Climate-Driven Fluctuations in Fish Stocks of the California Current

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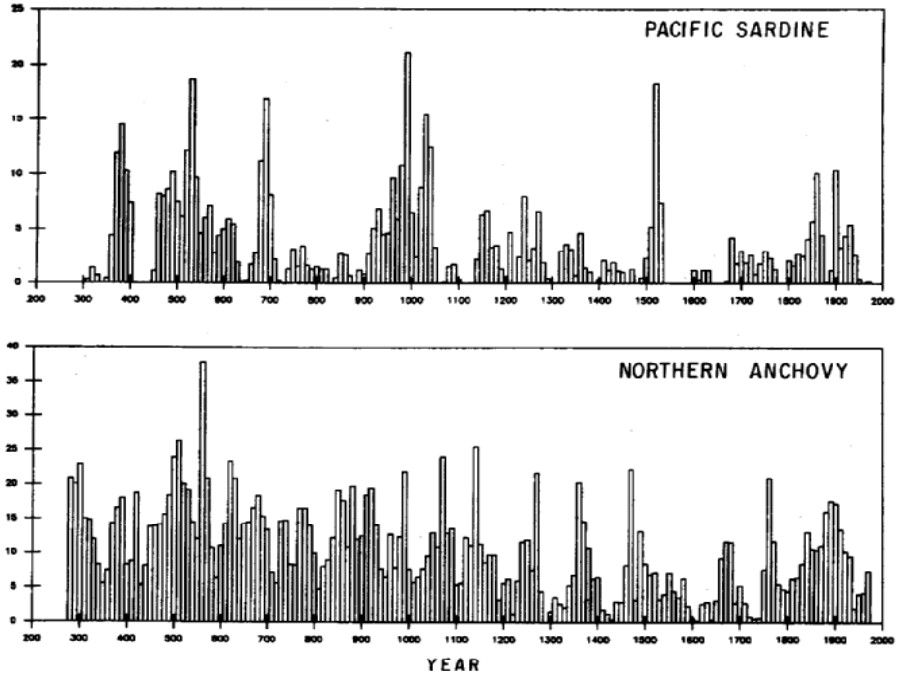
Sardines

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”

FAO San José 1983

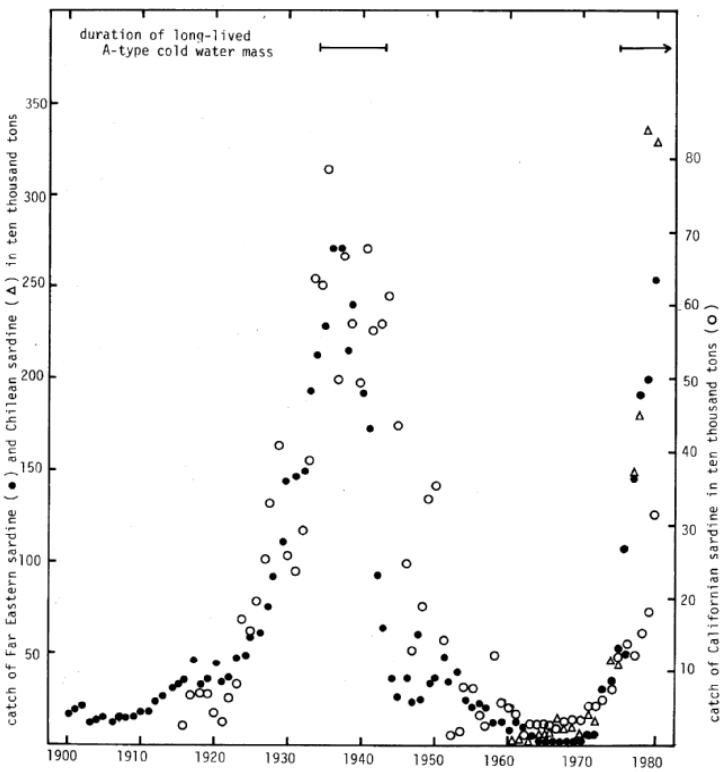
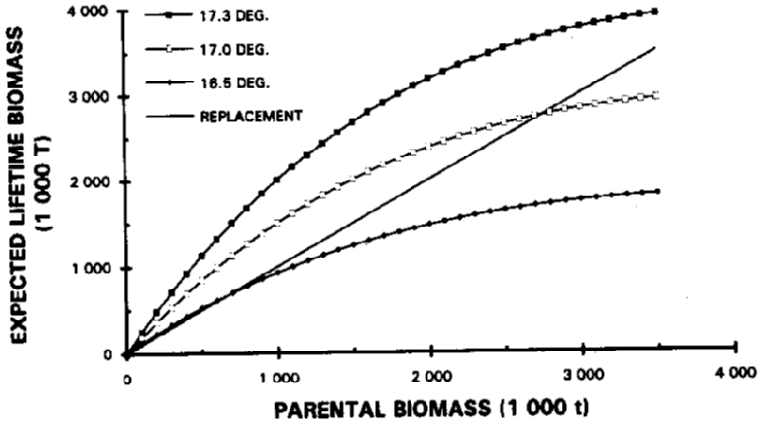


Fig.1. Large-scale variations in catch of three species of sardine, Far Eastern, Californian and Chilean.

- 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

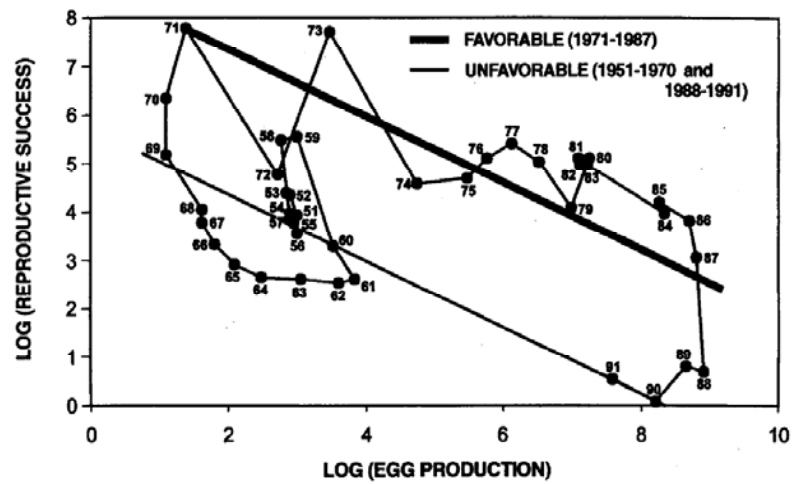
California Sardines Fishery vs. Environment

Fig. 6. Expected lifetime spawning biomass for recruits at mean three season SST levels of 16.3, 17.0, and 17.9°C from the management model [2] for log reproductive success.



- 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

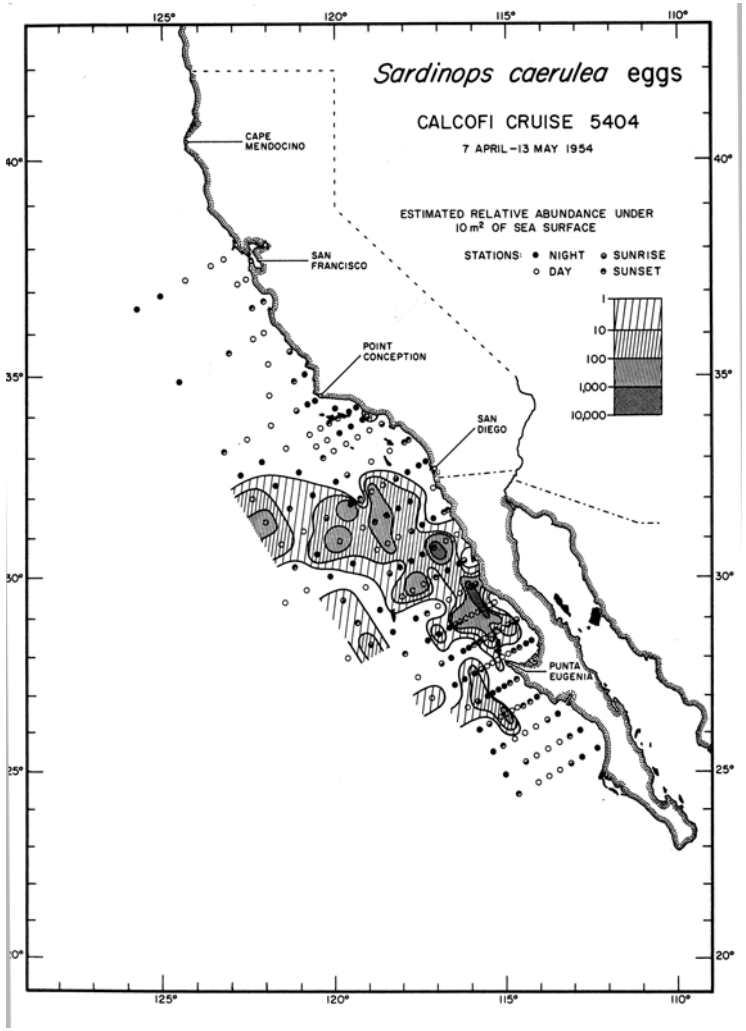
The Flow Hypothesis
Feeding and Fecundity

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

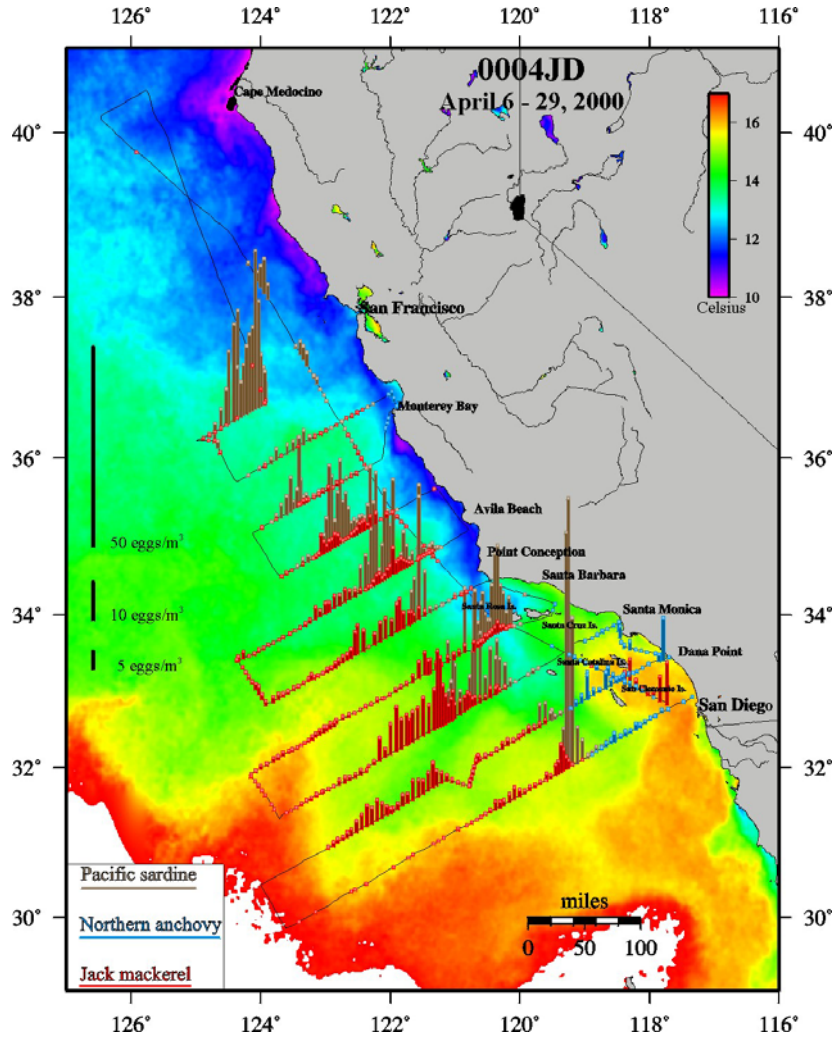
- A recent sardine landed in Oregon had 27% oil content
- Oil translates directly to fecundity in clupeoids due to indeterminate high frequency spawning
- Warmer northern water also avoids lower thermal limits

- Possible mesoscale, frontal effects on food supplies associated with flow conditions

1954


Sardinops caerulea eggs
CALCOFI CRUISE 5404
7 APRIL–13 MAY 1954
ESTIMATED RELATIVE ABUNDANCE UNDER 10 m² OF SEA SURFACE
STATIONS: NIGHT SUNRISE DAY SUNSET
1
10
100
1,000
10,000
CAPE MENDOCINO
SAN FRANCISCO
POINT CONCEPTION
SAN DIEGO
PUNTA EUGENIA
125°
120°
115°
110°
40°
35°
30°
25°
20°

2000


0004JD
April 6 - 29, 2000
Celsius
16
14
12
10
Cape Medocino
San Francisco
Monterey Bay
Avila Beach
Point Conception
Santa Barbara
Santa Monica
Dana Point
San Diego
50 eggs/m³
10 eggs/m³
5 eggs/m³
Pacific sardine
Northern anchovy
Jack mackerel
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116°
40°
38°
36°
34°
32°
30°

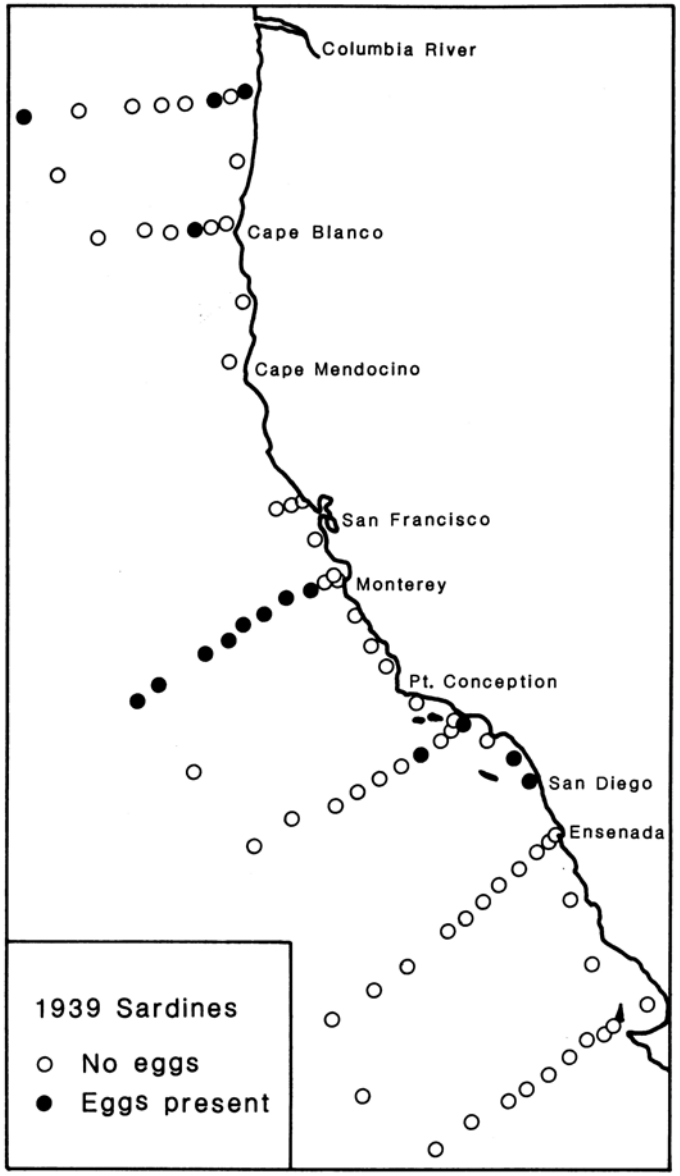
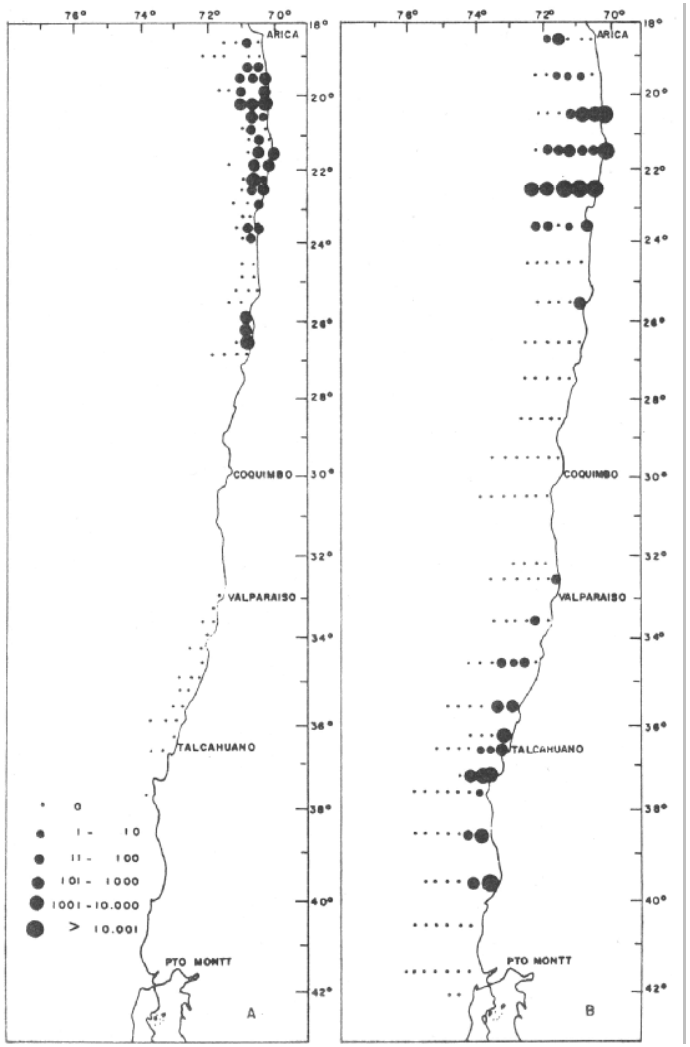


Figure 2. Locations of net tows taken to search for Pacific sardine eggs in May and June 1939 (Ahlstrom 1948). Net tows taken by Scofield (1934) were used to design the cruise.

The1939 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

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

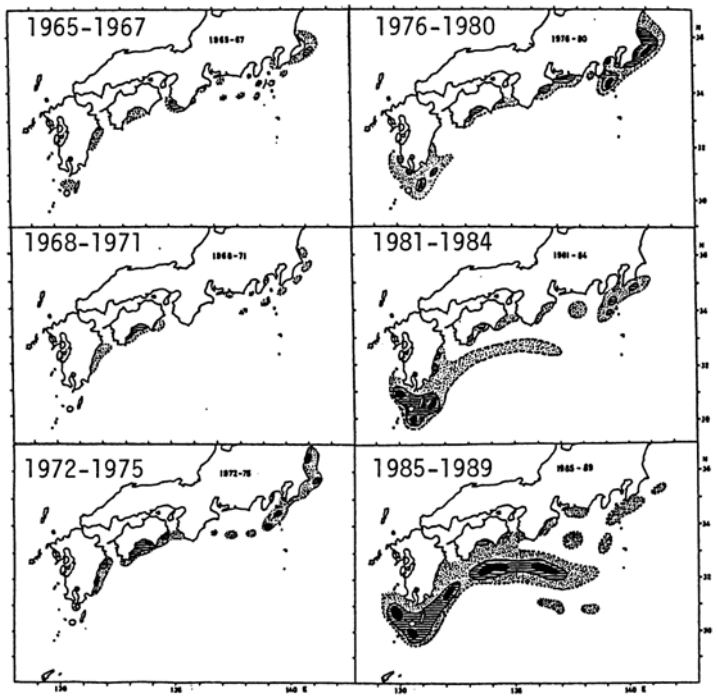
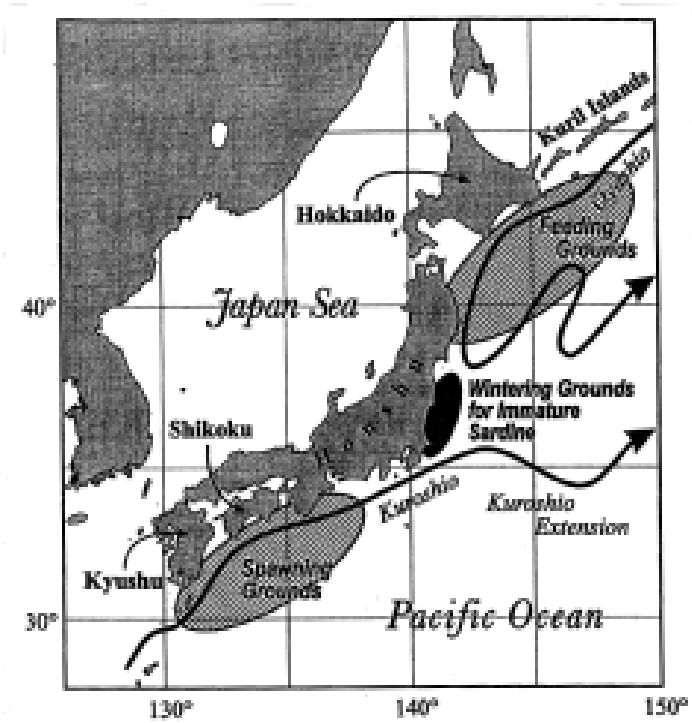


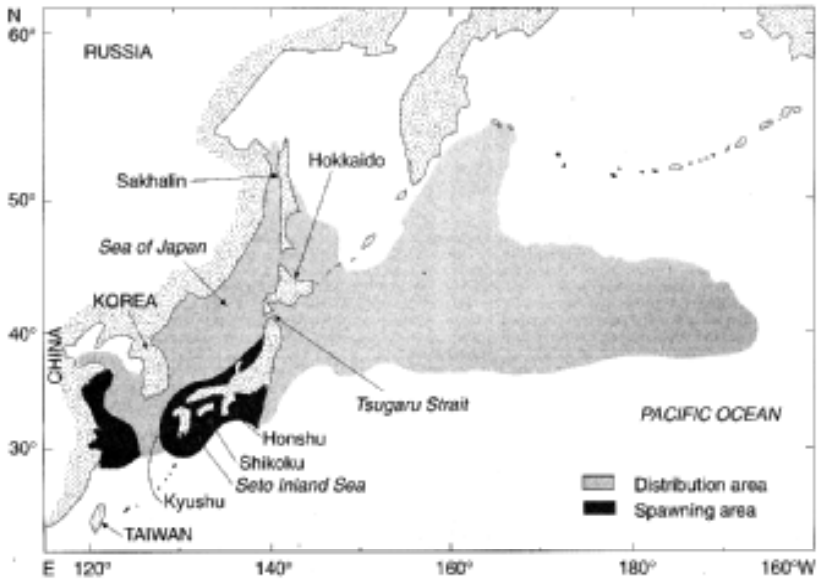
Fig. 3. Shift in the main spawning grounds of the Japanese sardine from 1965 to 1989 (Darker areas correspond to larger amounts of sardine eggs).

- 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!

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)

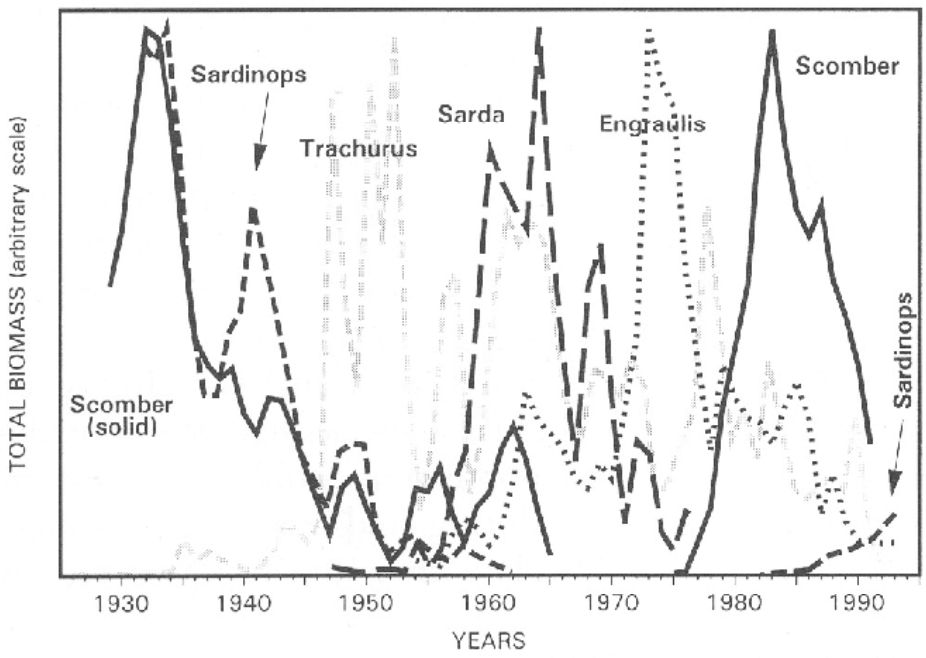
- Anchovies may be too small (size = swimming capability) to use the offshore habitat.
  - Restricted to the nearshore, they suffer from reduced plankton production during warm low-flow periods
  - They are able to benefit from high nearshore production during cool high-flow periods
- Anchovies potentially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

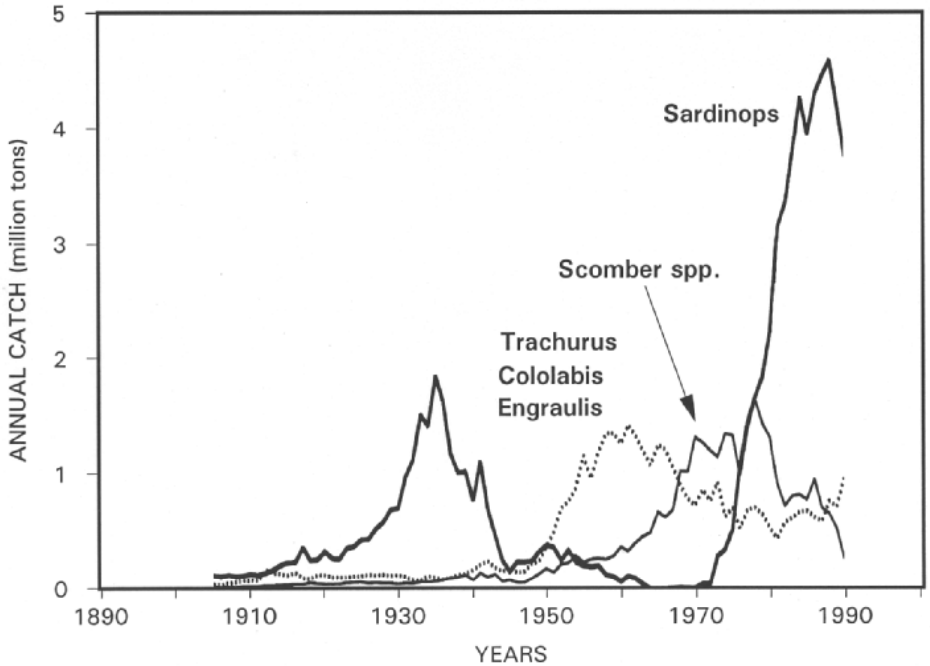
Calif. Current



- 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

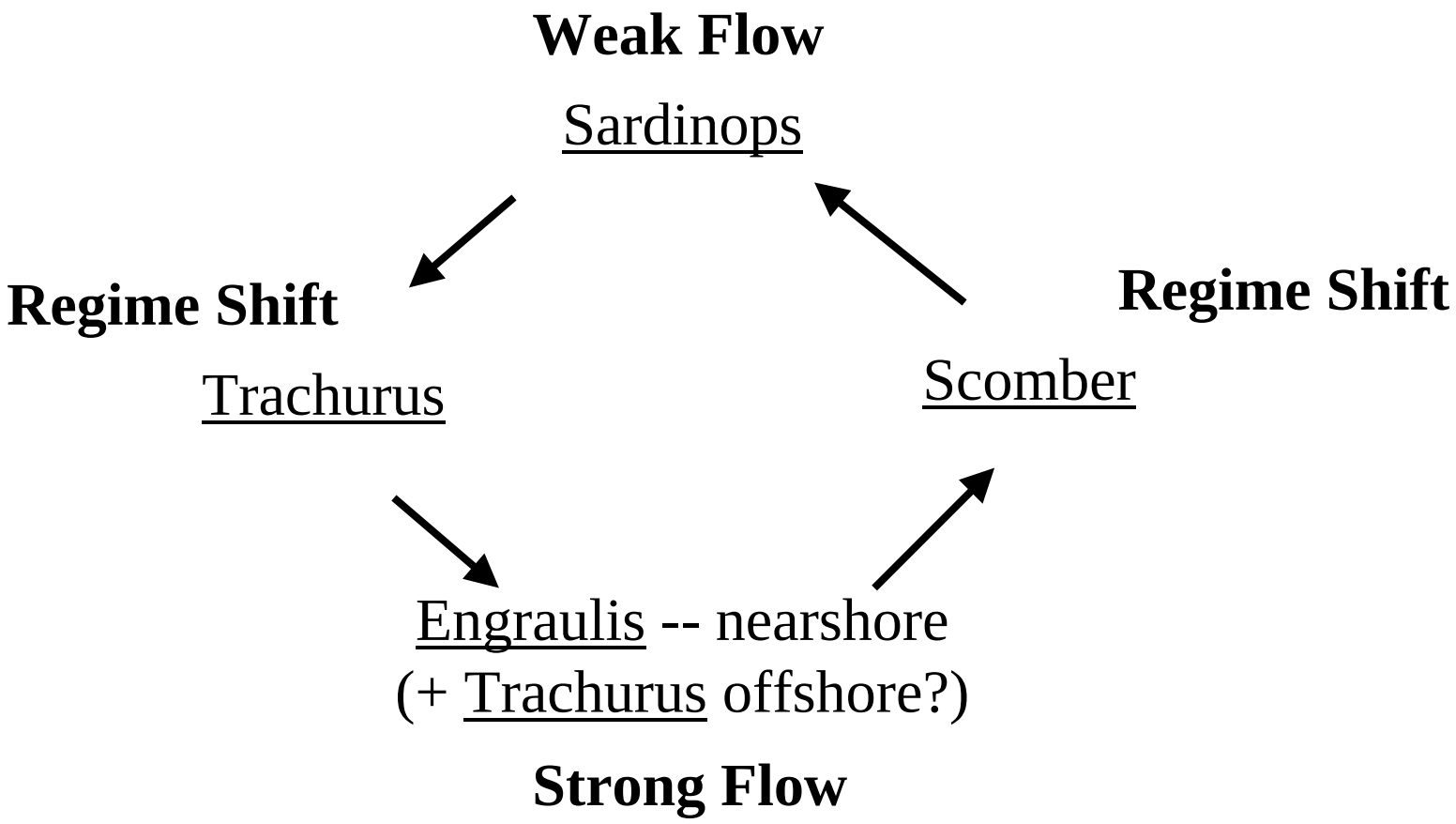
Japan



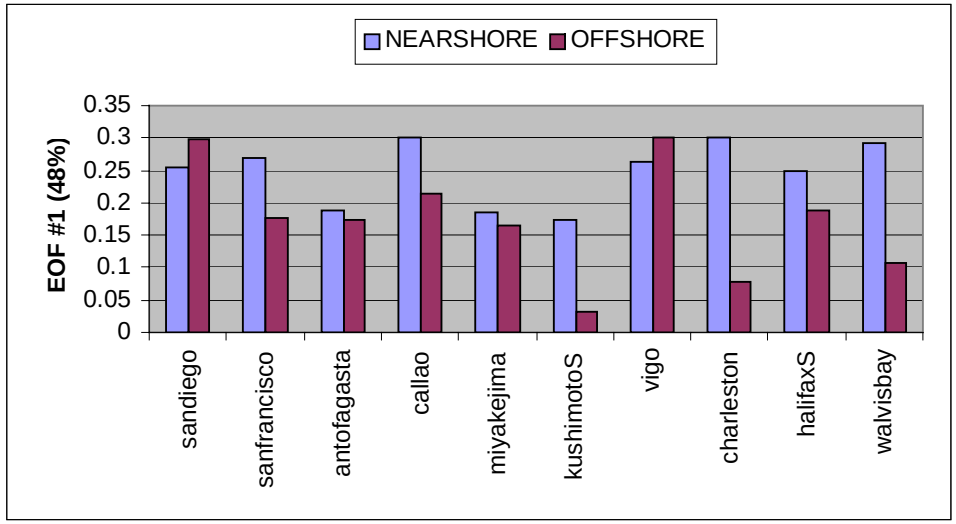
- Sequence is similar to California Current
- <u>Scomber</u> increase precedes <u>Sardinops</u>
- Recent developments:
  - <u>Sardinops</u> is gone
  - <u>Trachurus</u> is increasing

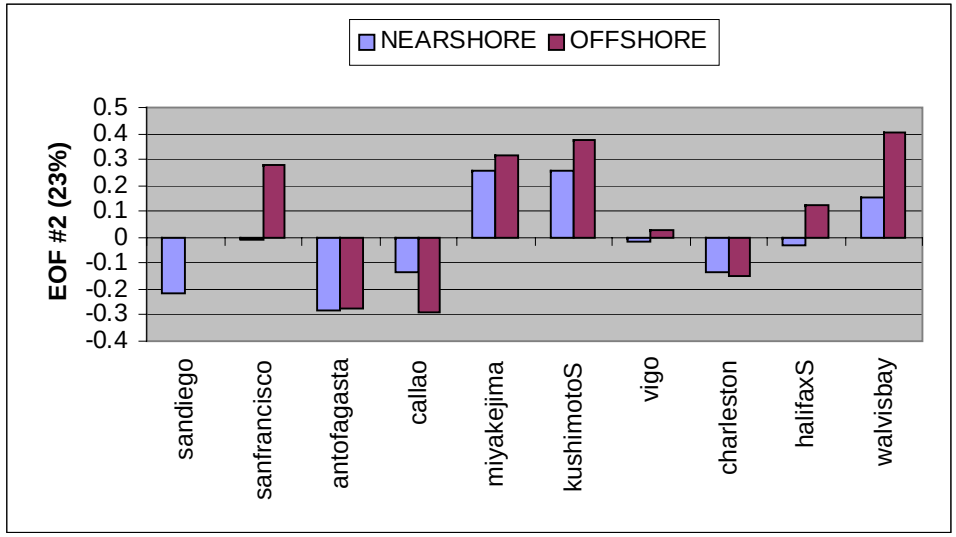
Species Relationships

Boundary Current Pelagics



Synchronicity: Global Circulation COADS SST 1953-2001

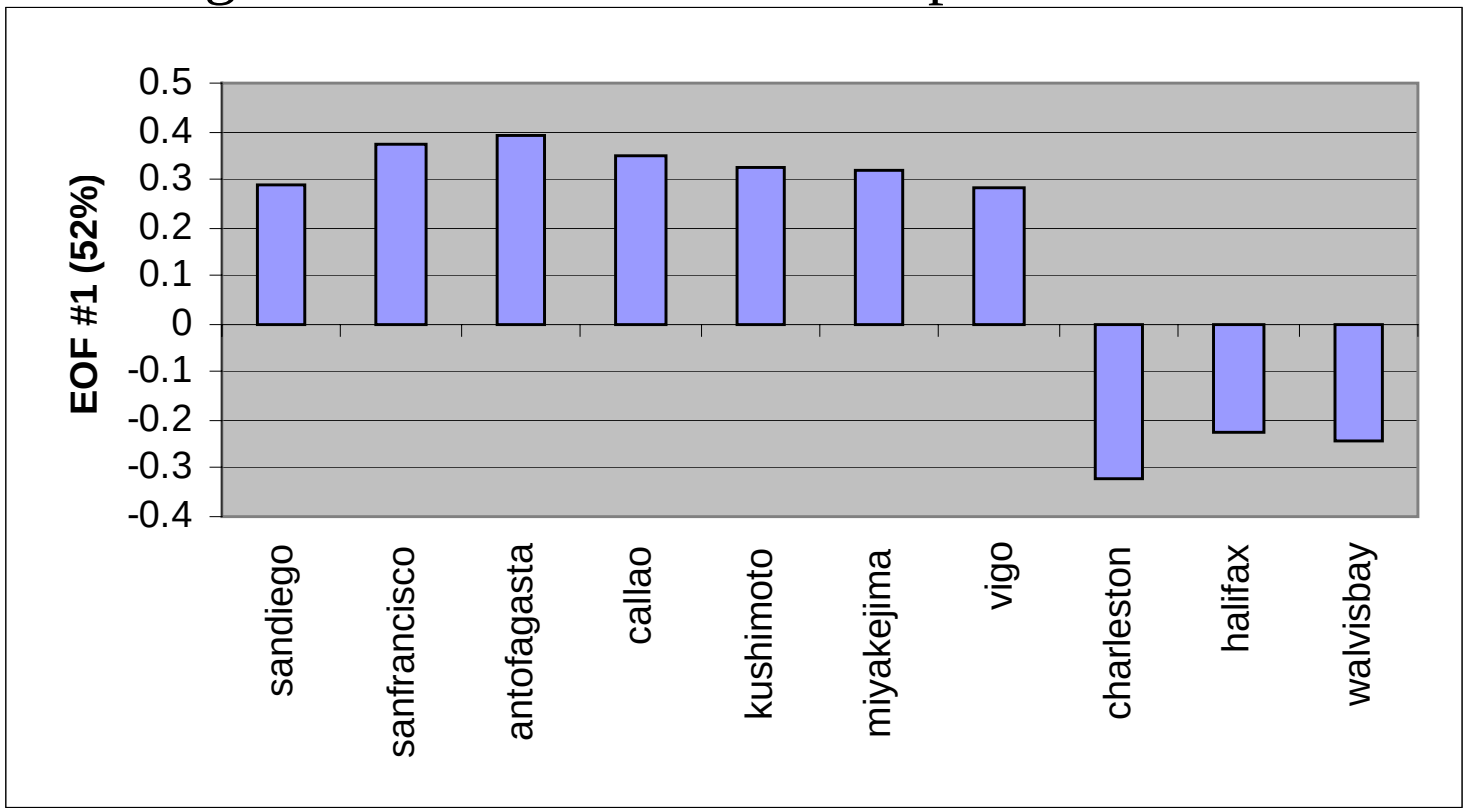




- 2° bands, near and far
- Low-pass filter (7-yr mean) to remove El Niño
- 1st EOF may be due to partial cycle
- 2nd EOF shows Peru/Chile vs Japan and inverse Benguela relationships
  - California is mixed

Synchronicity: Global Circulation (detrended) Coastal Sea Levels

- Intensity of N and S Pacific gyres tends to be linked
  - Benguela Current is 180º 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?