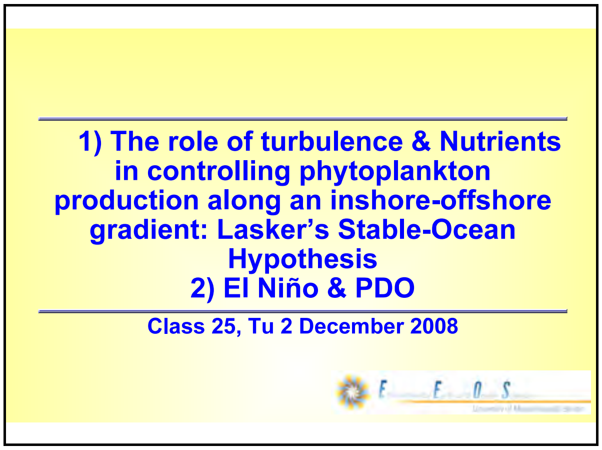
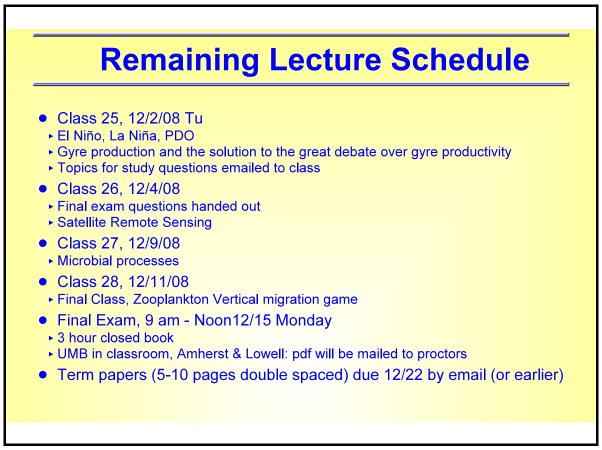


Slide 1 1) The role of turbulence & Nutrients in controlling phytoplankton production along an inshore-offshore gradient: Lasker's Stable-Ocean Hypothesis

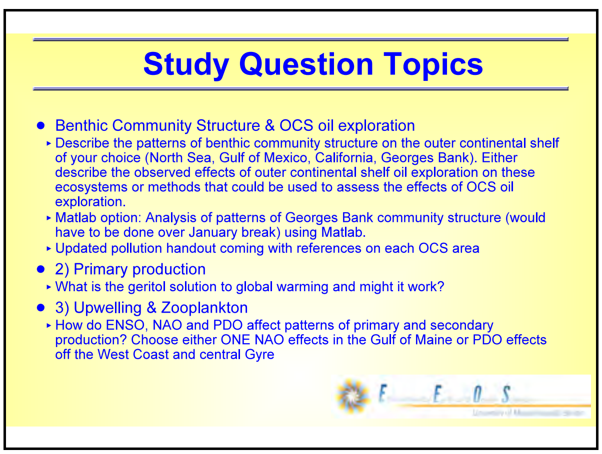
2) El Niño & PDO

NOTES:



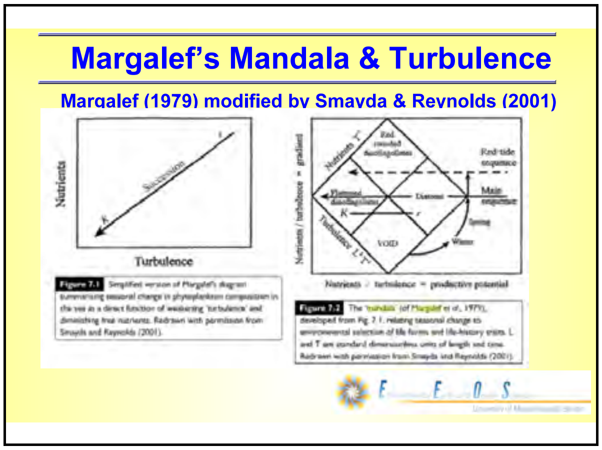
Slide 2 Remaining Lecture Schedule

NOTES:



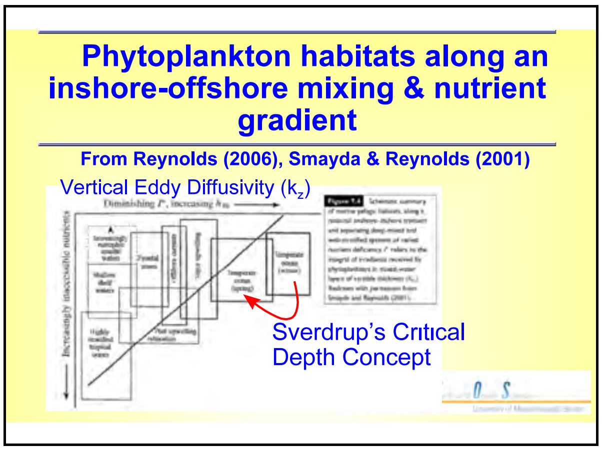
Slide 3 Study Question Topics

NOTES:



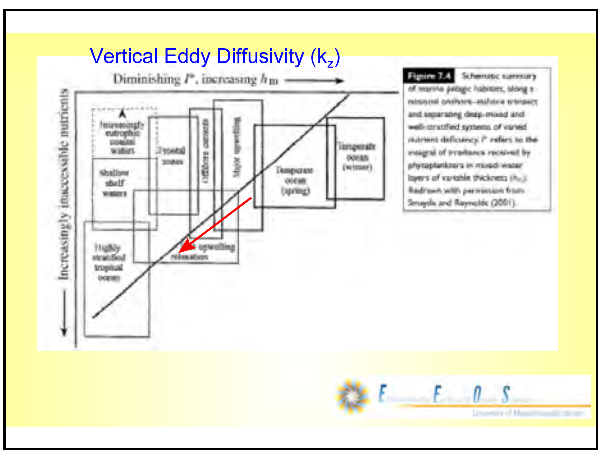
Slide 4 Margalef's Mandala & Turbulence

NOTES:



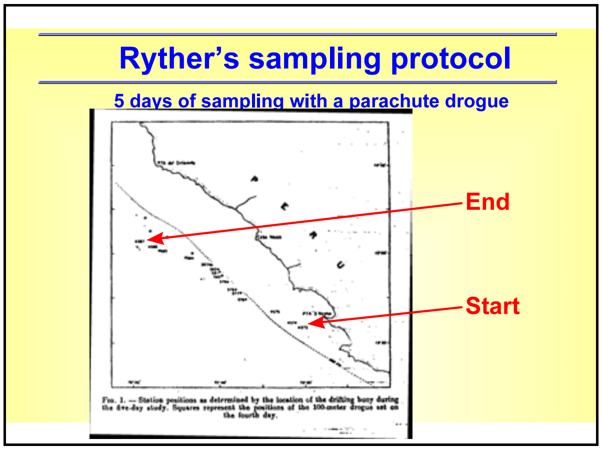
Slide 5 Phytoplankton habitats along an inshore-offshore mixing & nutrient gradient

NOTES:



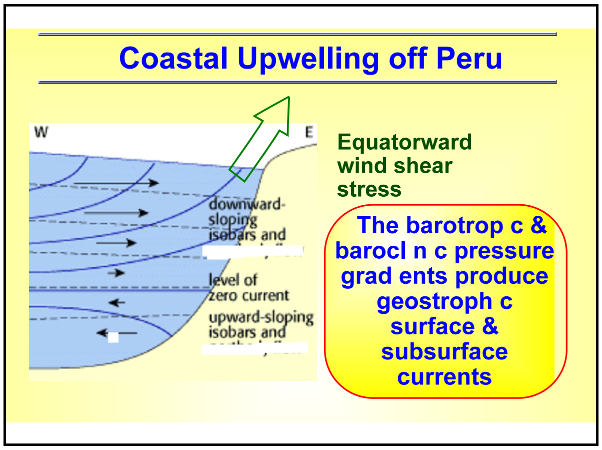
Slide 6

NOTES:



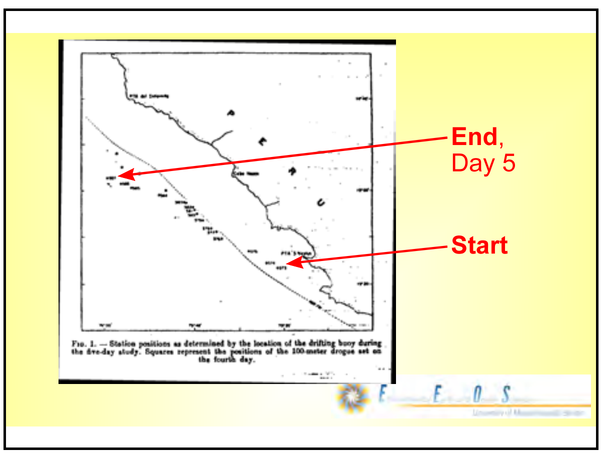
Slide 7 Ryther's sampling protocol

NOTES:



Slide 8 Coastal Upwelling off Peru

NOTES:

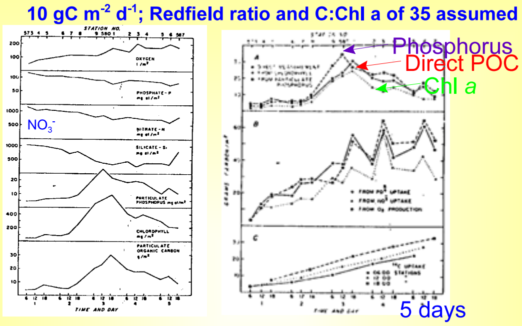


Slide 9

NOTES:

Production very high

10 gC m^{-2} d^{-1}; Redfield ratio and C:Chl a of 35 assumed



Slide 10 Production very high

NOTES:

Conclusions: Ryther et al. (1971)

Grazing implicated to account for decrease in biomass after day 3 – Could it be sinking?

- Phytoplankton species succession
  - *Chaetoceros debilis*, a diatom, most abundant species
  - Rapid replacement by *Chaetoceros socialis*
  - 9 species described
- Phytoplankton standing stock peaked at 3 days returned to low levels after 5 days
- Highest production measured in the ocean at that time
  - 3-11 g C m^{-2} d^{-1} production (Avg=10 g C m^{-2} d^{-1})
- Phytoplankton population ultimately controlled by grazing (or sinking)

Slide 11 Conclusions: Ryther et al. (1971)

NOTES:

Production at upwelling centers

MacIsaac et al.'s 4-stage succession (8-10 d period, 30-60 km advection from upwelling center)

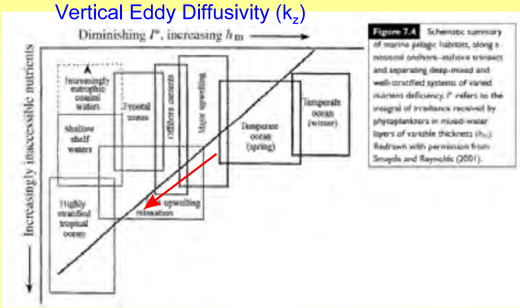
- Stage I: Seeding the water mass
  - High DIN, low temperature
  - High mixing (low average light intensity)
  - Seeding of the water mass stochastic
- Stage II: Shift up
  - P vs. I parameters (α and assimilation no.) adjust to new light regime
  - High nutrient uptake
- Stage III: Zone of peak growth, day 3 in Ryther et al. 1971
  - Zone of rapid successional change
- Stage IV: Shift down, Day 5 in Ryther
  - Nutrient depletion OR grazing

Note: Many of these changes in P vs. I and nutrient uptake characteristics may be associated phytoplankton succession

Slide 12 Production at upwelling centers

NOTES:

Vertical Eddy Diffusivity (k_z)



Slide 13

NOTES:

Critical depth and upwelling:

Huntsman & Barber (1977), discussed in Mann & Lazier

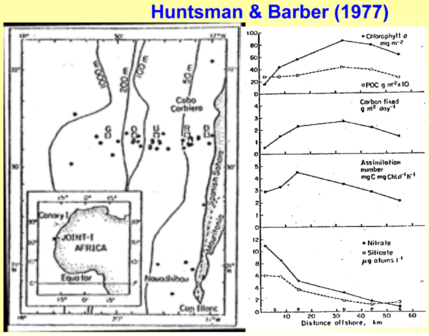
- Northwest African Upwelling
- High production is inversely correlated with upwelling favorable winds!
- Sverdrup's critical depth is key.
- Phytoplankton light-limited under high winds and vertical mixing regimes (wind speed>10 m s^{-1}).
  - Phytoplankton adjust the assimilation number in response to higher average light intensities
  - With mixing, no shade acclimation observed between shallow & deep phytoplankton samples
- Blooms occur after stratification events

Slide 14 Critical depth and upwelling:

NOTES:

NW African Upwelling

Huntsman & Barber (1977)



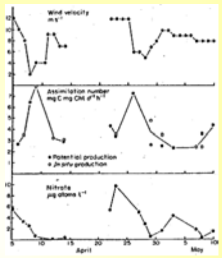
Slide 15 NW African Upwelling

NOTES:

NW African Upwelling

Primary productivity inversely correlated with upwelling-favorable winds Huntsman & Barber (1977)

- **With wind velocities over 10 m s^{-1}, phytoplankton are mixed so deep that they are light-limited**
  - **The mixed layer depth exceeds the critical depth**
- **When upwelling-favorable winds die down**
  - **Water column warms & stratifies**
  - **Assimilation number increases**
  - **Nitrate uptake at high rate**
- **Sverdrup's critical depth concept applies**



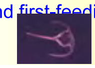
Slide 16 NW African Upwelling

NOTES:

Lasker's stable-ocean hypothesis

Species composition & non-steady state conditions key

- Why is there large year-to-year variability in Northern anchovy standing stocks off California?
- Are the 1st feeding larvae food limited?
  - Lasker took first- feeding larvae on-board ship
  - They starved except in water from the subsurface Chl *a* maximum (SSCM)
  - The SSCM dominated by 40-µm *Gymnodinium splendens*
- A period of stable water required after intense upwelling
  - Hunstman & Barber (1977) found that Chl *a* concentrations and production were inversely related to upwelling winds.
- During El Niño years, the water column is stable, but production is drastically reduced and first-feeding larvae starve

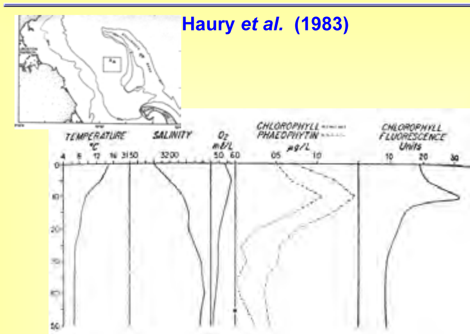


Slide 17 Lasker's stable-ocean hypothesis

NOTES:

MA Bay subsurface Chl *a* maxima

Haury *et al.* (1983)



Slide 18 MA Bay subsurface Chl a maxima

NOTES:

El Niño, La Niña & PDO

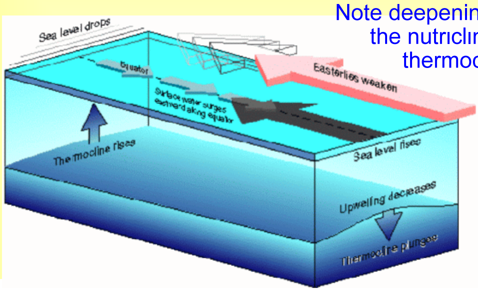
Slide 19 El Niño, La Niña & PDO

NOTES:

El Niño: warmer water than usual near Peruvian coast

Weakened easterly winds, and reduced SST gradient.

Note deepening of the nutricline & thermocline

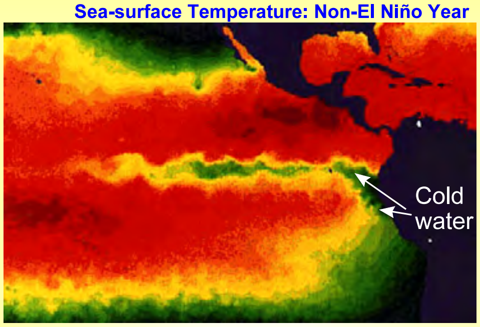


Slide 20 El Niño: warmer water than usual near Peruvian coast

NOTES:

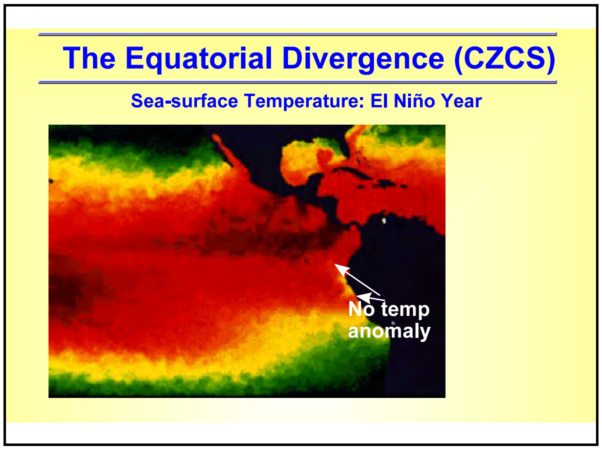
The Equatorial Divergence (CZCS)

Sea-surface Temperature: Non-El Niño Year



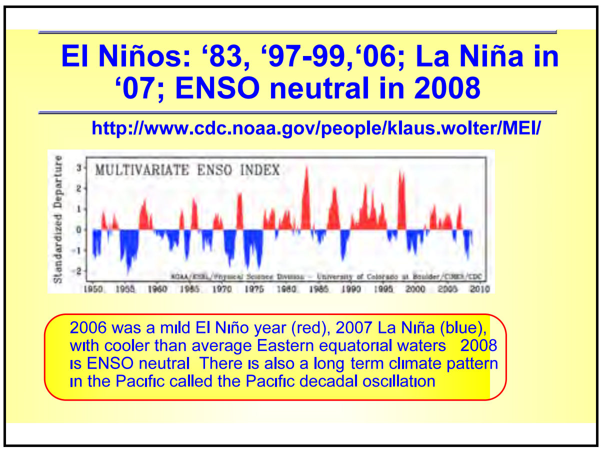
Slide 21 The Equatorial Divergence (CZCS)

NOTES:



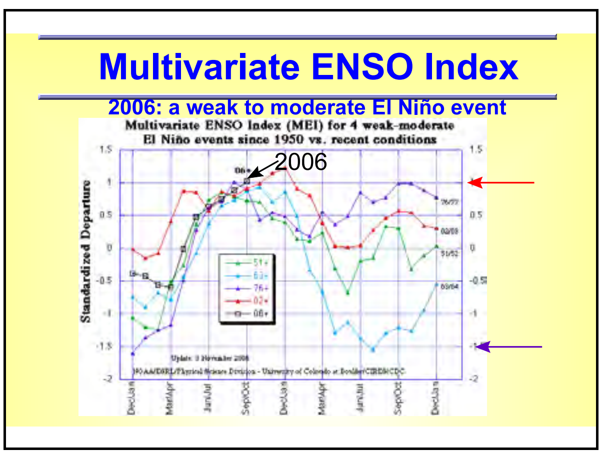
Slide 22 The Equatorial Divergence (CZCS)

NOTES:



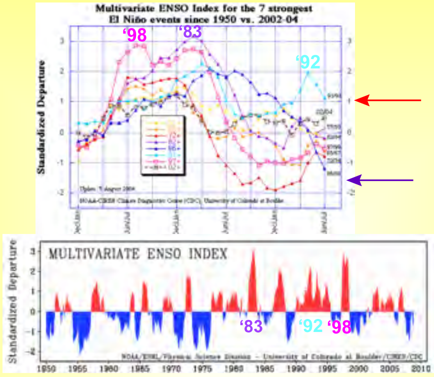
Slide 23 El Niños: '83, '97-99,'06; La Niña in '07; ENSO neutral in 2008

NOTES:



Slide 24 Multivariate ENSO Index

NOTES:

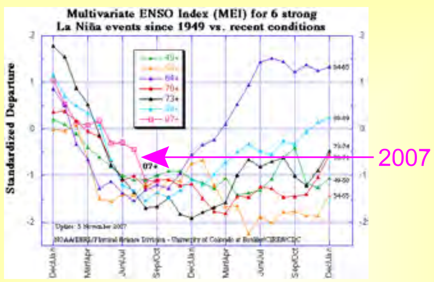


Slide 25

NOTES:

La Niña: colder water near eastern ocean boundary

Period of more intense Easterly winds



Slide 26 La Niña: colder water near eastern ocean boundary

NOTES:

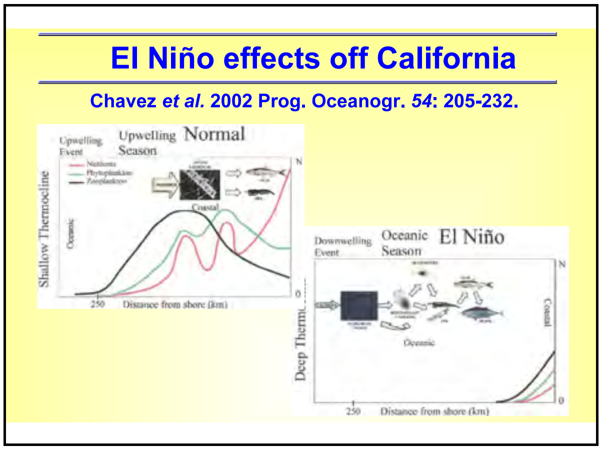
Ecological effects of El Niño

Barber & Chavez (1986) for ecological effects of '83 El Niño

- Reduced production near the coast and equator
  - In 1982-1983, production at the Peruvian upwelling center reduced despite "normal" equatorward winds
  - CO_2 flux to the atmosphere decreases: Why?
- Reduced abundance of microphytoplankton, macrozooplankton and fish
  - Birds along the equator abandon their nests, Schreiber & Schreiber (1984) Central Pacific seabirds and the El Niño Southern oscillation: 1982-1983 perspectives. Science 225: 713.
  - Fish populations are reduced or migrate

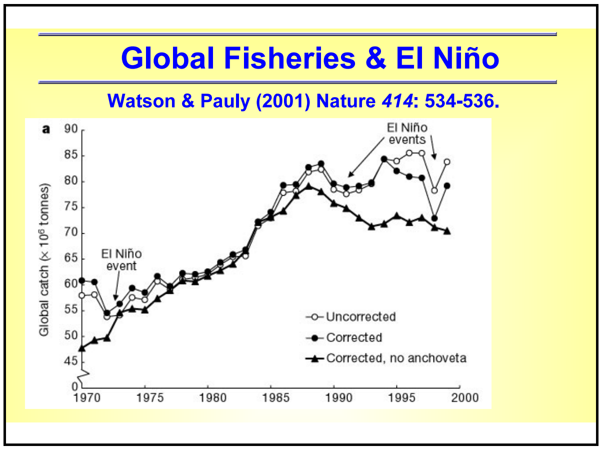
Slide 27 Ecological effects of El Niño

NOTES:



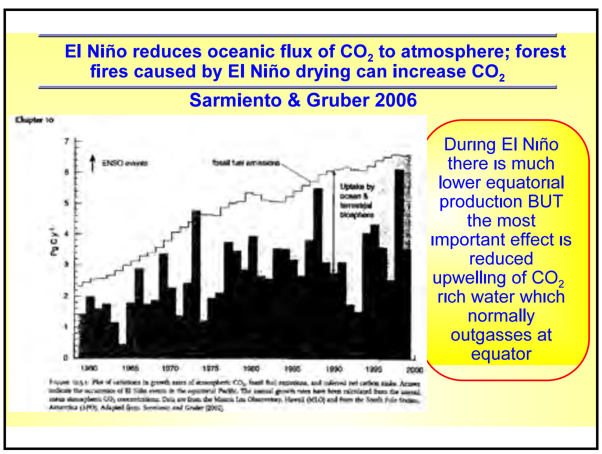
Slide 28 El Niño effects off California

NOTES:



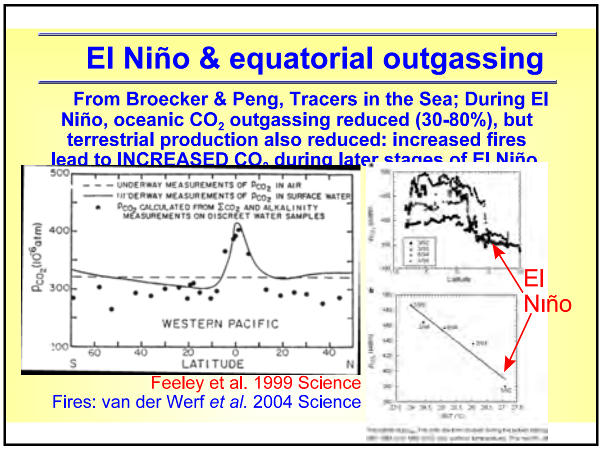
Slide 29 Global Fisheries & El Niño

NOTES:



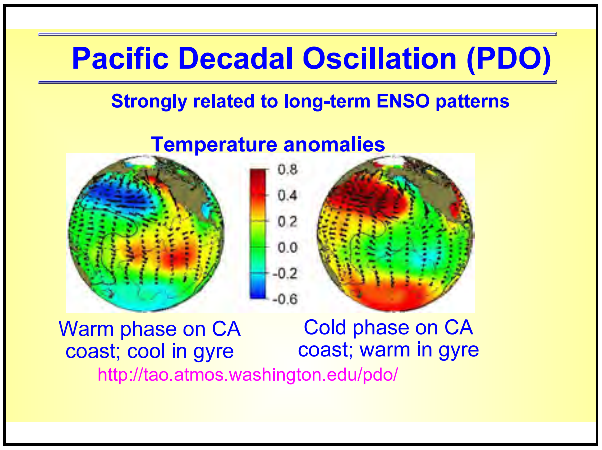
Slide 30 El Niño reduces oceanic flux of CO2 to atmosphere; forest fires caused by El Niño drying can increase CO2

NOTES:



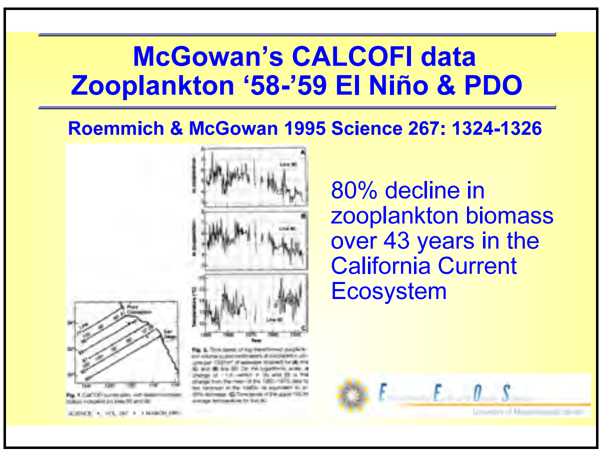
Slide 31 El Niño & equatorial outgassing

NOTES:



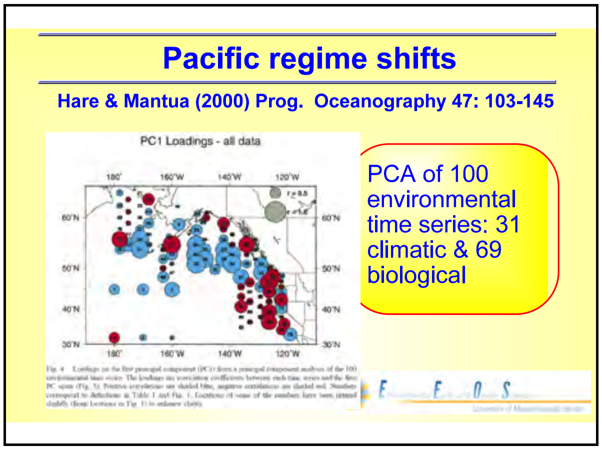
Slide 32 Pacific Decadal Oscillation (PDO)

NOTES:



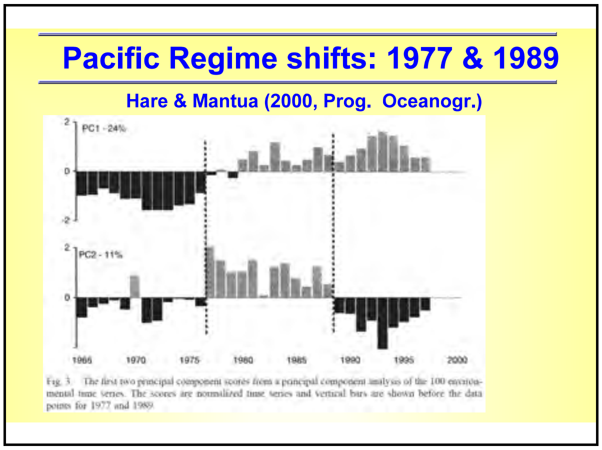
Slide 33 McGowan's CALCOFI data Zooplankton '58-'59 El Niño & PDO

NOTES:



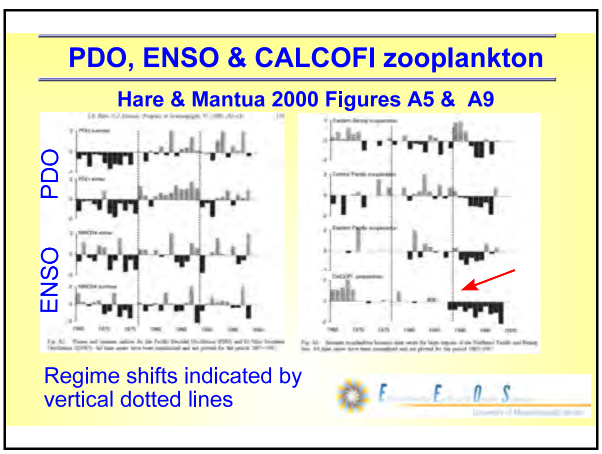
Slide 34 Pacific regime shifts

NOTES:



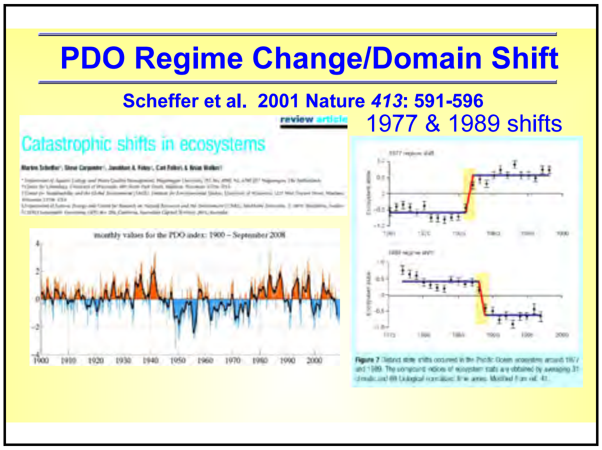
Slide 35 Pacific Regime shifts: 1977 & 1989

NOTES:



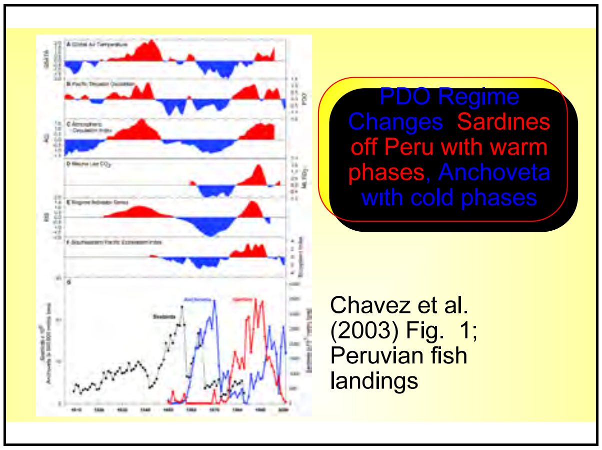
Slide 36 PDO, ENSO & CALCOFI zooplankton

NOTES:



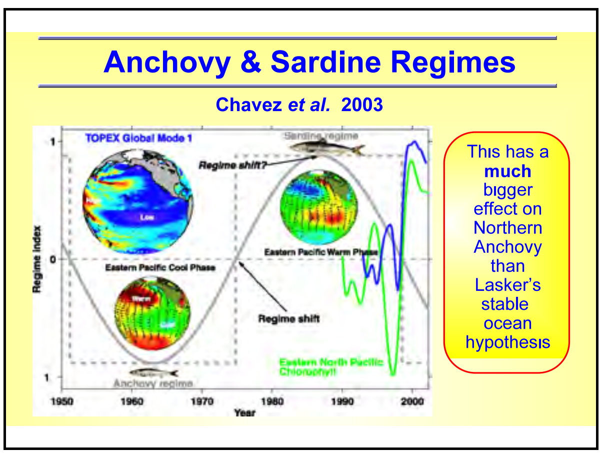
Slide 37 PDO Regime Change/Domain Shift

NOTES:



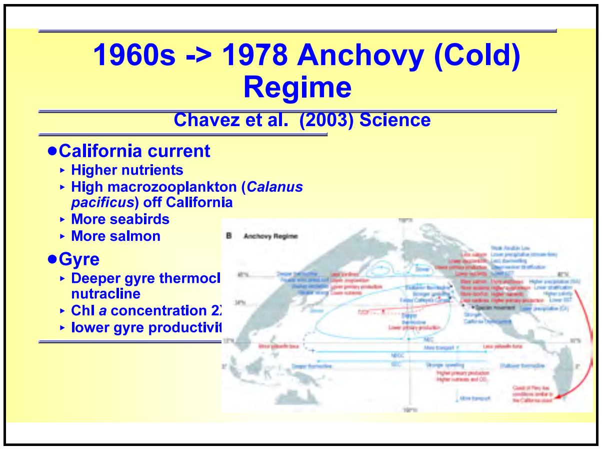
Slide 38

NOTES:



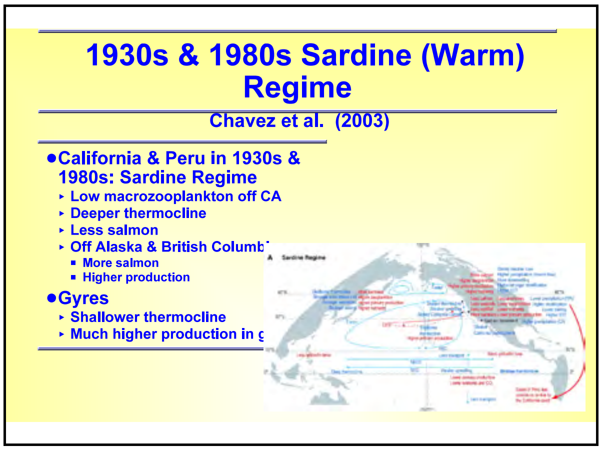
Slide 39 Anchovy & Sardine Regimes

NOTES:



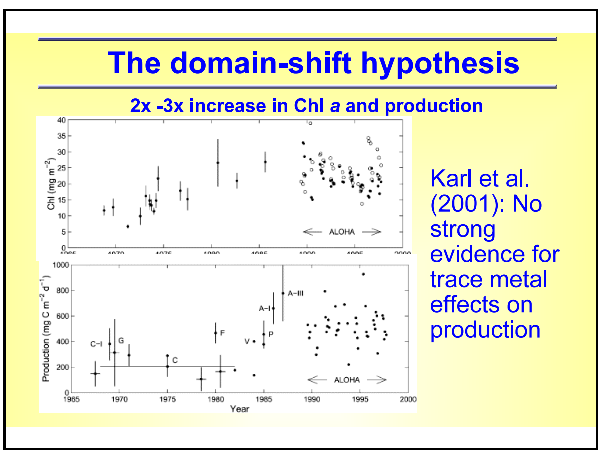
Slide 40 1960s -> 1978 Anchovy (Cold) Regime

NOTES:



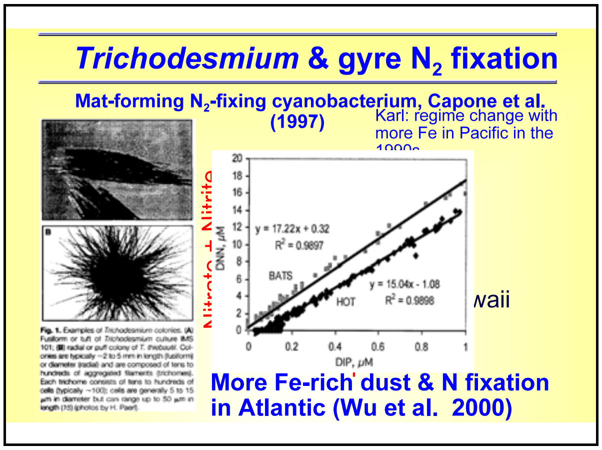
Slide 41 1930s & 1980s Sardine (Warm) Regime

NOTES:



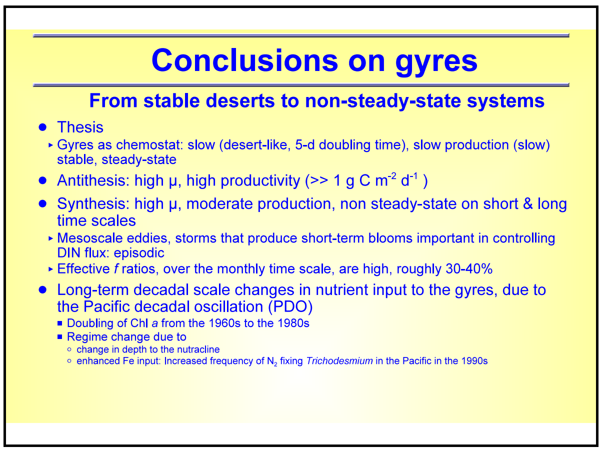
Slide 42 The domain-shift hypothesis

NOTES:



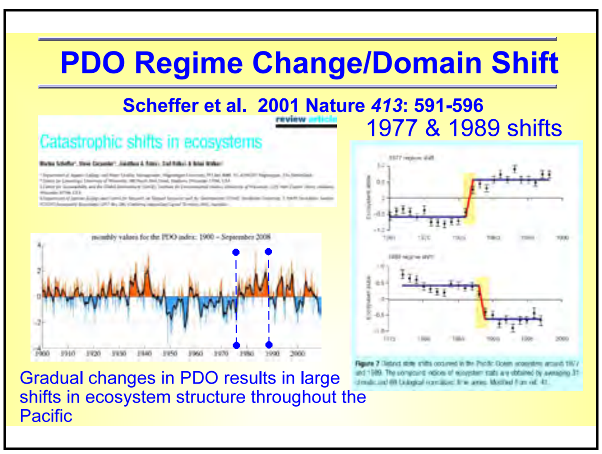
Slide 43 Trichodesmium & gyre N2 fixation

NOTES:



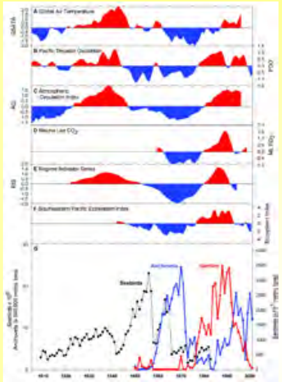
Slide 44 Conclusions on gyres

NOTES:



Slide 45 PDO Regime Change/Domain Shift

NOTES:



PDO Regime Changes: Sardines off Peru with warm phases, Anchoveta with cold phases

Chavez et al. (2003) Fig. 1; Peruvian fish landings

Slide 46

NOTES:

Conclusions on upwelling

Upwelling possible on all coasts & the equator

- Upwelling occurs along coasts and at the equator when winds are upwelling favorable
- Ekman mass transport, associated with the Ekman spiral, creates a divergence at the coast and at the equator
  - Ekman spiral due to the balance of drag & Coriolis forces
  - Surface current is 45° to the right of the wind in the surface.
  - Velocity declines with depth, spiralling clockwise in the N, counterclockwise in the S.
  - At the Ekman depth, or depth of frictional influence, the currents are oriented opposite to the surface current
  - Net Ekman mass transport is 90° to the right of wind in the Northern hemisphere (left in Southern hemisphere)
  - Ekman transport creates a sea-surface tilt and upwelling producing windward surface and opposite geostrophic counter currents.

Slide 47 Conclusions on upwelling

NOTES:

Conclusions: El Niño

- During El Niño years, easterly winds weaken, the pycnocline on the Eastern boundary deepens, and the pycnocline on the Western boundary deepens
- Despite upwelling favorable winds, upwelled water is warmer and contains lower nutrient concentrations.
- La Niña is a period of intensive Easterly winds, shallow pycnoclines and nutraclines on Eastern boundaries

Slide 48 Conclusions: El Niño

NOTES: