THE CENTER FOR INTEGRATED MARINE TECHNOLOGIES: LONG-TERM OCEAN OBSERVING SYSTEM IN MONTEREY BAY, IMPROVING THE UNDERSTANDING OF OCEAN AND COASTAL ECOSYSTEMS

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INTRODUCTION

The Center for Integrated Marine Technologies' (CIMT), a Coastal Observation Technology System (COTS) funded project within the Central and Northern California Ocean Observing System (CeNCOOS) seeks to understand the relationship between the physical dynamics and productivity, from wind to whales, of California's coastal ocean. CIMT provides an ecosystem-based understanding of Monterey Bay with a mission *to create a coastal ocean observing and forecasting system that provides a scientific basis for the management and conservation of Monterey Bay, and serves as a model for monitoring all of California's coastal marine resources*. This effort has been simultaneously collecting data via moorings, shipboard surveys, apex predator tagging and tracking, satellite, aircraft, and land-based remote sensing since 2002. Data integration provides new insights to complex interactions among resource characterization, climatic events, riverine input of iron, wind-driven coastal upwelling of nutrients to phytoplankton production, linkages to offshore water quality, and the distribution and abundance of animals from zooplankton to marine mammals. The CIMT data collected is being integrated in multiple formats from raw data to models to GIS and is being shared with stakeholders to develop products that meet user needs. This long term monitoring approach allows for an improved understanding of marine populations within ocean and coastal ecosystems and the ability to develop predictive models of how marine resources respond to variability in coastal dynamics. Information on monitoring Monterey Bay is valuable in the marine protected area process, water quality monitoring, restoring and maintaining ocean and coastal habitats and resources, and creating sustainable fisheries.

BACKGROUND

With increasing human populations, demands on coastal resources are increasing, leading to dramatic changes in coastal ecosystems. Because we rely on the ocean for food, commerce, mineral, and energy resources, as well as for recreation, it is critical that we develop conservation and management strategies that facilitate the sustainable use of marine resources while minimizing impacts on natural systems. A major impediment to achieving this has been a lack of an integrated understanding of the basic processes governing coastal ocean ecosystems.

In an effort to develop this understanding, the U.S. Commission on Ocean Policy recommended that the National Ocean Council make the development and implementation of a sustained, national Integrated Ocean Observing System (IOOS) a key element of its leadership and coordination role (recommendation 26-1). The IOOS is a system that: 1) is based on sound science and modern technologies, 2) provides timely access to data, and 3) makes effective use of existing resources, knowledge, and expertise (Malone 2001). Malone (2001) proposed that an ICOOS initially develop through the establishment of regional proof-of-concept pilot projects that incorporate existing programs and new initiatives into a coordinated and integrated system. Starting in 2002, the Coastal Observation Technology System (COTS) project funded the Center for Integrated Marine Technologies (CIMT) to develop one of several model demonstrations of regional coastal ocean observing systems based on combined knowledge, expertise, and efforts. In 2003, a regional component of IOOS was initiated (Central and Northern California Ocean Observing System – CeNCOOS) and CIMT joined as a partner in this regional effort.

The CIMT efforts are focused on the Monterey Bay region – from Pt. Año Nuevo on the North to Pt. Lobos on the South out to 122°05' west longitude. This region roughly encompasses the effects of the Davenport/Año Nuevo upwelling region (Rosenfeld et al. 1994). Monterey Bay is an ideal location for the development of a pilot sub-regional OOS. Presently, there are more than 20 federal, state, and private academic, research, and resource management agencies and institutions actively involved in studying, measuring, and monitoring the waters in and around Monterey Bay on an ongoing basis.

Coastal upwelling occurs along the eastern margins of ocean basins as winds moving from poles toward the equator act in combination with the Coriolis force to move surface waters offshore and draw cold, deep water to the surface (Barber & Smith 1981, McGowan et al. 1996). Upwelled water infuses surface waters with essential plant macronutrients such as nitrate, phosphate, and silicic acid, and this often leads to blooms of phytoplankton, forming the foundation of food chains that support coastal fisheries, seabirds and marine mammals. Along the California coastline, upwelling occurs during periods of strong northwesterly winds and is most intense in late spring and early summer, producing a band of cold water along the coast. This band is typically tens of km wide and separated from offshore warmer water by a series of highly variable jets, plumes and eddies (Strub et al. 1991).

Monterey Bay oceanography is strongly influenced by this persistent upwelling plume (Pennington & Chavez, 2000; Rosenfeld et al., 1994). During the spring and summer upwelling period, satellite imagery indicates cold surface water originates north of Monterey Bay near Davenport and appears to advect southwards across the mouth of the Monterey Bay as an upwelling plume (Davenport Upwelling Plume [DUP] [Pennington & Chavez, 2000]). During active upwelling, surface temperature is low and nitrate high in the DUP, but chlorophyll and total production values are typically low. Biomass-specific production rates are, however, high under these conditions. The low production and chlorophyll values found during active upwelling are apparently due to low phytoplankton biomass of water initially upwelled near Davenport (Service et al., 1998;

Kudela & Chavez, 2000). In the northeast corner of Monterey Bay, a seasonal front forms between the DUP and older, upwelled water residing in the wind shadow behind the Santa Cruz Mountains (Graham 1993). In this portion of Monterey Bay, chlorophyll values are often high but productivity/ biomass ratios low (Pennington & Chavez, 2000). Much of the productivity stimulated by DUP nutrients is probably advected offshore of Monterey Bay and the continental shelves, as has been found in other upwelling areas (Chavez et al., 1991; Hutchings et al., 1995).

During fall and winter, surface currents are northward both within Monterey Bay (Breaker & Broenkow 1994) and across its mouth (Paduan & Rosenfeld 1996). At this time the DUP is absent and the spatial distributions of surface temperature, salinity, primary production and chlorophyll are more uniform relative to the upwelling season. Studies have demonstrated that the supply of iron, a key micronutrient necessary for plant growth, plays a critical role in controlling phytoplankton. When coastal upwelling occurs in the spring, iron from the shelf sediments are entrained in upwelled water along with elevated concentrations of nitrate and silicic acid. Southerly currents result in the enormous productivity of this region being swept into Monterey Bay (Kudela & Dugdale 2000, Kudela & Chavez 2002).

Adding further complexity to coastal productivity are the influences of climatic events occurring interannually (El Niño/La Niña) and interdecadally (climatic regime shifts). Declines in upwelling, potentially linked to human activities, led to changes in productivity along the West Coast of North America beginning in 1977 (McGowan et al. 1998). However, a strong reversal, associated with multidecadal changes, occurred in the late 1990s (Chavez et al., 2003), making it clear that we need to understand the natural system before we can assess human impacts.

METHODS

A well-integrated interdisciplinary approach offers the best prospect of providing predictions regarding present and future effects of human activities on marine ecosystems. We have assembled a group of physical, biological, and geochemical oceanographers, ecologists, resources managers, and remote sensing experts, together with instrumentation and networking engineers who are working synergistically to develop an integrated Regional Coastal Ocean Observation System. Our unified goal is to create a well-integrated pilot system that will provide novel insights and critical data about the functioning of the California coastal upwelling ecosystem.

The CIMT has initiated a new approach to interdisciplinary coastal research by simultaneously collecting and integrating data collected via remote sensing, coastal observation moorings, shipboard surveys, and apex predator tagging and tracking. By utilizing technology on these different platforms, we can examine temporal changes in the Monterey Bay coastal environment using (mooring-based measurements) within local (ship-based measurements) and regional (satellite-based measurements). Individually, each component measures physical, biological and chemical components of coastal processes at specific temporal and spatial scales. Integrated together, they provide the data to develop predictive models across multiple spatial and temporal scales.

In its final report, the U.S. Commission on Ocean Policy proposed a list of core variables to be measured by the national IOOS (Table 1). CIMT currently measures 23 of 36 relevant variables (excluding variables concerning ice). In addition, CIMT measures 13 of 19 provisional IOOS core variables. From its inception, the CIMT has sought to develop the resources and technologies needed to: 1) develop an integrated, sustainable system to measure core IOOS environmental variables over the long-term, 2) archive and access these data products, 3) use data products in the development of predictive models to facilitate prognostication of change in the coastal environment with time, 4) identify a broad community of users for measured data products, and 5) create integrated data products that are accessible and understandable to community users. CIMT seeks to explicitly link new technologies across disciplines of marine science to address key questions of ecosystem indicators (marine populations) and public health.

Table 1. Proposed core variables for the IOOS (U.S. Commission on Ocean Policy).

Physical	**Chemical**	**Biological**
Salinity	Contaminants: water	Fish species
Water temperature	*Dissolved nutrients*	*Fish abundance/biomass*
Bathymetry	*Dissolved oxygen*	*Zooplankton species*
Sea level	*Carbon: total organic*	*Optical properties*
Directional wave spectra	Contaminants: sediments	*Ocean color*
Vector currents	*Suspended sediments*	*Pathogens: water*
Ice concentration	*pCO_2*	*Phytoplankton species*
Bottom characteristics	*Carbon: total inorganic*	Benthic abundance
Seafloor seismicity	*Total nitrogen: water*	Benthic species
Ice thickness		*Mammals: abundance*
Sea-surface height		*Mammals: mortality events*
		Bacterial biomass
		Chlorophyll-a
		Non-native species
		Phytoplankton abundance
		Phytoplankton productivity
		Wetlands: spatial extent
		Bioacoustics

Core variables measured by CIMT shown in italicized blue.

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