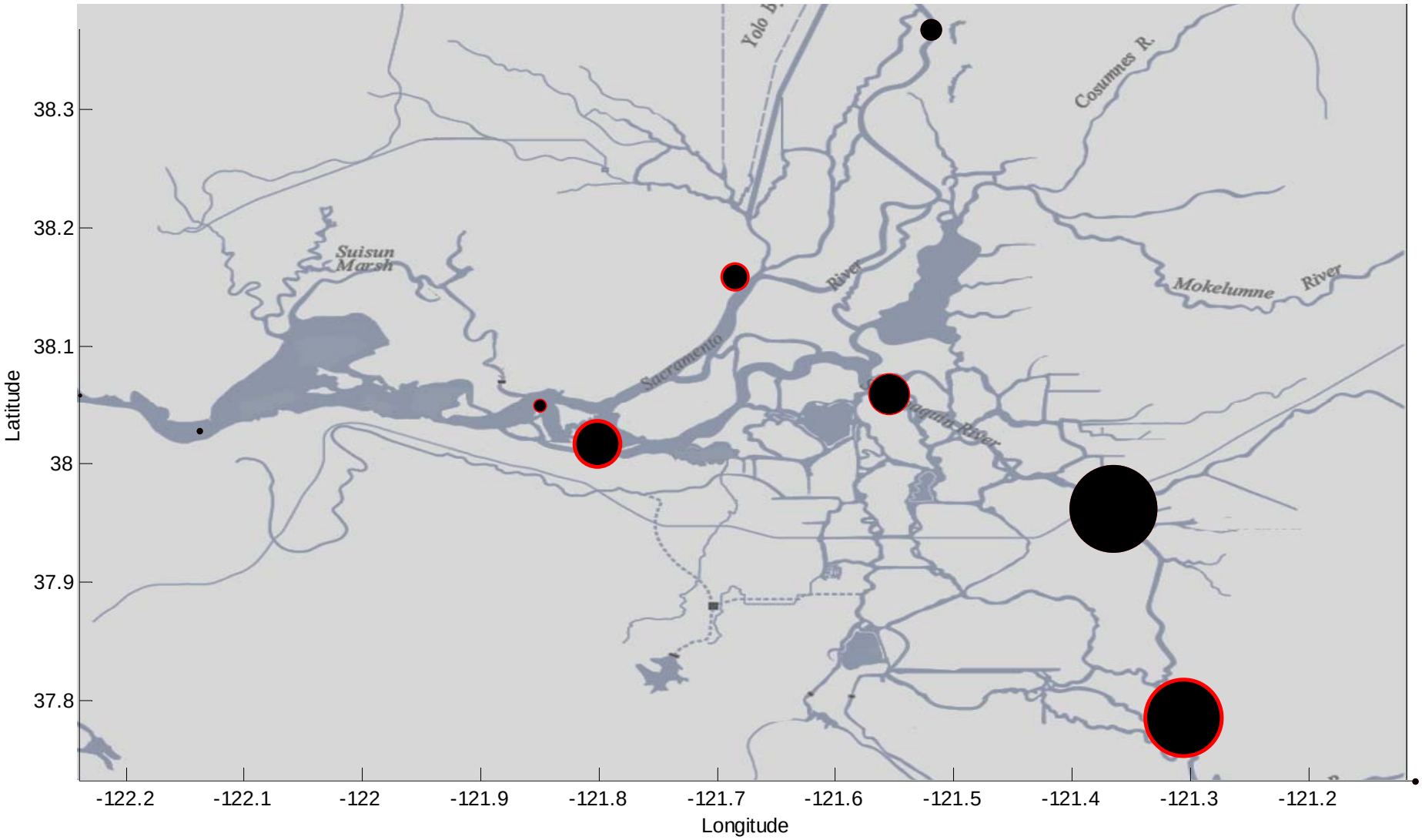


Projections (2010 - 2030)



Dot size is proportional to the average number of days per year in exceedence of 25^{0}C at each location under pcm b1 forcing.

Projections (2040 - 2060)



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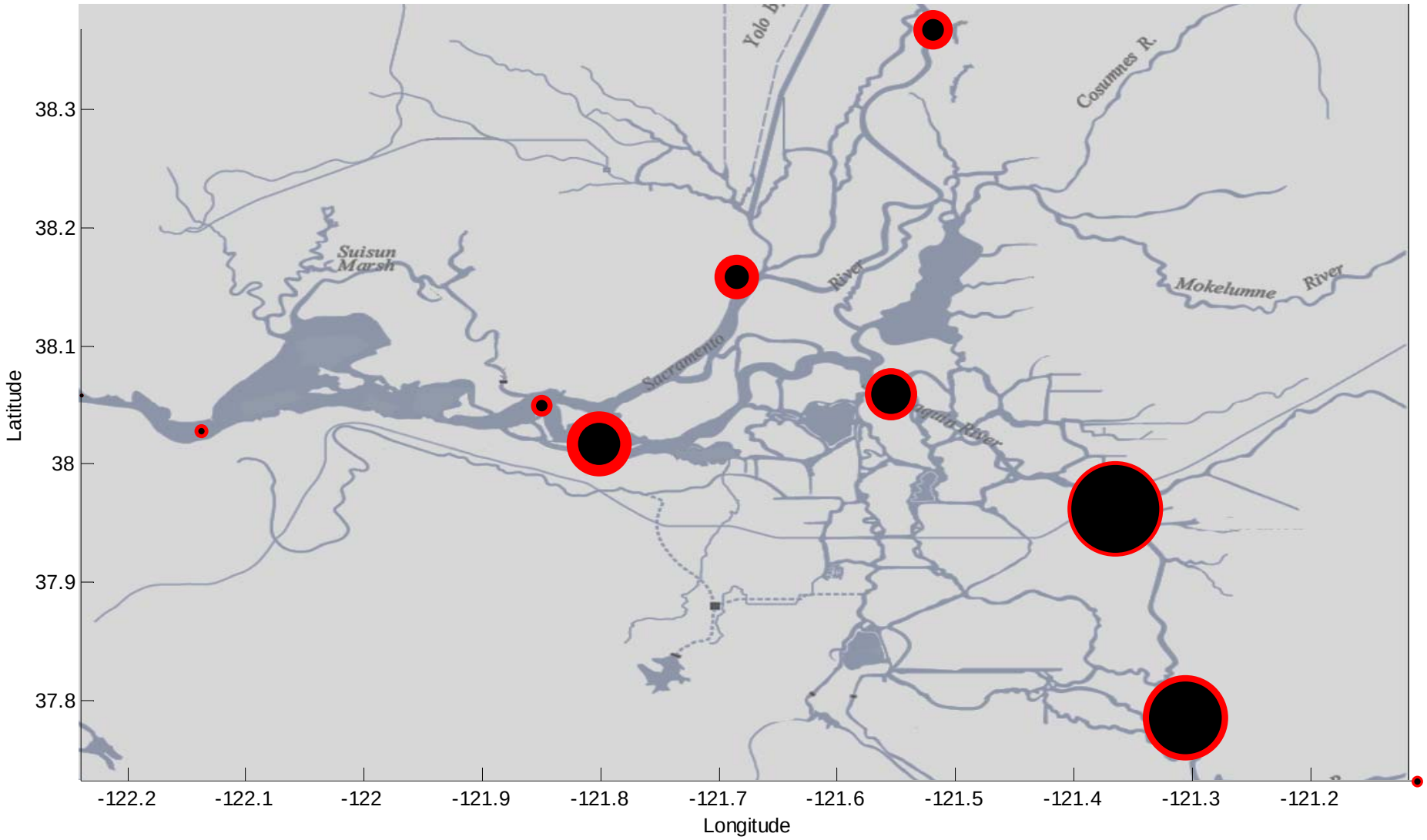

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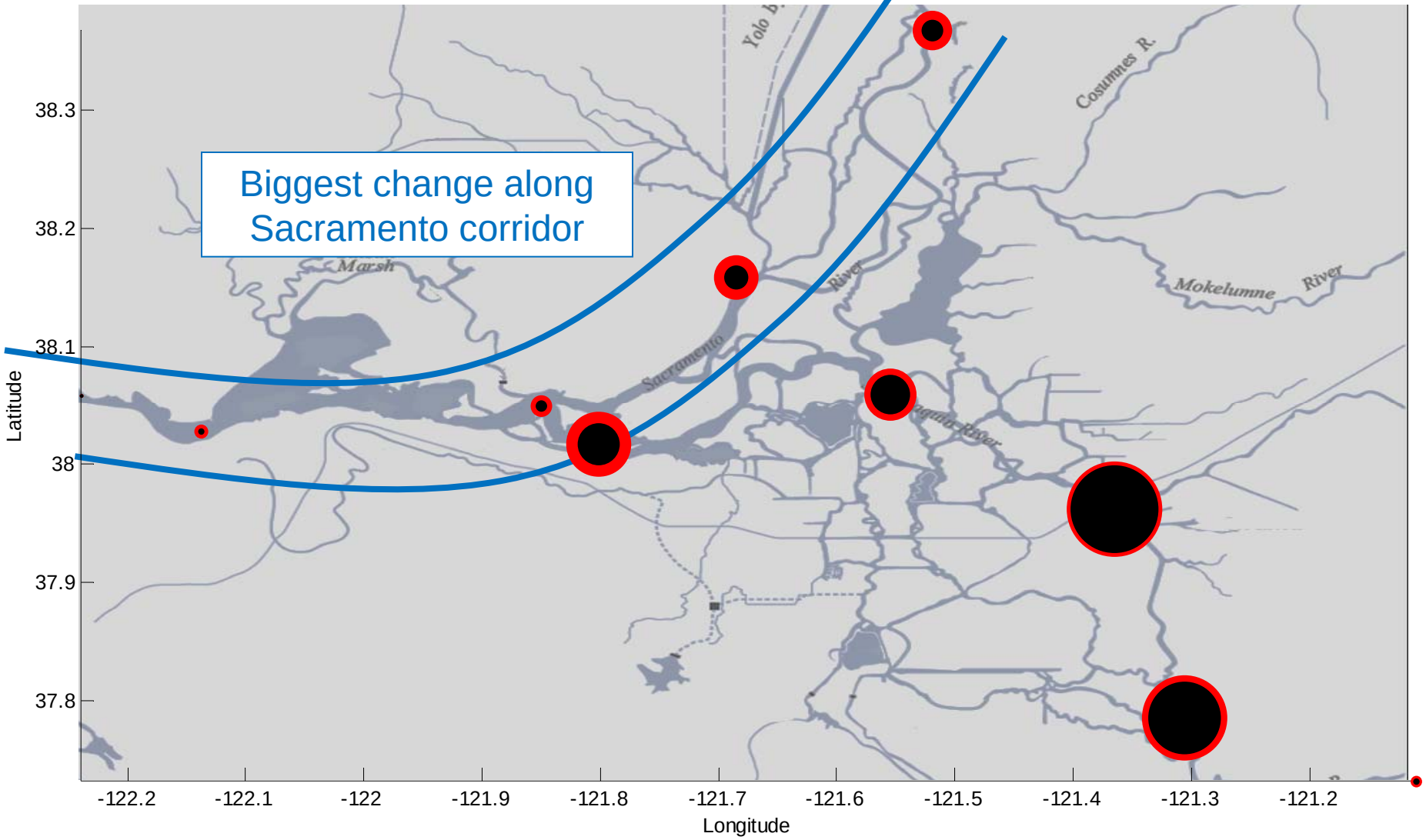

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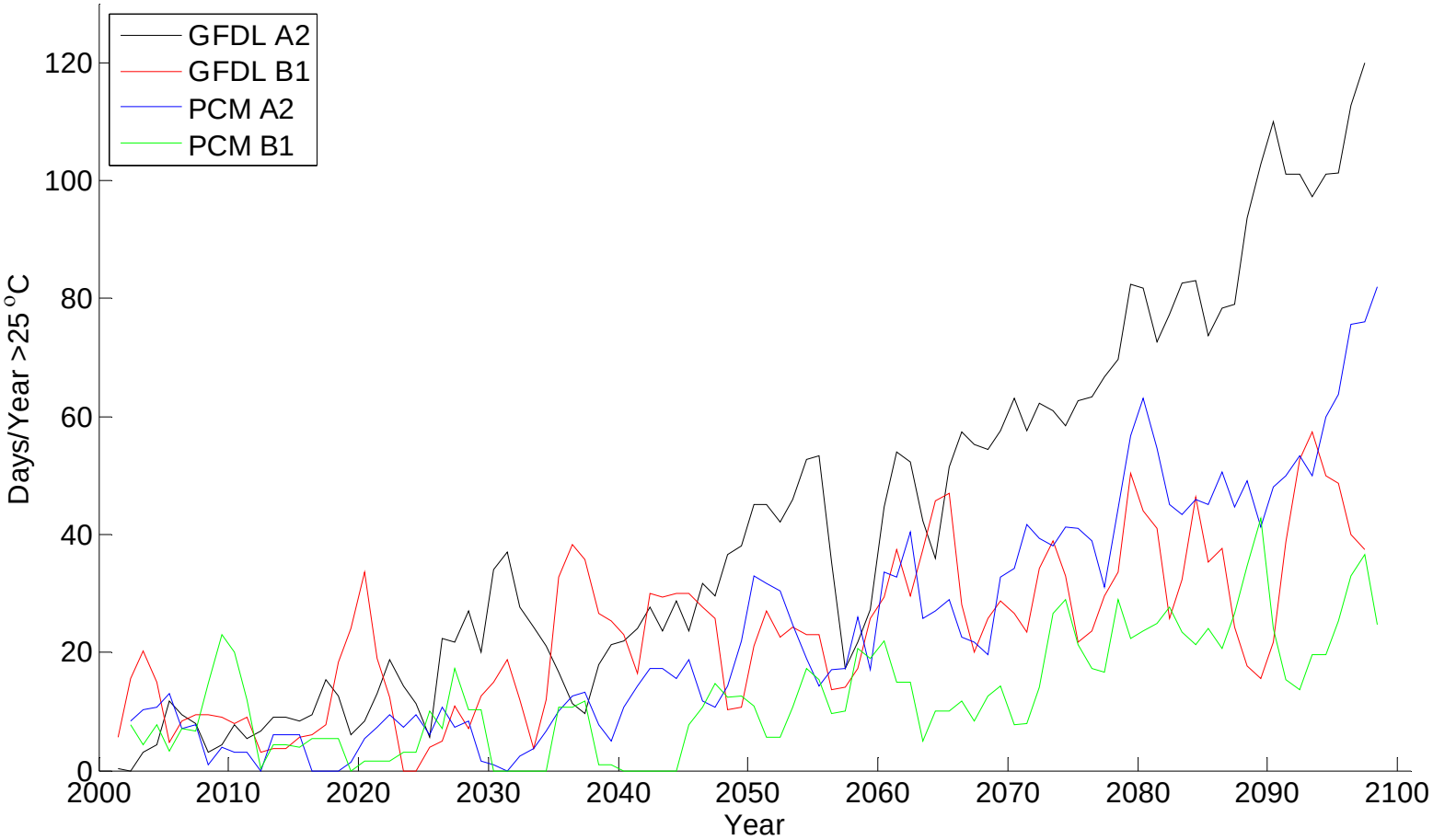
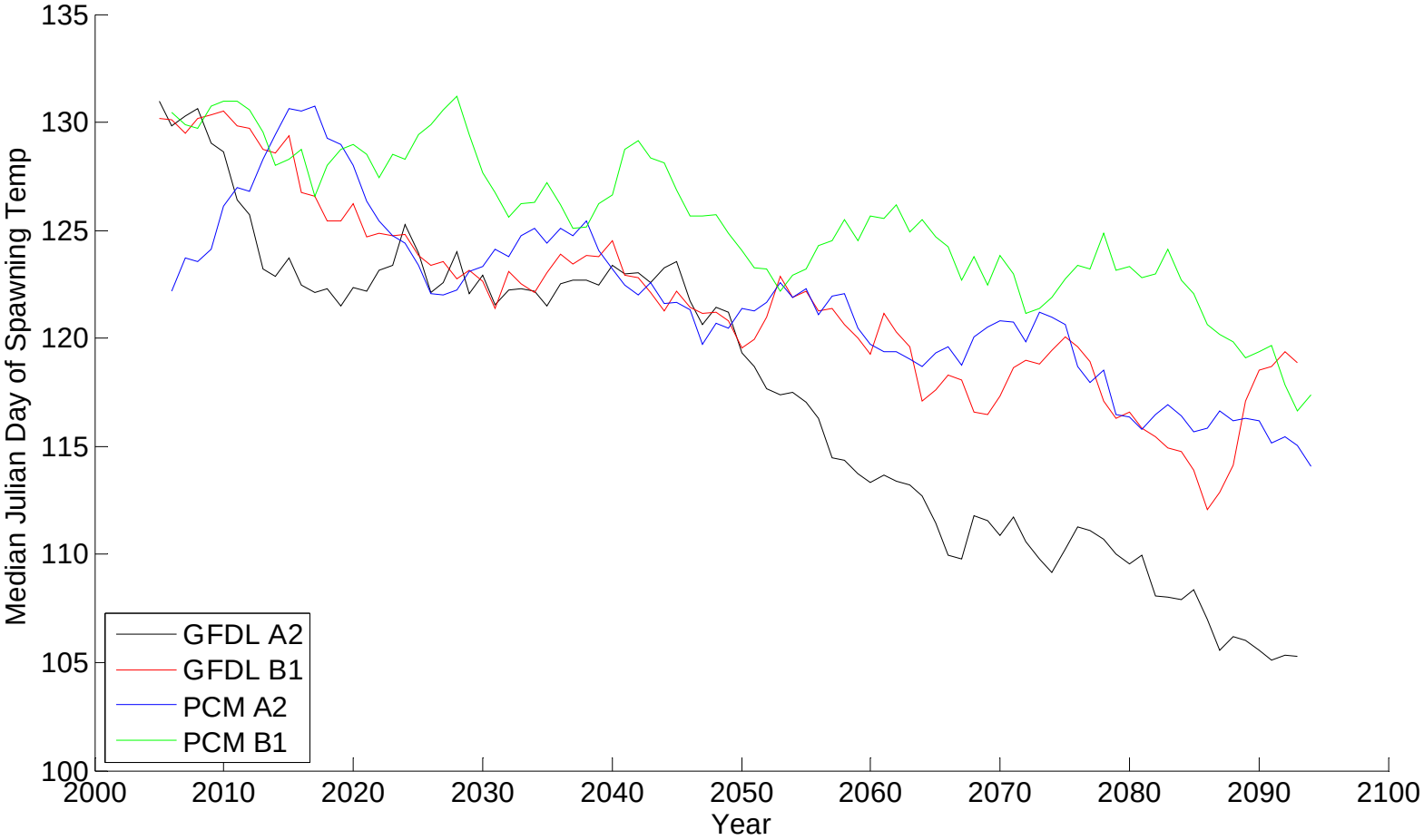
Ecological Implications



Ecological Implications

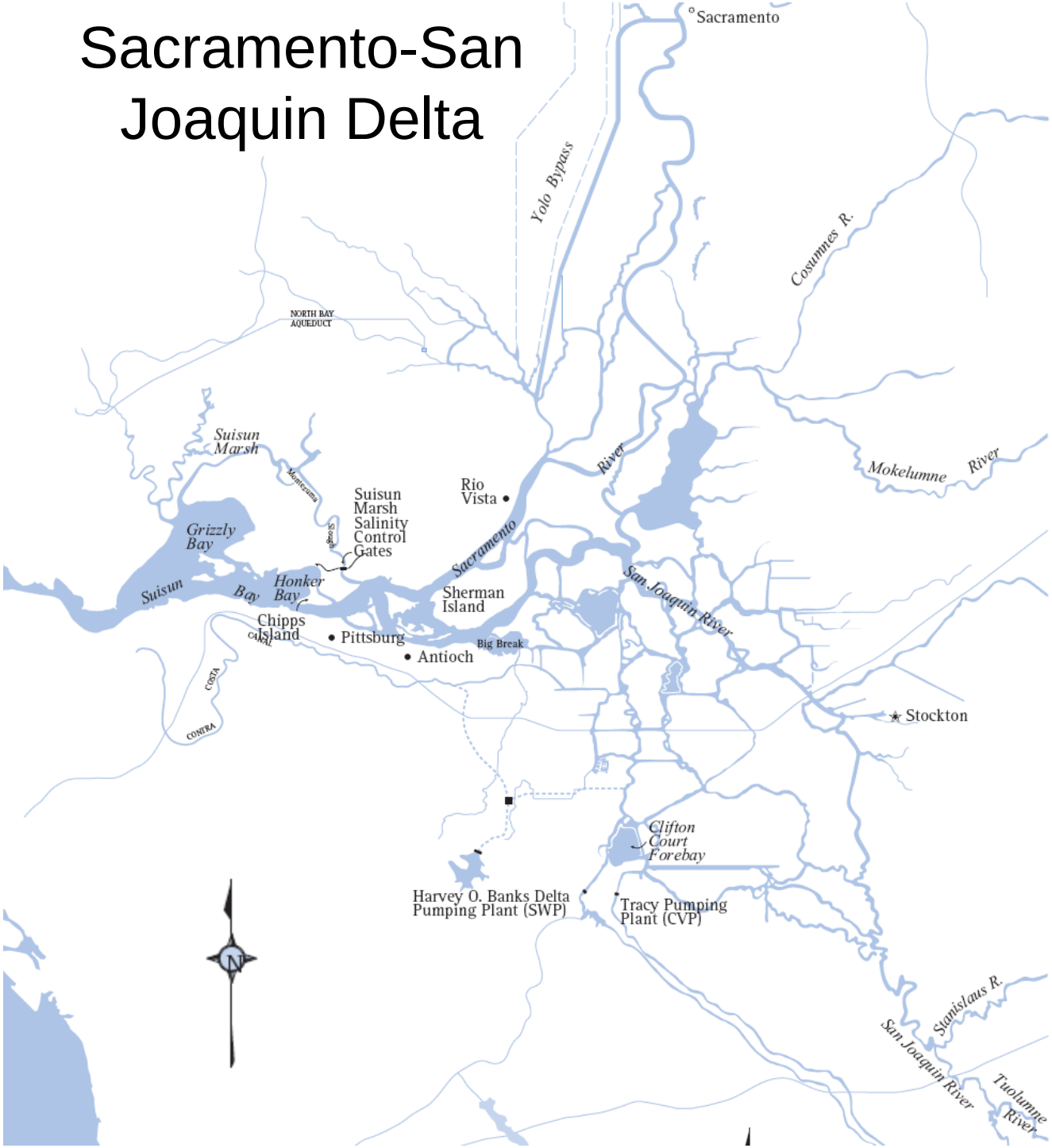


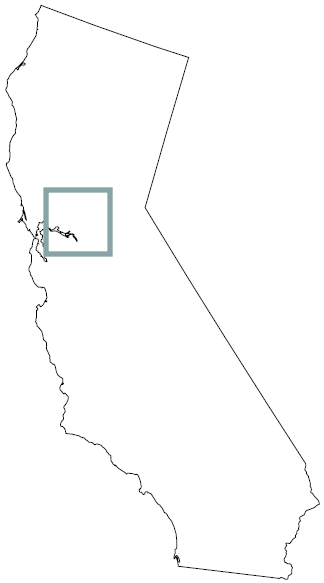
Present Work

- Despite warming trends, small scale dynamics may play a role in providing refugia for thermally sensitive species

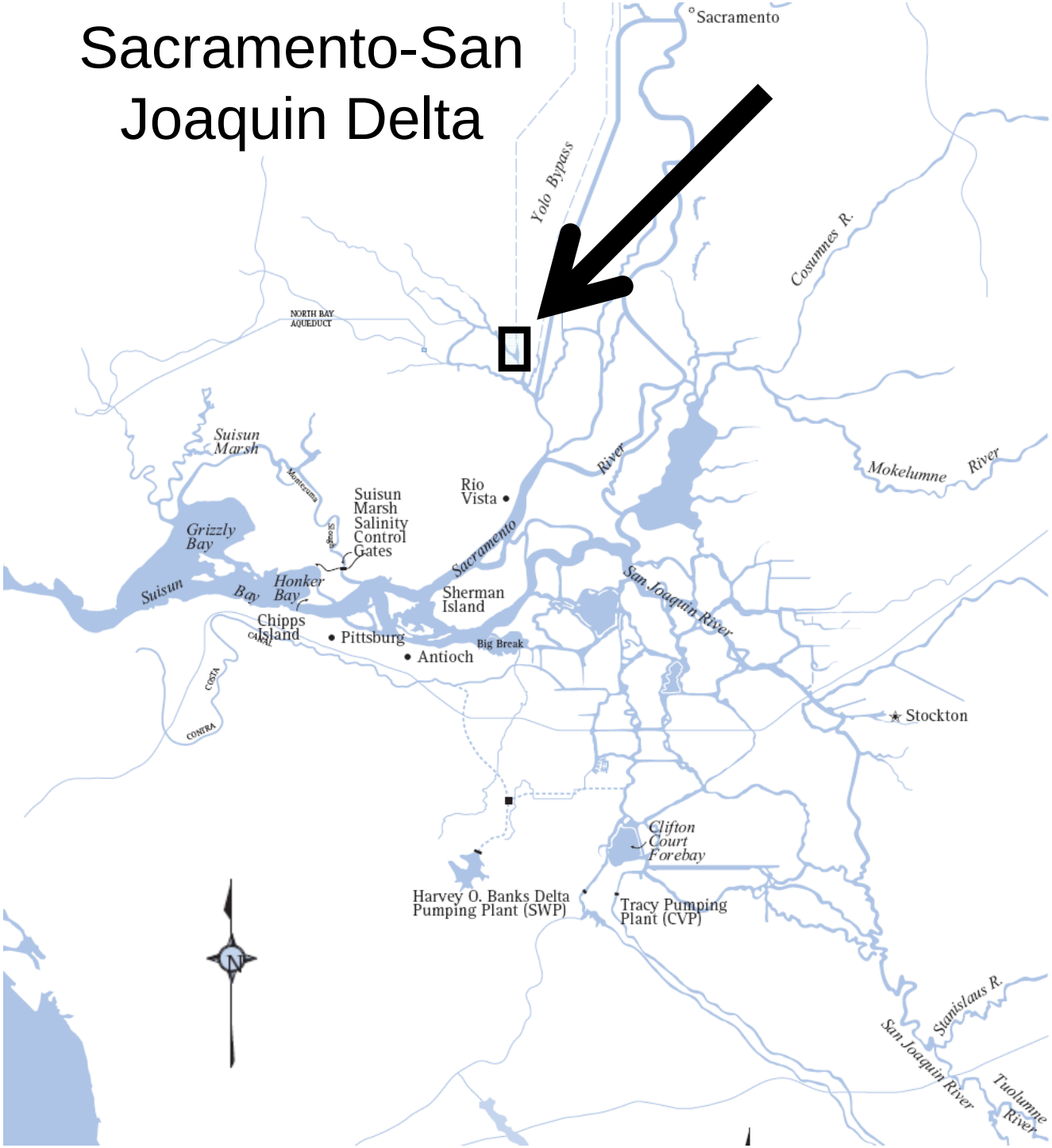
- Cache Slough

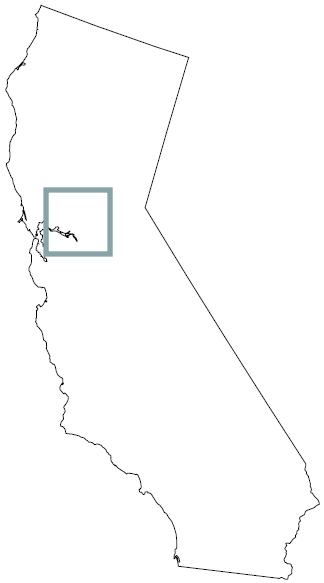
Sacramento-San Joaquin Delta





Sacramento-San Joaquin Delta





Liberty Island
French Island
Pro
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Pointer 10 S 613398.52 m E 4236818.16 m N elev 1 ft
Streaming 100%

Liberty Island
French Island
Pro
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©2007
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Pointer 10 S 613398.42 m E 4236818.61 m N elev 0 ft
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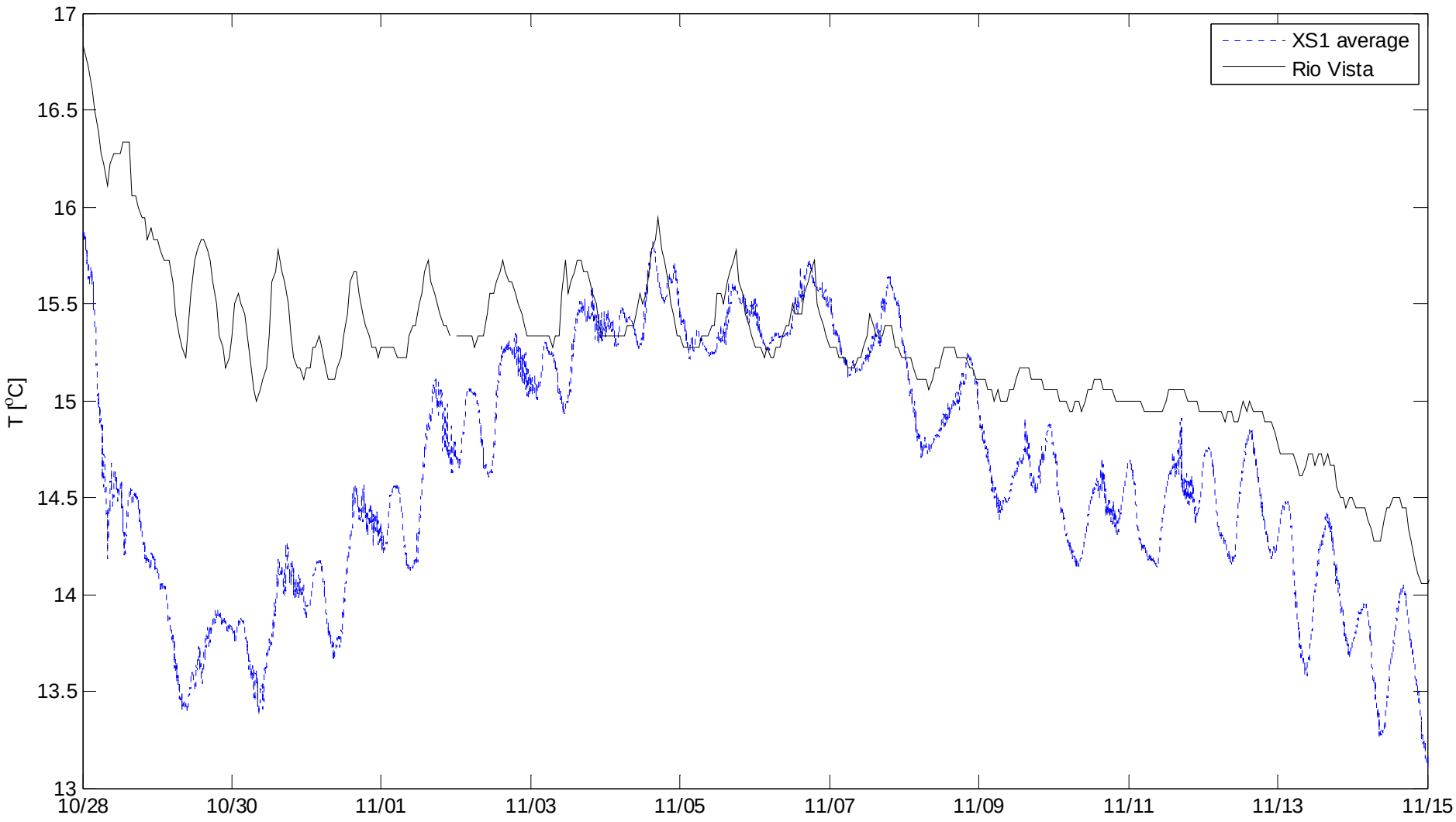
XS1 average
Rio Vista
T [°C]
17
16.5
16
15.5
15
14.5
14
13.5
13
10/28
10/30
11/01
11/03
11/05
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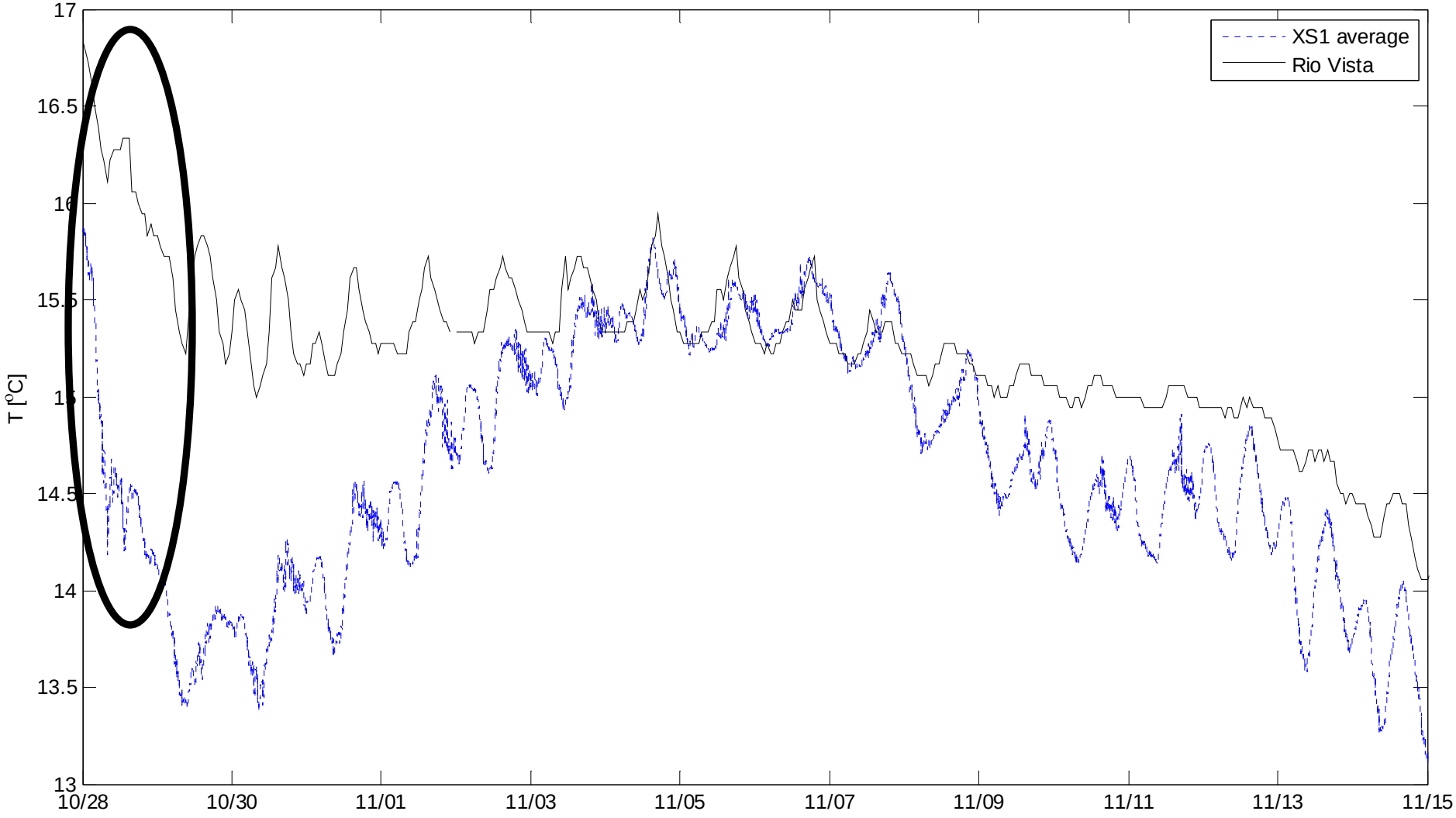
11/13
11/15


XS1 average
Rio Vista
T [°C]
17
16.5
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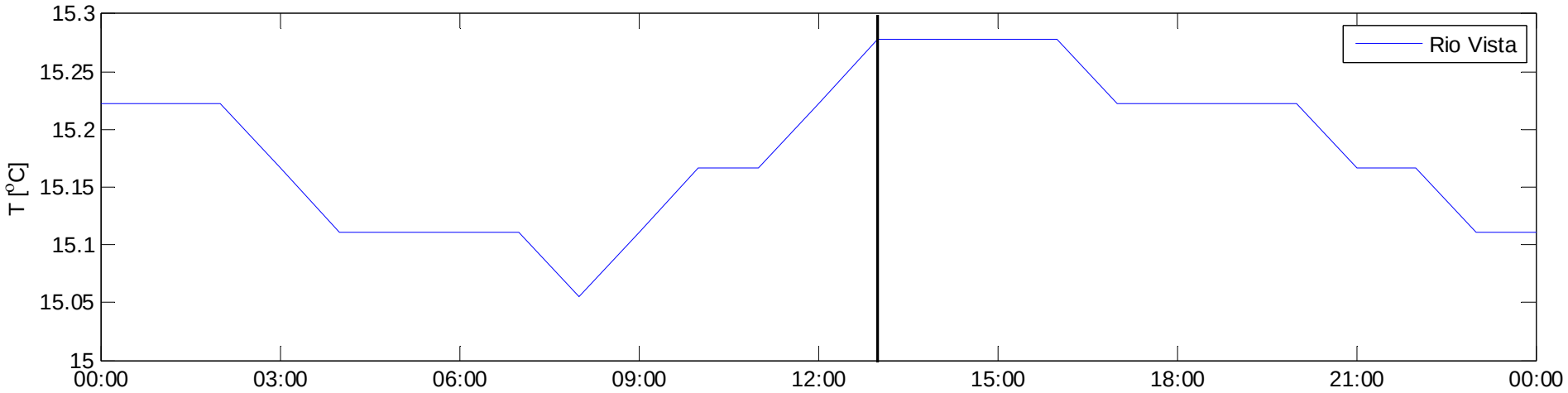
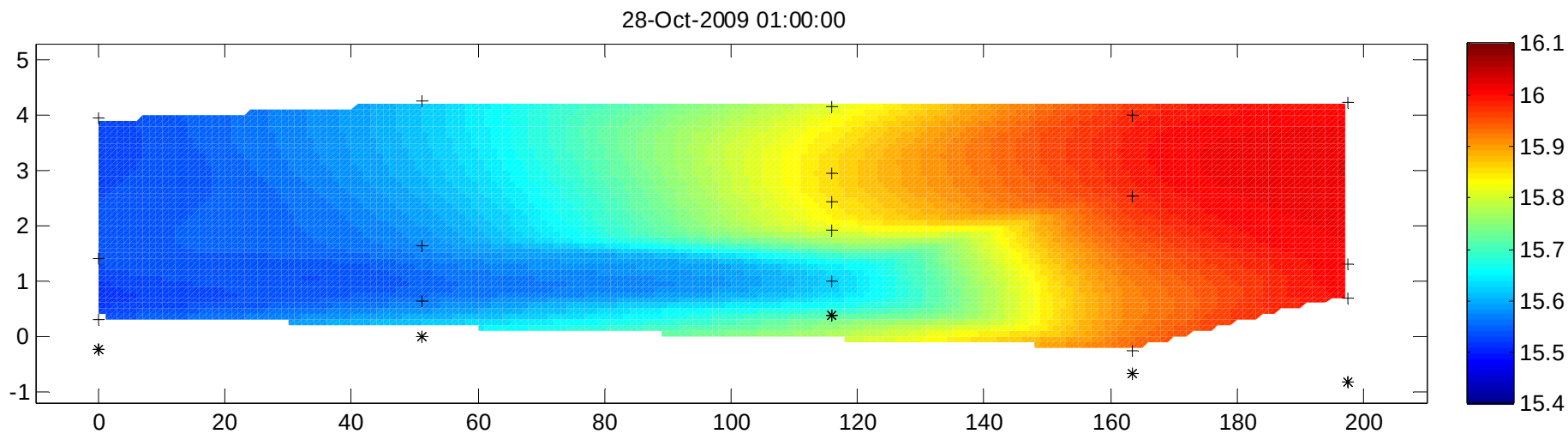
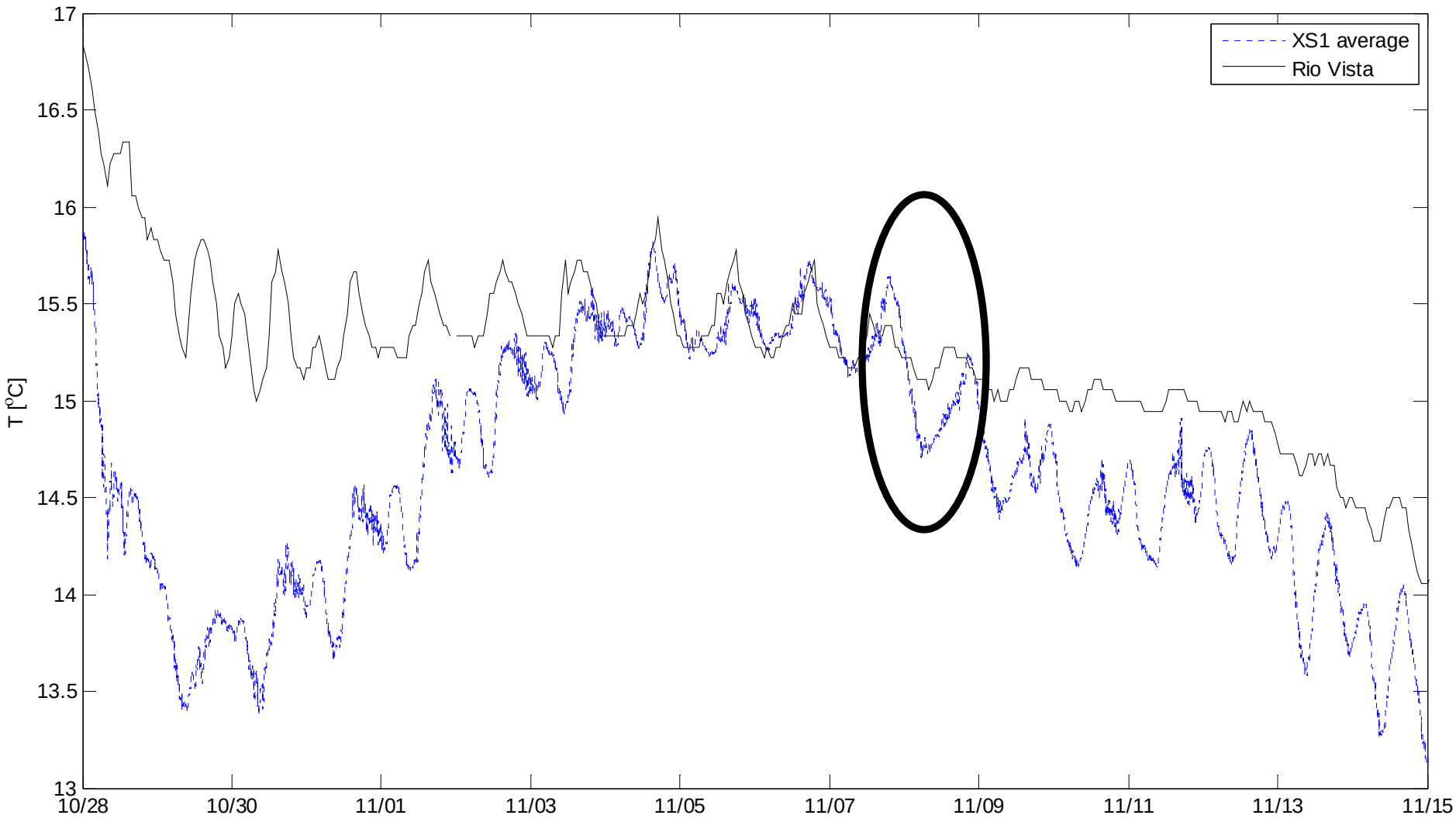

15.3
15.25
15.2
15.15
15.1
15.05
15
T [ºC]
00:00
03:00
06:00
09:00
12:00
15:00
18:00
21:00
00:00
Rio Vista


28-Oct-2009 01:00:00
5
4
3
2
1
0
-1
0
20
40
60
80
100
120
140
160
180
200
16.1
16
15.9
15.8
15.7
15.6
15.5
15.4


XS1 average
Rio Vista
T [°C]
17
16.5
16
15.5
15
14.5
14
13.5
13
10/28
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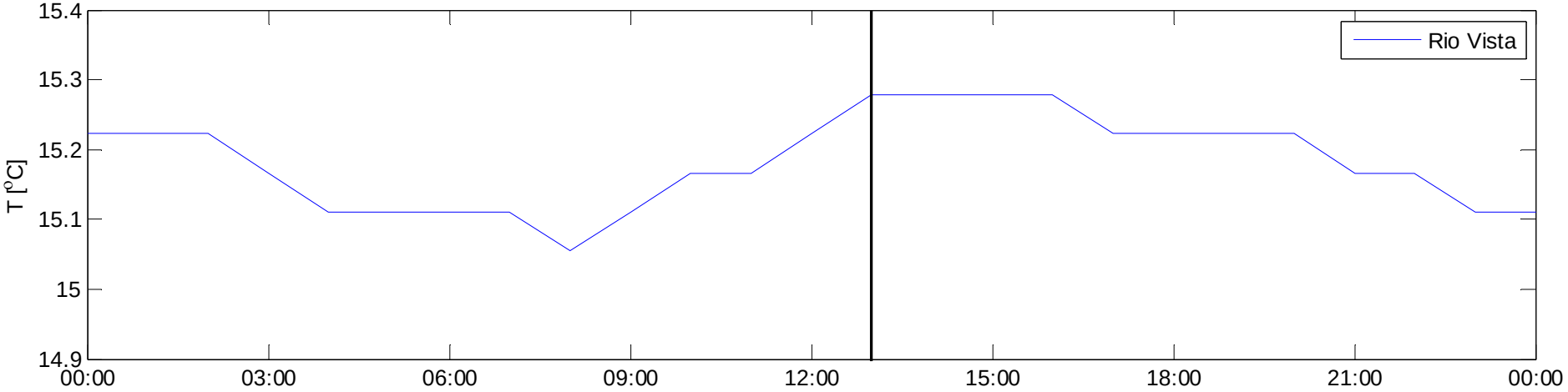
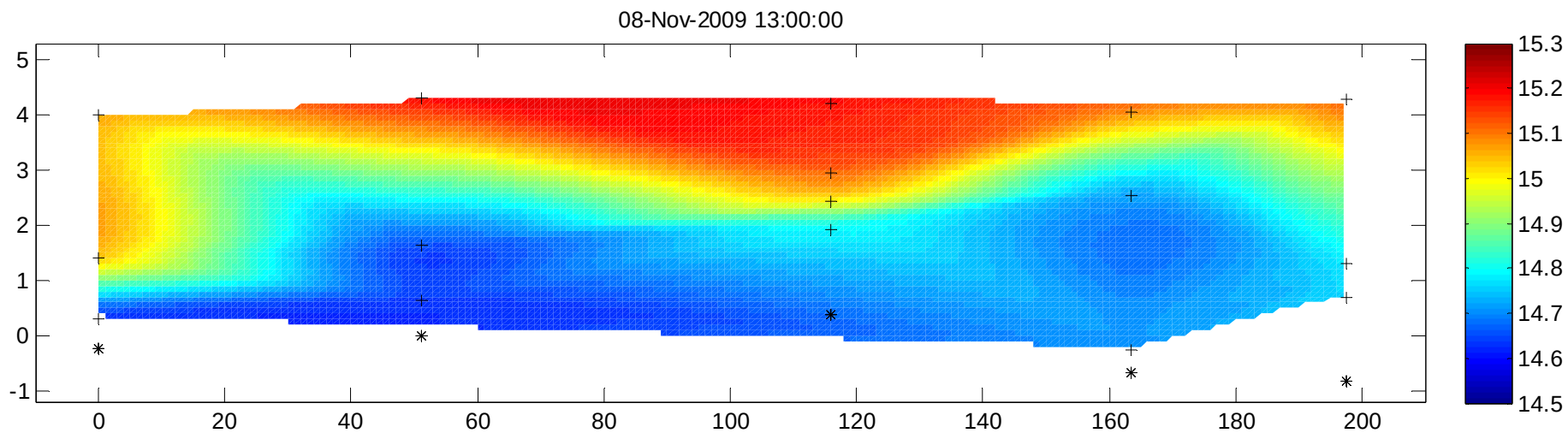
11/07
11/09
11/11
11/13
11/15

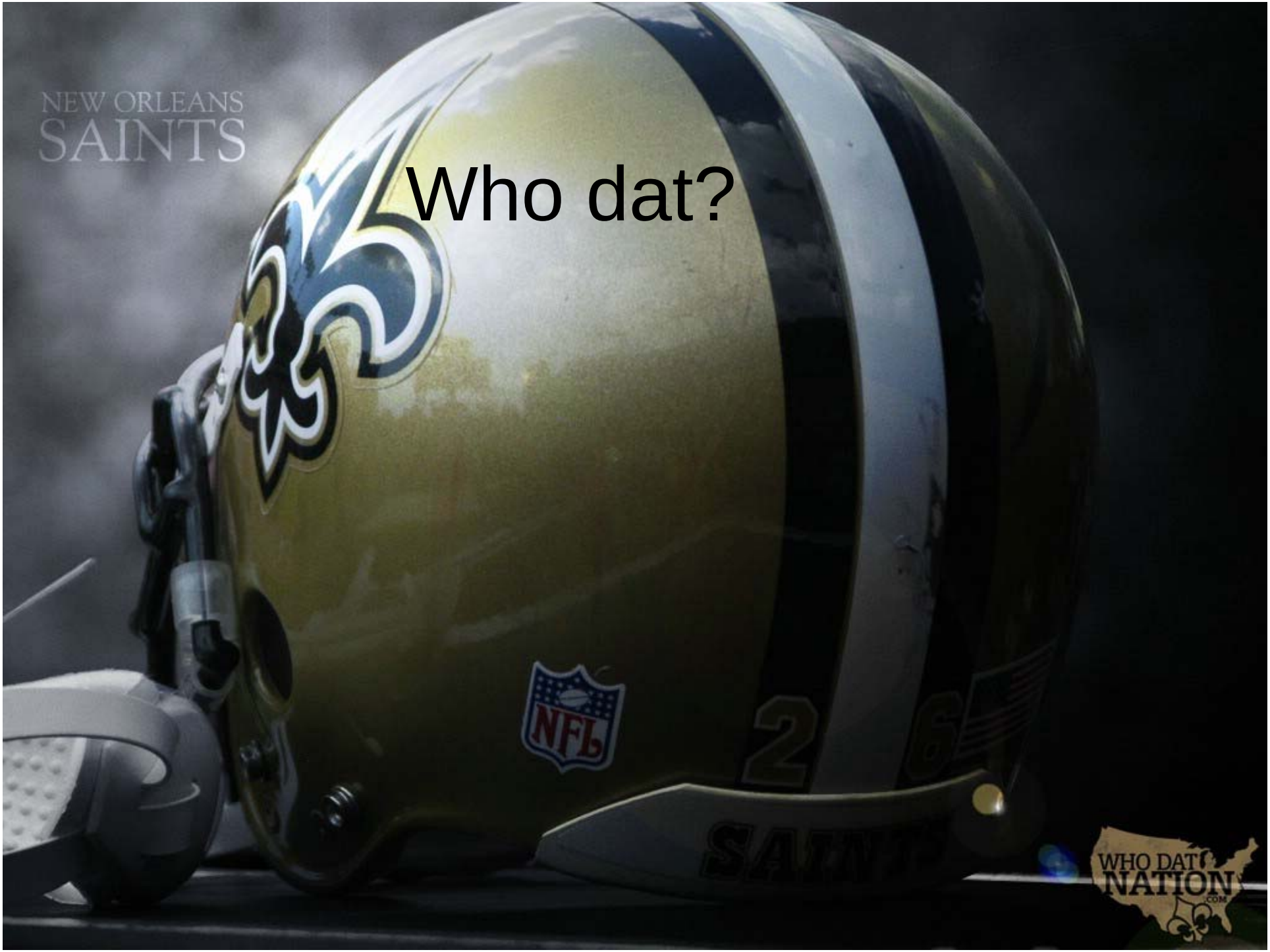

15.4
15.3
15.2
15.1
15
14.9
T [°C]
00:00
03:00
06:00
09:00
12:00
15:00
18:00
21:00
00:00
Rio Vista


08-Nov-2009 13:00:00
5
4
3
2
1
0
-1
0
20
40
60
80
100
120
140
160
180
200
15.3
15.2
15.1
15
14.9
14.8
14.7
14.6
14.5

Conclusions

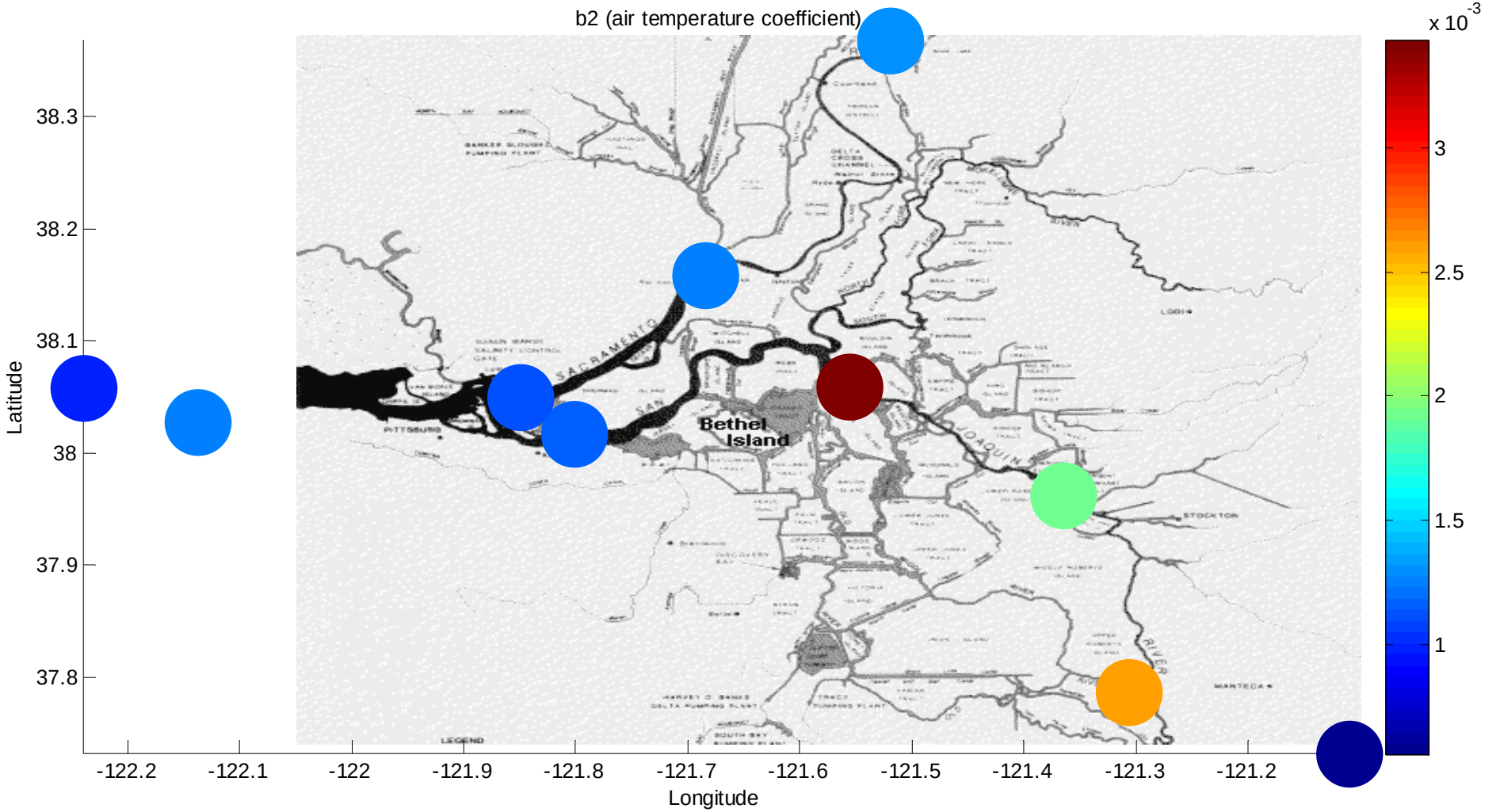
- Simple statistical model shows high predictive skill of water temperatures at locations throughout the Delta
- When forced by downscaled climate data:
  - The model predicts much higher frequency of exceedence of 25^0C along Sacramento corridor.
  - Spawning temperatures for smelt move earlier in the year
- Smaller scale temperature dynamics may be important for fish survival

Questions?

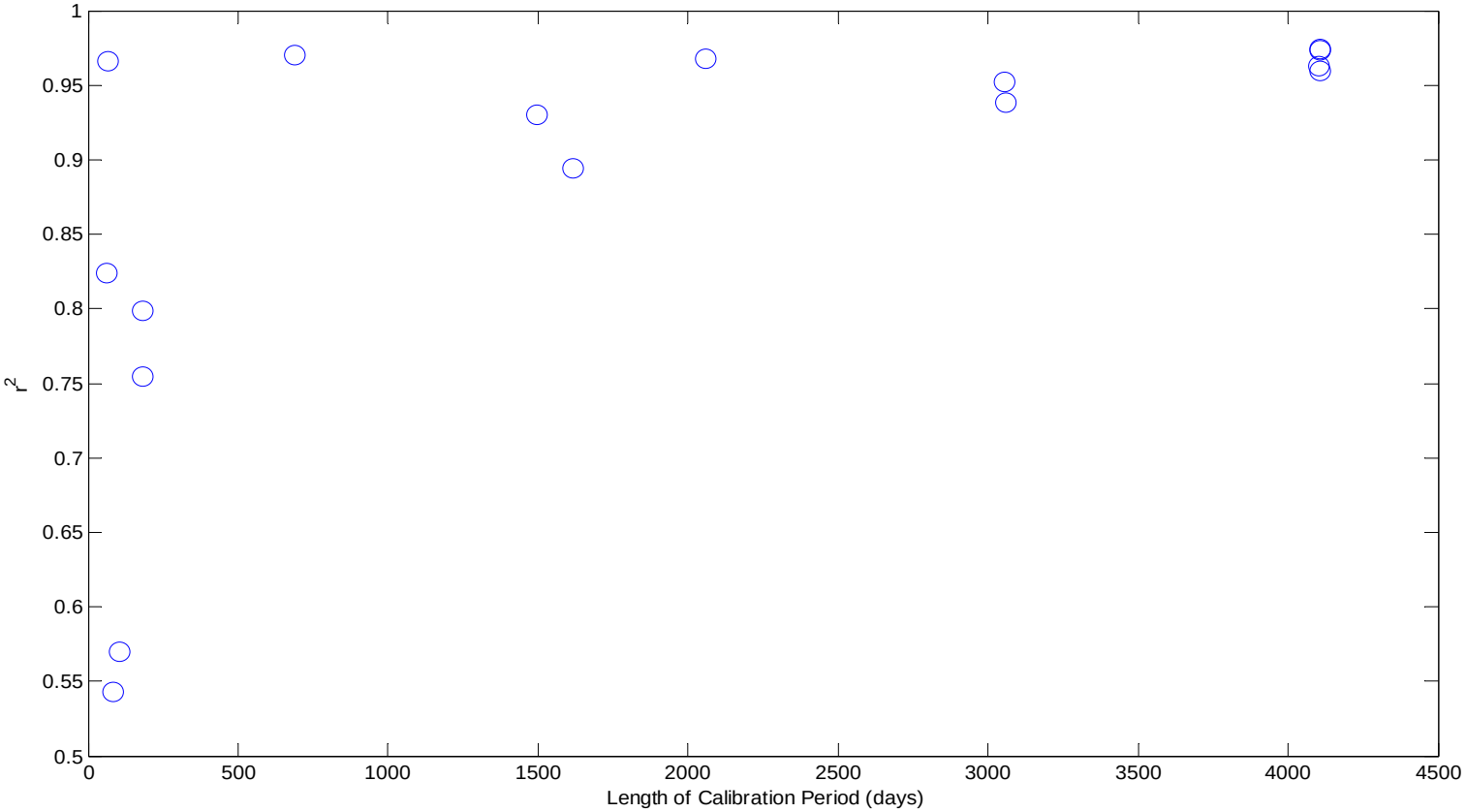


Who dat?

Dependence on Air Temperature

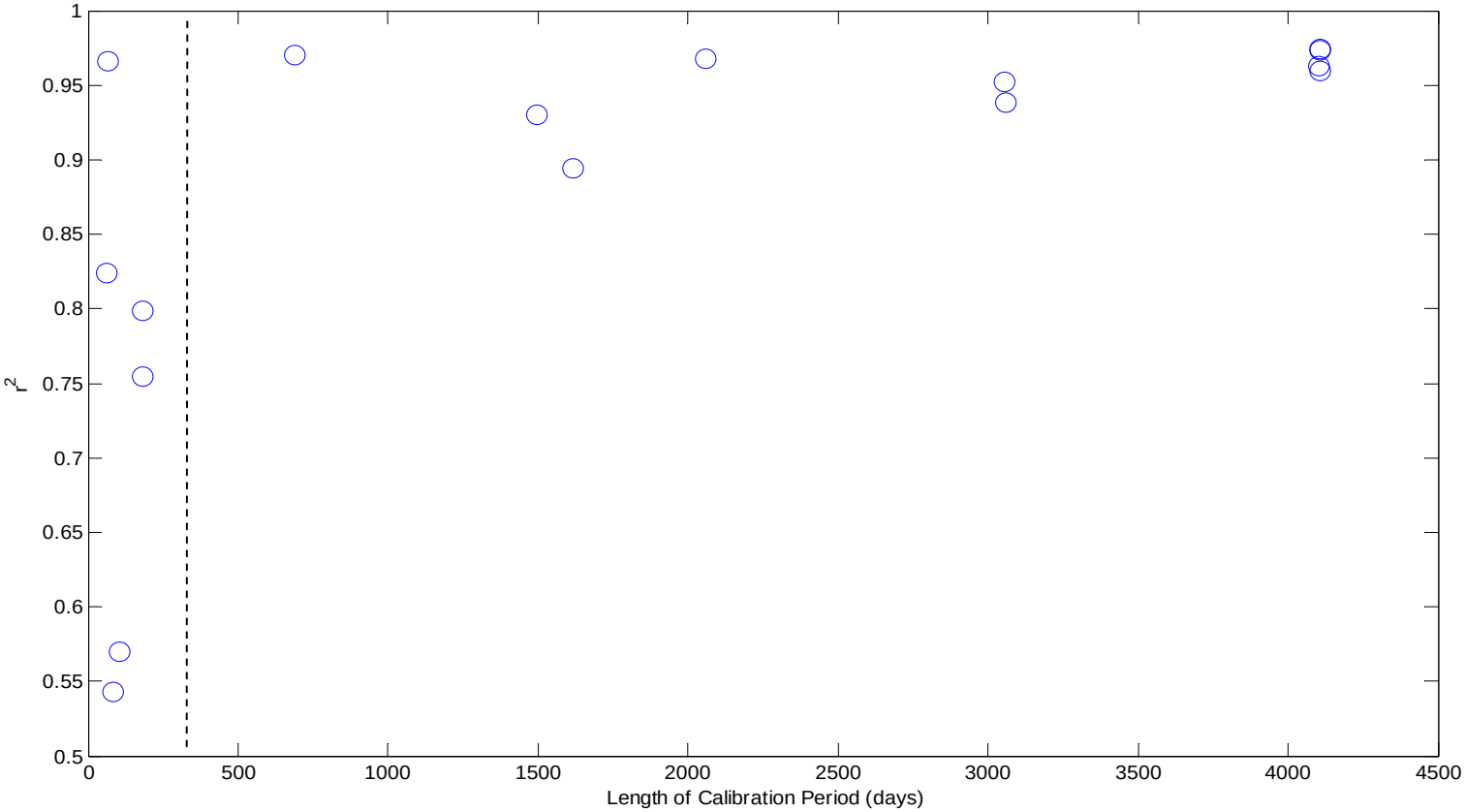


Water Temperature Model



Verification r^2 vs. Length of Calibration Period

Water Temperature Model



Calibration periods > 1 year greatly improve predictive skill of the model.

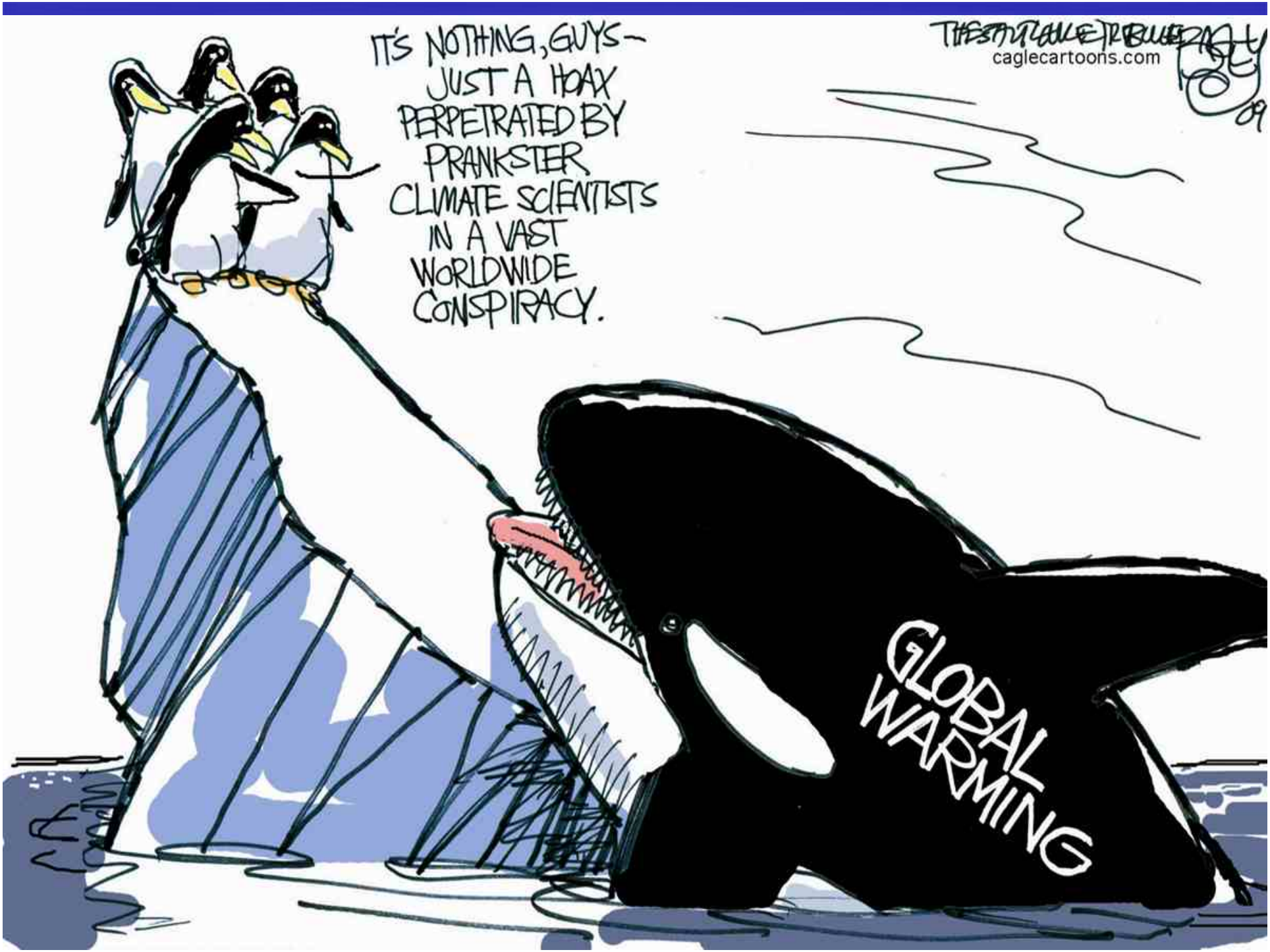
What Do Resource Managers and Researchers Need in Planning for Climate Change?

Russ Bellmer

California Department of Fish and Game

Outline

- Political setting
- Potential environmental changes
- Potential monitoring needs
- Some thoughts mixed in

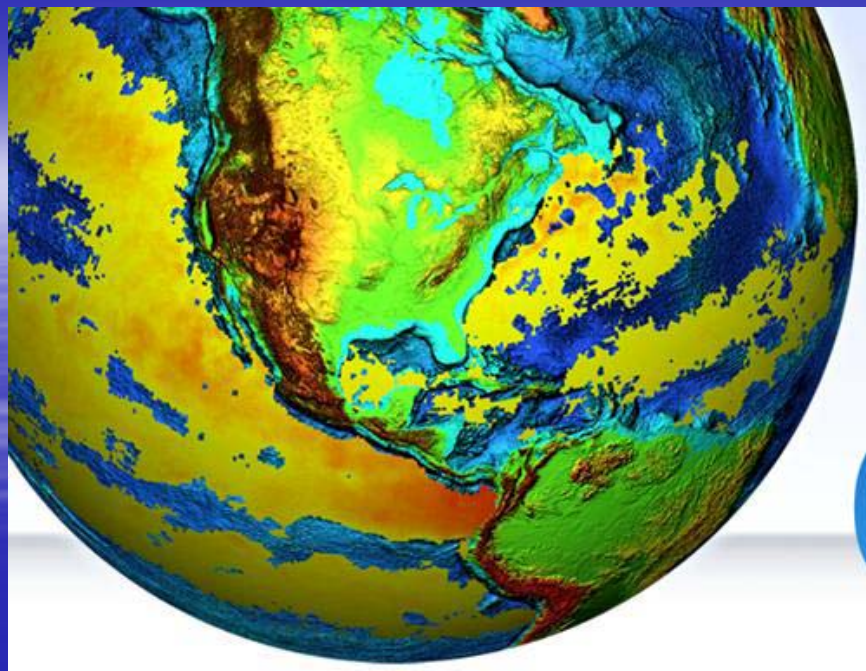

IT'S NOTHING, GUYS— JUST A HOAX PERPETRATED BY PRANKSTER CLIMATE SCIENTISTS IN A VAST WORLDWIDE CONSPIRACY.
caglecartoons.com
GLOBAL WARMING

What do the politicians say?

What do Natural Resource Managers Say?

- “As the climate changes, so must California”

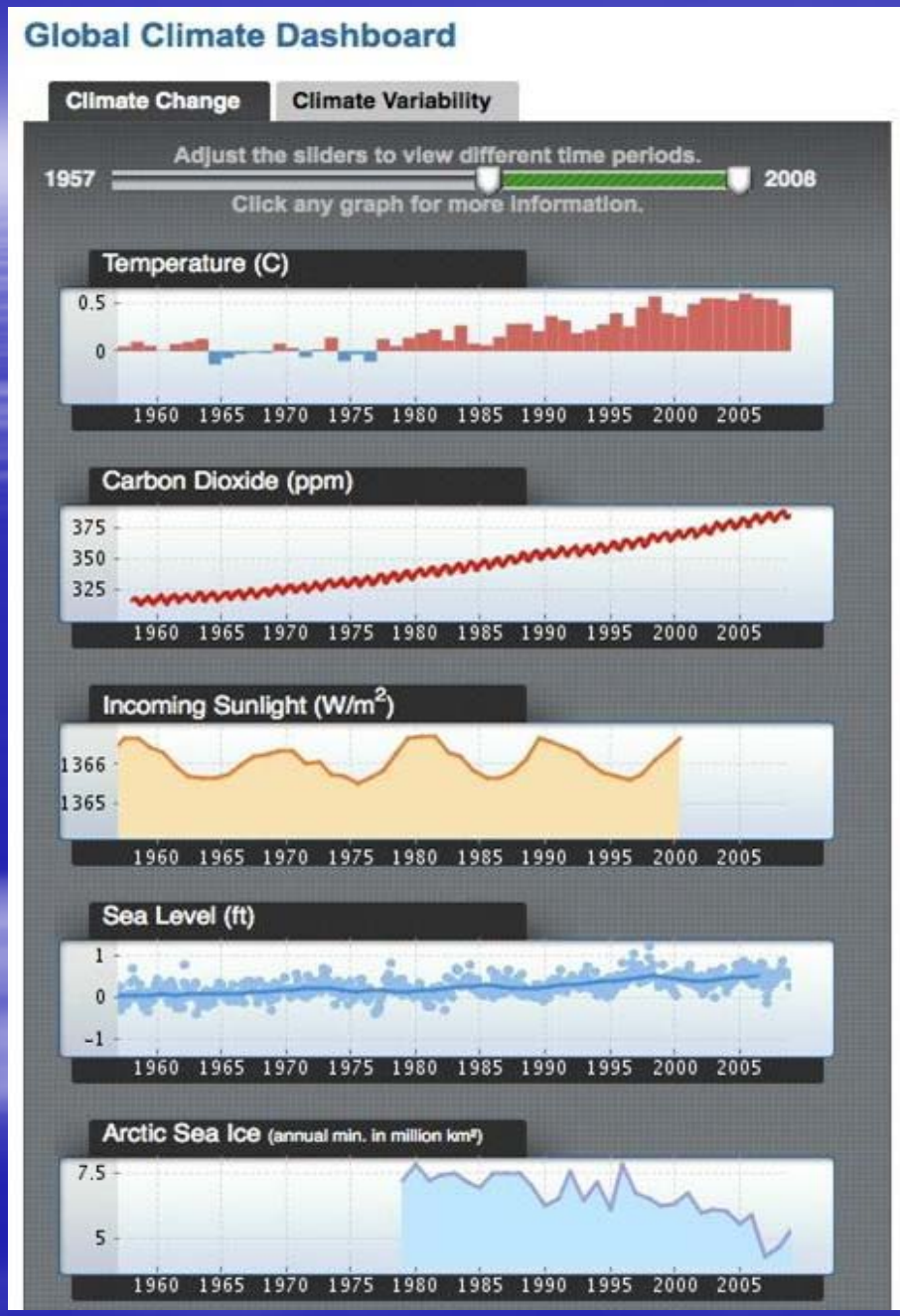
- “More Speedos and bikinis?”

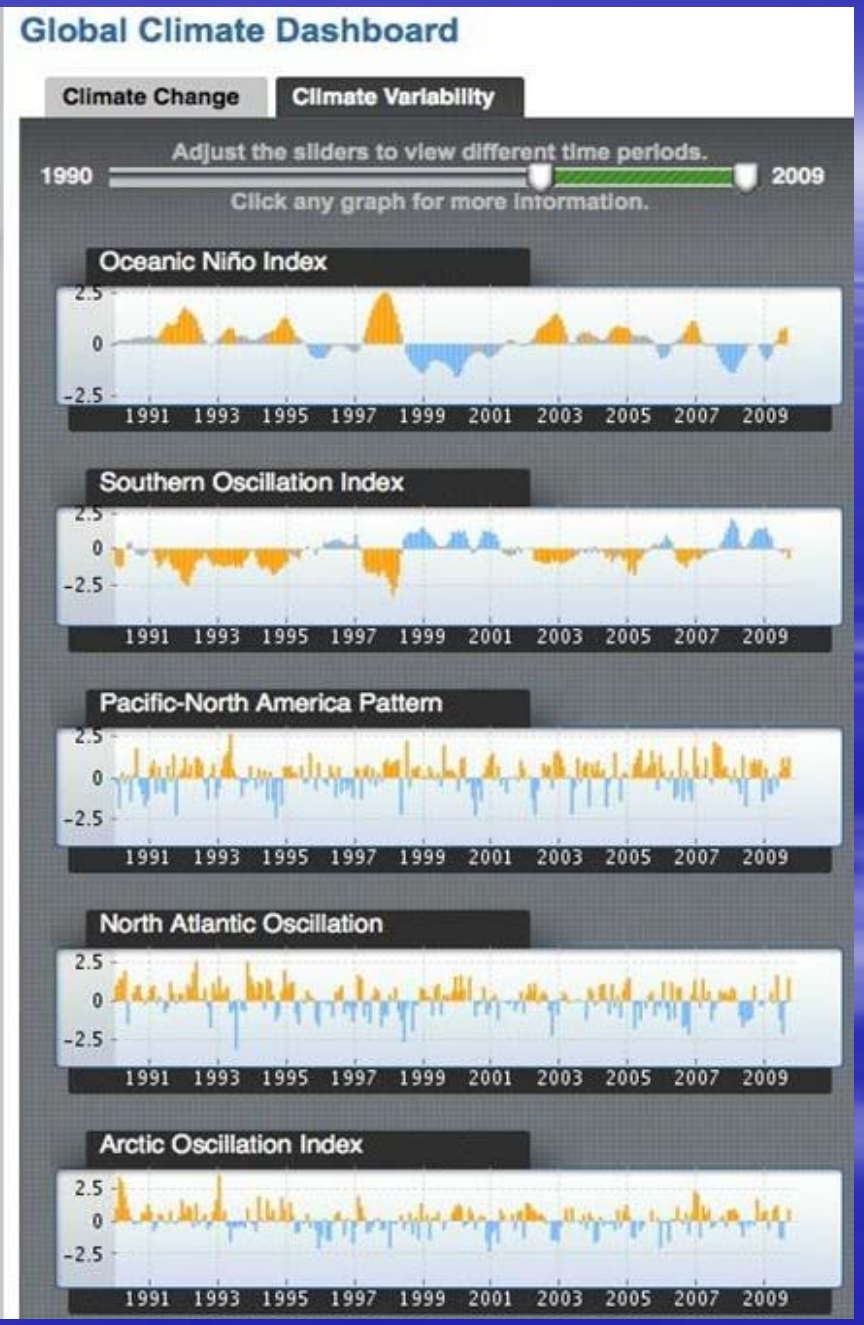


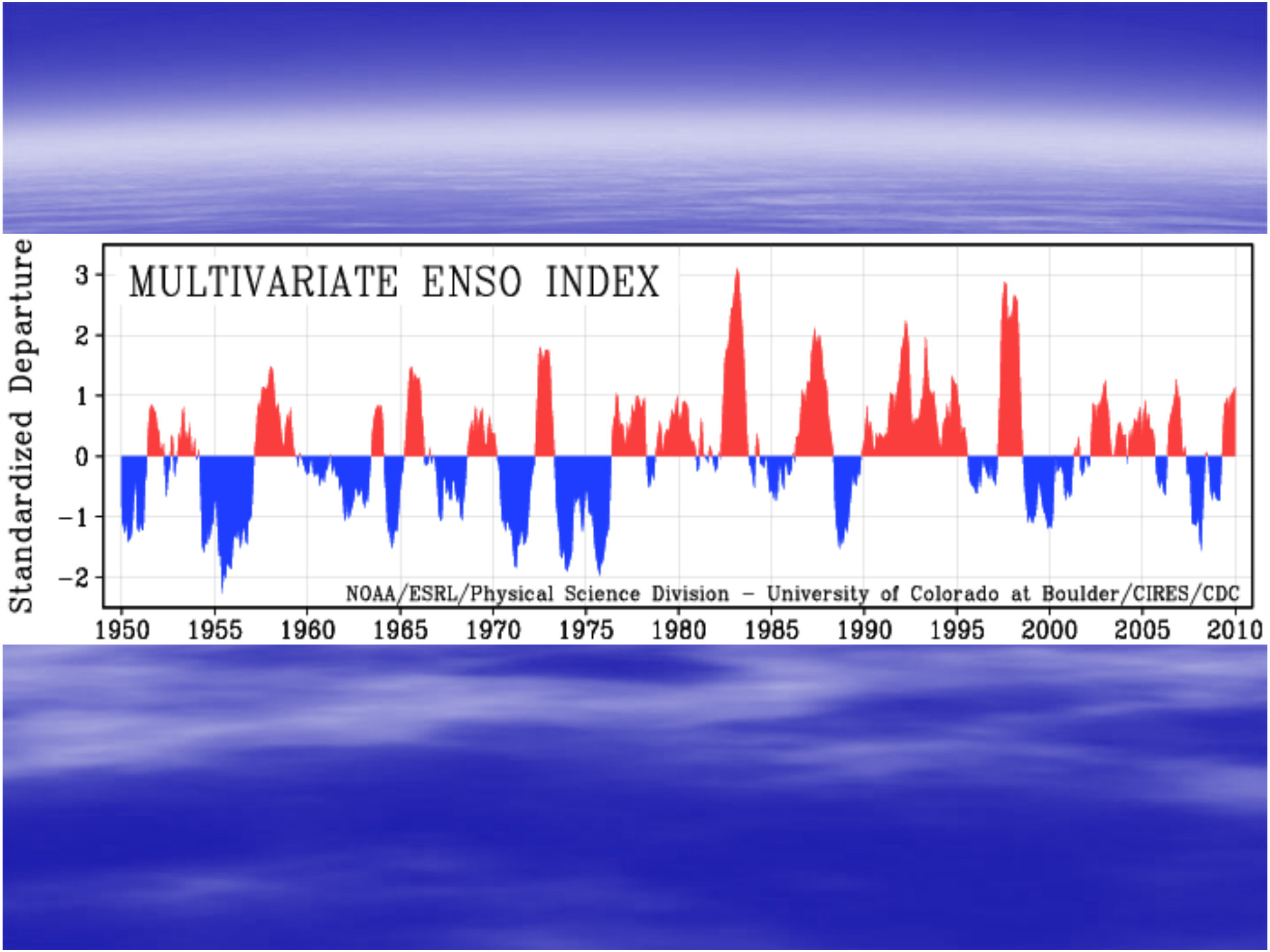
NOAA CLIMATE SERVICE

Dr. Jane Lubchenco

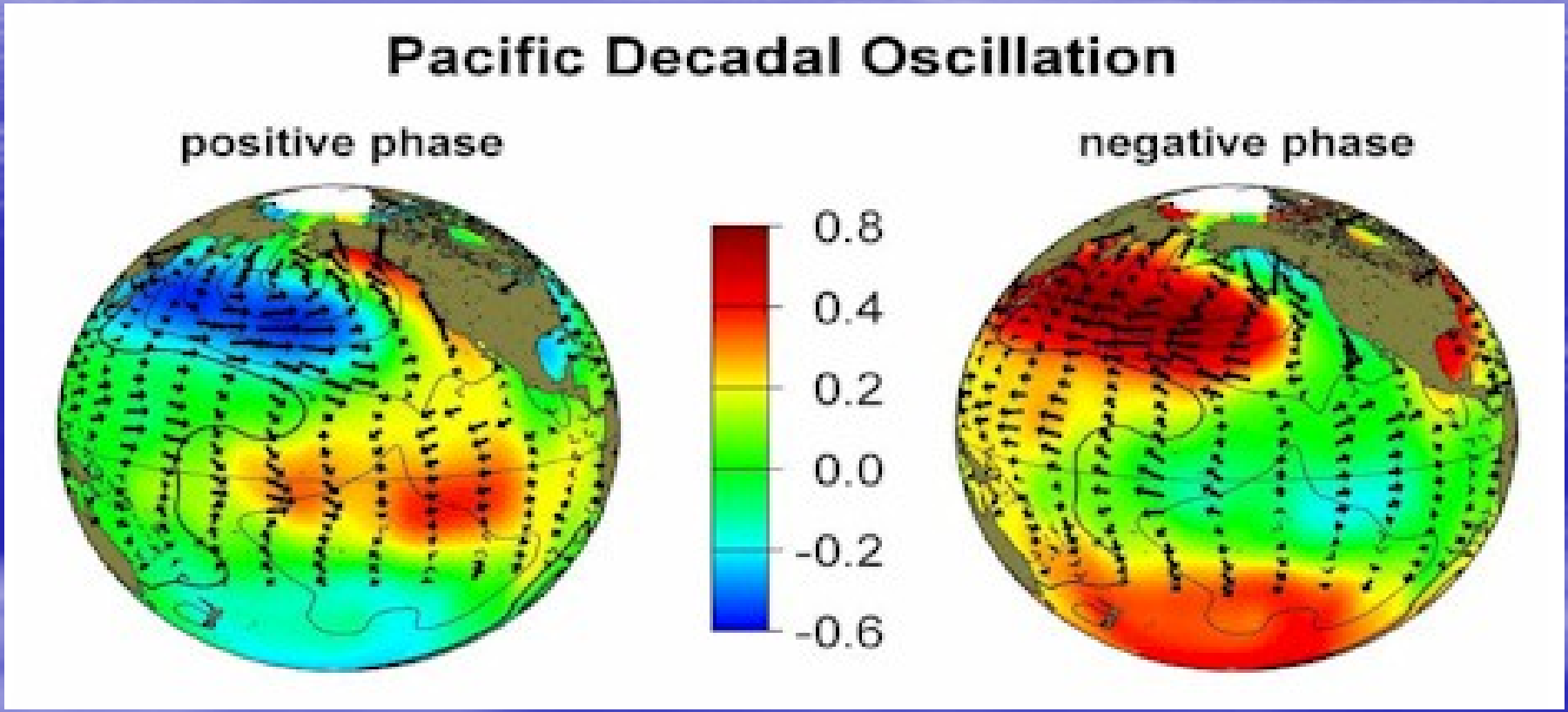
Under Secretary for Oceans & Atmosphere
NOAA Administrator
February 8, 2010

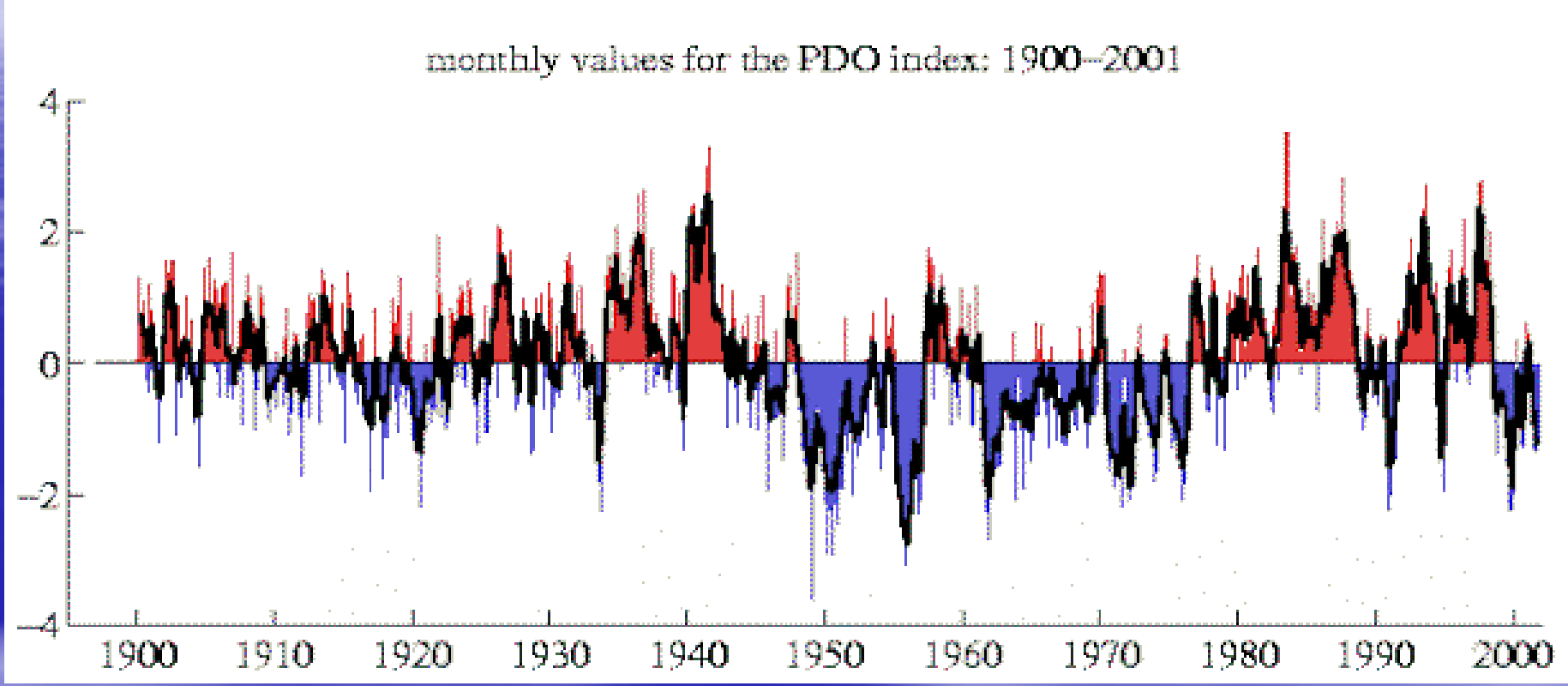

Global Climate Dashboard
Climate Change
Climate Variability
Adjust the sliders to view different time periods.
1957
2008
Click any graph for more information.
Temperature (C)
0.5
0
1960 1965 1970 1975 1980 1985 1990 1995 2000 2005
Carbon Dioxide (ppm)
375
350
325
1960 1965 1970 1975 1980 1985 1990 1995 2000 2005
Incoming Sunlight (W/m2)
1366
1365
1960 1965 1970 1975 1980 1985 1990 1995 2000 2005
Sea Level (ft)
1
0
-1
1960 1965 1970 1975 1980 1985 1990 1995 2000 2005
Arctic Sea Ice (annual min. in million km²)
7.5
5
1960 1965 1970 1975 1980 1985 1990 1995 2000 2005

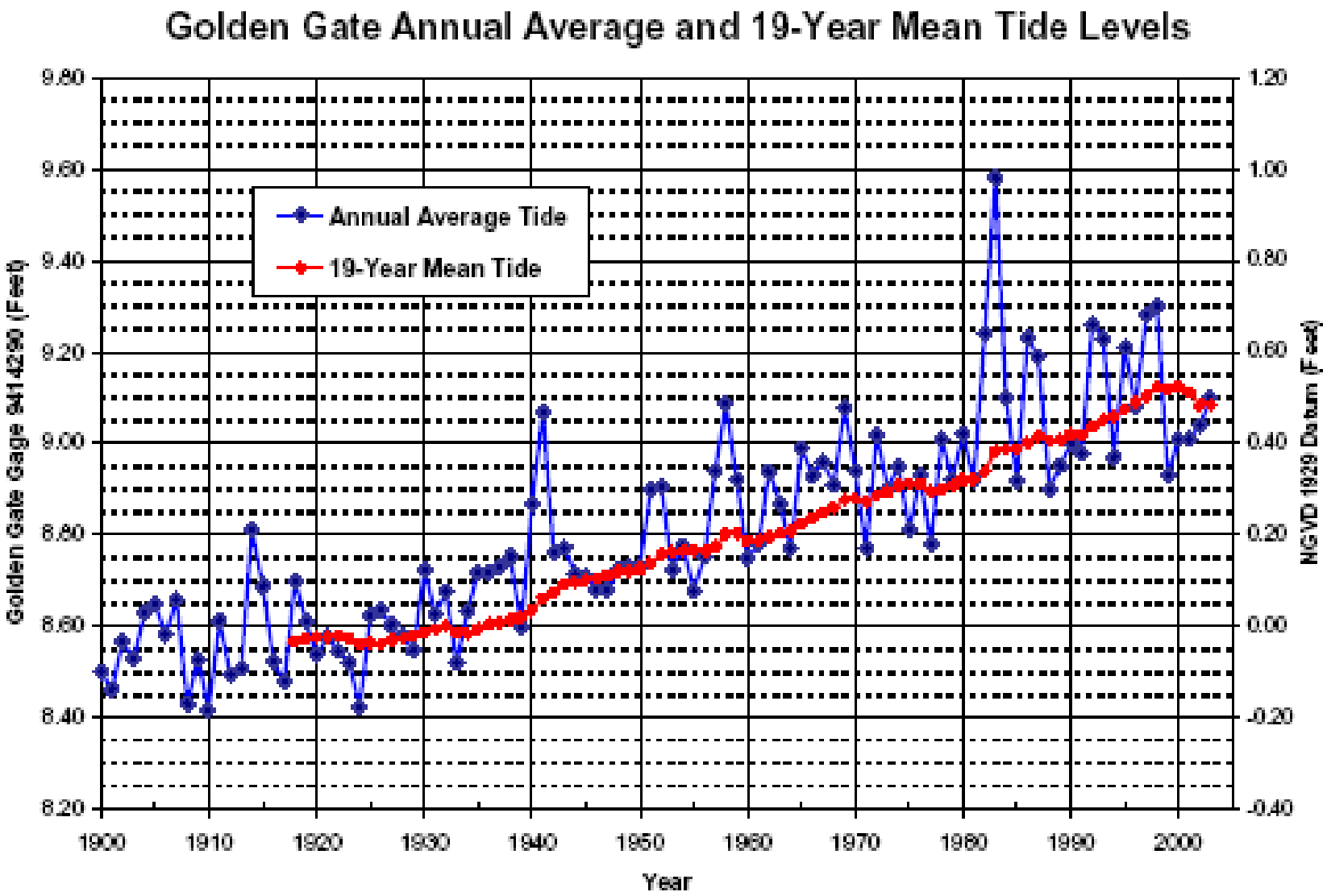

Global Climate Dashboard
Climate Change
Climate Variability
Adjust the sliders to view different time periods.
1990
2009
Click any graph for more information.
Oceanic Niño Index
2.5
0
-2.5
1991 1993 1995 1997 1999 2001 2003 2005 2007 2009
Southern Oscillation Index
2.5
0
-2.5
1991 1993 1995 1997 1999 2001 2003 2005 2007 2009
Pacific-North America Pattern
2.5
0
-2.5
1991 1993 1995 1997 1999 2001 2003 2005 2007 2009
North Atlantic Oscillation
2.5
0
-2.5
1991 1993 1995 1997 1999 2001 2003 2005 2007 2009
Arctic Oscillation Index
2.5
0
-2.5
1991 1993 1995 1997 1999 2001 2003 2005 2007 2009

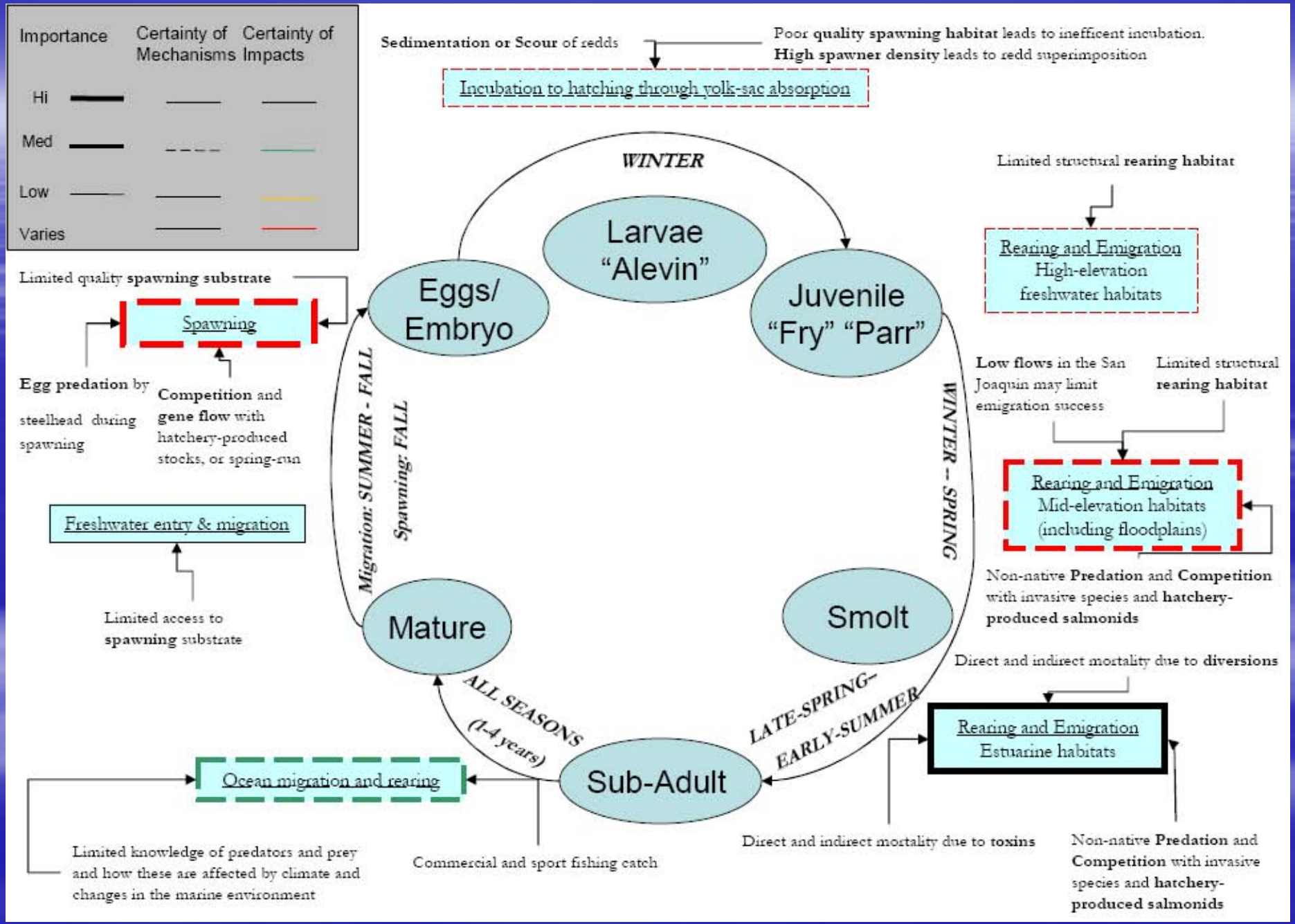

MULTIVARIATE ENSO INDEX
Standardized Departure
3
2
1
0
−1
−2
NOAA/ESRL/Physical Science Division – University of Colorado at Boulder/CIRES/CDC
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010

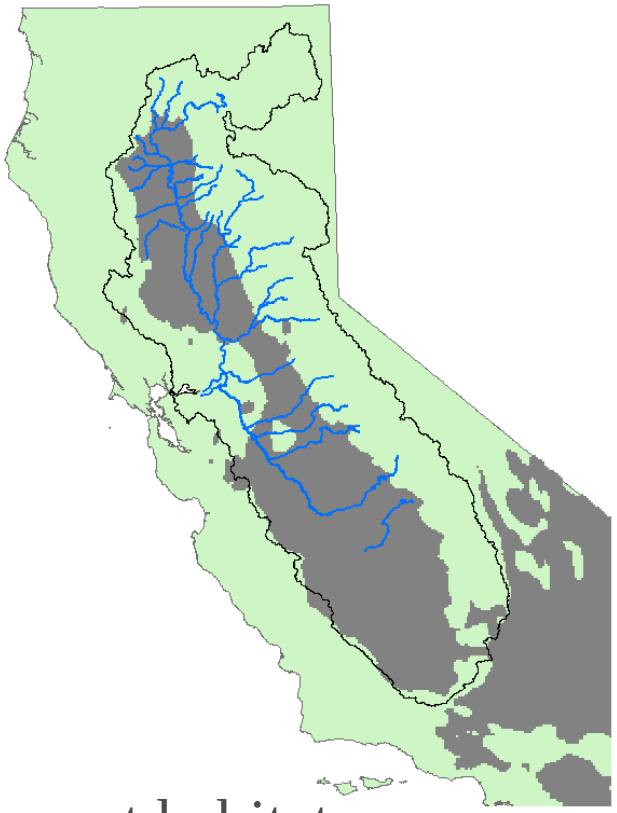
Pacific Decadal Oscillation (PDO)



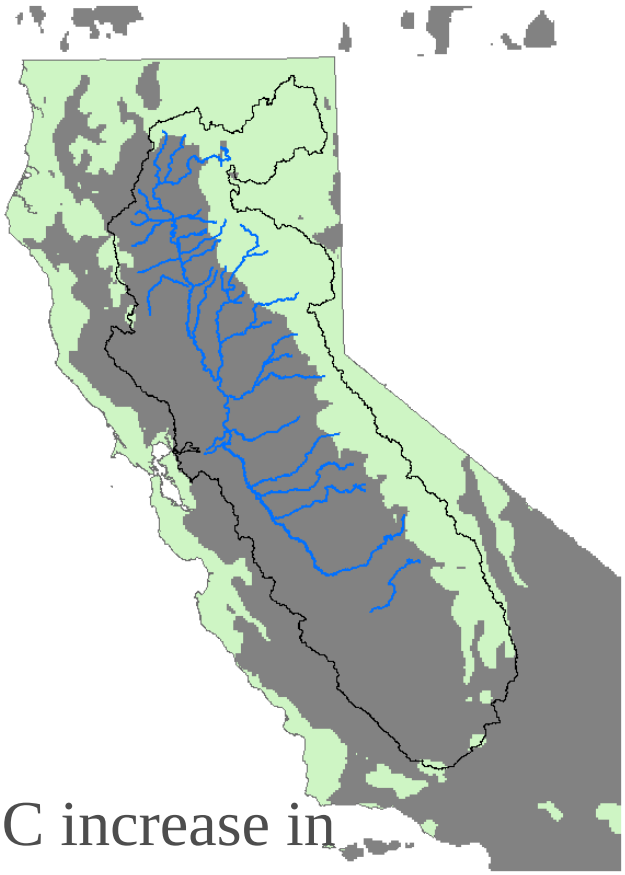

monthly values for the PDO index: 1900–2001
4
2
0
−2
−4
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000


Golden Gate Annual Average and 19-Year Mean Tide Levels
Annual Average Tide
19-Year Mean Tide
Golden Gate Gage 9414290 (Feet)
NGVD 1929 Datum (Feet)
Year
9.80
9.60
9.40
9.20
9.00
8.80
8.60
8.40
8.20
1.20
1.00
0.80
0.60
0.40
0.20
0.00
-0.20
-0.40
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000


Importance
Certainty of Mechanisms
Certainty of Impacts
Hi
Med
Low
Varies
Sedimentation or Scour of redds
Poor quality spawning habitat leads to inefficent incubation.
High spawner density leads to redd superimposition
Incubation to hatching through yolk-sac absorption
WINTER
Larvae "Alevin"
Limited structural rearing habitat
Rearing and Emigration
High-elevation freshwater habitats
Limited quality spawning substrate
Spawning
Eggs/ Embryo
Juvenile "Fry" "Parr"
Egg predation by steelhead during spawning
Competition and gene flow with hatchery-produced stocks, or spring-run
Low flows in the San Joaquin may limit emigration success
Limited structural rearing habitat
Migration: SUMMER - FALL
Spawning: FALL
WINTER -- SPRING
Rearing and Emigration
Mid-elevation habitats (including floodplains)
Freshwater entry & migration
Non-native Predation and Competition with invasive species and hatchery-produced salmonids
Limited access to spawning substrate
Mature
Smolt
Direct and indirect mortality due to diversions
ALL SEASONS
(1-4 years)
LATE-SPRING-
EARLY-SUMMER
Rearing and Emigration
Estuarine habitats
Ocean migration and rearing
Sub-Adult
Limited knowledge of predators and prey and how these are affected by climate and changes in the marine environment
Commercial and sport fishing catch
Direct and indirect mortality due to toxins
Non-native Predation and Competition with invasive species and hatchery-produced salmonids



Current habitat

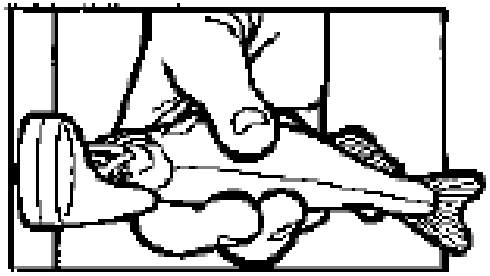


5°C increase in temperature habitat loss

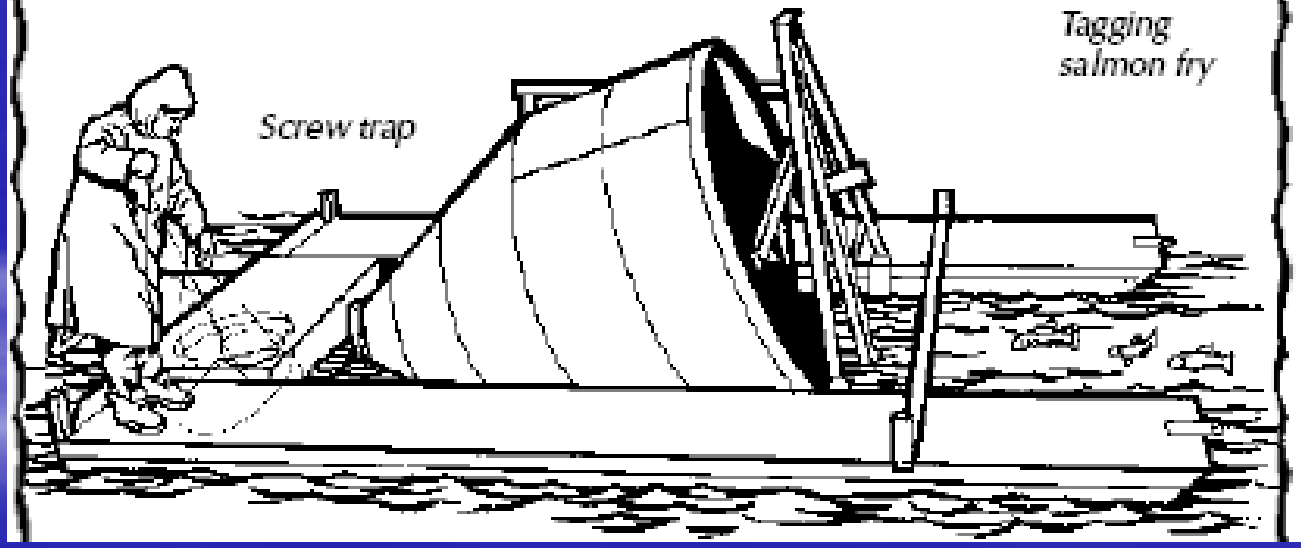
Table1 -- Generalized Approximate Optimum Temperature Ranges for Life History Stages in Chinook Salmon (these vary greatly with DO, flows, chemicals, turbidity, etc.)

Life History Stage	Approximate Temperature Ranges (in degrees Centigrade)
eggs	5-13 (10-13)
larvae	9-13 (14)
juvenile	15-18 (20)
smolt	13-20 (17-20)
sub-adult	7-20 (12-20)
mature adult	7-15 (12-15)

Discovering Secrets of Salmon



Tagging salmon fry

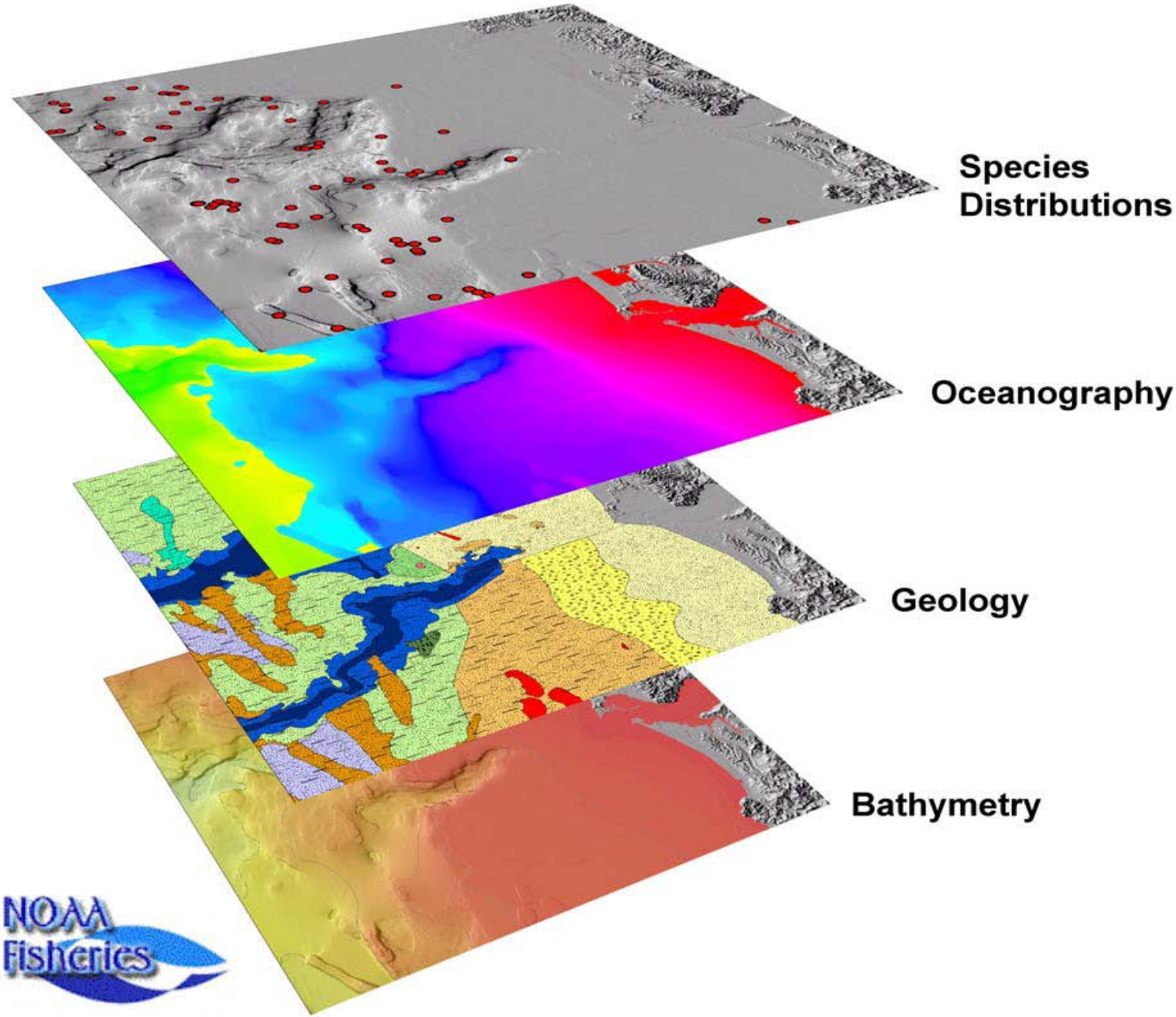


Population Based Monitoring

- Information at the appropriate life stages and spatial scales to evaluate adult salmonid abundance
- Productivity calculated as the trend in abundance over time
- Collection of juvenile distribution and relative abundance data
- Diversity evaluations

Monitoring Approaches

- Life cycle fixed stations
- Surveys selected randomly and spatially balanced for juveniles
- Habitat assessments
- Genetic diversity
- Marking hatcheries fish
- State wide approach


Species Distributions
Oceanography
Geology
Bathymetry
NOAA Fisheries

Ocean Species Data Needs

- Regional surveys for more species
- Species surveys that sample all habitats
- Increased frequency of surveys
- Surveys designed to track the abundance
- Increased catch and bycatch samples
- Increased spatial resolution of catch data
- Species surveys increased environmental information
- Data management

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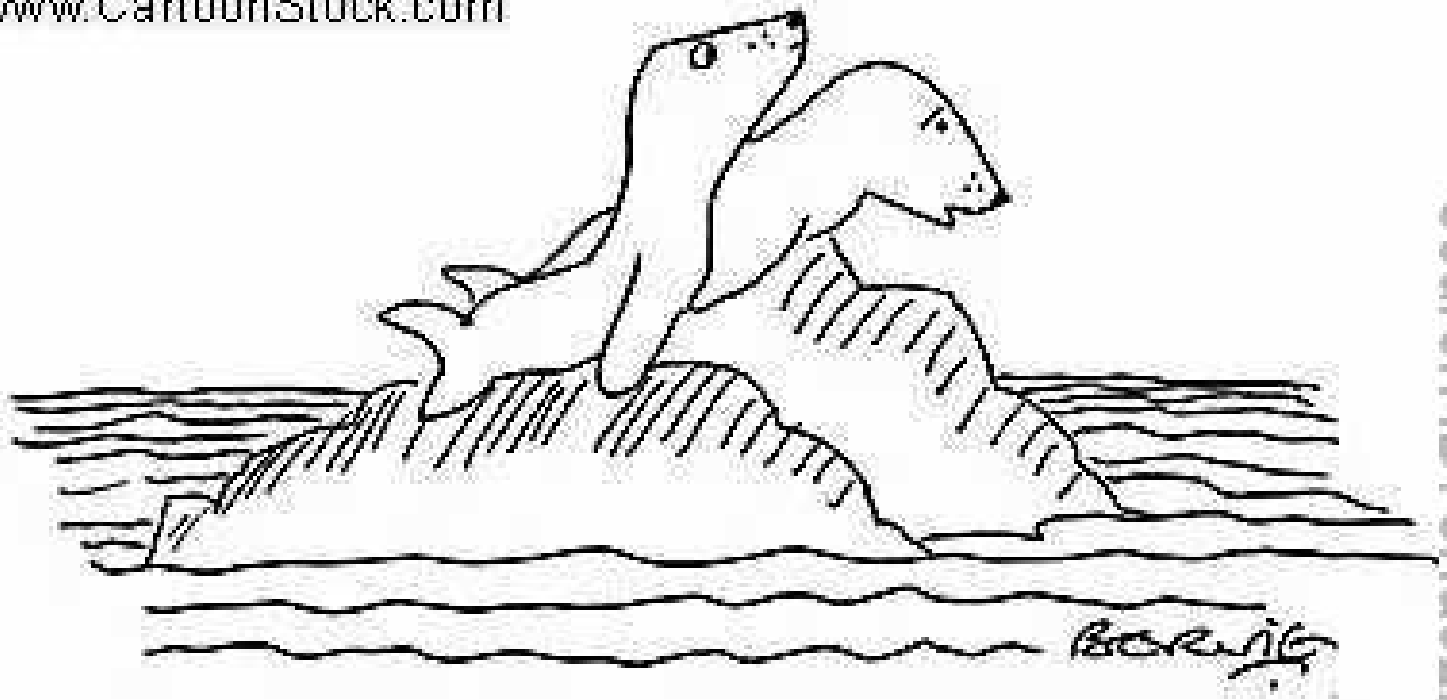


search ID: shu0225

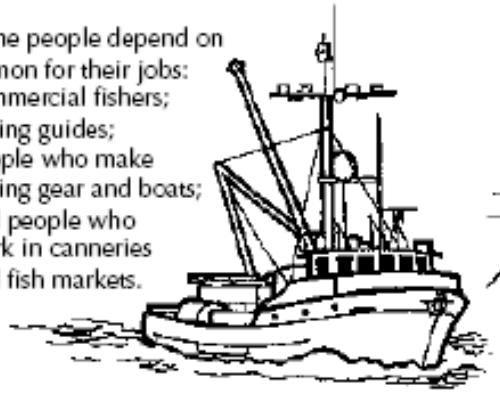
"THERE AREN'T PLENTY MORE FISH IN THE SEA..."

Attitudes and Limited Monitoring

- Fish need water -- known
- How much and when -- not known
- Living among cold water fish
- Non intrusive sampling
- Salmonid population trends
  - Landings
  - Hatcheries returns
  - In river monitoring
- Reason for Salmonid decline
  - Ocean
  - Freshwater

Why Do We Need Salmon?

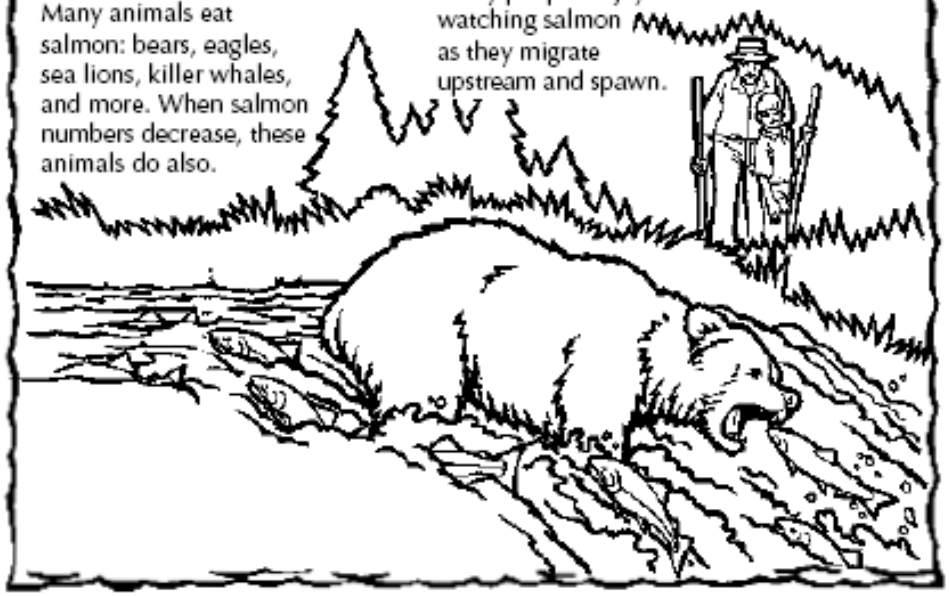
Some people depend on salmon for their jobs: commercial fishers; fishing guides; people who make fishing gear and boats; and people who work in canneries and fish markets.



Salmon are an important part of the culture and livelihoods of many Indian people.

Salmon are part of a healthy ecosystem. Many animals eat salmon: bears, eagles, sea lions, killer whales, and more. When salmon numbers decrease, these animals do also.

Many people enjoy watching salmon as they migrate upstream and spawn.



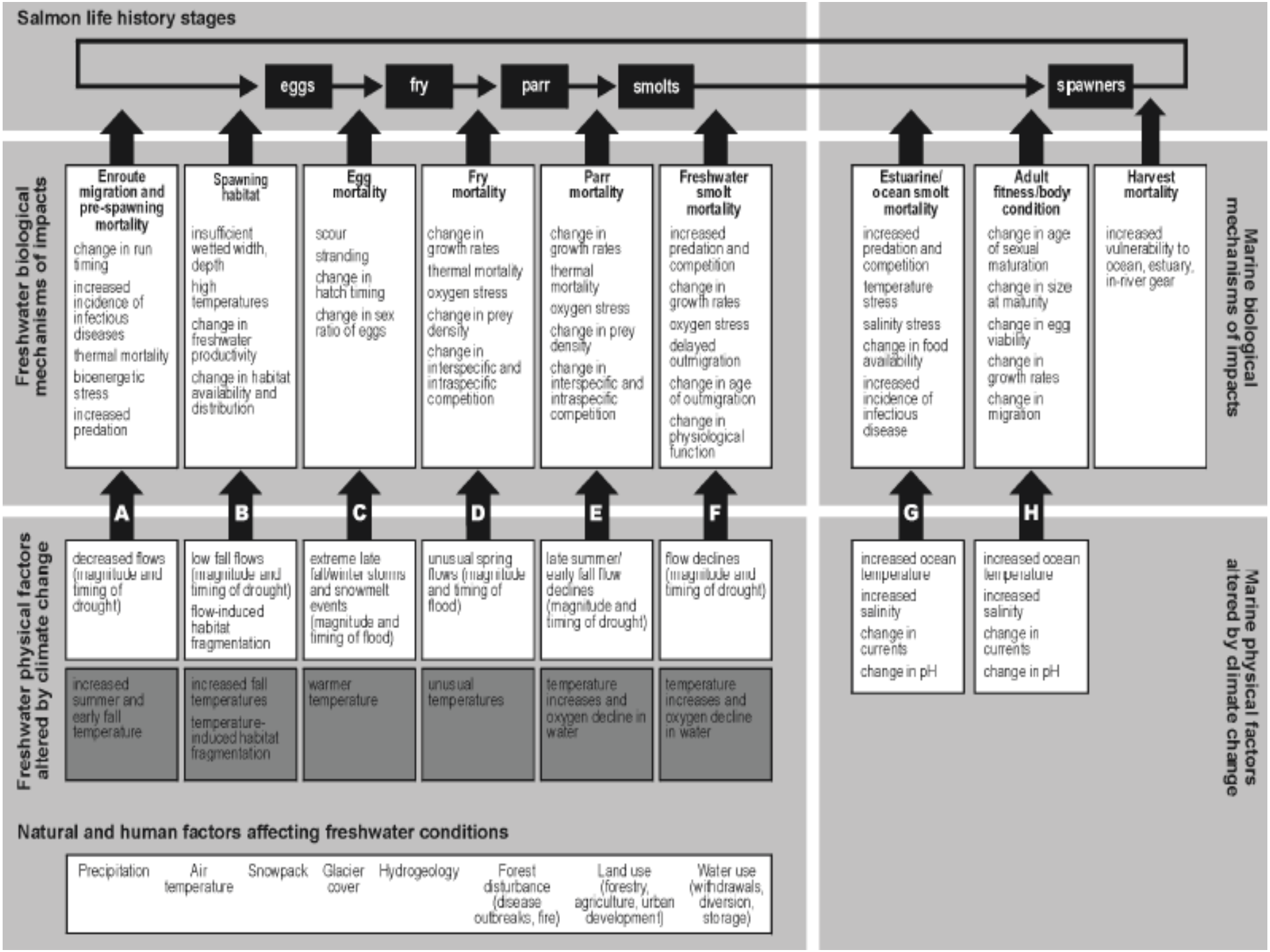
Acknowledgments

- Thanks to State & Federal Government for the funding Salmonid restoration
- Thanks to NOAA and DWR staff for discussions about temperature changes
- Thanks to the DFG staff and others for challenging conversation and inputs
- Most of all thanks to the people doing this outstanding work

LIFE
CYCLE
SALMON
Bonneville Power
Columbia River
Corps of Engineers
County and Local
Governments
PNW Terrestrial
Climate / ENSO
Relations
International
Pacific Northwest Utilities
Conference Committee
Pacific Salmon
Commission
PNW Terrestrial
Climate / North
Pacific Ocean
Pacific Fisheries
Management Council
Northwest Power
Planning Council
Generation
Northwest Indian
Fisheries Commission
National Marine
Conservation and
Environmental Organizations
CLIMATE
FORECASTS
Evaluation
Dissemination
Use
Coastal / Estuarine
Air - Sea
Interactions
Ocean Biological
Productivity / Climate
Interactions
Bureau of Indian Affairs
Federal Energy
Regulatory
Commission
Idaho Department of
Fish and Game
Canadian Department of
Fisheries and Oceans
Montana Department of Fish,
Wildlife and Parks
National Park Service
Environmental
Protection Agency
13 Columbia River Tribes
Alaska Department of Fish and Game

A climate-literate person

- understands the essential principles of Earth's climate system,
- knows how to assess scientifically credible information about climate,
- communicates about climate and climate change in a meaningful way, and
- is able to make informed and responsible decisions with regard to actions that may affect climate


Salmon life history stages
eggs
fry
parr
smolts
spawners
Freshwater biological mechanisms of impacts
Enroute migration and pre-spawning mortality
change in run timing
increased incidence of infectious diseases
thermal mortality
bioenergetic stress
increased predation
Spawning habitat
insufficient wetted width, depth
high temperatures
change in freshwater productivity
change in habitat availability and distribution
Egg mortality
scour
stranding
change in hatch timing
change in sex ratio of eggs
Fry mortality
change in growth rates
thermal mortality
oxygen stress
change in prey density
change in interspecific and intraspecific competition
Parr mortality
change in growth rates
thermal mortality
oxygen stress
change in prey density
change in interspecific and intraspecific competition
Freshwater smolt mortality
increased predation and competition
change in growth rates
oxygen stress
delayed outmigration
change in age of outmigration
change in physiological function
Estuarine/ ocean smolt mortality
increased predation and competition
temperature stress
salinity stress
change in food availability
increased incidence of infectious disease
Adult fitness/body condition
change in age of sexual maturation
change in size at maturity
change in egg viability
change in growth rates
change in migration
Harvest mortality
increased vulnerability to ocean, estuary, in-river gear
Marine biological mechanisms of impacts
A
B
C
D
E
F
G
H
Freshwater physical factors altered by climate change
decreased flows (magnitude and timing of drought)
low fall flows (magnitude and timing of drought)
flow-induced habitat fragmentation
extreme late fall/winter storms and snowmelt events (magnitude and timing of flood)
unusual spring flows (magnitude and timing of flood)
late summer/ early fall flow declines (magnitude and timing of drought)
flow declines (magnitude and timing of drought)
increased summer and early fall temperature
increased fall temperatures
temperature-induced habitat fragmentation
warmer temperature
unusual temperatures
temperature increases and oxygen decline in water
temperature increases and oxygen decline in water
Marine physical factors altered by climate change
increased ocean temperature
increased salinity
change in currents
change in pH
increased ocean temperature
increased salinity
change in currents
change in pH
Natural and human factors affecting freshwater conditions
Precipitation
Air temperature
Snowpack
Glacier cover
Hydrogeology
Forest disturbance (disease outbreaks, fire)
Land use (forestry, agriculture, urban development)
Water use (withdrawals, diversion, storage)

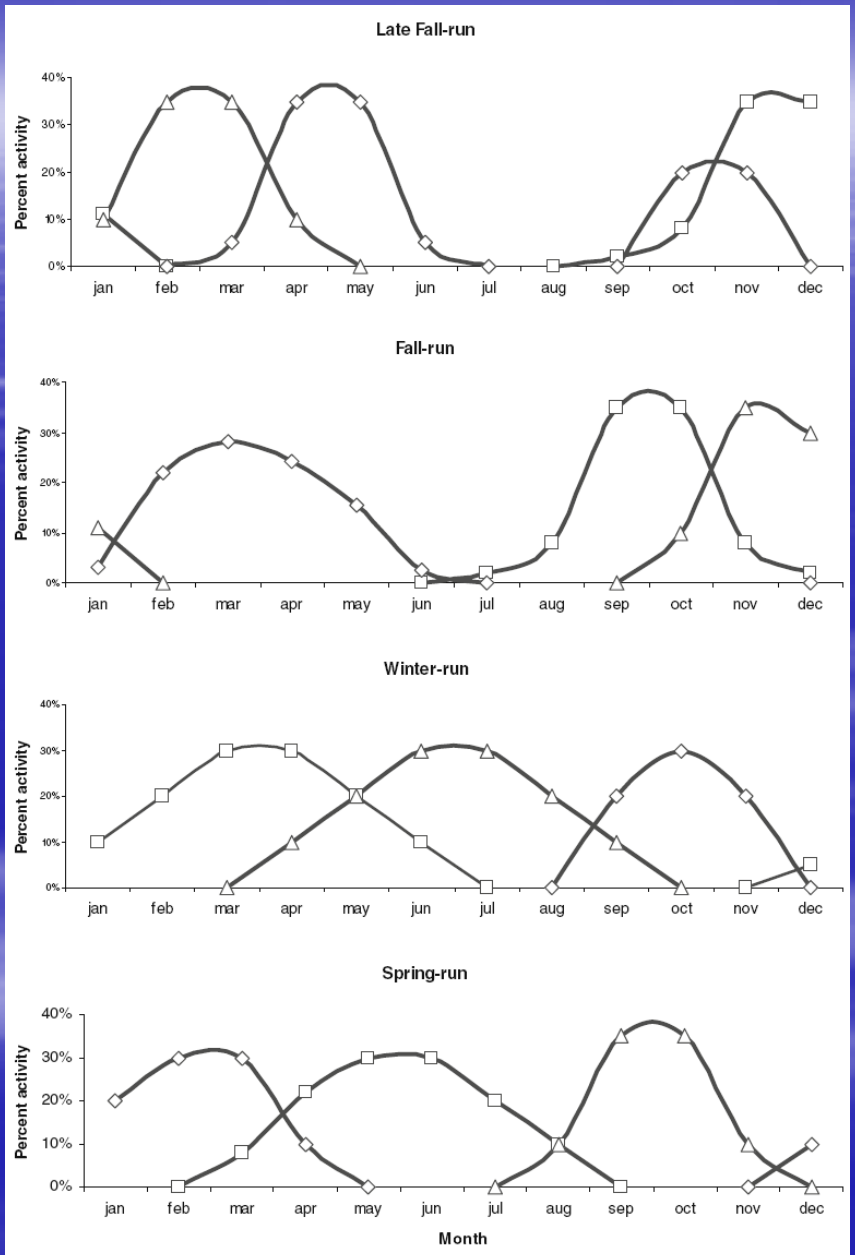
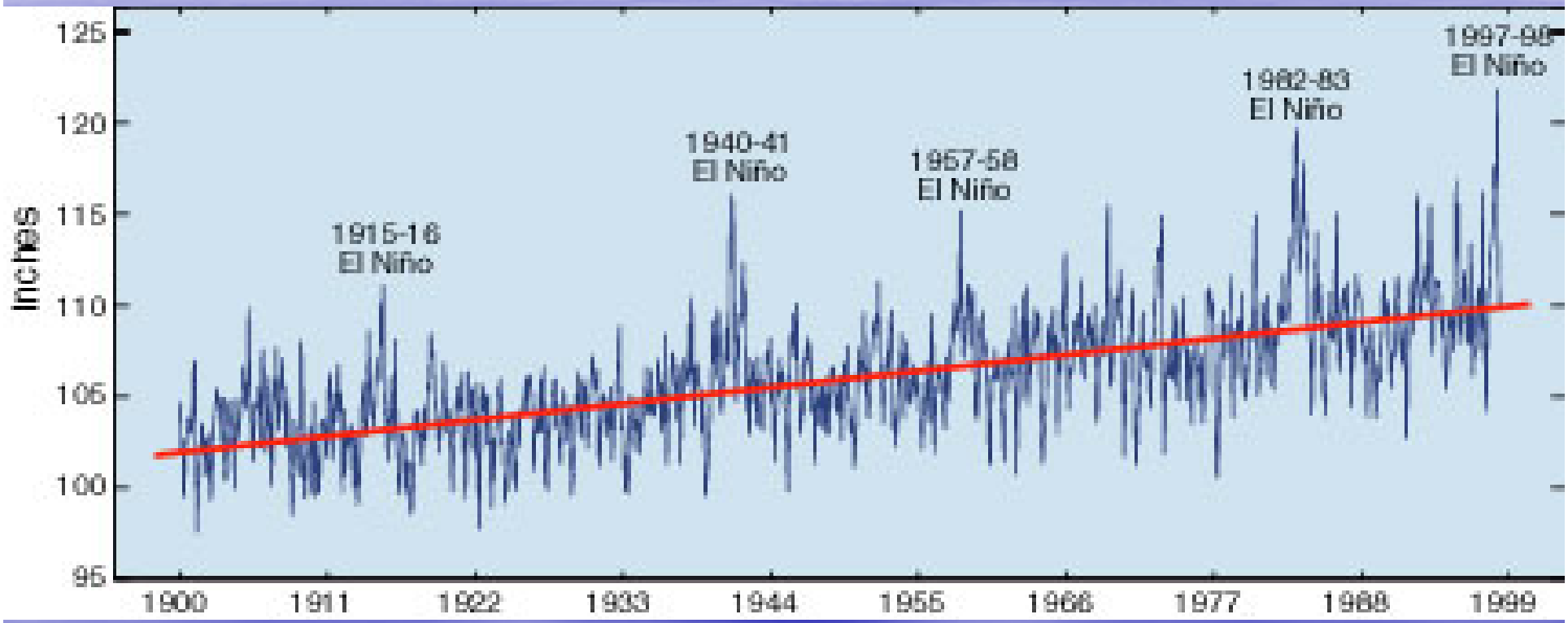


Fig. 1 Phenologies of reproductive events in freshwater phase of Chinook salmon life-cycle in the SV watershed. *open square* adult immigration; *open upright triangle* spawning and hatching; *open diamond* juvenile emigration. Compiled from data in NOAA (2001), DWR (1988), and U.S. DOI (1996)

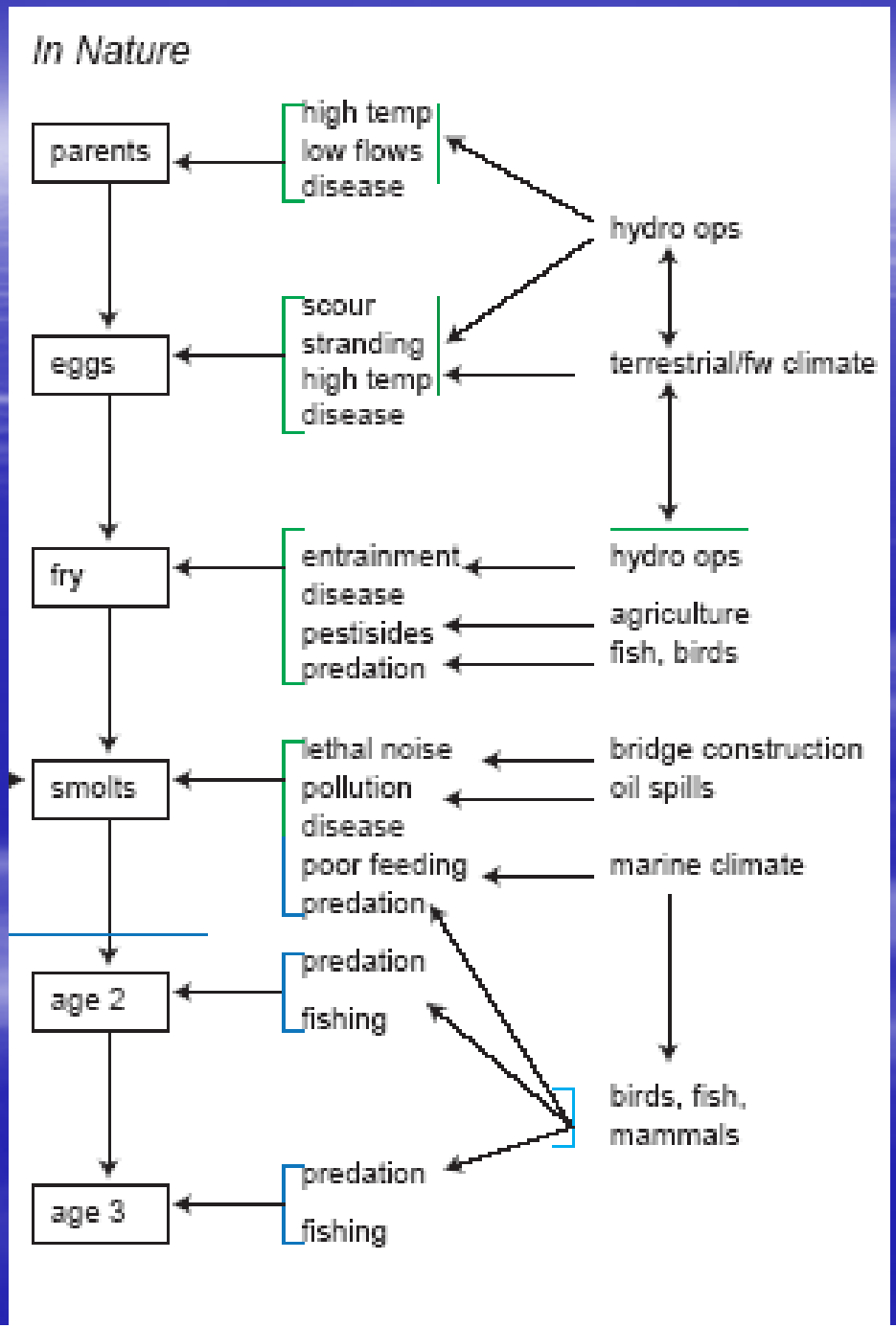
Next Steps

- workshop on natural resource mitigation, adaptation and research needs related to climate change in the Great Basin and Mojave Desert
- University of Nevada, Las Vegas on April 20 - 22, 2010
- www.wr.usgs.gov/workshops/


inches
125
120
115
110
105
100
95
1900
1911
1922
1933
1944
1955
1966
1977
1988
1999
1915-16
El Niño
1940-41
El Niño
1957-58
El Niño
1982-83
El Niño
1997-98
El Niño

It's complex

We don't have all the data



Viable Salmonid Population

- Abundance
- Productivity
- Spatial structure
- Diversity

Ocean Environmental Data Needs

- The physical and plankton properties of the California Current Ecosystem
- Many primary measurements needed
- Increased coordination and integration of databases between west-coast regional observing systems

What caused the Sacramento River fall Chinook stock collapse? Lindley etal 2009

- …unusual conditions affecting Sacramento River fall-run Chinook from the 2004 and 2005 brood years that could explain their poor performance, reaching the conclusion that unfavorable ocean conditions were the proximate cause.
- "But what about the ultimate causes?"

www.pcouncil.org/wp-content/uploads/H2b_WGR_0409.pdf