The Phenology of Coastal Upwelling in the California Current: Interannual Variability and Ecosystem Consequences

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• NOAA Fisheries and the Environment (FATE)
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California Current Large Marine Ecosystem

- Seasonal (coastal upwelling) & interannual (ENSO) forcing
- Highly productive marine ecosystem
- Eastern Boundary Upwelling System
Phenology (生物气候学):

1. The scientific study of periodic biological phenomena, such as flowering, breeding, and migration, in relation to climatic conditions.
2. The relationship between a periodic biological phenomenon and climatic conditions. (American Heritage Dictionary)

Lynn et al. (2003)
MOTIVATION

- Many marine species have life histories adapted to seasonal events in the environment.
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- How has the timing, intensity, and duration of coastal upwelling in the California Current changed in recent decades?

Task 1
MOTIVATION

- Many marine species have life histories adapted to seasonal events in the environment.

- How has the timing, intensity, and duration of coastal upwelling in the California Current changed in recent decades?

- How do phenological variations in upwelling impact foodwebs and trophic interactions?  **Task 2**
MOTIVATION

- Many marine species have life histories adapted to seasonal events in the environment.

- How has the timing, intensity, and duration of coastal upwelling in the California Current changed in recent decades?

- How do phenological variations in upwelling impact seabird reproductive success?

- What ecosystem impacts can we expect from climate-driven changes in the phenology of coastal upwelling?
TASK 1: Phenological Upwelling Indices

Can we develop simple indices that describe the phenology of coastal upwelling in the California Current?

- **Timing** of onset (spring transition)
- **Duration** of upwelling season
- **Intensity** of upwelling (episodic, integrated)

Use classical Bakun Upwelling Index:
- long time series (~40 yrs)
- often used in coastal oceanography, fisheries
- large-scale context
- *does not resolve cross-shelf variability, curl*
CUMULATIVE UPWELLING INDEX

Cumulative Upwelling Index (CUI) = Integrate UI from Jan 1st to Dec 31st

Schwing et al. (2006)
Bograd et al. (2008)
INDICES of COASTAL UPWELLING: (1) Timing

Spring Transition Index (STI) = Date of Minimum CUI
(END = Date of Maximum CUI)
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INDICES of COASTAL UPWELLING: (1) Timing

Spring Transition Index (STI) = Date of Minimum CUI
(END = Date of Maximum CUI)
INDICES of COASTAL UPWELLING: (2) Duration

Length of Upwelling Season Index (LUSI) = Total days between STI and END
Total Upwelling Magnitude Index (TUMI) = CUI Integrated between STI and END
Total Upwelling Magnitude Index (TUMI) = CUI Integrated between STI and END

(TDMI = CUI Integrated between END and next year’s STI)
INDICES of COASTAL UPWELLING

CAVEATS:
1) No definitive definition of ‘spring transition’
2) Relevance of indices depends on species life history strategies, plasticity, resilience
Interannual Variability in Cumulative Upwelling Index

STI = Julian Day 50 ± 34
END = Julian Day 331 ± 24
LUSI = 282 ± 45 days
Interannual Variability in Upwelling: (1) Timing

- Earlier onset of upwelling in south
- Trend to later spring transition in north
- Delayed upwelling during El Niño events
- Upwelling “surplus” or “deficit” at climatological transition date
Interannual Variability in Upwelling: (2) Duration

- Upwelling season shorter in north than south
- Trend to shorter upwelling season in north
- Highly variable length of upwelling season in central CCS
Interannual Variability in Upwelling: (3) Intensity

- High integrated upwelling in 1970s, 1998-2004
- Low integrated upwelling in 1980-1995
- 1998-2004: high TUMI, low LUSI --> intense upwelling
TASK 2: Impact on California Current Seabird Phenology?
SEABIRDS at the FARALLON ISLANDS

- Cassin’s Auklet: planktivorous
- Common Murre: piscivorous

- Two bird species from same location but different life strategies
- Look at the timing of egg laying (mean, variance)
PHENOLOGICAL CONSEQUENCES:
Seabird Reproduction

Sydeman et al (2006); Peterson et al (2007); PRBO (unpublished)
Early egg-laying = high reproductive success for both species
High variance is good for Auklets, bad for Murres

Abraham and Sydeman (2004); Reed et al (2008); PRBO (unpublished)
Egg-Laying Date vs. Upwelling Indices: Correlations

<table>
<thead>
<tr>
<th>Egg-Laying Date</th>
<th>Cassin’s Auklet</th>
<th>Common Murre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring Transition Date</td>
<td>0.46</td>
<td>0.46</td>
</tr>
<tr>
<td>Length of Upwelling Season</td>
<td>-0.52</td>
<td>-0.46</td>
</tr>
</tbody>
</table>

Early Upwelling → Early Egg-Laying (good)
ENvironmental data

Use satellite winds and SST to describe variations in upwelling:

- Northeast Pacific domain: ~ 120°-145°W, 30°-55°N
- NOAA/NCDC blended wind product: 25 km grid
- Pathfinder SST: 4.4 km grid
- Monthly means for 1987-2006
Lagged Correlations at 37.5°N - 123°W (example)

Murre’s Mean Lay Date & Jan Wind

Auklet’s Mean Lay Date & March SST

$r=0.65$

$r=0.82$
CORRELATION MAPS

- Compute correlations at all grid locations
- For SST and Alongshore Wind (V)
- For Murre and Auklet egg-laying date: mean and variance
- Monthly for September - April
- Different lags between environment and egg-laying
Lagged Correlation Maps: Mean Lay Date vs. Alongshore Wind

Northerly winds = Early egg-laying

+ correlation

Auklet (planktivorous)

Murre (piscivorous)
Lagged Correlation Maps: Mean Lay Date vs. SST

Auklet
planktivorous

Murre
piscivorous

+ correlation

Cool SSTs = Early egg-laying
Good (Early) & Bad (Late) Years for Cassin’s Auklet

• Jan-Feb mean winds (vectors) & Feb-Mar mean SST (colors)
• Good years: strong H, anomalously strong upwelling, cool SSTs
• Bad years: weak H, anomalously weak upwelling, warm SSTs
SUMMARY

1. Upwelling timing, duration and intensity highly variable;
2. Periods of high (low) integrated upwelling in 1970s and 1998-2004 (1980-95);
3. Trend towards later, shorter upwelling in northern California Current;
4. Delayed upwelling in El Niño years;
5. Winter pre-conditioning (upwelling) controls seabird reproductive timing;
6. Climate change changes in upwelling process;
7. Principal ecosystem effects of interannual-decadal climate variability could be phenological.

Durant et al. (2005)
NEXT STEPS

1. Determine large-scale forcing associated with upwelling phenology regimes;
2. Quantify event-scale indices: relaxation events, Lasker events;
3. Explore multivariate relationships between biological & upwelling series;
4. Include indices in California Current Integrated Ecosystem Assessment;
5. Forecast California Current upwelling & ecosystem response from climate models.
THANK YOU!

谢谢!
Lagged Correlation Map: Lay Date Variance vs. Alongshore Wind

- November mean winds vs. Murre egg-laying date variance
- strong positive correlation; related to storminess?
CUMULATIVE UPWELLING INDEX

Example: 39°N (NorCal) 1967-2005

Cumulative Upwelling Index (CUI) = Integrate UI from 1/1 to 12/31

**SD** = Climatological Start Date of Upwelling Season
**MD** = Climatological Mid-Point of Upwelling Season (Max. Slope)
**ED** = Climatological End Date of Upwelling Season

Schwing et al. (2006)
Bograd et al. (2008)