WIND, WHALES, AND HARMFUL ALGAL BLOOMS: THE DEVELOPMENT OF A COASTAL MONITORING SYSTEM IN MONTEREY BAY

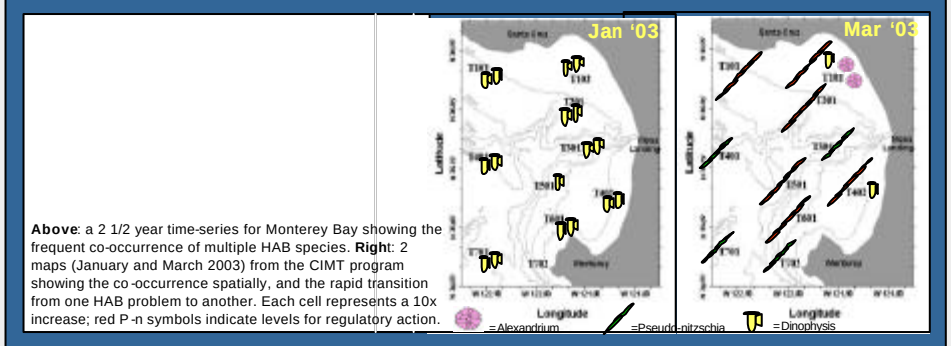
Raphael Kudela, Ken Bruland, and Mary Silver

Department of Ocean Sciences, University of California Santa Cruz, 1156 High St. Santa Cruz, CA 95064

Abstract

Coastal California is typically viewed as upwelling-dominated, with strong equatorward and Ekman-dominated offshore flows, bounded to the west by the broad, meandering California Current. This implies that biological and physical processes propagate predominantly southward, that coastal runoff has negligible impacts on the near-shore oceanographic conditions and that much of biological interest is driven by seasonally intense spring upwelling. Recent observations suggest that this view is misleading, and that the occurrence of infrequent but high-impact events such as precipitation-driven coastal runoff and poleward surface flow may dominate the biological signal over large spatial and temporal scales. These events can "fertilize" the coastal ocean with anthropogenically derived nutrients, and may catalyze or exacerbate HAB conditions in the coastal ocean. With funding from the National Oceanographic and Atmospheric Association (NOAA), several partner institutions in the Monterey Bay, California area have established a Center for Integrated Marine Technology (CIMT; http//cimt.ucsc.edu) with the scientific goal of describing how physical forcing (wind) eventually translates into the phenomenal biological productivity (such as whales) seen in central California, and how the presence of frequent HAB events (including both *Pseudo-nitzschia* and *Alexandrium* spp.) can occasionally result in dead whales. An overview of the CIMT program, its application to HAB monitoring, and some exciting new technologies and observations will be explored.

HABs in Monterey Bay

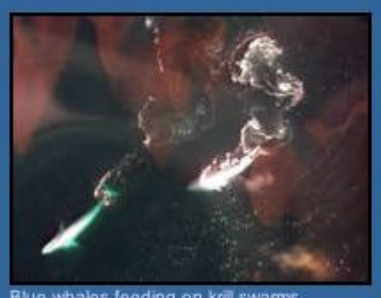


Above: a 2 1/2 year time-series for Monterey Bay showing the frequent co-occurrence of multiple HAB species. **Right**: 2 maps (January and March 2003) from the CIMT program showing the co-occurrence spatially, and the rapid transition from one HAB problem to another. Each cell represents a 10x increase; red P-n symbols indicate levels for regulatory action.

Historically, central California's spataiial extensive HAB events have been dominated by the toxigenic diatom *Pseudo-nitzschia* (timeline at right). Although Monterey Bay is known as a "hot spot" for domoic acid poisoning, enhanced monitoring as part of the CIMT program has shown that multiple HAB species, as well as non-toxic red tides, are frequently present. This highlights the need for rapid, sustained monitoring of both species and toxins.

Center for Integrated Marine Technologies

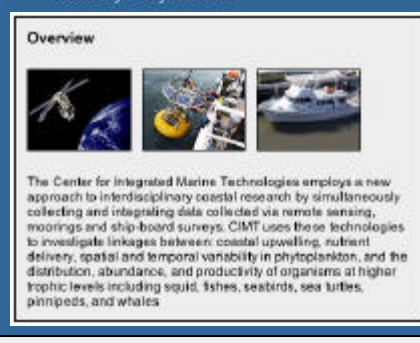
Wind to Whales Program

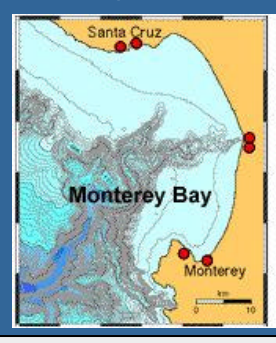


Blue whales feeding on krill swarms
Photo by Kelly Newton

Understanding the processes underlying coastal upwelling along the California coast using an interdisciplinary approach and emerging technology.

http://cimt.ucsc.edu



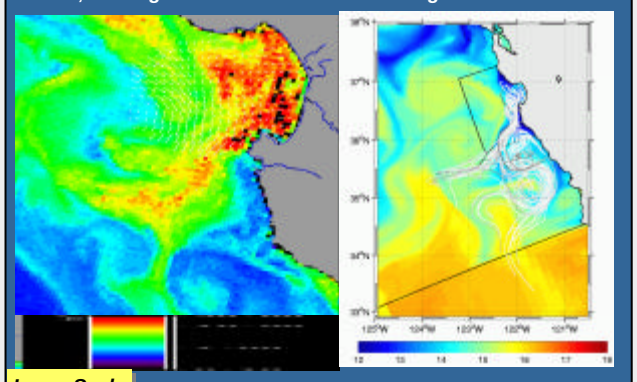


CIMT Partners

- University of California Santa Cruz
- National Marine Fisheries Service (NOAA)
- Monterey Bay Aquarium Research Institute
- Moss Landing Marine Laboratories
- Monterey Bay National Marine Sanctuary (NOAA)
- Naval Postgraduate School

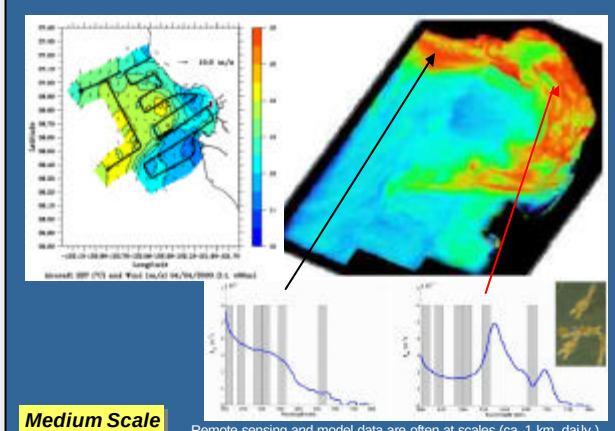
Integrating New Technology

A primary goal of CIMT is to integrate existing and emerging technology, and apply it to coastal issues such as HABs. Here we provide three examples, starting at large spatial scales, moving to the scale of individual organisms.



Large Scale

By combining SeaWiFS ocean color data with HF Radar vectors (left), we can improve feature-tracking of HAB events. In this image, from August 2000, it is apparent that the high-chl waters are moving offshore and southward. Elevated DA was found on southern beaches in Monterey, but not on the outer southern coast. More recently (October 2002), simulated drifter releases (right) in the ROMS coastal model help to determine potential sources and trajectories of a red tide event (*Ceratium* spp.) which appeared to advect into Monterey Bay from further north.

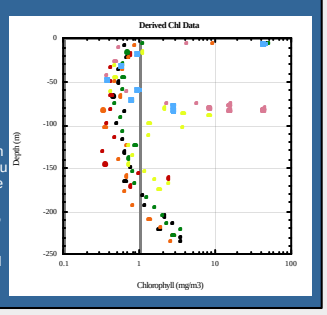


Medium Scale

Remote sensing and model data are often at scales (ca. 1 km, daily) that miss many of the spatial and temporal dynamics of bloom events. To address this, CIMT and collaborating groups have begun to use airborne overflights to provide sea surface temperature and winds (upper left) and hyperspectral color (upper right; AVIRIS image from October 2002). Hyperspectral imagery in particular can easily identify events such as the *Ceratium* red tide of October 2002, which was interspersed with a *Pseudo-nitzschia* dominated diatom population (reflectance graphs). SeaWiFS and MODIS would have missed these events, both because of poor spatial resolution but also inappropriate spectral bands (graphs, bars represent SeaWiFS bands).

Small Scale

Many HAB events are still ultimately "tracked" or detected by their impact on living marine resources. As part of CIMT, we are u using marine mammals to provide an "animal-eye view" of the Monterey Bay. Utilizing temperature thermistors and light attenuation from these tags, we can produce maps of mixed layer depth, chlorophyll, and animal behavior relative to ecological conditions. At right: derived chlorophyll from an elephant seal (top) translocation in Monterey Bay, showing a distinct chl-max.



1998: P-n bloom along much of the US West Coast
Severe bird and marine mammal mortality

1995: L. polyedrum Red Tide (extending from Baja to Monterey, CA)

2002: More than 500 sea lion, 20 dolphin Seizures in Southern California

1990 1992 1994 1996 1998 2000 2002 2003

1991: DA discovered in Monterey Bay, Major bird mortality event

2000: Highest recorded DA values in Monterey Bay Relatively few impacts on higher trophic levels

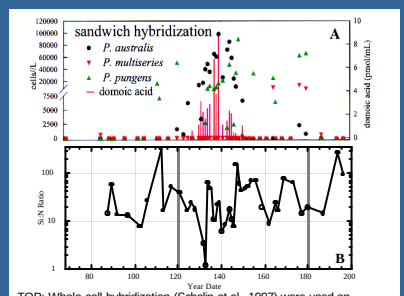
2003: Massive P-n bloom in Santa Barbara Channel (28 mg/L chl)

2000--A Case Study

The MBARI-sponsored MOOS Upper-Water-Column Science Experiment (MUSE)provided a large-scale, multi-institute, multi-disciplinary, field experiment in Monterey Bay August, 2000, fortuitously during a major HAB event.

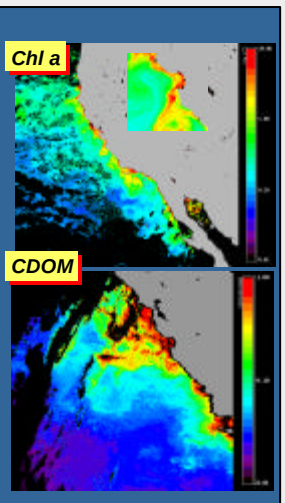
Although not intended to be a HAB study, the MUSE effort exemplified the power of a coordinated ocean observing network for understanding the ecophysiology of *Pseudo-nitzschia*, and provided a platform for evaluating several hypotheses based on a previous (1998) HAB event.

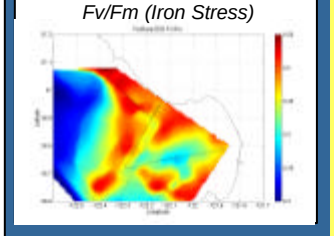
The MUSE project involved three ships, two aircraft, two satellites, two AUVs, several drifters, nine moorings, six gliders, and a host of small boats, designed to examine a natural iron feritlization event.



TOP: Whole-cell hybridization (Scholin et al., 1997) were used on samples collected from the Santa Cruz Wharf from Year Day 78-200, 1998. Panel A (reproduced from Scholin et al., 2000) shows the relative abundance of *P. australis, P. multiseries, and P. pungens*, together with DA levels. Panel B shows the Si:N ratio in the samples. Note the increase in *P. australis* following the increase in Si:N ratios (day 110), and the onset of DA accumulation following the minimum in Si:N ratios (ca. day 130).

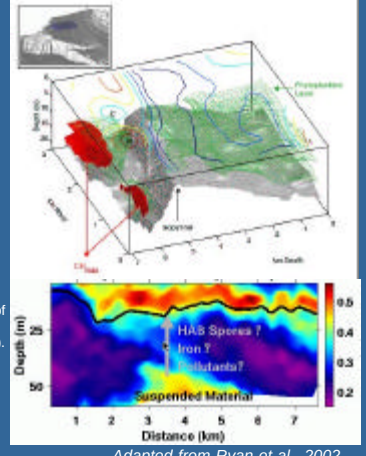
RIGHT: SeaWiFS imagery shows the large bloom in Monterey Bay, and the elevated CDOM (to ca. 400 kn offshore) attributed to riverine runoff.





Above, Left: During the 2000 Monterey Bay MUSE experiment, the dominant phyoplankton species was *Pseudo-nitzschia australis*. Water was collected from a nearly mono-specific near-surface bloom, and spiked with Nitrate (blue), Silicate (green), Desferol, which is an iron chelator (black), or nothing (red) in 9 Liter carboys. The carboys were then maintained under simulated in situ conditions for 6 days, and changes in biomass were monitored using chlorophyll (least specific, top panel), biogenic silica (specific to diatoms, middle panel), or *P. australis*-specific probes (bottom panel). Variable Fluorescence data collected at the same time (Chelsea FRR using nigh-time data) suggest that iron was generally non-limiting, based on the elevated (>0.4) Fv/Fm values.

Based on observations of possible nutrient-control of toxin production during 1998, we evaluated the importance of macro- and micronutrients during the 2000 bloom. There was no evidence for iron limitation, and *Pseudo-nitzschia* biomass was nitrogen (not silicon) limited. Substantial populations were associated with spatially large "thin layers".



Right: A a series of AUV and shipboard observations were conducted, providing a 3-D view of the waver column. A subsurface bloom of Pseudo-nitzschia australis was mapped, generally following a density gradient (top panel). This bloom extended spatially for several kilometers, with very little surface expression. A 2-D slice (bottom panel) depicting backscatter (particles), suggests that the phytoplankton bloom (elevated surface values) was being "fed" by a subsurface resuspension event, possibly providing a source of bio-available iron.

Adapted from Ryan et al., 2002

By creating a Center for Integrated Marine Technologies (CIMT), we are explicitly linking new technologies across disciplines of marine science to address key questions for marine resource managers – from physical forcing to fisheries and protected resources. This center provides the structure for an innovative new approach to understanding how key marine resources – fisheries, seabirds, sea turtles, and marine mammals – respond to short and long-term changes in physical oceanographic processes such as El Niño events, decadal oscillations, and long-term climate change. Such a comprehensive, integrated, interdisciplinary approach has been identified as the best approach to an integrated ocean observing system.

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