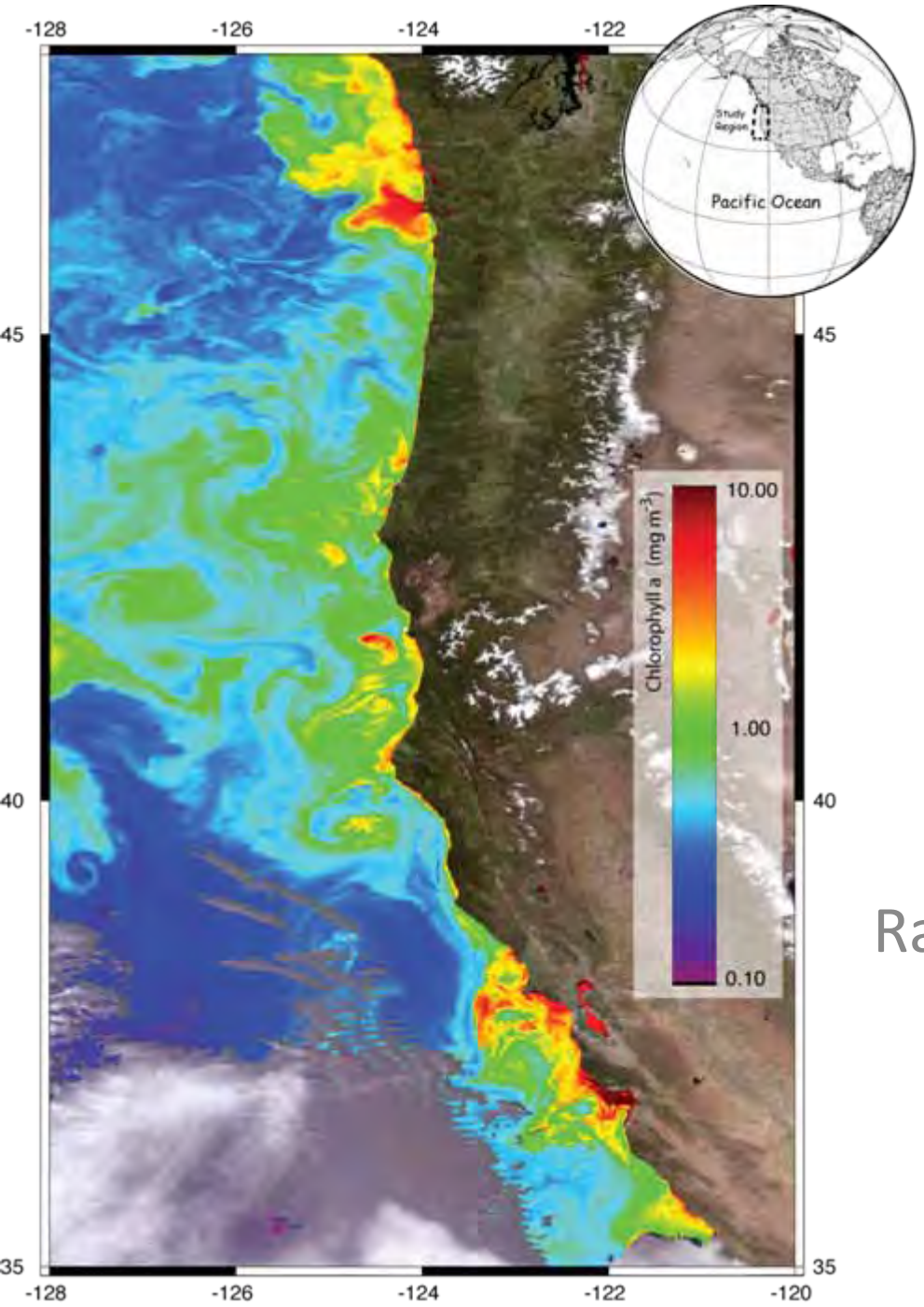
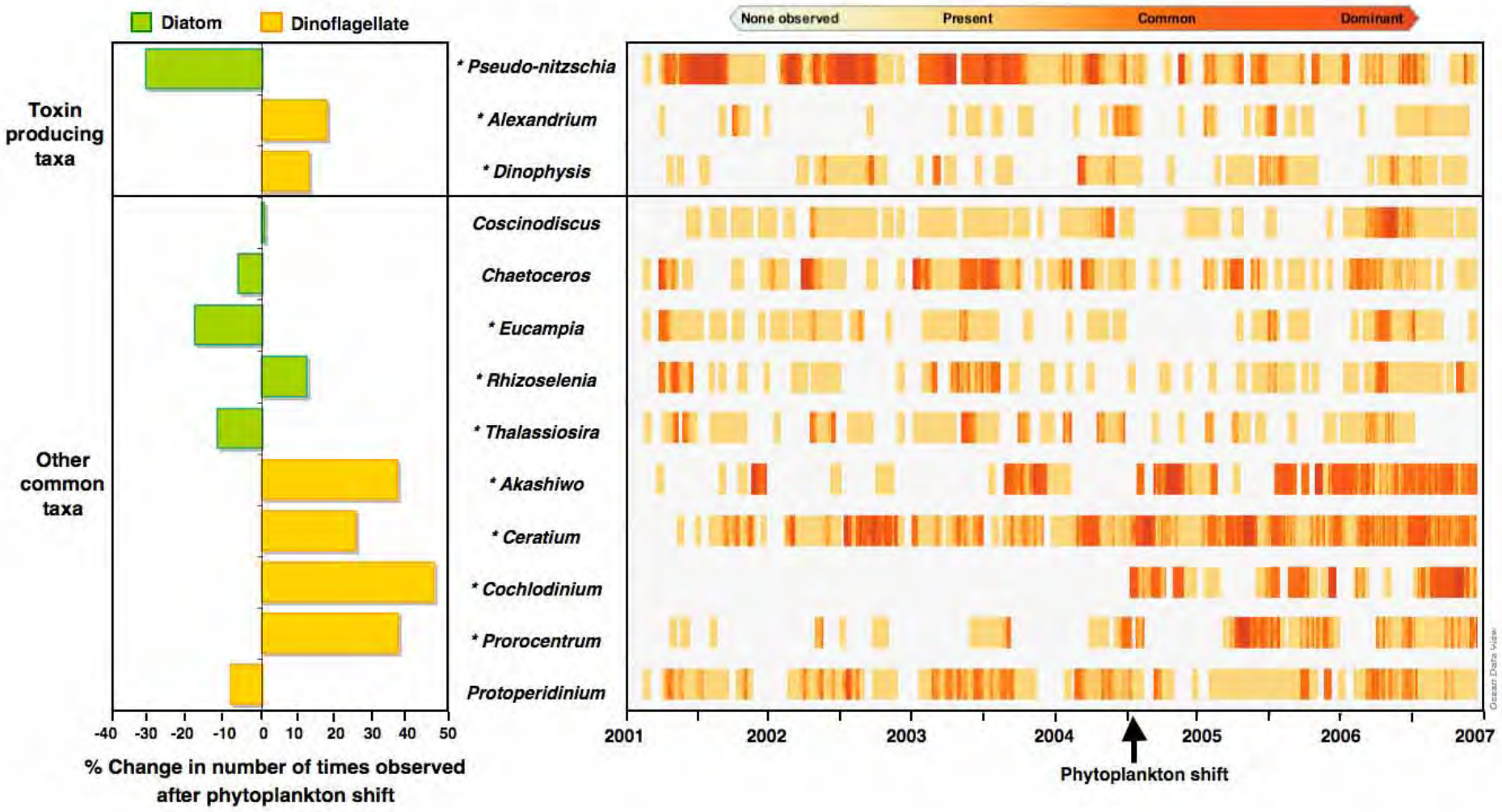


Decadal Changes in Dinoflagellate Abundance in the Central California Current Region

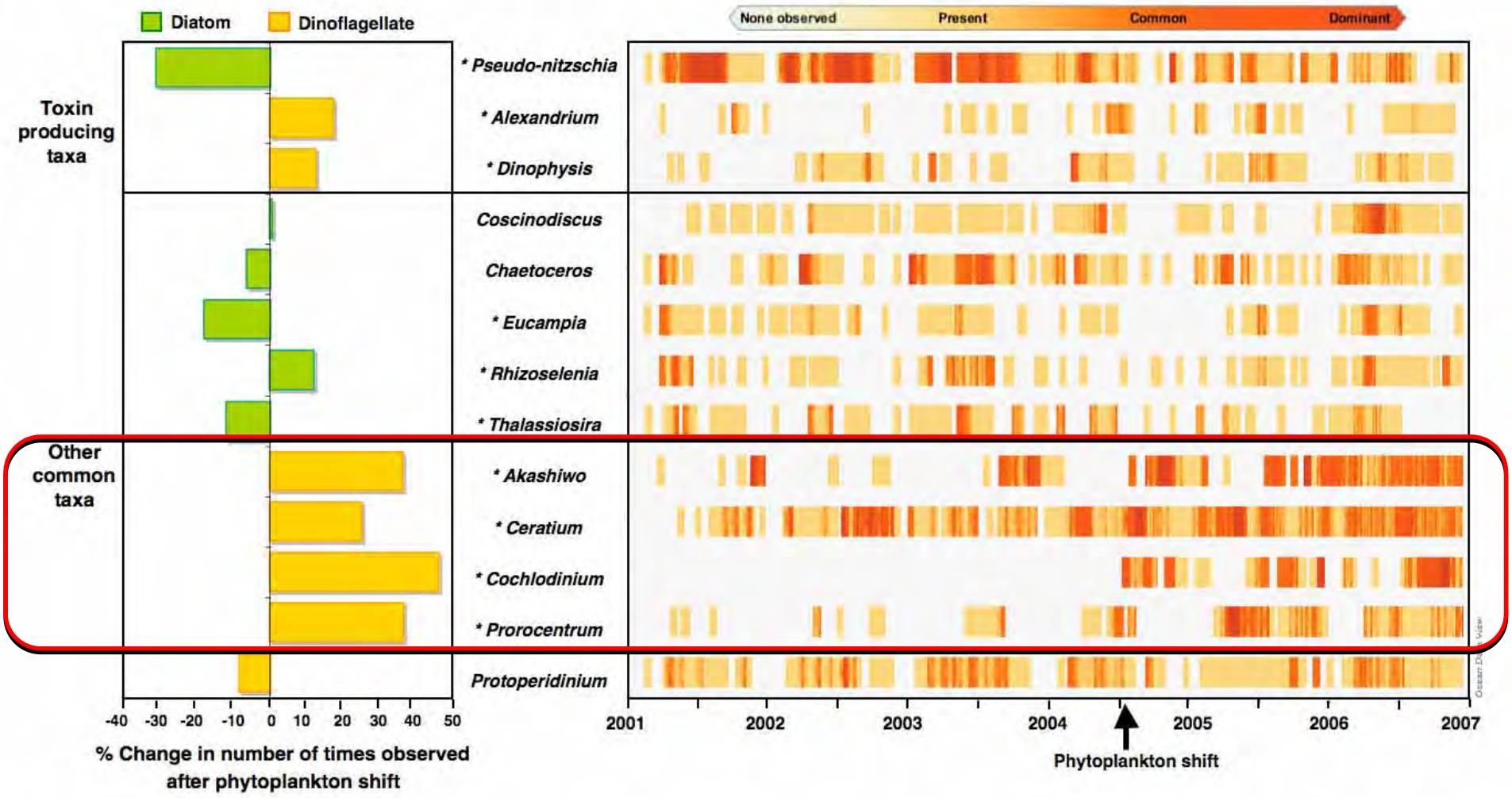
Raphael Kudela (UC Santa Cruz)
Mati Kahru (SIO)
John Ryan (MBARI)
Dave Foley (NOAA ERD)

Monterey Species Composition



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

Monterey Species Composition



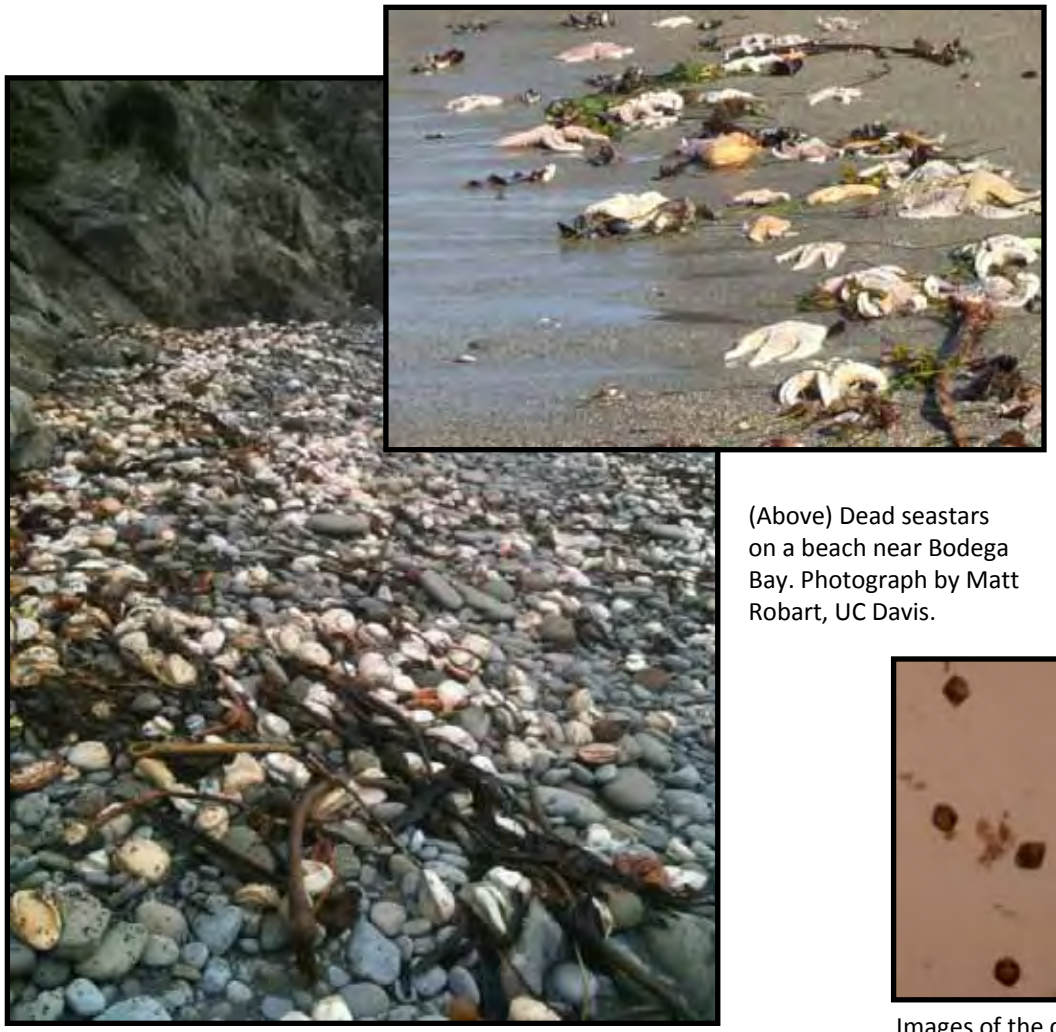
Jester et al., Harmful Algae 2009

Harmful Algal Bloom Marine Bird Mortality

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

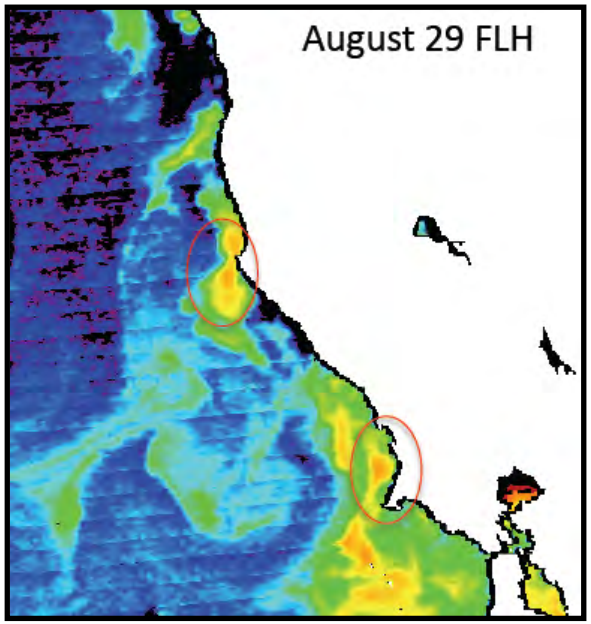
Shumway et al., 2003 Harmful Algae
Jessup et al. 2009 PLOSOne
COASST

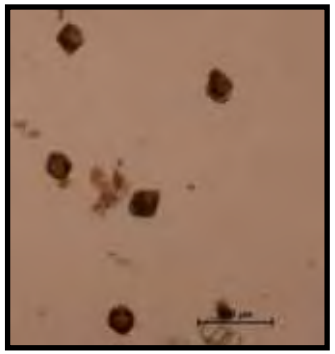
2011 Northern California

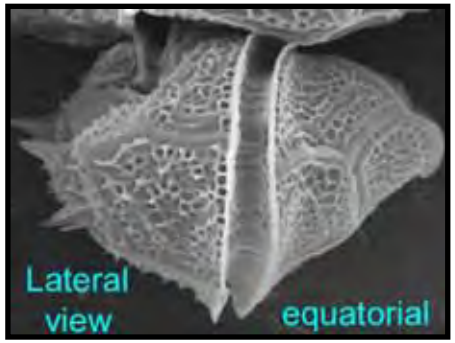


(Above) Dead abalone and gumboot chitons on the shore in Salt Point . Photograph by Nate Buck.

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

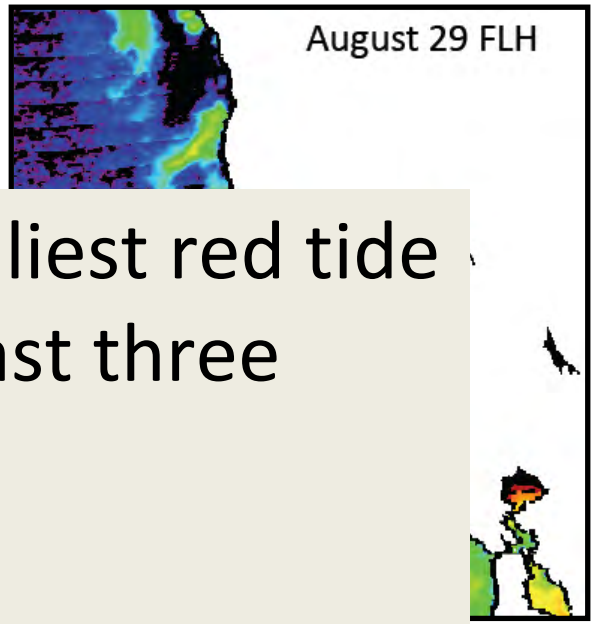






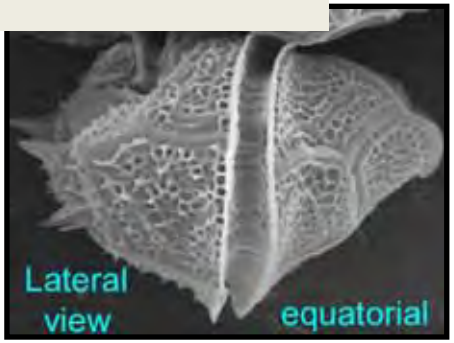
Images of the dinoflagellate *Gonyaulax spinifera* which composed the algal bloom during this time. Live image (top left) by Adele Paquin, and scanning electron microscope image (top right) by Charles O'Kelly.

2011 Northern California



"…this has been the deadliest red tide for state abalone in at least three decades."

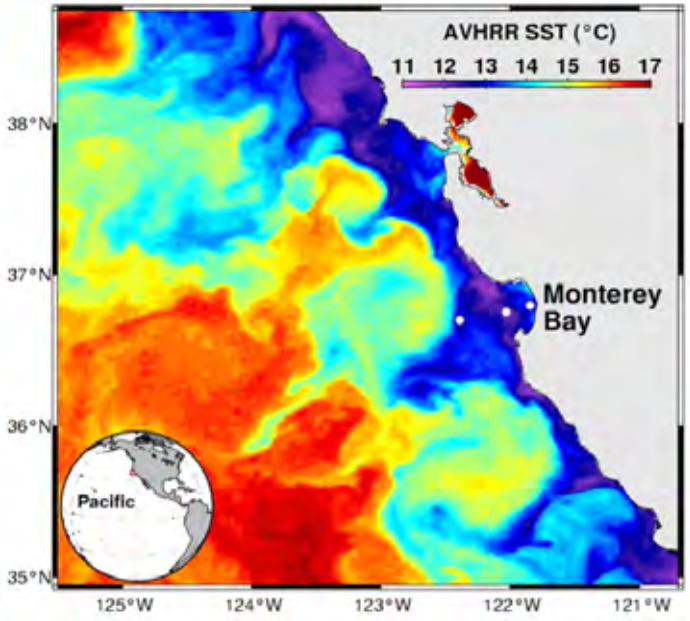
Press Democrat, 7-Sep-11



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

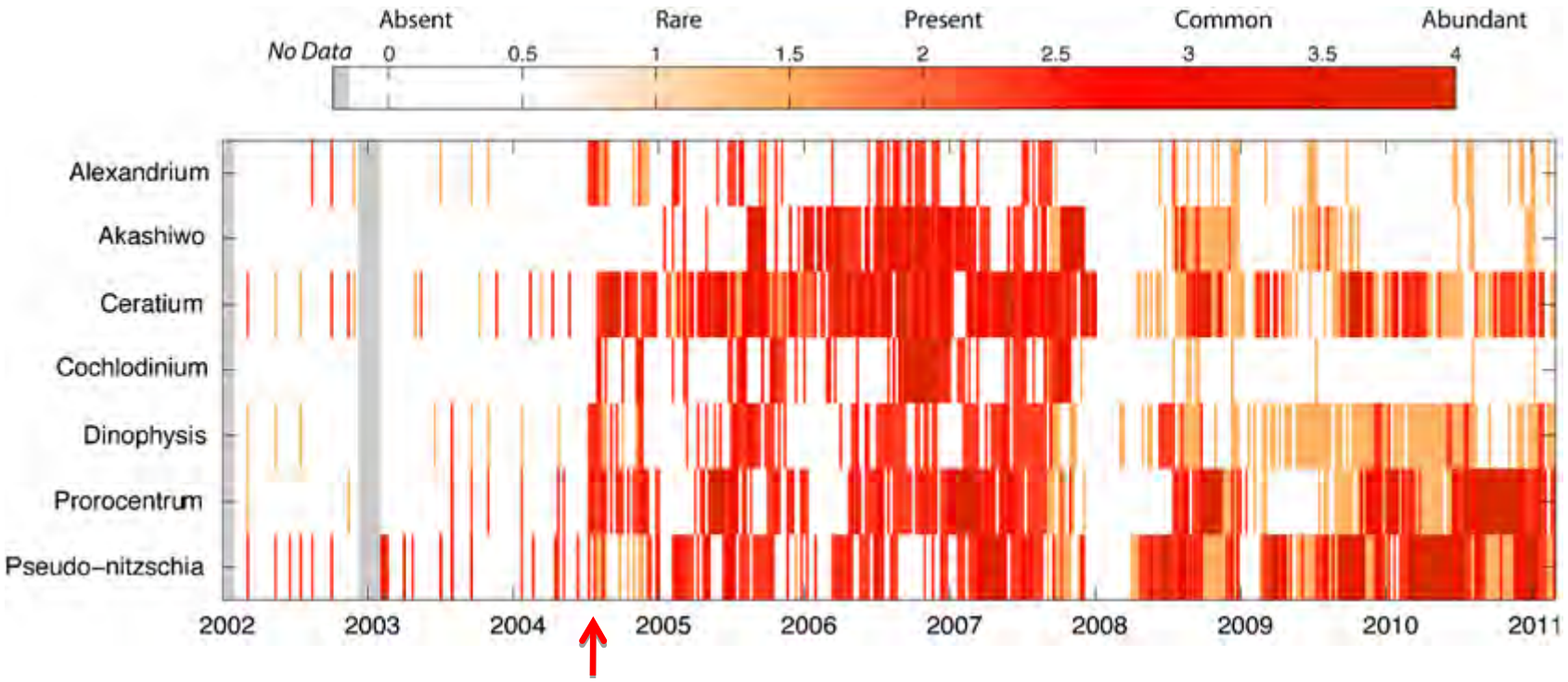
Images of the dinoflagellate *Gonyaulax spinifera* which composed the algal bloom during this time. Live image (top left) by Adele Paquin, and scanning electron microscope image (top right) by Charles O'Kelly.

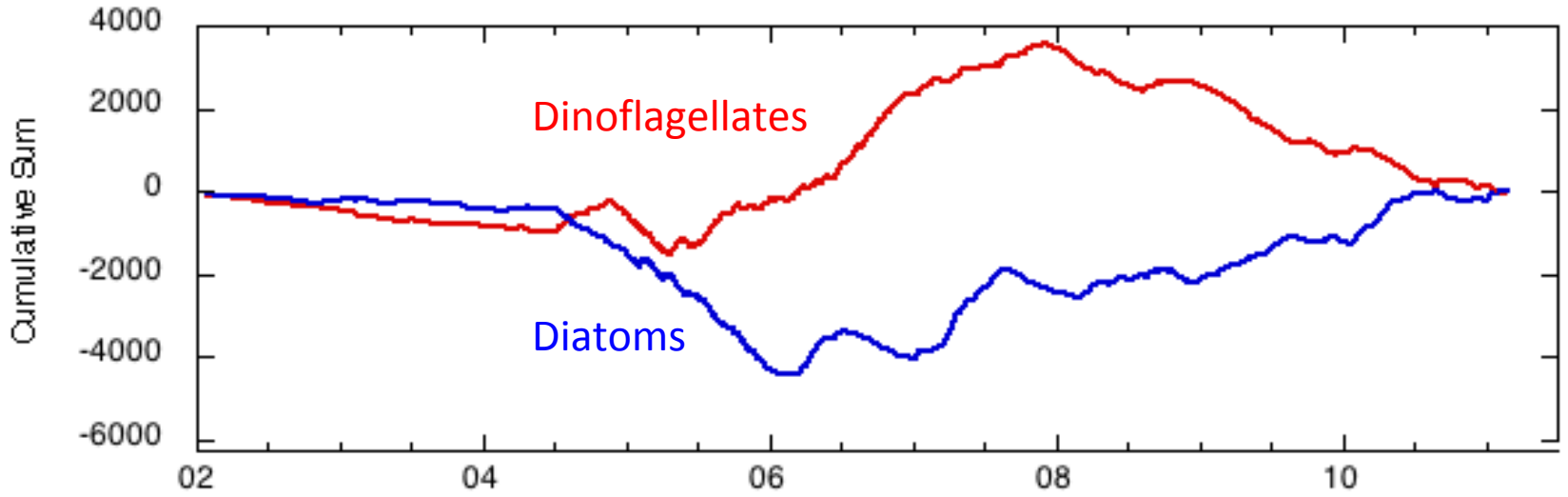
Quantifying Change



- 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

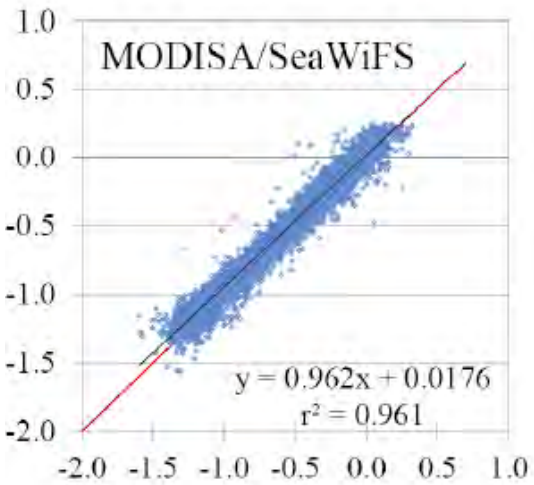


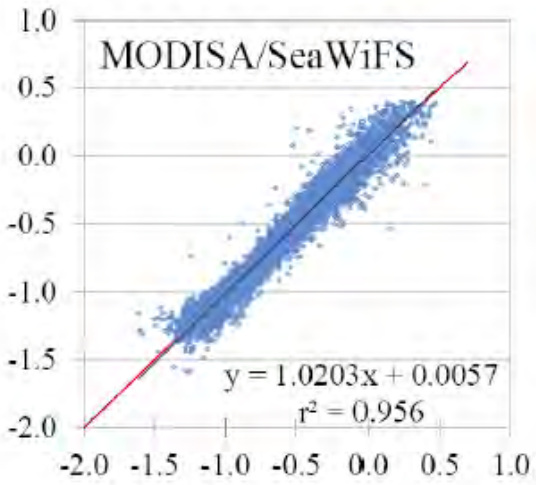


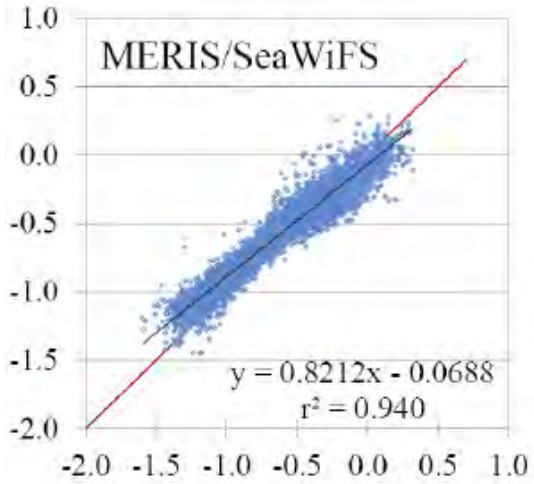
Merged Chlorophyll Product

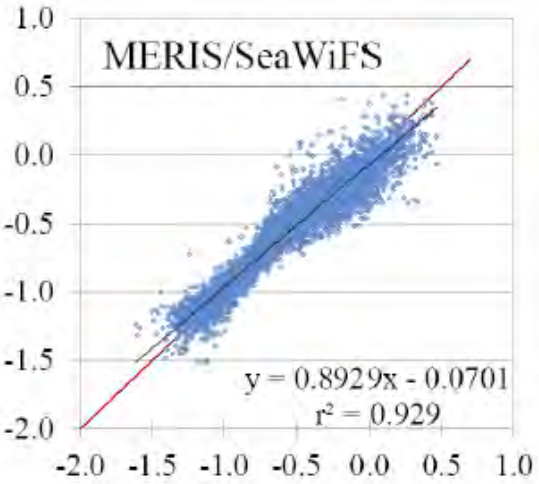
~10,500 matchups from the California Current used to create an optimized band-ratio algorithm for multiple sensors

Probably still underestimates very high chlorophyll values….



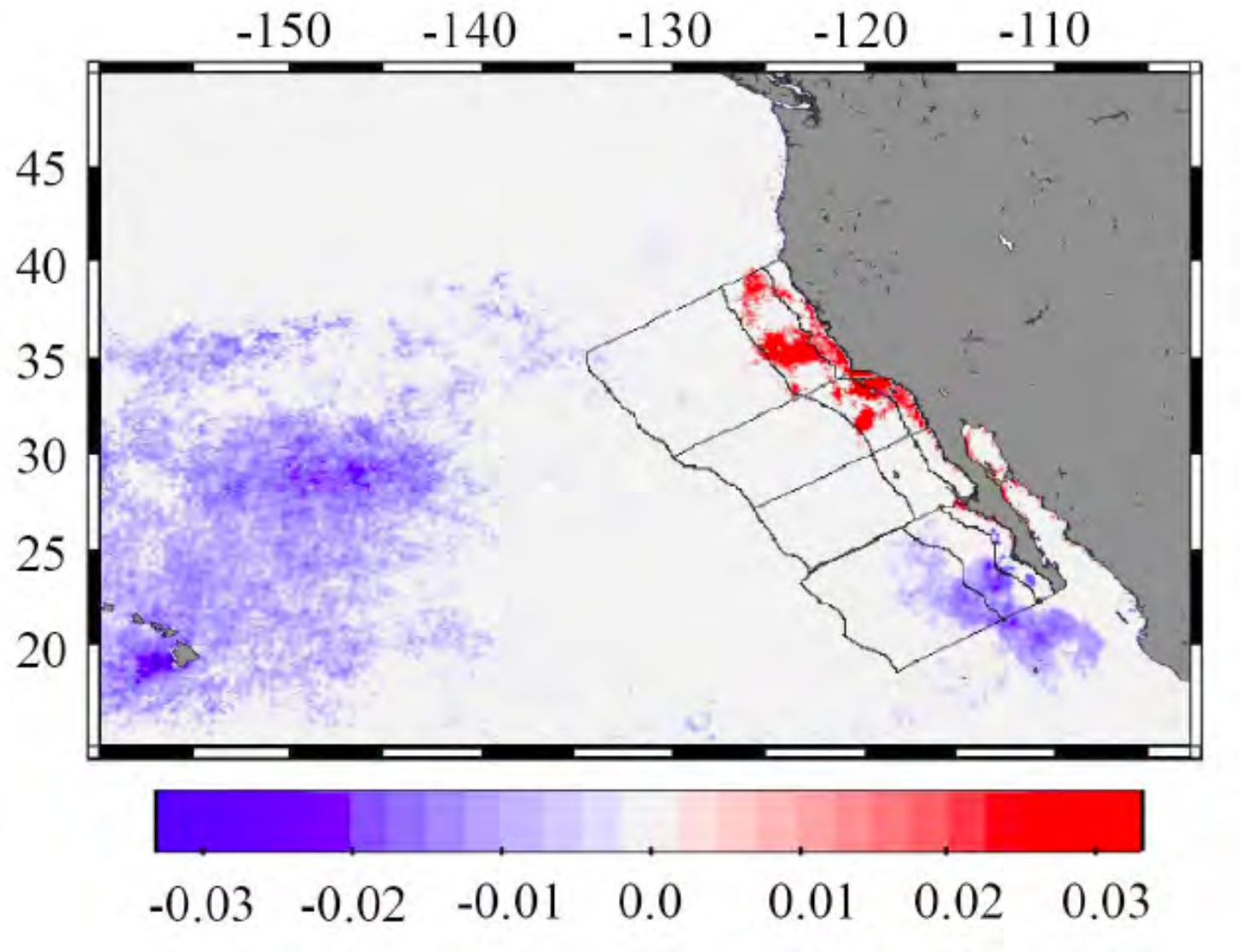




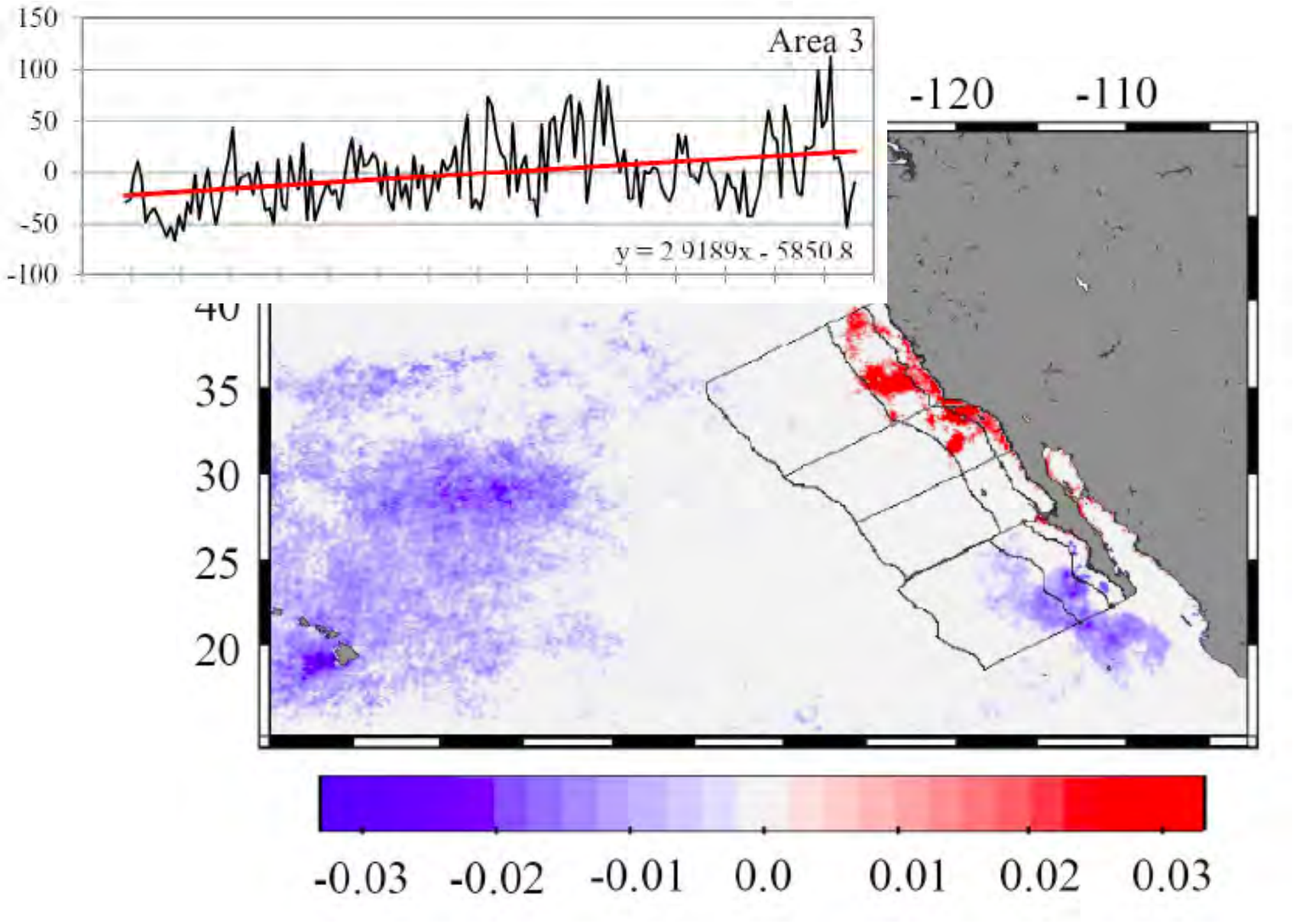


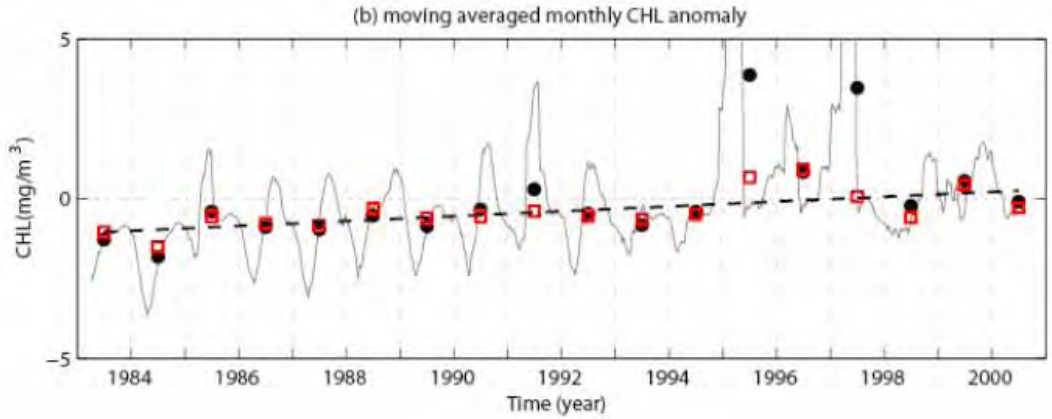
Kahru et al., DSR submitted (2011)

Chlorophyll trends, 1996-2011



Chlorophyll trends, 1996-2011

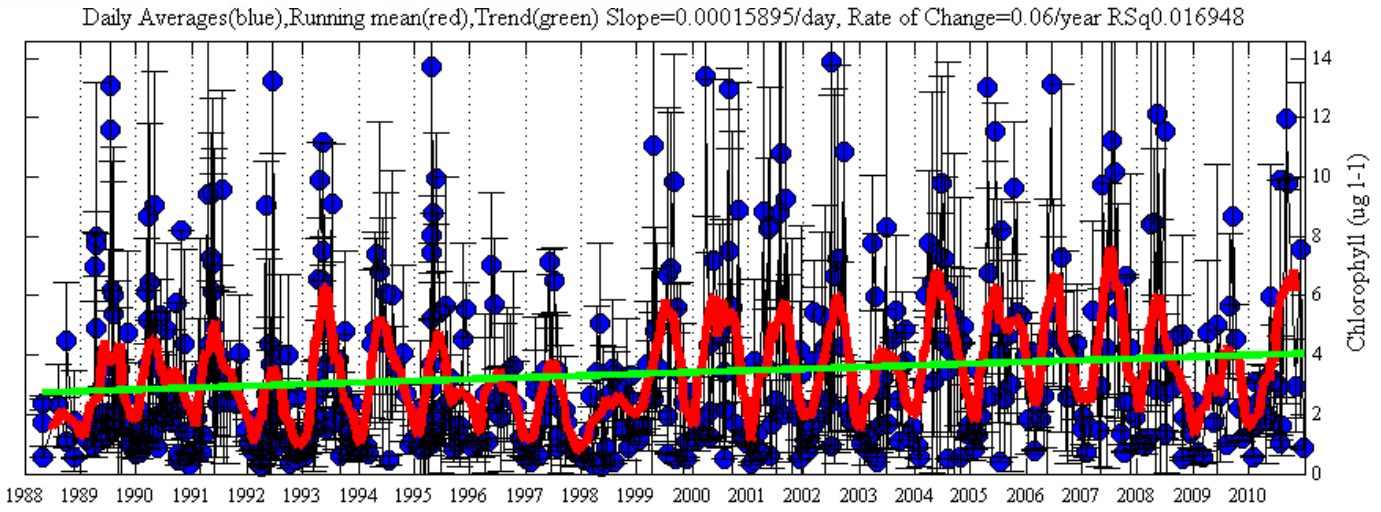




Scripps Pier: +0.076 per year

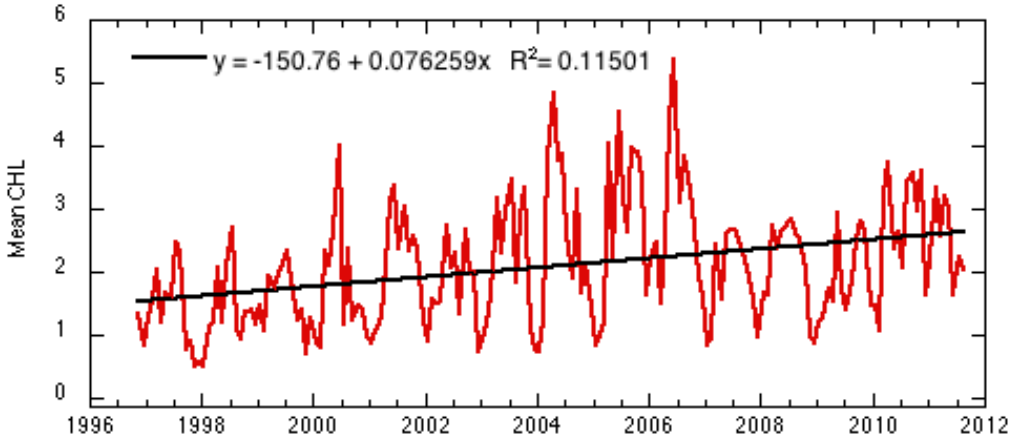
(Kim et al., Prog. Oceanogr. 2009)

MBARI: +0.06 per year

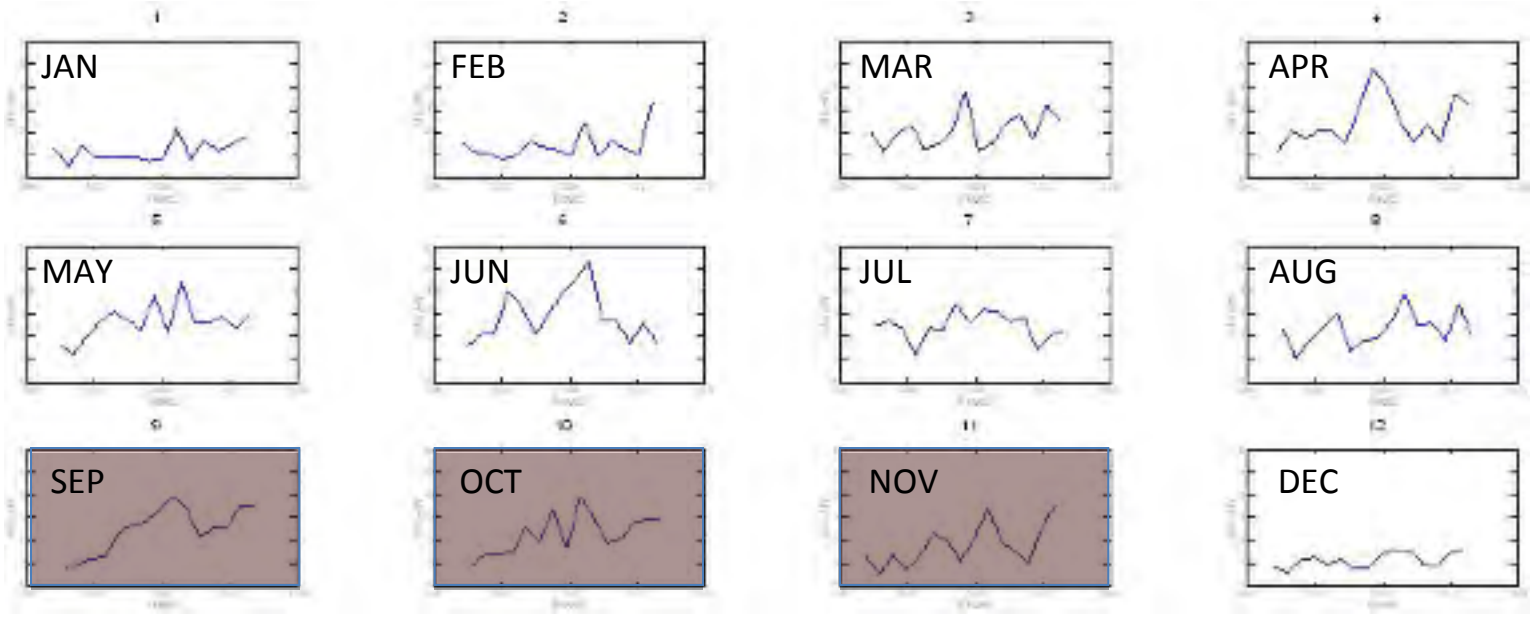


Satellite: +0.076 per year

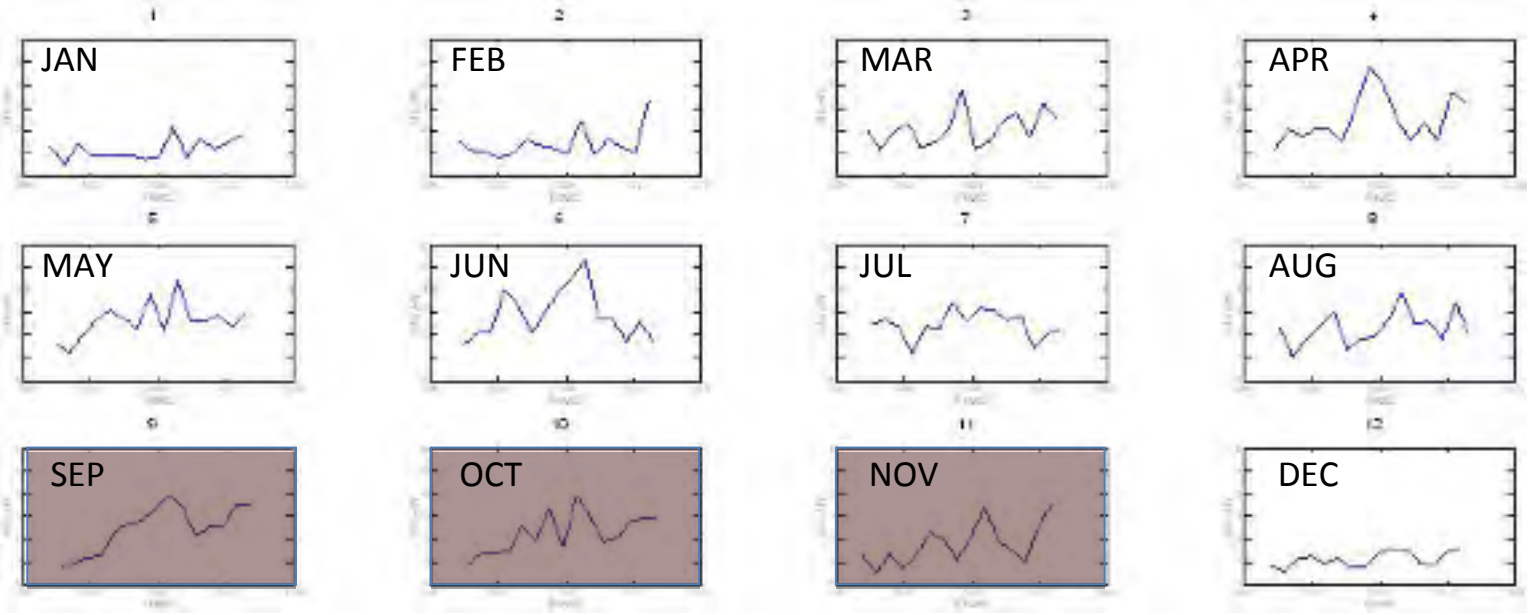
(Kahru et al. submitted)



Mean Monthly Trends in Chlorophyll

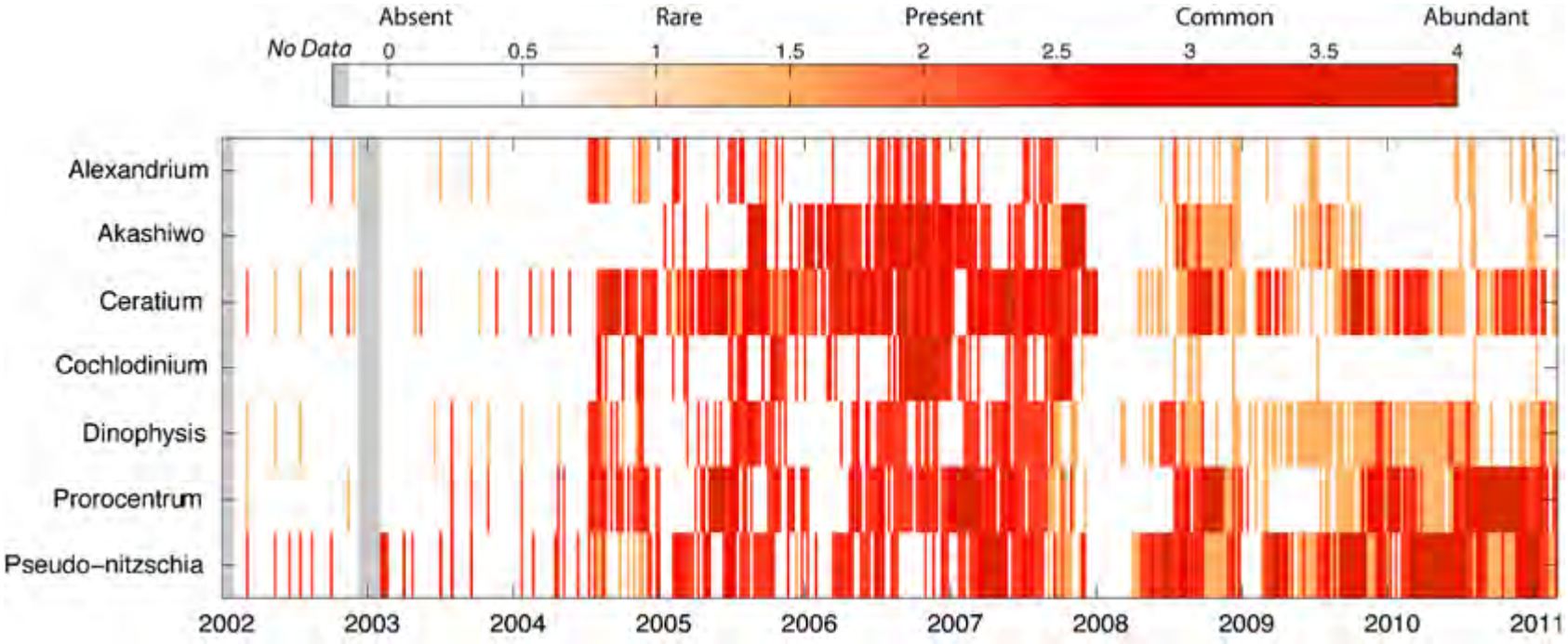


Median Monthly Trends in Chlorophyll

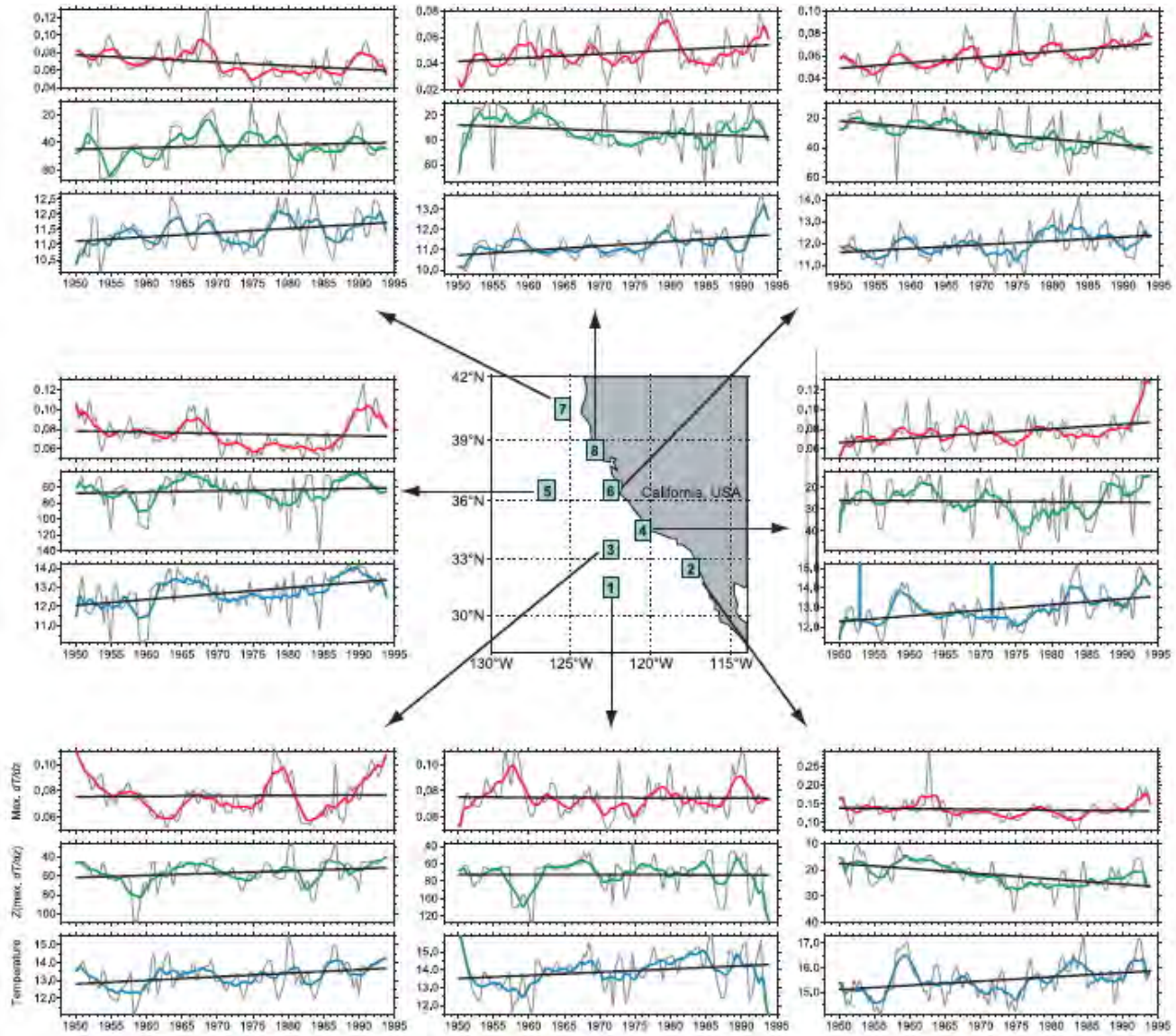


What is Driving the Trends?

- 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

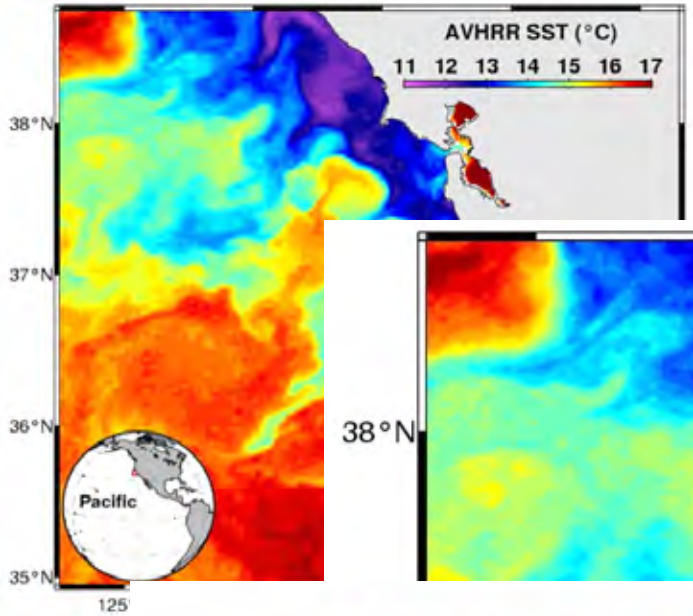


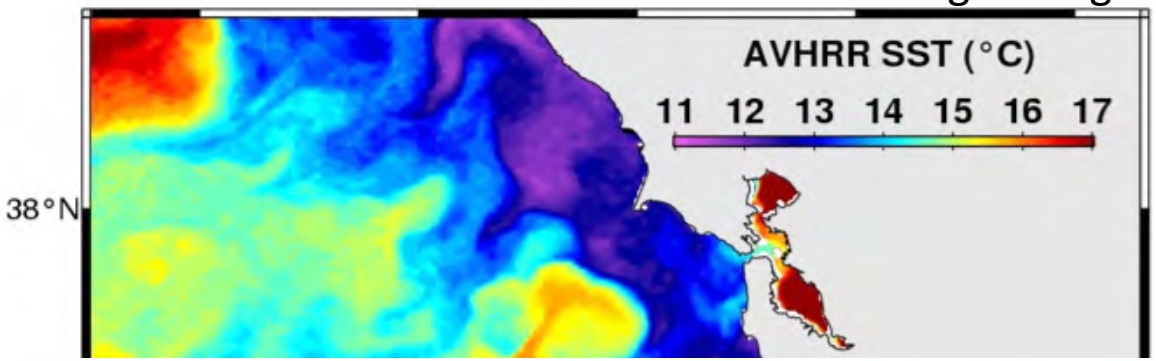
Stratification ↑

Depth ↓

Temperature ↑

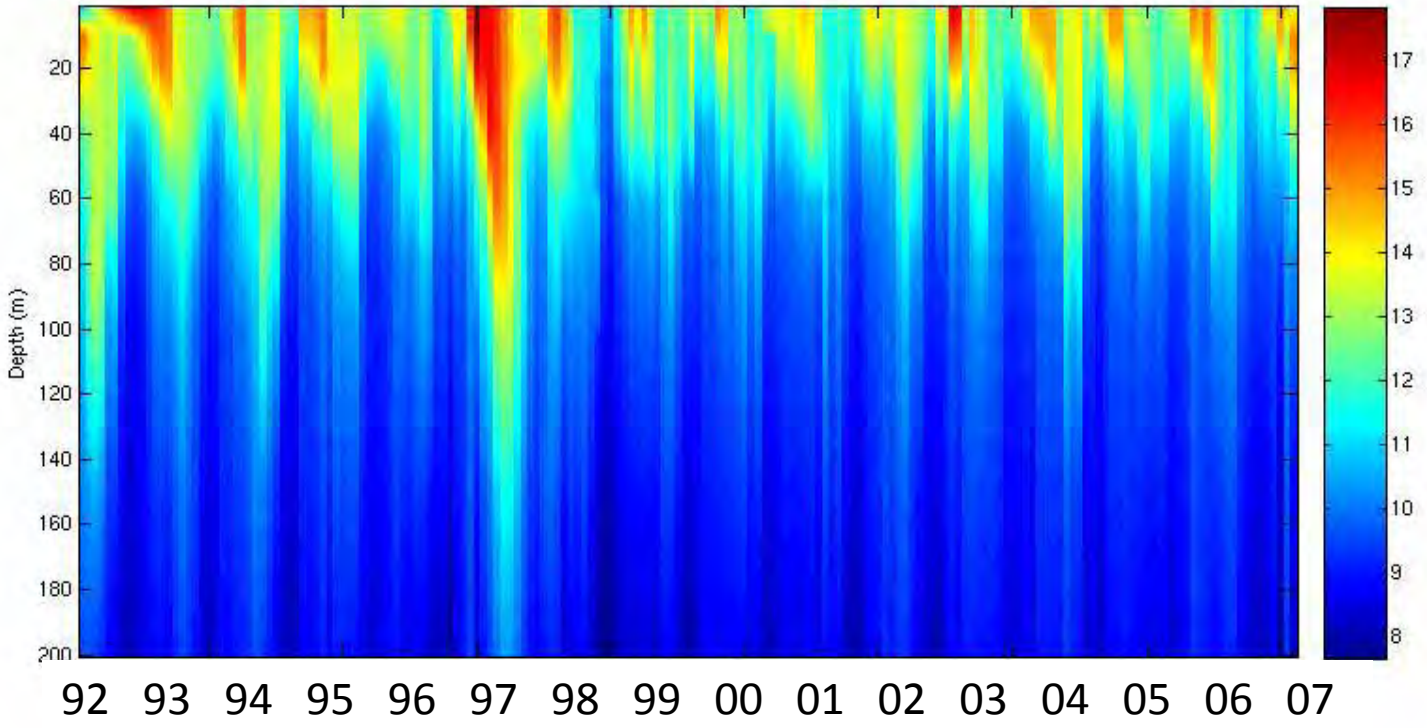
Palacios, D.M., S.J. Bograd, R. Mendelssohn, and F.B. Schwing. 2004. Long-term and seasonal trends in stratification in the California Current, 1950-1993. JGR 109, C10016.



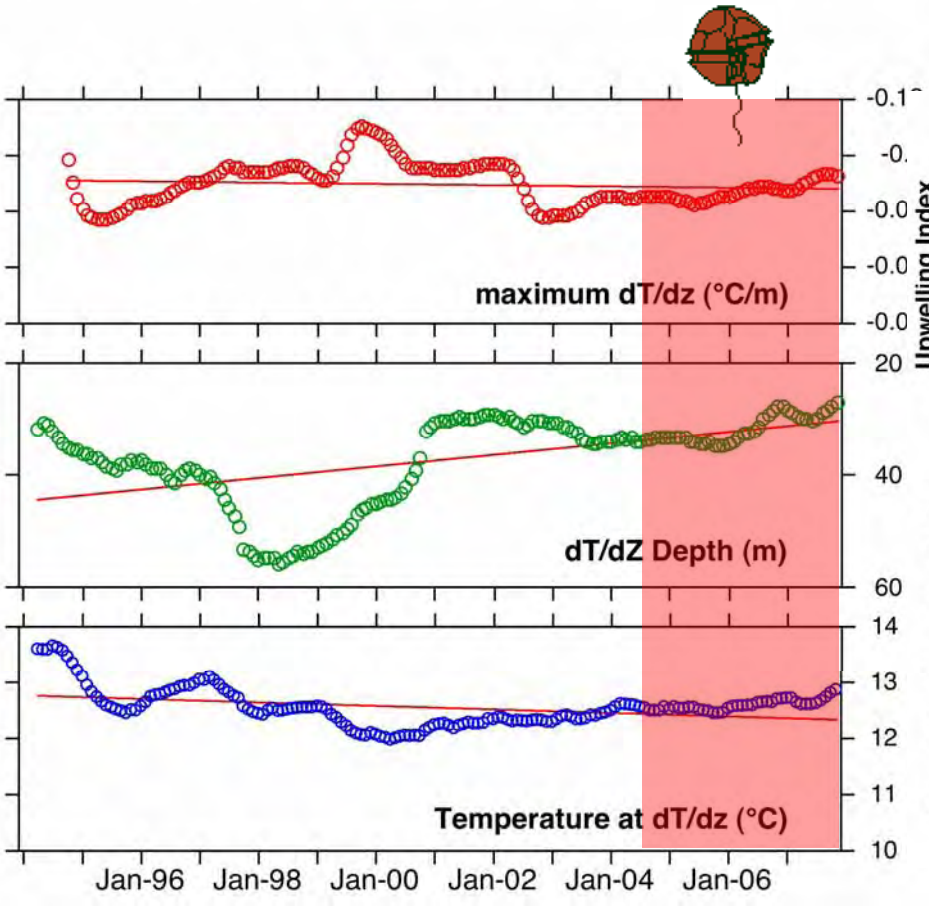


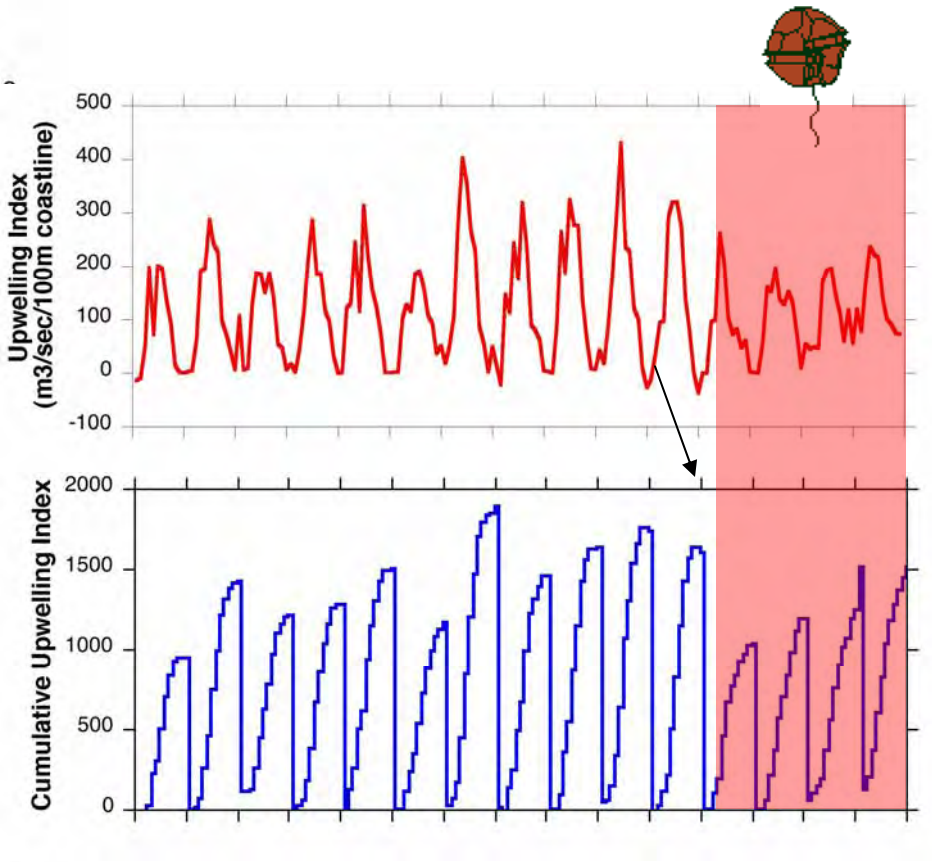
M2 Mooring:

- Bilinear interpolation
- 3x median filter (> 3 SD)
- 37 month moving average

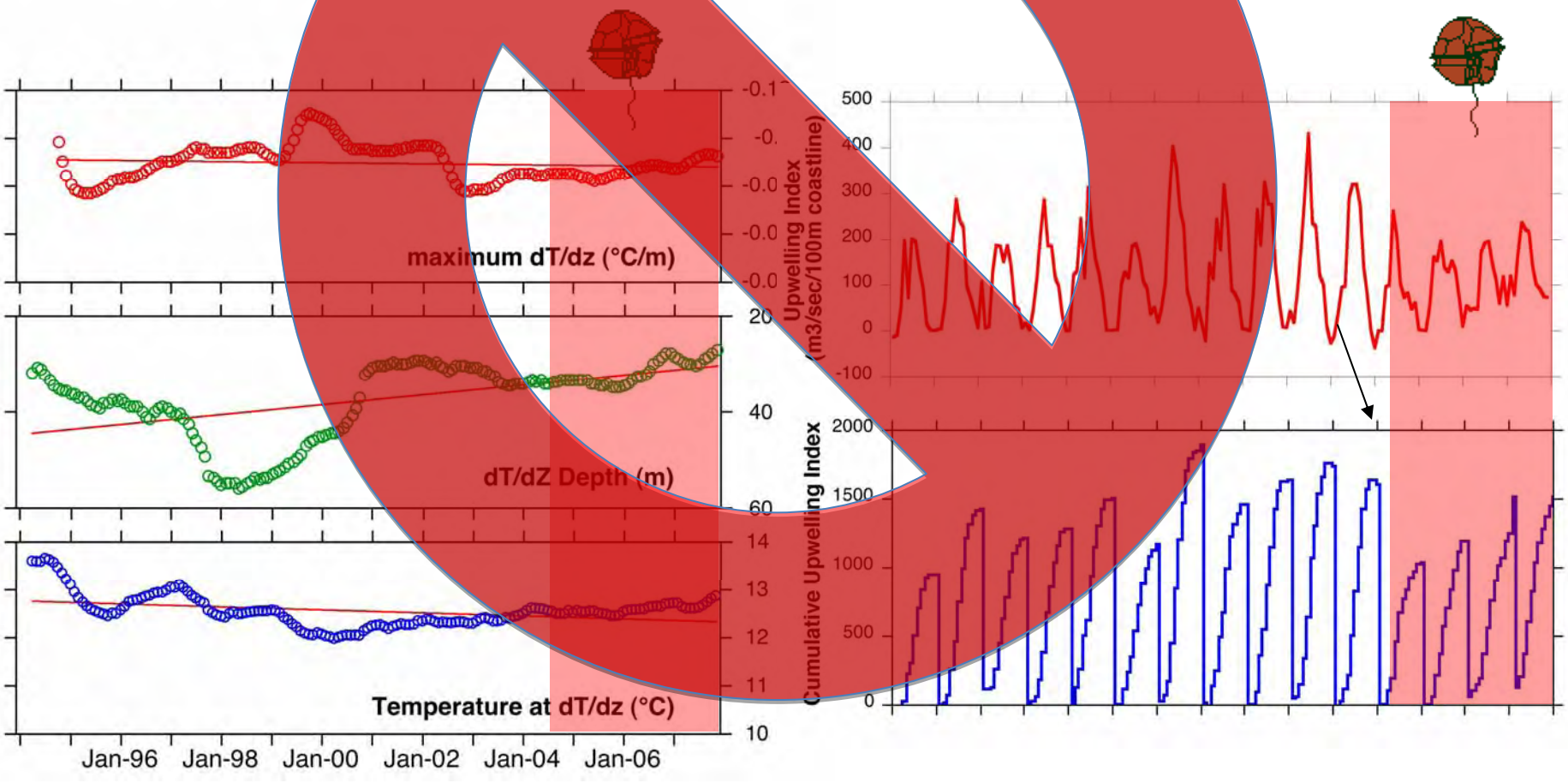


Long-term changes in stratification coupled to short-term changes in upwelling

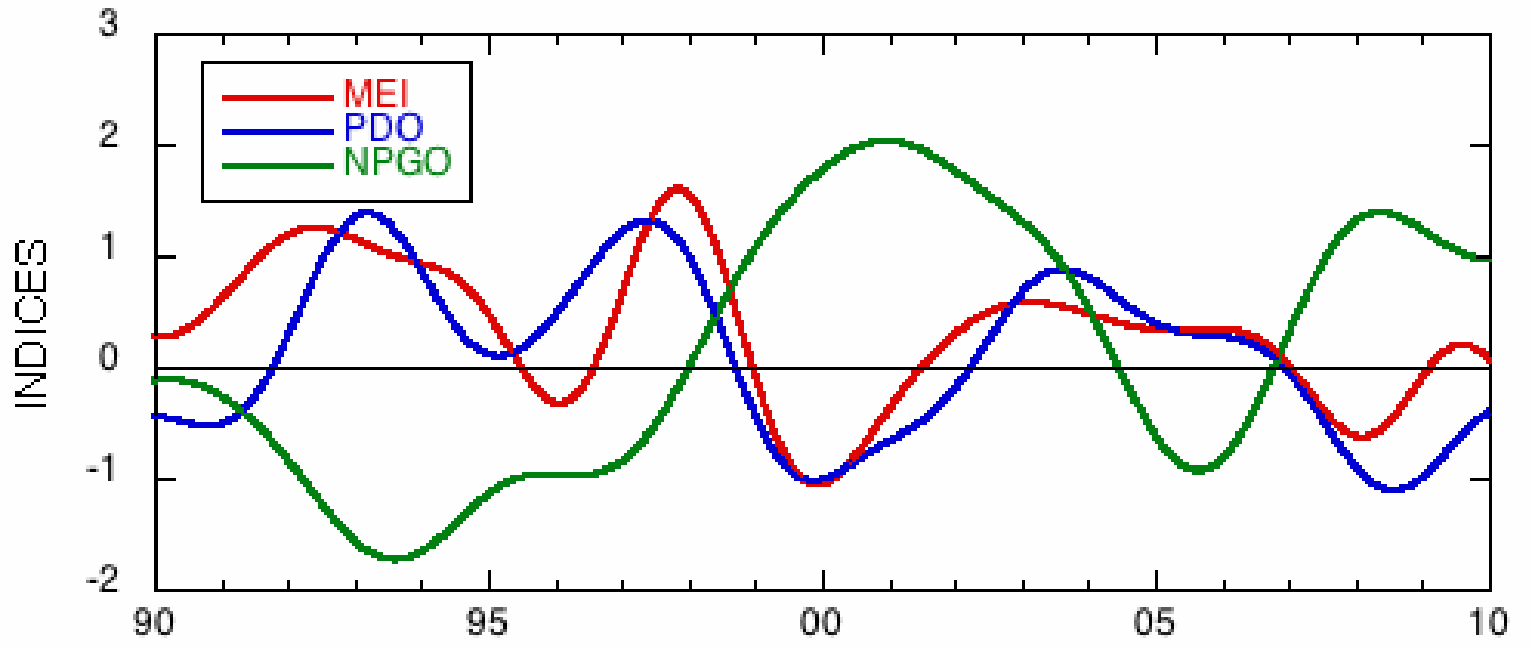




Long-term changes in stratification coupled to short-term changes in upwelling

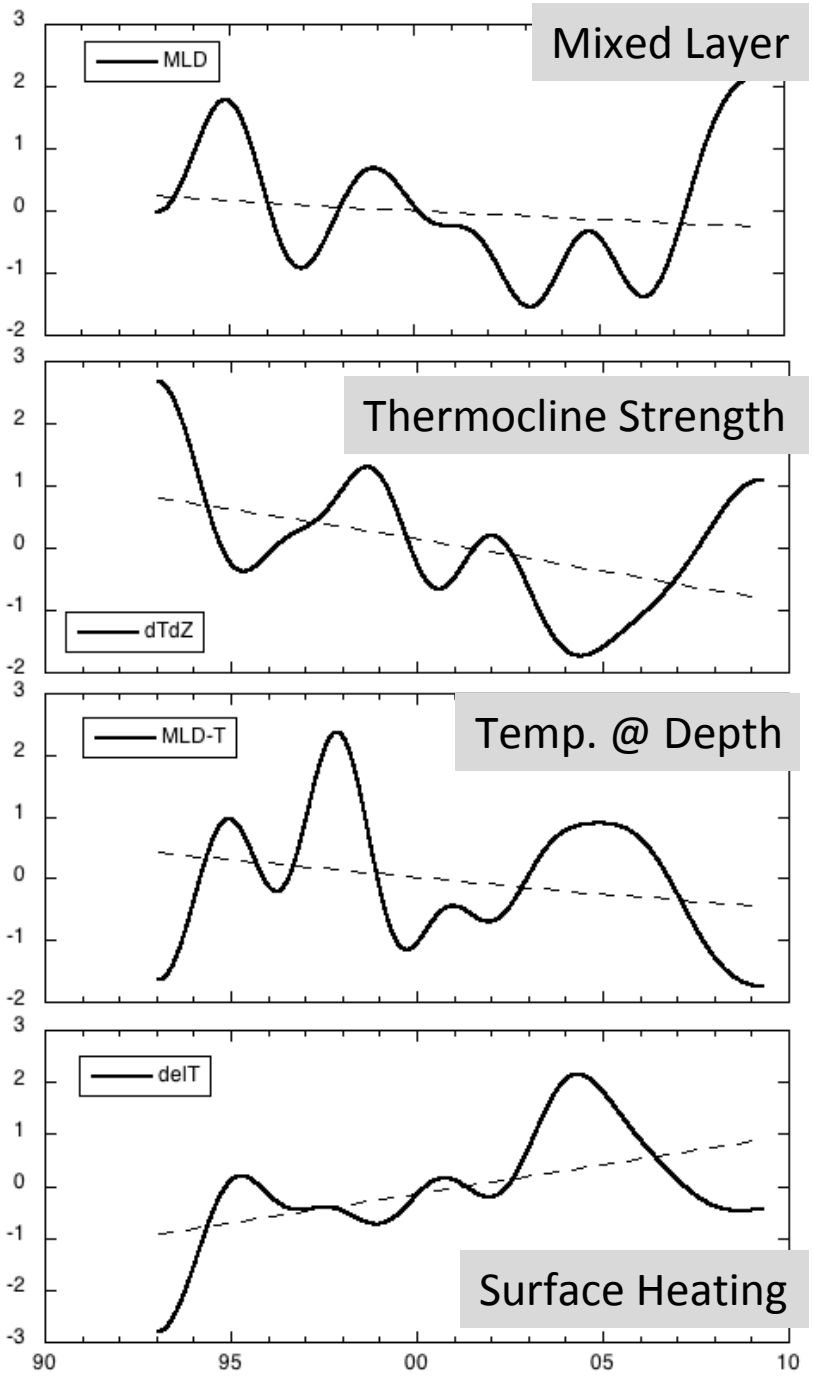


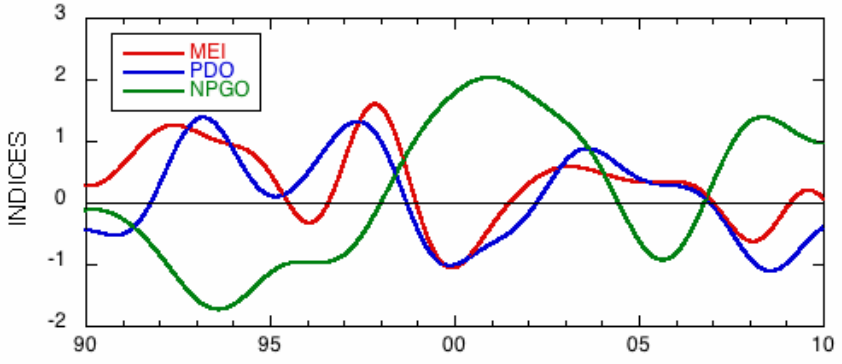
Extending the Time Series (~1993-2010)



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

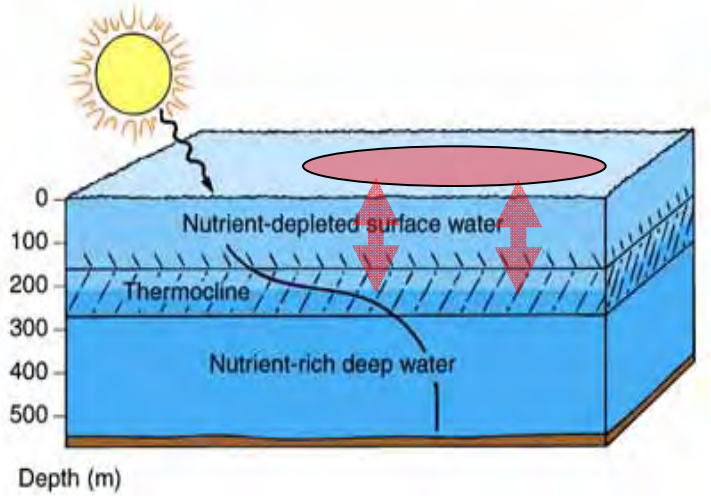
Mixed Layer Depth (MLD), Maximum Stratification (dTdZ), Temperature at that depth (MLD-T), and the difference between
SST and MLD-T were normalized and low-pass filtered

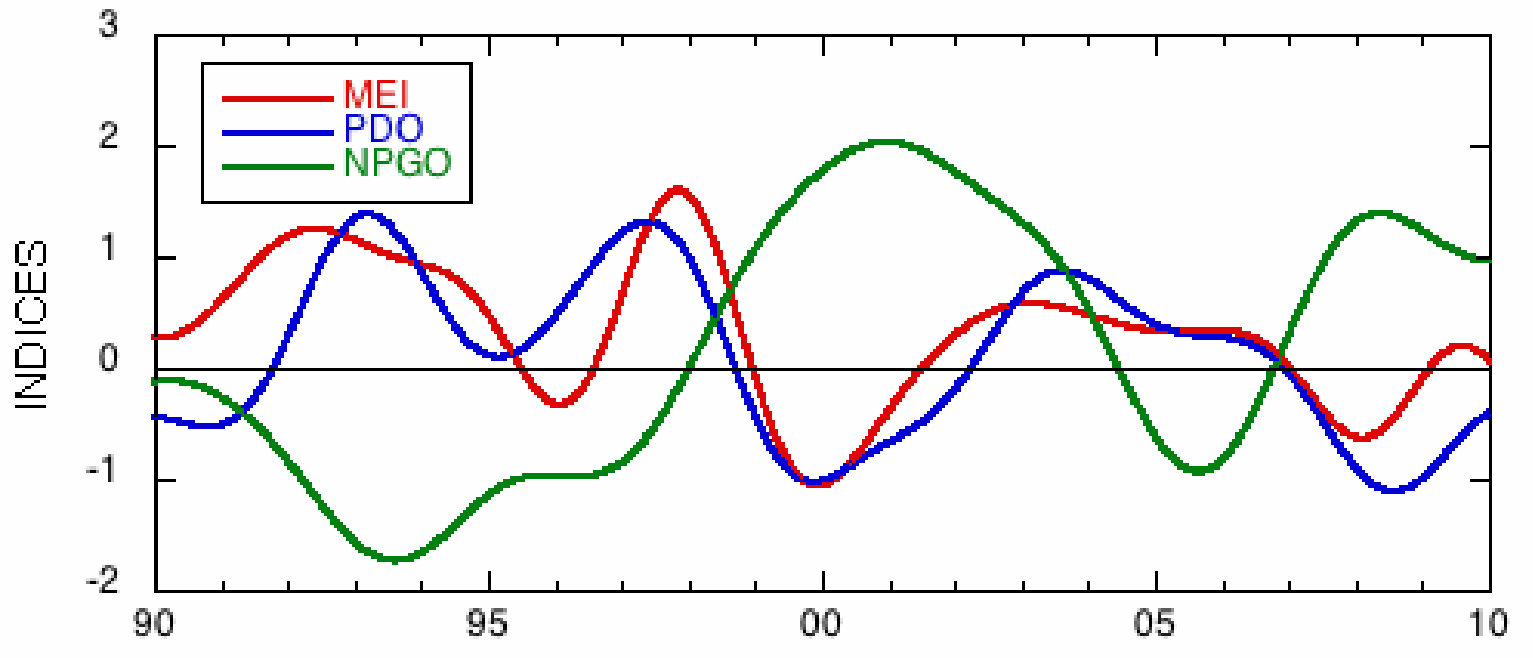




MLD is shallowing*
Thermocline strength is increasing
Thermocline temperature is cooling*
Surface waters are warming

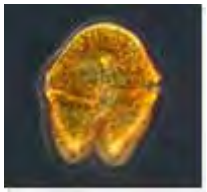
***Opposite the long-term trend reported by Palacios et al. 2004**

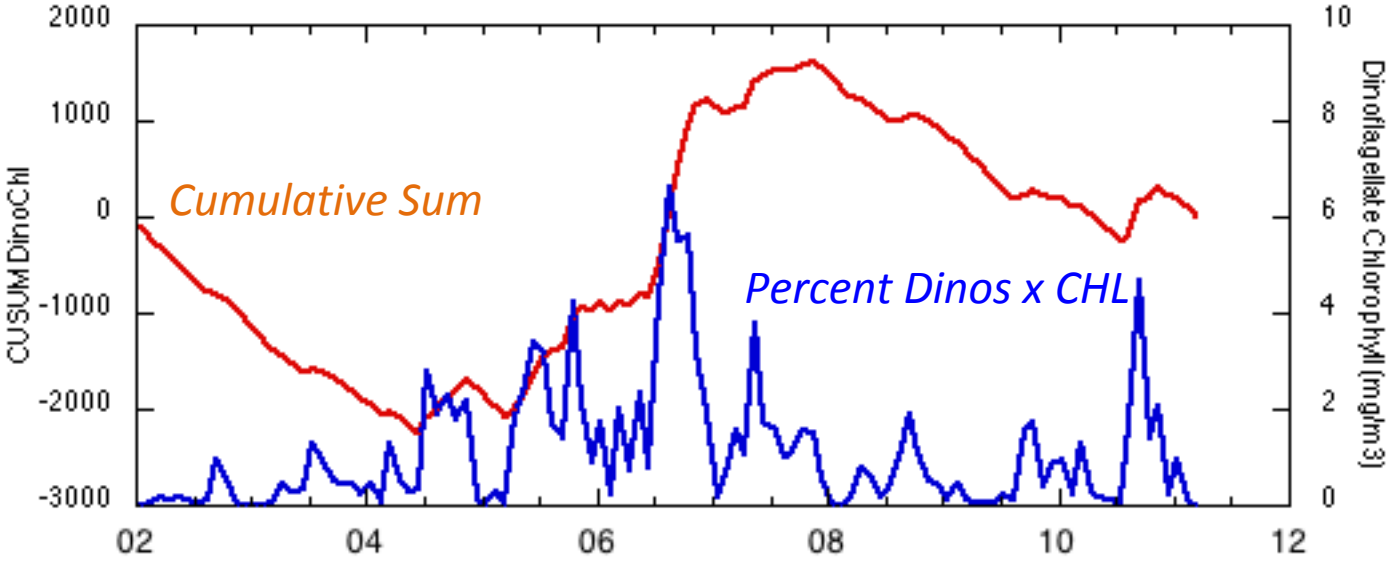




	MEI	PDO	NPGO
CHL Anomaly	-0.223	--	-0.209
Mixed Layer Depth	--	-0.244	-0.169
Intensity of Stratification	--	--	-0.137
Temp. @ max Stratification	+0.583	+0.481	-0.378

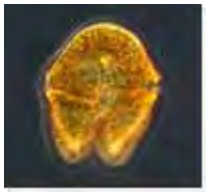
Dinoflagellate Time-Series

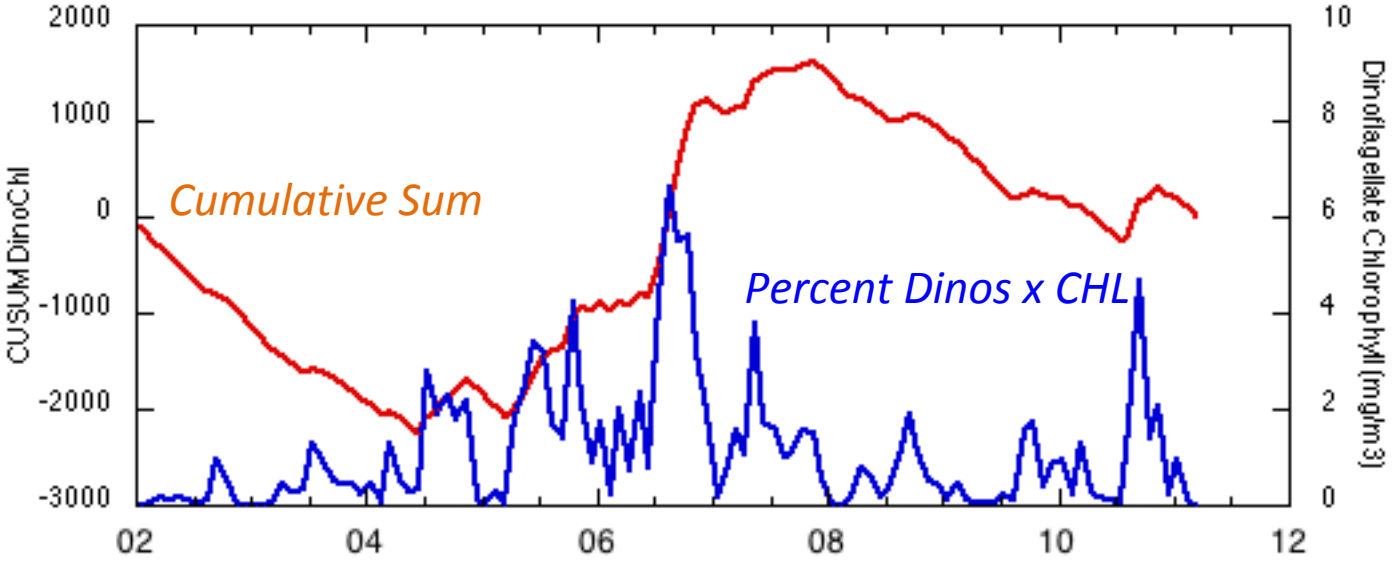




The time-series of relative abundance index RAI) at Santa Cruz Wharf was used to estimate percent dinoflagellates (weekly), and multiplied by the chlorophyll concentration (satellite) to generate a dinoflagellate time-series from 2002-2011….

Dinoflagellate Time-Series





CUMSUM x low-pass (13 month) correlations ($p<0.05$)

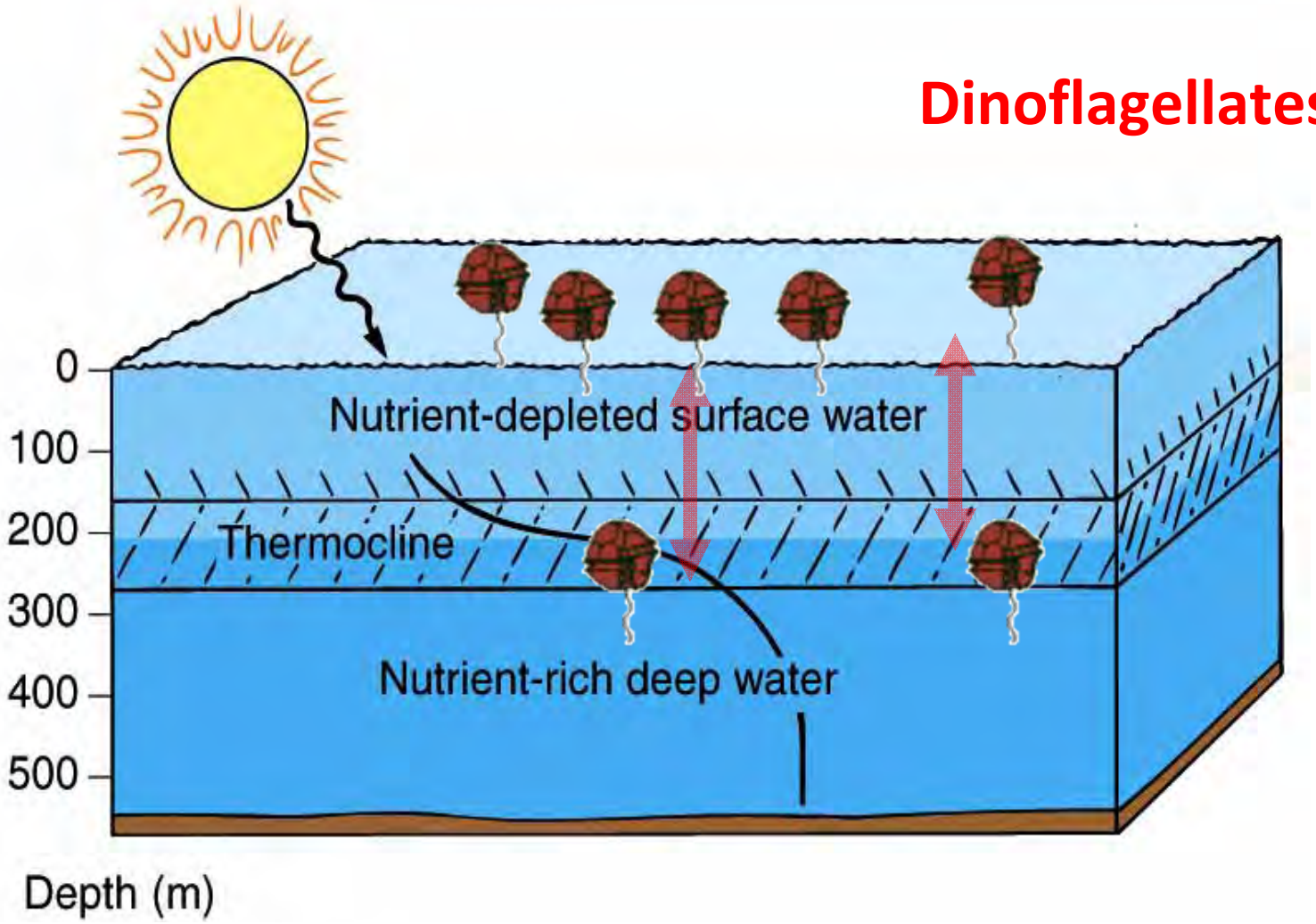
MEI	PDO	NPGO
-0.64	-0.86	+0.50
MLD	**dTdZ**	**MLD-T**
+0.324	-0.512	+0.523

Neither the CUMSUM nor the original time series are correlated with PFEL Upwelling Index with 0, 13, or 37 month low-pass filtering.

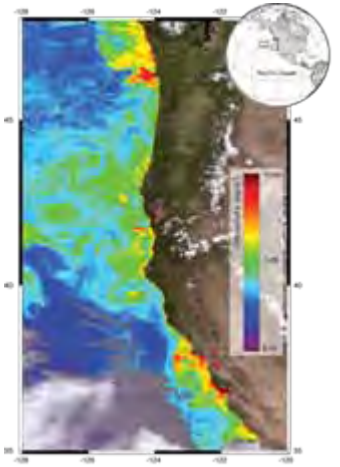
MLD is shallowing
Stratification is intensifying
Subsurface nutrients are increasing
Surface temperatures are increasing

MEI
PDO
NPGO
Other (?)

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