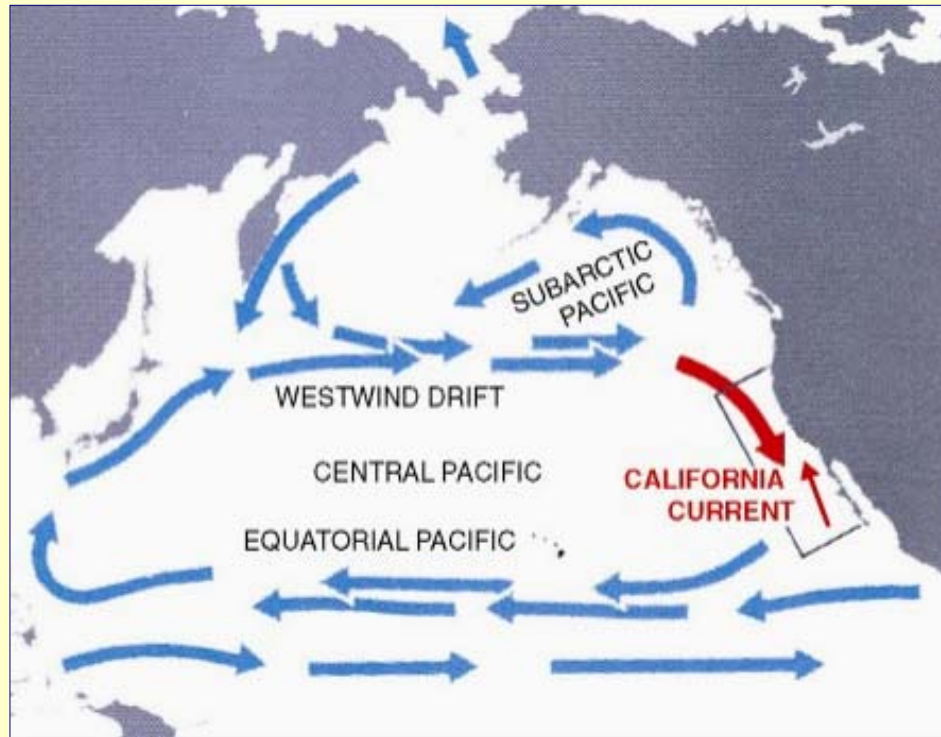


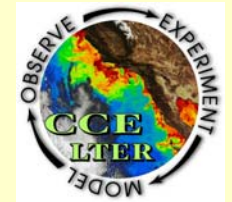
California Current Ecosystem:

Interactions of physical and biological processes



Mark D. Ohman

Scripps Institution of Oceanography
University of California, San Diego



- Highly productive marine ecosystem

- Modulates climate of much of the western U.S.

- Supports important fisheries for finfish as well as shellfish and other invertebrates

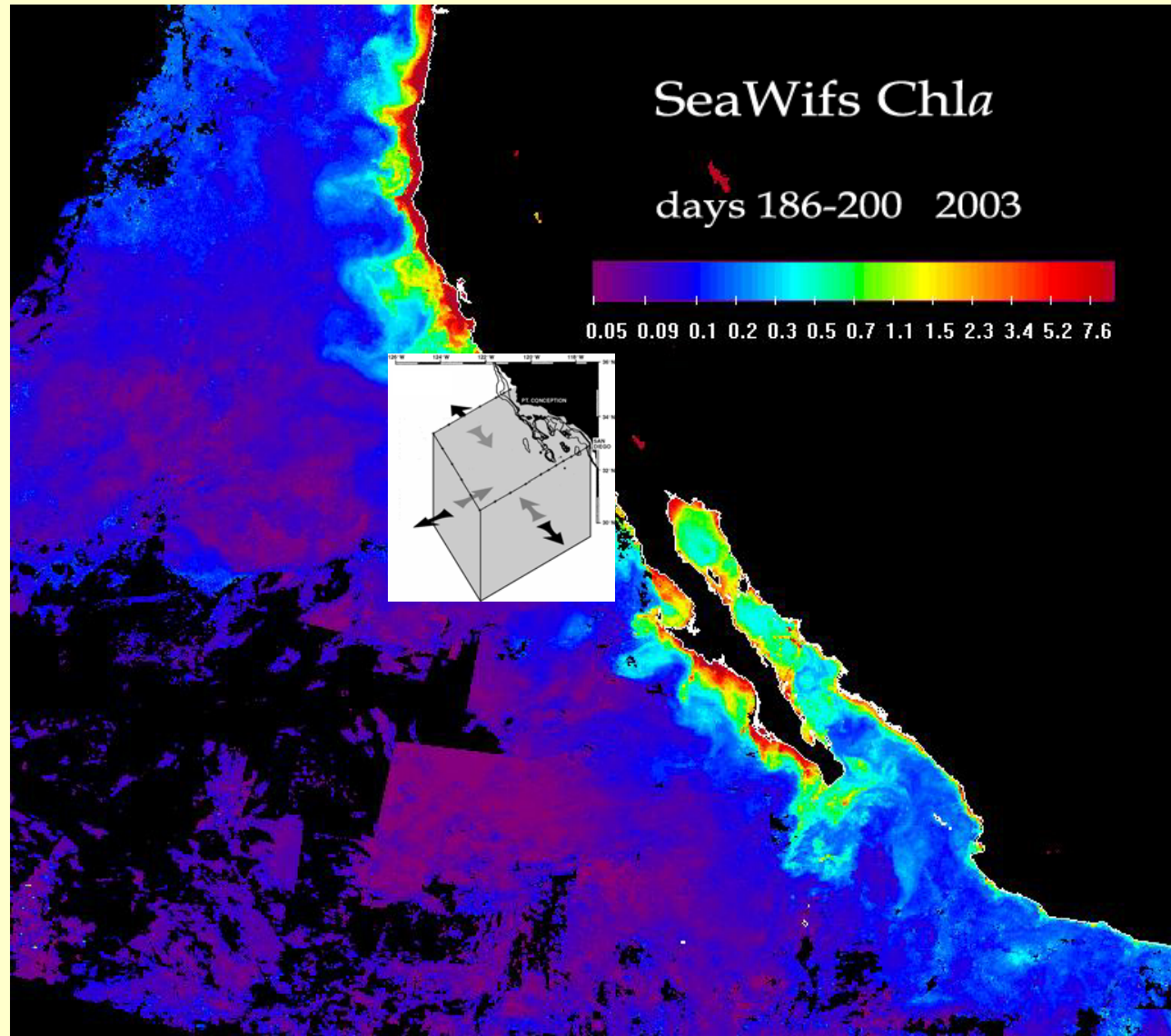
- Feeding grounds or/and migratory pathway for many marine mammals and birds

- Houses 5 National Marine Sanctuaries

- Important for tourism, shipping, and national defense

California Current Ecosystem

A coastal upwelling biome



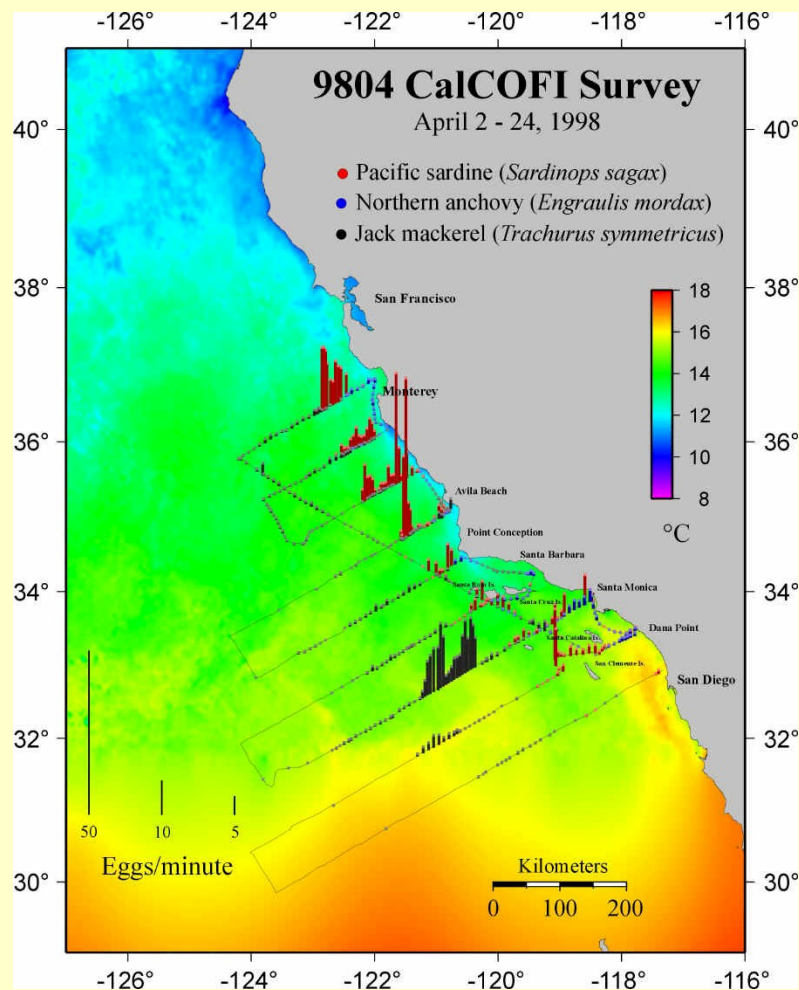
M. Kahru, B.G. Mitchell - Scripps

In addition to seasonal and year-to-year variation in rates of upwelling, processes on much longer time scales and larger spatial scales also affect ecosystems of the California Current, including:

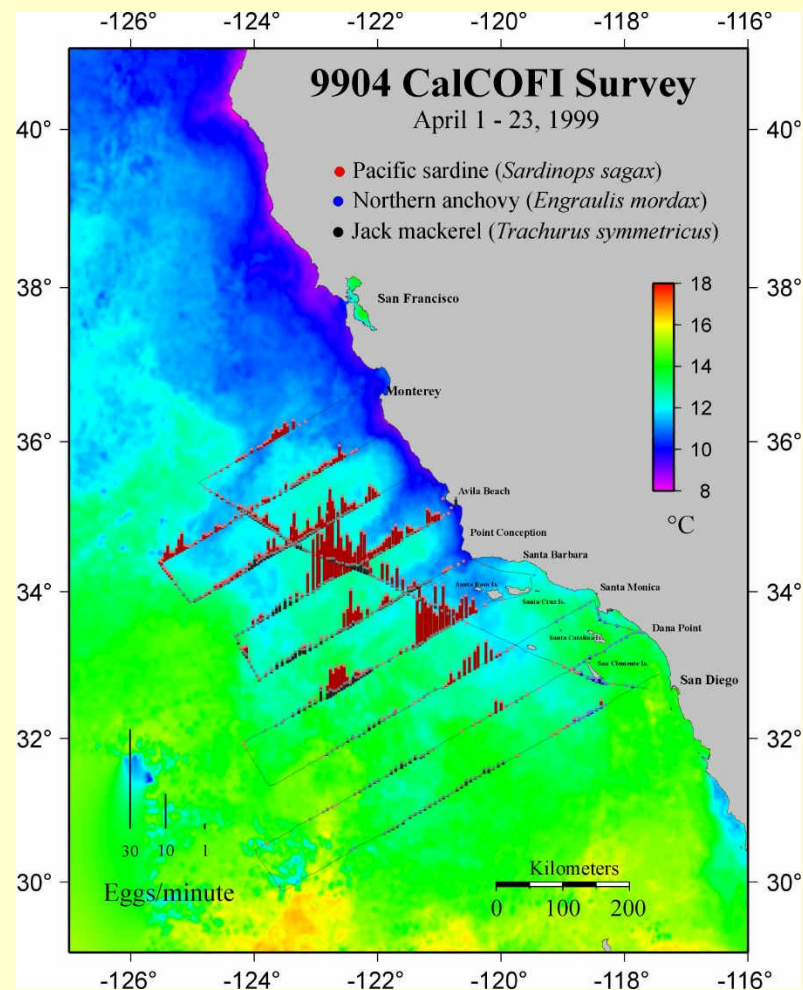
- El Niño
- Pacific Decadal Oscillation
- Long-term ocean warming trend

El Niño effect on oceanographic location of sardine spawning

El Niño

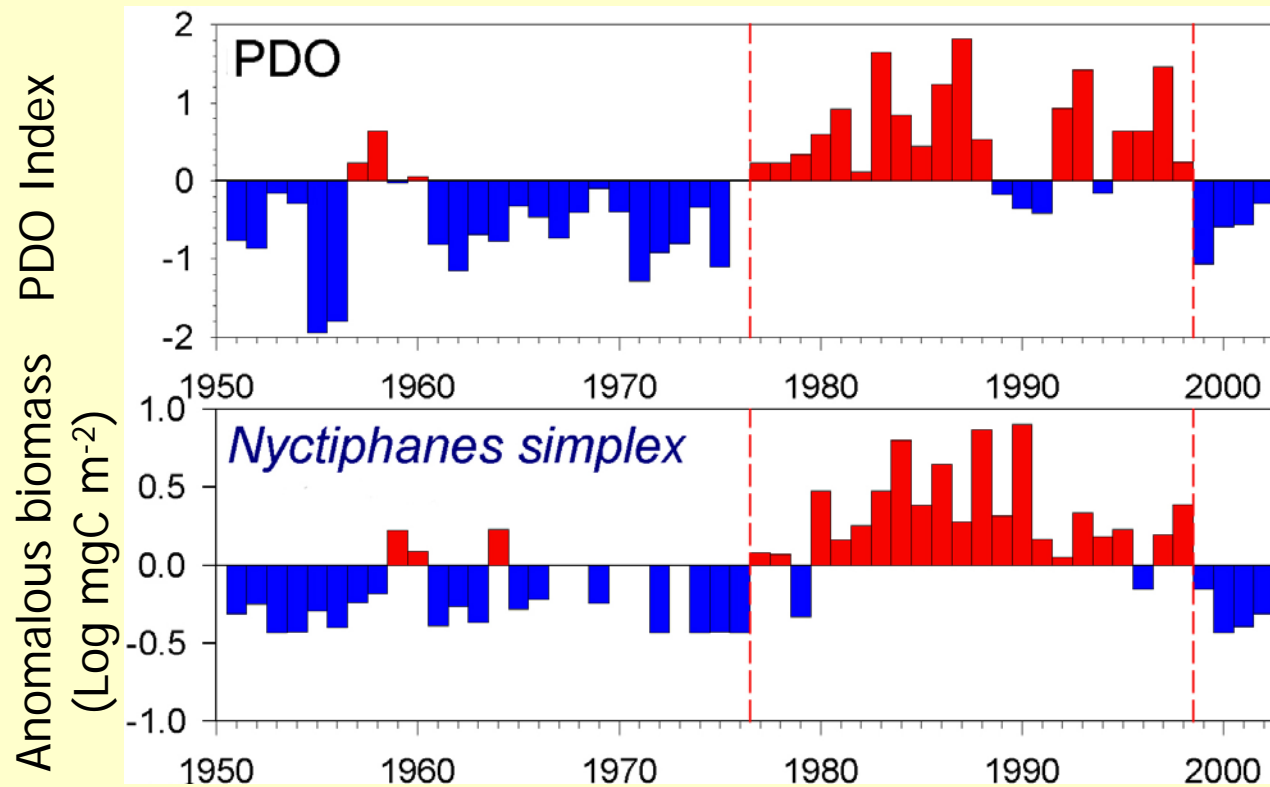


La Niña



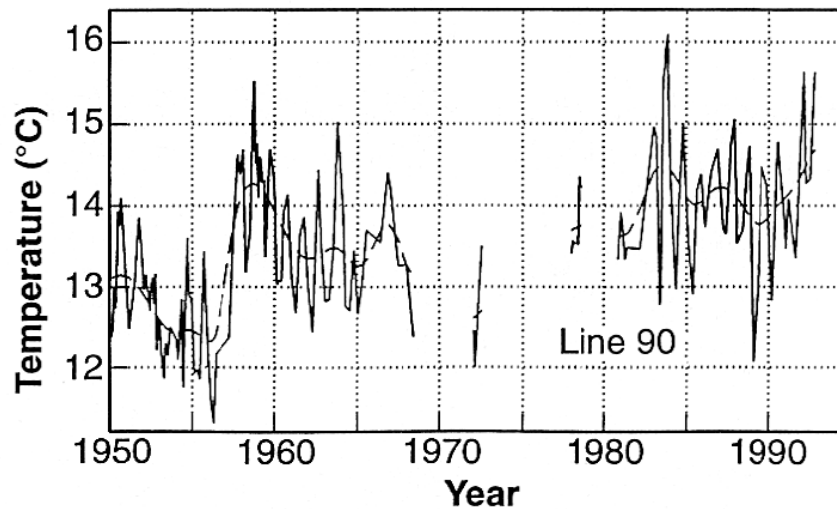
CalCOFI data courtesy of Southwest Fisheries Science Center/NMFS/NOAA

Pacific Decadal Oscillation and correlated fluctuations of marine zooplankton

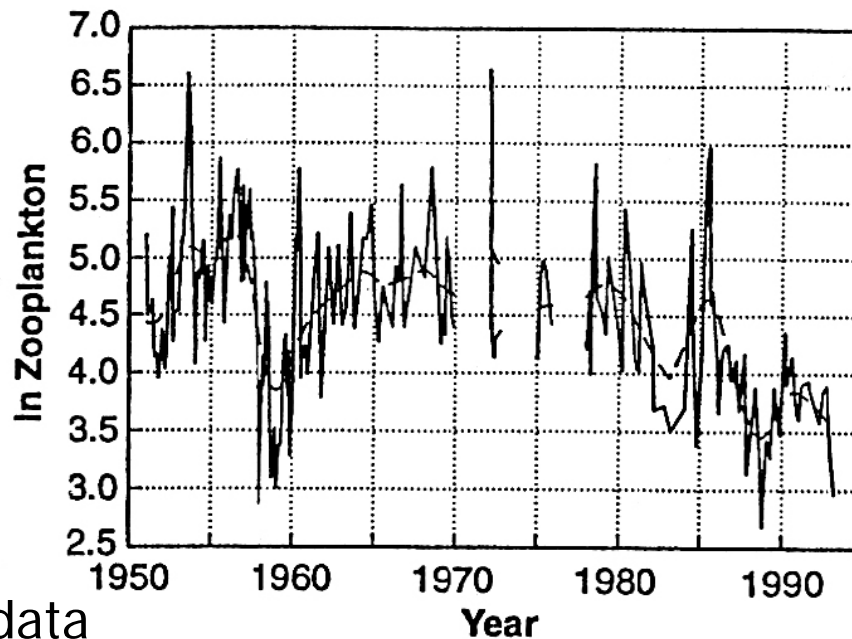


krill

Long-term Ocean Warming and effects on Zooplankton Biomass



Warming of 1.2-1.4° C



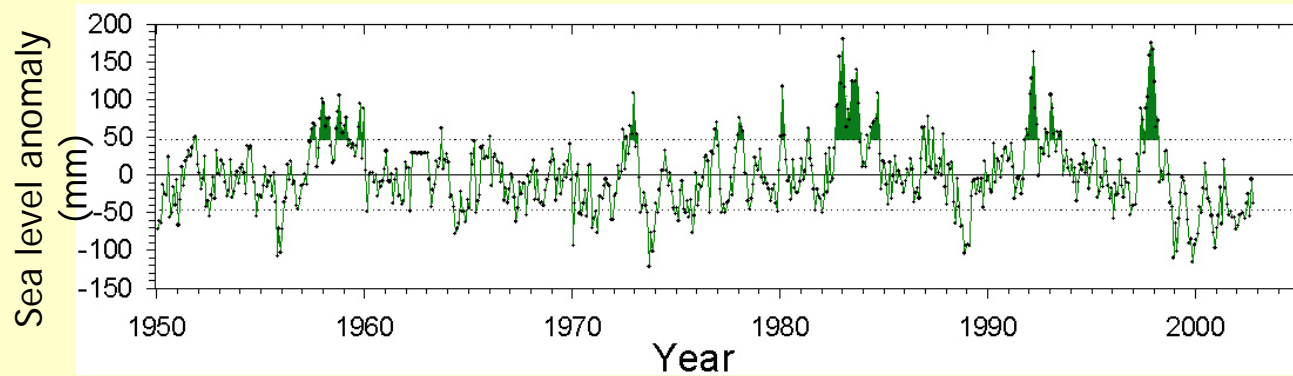
70% decline in
zooplankton biomass

N.B. This warming and decline
may have partially reversed
after 1999

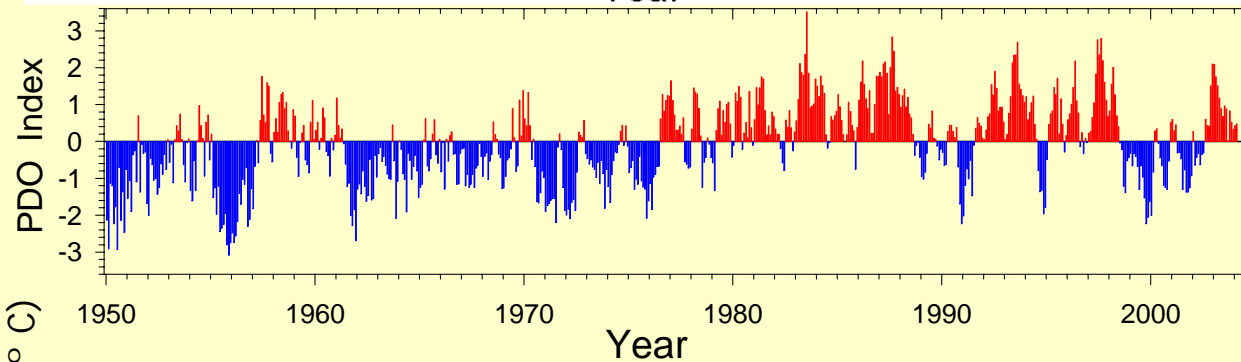
CalCOFI data

Roemmich and McGowan 1995 a,b

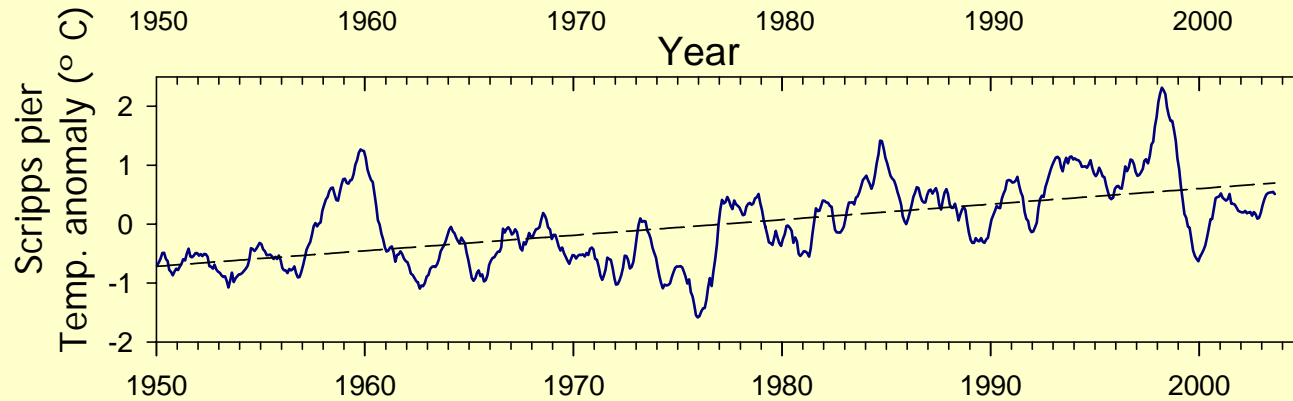
How will these different processes **interact** to affect living components of marine ecosystems ?



El Niño



PDO

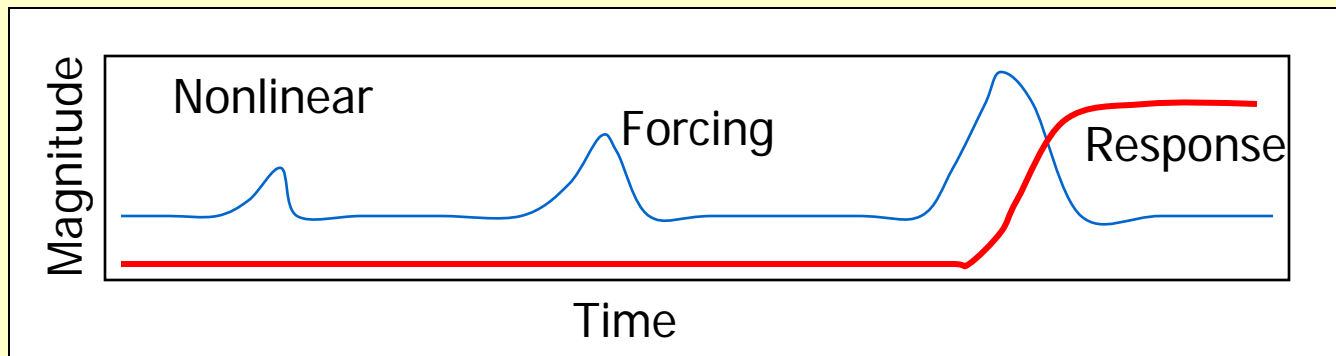
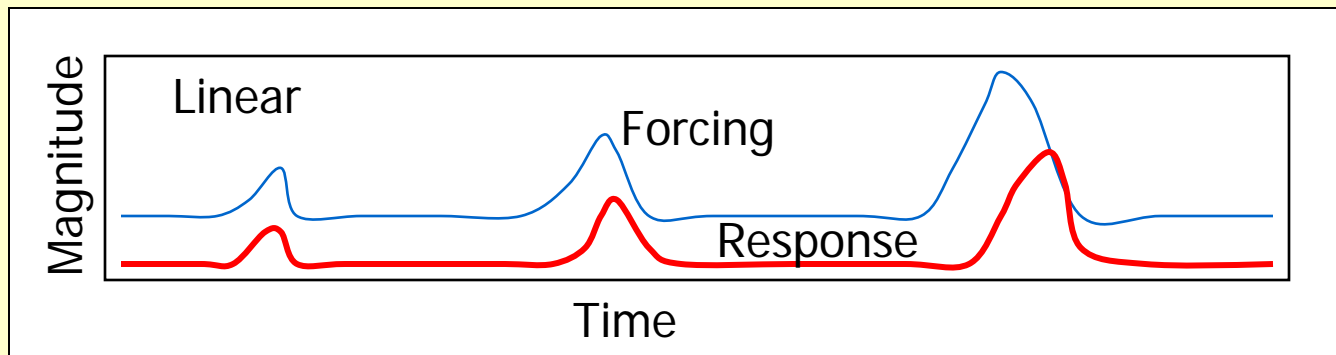


Warming Trend

Biological responses to changes in the physical environment are often *nonlinear*, hence ocean *ecosystem forecasting* cannot be done from physical measurements alone.

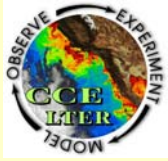
Supplemental Information

Linear vs. Nonlinear Responses



Nonlinear: commonly exhibit thresholds

courtesy of Peter Franks, SIO



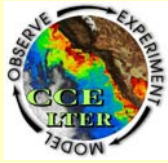
Physical time series from the North Pacific

Exhibit characteristics of linear red noise

<u>Time scale</u>	<u>Physical variable</u>	<u>Best θ</u>	<u>Δr</u>	<u>Nonlinear?</u>	<u>N</u>	<u>p-value</u>
weekly	Scripps Pier SST	0	0	NO	4226	1
monthly	Scripps Pier SST	0	0	NO	984	1
monthly	Pacific Grove SST	0	0	NO	945	1
monthly	Farallones SST	0	0	NO	764	1
monthly	PDO	0	0	NO	1248	1
monthly	NPI	0	0	NO	1260	1
monthly	SOI	0	0	NO	852	1
quarterly	Scripps Pier SST	0	0	NO	328	1
quarterly	PDO	0	0	NO	416	1
quarterly	NPI	0	0	NO	420	1
quarterly	SOI	0	0	NO	284	1
annual	Scripps Pier SST, composite	0	0	NO	984	1
annual	PDO, composite	0	0	NO	1248	1
annual	NPI, composite	0	0	NO	1260	1
annual	SOI, composite	0	0	NO	852	1

S-map method

θ = nonlinear tuning parameter, Δr = improvement in forecast skill (nonlinear - global linear model)



Biological time series from the North Pacific

⇒ Expect *nonlinear biological responses* to linear environmental forcing

<u>Time scale</u>	<u>Biological variable</u>	<u>Best θ</u>	<u>Δr</u>	<u>Nonlinear?</u>	<u>N</u>	<u>p-value</u>
weekly	Scripps Pier diatoms	0.3	0.139 *	YES	830	< 0.01
monthly	Scripps Pier diatoms	0.05	0.083	YES	206	0.134
quarterly	CalCOFI coastal larval fish	1.6	0.031 *	YES	3220	< 0.01
quarterly	CalCOFI coastal-oceanic larval fish	0.6	0.017	YES	1400	0.164
quarterly	CalCOFI oceanic larval fish	1.4	0.020 *	YES	4760	0.04
biannual	CalCOFI copepods	1.2	0.027	YES	1736	0.078
annual	CalCOFI copepods	0.4	0.015	YES	868	0.322
annual	CalCOFI coastal larval fish	0.6	0.060 *	YES	805	0.038
annual	CalCOFI coastal-oceanic larval fish	0.2	0.092	YES	350	0.063
annual	CalCOFI oceanic larval fish	0.6	0.017	YES	1190	0.273
annual	Chinook	0.4	0.44 *	YES	63	< 0.01
annual	Coho	0.3	0.117	YES	63	0.212
annual	Chum	0.175	0.767 *	YES	63	< 0.01
annual	Steelhead	0.2	0.272	YES	63	0.118
annual	Sockeye	0.7	0.168	YES	63	0.168
annual	Composite salmon and trout	0.3	0.078	YES	315	0.148

θ = nonlinear tuning parameter, Δr = improvement in forecast skill (nonlinear - global linear model)

Millennial-scale variations in California Current Ecosystems

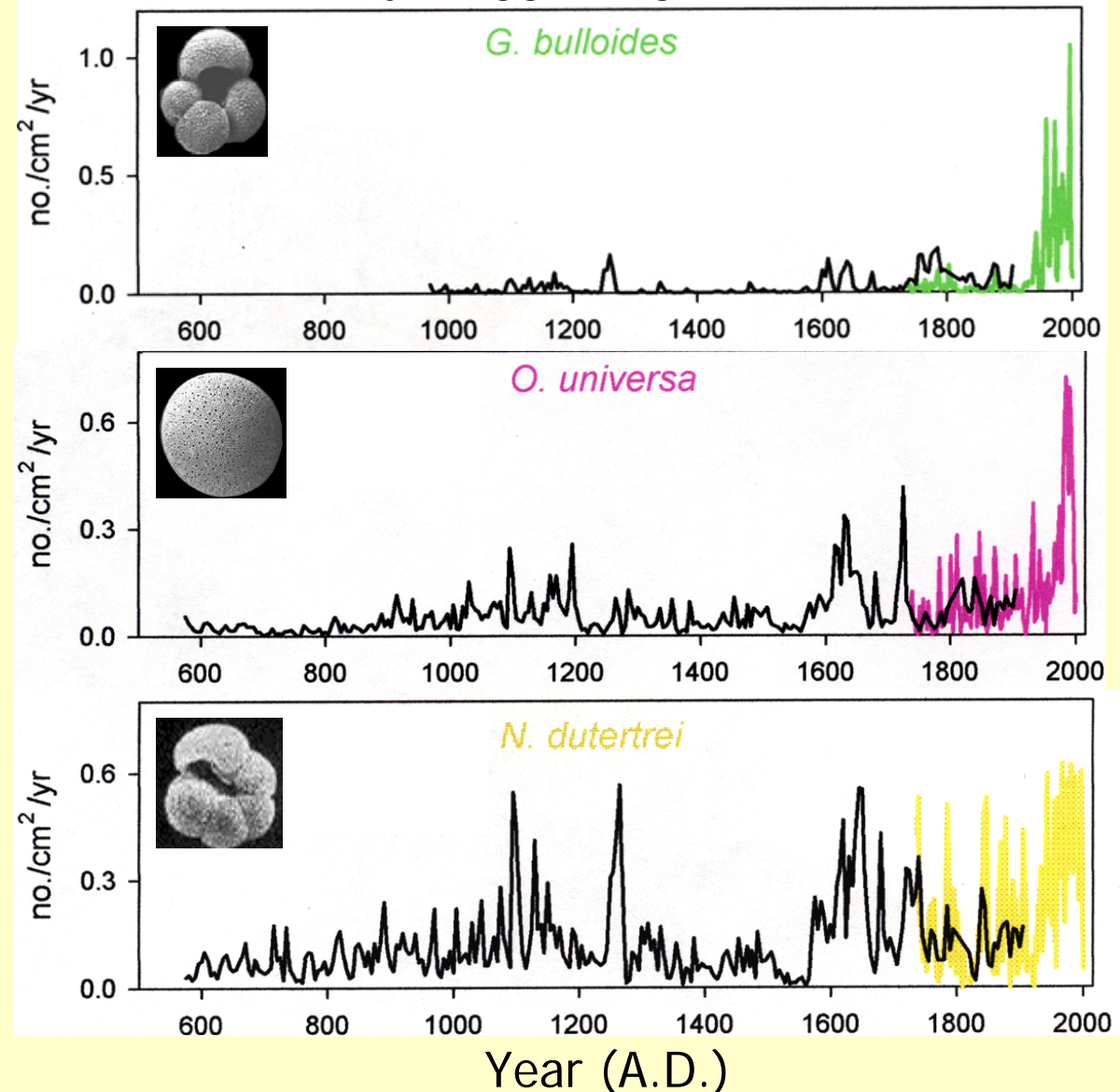
Long-term (millennial-scale) changes in the NE Pacific

Planktonic microfossils (foraminifera) from ocean sediments reveal unusual ocean conditions in the 20th century, suggesting recent ocean warming

David B. Field (2004)
SIO Ph.D. thesis

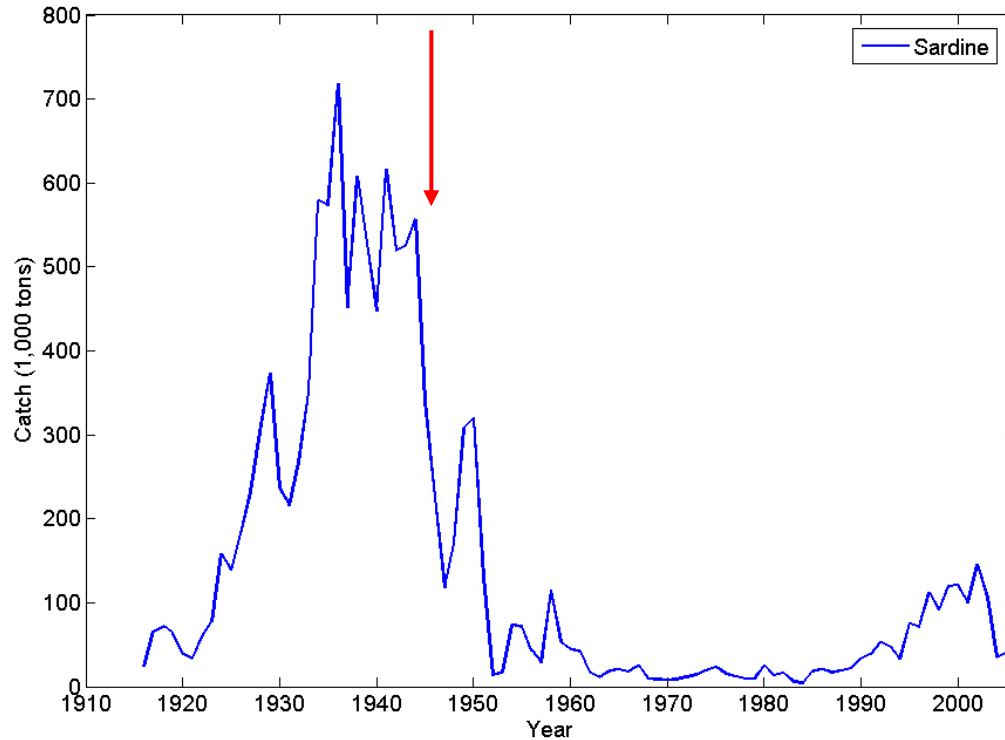
Sediment cores
from the Santa
Barbara Basin

Kasten cores
(~600-1900 A.D.)
Box cores
(~1750-2000 A.D.)



Historical variations in sardines and anchovies in the California Current

Crash of the California sardine in the 1940's:



Original Issue:

Overfishing?

or

a "natural" decline,

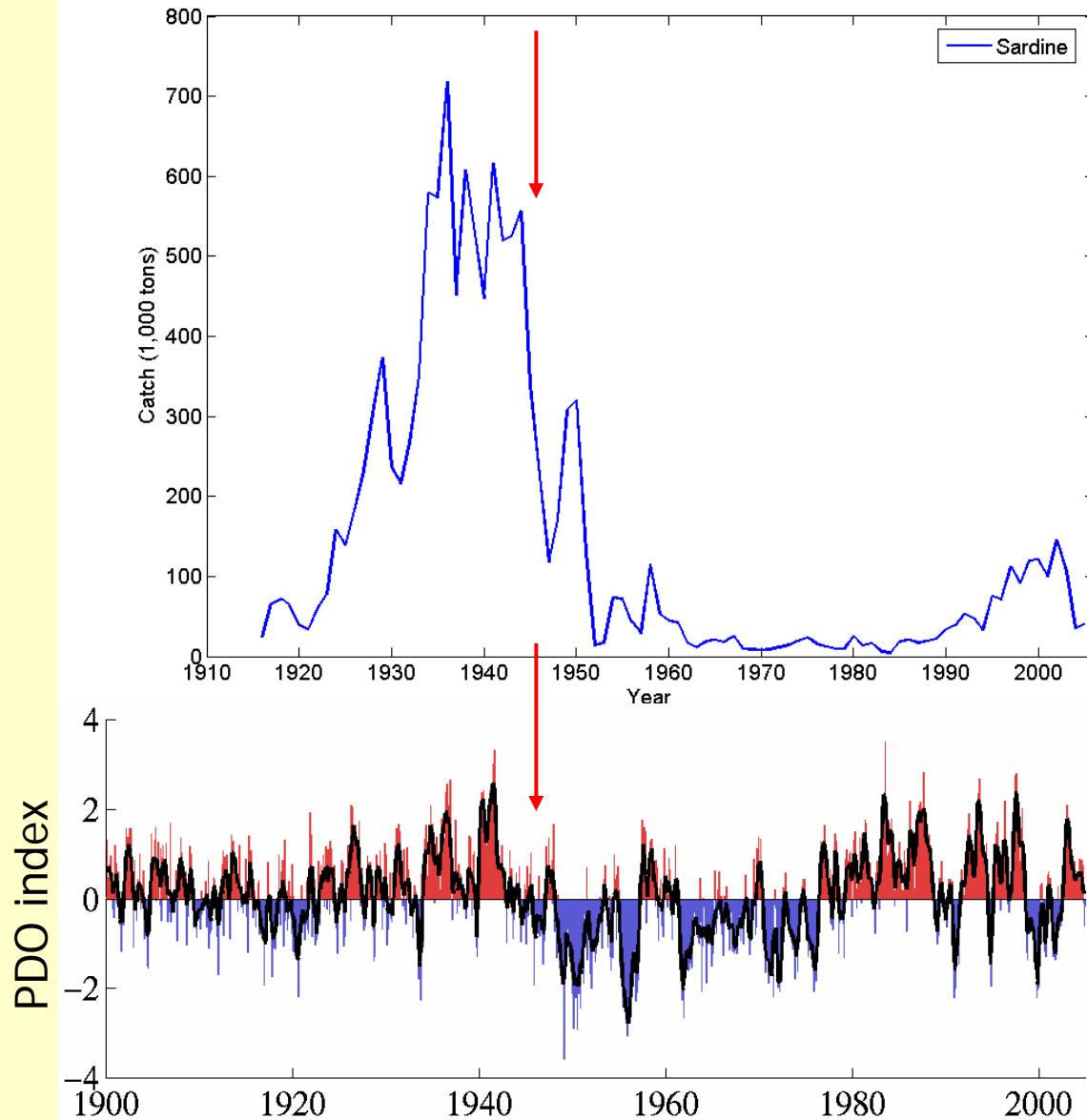
related to
environmental
variability?



In 1949 led to the creation of CalCOFI
(*California Cooperative Oceanic Fisheries
Investigations*)

Sardine catch courtesy of
D. Checkley/SIO & SWFSC/NMFS

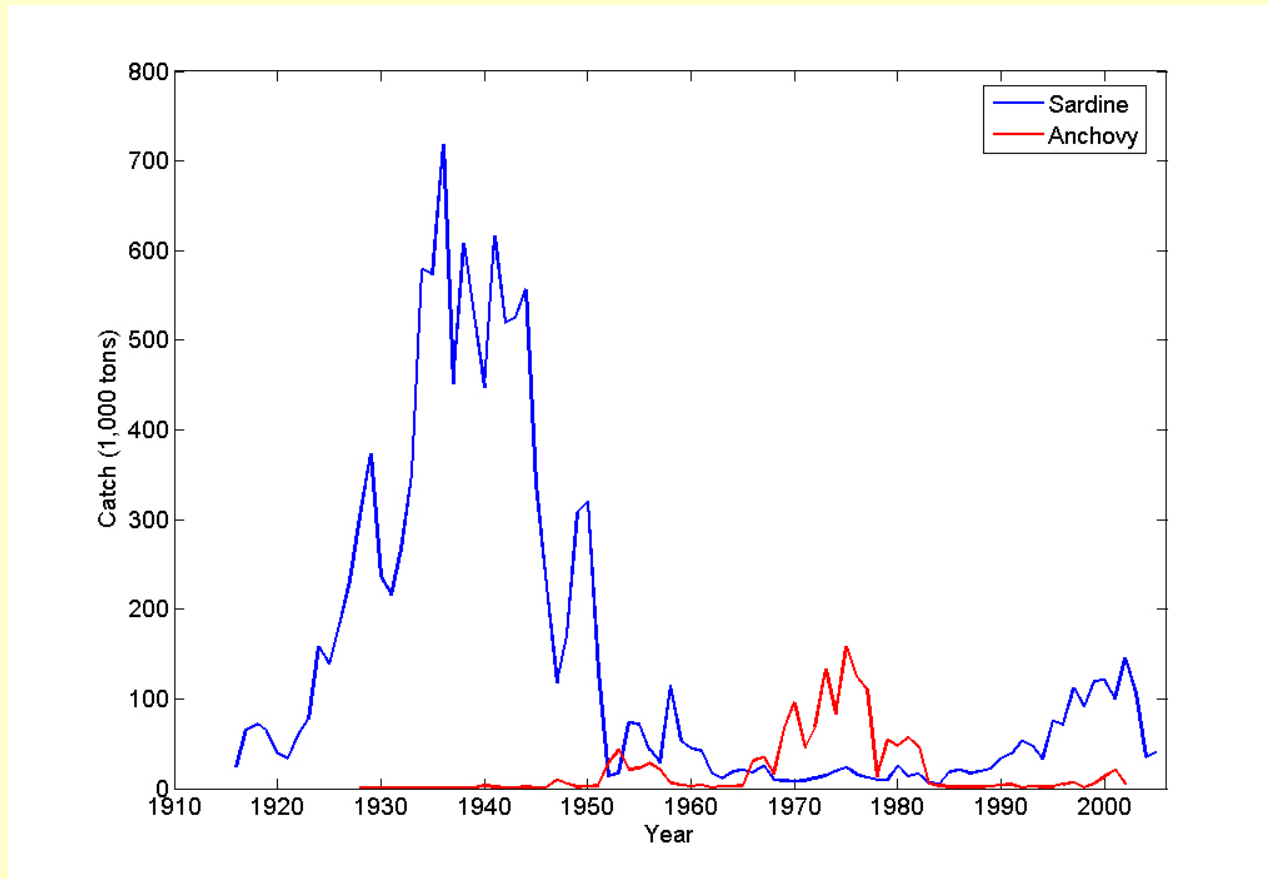
Crash of the California sardine in the 1940's:



Now recognized to be caused by a combination of increased fishing pressure in the post-war years *together with* a change in the ocean from a warmer to a cooler state in the early 1940's (see PDO)

Sardine figure courtesy of D. Checkley/SIO & SWFSC/NMFS

Out-of-phase variations of sardine and anchovy (20th century)



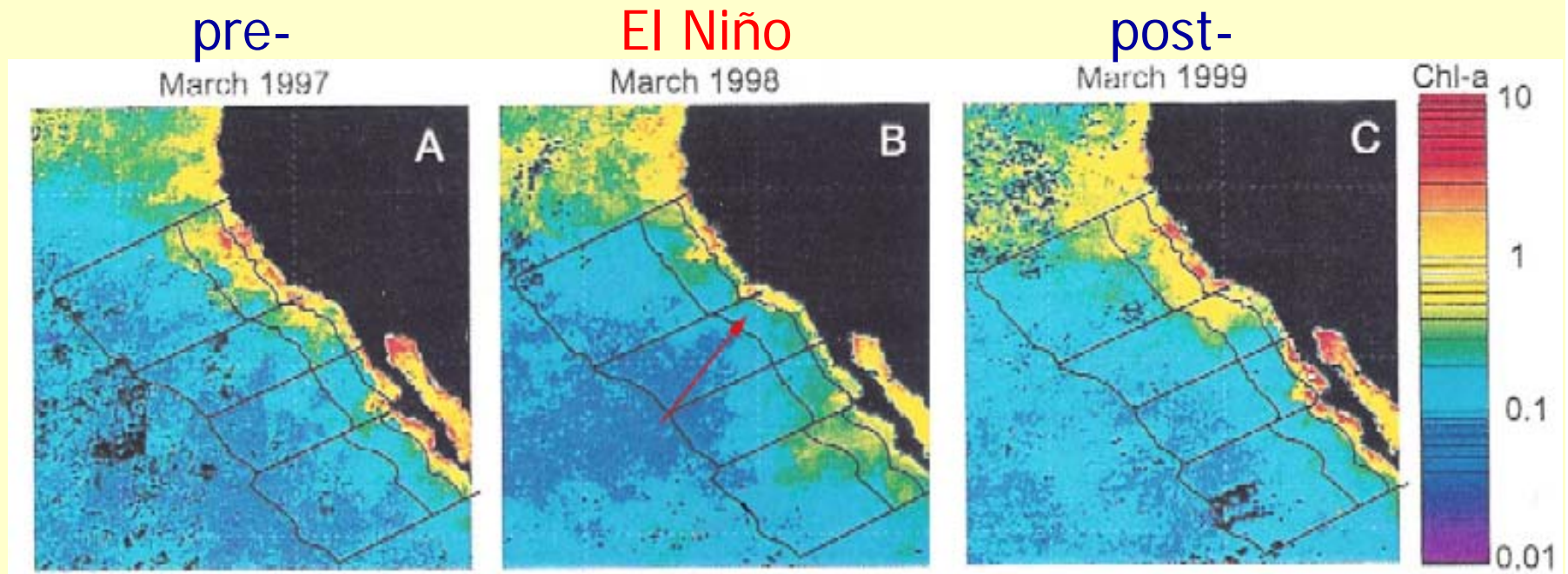
Also, similar out-of-phase oscillations of related species of sardines & anchovies in:

- NW Pacific off Japan
- SE Pacific off Peru
- SE Atlantic (Benguela Current)

Schwartzlose et al. 1999

El Niño – related effects on California Current Ecosystems

El Niño effects on primary production

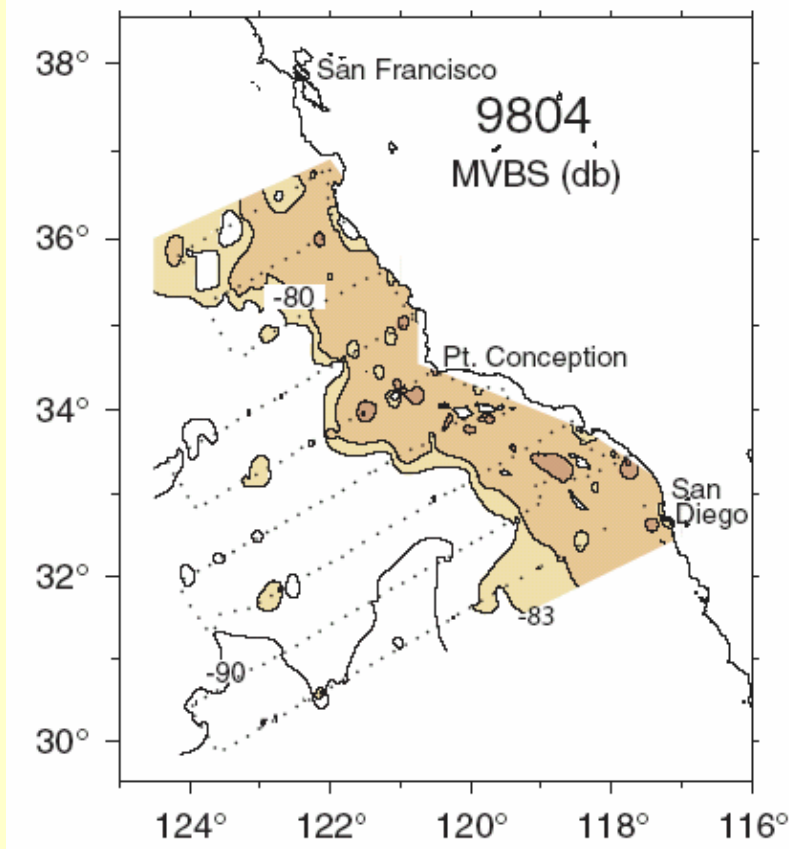


- Lower concentrations of phytoplankton
- Reduced areal extent of elevated phytoplankton biomass

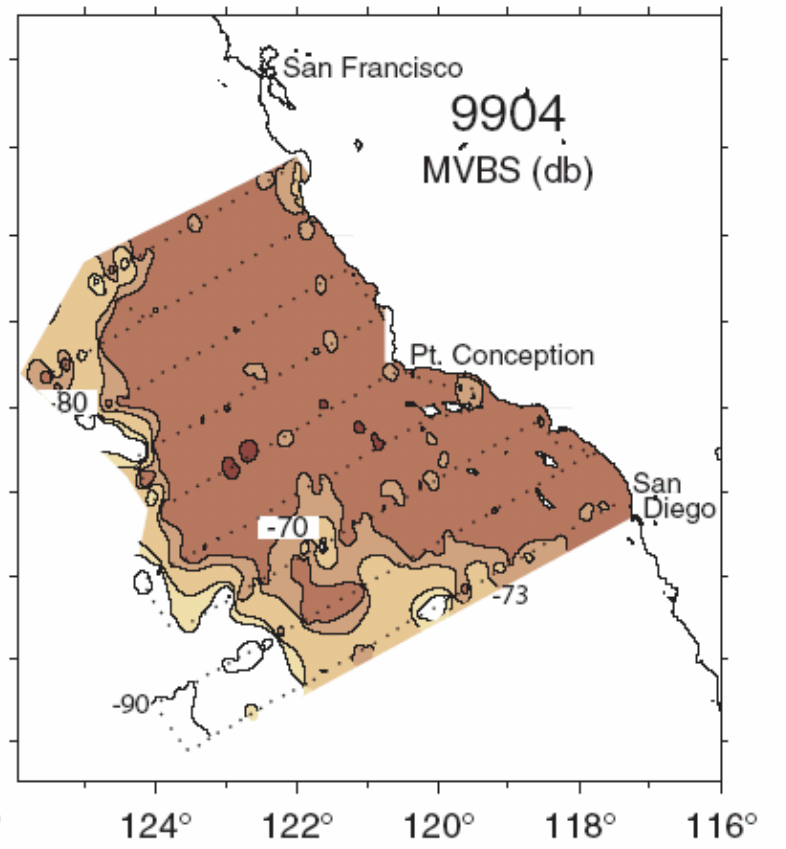
SeaWIFS satellite imagery
Kahru and Mitchell (2000)

El Niño effects on zooplankton biomass

El Niño



La Niña

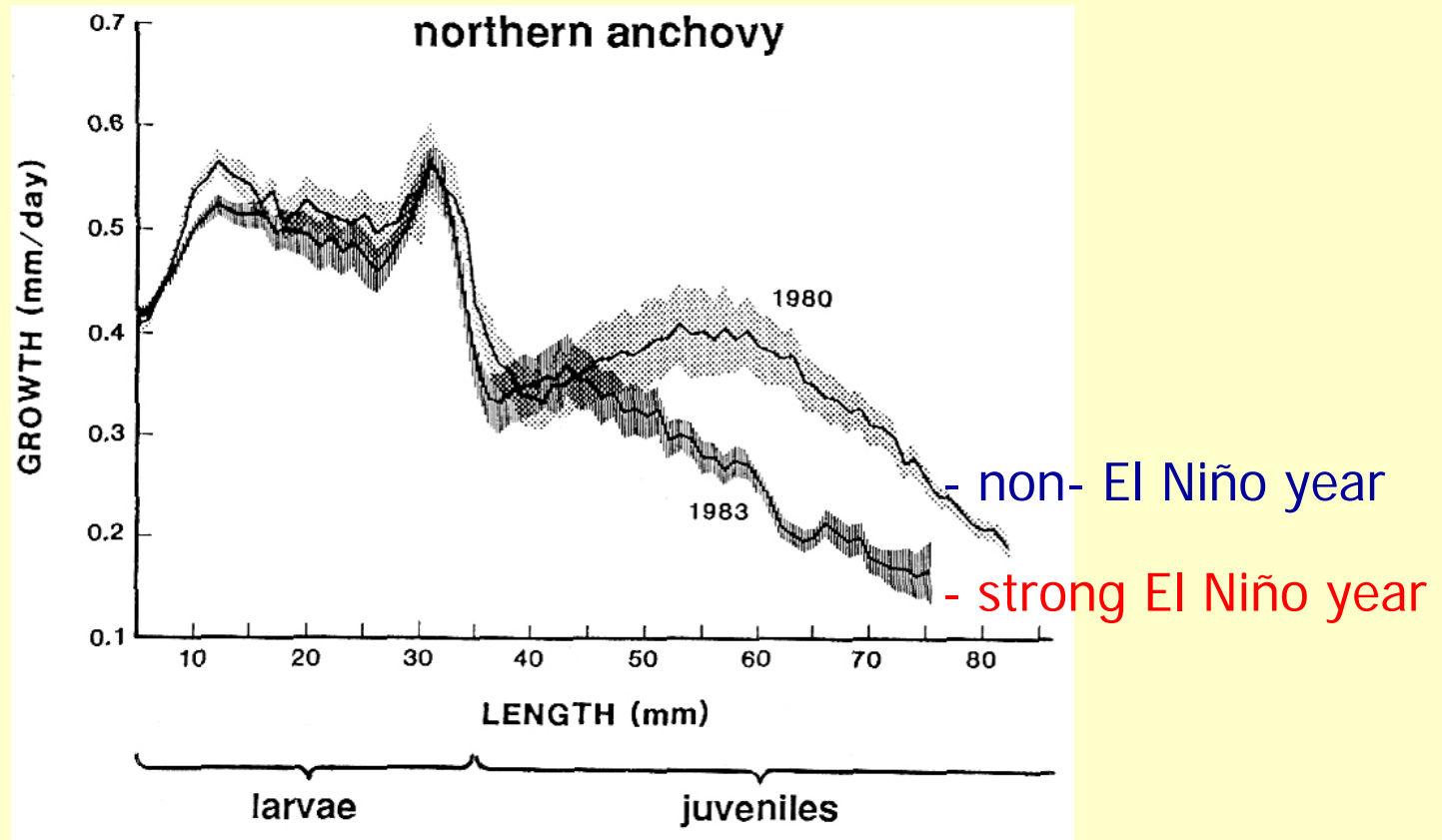


- Reduced zooplankton biomass
- Reduced areal extent of elevated zooplankton biomass

ADCP - Acoustic Backscatter Intensity

Lynn (2003)

El Niño effects on growth rate of juvenile anchovy



Engraulis mordax

Butler 1989

Research Sites

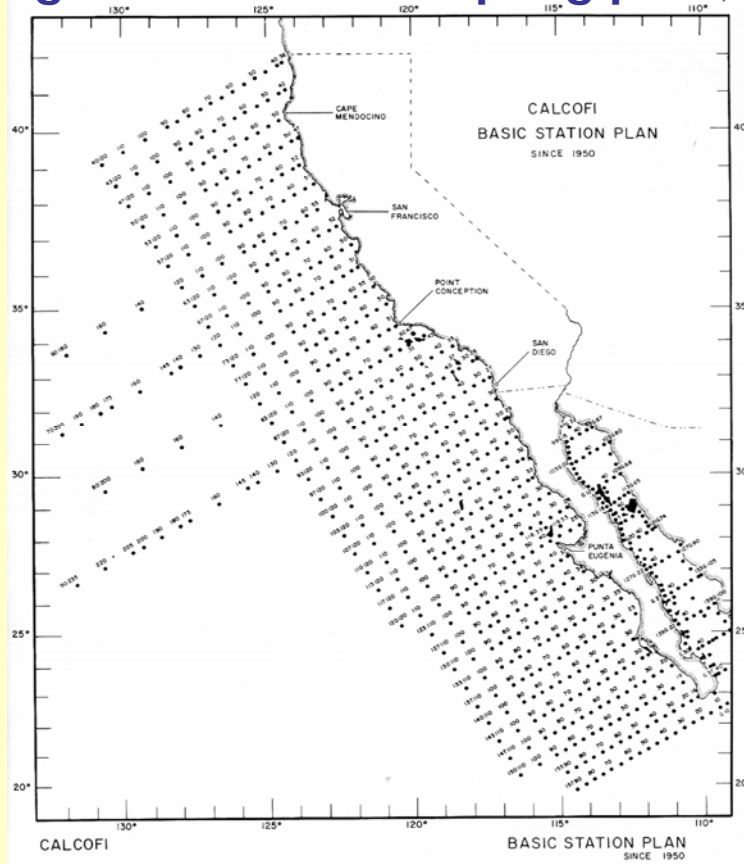


CalCOFI

California Cooperative Oceanic Fisheries Investigations

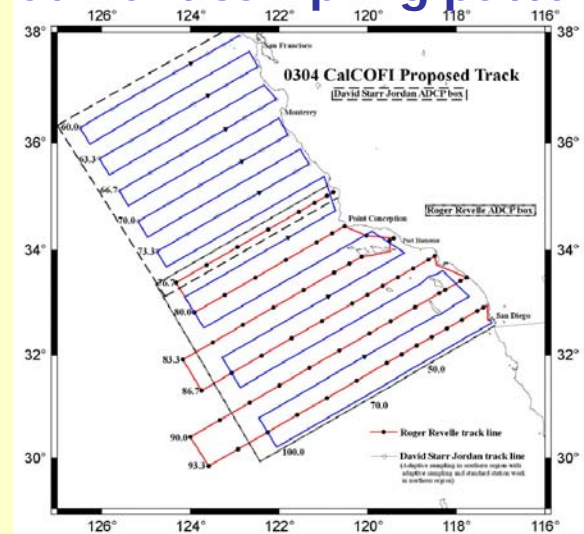
partners: Scripps Institution of Oceanography
U.S. National Marine Fisheries Service
California Dept. of Fish and Game

Original CalCOFI sampling pattern



- 1949 → present
- Among the most comprehensive biological-chemical-physical oceanographic time series

Current sampling pattern



NSF LTER (Long Term Ecological Research) Network – 26 sites

Terrestrial, Aquatic, & Urban systems



CCE-
California
Current
Ecosystem

Acknowledgments



NSF



U.S. GLOBEC NE Pacific Research Program



U.S. LTER Program



NMFS/NOAA



CalCOFI

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