Climate-Driven Fluctuations in Fish Stocks of the California Current

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Sardines

The Original “Indicator” Species

• But indicator of what?
  – Overfishing?
  – Environmental fluctuation?
The Paleosedimentary Record
Santa Barbara Basin – 2000 years

- Soutar and Isaacs, refined by Baumgartner et al.
- Large fluctuations in sardine abundance are “normal”
• Kawasaki showed near-simultaneous fluctuations in sardines off Japan, California and Peru/Chile

• This demonstrated that the fluctuations were not local, but at least hemispheric in scale
California Sardines
Fishery vs. Environment

- Jacobson and MacCall (1995) produced temperature dependent stock-recruitment curves
  - A sardine produces twice the recruits in favorable times
- During very cold periods, no level of fishing is sustainable
Japanese Sardines  
A Clear Regime Shift

- Wada and Jacobson (1998) estimated reproductive success under favorable and unfavorable conditions
- In Japan, sardines produce 20 times more recruits when conditions are favorable!
- Shifts are sudden
But how does it happen?

• The key paradox:
  “It remains unclear why sardines increase off Japan when local waters cool and become more productive, whereas they increase off California and Peru when those regions warm and become less productive” (Chavez et al. 2003)
A New Hypothesis
(Developed in Honolulu, 2001)

• The Kuroshio is cool when flow is weak
  – Source water is warm

• The California Current and Humbolt Current are warm when flow is weak
  – Source water is cold

• The error is in considering temperature as the environmental component

• It’s the flow!
The Flow Hypothesis
Physical Aspects

• Retention of larvae is a major problem for fishes living in boundary currents
  – Larval/juvenile development time is a rigid constraint

• Conditions of high flow rate result in high loss of offshore-spawned larvae

• Conditions of low flow rate allow use of the offshore regions for reproduction
  – Larvae are able to gain swimming capability before being lost from the system
The Flow Hypothesis
Feeding and Fecundity

In the California Current, northward migrating sardines gain access to rich food supplies (Parrish, Baumgartner hypotheses)

– A recent sardine landed in Oregon had 27% oil content
– Oil translates directly to fecundity in clupeoids due to indeterminate high frequency spawning
– Warmer northern water also avoids lower thermal limits

• Possible mesoscale, frontal effects on food supplies associated with flow conditions
The 1939 Survey

- Now the early surveys make more sense!
  - ca. 200,000 sq miles of habitat become available for sardines
- Older fish tend to live farther north (upstream) during low-flow periods
- The British Columbia “stock” may be linked to the California “stock” by an offshore corridor

Figure 2. Locations of net tows taken to search for Pacific sardine eggs in May and June 1939 (Ahlstrom 1948). Net tows taken by Scofield (1934) were used to design the cruise.
What about South America?

- Information is limited
  - Restricted to nearshore
- 1963-72 (left)
  - Sardines only in north
- 1981 (right)
  - Sardines suddenly appear at Talcahuano
- Analogous to California – British Columbia relationship
The Offshore Shift in Japan

- Spawning of Japanese sardines moved from nearshore into the vicinity of the Kuroshio Current
- They already were optimally positioned upstream at a time of high ocean productivity!

Fig. 3. Shift in the main spawning grounds of the Japanese sardine from 1965 to 1989 (Darker areas correspond to larger amounts of sardine eggs).
The Offshore Shift in Japan

- 4 million sq miles of productive habitat become available as nursery and feeding grounds
- Oyashio supplies nutrients
Sardine vs. Anchovy
(California and Peru/Chile)

• Anchovies may be too small (size = swimming capability) to use the offshore habitat.
  – Restricted to the nearshore, they suffer from reduced plankton production during warm low-flow periods
  – They are able to benefit from high nearshore production during cool high-flow periods

• Anchovies potentially can be abundant during sardine periods! (but usually are not)
  – The inverse relationship is a tendency, not a rule
  – The paleosedimentary record indicates episodes of simultaneous abundance
Pelagic Fish Assemblages

• Boundary currents share similar species lists
  – Sardinops (sardine)
  – Engraulis (anchovy)
  – Scomber (true mackerel)
  – Trachurus (jack mackerel)

• How does each species respond to changes in boundary current flow?
Pelagic Fish Assemblages

Calif. Current

- Major species are rarely abundant together
  - *Trachurus* is catch, others are abundance

- *Trachurus* and *Scomber* seem to follow regime shifts

- Fishing effects can change timing
  - *Sardinops* delayed due to low abundance
Pelagic Fish Assemblages

Japan

- Sequence is similar to California Current
- **Scomber** increase precedes **Sardinops**
- Recent developments:
  - **Sardinops** is gone
  - **Trachurus** is increasing
Species Relationships
Boundary Current Pelagics

Weak Flow
Sardinops

Regime Shift
Trachurus

Regime Shift
Scomber

Strong Flow
Engraulis -- nearshore
(+ Trachurus offshore?)
Synchronicity: Global Circulation
COADS SST 1953-2001

- 2° bands, near and far
- Low-pass filter (7-yr mean) to remove El Niño
- 1st EOF may be due to partial cycle
- 2nd EOF shows Peru/Chile vs Japan and inverse Benguela relationships
  - California is mixed
Synchronicity: Global Circulation (detrended) Coastal Sea Levels

- Intensity of N and S Pacific gyres tends to be linked
  - Benguela Current is 180° out of phase
Worldwide Pattern

• Synchronicity is only approximate

• Japan, South America and California Current are in phase
  – Japan and So. America may be synchronous
  – Calif. Current lags Japan and So. America

• South Africa is 180º out of phase
  – Sardines increased strongly in 1990’s

• Is Europe/Canary Current in phase?