Decadal Changes in Dinoflagellate Abundance in the Central California Current Region

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Monterey Species Composition

Jester et al., Harmful Algae 2009, 8:291-298.
Monterey Species Composition

Jester et al., Harmful Algae 2009
## Harmful Algal Bloom Marine Bird Mortality

<table>
<thead>
<tr>
<th>#</th>
<th>Affected Birds</th>
<th>Location, Year</th>
<th>HAB Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>2250</td>
<td>Black Ducks, other waterfowl</td>
<td>New Hampshire, 1972</td>
<td><em>Gonyaulax tamarensis</em></td>
</tr>
<tr>
<td>140</td>
<td>Brown Pelicans, Brandt’s Cormorants</td>
<td>Santa Cruz, CA, 1991</td>
<td><em>Pseudonitzschia australis</em></td>
</tr>
<tr>
<td>150</td>
<td>Brown Pelicans</td>
<td>Baja California, 1996</td>
<td><em>Pseudonitzschia spp.</em></td>
</tr>
<tr>
<td>550</td>
<td>Northern Fulmars, Common Murres, large grebes</td>
<td>Monterey Bay, CA, 2007</td>
<td><em>Akashiwo sanguinea</em></td>
</tr>
<tr>
<td>8000</td>
<td>Scoters, other divers</td>
<td>Washington State, 2009</td>
<td><em>Akashiwo sanguinea</em></td>
</tr>
</tbody>
</table>

*Shumway et al., 2003 Harmful Algae*  
*Jessup et al. 2009 PLOSOne*  
*COASST*
2011 Northern California

(Above) Dead abalone and gumboot chitons on the shore in Salt Point. Photograph by Nate Buck.

(Above) Dead seastars on a beach near Bodega Bay. Photograph by Matt Robart, UC Davis.

Images of the dinoflagellate *Gonyaulax spinifera* which composed the algal bloom during this time. Live image (top left) by Adele Paquin, and scanning electron microscope image (top right) by Charles O’Kelly.
“...this has been the deadliest red tide for state abalone in at least three decades.”

Press Democrat, 7-Sep-11

(Above) Dead abalone and gumboot chitons on the shore in Salt Point. Photograph by Nate Buck.

Images of the dinoflagellate *Gonyaulax spinifera* which composed the algal bloom during this time. Live image (top left) by Adele Paquin, and scanning electron microscope image (top right) by Charles O’Kelly.
Quantifying Change

• Focus on Monterey Bay, CA
  – Data sources:
    • Weekly sampling of algae, 2000-2011
    • MBARI time-series (~1989-2009)
    • PFEL Upwelling Index

• Larger Scale
  – Merged ocean color, 1996-2011
  – Scripps time-series

• Basin Scale
  – MEI, PDO, NPGO

• Global Scale (no—data records are too short)
Relative Abundance Index, Santa Cruz Wharf

- **Alexandrium**
- **Akashiwo**
- **Ceratium**
- **Cochlodinium**
- **Dinophysis**
- **Prorocentrum**
- **Pseudo-nitzschia**

**Graphs:**
- Cumulative Sum
  - **Dinoflagellates** (red)
  - **Diatoms** (blue)

**Legend:**
- Absent
- Rare
- Present
- Common
- Abundant
~10,500 matchups from the California Current used to create an optimized band-ratio algorithm for multiple sensors

Probably still underestimates very high chlorophyll values....

Kahru et al., DSR submitted (2011)
Chlorophyll trends, 1996-2011
Chlorophyll trends, 1996-2011
Scripps Pier: +0.076 per year
(Kim et al., Prog. Oceanogr. 2009)

MBARI: +0.06 per year

Satellite: +0.076 per year
(Kahru et al. submitted)
Mean Monthly Trends in Chlorophyll

Median Monthly Trends in Chlorophyll
What is Driving the Trends?

- Surface chlorophyll increased linearly over the past ~25 years
- Bloom maxima in Central California have also increased over ~ 15 years
- Dinoflagellates (and HABs) have increased after 2004 (short time series!)
State-Space Model Decomposition of the World Ocean Database

M2 Mooring:
- Bilinear interpolation
- 3x median filter (> 3 SD)
- 37 month moving average
Long-term changes in stratification coupled to short-term changes in upwelling
Long-term changes in stratification coupled to short-term changes in upwelling.
Extending the Time Series (~1993-2010)

Major indices were low-pass filtered with a 37-month window (following Palacios et al. 2004)

Mixed Layer Depth (MLD), Maximum Stratification (dTdZ), Temperature at that depth (MLD-T), and the difference between SST and MLD-T were normalized and low-pass filtered.
MLD is shallowing*
Thermocline strength is increasing
Thermocline temperature is cooling*
Surface waters are warming

*Opposite the long-term trend reported by Palacios et al. 2004
<table>
<thead>
<tr>
<th></th>
<th>MEI</th>
<th>PDO</th>
<th>NPGO</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHL Anomaly</td>
<td>-0.223</td>
<td>--</td>
<td>-0.209</td>
</tr>
<tr>
<td>Mixed Layer Depth</td>
<td>--</td>
<td>-0.244</td>
<td>-0.169</td>
</tr>
<tr>
<td>Intensity of Stratification</td>
<td>--</td>
<td>--</td>
<td>-0.137</td>
</tr>
<tr>
<td>Temp. @ max Stratification</td>
<td>+0.583</td>
<td>+0.481</td>
<td>-0.378</td>
</tr>
</tbody>
</table>
The time-series of relative abundance index RAI) at Santa Cruz Wharf was used to estimate percent dinoflagellates (weekly), and multiplied by the chlorophyll concentration (satellite) to generate a dinoflagellate time-series from 2002-2011....
Neither the CUMSUM nor the original time series are correlated with PFEL Upwelling Index with 0, 13, or 37 month low-pass filtering.
MLD is shallowing
Stratification is intensifying
Subsurface nutrients are increasing
Surface temperatures are increasing

Dinoflagellates Win!
Summary

• True red tides have become increasingly problematic in the California Current, and dinoflagellates have increased in Monterey Bay
• The physical environment has been shifting towards dinoflagellate-favorable conditions
• These physical changes are moderately correlated to basin-scale indices
• Dinoflagellate abundance is STRONGLY correlated to PDO (-), MEI (-) and NPGO (+), probably through modulation of MLD, Stratification, and Nutrients at depth