Ecosystem Indicators

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In the California Current there are numerous indicators to describe the state of the ecosystem:

- Both environmental and biological
- Long-term time series
- Wide range of variables and trophic levels
Environmental Indicators

- CalCOFI (1950): Profiles - Temperature, Salinity, Density, Nutrients, Chlorophyll, O2
- Shore Stations (1920’s): Temperature and Salinity
- Sea Level (1920’s, 1970’s)
- NDBC Buoys (1980’s): wind, SST, SLP, air temperature
- Moorings: Profiles

- Winter mode of upwelling variability
- MOCI: Multivariate Ocean Climate Indicator
Biological Indicators

- Macro-zooplankton, fish egg and larvae abundance (CalCOFI)
- Copepod Index: zooplankton biomass and community composition (Peterson)
- Juvenile rockfish abundance (cruises) and growth chronologies (otholits)
- Forage fish (Sardine and Anchovy) abundance assessments
- Salmon abundance measured as returns/escapement
- Marine mammals abundance
- Seabirds (abundance @sea, productivity and phenology @ Is.)
Which indicators indicate ENSO?

Environmental indicators:
- $T$
- $\tau$
- Sea Level
- Chemistry
- Nutrients

Biological indicators:
- phytoplankton
- zooplankton
- forage fish
- predatory fish
- fisheries
- mammals
- seabirds

Which indicators indicate ENSO?
Sea Surface Temperature

**Scripps**

Scripps Pier, Temperature, Monthly Anomaly, Shore Station Program

**Farallons**

Farallon Island, Temperature, Monthly Anomaly, Shore Station Program

Shore Station Program
Sea Surface Temperature

Scrippps
Scripps Pier, Temperature, Monthly Anomaly, Shore Station Program

Farallons
Farallon Island, Temperature, Monthly Anomaly, Shore Station Program

Shore Station Program
Upwelling-favorable winds

- \( \tau \)-anomalies

- NDBC/NOAA buoys
Upwelling-favorable winds

\( \tau \)-anomalies

latitude

upwelling

1980 1990 2000 2010

NDBC/NOAA buoys
Sea birds

Figure 31. Standardized productivity anomalies (annual productivity—long term mean) for 8 species of seabirds on SEFI, 1971–2014. The dashed lines represent the 80% confidence interval for the long-term mean.

Breeding Success @ Farallon Islands
CalCOFI Rep., Vol 56, 2015
Sea birds

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Which indicators indicate ENSO?

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- T
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- zooplankton
- forage fish
- predatory fish
- fisheries
- mammals
- seabirds

ENSO
To describe the ecosystem state in relation to ENSO
To describe the ecosystem state in relation to ENSO

Sensitivity to ENSO

Sensitivity to other events
To describe the ecosystem state in relation to ENSO
To describe the ecosystem state in relation to ENSO

Sensitivity to ENSO

Sensitivity to other events
Environmental Indicators

• In the California Current environmental variables are synchronized by climatic events

• Most variables are impacted by ENSO in different degrees
Multivariate Ocean Climate Indicator

**MOCI**

- Alongshore Wind
- Sea Surface Temperature
- Air Temperature
- Sea Level Pressure
- Upwelling Index
- Sea Level

**Climate Indices:**
- MEI
- PDO
- NPGO
- NOI

Principal Component Analysis (seasonal values)
Northern California MOCI: 38-42°N

Central California MOCI: 34.5-38°N

Southern California MOCI: 32-34.5°N
Northern California MOCI: 38-42°N

Central California MOCI: 34.5-38°N

Southern California MOCI: 32-34.5°N

Winter EV

72%

70%

58%
Winter/early spring upwelling

Principal Component Analysis

Principal components analysis scores for monthly upwelling intensity data in the California Current Ecosystem. The analysis included five locations between 33 and 45° N latitude, with a total of 60 variables (12 months per year, per site). (b) The leading principal component (PC1) extracted from monthly upwelling intensity data in the California Current Ecosystem. (c) The second principal component exhibited unusually positive values in 2007 and 2008 (Fig. 2a and b). (d) Spearman's correlations (loadings) between PC1 and the monthly upwelling intensity data.
Among the biological time series, a subset of variables whereas Pacific sardine recruitment significantly correlated with the most biological measurements (timing of egg-laying in auklets and murres) were reversed so that all correlations were positive. Pigeon guillemot reproductive success for pigeon guillemot, pelagic cormorant, common murre phenology, and reproductive success of Cassin’s auklet and common murre were strongly correlated among one another.

For clarity, the signs for phenology were reversed so that all correlations were positive. Pigeon guillemot reproductive success significantly correlated only with Cassin’s auklet timing of egg-laying. The leading principal component (PC1) extracted from monthly upwelling intensity data (UI) in the California Current Ecosystem (Fig. 4a) was not significantly correlated with long-term trends, though it was significantly correlated with wintertime upwelling (Table 1A, B). For clarity, the signs for phenology were reversed so that all correlations were positive. Pigeon guillemot reproductive success significantly correlated with the most biological measurements (timing of egg-laying in auklets and murres) were reversed so that all correlations were positive.

When PCA was repeated for each of the five locations, variance explained by the leading (78% variance explained) and fourth (7.3% variance explained) principal components did not show a clear pattern when considered further in the analysis. At all latitudes, the leading principal component correlated with summer months (Fig. 1a, b, c, d, e). For clarity, the signs for phenology were reversed so that all correlations were positive. Pigeon guillemot reproductive success significantly correlated with the most biological measurements (timing of egg-laying in auklets and murres) were reversed so that all correlations were positive.

In the southern part of the region, possibly related to the early onset of that year’s El Nin?o and the PCA: the splitnose rockfish otolith chronology, Cas- (Fig. 1a, b, c, d, e). For clarity, the signs for phenology were reversed so that all correlations were positive. Pigeon guillemot reproductive success significantly correlated with the most biological measurements (timing of egg-laying in auklets and murres) were reversed so that all correlations were positive.

Biological Time Series

Biological Time Series

Figure 4. Principal component analysis of environmental variables from 1988 to 2010. Loadings of SST against PC1. (b) The leading principal component (PC1) extracted from monthly upwelling intensity data in the California Current Ecosystem. The results were divided by season: winter (January –March), spring (April–June), summer (July–September), and fall (October–December). (c) Spearman’s correlations (loadings) between PC1 and the monthly upwelling intensity data. (d) Spearman’s correlations (loadings) between PC2 and the monthly upwelling intensity data.
Biological Indicators

- Biology is more complex

- Environmental impacts:
  - Direct: transport for plankton
    - Physical processes behind not easily resolved due to synchrony
Zooplankton - CalCOFI

Chelton et al., 1982 JMR
Zooplankton Trinidad Line

The PDO is the leading principle characteristic of shelf waters off Oregon, Washington, Vancouver Island, and the Gulf of Alaska as well as the Bering Sea. In the present study, we focused on seven cold neritic species: 

- *Acartia longiremis*
- *Calanus marshallae*
- *Pseudocalanus
calicystis*
- *Epilabidocera longipedata*
- *Tortanus discaudatus*
- *Oncorhynchus kisutch* juveniles and returned as adults in the autumn.

Production Index (OPI) which is calculated by summing the number of adults that return to their hatcheries, and describes a low frequency climate pattern in this region.

Wind data were downloaded from http://jisao.washington.edu/pdo. The PDO is the leading principle characteristic of shelf waters off Oregon, Washington, Vancouver Island, and the Gulf of Alaska as well as the Bering Sea.
Biological Indicators

- Environmental impacts:
  - Trophic mechanisms: food availability for predators
    - Need of mechanistic models to explain biological variability, correlations can be misleading
Aurelia spp. and Chrysaora spp.) were unusually low in 2015 (Fig. 21), catches of pelagic tunicates (primarily Salpa spp., Thetys vagina and Pyrosoma spp.) were at extreme to record high levels. Finally, despite the high abundance (inferring high productivity and transport of subarctic water) of both YOY ground fish and of pelagic tunicates, the 2015 survey also encountered unusually high numbers of warm water species (many of which had never previously been encountered), which are typically considered to be harbingers of strong El Niño YOY rock fish and other ground fish were at very low levels in both 2014 and 2015 (R. Brodeur, unpublished data), consistent with occasionally dramatic differences in catch rates of YOY rock fish over broader spatial scales (Ralston and Stewart 2013).

In addition to the high catches of YOY rock fish and other ground fish, catches tended to be very high for a suite of both less commonly encountered and less consistently reported (over the course of the time series) species. Although catches of scyphozoan jellyfish (primarily jellyfish) were at record high levels in 2015 (Fig. 21), catches of pelagic tunicates (primarily Salpa spp., Thetys vagina and Pyrosoma spp.) were at extreme to record high levels. Finally, despite the high abundance (inferring high productivity and transport of subarctic water) of both YOY ground fish and of pelagic tunicates, the 2015 survey also encountered unusually high numbers of warm water species (many of which had never previously been encountered), which are typically considered to be harbingers of strong El Niño YOY rock fish and other ground fish were at very low levels in both 2014 and 2015 (R. Brodeur, unpublished data), consistent with occasionally dramatic differences in catch rates of YOY rock fish over broader spatial scales (Ralston and Stewart 2013).

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Breeding Success @ Farallon Islands
CalCOFI Rep., Vol 56, 2015

Figure 31. Standardized productivity anomalies (annual productivity—long term mean) for 8 species of seabirds on SEFI, 1971–2014.

- Western Gull
- Cassin’s Auklet
- Pigeon Guillemot
- Brandt’s Cormorant
- Ashy Storm petrel
- Common Murre
- Rhinoceros Auklet
- Pelagic Cormorant
Sea birds

Standardized productivity anomalies (annual productivity—long term mean) for 8 species of seabirds on SEFI, 1971–2014.

- Western Gull
- Common Murre
- Cassin's Auklet
- Pelagic Cormorant

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Timing

• In the California Current, many environmental variables are synchronized by climatic events
  • Winter season
  • Highly related to ENSO
...shared by some biological indicators
Winter season & PC$_{bio}$

seabirds rockfish in PC$_{bio}$
MOCI all seasons

Southern Copepod Index

Winter season & PC\text{bio}
**Winter & summer indicators**

**Fig. 6** (a) Normalized time series of upwelling PC2 at 39°N (winter mode), the splitnose growth-increment chronology, and negative values of auklet lay date. Negative values of auklet lay date are shown to facilitate comparison. (b) Auklet lay date (day of year) and PC2 at 39°N, (c) the splitnose rockfish growth-increment chronology and PC2 at 39°N, and (d) and (e) auklet fledgling success and coastwide upwelling PC1. Fledgling success was 0 in 2005 and 2006.

**Table 2** Spearman's rank coefficients ($\rho$) and level of significance ($P$) for correlations between upwelling modes in the California Current Ecosystem and biological time series

<table>
<thead>
<tr>
<th>Biological time series</th>
<th>Span (years)</th>
<th>PC1</th>
<th>PC2</th>
<th>PC1</th>
<th>PC2</th>
<th>PC1</th>
<th>PC2</th>
<th>PC1</th>
<th>PC2</th>
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<tr>
<td>Murre lay date</td>
<td>1972:2006</td>
<td>0.16</td>
<td>0.37</td>
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<td>0.49</td>
<td>0.07</td>
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<tr>
<td>Auklet lay date</td>
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<td>0.31</td>
<td>0.07</td>
<td>0.36</td>
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<td>0.21</td>
<td>0.23</td>
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<td>0.001</td>
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<tr>
<td>Murre success</td>
<td>1972:2006</td>
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<td></td>
<td>0.10</td>
<td>0.55</td>
<td>0.08</td>
<td>0.64</td>
<td>0.35</td>
<td>0.04</td>
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<tr>
<td>Auklet success</td>
<td>1972:2006</td>
<td></td>
<td></td>
<td>0.51</td>
<td>0.002</td>
<td>0.22</td>
<td>0.20</td>
<td>0.33</td>
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<tr>
<td>Splitnose crn</td>
<td>1946:2006</td>
<td>0.15</td>
<td>0.23</td>
<td></td>
<td></td>
<td>0.42</td>
<td>0.001</td>
<td>0.17</td>
<td>0.18</td>
</tr>
<tr>
<td>Yelloweye crn</td>
<td>1946:2003</td>
<td></td>
<td>0.04</td>
<td>0.77</td>
<td>0.21</td>
<td>0.12</td>
<td>0.23</td>
<td>0.45</td>
<td>0.001</td>
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<tr>
<td>Salmon crn</td>
<td>1978:2001</td>
<td></td>
<td></td>
<td>0.54</td>
<td>0.006</td>
<td>0.25</td>
<td>0.23</td>
<td>0.32</td>
<td>0.12</td>
</tr>
</tbody>
</table>
Ecosystem Indicators

- What are indicators indicating:
  - ENSO, other-than-ENSO, ENSO+others
- Need of mechanistic understanding of biological indicators
- Synchrony in the California Current
  - winter, related to ENSO, bio/phy