Digital photograph (unenhanced) of a breaking wave containing the bioluminescent dinoflagellate species, *Lingulodinium polyedra*, taken along the central coast of California during a red tide in October 2003 (with permission from Rosalba Dominguez).

Unique optical spectral signals during the times of the HABs show promise in using optics for detection and identification of HABs (Figure X.14). HAB species identification is possible, in principle, using direct measurements of hyperspectral absorption coefficient or potentially with hyperspectral radiometric measurements. Radiometric measurements would need to be coupled with remote sensing reflectance inversion models to derive the IOPs (e.g., Roesler and Perry, 1995). Spectral deconvolution procedures would then be utilized to arrive at the absorption coefficient for phytoplankton (Schofield et al., 2004 and references therein). Derived hyperspectral absorption data, used in combination with spectral techniques such as derivative analysis (usually the fourth derivative), spectral angle mapping, spectral deconvolution, and similarity indices (also called spectral angle mapping in image analysis), can aid in the characterization of marine ecosystems including the detection and identification of HABs (Millie et al., 1995, 1997; Kirkpatrick et al., 2000; Lohrenz et al., 1999); however, to date these methods have required manipulation of samples for spectrophotometry. Spectral analysis, performed on phytoplankton absorption data, can aid in the identification of specific pigment absorption peaks and important wavelength ratios. This method has been shown to be successful for the detection of the red tide dinoflagellate *Karenia brevis* (Millie et al., 1995; 1997; Kirkpatrick et al., 2000). *K. brevis* can be identified by its accessory pigment, Gyroxanthin –diester, which has unique absorption peaks at 444 and 469 nm (Örnólfsdóttir et al., 2003; Figure 1 in Chang et al., 2004). Limitations of the above method are: (1) it is sometimes necessary and difficult to tune spectral inversion and deconvolution techniques for specific environments; (2) not all HAB species have unique accessory pigments that can be distinguished from other species; (3) some HAB species have toxic and non-toxic states (e.g., *Pseudo-nitzschia australis*); and (4) the methods presented above have not been validated with analyses of remotely sensed ocean color.

The promise and limitations of optical detection systems show that *in situ* optical measurements must be complemented with laboratory-based analyses using microscopic or molecular methods until robust relationships between optical properties and HAB species are quantified. In addition, phytoplankton physiological and physiochemical changes (e.g., nutrient limitation) can be investigated through these complementary laboratory analyses. All collected data should be made available for various biological/chemical/optical/physical data assimilation models for HAB prediction purposes (Franks, 1997; Schofield et al., 1999; Franks, 2005)

X.5 Summary and conclusions

Physical and chemical as well as biological processes are important for understanding, monitoring, and predicting the dynamics of harmful algal blooms. The coastal ocean, where most HABs occur, is considerably more complex than the open ocean as there is greater diversity of organisms and the time and space scales of variability are shorter. Progress in HAB research will require new interdisciplinary instrumentation, use of a