Zooplankton and Phytoplankton Contributors to Bioluminescence in Monterey Bay

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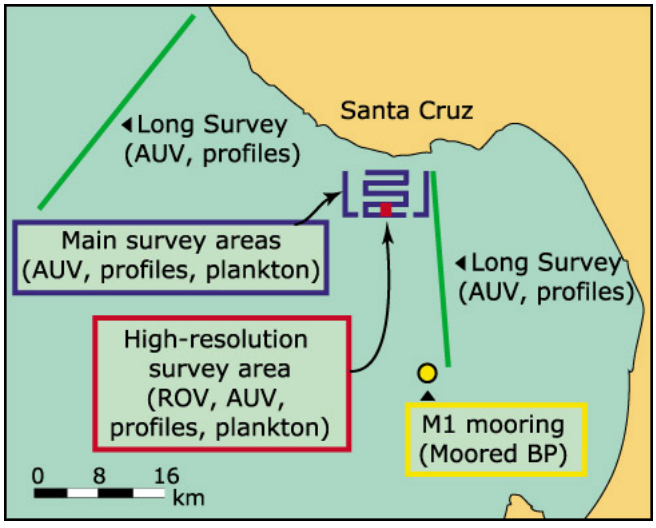
LONG-TERM GOALS

My long term goal is to understand and predict the distribution of marine bioluminescence, using the most advanced technology available for measuring light in the sea. I am especially interested in the organisms that cause luminescence, and their relative contributions to the oceanic light-field.

OBJECTIVES

My objectives were to measure luminescence and a suite of physical and biological factors across fronts and in varying water masses that typify coastal zones. Toward this end we operated on scales ranging from > 20 km to less than 1 km (Figure 1). Large scale transects (green) were used to provide a picture of the area surrounding the study site — maximizing the variability in the luminescent signals and sources detected. Medium scale (3-10 km; blue) transects were repeated over several nights to provide data on variability with time, and fine scale surveys (intensive sampling within a 1 km square; red) were repeated several times during particular nights to examine fine structure and rapid changes in bioluminescence distributions. An overarching objective was to provide data that would fit into the larger modeling efforts which were (and will be) directed toward this area.



1. The study sites, labelled with sampling programs that were successfully completed.

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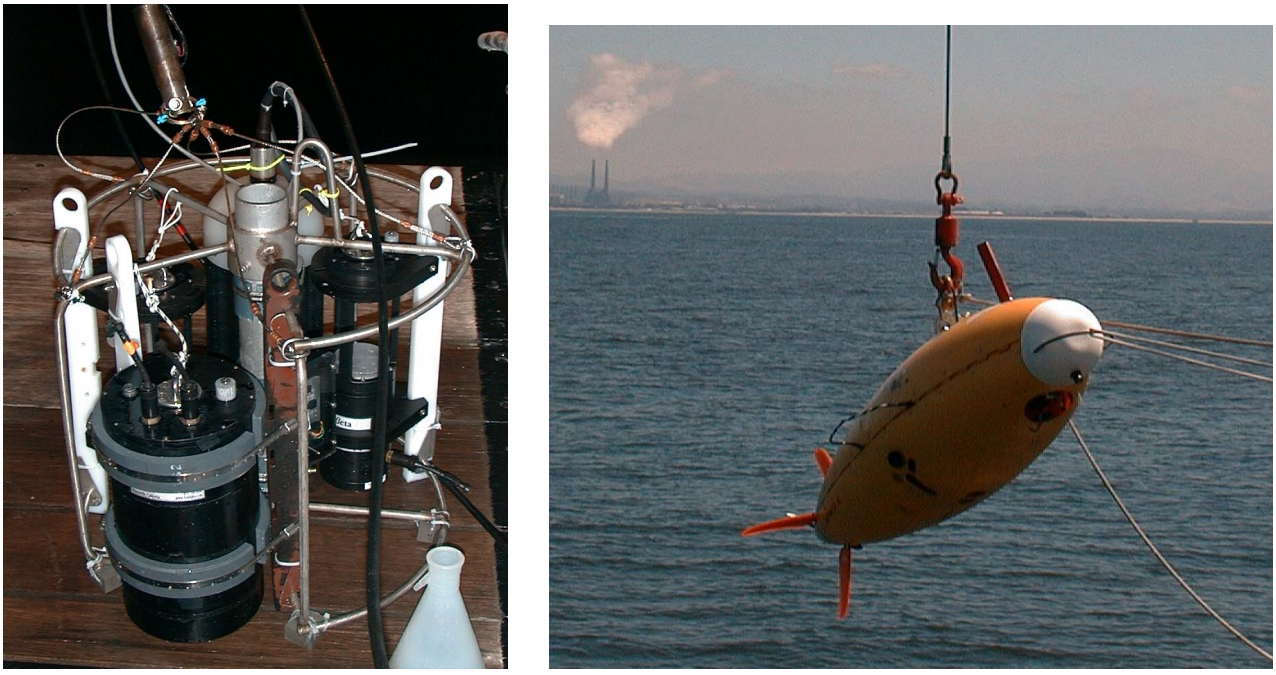
APPROACH

Sampling was coordinated with many instruments, platforms, and ships. Stationed on the R/V Pt. Sur were (a) an optical profiling cage, which measured temperature, luminescence, absorption, scattering, fluorescence, and optical backscatter (OBS), and (b) an AUV (provided by ONR support to Jim Bellingham; see his report for details), which measured luminescence, fluorescence, OBS, temperature and salinity (Figure 2). The AUV was programmed for a particular mission, and the ship would follow the same track, taking profiles at regular stations along the way. Bathyphotometers were provided by James Case. (See his ONR report for details.)

Zooplankton and phytoplankton samples, as well as additional bioluminescence profiles, were taken at several discrete depths at each station using specially built large-volume Schindler traps. This package was deployed from the R/V Shana Rae at complementary stations throughout the operation. (See Moline report for more details.) These samples also included chlorophyll and nutrients at each depth.

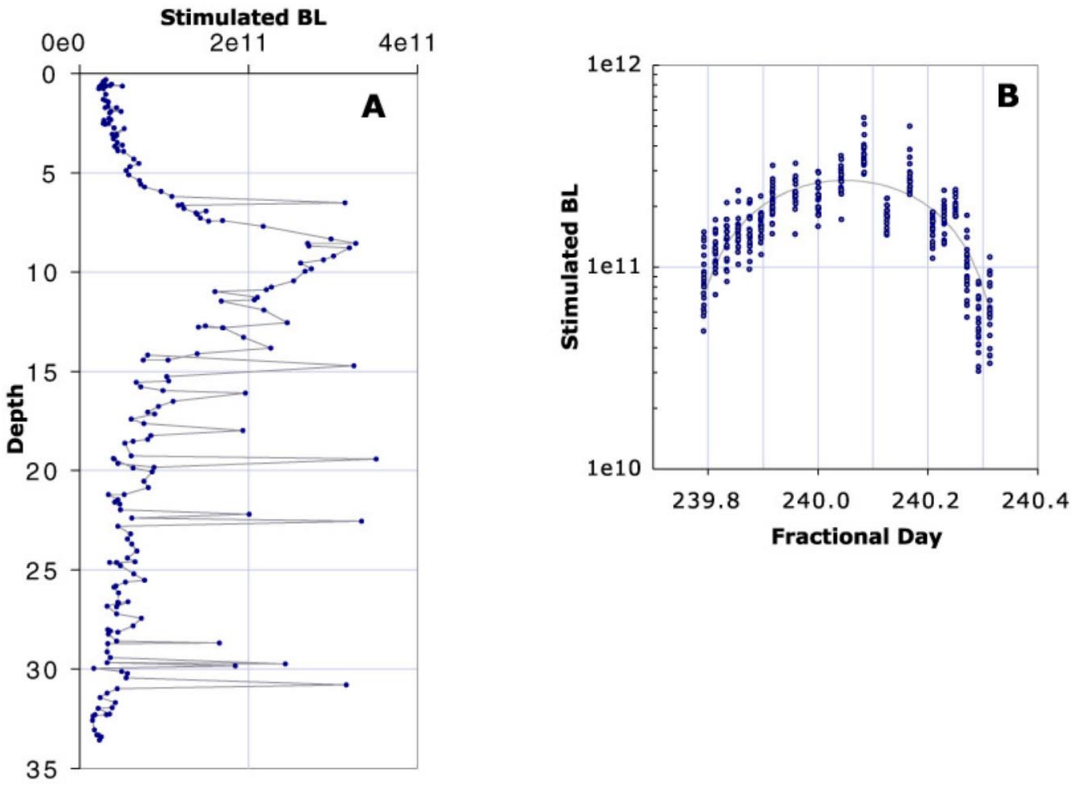


2. The optical profiling package (left) and AUV (right) used for surveys. (Photos: C. Herren)

Fine-scale measurements were conducted with the above platforms, with the addition of a bathyphotometer and low-light imaging system mounted aboard the ROV Ventana. (See Widder report for details.) A time-series was also obtained from an instrument mounted on the M1 mooring.

WORK COMPLETED

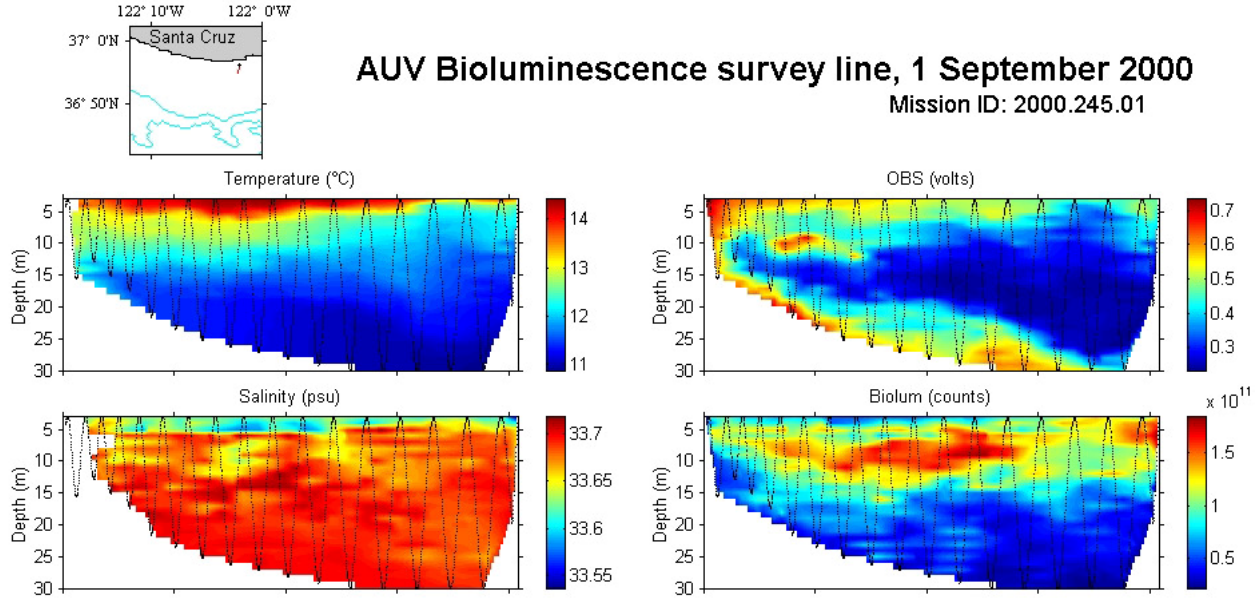
During the cruise, we completed 67 successful AUV runs, and occupied 48 profiling stations with the optics package and 34 stations with the zooplankton-phytoplankton-nutrient sampling package. There were two AUV runs of more than 20 kilometers. One run was situated just outside the bay heading offshore across the hypothesized source region, and the other was within the bay, extending south from the coast to the M1 mooring at the center of the bay (Fig.1). High resolution surveys were successfully coordinated with the ROV, which ran 43 transects in the course of 2 nights.



3. (A) Representative data from the profiling package shows a large subsurface dinoflagellate signal, punctuated by discrete zooplankton flashes. (B) Mooring data (depth 10m) illustrates the diel cycle commonly associated with vertical migration and circadian rhythms. 240.0 is midnight.

RESULTS

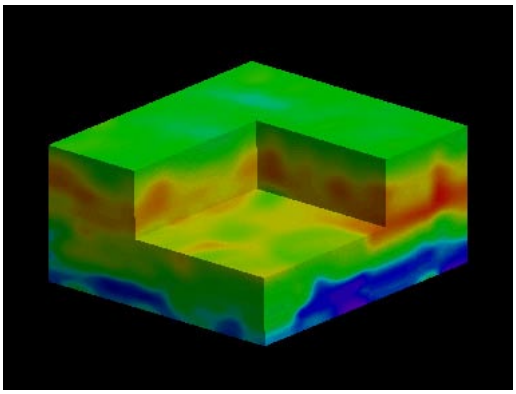
Although there was no pronounced frontal feature present during the experiment, we did encounter an unusual bloom of dinoflagellates, which generated luminescence in the near-shore regions. Their pronounced bioluminescence was noted in a maximum just below the warm surface waters. Zooplankton sources were commonly found at greater depths (Figure 3A), and they became increasingly important as we transited offshore. Mooring data showed the diel cycle of luminescence (Figure 3B).



4. AUV mission heading offshore. (Not shown: fluorometer, flow through biolum sensor)

AUV runs were particularly illustrative of the distribution and patchiness of bioluminescence and gave many indications of factors which were correlated (positively and negatively) with bioluminescence (Figure 4). Preliminarily, high temperature and high salinity were inversely correlated with luminescence, and fluorometer or OBS readings were not good predictors of bioluminescence. Luminescence was most strongly associated with the bottom of the thermocline (and pycnocline) throughout our sampling stations. The ability to program the AUV to run at a minimum altitude above the bottom allowd us to sample safely close to shore, which is not possible with towed devices. (Note increasing depth and resuspended of bottom material in the OBS data in Figure 4.)

Using high-resolution sampling patterns, concentrated on one-km square areas offshore (Figure 5), in addition to were able to examine how the distribution of luminescent sources changes over short time-scales and small areas. Note the subsurface peak, and the fall-off in luminescence at the bottom (30m).



5. Stimulated bioluminescence in a 1-km square, 30-m deep volume (depth magnified 50x)

Finally, the optical data such as beam attenuation allow us to calculate how much light would be visible at the surface, given stimulation of luminescence at a particular depth (Figure 6).

IMPACT/APPLICATION

At this time, only preliminary analyses have been conducted, but it appears that this experiment comprises perhaps the most comprehensive set of luminescence, biological and physical measurements ever assembled. It will provide an excellent understanding of the factors controlling the distribution of bioluminescence in a coastal environment during this oceanographic season. The sampling was extraordinarily successful considering the of multiple sampling platforms, procedures, and personnel that had to be coördinated. The methods and protocols worked out will also be useful in making future studies of this kind even more efficient.

TRANSITIONS

The instruments and platforms tested during these experiments will have excellent applicability to future studies of coastal and oceanic bioluminescence, at a range of time- and space-scales.

RELATED PROJECTS

ONR-supported projects of Mark Moline, Edith Widder, James Case, and Christy Herren are all intimately linked with the sampling and analysis which I have described. The entire project is part of the MUSE project, most closely associated with the work of Francisco Chavez and Ken Johnson of MBARI. AUV equipment and expertise were provided through ONR grants to Jim Bellingham. These data are to be included in modelling efforts by Jeff Paduan's team from the Naval Postgraduate School, Dennis McGillicuddy from WHOI, Paul Bissett from FERI, and others. In addition, I benefitted from a trip to the LEO-15 site, courtesy of Mark Moline's funding. This gave me and the other investigators a chance to test out instruments and procedures which were eventually applied in the Monterey experiment.

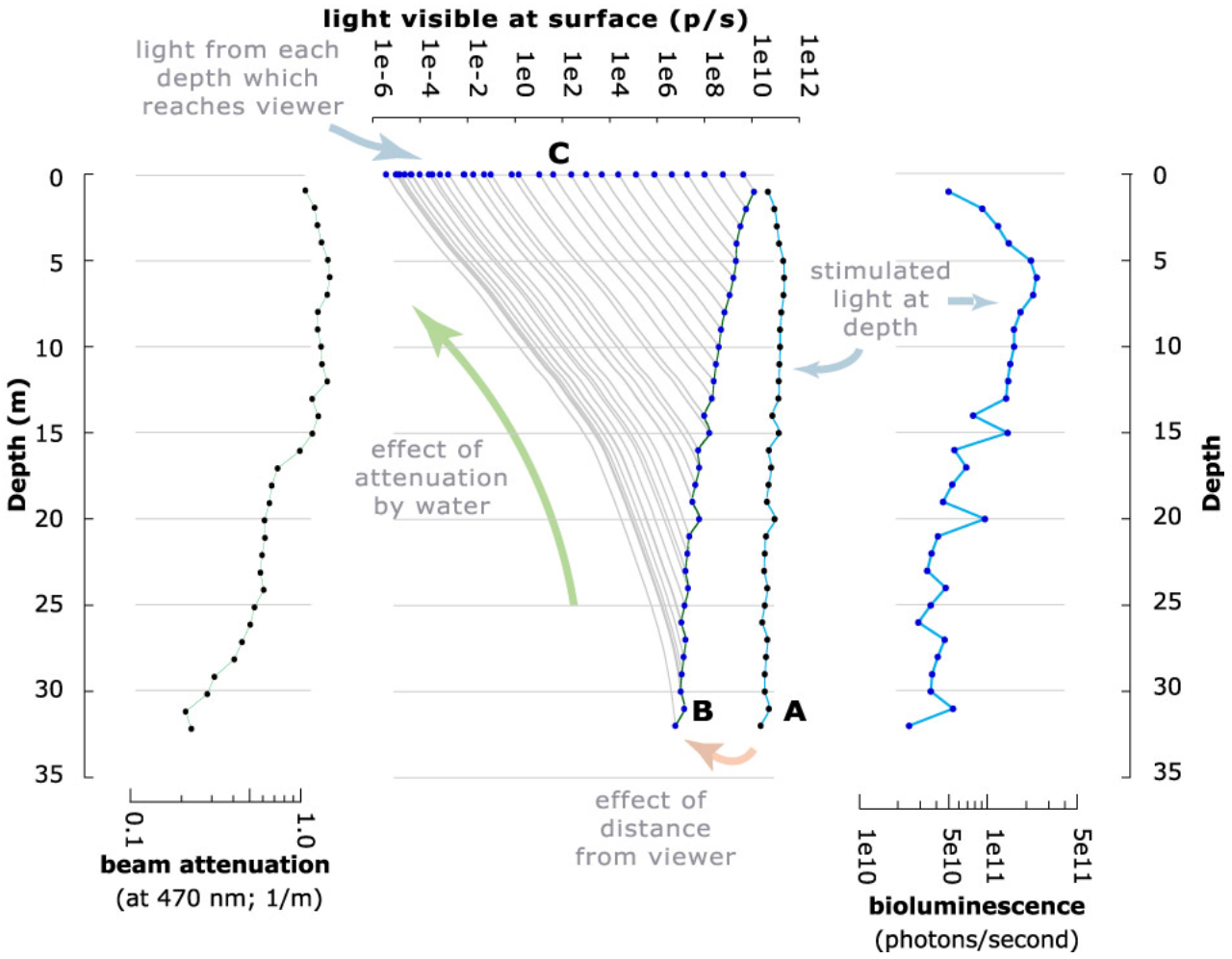


Figure 6. Transmission of light to the surface. Using the beam attenuation coefficient (left graph) and the stimulated bioluminescence (A, rightmost graph), we can calculate the amount of light which will reach the surface (C) from a particular depth. The original light (A) decreases based on the least-squares law (A..B) and the depth-specific attenuation (B..C) as it travels to the surface. For example, of the light produced at 15 meters, only 1 photon/second reaches an observer at 0 meters.