# RADIATIVE TRANSFER MODELING FOR COBOP

Curtis D. Mobley
Sequoia Scientific, Inc.
9725 S.E. 36th Street, Suite 308
Mercer Island, WA 98040
phone: 206-230-8166 x 109   fax: 206-230-8175   email: mobley@sequoiasci.com
Award Number: N0001497C0018

## LONG-TERM GOAL

The overall goal of this work is to take oceanic radiative transfer theory into a new domain: shallow water with highly variable bottom topography and bottom optical properties, including fluorescent bottom substances.

## OBJECTIVES

Currently available models for seagrass productivity use very simple parameterizations of the underwater light field (Zimmerman, et al., 1994).  The  objective of this year's work was to investigate how improved radiative transfer calculations can improve models for seagrass productivity.

## APPROACH

It is particularly difficult to predict the light field within a seagrass canopy.  This is because the grass leaves have non-randomly oriented surfaces, which makes the bulk inherent optical properties of the water-plus-grass system nonisotropic.  For example, the beam attenuation within an oriented-leaf canopy depends not just on location but also on "direction," e.g. beam attenuation is different for directions parallel and perpendicular to the typical leaf orientation.  No presently available radiative transfer model used in optical oceanography is designed for nonisotropic media.  Therefore, in this initial study, the grass leaves were modeled as "chopped up" leaves with the same total biomass distribution as measured in natural canopies (Zimmerman and Mobley, 1997a).  Modeling the leaves as small, randomly oriented particles (analogous to phytoplankton) makes the system isotropic, and therefore amenable to modeling by the Hydrolight radiative transfer numerical model (Mobley, 1994, 1995).

## WORK COMPLETED

Using data provided by R. Zimmerman on seagrass (*Zostera marina* L.) leaf spectral absorbances, leaf length distributions, and other leaf parameters, simple models of the absorption and scattering properties of the grass canopy were developed.  Using these models as input to Hydrolight, dozens of simulations were performed for different canopy heights (0.5 to 1.5 m), different numbers of leaves per square meter of bottom (25 to 300 leaves/$m^2$), different water optical properties (clear and turbid water), different bottom types (sand and mud), and different

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environmental conditions (winter vs. summer, morning/evening vs. noon). Hydrolight was run over near-UV and visible wavelengths to compute PAR (photosynthetically available radiation) as a function of depth within the grass canopy.  The computed PAR profiles were then used by R. Zimmerman in his models for biomass productivity of seagrass canopies to quantify the changes in predicted productivity that result from the improved PAR predictions.

In a separate collaboration with N. Max of Lawrence Livermore National Laboratory, the standard (isotropic) version of Hydrolight is being modified for use in anisotropic leaf canopies.  This modified version of Hydrolight should lead to still better computations of the light field within seagrass canopies.

## RESULTS

Significant improvements in our ability to predict seagrass primary productivity were obtained as a consequence of the improved PAR computations.  Previous production models have simply used a diffuse attenuation coefficient for PAR within the water column *above* the grass canopy to extrapolate the PAR profile from the water column into the grass canopy.  Figures 1 and 2 show that actual depth profiles of PAR computed by Hydrolight for various conditions typical of the seagrass beds in Monterey Bay.  It is clear that simply extrapolating the PAR profiles from the water column (above a depth of ~5.5 m in these figures) into the canopy would give PAR values much too large within the grass canopy.
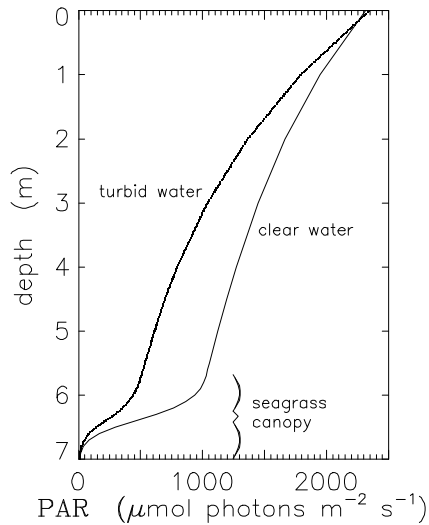


Fig. 1.  PAR as computed for clear ($Chl = 0.5$ mg Chl m$^{-3}$) and turbid ($Chl = 3.0$ mg Chl m$^{-3}$) waters.  There were 50 grass shoots per square meter of bottom, which was a dark mud. The sun zenith angle corresponded to noon on the summer solstice.
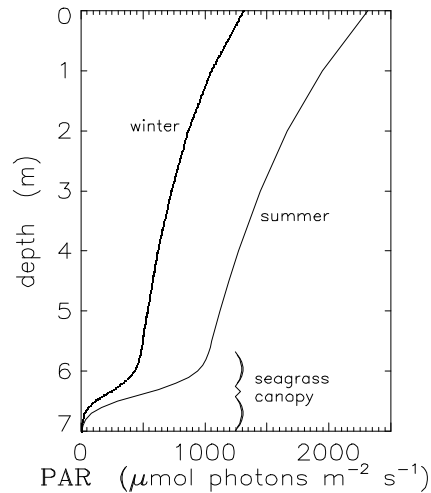
Fig. 2. PAR as computed for sun zenith angles corresponding to noon on the summer and winter solstices. The water was clear ($Chl = 0.5$ mg Chl m$^{-3}$), and there were 50 grass shoots per square meter of bottom, which was a dark mud.

Figure 3 illustrates the effect of grass shoot density on the PAR profile within the grass canopy. It is clear that the high absorption by the grass leaves greatly reduces PAR deep within a dense canopy.
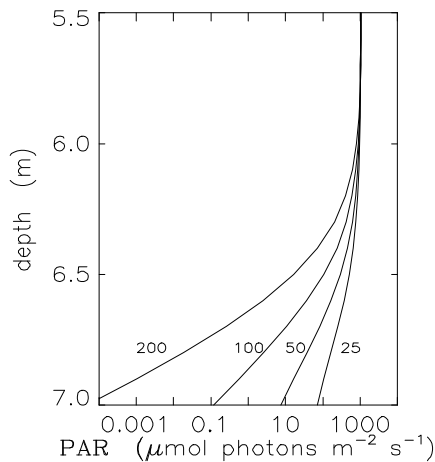


Fig. 3. PAR within a grass canopy (below ~6 m depth) for shoot densities of 25, 50, 100, and 200 shoots per square meter of bottom. The water was clear ($Chl = 0.5$ mg Chl m$^{-3}$) and the bottom was a dark mud. The sun zenith angle corresponded to noon on the summer solstice.

Use of these PAR profiles leads to predictions of seasonal maximum shoot densities and other quantities of interest that are fully testable by, and wholly consistent with, field observations. The details of these productivity calculations can be seen in Zimmerman and Mobley (1997a, 1997b, 1997c) and in the companion annual report by R. Zimmerman. Although the present modeling of the optical properties of the grass leaves is still oversimplified, these PAR calculations are a significant improvement over what was previously available.

## IMPACT/APPLICATIONS

Seagrasses are extremely important ecological resources whose distribution and health are fundamental to fisheries, shallow-water sea-bed erosion, and water quality. However, seagrass beds are very vulnerable to anthropogenic modifications of coastal waters, and grass beds have severely declined in recent years, for reasons that are hotly debated. An improved ability to predict grass production as a function of water quality parameters is greatly needed by coastal-zone management agencies, who are at present expending large sums of money attempting to reduce losses of the remaining grass beds.

## TRANSITIONS

As discussed above, the radiative transfer modeling is fundamental to the seagrass production studies being carried out by R. Zimmerman. There are no other transitions yet, because this work is just beginning. However, we expect that our seagrass modeling methodology will attract considerable attention by seagrass management agencies because it is applicable to problems now being addressed by NOAA, the U. S. Army Corps of Engineers, and many state agencies.

## RELATED PROJECTS

1. The radiative transfer modeling efforts outlined above are fundamental to the seagrass production studies being carried out by R. Zimmerman, who is separately funded by ONR.

2. I am working with R. Maffione, who is funded by ONR for field measurements in seagrass beds and who is also developing an improved model of light propagation within grass canopies, which will use the Hydrolight values at the top of the grass canopy as input. We also are collaborating on the use of Hydrolight to perform closure studies with Maffione's BSAP (Benthic Stationary Autonomous Profiler) data.

3. I am collaborating with N. Max, who is funded by the Department of Energy at Lawrence Livermore National Laboratory for radiative transfer studies of plant canopies. Max's modifications to Hydrolight, which already have been applied to maple tree and bamboo canopies (Max, et al., 1997), may be useful in future studies of seagrass canopies.

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