CoBOP Coral Reefs: Optical Closure of a Coral Reef Submarine Light Field

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LONG–TERM GOALS

Our long-term goal concerns the application of biological optics to the interpretation of changes in the color of the ocean, with specific reference to the interaction between oceanographic processes and the time and space distributions of suspended and submerged biota. Central to this goal is the attainment of optical closure, i.e. understanding the important factors which affect the attenuation and reflectance of light from the water column, such as tidal variability, and the optical properties of benthic marine organisms. We seek to develop new bio-optical methods and to identify the potentials and limitations of bio-optical methods for the measurement of growth, biomass and biodiversity in benthic marine photosynthetic organisms.

OBJECTIVES

This year we have continued to explore and extend datasets collected during CoBOP field exercises in the areas of: 1) the optical properties of benthic organisms and 2) tidally induced optical variability, through experiments in the local waters off Boothbay Harbor, ME. We have addressed the causes of variability in the reflectance signatures of macro- and microalgae. The effects of thallus thickness and the incidence angle of the source light have been quantified for spectral reflectance measurements of macroalgae. We have attempted to obtain optical closure within the thallus by measurement of both reflectance and beam transmission. Similar measurements were made on microalgae of different species and differing cell size. These data are presently being analyzed. A hyperspectral reflectance mooring was deployed for the summer in the mouth of the New Meadows River which measured hourly AOP values throughout the day period for eight weeks in order to develop longer-term, lower resolution tidal records to compare with our short-term (2-3 week), high resolution (every 3 minutes) records obtained under CoBOP.

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Our long-term goal concerns the application of biological optics to the interpretation of changes in the color of the ocean, with specific reference to the interaction between oceanographic processes and the time and space distributions of suspended and submerged biota. Central to this goal is the attainment of optical closure, i.e. understanding the important factors which affect the attenuation and reflectance of light from the water column, such as tidal variability, and the optical properties of benthic marine organisms. We seek to develop new bio-optical methods and to identify the potentials and limitations of bio-optical methods for the measurement of growth, biomass and biodiversity in benthic marine photosynthetic organisms.

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APPROACH

Sara Woodman Yentsch and Charles Yentsch have measured spectral reflectance on samples of algae in the lab using a fiber-optic spectral reflectometer (Analytical Spectral Devices, FieldSpec) with a tungsten-halogen light source. The effect of increasing thallus thickness on spectral reflectance was investigated by using circular sections of macroalgae punched from fronds and stacked to increase thickness. Sensitivity of spectral reflectance to the angle of incidence studied by changing the angle of the light source with respect to the detector fixed at 40 degrees. David Phinney and undergraduate intern Lara Slifka maintained a Satlantic HyperTSRB mooring with 490nm K-chain in 20 meters of water for eight weeks during the summer of 2002. The mooring was serviced weekly to download data and clean any fouling, CTD/optics profiles and calibration water samples were also collected.

WORK COMPLETED

The amount of spectral reflectance at visible and near infrared wavelengths as a function of incidence angle of the source has been quantified for two species of macroalgae and ten species of microalgae. We have measured spectral reflectance as a function of algal thallus thickness for two species of macroalgae and completed thallus optical closure using light transmission and reflection measured at visible and near infrared wavelengths for two species of macroalgae. Eight continuous weeks of hourly, daytime hyperspectral downwelling irradiance, upwelling radiance, remote sensing reflectance and k490 (m^{-1}) were obtained between July 12 and September 10, 2002. Eight profiles of temperature, salinity, c488 and chlorophyll fluorescence as a function of depth with surface values for chlorophyll and total suspended solids concentrations as well as particulate and dissolved components of spectral absorption were collected.

RESULTS

Measurements of spectral reflectance as a function of incidence angle clearly demonstrate that the thallus of macroalgae and cells of microalgae act as ideal diffusers where reflectance follows the cosine of the angle of light incident on the plant surface. The question arises: can the total hemisphere of scattered light be represented by one viewing angle? The two extremes occur when the angle between the light paths of the source and detector are small (< 10 degrees) and when they approach 90 degrees. At small angles, one assumes that the detected light is dominated by reflection and elastic scattering, whereas, at larger angles, the detected light becomes a complex of diffuse inelastic scattering with some contribution from elastic scattering. In the macroalgae *Laminaria* (Figure 1), changing the incidence angle has the primary effect of changing the albedo and the amount of near infrared reflectance. As the viewing angle moves from the vertical (6 degrees) towards the horizontal (>50 degrees) there are parallel decreases in both. By increasing the incidence angle the reflectance changes from 15% to >5% at 600nm and from 30% to 5% at 800nm. The change in angle also effects the spectral definition of the absorption bands at visible wavelengths. To be an ideal diffuser the thallus must be of sufficient thickness to de-collimate the incident radiation. Contrary to studies of the leaves of higher plants, the algal disk stacking experiments had little effect on changing the spectral signature of the two macroalgae *Ulva* and *Laminaria*. We believe that the additions used were probably too small to markedly effect changes in light paths of these algae. By re-arranging the focused light source and detector, collimated light transmission was also measured on the macroalgae. These measurements showed sharp peaks of reduced visible light transmission due to the dominance of absorption by photosynthetic pigments, as well as high transparency in the near infrared. In summary, our question initially addressed the possibility of using hyperspectral reflectance for estimates of photosynthetic kinetics and diversity indices based on some index of biomass. The variability in spectral reflectance ratios are severely complicated by multi-scattering phenomena from a variety of plant materials with differing thallus thickness and, hence, light paths. In short, interpretation of kinetics driven by pigment absorption is very difficult without a measure of light transmission.

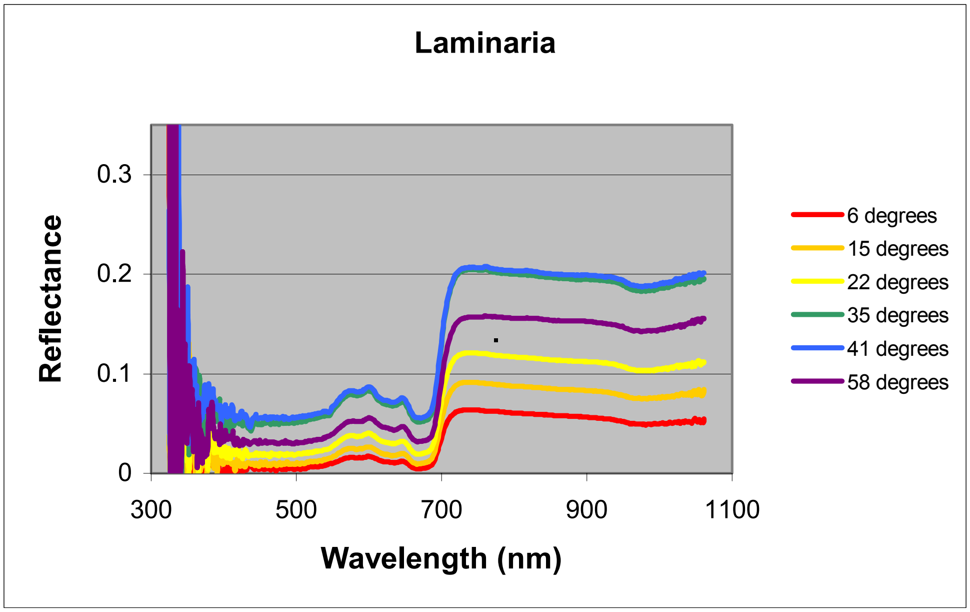

Figure 1. Effect of angle of incidence of the light source on spectral reflectance from kelp (*Laminaria sp.*). Lowest values are seen when the source is nearly vertical (6 degrees) or approaching horizontal, highest values are seen when the incidence angle occurs between 35 and 45 degrees.

The influence of tidal variability on spectral upwelling radiance and the apparent optical properties of remote sensing reflectance and diffuse attenuation were demonstrated using low frequency (hourly) data from the mooring in the New Meadows River (Figure 2). Chlorophyll concentrations (calculated using the SeaWiFS OC4 version 4 algorithm) ranged between 4 and 10 μg/L while k490 ranged from 0.25 and 0.5 m^{-1} calculated from downwelling irradiance sensors suspended at four depths beneath the radiometer buoy (K-chain). In general, optical properties were inversely proportional to the state of the tide with lowest chlorophyll and diffuse attenuation values observed at high tide and highest values observed at low tide. This is consistent with coastal datasets we have collected in other regions. However, our Lee Stocking Island data from May of 1998, 1999 and 2000 was noticeably devoid of tidal influences and remarkably consistent from year to year. While this phenomenon was ideal for studies of optical closure, it has proven difficult for our studies of tidal variability.

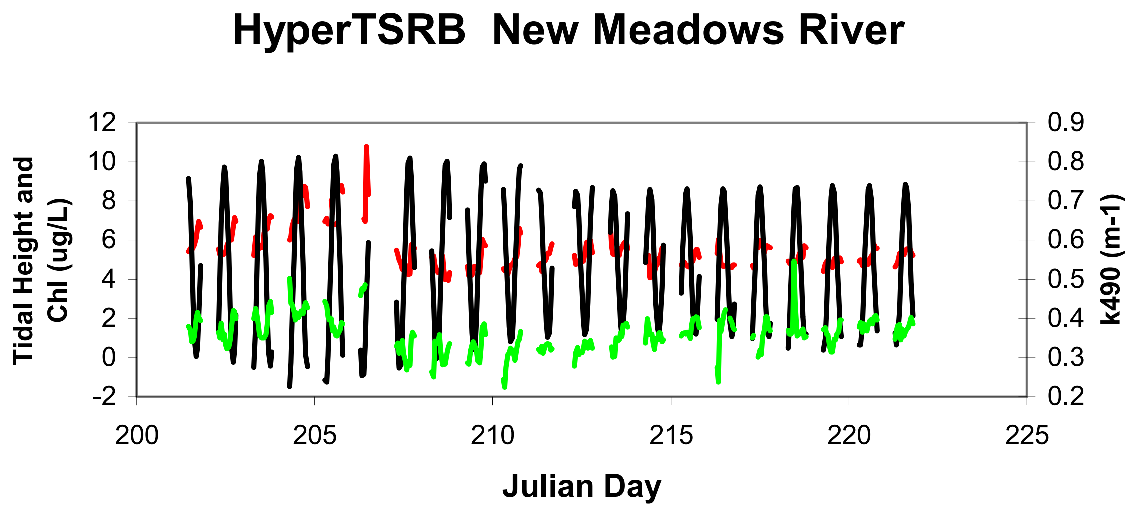

Figure 2. Hyperspectral mooring data showing tidal height in feet (black), OC4 calculated chlorophyll concentration (red) and k490 (green) over three weeks. Chlorophyll was calculated using radiometer data while diffuse attenuation was calculated from separate sensors.

IMPACT/APPLICATIONS

The original thrust of our effort was assessment of the use of reflectance for remote measurement of benthic communities. As is often the case, the mechanics of sensor development out stripped those who required the data for scientific projects. We were aware from rather simple measurements that water attenuation over depth would severely limit the usefulness of passive techniques. Our approach using reflectance was naïve, yet instructive. The time is ripe for people who are convinced that reflectance spectral measurements can be useful to talk. What are the science questions we need to ask? What are the levels of accuracy needed? Is the technique best implemented from aircraft, satellite, sea surface or subsurface observations? Finally, what optical instrumentation is needed: passive or active, multispectral or hyperspectral?

TRANSITIONS

We do not believe that we have much of an audience among the remote sensing community insofar as the usefulness of spectral reflectance as a tool to estimate important biological characteristics of benthic communities. The major studies in remote sensing have largely focused on the effects of benthic reflectance on atmospheric correction. We believe that this would change if there were frank discussions between benthic ecologists and those familiar with the optical problems. Similarly, optical models in shallow coastal waters do not seem to include optical variability due to tides, perhaps due to the lack of parameterization that would reduce computational requirements for implementation in the models. We continue to demonstrate the importance of tidally induced variability in many regions.

RELATED PROJECTS

Within the COBOP program we have relied on the expertise of Dr. Mike Lesser at the University of New Hampshire and Dr. Ken Voss at the University of Miami. With regard to BRDF measurements, we have discussed some of the optical difficulties of the measurement with Dr. Voss and how they can compromise the use of aircraft/satellite observations. Collaborative research with Dr. Brian Lapointe at Harbor Branch Oceanographic Institution has helped us greatly with the integration of successional patterns of macroalgae and associated changes to the reflectance spectra.

PUBLICATIONS

D'Sa, E.J., J.B. Zaitzeff, C.S. Yentsch, J.L. Miller and R. Ives. 2001. Rapid remote assessment of salinity and ocean color in Florida Bay. In: The Everglades, Florida Bay and Coral Reefs of the Florida Keys: An Ecosystem Source Book. J.W. Porter and K.G Porter (eds.), CRC Press, NY, pp. 451-460.

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